SURVEY OF INDIA

HANDBOOK OF TOPOGRAPHY

CHAPTER XII

THIRD EDITION

(Corrected up to 31st August 1970)

PHOTOGRAMMETRIC SURVEY (AIR SURVEY)

PUBLISHED BY ORDER OF
BRIGADIER J. S. PAINTAL, M.I.S., M.I.E.,
SURVEYOR GENERAL OF INDIA

PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA,
DEHRA DŪN, 1973

Price Rupees Seven and Seventyfive paise

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PREFACE TO FIRST (PROVISIONAL) EDITION

The science of air survey is a young science and as such is in state of rapid evolution.

Considerable time is required for research results to be published and reach India, and further time is necessary to reduce the results to a working form suitable to the conditions of the country. This chapter cannot, therefore, be considered as the latest information on the most accurate methods evolved, and must be regarded as a provisional publication. It endeavours to bring the routine practice of air survey into line with ordinary ground surveys, in the matters of the systematic preparation and survey, and the storage of all records so that the best results can be obtained from given data and so that the records will be accessible when required.

The main problem in air survey must always be the accuracy of the results in the dimension parallel to the camera axis. In vertical photography this is the determination of heights or contouring. Two factors are at work in air survey progress to day. The first is the improvement in the standard of flying to reduce tilt, which is being achieved by the use of automatic gyroscopic controls, the second is the inclusion of larger areas of country in one photograph.

The tendency of the first will be to make the simpler and approximate methods of height-finding more accurate, till the standard required for rigorous contouring is obtained directly from these methods. The tendency of the second is to decrease the accuracy of contouring with a given photo-tilt. It is likely, however, that progress in the first will outstrip that in the second, and that the laborious methods of finding approximate heights by the plumb point method will in time be entirely superseded.

To obtain accurate contouring by any graphical method it is essential that the surveyor employed should be fully qualified in this class of work in ordinary ground surveys, and have ample experience in the field of all types of country.

MURREE
19–7–32.

D. R. CRONE,
CAPT., R.E.,
Officer in Charge No. 18 (Air Survey) Party.

PREFACE TO SECOND EDITION

One of the main tasks of photogrammetry with which India is especially concerned and which has to a large extent determined the direction of research, is the mapping of large areas of unadministered tribal territory which are inaccessible on the ground. The development of precise methods in dealing with this and other problems is very largely due to original research carried out by Captain (now Major) D. R. Crone, R.E.

The search for a method of fixing heights sufficient and accurate enough to enable maps of areas in which there is little or no trigonometrical control, to be contoured from vertical photographs, was terminated in India when Captain Crone produced his method of determining the tilts of high oblique air photographs.

The elements of this method were published as an amendment (No. 4 of 29–10–34) to the first edition of this chapter. Air survey in India has now been organised to utilize this method fully both for amplifying planimetric control and for providing the dense network of heights required for contouring vertical photographs. This edition of the chapter attempts to detail this new routine.

One of the advantages of air survey is the rapidity with which maps can be made and published. By evolving the 'black and white, method of colour separation by which maps in two colours can be reproduced directly from the air survey compilation Captain R. C. N. Jenney, R.E. has greatly increased this advantage.

A section has been added dealing with surveying from ground photographs. Many of the problems and operations in this work are identical with those in air survey and this section has therefore been included in the chapter without any alteration of the title.

DEHRA DŪN
18–10–39.

C. G. LEWIS,
BRIGADIER,
Surveyor General of India.

PREFACE TO THIRD EDITION

With the advent of restitution instruments and mechanical plotting the speed and accuracy of surveys using Aerial Photographs have increased considerably. The Survey of India took seriously to photogrammetry in 1954 with the acquisition of a number of stereoplotters. The advantages of photogrammetric method are now fully recognised and we aim at introduction of photogrammetry in topographical circles subject to availability of resources. It is hoped that in the years to come we shall have sufficient instruments to equip the department to meet the expanding need of surveys in India and also render assistance to neighbouring countries in the cartographic field.

In keeping with the shift of emphasis from manual to mechanical plotting this chapter has been re-designated and completely re-written in order to include the modern methods and notes on instruments used in photogrammetry.

DEHRA DŪN
13-7-71.

J. S. PAINTAL,
BRIGADIER,
Surveyor General of India.

LIST OF CHAPTERS OF THE HANDBOOK OF TOPOGRAPHY

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,,	II.	Constitution and Duties of a Survey Party.
,,	III.	Triangulation and its Computation.
,,	IV.	Theodolite Traversing.
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SECTION I.—INTRODUCTORY

1. **Photogrammetry.**—Photogrammetry is defined as the science of obtaining reliable measurements by means of photography and in a broader context includes photo-interpretation. Thus, it is understood to include the use of photographs for various purposes such as construction of topographical maps, preparation of mosaics, interpretation of geology, evaluation of forest resources, classification of soils, urban area planning, highway engineering, and other miscellaneous applications. The concept of measurement will, however, be regarded as implicit in the term "photogrammetry" for the purpose of this Chapter.

Photographic interpretation is that branch in which aerial or terrestrial photographs are used for evaluation, analysis and interpretation of object images which appear on the photographs.

Photogrammetry is divided into two distinct branches, viz., aerial photogrammetry and terrestrial photogrammetry, according to the types of photographs used. *Aerial photogrammetry* denotes that branch of photogrammetry in which the measurements are made from photographs taken from an air-borne camera. *Terrestrial photogrammetry* denotes that branch of photogrammetry in which the measurements are made from photographs taken from points on the ground.

According to the manner in which photographs are used, aerial photogrammetry can be further sub-divided into single-image and double-image plotting methods, the later being termed as *stereophotogrammetry*, which can also be broadly catagorised into analogue and analytical methods. In analogue methods overlapping pairs of photographs are observed and measured in a stereoscopic viewing device which gives a three dimensional effect. In analytical photogrammetry problems are solved by mathematical computation, using measurements on photographs as an input data.

In the practice of arieal and terrestrial photogrammetry it is essential to carry out a certain amount of interpretation in addition to making measurements. Consequently, photogrammetry is considered as a combination of interpretation and measurement. The most important application of aerial photogrammetry is in the production of topographical maps and mosaics. Experience so far gained in photogrammetry has shown that a considerable part of time-consuming control provision and detail survey by ground method can be replaced by photogrammetric methods. The purpose of this handbook is to furnish in a concise form the details of procedures followed and instruments required to undertake photogrammetric surveys as carried out in the Survey of India.

2. Historical background.—The first known photographs were produced by Niepce and Daguerre in 1839. The French geodesist Arago recommended the use of photographs for preparation of topographical maps in 1840. Another Frenchman Colonel A. Laussedat may be regarded as the founder of photogrammetry though he called his technique 'Metrophotographie'. Most of Laussedat's mapping work was made from terrestrial photography taken by a Phototheodolite which is a combination of a theodolite and a camera. In 1859 Laussedat described the method of surveying from photographs taken with the Phototheodolite and in 1867 exhibited a plan of Paris prepared by photographic surveys.

In Germany, Dr. A. Meydenbauer almost simultaneously but independently carried out measurements of architectural details using two photographs of the building. The word 'Photogrammetry' appeared for the first time in one of his publications in 1893. In Germany, photographs were used by Jordan in 1873 for the survey of Dachel Oasis and by S. Finsterwalder in surveying of Alpine glaciers. Hauk developed the important epipolar theory in 1883 and constructed the perspectograph, an apparatus for construction of a third perspective from two given perspectives. S. Finsterwalder published his book 'The Fundamental Geometry of Photogrammetry' in 1889 which explained the basic principles of photogrammetry in the perspective sense.

In Canada, Captain E. Deville, Surveyor General of Dominion Lands introduced the use of terrestrial photogrammetry for topographical mapping in 1888. Deville invented the first stereoscopic plotting instrument and published his book 'Photographic Surveying' in 1895.

In the United States of America, Lieutenant H. A. Reed described in his book "Photography Applied to Surveying" published in 1888 the earliest known applications of photogrammetry from balloon photography by the Union Army in 1862. The principles of radial plotting were established in 1893 by C. B. Adams of U.S. Army, who took out a patent for making maps using photographs taken from balloons.

The first experiments with aerial photography in Russia were made in 1886, when Kovanka took pictures of the Kronstadt and Petersburg fortresses during a free balloon flight. These pictures demonstrated the importance of aerial photography.

Scheimpflug, an Austrian Captain, developed the idea of the double projector in 1898 and first conceived the idea of representation of terrian in the form of photo-maps composed of aerial photographs. He originated the theory of perspective transformation and also the idea of radial triangulation.

Stereophotogrammetry came into use with the discovery of the principle of the floating mark by F. Stolze in 1892 and the subsequent development of a practical method of measurement with floating marks by Dr. C. Pulfrich. The principle of floating mark and stereoscope was incorporated by Pulfrich in his stereocomparator in 1901. H. G. Fourcade (South Africa) described independently a similar construction in 1902. In Vienna, A. von Hubl developed the stereocomparator early in the twentieth century. Rost constructed the first stereoautograph in 1908 based on the design of E. von Orel. The Stereoautograph permitted plotting of a map through mechanical projection of a spatial model formed by stereoscopic observation of a pair of terrestrial photographs.

Aerial photogrammetry in its present sense was practically started in the twentieth century with the development of aeroplanes. The first recorded photographs taken from an aeroplane were made on 24 April 1909 by Wilbur Wright, who took the motion pictures over Centocelli, Italy. Photographs taken from aeroplanes were published by H. Chapmann (U.K.) in 1913. In the same year Captain Tardivo exhibited in the First International Congress of Photogrammetry held in Vienna a mosaic of the city of Benghazi (Libya), prepared from photographs taken from aeroplanes. These are the few uses of pre-war aerial photography.

Aerial photography on a large scale was carried out during the first World War. The first aerial photographs of German-held territory were made by Lieutenant Lawas of the Royal Air Force (U.K.). In 1915, O. Messter built the first film aerial camera in Germany. At about the same time the first practical aerial camera was designed and produced by Lt. Col. J. T. C. Moore Brabazon of the R.A.F. in England and by J. W. Bagley and A. Brock in the U.S.A. By the end of 1918 aerial photography had become one of the most important sources of military information. Rectifiers for the production of controlled mosaics were also designed during this period.

In 1915, Gasser built his double projector for vertical photographs incorporating Scheimpflug's basic idea. In 1920, first Autocartograph was completed by the Heyde company based on the design of Hugershoff; for the first time it made possible terrain mapping from arbitrarily directed photographic images. In 1923, it was followed by the Zeiss Stereoplanigraph designed by Bauersfeld. Similar solutions were invented by Poivilliers in France, Nistri in Italy and Wild in Switzerland during this period.

The possibilities of the radial line methods were again dealt with by Scheimpflug in 1906 and Finsterwalder in 1921. The development of this method as a practical proposition was given real impetus by the work of Major J. W. Bagley (U.S.A.) in 1923 and by Lieutenant M. Hotine (U.K.) in 1926 who experimented on an area near Arundel whence the method derived its name "Arundel method". The invention of the slotted template method in the U.S.A. in 1931 by C. W. Collier and L. T. Eliel increased the use of radial line method.

The first precise statement of the aerial triangulation problem was made by Umberto Nistri (Italy) in 1919. The principles of relative orientation were explained by von Gruber in 1924. Nistri's triangulation instrument Multiplo was manufactured in 1932. Zeiss introduced the Multiplex in 1933 and extended it to a triangulation instrument. In 1935, von Gruber published a detailed procedure of aerial triangulation which can be considered a milestone in the history of photogrammetry. The propagation of errors in aerial triangulation was investigated jointly by von Gruber (Germany) and W. Schermerhorn (The Netherlands) at about the same time.

A large variety of precision stereoplotting instruments has been introduced during 1952–66 which has increased the economy and efficiency of photogrammetric survey methods considerably. Introduction of electronic dodger printers has made better photographic prints possible which assist in extracting increased information from aerial photographs. A large number of high precision stereocomparators with automatic registration devices were introduced in 1960. With the introduction of high-speed sequence-controlled electronic computers and precision stereocomparators, the analytical aerial triangulation has received a fresh impetus. Today, photogrammetry is recognised as a basic procedure in all types of mapping and is being increasingly used to a great advantage in numerous other fields.

3. **Development in Survey of India.**—Terrestrial photogrammetry was first tried in Survey of India towards the end of the nineteenth century when a Phototheodolite of Bridges-Lee make was procured in 1899 for the evaluation of its mapping potentialities. Lieutenants Tandy and Hirst and Mr. Eccles who experimented with the Phototheodolite for small scale survey of the Kalunga Hill (Dehra Dūn) during 1899–1900 were satisfied with the quality but not with the speed of mapping from terrestrial photographs and recommended their use only as an auxiliary to the plane-table in steep mountainous country. Lieutinant K. Mason used the terrestrial method during his triangulation expedition to the Pamirs in the summer of 1913, and for exploration of the Shaksgam Valley and Aghil ranges in the Karakoram Himalayas in 1926. One Wild Phototheodolite was purchased by the Survey of India department in 1928. During 1928–29, Lieutenant I. H. R. Wilson attempted cadastral survey on the scale of 66 inches to 1 mile in the Almora District of Uttar Pradesh from terrestrial photographs taken by the Wild Phototheodolite. The terrestrial photogrammetric method, however, did not find general use in the department because the type of terrain for which it was most suitable was seldom encountered in India except in very high hills.

Section I.—INTRODUCTORY

Air survey or the technique of preparation of topographical maps of requisite accuracy from aerial photographs can be said to date from the early years of the First World War (1914–1918), when the aerial photographs were utilised to meet the war needs. The first reference to surveying from the aerial photographs dates back to 1916, when in the Mesopotomian front Major C. P. Guntur of the Survey of India used aerial photographs for the provision of maps of the country beyond the enemy lines. During 1917–18, aerial photography was extensively employed near Salonika for the preparation of 1 : 20,000 scale maps of the enemy area when approximate contours were drawn by viewing the overlaps of the air photographs stereoscopically. Broadly speaking no exact contouring was attempted while carrying out aerial survey from vertical air photographs during the war. In 1918, air sketching was resorted to by Major Beazeley in Mespotamia, for sketching details from an aeroplane in cases where there was insufficient time to photograph the area and to carry out air survey.

In view of the great development of air photo mapping during the first World War, Captain H. H. Thomas of the Royal Air Force was deputed to visit India during the winter of 1918–19, for advising the Indian Government in the peace time uses of air survey. Based on his report, experiments for 1-inch scale topographical and large scale city surveys were carried out at Agra early in 1920. Encouraged by the success of this experiment, No. 18 Party was reorganized as an Air Survey Party from 1st October 1923 in order to take up aerial survey of the Irrawaddy Delta forests which was successfully completed during 1923–24.

The Indian Air Survey Committee consisting of officers of the Survey of India, Royal Air Force, General Staff and the Director of Civil Aviation was formed in March 1927 to collect information and to watch development in air survey both for civil and military purposes and to act as advisers to the Government of India on all questions connected with air survey. During this period air survey was carried out for details only from rectified mosaics.

A more advanced method of plotting from aerial photographs for hilly country, as described by Hotine in the survey of Glen Clova, modified to suit Indian conditions was introduced by Captain D. R. Crone during 1930–31. During 1931–32, Captain Crone visited England and Switzerland with a view to study the latest air survey methods in these countries. On his return, he developed the method of extension of height control using oblique photographs. Research for meeting the topographical accuracy standards and determination of heights from the air photographs was continued in No. 18 (Air Survey) Party during 1930–33. First provisional edition of Chapter XII of the Handbook of Topography on Air Surveying compiled by Captain D. R. Crone was published in 1933. During this period, the method of surveying contours on vertical aerial photographs was introduced as an experimental measure, but the main stress continued to be on the use of oblique photographs.

In 1939–40 some military air survey exercises were carried out in Naushera with the primary object of rapid production of 1 : 50,000 scale topographical maps and 1 : 25,000 scale battle maps. During these years, air survey was carried out mostly for detail only with the contours either being surveyed on the ground or by using oblique photographs in inaccessible areas.

A stereocomparator manufactured by the Cambridge Instrument Company, with the optical work by Messers Ross was received in 1938 and stereocomparator control work from obique air photographs was undertaken for control of air survey in tribal territories in 1939. A parallax measuring bar was designed for use with the MIO pattern mirror stereoscopes for extension of height control from parallax measurements.

Until the Second World War, however, standard topographical maps of the Survey of India were not produced in No. 18 (Air Survey) Party, activities being confined to special maps for the Northern Command and the Air Force. The experiment with modern air survey methods was greatly developed during the Second World War and with the acquisition of slotted template equipment for the extension of planimetric control, great impetus was given to the use of graphical air survey methods, not only for the revision of existing maps but also for the preparation of new maps. After the Second World War, air photographs were widely used to produce standard topographical maps as well as project maps on all scales for the irrigation and hydroelectric development schemes.

In 1948 Brigadier G. F. Heaney, Surveyor General, initiated the proposal for training of the Survey of India officers in London with a view to introduction of photogrammetric survey in India. The first photogrammetric instrument, the Multiplex, was received in India towards the end of 1950 but could not be installed due to defective tables and lack of air-conditioned accommodation.

In October 1951 Colonel I. H. R. Wilson, Surveyor General based on the recommendations of Dr. C. A. Hart, who was then in India in the capacity of the Vice-Chancellor of the University of Roorkee, asked for some Wild stereoplotting instruments to increase the speed of national mapping and requested for the services of some foreign experts to impart photogrammetric training in India. These recommendations were further strengthened by Professor W. Schermerhorn of the Netherlands, who visited India towards the end of 1952 as the Technical Adviser from the United Nations Organisation.

During the period 1954–66, sufficient experience has been gained in India in photogrammetric survey methods employing precision stereo-plotters. With one Wild A7 and one Wild RC 5a aerial camera in 1954, we developed rapidly in this sphere, adding a number of precision plotters. At present the department holds twelve Wild A7, twenty Wild A8, twentyeight Wild B8, six Kern PG2 and three Multiplex spread over a number of units carrying out photogrammetric surveys on scales ranging from 1 : 1,000 to 1 : 50,000.

4. **Modern trends in photogrammetry.**—Though photogrammetry in its present form is comparatively a young science, phenomenal progress has been made in photogrammetry during the last two decades. The superwide angle photography with Wild RC 9 camera fitted with superavaigon lens is being increasingly used for small scale topographical mapping on scales 1 : 50,000 to 1 : 250,000. The necessity of electronic dodger printers for the preparation of better quality photographic prints has been widely accepted. The use of stabilised mounts is expected to lead to simplification in photogrammetric instrumentation. A new system ANSQ-28 being developed in U.S.A. is likely to add to great speed and further improve quality of aerial photography.

The AP-C Analytical Stereoplotter, the latest type of stereoplotter designed by Dr. U. Helava of the National Research Council, Canada and developed jointly by Bendix Corporation, U.S.A. and O.M.I., Italy, is an analytical plotter incorporating electronic and electrical concepts and represents a great advancement in photogrammetric instrumentation. It has a plotting speed of 2 to 3 millimeters per second and an overall accuracy of the order of 5 microns. Though the system is designed primarily of vertical photography with a maximum frame size of 23 cm by 23 cm, oblique and convergent photography with focal lengths up to 60 centimetres can also be accommodated.

Photo interpretation which was first introduced in the nineteenth century has advanced through stages of experiment to a valuable technique for the study of many civil and military problems. In 1951 a separate commission on photo interpretation was established by the International Society of Photogrammetry. The methods of photo interpretation have been found to be precise and reliable and are being increasingly used in the various disciplines of geology, soil survey, forestry, etc., on reasons of speed, accuracy and economy, when compared with conventional ground methods.

5. **Place of photogrammetry in mapping.**—The most important application of photogrammetry is in topographical mapping. The aerial photographs are the basic tool for the practice of photogrammetry and it is important to have a good well-flown aerial photography as it enhances the speed and economy of the photogrammetric method. The use of aerial photographs for topographical mapping purposes falls under one of the two headings :—

(*a*) using a single photograph ;

(*b*) using a stereo pair of photographs.

SECTION I.—INTRODUCTORY

A single photograph consisting of a single bundle of rays can provide only planimetric information. If the terrain photographed is reasonably flat and the angle of tilt in near vertical photographs is less than 3 grades, the single photographs themselves may be considered as maps and they may be assembled in mosaics to provide photo maps of the area. For many practical uses, aerial mosaics are ideally suited.

The more important surveying unit in photogrammetry is the stereo pair. The branch of stereo-photogrammetry divides itself into the main heads of graphical and mechanical methods. The graphical method which is usually referred to as air survey, makes use of simple instruments and the processes of intersection, interpolation, height fixing and sketching of detail and contours as adopted in the ground survey methods and is suitable where high initial investment and high accuracy is not required. The mechanical method which makes use of precision *restitution instruments* to reconstruct a scaled model of the terrain photographed through the processes of relative and absolute orientations, is more accurate and economical and is commonly referred to as the photogrammetric method.

For photogrammetric survey, at least four control points are required for each stereo pair. The provision of this basic control by ground method is a time-consuming and expensive operation. The cost of ground control provision is considerably reduced by extension of control by aerial triangulation where photographs are used for bridging between ground control points. Planimetric aerial triangulation makes use of radial line principles either in graphical or mechanical or analytical form for extension of planimetric control. Spatial aerial triangulation carried out in three dimensional space in the stereoplotting instruments or by the analytical method is used for extension of both planimetric and height control. Reduction in the requirement of the basic ground control results in greater economy in the photogrammetric mapping procedure.

The accuracy of photogrammetric mapping is largely dependent on the quality, location and accurate identification of ground control points. Provision of ground control points for photogrammetric survey, therefore, deserves special consideration.

This Chapter deals with the special requirements of aerial photography and ground control points for photogrammetric survey and the procedures for aerial triangulation and plotting of the detail and contours for complete topographical mapping both by graphical air survey and photogrammetric methods. Terrestrial photogrammetry and use of oblique photographs will not be treated in this Chapter because these are not used in the department at present.

SECTION I.—INTRODUCTORY

The basic principles of survey enumerated below apply equally to photogrammetric survey methods :—

(*a*) Working from the whole to part,

(*b*) Economy of control,

(*c*) Good adjustment of all instruments,

(*d*) Application of independent check.

The essential requirements for smooth, rapid and economic working of photogrammetric method involving a multitude of records being dealt by a number of people are sound planning, good organisation and quality control at every step of the photogrammetric procedure, whether for extension of control or plotting of detail and contours.

SECTION II.—AERIAL PHOTOGRAPHY

6. Types of photographs.—Photographs used in surveying can be divided into the following main classes according to the direction of the camera axis :—

(*a*) Vertical photographs.

(*b*) Oblique photographs.

(*c*) Convergent photographs.

(*d*) Trimetrogon photography.

(*e*) Terrestrial photographs.

(*a*) *Vertical air photographs.*—These are taken with the axis of the aerial camera (air borne) vertical or nearly vertical. A vertical photograph closely resembles a map and is particularly suitable for obtaining uniform coverage. These are particularly suitable for topographical mapping and are, therefore, used in the Survey of India.

(*b*) *Oblique photographs.*—These are taken with the axis of the aerial camera (air borne) intentionally tilted from the vertical. These photographs cover large areas of ground but clarity of details diminishes towards the far end of the photograph. Low oblique are those on which the horizon does not appear. These are sometimes used to compile reconnaissance maps of inaccessible areas. High oblique are those which are tilted sufficiently to contain the apparent horizon. These were previously used for extension of planimetric and height control, when the available ground control was insufficient. With the introduction of radial and aerial triangulations oblique photographs are seldom used in the department.

(*c*) *Convergent photographs.*—These are low oblique photographs taken with two cameras exposed simultaneously at successive exposure stations, with their axes tilted at a fixed inclination from the vertical in the direction of the flight line so that the forward exposure of the first station forms a stereo pair with the backward exposure of the next station. Special plotting instruments are required for compiling topographical maps from convergent photographs.

(*d*) *Trimetrogon photography.*—Another type of photography which is a combination of a vertical and two oblique photographs is trimetrogon photography. These are used in U.S.A. for rapid production of reconnaissance maps on small scales. Oblique sketchmasters are used for map compilation from the wing oblique photographs.

(*e*) *Terrestrial photographs.*—These are taken with phototheodolites from camera stations on the ground with the axis of the camera horizontal or nearly horizontal and they present the more familiar elevation view. These are used for survey of structures and monuments of architectural or archeological value.

7. **Convergent Photography.**—The advantages of convergent photography are :—

(*a*) It gives better height precision for a given photo scale due to its larger base/height ratio.

(*b*) A larger area is covered by one model for a given photo scale and thus fewer models are required for a specified area.

The disadvantages of convergent photography are :—

(*a*) Aerial triangulation is difficult. It does not give the height precision given by vertical photography due to greater effect of inner orientation errors in convergent aerial triangulation.

(*b*) Special restitution instruments are required.

(*c*) Mosaics cannot be constructed.

Thus convergent photography is useful for a project involving only one strip (say a road project) and where full height control for each model is available. This could be used for photo-interpretation too. For topographical mapping, the vertical photography is useful.

8. **Angles of photography.**—Photographs can also be divided into three classes according to the regular field of the lens used in the camera for photography, viz.

(*a*) Normal angle,

(*b*) Wide angle,

(*c*) Super-wide angle.

Normal angle (or standard angle) lens has a coverage upto 70° and a focal length ranging from about 200 mm to 300 mm. The advantages of normal angle photography are :

(*i*) less dead ground is encountered and is hence more useful in mountainous terrain and built up areas ;

(*ii*) it is suitable for rectification due to smaller relief displacements.

The disadvantages are :

(*i*) very high flying is necessary for small scale photography ;

(*ii*) it gives lower height precision for a given photo scale due to smaller base/height ratio.

Wide angle lens has a coverage between 70° and 100° and a focal length ranging from about 100 mm to 150 mm. These are useful for low flights and high speed photography and hence preferred to normal angle lens.

Super-wide angle lens has an angle of coverage of about 120° and a focal length ranging from 45 mm to 90 mm. Since this gives the smallest scale photography for a given height ceiling and the best height precision for a given photo scale (due to large base/height ratio) some of the foreign countries make use of it. The main disadvantages of super-wide angle photography are :

(*i*) it requires special restitution instruments ;

(*ii*) edges are less sharp and not bright ;

(*iii*) it may give stereoscopic difficulties due to dead ground/steep slopes ;

(*iv*) it is not suitable for rectification due to greater relief displacements.

9. Negatives of photographs.—Photography is also classified according to the type of negatives used :

(*a*) Glass plate,

(*b*) Film.

Glass plate is more stable than film and its flatness can be guaranteed. But they are heavy and bulky ; they are liable to break. Films are unbreakable and easy to handle. A film magazine can usually contain twice as many exposures as a plate magazine.

10. Reseau photography.—Yet another classification of photography is

(*a*) Reseau photography.

(*b*) Plain photography.

Reseau photography is one in which a set of squares appear on each photograph and might give improved precision with aero triangulation, but only if analytical methods are used. Also reseau gives the indication regarding the flatness of the film at the time of exposure.

In India, however, we are using vertical photography with wide-angle or normal angle lens. Films are used and no reseau is exposed simultaneously.

11. Aerial cameras.—The aerial cameras for survey photography should be distortion-free and of high resolving power ; its optical unit holding the lens, fiducial marks and the plane which defines the focal plane should be housed in a rigid mechanical structure. The main types of aerial cameras in use are :—

(*a*) *Normal or standard angle camera*, which has a lens with an angle of coverage upto 70° and the focal length ranges from about 200 mm to 300 mm. Cameras of this type in use in India are Williamson Ross Eagle IX Mark II (Service No. F/52), f=300 mm ; and Wild RC 5a, f=210 mm.

(*b*) *Wide-angle camera,* which has a lens with an angle of coverage between 70° to 100° and the focal length ranges from about 100 mm to 150 mm. Cameras of this type in use in India are Williamson Ross Eagle IX Mark II (Service No. F/49), f=153 mm ; Wild RC 5a, f=115 mm; Wild RC 8, f=115 mm, and Zeiss RMK II, f=153 mm.

Wild RC 9 superwide-angle cameras having an angle of coverage of about 120° and the focal length ranging from 45 mm to 90 mm, is another important type of camera which is suitable for small scale photography. This camera has not yet been introduced in India.

12. **Components of aerial cameras.**—The major components of an aerial camera are : lens, lens cone, shutter and diaphragm, camera body, camera drive mechanism, film magazine, focal plane, and film flattening device.

The *lens* is composed of a number of elements which should be so assembled as to form one optical axis for the whole lens. The lens assembly should be distortion-free, free from aberrations and of high resolution. The lens surfaces should have anti-reflection coating.

The *lens cone* supports the lens and retains it at a predetermined distance and position from the film or plate negative, and serves to exclude direct light from striking the negative emulsion. The interior of the lens cone is painted black to reduce reflection.

The *shutter* and *diaphragm* of an aerial camera functions as a light valve and regulates the amount of light and time for which it is permitted to pass through the lens and expose the film or plate. The various types in use are louver, focal-plane, between-the-lens and rotary-disc shutters.

The *camera body* houses the camera drive mechanism driving motor, operating handles and levers, electrical connections and switches and other accessories, if any.

The *camera drive mechanism* is the power unit and power distributor for the entire camera. The electric motor operates the cams, gears and shafts of the camera. The power is routed to the shutter and the film by means of rods and couplings. When a cycle is complete the camera drive recieves an electrical or mechanical impulse, operates the shutter, and thus exposes the film or plate.

The *film magazine* contains the film and has a driving mechanism which receives power from the camera drive mechanism and thereby shifts the film after each exposure has been made. In addition, the magazine contains a device for holding the film flat in the focal plane while the exposure is made.

The *principal focus* of an aerial camera is the point on the camera axis where a bundle of rays parallel to the axis converages.

The *focal plane* of an aerial camera is the plane at right angle to the camera axis, and passes through the principal focus. A metal plate known as 'locating back' is used in modern aerial cameras for placing the film in the exact focal plane.

The *film flattening* is usually accomplished in modern aerial cameras by vacuum system. The 'locating back' has grooves in which there are small holes which lead to a central vacuum connection and holds the film firmly against the focal plane frame at the moment of exposure.

13. **Survey aircrafts in use.**—In India, aerial photography is at present carried out by two flying agencies, namely, the Indian Air Force and Messrs. Air Survey Company of India (Private) Limited, Dum Dum. The selection of aircraft for survey photography is done by the flying agency.

The two main factors which are required to be considered for the selection of aircraft are ceiling height of the aircraft and its flying range. An aircraft for survey photography should have the requisite minimum speed, a high rate of climb, good stability while in flight and un-obstructed view in all directions for ease of navigation. It should be able to remain in the air long enough to take advantage of suitable photographic time, spacious to accommodate all necessary equipment, and powerful enough to carry its full load to the maximum flying height specified. The following aircrafts are in use in India :

		Ceiling Height
Canberra	..	15,500 metres
Dakota	..	7,300 metres
Cessna	..	8,000 metres
Dominie	..	5,200 metres

14. **Camera calibration.**—Before any photography is carried out all cameras likely to be used on the photographic task *must* be calibrated. The calibration of aerial cameras is essential to ensure accuracy of photogrammetric measurements. The camera calibration consists of the determination of the inner orientation elements, the value of the principal distance and the co-ordinates of the principal point relative to the fiducial centre as origin. This is the responsibility of the flying agency. Lines joining the opposite

fiducial marks should intersect at 90° within a tolerance of ± 1 minute of arc. The co-ordinates of the principal point with respect to the fiducial axes co-ordinate system should not be larger than 0·03 mm in perpendicular direction. The average radial distortion as measured at any point should not depart from the distortion curve supplied by the manufacturers by more than ± 0·005 mm. The filter and the camera port glass should be plane parallel and optically flat. All cameras used should be recalibrated at the close of the flying operations. When recalibration provides new calibration data, the date of supersession should be clearly indicated.

The flying agency should supply a copy of the Camera Calibration Report, indicating the following :—

(*a*) The manufacturer's name and type of camera.

(*b*) The serial numbers of the camera optical unit and the lens.

(*c*) The distances between the fiducial marks.

(*d*) The angle of intersection of the fiducial axes.

(*e*) The co-ordinates of the principal point relative to the fiducial axes with the fiducial centre as origin.

(*f*) The co-ordinates of the reseau crosses where a reseau is used.

(*g*) The calibrated focal length or principal distance of the camera together with the corresponding radial distortion curve.

(*h*) The unflatness of the focal plane, if any.

15. **Emulsions and Filters.**—A fine grain, high speed and high resolving power emulsion with good colour sensitivity is required for rendering of fine details during the short exposure time used in aerial photography to avoid image movement. The aerial film should have a non-shrinkable topographic safety support base. The aerial films may be panchromatic, infra-red, colour and spectrazonal (or false colour).

All aerial photographs are made through filters which are coloured plates of glass or glass plates with a layer of dyed gelatine in between, placed over the camera lens. The filters are generally yellow or red in colour. The function of the yellow filter is to absorb blue and violet light so that the photograph is made by green and red ; it is therefore, referred to as 'minus blue' filter. The function of the red filters is to absorb blue, violet and green light, thus confining the exposure to the long wave-lengths of the visible spectrum. The main function of filters is clear rendering of ground detail by atmospheric haze penetration.

The *panchromatic* emulsions are predominantly used in aerial photography. The best compromise between speed and sharpness is chosen, depending on the type of camera, lighting conditions, photo scale and the type of terrain. The film is used in combination with the minus blue filter the spectral absorption of which ends at 500 mm wavelength.

For *infra-red* photography, the aerial film emulsion has infra-red sensitivity and is used in combination with a minus blue filter the spectral absorption of which ends at a wavelength of 500 mm. The infra-red film is also used in combination with a red filter absorbing all the visible spectral region wavelengths except red and transmitting red and infra-red. In this photography differentiation between water and vegetation is greatly facilitated, because vegetation reflects a large proportion of infra-red light whereas water and soil which reflect practically no infra-red light appear nearly black on infra-red photographs.

The aerial *colour* film is a three layer film which should be used in combination with suitable filters chosen appropriate to flying height and haze conditions. Colour photography is useful only on large scale because medium scale photography produces such pronounced haze effects and has such a low colour resolution that the resulting images have hardly any advantage over black and white panchromatic photography.

The *spectrazonal* film is a two layer film which separately records spectral regions in the green, in the yellow-red, and in the infra-red. This type of film which is a modification of three layer aerial colour film is of greater practical value than the standard colour film due to reduced haze effect and has greater interpretational possibilities than infra-red film. This film is more expensive and its processing is more delicate and complicated than in the case of standard panchromatic and infra-red photography.

The aerial films in general use are, Aerographic Super XX, Aerographic Tri-X, Aerographic Infra-red, and Ektachrome Aero of Kodak, Aeropan and Agfacolour of Agfa, and special Aviphot Pan 30 and 33 films of Gevaert. The aerial films are available in lengths of 100, 200, 500 and 1000 feet, the last one being mostly used for reconnaissance photography.

16. Lay-out of photographic task.—The lay-out of the area to be photographed indicating north, south, east and west limits are marked on the existing published ¼-inch or 1 : 250,000 scale maps of the area. The area, if too large, is divided into smaller blocks and marked A, B or C. If possible, the flying area should be bounded by natural features so as to be easily recognisable from the air ; it should preferably be rectangular in shape.

Aerial photographs are flown in strips to cover the specified area. For convenience of handling, it is advisable to keep the number of strips to the minimum. The flight direction of main strips which are called *filling-in* strips is, therefore, kept along the length of the area. This direction which should either be in cardinal directions, viz., East-West or North-South or any other direction when flown along any particular natural features, should be clearly indicated. Where economy in ground control is desired, photographic control strips called *tie strips* are flown at right angles to the filling-in strips. Sometimes tie strips are flown across filling-in strips to connect points of ground control. The spacing of tie strips depends on the accuracy of survey desired.

17. **Design of photographic specifications.**—The design of photographic specifications consists of the choice of scale of photography, camera, lens, and overlaps – all of which are dictated by the topography, scale, contour interval, accuracy requirements of the final and available equipment.

If the graphical method of air survey is to be followed, the *scale of photography* is usually chosen to be the same as that of air survey. When stereoplotting instruments are used for survey, the precision of the plotting instrument and its enlargement ratio, the precision of contours are also taken into consideration while deciding the scale of photography. This aspect has been dealt in greater detail in Section XIII of this Chapter.

The choice of *camera and lens* has to be made from the following cameras available in India :—

Camera	*Focal length of Lens*	*Format size*
Wild RC 5a ..	11·5 cm and 21 cm	18 cm × 18 cm
Wild RC 8 ..	11·5 cm	18 cm × 18 cm
RMK 15/23 ..	15 cm	23 cm × 23 cm
Eagle IX/F.49 & F.52	15 cm and 30 cm	23 cm × 23 cm

For stereoscopic plotting of photographs there should be at least 50% overlap between two consecutive photographs. The forward *overlap* in flight direction should normally be 60%. In mountainous terrain with large relief variations, a greater forward overlap, i.e., 65%to 70% is preferable in order to avoid short overlaps. In case of block photography where saving in control point is achieved, a forward overlap of 80% is used and photographs having matching edges with photographs of adjacent strips and having at least 60% overlap amongst the photographs of the same strip, are chosen for actual work.

The *lateral overlap* between strips should be just sufficient to provide certainty of identification of common detail and to allow for the defects of lateral tilt and slight deviations from the flight course in the length of the strip. As a measure of economy the lateral overlap should be the minimum. In most cases a lateral overlap of 20% should suffice. In mountainous terrain a lateral overlap of 30% is recommended.

Section II.—AERIAL PHOTOGRAPHY

18. Flight control instruments.—The use of flight control instruments results in the reduction of basic ground control points which in turn increases the economy, accuracy and speed of the photogrammetric method. The flight control instruments in common use are: statoscope, horizon camera, gyroscope, the solar periscope and the radar altimeter. Some electronic measuring instruments such as Shoran, Hiran and Aerodist are being used in some western countries for providing planimetric position of air station. The *statoscope* records the differential heights of the successive exposure stations which can be introduced in the stereo-plotting instrument during aerial triangulation. The *horizon camera* photographs the horizon in two or four directions; the longitudinal and lateral tilts of $\pm 6^c$ accuracy are obtained by stereoscopic measurements of horizon photographs which are used during aerial triangulation. The *gyroscope* is capable of providing tilt values of $\pm 20^c$ accuracy. The *solar periscope* is capable of providing tilt values of $\pm 5^c$ accuracy. The Airborne Profile Recorder (A.P.R.) is a radar altimeter which provides a continuous record of ground clearance by electronic measurement and is used for computing flying heights of successive exposures. The flight control instruments are specially useful for areas where ground control is sparse and is difficult to provide due to inaccessibility.

19. Indenting aerial photography.—The Survey parties of the department can obtain aerial photography by placing their demand on the Surveyor General of India through the Circle Directors. In India the season for aerial photography, which largely depends on good weather conditions is from October to April. Since a number of formalities and a good deal of planning are to be completed by the department and the photographic agencies before undertaking the aerial photography, it is essential that all demands should reach the Surveyor General of India by May every year. While placing demands for aerial photography the following details should be supplied in order to avoid ambiguity and consequent delay :—

(*a*) Purpose of photography.

(*b*) Layout of the area to be photographed marked on published maps on 1 inch to 4 miles or 1 : 250,000 scale. For photography on large scale, existing 1-inch or 1 : 50,000 maps should be used. The general direction of flight should be stated.

(*c*) Scale of photography.

(*d*) Overlaps - both forward and lateral should be stated.

(*e*) Camera and focal length of lens preferred.

(*f*) Season and time of photography preferred.

(*g*) Requirements of number of sets of contact prints and their types, i.e., glossy or matt, number of enlargements, mosaics, photo indexes, camera calibration report, etc., should be stated.

20. **Numbering of photographic task.**—Every aerial photographic task is allotted a job number by the Surveyor General of India for easy reference and handling. The photographic tasks carried out by the Indian Air Force are allotted numbers suffixed by 'A', e.g., 346-A. Other numbering used by the Indian Air Force for tasks not allotted by the Surveyor General of India, are GS/A, OC/9/60 etc. The photographic tasks carried out by M/S Air Survey Company (Private) Limited Dum Dum, are allotted numbers suffixed by 'B', e.g., 331-B. Some old tasks, carried out by I.A.S. & T. Ltd. Dum Dum (old name of M/S Air Survey Company) were suffixed by 'E', 'S' and 'G' e.g. 311 E, 519 S and 613 G.

21. **Planning for flight.**—The planning for the photographic task is taken up by the flying agency after the photographic specifications have been received. This is carried out with a view to produce aerial photographs with economy and speed according to the specifications laid down. It consists of laying down the flight lines and start and finish points for each run on the flight maps, computing flying height of aircraft to achieve the desired scale, aircraft speed, exposure intervals, estimated number of exposures in each run and for the entire tasks, number of linear miles of flying necessary and estimated time of turns, practice runs, etc. The selection of filter and determination of exposure of shutter speed and relative aperture are also done at this time. The choice of aircraft is dictated by its ceiling height, the desired photo scale and the particular camera that it can carry. Other important factors which are considered are distances from the base to the area of photography, the number of exposures in one sortie and duration of flight for one sortie specially where changing of film magazines during flight is not possible.

22. **Navigational aids.**—The efficiency of aerial navigation directly affects the efficiency and economy of the photogrammetric method. Accuracy of flight maps is closely related to accuracy of navigation whenever visual navigation for photography is used. The flight maps should, therefore, be prepared on the largest scale existing maps of the area. The availability of easily identifiable topographical features greatly facilitates visual navigation. Lack of identifiable features as in vast desert, forest or snow covered areas makes good flight difficult. The efficiency of navigation in such areas and for areas where accurate flight maps are not available can be increased by instrument navigation. The use of good navigation instruments improves the efficiency of photographic coverage by maintaining minimum constant lateral overlaps

by accurate navigation particularly when experienced aircrew is not available.

23. Processing of aerial films.—The accuracy of photogrammetric survey depends, to a large extent, on the quality of photographic prints. The quality of prints depends on the film used and the method of processing. Nonshrink topographic base aerial film should always be used for photography for photogrammetric survey. Processing of the exposed film negatives should be carried out carefully under good laboratory conditions in order to ensure dimensional stability and geometrical accuracy. Aerial negatives are ideally dried slowly in air of about 55 percent relative humidity without any use of heat, thus avoiding stresses as far as possible. The relative humidity of 50% to 60% and temperature of 70°F to 90°F are the limits which the film negatives should be maintained at all times of exposure, transportation, processing and storage. Processing of negatives, soon after photography, is desirable for early indexing.

24. Indexing.—The flying agency is responsible for the preparation of photo index on a suitable scale generally on ¼-inch or 1 : 250,000. Field contact prints on single weight glossy paper are prepared for indexing and for identifying gaps in the photography. The photo index is essential for easy handling and reference of individual photographs.

Indexing of vertical photographs is carried out by laying them out in single strips or as mosaics of complete area. Each single print is examined against the existing ¼-inch or 1 : 250,000 scale map and its position is marked on the map. In this way positions of several photographs of a strip are marked, thereby indicating the position of the strip. The positions of the adjacent strips are marked in different colours. For proper indexing, the existing map should be reasonably accurate. For accurate aerial photography of areas of which no reliable map coverage exists, it is desirable to initially prepare a photo mosaic on a scale smaller than that of actual photography.

On completion of indexing of photographs of the area it will be clear whether any gaps or short overlaps have been left. If considered necessary, the gaps and short overlaps are covered by re-flights. The photo index is then prepared on tracing cloth on which the common edges of adjacent strips and usable outer limits of the end strips are indicated by lines. The strip or run numbers are indicated at the beginning and end of each flight line, with some of the photo numbers say first and last and every tenth photo shown clearly.

The graticule lines for both latitude and longitude are drawn at intervals of 15 minutes and all the graticule values are entered. The following information is provided on the top margin of the photo index :—Photographic Specification or Task Number, title of job, scale of index, scale of photography, aerial camera and focal length of the lens with its number and date of photography. The photo index may also contain a legend at the bottom which indicates the sortie numbers with their dates of flight and the strip numbers flown in each sortie. A number of diazo copies of the photo index is prepared for the users while the original on tracing cloth is preserved by the flying agency for later additions, if any.

25. **Photographic prints.**—On completion of an aerial photographic task the following materials are supplied by the flying agency to the survey party :—two sets of contact prints, two sets of photo index and one set of camera calibration report. Other requirements of the survey party, if any, are also supplied by the flying agency but are charged for separately.

The prints required by the survey party are usually three sets, one set of smooth matt prints and two sets of unglazed glossy prints. Pencils can be used on matt prints which are, therefore, used for detail chalking or as ground verification copies. Detail is clearer and easier to interpret on glossy prints and one set of these prints is used for post-pointing of ground control and the other set is used by the surveyor to interpret doubtful details during aerial triangulation and plotting and by the section officer when examining the completed work. Positive transparencies on film or glass plates called diapositives, are used in certain types of photogrammetric plotting instruments. Diapositives on glass plates are used for precision photogrammetric plotting.

Ordinary photographic paper which consists of cellulose fibres undergoes dimensional changes when wet and again when dried. When photographic paper prints are to be used for air survey the dimensional changes should be minimum. The waterproof paper in which dimensional changes are reduced by a water-resisting lacquer coating, are used for this purpose. The best result is achieved by using the Agfa correctostat paper in which the dimensional changes are minimized due to the presence of an inner layer of aluminium foil.

26. **Scrutiny of photographs.**—The scrutiny of the completed photographic task is essential to establish its suitability for the intended use. A thorough physical inspection of the film negative where possible and aerial photographs should be carried out by the survey party indenting the photographs and a scrutiny report prepared in quadruplicate under the following headings :—

(*a*) Particulars of photography - which should include Specification of Task Number, scale of photography camera used, focal length of lens and date of photography.

(*b*) General – The general information regarding the purpose of aerial photography, incidence on degree sheet and direction of flight of filling-in and tie-strips should be stated here.

(*c*) Definition – The defects of definition are examined by strip-wise inspection of both the film negatives and glossy contact prints. Suitability of aerial photography for its intended use should be stated here.

(*d*) Overlaps – The percentage of both types of overlaps, forward and lateral, is checked strip-wise and is recorded.

(*e*) Crabbing – The percentage of crabbing is examined strip-wise and recorded.

(*f*) Scale of photography – The scale of photography should be determined for at least three photographs in each strip and average scale calculated and compared against the scale of photography ordered.

(*g*) Gaps – The scrutiny report should be accompanied by a trace on the scale of photo index showing the following :—

(*i*) Limits of area having stereoscopic coverage.

(*ii*) Actual gaps in photography.

(*iii*) Resulting gaps in photography caused by short overlaps both in forward and lateral directions.

(*iv*) Limits of areas of defective photography due to clouds, shadows, etc.

(*v*) Limits of areas recommended for re-photography.

(*h*) Area photographed – Area having stereoscopic coverage should be measured by planimeter and be compared against area ordered for photography and the result should be recorded.

(*i*) Defects in negatives – The film negatives are examined for clear appearance of fiducial marks and of numbering of film, strips and individual photographs, definition and dimensional changes (by measurement).

(*j*) Conclusion – Area figures for which deduction in the cost of aerial photography is recommended due to gaps, short overlaps or other defects, e.g., clouds, shadows, etc., rendering the aerial photography unsuitable for survey purpose, should be indicated here.

The scrutiny report should be prepared by the survey party in quadruplicate of which three copies should be forwarded to the Circle Director for sending two copies to the Surveyor General of

India with recommendations for re-photography and deduction in the cost of aerial photography, if any.

27. **Registration of photographs.**—All photographs and their indexes received in the survey party should be immediately entered in the air photo stock register on form O. 141(c) by the party record-keeper and thereafter a record is kept of all their movements in or out of the party. On their receipt in the survey party the photographs are sorted into strips and put into air photography envelopes on form O. 141(d) strip-wise and the relevant data regarding the photographs are entered in the appropriate places, on the face of the envelope. The record-keeper also maintains an air photo distribution register on form O. 141 (c) in which all internal bulk issues to and receipts from camp or section officers are entered. The supervising (camp or section) officer may also maintain a separate air photo register on form O. 141(c) for correct recording of individual issues to surveyors or air survey draftsmen.

SECTION III.—STEREOSCOPY

28. Natural stereoscopic vision.—The main advantage of aerial photogrammetry is that it presents a three-dimensional model of the terrain by stereoscopic vision. Stereoscopic vision is an essential prerequisite for the application of photogrammetric methods of survey. Though monocular vision conveys some idea of depth, no high degree of accuracy in distance or depth determination is possible with monocular vision. It is through binocular vision that the quality of human vision is greatly improved. In photogrammetry we are mainly concerned with the application of binocular vision which enables us to obtain a spatial or three-dimensional impression of a model formed by two overlapping photographs of the same object taken from two different points.

Natural stereoscopic perception constitutes the highest degree of visual unison. Each eye directly perceives an image of the viewed object (half image) and both image halves are co-ordinated in the brain, where they blend together. The two image halves are not exactly identical as the two eyes are separated laterally and occupy different view points. This lateral shift of the two images is known as binocluar parallex. The two factors which must be present to convey depth perception are the degree of convergency of the eyes and the actual stereoscopic vision.

29. The human eye.—The human eye resembles a photographic camera in certain respects. A diagram of the horizontal section of the human eye is given in figure III·1. In the human eye the lens system comprising of the *cornea*, the anterior chamber of *acqueous humour* and the crystalline *lens*, forms an image on the *retina* which corresponds to the negative plane of the camera. The nervous impulses from the retina are conveyed by the optic nerve to the brain, where the impulses from the two eyes are integrated to give a three-dimensional impression in binocular stereoscopic vision. Critical focussing is achieved by varying the radii of curvature of the eye lens with the help of the circular muscles, the *corpus ciliare*, which has the effect of varying the focal length.

The retina consists of photo-sensitive cells and when both images of the same point fall on these cells in the retina then the two are seen as one point. The human eye has a resolving power of one minute of arc. On the retina there is a small area, the *fovea centralis*, over which the resolving power of retina is the maximum. However, the eye lens is not so accurate and there can be a diffusion disc of upto four minutes of arc due to spherical aberration. Any object to be clearly distinguished by the retina should subtend at the eye an angle somewhat larger than one minute and preferably four minutes of arc. This characteristic of the human eye is fundamental for the precision in stereophotogrammetric determination of distance differences which in photogrammetry correspond to elevation variations.

In binocular stereoscopic vision of a point, the visual axes of both the eyes rotate in their sockets to converge on that point and at the same time the radius of curvature of the crystalline lens is altered to bring the point into focus on the retina. The former action is known as *convergence* and the latter as *accommodation*. The relative convergence of the optical axes of the two eyes when observing points at varying distances from the eyes is important. In figure III·2 the convergence of the axes of the eyes when gazing at point P is p, and when gazing at Q it is q. Thus the angle p conveys the perception that P is at a distance Pd and the angle q conveys the perception that Q is at a distance Qd ; and the angle p − q conveys the perception that the distance between the two points P and Q is Qd − Pd. The angles p and q are called the *parallactic angles* for the two points. Stereoscopic vision with the normal naked eye is not possible at distances closer than about 250 mm, unless the eyes are aided by lenses. The perception of depth by stereoscopic vision is not possible beyond about 600 metres because the parallactic angle is too small beyond that distance.

30. Artificial stereoscopic vision.—Natural stereoscopic vision is based on the fact that horizontal parallaxes occur between both image halves because of the depth differences in the viewed object. Since each eye is only capable of registering directions towards points, it is possible to provide a substitute for a view in natural space by presenting a photographic image to each eye. In so far as such images represent views of space from different points and therefore, differ from each other by amounts of horizontal parallax, retinal images are formed similar to those obtained when viewing in actual space.

In photogrammetry, instead of viewing in actual space, we observe, two aerial photographs of the same area taken from two different view points and thus presenting two dissimilar views of the same area. Under suitable conditions, a three-dimensional impression or a stereoscopic model very similar to that of natural space is obtained from the two aerial photographs.

If the overlaps of the stereo pair are kept inwards and observed stereoscopically, we obtain an orthoscopic view, i.e., the elevations and depths appear in their natural order. If the overlaps are outwards, pseudoscopic view is obtained in which the natural order is reversed.

The essential conditions for stereoscopic vision are :

(*a*) Separate images must be presented, practically simultaneously to each eye but must exhibit parallexes i.e. views from different points.

(*b*) The direction of vision to corresponding image points must intersect in space.

(*c*) If images are to be viewed with the naked eye, corresponding distant points of the two images should not have any greater relative separation than the interocular distance.

31. Requirement of a stereoscopic pair.—In order to produce a spatial model, the two photographs must fulfill the following conditions :—

(*a*) The two photographs must have adequate common overlap.

(*b*) The camera axes should be approximately coplanar.

(*c*) The convergence of the optical axes of the cameras must not be too large and no greater convergence should be experienced than in natural vision.

(*d*) The scale of the photographs should be approximately the same. Though difference in scale of up to 15% can be tolerated, when scale difference exceeds 5% continuous observation and measurement become difficult.

32. Stereoscopic observation with naked eyes.—It is possible to observe a pair of photographs stereoscopically without any optical aids but it is tiring. If one looks at a stereoscopic pair with naked eyes, the eye axes have to be directed almost parallel, but at the same time the accommodation must be adjusted for vision at close distance. Moreover, this method of stereoscopic viewing restricts the amount of overlap area which can be seen at one time. In order to be seen stereoscopically, the photographs must be held one on top of the other which is difficult. The difficulties of stereoscopic viewing are obviated by optical devices, known as stereoscopes, which permit simulteous viewing of a pair of photographs.

33. Different types of stereoscopes.—The stereoscope, the simplest aid to stereoscopic viewing, plays an important role in photogrammetry. Two types of stereoscopes which are commonly used in the Survey of India are, lens or pocket stereoscope and mirror steroscope.

(*a*) *Lens stereoscope.*—The most important parts of a lens stereoscope are the two single positive lenses with focal length less than 250 mm, which are mounted at normal eye base (65 mm) apart and its principle is illustrated in figure III·3. The pocket stereoscopes usually have plano-convex lenses, the upper side being flat with a focal length of 100 mm. The magnification is given by $\frac{250}{100} = 2 \cdot 5$ times. The images are so placed under the stereoscope that corresponding details lie at about the same distance from each other. The rays emanating from the image details are parallel after their passage through the lenses, and the eyes can adjust themselves for sharp vision at long distance. The same conditions as the direct stereoscopic viewing accordingly prevail, and the stereoscopic vision is greatly facilitated. This is a cheap and portable instrument, with a large field of view. The lens stereoscope is best suited only for small format photographs.

(*b*) *Mirror stereoscope.*—The principle of mirror stereoscope is illustrated by figure III·4. Two mirrors or more often a pair of mirrors, a prism and a lens are the main components of a mirror stereoscope. The refraction power of the lens is such that the outgoing rays become parallel. Since the distance from the lens to the image plane is rather long i.e. about 300 mm, the refraction power of the lens is lessened and there is a reduction of $\frac{250}{300} = 0{\cdot}8$ times Mirror stereoscopes are, therefore, provided with binoculars with magnification factors of 4 to 6 times and sometimes of 8 times. The visual field is automatically lessened to a corresponding degree during the enlargement process. The mirror stereoscope is used for continuous viewing of large format photographs as the visual base in this instrument is enlarged by double reflections. The modern mirror stereoscopes have double reflecting prisms incorporated in their viewing systems to permit oblique viewing which is more comfortable.

34. Other methods of stereoscopic viewing.—Other methods of stereoscopic viewing make use of superimposition of two images of the photos to be viewed stereoscopically. The superimposition of the two images can be achieved by separation by colour filters, polarized filters or intermittent light.

(*a*) *Separation by colour filters.*—The photo images are either printed or projected in complementary colours. By placing a filter of the same colour over each eye correspondingly, each picture is observed by one eye only. This method is also known as *anaglyph* method.

Our eyes are sensitive to electromagnetic waves between 380 and 780 millimicrons which is called light and consists of bands of different colours. When, under normal conditions, we see all these wavelengths together the sensation is white light. Filters are coloured glasses absorbing part of the light. A pair of filters can be used to separate the two pictures projected over each other. Multiplex uses red and blue filters and Kelsh Plotter uses red and green filters. In all cases of blue or green filters some red light is allowed to pass because if the red is entirely cut out so much light will be stopped that it will be difficult to use them.

With projected photos, the filter is placed over the light source of each projector so that one photo is projected in red and the other in blue. When we wear spectacles with the appropriate filters of the same colour in the projectors, ideally the red picture cannot be seen by the eye covered by the red filter which can only see the blue picture and vice versa. Therefore, the separation is attained and a stereoscopic impression results.

The disadvantages of red and blue filter combination are :—

(1) The colour contrast is tiring to the eyes due to the disturbances caused by the chromatic retinal rivalry known as colour bombardment.

(2) A large amount of light energy is lost (Red 87%, Blue 67%) by absorption. The blue filter which absorbs the infra-red gets extremely hot.

(*b*) *Separation by polarised filters.*—If in place of complementary colour filters, polarized filters are used these will polarize the projection rays of the two component images perpendicularly to each other (plane polarization).

Filters of polarizing light consist of a thin film of plastic prepared in such a way that the molecules, which are long and thin are laid end to end, thus allowing only one phase of the light to pass through the filter, the other being reflected by the molecules. For stereoscopic vision, we use two such filters, so that the molecules of one filter are at right angles to the molecules of the other filter.

In a plotting instrument, the filters are so placed that the polarized light rays forming the left image are at right angles to the light rays forming the right image. By putting on spectacles so oriented that the filter molecules are parallel to the respective projector filter molecules, it is possible to see only one image with each eye.

The advantage of polarizing filters are :

(1) only 50% light loss occurs in both projectors,

(2) there is no colour contrast between the two pictures, and

(3) it is possible to use colour photography.

The biggest disadvantage why it cannot be used in photogrammetry is that the surface on which the image is projected should be diffused, so that it can be viewed equally well from all directions; but such a surface will act as a depolarizer and no stereoscopic image can be seen. The directional sensitivity of the polarized light to the observer's head movements has proved disadvantages. Polarized light is used in three-dimensional motion pictures and colour slides. This is possible as the angle of observation is very small. The spectacles which are used as analysers have their filters set at 45° to the plane of polarization for obtaining the maximum colour effect. When held upside down it gives a pseudoscopic effect. As polarizer some reflecting surfaces, e.g., dark glass, plastic or lino can be used.

(*c*) *Separation by intermittent light.*—Finally the inertia of the human eye can be exploited by presenting two component images. The phenomenon that intermittent light if sufficiently rapid i.e. 35–50 cycles per second is seen by the eye as continuous light is known as persistent vision.

By means of projectors and synchronised shutters over the eyes it is possible to arrange for the right eye to see the right image only and for the left eye the left image. The light is supplied at 50 to 60 cycles per second and the shutters over the eyes are made to coincide with this speed. Thus by changing the phase of the current it is possible to obtain a pseudoscopic image. By taking the average height reading of the stereoscopic and the pseudoscopic image it is possible to eliminate operator differences in positioning the floating mark.

35. **The floating mark.**—The floating mark is a reference mark lying in the plane of the object space of a photograph used for examining or measuring a stereoscopic model and is seen as occupying a position in the three-dimensional space formed by the stereoscopic fusion of a pair of photographs. If we put two identical marks, say black dots, on corresponding points on a pair of overlapping photographs and view them under the stereoscope we shall see that the two dots appear as one as if it is part of the stereoscopic image. The fused dot will coincide in position and height with that point of the model.

By making these marks on a transparent medium they may be moved separately over each photograph and thus vary the difference of parallax existing between the marks and the point of the model under examination. A fused mark of this nature will appear to float in space relative to the landscape and may be made to recede from or approach the ground by varying the differences of parallax existing between the mark and the part of the photograph under examination.

The floating mark may be of any of the following types :—

(*a*) A black dot as in Wild A7 or A8.

(*b*) A luminous light dot as in Multiplex or Kern PG-2.

(*c*) A coloured dot as in Zeiss Stereoplanigraph or Stereotope.

The advantage of a light spot or coloured dot is that it will show up clearly against details like forests that would obscure a black dot. The size of a floating mark varies from 0·03 to 0·06 mm. The floating mark should be as small as possible and provide only moderate contrast with the photographic images. The floating marks have different shapes like circle, dot, cross, or T-shape, but the dot is most commonly used.

36. **Stereoscopic measurements.**—The preconditions for successful execution of stereo-photogrammetric measurements apart

from good stereoscopic sight are practice in the guiding of the measuring mark and experience in judging the spatial image and in recognizing stereoscopic defects. Experience has shown that persons with normal sight or who wear suitable spectacles, can generally also see stereoscopically.

Some of the important rules for the performance of stereoscopic measurements are :

(1) Never stare at the floating mark as then the stereoscopic vision suffers.

(2) Never gaze at one point in particular ; give the eye an opportunity to move. Before measuring, move around the point and then gradually bring it down to the ground.

(3) It is preferable to come down to touch the ground from a floating position. In instruments where it is possible to change from stereoscopy to pseudoscopy it is advisable to measure in both ways and take the mean.

(4) The two photographs should be equally illuminated. Sense impressions from two differently illuminated photographs take different times to reach the brain and residual parallaxes remain.

(5) When viewing photographs through a binocular lens system, the system should be properly focussed.

37. **Orientation of a pair of photographs for stereoscopic viewing.**—In order to obatin a good three-dimensional impression of the terrain, the photographs should be properly oriented under the stereoscope. This orientation is performed in the following way :—

(*a*) Draw a straight line on a piece of paper and indicate a point L on the left of this line.

(*b*) Focus and adjust the binoculars where existing.

(*c*) Place the stereoscope over the line in such a way that when looking through the left eye-piece with left eye only, point L is visible in the centre of field of vision and when looking with both eyes the lines coincide.

(*d*) Indicate a point R on the line which must be in the centre of the right field of vision when looking with one eye through the right eye-piece. Now when looking with both eyes and with parallel eye axis the points L and R should coincide. The distance L–R is the instrument base of the stereoscope used.

(*e*) Fix the stereoscopic pair of air photographs with selotape or lead weights in such a way that the flight lines of the consecutive air photographs are in direct line and the distance between the principal points of the left hand photo and the right hand photo equals the length of base of the stereoscope and all shadows fall towards the observer. Now the air photos are oriented properly for stereoscopic examination.

(*f*) Place the stereoscope over the oriented air photos in such a way that flight lines coincide when looking with both eyes. Eye base, instrument base and photo base are all in one plane now. In this position the air photographs can be observed stereoscopically without strain.

(*g*) The rest of the stereoscopic overlap can be scanned by moving the stereoscope parallel to the position as described above.

(*h*) Practice with two or three different pairs of air photographs.

SECTION IV.—FUNDAMENTAL CONCEPTS OF PHOTOGRAMMETRY

38. Elementary mathematical concepts.—An aerial photograph is a central projection. In an ideal case of an *absolutely* vertical photograph of a *completely* flat terrain the aerial photograph will be geometrically the same as the corresponding map of the area. However, due to tilt of the photograph and relief variation of ground photographed, an aerial photograph differs geometrically from the map of the corresponding area.

The central perspective is characterised by the fact that all the straight lines joining corresponding points, i.e., straight lines joining object points to their corresponding images, pass through one point. This point is known as the perspective centre and is illustrated in figure IV·1.

Straight lines AA′, BB′, etc., joining corresponding points in object space and the image plane are known as perspective rays and pass through the perspective centre 'O'. A plane in-between the perspective centre and the object is known as a positive plane.

39. Geometry of perspective projection.—To study the properties of an aerial photograph it is necessary to understand the geometry of perspective projection. Some properties of this projection have been dealt with in the following lines. In figure IV·2, plane I can be considered as ground plane and plane II as positive plane of photograph.

(*a*) AB, the line of intersection of the object and image plane is known as the *axis of homology* or the *axis of perspective*.

(*b*) A plane parallel to plane I and passing through the perspective centre 'O' cuts the plane II in a line CD which is known as the *horizon line*. Horizon line and axis of homology are always parallel to each other.

(*c*) Images of all objects infinitely distant on the right of AB will be formed on the horizon line. Points on the horizon line are known as *vanishing points*.

(*d*) It is a fundamental property of perspective projection that a line in one plane projects as a line in the other plane, the two lines meeting at the axis of homology.

(*e*) A plane which is perpendicular to both the planes and passes through the perspective centre is known as the *principal plane*. The lines of intersection of this plane with the two planes are known as *principal lines*. EF and EH are the principal lines.

(*f*) The angle 'θ' between the principal lines is the angle between the perspective planes. When this angle 'θ' is 'Zero' the plane II can be considered as an absolutely vertical photograph. In normal vertical photography, this angle seldom exceeds a couple of grades.

(*g*) All images of parallel lines converge to a vanishing point. Thus images of all lines parallel to the principal lines in the object plane will converge to H.

(*h*) ON and OP are the perpendiculars from O on to the planes I and II respectively. The line bisecting the angle PON meets the principal lines of planes I & II in I′ and I. These are called *isocentres*. There are two sets of isocentres but only one will appear on the photograph. One of the most important properties of the isocentre is that angles subtended by different objects at I′ in plane I are the same as corresponding angles subtended at I in plane II, if the plane I, i.e., ground is flat.

(*i*) Any point in plane I such as X has a corresponding position X′ in plane II. Such pairs are called *homologous points*.

(*j*) If two planes are projectively related as in fig. IV·3 certain important relationships exist between the corresponding details in planes I and II.

O″1, O″2, O″3 & O″4 on plane II are the images of O′1, O′2, O′3 & O′4 in plane I. Let there be another line in plane I which cuts the lines O′1, O′2, etc., in 1′, 2′, 3′ and 4′ then it can be shown that

$$\frac{12}{24} \Big| \frac{13}{34} = \frac{1'\,2'}{2'\,4'} \Big| \frac{1'\,3'}{3'\,4'} = \text{r}.$$

This ratio is known as the ***anharmonic ratio*** of the four distances ; because of the constancy of the ratio a unique position can be found for this line in plane II as well so that 1″ falls on line O″1, 2″ falls on line O″2 and so on. This property is used in graphical rectification and will be dealt with later.

40. Important terms.—Since an aerial photograph is a perspective projection the definitions and concepts enumerated above apply to it as well. The terms as applied to vertical photography are

(*a*) *Perspective centre.*—The lens of the camera can be taken as the perspective centre. Normally two perspective centres are associated with an aerial camera, external perspective centre and internal perspective centre.

(*b*) Perpendicular from the perspective centre on to the ground intersects the ground in a point which is known as the *ground plumb point*. Its intersection with the photograph is termed *photo plumb point*. In figure IV · 2 they are N and n respectively.

(*c*) Perpendicular from the perspective centre on to the photograph intersects the photograph in the *principal point*. The length of this perpendicular intercept oh denoted by 'c' is the *principal distance*.

(*d*) ***Tilt***.—The angle between the horizon plane and photograph can be resolved in two components, one in the direction of flight and the other at right angles to it. The direction of flight is normally taken as X and a direction perpendicular to it as Y (fig. IV · 4).

(*i*) The component about the Y axis, i.e., in the direction of X is known as phi (ϕ) tilt or X-tilt or fore and aft tilt or tip.

(*ii*) The component about the X-axis i.e. in the direction of Y is known as omega (ω) tilt or Y-tilt or lateral tilt.

(*e*) ***Isocentres***.—I and I′ are the isocentres. As before, angles are the same at I and I′ if plane I, i.e., ground is flat.

It is very important to remember that angles are true at the isocentres only when the ground is flat.

(*f*) ***Plate parallel***.—All horizontal lines parallel to the horizon line or axis of homology are termed as plate parallels. Thus in fig. IV · 2 all lines parallel to CD will be termed plate parallels.

(*g*) *Scale of photographs*.—In the case of a *truly* vertical photograph of *flat* terrain scale of photograph $= \frac{f}{H}$, where f is the principal distance and H the flying height above mean terrain level. In the case of tilted photograph the scale is not constant. It is constant along any particular plate parallel but varies in different plate parallels.

(*h*) ***Axis of tilt***.—The plate parallel which passes through the principal point is defined as axis of tilt. In fig. IV · 2 a line in plane II parallel to CD and passing through H will be the axis of tilt.

(*i*) *Isometric parallel.*—The plate parallel passing through the isocentre 'i' is termed the isometric parallel. It can be proved that this is the only parallel along which the scale $= \frac{f}{H}$, i.e., the same as in the case of a vertical photograph.

41. **Image displacement due to relief.**—Let 'O' be a camera station from which a *truly vertical photograph* is taken (ref. fig. IV·5). It will be seen that if the point P_1 has no elevation it will photograph at P′ but if it has an elevation 'Δz' then it will photograph at P″, i.e., the image will appear displaced by P′P″. This is known as relief displacement. It can be shown that its magnitude is equal to $N'P'' \cdot \frac{\Delta Z}{Z}$ and that it is radial from the plumb point.

42. **Image displacement due to tilt**—(*a*) ***Flat terrain.***—Let O (in fig. IV·6) be the perspective centre and I and II be the positive planes for a truly vertical and tilted photographs respectively. The figure shows a cross-section in the principal plane ; for a point 'A' which appears at a′ in I and at a in II the displacement is equal to ia′–ia. It can be shown that it is equal to $\frac{ia \cdot \text{Sin}\theta}{f - ia \cdot \text{Sin}\theta}$ and s radial from the isocentre. When the point b′ is non-axial in plane I (ref. fig. IV·7) the tilt displacement which is still radial from the isocentre can be shown to be equal to

$$ib' - ib = \frac{ib^2 \text{ Sin } \theta. \text{ Cos } \phi}{f - ib \text{ . Sin } \theta. \text{ Cos } \phi}.$$

(*b*) *Accidented terrain.*—Displacements due to relief are radial from the plumb point and displacements due to tilt are radial from the isocentre. However, there is no such point where angles are true to the corresponding angles on the ground in the case of a tilted photograph of an accidented terrain (i.e., terrain in which there are elevational differences).

43. **Stereoscopic parallax and determination of heights.**—The feasibility of finding height differences of objects in the object space with the help of measurement of parallax from overlapping photographs of the area concerned is one of the most important qualities of photographs. It will be seen that because of relief there is a certain amount of relief displacement of the same point in two adjacent photographs that gives the parallax difference which is related to the height of the point under consideration. *Stereoscopic parallax* is the change in position of the image of a point on two adjacent photographs, due to the change in the position of the camera. Thus stereoscopic parallax of A in fig. IV·8 is a′a″ and that of B is b′b″. It can readily be seen that points at the same

level will have the same parallax. The parallax of all points at the same level as A will be equal to a′a″. When a point is at a different level, e.g., B_1 its parallax becomes different from a′a″. It is this difference which is related to the height of the point and is of utmost utility in photogrammetry.

In normal work one of the principal points is chosen as the reference point. Then, if say principal point of the left hand photograph is chosen as the reference point, P_R is found by measuring the distance between the principal point of the right hand photograph and the principal point of the left hand photograph as transferred to the right hand photograph.

The relationship between parallax and height differences can be derived with the help of fig. IV·8.

From similar triangles, for a point A,

we have $\frac{Z_A}{B} = \frac{c}{P_A}$ or $Z = \frac{B \cdot c}{P_A}$.

Similarly for any other point A

$$Z_R = \frac{B \cdot c}{P_R} \quad \ldots\ldots\ldots\ldots\ldots\ldots (IV\text{–}1).$$

The height difference ΔZ is then given by

$$\Delta Z = Z_A - Z_R$$

$$= B \cdot c \left(\frac{1}{P_A} - \frac{1}{P_R} \right)$$

$$= B \cdot c \, \frac{P_R - P_A}{P_R \cdot P_A}$$

$$\because P_A - P_R = \Delta P,$$

$$\Delta Z = - \frac{B \cdot c}{P_R} \cdot \frac{\Delta P}{P_R + \Delta P} \quad \ldots\ldots\ldots (IV\text{–}2)$$

Substituting (IV–1) in (IV–2), we get :

$$\Delta Z = - \frac{Z_R}{P_R + \Delta P} \cdot \Delta P \ldots\ldots\ldots\ldots (IV\text{–}3).$$

In this formula, Z_R is the flying height over a reference point. We will use the left hand principal point as reference point ; so P_R must be parallax of this point and it can be measured on the right hand photograph. It is often indicated as b′ (base at photo scale).

Sometimes it may be necessary to compute ΔP for a certain ΔZ. The inverse formula is given by

$$\Delta P = - \frac{P_R}{Z_R + \Delta Z} \cdot \Delta Z \ldots\ldots\ldots\ldots (IV\text{–}4)$$

The minus sign may be confusing to the reader. We defined $\Delta Z = Z_A - Z_R$. That means, if the flying height over point A is larger than that over reference point, ΔZ is positive. If the point under consideration is higher than the reference point ΔZ would be negative and hence parallax difference ΔP would be positive and *vice versa.*

Similarly it can be proved that

$$\Delta h = \frac{Z_R}{P_R + \Delta P} \cdot \Delta P \quad \ldots\ldots\ldots\ldots (IV\text{–}5).$$

The formulas in equations (IV–4) and (IV–5) are very important. An example will clarify the use. Let the data be as follows :—

(*a*) size of picture 18 cm × 18 cm

(*b*) flying height above reference plane = 5,000 metres

(*c*) base as measured in right hand photograph = 70 mm then parallex for a height difference of 100 metres above reference

$$\text{plane} = -\frac{70 \times (-100)}{5000 - 100} \text{ mm}$$

$$= + \frac{7000}{4900} = + \frac{10}{7} = + 1 \cdot 43 \text{ mm.}$$

Similarly, knowing parallax, which can be measured on the photograph, height differences can be determined. For the same example

$$\Delta h = \frac{5000}{70 + 1 \cdot 43} \times 1 \cdot 43 \text{ metres}$$

$$= + \frac{5000 \times 1 \cdot 43}{73 \cdot 43}$$

$$= \frac{7150}{71 \cdot 43} \simeq 100 \text{ metres.}$$

It must be kept in mind that these formulas give correct result only when the photographs are truly vertical. The presence of tilt in either one or both of the photographs disturbs the relationship. This will be dealt with later.

44. **Basic theory of orientation.**—A single photograph is a central projection of the area photographed. It has nine degrees of freedom, i.e., the three co-ordinates X, Y, Z of the exposure station with respect to the ground and three rotational freedoms which could be resolved in terms of rotations around direction of flight and two other axes perpendicular to it. These six unknowns in respect of a photograph are known as elements of exterior orientation. The remaining three refer to the inner geometry of the camera, i.e., the principal distance and the position of principal point with respect to the fiducial marks. These three are normally known and constitute elements of inner orientation. Thus for all practical

purposes, unknowns in respect of single photograph can be taken as six which are the elements of exterior orientation. As a natural corollary it is clear that co-ordinates of a point on the photograph can be expressed in terms of six unknowns, and that if photo and corresponding ground co-ordinates of three points are known the photograph can be oriented.

In the case of a single photograph the relationship between photo and corresponding ground co-ordinates is expressed by the formulæ,

$$x = \frac{a_1 X + b_1 Y + c_1 Z}{a_3 X + b_3 Y + c_3 Z} \qquad \text{(IV-6)}$$

$$y = \frac{a_2 X + b_2 Y + c_2 Z}{a_3 X + b_3 Y + c_3 Z} \qquad \text{(IV-7)}$$

Where x, y are the co-ordinates on the photographs and X, Y, Z the co-ordinates of corresponding ground points. As will be seen these two are related by 9 co-efficients a_1, b_1, etc. These 9 co-efficients are functions of 9 elements of orientation. Out of the 9 elements of orientation we have assumed that three elements (i.e., elements of inner orientation) are known ; *thus there remain only six unknowns.* If six equations can be formed, i.e., if three points are known, all the unknowns can be solved.

In surveying, the reverse problem of determining the ground co-ordinates from measurements on the photograph is more important and it can be seen that the three ground co-ordinates X, Y, Z cannot be determined from the two plate co-ordinates X, Y since the central projection is not reversible. However, the X, Y co-ordinates of points on a plane "Z constant" can be determined; the relationship is

$$X - X_1 = \frac{p_1 x + q_1 y + r_1}{p_3 x + q_3 y + r_3} \qquad \text{(IV-8)}$$

$$\text{and } Y - Y_1 = \frac{p_2 x + q_2 y + r_2}{p_3 x + q_3 y + r_3} \qquad \text{(IV-9)}.$$

In this X_1, Y_1 are the ground co-ordinates of the projection centre and p_1, p_2, etc., are the 9 unknowns which can be determined if inner orientation elements and co-ordinates of three other points are known. This is one of the basic equations in photogrammetry.

45. Geometry of stereoscopic pairs.—It was seen that with the help of measurement on a single photograph relative differences of heights cannot be determined. A pair of overlapping photographs can, however, be used to obtain reconstruction in space of the terrain that is common to the two photographs. Since there are six unknowns for each photograph (it is assumed that the inner orientation is known) 12 conditions will have to be fulfilled. These are achieved by

(*a*) *Relative orientation* :—The two projectors are manipulated relative to each other in such a way that all corresponding rays intersect in space. This condition can be achieved if it is ensured that at least 5 corresponding rays intersect in space. Thus five degrees of freedom are fixed in this way.

(*b*) *Absolute orientation* :—The relatively oriented model is scaled and levelled so that it is brought into appropriate position with respect to the instrument co-ordinate system (which in turn is related to the ground co-ordinate system). For scaling, a minimum of two points should be known in X and Y and for levelling, a minimum of three non-collinear height points should be known. These two operations will fix the remaining seven unknowns.

46. Mathematical basis of relative orientation.—In figure IV·9 the projection of a particular point is shown with two projectors. This can represent two of the innumerable rays constituting the whole projection. Let the two rays intersect the projection plane in A_1 and A_2. The distance A_1A_2 when line A_1A_2 is perpendicular to the base line is known as the Y-parallax. When the line A_1A_2 is perpendicular to the base line, X-parallax of the point is zero. When the distance $A_1A_2=0$ it means that the two rays intersect each other.

A_1A_2, i.e., Y-parallax can be made zero for a paticular point by the relative movement of the elements of exterior orientation of the projector. The differential change in the x and y co-ordinates of projected points can be expressed as

$$\Delta x_1 = z \left[1 + \left(\frac{x}{z} \right)^2 \right] \Delta\phi_1 - \frac{xy}{z} \Delta\omega_1 - y\, \Delta k_1 + \Delta bx_1 - \frac{x}{z} \cdot \Delta bz_1$$

and $$\Delta y_1 = \frac{xy}{z} \cdot \Delta\phi_1 - z \left[1 + \left(\frac{y}{z} \right)^2 \right] \Delta\omega_1 + x \cdot \Delta k_1 + \Delta by_1 - \frac{y}{z} . \Delta bz_1$$

where x, y, z are co-ordinate differences with respect to the left hand projection centre

and $\Delta\phi_1$ change in phi (ϕ) in the left hand camera

$\Delta\omega_1$ change in omega (ω) in the left hand camera

(Suffix 1 refers to the left hand camera).

Similarly when elements of projector II are moved

$$\Delta x_2 = z\left[1 + \frac{(x-b)^2}{z^2}\right]\Delta\phi_2 - \frac{(x-b)y}{z} . \Delta\omega_2 - y \cdot \Delta k_2 + \Delta bx_2 - \frac{(x-b)}{z} \cdot \Delta bz_2$$

and $$\Delta y_2 = \frac{(x-b)}{z} . y . \Delta\phi_2 - z\left(1 + \frac{y^2}{z^2}\right)\Delta\omega_2 + (x-b) . \Delta k_2 + \Delta by_2 - \frac{y}{z} . \Delta bz_2 .$$

The equations given above indicate the relationship between small corrections which are to be given to the orientation elements to remove the Y-parallax that will be found in the model. Thus

$$-P_y \text{ (error)} = \Delta y_1 - \Delta y_2$$

$$= \left[\frac{xy}{z} \cdot \Delta\phi_1 - \frac{(x-b)y}{z} . \Delta\phi_2 \right] - \left[z\left(1+\frac{y^2}{z^2}\right)(\Delta\omega_1 - \Delta\omega_2)\right]$$

$$+ [x . \Delta k_1 - (x-b) . \Delta k_2] + (\Delta by_1 - \Delta by_2)$$

$$- \frac{y}{z} (\Delta bz_1 - \Delta bz_2)$$

where differential movements of the elements of orientation are corrections to the elements of orientation.

This can be arranged in the following form as well

$$-P_y = \frac{xy}{z}(\Delta\phi_1 - \Delta\phi_2) - \frac{y^2}{z}(\Delta\omega_1 - \Delta\omega_2) - \frac{y}{z}(\Delta bz_1 - \Delta bz_2 - b\,\Delta\phi_2$$

$$+ x(\Delta k_1 - \Delta k_2) + [\Delta by_1 - \Delta by_2 + b \cdot \Delta k_2 - z(\Delta\omega_1 - \Delta\omega_2)]$$

$$= \frac{xy}{z} \cdot \Delta A - \frac{y^2}{z} \cdot \Delta B - \frac{y}{z} \Delta C + x \cdot \Delta D + E \text{ .... (IV–10).}$$

Thus with five equations formed by measuring Y-parallaxes at 5 known points in a model the 5 unknowns Δ A, Δ B, etc., can be determined. For relative orientation one element from each group can be taken. The elements may, e.g., be taken as

(*a*) In A–7 for Aerial triangulation—

(*i*) Ist model ϕ_1, ϕ_2, ω_1, K_1, K_2

(*ii*) 2nd model ϕ_{new}, ω_{new}, K_{new}, by_{new}, bz_{new}

(*b*) In A–8 for normal plotting—

K_1, K_2, ϕ_1, ϕ_2 and ω_1 or ω_2.

It can be deduced that only 50 different combinations are available for orientation.

47. Geometrical concept of relative orientation.—As already mentioned earlier projective geometry proves that all corresponding rays of two homologous bundles will intersect if specifically chosen five corresponding rays of the two bundles intersect. Fig. IV ·9 shows two projectors with which a stereoscopic pair of photographs is being projected. Corresponding rays, e.g., $O_1 A_1$ and $O_2 A_2$ do not normally intersect. The distance between A_1A_2 can be indicated with a component in X-direction known as X-parallax. By keeping the projectors fixed but by lowering or raising the projection table, X-parallax can be made zero ; if in this position of the projection table by manipulating one of the projectors the Y-parallax is also made zero, then O_1 A_1 and O_2 A_2 intersect.

In this way if pairs of corresponding rays are made to intersect, all the corresponding rays of the model will be intersecting, i.e., the model will be free of Y-parallax. The six points in the model which are generally used for the elimination of Y-parallax are also indicated in fig. IV·10.

The sequence of numbering is more or less universally accepted and will be adhered to in this Chapter as well. Points 3 & 5 are so selected that the rays O_1 5 and O_1 3 subtend equal angles at O_1 which means that in a model of flat terrain distance 13=15. Further the points should be selected about 5 mm from the edge in the negative/diapositive.

48. Elements available for orientation.—For each projector three elements of translation, bx, by, bz and three elements of rotation, kappa (K), phi (ϕ) and omega (ω) are available. The elements of left hand projector normally carry the suffix 1 and those of right hand 2, thus the elements available are

$bx_1, by_1, bz_1, K_1, \phi_1$ and ω_1
$bx_2, by_2, bz_2, K_2, \phi_2$ and ω_2.

Suppose now that one projector was fixed, it should then also be possible to make the model free of Y-parallax by manipulating elements of one projector. Out of the six elements of one projector, one, i.e., 'bx' does not affect Y-parallax but only affects the scale of projection; the remaining five are just sufficient to remove Y-parallax at the five standard locations, i.e., to make the model free of Y-parallax.

The effect of small movements of the elements of orientation at different points in the model can be demonstrated with the help of simple diagrams. For this analysis an oriented model of flat terrain will be the starting point. The elements of orientation, one at a time, will then be given a slight movement and their effect studied.

The axes system followed is as in fig. IV·10. Distances 'b' and 'd' are in the projection. Y-parallax is defined as $Y_r - Y_1$ and is positive when it is in the positive direction of Y. Vectorially join by an arrow the intersection of left hand projector to the corresponding intersection of the right hand projector. If the arrow points in positive direction of Y, the Y-parallax at the point is positive.

Effects of Kappa 'K_1'.—(In the diagrams, dotted lines represent the position of the rays after the introduction of small movements to the element of orientation. The firm lines indicate the position when the model was oriented, thus indicating the positions of intersections of right hand projector. The dotted line arrows indicate the X-parallax introduced and the firm line arrows indicate the Y-parallax introduced).

It is clear from fig. IV·11 that $Py_1=Py_3=Py_5=0$ and $Py_2=Py_4=Py_6=-b\cdot\Delta K_1$.

Effect of Omega (ω).—Fig. IV·12 is a section of left hand projector as viewed from right to left. From the figure it can be seen that

$$Py_1=Py_2=-z\cdot\Delta\omega_1$$

$$\text{and } Py_3=Py_4=Py_5=Py_6=-BC$$

$$=-B'C\cdot\sec a$$

$$=-[\sqrt{(z^2+d^2)}]\cdot\Delta\omega_1\cdot\frac{\sqrt{(z^2+d^2)}}{z}$$

$$=-z(1+\frac{d^2}{z^2})\cdot\Delta\omega_1$$

The effect on the six points is as in fig. IV·13.

This distribution can be split up in two groups. The effect as in fig. IV·14 is the same as that of movement of "by" ; the effect in fig. IV·15 is the characteristic effect of omega.

To remove a Y-parallax patterns in fig. IV·16(a) manipulation of two elements, i.e., by and $\Delta\omega$ will be required essentially. Thus the sequence will be

(*a*) Y-parallax which is characteristic of omega can be equated to $\frac{d^2}{z}\,\Delta\omega$ as in fig. IV·16(a).

(*b*) By manipulating omega (ω_1) Y-parallax equal to ($\frac{d^2}{z}\,\Delta\omega+z\,\Delta\omega$) but in the opposite direction is introduced at points 3, 4, 5 and 6.

(*c*) The remaining Y-parallax $z\cdot\,\Delta\omega$ at points 1, 2, 3, 4, 5 and 6 as in fig. IV·16(c) is removed by manipulating "by".

Suppose the Y-parallax to be removed at points 3, 4, 5 and 6 was $\frac{d^2}{z}\,\Delta\omega_1$. To remove this, $\Delta\bar{\omega}$ will have to be introduced so that Y-parallax at all points may become $z.\,\Delta\omega_1$ (but in the opposite sense).

The omega movement required for removing only $\frac{d^2}{z}\,\Delta\omega_1$ at points 3, 4, 5 and 6 would be $\Delta\bar{\omega}=\dfrac{(d^2/z)\,\Delta\omega_1}{(\frac{d^2}{z}+z)}$

Thus an overcorrection will have to be applied and this over-correction $= \Delta\omega_1 - \Delta\bar{\omega} = \Delta\omega_1 - \dfrac{(d^2/z)\Delta\omega_1}{(\frac{d^2}{z}+z)}$

$$= \frac{z \cdot \Delta\omega_1}{(\frac{d^2}{z}+z)}$$

The overcorrection factor will be

$$\frac{\Delta\omega_1 - \Delta\bar{\omega}}{\Delta\bar{\omega}} = \frac{z \cdot \Delta\omega_1 \cdot (\frac{d^2}{z}+z)}{(\frac{d^2}{z}+z) \cdot \frac{d^2}{z} \cdot \Delta\omega_1}$$

$$= \frac{z^2}{d^2}$$

Effect of phi (ϕ).—Let the left hand projector get a small positive phi (ϕ) motion and let the angle $60_1\,2 = \theta$ (ref. to fig. IV–17). When the projector moves, the angle between the rays will remain the same, i.e., the angle $6'\,0_1\,2'$ will be θ. Let angle $10_1\,2$ be equal to 'a'

Then $\tan\theta = \dfrac{d}{\sqrt{b^2+z^2}}$ and $\tan$ 'a' $= \dfrac{b}{z}$

Angle $2'\,22''$ would also be equal to 'a', $22''$ being perpendicular to $0_1 2''$

In trianlge $20_1 2''$, $22'' = 0_1\,2 \cdot \Delta\phi$

and $2'\,2'' = 0_1\,2 \cdot \Delta\phi \cdot \tan$ 'a'.

The Y-parallax introduced at point 6

$$= 26 - 2'\,6'$$
$$= 0_1\,2\tan\theta - (\,0_1 2'' - 2'2''\,)\tan\theta$$
$$= 2'\,2''\tan\theta \;(\text{ since } 0_1 2 = 0_1 2''\,)$$
$$= 0_1 2 \cdot \Delta\phi \cdot \tan\text{ 'a'} \cdot \tan\theta$$
$$= \sqrt{b^2+z^2}\,) \cdot \frac{b}{z} \cdot \frac{d}{\sqrt{(\,b^2+z^2\,)}} \cdot \Delta\phi$$
$$= \frac{bd}{z} \cdot \Delta\phi$$

It can be seen that $Py_1 = Py_3 = Py_5 = Py_2 = 0$

$$Py_4 = \frac{bd}{z}\Delta\phi$$

and $$Py_6 = -\frac{bd}{z}\Delta\phi$$

The pattern of Y-parallax will be as shown in figure IV·18.

Effect of bz.—The pattern of Y-parallax introduced with bz can be derived from fig. IV·19. It is shown in fig. IV·21.

In fig. IV ·20 is given a cross-section at the left hand projection centre. The magnitude of Y-parallax introduced at point 5 is 55′.

In triangle A55′, 55′ = A5′ ·tan ‘a’

$$= \Delta bz \tan \text{‘a’}$$

$$= \Delta bz_1 \cdot \frac{d}{z}$$

Thus the Y-parallax would be $Py_1 = Py_2 = 0$

$$Py_3 = Py_4 = \frac{d}{z} \cdot \Delta\, bz_1$$

$$Py_5 = Py_6 = -\frac{d}{z} \cdot \Delta\, bz.$$

Effect of ‘by’.—The effect of by is the same on all points in the model. The pattern of Y-parallax is in fig. IV ·22.

The characteristic effect of Y-parallax of small positive changes in the elements of orientation is given in fig. IV ·23.

(*a*) It can be seen that the effect of K_1 and K_2 is the same as that of by_1 or by_2. All these are put in a group and termed translation group.

(*b*) Similarly the effect of ϕ_1 and ϕ_2 is the same as that of bz_1 or bz_2. These are grouped under one head and termed scale group.

(*c*) The effect of ω_1 and ω_2 is similar. This is termed as omega group.

49. Selection of elements of relative orientation.—For relative orientation 5 independent elements should be chosen such that

(*a*) there is one element from omega group (ω_1, ω_2).

(*b*) there are two elements from translation group (K_1, K_2, by_1, by_2).

(*c*) there are two elements from scale group (ϕ_1, ϕ_2, bz_1, bz_2).

The drill for orientation could then be as follows :—

(*a*) Remove parallax at points 1 and 2 with the elements of translation group (two elements in all).

(*b*) Remove Y-parallax at one of the wing points say point 3 with one of the elements of scale group.

(*c*) Remove Y-parallax at a point on the other side of the base opposite to the point chosen in (*b*) (in this case 5) with the element of the omega group and apply overcorrection

The overcorrection can be shown to be :

$$\tfrac{1}{2}\left(\frac{z^2}{d^2} - 1 \right).$$

(*d*) Remove Y-parallax at points 1 and 2 with the elements of translation group as in para (*a*) above.

(*e*) Remove Y-parallax at the wing points adjoining to the one chosen in (*b*) (point 4 in this case) with the second element of the scale group.

(*f*) Repeat the whole drill.

This is the general sequence of the drill for orientation.

A complete reconstruction of a stereoscopic model in a photogrammetric machine involves :—

(*a*) Inner orientation—introduction of plotting principal distance and centering of the photograph/negative/diapositive.

(*b*) Relative orientation—removal of Y-parallax in the model.

(*c*) Absolute orientation—scaling and levelling to known values.

50. **Model deformation.**—It has been explained that in stereophotogrammetry heights of points relative to each other are determined by making use of differences of X-parallaxes of various points. When the two photographs of a model are not in their exact correct relative positions with respect to each other the points in model will contain certain additional X-parallax which would not have been there had the photographs been in their correct relative positions with respect to each other. These additional X-parallaxes vary in different parts of the model and give rise to varying deformation in various parts of the model. Thus a model of a flat ground under these circumstances may appear warped.

It will be more clear from the illustration as in fig. IV ·24 which should be seen stereoscopically. Left hand projection, in an optical projection instrument, e.g., Multiplex, is the correct vertical projection of a flat ground, the right hand projection of the same figure is not a vertical projection but has been projected with some omega inclination. The result is that the flat ground appears twisted around 1–2, point 3 being higher and point 5 being lower than points 1, 2, 4 and 6 which represent the correct level.

In a normal near-vertical photograph such X and Y displacements are inherent as it is not as yet possible to take absolutely vertical photography and as such when parallaxes are measured with a normal parallax bar, the parallaxes are burdened with such discrepancies giving a model which is deformed. The pattern and extent of deformation can best be studied by keeping the left hand projection correct and by considering the effect of one element of exterior orientation at a time on the right hand projection.

(*a*) *Influence of bx.*—(In all the diagrams that follow the tip of the arrow shows the new positions of points in right hand projection).

Fig. IV ·25 shows the effect of 'bx' in the right hand projection. Since there is a constant shift in all points it does not result in any deformation but only result in a shift of height scale.

(*b*) *Influence of 'by'*.—'by' gives a constant shift in Y-direction only and has no influence on X-parallax and hence does not result in any deformations (ref. to fig. IV ·26).

(*c*) *Influence of 'bz'*.—The X and Y movements of points because of bz is as shown in fig. IV ·27. In points 1, 3 and 5 an erroneous X-parallax is measured. This error is the same in all points. The deformation in the model will be as shown in fig. IV ·28.

(*d*) *Influence of phi* (ϕ).—The effect of phi (ϕ) is as shown in fig. IV ·29. The X-parallax discrepancies in a section through point 1 are more than in a section through point 2. The variation of X-parallax is quadratic in the direction of x. This gives a parabolic cylindrical deformation surface, as shown in fig. IV ·30.

(*e*) *Influence of omega* (ω).—It will be seen from fig. IV ·31 that the change in X-parallax in points 3 and 5 is in opposite direction, while there is no X-parallax change at points 1, 2, 4 and 6. The resulting model deformation is as shown in fig. IV ·32 which is well known as omega twist effect and is mathematically a hyperbolic paraboloid.

(*f*) *Influence of kappa* (K).—It can be seen from fig. IV ·33 that there is no X-parallax at points 1 and 2, while at points 3 and 4 it is equal and opposite to that at 5 and 6. This results in certain tilt in the model as shown in fig. IV ·34.

A little scrutiny of the deformed surfaces will make it clear that it is the effect of 'ϕ' and 'ω' only which is non-linear. After relative orientation has been completed there will still be residual errors in the various elements of orientation, giving a certain amount of deformation in the model. Part of the model deformation due to residual errors in 'ϕ' and 'ω' (being non-linear) cannot be eliminated during absolute orientation.

Section V.— RADIAL LINE METHODS

51. Radial line principles.—Radial line triangulation is a form of aerial triangulation procedure in which directions from the approximate photo centre of each photograph in a strip are used for horizontal control extension by successive intersection and resection of these direction lines. The fundamental feature of radial line triangulation is that measurements are made in the plane of the photograph itself.

The great advantage of radial line triangulation is that it affords a comparatively cheap method of planimetric control extension. The equipment needed is inexpensive and the procedures can be adapted to suit the requirements of accuracy.

The basic principle in this method is that in a truly vertical photograph, even in terrain with relief, angles are true at the photo centre. In practice, however, photographs can be only 'near-vertical'. If, therefore, one has a tilted photograph of accidented terrain, no single point can be used as the centre of rediation. In Section IV it was explained that image displacements due to tilt are radial from the isocentre and that image displacements due to relief are radial from the plumb point. The question then arises as to which point could be assumed as the most suitable centre for the measurement of the directions. The assumption should, of course, result only in errors that are acceptable and also the point should be physically identifiable and capable of being marked.

The nadir or plumb point and the isocentre can be identified and physically marked only when the direction and amount of photo tilt have been determined. There are various means of ascertaining this data. Amongst these are the use of a spirit level rigidly connected with the camera, gyroscope, horizon cameras and the measurement of X- and Y-parallaxes. The procedure of using the isocentre or plumb point as the radial centre has not found wide practical use. The use of auxiliary instruments in flight detracts to some extent from the simplicity of the procedures of the radial line methods.

In the practice of surveying from near-vertical photographs, principal point radial triangulation has proved effective and is the normal method of radial line triangulation adopted for topographical mapping.

In a near-vertical photograph the *assumption* that angles are true at the principal point, of course, gives rise to certain errors. The errors given below are those arising due to tilt and relief shown separately. The errors are in photo directions measured at the principal point :—

Error due to tilt $= \frac{1}{4} \Delta i^2 \sin 2\theta$

Error due to relief $= \Delta i \operatorname{Tan} \beta \operatorname{Cos} \theta$

where Δi is the total photo tilt (i.e. not its components 'fore and aft' tilt and 'lateral tilt' but the maximum inclination of the photographs to the horizontal).

β is the angular elevation of a point where the error is being evaluated. The angle is with reference to the horizontal through the ground principal point.

θ is the angle measured at the ground principal point between ground points and the principal line.

The errors given above are systematic errors in photo directions. With a tilt of 4^g the maximum error in photo direction due to tilt is about 6^c. The error due to relief in the same photograph with $\tan \beta = 0 \cdot 05$, is 20^c. With a tilt of 2^g the figures for maximum errors in photo directions due to tilt and relief are $1 \cdot 7^c$ and 10^c. The effect of these systematic errors have been analysed thoroughly and this is of great importance particularly in analytical radial triangulation in which photo directions are measured in a radial triangulator.

To evaluate the errors in terms of linear image displacement arising in principal point radial triangulation due to Radial Line Assumption that the radials from the principal point are angularly true, the following formulæ are more handy :—

Error due to tilt $= \dfrac{Ix. \Delta i^2 . \sin 2\theta}{4}$

Where Ix is the distance from the isocentre to the point. For pratical purposes the distance can be measured from the principal point itself.

Error due to relief $= \dfrac{h}{H} \cdot f \tan i$

Where f is the focal length, h is the height of the point above ground datum and H the height of the aircraft above this datum.

Example (*a*) Format = 23 cm × 23 cm, tilt = 3^g

The value of Ix can be assumed to be 16 cm.

The displacement due to tilt $= \dfrac{16}{4} \times 0 \cdot 047 \times 1$ cm

$= 0 \cdot 008$ cm

(*b*) Assuming a flying height of 4000 metres and a principal distance of 150 mm the relief displacement for a point 500 metres above datum plane is

$= \dfrac{500}{4000} \times 150 \times 0 \cdot 047$ mm

$= 0 \cdot 9$ cm

Generally, with a ground relief of about 10% of the flying height and a tilt of about 3·5 grades, the principal points can be used as the centre for radial line triangulation for medium and small scale topographical mapping without significant errors being introduced.

52. Extension of control by graphical method.—By applying the foregoing principles horizontal control can be extended between ground control. The additional control points established by radial line methods are known as *pass points.*

Radial triangulation may be carried out by any of the following methods :—

(*a*) Graphical

(*b*) Mechanical

(*c*) Analytical

Steps in the graphical method begin with the marking of the radial centre, which in the departmental practice, has always been the principal point. This is obtained usually by marking the intersection point of the lines connecting opposite fiducial marks. In the three-fold overlap of three photos of a strip, two common points are selected and marked, one above the base line and one below the base line. These points are called *minor control points.* In V·1 (*a*) they are indicated by 2u and 2l. The figure '2' indicates photo number. For points above the base line, the letter 'u' is used as suffix and for points below base line the letter 'l' is used as suffix.

The principal point and these minor control points are transferred to adjoining photos. After these steps, the photographs of a strip have a pattern of a point on each photo, as shown in figure V·1 (*a*) and V·1 (*b*).

The tie-in between one strip and another is achieved by selecting *lateral control points.* These are chosen in about the centre of the lateral overlap, in every third photograph. A suitable numbering system for lateral control points would be to designate them by photo number/lower strip number. Thus 23/7 would mean the lateral control point in photo 23 of strip 7, which would also appear in the strip north of this strip 7. Each lateral control point has to be transferred to as many adjoining photographs as possible. Where a minor control point serves the purpose also of a lateral control point, a lateral control point in addition to the minor control point, is not necessary.

The next step is base lining and drawing the radial lines. The principal point on each photograph is connected by a line, usually in vermillion red, with the principal points transferred on the same photo from adjoining photos. An extension is also drawn for about an inch near the edge opposite the transferred principal point.

The subsequent steps are carried out on a long strip of transparent material like kodatrace. (See fig. V·2).

This transparent material is placed on the first photo. The principal point is marked on the transparent medium and the directions from it, to the minor control points, ground control points and lateral control points are traced. The first photo is removed and the next photo is placed under the trace. The kodatrace strip and the photo are mutually shifted and rotated in such a way that the direction 1–2 on the former coincides with the corresponding base line on the photo. On the line 1–2 in the kodatrace, principal point 2 is now marked in such a way that the distance 1–2 on the trace corresponds to the mean strip scale or to the scale on which the graphical triangulation is to be executed. Usually the first base line is scaled on the kodatrace strip to the mean strip scale.

With the second photo now in position, radial lines to the points in it are traced as before and also the base line direction 2–3 is traced. Photo number 3 is slipped under the transparent kodatrace and it is oriented by making the base line on it, viz., 2–3, coincide with the direction 2–3 on the photograph No. 3. Principal point 3 on this line is resected by making use of the radial lines on photo 3 to points 2l and 2u. Their positions having been already intersected on the strip of kodatrace earlier from photos 1 and 2, and the azimuth of 2–3 having been also determined, resection of photo 3 is possible. Thus by a process of intersection and resection positions of all minor control points, lateral control points and ground control points are intersected. The positions of principal points are resected. Fig. V·2 shows a minor control plot.

Short overlap.—As part of flight planning for photography, the fore-and-aft overlaps between photographs of a strip are specified, which is usually 60% or more, for survey by graphical or photogrammetric methods, so that it is always possible to get about 10% area common to three consecutive photographs of the strip. This common overlap is called *supralap*. If the fore-and-aft overlap falls below 50 per cent, no point can be found in a photograph which will be common to *both* the adjacent photographs of the strip. This situation is known as "short overlap".

When such a situation arises, it is worthwhile to break the principal point traverse and treat the two portions on either side of the short overlap as independent strips. However, a less rigorous solution which may be used in unavoidable circumstances is described below.

Suppose there is no supralap between models 8–9 and 9–10 of a particular strip (see fig. V·4), and the principal point p_9, m.c. points A and B have been fixed in the usual manner. The principal point base p_9 p_{10} is marked on photos P-9 and P-10 as follows :—

Superimpose P–10 over P–9 such that corresponding details/points along the direction of flight, on the available overlap, fall one over the other as far as possible, deviations if any being in the direction of flight. A light box may be used. In this position, ink up on P–10, in light blue, the line joining p_{10} and p_9. Select two points X and Y on this line at two extremities (see fig. V·5) within the overlap. Transfer these to P–9 ; let them be X′ and Y′. If p_{10} YX is the p.p. base, then p_9 Y′ will pass through X′. Otherwise the process is repeated, till a pair of such points X, Y satisfy the condition that both p_9 X′Y′ and p_{10} XY are straight lines.

Since A and B do not appear on P–10, two substitute m.c. points, a and b, which appear on both P–9 and P–10 are now selected such that they are not far away from A, B and at about the same heights as A, B respectively. (See fig. V·4).

Let A′ and B′ be the m.c. plot positions of A and B. (See fig. V·6). Trace the photo positions of A, a, B and b on the m.c. plot. Join p_9a and Aa. Through A′ draw a parallel to Aa to cut p_9a at a′. This is the plot position of photo point a. Similarly b′ is obtained.

Since a′, b′ and the p.p. base p_9p_{10} are known, p_{10} is fixed in the usual manner and the principal point traverse is continued.

The assumptions made in the above operations are (*i*) the base line has been located with reasonable accuracy and (*ii*) the scale of the photograph around A and a (and similarly around B and b) is constant.

Triangle of error.—Occasionally the process of resection may yield a small triangle of error. The back rays from the previously intersected points may not resect on the base line direction. Usually the triangle is small and the mean position can be accepted.

If this triangle is large, the position of the principal point of a photo can also be 'solved' graphically. But such a solution should not normally be necessary and efforts should be made to eliminate or minimise the triangle by rechecking the transfer of points, the radial line directions and the base line. In the case of a large triangle resulting inevitably due to a systematic accumulation of errors caused by a combination of ground relief and tilt, the following solution is recommended. See fig. V·3, showing photo 3 in position. '2' represents the distance between the previously intersected position of 2u and the point obtained by tracing its position with radial line 3–2u and base line 2–3 in correct orientation. Similarly '3' represents the distance between the intersected position of 2u and its traced position obtained with the radial line 3–2u in correct orientation alongwith the base line also correctly oriented. In each of these positions the principal point 2, i.e. the transferred P.P., is also pricked yielding P_e and P_f on the position obtained with radial line through 2u in position and P_f with radial line 2l in position. P_eP_f is next divided in the ratio of distances 3 and 2. The point so obtained is marked P'_2 in the figure V·3. Let the distance P'_2P_2 be designated by '3'. The principal point position of photo 3 is marked on the kodatrace within the triangle of error by setting it off at distances in the ratio of 1, 2 and 3 from the respective sides of the triangle.

The next step is the scaling of the *minor control plot* which is the term used to describe the kodatrace strip in which all the minor control, lateral control and ground control points are intersected. It also contains the resected principal points all on some uniform scale, determined initially by the choice of a base length for the first photo base.

This arbitrary scale has now to be changed to the scale of a plot sheet in which the ground control points are plotted to a required scale of survey.

This is done in the following way. See figure V·7. Points A and B, both ground control points, are available on the minor control plot as well as on the plot sheet. The minor control plot is placed on the plot sheet in such a way that 'A' on the minor control plot coincides with 'A' on the plot sheet and 'AB' on the minor control plot coincides with the direction 'AB' on the plot sheet. A correction has to be applied to the position of P. The direction of this correction is along 'AP' (in figure V·7) on the minor control plot. The magnitude is arrived at as follows.

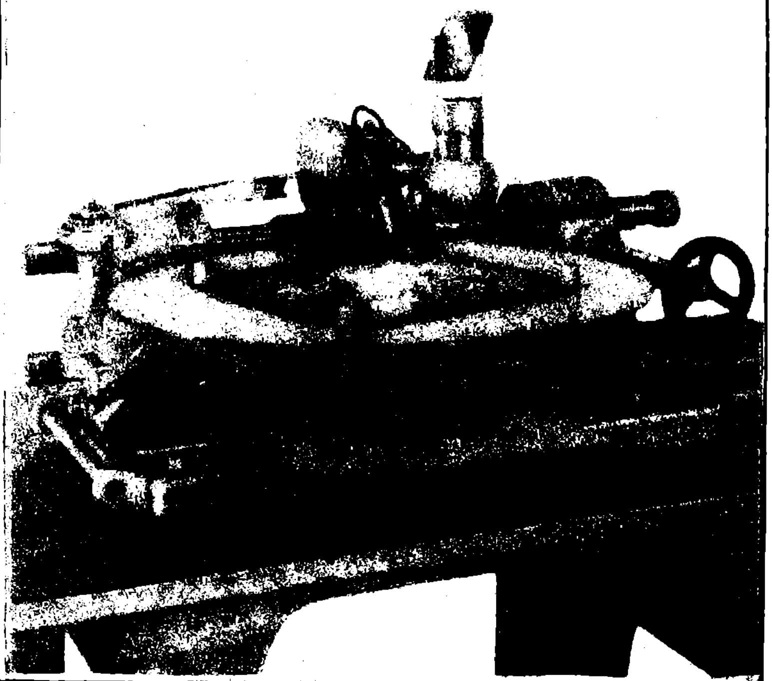
With the minor control plot in position, as described, over the plot sheet, draw a semi-circle with centre 'B' on the minor control plot and radius BB. Draw the tangent AC. Draw another arc of a circle with centre 'A' and radius AP. Drop a perpendicular from 't', the point where this arc cuts AB, on AC. The length of this perpendicular is the magnitude of this correction. In this case the sign will be positive i.e. the displacement of 'P' will be outwards.

Where every strip does not have two ground control points, two adjoining minor control plots can be brought on the scale of either of them–with the help of lateral control points common at the ends of the two minor control plots. Once these key end points and ground control on a number of adjoining minor control plots are scaled on a uniform scale on a combined minor control plot, the latter can be used to fix these key points on a plot sheet. All that would then remain to be done is to scale each of the original minor control plots between these key points, some of which would appear in every one of the original minor control plots.

53. **Extension of control by mechanical slotted templet method.**—The slotted templet method is a method in which the graphical procedures described above are replaced by one in which templets with radial line slots are assembled on a base sheet. It can be used for all air surveys with near-vertical photographs where normal graphical methods are applicable. It is particularly

Slot Cutters for Mechanical Radial Triangulation

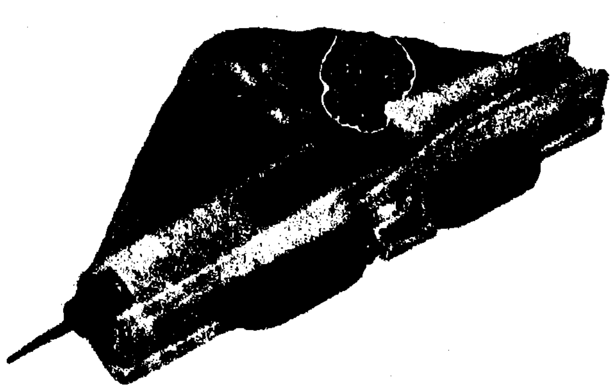
PLATE V.A



RS I Radial Secator

Two-story slot cutter for the production of templet assemblies, with automatic variation of scale between aerial photograph and templet from 0.5 to 2.0× for 7″×7″ (18×18 cm) photography and from 0.5 to 1.5× for 9″×9″ (23×23 cm) photography. Correcting devices are provided for angular distortions (0–25ᵍ) and radial displacements of the slots from –30 to +100 mm.

PLATE V.B

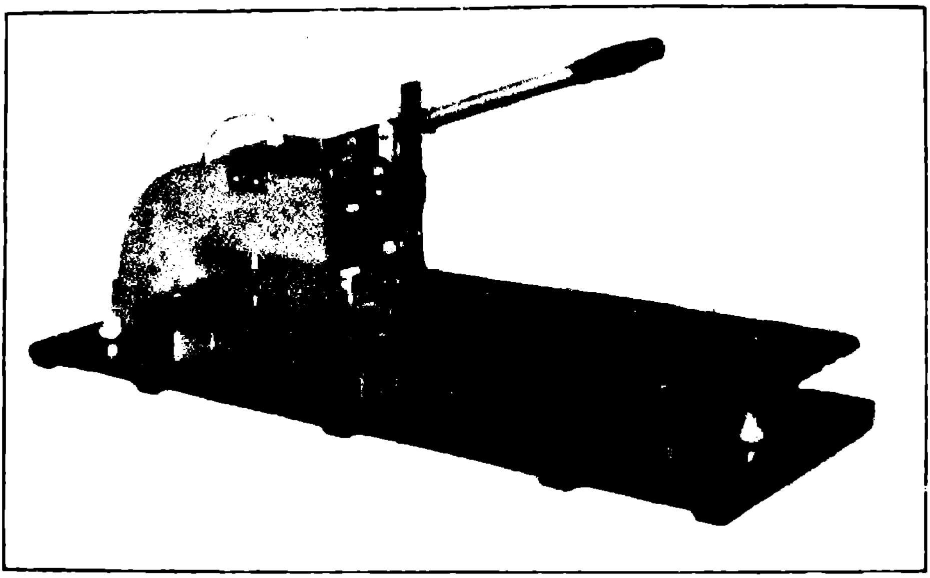


RS II Radial Secator

Simple, bridge-type slot cutter for processing smaller radial triangulation nets and for training purposes; without correcting devices; for cutting templets in the photo scale.

REG. No. 3022 HD'72 PRINTED AT THE 101 (H.L.O.) PRINTING GROUP OF SURVEY OF INDIA.
4,000 '75.

PLATE V.C



Slot Cutter

A conventional type of templet slot cutter.

Length of slot-50 mm and width-3.94 mm .

REG. No. 3022 HD'72 - 4,000'75.   Printed at the 101 (H.L.O.) Printing Group of Survey of India.

useful where ground control is sparse, or where large areas are concerned. Where the identification of stations is not of uniform accuracy, a slotted templet assembly, by virtue of intrinsic advantages of simultaneous assembly, helps to locate those stations whose identification is least reliable.

The material needed for a slotted templet assembly are briefly described below :—

Templets.—These should be rigid and mechanically stable. The material should not warp easily and should be capable of easy slotting, resulting in clean-edge slots. The material should not damage the cutter blade. Transparent templets like celluloid or film templets have their advantages in that the radial lines can be marked on them. This is necessary when using certain types of slotting machines. When using the Zeiss Radial Secator, R.S. I (Plate V·A), transparency is not an essential quality required on templets.

Studs.—These pass through the slots and pins can be passed through them to fix them and mark the intersection points of the slots. A kind of 'floating stud' (not in use in the department) is also available. This is of particular use for ground control points determined by astronomical means etc.

Markers.—These are of thin plastic and of various shapes used to mark the various pass points, ground control and minor control points to distinguish them at a glance.

Base Board.—Usually hardboard is used as a base on which templets can be assembled. Suitable sizes can be built up by joining sections of lesser size. The base board should be smooth, dimensionally stable and provide a good surface for inking in projections, control points etc.

Slot cutter.—Plate V.B. shows the Zeiss radial secator R.S. II and plate V.C. the older slot cutter.

Other material like a gunter scale, a beam compass etc. are necessary for projection and plotting. For very large projections, a theodolite is required for setting out the projection.

Preliminary work connected with slotted templet assembly.—

(*a*) The approximate scale of the photographs, for which the combination is to be executed, is worked out and the combination scale is selected. In this connection it must be borne in mind that the method permits assembly of templets also on a scale considerably different from that of the photographs but that the inconvenience of surveying details on a section differing in scale from that of the photographs will persist, unless the photographs are reproduced on a scale approximately equal to that of plotting. Usually the plotting is done on a scale which is a round figure approximately equal to that of the available photography.

(*b*) The photographs should be indexed on a map of suitable scale. Usually for compiling on a scale on 1 : 50,000, the photo index is prepared on a scale, 1 inch = 4 miles or 1 : 250,000. On this index all available control points are plotted.

(*c*) The ground control points usually post-pointed in the field are examined for correctness of number and description. They are transferred on as many adjoining photographs of the specification as possible. These are compared against the index mentioned against step 'b' above to ensure that no points have been left out. At this stage the reliability of the points is also examined. Points of which the identification is doubtful or whose co-ordinates have not proved during computation are marked by a distinguishing mark. If some difficulty arises during the combination, one can always eliminate these points to arrive at a good fit for the templets in the assembly.

(*d*) The principal points are marked on all the photographs and their positions transferred to adjoining photos of the strip. The minor control points and lateral control points are selected and transferred to adjoining photographs. They are also numbered appropriately and all these numbers are entered on the above mentioned photo index or a schematic diagram is prepared showing the ground control points and these lateral control and minor control points. Such a diagram proves useful for the following purposes :—

(*i*) ensuring the templets have been completely slotted and that no slots have been omitted.

(*ii*) ensuring that all points have been fixed and the assembly is complete, before dismantling.

(*e*) The templets have then to be prepared for slotting. If the slotting machine is a Zeiss Radial Secator (RS I) it is not necessary to prick the points from the photo to the templet, nor is it necessary to draw radial lines. It is sufficient to mark the points on the photographs. These image points on the photographs are viewed through a movable microscope. The turn-table carrying the photograph is rotated also to bring the same image point under the centering mark in the miscroscope. The templet below the turn-table is automatically rotated by an equal amount into position over the cutter blade.

A slot cutter of the older and more conventional type and RS II will require radial lines to be drawn on the templet in addition to pricking the points through the photograph on the templet. Along these radials can be set off any desired enlargement or reduction ratio.

Whether for the Zeiss RS I or the older conventional cutter the templets have to be punched with a centre punch. The diameter of this would be the same as that of the stud which will be passed through it. The Zeiss RS I is to some extent a semi-automatic cutter. In the case of the older pattern slot cutter and RS II the templet has to be rotated by hand and also moved backward and forward along a groove in which the centre stud can be made to slide till the centering pin of a die in the slot cutter is over the marked point. Fig. V ·8 shows a completed templet on which points have been numbered. A brief description of the numbering pattern is given below. The photograph to which the templet pertains is No. 26 of strip 17.

26 u 26 l	Minor control points north and south respectively.
18 l	A lateral control point chosen on photo No. 18 of strip No. 16 to the north of this photo.
32 u	A lateral control point chosen on photo No. 32 of strip No. 18 to the south of this photo.
25 u 25 l 27 u 27 l	Minor control points from adjoining photos No 25 and No. 27 of the same strip transferred to photo No. 26.
31 u	A lateral control point chosen on photo No. 31 of strip No. 18 to the south of this photo.

In addition to these, ground control points are also pricked and their numbers entered in distinct colours.

The templets are then examined to ensure that no points are omitted. They are then slotted and after slotting is completed they are again examined to ensure that the slots have been correctly and completely done. This examination is facilitated by a scrutiny of the punchings. These should be examined to ensure that the pricked points appear on the longitudinal axis of the punchings.

The Assembly.—A projection has to be drawn on a base board which may be of heavy straw board or pressed fibre board. Zinc sheet, hard wooden planks etc. are unsuitable for direct nailing of the templets because the pins passing through the studs tend to get deflected when the pins are nailed in. For areas measuring upto 3 metres × 2 metres the grid may be constructed on the base board by the usual drawing office methods using beam compass, straight edge and aids like a fine thread.

Sheets of rag litho paper, gridded to the scale of the combined plot with 1000-metre squares, may be laid down on to the assembly board. Care has to be taken in laying down a number of these grid sheets to ensure that they are accurately oriented with relation to one another.

For very large projections, theodolites can be used for setting out the projection. The procedure consists essentialy in using two theodolites described in the following paragraphs.

SECTION V.—RADIAL LINE METHODS

The gridding of large assembly boards.—The following is a method of setting out large projections :—

(1) Set up theodolite No. 1 as close as possible to the end of the proposed central construction line, and as low as convenient.

(2) Level carefully and check adjustment by plunging the theodolite several times on a point at the far end of the construction line on opposite faces.

(3) When the instrument is in perfect adjustment, set a series of points about three feet apart down the central construction line. This is done by locking the horizontal plate and sighting down the board at three feet intervals, and moving a fine needle into the point where the cross hairs intersect the board.

(4) Theodolite No. 2 is next set up as closely as possible to the position of one of the perpendicular construction lines, and adjusted by plunging in the same manner as with theodolite No. 1.

5) When theodolite No. 2 is perfectly adjusted, set cross-hairs of theodolite No. 1 on the far end of the central construction line. Set horizontal vernier to zero and turn off angle until theodolite No. 1 is sighting on the axis of vertical rotation of theodolite No. 2, and the cross-hairs of the two instruments may be now brought into coincidence by sighting theodolite No. 1. It is very important that for this step each telescope be focussed at infinity. This may be done by focussing both on a distant object, or by focussing only one on a distant object, and then making the stadia hairs on the other coincide. Set horizontal vernier of theodolite No. 2 to zero. Read angle on theodolite No. 1, and then turn theodolite No. 2 to the complement of this angle. Lock theodolite No. 2 and set points along construction line. This procedure will make the angle at the intersection lines a true 90° angle and will ensure that all construction lines are straight.

This same procedure may be repeated for as many other parallel construction lines as are necessary ; merely change the location of theodolite No. 2.

(6) A final beam compass check is made before plotting begins. This is done by setting off equal distances on the central and parallel construction lines and checking across the diagonals.

(7) When the two bases are constructed accurately the projection can proceed normally.

Special points regarding the assembly.—Now the grid bases is ready and the templets are also ready, all the control points are plotted on the grid base. At these ground control points metal studs are fixed. The procedure consists in accurately nailing a strong pin at the control point and then dropping the stud over the shaft of the pin. The strip which has the maximum number of control points is laid down first. Adjoining strips may then be laid down in a continuous sequence. It is also possible to lay down alternate strips first, placing the strips in the gaps subsequently This method could be adopted only if these alternate strips had adequate ground control to enable their being laid down independently.

The efficiency of the slotted templet system requires that friction between the various components be kept down to a minimum. The friction between the slots and the studs can be cut down by ensuring that the studs are neither too tight nor loose in the slots and also ensuring that they are straight. Templets should have their edges properly trimmed. They should be smooth and have a friction-free surface and at the same time should not be liable to distortion.

Dismantling the assembly.—Before dismentling the assembly it has to be carefully examined to see that no templets are forced or twisted out of shape. The assembly can be moved in or out i.e. slightly stretched out or contracted when templets at the peripheral ground control points are being fitted in. Whenever individual templets are being rotated within the assembly great care has to be exercised.

The studs should be in a natural free vertical position and should not be inclined or appear to be pushed out of place by undue stresses.

The studs are nailed down. Studs well spaced between ground control are first nailed down with special pins. If the base is of metal then the stud centres are merely pricked with the pins, in which case care has to be exercised during dismantling and numbering. After the studs are held in their places by pins, firmly but carefully driven in, the templets are removed one by one. The uncovered stud is ringed, numbered and then unpinned. We now have the base board with its projection, the plotted ground control and the intersected pass points and principal points.

Cases of errors in assemblies.—The final assembly is the end product of a series of operations each one of which has to be correctly carried out and checked at every stage.

Errors at any stage if undetected will result in an ill-fitting assembly and it is more time-consuming to go through all the steps again than to exercise care at every stage by elaborate double checks. Very often it is a cumulative effect of generally inaccurate work rather than a gross mistake at any one stage.

It may happen that certain trig. control points are difficult to identify at preparation stage of the photographs. In such cases the templets can always be assembled ignoring the particular trig. points which can be identified later by means of measurements to adjacent principal and minor control points. The identification of the trig. points can often be finally decided after reference to its description. In case a trig. point is so close to the principal point as to prevent the use of two separate studs, the assembly can be built up ignoring the principal point. Afterwards the principal point can be resected from the trig. point and from the adjoining principal point bases.

The majority of errors are due to misidentified points or bad slot cutting. The case of a doubtful templet should be examined as follows :—

(*a*) Examine the identity of minor control points on the photographs and check their correct transference on all relevant photos.

(*b*) Examine the identity of lateral control points for three photographs on each side on each strip.

(*c*) Examine the transference of principal points for three photographs.

(*d*) Place the doubtful templet over its photograph with the principal point centrally in the punched hole and correctly oriented and see whether all other points are central in their slots. If the slot punchings have been carefully examined this is a test of the principal point punching only.

(*e*) If no errors are found, work round the area omitting the faulty photographs and resect it in afterwards.

(*f*) If the area cannot be worked round owing to repetition of these errors and there are more than two ground control points in use, see if the error is due to faulty control point by releasing the suspected stud from the plot (by unnailing or ungumming the stud).

(*g*) If no remedy is found, but there is evidence of considerable tilt combined with very great height relief, the attempt to set up the whole area should be abandoned, pairs of adjacent strips with least tilt should be assembled with minor control and principal points as near one height plane as possible. These strips should be nailed down and the intermediate templets fitted in, placing them under strain if necessary.

54. **Organisation of work.**—In the case of slotted templet combination for a large area, the work should be organised exclusively for the job under a separate technical section with sufficient potential to carry out :—

(*i*) Selection and marking of minor control points and principal points ;

(*ii*) Pricking and numbering of templets ;

(*iii*) Centre-punching and slotting ;

(*iv*) Examination of slotting and punchings ;

(*v*) Projection and plotting of base board ;

(*vi*) Assembling the templets marking principal points/pass points and

(*vii*) Reading and recording of co-ordinates of principal points/pass points.

55. **Stereotemplet assembly.**—In a slotted templet assembly the photographs are replaced each by a slotted templet. Naturally the radial directions in the templet are burdened with the displacement errors due to tilt and relief.

In a stereotemplet assembly it is not the photographs which are replaced individually by templets. The overlap or "model" itself is replaced by a *pair of templets.* Each pair is a composite unit and these pairs are the basic units of the assembly. The pass point locations are obtained not from a photograph but a stereomodel as restituted in a stereoplotting machine. A stereotemplet of a single stereoscopic model is shown in figure V·9.

To prepare such a templet, the model is first oriented in a stereoplotting machine like a Multiplex, Wild A8, Kern PG2 or Wild A7 etc. The absolute orientation, if performed only approximately will do. All the pass points and control points are plotted on the templet itself. An exact duplicate of this is prepared. On one of these templets one corner pass point is centrepunched and slots are cut radially from this, centred on the remaining points. In the duplicate templet another point is selected for centre-punching as indicated in fig. V·10.

For the purpose of the stereotemplet assembly itself, it is not necessary to slot the principal points. If these are required for subsequent survey, they can be slotted and included in the combination. Of course, these principal points serve as check at the junction of two stereotemplets also.

This is illustrated in fig. V·10.

Only two pass points are essential to connect two stereomodels. If the principal point is also used it serves as a check on the correctness of the intersection of the pass points, their identification and transference etc. Generally a stereotemplet assembly would be used where the relief and tilt are excessive and a slotted templet combination would not yield good results. It is doubtful, therefore, if a stereotemplet combination would be carried out to merely fix the principal points to be followed by radial intersections from them and tracing, by hand, of details. The more useful practice would be to fix a minimum of four pass points which would be used later on for orientation either in a stereoplotting machine like A8, B8 etc. or in a stereotope.

The usual practice in the department has been to plot the pass points, ground control points and other points to be fixed during the stereotemplet assembly during the aerial triangulation observation phase on a graph paper. The plotted positions are transferred to templets which are then centrepunched at the appropriate pass points and slotted. The same strip of graph paper can also serve as the base for the height adjustment.

A study of the figures will also convey the advantages of stereotemplets. The base which can be selected in a stereotemplet need not necessarily be on the long diagonal. There are many advantages in this method besides the basic advantage of doing away with the effects of tilt and relief. One of these is the facility this method affords for including multiple models in one stereotemplet pair. All that is needed is an instrument which is capable of orienting adjacent models on a uniform scale. The intersections in a stereotemplet are less acute and consequently more reliable than in a slotted templet. Because of a number of foregoing factors less ground control is required for stereotemplets.

The material and instruments used are generally the same as those needed for the slotted templet. The Carl Zeiss Radial Secator RS I cannot be used for cutting stereotemplets. Another cutter the RS II has been developed by the firm. Alternatively conventional slotters can be used. The templet material has to be even more friction-free than required for slotted templet assemblies.

56. Analytical radial triangulation.—The aim in these procedures is to measure directions in photographs using stereoscopy, in special instruments developed for the purpose. The slotted templet and stereotemplet assemblies are mechanical solutions to the problem of location of pass points and principal points. In analytical radial triangulation the measured directions are used in computations to derive strip co-ordinates purely numerically.

Figure V·11 depicts the basic unit of computation in analytical radial triangulation. Photos 1 and 2 are first placed in the instrument and angles a, c, b and f are measured, 2a and 2b being pass points. Then photo 1 is replaced by photo 3 and angles in model 2–3 are next recorded. The recorded angles at the end of the observation of a strip are then adjusted. One method of adjustment takes into consideration the condition that base 2–3 can be computed either by applying the sine condition to angles a, c, d and g or to b, f, e and k. With the help of this condition corrections to these angles can be worked out. These computed corrections are applied to the observed directions and the corrected angles are used to compute strip co-ordinates. The more commonly used radial triangulators are those manufactured by both the Wild and the Zeiss factories. Film diapositives are used in the instruments and the methods of marking are generally the same as that for aerial triangulation. A simplified numbering system like the one used for the slotted templet assembly should suffice.

57. **Map compilation by Arundel method.**—*Control.*—The control required for air survey can be divided into :—

(*a*) Planimetric,

(*b*) Height.

As we have seen in foregoing paras of this Section, requirements of planimetric ground control can be minimised by resorting to extension of ground control by the use of methods based on radial line principles. The methods, to summarise, are :—

(*a*) Purely graphical – preparation of minor control plots and combination plots.

(*b*) Slotted templet method which is a mechanical method.

(*c*) Stereotemplet method which is mechanical ; this method, however, is in conjunction with a stereo-plotting machine.

(*d*) Analytical methods which employ radial triangulation instruments like the Wild Radial Triangulator.

All these methods aim at extending planimetric control. In the procedures of air survey that come within the scope of this Section, the problem of heights is tackeled separately. Radial triangulation has no solution to the problem of extension of height control. Radial line procedures for extension of plan control can be followed by direct contouring on photos in which case almost as many height control points are required to be post-pointed as would be provided in the field by a plane-tabler with a clinometer or by a triangulator with a theodolite. If, however, a parallax bar is made use of, then 4 to 5 points prodvided in the field per overlap would do for providing sufficient density of height control points required for contouring on photographs. The following are the steps in the survey by radial line methods :—

Steps in detail survey by radial line methods.—(*i*) Marking the principal point on the photos and choosing and marking the minor control points and lateral control points,

(*ii*) Transferring the principal points, minor control points and lateral control points to adjacent photos,

(*iii*) Radial line and base line drawing,

(*iv*) Preparation of minor control plot and scaling,

(*v*) Combination of minor control plots on to the projection, (steps *iii*, *iv*, *v* can be replaced by steps in preparation of slotted templet assembly),

(*vi*) Interpretation and chalking of detail on the photos,

(*vii*) Survey of the detail,

(*viii*) Obtaining blue prints for verification and contouring on the ground,

(*ix*) Accessory work like traces, etc.

A variation in these steps would result if photographs are verified in the field and height control, for direct contouring on the photos, is provided in the field. These steps would replace step (*vi*) in the list above. The details and contours would, in this case, be surveyed from the air photographs themselves. In this case item (*viii*), viz., blue prints for verification and contouring on the ground would be deleted.

Preparation of sections.—The air survey being done after photos have been verified and heighted in the field or unverified photos for the purpose of obtaining blue prints, is executed on air survey sections. These are prepared by tracing from the control sheet on which all the minor control plots are combined or intersected. If slotted templet method have been used, then the air survey sections are traced from the base on which the templets are combined. The air survey section has to be on a transparent medium like kodatrace or astrafoil. Astrofoil is a very stable and convenient material. The air survey section has, besides grid and graticule lines, all marginal items like O. 144 (Air), a table of trigonometrical points falling within the area and a space set out for examination remarks. All the trigonometrical points must be listed whether the points are identified or not. In case odd points have been rejected during the combination, remarks to this effect must be entered in the list of points after proper investigation. Control points must be plotted on the air survey section with respect to the grid or graticule lines. These should not be traced off like pass points or principal points.

Interpretation of detail on photographs.—All photographs of the section are examined by the surveyor under the stereoscope and detail which will appear on the final map is interpreted and chalked on alternate photos in the order indicated below. The general principle is to ink up the isolated smaller details, which are likely to be covered during the inking of larger detail, in the first stage.

(*i*) Towers, mosques, temples, telegraph posts, power pylons, isolated huts, graves, etc.,

(*ii*) Items of line detail like footpaths, pack tracks, roads, tramways, railways, pipe lines, transmission and telegraph lines, etc.

(*iii*) Village blocks, tanks, etc., and broader items of line detail like major irrigation channels, double line rivers, and perennial single line streams, cuttings, embankments, etc.,

(*iv*) Dry streams and ridge lines.

SECTION V.—RADIAL LINE METHODS

Inking will be done according to the conventional signs in use. Colours to be used will generally be the same as those that appear in the final map. Where, however, perennial water courses cannot be decided prior to field verification, the streams can be inked in light blue or inked only after field verification. Where the line detail is very sharp, e.g., a straight sharply defined canal, well defined railway curve, etc., it need not be inked. Tracing done from the original photographic image will be more accurate. Inking introduces considerable drafting errors and discretion must be used where it is felt that inking is superfluous or likely to lead to errors. Ridge lines are inked in green when necessary. Cultivation limit *dots* are generally omitted in photos and these limits are indicated only by a yellow riband.

Compilation of detail.—On completion of interpretation, a number of well-chosen points on the photo at various levels are intersected on the air survey section. The density of these chosen points will depend on the density of detail that has to be traced. In a dense jungle area these intersected points can assist the plane-tabler in the field for controlling plane-table traverses. Intersections at changes of slopes and other well-identified points can also assist the plane-tabler when heights are being provided on the blue print by him in the field. Details lying on or near the base line cannot be intersected. These points are fixed by interpolation. Suppose that "a_1" one photo image of a ground point "A" is twice as far from its principal point "P_1", as the other photo image, on the overlapping photo, "a_2" is from its principal point "P_2". Then the position of "a" is interpolated such that $aa_1 : aa_2 : \ : 2 : 1$

The framework of intersections having been completed, detail is drawn into correct position within each small triangle formed by the intersected points ; this final adjustment is carried out by eye. The details in the section are inked up in appropriate colours. The ridge lines need not be inked in and their lines may remain as pencil impressions.

Contouring.—Accurate contouring can be carried out on air photographs by a surveyor who has excellent stereoscopic vision and has ample experience and is fully qualified in the contouring of all types of country in ground survey in the field. Prolonged training and practice is needed to ensure correct direct contouring on photos, under a mirror stereoscope by a surveyor. A dense net work of judiciously distributed heights is also necessary. Where contouring is to be done on blue prints of detail prepared by air survey, the methods are similar to the normal plane-tabling methods except that the plane-tabler's job is made such easier because he has an accurate blue print. Where it is intended to use a parallax bar a dense network of heights in each overlap would not be necessary. About 4 or 5 height control points, including those provided for check, per overlap, for providing necessary height points for photo contouring, will suffice. Contours are also compiled in the same way as lines of detail. Small areas within the intersected points are traced from the contoured photos. Detail which is already traced can also be used during this step. The contour lines are inked in burnt number.

Completion of section.—The section is completed in respect of standard border items. A complete examination of the section is carried out by the supervisory officers. A final check of all rejected ground control points is carried out and these are ruled out in red in the list of points. The sections are then ready to be sent to the reproduction offices for obtaining blue prints in case contouring and completion are to be done in the field. A sufficient number of prints on tracing cloth or rag litho paper may also be indented, along with the blue prints. These could serve as colour traces or height records and boundary guides. If, however, both details and contours have been compiled from photos that have been verified and heighted in the field, material for fair-drawing would have to be obtained.

SECTION VI.—RECTIFICATION

58. Theory of rectification.—Rectification is the process by which a tilted configuration in a plane is fitted on to a similar but per-determined configuration on another plane through a perspective transformation. As applied to a tilted photograph of a flat, or low-undulating or gently-sloping terrain rectification aims at removing the distortion caused by the tilt, and in the course of the process, scale of the rectified print can also be changed.

In a projective transformation, points and straight lines project into points and straight lines respectively. Distances do not remain the same, but the cross or the anharmonic ratio of any four collinear points or any four concurrent coplaner lines is invariant. This property is made use of in the rectification of an aerial photograph. It is possible to reproject the pencil of rays by suitably adjusting the negative and projection planes of a rectifier so that an orthogonal projection of the photograph is obtained to form a map which can be construed as a plane parallel to the ground datum plane. (See fig. VI ·1).

Since a space homology can be determined by a transformation which is linear in a system of homogeneous co-ordinates nine parameters will have to be computed to fix the transformation. Disregarding the principal distance setting of the projector, which only determines the scale of the positive, the homology can be completely determined by eight of the above degrees of freedom. Out of these, shifts in the plane of the negative along two mutually perpendicular directions and a swing in its own plane can be achieved by manually setting the negative or positive plane accordingly. Hence a rectifier can be said to have effectively five degrees of freedom. These are the two tilts of the easel plane, the two tilts of the negative plane and one "distance setting" for the positive and negative planes from the projection centre. In the case of a fully automatic rectifiers, this is further reduced to three due to mechanical inversors. These are the two tilts of the positive plane and the movement of the lens carriage in the vertical direction (to be set empirically by the operator).

The rectification of any photograph cannot

(*i*) produce the effect of

(*a*) changing the geometrical position of the exposure station and

(*b*) removal of relief displacements or distortions in the images of the details or

(*ii*) give any information regarding height data or contours.

Section V.—RECTIFICATION

The normal methods of rectification are graphical and optical-mechanical ; for the former, paper prints and for the latter, film negatives are used. Only by optical-mechanical method we can produce a rectified photograph and by graphical method we can rectify a few selected details. To minimise the effect of the relief displacements in the details, photographs taken with long focal length cameras are best suited for rectification.

Rectification by analytical or digital methods is being tried but is not popular in view of remarkable developments in the direction of orthophotography, in which a photograph taken in the central projection is transformed into one of the orthogonal projection. Rectified photographs are normally used

(*i*) for the preparation of mosaics with or without contours,

(*ii*) for the production of accurate planimetric maps by graphical methods and

(*iii*) as a basis for plotting by means of simple and cheap plotting instruments, which do not have facilities to remove the effects due to model deformations.

59. **Graphical rectification.**—Fig. VI ·2 and 3 illustrate the well-known paper-strip method of rectification using the property of invariance mentioned above. a, b, *c* and *d* are four points – no three of them collinear – on the photographs and *A*, *B*, *C* and *D* the corresponding positions on the map or on a plot sheet.

The procedure to locate the rectified map position *E* of point *e* on the photograph is as below :

On a paper strip placed across the lines *ab*, *ac*, *ae* and *ad* the intercepts b', e', c' and d' are marked. This strip is then oriented with the points b', c' and d' falling on the rays *AB*, *AD* and *AC* respectively. The line Ae' fixes the direction of *AE*, for $a\,(\,bced\,) = (\,b'\,c'\,e'\,d'\,) = A(\,BCe'\,D\,) = A(\,BCED\,)$. Similarly the direction of *DE* can also be determined by considering the pencil *d*(*abce*). The intersection of these two directions will determine the map position of *E*. A check, if necessary, can be made using the pencil *c*(*bade*) *or b*(*ceda*).

As rectification of individual points is slow, the procedure can be simplified by extending the principle of invariance to a complete quadrilateral for the purpose of surveying. If the quadrilaterals, *abcd* and *ABCD* be devided into smaller ones $a'bb'o'$, etc., and $A'BB'O'$, etc., as shown in figs. IV ·4 and 5 then the same projective transformation which transforms *abcd* into *ABCD* will also transform $a'bb'o'$, etc., into $A'BB'O$, etc. A continuation of this subdividing process will produce a net-work of dense control for subsequent survey of details by interpolation.

These methods are not economical for mapping large areas, but are useful for carrying out urgent and small tasks without the use of complicated and costly instruments.

Section V.—RECTIFICATION

60. Optical-mechanical rectification.—The process of optical-mechanical rectification employs the theory of projective transformation with the aid of optical and mechanical contrivances. The rectifier should be capable of enlargement as well as reduction. An apperatus of this typs consists of three planes, viz., a negative plane, the projection (or easel) plane and a suitable lens at the projection centre. The working principle of the apparatus is based on two requirements : (*i*) projective-geometric requirement : the points on the image must be brought into perspective positions with an orthogonal projection of the same points on a given scale *via* a bundle of rays through a perspective centre (which is a lens) and (*ii*) optical laws : the projection should be sharp at all points irrespective of the inclination of the two planes.

Based on these two requirements, a specific condition known as *Scheimpflug Condition* has to be fulfilled. It states that when images from one plane (say a negative plane) are projected on to another plane (say a positive plane), through a lens and where one image is in sharp focus, all other images will also be in sharp focus, if the planes of the negative, the lens and the positive intersect in a common line. For one image to be in sharp focus, on the positive plane, Newton's Condition (or lens equation), $XX'=F^2$ should be satisfied, where X and X′ are ultra-focal distances. This is automatically fulfilled if the Vanishing Point Condition is satisfied.

The change in scale and the above conditions are simultaneously obtained by distributing the various degrees of freedom among the three planes, depending upon the type of construction of the rectifier. These planes are, therefore, capable of tilts, rotations and shifts.

61. Rectifiers.—Rectifiers are automatic or non-automatic, either single- or multi-stage. Fig. IV·6 is a schematic diagram of a rectifier. A light source S with condenser C projects a negative kept in the negative carrier N, through lens L on to the control-templet or photographic paper kept on the easel plane, T.

Non-automatic rectifiers are generally designed with a fixed axis of reference and a non-displaceable negative carrier ; the lens can be tilted. Such rectifiers require all the angular and linear elements satisfying Scheimpflug and Newton's Conditions to be pre-determined and accurately set on them.

In automatic rectifiers the fulfilment of the Newton's Condition for one point and the Scheimpflug Condition are ensured by mechanical linkages known as "Inversors". The Vanishing Point Condition is also satisfied automatically using electro-mechanical devices.

Based on the distribution of degrees of freedom, which decides the principles of construction, the rectifiers can be classified into three catagories :—

(*i*) Fixed optical axis and single axis of rotation for each of the remaining planes.

(*ii*) Fixed optical axis and two axes of rotation for each plane.

(*iii*) Fixed negative plane with moveable optical axis with one or two axes of rotation for the easel plane.

62. Zeiss SEG V Rectifier.—The Survey of India uses the automatic rectifier Zeiss SEG V belonging to category (*ii*). The following are its important features :—

In this instrument (see the schematic fig. VI·8) the easel plane (size 1 m × 1 m) is mounted on a ball-and-socket joint and can be tilted around two rectangular axes (upto ± 13°) by means of two handwheels. The negative carrier (which normally can take negatives of size 24 cm × 24 cm, either single or uncut film rolls and with the aid of a special device, can accommodate upto size 30 cm × 30 cm but can rectify only an area covered by 23 cm × 23 cm), is located in the photo carriage and can be rotated about two axes at right angles.

When the easel plane is tilted, the Carpentier Inversor tilts the negative carrier to satisfy the Scheimpflug Condition and when the distance between the lens and the projection table is altered to get the required enlargement or reduction (range 0·5 to 6·5 times) by moving the foot pedal, the Cam Inversor ensures the setting of the negative plane to satisfy the Newton's Condition between the points where the optical axis meets the negative and the easel planes. The Vanishing Point Condition is fulfilled by electro-mechanical means. A computer (working on the basis of an approximate formula), which receives information regarding the table tilts and the enlargement (reduction) settings during the process of rectification determines the two components of the displacement, to be imparted to the negative, and transmits them in the form of electrical impulses to two servo-motors which ensure the necessary movement of the negative, in its own plane.

For the lighting system the double Fresnel step lens has been used in combination with a mercury vapour lamp which produces high intensity actinic light and low heat generation.

Illuminated scales have been provided on the instrument body to read and set (if necessary) enlargement ratio, tilt components and camera focal length and two narrow scales on the photo carriage for the negative displacements which can also be set, if required manually.

A practically distortion-free lens (Topogon V, f = 18 cm, wide angle) and a built-in exposure timer (1 sec. to 6 min.) with automatic introduction of diaphragm are other special features.

63. Operational procedure.—In the Survey of India, only rectification of photographs of flat and low-undulating terrain is generally carried out using only three degrees of freedom of the rectifier. The Vanishing Point Control is not disengaged during the process.

There are two different methods of determining rectification settings, viz., direct rectification in which settings are computed from the orientation elements of the photographs and empirical rectification in which the elements are determined by an iteration process of trial and error. Direct rectification is not in use in this department and is not described.

Empirical rectification for flat terrain.—In this method the projected image on the easel plane of a set of non-collinear points on the negative are made to coincide as best as possible with their plotted positions on the control-templet. The points on which the adjustments are made (called pass points) are generally obtained by slotted templet triangulation or from existing maps ; in exceptional cases they are obtained from aerial triangulation or direct measurements on the ground. Although three non-collinear (preferably at the three corners of the photo) pass points are required for rectification of photographs of flat-horizontal terrain, as only three degrees of freedom are made use of, yet four points (no three of them are collinear) are generally used as it not only provides a good check of the procedure followed and the accuracy of the three points used for rectification but also avoids the necessity of treating the area outside the control points as extra-polated.

Drill.—Rectification work on the SEG V is performed according to the following procedure :—

(*a*) *Preparatory work.*—(*i*) Plot the pass points on a gridded transparent astrofoil sheet, the numbering and co-ordinates should be mirror reversed since the control-templet will be used face down on the easel table. (This is done for introducing the grid on the rectified print, and if this is not required, then the pass points may be plotted on a sheet of white paper having the same thickness as the photographic paper). Draw blue circles of 2 mm diameter around the plotted position.

(*ii*) Mark the control points (on the non-emulsion side) by blue ink circles (1 mm diameter) on the negative, if they are not well-defined details.

(In the sketches given in figs. VI ·7 and 9, points 1 to 4 indicate the plotted positions of the pass points on the control-templet and 1′, 2′, 3′ and 4′ the projected images of these points).

(*b*) *Work on the rectifier.*—*Step 1.*—Set the camera focal length on the appropriate setting scale ; choose the approximate enlargement ratio and set the easel tilts on zero.

Step 2.—Centre the negative (with emulsion side down) on the negative carrier with the help of the fiducial marks.

Step 3.—Place a sheet of white paper having the same thickness as the photographic paper that will be used on the easel plane. Lay on top the control templet face down and arrange it flat.

Step 4.—Compare the projected images with those plotted on the-control templet ; bring two diagonal points 1 and 3 (say) to coincide with 1′ and 3′ by changing the enlargement ratio, using the foot pedal, and rotating and translating the control-templet.

Step 5.—Consider the larger of the two components of the discrepancy in point 2. In fig. VI·7 the Y-component is larger. So, remove half of it by tilting the easel plane about Y-axis. (If X-component is larger, tilt the easel plane about the X-axis). Translate and rescale the templet again on the diagonal 1–3.

Step 6.—Remove half the X-component of the discrepancy (which will now be larger, in this case) in point 2 by tilting about X-axis ; translate and rescale on diagonal 1–3. Repeat the steps 4, 5 and 6 if necessary, until 2 conicides with 2′.

Steps 7.—Check point 4. Any small residual (which will generally be less than 1 mm) still left in point 4 is to be distributed by slightly adjusting the tilts, scale and swinging and translating the templet.

Step 8.—Remove the control-templet and the white paper. Introduce the photographic paper. Adjust the exposure timer, filter, etc., and carry out the necessary processes required for a positive paper print. Except for step 8, all others can be carried out under normal light.

(With the slotted templet control, residual errors at the pass point for flat horizontal terrain can be upto 0·5 mm depending on the enlargement ratio).

Other Methods.—With SEG V, rectification of photographs of non-flat terrain can also be carried out. There are three different methods :—

(*a*) *Affine rectification method using all 5 degrees of freedom.*—The procedure is based on the geometrical property that any quadrilateral can be made to correspond to any other by a direct projective transformation. The procedure is same as for the flat-horizontal terrain except that the Vanishing Point Control is disconnected and residual error at the point 4 is distributed to other points, and a best fit is obtained, by computing the settings required for the Vanishing Point Control based on the information regarding the table tilts, the focal length, mean-distance between pass points and the discrepancy at point 4.

(*b*) *Perspective rectification on to a horizontal plane.*—The procedure is the same as for the flat terrain, but a datum plane is chosen and the pass points are given radial displacements $\left(=\frac{\Delta z.\ r}{z}\right)$

with nadir point (as an approximation, the projection of principal point will suffice) as centre. These displaced positions, which correspond to displaced images of the pass points appearing on the negative are used instead of the plotted positions.

(*c*) *Perspective rectification by zones.*—This is carried out using the method of perspective rectification on to a horizontal datum plane as the basic procedure. A contour plan on the scale of rectification and with a suitable interval depending upon the nature of the terrain is to be prepared. The area covered by the photograph is to be considered as divided into zones bounded by contour lines. Each zone, with a datum plane midway between the contours, is then exposed separately but successively with a mask, prepared from the contour plan, laid over the remaining part of the sensitised sheet so as to expose only the particular zone. The cumulative result of these successive exposures will be a rectified print.

To get the initial settings three control points are required and then for each zone – starting from the datum plane the enlargement ratio is to be decreased (by $\frac{\Delta h}{f}$ where Δh is the contour interval reduced to the scale of rectification and f is the camera focal length) with increasing elevation and *vice-versa*.

SECTION VII.—AERIAL MOSAICS

64. General.—*Mosaic.*—An aerial mosaic is an assembly of aerial photographs edges of which have been matched together systematically to form a composite pictorial view of a portion of earth's surface covered by these photographs.

Perfect matching of edges is, however, not possible due to variation of the altitude of aircraft, large differences in the terrain relief, tilt of the aircraft, errors in the photography, developing and printing processes, etc.

Types of mosaics.—Based on the properties of the individual photographs the control points and the method of compilation, the mosaics are classified into the following types :—

(*a*) *Uncontrolled mosaic* is compiled with little or no control, by matching image details in adjoining photographs, with little or no tilt distortion removed.

(*b*) *Controlled mosaic* is compiled from scaled and rectified photographs to remove the tilt distortion and is based on accurate control points.

(*c*) *Semi-controlled mosaic* is sometimes compiled to meet the intermediate requirements of (*a*) and (*b*) above.

(*d*) *Orthophoto mosaic* is an assembly of orthophotographs having a common scale and in which both the tilt and relief distortions have been removed through use of special instruments, called orthoprojectors. When orthophotomosaic is fitted to accurate control points, this is as accurate as a map.

Further, a moasic may or may not be annotated.

Properties of mosaics.—A mosaic offers a comprehensive and complete record. It has a wealth of details of the entire area under study. Except for orthophotomosaics, they suffer from non-uniformity of scales. A mosaic contains all the details in the shape of photographic images unless a particular major detail or feature have been annotated. Accuracy of a mosaic depends upon the amount of terrain relief, the exactness and type of photographic rectification and the accuracy and density of control on to which the photographs have been fitted while mosaicing.

Applications.—Mosaics are of great value in all types of planning activities. The study of geological features, flood control problems, irrigation projects and investigation of natural resources, e.g., soils and forestry can be greatly simplified by the use of mosaics. For highway and railway locations and for alignment of pipe lines, transmission lines, etc., the mosaics permit selection of best possible locations without extensive preliminary field surveys. Mosaics are also useful for urban planning.

Advantages.—A mosaic can be used and appreciated without training in photogrammetry or knowledge of symbols. A mosaic shows a wealth of details and no detail of the terrain is omitted. Certain terrain features can be more easily recognised and interpreted on a mosaic compared to a map. A mosaic can be prepared more rapidly and economically than a map.

Limitations.—Excessive details obscuring important features, lack of topographic information, lack of names of places and features, inaccuracy of planimetric details due to relief, tilt and scale variations are the main limitations of a mosaic.

Excessive details can be minimised by proper selection of scale, by choice of contrast in printing the mosaic and by annotation. Use of stick-up-letters can provide the names. Inaccuracies in planimmetry can be considerably minimised by use of controlled mosaics and completely removed by the use of orthophoto mosaics.

65. Planning for mosaics.—When ordering for aerial photography with a view to mosaic compilation, a few factors have to be considered. The main factors to be considered while planning a mosaic compilation programme are : scale of mosaic, scale of photography, focal length of the aerial camera to be used, overlap and the requirements of horizontal control points. The intended use of the mosaic, the accuracy desired to be attained, the nature of the terrain and the availability of time and funds govern the considerations of these factors. Also, at this stage, it is worthwhile to consider other materials—mounting boards, adhesive, etc., and photographic paper to be used.

Scale of mosaic.—The scale of a mosaic is dependent mainly on the intended use. The following scales are generally used :—

(*a*) *Small scale* (*1 : 20,000 or smaller*)—for use in geology, soil survey, forestry, reclamation work, flood control and other studies of large areas.

(*b*) *Medium scale* (*1 : 10,000 to 1 : 20,000*)—for use in town planning, preliminary location work for highways, railways, transmission lines and pipe lines, etc.

(*c*) *Large scale* (*1 : 10,000 and larger*)—for special detailed investigations in urban, highway work, railroad planning, housing and industrial building sites, bridge locations, preparation of tax maps and land-evaluation surveys, strip-mining plans, and other engineering studies.

Scale of photography.—The scale of aerial photography is directly related to the scale of the mosaic. If the negative quality is good and the laboratory techniques and equipment are adequate, the enlargement from aerial photography to mosaic can extend up to about four times. Under present Indian working conditions, enlargement should be limited to two times only. For speed and economy, the compilation scale should be the same as the photograph scale, but more accuracy can be obtained by compiling at a scale of $1\frac{1}{4}$ to $1\frac{1}{2}$ times the photo scale.

Focal length of the aerial camera.—The focal length of the aerial camera is related to the flying height of the aircraft and the amount of relief displacement. With a short focal length camera, the aeroplane can fly low, thus directly affecting the ease and cost of flying operations. Also, when small-scale photography is required, ceiling limitations of the aircraft used may indicate the use of a short focal length camera. On the other hand, with the long focal length camera, the flying height is increased thereby reducing the relief displacement and the variation of the scales between successive photographs. At higher altitudes, the variation in flying height can be held smaller ; also its effect on scale will be less.

Generally focal lengths of 15 cm, 21 cm and 30 cm are used for photography for mosaic compilation. In rugged areas, where the scale of mosaic is small, 15 cm lens (e.g., Wild R. C 5 a) will be most suitable whereas 30 cm lens (e.g., Ross Eagle IX) will best neet the requirements of a mosaic of urban area. The 21 cm lens (e.g., Wild RC 5 a) is suitable for practically all types of mosaics.

When photography is taken to serve the dual purpose for the compilation of maps and mosaics, the requirements of photogrammetric mapping should govern the factors in flight planning.

Overlap.—Though the normal requirements are 60 percent forward lap and 30 percent side lap, larger overlaps are prescribed at times so that smaller portion of each photograph is used, thereby reducing relief displacements and thus increasing the accuracy.

Requirement of horizontal control.—The horizontal control governs the planimetry of the mosaic and thus the accuracy of the mosaic. The intended use of the mosaic is, therefore, the principal factor for deciding the type, quality and distribution of control needed.

First, the existing control points should be investigated. If the existing ground control points are not sufficient, it should be supplemented by radial triangulation. If necessary, the identifiable control points on the existing maps should be used. If this is not possible, the visit to the ground is resorted to for providing the necessary control. At times the existing maps are used for controlling the mosaic compilation by utilising the various details.

Mounting boards.—Several types of mounting boards which have been treated to withstand moisture are used. A veneer of birch or maple that is smoothly sanded and periodically sealed with a resin is fairly satisfactory. Fir plywood is not satisfactory because the alternate boards of hard and soft wood may cause ridges to appear in finished mosaic. Open-grained plywoods like walnut mahogany, and oak are not recommended. The following types of Indian plywood are also suitable : Aero, National Rocket and Sitapur Plywood Products of thicknesses 4 mm and 6 mm. A piece of masonite board 1/8 inch thick is a very satisfacotry mounting board. The mounting board size varies from 5 feet by 3 feet to 8 feet by 4 feet. If contact size reproductions are required, the maximum sizes of film or bromide paper restricts the size of mosaic.

Adhesive.—The most convenient adhesive to work with in mounting photographs in mosaic construction is gum arabic which comes in powdered form or in tear-drop form. The powdered gum arabic though expensive is easier to prepare in small batches, and the adhesive is prepared in warm water in proportion of 5 pounds of gum to 1 gallon of water and by stirring the mixture all the time until it attains the consistency of strained honey. To prevent the mixture from becoming sour, 3 or 4 ounces of salicylic acid should be added to each gallon of adhesive. Two ounces of glycerine added to each gallon of adhesive will prevent the mounted photographs from becoming brittle and curling at edges.

Photographic paper.—Generally single weight glossy paper is used for uncontrolled mosaics. For higher quality. glossy photographic paper of double weight or waterproof type should be used for construction of mosaic, as differential expansion factor of photographic paper during exposure, drying and application of adhesive in single weight paper may be as much as 1% normal to the grain. For construction of controlled mosaics, it has been found expedient to use foil-mounted correctostat bromide paper for alternate photographs. In making rectified prints, it is a good practice to keep the direction of the photographic paper grain constant.

66. Mosaic construction.—*General.*—There are a few processes common to all types of mosaic construction and a few pertaining to the specific type of mosaic. We will first describe the complete process involved in construction of the controlled mosaic.

Controlled mosaics.—Compilation of a controlled mosaic is an elaborate and precision technique and should be carried out by an organisation fully equipped to carry out rectification of photograph. It is a very accurate form of mosaic. The photographs are rectified and scaled before assembly in order to remove the errors due to tilt displacements and scale differences. The graticule lines and the control plotted on a transparent sheet is kept above the sensitive film so that these appear on the final rectified photographs. For details of rectification procedures, Section VI should be referred to. Proper control is provided before-hand for rectification as outlined in para 65. The focal length of the aerial camera, overlap and scale of photography is so chosen at the planning stage as to restrict the errors due to relief displacement within tolerable limits.

The photographs are then assembled. The different processes involved are :

(*a*) Preparing the mosaic board.

(*b*) Marking the cut lines.

(*c*) Feathering.

(*d*) Mounting.

(*e*) Blending.

Preparing the mosaic board.—The size of the board is limited only to convenience and available space. If the programme includes topographical mapping, the mosaic sheets frequently conform to the size and scale of the map sheets. The mosaic board is cleaned and the grid lines are projected on it. The control points are also plotted.

At this stage, in addition to photographs, adhesive, razor blade, sand paper, a pail of water, sponges and a squeegee made from 1/16 inch thick celluloid piece whose edges and corners have been rounded off or a small rubber roller and some pins or needles are collected.

Marking the cut lines.—The cut lines of each photograph are marked by grease pencil by matching the edges. Matching is done in the following priority :

(*a*) Graticle lines at the edges.

(*b*) Control with respect to the plotted positions on the board.

(*c*) Details at the edges.

(*d*) Tone at the edges.

When the cut line has been marked, using a very light pressure and a very sharp blade, only emulsion is out and not the paper.

Feathering.—The photograph is gently folded back, away from the emulsion for the part to be discarded. The discarded portion is torn back toward the portion to be used, leaving the edges of the retained portion thinner than the remainder of the print. This process gives the edge of the photograph a feathered appearance. The feathering should be done in such a way that on one edge of the photograph, white portion of photographic paper is retained and on the corresponding edge of the other photograph, white portion of the photographic paper is removed below the emulsion. It is better to decide the pattern for the same by a proper scheme drawn on a separate paper indicating the layout of the mosaic.

This is very important to ensure proper smoothness where layers of prints are mounted and to make the edges less perceptible to the eye and to the copy camera.

Mounting.—The first photograph to be mounted is placed at its position and the positions of its control points relative to their plotted positions are checked. The adhesive is spread into the back of the print by hand, and the print is then placed in position on the mounting board. A needle is pushed through the principal point and a second needle through another control point. The needle through principal point is centred on the mounting board position of the principal point, the other needle is centred on the corresponding control point on the mounting board. This operation positions and orients the photograph on the mounting board. Before the point is squeegeed down, the coincidence of other control points may be checked visually by flipping the edges of the photograph over the mounting board. A slight amount of rotation may be necessary to strike an average coincidence of all points. However, the position of the principal point should be held fixed. The photograph is then secured by means of the squeegee. Adhesive is then wiped out from the surface of the point and the board by means of a damp sponge. After the adhesive has set, the second print is oriented on to the control and flipped over the first print to permit a visual selection of the cut line.

After cutting and feather edging, the second print is placed in its position to fit its principal point and other control points. The adhesive is applied and the print is matched to the principal point and the other control points. The second print is squeegeed into place, and the excess adhesive is wiped from the face of the print and from the board. The direction of squeeging is always towards the edge of the print being mounted. In this way all other photographs are fitted in their positions.

Loose print edges sometimes occur and a stronger adhesive such as caseinglue is used to make such edges adhere.

Blending.—To obtain photograph with matching tones and colours, blending or touching up is desirable to be done on mosaic before making its copies. This is accomplished by touching with a photographic dye, e.g., spotone. Small areas where emulsion has been destroyed should be matched by using a very soft graphite pencil. Any extensive loss of detail should be repaired by patch work.

Semi-controlled mosaic.—When arrangements for rectification are not readily available, it is not possible to compile a controlled mosaic. Under such circumstances and for reasons of speed semi-controlled mosaics are compiled. For compiling a semi-controlled mosaic the photographs are enlarged or reduced to the scale of mosaic compilation. If adequate ground or map control points are not available for scaling, control extension is carried out by radial triangulation. In very rare cases when no control is available and there is urgent requirement of a mosaic, or where the accuracy requirements do not demand more precise control, an azimuth line or a series of azimuth lines may be used to afford simple control for semi-controlled mosaic. The azimuth line is prepared as follows. The photographs are laid on the map table in proper sequence, care being taken to match images between successive photographs. As each photo is placed, it is held in position along its edges by small weights. A straight edge is laid over the strip as so to pass through the centres of as many photographs as possible, and a fine line is drawn across the face of the top photograph. The photographs are then separated. In the common portions of first and second photographs two points a and b are selected on first photo which are transferred to the second photo. A fine line is drawn across the face of this photograph and a new pair of points c and d are chosen on it which also appear on the third photograph. The process is continued throughout the remainder of the strip.

The azimuth line control is very useful in that it prevents the flight strips from swinging off line as the photographs are mounted. It also prevents errors caused by mis-matches from accumulating towards the corners of the mosaic. This type of control is very easy to prepare.

Before assembly all the photographs are either scaled, if possible, or marked with the azimuth line. Each photograph is then trimmed, featheredged as in the case of controlled mosaic and assembled in position oriented either on the control or on the azimuth line.

Uncontrolled mosaic.—Mosaics requiring less accuracy can be compiled by less rigid methods. In uncontrolled mosaic an effort is made to bring the photographs to a common scale if some ground control points are existing in the area. If not, the uncontrolled mosaic is assembled in such a way that photographs match edge to edge. Each photograph is trimmed and featheredged before it is pasted on the mounting board. However, the circumstances under which uncontrolled mosaics will be compiled should be rare. Sufficient ground or map control data are available throughout the country to prepare at least semi-controlled mosaic.

Orthophoto mosaics.—It is the most accurate form of mosaic and can only be prepared by an organisation fully equipped to prepare orthophotographs by use of special instruments for differential rectification like orthoprojectors. Through these instruments tilt and relief distortions are removed. When properly assembled to accurate ground control, an orthophoto mosaic is as accurate as a planimetric map.

67. Annotation and reproduction.—(*Editing*)—After the assembly of all the photographs has been completed, the grease pencil marks are removed from the face of the prints with a cleaning fluid, generally benzol, care being taken not to disturb the edges of the prints.

As a rule this is followed by slight touching up of the mosaic to eliminate differences in tone and disturbing influences in the photograph, e.g., trails of smoke, vehicles, reflections of water surfaces, etc. A black dye, which is diluted in water to produce the various shades, shades of grey is applied with a soft brush to obtain a balanced tone throughout the mosaic.

The mosaic is completed by mounting a white border along the four margins.

(b) *Annotation.*—Mosaics should contain sufficient information to fulfil the requirements of a map substitute. The grid lines are usually drawn in white on the face of the mosaic in case of controlled and semi-controlled mosaics. The tilte and authorship of the mosaic should be indicated. A graphic scale as well as the numerical scale are given in the controlled mosaic.

Body information, i.e., names of various planimetric and cultural details are also entered on the mosaic in ink, contrasting to the surface on which it is written. Care should be taken not to crowd a mosaic with too much of information.

Border information is usually placed on the white border material. Grid values are entered within the border. The destination names and distances are also entered in this border.

Reproduction.—After completion of the mosaic, photographic copies are made for general use and the master mosaic is preserved. Photographic copies are made with large size copy cameras. Usually the negative is made on 1 to 1 scale, and copy prints are made from the negative contact printing. This ensures minimum loss of detail. However, if scale change is required the negative is prepared on the desired scale and copies are made by contact printing.

Section VIII.—STEREOPLOTTING INSTRUMENTS

68. Principles of design.—*The basic problem.*—A stereoplotting instrument aims at recreating a spatial model formed either by the intersection of two mechanical space rods or by the intersection of light rays. The reconstruction of the terrain appearing in an overlapping pair of photographs, to a chosen scale, by a stereoplotting instrument is achieved by

(*i*) making it possible for each of a pair of photographs (or their negatives) to be placed in the instrument and give it certain orientations in the axis system of the instrument.

(*ii*) using certain mechanical and/or optical devices to view the overlapping pair stereoscopically and at the same time trying to materialise (i.e., to fix the observed point in the axis system of the machine) the intersection of the homologous rays of the picture for the point observed.

The problem is illustrated in figure VIII ·1. Here we have two cameras that have photographed the same portion of the terrain in both the photographs taken from camera positions S_1 and S_2. The three *non-collinear* points A, B, C have been photographed at points a_1, b_1, c_1 and a_2, b_2, c_2. It will be seen quite easily that as long as S_1 and S_2 are not identical, the positions of a_1, b_1, c_1 and a_2, b_2, c_2 with respect to the respective fiducial marks will never be the same. Now inversely if the positions of A, B, C are known in the axis system of projection and if we were given the two pictures a_1, b_1, c_1 and a_2, b_2, c_2 in their respective cameras it would be quite simple to resect the camera positions S_1 and S_2. To do this we have data in the form of the image co-ordinates of a_1, b_1, c_1 and a_2, b_2, c_2 and the ground co-ordinates of A, B and C. The image co-ordinates could, of course, be measured and the positions S_1 and S_2 alongwith the camera orientation computed. A stereoplotting instrument, however, achieves the proper camera orientations and intersections of homologous rays by incorporating in it various mechanical and optical devices that permit the photographs to assume certain chosen orientations, and also realize the intersection of the rays. Because physical movements replace calculations, stereoplotting instruments are also known as *analogue instruments*.

Brief history of stereoplotting instruments.—The basic problem briefly reviewed above has found varied solutions. In fact, one system of classification classes these instruments as optical, mechanical or optical-mechanical depending on the principle employed in the reconstruction of the spatial model.

It was in 1898 that Theodor Scheimpflug first projected a model using the method of "double projection". He photographed a model with two fixed cameras, since at that time air photography was not fully developed. After developing the negatives he placed them again exactly in the same camera. He then illuminated the negatives from behind and with the cameras placed in exactly the same position in which the picture was taken, the projected rays of light took exactly the same paths out of the cameras as they had taken on entering to make the photographs. His experiment is illustrated in figure VIII·2. This principle of optical reconstruction is sometimes also termed the *Porro-Koppe principle.*

From those early days modern stereophotogrammetry has, no doubt, advanced very far. Among the many landmarks in the progress of this technology the following deserve special mention :—

(*i*) The discovery of a practical method of measuring with floating marks by Dr. Carl Pulfrich of the Zeiss firm and the prectical implementation by him of the idea of a floating mark originated by Stolze in 1892.

(*ii*) The practical use of the aeroplane during the First World War. It was only when flying became a practical reality that one could think of air photography. Although the principles of photogrammetry had been enunciated much earlier, the development of the aeroplane gave the impetus to air photography that resulted in the rapid progress of photogrammetry.

(*iii*) The introduction of aerial triangulation with the building of the Multiplex by the Zeiss firm in 1934. It can be imagined that prior to this, it was necessary to have ground control in each pair. Today the perfection of a variety of instruments, both of the Multiplex type and other types, with which aerial triangulation can be executed has made photogrammetry particularly valuable for underdeveloped countries. The bottle-neck that would have been caused, in the production of maps vitally needed for planning, by having to provide ground control in each model, can be easily imagined.

Broad classification.—As already mentioned above the basic problem of recreating a model of the terrain with a stereoplotting instrument was solved in various ways leading to a variety of such instruments. The three classes of which we have examples in India are :—

(*i*) *Instruments based on the principles of optical projection* i.e., in which the reprojected optical rays are made to intersect and this projection on a small opaque screen is viewed directly. The stereo effect is generally effected by use of the anaglyph principle. Although originally developed by Zeiss and Nistri in Europe this type of instrument has grown to its full stature in the U.S.A. Generally known as Multiplex type, instruments employing this principle are, for example, The Kelsh plotter, The Gamble plotter, The Bausch & Lomb Balplex and Twinplex. In Survey of India we have some instruments of Multiplex projectors made by the firm of Williamson & Ross.

(*ii*) *Instruments based on the principles of optical-mechanical projection.*—The projection here also is through a lens. The main difference between this class and class (*i*) mentioned above is that in the latter there is a certain plane of best definition, about which the highest and lowest portions of the terrain lie in a certain restricted "zone of best definition". In instruments of the class (*ii*) type, however, the measuring marks are different in principle from the one used in the Multiplex in that there are two marks. Moreover, there is an auxiliary lens system between each of the two measuring marks and the main projection lens. This as can be seen from figure VIII ·3 serves the purpose of placing the mark at infinity, as far as the diapositive is concerned. So, whenever the floating mark, obtained by fusing the two measuring marks, is set in the model, the image is sharp and well defined.

In India we have the Zeiss stereoplanigraph as an example of this type of instrument.

(*iii*) *An instrument with mechanical projection* is one in which the lens is replaced by a mechanical joint (a universal joint also called a mechanical cardan) about which a metal rod can rotate to simultate the path of the original light ray. Two such rods, i.e., one for each of a pair of diapositives in an instrument thus centred each around its cardan joint, can materialise the point at which the floating mark is brought to rest in the model. It was E. Santoni of Italy who first constructed an instrument of this type in 1921. Today the Santoni stereoplotting instruments are all based on the mechanical projection principle. The majority of stereoplotting instruments used for productive plotting in the Survey of India are based on this principle. These are the Wild Autograph A7, Wild Autograph A8, Wild B8 and the Kern PG2.

(*iv*) Besides the above three classes of instruments there are instruments of *photogoniometer type.* In this type the projectors are equipped with lenses that have a focal length and principal distance equal to that of the camera with which the picture was originally taken. The negatives are viewed through telescopes and these projection lenses. The viewing system has measuring marks built into it. Since the rays emerging from the projector lens are parallel and since the telescope is focussed for infinity, a sharp image of all points on the negative is obtained. We have no instruments of this class in India. The Thomson Watts Plotter and the Poivilliers B are the more renowned instruments belonging to this class.

SECTION VIII.—STEREOPLOTTING INSTRUMENTS

69. General points about stereoplotting instruments.—*Lens Distortion Compensation* :—The inherent and residual defects of an aerial camera lens result in displacements of image points on the negative or diapositive. These displacements result in a deformed bundle of rays emanating from the projection centre in a stereoplotting instrument. This influence of lens distortion is shown in diagram VIII·4.

There are many ways of compensating these distortions. In general these can be classified into

(*i*) The porro system.
(*ii*) Use of distortion-free diapositives.
(*iii*) Use of compensation plates.
(*iv*) Variation of principal distances.
(*v*) Radial shifting of the photograph or perspective centre
(*vi*) Use of correction surfaces.

From figure VIII ·4, it will be seen that the radial displacment $\Delta r = ha_2 - ha_1$. The diagram with the sign for Δr is taken from The American Manual of Photogrammetry. In some countries the sign is negative for Δr in the above formula. In any case the problem is to restore the value of the angle as nearly truly as possible.

Lens Distortion Compensation in India.—In general either compensated diapositives are used or compensation plates are used. The principle of compensation plates is illustarated in figure VIII·5. The thickness of the compensation plate is varied radially to conform to a pattern that can nullify to a large extent the distortion characteristics of the exposure camera lens. The makers of the various instrument like the Wild A7, Wild A8, etc., or the Zeiss C8 supply compensation plates to match the particular distortion characteristics of a family of exposure camera lenses. These compensation plates are inserted with the emulsion surface in contact with the flat surface of the plate.

Very often the necessity arises to produce diapositives that are distortion-free. This can happen, for example, when compensating plates are not available in sufficient quantity for a wide variety of instruments to be employed in the plotting stage. The diapositives are printed in a reduction printer which is in use in the department. In this the printing done is through a lens and not by contact. With the help of just one compensation plate inserted between the negative stage and the projection lens in the printer all the diapositives produced by the printer can be considered distortion-free for practical purposes. Incidentally this stage of producing diapositives with a reduction printer ill-affords the facility of producing diapostives with standardised principal distances. The necessity for this can arise when an organisation is faced with the problem of having negatives that have a principal distance which cannot be accommodated within the range of plotting instrument.

The other methods of lens distortion mentioned above are not considered here because they are not applicable to the instruments in general use in India. Incidentally it must be mentioned that photography taken with Wild air survey cameras equipped with the Aviogon, Aviotar and Infragon lenses are considered distortion-free and therefore do not need any compensation.

The question of compensation, when it does arise at all, is usually connected with all aerial triangulation and with large scale precision plotting. For plotting on small and medium exposures taken with standard aerial cameras are *usually* considered distortion-free.

The Zeiss Parallelogram.—See figures VIII·6 and VIII·7. Figure VIII·6 shows the situation that would result if the two plotting cameras were placed in such a way that the metal space rods representing the light rays actually intersected. Now in many cases it is not desirable that the rods actually intersect. One of the immediate causes of this would be to limit the application of a variation to the base length 'b' to the perspective centres. In order to enable the perspective centre to be kept fixed, the space rod on the right is shifted to a parallel position as shown in figure VIII·7. Now it can be seen that each displacement can be applied to one of the slides on the base carriage. The latter is the name given to the carriage that has replaced the intersection point. It can be seen that one of the displacements that can be given is in the direction of the base itself thus altering the quantity S — bx. Thus, the variation of model scale is introduced by applying a change to "S — bx" without altering the positions of the perspective centres. This variation of "S — bx" is applied at the base carriage.

There are many resultant advantages in this arrangement. One such is the possibility of introducing a model scale smaller than the original photo scale. The greater physical separation of the projector bodies and the introduction of the scale variation at the base carriage avoids the projector bodies clashing or getting entangled together. This, they would surely have done if such an arrangement were not there.

Another great advantage resulting from this arrangement is the possibility of doing continuous aerial triangulation, on instruments equipped with the Zeiss parallelogram, by the aero polygon method described in Section X. The use of the Zeiss parallelogram as far as this aerial triangulation is concerned is illustrated in figures VIII·8 to VIII·11. The major problem in building an instrument suited for continuous aerial triangulation in strips is to have a base carriage long enough to enable the base to be set 'Inside" or "Outside" the parallelogram. Figure VIII·8 is a sort of simplified form of figure VIII ·7. To incorporate the Zeiss parallelogram the right projector has been shifted further to the right and now the single intersection point can be considered to have been split into the two points B′ and B″. The middle of the base carriage B′ B″ now can be considered to represent the single intersection point represented by B in the case without the Zeiss parallelogram. Figure VIII ·9 shows the position at the time of exposure in the cameras. Overlaps 1–2 and 2–3 are indicated. Figure 10 shows the position in the instrument with the overlap 1–2 as they were at the time of exposure, i.e., in the proper sequence from left to right in the direction of flight.

Figure 11 shows next overlap in the instrument after the triangulation observations in the first model is over. Now since photograph 2 has been fixed in the instrument and oriented firmly we are not in a position to bring this diapositive on the left. Now placing diapositive 3 on the left we see that we have to place the base outside the parallelogram to secure an intersection. The overlaps are now inside. As was explained earlier, the instrument has to have a sufficiently large base to enable this operation to be carried out and the base to be "placed outside". The size of the instrument and the need to maintain high precision even with this increased size, adds very greatly to the cost of the instrument. It can now be imagined why an A7 costs about 4 ·5 times as much as an A8.

70. Important components in stereoplotting instruments.—*Dove Prisms.*—The fact that the photographs are placed in a sequence against the normal sequence, as mentioned in the foregoing paras necessitates certain complications in the optical system to ensure that a stereoscopic relief (and not pseudoscopic) is seen. This is done by the introduction of necessary prisms brought into the optical train so that the image from the left diapositive is brought into the right ocular and the image of the right diapositive is brought into the left eye. But one result of this is that the final image (since viewing is done against the line of flight) appears rotated by 200 grades about the line of flight. Thus for example an arrow should point $\overset{N}{\underset{S}{\uparrow}}$ would appear $\overset{N}{\underset{S}{\downarrow}}$.

To restore the original situation, dove prisms are rotated. Figures VII ·12 and VIII ·13 illustrate how a 100 grade rotation of the dove prism causes a 200 grade rotation of the image.

Axes of rotation.—In order to get a good stereoscopic view the condition of epipolarity must be satisfied by the lines of vision. This is nothing other than satifying the condition of natural vision in which, our lines of vision intersect in the point images which we are seeing in space. The two lines lie automatically in a plane and this is the basic condition of coplanarity or epipolarity to be satisfied.

Another way of stating the same condition is that X-direction must be parallel to the eye base. Now this condition can be fulfilled only by the use of a particular arrangement of the primary and secondary axes in the 3-axes system of the projector. Of course, it will be seen later that this problem is met with only where optical projection is maintained as in the case of the stereoplanigraph C8. See figure VIII·14. If the Y-axis is a primary axis then a rotation of the X-axis about this will cause the line of sight to be inclined as shown. The scanning of the picture plane in the Y-direction by this inclined line of sight would trace in the picture plane a straight line trace in the Y-direction. This would simply be intersection of two planes, the photo plane and the plane generated by the line of sight rotated about the axis II. If now the scanning is done in the X-direction the line of sight would be rotated about the Y-axis and would generate a cone unless the scanning is done along the "equatorial line" AA. At any other line the intersection would be that of a cone and a plane (i.e., the photo plane) and the result would be a curved trace and not a line parallel to the X-axis. Thus it can be seen that "X-lines" will not be parallel to the eye base, which will be necessary for epipolarity. Similarly if the X-axis is a primary axis the Y-lines will be thrown out of parallel causing certain exagerrated relief effects. This problem arises in an instrument like the Stereoplanigraph C8. In instruments like the Autograph A7 or A8 where the observation is orthogonal with respect to the plate, the difficulty does not arise at all.

Conditions for good stereoscopic fusion.—Apart from the condition of epipolarity the other conditions which have to be fulfilled for proper stereofusion are :—

(*i*) An overlapping pair of pictures must be presented to the eye.

(*ii*) The eye base must be suitable and comfortable for the viewer. Besides, the angle of convergence that has to be brought into play must not exceed that possible for the normal unaided eye, i.e., about 20°.

(*iii*) Equal scale for right and left image points. In instruments of the Multiplex type this condition is automatically fulfilled. What we are seeing here is not the image but the projection. During the reversal process the size of the original object is restored, on a certain scale and there is no disparity between the images as projected from the right and left cameras. Even in projections of convergent photography there will be no disparity. In a mechanical type of instrument like the Wild A7 or A8 convergent photography cannot be utilised because it is the diapositives (i.e., the images) that are being viewed directly and since corresponding images of objects will appear dissimilar in case of convergent photographs one cannot view them stereoscopically. This is one of the reasons that only near vertical photographs can be used in an

A7 or A8. A stereoplanigraph being an optical projection instrument, can take covergent photography.

In instruments of the photogoniometer type *a pancratic system* is needed to see images compensated for unequal magnification caused by the images being viewed thruugh telescopes inclined at various angles.

(*iv*) *Good illumination* is an essential condition for good observation. The problems of illumination differ from instrument to instrument ; generally speaking, however, they are more complicated in optical instruments like the Multiplex type, and a little less so, in the Stereoplanigraph C8. In the mechanical type of instruments like the Autograph series it is only a question of viewing (somewhat similar to the situation under an ordinary stercoscape) and so powerful condensing lenses or guided reflectors (Kelsh, C8) are not required. In the earlier Multiplex type, of which we have a few in the department, a powerful source of light has to be condensed on the diapositivs. Since the original negative size would have been impossible of illumination without entailing vast problems of cooling and condensing lens aberrations, reduced diapositives had to be restored to. The Kelsh plotters got over this problem by guided illumination falling on the area under observation. They are thus in a position to accommodate unreduced diapositives.

Devices for measuring co-ordinates and/or for plotting the model.—One has to distinguish here between instruments in which aerial triangulation can be performed and those in which only plotting can be done. In the more expensive instruments which are equipped for aerial triangulation by the aero polygon method, with a Zeiss parallelogram for "base in" and "base out" facilities, co-ordinate measuring devices are provided. These can be read out or mechanically/electronically recorded. In instruments whose primary function is plotting, the machnie as such is not equipped with co-ordinate drums. The Kern PG2 and the Wild B8, for example, has no co-ordinate measuring drums. The Autograph A8 (older type) has co-ordinate drums on the drawing table.

The essence of the measuring system is the floating mark. The design of this mark differs from instrument to instrument. In the Multiplex type of instruments the mark is an illuminated perforated dot on the screen on which the projection is effected. In instruments like the Stereoplanigraph C8 or in the Autograph, etc., the two measuring marks are built into the optical system.

71. Description of stereoplotting instruments in India.—*Zeiss Stereoplanigraph C8.*—Fig. VIII ·15 is a schematic diagram of the instrument. Other diagrams can be referred to, in the working manuals. As in the case of other instruments, the salient features only are described below :—

The projection system.—There are no space rods in this instrument. The image is projected on to the two plane mirrors at the centres of which are also the projected images of the measuring marks. The projected image is reflected into the optical train which ends with the oculars near the operator's eyes. The projection system consists of the photo carriers, auxiliary optical systems, the main projection lens, measuring mark and the guided illumination that swings above the plate carriers. The distance (a function of the image position on the plate) between the projection lens and the image point and between the former and the measuring mark is a variable factor. Irrespective of this a sharp image has to be focussed on the plane mirror at the measuring mark. This is achieved by the auxiliary lens system. This consists of two lenses whose combined focal length is a function of their mutual separation. This separation is controlled by the hyperbolically shaped edge in such a way that the combined focal length causes a sharp image to fall at all times on the measuring mark. The mirror also functions as an optical cardan and will be described here although it is an essential part of the optical system. The mirror has its primary and secondary axis of rotation fixed in such a way that whatever the direction of the incident ray from the projection lens, the exit ray must go out in a fixed direction parallel to the X-axis to enter the fixed observation system on the operator's side. The optical cardan mirror has a fixed primary X-axis and a secondary Y-axis. The C8 being an optical instrument has a lens with a fixed principal distance. Minor variations are possible to accommodate the correct principal distance as derived from the camera calibration data or from film shrinkage distances. An ample range of 15 mm has been provided for this purpose, within which variations from the focal length can be accepted.

The universal photo carrier of this instrument is a unique feature. It can be separated into the following three parts :—

(*i*) The central portion for setting the swing (Kappa) and the calibrated focal length.

(*ii*) The lens cone which can be changed to suit the exposure camera lens. The carrier can take lenses from 90 to 310 mm and format size upto 23 cm × 23 cm.

(*iii*) The photo frame which can hold the photographs and if necessary the correction plate for compensation.

The illumination of the photograph is controlled accurately by means of a parabolic mirror closely guided by a parallelogram (a kind of pantagraph) formed by two rods.

The observation system.—From the time the emergent ray reaches the optical cardan mirror it can be considered to have entered the observation system of the instrument. As discussed under the general principles of design it is essential to present images to the left eye and right eye of equal size and "aspect". The rotation of the optical cardan about the X-axis (optical axis) necessitates an automatically controlled Dove prism that compensates for the image rotation caused by the aforesaid rotation of the optical cardan.

The rotation elements are applied at the camera and the displacements bx, by, bz at the base carriage. As for absolute orientation, a common rotation of both the cameras around X-axis is possible. All orientation values can be conveniently read from the operator's seat on illuminated dials.

The instrument as already mentioned has the Zeiss parallelogram, and therefore, aerial triangulation by aero-polygon method is possible. The optical elements, i.e., prisms and lenses in the observation system are illustrated in figure VIII·15.

The measuring system.—This consists of the measuring marks, the three-diamensional compound slide with guide spindles, the drive mechanisms and the printing contours. The camera bridge is raised or lowered on the Z-column in accordance with the height measured. This Z-motion can be controlled either by a foot disc or an electric motor. The Z-column as can be seen from figure VIII·15 is mounted on a primary Y-rail. The base carriage moves along the X-rail. The X- and Y-co-ordinates movements are effected by means of handwheels. The sense of rotation of all three X, Y, Z motions can be reversed to suit the habit of the operator. The Y and Z co-ordinates can be exchanged thus facilitating terrestrial photogrammetry. In the sense that the C8 can accommodate near vertical, oblique, convergent and terrestrial photographs and also execute aerial triangulation, it is a universal instrument. For observations in mountainous terrain the Z-motion can be driven by an electric motor and the foot disc need not be used.

A unique feature of the C8 is its mechanical co-ordinate registering device. When large scale work particularly cadatrsal mapping is involved this mechanical co-ordinate registering device can save a lot of man-hours because all that has to be done is to press a lever provided for the purpose. The co-ordinates of the point read, are automatically printed including carbon copies if desired.

The planimetric movements are transmitted to the drawing table by mechanical connections over a variable speed gear. By simply interchanging the various gears a variety of fixed model to map scale ratios are possible ranging from 5 : 1 to 1: 10. The elevation can be read off in metres or feet in 13 different scales.

A variety of special attachments can be had from the makers. The most popular at the moment is an automatic electronic coordinate registration device, knwon as the Ecomat. The versatality of the instrument is greatly increased by an arrangement for profiling in any direction.

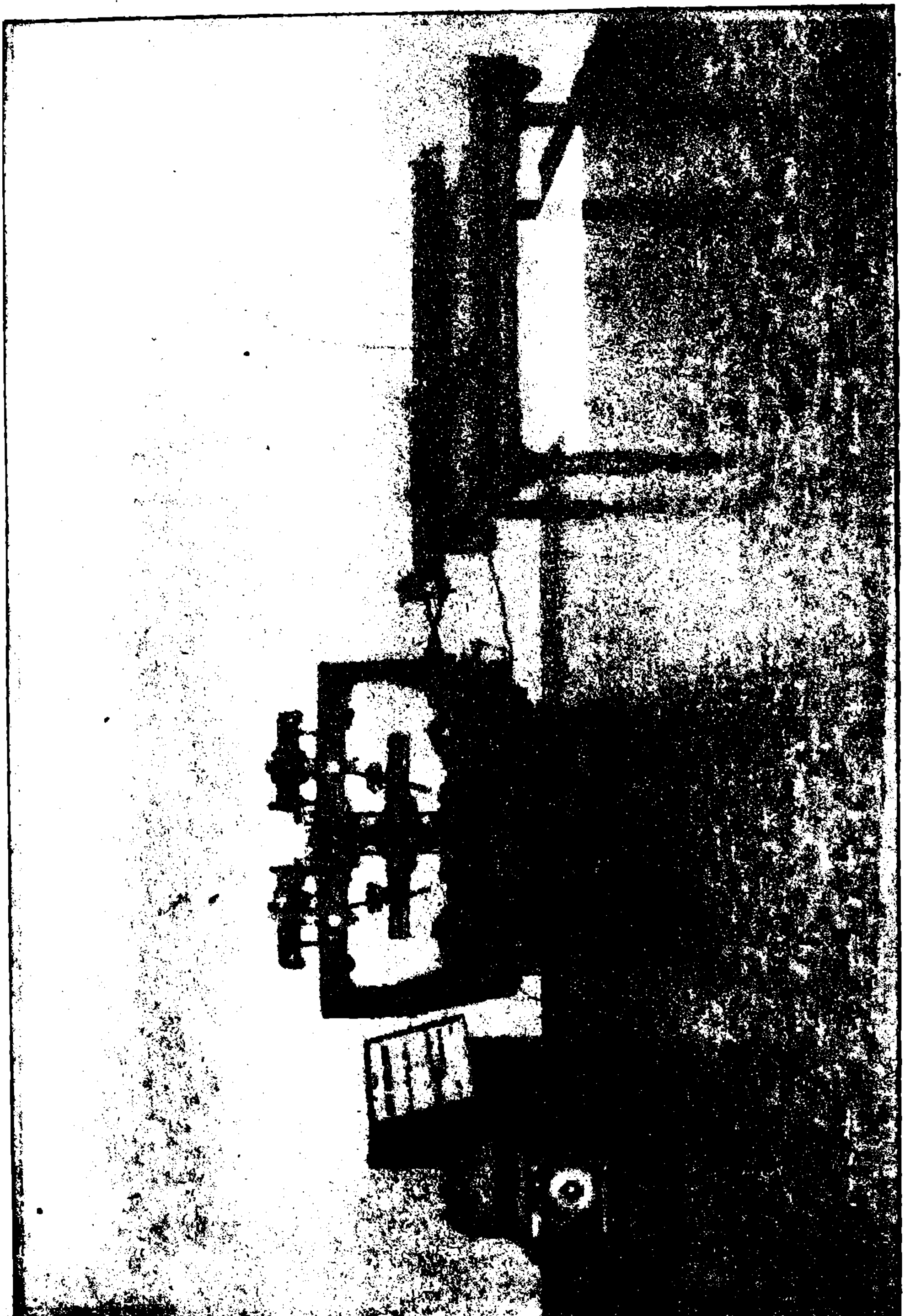
Wild Autograph A7.—This is a high precision universal plotting instrument of the mechanical projection type. E. Santoni and Wild are the pioneers in the construction of this type of instrument. It was in 1935 with their A5 that Wild commenced production of the mechanical type of instrument. Since then they have adhered to this principle which has now been perfected in their A7 which is a universal type of instrument in the sense that triangulation by the aeropolygon method can be executed on it. A diagram illustrating the working principles is shown in figures VIII ·16 and VIII ·17. See also plate VIII ·A.

The projection and observation system.—Nearest the negative/diapositive is this microscope mounted on a *swinging girder*. The measuring mark 'M' is housed in the microscope and moves always in a plane parallel to the picture plane and the observation is always orthogonal. Since the A7 has a variable principle distance, the plate carrier has to be sometimes raised or lowered. However, it is so arranged that the measuring mark which remains at a fixed distance of 70 mm from the picture plane always receives a sharp image. The optical system consisting of a train of lenses and prisms so arranged that the rays emerging from the measuring mark plane are conveyed in a parallel pencil to the ocular.

Rotation elements being imparted to the plate carrier, it is inevitable that epipolar traces on the planes undergo minor apparent rotations. Dove prisms are provided and these can be used to get a stereoscopic view without causing undue strain to the eyes of the operator. Once the Dove prism is adjusted to suit the eyes of the operator it should not be necessary to disturb its settings.

A lever in the instrument called the triangulation lever diverts the rays from the right diapositive to the left ocular and *vice versa*. This becomes necessary during alternate model observation during aerial triangulation by the aeropolygon method. As explained earlier in order not to disturb the disapoitive already in place, it becomes necessary to observe the averlapping pair placed in the instrument against the sequence of flight. Besides this there is also a lever called the diapositive lever. It becomes necessary to use this to compensate for image reversal caused by placing diapositives with emulsion downwards.

The oculars can be used either with 8, 5 or 10 magnification. With larger magnification it is possible to see with increased definition. One of the unique features of this observation system, besides the fact that it is always orthogonal, is that, between the measuring mark and the emulsion there is only a simple lens system. The measuring mark itself is a small, round, jet black mark of a diameter of 0·04 mm. The plane in which the measuring mark is constrained



Wild A7 Universal Autograph for aerial and terrestrial photogrammetry, especially equipped for aerial triangulation. Largest picture format 23 cm × 23 cm (9" × 9"). For restitution of negatives and diapositives on film or glass.

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to move is always parallel to the picture plane. This orthogonal observation and the short path of 70 mm between the emulsion and the measuring mark with a simple and constant lens system, secures for every operator an easy and comfortable view. The illumination is provided by a 6 volt bulb. The necessary step-down from Mains is achieved by a transformer.

The instrument has a large range of focal length setting from 98 to 215 mm. There is no question of change of lenses or plotting cameras. A continuous setting upto an accuracy of 0·01 mm is possible. In addition, compensation plates can also be inserted as necessary. The maximum format size is 23 cm × 23 cm.

The measuring system.—The instrument is equipped with the Zeiss parallelogram and it is, therefore, possible to do strip triangulation as in the Stereoplanigraph C8, keeping "base out" and "base in" as necessary. The movement of the measuring mark for scanning/plotting is actuated by a two-stag drive with a normal and high gear. The sense of rotation between handwheels and the spindles can be reversed and the operator can assign to the movement of the floating mark, the direction he desires, in the machine axis system of the instrument. There are three counters one each for x, y and z co-ordinates, that enable the x-, y-drums to yeild machine co-ordinates in millimeters. The elevations can be read directly in meters or feet by varying a gear provided for the purpose. The least count on the z-drum can be arrived at by consulting the operators' manual provided by the makers with the instrument. This is indicated in the manual for the various height gear ratios.

The instrument has set X, Y and Z ranges in its machine axis system, *viz.*,

X	+ 280 to − 280 mm
Y	+ 350 to − 420 mm
Z	140 to 490 mm

This along with the permissible bx range, viz., + 280 to − 280 mm will determine the scale of the model that can be accommodated, in the machine axis system, for a particular stereo pair.

The movement from the Autograph to the drawing table is transmitted through a universal gear box with shift knobs. The drive is actually provided through two extendable cardan shafts connected to two ball and socket joints of the table drive. The axial directions for the X- and Y-movements on the drawing table co-ordinatograph is also *reversible.* The axis can also be interchanged. A wide range of model to map ratio is possible.

A special co-ordinate printer is also available as an extra item to print the instrument co-ordinates. This is known as the Wild EK 5 Electric Co-ordinate Printer. Another special attachment that is available is the Wild PR 1 Profiloscope for plotting of profiles and cross sections.

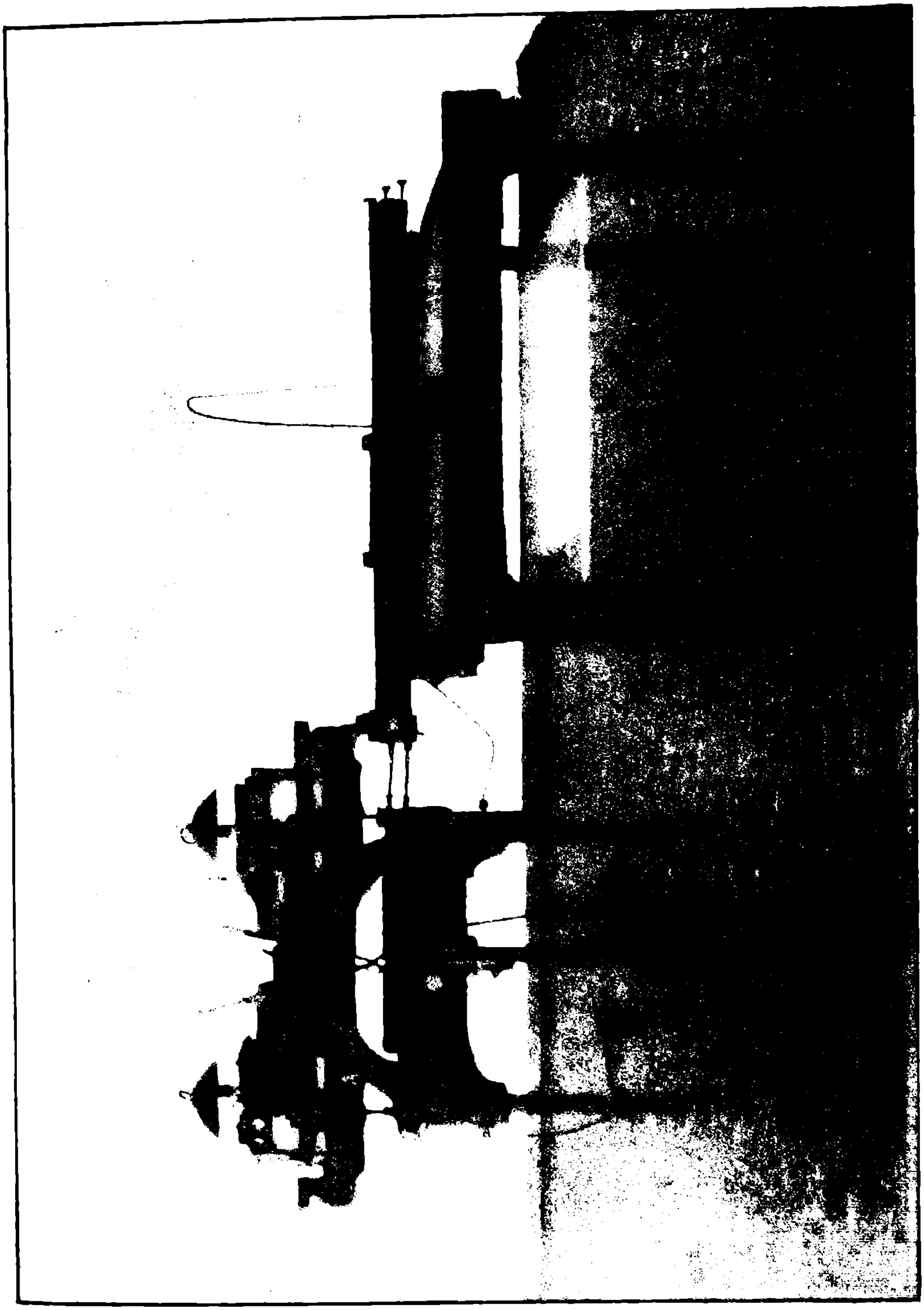
Wild Autograph A8.—A diagram showing the optical and mechanical elements of this instrument has been given in figure VIII·18. See also Plate VIII·B.

With the advent of very high quality camera lenses it became possible to secure good survey photography even from high altitudes. To economise with these high altitude photographs it was necessary to have an instrument that could plot on large scale even with this small scale photograph. The A8 which is essentially a precision plotter was developed to meet this requirement. The A8 can, of course, be employed for mapping on small and medium scale also. The model to plotting table ratio can be altered from 1 : 4 to 4 : 1. Map scales of even 1 : 1000 are possible in this extremly precise plotter. The A8 has a calibrated focal length ranging from 98 to 215 mm and the maximum picture size it can take is 23 cm × 23 cm. The X-movement in the machine axis system has a range of 335 mm, the Y-movement has 440 mm and the height range is 175 mm. Thses figures and the bx range from 65 mm to 220 mm determine the model scale.

The projection device.—There is a mechanical projection device and the intersection triangle made up of the space rods and the spatial point are shown in the diagram VIII·18. There is no Zeiss parallelogram in this instrument. Instead, a large separation between the projectors has been achieved by having an arrangement of a "scissors" type that is referred to popularly as "the lazy tongs". One end of the lazy tongs, as can be seen, houses the cardan joint around which the space rod swivels and the other end carries the objective with its measuring mark. The instrument has a symmetric arrangement of rotation elements that can be given to the two plate holders. It has no by or bz movement but it has a common Φ movement. It is possible to insert correction plates instead of the ordinary picture carriers thus ensuring a distortion-free projection. The same picture carrier, correction plates and grid plates can be used in the A7 and A8.

The observation system.—As in the case of the A7 the observation is maintained orthogonal and the simple short optical path from the measuring mark to the emulsion provides the operator with a comfortable view without undue strain in his eyes. Correction for non-parallelism of the eye axis is also provided. The instrument has an excellent large field of view and scanning is facilitated thereby. As can be seen in fig. VIII·18 a dove prism is provided in the optical path and this compensates image rotations which occur in the case of very big movements of orientations of the cameras. Illumination is effected by a simple 6-volt bulb.

The measuring system.—The X- and Y-movements are effected by hand-wheels and the Z-movements by a foot disc. The hand-wheels have both high and low speed gear ratios permitting quick and slow scanning. In addition a handle with a disengaging device



Wild A8 stereoplotting machine for plotting of vertical aerial photographs. For negatives and diapositives on film or glass plates. Calibrated focal length adjustable from 98 to 215 mm.

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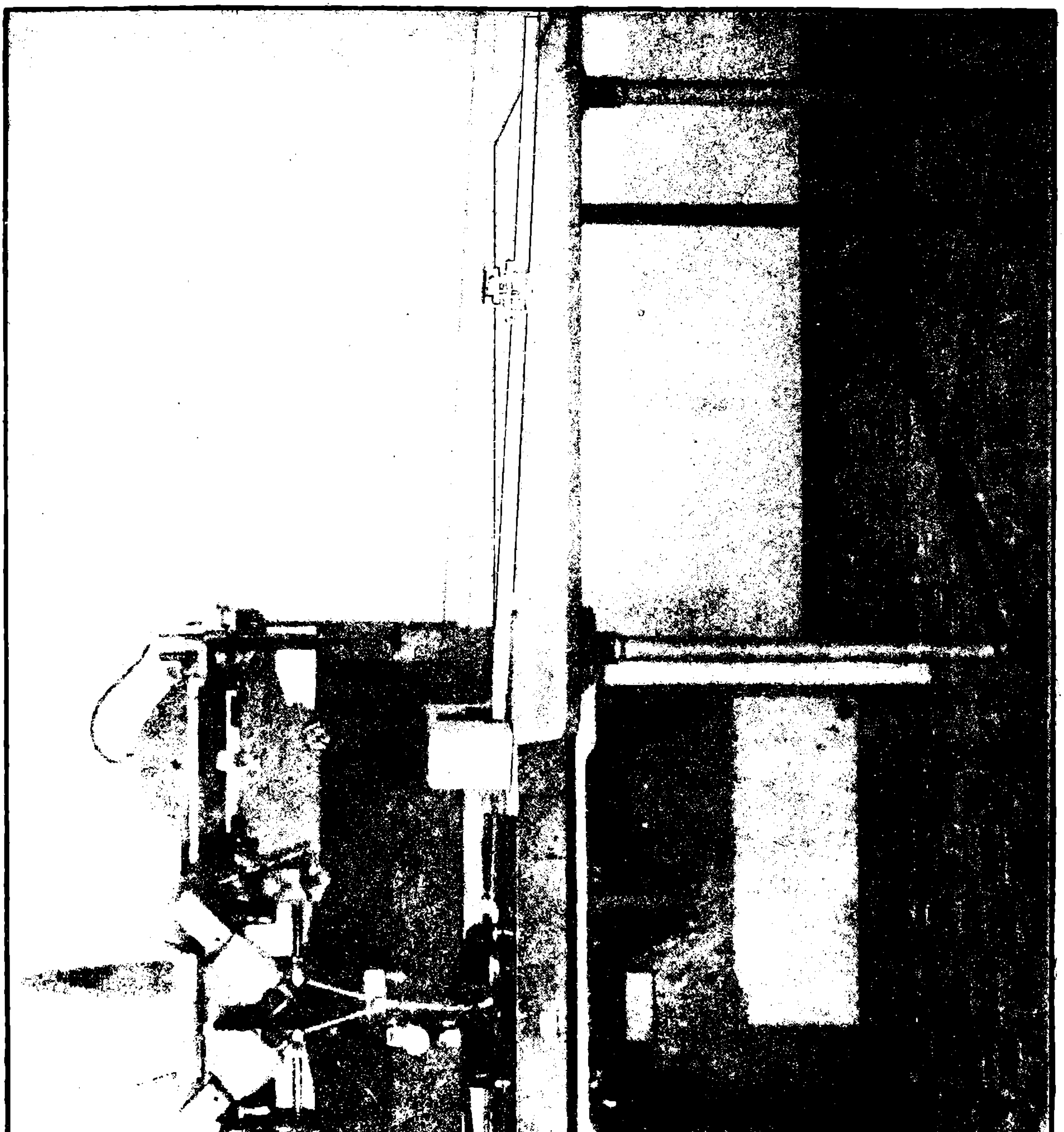

Wild B8 «Aviograph» Stereoplotter with attached plotting table and linear pantograph, for plotting at medium scales.

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is fitted on the X-carriage and with the help of this the carriage can be rapidly slided in the X- and Y-directions and while this is being done the X- and Y-hand-wheels are disengaged. A foot disc operated by the right foot drives the Z spindle through a cardan shaft and this spindle thus raises or lowers the Z-column on which a rough reading scale is fixed. Finer readings are read off on illuminated glass scale. A number of glass scales are provided each having a particular model scale entered on it. Depending on the model scale applicable the appropriate glass scale is chosen for insertion in the holder attached to the Z-column. For the usual model scales, heights can be read off directly in feet or metres.

The plotting table.—A gear is provided between the plotting table and the instrument. By choosing the appropriate gear various model to map scales are rendered possible as mentioned earlier. Two sizes of drawing table are made available by the makers, a large one measuring 133 cm × 180 cm and a small one measuring 130 cm × 98 cm. Co-ordinate drums are provided on the drawing table and map co-ordinates can be read off. Now the makers have introduced an electric co-ordinate printer, the EK5, that can be attached to the A8 also.

Wild B8.—The B8 introduced by Wild was aimed at meeting the requirements of topographical plotting, particularly on medium and small scales from wide and superwide angles. We have a number of these in the department. It is also a mechanical projection instrument. Figure VIII · 19 shows the construction principles. See also Plate VIII · C.

The projection system.—It has a very elegent, simple design. In fact this characteristic renders it very useful for training purposes. As in the case of A8 it has for relative orientation, the tilt ω, the tip ϕ and the swing k for each photograph. The space rods are separated at their lower ends by a small distance, which is clearly shown in fig. VIII · 19. The base tube (i.e., the tube on which the adjustable base bx is mounted) can be inclined about the central pivot, representing common Φ. The plotting camera is carried by the camera carriers and these are to be changed to suit the focal length of the plotting camera. The focal lengths available are 152 mm, 115 mm, 100 mm and 88 · 5 mm. At present in the department we have only the two former ones.

It will be observed from the schematic diagram VIII · 19 that the projection centre is above the picture plane.

The maximum enlargements possible from picture to model scale with a focal length of 152 mm is approximately 1 · 4 to 2 · 1 × and for a focal length of 115 mm this is approximately 1 · 5 to 2 · 4 ×.

The observation system.—Negatives or diapositives can be secured to the picture carriers and these as usual are illuminated from above. The microscope carriage moves on a cross rail system below the pictures in a plane parallel to that of the picture. As in the case of other Wild instruments mentioned in this section, observation is orthogonal.

The instrument has a very good field of view and the operator has a very good view of the terrain. One of the special features in the optical train is the Abbe prism. When the camera tilts are excessive,e specially large ω differences, rotated images are presented to the eyes. To correct these rotations this prism is introduced and functions like a Dove prism. The optical system has a six-fold magnification. The tie rods with the viewing miscroscope always move in the epipolar plane.

As in the case of the Autograph the distance between the picture and the measuring mark is kept constant and a sharp image is always focussed on the measuring mark.

The measuring system.—Both scanning and plotting are done by moving the free-hand guidance system provided with a good hand grip. Direct reading of terrain heights in metres or feet is possible from glass scales appropriate to the model scale inserted in the holder near the hand grip. The whole system is mounted on a stable wooden desk on which the instrument stands mounted on 3 foot-screws. Normally when plotting on scales smaller than the model, plotting is done directly by the reducing pantograph which is the usual parallelogram device. For this, an extra drawing table is not required. This pantograph has reduction ratios ranging between 5 : 4 and 5 : 1. A linear type of pantograph is also available from the makers for plotting at scales larger or smaller than the model scale. Enlargement ratios upto 2 : 5 and reductions ratios down to 5 : 2 are possible through adjustable gears. The whole instrument is extremely easy to understand, operate and assemble.

Kern PG-2.—This instrument is a mechanical type projection instrument but it is quite different in its construction from any other mechanical projection type in use today. One of the aims of the design is to provide an instrument with principal distances of a continuous and wide range. The makers have actually been able to provide a continuous range from 85 mm to 155 mm. Till recently this was the only plotter in the mechanical projection class that could take both wide and superwide angle photography. The elements of orientation that are incorporated are K_1, K_2, ω_1, ϕ_2 and bz_2. The elements of absolute orientation available are Φ, Ω & B_x. It is also intended to have orthogonal viewing.

The projection system.—One of the most striking features of the instrument is that the pictures under observation, at all times, remain absolutely horizontal as the orientation elements are applied not to the picture carriers but to the projection system. This treatment does away with the necessity for optical cardans and joints.

Figure VIII · 20 shows a schematic diagram that would also serve to illustrate the working principle. The key notes of this are :—

(*i*) The unique cardan joint that is quite unlike the one found in any mechanical projection type instrument. Centered around this cardan joint are two primary and two secondary axes. This makes it possible for the space rod's spatial rotation to be projected into component rotations in the XZ plane and the YZ plane, to the X-rods and Y-rods which are seen as flat rods centered around the 4 primary axes of the two double cardan joints. The left plate has its X- and Y-rods and so has the right plate. The X-rods move the picture carriers in the X-direction during scanning and the Y-rods move the objectives in the Y-direction. This is how the scanning is achieved. The instrument can be considered to have a Zeiss parallelogram in that the perspective centres are fixed but there is no possibility of keeping "base out".

(*ii*) What the space rods do in a way, is to measure the x and y co-ordinates of the plates, these co-ordinates, of course, being corrected for errors in position caused by the tips and tilts, viz., ϕ and ω. Now in these errors, there are constant parts, being a function of the tip and tilt and the principal distance itself. There are variable parts that are functions of tips, tilts, the image coordinates x and y and the principal distance. The actual scanned motions in the X- and Y-directions are corrected for these constant and variable parts, in the projection system of the instrument.

(*iii*) Above the projection centres the x and y motions are completely separated. The corrections for tip and tilt (ϕ and ω) and the plotting principal distance can be considered, therefore, for the x and y motions separately. Model deformations can, therefore, be removed to a large extent without introducing Y-parallaxes.

The observation system.—The unique mechanical projection described above and pictured in figure VIII · 20 results in a rather unique and simple observing system. The observation being orthogonal and the picture being always horizontal eliminates the necessity for Dove prisms as already explained. The observer has a choice of 2, 4 or 8 × magnification as well as two types of luminous floating marks. The exit pupils are situated at a slight distance away from the oculars, i.e., 35 mm. Operators who do not wear glasses will have to get used to this distance. Optical train is also simpler in this instrument.

The instrument is essentially a topographic plotter. It has an attachment, *viz.*, a glass microscope fitted on to the space rods, that enables bridging to be executed—only height bridging—quite conveniently. The instrument has an extremely good height accuracy and it is possible to use the instrument for scales larger than medium.

The measuring system.—After completion of relative orientation the scale can be applied at the base bridge. Levelling of the model is, however, achieved by applying the absolute tip and tilt to the drawing table. This results in the Z reference plane along with the scanning carriage and the pantograph working on a tilted plane. This difficulty has been countered by means of a special brake provided for the purpose.

A parallelogram system maintains the base bridge parallel to the X-direction at the same time transferring its motions during scanning to the polar pantograph system. At the pole of the pantograph, a combination from amongst 15 available transmission discs, provide the necessary range of model to map scale ratios required. The range is between 1 : 2 to 2 : 1. A steel tape transmits the motion to the pencil point. Since the survey is done on a tilted table, the tracing pencil does not give uniform lines in all directions.

As for elevations, these can be read directly in metres or feet for any odd model scale, on a dial gauge that is also attached to the base carriage. During contouring the elevation can be locked. The range in the Z-direction is 60 mm. In the X- and Y-directions the model ranges are 150 mm and 260 mm respectively.

Particularly because it is able to plot from superwide angle photography, the PG-2 is equipped with a correction device for compensating elevation errors due to the earth's curvature. Changing Z_m (mean projection distance) for different model scales is a drawback in the instrument.

Zeiss Stereotope.—This instrument falls in the catagory of approximate instruments. Thse are so called because in these-instruments there is no construction of either an optical or mechanical model. In the stereotope ordinary measurements as in the case of a parallax bar are made and the resulting measurements are corrected, in accordance with certain approximate formula, to yield heights good enough for small scale mapping. Automatic rectifying mechanisms eliminate errors arising out of relief and tilt displacements, as far as planimetric displacements are concerned.

Working principles.—General.—In the stereotope the problem of making a map from a photograph (not really a pair of photographs as in the case of the stereoplotting instruments mentioned earlier) is resolved into the following four operations :—

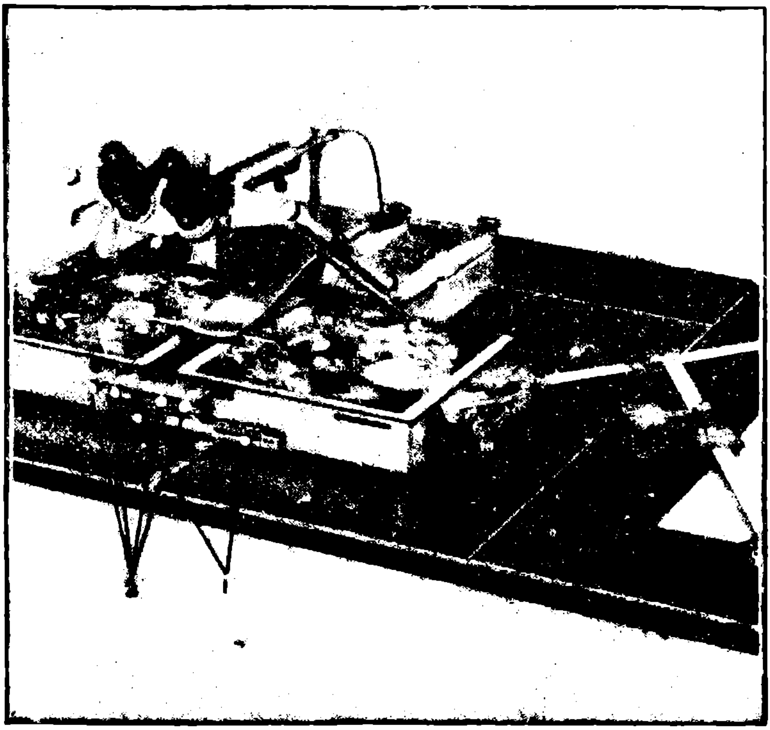
(*i*) Conversion of central perspective into an orthogonal projection.

(*ii*) Removing errors in parallax measurements, executed by the built-in-parallax bar, caused by the tips and tilts in the photographs.

(*iii*) Removing effects of tips and tilts in planimetric positions.

(*iv*) Correcting the changing photo scale to a constant map scale. All these corrections are "computed" mechanically by the use of mechanical devices that apply the final corrections required

PLATE VIII.D



STEREOTOPE

Simple plotting instrument for the compilation of small-scale topographic maps, with OV Mirror Stereoscope as viewing system, photo-carriage with parallel-motion device and built-in mechanical computers, parallax-measuring system and pantograph (magnification range 0.2 to 2.5×), independent of camera focal length.

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to either the parallax bar readings (for heights) or to the photograph (for plan).

Correction described in sub. para (*i*) above, *viz.*, corrections due to relief, radial from the nadir point is a function of the base, image co-ordinates x and y, and parallax px (which is in reality a function of the elevation). Plate VIII·D shows one view of the instrument. The base can be set, after it is read off from the picture, on the scale provided in the front of the instrument (item 1 of plate). The three other variables, viz., Δ p, x and y co-ordinates are automatically fed into one of the computers in the instruments.

This computer, referred to as Computer II in the manual, has a system of mechanical linkages. The corrected x and y co-ordinates are fed into the pantograph take off.

Correction described in sub. para (ii) above is illustrated in figure VIII·21. A flat terrain plane would be deformed into a hyperboloid because photographs are being viewed in a horizontal position. A correction surface has to be introduced with an opposite sign to nullify this deformed surface. This correction surface should, in reality, be a combination of an 'ω' deformation and a 'ϕ' cylinder. The correction surface actually applied in the stereotope, however, ignores the small deviation in the 'ϕ' cylinder from the plane containing the limiting edges of the cylinder. This is why, it is stated in the case of the stereotope, that the 'ϕ' cylinder correction is ignored. The correction surface is introduced by moving the four screws, visible in front of the instrument (item 2 of Plate VIII·A) in turn, so that the "ground" at a control point is forced to rest on the floating mark. The latter is preadjusted in elevation to equal the given elevation of the control point, by setting precomputed readings on the parallax bar.

The four screws alter the inclinations of certain mechanical linkages set in a flat positions in such a way that the parallax bar readings read off at the scale, are corrected in accordance with a formula of the type :—

$p = ax' + by' + cx' \cdot y' + d$ in which x' snd y' represent the image co-ordinates. The constants a, b, c, d are determined by the settings on the four screws. These settings are controlled by the heights of the given control points at the four corners. This computer is referred to as Computer I.

The correction referred to in sub. para (iii) above is accomplished by means of a rectifying computer. This is operated by two screws at the rear of the instrument. These two screws are moved empirically till the images of four control points in the four corners of the model are fitted for planimetry also, on the plot sheet. This operation is similar to that done under a rectifier. This rectifying computer is coupled to Computer II and in fact the co-ordinates fed into this computer are those corrected for relief by Computer II.

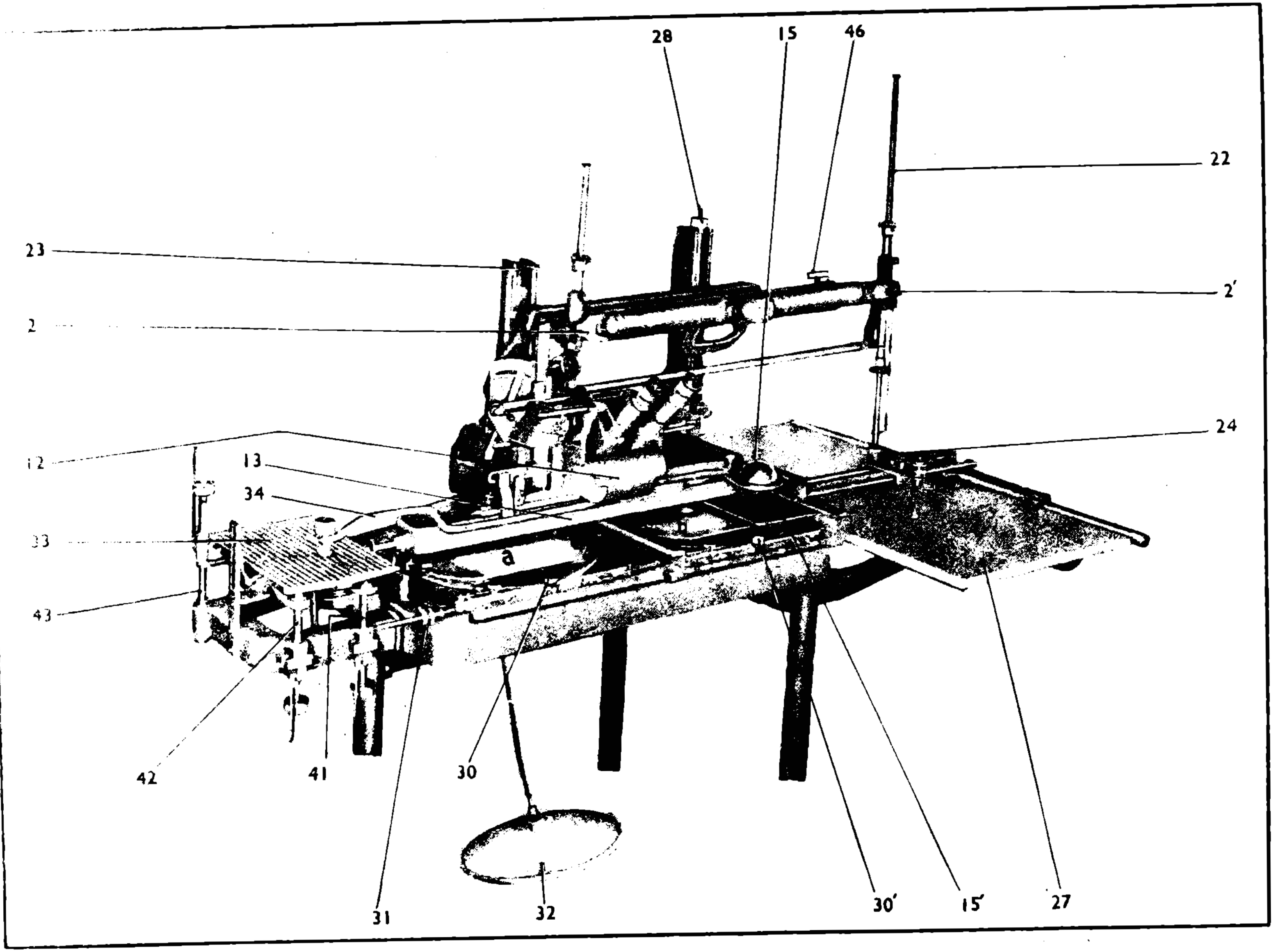
A pantograph completes the job of converting the photo scale into a map scale. It is the left hand photo which is corrected and converted into the map.

Brief description.—The instrument can take contact points up to 23 cm. × 23 cm. The base setting is from 45 to 120 mm. Although terrain with large relief differences can be plotted, sometimes by adopting special procedures, the instrument is really meant for medium and low relief. The elevation range for normal working corresponds to about 15% of flying height. The maximum tilts that it can accommodate is 4 grades. The pantograph permits a magnification of upto 2·5 : 1 and a reduction of upto 1 : 5. An attachment known as a parallax converter is available. This is a kind of dial gauge from which parallax values corresponding to given elevations can be read off. This avoids use of conventional forms and computations. The latter are described elaborately in the Manual. Departmental forms that are almost self-explanatory are also available.

Santoni Stereomicrometer.—This instrument (Plates VIII·E and VIII·F) uses a different mechanism to give the same type of adjustment as introduced by mechanical computers in the Zeiss Stereotope. A spatial pantograph (1) provides the connection between the scanning stereoscope and the plotting table (3).

The scale is adjusted by raising or lowering parallel guidance (2) by means of screw 28 so that the plotting point (24) moves from the plotted position of one control point to that of the other when the scanning mark travels between the photo positions of these two points. It is obvious that the higher the guidance bar the bigger is the enlargement of the plot.

'P' or principal distance is set on scale 23. Three height scales (20) corresponding to principal distances of 115 mm, 152 mm and 200 mm are provided with the instrument. These scales have hyperbolic graduations to provide for second order term of parallax equation $h = Z_0 \frac{\Delta P}{p + \Delta p}$. The X- carriage (12) rests on Y-carriage (13) connected to a ball (15) resting on a plate or hardened rubber (15′). Rotating the ball yields combined displacement of the scanning system such that unit displacement of the ball yields double displacement of the measuring mark relative to the R.H. photograph. Knobs (30 & 30′) are used to impart small rotation to the photograph carriers. Screw 31 is used to fix the initial bx setting. Foot disc 32 is provided to give 'b_y' displacement to the L.H. photo carrier. The rear carriage 16 is moved along a vertical track in order to incline ruler 18 to tangent settings on sector 19 representing $\frac{bx}{f}$ providing correction to height scale readings in keeping with the variation in height.



Stereomicrometer

A simple approximate type of stereoplotter with number of correction devices for different exposure conditions

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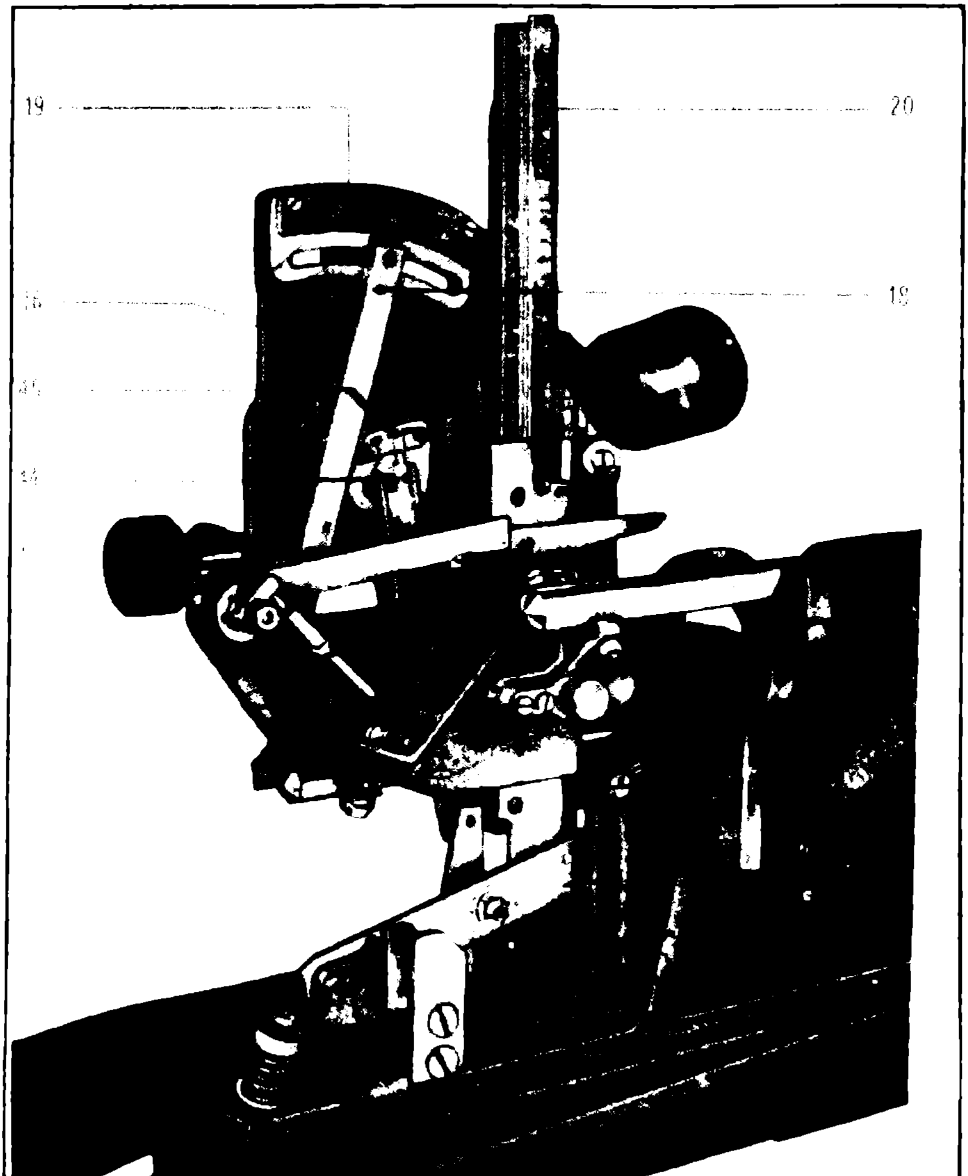
PLATE VIII.F



Stereomicrometer (Another view)

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An altimetric corrector device (33) called 'Cavalcanti Surface' is provided at left of the instrument. It consists of a deformable surface consisting of a system of cylindrical rods which is adjustable by means of 3 screws (41, 42, 43). A feeler 34 imparts slight tilts comparable to displacements in parallax to the left hand viewing mirror (5). For mountainous area a link block (44) is set to the principal distance used (P) in order to yield a driving ratio $\frac{n}{m}$ given by the relationship $\frac{dx'}{hc} = k \cdot \frac{n}{m}$ where k is a constant.

In case of residual planimetric errors after altimetric adjustment, correction is performed by tilting the drawing table (27) in X- direction corresponding to ϕ- correction and by rotating the projection beam by means of knob 46 approximating ω correction.

The instrument can be used for mapping from paper prints or from negatives or diapositives on film or on glass of vertical or near-vertical photographs. The plate corriers are interchangeable permitting carrying forward of k- orientation in case bridging of a couple of models is desired to be carried out on the stereomicrometer. The instrument admits of 1/2 reduction and upto 1·5 enlargement.

72. **Other stereoplotting instruments of repute.**—*General.*—Developments in photogrammetric plotting and stereoplotting instruments in the United States have mostly centered around the Double-projection Direct-Viewing instruments. As stated earlier these were categorised broadly as belonging to the Multiplex type. The trend in this direction was started when the Bansch & Lomb Company of the U.S.A. obtained the licence from Zeiss, in 1936, to manufacture the Multiplex.

The Multiplex (Williamson).—The Multiplex instruments which we have in India are manufactured by the Williamson Company of England. This is similar in many respects to the Bansch & Lomb Multiplex. The instrument can take only reduced diapositives of either 50 mm × 50 mm or 54 mm × 54 mm. These diapositives have to be made in a special reduction printer.

The projection system consists of the illumination system, the projection lens and the diapositive in between. The illumination system consists of a 100 watt light source with its reflector and colour filter. This light is concentrated by a powerful condenser through the diapositive on the projection lens which is of fixed focal length of 30 mm principal distance. Quite naturally this condenser lens system generates a good amount of heat and the whole lamp house is therefore provided with a cooling system to counter this. Any lens distortion compensation that has to be done is carried out at the time of obtaining the diapositives, which are printed through Compensation plates in the reduction pointer.

A centering device is provided for centering the diapositives on the stage plate in the projector. To carry out relative orientation the elements by, bz, and also the rotation elements can be applied to either of the projectors. The projectors can also be shifted along the main carrying bar by using the bx screw to scale the models. Absolute orientation is effected by manipulating the supporting screws, which carry the main bar on which the projectors are mounted. The supporting frame that rests on the floor, carries these supporting screws and also the plotting table. This plotting table can be of slate or aluminium but it has necessarily to have a flat surface finished to a close tolerance. The plotting table carries the tracing platen and also forms the reference level for height measurements.

The measuring device consists of the movable platen mentioned above. A single perforated light mark in the centre of the platen is the measuring mark. A hand grip on the column on which the platen is mounted enables it to be moved in the X and Y directions. The platen can be moved up and down with its measuring mark, in the stereomodel space and the light can be read in metres or feet. The model will be viewed through a red-green spectacles.

The electrical system consists of a voltage regulator with four circuits and a transformer to reduce the supply to 30 volts.

The following are some particulars of interest with regard to the instrument. Multiplex instruments of the type that we have in the department are said to have an American C factor that lies between 500 and 1000. If a figure of 750 is taken as a measure, the smallest contour interval possible is given by

$$h = \frac{\text{Flying height above mean terrain}}{750}$$

The type of projector described above can be used in sets of 2 or 3 as is normally done for plotting. It is also possible to mount 6 projectors at a time as is normally done for bridging. The zone of best definition, in the model, lies from a distance of 270 mm to 450 mm from the projection centre. Although the diapositives are of a reduced scale, the model scale because of this projection distance, is still considerably larger than the original photo scale. This characteristic must be always remembered with this type of instrument when plotting on manuscripts on medium and small scales. One should not have a scale of photography that would entail a heavy reduction from model to manuscript. A certain amount of difficulty during stereoscopic observation is caused by the strong reduction from photograph to diapositive and the even stronger enlargement from diapositive to model. The bulky condenser lens with its own aberrations also contributes in some measure, to this difficulty. In instruments, subsequently mentioned in this section, which are modifications of this basic Multiplex type, e.g., The Kelsh Plotter, The Gamble Plotter, etc., most of these difficulties have been solved. One of the most useful characteristics of the Multiplex type of instrument is the economy inherent in its simple construction. This also results in simplicity of training and maintenance procedures.

The Kelsh Plotter.—The disadvantages of the Multiplex mentioned above have been completely removed in this. Like the Multiplex described above, it is a double projection device, that projects a model to be viewed by red-green spectacles. The model is projected on to a sturdy slate-topped table surface, supported on a welded steel under-structure.

The Projection system.—The Kelsh plotter uses 9 inches × 9 inches full size diapositives made directly from the negatives. The swinging light source that concentrates the light on the projection lens is guided by two guide rods, linking the light source to the movable platen. Thus, only the portions projected on to the platen are illuminated. It is not, therefore, necessary for this light source to be as powerful as the one in the original Bausch & Lomb (or Williamson) Multiplex. The guide rods described above, that link the swinging light source to the tracing table, are telescopic. These guide rods actuate aspheric ball cams fitted on to each of the projectors. Thereby the lenses are moved along the optical axis by precalculated and continuously varying amounts. This results in effect, in the principal distances being also continuously varied. The projected image is automatically and continuously connected for radial lens distortion. In case distortion-free diapositives are being used the aspherical cam can either be disconnected or substituted by a spherical cam of course, in the stereomodel, due to varying projection distances, the connection caused by the cam are magnified to different degrees, resulting in slightly erroneous compensation. The magnitude of this error would depend on the difference between the nominal projection distance and the actual distance of the point in the 'Z' direction in the stereo model. In practice this error in compensation is not material enough to be taken into account. One must, however, be aware of these design characteristics of the different types of instruments.

The measuring and plotting devices.—The Kelsh Plotters have for each projector, the three rotational elements and three elements of shift. The tracks on which the projectors move are supported on frames which rest on four foot-screws resting on the main supports. Absolute orientation can be performed by these four foot-screws. Level bubbles can be fitted on to the projectors to permit the tilts of one projector to be transferred to the other. This permits continuous aerial triangulation to be executed on the Kelsh Plotter. The tracing platen can be moved about free-hand in the x- and y- direction, on the supporting tracing table. This platen has a perforated dot that is illuminated from below and serves as a measuring mark. The platen can be moved up and down for height measurements, as it is mounted on a screw-threaded column. As already mentioned, this platen is attached by means of guide rods to the swinging light source. The scale of the model is usually 5 times the scale of the photograph. This characteristic usually calls for a considerable amount of reduction from manuscript to map. A precision pantograph can be supplied as an extra item if required.

Other Double-Projection Plotters include Balplex plotter, the Nistri Photocartograph, the Gamble stereoplotter Zeiss DP1, DP2, etc. These are optical projection instruments based on the anaglyph principle.

Amongst other stereoplotters with optical/mechanical projection, the following can be mentioned :—

(*i*) Nistri Photostereograph
(*ii*) Thompson-Watts Plotter
(*iii*) Santoni Stereo-cartografo
(*iv*) Galileo-Santoni Stereosimplex.

For a full description of these instruments, relevant manuals and pamphlets should be referred to.

73. **Testing and adjustment of photogrammetric instruments.**—All instruments are tested and adjusted by factory mechanics before and after they are installed. Due to certain inherent weakness, wear and tear, etc., the instruments may go out of adjustment after a certain period. Periodical checks are, therefore, required to be done at prescribed intervals, depending on the stability of adjustment. Particularly, before carrying out a survey requiring greater precision, it is useful to check the adjustment to decide if the work can be satisfactorily carried out in the particular instrument. The general objective of testing is to judge its functional capabilities and limitations.

A distinction should be made regarding (*i*) precise adjustment and (*ii*) ordinary or office adjustment. The precise adjustment is carried out by the manufacturers with special tools which are generally not available with the users. The office or ordinary adjustment is carried out by the users/departmental mechanics according to procedure laid down in operational manual. The necessary tools for this purpose are normally received with the instrument. A thorough knowledge of mechanical construction of the instrument and good understanding of the functions of its various parts are pre-requisites for any testing and adjustment. The following paras give the brief particulars of testing and adjustment generally carried out by the operators/workshop mechanics of the department.

Grid plates.—All the adjustments and tests are carried out using a set of grid "plates" supplied by the manufacturers alongwith the instrument. The grid plate is an optically flat high quality glass engraved with fine and uniformly spaced line mesh, the length between any two points of which is claimed to be accurate to about 2 or 3 microns.

Monocular grid measurement.—The object is to find out to what extent and within what accuracy each projector and its optical/mechanical system can recover the perspective geometry for planimetry. This is done by observations to grid corners of the grid plate, independently for each projector.

Errors in the setting of focal length or principal distance, projection distance, nonverticality of the space rods, etc., falsify the spatial model obtaind and must, therefore, be corrected at all costs. Before performing these tests and adjustments the instrument paramenters, particularly K, ϕ and ω are brought to their "zero settings", although for the practical purposes, unless the work is processed analytically, any minor "zero errors" do not matter.

Before the grid plate is mounted on to the projector the grid points to be used in subsequent measurements should be marked on the rear face of the plate with a wax pencil. A nine point grid, as in fig. (*a*) or a 25-point grid, as in fig. (*b*) to determine the planimetric accuracy is generally used (see forms 12 A Phot. and 12 Phot.).

·1	·3	·5	·1	·2	·3	·4	·5
	·		·10	·9	·8	·7	·6
·11	·13	·15	·11	·12	·13	·14	·15
			·20	·19	·18	·17	·16
·21	·23	·25	·21	·22	·23	·23	·25

Fig. (*a*) Fig. (*b*)

Empirical "zero setting".—All the elements are initially set at their instrument zero positions. The Z column is kept at the middle of its run.

Kappa setting.—The measuring mark is set on the control point, 13, by using x, y motions. The mark is then moved to 3 or 23. (See fig. *a*). Any deviation perpendicular to the motion is eliminated by Kappa rotation. A check is made by setting the mark at 11 and moving it to 15. The zero error is noted.

Omega setting.—After Kappa setting, the measuring mark is placed at 11 (or 15) and moved to 1 (or 5) or to 21 (or 25). The amount of deviation in x-direction is removed by omega rotation. If 1–11–21 is used for correcting, 5–15–25 can be used for checking. The zero error is noted.

Phi setting.—Similar to omega setting, use now the longitudinal direction, 1–3–15 and 21–23–25 for obtaining the zero error in Phi setting.

Zo (Projection distance) setting.—(See fig. VIII·22). With projection distance Z_1 (= ON), record the x-co-ordinates of points 11 and 15. Let D_2 be the difference of x-co-ordinates, i.e., the length of AB. With projection distance Z_2, record the x-co-ordinates of the same two points. Let D_2 be the difference of the x-co-ordinates, i.e., the length of A′ B′.

$$\text{Since } \frac{ON}{AB} = \frac{B'K}{CB} = \frac{\Delta z}{AB - A'B'},$$

$$\text{we have } ON = \frac{AB \cdot \Delta z}{AB - A'B'} = \frac{D_1 \cdot \Delta Z}{D_1 - D_2}$$

$\therefore Z_0 = Z_1 - ON$, which is the zero error. D_1, D_2 can also be measured in the Y-direction, and a weighted mean obtained for Z.

We have thus determined the zero errors (very nearly). The indexes are corrected by loosening the grub screws and then re-tightened. The final corrections will be obtained while carrying out the monocular grid measurement for planimetry. They will then be so small that they are only computed, but not generally applied.

Setting of principal distance (f).—(See fig. VIII·22). By the same process as above,

$$\frac{f}{g} = \frac{Z_2}{A'B'} = \frac{Z_1}{AB} = \frac{Z_1 - Z_2}{AB - A'B'} = \frac{\Delta Z}{D_1 - D_2}$$

$$\therefore f = \frac{g \cdot \Delta Z}{D_1 - D_2}\text{ - }$$ Thus the exact principal distance is known

This is set on the principal distance scale, by shifting the vernier drum, using grub screws.

For practical purposes, 'f' is set at 150 mm, Z_1 at 450 mm and Z_2 at 250 mm. (See 13 Phot).

Testing of verticality of space rods.—When a space rod is brought to a vertical position, it should remain vertical for all changes in the datum plane.

With $Z_1 = 3\ f = 450$ mm (see fig. VIII·23), the measuring mark is set at the grid intersection near the plate centre. Let X_1, Y_1 be the X and Y readings. With $Z_2 = f = 150$ mm, the measuring mark is again set at the same grid intersection. Let X_2, Y_2 be the X and Y readings. Then X_0, Y_0, the co-ordinates for which the space rod is vertical, are given by

$$\frac{X_0 - X_1}{X_2 - X_1} = \frac{Z_1}{Z_1 - Z_2} = \frac{3}{2}\ ; \quad \frac{Y_0 - Y_1}{Y_2 - Y_1} = \frac{Z_1}{Z_1 - Z_2} = \frac{3}{2}$$

$$\text{Hence } X_0 = X_1 + \frac{3}{2}\ (X_2 - X_1)$$

$$Y_0 = Y_1 + \frac{3}{2}\ (Y_2 - Y_1)$$

By movement of the hand-wheels, the readings X_0 and Y_0 are set on the X- and Y-drums. Obviously the measuring mark will not coincide with the grid intersection. The picture carrier is now centred by setting the ball bearings so that floating mark and the grid intersection coincide. Please see instrument manual as to how this is done.

Mean square error in planimetry.—After the above adjustments and zero settings have been completed, each projector is tested for the accuracy which can be achieved, i.e., the physical realisation of a hypothetical (mathematically accurate) model, which the projector is capable of. Making use of 9-point or 25-point grid, differences between machine co-ordinates and the theoretical plate co-ordinates are obtained. From the residuals, mean square error of planimetry is computed, either by a strict least square adjustment or by semigraphic method. This should not normally exceed 10 microns on the negative scale.

Stereoscopic grid measurement.—The object of stereoscopic grid test is to find out to what extent, and within what accuracy the instrument can reproduce depth in a model or in other words enable us to read the difference in depth in a model. This is done by observing a pair of grid plates, placed on both projectors, stereoscopically. It is customary to incline the stereo-model slightly so as to obtain varying height readings for the different points.

Mean square error in altimetry.—Making use of 25-point or 49-point or 77-point grid, differences between machine heights and the hypothetical heights (computed mathematically after allowing for ϕ and ω tilts) are obtained. From the residuals, m.s.e. in altimetry is computed. This is usually expressed in terms of flying height of 1000 metres unit. If m.s.e. was found to be 1·5 metres, for a flight altitude, 3000 metres, the same is expressed as $\pm$ 0·5$^0/_{00}$. Normally m.s.e. with Wild A7 should be less than 0·1$^0/_{00}$ and with Wild A8, less than 0·2$^0/_{00}$. Departmental forms 11 Phot and 11-A Phot are used for stereoscopic grid measurement.

Where read-out systems for x and y co-ordinates are not provided, grid plates are mounted on both projector, relative and absolute orientations carried out. The measuring mark is placed at the required grid corners and their positions are pricked on a plot sheet, independently for each projector. The co-ordinates are read off in a co-ordinatograph. Computations are then carried out in the usual manner, on 12 Phot or 12 A Phot for planimetry.

For more sophisticated tests by trained autograph machanics, operational manuals of the concerned instruments should be consulted. The operators are advised not to tamper with any of the existing adjustments without the knowledge of the officer-in-charge of the unit.

74. Maintenance of instruments.—The top performance of any instrument depends upon the care with which it is handled and maintained. The photogrammetric instruments being particularly imported at high costs, it is both difficult and expensive to replace the worn-out/damaged accessories/parts. As such the maintenance operations stipulated for them should be carried out conscientiously, and must be rigorously checked by the supervisory officers.

Frequency of maintenance.—No norm can be set for the frequency of maintenance. However, time intervals mentioned in 19 Phot forms should be scrupulously followed. These are, in fact, valid for instruments housed in dust-proof air-conditioned accommodation, where temperature variation and humidity are controlled. Hence the frequency of cleaning and lubrication should be varied according to conditions.

In the following paras, general instructions are given for routine maintenance. For full details, reference should be made to instrument manuals.

Cleansing agents and cleaning material.—It is necessary to use the right type of cleansing agents and lubricants for various components of the instrument. The instrument should, at all time, be kept dust-free, dusting if necessary, two to three times a day. A general guide to cleanliness and maintenance is given below :—

Optical parts.—Soft lens brush should be used to remove dust. Chamois-leather-tipped sticks are available to clean the surface with very little ether. No benzine should ever be used for cleaning optical parts. No mirror or lens should be touched with fingers. While cleaning other parts, optical parts should be covered with tissue paper pieces.

Picture carriers should be cleaned with a soft muslin cloth damped with alcohol and then with a clean chamois leather piece.

Ground steel parts.—(Space rods, micro. carriage rail system, etc.). These are to be cleaned with a lint-free cloth damped with ether. After cleaning, a thin film of machine oil should be applied with a glazed tissue paper. They are to be kept free from grease.

Spindles.—They are first cleaned with spindle brush using benzine. Finally a thin coat of spindle grease is applied. Treat the level wheels and drawing-table gear in the same manner. Use aseol grease for shafts. Undergreasing or dryness of parts is as harmful as overgreasing. A correct balance should be maintained.

Roller bearings.—A drop or two of moebius oil should be given to all roller bearings, space rod hinge joints, joints of Phi spindles, the castors of the cantilever frame, etc. At all places where small holes are provided, syringe with benzine and after sometime, give drop or two of moebius oil or three-in-one oil.

On completion of the above cleaning/lubricating process, the instrument should be operated by moving all the gears, shafts and spindles so that oil/lubricant is well-distributed.

Normally daily maintenance should not take more than half an hour, weekly maintenance about 2 hours and monthly maintenance, about 6 hours, which should be done as a sacred duty.

Handling during work.—The instrument should be handled very carefully. Brisk and careless movements of X- and Y-carriages should be avoided. Alarm-bell is only a guide; but the operator should never move the carriage beyond specified limits. If there is any hard/harsh movement, it must be investigated and reported for remedy, immediately, to the section officer and to the officer-in-charge of the unit.

Breakable parts like glass scale, picture carrier, etc., require very delicate handling. Supervisory officers should explain to the operators, the procedures for changing the glass scales, diapositives, etc., without causing damage to the breakable parts.

Overhauling.—It is preferable to get the instrument checked up and overhauled by competent mechanics at certain definite intervals say two years; the older an instrument, the greater should be this frequency.

SECTION IX.—OPERATION OF PHOTOGRAPHIC INSTRUMENTS

75. **Methods of interior orientation.**—Every photo can be considered as a section of a bundle of rays by a plane. This bundle of rays can be reconstituted through fulfilling two conditions :—

(*i*) the negative/diapositive must be set at a distance from the interior perspective centre of the projection lens equal to the principal distance of the photographic camera and

(*ii*) the perpendicular from the interior perspective centre must intersect the plane of the negative/diapositive at the principal point of the picture.

In actual practice the principal distance for A-7, A-8 is set on focal length column, for B-8 by using camera carriers of exchangable focal length alongwith four vernier scales and in case of P.G. 2 by setting it on the instrument at the four knobs Cx_1, Cx_2, and Cy_1, Cy_2, and the negative/diapositive is centered on the picture carriers in such a manner that the fiducial marks on the picture register with the ones provided on the glass plate. Due allowances should be made for the enlargement or reduction in dimension of the pictures by proportionately enlarging or reducting the value of principal distance (if appreciable). In case of unequal changes in the X, Y directions of the pictures a mean value should be used for A-7, A-8 and B-8 and actual values, calculated for X and Y directions separately, are set on the corresponding knobs for Kern PG2.

Model scale.—Choice of a model scale for plotting and introduction of an approximate model scale is the next step after the interior (or inner) orientation. The model scale should be so chosen that it is workable in the whole range of the terrain relief ; also it is desirable to have the largest possible model scale.

Flying height above mean sea level is always approximately known. Also, the required plotting scale and the focal length of the aerial camera are known. The heights of the highest and lowest points of the terrain can be approximately estimated with the help of the given control points in the model. The ranges of the instrument can be found either by consulting the respective instruction manual or by actually measuring with a ruler on the instrument. The following ratios can now be computed :—

$$\frac{H-h\,(\max)}{Z\,(\min)} \quad \text{and} \quad \frac{H-h\,(\min)}{Z\,(\max)}, \text{ where}$$

H = Flying height of aircraft above mean sea level,

h (max), h (min) = Maximum and minimum terrain heights in the model,

Z (max), Z (min) = Max. and min. Z-ranges of the instrument.

The model scale number should be chosen so that it lies in between the above two ratios.

Next, the X and Y dimensions of the model should be checked so as to correspond to the instrument ranges in X and Y directions.

Further, the following are the two more limiting factors :

(*a*) Since measurements of height are performed in the model, scale should correspond to one of the available glass height scales or the available gear ratios as the case may be.

(*b*) The model scale selected should also produce the desired mapping scale using one of the available gear ratios of the pantograph or drawing table transmission.

If several model scales meeting these requirements are possible, as will generally be the case, the largest model scale is selected.

In the instruction manual of the various instruments, tables are also given to facilitate the choice of the model scale, It is, however, considered preferable to use the above drill.

Introducing the approximate model scale.—It is desirable to introduce the model scale at least approximately for relative orientation, so as to keep the scale correction, which is necessary subsequently for the absolute orientation, as small as possible. That will also help in reducing the iterations between "final" relative and absolute orientations, especially in instruments provided with 'by'.

It is easiest to set the approximate model scale with the base b, given by the following formula :

$$b_{(\text{Model})} = \frac{\text{Picture scale number}}{\text{Model scale number}} \times b_{(\text{photo})}$$

In vertical photograph of flat terrain, $b_{(\text{photo})}$ is given by the distance between the two principal points.

After setting the model base and adjusting the eye base for comfort, the model flight height is varied by turning the drum/foot disc until the same part of the terrain is seen in both the eye dieces.

76. Methods for exterior orientation.—The exterior orientation of a model consists of (*i*) relative orientation, by which the perspective relationship between the pair of photographs, as at the time of exposure, is recovered ; and (*ii*) absolute orientation, by which the model as a unit is related to the geographical position, on a desired scale.

(*a*) *Relative orientation of the model.*—This is accomplished by a systematic procedure of applying rotations and translations to the diapositives mounted in the plotting instruments, at the same time observing the images at suitably selected positions in the model and noting the differences in Y direction (known as Y-parallax), until corresponding images are made to coincide over the entire model area. This is also known as clearing Y-parallax over the entire model. (See fig. IX·1).

There are two basic procedures for accomplishing relative orientation of the stereo-model, viz., relative orientation by using both projectors and relative orientation by using one projector only. In addition, there are many variations of the basic procedures adopted for clearing the Y-parallax by projector movements. The procedures given hereunder are the standard variations in common use in the photogrammetric units of the department.

Two projector method of empirical relative orientation in common use for stereoplotters A7, A8 and B8 consists in using the rotation elements K, ϕ and ω of the projectors and without the use of translational motions.

(1) Clear Y-parallexnear position 1 with K_2.

(2) „ „ „ 2 with K_1.

(3) „ „ „ 3 with ϕ_2.

(4) „ „ „ 4 with ϕ_1.

(5) Overcorrect the Y-parallax at 5 (or 6) with ω_2 (or ω_1), the total overcorrection factor in this case being $\frac{1}{2} \left(1 + \frac{f^2}{d^2} \right)$ where f is the focal length of the camera and d is the average distance of points, 3, 4, 5, 6, in y-direction as measured on photograph.

(6) Repeat steps 1 to 4 as above.

(7) Check at location 6 (or 5) and repeat the procedure until all positions have been cleared of Y-parallax.

(*Note* :—If initial K_1 is kept fixed, e.g., in certain cases of aerial triangulation starting model, use K_2 and by_2. In this case, the first two steps will be replaced as below :—

(1) clear Y-parallax near 2 with by_2

(2) clear Y-parallax near 1 with K_2.).

While clearing Y-parallax at various positions mentioned above, the presence of X-parallax would always be eliminated by changing the datum by moving the Z-column of the plotting machine. Sometimes, this elimination of X-parallax is also affected by the X-movement of the projectors relative to each other.

One projector method of empirical relative orientation is sometimes adopted during bridging in aerial triangulation being conducted on universal type of stereoplotters like Multiplex and Wild A7.

Referring to fig. IX · 1 and the locations 1 to 6 shown thereat (known as Neat points) the following motions are applied to the right hand projector, assuming that the left hand projector has to be kept stationary :

(1) Clear Y-parallax at 2 with dy_2

(2) „ „ „ 1 „ K_2

(3) „ „ „ 4 „ dz_2

(4) „ „ „ 3 „ ϕ_2

(5) Overcorrect the Y-parallax at 6 with ω_2, total over-correction factor being $\frac{1}{2}(1 + \frac{f^2}{d^2})$ ['f' and 'd' already explained in step (5) of para 3].

(6) Repeat the above steps 1 to 5 until no Y-parallax is found at any of the five positions 1, 2, 3, 4 and 6.

(7) Check position 5. If Y-parallax is found, repeat the above.

The X-parallax would be eliminated as already explained, by the Z-column (or X-separation of the projectors).

If the left hand projector is required to be used, keeping the right hand projector as stationary, the positions 1, 3 and 5 are reversed with 2, 4 and 6 respectively. Positions 3 and 4 may be reversed with positions 5 and 6 respectively, in any procedure.

Except for those plotters that do not have translational motions (by and bz) as in Wild A-8, B-8, it is always possible to use either method.

While carrying out stereo-aero-triangulation, the empirical method of relative orientation as described above is further augmented by the *Numerical Relative Orientation.* The method of numerical orientation consists in observing Y-parallaxes at the six standard locations of fig. IX · 1 on the 'by' drum of the right hand projector (assuming that the left hand projector is to be kept fixed) and then computing K_2, ϕ_2, ω_2 and bz_2 of the right hand projector. These computed values are then introduced and finally Y-parallax is removed at the six conventional points with by_2 and average value of by_2 introduced.

Method of numerical relative orientation on Wild A-7-Single projector movements.—Y-parallaxes at 6 conventional positions are measured with the help of 'by' element of the right hand projector in the case of *base in* (space rods inwards) and left hand projector in the case of *base out* (space rods outwards). Each of the reading is taken thrice and recorded in the form (4 Phot). Before starting numerical orientation, relative orientation is performed by empirical method so that the residual parallaxes in the model are about

$\pm 0 \cdot 50$ mm. Values of h, b, and d as explained below and in the fig. IX·2 are also recorded in the model scale and are read in mm.

Case I-Right camera used for rel. orientation.

(*i*) Mean of the six 'by readings is substracted from individual 'by' readings which gives the value of Y-parallax at each point, indicated as p_1, p_2, p_3, p_4, p_5 and p_6 on the form.

(*ii*) The corrections to be aplied to relative orientation elements are calculated with the help of following formulae :—

$$dK \text{ (right projector)} = + \left[\frac{p_1 + p_3 + p_5}{3} - \frac{p_2 + p_4 + p_6}{3}\right]\frac{\rho^c}{b}$$

$$d\omega \text{ (,,)} = + \frac{h}{4d^2}\left[(2p_1 - p_3 - p_5) + (2p_2 - p_4 - p_6)\right]\rho^c$$

$$dbz \text{ (,,)} = - \frac{h}{2d}\left[p_4 - p_6\right] mm$$

$$d\phi \text{ (,,)} = + \frac{h}{2bd}\left[(p_3 - p_5) - (p_4 - p_6)\right]\rho^c$$

where $\rho = 6366$.

The calculated value of corrections are algebraically added to the readings of K, ω and bz of the right projector (or the projector used while taking Y-parallax readings). Care should be taken against backlash. After setting these values on the right hand projector nearly uniform parallax will appear at all the six points, which may be removed at point No. 1 or 2 in the model with the help of 'by' element and then Y-parallaxes are checked at the remaining five positions. If even after this, Y-parallax is noticed at any of the points, the process is repeated till the model is free of Y-parallaxes within $\pm 0 \cdot 04$ mm.

If relative orientation is performed by moving left hand projector in *base in* or right hand projector in *base out*, the following formulae are used with respect to the conventional positions shown in fig. IX·3.

Case II—Left camera used in relative orientation.

$$dK \text{ (of left projector)} = - \frac{1}{b}\left(\frac{p_1 + p_3 + p_5}{3} - \frac{p_2 + p_4 + p_6}{3}\right)\rho^c$$

$$d\omega \text{ (,,)} = + \frac{h}{4d^2}\left[(2p_1 - p_3 - p_5) + (2p_2 - p_4 - p_6)\right]\rho^c$$

$$dbz \text{ (,,)} = - \frac{h}{2d}(p_4 - p_6) mm$$

$$d\omega \text{ (,,)} = - \frac{h}{2bd}\left[(p_3 - p_5) - (p_4 - p_6)\right]\rho^c$$

(h, b and d are the same as in Case I above).

Method of numerical relative orientation using both cameras on A7.—Form 3 Phot. or 3A Phot. is used where h, b and d are the same as explained above. 'by' element is used to measure Y-parallax at 6 conventional positions as already explained. But to remove Y-parallax from the model, instead of 'bz' element of the camera (used for taking 'by' readings), ϕ of the other camera is used. The corrections are calculated with the help of following formulae :—

Base in (Right projector)	·3	·4
Base out (Left projector)	·1	·2
Formulae.—	·5	·6

$$dK \text{ (of right proj.)} = +\frac{1}{3b}\Big[(p_1+p_3+p_5)-(p_2+p_4+p_6)\Big]\rho^c$$

$$d\omega \text{ (,,)} = +\frac{h}{4d^2}\Big[(2p_1-p_3-p_5)+(2p_2-p_4-p_6)\Big]\rho^c$$

$$d\phi \text{ (of left proj.)} = +\frac{h}{2bd}(p_4-p_6)\rho^c$$

$$d\phi \text{ (of right proj.)} = +\frac{h}{2bd}(p_3-p_5)\rho^c$$

Base in (Left projector)	·4	·3
Base out (Right projector)	·2	·1
	·6	·5

Formulae :—

$$dK \text{ (of left proj.)} = -\frac{1}{3b}\Big[(p_1+p_3+p_5)-(p_2+p_4+p_6)\Big]\rho^c$$

$$d\omega \text{ (,,)} = +\frac{h}{4d^2}\Big[(2p_1-p_3-p_5)+(2p_2-p_4-p_6)\Big]\rho^c$$

$$d\phi \text{ (,,)} = -\frac{h}{2bd}\Big[p_3-p_5\Big]\rho^c$$

$$d\phi \text{ (of right proj.)} = -\frac{h}{2bd}\Big[p_4-p_6\Big]\rho^c$$

The correction values are set on the machine dials by algebraically adding them to the existing readings on dials. Remaining Y-parallax is removed by 'by' element and procedure is repeated, if necessary, till model becomes free of Y-parallax (within $\pm 0\cdot 04$ mm.). Form 3B Phot., measuring parallaxes with ω, can also be made use of.

(*Note* :—It is advised that due to backlash in setting of element the Y-parallaxes at positions 1 and 2 are finally eliminated empirically).

Advantages of numerical method.—(*i*) Better precision than from empirical methods as the computed value of each element of orientation is arrived at from observations in all points where it has effect. (*ii*) the method is impersonal as far as distribution of parallaxes is concerned.

Limitation of numerical method.—The above formulae are true for nearly flat terrain. For the hilly terrain, a further modification is required in the 6 conventional positions. For taking Y-parallax readings, 3 and 5, 4 and 6 points are selected in such a way that the inclination of the space rod with its vertical is the same in position number 3 or 5 and 4 or 6.

(*b*) *Absolute orientation.*—Once the relative orientation is completed, a replica of the terrain photographed is obtained, but the scale and orientation (with reference to the datum plane) are undetermined. It is, therefore, necessary to correct the scale (by altering the distance between the perspective centres) and to rotate the model round and displace it along three different directions relative to the map, until the heights and distances of known points agree. Thus the absolute orientation demands the fixation of seven elements.

Scale setting and rotation of the model.—Plot the known points on a sheet on scale of plotting and proceed as under :—

(*i*) In order to obtain the correct scale the distance separating two known points (preferably distant-most) must be measured and compared against the given. This will give a factor of enlargement or reduction which can be applied to the base components ('bx' setting for instruments other than A-7 and multiplex would do). The scale must be accurately known for levelling the model and this is more important when the model has points of greater relief differences.

Details of practical procedures for various plotters are given in the relevant manuals which should be consulted.

(*ii*) For determination of the angles of rotation, the heights of three points forming as large a triangle as possible must be known. The rotation about Z-axis having already been imparted to the plot sheet by fixing the position of one of the points (say 1- see fig. IX·4) and turning the sheet about this point until the projection of a second point (say 2) lies on the corresponding side of the triangle, the horizontal positions of the points (1, 2 & 3) are correctly oriented relative to the model. The rotations about X- and Y-axes must be given to the projectors since the plotting table is usually rigid. Cases of individual instruments are described in their manuals which should be consulted.

The heights of three given points (see fig. IX·4) are determined by setting the height of point 1 (say) at the known value and comparing heights of 2 and 3 against their known values. Points 2 and

3 show errors Δh_2 and Δh_3, say. After this, mark the directions of the X and Y axes through point Nos. 1 and 2 or as convenient so that the points 1′ and 2′ are interpolated positions between points Nos. 2 and 3, and 1 and 3 respectively. The height errors $\Delta h'_1$ and $\Delta h'_2$ for the intersection points 1′ and 2′ are determined by graphical interpolations. The distances S_1 and S_2 are measured (in metres) and the values of $\Delta\Phi$ and $\Delta\Omega$ obtained by means of the following relations. Circular measure is converted to angular measure by the factor ρ (6366), result being obtained in centecimal minutes. (Δh_1 will be zero, if the height of 1 was set in the counter.).

$$\Delta\Phi = \frac{\Delta h'_1 - \Delta h_1}{S_1} \rho$$

$$\Delta\Omega = \frac{\Delta h'_2 - \Delta h_2}{S_2} \rho$$

A common rotation is given to the projectors according to these values in tip and tilt directions including the base (taking the sign into account).

77. Operation procedure with Wild instruments.—*Introduction.*—Instruments of 'Wild' are based on mechanical projection system, main differences being on account of accuracy achievements due to simplification of the projection and viewing systems from one type to the other.

A-7 is classed as a universal instrument and is used for aerial triangulation and large scale plotting. A-8 is a precision plotter used for medium and large scale plotting while B-8 is meant for plotting on small and medium scales only.

Preliminary work.—This consists of choosing the model scale and mounting the diapositive on picture carriers with accurate inner orientation, which have been explained earlier. Then comes exterior orientation of the model.

Relative orientation.—On A7 choice of all the orientation elements of both the projectors is available with the proviso that rotations are given to the cameras about the projection centre, separation of which remains fixed. The linear movements are given to the space rod sleeves, except the base component (bx) which is given systematically to both the space rods by a handle and knob arrangement.

For relative orientation on A8 the choice is limited to rotational movements of the two cameras and a base setting arrangement which controls the seperation of the space rods and the cameras.

Relative orientation on B8 is similar to that on A8 and the choice of elements of orientation is also the same.

Absolute orientation.—On A7 the scale transmission from model to the table is through transmission gears and changes can be brought about by changing the arrangement of knob settings. On A8 this is done by changing the gear ratios available with the equipment. In case of B8 the transmission from the model to the plotting table is with the help of a linear pantograph which works by changing discs for change of scale ratios.

Plotting.—When the two photographs/diapositives of a stereo-pair have been correctly set in position the operator sees a stereo-scopic model ; also the two floating marks blend into one single mark in space. By means of the hand wheels and foot disc for A7 and A8 and manipulating tracing stand and its height drum for B8, the mark can be set to any desired terrain point or made to follow any terrian line. When the height is set to a fixed value and the mark is moved so that it is always on the surface of the terrian the mark and the drawing pencil describe a contour line.

The air survey section is prepared on which control data are plotted and used for absolute orientation. During plotting, sufficient heights are taken at well-identifiable points and recorded both on the section and on a separate height trace. A separate colour trace may also be prepared at the discretion of the officer-in-charge of the party.

Normally details and contours are drawn in proper colours and symbols using coloured leads in the tracer. Inking is done subsequently by the draftsmen. Cliffs and other features/detail likely to be missed or wrongly inked by draftsmen may be inked up by the operators.

All accessory records such as 10 Phot, list of points, etc., should be kept up-to-date. These will be checked *pari passu* by shift officers and section officers, and their remarks entered where necessary.

A record of mean square error in planimetry and in heights should invariably be kept in the sheet file.

78. Operation procedure with Multiplex.—*Introduction.*—Multiplex is a stereo-plotting instrument based on optical projection system. It uses negatives taken from a Eagle IX film camera fitted with a Ross 15 cm wide angle survey lens. Projectors represent the taking cameras and the instrument takes/uses reduced diapositives made with the help of Williamson Multiplex Reduction Printer.

Orientation procedure.—Before commencing orientation, cooling unit is switched on after connecting the plug with the power line. Transformer and voltage regulator are also put in circuit and switched on after carefully connecting the projector leads with the proper plug points on the back side of the base bar assembly. Tracing table is connected with O or L plug points marked on the back of base bar assembly. Inlets of hoses for air flow into the projectors (which are to be used) are also opened.

Orientation of the stereomodel is accomplished in the following three stages :

Inner orientation.—Reduced diapostives forming a stereomodel are gently placed on the stage plates after carefully removing the condensor housings of the two adjoining projectors. Overlapping area should be outward and emulsion is kept downward. With the help of tangent screws provided with stage plate (which move the diapositives in two perpendicular directions) the cross on the diapositive and the dot in the stage plate are made to coincide. Condenser housings together with their filters are kept back in position and air hoses connected to the in-take valves of the projectors.

Relative orientation.—(Removal of Y-parallax from the stereomodel). Introduce distance equal to about $2 \cdot 4 \times b$, where 'b' is the mean photo base of the two photographs making the stereomodel, on base-bar assembly between the indexes of the 'bx' element of the two projectors. Adjust the height of the tracing table accordingly.

Relative orientation on Multiplex can be performed either by moving elements of both projectors or of one. Each Multiplex projector has been provided with 6 elements for relative orientation, namely bx, by, bz, K, ω and ϕ.

Relative orientation by motion of one projector only.—6 conventional positions are used to remove Y-parallax from the model. Procedure is as under for right projector :—

Remove Y-parallax at position 2 by 'by' (right projector)

,, ,, at 1 by 'K' (swing of right projector)

Repeat process till 1, 2 are free of Y-parallax.

Remove Y-parallax at 4 by 'bz' of right projector.

,, ,, at 3 by ϕ (tip of right projector).

Repeat process till 1, 2, 3 and 4 are free from Y-parallax.

Remove Y-parallax at 5 or 6 with ω of right projector.

Overcorrection roughly equal to 3 times the correction (applied at 5 or 6) is applied by continuous motion of the ω (right) screw at 5 or 6 position. Sharp details in the model may be selected for good judgement of the amount of correction and overcorrection to be applied in any particular case.

Repeat the procedure till 5 or 6 point is free of Y-parallax and no overcorrection is further necessary.

Check position 6 (or 5) not used in the removal of Y-parallax from the model. On completion of the procedure, entire model is checked to ensure that no appreciable amount of Y-parallax is left in the stereomodel. During final stages of the removal of Y-parallax in the model, anaglyph should be used. Colour glasses pertaining to the left or right eye of the operator should correspond with the respective filters in the projector and black cross marked on the tracing table top should be used for final adjustment/removal of Y-parallax in the model.

Relative orientation by motion of both projectors.—Operational procedure with both projector movements is the same as for one projector with the following changes :—

Y-parallax at piont No. 2 is removed by K (swing of left projector), instead of 'by' (of right projector) as in the last drill and Y-parallax at point No. 4 is removed by ϕ (tip of left projector) instead of ϕ of right as in last drill.

Except for these two modifications, the procedure remains similar.

During the procedure of removal of Y-parallax in a stereomodel X-parallax at each point in the model is also simultaneously adjusted by lowering or raising the tracing table top, so that when any point is intersected at the tracing table its X- and Y-parallaxes are completely removed.

Absolute orientation.—(*i*) *Scaling.*—All available control points in the stereomodel are plotted on a plot sheet with scale factor equal to 5/12 mean photo scale factor. Minimum points required for scaling are two, preferably such two points should be located at the ends of the longest diagonal in the neat model. Identify the two control points, situated farthest apart in the model. Orientation of the plot sheet is effected by making the control points in the model in the same line as the control points plotted on the plot sheet. Difference in scale is adjusted by simple translation of projector II with respect to projector I and eliminating any parallaxes introduced by 'by' and 'bz' elements thus introducing the translation along the straight line joining the two perspective centres. After adjustment of scale of the model on two points, the accuracy of scaling is checked by going to a third point situated in the model and checking the model position with the plotted position of the point on the plot sheet. In case of non-agreement plotting of control points and identification on photos have to be checked. Small errors of scale in the model (for all available control points) can be adjusted to get the best fit.

(*ii*) *Horizontalisation.*—Horizontalising a model is necessarily done in two steps, tilting the model as a whole about the X-axis and tipping the model as a whole about Y-axis. In order to maintain the datum, the projectors may be raised or lowered equally either by the bar or by equal movements of 'bz' or the tracing table (index adjusted). If the vertical control is well-placed, that is, if the elevations are on a line perpendicular to the axis of rotation, the model can be horizontalised about that axis by rotating the model as a whole until the model elevations agree with the ground elevations. However, if the vertical control is not placed perpendicular to the axis of rotation (and usually this is the case) errors of elevations will have components perpendicular to both axes and the amount of common tilt and common tip will have to be arrived at by trial and error.

First of all calculate the elevations of (at least) three spot heights (not falling in a line) in mm by the following formula :—

$$\text{Height of any point in mm} = \frac{\text{height of the point in metres}}{\text{plotting scale factor}} \times 100.$$

In horizontalisation one vertical control point is selected as the index by setting the index of the tracing table vernier to agree with that elevation. Differences of elevations of all other points are noted with respect to this point on which index is set. Depending upon the values of differences of the three control points, the amount of tip and tilt required is then estimated and the model is tilted and tipped as a whole.

There are two methods of horizontalising a model, the first by using the projectors, the second by using the bar.

Horizontalisation using projector movement.—In this method both projectors are tipped, tilted by an equal amount. After deciding the direction in which tilt must be applied select an image point in the model and introduce Y-parallax by tilting one of the projectors by an estimated amount. Tilt the second projector till Y-parallax at that point is removed. Check elevations and repeat the process until elevation differences in the direction of tilt agree with correct elevations. For horizontalising in the tip direction, select an image point midway between the two principal points. With the floating mark on the ground, introduce parallax by tipping one of the projectors by an estimated amount in the correct direction. Tip the second projector until the floating mark again appears to be on the ground. When both projectors are tipped, Y-parallax is introduced in the model which can be removed by 'bz' of one or both projectors. This in turn may require small amounts of 'bx' and 'by'. Check elevations and repeat the process till all points record correct difference of elevations in the model. After all these operations model should be free from Y-parallax.

Horizontalisation using the bar.—Horizontalisation by means of the bar is quicker and easier to master ; it is usually used for the final accurate horizontalisation, to keep the bar from departing too much from the horizontal. Elevations in the model should not before using the bar for horizontalisation, differ by more than 0·5 mm from their true elevations. The horizontalisation is accomplished by using the handwheels and foot screws of the base-bar till the elevation differences of control point record their correct values. After this the model should be checked to ensure complete removal of Y-parallax from the model.

Tracing of details and contours.—After the orientation details and contours are surveyed from the stereomodel in the usual way. It should be ensured that the tracing pencil is in proper adjustment.

79. Operation procedure with Kern PG 2.—*Introduction.*—Kern PG 2 stereoplotting instrument which is based on mechanical projection system, is specially suitable for topographical maps. The instrument can use any photography with focal length between 85 mm to 172 mm with format upto 9″ × 9″. Instrument is attached with a polar pantograph which can give reduction upto 2 times and enlargement also upto 2 times from the model scale to the plotting scale. By a simple device the heights can be made to read feet or metres.

Preliminary operations.—(*i*) *Choice of the model scale.*—Suitable model scale value is determined by the following formulae :—

Model scale factor (mm) in the case of normal and wide angle photography $\begin{cases} = 5 \cdot 6 \times \text{Mean flying height above the mean terrain in metres} \\ = 1 \cdot 8 \times \quad " \quad \text{in feet} \end{cases}$

Plotting scale being known, the values of the transmission ratios can be calculated and set in advance in the polar pantograph. Suitable ratios for any set of model scales and plotting scales can be chosen with the help of the tables given in the manual.

(*ii*) *Setting of the plotting principal distance.*—The plotting principal distance is taken equal to the calibrated focal length of the taking camera and is set at the four knobs Cx_1, Cx_2, Cy_1 and Cy_2. In case there is different distortion for X- and Y-directions (due to film shrinkage) it is possible to introduce corrections to either Cx or Cy in order to compensate this effect.

(*iii*) *Setting of the projection distance.*—The Z-column range in this instrument is limited to 60 mm. It is necessary to set the mean projection distance (Zm) by varying the height of the main frame with the help of three (adjustable) columns forming the support of the main frame. Range of (Zm) setting in this instrument is from 102 to 172 mm., i.e., 7 cm, in steps of one centimetre. The required setting can be determined from

$$Zm = \frac{Hm \cdot 10^3}{Mm}$$ (where Mm = Model scale factor,

and Hm = Flying height in metres above mean terrain level).

or

$$Zm = \frac{300 \cdot Hm}{Mm}$$ (When Hm is known in feet).

The nearest available step should be introduced.

(*iv*) *Setting of the transmission ratio to the drawing table and height contour.*—Depending on the values of model scale and plotting scale, ratio 'n' is determined and set on the disc. Similarly from the tables suitable arm settings (short arm with a constant length of 20 mm and the long arm of variable length from 25 to 60 mm—designated as 'A') for height transmission are also determined and set on the ratio arm. The values of the smallest interval on the height counter for a particular model scale is indicated in the tables A to H given in the manual. Corresponding arm length 'A' is also indicated in the tables. A useful check whether the actual arm length is correct can be made by determining the value read at the height contour for a calibrated distance of 40 mm of Z-column range. The method of checking is given in detail in the instrument manual which may be consulted.

Orientation procedure.—(*i*) *Interior orientation.*—As explained in sub-para (*ii*) above, plotting principal distance is set in the instrument. Diapositives (or negatives) on film base should be placed with emulsion side upward and overlap inward. Centering may be done carefully by keeping picture carriers on light box specially meant for this job. After centering clamping should be carefully done. Picture carriers are placed in position and lamp supports are pointed to the front.

(*ii*) *Relative orientation.*—For relative orientation in this instrument only five elements which are minimum for doing relative orientation are provided. These elements are K_1, K_2, $b\phi$ (inclination of base) and ω_1 (of the left projector) in two components as ωx_1 and ωy_1 and ϕ_2 (of the right projector) in two components as ϕx_2 and ϕy_2 in XZ and YZ planes respectively. The resulting effect of this is that ωy_1 and ϕy_2 cause effect only in the Y-parallax in the model. Similarly ωx_1 and ϕx_2 effect only X-parallaxes in the model. The two operations are independent and as such relative orientation is performed in the following two stages :—

(*a*) *Removal of Y-parallax from the model.*—The procedure is as under and elements/components used are : K_1, K_2, ωy_1, ϕy_2 and $b\phi$. X-parallexes are not influenced in the operations of these elements/components. For removal of Y-parallax the same 6 conventional positions are used.

Step I—Points 1 and 2 are made free of Y-parallax with the help of K_2 and K_1 respectively.

Step II—At point No. 4—Y-parallex is removed with $b\phi$

Step III—At point No. 3—Y-parallax is removed with ϕy_2

Step IV—Apply correction Δc according to ϕy_2 (from diagram in manual), sign being always negative.

(Repeat steps I to III after every correction Δc)

Step V—Remove Y-parallax at 5 and 6 with ωy_1 and set mean at ωy_1 Overcorrect this by an amount equal to $\frac{1}{2}$ (n–1)

$$\text{where } n = \frac{f_2}{d_2}$$

f = focal length

d = distance between 1 to 3 or 1 to 5, etc.

(*Note* :—When the elevation differences in the orientation points are larger than 10% of Z, the correction must be determined according to a graphical procedure).

Step VI—Repeat steps I to V until all points are free of Y-parallax.

Step VII—Remove Y-parallax in points 4 and 6 by means of $b\phi$ introduce mean value.

Step VIII—Remove Y-parallax in points 3 and 5 by means of ϕy_1— introduce mean value.

(*b*) *Removel of X-parallax from the model.*—Proceed as follows.- Correction Δc is introduced in column CX_1 according to ωy_1 ; same graph is used for finding out Δc for ϕy_2 and ωy_1. ωy_1 and ϕy_2 values are introduced at ωx_1 and ϕx_2. By this correction, the influence of X-parallaxes of ω_1 and ϕ_2 is also eliminated.

Influence of the Earth's curvature can also be eliminated in PG 2 with the help of a special device. (Please refer to manual for details).

(*iii*) *Absolute orientation.*—Absolute orientation is done in two steps, as usual.

(*a*) *Scaling.*—Scaling can be done in the usual manner with the help of two points separated as far as possible in the model by changing the base setting (B), all available control having been plotted on a plot sheet on map scale. Transmission ratios should have been set correctly. The plot sheet is rotated and shifted as necessary. If 'Δs' is the difference in plotted map distance and model distance between the two points, then the required amount of correction is given by the relation $dB = B \cdot \Delta s$

Where S = model distance between the points

S′ = Plotted map distance between the points

$\Delta s = S' - S$

dB = Correction to be applied to the machine base.

Repeat this process till scaling is within the drawing accuracy. When more than two control points are available, the mean of the scale for two distances must be introduced at least when the discrepancies are small.

(*b*) *Horizontalisation.*—For levelling in the PG 2 inclinations of the reference plane (plotting table) are available, one in X-direction and one in Y-direction. In order to determine the values for these components at least three known elevation points are required in one model, and pre-condition is that these three points should not lie in one straight line and preferably should form a big right angled triangle.

The tangent of the angle of inclination is $\frac{\Delta h}{L}$ where Δh is the difference in height and L is the distance between two points in X- and Y-directions separately. Calculated values of tangents can introduced in this instrument. The unit of scale is $\frac{1}{1000}$. Easiest way for horizontalising is to do it in two steps. At first, that pair of available elevation points is chosen from which the connecting line fits best to either X- or Y-directions of the model. From these points, Ω or Φ can be calculated and set on the corresponding knob. After introduction of this value to the corresponding knob, every point of the considered line has the right elevation in the model. That means we are able to choose a point on this line which is situated on the perpendicular line through the third elevation point. From the error in elevation and the distance, the second levelling element can be determined.

Method of detail and contour survey.—Details and contours are surveyed in the usual manner. Tracing table is provided for scanning the area. Height is also controlled with hands while doing plotting in this instrument. The rest is similar to all other photogrammetric instruments.

80. Operation procedure with Stereotope.—*Introduction.*—Zeiss stereotope is a plotting instrument which is very suitable for compilation of topographical maps. The design of the instrument is mechanical and its operation is very simple and requires comparatively less time for achieving efficiency in its use.

The instrument consists of the following three main parts :—

(*i*) Oblique viewing stereoscope.

(*ii*) Photo carriage with built-in rectiputers.

(*iii*) Pivot with pantograph.

Operation procedure.—(*i*) *Assembling and disassembling of instrument.*—The instrument and its equipment along with diapositive attachment are contained in three boxes. O.V. mirror stereoscope comes in one box and a larger case contains all the elements of stereotope and its accessories ; a third box contains diapositive attachment.

The instrument is assembled on a stable, flat table with a surface area of about 85 × 150 cm. It is taken out of the container very carefully and assembled item by item as per instructions given in the manual—(for details please refer to the manual). Disassembling can also be done in the same manner by proceeding in the reverse sequence and packing it in respective boxes.

(*ii*) *Adjustment of stereotope.*—Before starting actual work the operator should adjust the focus of the monoculars and check for squint correction if any. Eye base may also be set correctly before work.

(*iii*) *Positioning of the photographs.*—With the help of guide-lines marked on top of the picture carriers, the two photos forming a model are set on the picture carriers. For this operation it is necessary to extend the photo base on the two photographs and draw perpendicular lines from the p.p. of the left hand photo and its transferred portion in right hand photo. Overlap is kept inward. Photos are fixed with the help of cellotape and magnets. To facilitate this operation, measuring mark bridge may be turned by 100 g.

(*iv*) *Computations and setting of Computer I.*—By using the following parallax formula, parallax values for the four control points can be calculated ; preferably these four control ponits should form a neat rectangle in the model whose shorter side should be parallel and nearly equal to the photo base.

$$\Delta p_x = \frac{b' \cdot \Delta H}{h_0 - \Delta H}$$

where $\Delta p_x = p_{x1} - p_{x0}$

p_{x1} = Parallax value of any point.

p_{x0} = 15·00 cm i.e. the parallax reading at left hand nadir point (can slightly vary from this value).

b' = Photo base in r.h. photo.

h_0 = Flying height in metres above the height of left hand nadir point.

The above formula can be used to determine the flying height of left hand nadir point. To calculate the height of left hand nadir point, two points which lie in a line perpendicular to the base line and on opposite side of the left hand p.p. are considered and mean of the two sets of readings on computation gives this height. A further correction is also applied to the calculated flying height (h′) of the left hand nadir point and the final height (h_0) is arrived with the help of the following formula [please refer to form 20 (Phot.) for details].

$$H'o = \frac{[H_1]}{4}; \Delta Ho = H'o - Ho$$

where ho $= h'o + \Delta Ho$

H'o = mean of the heights of four control points – defines the mean plane.

h'o = flying height above mean plane.

$$= \frac{f(mm) \times \text{Photo scale factor}}{1000} \text{ metres.}$$

After calculation, the model is oriented with the help of Computer I, which consists of four correction screws. Each screw effects one corner of the model rectangle, A B C D. Set the calculated parallax value on the X-parallax thimble for point A in the upper right corner ; view the stereomodel and turn screw A (meant for this corner) till the two floating marks coincide and appear to touch the ground level at the point. Next repeat this procedure for a point located near B in the lower right corner of the model ; use screw B till floating marks coincide and touch the ground. Same procedure is repeated for points C and D in lower left and upper left corners respectively. Repeat this process till all the four control points read their calculated parallax values within $\pm 0 \cdot 04$ mm. Accuracy of the orientation is verified with the help of additional check points appearing in the model. Heights of check points are calculated from observed X-parallaxes which should agree within one-third of the V·I.

After this orientation process, deformations of the model caused by picture tilt or a difference in flying height have been eliminated and correct absolute elevations may be measured over the entire model within the area bounded by the control points.

(*v*) *Setting of Computer II.*—Computer II is designed to correct the radial differences in position inherent in central perspective photographs and produced by elevation differences in the terrain (perspective distortion) caused by perspective projection. It is, therefore, necessary to set the base b' of the right hand photograph on the scale in front of the instrument.

(*vi*) *Setting and connection of the pantograph.*—The pantograph attached with the stereotope instrument can give magnification upto 2·5 times and reductions upto 5 times ; the pivot position is inside from 0·5 times reduction to 2·5 times magnification and outside from 0·5 times reduction to 5 times reduction. Use of magnification should, however, be avoided.

Depending on ratio of $\frac{mb}{mk}$ i.e., $\frac{\text{Photo scale}}{\text{Plotting scale}}$, pantograph settings are determined with the help of graph (please refer to manual) or by trial, keeping in view that 25·00 on reading of the pantograph values gives 1 : 1 ratio. Pivot and pencil are also set in correct positions and pantograph is connected to the respective take-off of the stereotope. Pivot is kept in such a position that pantograph arms make a rectangle when the floating marks are kept in the centre of the stereomodel.

Accurate setting of pantograph is determined from the distance between the two control points which are approximately on the vertical line of the left hand p.p. Pantograph is adjusted till both of these points on plot sheet and in the model agree within $\pm 0 \cdot 5$ mm. Final adjustment may be done by trial or by calculations – (for details refer manual).

(*vii*) *Setting of the rectifying computer.*—The rectifying computer is coupled with Computer II. This computer corrects the "projective distortion" which appears if the left photograph is tilted. This correction is made in the direction of two components. The zero position of the left hand slide is 40·00 and of the right hand slide is 100·00. These slides may be displaced toward right or left depending upon the shift in plan positions of the other two control points which have not been used for scaling, i.e., two points located near positions A, B. The adjustment of slides is done by trial. Model is supposed to have been scaled when the resulting accuracy of plan position is within $\pm 0 \cdot 7$ mm.

Method of detail and contour survey.—Details are plotted by keeping the floating mark on the terrain, and scanning is done by moving/sliding the photo carriage with X- and Y-parallax thimbles being simultaneously operated by right hand, and left hand respectively. Tracing pencil point is controlled by a wire release.

For contouring, the respective calculated contour values in terms of X-parallaxes (mm) are set on the X-parallax thimble and then floating mark is moved in such a way that it keeps touching the ground and Y-parallax is removed simultaneously as before. Spot heights may be measured in terms of X-parallaxes and then calculated in terms of ground heights with the help of parallax formula.

Plotting of terrain with large relief differences.—For plotting of terrain with large relief difference, the following points are to be considered carefully :—

(*a*) The reference plane may depart strongly from a mean datum placed through the control points.

(*b*) Errors in measurement of base, due to picture tilt, may seriously affect the measurement of elevations.

(*c*) Increase of vertical accuracy.

In case (*a*) the model is plotted in two stages by changing the datum by shifting the right hand photo parallel to a line perpendicular to the photo base towards left or right side depending upon the direction of change of datum. The amount of displacement can be determined under stereoscopic observations and measured in mm ; the new Pxo = $15 \cdot 00 - \Delta x$., and Px(New) = Px (Old) $-$ ΔPx. The displacement Δx is positive for a shift to right side and is negative for displacement towards left side. The X-parallax value of control points will change by a constant factor Δx.

Since an accurate parallel displacement of the photograph can not be attained, a re-orientation of rectiputer I is needed. Base setting for Computer II is b(New) = b′(Old) + Δx for displacement towards right and is b′(New) = b(Old) $-$ Δx for a displacement towards left. Also check pantograph setting, if scale setting was done before displacement (Δx). Rectifying computer may also be required to be adjusted in case of large displacement.

Errors in the measurement of the base (which is falsified due to picture tilt) will influence heighting accuracy in models with excessive relief. With the help of an extreme elevation point (at peak or valley) the corrected base $b'' = \dfrac{\Delta px \cdot ho}{\Delta h} - \Delta px$ where Δpx is the X-parallax for a change of relief of Δh with respect to left nadir point, ho is the flying height above left hand nadir point. This corrected value, b″ is then used for recomputation of X-parallax of control points (A, B, C and D) and setting of base value on rectiputer II.

$$\Delta px \ (\text{correct}) = \Delta px \ (\text{Old}) \times \frac{b''}{b'} ;$$

$$px \ (\text{correct}) = Po + \Delta px \ (\text{correct}).$$

Vertical accuracy in case of large relief differences can be improved by plotting the model in two halves. Two additional control points in the middle of the model (one between top two and another between bottom two) are required. In first stage model is oriented on 4 corner control points and Computer I is adjusted ; then differences of additional central control points are adjusted for left half of the model and model is surveyed. Similarly the right side of the model is oriented after setting the model on extreme right side points and central control points. Small adjustments for scale and rectifying computer may be necessary in the two cases—(for details refer to the manual).

81. Operation procedure with Stereomicrometer.—*Introduction.*—Special features of this instrument are (*i*) the spatial pantograph, (*ii*) special height scales and (*iii*) the "Cavalcanti Surface" as corrector device.

Sequence of operations.—(See plates VIII B and VIII C). Plotting with the stereomicrometer calls for the following operation procedures :—

(*a*) Preliminary work.—

(*i*) Set carriage 16 at 0 with knob 17.

(*ii*) Mount the special scale for the standard value nearest to the camera focal length and adjust to zero of the vernier.

(*iii*) Using screw 23 set the principal distance.

(*iv*) Adjust link block 44 on scale 45 at the value corresponding to the focal length.

(*b*) Setting each photograph.—

(*i*) (a) Set drawing table horizontal.

(b) Set traverse area 2 at zero with knob 46.

(c) Level altimetric correction device.

(d) Set 'by' at zero using foot disc.

(*ii*) Remove plate holder and mount the photograph duly centred.

(*iii*) Set ruler at 0·5 to begin with.

(*iv*) Set carriages X and Y at zero positions and select detail near the principal point to serve as reference point for heights in the right hand photograph.

(*c*) Altimetry.—

(*i*) Remove Y-parallax at both principal points with K-rotation using screws, 30 and 30′.

(*ii*) Measure p.p. base (bx) and calculate $\frac{bx}{f}$ for setting of ruler 18.

(*iii*) Set plot sheet on table and adjust magnitude of enlargement/reduction by means of screw 28. Adjust balance of rod 22 with suitable springs.

(*iv*) Make rod 22 vertical and measure (with the special scale provided) the distance Zc between cardan joint 24 and 2′. Calculate value (Cm) of height scale division by formula.

$$Cm = Zc \cdot \frac{S}{2000} \cdot \frac{fp}{fr}$$

where S is denominator of representative fraction of scale, fp is the exposure focal length and fr the plotting focal length.

(*v*) Using this value of Cm and heights of two control points in the vertical cross section through P_2 deduce height of P_2 and accept mean as correct datum value.

(*vi*) With this datum and the value of Cm calculate scale readings for points 3, 4, 5 & 6 spaced in the model as below :

3.	4.
1.	2.
5.	6.

(*vii*) Set calculated value of scale reading for a point on scale 20 with knob and set floating mark on the point with the help of the cavalcanti surface using screw nearest to the feeler.

(*viii*) Adjust similarly for two other points and check at the fourth point. In case of discrepancy remove half the error with screw 31 and half with the screw nearest to the feeler. Repeat till discrepancies at these four points are smaller than 0·2 of the proposed contour interval. (Special forms to record the various steps are available).

(*d*) Planimetry.—

(*i*) Although scaling was done at step (*c*) (*iii*) is should be repeated if there are discrepancies at points 4 & 6 ;

(*ii*) Check at points 3 & 5. In case of any discrepancy correct empirically by tilting the table in X-direction and the projection beam in Y-direction.

Plotting is started after the model discrepancies have been reduced to the minimum acceptable limits. The scanning system is moved along the item of detail with right hand by moving the ball keeping the floating mark in contact with the ground by manipulating knob 17 and using the foot disc to remove Y-parallax as necessary. In plotting contours the height scale reading is set by means of knob 17 to the calculated scale reading for a contour. The floating mark is taken along the contour using ball (15) and removing Y-parallax with foot disc as necessary. The work of plotting can be carried out either

(*i*) by complete survey of detail in small areas

or (*ii*) by completing one type of detail at a time.

The plot sheet should be touched up or edited at the end of every stage of plotting.

The main source of error in plotting with a stereomicrometer is the difference between the exposure focal length and the focal lengths available for plotting. The development of errors in affine plotting of this nature is mainly in altimetric evaluation and is a second order curve resembling a hyperbola. It is, therefore, advisable not to use this instrument for contour tracing in areas of high relief when a camera of focal length very close to the ones for which standard scales are provided is not available. For all other areas and when suitable camera is available the instrument can be used for all mapping on scales of 1 : 10,000 and smaller.

This instrument is designed to provide overall correction for lens distortion and imperfection in flying. In order to obtain optimum results only correctostat prints, positive/negative on glass plate or distortion-free plastic film should be used.

82. Important hints.—

Orientation :—(*i*) *Inner orientation* :—Generally there arise no troubles during this operation. Collimating marks of the diapositive may not, sometimes, superimpose perfectly over those of the picture-plate. Under such circumstance, the best possible inner orientation is achieved by exactly superimposing the principal point of the picture, if one exists, over that of the plate, and distributing the residual errors on all the collimating marks equally.

(*ii*) *Relative orientation* :—(*a*) The plotting principal distance/focal length if wrongly set in one camera, relative orientation cannot be achieved. Check for this and set the values correctly. In case focal length setting is wrongly made by the same amount on both the columns, relative orientation will be achieved, but during horizontalisation after scaling, heights being on a different scale than the plan, will not agree as the height scale used being in agreement with the scale of the planimetry only. This sort of disagreement will be more pronounced in case of models of great relief differences. If the heights can be read on the scale which corresponds to focal length setting one can get correct results but it is preferable to make a correct setting of plotting principal distance.

(*b*) If the model shows parallaxes due to local distortions in the film base or emulsion shift, etc., it is not possible, at the first instant to make out the cause of odd behaviour of Y-parallaxes. A change of position of the points used in relative orientation may help to achieve relative orientation ; but such parallaxes cannot be eliminated. A second copy of the positive print may help but if the distortion exists in the negative one cannot help it and has to make the best of a bad situation. If such parallaxes disturb the plotting operation one may use ω or 'by' (on A-7) for local elimination of Y-parallaxes and set it back to the original value.

(*iii*) *Absolute orientation* :—(*a*) In every model certain residual errors in Y-parallaxes is invariably present, as relative orientation cannot be achieved perfectly free from Y-parallaxes due to various causes. This affects the height and plan of a given point and minor model deformations occur. Also inherent minor errors in the ground/aerial triangulation control points also account for model deformations. One has to make the best fit for heights and plan which may be acceptable for the scale of plotting. The plan and height discrepancies of common points between adjoining models will be of different orders and this will necessitate marginal adjustments. Proper record of individual model discrepancies is necessary to help in arriving at a best fit between adjoining models.

(*b*) In hilly and jungle terrains shadows play a very important part and result in defective observations for the same point from model to model. One has to be careful in such a case. In case of snow areas the background shows poor resistance to the floating mark and height observations can easily be burdened with errors and one has to make allowance for observations in such areas also.

(*c*) Dimensions of negatives/diapositives should invariably be checked for dimensional changes. Uniform change in dimensions can be corrected by reducing or enlarging the plotting principal distance, as the case may be, proportionately, if the changes are appreciable and warrant a change. Unequal dimensional changes of the negatives/diapositives can be corrected by taking a mean value for the plotting principal distance if the changes are not too large.

(*d*) Use of a wrong glass scale will throw heights out. The effect will be pronounced for hilly terrain and it may be difficult to detect the mistake in case of areas with low relief. So care is required in inserting the proper height scale or height-gear combination. Also, the errors will not show up for points which have about the same height as the point on which initial height has been set.

Plotting.—(*i*) In wooded areas average height of trees may be taken into account and contours plotted by moving the floating mark over tree tops and checks made by taking spot height where-ever possible.

(*ii*) In snow regions if contrast is poor the wooly nature of the background will make it difficult to plot contours continuously and the operator may take some spot heights to control his contour lines.

SECTION X.—AERIAL TRIANGULATION

83. **Introduction.**—Aerial triangulation is the process of supplementing planimetric and altimetric control points (also called pass pionts) for orienting individual models on the stereo-plotting instruments, as the provision of ground control points in individual models is not only inconvenient, uneconomical and slow but also difficult to fulfil the necessary geometrical requirements of the ideal location in each model to achieve the requisite accuracy.

The following are some of the important methods of analogue aerial triangulation :—

(*i*) *Aero-polygon.*—In this method the re-establishment of the strip is carried out in the stereo-plotting instrument by recreating the chains of successive bundles of rays as existed at the time of exposure.

(*ii*) *Aero-levelling.*—In this method the re-establishment of the strip is carried out in the stereo-plotting instrument such that the strip axis is kept at a constant height from the datum plane. This method is followed to avoid the complications caused by the earth curvature and systematic instrumental errors or when the data pertaining to the aerial camera-sations, provided by the Statoscope or Air-borne Profile Recorder is available.

(*iii*) *Independent model.*—In this method, each model is observed independently after relative orientation and subsequent connections are carried out by computations.

(*iv*) *Analytical* (*digital*).—In this method the plate co-ordinates are read on stereo/mono comparators and the entire process of relative, absolute orientations and subsequent adjustments of the strip are carried out by computations. These computations being rather heavy will require the use of electronic computer.

In all the above procedures any auxiliary data, from Horizon Camera, Gyroscope, Air-borne Profile Recorder, etc., can be used either at the time of observation or, preferably, at the time of adjustment.

Aero-polygon method is mainly followed in this department and so the principles, procedure of observation and the method of adjustment are explained in this section in respect of this method.

Assuming that the first model is absolutely oriented, i.e., the left and the right photographs are oriented in space correctly as at the time of exposure, the third photograph is brought into the correct orientation by relatively orienting it with the second photograph without disturbing the absolute orientation of the first model. Thus the second model is in its correct azimuth, longitudinal tilt and lateral tilt, and so is in the co-ordinate system of the first model **except for the scale. Determination of scale, i.e., the setting of** correct 'bx' can be indirectly done by measuring and comparing the heights of a point, above an arbitrary datum, observed in the two models as shown in fig. X·1. Scale can also be determined by comparing any other linear measurements common to the two models, but will be less accurate. The ideal control distribution is shown in fig. X·2. (Also see Section XII).

The requisite density of the ground control can be considerably reduced for planimetry if the block adjustment method is used in which case the plan control points are required only at the periphery of the block, but for heights reduction in ground control points per strip is not much.

The normal length of the strip for aerial triangulation which can be adjusted by graphical method will depend upon the scale of photography, distribution of ground control points and the accuracy aimed at.

In addition to the aerial triangulation for the survey of 1 : 50,000 or 1 : 25,000 scale topographical maps, it is often necessary to provide control for the production of maps specially required for large scale irrigation and other special surveys. The accuracy of control required for these large scale surveys will demand rigorous methods of adjustments and special procedures should be followed.

The following material should be collected before commencing the aerial triangulation :—

(*i*) *Photo-index* with calibration data, etc.

(*ii*) *Photos* with all the available control – pre-pointed/post-pointed and with suitable sketches.

(*iii*) *Diapositives,* compensated/uncompensated depending upon the type of the camera used.

(*iv*) *Ground control data.*—Planimetry should be in terms of grid metres/yards. Suitable sketches of the ground control points and information regarding the accuracy of the points and their suitablity for planimetric/height adjustment should be collected. It is absolutely essential that the ground control points are all in one specific system. Data pertaining to the aerial triangulation of margins will also be required for adjustment of the strips.

The above material and data should be examined by the officer-in-charge of the party, who is responsible for the triangulation, before commencing the work ; he should ensure that the quality of the diapositives, the ground control, etc., are of the required standard to achieve the requisite accuracy.

84. Preparatory work.—As, in aerial triangulation, we deal with a large number of photographs, careful planning and preparatory work, systematic procedures of observation and adjustment and rigorous supervision should be strictly followed to achieve accurate results.

(*a*) It is very important to have a planning index, as this will guide all subsequent operations. The procedure out-lined below is to be followed for preparing the index. (See also Appendix 'C' for further details).

(*i*) Examine the photographs for short overlaps, gaps due to cloud-patches, etc.

(*ii*) Mark the principal points on the photographs in red.

(*iii*) On a published map of the area (scale not smaller than a fourth of that of the photographs) mark the principal points to indicate the relative positions of all photographs. This should be done by comparing the details on the photographs with those on the map. (If no suitable map is available then the index is to be prepared on blank paper).

(*iv*) Central points.—Near the principal point of each photo select a *well-defined* point and mark them on photo, by dots and circles of 5 mm radius in green. Show them on the index. Points are to be numbered as 312/36-C, 312/37-C, etc. (or 31203601, 31203701, etc.) where 312 is the strip number, 36, 37, etc., are the photo numbers.

(*v*) Select the *tie points* between contiguous strips as explained below :—

Take two photographs of adjacent strips (say, of strip Nos. 312 and 313) the principal points of which lie approximately opposite as could be seen from index (e.g., photos 312/37 and 313/105, in fig. X·3).

Superimpose them and an area around a well-defined point approximately midway (on the lateral overlap) between the two principal points is to be shown by a circle of diameter 2 cm (using china-graph pencil) on one of the photographs. Transfer these circles on the other photographs with the help of details. Check whether this area also appears in full on photos 312/37, 312/35 and 313/104, 313/106 and if so, mark the tie point (with a dot and a circle of radius 5 mm in green) on photos 312/37 and 313/105 using a stereoscope. Plot this position approximately on the index and connect it by lines with the principal points—see fig. X·3.

Numbering of the tie points will be as follows :—

Start with the top strip, say strip No. 312. The upper points are numbered as 312/1-U, 312/2-U, 312/3-U, etc. (or 31200103, 31200203, 31200303, etc.) and the lower points 312/1-L, 312/2-L, 312/3-L, etc., (or 31200105, 31200205, 31200305, etc.). For the second strip the upper points are not numbered when they are common with the lower points of upper strip. Number the lower points 313/1-L, 313/2-L, 313/3-L, etc.....(or 31300105, 31300205, 31300305, etc.).

If the area covered by the circle does not appear fully (or does not at all appear) on one or more of the six photos then 2 points should be selected in the lateral overlap one vertically below the first principal point and the other vertically above the second principal point. Each of these points will appear on 5 photos and not on 6. These should be marked again only on one of the photos of each strip and numbered properly. Simple sketches of the points as seen through mirror stereoscope with 6 X enlargement should be made in pencil on form 1 Phot. The final position of the point actually observed will be pricked on the photograph and marked on form 1 Phot. during observation of the aerial triangulation.

(*vi*) Examine the control points and mark them on the index in suitable symbols. If the control points are not post-pointed/pre-pointed in the field then they are to be office-post-pointed on the photographs. The sketch as prepared by the field-hand should be drawn on the back of the photo, if not done in the field.

(*vii*) When we have exclusively parallel strips the marking is finished as explained above but with tie and cross strips or when photography is executed in several blocks of short parallel strips each strip having a different azimuth, the various situations arising should be settled at the planning stage by the Section Officer.

(*b*) A schematic diagram will be prepared on form 2 Phot. directing the sequence of observation to be followed.

(*c*) In order to stay within the range of 'by' during the aerial triangulation the following procedures will be followed, especially for long strips or those having considerable 'crab'.

(*i*) Execute a graphical "Traverse" of the principal points using mean principal point bases.

(*ii*) On this "Traverse" sheet draw a line through the first principal point such that the distances of the extreme principal points on either side from the line are equal.

(*iii*) Keep the first photograph under the "Traverse" sheet, align the base line and prick a point on the mean line at the right edge of the photo.

(*iv*) Join the principal point with this prick ; this line should be treated as the zero direction of the instrument.

It is essential that the officer who guides the preparatory work should have good previous experience in the procedures of observation and adjustment.

By the procedure indicated in the preparatory work, it will be seen that only 6 points are provided for each model. It is advisable, when employing inexperienced operators on observation, additional points besides the minimum required are also ordered to be observed, as a precaution against any of the tie points not proving during the adjustment. These extra points (very close to the six points) need not be adjusted unless necessity arises.

The index and the schematic diagram should be examined by the officer-in-charge of the party, who should decide the general programme of observations.

85. **Aerial triangulation on Multiplex.**—Multiplex is an instrument specially designed for small scale aerial triangulation combined with plotting and bars with 6 to 24 projectors are still in use outside India. Although in Survey of India aerial triangulation on Multiplex is not being carried out, but, as the procedure of aero-polygon method of aerial triangulation executed on the multiplex is highly instructive and will enable to understand the principles clearly, it is given below, in brief.

(*i*) On the Multiplex table set the plot sheet with control points.

(*ii*) Set all the elements of the projectors in zero position.

(*iii*) Introduce the diapositives in all the projectors. (The diapositives are reduced to workable dimensions on a reduction printer supplied with the instrument).

(*iv*) Calculate 'bx' and set the provisional value of 'bx' of the first model.

$$b_x = \frac{\text{model scale}}{\text{photo scale}} \times (\text{ mean principal-point-base })$$.

Introduce this "b_x" for all models.

(*v*) Illuminate the left hand projector. Bring the floating mark over the projection of the principal point and move it to the right edge of the projection. Swing the projector and shift the floating mark towards the right until an identifiable point lying on the line of zero direction marked on the paper print [see para 84 *c* (*iv*)], falls on the floating mark.

(*vi*) Carry out the relative orientation of the first model, keeping the elements "b_z" in its zero position and not using "b_x" and "b_y" of the left projector.

(*vii*) Carry out provisional levelling for Ω by tilting the main frame. No levelling is to be done in Φ direction.

(*viii*) *Scale transfer*.—Select a point in the immediate neighbourhood of the principal point of the second photo. The point should be chosen in flat terrain and should be sufficiently sharp to enable the floating mark to be set on the ground. It should also appear on the third photo. A neat clear diagram of the point should be made so that it can be easily identified in the next model. Measure and note the height of the point.

(*ix*) Switch-off the first projector and switch-on the third projector. Using the elements of the third projector only, carry out an approximate relative orientation. Set the floating mark at the recorded height of the scale transfer point and bring it under the point. Adjust 'b_x' by moving the third projector until the floating mark appears to be on the terrain containing the scale transfer point.

Carry out the final relative orientation followed by the exact scale transfer. The final scale transfer can be checked by examining the intersection of the rays from the first and third projectors (although the rays may be of the same colour). In this way the successive models are oriented and connected to each other.

At the end of the strip errors at the control points can be seen by comparing the plotted positions.

(*x*) Carry out approximate absolute orientation, only for heights (levelling) as for a single model.

(*xi*) Shift and rotate the control sheet so that the projection of the first control point is over its plotted position and the projection of the last one is on the line joining the plotted position of the first with the last control point. Calculate the required scale correction from $\Delta s = \frac{Df_1 - D'f_1}{D'f_1}$ where Df_1 is the distance between the first and the last control points as on plot sheet and $D'f_1$ that made by their projection.

(*xii*) Start with the first model, adjust the 'b_x' until the old height "h" of a point as read from the model is corrected to $h - \Delta s \cdot z$, where "z" (which is in the same terms as "h") is the distance between the model point and the instrument base.

(*xiii*) Correct the relative orientation of the first model and repeat the process model after model until the scaling is satisfactory. The strip as a whole is then levelled by tilting the frame until the required model heights for 3 control points are obtained.

It will be seen that in the above procedure, the observation and adjustment (linear corrections) are carried out simultaneously. Further the effect due to the earth curvature and non-linear corrections are not removed.

It can be easily shown that for a small strip triangulated on Multiplex, the height error in the middle of the strip due to earth curvature *alone* will be $0 \cdot 02 \times L^2$ metres (approximate), where L is the length (on the terrain) of the strip, in kilometres. Due to this limitation the method is practically useless even for topographical mapping.

86. Aerial triangulation on Wild A7.—This is the normal procedure used in the Survey of India for aerial triangulation. The description of the instrument is given in section VIII.

Section X.—AERIAL TRIANGULATION

Apart from the preparatory work as explained in para 84 the following additional preliminary work should also be carried out :—

(*i*) The gear ratio for the heights should be selected in such a way that values in metres/feet are directly read on the height counter. (If the first model cannot be scaled, the gear ratio for the heights should be kept at unity ; in this case heights are to be recorded in model millimetres).

(*ii*) The model scale should be chosen as large as possible. This depends upon the focal length of the aerial survey camera, the maximum 'b_x' and 'Z' ranges of the instrument and the nature of the terrain, e.g., consider the photography with focal length 150 mm. The 'Z' range of Wild A7 is from 140 to 490 mm. After taking into consideration, the effect of earth curvature, the nature of the terrain covered by the entire strip (which can be easily ascertained from the index map or from the photos), choose a suitable 'Z' value, say 400 mm. With the photo scale 1 : 65,000 (approximate), this model scale will be 1 : $\frac{150}{400} \times 65{,}000$ or 1 : 25,000 (say).

If the ground is very flat the model scale can be increased.

Having, thus, decided the model scale the initial 'b_x' can be calculated easily.

Drill for observation.—(*i*) Set the instrument base "inside", with b_x value as computed, and the relative orientation elements in their 'zero' positions. Triangulation lever (to be positioned away from the operator), diapositive lever (to be pulled to the left if diapositives are used or to the right if negatives are used), dove prisms (indices to be outwards), sense of rotation of handwheels, Y–Z knob and order of transmission to plotting table, etc., are to be set properly.

(*ii*) Carry out the inner orientation for the first pair of diapositives (overlap outside).

If the diapositives are on the film, the variations in the dimensions should be checked and the inner orientation should be improved by introducing the effective focal length.

(*iii*) Set the zero direction to coincide with the instrument axis to avoid the "running out" of the element 'b_y'.

View through the left eye-piece ; set the floating mark on the principal point and move the X-carriage to the right until the floating mark is at the right edge of the diapositive. Swing the left projector and shift/move the X-carriage slightly, until a well-defined point falling on the zero direction as appearing on the paper prints is covered by the floating mark.

(*iv*) Carry out an approximate empirical relative orientation. Improve this by numerical relative orientation using the right projector elements other than 'b_z' and of the left projector. (Use form 3 Phot).

(*v*) Carry out the absolute orientation using the control points. The scaling and levelling should be carried out as precisely as possible. Since the absolute orientation will disturb slightly the relative orientation, steps (*iv*) & (*v*) should be done in iteration.

(*vi*) The exact "setting" of the first model (absolute orientation) is entered on form 10 Phot. This is checked by the section officer or the officer-in-charge of the preparatory work.

(*vii*) Choose initial x and y (which are always read in model mm) values suitably on the respective counters and fasten the butterfly screws. (Generally, the machine co-ordinate system x, y, is chosen in such a way that no negative co-ordinates occur and that the x-axis is nearly as far as possible parallel to the strip axis). Height reading should agree with the ground control height.

It is essential that the setting of the height counter is *never altered* throughout the triangulation.

(*viii*) Identify the points to be observed, with the help of the sketches. Sketches prepared during the observation of the adjacent strips, if any, available for the tie-points and field sketches for the ground control points should also be consulted. Observe and record the machine co-ordinates of points (including control points) on form 5 Phot. according to the sequence shown on the schematic diagram on form 2 Phot. Record brief descriptions of the observed points in the remarks column. First set of observations and recording of the co-ordinates are made as directed in the schematic diagram and the repeat observations (2 sets of observations for each model) are made in the opposite direction to eliminate errors due to back-lash and other mechanical and optical limitations. Setting of the floating marks should be done very carefully and in the same direction and there should not be any residual X-parallax. A remark regarding the residual Y-parallax, if noticed, at any of the observed points should be made. During the opposite round, any gross errors made in the previous recording should be checked. The two sets of co-ordinates read in the same models should agree within 0·04 mm on model scale.

(*ix*) Indicate the exact point observed on form 1 Phot., and mark the exact positions on photograph.

(*x*) *Scale transfer points.*—Choose 3 scale transfer points in the immediate vicinity of the principal point of the right photo such that these points also appear in the next model. These points should be chosen as far as possible in locally flat terrain with sufficient photographic texture. Observe heights (3 sets for each) and record the readings on form 6 Phot. and calculate the mean heights for each point. The three readings on each point should agree within 0·04 mm on model scale. Make simple, clear planimetric sketches of areas around scale transfer points.

(*xi*) Record the orientation elements on form 5 Phot. and check them against those appearing on form 3 Phot. Now, complete all other columns for this model.

(*xii*) Remove the diapositive from the left hand projector and carry out the inner orientation for the third diapositive. The overlap of this with the second diapositive, should be now "inside".

(*xiii*) Change the base from "inside" to "outside" and set approximate value for 'b_x' ; rotate the dove prisms (indices inwards) and pull the triangulation lever (towards the operator).

(*xiv*) Carry out an approximate relative orientation using the elements of projector with the new diapositive.

(*xv*) Scale the model with the help of one of the scale transfer points. Set the mean height of this point on the height counter (only by moving the foot disc) and eliminate the X-parallax by 'b_x'movement.

(*xvi*) Perform the numerical orientation using the elements of projector with the new diapositive, on form 4 Phot.

(*xvii*) Carry out the final scale transfer. Set the height counter on the mean height of the first scale transfer point. Remove the X-parallax at this point with the slow motion tangent knob of b_x setting. Read and record the 'b_x' value. Do this for the remaining scale transfer points also. Repeat and record for each point, 3 sets of 'b_x' readings. Compute the mean of the 9 'b_x' readings ; set it as the final 'b_x' value. The "b_x" values must agree within 0·04 mm for wide angle photography.

(*xviii*) Observe the central point near the principal point of the right photo. Set the 'x'- and 'y'-counter values on those measured in the previous model for this point, i.e., 'x'- and 'y'-counters are to be set such that the machine co-ordinates observed in second model are in the same system as in the first model.

Now repeat the steps (*vii*) to (*xi*). Remove the diapositive from right hand projector and introduce the fourth diapositive (overlap outwards). Change the base from "outside" to "inside', push triangulation lever away from operator and rotate dove prism (indices outwards) and carry out the steps from (*xiii*) onwards.

Repeat the procedure model after model.

As the central point is situated very close to the scale transfer points and as it is used for the 'x' and 'y' connections there should not be any difference in the two sets of co-ordinates observed for this point. In the case of the wing points the errors due to relative orientation and error due to scale transfer will effect the co-ordinates, but these should be within limits mentioned in para 88(*ii*)(*a*).

In the case of large strips there is a possibility of "running out" of elements b_z and ϕ. 'b_y' has been taken care of during preparatory work. Setting 'b_z' element back and correcting the datum plane suitably can be made before reaching the critical value. It will only create a break in the propagation of instrumental errors in the strip but no computation is involved. In the case of ϕ, setting of this element back and correcting the model heights will involve computations apart from the discontinuity in the triangulation and this should be avoided. To overcome this difficulty after the first model is absolutely oriented, it may be "tipped up" by an amount ϕ_t ($\simeq \frac{1}{2}$ L centecimal minutes, where L is the length of the strip on the ground in km.).

It is not advisable to carry out the aerial triangulation of two contiguous strips simultaneously, for there is every chance of setting of the measuring mark on the tie points marked on the photographs of 2 strips being done at different places by two observers. It should be ensured that observers are provided with all information regarding the exact location of the tie points measured in the upper and lower contiguous strips. Form 1 Photo. of the upper and lower strips should invariably be made available to the observers.

It may occasionally happen that the observer could not identify a specific point marked during preparatory work and has observed some other point close to it. This should be brought immediately to the notice of the section officer who should make necessary changes on all the records of preliminary work affected by this.

The heights should always be observed, if possible, to the ground level as well as to the top of every point. For photogrammetric plotting work it is usually more convenient to have the ground height. Clear description should be made on form 5 Phot. for every point observed.

It is absolutely essential that the observed machine co-ordinates of the control points which will be used for adjustment are personally checked by the section officer to avoid complications at the time of adjustment. The exact location observed should agree with field sketch. In case of doubt the matter should be brought to the notice of the officer-in-charge of the party. If the control points are office post-pointed during preparatory work without a sketch the officer who did this post-pointing should check its exact position on the model.

87. **Aerial triangulation on Wild A8 Autograph or other precision plotters.**—The Wild A8, which is without parallelogram

of ZEISS, 'b_y' or 'b_z', is only a stereoplotter as accurate as the Wild A7 for plotting, but aerial triangulation is possible on it by suitably modifying the method of observation.

The preparatory work for aerial triangulation on Wild A8 is same as for normal aero-polygon method on Wild A7.

Having completed the absolute orientation of the first model with the available elements the co-ordinates of the points are recorded. The second diapositive is to be transferred with its plate-holder from the right hand projector to the left hand projector and third is to be mounted on the right. But with a view to transfer ϕ and ω along with the second diapositive a special cross-bubble, which can be kept only in one position on the plate holder, is used. The cross-bubble is, first, placed on the right plate and is levelled with the help of the foot screws. After the second model is relatively oriented using elements other than ω_2, the cross-bubble is placed in the same position on the plate holder of the left hand projector, which now contains the second diapositive. Using ϕ and ω_1, the levelling of the bubbles is achieved ; the resulting parallax is removed using ω_2. The scale transfer can be executed just as in Wild A7, but, the height observed is to be corrected for common ϕ. Further, the new model will have a different azimuth from that of the first. The azimuth of the model and the scale are computed by linear conformal transformation using the points common with the previous model. All the co-ordinates are, then, brought into the same system as the first. In view of this, 'b_x' is kept constant throughout the triangulation. The transfer of ϕ and ω is sufficiently accurate and there are various methods by which these can be checked.

It is possible that each model can be relatively oriented with a constant 'b_x' and absolutely oriented fairly well with the help of various terrain features. These models can be adjusted using analogue or digital block-adjustment methods.

It is also possible to carry out triangulation on Kern PG2 with the help of the special polar co-ordinate (planimetry) measuring auxiliary device, that can be attached in combination with electronic read-out device to the instrument. The computation for planimetry is laborious and will require the help of electronic computers. Both Kern PG2 and Wild B8 can be used for height by the procedure similar to that explained for Wild A8 and planimetry by stereo-templet combination.

In view of the instruments without parallelogram of Zeiss being cheaper than those with, the method of independent models is very popular in many small survey organisations.

88. Propagation of errors in strip triangulation.—(*i*) *Sources and types of errors.*—The main source of errors in aerial triangulation are the diapositives (which are burdened with all kinds of errors introduced in the process of obtaining them), instrument (errors which can be known to a certain extent and remain practically constant under a given condition) and the observer. Further, in the procedure of analogue aerial triangulation, there are errors due to inner orientation, relative orientation (including model deformation due to these), scale transfer, co-ordinate connection and co-ordinate measurement.

These errors are usually classified into systematic and random errors which is rather an over-simplification ; for actually these are more complicated due to strong correlation, e.g., film shrinkage, which introduces errors appearing to be systematic per photograph but can be random when we consider a group. As it is impossible to investigate the various sources of errors separately, only the cumulative effec of all the errors on the strip co-ordinates is examined.

(*ii*) *Effects of errors on the strip co-ordinates.*—(*a*) *At the common overlap of the adjacent models.*—Discrepancies at the common wing points between two contiguous models can generally be as much as

0·04 mm for 'x'-co-ordinate and

0·10 mm for 'y'-co-ordinate on model scale.

0·30 $^{0}/_{00}$ of flying height for heights.

These discrepancies should be carefully watched during aerial triangulation. These are generally due to bad relative orientation, poor quality of photography, errors due to alternate change of base from "inside" to "outside" or *vice-versa*, etc. They are removed by taking the mean of the co-ordinates measured twice in a strip. After doing this the models are not distinguished any longer and the strip as a whole is considered.

(*b*) *Strip deformation.*—The most dangerous effect of the errors is the strip deformation which can be of considerable magnitude. On the topographical scale the last model of the strip can differ by several hundreds of metres from the ground co-ordinates. The study of the propagation of errors is confined only to the study of these strip deformations.

(*iii*) *Propagation of errors in aero-polygon method of aerial triangulation.*—The aero-polygon method as explained earlier consists of relative orientation of models, scale transfer from one model to the next and co-ordinate connection. Further, azimuth, longitudinal tilt, lateral tilt, and co-ordinate axes system are transferred from one model to the next in the instrument itself.

The errors due to relative orientation and co-ordinate connections are assumed to be negligible. The models are assumed to be internally error-free and the strip deformation is assumed to be due to the errors in the tranfer of scale, azimuth, longitudinal tilt and lateral tilt.

Although the real observations are X- and Y-parallaxes, the simplified assumptions are made to avoid highly complicated algebraic computations in deriving the formulæ for the accumulation of errors in the observed machine co-ordinates. The graphical representation of the effect of these transfer errors (Δs_i, Δa_i, $\Delta\phi_i$ and $\Delta\omega_i$ from model i to i+1) is shown in figure X·4.

From these figures the following formulæ can be derived. (For the sake of completeness the first model is *not* shown as error-free).

Scale error of model i

$$\Delta s_i = \Delta s_1 + \sum_{1}^{i-1} \Delta s_k$$

Azimuth error of model i

$$\Delta A_i = \Delta A_1 + \sum_{1}^{i-1} \Delta a_k$$

Longitudinal tilt error of model i

$$\Delta \Phi_i = \Delta \Phi_1 + \sum_{1}^{i-1} \Delta \phi_k$$

Lateral tilt error

$$\Delta \Omega_i = \Delta \Omega_1 + \sum_{1}^{i-1} \Delta \omega_k \qquad \text{(I)}$$

Making use of the above results the errors in an arbitrary point in model i, when derived will, in terms of these transfer element errors, be as below :—

$$\Delta x = \Delta x_0 + x\Delta s_1 - y\Delta A_1 + z\Delta\Phi_1 + \sum_{1}^{i-1} (x - x_k) \Delta s_k - y \sum_{1}^{i-1} \Delta a_k + z \sum_{1}^{i-1} \Delta\phi_k$$

$$\Delta y = \Delta y_0 + x\Delta A_1 + y\Delta s_1 - z\Delta\Omega_1 + \sum_{1}^{i-1} (x - x_k) \Delta a_k + y \sum_{1}^{i-1} \Delta s_k - z \sum_{1}^{i-1} \Delta\omega_k$$

$$\Delta z = \Delta z_0 - x\Delta\Phi_1 + y\Delta\Omega_1 + z\Delta s_1 - \sum_{1}^{i-1} (x - x_k) \Delta\phi_k + y \sum_{1}^{i-1} \Delta\omega_k + z \sum_{1}^{i-1} \Delta s_k \qquad \text{(II)}$$

These results are derived without making any specific assumptions on the nature of the transfer errors and without taking into consideration the setting errors.

(*iv*) *Effect of constant transfer errors.*—Constant transfer errors always occur in practice. Most of the systematic errors due to mechanical and optical limitations of the instrument (as could be seen from the constant projection errors during 9 points grid measurements), camera lens distortion, atmospheric refraction, etc., are approximately constant. Further, the existence of constant projection errors, yields always constant transfer errors. With a constant parallax pattern repeated model after model with change of base, constant transfer errors will always appear. So it can be considered that the constant transfer errors are the main cause of deformation in the strip. This deformation can be examined with the help of the results derived above, which on simplification (with suitable mathematical approximations) will reduce to

$$\Delta x = \Delta x_0 + x\Delta s_1 - y\Delta A_1 + z\Delta\Phi_1 + x^2\frac{\Delta s}{2b} - xy\frac{\Delta a}{b} + xz\frac{\Delta\phi}{b}$$

$$\Delta y = \Delta y_0 + x\Delta A_1 + y\Delta s_1 - z\Delta\Omega_1 + xy\frac{\Delta s}{b} + x^2\frac{\Delta a}{2b} - xz\frac{\Delta\omega}{b}$$

$$\Delta Z = \Delta z_0 + x\Delta\Phi_1 + y\Delta\Omega_1 + z\Delta s_1 + xy\frac{\Delta\omega}{b} - x^2\frac{\Delta\phi}{2b} + xz\frac{\Delta s}{b} \quad \text{(III)}$$

Using parameters instead of transfer errors the results can be written as below :—

$$\Delta X = a_0 + a_1x - b_1y + c_1z + a_2x^2 - 2b_2xy + 2c_2xz$$

$$\Delta Y = b_0 + b_1x + a_1y - d_1z + b_2x^2 + 2a_2xy - 2d_2xz$$

$$\Delta Z = c_0 + c_1x + d_1y + a_1z - c_2x^2 + 2d_2xy + 2a_2xz \qquad \text{(IV)}$$

A study of this will indicate the strip deformation due to constant errors follow second degree polynomials, with 11 parameters, only 4 of which (a_2, b_2, c_2 and d_2) constitute the deformation.

From the above results it can be seen that deformations in the co-ordinates are interdependent. In the case of flat terrain the 'Z' can be considered as constant and so the result will reduce to

$$\Delta X = a_0 + a_1x + a_2x^2 - y\,(b_1 + 2b_2x)$$

$$\Delta Y = b_0 + b_1x + b_2x^2 + y\,(a_1 + 2a_2x)$$

$$\Delta Z = c_0 + c_1x + c_2x^2 + y\,(d_1 + 2d_2x) \qquad \text{(V)}$$

This indicates that the deformation in palnimetry for horizontal terrain are practically independent from that for the height.

Further, when these transfer element errors are linear functions of number of models, etc., it can be shown the resulting polynomials will be of third degree.

(*v*) *Effect of random transfer errors.*—Apart from the constant transfer errors the presence of random transfer errors can be expected, as all the operations connecting the models during aero-polygon method of aerial triangulation involve various factors. These are assumed to be governed by the normal probability distribution.

While the strip deformation due to constant transfer errors can be found out, the effect of the random transfer errors cannot be precisely determined. Hence, the strip deformation due to random transfer errors cannot be described by rigorous mathematical formulæ.

Applying the law of propagation of errors to the results II contained in para 88(*iii*), it can be shown (even assuming that the transfer errors elements are independent which can be proved only for theoretically ideal case for the models which are internally error-free), that the machine co-ordinates of observations are highly correlated. Further, because of the assumed normal distribution and the smallness of the transfer errors the strip deformation due to random errors are locally smooth with many directional changes. For small strips, say 10 to 15 models, these deformations are fairly close to polynomials of second or third degree. This, of course, does not mean that the strip deformation due to random errors generate second or third degree polynomial as due to the constant errors.

Due to the smoothness of the strip deformation produced by random errors for small strips and as constant errors are likely to be more predominant than random errors, simple second or third degree polynomial can be used to correct the major effects of the random errors fairly well.

Application of law of propagation of error to the results II given in para 88(*iii*) indicates that due to random transfer errors, the errors in the unadjusted co-ordinates of points in a strip increase approximately proportional to $x^{3/2}$ and that the correlation is very strong with the neighbouring points.

89. Strip adjustment by interpolation methods.—Although the true deformation of unadjusted strip cannot be known, yet by making use of the smoothness of the error surfaces and by determining points on them with the help of the errors as indicated by the ground control points, it is possible to find out suitable second or third order polynomials which can be made use of to correct the observed co-ordinates. However, the corrections so interpolated will deviate from the true ones. These deviations will be of very small magnitude for short strips.

(*i*) *Numerical interpolation for short strips.*—If the terrain is highly undulating then the results IV in para 88(*iv*) which give corrections for an arbitrary point on the strip, can be used. In this case 11 parameters (a_0, b_0, c_0, a_1, b_1, c_1, d_1, a_2, b_2, c_2 and d_2) are to be determined.

For approximately flat terrain the results V in para 88(*iv*) can be used. In this case 6 parameters are to be determined for planimetry and 5 for heights.

Each planimetric control point will generate two equations and a height control point one equation. Having determined the parameters the corrections for other points can be computed.

The computation of these parameters can be done using the principle of Gauss' Algorithm. When the number of equations are more than the number of parameters, the principle of least squares is used to get the best values of the unknowns.

(*ii*) *Graphical interpolation for short strips* (*for fairly flat terrain*).—Instead of the elaborate computations involved in the numerical interpolation, the adjustment can be carried out satisfactorily using graphical method.

In the graphical (J. M. Zarzycki) adjustment each co-ordinate is adjusted independently. As these surfaces cannot be drawn, curves produced by their intersection of the surface with those planes (perpendicular to the datum plane) passing through the strip axis and the extreme lateral limits (parallel to the strip axis) are used for interpolation.

The correction surfaces for each co-ordinate (one such correction surface is given in fig. X·5) is, therefore, represented by 3 parabolas (the central one is redundant). With a view to draw these correction curves, 3 bands of control points (each band containing 3 control points) one in the beginning, one in the middle and one in the end are required. The ideal case is when each band is at right angles to the strip axis and the points distributed on the extreme lateral limits and on the central axis ; satisfactory curves can be drawn even when the control points in each band lie approximately in a straight line.

The best values of the errors at the point on the central axis and the extreme lateral limits of the strip are to be determined. To get them, for each cross section a best fit is determined by drawing datum correction graphs—see fig. X·6(*a*).

If the three control points are not in one line an iterative procedure is followed. As the first step, a central parabola is drawn approximately and the central point is corrected for the shift in the X-co-ordinates from the ideal cross-section ; with this value the datum correction graph is drawn for the cross-section.

Preliminary work.—Examine the record of observations on form 5 Phot. Co-ordinates of points observed in consecutive models should agree within the permissible limits. Deduce the means and enter the planimetry (x and y) on form 8 Phot. and heights on form 9 Phot. Enter the co-ordinates of ground control points.

Planimetric adjustment.—(*i*) Choose two reliable ground control points, one at the beginning and the other at the end of the strip. If necessary use more ground control points. Calculate the transformation parameters on form 7 Phot.

(*ii*) Transform all machine co-ordinates and enter the transformed co-ordinates X_t and Y_t on form 8 Phot.

(*iii*) Calculate the differences $X_g - X_t$ and $Y_g - Y_t$ for the control points.

(*iv*) On a large graph sheet, which can contain the three correction curves, plot the strip co-ordinates, X_t, Y_t. From the plotted co-ordinates decide the central line (i.e., strip axis), the upper and the lower lines. The upper, central and lower lines are drawn in red, green and blue colours respectively. The adjustment curves for points on these lines are to be drawn.

(*v*) Choose three bands of control points, one in the beginning, one in the middle and one in the end and draw datum correction graph for each band and co-ordinate separately as shown in fig. X·6(*a*) and 6(*b*).

(*vi*) Choose a suitable scale for correction (x and y should have the same) and plot the values read from the datum correction graphs.

(*vii*) Draw the correction curves (3 each for x and y separately) using plastic spline (as in fig. X·7).

(*viii*) Read the corrections from the graph, using parabolic interpolation in X-direction and linear interpolation in Y-direction. Enter the corrections on form 8 Phot. and compute the adjusted co-ordinates.

Height adjustment.—The procedure of drawing the correction curves for the height is similar to 'x' and 'y' except for the following additional work which should be done for long strips or when there are large accumulated height or scale errors at the end of the strip.

(*i*) From the parameters calculated for planimetry (on form 7 Phot.) find the mean scale of the strip and reduce all the heights to the mean scale by multiplying the heights by the ratio,

$$\frac{\text{Mean scale}}{\text{Scale of first model}}.$$

(*ii*) Carry out the levelling of the strip in the longitudinal directions to remove major part of the effect due to earth curvature and systematic longitudinal tilt transfer errors. Using the heights of the extreme points calculate the parameters 'm' and 'c' in the formula $\Delta z_i = m x_i + c$ and then compute these corrections.

Graphical interpolation for mountainous terrain.—For mountainous terrain (i.e., when the relief is more than 10% of the flying height) the correction term containing z (or h) of the correction formula IV in para 88(*iv*) should also be taken into consideration. A simultaneous three dimensional graphical adjustment using x, y, z will involve more complications. But the graphical adjustment for flat terrain can be modified to meet the normal demands of topographical mapping and applying the following additional corrections to the transformed co-ordinates (x, y and h). The corrections should be applied to the ground control first, then only the residual corrections should be worked out for each band for drawing correction graph. For the required pass points these will be applied in addition to the graphical corrections.

X-Co-ordinate : Correction to remove the error due to the effect of longitudinal tilt of the whole strip $= +(h_{ki}—h_0)\Delta\Phi$.

Y-Co-ordinate : Correction to remove the error due to the effect of longitudinal tilt of the whole strip $= -(h_{ko}-h_0)\Delta\Omega$.

Altimetry : Correction to remove the error due to the effect of scale error in each model. (This is in addition to the mean scale correction) $= +(h_{ki}-h_0)\Delta s_i$.

Where h_{ki} is the height of point K in model i, h_0 height of the reference plane (chosen for first model) $\Delta\phi$ and $\Delta\Omega$ are the longitudinal and lateral tilts of the strip and Δs_i is the scale error of the model i ; $\Delta\Phi$ and $\Delta\Omega$ can be calculated based on the formula, $-X_t.\Delta\Phi + Y_t\Delta\Omega + dho =$ Ground height — machine height, using 3 or 4 points suitably chosen at the beginning and end of the strip (X_t and Y_t are transformed but uncorrected co-ordinates). The slope of the tangent to the central curve of the correction graphs of the X-co-ordinates at the point where ordinate at the left principal point of model i meets the curve will give Δs_i. Proper units and signs should be taken while computing these.

Only after applying these corrections the final correction graphs should be drawn. The co-ordinates should be given the corrections read from the graphs as well as the computed corrections using the above formulæ. Generally for topographical mapping only heights need be corrected, for the errors in X- and Y-co-ordinates due to height will be comparatively small.

The following special points regarding graphical method of adjustment should be noted :—

(*i*) Graphical method needs ideal distribution of ground control points or with only small deviations from the ideal. As ground control points can never be fixed in ideal positions as required for strip adjustments, interpolation or extrapolation will be required to bring the control points to the ideal position. Large deviation from the ideal distribution and location will lower the reliability of the correction curves ; thereby the adjusted co-ordinates will not be sufficiently accurate.

(*ii*) It is efficient only when the errors are small.

(*iii*) For very long strips the effect of the earth curvature should also be removed by numerical computations.

(*iv*) The choice of the control points for adjustment is a matter requiring judgement and should always be approved of by the officer-in-charge of the party who should for this purpose go through the observations on form 5 Phot.

(*v*) Those strips which contain maximum control points are to be adjusted first and the remaining strips with less number of control points should be adjusted with as much information as available from the contiguous (adjusted) strips.

(*vi*) Computations on form 7 Phot. and the calculation of transformed machine co-ordinates to be entered on forms 8 Phot. and 9 Phot. should be done in duplicate.

(*vii*) Carrying out first preliminary graphical adjustment and again adjusting the residual errors on an excessively large scale is not correct.

(*viii*) Precision of drawing the curves and the accuracy of reading the corrections must be of a comparable order with the precision of measurement in the instrument.

(*ix*) When large number of control points are clustered at a particular point, the mean datum-correction graph is to be drawn ; this will reduce the complication involved in using large number of control points while drawing the parabolas.

(*x*) When the strip axis is not parallel to the ground co-ordinates axis system, then the points are to be approximately plotted on a separate paper, which may be pasted or the points pricked/transferred on the graph paper on which adjustment curves are drawn such that the strip axis is parallel to the horizontal line.

(*xi*) When the curvatures of the correction curves are too much additional points should be determined numerically. Additional points can also be determined graphically as explained below. See fig. X·8 in which a, b and c are three given points on a parabola.

(*a*) Join cb ; extend till it meets the vertical at 'd', in 'e'.

(*b*) Join ab and from 'e' draw a line parallel to ab and extend it till it meets the vertical from 'c' in 'f'.

(*c*) Join af—the intersection (M) of this with vertical at 'd' will be the required point on the parabola.

(*xii*) To facilitate linear interpolation in the Y-direction when there is a large separation between the correction curves an interpolation wedge (interpolator) as in fig. X·9 equally divided into a number of sectors depending upon the width of the area covered by the strip should be prepared on graph paper. During interpolation the wedge is to be placed in such a manner that its axis is parallel to the horizontal line and three collinear points (two on the extreme radii and one on the axis lying on a vertical line) coincide with the point of intersection of parabolas with vertical line passing through the point for which the correction is to be read. The correction can be easily read off by comparing the location of the point in Y-direction with the corresponding sector of the interpolator.

90. **Block adjustment.**—The Survey of India uses for block adjustment, analogue computers developed by Dr. H. G. Jerie in 1957 at the International Training Centre for Aerial Survey at Delft, the Netherlands. The principle, the main parts and the working procedure, etc., are explained below.

Planimetric adjustment.—The photogrammetric block is divided into approximately square sections which, depending on the required precision of the points, size of the block, time, etc., can consist of (normally) two models or portions of several adjacent strips such as 2 × 4 models, 3 × 6 models or 4 × 8 models, etc. It can also be used to adjust internally adjusted blocks or lay-outs of slotted templets or stereo-templets.

The strips are first transformed one by one to the known ground control system to obtain the provisional co-ordinates to bring out the absolute discrepancies (differences between the provisional co-ordinates and the terrain co-ordinates of ground control points) and the relative discrepancies (the differences between the provisional co-ordinates of tie points in contignous strips from their mean provisional value). The adjustment is to find co-ordinates with discrepancies decreased as far as possible by finding the elements of an appropriate linear transformation for each section, which will produce the two shifts, a rotation and a change of scale based on the data deduced from the absolute and relative discrepancies of the entire block. The computer mainly consists of section templets (stereo-templets consisting of four section points, control points which fall in the area covered by the section and two auxiliary points on Y- or X-axis which are chosen symmetrically with respect to section centre), which act as the logical arithmetic unit of the computer and to provide the necessary output data with the help of the auxiliary points for the numerical computations of the required transformation parameters ; multiplets (mechanical devices consisting of base plates, each with four metal arms which can be fixed in any position with elastically connected studs) serve as the input device to introduce relative discrepancies, and elastic bound studs for introducing absolute discrepancies.

On a baseboard, elastically-bound studs are positioned over the control points (plotted on the scale of the templets after taking into account the spread of multiplets which are shifted by 120 mm each on X- and Y-directions) and the multiplets and the section templets are assembled (initial lay-out). The positions (called zero positions) of the auxiliary points are then pricked on to the plotted sheet.

A suitable correction scale is chosen and the discrepancies are introduced into the lay-out through the multiplets using a special setting device for relative discrepancies and by refixing the elastically bound studs by shifting them in their new position by plotting the absolute discrepancies. On reassembly of the lay-out with all the introduced discrepancies the section templets will be displaced, rotated, and changed in scale to adopt as best as they could against the tension of the springs of the multiplets and the entire elastic system will adjust freely into a state of equilibrium. The new positions of the auxiliary points are pricked again onto the baseboard. Based on their displacements with respect to their zero positions the transformation elements for each section are deduced and the provisional transformed values of all tie points and control points are corrected to get the next set of residual relative and absolute discrepancies which are again introduced into the computer on a scale considerably larger than the first to get the second set of the transformation elements and thereby the corrections to the co-ordinates. The iteration process (generally not more than two) is continued until the desired precision (or the limiting capacity of the computer) is achieved.

With 14 to 18 control points well distributed along the corners and perimeter, a block of 200 to 250 models can be adjusted simultaneously. The four points should be at the four corners of the block and most of the remaining at the periphery (see fig. X·10). Additional points inside the block are required only to ensure or confirm the accuracy achieved. With very good photography, ground control and using point transfer device, co-ordinates of tie points can be adjusted within 0·06 mm to 0·08 mm on the scale of the negative.

Height adjustment.—The ITC-Jerie vertical analogue computer can be employed for the adjustment of a height block.

Rigid plastic ribs of rectangular cross-section screwed on elastic rods suspended in front of a vertically mounted base-board represents the individual strips. For mechanical reasons reference planes alternating between 200 mm to 300 mm are chosen.

The rods are elastically connected to posts representing the discrepancies at control points and between strips at locations corresponding to tie points. The bending and tension stresses caused by the tensions in the springs at the control points and tie points deform the elastic rods. These deformations are resisted by the rods and the whole assembly comes to an equilibrium in positions representing a linear adjustment of the errors in accordance with the theory of least squares.

The systematic parabolic deformation of the strips are removed first by computations. Then the absolute discrepancies are introduced, by means of a special device on vertical rods fixed over the plotted positions of the control points using elastic bound studs at distances from the reference plane proportional to the discrepancies. The relative discrepancies (the differences between heights of a tie point in two adjacent strips) are introduced by means of a second device. As in the case of planimetry the discrepancies are to be introduced in an exaggerated scale.

When these discrepancies are introduced the elastic rods undergo deformations and the corrections for all points can be scaled off. No iteration is required. A cursory inspection will reveal any undue stress at any particular point, which may be rejected.

Ideal control requirement is similar to those for strip adjustment – three bands of two points across the strip axis ; one band in the beginning, one in the middle and one at the end. But considerable departure from the ideal locations can be made. (See fig. X·11).

Accuracy of the adjustment decreases considerably when the number of models between the band of control increases or when the flying height increases. With control points provided at every 8 to 10 models apart, it is possible to achieve points with relative accuracy of 0·2 to 0·6‰ of flying height. As large number of spring connections are involved and only one assembly is done it is always advisable to provide more control points at the periphery and inside of the block as check points to ensure the reliability of the adjustment.

SECTION XI.—REVISION SURVEYS USING AERIAL PHOTOGRAPHS

91. General.—Revision surveys are those carried out in areas where the existing Original Surveys are on the same or on a larger scale. If revision is limited to checking of specified items of details reported to have undergone changes (e.g., office copy corrections), these are referred to as Verification Surveys. Revision surveys are essential to keep the map up-to-date.

Revision on the maps and charts becomes necessary

(*a*) when there have been so many changes in an area that the existing map is out of date. In 1905, a revision cycle of 25 years was decided upon for 1-inch coverage ;

(*b*) when the stocks of a map have run so low that reprinting is imperative and as such all the changes can be incorporated in the new edition at this stage ;

(*c*) if there is need for keeping a map or chart always up-to-date, e.g., aeronautical charts, guide maps for places of intensive tourist activities, etc. ; in such cases a very short cycle of Revision Survey becomes essential.

The revision of all large scale, topographical, geographical and special maps is imperative.

Importance of aerial photographs for revision surveys.—The basic coverage of India is provided by 1 : 50,000 maps at present. With the development of the country, it is clear that changes specially in details will be rapid. Therefore, along with the development, the department may have to accept new commitments. Also, the aeronautical charts and guide maps may have to be kept up-to-date continuously. Thus, we need to revise our maps very rapidly.

Using aerial photographs, which have been taken fresh, revision can be carried out with increased speed – thus not only cutting down the need for a large establishment but also shortening the cycle of revision. Office copy corrections (Verification Surveys) can be carried out straightaway using an aerial photographs without a visit to the ground. Using aerial photographs, large scale surveys carried out for a project can be corrected incorporating the details which come into existence due to execution of the project.

92. Methods for revision.—The general methods of map revision using aerial photographs are :

(*a*) Without use of any special equipment :

(*i*) Purple-print method.

(*ii*) Kodaline print method.

(*iii*) Comparison and hand corrections.

(*b*) Rectification methods :

(*i*) Using rectified photographs.

(*ii*) Using instruments of the "Camera Lucida" type.

(*c*) Using approximate instruments, e.g., stereomicrometer, stereotope, etc.

(*d*) Using stereoscopic restitution instruments with a correct reconstruction of the perspective bundles, e.g., Wild B8, Kern PG2, Wild A8, etc.

Choice of the method.—The method selected will depend on the following factors :—

(*a*) The nature of the terrain.

(*b*) The accuracy of the previous survey.

(*c*) The extent of the corrections.

(*d*) Availability of the instruments.

When the area is hilly, accuracy of the previous survey is doubtful and the corrections are very heavy, resurvey is advisable. Resurvey can be carried out preferably using stereoscopic restitution instruments with a correct perspective bundle ; but in case of non-availability of these instruments either approximate instruments or purple-print method could be resorted to.

When the area is flat, the previous work is reliable and corrections are not heavy, rectification or kodaline print method can usually be employed.

If the previous work is thoroughly reliable, the country hilly, and the corrections not too heavy, hand corrections from prints or mosaics are of great value. It may be speedier to utilise Stereoscopic Restitution Instruments in cases of corrections localised in a small area.

An examination of the latest photographs against the existing maps will reveal the most economical method of revision work to be carried out.

Procedures will also be governed by the available fair-drawn materials and the standing plates. In cases of Verification Surveys and very light revision, it may be fruitful and economical to correct the old F.D.Os./Standing Plates. If the topographical features have not undergone any change, old contour original can be accepted as such. If the intention is to produce 1/50,000 map (on metric system) using 1-inch maps (on F.P.S. system), contour original may have to be replaced completely while other originals could be revised after corrections.

Choice of the method and procedures to be adopted will vary depending on each individual case. Here only the principles of the different methods, in brief, will be discussed. The purple-print, kodaline print and hand corrections methods will, however, be discussed in detail to assist in evolving the working procedures using other methods. Officer-in-charge units will take decision in every case depending on the circumstances.

93. Purple-print method.—This is suited for heavy revision.

(*i*) A combined print of the map is obtained from the standing plates on tracing paper and a purple-print "in reverse" on the glossy side of kodatrace, so that when looking at it from the matt side, it appears the right way up. These prints may be in any colour except red or green, but it has been found most convenient to work with them in purple. The tracing paper print will constitute an Insertion & Deletion Guide. Where there is no particular haste about the production of the new map, the kodatrace will take the place of a P.T. (or air survey) section ; but if there is haste, it will form a Fair Drawn Original (F.D.O.) in black and white.

(*ii*) Next, superimpose the tracing paper print (with reference to unaltered adjoining detail) over each air photo in turn and examine it very carefully, bit by bit, to see what requires alteration. As soon as anything is found, fuse the two photos and chalk-up the item on one of them.

(*iii*) Trace this item accurately (as one does in normal air survey) on to the tracing paper. All additions or insertions on the tracing paper are to be in red and all deletions in green ; the latter is best done either by inking along with item or by putting strokes across it, but it must be done thoroughly and completely.

(*iv*) Do this for detail. Then, fuse all the photos systematically and compare the stereoscopic impression of relief visually against what is printed on the tracing paper. Alterations are to be done as for detail. If, however, the original survey was done reasonably well, it will be found that contouring requires little or no change.

(*v*) Next, trace all insertions of detail from the tracing paper on to the kodatrace (matt side) and ink up not only these but *ALL* detail appearing in purple on the kodatrace, with the exception of deletions. If the maps is required quickly, this inking should be done entirely in black and its quality should be reasonably good. If not required quickly, the inking should be done in normal P.T. colours, while its quality need only be that of an average P.T. (or air survey) section.

(*vi*) Do the same for contours, inking up neatly in white if a rapid map is required, otherwise in brown. When tracing for inking in white, the tracing should be done with white pencil. If there are no corrections to the contours nothing need be inked up on the kodatrace ; (in this case contours will be printed from the plate from which purple was laid down). Where contour corrections are few and scattered, the Insertion & Deletion Guide can be sent to the Reproduction Office for correcting the standing plate (instead of inking up the entire kodatrace) ; where they are heavy but localized, only such areas should be inked up on the kodatrace so that the Reproduction Office may prepare a small negative for stripping-in (in preference to correcting the existing plate by hand, if they wish).

(*vii*) If inking had to be done in black and white, then a black + and a white X has to be drawn at the corners of the kodatrace, one on top of the other, for registration during reproduction.

(*viii*) The word "combined" has been used at (*i*) above. If there was a separate name original for the map, then this would mean detail and contours combined ; otherwise it would mean names (and heights, etc.), detail and contours combined. In the former case no action is required regarding typing, unless a name, etc., is, definitely known to be wrong, in which case action will be taken as in the second instance, below, for the particular name, etc.

If there is no separate name original and the map is required quickly, then all purple impressions of names, etc., on the kodatrace to be gone over by hand in black, or, if a better-looking map is required, they have to be typed on transparent adhesive tape pasted down on the matt side of the kodatrace.

(*ix*) If time permits, a print of the revised map containing names, etc., also will have to be taken to the field for verification mainly of detail, etc., which is not identifiable on the photos, such information subsequently being incorporated on the kodatrace before it goes for publication.

(*x*) When maps are required quickly, standard headings, footnotes, symbol tables, etc., on film are arranged for and pinned on the kodatrace in their correct positions after slight alterations have been carried out where essential.

(*xi*) Reproduction for a rapidly required map will be done by the Black-and-white Process ; otherwise by the normal methods after fair-mapping has been done on blue-prints.

Reproduction Office will sponge off all purple from the back of the kodatrace before photography is commenced.

Note :—The kodatrace should receive the minimum of handling during revision, else the purple will rub off and inking will become difficult and inaccurate.

Section Officers are to examine the Insertion and Deletion Guides against the photos. After stages (*iii*) and (*iv*) and, finally, they are to examine the kodatrace thoroughly in all respects when it is quite complete and before it is submitted for O.C's. scrutiny.

94. Kodaline print method.—It is suited for light revision. It is not permissible to meddle with P.T. sections or F.D.Os., of the previous survey; besides, such P.T. sections or F.D.Os., not being on transparent media, as a rule, it would be difficult and inaccurate transferring anything from air photos on to them. If therefore, where revision is light, the above methods are employed, it may necessitate the inking-up of as much as 90–95 percent of the purple where there is not a single correction – resulting in a tremendous waste of time and labour. Furthermore, revision of this category has to be done speedily and the above methods would only produce maps of indifferent (and even poor) quality, from an artistic point of view. Consequently the following method has been devised for meeting the situation :—

(*i*) Obtain kodaline prints (or film positives) complete with headings, etc., of the existing map for outline (or outline and names etc.), depending upon whether there is not, or is, separate name original – and for contours, separately. In actual practice, a comparison of the photos against the map will usually give an indication as to whether the last kodaline is required or not. Also, obtain a combined print (or separate prints) of the map in any colour except black or reddish brown, on bank post or rag litho paper.

(*ii*) Then, repeat the procedure at 93 (*ii*), above but using the kodaline itself (because corrections will be few).

(*iii*) Trace (and ink) the items on to the kodaline with photopake (used in an ordinary crowquill, mapping or 303 pen). Anything for deletion may be removed in two ways :—

(*a*) Erase lightly with a razor blade, or

(*b*) Wet the kodaline. Sharpen an ordinary pen holder to the shape of a spatula and rub it (at an angle) on the kodaline, when it will be found that the wet emulsion comes off.

(*iv*) For examination—all additions can be seen because they are in reddish brown. All deletions can be detected by superimposing the kodaline over the paper print.

(*v*) Normally, the kodaline will form the F.D.Os. for reproduction ; but on sheets where alterations are very few, they could probably be carried out by hand on the plate ; (in this case, however, deletions would have to be marked on the paper print as a guide for the reproduction office).

95. Comparison and hand correction.—It is suited for light revision. For this method of revision thoroughly reliable surveyors must be employed, preferably those with experience of map examination. A print of the previous work is taken, and on it is drawn lightly in pencil the lines indicating the limits of the areas covered by strips. The surveyor takes a strip and examines each overlap in the stereoscope against the existing map. When he comes across a place where a deletion appears to be necessary on the existing map, he rings the area on the photo in green ink and passes on. Where addition and corrections to shape are necessary he chalks up the new detail in the appropriate colour and at the same time pricks and rings three points which appear on the photograph and the map sheet and seem reliable, so that the new detail is enclosed in the triangle formed by these points. On completion of the examination of that overlap the surveyor takes the photograph, and setting a pair of proportional compasses to the difference of scale between the photograph and the existing map as obtained by a comparison of each pair of the three surrounding points, the surveyor marks off the main features of the new detail by measurement from each of the three points and then sketches the new detail in. If new detail covers a considerable area, or if suitable points for measuring cannot be found close to the new detail, the two or more photographs containing the new detail are plotted and compiled as in original compilation. The result is now brought to the scale of the map sheet, either by photography, or by pantograph or else by squaring the map sheet and the compilation with squares of size proportional to the two scales, and transferring the detail by eye. When the whole area has been examined and all additions carried out, areas where deletions are indicated are again examined under a magnifying stereoscope. If deletions still appear necessary they are entered on the map sheet. Throughout revision work by this method, the convention showing additions in red on the map sheet and deletions by green on the photographs must be observed.

96. Revision using instruments of the "Camera Lucida" type.—A rapid and accurate method of revision is provided by direct optical projection 'particularly of a country with low percentage relief.

Simple anharmonic rectifiers based on the principle of the Camera Lucida can be employed. (Popular ones are—The Trorey Anharmonic Rectifier and the Abrams vertical sketch-master). The device consists of a semi-silvered reflecting surface (a prism or a simple mirror) which causes the image of a photograph to be superimposed onto a map sheet placed in another convenient plane. The photo carriage is capable of being tilted and tipped and swung so as to render the virtual image free from tilt distortions and to the correct scale. (See figure XI·1).

In practice, the details on the photograph are inked in bright colours. The photo carriage is so placed as to cause the images of 4 reliable points to coincide with their map positions. All the details are then traced on the map.

97. Rectification method.—In flat terrains, existing maps can be conveniently and quickly corrected using rectified photographs. The rectified prints should be on the scale of the map to be corrected. Rectification is done in Zeiss SEG V Rectifier. Two methods of revision are possible :—

(*i*) *When the changes are few.*—The method suggested in para 94 will be adopted.

(*ii*) *When the changes are heavy.*—The rectified photographs will be inked up in proper colours, taking as much help as possible from the existing map. Astrafoil section will then be prepared by directly tracing the details from each photograph, correctly positioned over control points or reliable detail points. A quick ground verification either on the inked-up prints or on blue prints obtained from the astrafoil sections, for names and such detail which are not identifiable on the photos is essential, before sending the material for fair-drawing/publication, unless the maps are very urgently required.

SECTION XII.—FIELD SURVEYS FOR PHOTOGRAMMETRY

98. Ground control requirements for air survey.—

Introduction.—The major use of aerial photogrammetry being preparation of topographical maps and base maps for forest and soil surveys, etc., a reasonable practical standard of accuracy acceptable for deliberate rigorous work has to be specified before laying down the density and pattern of horizontal and vertical ground control required for the survey. Normally the following standards may be considered reasonable.

Planimetric accuracy on the final map.—About 90% of the well-defined detail checked on the ground to agree within 0·5 mm on the scale of publication.

Height accuracy.—About 90% of the elevations interpolated from contours on the map to be correct within half the contour interval and no error to exceed the contour interval. Spot heights appearing on the map to agree within one quarter of the contour interval, when checked on the ground.

The above standards will then stipulate the degree of accuracy required in the control points themselves and the method of providing the required control.

The planimetric and height accuracy of the ground control points should at least be of the topo triangulation, for compilation of the medium and small scale maps.

The density and pattern of such ground control will then depend upon the method adopted for further extension of the ground control as well as the method employed for subsequent air survey of detail and contours.

Selection and identification of points.—The accuracy of compilation depends equally on the suitable selection and correct identification of such control points on the aerial photographs. The plan control for photogrammetric purposes has to be sharp and well-defined points of detail. The height control points, on the other hand, should be on a level stretch of ground *or* on a very gentle and regular slope, so that slight horizontal error in setting the floating mark on the identified point does not result in appreciable error in elevation readings. In fact, when the mapping requirements are rigid and scale is larger, it is usually necessary to have separate points for horizontal and vertical control. For higher precision it is necessary to signalise the control points, before the aerial photography is flown.

Control identification is the most important step in photogrammetric work ; misidentification or poor identification of a control point invalidates the field control on which the work is based and

creates problems and uncertainties which are extremely wasteful in time and effort in both control extension and map compilation.

Conical peaks, isolated bushes, junctions of tracks, field bunds, corners of large prominent buildings, rock pinacles, etc., are ideal points both for plan and height control ; there should be no ambiguity while identifying them during photogrammetric work.

It is for this reason that "Office Post-pointing" is discouraged. The accuracy required for the identification in terms of ground distance depends on the scale of the map being produced ; the requirements are rigid because the photographs are relatively on smaller scale.

Horizontal control for small and medium scale maps.—

(*a*) *Air survey by radial line method.*—(*i*) *Arundel method.*—In this case each strip should be independently controlled, for scaling and checks. Generally three points per strip are necessary though two are sufficient, in a strip of about 20 to 25 overlaps. They should be available in the first and last overlaps and then after every 10th or 12th overlap. Control at every 6th or 8th overlap is preferable. If tie strips are flown at regular intervals, these ground control points are required in the tie strips, with additional control at the middle of each filling-in strip, if the tie strips are too far apart.

The ground control should preferably be located at least 4 cm away from the principal point base.

Since subsequent survey is based on the correct location of the principal points on the map, care is required at every stage of this graphical radial triangulation.

(*ii*) *Mechanical method.*—The mechanical radial triangulation using slotted templet equipment for extension of planimetric control is more or less a simultaneous block adjustment for flat and undulating terrains. The number of control points required is very much reduced, since several strips are simultaneously tackled.

According to normal accuracy standards, 90% of the well-identifiable points on the map should be accurate to 0·5 mm on the publication scale. This will mean that the arithmetic mean error acceptable will be 0·25 mm on publication scale. If *r* is the ratio between publication scale and the compilation scale (where compilation scale is the same as photo scale), the number of control points required is given by an empirical formula (due to Mr. Trorey),

$$ce^2 = k^2t,$$

in which k is a constant, generally taken on 0·16, e is the arithmetic mean error on compilation scale, t is the number of overlaps/templets used and c is the number of control points required.

With e = 0·25 × r, k = 0·16, this works out approximately to $0 \cdot 4t/r^2$. Assuming a compilation scale of 1 : 25,000 for a publication scale 1 : 50,000, the number of control points required for a block of 6 strips × 16 overlaps is about 10.

(*b*) *Photogrammetric methods, using precision stereo-plotters like Wild A7.*—The principle of survey is to obtain an orthogonal projection of the stereo model, on a map sheet, through the process of "absolute orientation". Each model requires a certain amount of specific control for scaling and levelling.

Planimetric control needed to scale each model consist of a minimum of two points, far apart, at the corners of the "neat model". As a check a third point is necessary. All these controls are either provided by spatial aerial triangulation on universal plotting machines (with subsequent stereo-templete combination or numerical adjustment) or by slotted template combination if the terrain is flat or gently undulating.

(*i*) The ground control required for this should be preferably planned for strip triangulation and adjustment rather than for block adjustment. The minimum requirement is 3 points in the first model and one or two at the end model. But, for graphical adjustment an additional point at the centre of each such model is also required besides bands of such control at every 6th or 7th model see fig. a).

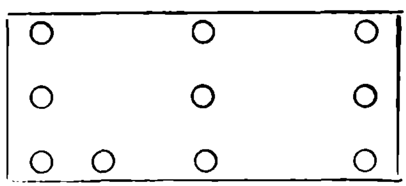

Fig. a

(*ii*) If specifically required for planimetric block adjustment (using Jerie's equipment), the requirement of ground control is as follows :—

(A) One point each at the four corner models of the block (which is just the minimum).

(B) (*a*) One additional point each in the first and end model of alternate strips, with

(*b*) One additional point in every section (of two models) in the first and the last strips,

(This perifery control is necessary to reduce the errors) and

(C) One or two points in the centre of the block (desirable).

An empirical formula in this connection can be given as below. The number of control points required $= 4 + k\sqrt{n}$ where n is the number of models to be controlled and k is a constant, varying from 1 to 1·5 depending on the size of the block.

(*iii*) Wherever tie strips are available, the ground control will be provided in the tie strips only, the pattern being the same as for strip triangulation. The additional control required for the individual strip triangulation (of filling-in strips) are provided by aerial triangulation of the tie strips.

Vertical Control.—(*a*) *For graphical methods.*—A minimum of 6 heights are required per overlap, one near each m.c.p. and at the highest and lowest ground, such that the lines joining the two pairs of points are preferably normal to the principal line.

In addition, heights for another 12 or so must be found from stereoscopic parallax measurement and computation. Occasionally where the ground is very regular, fewer points are required so that each important hill and valley has a height somewhere near the highest or lowest level respectively.

(*b*) *For photogrammetric methods on precision plotters.*—As already mentioned, the work is carried out by the process of "absolute orientation" of each model. The levelling of the model requires a minimum of 3 points, ideally situated at the three extreme corners, two for correcting the x-tilt and two for correcting y-tilt. A fourth point will serve as a check, at the remaining corner.

(*i*) As before, all these model control points need not be provided on the ground. Ground control requirements are limited to sufficient control for strip triangulation and adjustment. A minimum of 4 control points in the first model, 2 at the end model and 2 at every 6th or 7th model are required for this purpose. For graphical adjustment, an additional control at the centre of each such model is required. The control pattern is indicated in figure b.

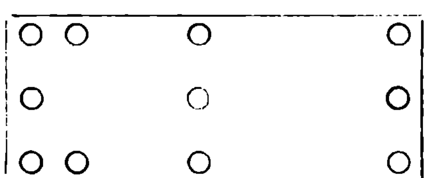

Fig. b

(*ii*) Even if block adjustment by Jerie's analogue computer is specifically indicated, the ground control pattern will be as for strip adjustment, since the systematic parabolic deformation will have to be removed by computations.

(*iii*) When properly spaced tie strips are flown, the pattern of control required for individual strip triangulation (of filling-in strips) can be provided by the aerial triangulation of tie strips.

Survey by Stereotopes.—Model deformations are approximately rectified by mechanical rectiputers, if at least 4 control points of known planimetry and elevation per model located at the 4 corners of the neat model are available. Though these points could be provided by aerial triangulation, an alternate method would be (*i*) to provide height control at these points by clinometer, during photo-verification and (*ii*) to obtain the planimetry by slotted template combination, on the scale of survey.

Special requirements for large scale surveys.—Large scale surveys can be mainly grouped into two categories :—

(*i*) Those surveyed using smaller scale photographs, e.g., survey on 1 : 5,000 scale from 1 : 15,000 scale photography.

(*ii*) Scale of survey is approximately the same as scale of photography, e.g., photography on scale 1 : 5,000 for survey on the same scale.

In case (*i*) above, the required accuracy in plan and height can be achieved if the individual model control – one each at the corners of the neat model – are provided on the ground and accurately post-pointed. Where the contour interval is smaller than four times the standard error of observations of the plotting instrument for the particular flight altitude, it is preferable to carry out the planimetric survey by the plotter and contouring by ground methods, unless a close net-work of levelled heights are available in each model.

The control requirements in respect of case (*ii*) are similar to those already laid down for normal aerial triangulation for control extension, viz., provision of bands of control in the first and last models and at every 6th or 7th model for bridging.

Factors affecting accuracy.—Accuracy of height determination by photogrammetric instruments depends on several factors, of which the scale of photography and quality of the ground control points are important. However, ground levelling cannot be superseded by aerial triangulation heights. Planimetric accuracy standards should be carefully reviewed and relaxed for terrain obscured by vegetation.

The control required for photogrammetric survey depend upon

(*i*) the scale of photography *vis-a-vis* scale of final map.

(*ii*) the precision needed by the map-user,

(*iii*) whether pre-pointing is employed or post-pointing will be done and

(*iv*) the method/instrument employed for the detail survey.

Similarly density of control varies from the view-point of accuracy standards, adjustment procedures, and the number of models which can be successfully bridged by the instrument used. Although the bridging span is indicated as 6 to 7 models, it may be decreased or increased.

The surveyor providing the ground control should invariably take all precautions to ensure correct density, right type of control, proper identification on photographs and preparation of reasonably large-sized schematic diagrams, for the use of the photogrammetric operators. The entire accuracy of a high class triangulation or traverse is lost if the point is not identified equally accurately on the photographs.

99. **Methods for provision of ground control.**—Planimetric ground control may be provided by :—

(*a*) Triangulation by theodolite or plane-table and clinometre ;

(*b*) Trilateration with electronic distancers ;

(*c*) Traverses either with theodolite, plane-table or compass within the area with distances measured by electronic means or by tacheometer, subtense or telemeter bar or with chains ;

(*d*) Photo-theodolite work ;

and/or(*e*) Astronomical observations.

Height control may be provided by :—

(*a*) Theodolite or clinometer or automatic alidade ; and/or

(*b*) Altimetric devices such as barometers or hypsometers.

The methods of carrying out any of these are given in the appropriate chapters of this handbook ; photo-theodolite work is dealt with in Departmental Paper No. 14.

Astronomical observations and hypsometer readings have low relative accuracy. These are useful only when other means of fixing ground control are not feasible.

In selecting points as control for photogrammetric mapping the ease in identification and marking of the selected position on the photograph must be kept constantly in mind (see also para 98).

100. **Use of electronic distance measuring methods.**—A triangulation series is run either as a grid iron frame or as a mesh and there are bound to be redundant points when control is required merely along certain axes or at predetermined intervals. There is the additional difficulty of providing control points in close groups as required in photogrammetric surveys. In actual fact locations are seldom available in the terrains suitable for triangulation for ideal placement of ground control.

Clearing long lines for surface taping is a very laborious and slow process. Traverses with theodolite and chain or tape can, therefore, be carried out in open flat country or along tracks and are not suitable for providing control in hilly areas or in jungle with dense undergrowth. Hunter Short Base traverse is suitable for low scrub or grassland and cannot be used in built-up or forest areas.

Electronic distancers using very high frequency radio waves or modulated light waves are now available for linear measurements. Instruments of the latter type such as the *Geodimeter* involve as little clearance as a hole of 10 cm. diameter in the foliage and yield a high precision of 1/10,000 even for a short distance of 100 metres. Apart from actual impediments in the line of sight or dense haze instruments using light waves are free from interference. Their day time efficiency is, however, limited between 3 and 5 kilometres.

Instruments using radio waves like the *Tellurometer* are ideally suited for measurement of medium to long lines in mountainous country and in all other cases where theodolite traversing cannot be carried out. In order to obtain best results from this type of equipment the instrument stations should be elevated so that ground reflections of the stray parts of the radio beam have very little effect on the measurement. These instruments can measure distances upto 80 km in fair weather to an accuracy of 10 cm., ± 2 per part in million. Since the distances are measured from both ends of a line, intersection or visibility from a second or third station is not necessary.

A tellurometer traverse is ideally suited for provision of control for photogrammetric surveys in undulating or hilly terrain as it allows long hops to arrive in the required overlap and makes it easy to fix a group of points by radiation in any desired arrangement.

In built up areas, along heavy traffic lanes or transmission lines, and along tracks in dense forest where long lines of sight are not practicable a geodimeter provides a very convenient means of fixing ground control points. A geodimeter traverse where long legs of upto 35 kilometres are measured at night and the control for orientation of the selected models fixed in the day time is the quickest means of fixing ground control in the special pattern suited to photogrammetric surveys.

101. Pre-pointing and Post-pointing.—The ground control for use in photogrammetric surveys is as good or as bad as the accuracy with which the position thereof is identified in the aerial photography. The provision of control may be done either before or after photography. Each course has its advantages and disadvantages.

Pre-pointing or marking the positions of the control points on the ground prior to photography is the ideal method for ensuring correct identification of ground control. The size of the marks or signals should be of sufficient width and length in plan to appear clearly on the photographs. The mark is generally a cross whose length (A) and width (B) are based on the formulæ, A = M/2 mm and B = M/20 mm, where M is the denominator of the photo scale representative fraction. Luminous marks or marks with high reflectivity like glazed alluminium sheets will photograph even if slightly less in dimensions because of scatter of intense light energy in the exposed film. Signalising or marking of points should be carried out during reconnaissance.

Pre-pointing has the advantages that

(*i*) the identification of points is impersonal and beyond dispute ;

(*ii*) control is fixed during time convenient for field work without waiting for photography ;

and (*iii*) mapping can start immediately on receipt of photographs.

Its limitations are that (*i*) correct placing of control to suit the requirements of plotting is not possible (*ii*) destruction of the marks may lead to serious dislocation of work (*iii*) the field hand does not have any idea of the lines of communication in case no previous reliable maps exist. It is, therefore, desirable that comprehensive and detailed description of the points supplemented by large scale planimetric sketches or panoramic photographs must be prepared at the spot by the party fixing the control. If photography is carried out with 80% fore-and-aft overlap, it will generally be possible to select sets in which the pre-marked control is well placed. In all eventualities it is always safe to provide 10–15% extra points.

Post-pointing, when control is provided after receipt of photography, ensures that

(*i*) points are provided in the most suitable locations with regard to photographs or strips and their number kept to the minimum essential for the job ;

and (*ii*) only those points are selected as control which are identifiable on the photographs.

There is, however, a big gap between date of photography and the commencement of mapping. Also any misidentification will seriously affect accuracy of the map.

Identification of control and marking on photographs.—Identification of control is such an important job that only staff with good stereoscopic fusion and well trained in photogrammetry should be employed on post-pointing.

If a fresh control survey is planned it will be advantageous to select stations and points in positions clearly identifiable or very close to identifiable detail. The identification should be carried out under fusion even in the most obvious cases. Care should be taken not to mark the point on the shadow which is invariably better defined than the object.

The most accurate position is the one capable of direct identification on photograph. In case of doubt recourse may be taken to any of the following methods :—

(*i*) *Resection* using a minimum of four well-identified points at the same level and very close to the probable position.

(*ii*) *Distance and direction or radiation* from a well-identified point approximately at the same level.

(*iii*) *Intersection* from at least three well-identified positions at approximately the same level.

(*iv*) When a point falls along straight portion of a road, track, canal or railway the photograph may be oriented along the straight stretch and a ray taken from an identifiable point nearby.

In all cases the location so determined must be checked under fusion with reference to surrounding detail and exhaustive descriptions and large scale sketches giving orthogonal or vertical view of the ground maintained for subsequent check during plotting.

Height control.—Points selected as height control should cover the whole range of relief in the terrain and should as far as possible be in flat ground.

Marking of control points.—The identified position of ground control points should not be pricked through but enclosed in a circle of 1 cm diameter both on the face and the reverse of the photograph with the reference number, allotted to the point, written alongside.

102. Field completion surveys.—*General.*—Interpretation of topographical detail from aerial photographs can never yeild complete information required in preparing a map. Some detail like telegraph and power lines are too small to be recorded in the photographs. Others like temples or tombs presents difficulties in differentiation. Detail sheltered under trees or under cloud patches or shade presents no means of identification. Springs, wells, and changes from non-perennial to perennial streams are difficult to locate merely by looking at a photograph. Classification of communications, collection of names and marking of administrative or reserved forests boundaries necessitate a visit to the area.

This verification survey may be carried out either before photogrammetric survey on photographs or after the survey on a blue print of the compilation.

Photo verification.—The aim of field operations in photo verification is to :—

(*a*) Verify and ink in proper colours and by cartographic symbols according to correct classification, the following detail :—

(*i*) Lines of communication, i.e., foot-paths, cart-tracks, unmetalled and metalled roads, railways and their gauges with distance stones, bridges, destinations, etc.

(*ii*) Rivers, streams, canals both perennial and dry with distance stones, viaducts, siphons, bridges (both permanent and seasonal), ferries, fords, rapids, falls, etc.

(*iii*) Village/town sites showing main lanes ;

(*iv*) Cultural detail like temples, mosques, churches, chhatries, forts, etc.

(*v*) Cultivation limits, gardens, orchards and other vegetation like bamboo, palmyra, banana, cactus, etc.

(*vi*) Public utility services like P.O., T.O., R.H., power lines, pipe lines, telephone and telegraph lines, etc. and

(*vii*) Administrative (*Tehsil*, District, State and International) boundaries, reserved forest boundaries, etc.

(*b*) Collect names of villages, towns, streets, roads, rivers, streams, hill ranges and tribal areas.

(*c*) Identify and mark all trigonometric control points and bench-marks of all types.

(*d*) Provide height control points for horizontalisation of the model.

Comparison with existing map.—Every verifier must carry the largest scale topographical map of the area to check the information being collected. He must not copy the names or their spellings from the map. The names should be noted according to local pronunciation with relevant accents. Major changes in topography due to development of the area should be recorded in distinctive colours in the map as well.

Traces and guides.—As in planetabling a colour trace and a village or name list are maintained as auxiliary records in photo verification. The photo verification colour trace contains all the information inked in the photograph including single huts. Anything that is likely to be overlooked or is liable to misinterpretation should be emphasized.

The colour traces should be so prepared as to correspond to sheet limits and in minimum sections necessary to cover the sheet. Reference numbers are entered both on the photograph and on the colour trace.

Verification of boundaries by revenue officials in the field on the colour traces is meaningless as no such official is trained or used to photo-reading. A separate composite trace showing ridge lines and other detail within 2 cm on both sides of the boundary line should be prepared with the help of photographs under fusion and got verified by local revenue authorities.

When auxiliary heights are provided by the photo verifier a field height trace should also be maintained. Not less than three clinometric readings should be taken to the selected points. The positions of these points should be carefully marked on the photographs with proper reference numbers.

Ground verification of air surveyed compilation.—When photography is received late or when pre-pointing has been done and sufficient time for completion of photo verification during the field season is not available photogrammetric survey is completed for detail as interpreted from photographs and for contours if sufficient height control exists. A blue or grey print of the air-surveyed compilation is taken to the field in the ensuring field season for completion.

On reaching the field the blue print verifier provides auxiliary control as necessary and carries out surveys for the detail mentioned above basing his fixings on surveyed detail and ink up the entire section as in normal plane-tabling. Detail found wrong is deleted from the blue-print.

It must, however, be remembered that air survey provides by far the most faithful representation of the terrain. Unless the compilation is based upon wrongly identified control - which will show up during orientation of the model, its overall accuracy is better than plane-tabling. If any check on accuracy is necessary it should be done with a tacheometer traverse.

Contouring.—When contouring is required to be done in the field auxiliary height control points should be fixed. The interpolation and drafting of contours is done in the usual manner deducing heights of fixings from trigonometrical or auxiliary points. The positions of height points are fixed correctly relative to nearby detail.

Auxiliary records.—The following auxiliary records are required to be maintained :—

(*i*) Field colour trace,

(*ii*) Field height trace and height book, in case contouring is done in the field,

(*iii*) Insertion/or deletion guide,

(*iv*) Name list.

The colour trace and the insertion/deletion guide are prepared on a reverse print of the air-surveyed compilation. The insertion/ deletion guide will show all new details and corrections in crimson and the misidentified detail or other detail found wrong is inked over or scored out in green.

Section XIII.—PLANNING FOR PHOTOGRAMMETRIC SURVEYS

103. Need for planning.—The importance of planning before actually any job is undertaken need not be over-emphasised. It is all the more so when a precision job like photogrammetric survey, which is also quite expensive, is to be taken up. The scope of this section is, therefore, to layout some of the important considerations, that have to be brought about in advance, before the photogrammetric survey is actually taken up.

When a photogrammetric survey is under consideration, there is the possibility that a detailed set of specifications is already available and the planning only consists of selecting the best means to accomplish what has been specified. The other possibility is that the need for photographic and topographic information exists but one does not know how to proceed due to inadequate photogrammetric background. The subject-matter of this section, therefore, includes planning of production and also how to conceive a photogrammetric programme.

For logical planning of photogrammetric surveys, a knowledge of the different products of aerial photography and photogrammetry and their use is necessary. These are :

(1) Photographic negative.

(2) Contact print on paper - single, double weight, correctostat.

(3) Diapositive on film/glass.

(4) Enlargements - rectified or otherwise.

(5) Photo mosaics.

(6) Planimetric maps.

(7) Contoured photo mosaics.

(8) Topographic maps.

It has to be considered by the planner whether any one or more of the above will meet with the requirements of the indentor, keeping in mind the purpose, cost and other factors.

Whatever is the actual requirement of the indentor, once it has been decided that photogrammetric surveys are to be undertaken, the first and most essential item is, of course, the aerial photography. Planning for aerial photography and preparing the air photo specifications to enable the flying agency to carry out the photographic mission successfully and satisfactorily will, therefore, be the primary job of the photogrammetric planner. This will depend upon the scale and contour interval of mapping, nature of the terrain, relative heights in the terrain, focal length and format of the camera available, capacity of the aircraft, types of photogrammetric instruments available for subsequent plotting/rectification and other factors.

SECTION XIII.—PHOTOGRAMMETRIC SURVEYS

104. Planning for aerial photography.—The characteristics of the aerial photography are to be determined based upon the purpose for which the photography is intended. The planning can then be suitably made by selecting from all available sources the photographic equipment, materials, flight plans, etc.

Choice of emulsion.—Three principal types of emulsion are used in aerial photography. They are (*i*) panchromatic - most commonly used for general aerial photography. Various combinations of speed and resolving power are available. Suitable combinations may be chosen to depend upon the exposure interval; (*ii*) infrared ; (*iii*) colour. These two are still not developed and used in our country. However, the planner may keep in mind their specific advantages in certain fields like photo-interpretation for forestry, geology, etc., so that at a future date their use could be contemplated.

Stability of the base.—For purpose of photogrammetric surveys it is essential that the emulsion base is stable so that they do not cause undue distortion. Three types of base are commonly used. These are : (*i*) glass plate, (*ii*) polyster base film and (*iii*) topographic base film. Glass plates are perfect in dimensional stability and have, therefore, been generally used in precision work - particularly large scale surveys. However, due to their being easily breakable, heavy and thick, films are generally preferred. Out of the two films mentioned, polyster base film is more stable and are preferable, if available. Topo base film is reasonably stable and somewhat less expensive. These are generally being used by us, both for negatives and diapositives.

Choice of the camera.—Generally all our photography for photogrammetric surveying are with precision vertical cameras. We have, therefore, only to choose between the available types, keeping in mind their format and principal distances. RC 5a camera is preferable to Eagle IX camera due to the quality of resolution of the lens. The latter is preferable from the point of view of format which is 23 cm × 23 cm compared to 18 cm × 18 cm of the RC 5a camera. Zeiss RMK 15/23 is preferable to both due to its better quality of resolution and bigger format. Superwide angle cameras for small scale surveys need be considered.

Choice of aircraft.—The factors that will influence the choice of an aircraft are : load capacity, speed, ceiling, stability, working space, operating cost, etc. Keeping in view the principal distance of the camera, the scale of photography required, suitable aircraft will have to be chosen that can fly upto the required altitude. In case of very large scale surveys, when large scale photography will be needed, the capacity to fly at lower altitudes should also be considered.

Flight planning.—The area for photography having been decided, it is now necessary to prepare a detailed specification as to the exact direction and layout of the different photographic sorties so that the flying agency could carry out the flying accordingly. This planning would naturally presume a knowledge of the type of camera, aircraft, etc., that are available at our resources. Based upon the principal distance of the camera and flying height of the aircraft, in order to obtain the photography on a desired mean scale, the exact air base and the distance between two lateral strips need be calculated. This information should preferably be marked on an existing ¼-inch scale map as well as on a tracing paper, indicating clearly the area for photography, the strip locations, the distance between two principal points and the flying height above m.s.l. at which the aircraft should fly. This flight plan should also take into consideration the varying terrain heights and make necessary corrections in the flying height to maintain the mean scale of photography and also with a view to avoid short overlaps and gaps between lateral strips. Necessary marginal coverage need also be provided.

The specifications regarding the lens, camera, flying height, overlaps, etc., should be completed on the Air Photo Specification form [Form 535 G (AIR) – for specimen form see Appendix 'A'].

The above form, alongwith the marked-up maps, traces, etc., should be forwarded, through the Director, to the Surveyor General of India who will arrange for ordering the aerial photography.

While planning the above, consideration should also be made as to whether tie strips are required to be flown, keeping in view existing ground control and proposed methods of control extension. Accordingly, the flight plan should also indicate the locations of the proposed tie strips with the data regarding their scale, etc., in case it is proposed to have them on different scales. Generally, tie strips, which are mainly intended for aerial triangulation, are demanded on a much smaller scale than the filling-in strips.

In order to facilitate quick planning of flight programmes, the necessary data have been compiled, for some of the standard scales of photography, and tabulated at Appendix 'B'. This can be referred to while preparing flight plans.

During this stage of planning, it may also be kept in mind whether any of the auxiliary devices, like statoscope, solar periscope, APR etc., are to be made use of during the flying. If so, the necessary specifications regarding the same need also be supplied to the flying agency.

After flying and checking up the negatives for gaps, clouds and any other defects in photographic image quality, the necessary sets of contact prints on paper (glossy or matt), correctostat paper prints, film diapositives, etc., should be asked for. The requirements of field units for post-pointing of control and verification of detail and the requirements of photogrammetric units for combination, aerial triangulation and plotting need be kept in view, while ordering for the prints. Necessary cover plots, air information slip and camera calibration charts need also be asked for. It should be impressed upon the flying agency the need for camera calibration immediately before every photographic task and they should be asked to supply us the latest calibration chart pertaining to the camera. The need for avoiding excessive crabbing, sudden changes in flying height and increased tilts/tips should also be impressed. Films which are likely to be fogged due to aging, should be avoided. The need for image quality, dimensional stability need be emphasised for the photography which is meant for photogrammetric survey purposes as opposed to reconnaissance photography.

105. Planning for field control.—During the planning for photogrammetric surveys, one of the important pre-requisites to be attended to is the nature, quality and correct identification of ground control. The accuracy of the ground control, which is the framework on which the entire procedures of control extension and photogrammetric plotting will depend, will depend upon the scale and other requirements of survey. Whatever refinements in the procedures of adjustment may be used, unless the framework is accurate enough for the purpose of the survey, no improvements could be achieved. It is, therefore, necessary to lay down, for the guidance of the field parties, the degrees of accuracy required in the control. It should also be considered whether pre-marking of the control is required to be done and if so what shall be the size, shape, colour, etc., of the marks on the ground. In case it is decided to do the post-pointing, field parties should be asked to supply detailed sketches for each point post-pointed, alongwith the control data and the pricked position on the photographs.

The system of co-ordinates, whether spherical or plane, should be decided. Methods of aerial triangulation observation and adjustment procedures should be planned in advance and accordingly, an index on ¼-inch scale indicating the layout of control requirement (both planimetric and height) should be prepared and given to the field parties. Suitability of points to be chosen as control points, for purposes of plan and heights, need be indicated.

106. Planning for stereo-compilation.—Planning extension of control should be considered after collecting all available data, photographs, etc., of the area, whether planimetric control need be extended by slotted templet procedure before the aerial triangulation for heights is taken up or stereo-templet combination need be done after aerial triangulation for heights only is completed. It may also be considered at this stage, whether aerial triangulation for planimetry need also be done and adjustments carried out. In case it is decided that aerial triangulation for plan and/or heights are to be done, the procedure should also be planned in advance. The alternatives shall be :

(*i*) Aerial triangulation, by bridging, using analogue instruments like Wild A7, followed by strip adjustments and subsequent block adjustments ;

(*ii*) Aerial triangulation by independent model method, using analogue instruments like Wild A8, followed by computations for strip and block adjustments ; and

(*iii*) Aerial triangulation by using stereo/mono comparators and computational procedure for the entire process of building up the model, strip and the block.

The adjustment procedures need also be planned in advance. The possible alternatives are :

(*i*) strip adjustment by graphical method followed by ITC-Jerie analogue method for block adjustment ;

(*ii*) strip adjustment followed by block adjustment using standard programmes for electronic computers.

Subsequent to this, the aerial triangulation data need be supplied to the plotting sections who will arrange to plan the layout of air survey sections, depending upon the type of instruments available for plotting and their capabilities ; arrange to prepare the sections by projecting the grid/spherical layout and plotting the control data and then take up the survey on the plotting instruments.

Subsequently, these sections are inked up, edited as necessary, margins adjusted, scrutinised for errors and omissions in respect of ground verified details, etc., and submitted for fair-drawing.

This will complete the procedure for planning the photogrammetric production.

107. Planning for large scale special surveys.—The above procedures of planning are generally applicable to all surveys on medium and small scales. But while carrying out special surveys on larger scales, e.g., 1:1000, 1:5,000, etc. (for preparing city/cantonment maps, project maps or cadastral maps), the methods and procedures described in the foregoing paragraphs need modification to meet the stipulated standards of the map user.

The flight planning should cater for large scale photography. But too large a scale also creates problems like low flying of the aircraft and consequent results of dead ground, loss of definition due to fast image movement, etc. Hence a proper choice of lens to avoid very low flight, a suitable scale to resolve the maximum amount of detail from the photographs and the use of precision cameras fitted with fast and efficient between-the-lens shutter are the factors which need attention while planning for aerial photography.

Similarly ground control for such surveys should be planned to cope up with the accuracy standards. Individual models should preferably be ground-controlled. The planimetric extension can, however, be achieved by analytical methods of adjustment of aerial triangulation, the required ground-control being pre-pointed. The methods of providing horizontal and vertical control, before and after photography, should be planned. Altimetry should preferably be provided by spirit levelling.

Stereocompilation, which is influenced by the map requirements, call for the use of instruments like Wild A7, owing to larger enlargements ratios and smaller contour intervals. If planimetric control is to be extended for individual model control, the process of such extension, the method of subsequent adjustment and computations, etc., should be pre-planned. In most of the surveys of this type, time factor is also a consideration and the entire project needs judicious planning to prevent wastage of manpower and funds.

108. **Organisation.**—The constitution of a photogrammetric survey party depends upon the number and type of photogrammetric instruments allotted to the party. Normally a photo. party may be equipped with two A7's, and eight other types of precision plotters (A8's, B8's and PG 2's) working in two shifts, apart from Radial Secators RS I, RS II and computing machines, hand and electric. The strength of the party may, therefore, consist of an officer-in-charge, one Deputy Superintending Surveyor, three Class II officers about 28 to 30 Class III, Div. I officers, 24 Class III Division II officers (Air Survey Draftsmen and D'men), 5 Computers or Topo Auxiliaries, one R.K., one S.K., 5 Clerks (one Head Clerk, one U.D. and three L.D.) and Class IV staff as required.

A photogrammetric unit with the above-mentioned strength of instruments and personnel is likely to handle a work-load of about three times that of a field unit. With a view to ensure efficient and smooth flow of work, the following pattern of organisation for technical work in the unit is suggested.

(*a*) One Dy. Superintending Surveyor will be required to assist the officer-in-charge of the party in his day-to-day routine administrative work and for better co-ordination between various sections of the unit. In addition he will be responsible to collect all records of various tasks allotted to the unit, their scrutiny and correspondence in this connection with the units concerned ; also he will carry out the final scrutiny of the air survey sections submitted by the section officers, on completion of the photogrammetric plotting. He will be assisted by a Surveyor and a few air survey Draftsmen/Draftsmen.

(*b*) *Planning section.*—This section is responsible for the following items of work :—

(*i*) Planning for aerial triangulation.
(*ii*) Carrying out aerial triangulation observations on A7.
(*iii*) Graphical/analytical adjustment of strips and blocks.
(*iv*) Slotted/stereo templet combination, as necessary.
(*v*) Preparation of air survey sections and combination plots.
(*vi*) Preparation of data volumes – combined for ground control and aerial triangulation.
(*vii*) Preparation of draft air photo specification, analysis of ground control requirements for jobs allotted.

An experienced Class II Officer assisted by a Surveyor (selection grade), six Surveyors, ten Air Survey Draftsmen/Draftsmen and five Computers will be required to carry out these tasks.

(*c*) *Plotting section.*—Two plotting sections with four stereoplotting instruments each may be organised for photogrammetric survey. These sections will be responsible for preparation of air survey sections (based on the data supplied by the planning section), their inking, preliminary scrutiny by the section officers and submission of sheets to the officer-in-charge of the party, on due dates.

A Class II Officer assisted by two Surveyors (selection grade) (as shift officers), eight Durveyors (as operators) and six Draftsmen (for inking) are required to carry out these tasks, in each section.

109. Costing of photogrammetric survey.—One of the important duties of a planner is to prepare estimates of cost and time for any project to be undertaken. This estimate will also enable him to plan the allocation of instruments, allotment of personnel, etc., to suit the needs of the particular project and also to organise the photogrammetric unit on the right lines.

Estimate of time.—The demands on photogrammetric units are likely to be multipurpose. This may range from normal topographical survey on 1 : 50,000 scale to a very large scale survey of (say some dam site) on 1 : 1,000 scale. The detailed estimates of time required for carrying out aerial triangulation, photogrammetric plotting, etc., will have to be worked out for each job based on the scale of survey, the vertical interval, the scale of photography, the nature of the terrain and the type of intrument used. Thus, it would be neither possible nor desirable to list completely the outturn figures for such varied scales of survey in order to evaluate the possible requirement of time.

However, any estimate of time should also take into consideration all other items of work involved prior and subsequent to the actual work on the machines. These include the preparatory work, planning, combination, adjustment of aerial triangulation, preparation of air survey section, inking and scrutiny of the air survey sections.

The time taken for aerial photography, etc., which should precede the field work/photogrammetric operations has not been included in the above estimates, but will be necessary for planning purposes.

Estimate of cost.—(*i*) *Cost of aerial photography.*—The photographic agencies fix the cost of photography from time to time depending upon their working cost and the same has, therefore, to be obtained from them. In India, the two available agencies are the Indian Air Force and the Air Survey Co. of India Private Ltd. The former has fixed their cost at a specific rate per flying hour for the area photographed depending on the aircraft used and the actual expenditure incurred irrespective of the scale of the photography, while the latter has a varying rate depending upon the scale of photography based on a formula—

Cost $= A. S^2 + B.S. + C$ rupees per sq. mile, where A, B, C are constants fixed by charter and S is the number of inches per mile, for the negative scale.

The above cost includes the cost of supply of two sets of contact prints on paper. All other requirements like film diapositives, etc., will be on extra cost.

(*ii*) *Cost of field work.*—This will depend upon the nature of the terrain, the scale of photograph, the availability of suitable means of transport, etc., and will be calculated based upon the number of triangulators, traversers, levellers and photo-verifiers, etc., required and the strength of the squad, the distance of the area from the headquarters of the party and other factors. The estimation of this part of the cost need not be detailed here, as it is felt that this is not a part, actually, of photogrammetric planning.

(*iii*) *Cost of photogrammetric work.*—This will of course be calculated based upon the time taken for aerial triangulation, including its preparation of air survey sections, photogrammetric plotting, inking, scrutiny, compilation, etc., and the actual number of men employed on the job and their pay and allowances.

In addition, depreciation for the cost of photogrammetric instruments employed, at 5% of their book value (assuming the average life of the instrument as 20 years) should also be added to the gross cost of the survey over and above 30% departmental overhead charges.

110. Maintenance and disposal of records.—Due to the nature of duties in a photogrammetric unit and due to increased volume of work, large volume of records move through a photogrammetric unit. Some hints regarding the proper maintenance and disposal of the same are given in this sub-section.

Records to be submitted to Photo Unit by Field Party.—The field unit, which carries out ground control and photo verification, for subsequent photogrammetric survey, shall submit the undermentioned records to the photogrammetric unit :—

(*i*) Photograph – Verified, post-pointed and blank set.

(*ii*) Colour traces for verification.

(*iii*) Village list (22 Topo).

(*iv*) Boundary Verification Chart.

(*v*) Insertion and Deletion Guide.

(*vi*) Camp Officer's Chart.

(*vii*) Trig., traverse and levelling data including marginal data.

(*viii*) Triangulation, traverse and levelling charts.

(*ix*) Sketches and description of control points.

(*x*) List of old control points which do not exist on the ground/could not be post-pointed.

(*xi*) Sheet file.

(*xii*) Data for History Sheet.

Records to be submitted to Fair Drawing Unit by Photo Unit.—At the time of submission of the sheet after photogrammetric survey, to the fair drawing unit, Photo unit should submit the following records :—

(*i*) Air survey sections.

(*ii*) Height and colour traces of the above sections prepared by the photo unit.

(*iii*) Verified photographs.

(*iv*) Colour traces for verification, prepared by the field unit.

(*v*) Village list.

(*vi*) Boundary verification chart.

(*vii*) Insertion & deletion guide, if any.

(*viii*) Camp Officer's Chart.

(*ix*) List of trig. control points accepted/rejected during the photogrammetric survey.

(*x*) Sheet file.

(*xi*) Data for History Sheet.

Records which are to be destroyed, by the Photo Unit.—

(*i*) Maintenance forms pertaining to machines may be destroyed after a period of 3 years.

(*ii*) Combination plot sheet and templets may be destroyed after the subject sheet and its adjoining sheets are published.

(*iii*) 10 Phot., 20 Phot. forms may be destroyed after the subject sheet and its adjoining sheets are published.

Records to be preserved in the Photo Unit.—

(*i*) One set of photographs pertaining to aerial triangulation.

(*ii*) All diapositives.

(*iii*) All trig. data, aerial triangulation data.

(*iv*) Aerial triangulation files.

(*v*) Sheet files.

SECTION XIV.—AERIAL PHOTOGRAPHIC INTERPRETATION

111. **Scope.**—Photographic interpretation is the art of examining photographic images for the purpose of identifying objects and evaluating their significance and is extensively used by the surveyors, engineers, foresters, soil surveyors, geologists, urban planners, regional planners and other specialists.

While photographing, the camera obtains a permanent record suitable for investigations for various purposes. Even in inaccessible areas, the camera records images which permit rapid and accurate measurement and interpretation.

Photographs may be taken from an aircraft or from the ground. However, aerial and terrestrial photographs are complementary and are interpreted by similar or identical methods. Aerial photographs constitute a detailed and illuminating report on the natural and cultural features of the earth's surface. The permanence and accuracy of the photographic images permit the interpreter to conduct a thorough and complete study of the area. The large area covered in a stereoscopic pair of aerial photographs permits the photo interpreter to study relations between different images and their surroundings over an extensive area which a ground observer may not always succeed in having. Perception of relief by observation of a stereoscopic pair assists in identification of many important objects.

Photographic interpretation as practised today is usually considered to date from the work of Daguerre (1787-1851) and other pioneers of the nineteenth century. In a hundred year's time, photo interpretation has advanced through stages of experiment to a respected place in military and civilian professional circles. Its methods are precise, its results are reliable, and its value widely recognised.

112. **Basic considerations.**—Aerial photographs have been increasingly used for interpretation purposes for about a century with many advantages over the ground cruise method. In the aerial photographs, large areas are brought in the office of the interpreter which he can examine in great details in a shorter time and without being fatigued or hampered by weather vagaries. Thus the *saving of time* is considerable.

Since the aerial photographs are capable of detailed investigations without the necessity of any additional effort of field attendants as is normal in the ground method, the results of photo interpretation are more *accurate* and *reliable*. Furthermore, since the photographs are always available, it is capable of *independent check* by more qualified and experienced supervisors any time later on.

SECTION XIV.—PHOTOGRAPHIC INTERPRETATION

Due to the considerable cutting down of ground work cost, the *economy* of the use of air photographs is more pronounced. In economically developed countries where there is perennial shortage of manpower and the wages are high, the techniques of aerial photo interpretation are being increasingly used on grounds of speed and economy.

The aerial photographs offer a definite possibility of being used as *base maps* for recording photo interpretation data though on a slightly varying scale depending on the terrain but which is easily capable of being compiled into an accurate base map.

One of the main advantages of the air photographs is the *multi-purpose use* these can be put to and the various inter-related information which can be extracted from the photographs.

113. Principles of photo-interpretation.—The fundamental principle of photographic interpretation is the study of the characteristics of the photographic images which assist in their easy recognition and accurate identification. Image characteristics fall into two general groups, qualitative and quantitative. Such properties as texture, pattern, tone and shape are qualitative ; they cannot be measured in the usual sense, but must be appraised subjectively. Areas, distances, vertical and horizontal angles and heights are quantities which can be measured.

114. Characteristics of photographic images.—The objects are imaged on most aerial photographs at very small scales. Because of the unfamiliar vertical view and the small scale, some elements of appearance assume greater importance in identification and recognition of objects on aerial photographs. The following most important characteristics of photographic images assist in their identification :

Size.—The size of an object is one of the most useful clues to its identity. When faced with an unknown object, it is always advisable to measure it. When working with photography of variable scales, the interpreter should make frequent measurements of the objects of interest. Realizing that size can be three-dimensional, the interpreter can make parallax measurements where necessary.

Shape.—The shapes of objects seen in vertical view are sometimes surprisingly difficult to interpret. The ability to understand and make use of the plan view has to be acquired with practice. The plan view of objects is an important and sometimes conclusive indication of their structure, composition and function. Much of the training of the photo interpreter is aimed at the reorientation of his perceptions, so that he can easily recognise objects seen from above. This reorientation is greatly aided by the impression of depth in stereoscopic pairs. The value of shape to the interpreter is that it delimits the class of objects to which an unknown must belong ; it frequently allows a conclusive identification and it aids the understanding of significance and function.

Shadow.—Shadows are familiar phenomenon, and in day to day life we often judge the size and shape of objects or persons by observing the shadows they cast. The shadows present in aerial photographs sometimes help the interpreter by providing him with profile representations of objects of interest. Shadows are particularly helpful if the objects are very small or lack tonal contrast with their surroundings. Under these conditions the sharp tonal gradients of the shadows may enable the interpreter to identify objects which themselves are just at the threshold of recognition. General purpose aerial photography is usually flown within two hours of local noon so that shadows will be present but small. Shadows have important effects on the photo interpreter's perception of depth.

Tone and colour.—Colour perception is an important element of our awareness of our environment but in black-and-white photographs, distinctions between hues are lost and objects are observed in tones of grey. The tones of photographic images are influenced by many factors like spectral reflectivity of an object and its background, spectral sensitivity of the photographic film, spectral scattering by atmospheric haze particles and spectral transmission by the photographic filter. A body of water may appear in tone ranging from white to black, depending on the angle of sun and the number of wave surfaces reflecting light to the camera lens. When the photo interpreter understands the factors which govern photographic tone, he regards the tones of objects of interest as major clues to their identity or composition. The soil scientist uses tonal variations to classify soils ; the forester to distinguish hardwood from coniferous trees ; the geologist to map lithology and structure or prospect for minerals. In single photographs, where the shapes of objects must be inferred from monocular clues tone is particularly important.

Texture.—Texture in aerial photographs is created by tonal repetitions in groups of objects which are too small to be discerned as individuals. It follows that the size of object required to produce texture varies with the scale of photography. In large scale photographs, trees can be seen as individuals ; their leaves cannot be discerned separately, but contribute to the texture of the tree crowns. In photographs of smaller scale, the crowns contribute to the texture of the whole stand of trees.

Pattern.—Students of earth science have always laid great stress on the pattern or the spatial arrangement of objects as an important clue to their origin or function or both. The varying relations between organisms and their environment produce characteristic patterns of plant association. Regional patterns which formerly could be studied only through laborious ground observation are instantly and clearly visible in aerial photographs. Cultural features are conspicuous in aerial photographs because they consist of straight lines or other regular configurations.

115. **Techniques of photo interpretation**.—Aerial photo-interpretation entails careful study of a large number of aerial photographs with the help of proper equipment and by handling the photographs in a systematic manner. The search for data has to be made in a methodical way and inferences made based on available evidence. Photo interpretation keys and oblique photographs are used by interpreters as valuable aids for efficient photo interpretation.

The aerial photo interpretation can be carried out in the following sequence :

(*a*) The examination and identification of important images with the help of tone, texture, pattern, configuration and other characteristics of photographic images.

(*b*) Measurement of images by means of scales or other instruments.

(*c*) Analysis and evaluation of interpreted items.

(*d*) Field checking, where possible.

(*e*) Presentation of the results of photo interpretation.

116. **Equipment**.—The photo interpreter can do most of his work with three simple items of equipment ; a stereoscope, a grease or china marking pencil, and a measuring rule. The lens or mirror stereoscopes are generally used but the lenses should be of good quality, without objectionable distortions and of high resolving power. Mirror stereoscopes should be fitted with binocular attachment of minimum 4 X magnification. The grease or china marking pencil is convenient for drawing on the photographs. It can be used on glossy as well as mattefinish prints, and the marks can be removed by a soft cloth, dry or moistened with alcohol or other solvent. Some interpreters prefer to use overlays for annotation. A parallax bar is sometimes used for determining relative height differences and slope. The basic measuring device is a plastic rule with millimetre divisions.

117. **Handling the photographs**.—Most photo interpretation today is done with paper prints. A certain "specification" or "mission" or a set of photographs may consist of hundreds of exposures from the aerial camera. Since the photographs of a specification are numbered, orderly arrangement is easy and should

be the first step in any job of interpretation. An orderly method of handling prints is as follows :—

(*a*) Arrange the photographs of each sortie or strip numerically face up.

(*b*) Stack strips in the sequence they will be examined and place paper separator between them.

(*c*) Turn the stack so that the line of flight extends from left to right with respect to the observer and preferably so that the shadows fall toward the observer.

(*d*) Place photography to be used for comparison outside rather than in the stack.

(*e*) As the prints are examined, stack them face down, still in numerical order. Having adopted some orderly way of handling his photographs, the photo interpreter should follow it habitually.

118. Stereoscopic viewing.—Binocular vision, taken for granted in daily life, should be fully understood and consciously exploited by the photo interpreter, for he can get much more information from stereoscopic pairs than from single prints. Careful orientation of stereoscopic pairs will produce a clear image and minimize eye strain. The lenses of the stereoscopic should be cleaned at least once a day. Dust, perspiration, eyelashes, dandruff, etc., which collect on the lenses, are not conducive to clarity of vision. It is better to wipe the lenses with lens tissue or a silicon paper than with an old handkerchief.

119. Method of search.—A job of interpretation could be begun by close examination of all details which are thought to be relevant or by scanning the area as a whole or a large part of it. A good practice is to lay down an overlapping run of a dozen or more photographs and to scan this group before examining each stereoscopic pair. Before drawing planimetric data or counting objects, the interpreter should delineate effective areas on the photographs which can be established by drawing lines along bisectors of the forward and lateral overlaps.

There are two general ways to study aerial photography : the "fishing expedition" and the logical search. The method of examining every image in every photograph so as not to miss anything is known as the *fishing expedition*. It requires more leisurely effort than the interpreter can usually afford to make. In order to work more efficiently in the time available when the photo interpreter searches only those areas in which the objects of interest are likely to be found and disregards large number of photographs which are not likely to contain the desired information – this method is ***logical search***, a combination of quick scanning and intensive study.

120. Convergence of evidence.—In order to identify objects he has not seen before, or to understand the meaning of objects once identified, the photo interpreter exploits the principle of convergence of evidence. There may be many clues to the identity of an unknown object. None of the clues is infallible by itself; but if all or most of the clues point to the same conclusion, the conclusion is probably correct. Photo interpretation is thus an art of probabilities. The difficult part of photo interpretation consists in judgement of degrees of probability.

121. Photo interpretation keys.—A photo interpretation key helps the interpreter to organize the information present in aerial photographs, and guides him to a correct identification of unknown objects. It differs from the keys used in many disciplines in that it consists essentially of illustration.

122. Oblique photographs.—Oblique photographs have two main advantages. First, they show objects on the earth's surface in aspects and space relations which are familiar to everyone. Second, they cover much larger areas than vertical photographs taken at the same altitude – a high oblique's usable area covers about eight to ten times the area of a vertical. Oblique photographs can be taken under a cloud cover, a distinct advantage when speed is required and overcast weather prevails. For these reasons, obliques are useful for presenting to the public information about forest and park recreation, wildlife management, urban planning, and other subjects of general interest.

123. Field checking.—In almost every job of interpretation there will be unknowns or uncertain conclusions which must be checked in the field. The interpreter must accept the responsibility of field checking whenever it is feasible. The amount of field work which will be necessary varies with the intensiveness and accuracy requirement of the study, the complexity of the area, the number of the photographs, and the ability of the interpreter.

124. Report.—The field checking should be followed by a final study of the aerial photographs. The previous office interpretation is corrected based on the field checking and the photo interpretation is finalised. The final results of the photo interpretation are now presented in a report which will state the findings of the photo interpretation analysis as checked by field work, interpret these findings in terms of productivity and recommend methods of utilisation or improvements in management practices.

125. Application to Geology.—The surface features of the earth and the geological data are recorded very comprehensively on the aerial photographs. Photo-geology which covers all the aspects of geological photo interpretation has been accepted as one of the most powerful geological tools. Photo-geologic investigations are carried out by the application of the principles of geomorphology which is defined as the analysis of surface forms. Though colour patterns on the earth's surface is an important clue to regional geology, the elements mostly used by the geologists are land form and drainage pattern. The characteristics of land forms – their shape, pattern and geogenesis can be studied by the stereoscopic examination of pairs of aerial photographs.

Aerial photographs when examined stereoscopically provide an accurate relief model of the ground in which the major topographic features are well defined. It is generally possible to recognise geologic features as faults, folds, dikes and veins on aerial photographs. The affects of erosional and depositional agents as wind, streams, water and glaciers can be studied on aerial photographs.

In the field the geologist uses aerial photographs to locate his position and to guide his traverse. Locations and geologic data can be plotted directly on the aerial photographs or on transparent overlay sheets. Ground checking of geologic data is greatly facilitated by the selection of suitable sites for field checking from aerial photographs. The ground work for geological exploration is considerably reduced by the use of aerial photo interpretation techniques which is its greatest economical advantage.

Since a certain mineral usually occurs in some specific morphological complex, the areas which do not exhibit associative morphology can be eliminated by a systematic stereoscopic study of aerial photographs. Vertical aerial photographs on 1 : 20,000 scale are used for geological interpretation. Of late, colour photographs are being increasingly used for photo-geological analysis.

126. Application to Forestry.—In the field of forestry, photo interpretation has many important uses, including the classification of forest stands and types ; survey of mortality and depletion ; planning of reforestation, recreation and road construction ; inventory of timber and other forest products ; and related applications. Reliable measurements of tree heights, crown densities, and crown diameters can be made from aerial photographs. The stem diameter can be correlated with the crown diameter dimensions. Reasonably accurate estimate regarding timber volume can be obtained from aerial photographs.

Tone and texture offer useful clues of species composition and stand structure. The properties of photographic images and the ease and reliability of photo interpretation are strongly affected by the equipment, materials and methods of processing used. The season of photography, time of day, and weather conditions also affect the images. In photo interpretation for forestry purposes, the interpretor makes use of the characteristics of images as texture, pattern, tone and shape. Some trees are recognised by distinctive tree crowns. Satisfactory estimates of volumes can be made on vertical panchromatic or infra-red aerial photography on 1 : 30,000 scale for reconnaissance, on 1 : 15,000 scale for management planning and on 1 : 8,000 scale for timber sale and other inventories.

Forest maps can be classified into three broad groups, namely, general vegetation map, forest type map and forest stand map. General vegetation maps are made on scale 1 : 100,000 and aerial photography on scale 1 : 60,000 is sufficient for the preparation of these maps. Forest type maps are made on scales ranging from 1 : 40,000 to 1 : 60,000. Information relating to species composition, average height, age and crown density of trees are collected for the preparation of forest type maps. In a tropical forest where the number of species vary widely, the largest scale map that can be prepared is forest type maps. In temperate region, it is possible to prepare detailed forest stand maps on 1 : 5,000 to 1 : 10,000 scale.

Tree diseases can be spotted from colour photographs and study of pests, insects and fungus can be made. Another important application of the aerial photographs is for road location for the exportation of timber.

127. **Application to Soil Survey.**—Aerial photographs offer a wealth of ground details and are of great help for soil survey and mapping. The photo image usually reveals the general terrain conditions which can be correlated with specific soil units and, therefore, the aerial photographs are most important for general soil investigations, in which soil complexes, soil associations, or miscellaneous land types are studied. In detailed soil studies, aerial photographs serve as field maps and working maps on which some soil boundaries can be plotted after a stereoscopic examination.

The main advantage of aerial photographs as applied to soil survey is that they offer an overall view of a large area, uninterrupted by vegetation, topographical features and other features which restrict visibility. All facts necessary for soil classification cannot be derived from aerial photographs alone. Proper field control work and laboratory tests are necessary.

The most important of the photo interpretation techniques for soil study is the systematic analysis of pedological elements in aerial photographs. A large number of soil boundaries can be mapped on aerial photographs. Following this delineation, a tentative classification of the mapping units are made. The mapping units are mostly soil complex, soil associations, and soil phases. The results are incorporated on a photo-analytical map which serves as a basis for field work. The mapping units are studied and described in the field, the soil boundaries are checked and necessary corrections and additions are made. The preliminary photo-analysis reduces the field work by 75%. The amount of field work to be carried out depends on the requirements which the maps should fulfil as regards detail and accuracy.

The success of aerial photo interpretation for soil survey depends to a large extent on the quality and interpretability of aerial photographs which in turn is dependent on the scale of photographs, the nature of terrain, season, date and time of photography. Photographs for soil survey purposes are flown on 1 : 20,000 scale and enlargements of twice the contact scale are used in the field.

128. **Application to Highway Engineering.**—The use of aerial photographs for highway engineering is manifold. Aerial photographs are the basic source of qualitative information and quantitative data. The qualitative information is obtained by photographic interpretation and analysis, and the quantitative data from photogrammetric measurements.

Aerial photographs have been used most extensively for route location in highway engineering. Information regarding the nature of terrain, topography, vegetation, drainage, erosion, nature and depth of soil, amount of cut and fill required, number of bridges and culverts required, service to adjoining area and similar other aspects of highway engineering can be obtained from the stereoscopic examination of photographs. Aerial photographs are used for reconnaissance survey of an area to determine the most feasible, serviceable and economical route alternatives. Aerial photographs also serve as indicators of sources of construction materials by site, type, condition and quantity ; and serve as a means of identifying trees for landscaping purposes.

Vertical aerial photographs on scale 1 : 15,000 to 1 : 20,000 are used for photo interpretation for highway engineering for route alignment. For urban areas a somewhat larger scale upto 1 : 5,000 is used.

129. **Application to Urban Area Analysis.**—In the field of urban area analysis, photo interpretation has been used for many purposes such as description of urban morphology, statement and testing of theories of urban growth and structure, measurement of traffic as a function of land use, estimation of distribution of population, market research, location of stores and industrial plants, and estimation of public utilities requirements. Urban area analysis is considered the province of several disciplines like the social scientist, economist, urban geographer or sociologist and hence the practice of urban photo interpretation is not confined to any one profession. The photo interpreter interprets photographs of the urban area by dint of deduction, inference and association.

Photo interpretation of a city frequently takes a map-like form and it is the ease with which the areas can be obtained from aerial photographs which commends photo interpretation to the student of urban areas. In the aerial photographs are found large and congested city areas in the office of the town planner which he can examine in greater details in a shorter time unhampered by weather and physical fatigue. The aerial photographs have been used as supplementary source data for the social scientist concerned with urban and regional analysis.

In order to solve the problems of urban area analysis, the interpreter depends on the study of the characteristics of photographic images which fall into two general groups, qualitative and quantitative. To the urban area interpreter, the most important qualitative characteristics are shape, size, shadows, pattern and association. Areas, distances and heights are quantities which can be measured. In addition, the interpreter interprets the urban area by dint of deduction, and inference when the careful observations on aerial photographs are combined with knowledge from other sources in order to obtain information that cannot be directly observed in the photo image itself. For general land use study, a scale of aerial photography of 1 : 20,000 to 1 : 31,680 will suffice. For photo-sociometric studies, scales of 1 : 6,000 to 1 : 10,000 are used.

130. Miscellaneous applications.—During the last decade the use of aerial photographs has increased so much that they have now become one of the indispensable tools for the investigation and solution of many engineering and other problems.

The location, design and construction of base embankments for railways can be carried out rapidly and economically by using aerial photographs in the same way as in highway engineering. In selecting routes for power lines, aerial photographs help the engineer to find that alignment of poles which will provide the shortest most practical route, and to locate the positions of poles and towers where the foundations are good.

Aerial photographs on scale 1 : 10,000 or larger, clearly show the street patterns, buildings, cars and traffic jams, vehicle counts and other special traffic studies can be made more quickly and accurately using aerial photographs. Planning for efficient traffic flow in urban area is greatly facilitated by the use of aerial photographs by traffic engineers.

Aerial photo interpretation assists greatly in the planning of dikes, dams and similar flood control structures. Accurate mapping of the surface soils of flood plains can be carried out by careful study of the photographic tones which give some indication of the soil texture and moisture content. Old channels buried by successive flood deposits though invisible to the ground observer, can be detected on aerial photographs.

SECTION XIV.—PHOTOGRAPHIC INTERPRETATION

In recent years aerial photographic interpretation has been used for the study of archæological ruins and their surroundings. Aerial photographs are being used for the wildlife management. They are also used for motion studies, medicine and surgery, astronomical studies, and radiography. There are many other applications of photo interpretation which cannot be described here because of space limitations. The importance of photo interpretation has increased so much that the International Society of Photogrammetry has set up a separate commission for photo interpretation. Aerial photo interpretation is a comparatively modern science and there is every indication that in the future there will be increased activity in aerial photo interpretation all over the world, and particularly in India.

APPIDIX 'A'

SECRET/RESTRICTED/IMMEDIATE/MOST IMMEDIATE.

535 G (AIR)

SURVEY OF INDIA

AIR PHOTO SPECIFICATION No............DATED.............................

(Vertical air photography by the Indian Air Force / Air Survey Co. of India Private Ltd.)

Job Title—

---

1. INDENTOR.—

2. PURPOSE.—

3. (a) AREA.—...............sq. km (as marked on the enclosed Map sheet)
   (b) ADMINISTRATIVE STATES COVERED.—
   (c) 1 : 50,000 SHEETS COVERED.—

4. (a) NEGATIVE SCALE.—
   (b) FLYING HEIGHT (ABOVE M.S.L.).—

5. CAMERA AND LENS.—(a) Camera :—Eagle IX/RC5(a)/RC8/RMK
   (b) Focal length of lens :—6 inches/11·5 cm./15 cm.
   (c) Format :—18 cm. × 18 cm./23 cm. × 23 cm.

6. (a) OVERLAPS.—fore and aft : lateral :
   (b) No. AND DIRECTION OF STRIPS.—

7. REQUIREMENTS.—(i) *Contact prints*............... sets.
   (ii) *Enlargements*
   (iii) *Mosaics*
   (iv) *Photo indexes*
   (v) *Camera Calibration Charts*
   (vi) *Photographic Reconnaissance Report*
   (vii) *Diapositives.*
   (viii)

P.T.O.

APPENDIX 'A'

8. PRIORITY.—

9. DESPATCH INSTRUCTIONS.—

(*a*) *To the Surveyor General of India, Post Box No. 37, Dehra Dun.*

(*i*) One set of contact prints on glossy paper.

(*ii*) Two sets of photo-indexes.

(*iii*) One set of camera calibration charts.

(*iv*) One set of photographic reconnaissance report.

(*v*)

(*b*)

10. MISCELLANEOUS INSTRUCTIONS.—

FOR SURVEYOR GENERAL OF INDIA.

Issue No. T-.................. dated ....

DISTRIBUTION.—

APPIDIX 'B'

AERIAL PHOTOGRAPHY
FLIGHT PLANNING DATA

1. Camera	**Eagle IX/RMK 15/23**	**RC. 5a**
2. Focal length	**15·3 cms**	**11·48 cms**
3. Format	**23 cm = 23 cm**	**18 cm × 18 cm**
4. Overlap-Lateral/fore & aft.	**25%/60%**	**25%/60%**

		Flying height in metres	Lateral distance between strips km	Air base km	Area of format sq. km	Effective area of model sq. km	Flying height in metres	Lateral distance between strips km	Air base km	Area of format sq. km	Effective area of model sq. km
5. Scale of Photography	1 : 60,000	9150	10·35	5·52	190·4	57.1	6900	8·10	4·32	116·6	35·0
Do.	1 : 50,000	7600	8·62	4·60	132·2	39·7	5750	6·75	3·60	81·0	24·3
Do.	1 : 40,000	6100	6·90	3·68	84·6	25·4	4600	5·40	2·88	51·8	15·6
Do.	1 : 30,000	4550	5·18	2·76	47·6	14·3	3450	4·05	2·16	29·2	8·8
Do.	1 : 25,000	3800	4·31	2·30	33·1	9·9	2850	2·38	1·80	20·2	4·3
Do.	1 : 20,000	3050	3·45	1·84	21·2	6·3	2300	2·70	1·44	13·0	3·9
Do.	1 : 10,000	1500	1·72	0·92	5·3	1·6	1150	1·35	0·72	3·2	1·0
Do.	1 : 5,000	750	0·86	0·46	1·3	0·4	600	0·68	0·36	0·8	0·25

All these distances are on the ground.

APPENDIX 'C'

AERIAL TRIANGULATION SYMBOLS AND NUMBERING SYSTEM

Type of points	Last two digits of the numbering system	Symbol on photos, planning index, etc.	Colour of symbol and of number	Eight digit number
A. Model Control Points				
Principal point ..	00	A dot with 3 mm ticks just above and below	Red	32305600
Pass/tie point ..	01 to 09	A dot within a circle of 5 mm diameter	Green	32305601
Scale transfer point	11 to 19	A dot within circle of 3 mm diameter	,,	3230561
B. Ground Control Points				
G.T. station ..	21 to 29	A dot within a circle of 6 mm diameter	Red	32305621
G.T. I.P. ..	21 to 29	A dot within a circle of 3 mm diameter	,,	32305624
Topo station ..	31 to 39	A dot within a circle of 6 mm diameter	Black	32305635
Topo I.P. ..	31 to 39	A dot within a circle of 3 mm diameter	,,	32305635
Traverse station ..	41 to 49	A dot within a circle of 4 mm diameter	Blue	32305641
Traverse I.P. ..	41 to 49	A dot within a circle of 3 mm diameter	,,	32305646
Bench-mark ..	51 to 59	A dot with 4 symmetric ticks, 3 mm each	Green	32305651
Clino height ..	61 to 69	,,	Red	32305661
Map position/P.T. fixing, A.P., etc.	71 to 79	,,	Blue	32305671
C. Block Control Points				
Block point ..	91 to 95	A dot within a circle of 6 mm diameter	Green	32305691
D. Other Points				
Lowest point in model ..	98	A dot within a circle of 5 mm diameter	Green	32305698
Highest point in model ..	99	,,	,,	32305699

NOTE :—1. First three digits indicate strip number ; the next three, left photo number ; the last two, point number.

2. Generally, number is entered to the left of the symbol ; height, if known, to the right.

3. In the case of tie strips, the initial number will begin with 9, e.g., tie strip 4, will be indicated by 904.

4. Generally, the pass points are numbered 01 (central), 03 (upper) and 05 (lower) ; 02, 04, 06 to 09 may be allotted to other pass/tie points. Any common point between two strips will be numbered once only and this will be done for the upper strip of the two.

APPIDIX 'D'

LIST OF FORMS USED IN PHOTOGRAMMETRIC SURVEY

Serial No.	*Form No.*	*Particulars*
1	1 Phot	Sketches and co-ordinates of control points (field post-pointed).
2	1A Phot	Sketches, co-ordinates and particulars of control points.
3	1B Phot	Sketches of control points.
4	1C Phot	List of co-ordinates and heights by Aerial Triangulation.
		PLANNING FOR AERIAL TRIANGULATION
5	2 Phot	Schematic diagram for Aerial Triangulation.
6	2A Phot	Schematic diagram for Planimetric Block Adjustment.
7	2B Phot	Schematic diagram for Altimetric Block Adjustment.
8	2C Phot	Instruction for Photogrammetric Survey.
9	2D Phot	Instruction for Aerial Triangulation.
10	2E Phot	Planning index for Photogrammetric survey.
11	2F Phot	Information for Photogrammetric Survey of Individual Sheets.
		RELATIVE ORIENTATION
12	3 Phot	Numerical relative orientation for flat terrain with ϕ_1 and ϕ_2.
13	3A Phot	Numerical relative orientation for flat terrain with ϕ_1 and ϕ_2 (Using K_1 and K_2).
14	3B Phot	Numerical relative orientation for flat terrain with ϕ_1 and ϕ_2 (Parallaxes measured with ω).
15	4 Phot	Numerical relative orientation for flat terrain (or moderately-undulating) terrain with bz and ϕ or using one projector.
16	4A Phot	Over correction factor for solving ω for mountainous terrain.

LIST OF FORMS USED IN PHOTOGRAMMETRIC SURVEY

Aerial Triangulation Observation

17	5 Phot	Machine co-ordinates and elements or orientation.
18	5A Phot	Machine co-ordinates and elements of orientation.
19	5C Phot	List of machine co-ordinates and heights.
20	5D Phot	Machine heights and elements of orientation.
21	5E Phot	Machine co-ordinates, elements of orientation and scale transfer.
22	6 Phot	Scale transfer.

Adjustment of Co-ordinates and Heights

23	7 Phot	Conformal Transformation of Co-ordinates (Planimetry).
24	7A Phot	Transformation of heights.
25	7B Phot	Elements of Strip Adjustment.
26	7C Phot	Parabolic correction of co-ordinates & heights.
27	7D Phot	Affine Transformation of co-ordinates (Planimetry).
28	8 Phot	Deduction of co-ordinates.
29	8A Phot	Strip Adjustment by Graphical Interpolation.
30	8B Phot	Adjustment of co-ordinates and heights.
31	8C Phot	Datum correction graphs.
32	9 Phot	Deduction of heights.

Plotting Data of Plot Sheet

33	10 Phot (A8)	Data for Plot sheet – for plotting work on Wild A8.
34	10 Phot (B8)	Data for Plot Sheet – for plotting work on Wild B8.
35	10 Phot (A7)	Data for plot sheet – for plotting work on Wild A7.
36	10 Phot (PG-2)	Data for plot sheet – for plotting work on Kern PG-2.

APPENDIX 'D'

LIST OF FORMS USED IN PHOTOGRAMMETRIC SURVEY

Testing of Instruments

37	11 Phot	Testing of Instruments – Stereoscopic Grid Measurements (Graphical Method).
38	11A Phot	Testing of Instruments – Stereoscopic Grid Measurement (Analytical Method).
39	12 Phot	Testing of Instruments – Monocular Grid Measurement.
40	12A Phot	Testing of Instrument – Monocular Grid.
41	13 Phot	Testing of Instrument – Correction to Principal Distance (focal length).

Rectification

42	17 Phot (Seg. V)	Elements for Rectification*.
43	18 Phot (Seg. V)	Affine Rectification*.

Maintenance of Instrument

44	19 Phot (A8)	Maintenance of Machine for Wild A8.
45	19 Phot (A7)	Maintenance of Machine for Wild A7.
46	19 Phot (A8)	Maintenance of Machine for Wild B8.
47	19 Phot (PG-2)	Maintenance of Machine for Kern PG-2.
48	19A Phot	Handing over of Instrument.
49	19B Phot	Instrument Diary.
50	19 Phot (PR1)	Work time study for Stereoplotting.
51	19 Phot (PR 2)	Work time study for Aerial Triangulation.

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52	20 Phot	Data sheet for plotting on Stereotopes.

(* These are under printing).

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„ Stereoplanigraph C8	71	87
„ Stereotope	71	96

M.P.—P.O.—J.S. 160—29-7-71—4,000

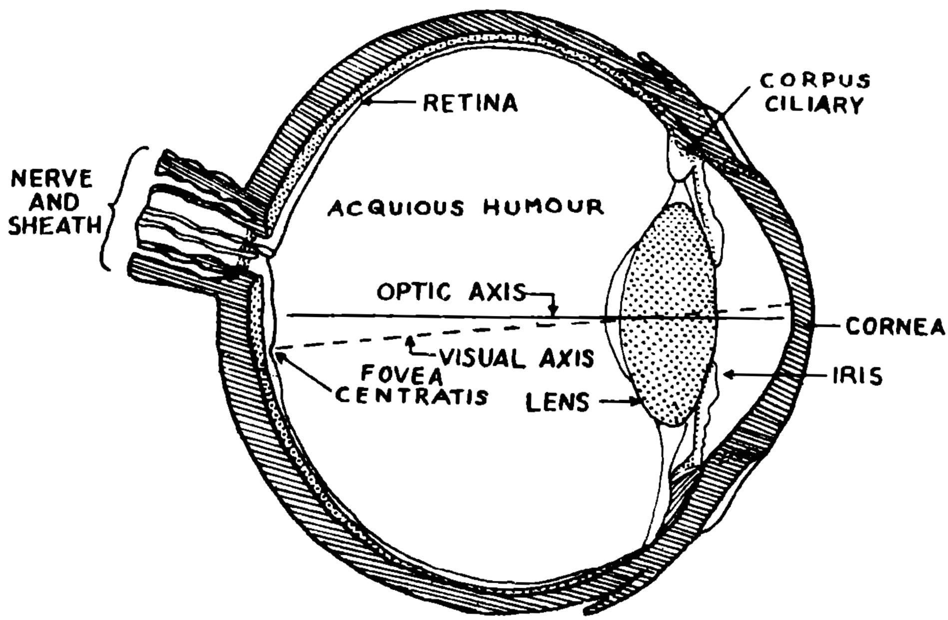

Fig. III. 1
The human eye

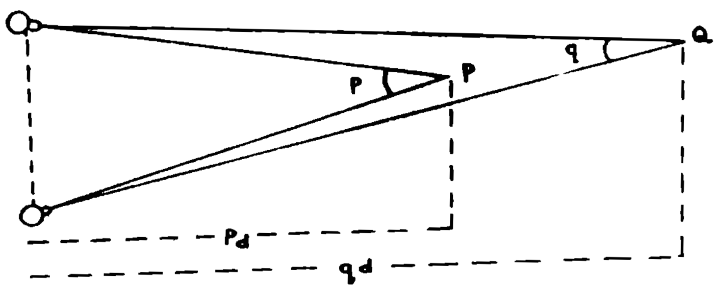

Fig. III. 2
Convergence of eye axes

Reg. No. 3959 P.Z.D.'72-4000'73 PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

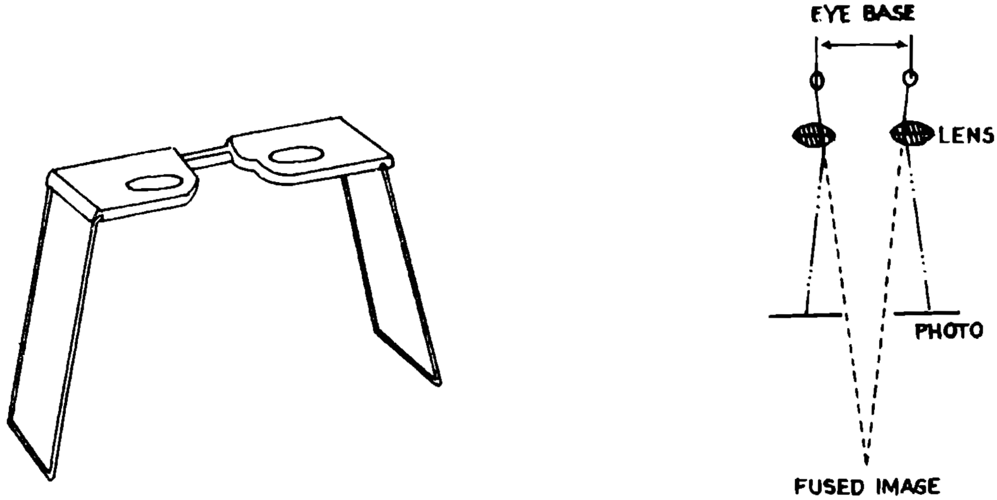

Fig. III.3
Pocket stereoscope

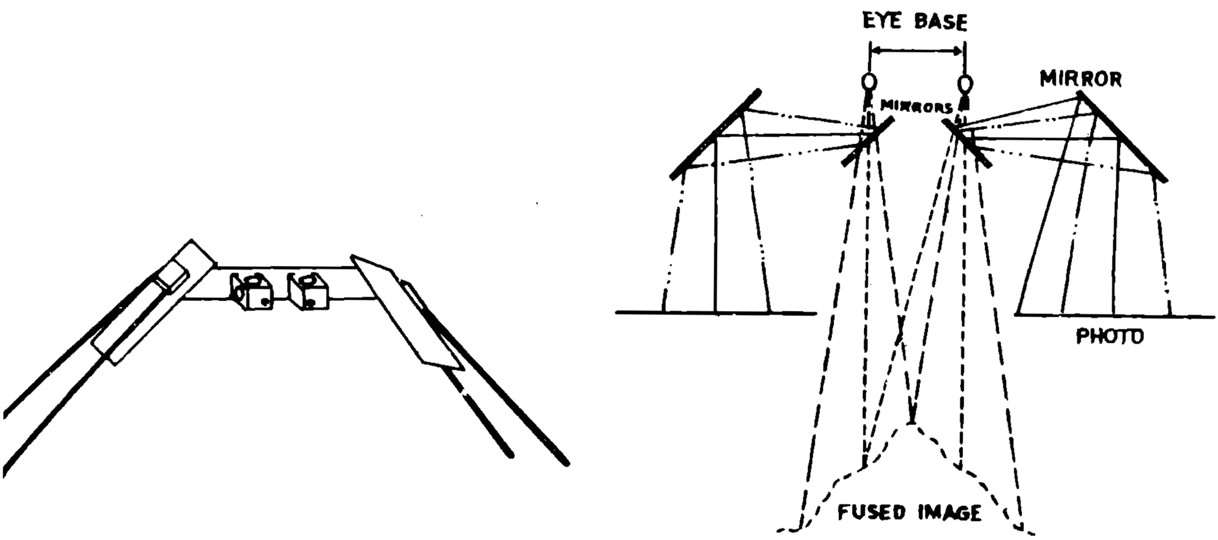

Fig. III.4
Mirror stereoscope

Reg. No. 3959 P.Z.D.'72-4000'73.
PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

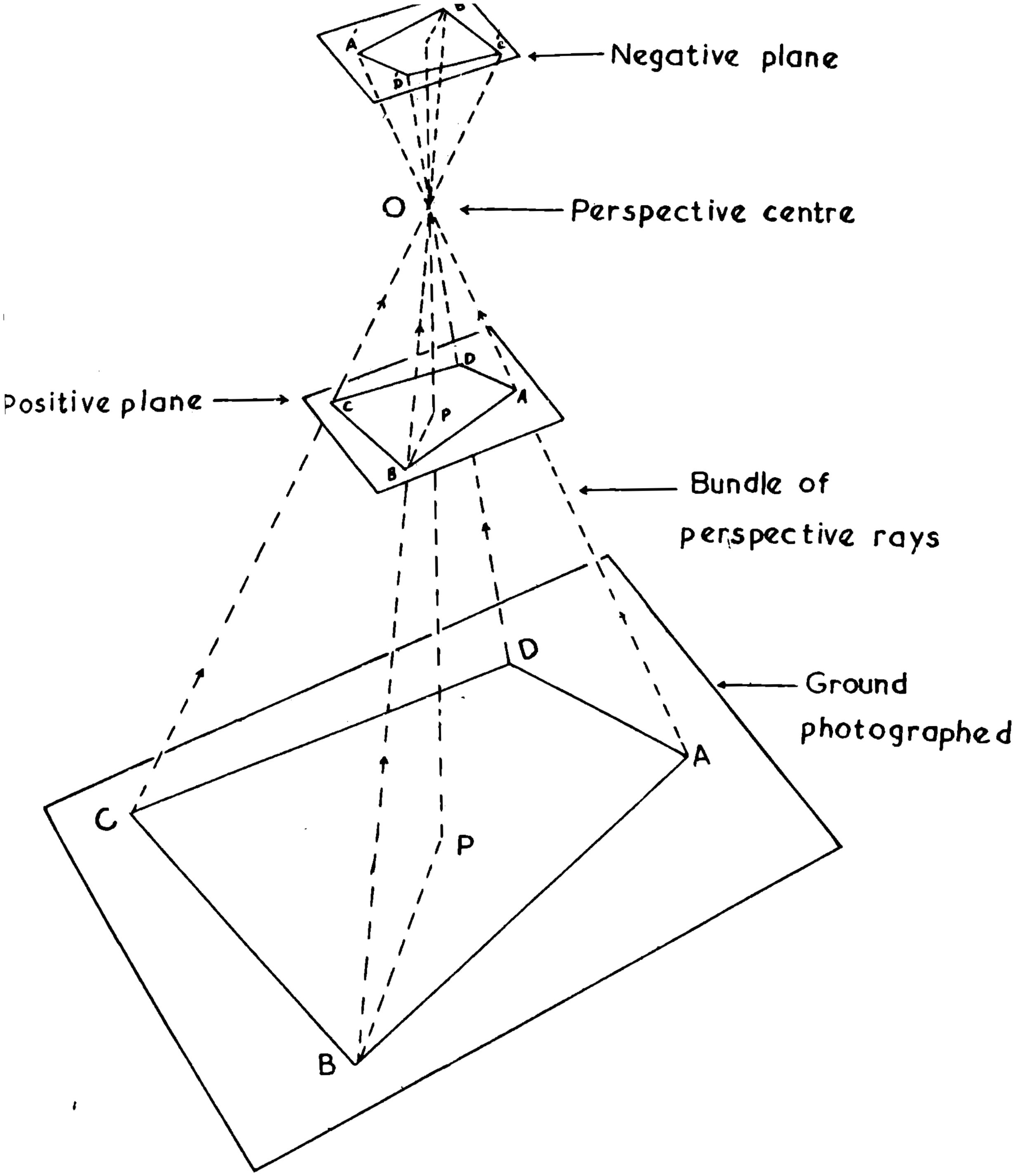

Fig. IV.1
Central perspective

R. No. 3959 P.Z.D.'72-4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

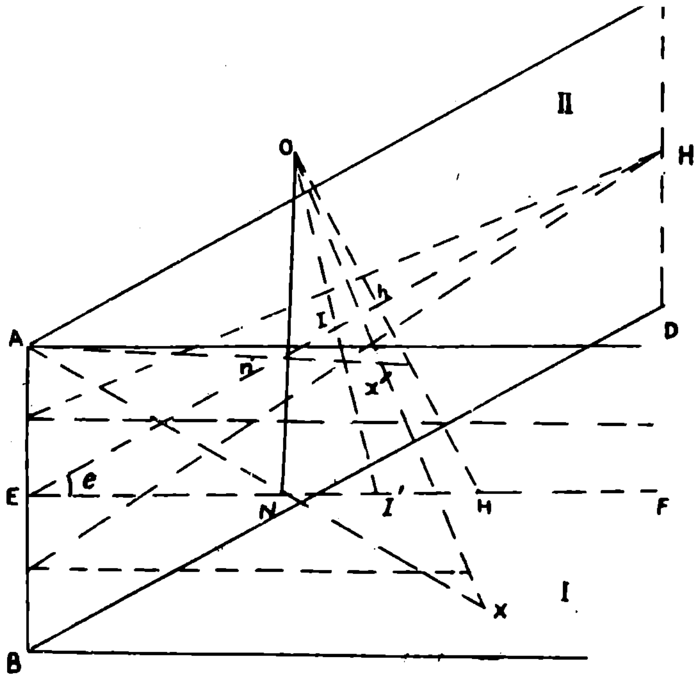

Fig. IV.2
Perspective projection

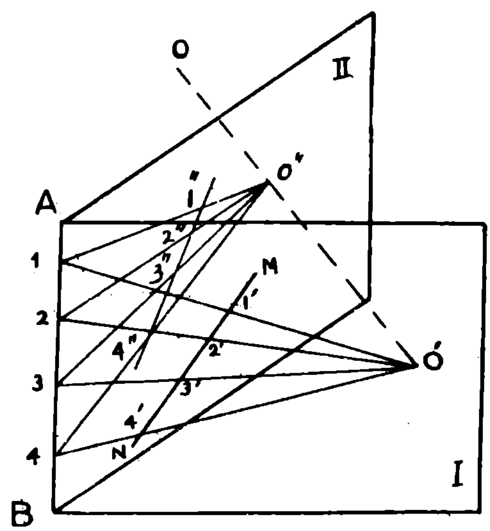

Fig. IV. 3
Anharmonic ratio

No. 3959 P.Z.D.'72-4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

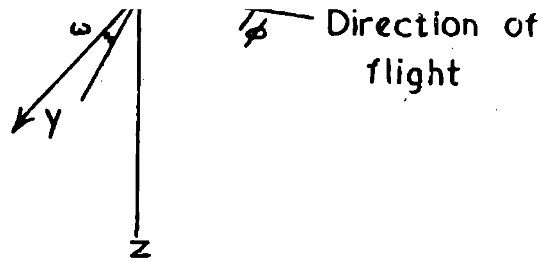

Fig. IV. 4
Instrument axes

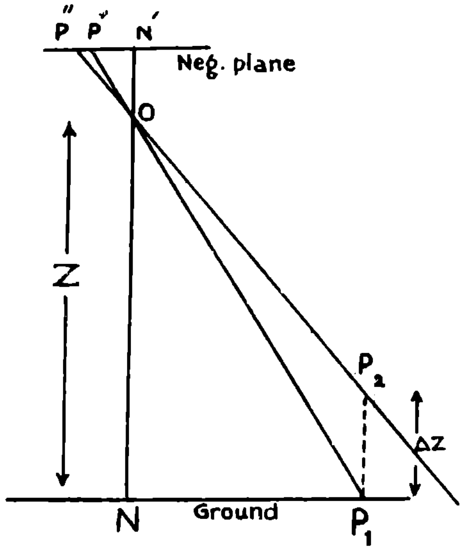

Fig. IV. 5
Relief displacement

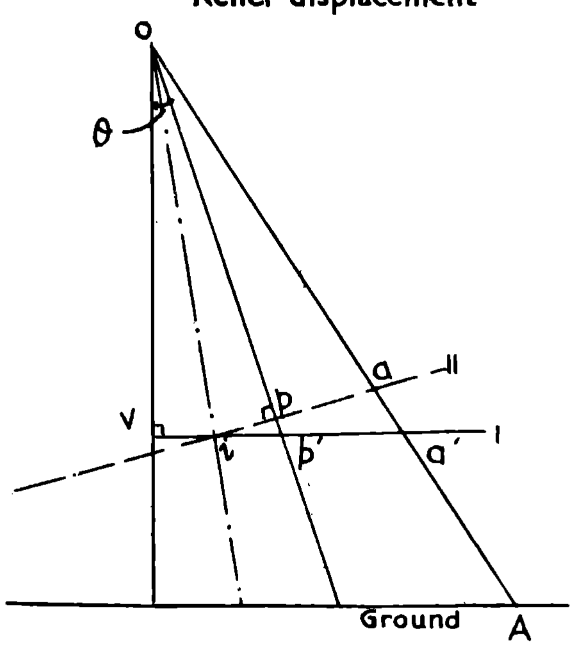

Fig. IV. 6
Tilt displacement

No. 3959 P.Z.D.'72-4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

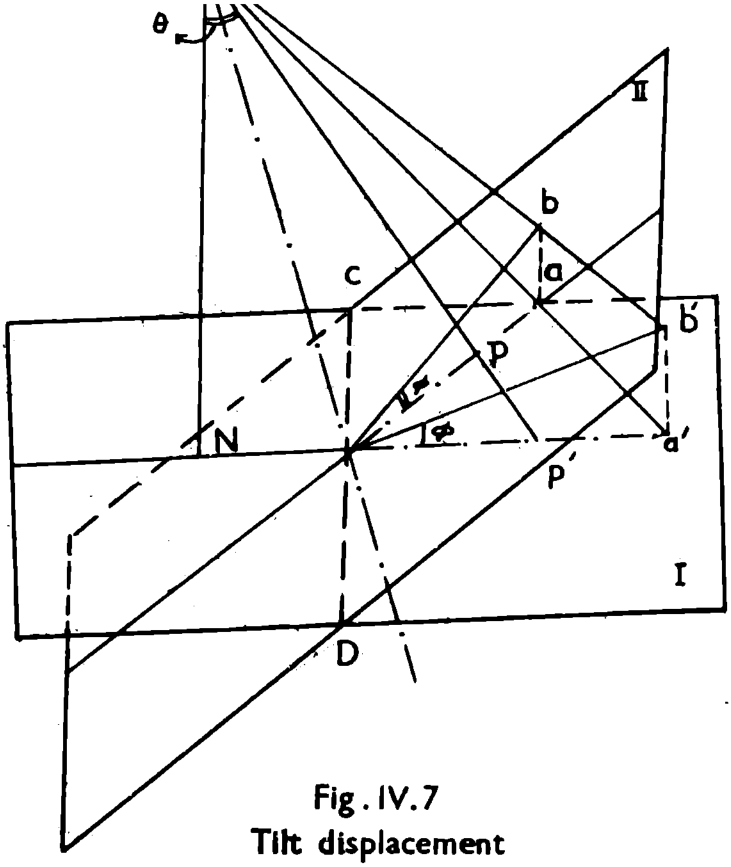

Fig. IV.7
Tilt displacement

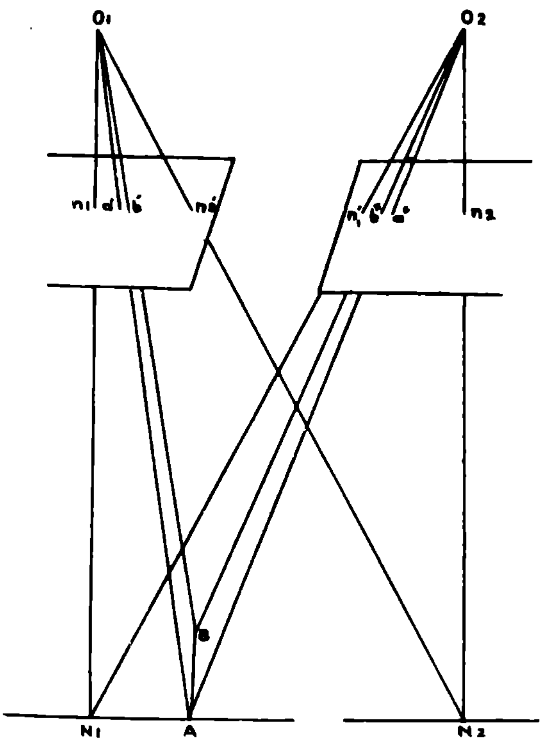

Fig. IV.8
X-parallax

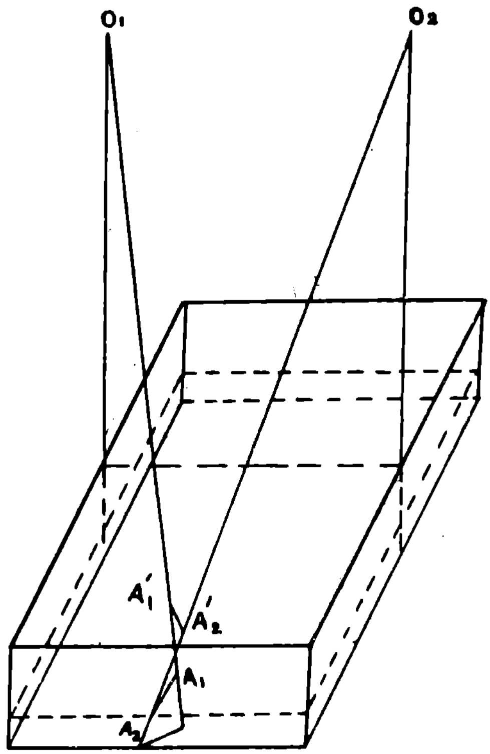

Fig. IV.9
Y-parallax

Reg. No. 3959 P.Z.D.'72-4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

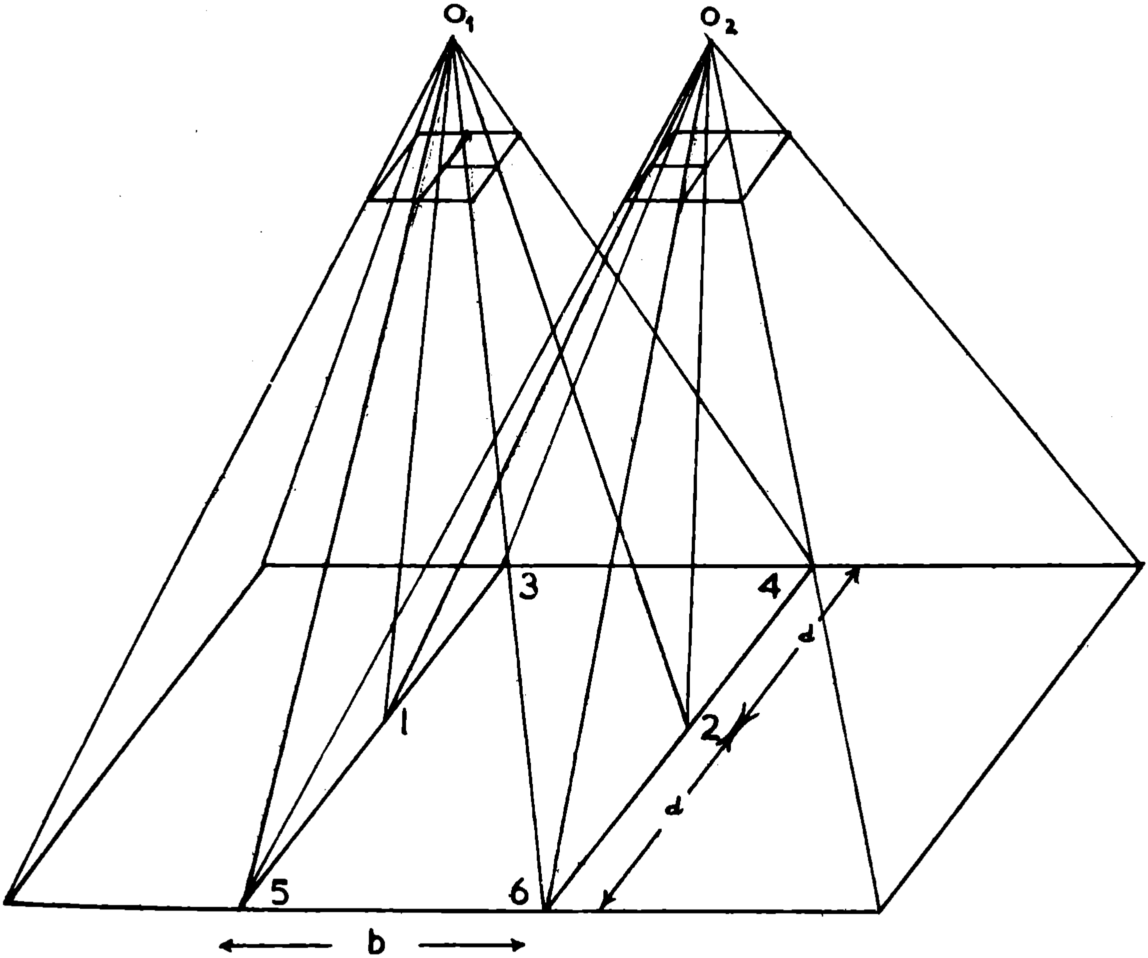

Fig. IV. 10
Parallax-free model

[illegible] D.'72-4000'73.

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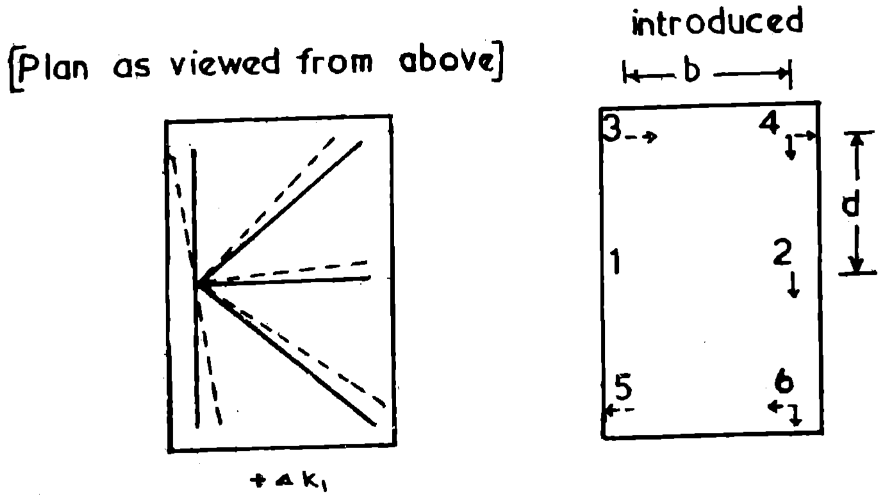


Fig. IV. 11
Effect of kappa

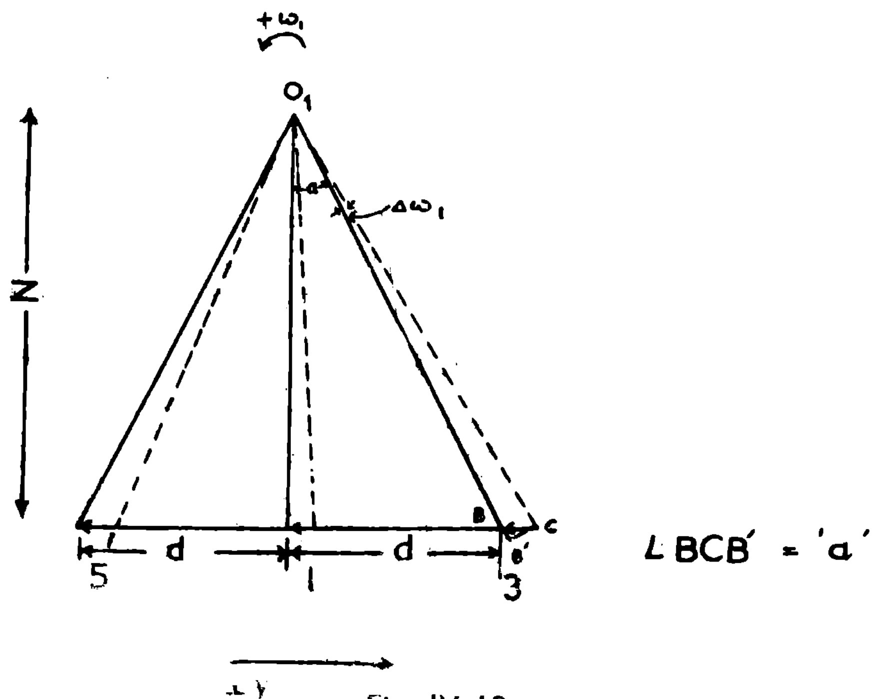


Fig. IV. 12
Effect of omega

Reg. No. 3959 P.Z.D.'72–4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

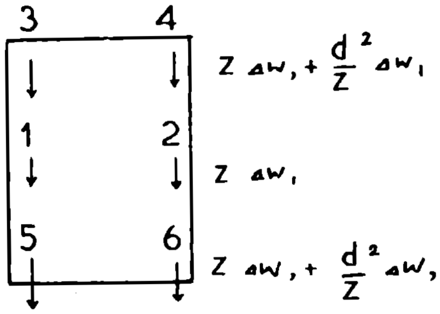


Fig. IV. 13

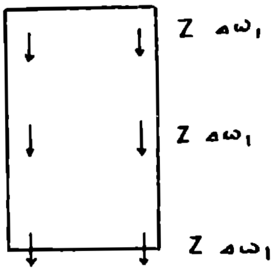


Fig. IV. 14

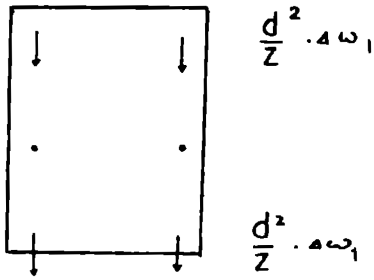


Fig. IV. 15

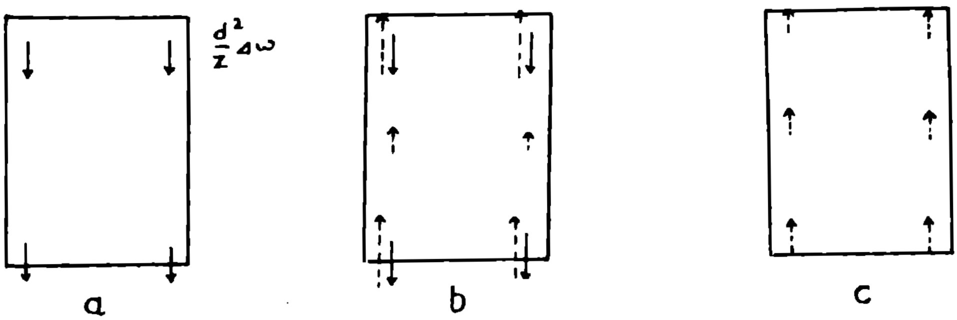


Fig. IV. 16

Reg. No. 3959 P.Z.D.'72-4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

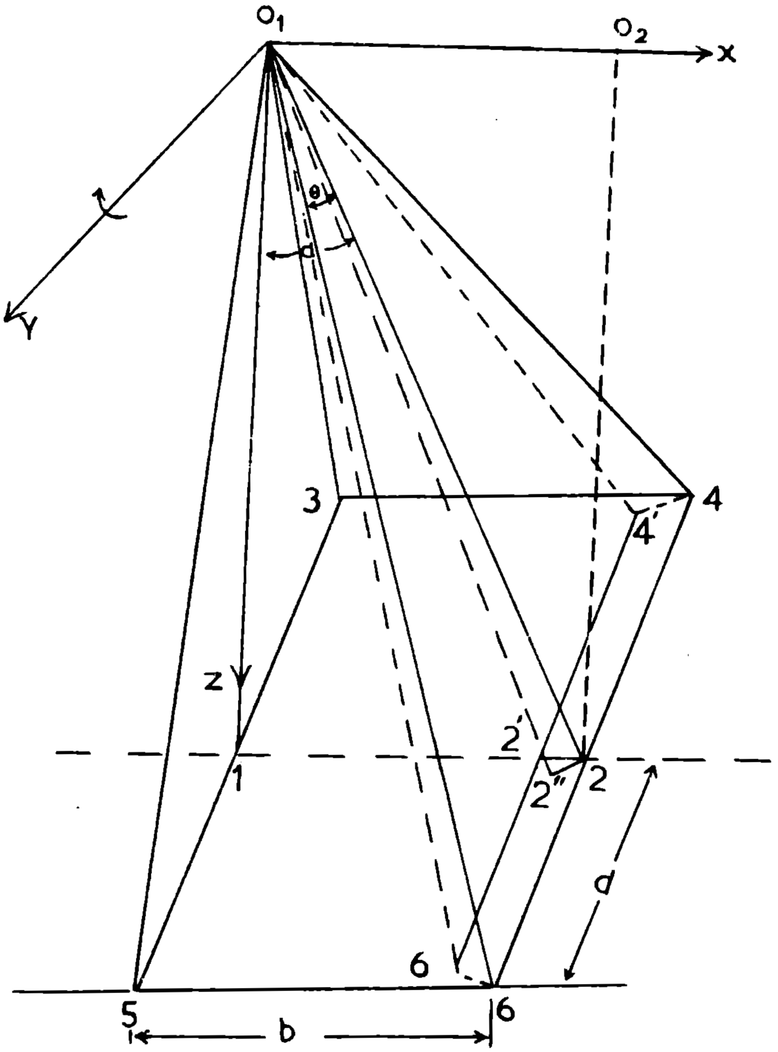


Fig. IV. 17

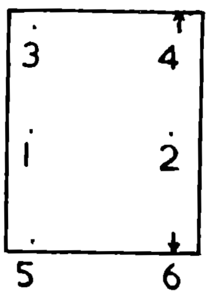


Fig. IV. 18

59 P.Z.D.'72-4000'73. PRINTED AT THE IGI (P.Z.O.) PRINTING GROUP

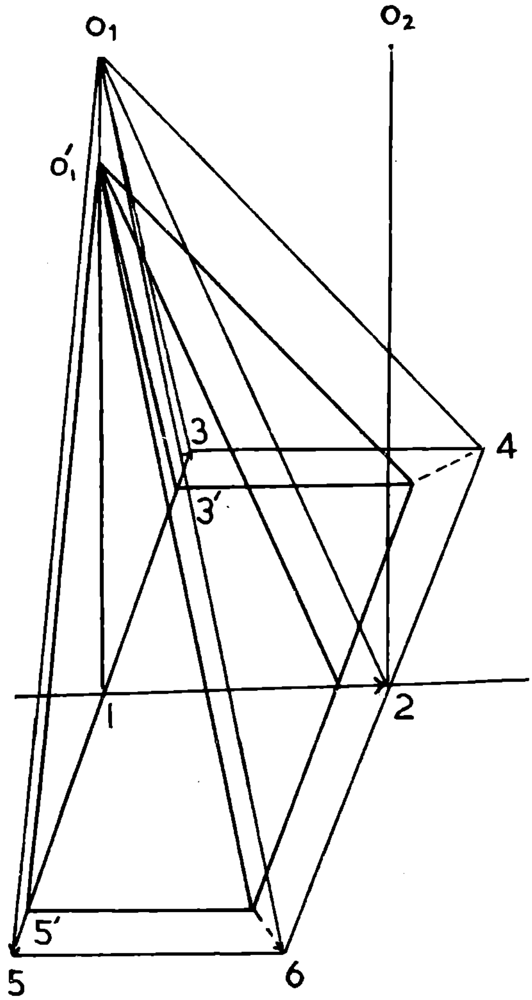


Fig. IV.19

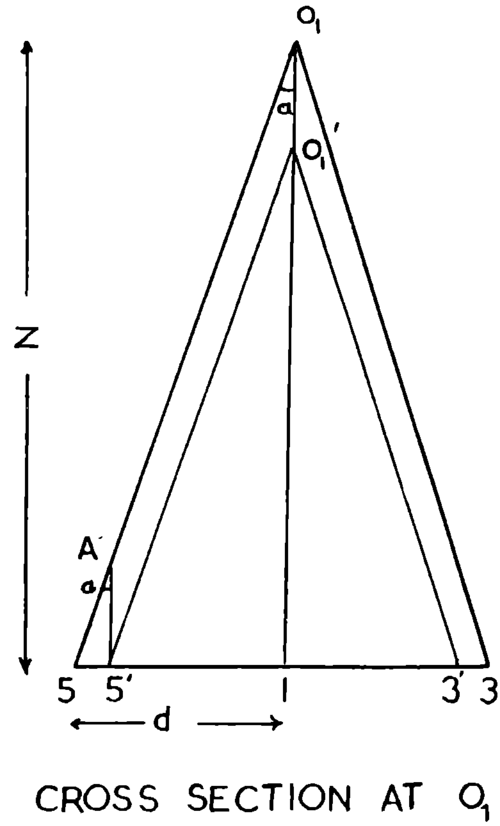


Fig. IV.20

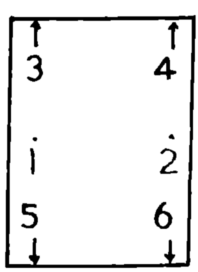


Fig. IV.21
Effect of bz

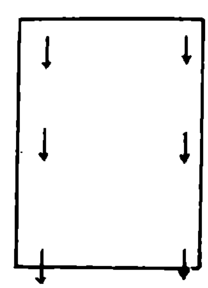


Fig. IV.22
Effect of by

Reg. No. 3959 P.Z.D.'72-4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

Effects of orientation elements

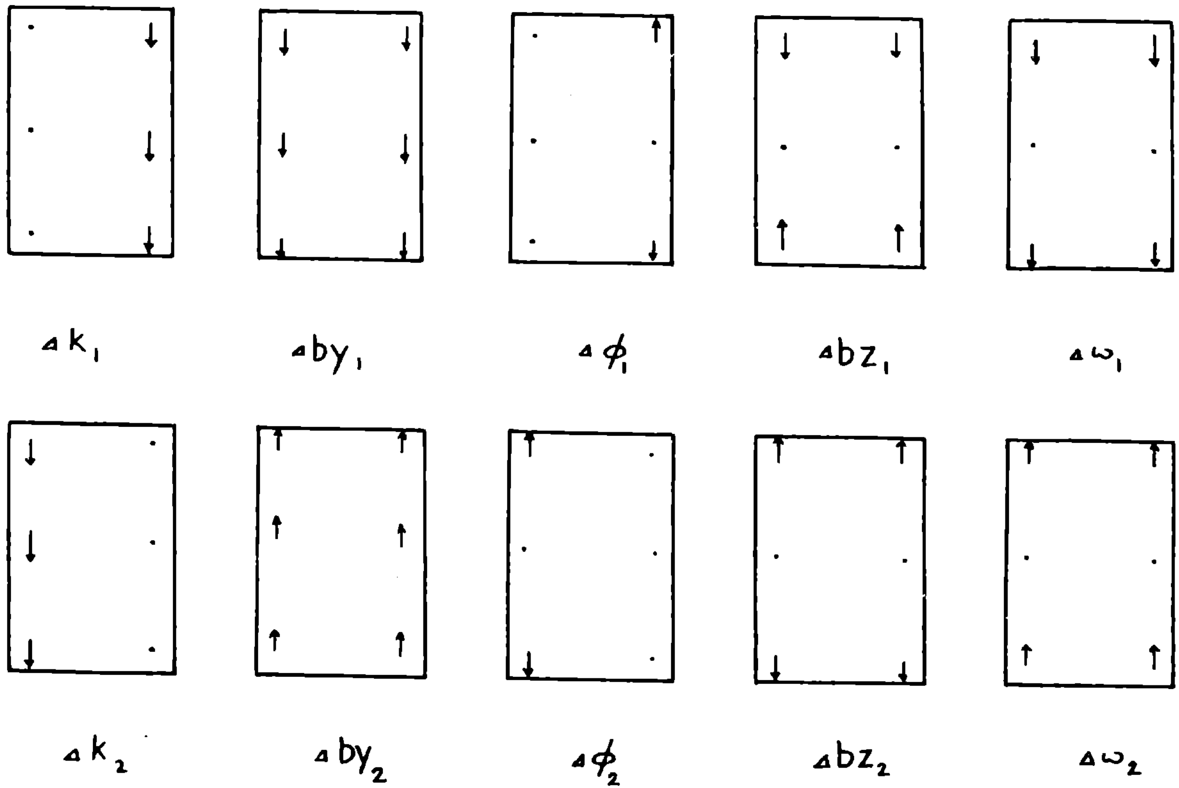
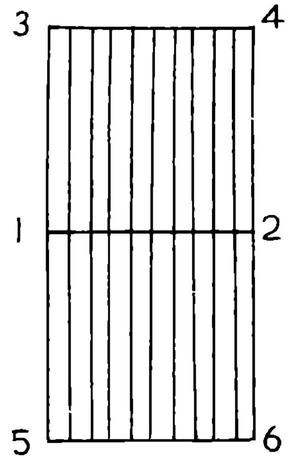


Fig. IV. 23

Z.D.'72-4000'73.
PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY

Model deformation



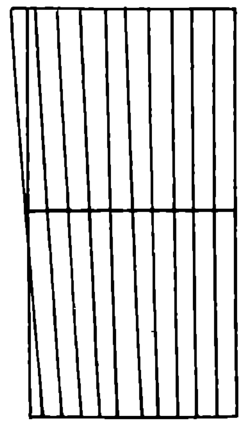


Fig. IV. 24

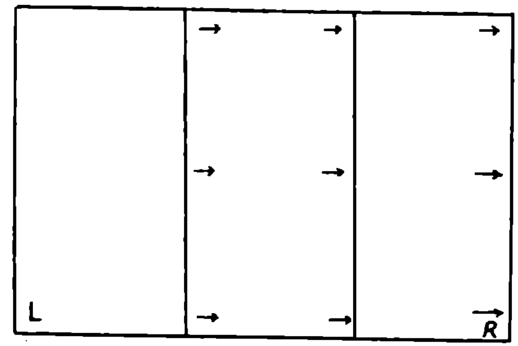


Fig. IV. 25

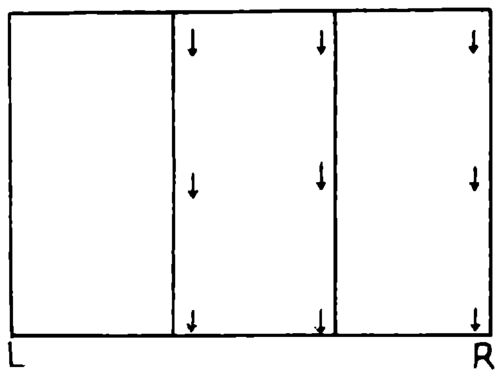


Fig. IV. 26

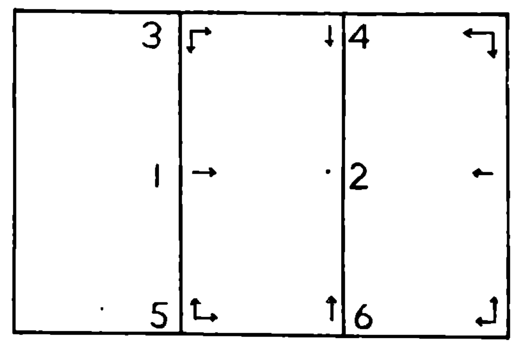


Fig. IV. 27

Reg. No. 3959 P.Z.D.'72-4000'73.

PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

Model deformation

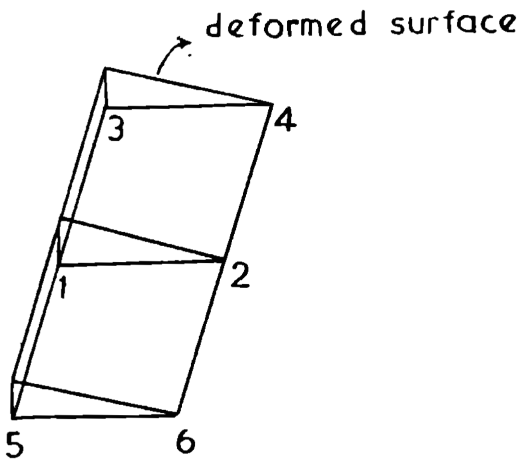


Fig. IV. 28

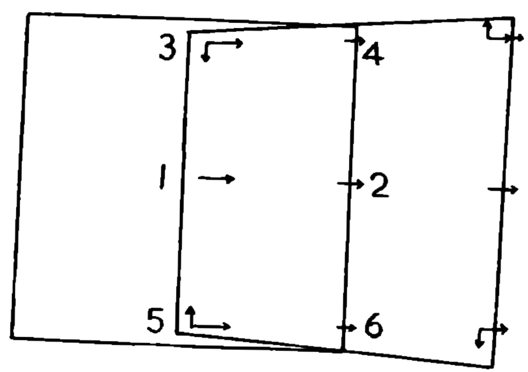


Fig. IV. 29

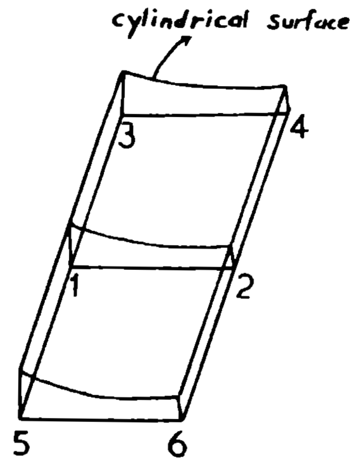


Fig. IV. 30

Reg. No. 3959 P.Z D.'72-4000'73.
PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

Model deformation

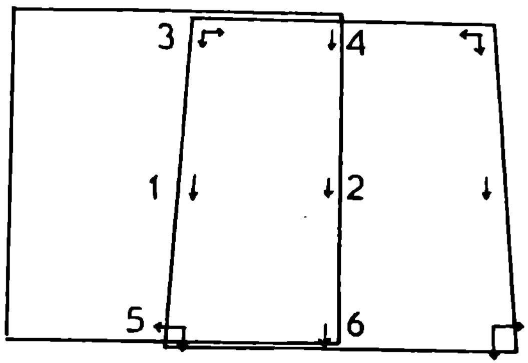


Fig. IV. 31

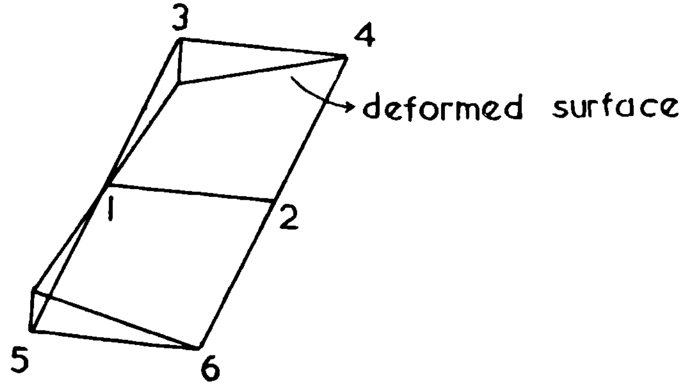


Fig. IV. 32

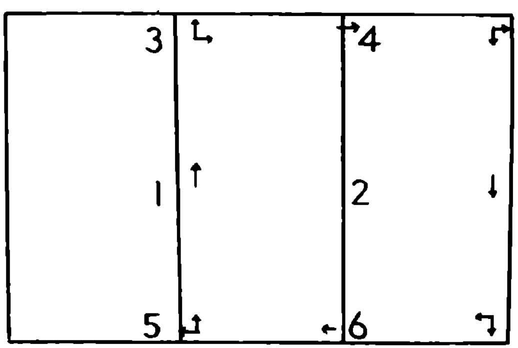


Fig. IV. 33

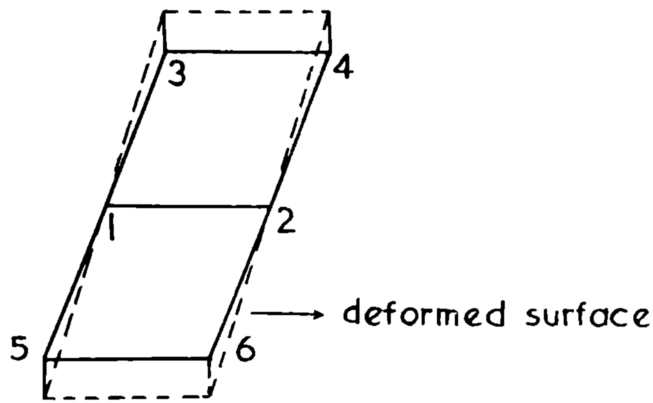


Fig. IV. 34

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Reg. No. 3959 P.Z.D.'72-4000'73.

Strip 6
Photos 2 & 3

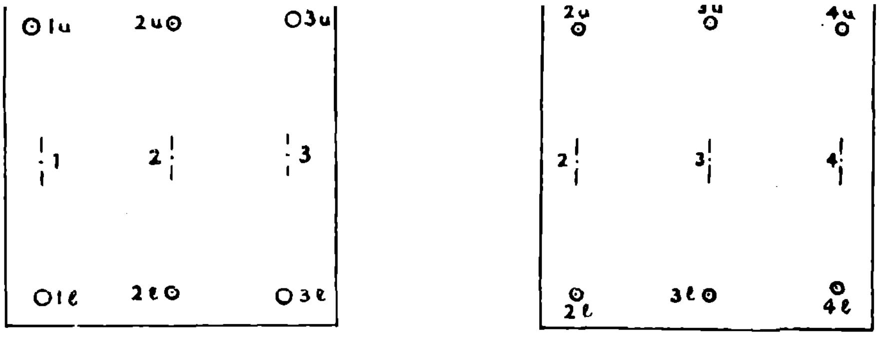


Fig. V. I M.C.Points

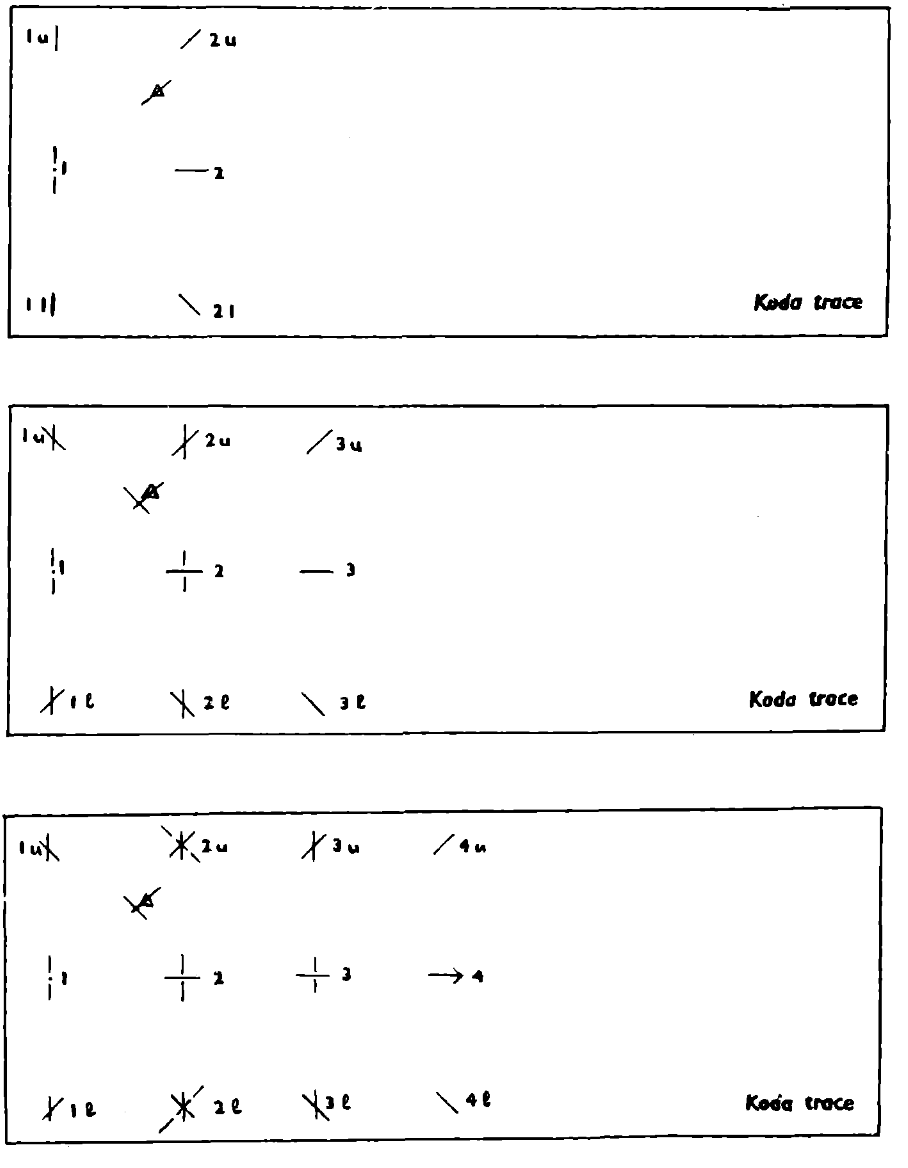
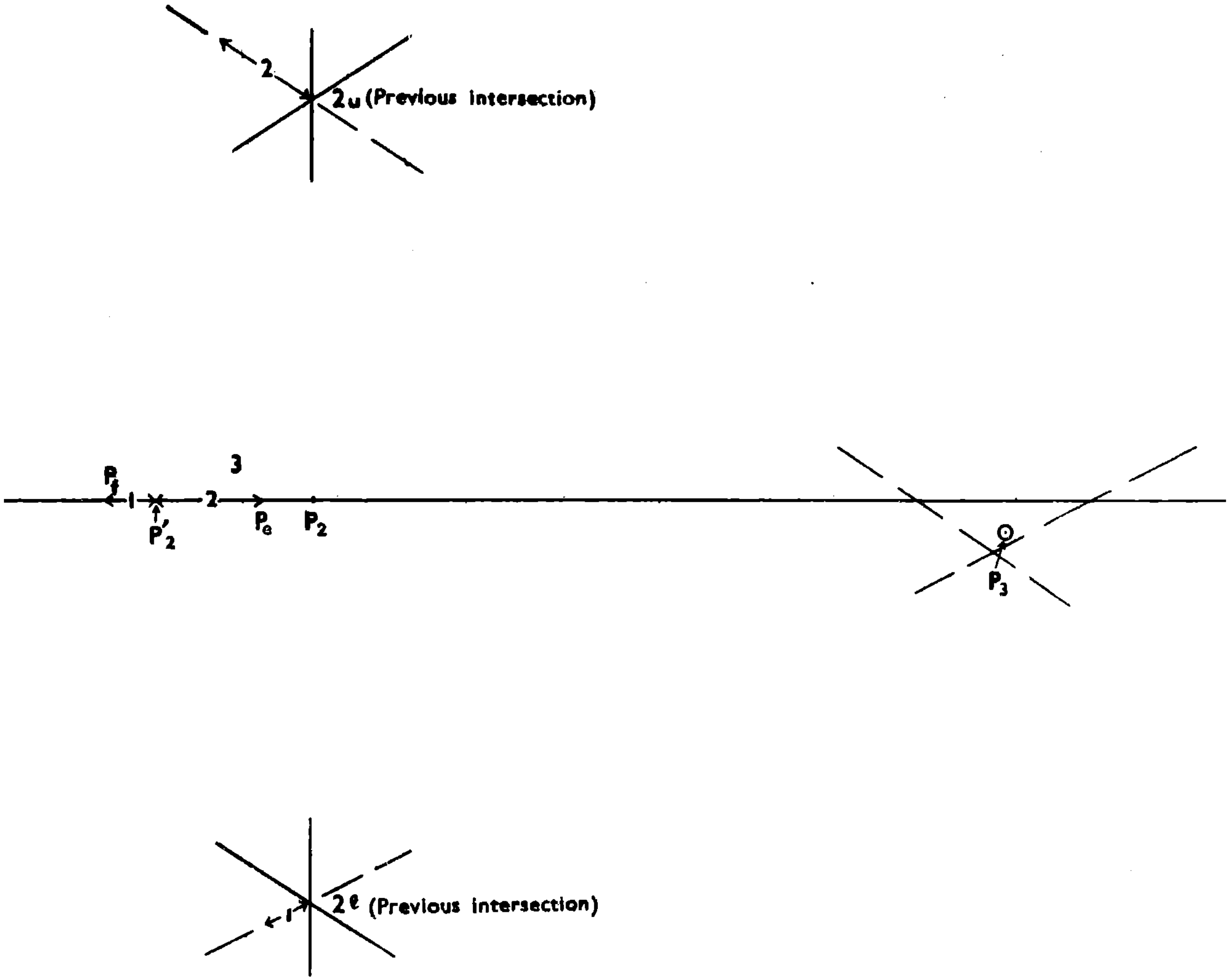


Fig. V. 2 M.C.Plot

Reg. No. 3959 P.Z.D.'72-4000'73.

PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.



P_e : Transferred Principal point with ray 2u

P_ℓ : Transferred Principal point with ray 2 ℓ

Fig. V. 3
Triangle of error

Reg. No. 3959 P.Z.D.'72-4000'73.

Printed at the 103 (P.Z.O.) Printing Group of Survey of India

Short overlap

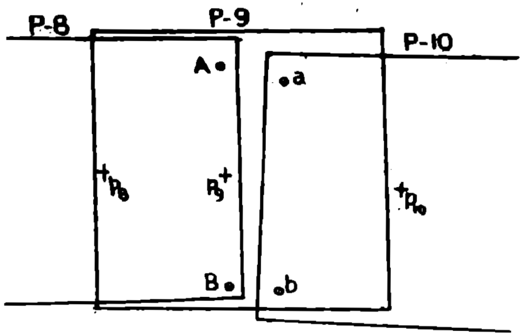


Fig. V.4

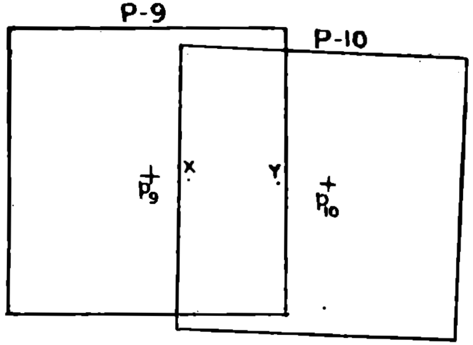


Fig. V.5

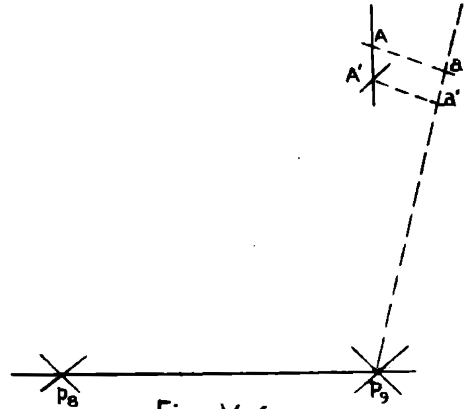


Fig. V.6

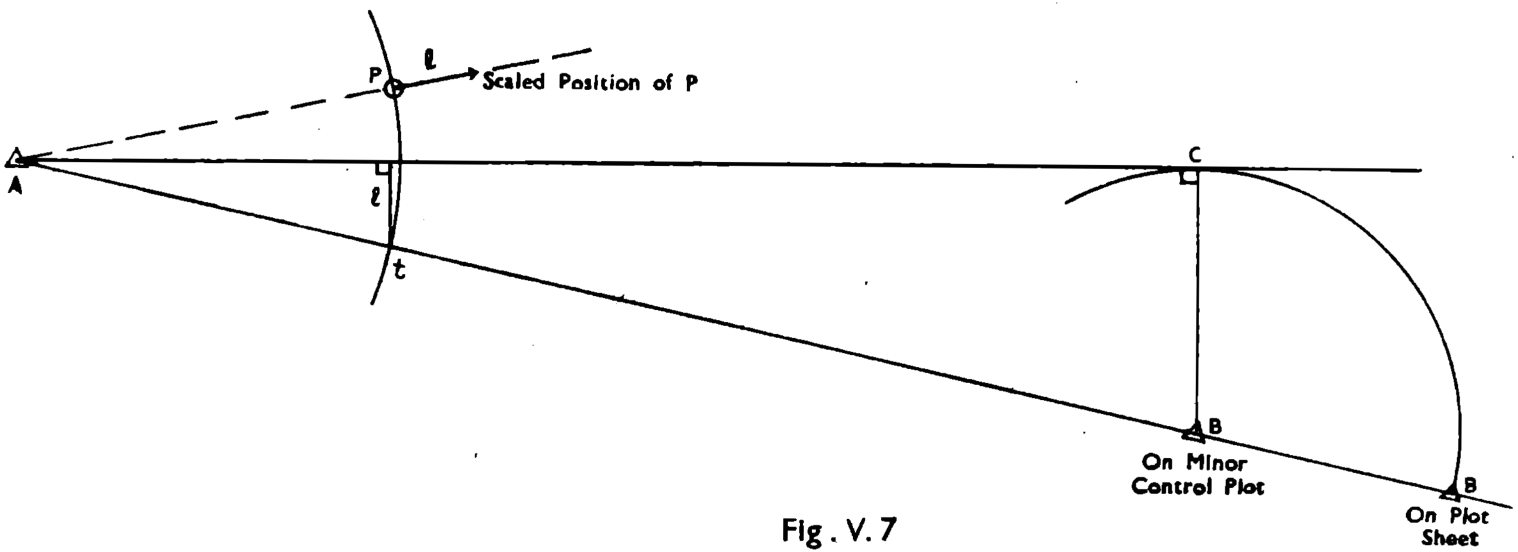


Fig. V.7
Scaling of m.c. plot

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Reg. No. 3959 P.Z.D.'72-4000'73.

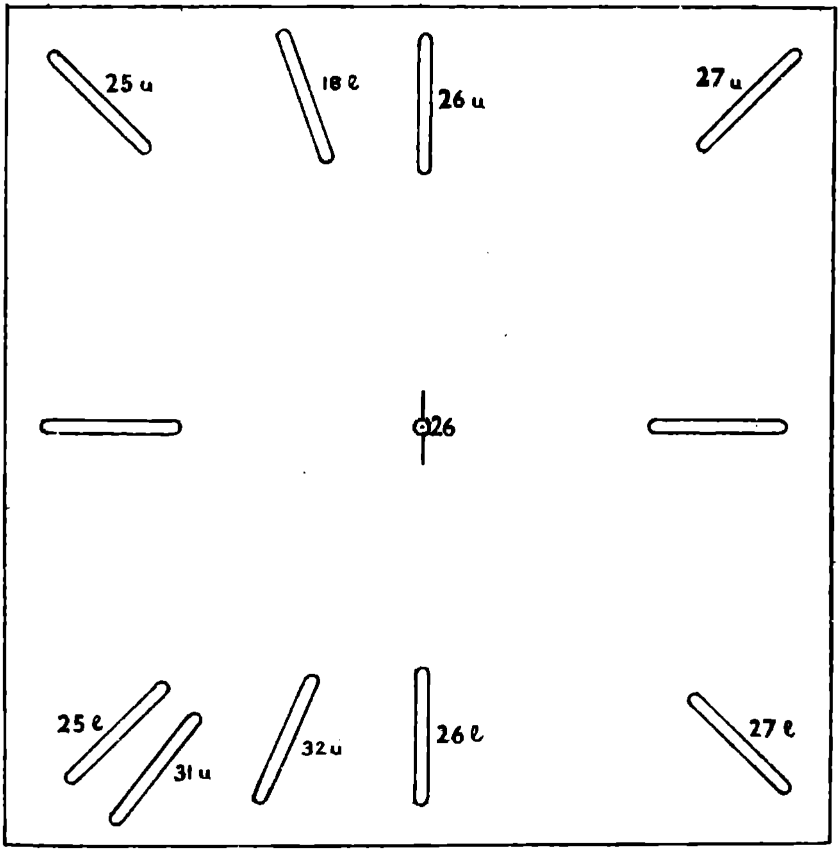
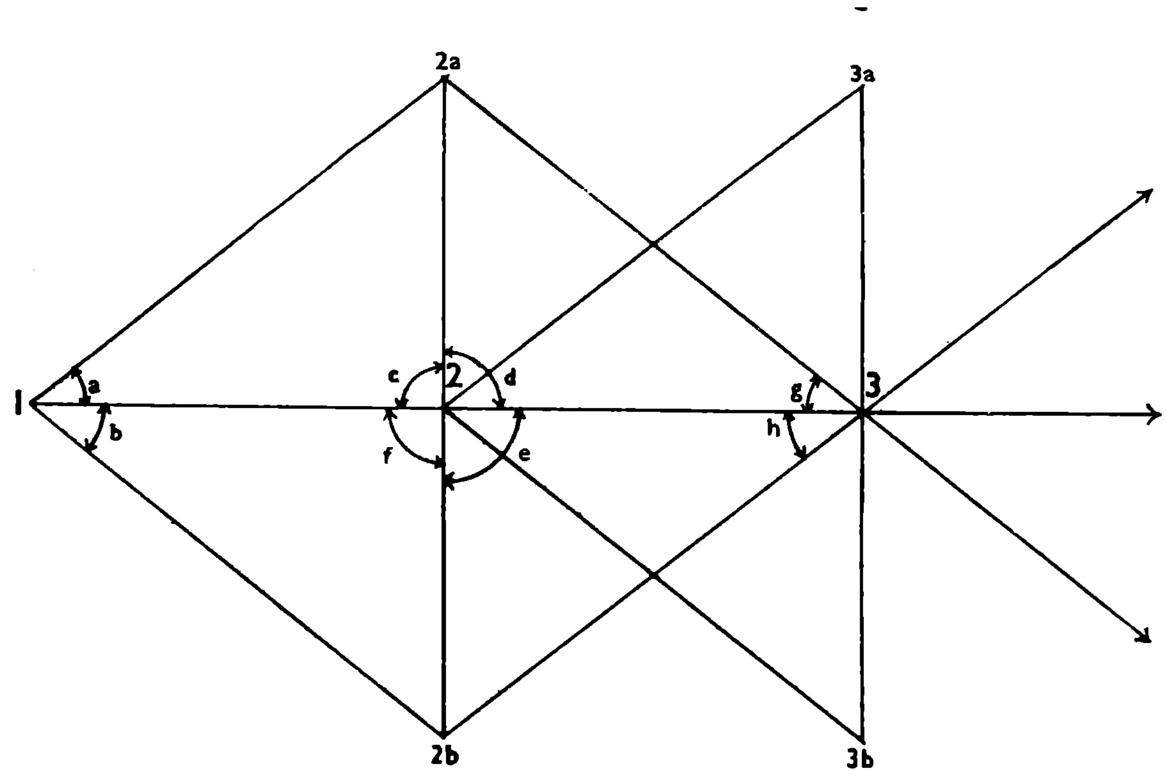


Fig . V. 8
Slotted templet

D.'72-4000' 75.   PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA



1, 2, 3......... Principal points

a, b,.........g : Angles measured in Radial Triangulator

2a, 2b, 3a, 3b : Pass points

Fig. V.11
Radial triangulator

No. 3959 P.Z.D.'72-4000'73.

PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

Projective transformation

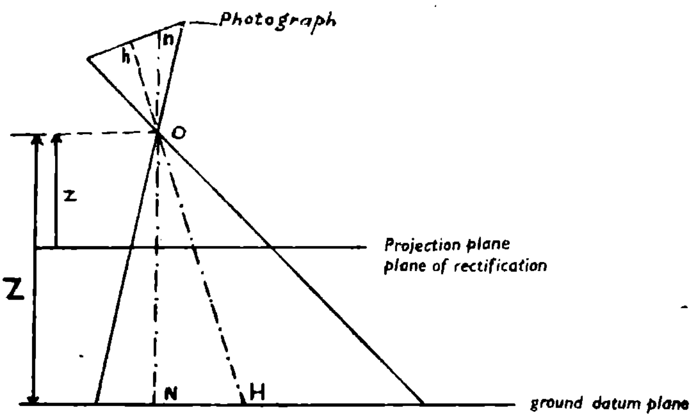


Fig. VI.1

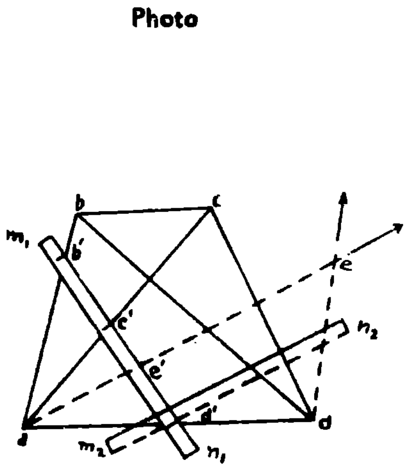


Fig. VI.2

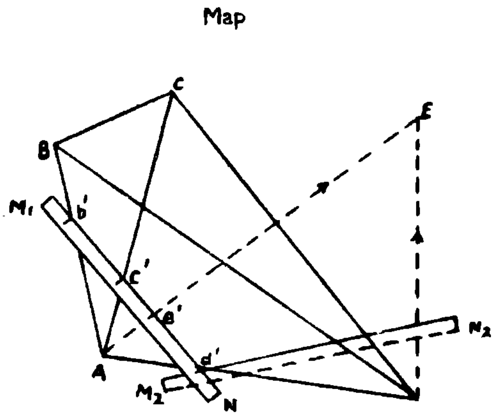


Fig. VI.3

Map

i9 P.Z.D.'72-4000' 73.

PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF

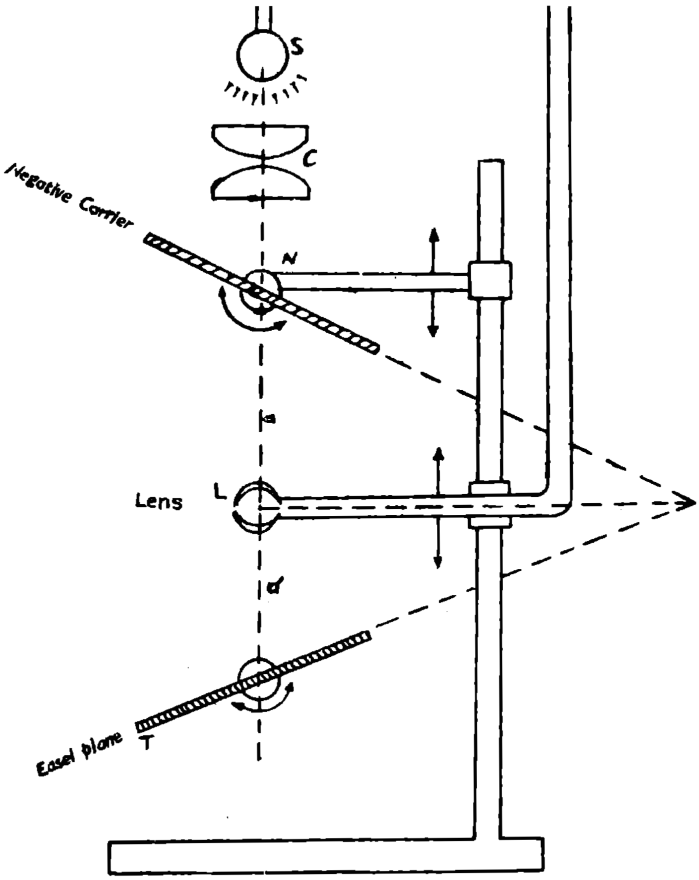


Fig. VI.6 Rectifier

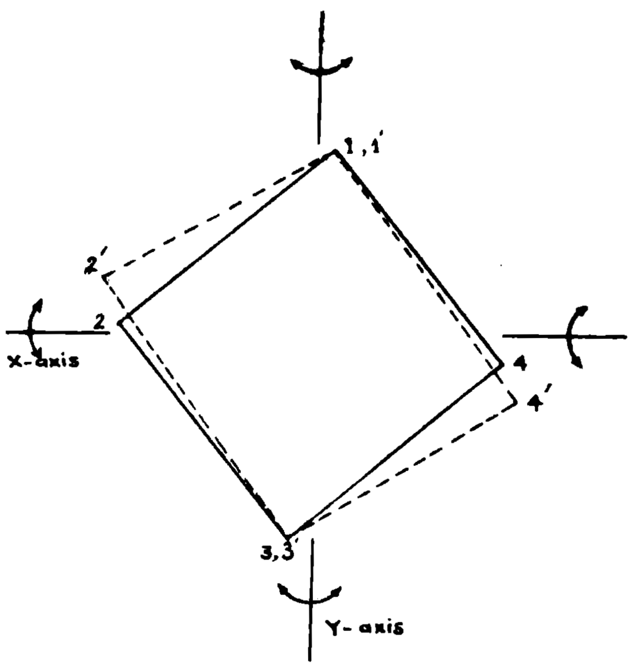


Fig. VI.7
Projected images on the plot sheet

Reg. No. 3959 P.Z.D.'72-4000' 73.

PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

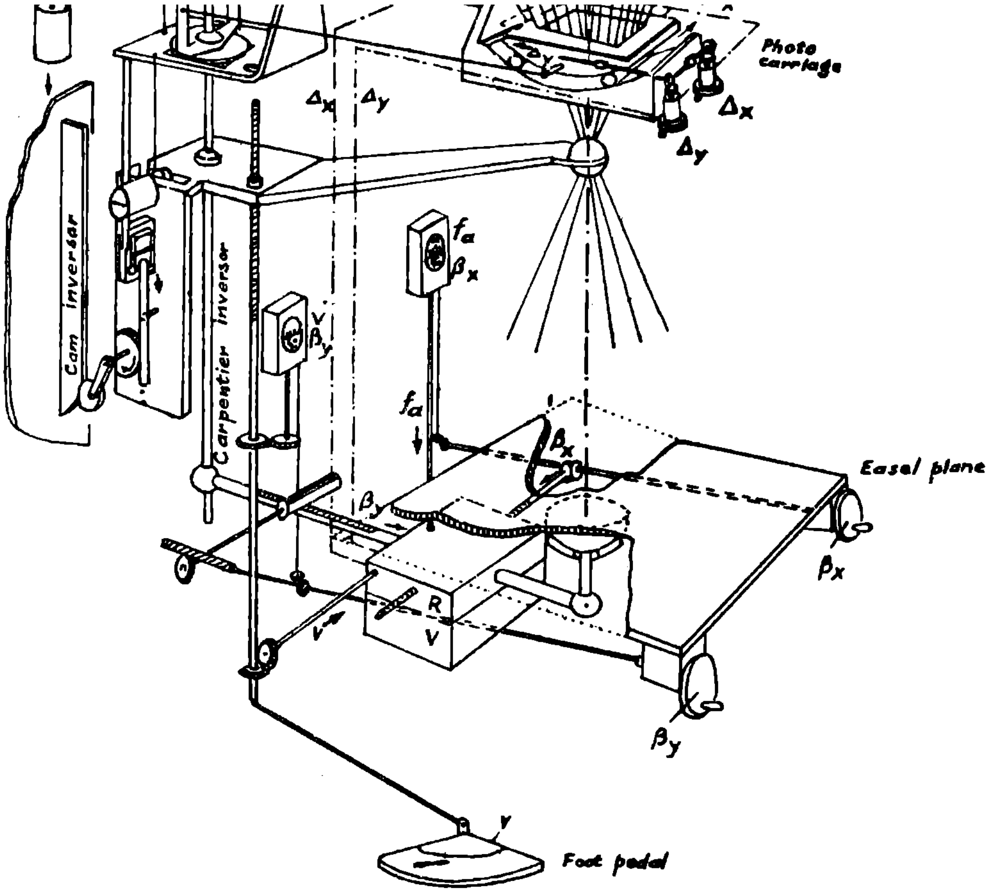


Fig. VI.8

Zeiss SEG V Rectifier
Schematic diagram

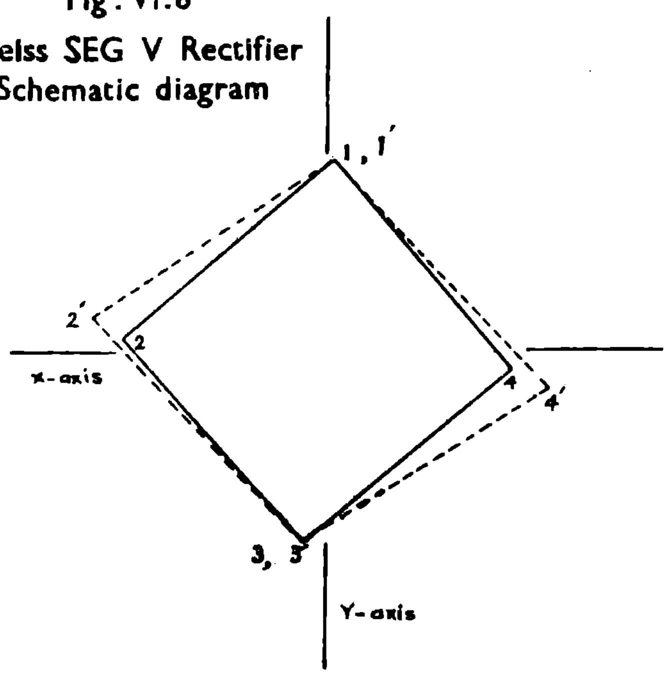


Fig. VI.9
Projected images on the plot sheet

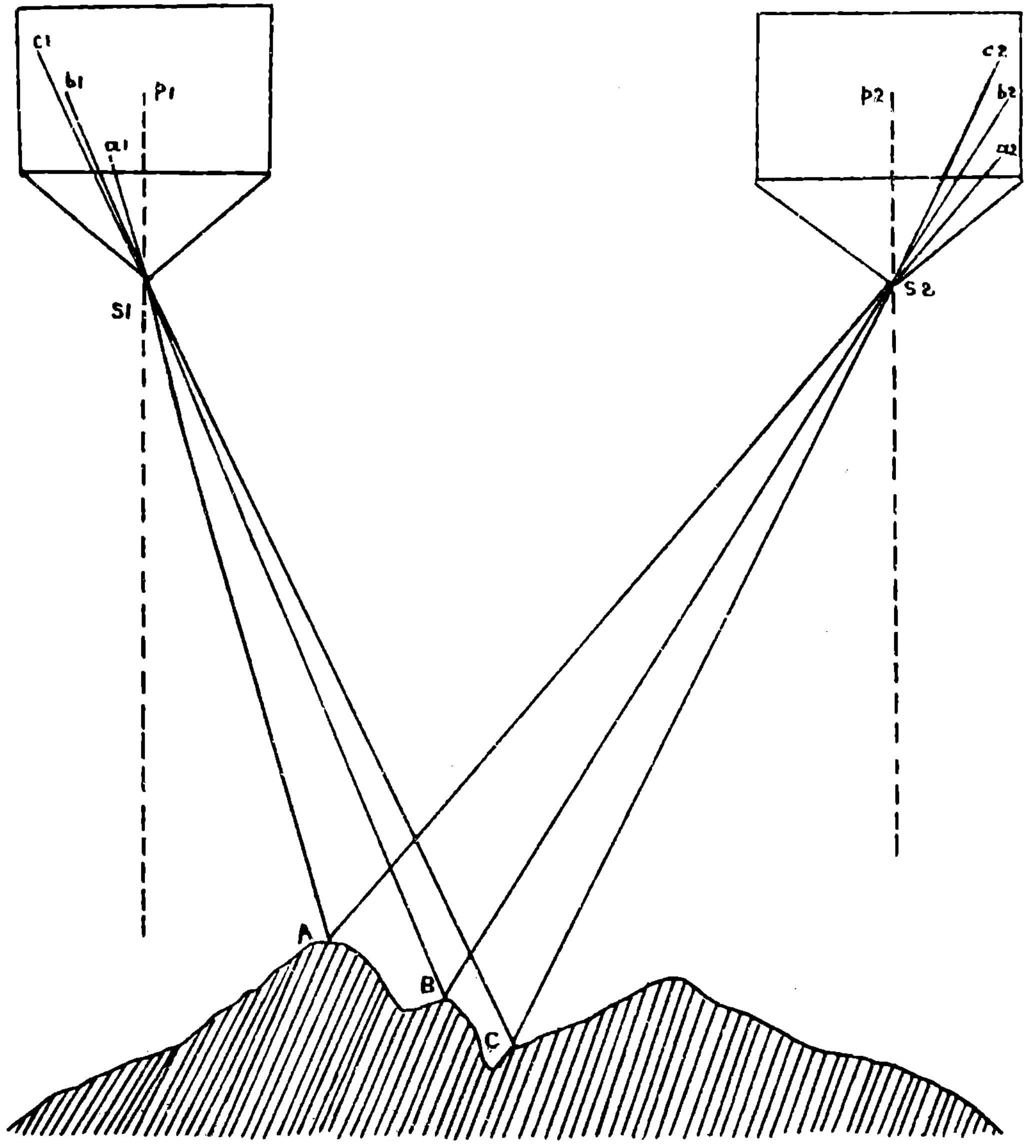


Fig. VIII.1

Homologous rays

Reg. No. 3959 P.Z.D.'72-4000'73.

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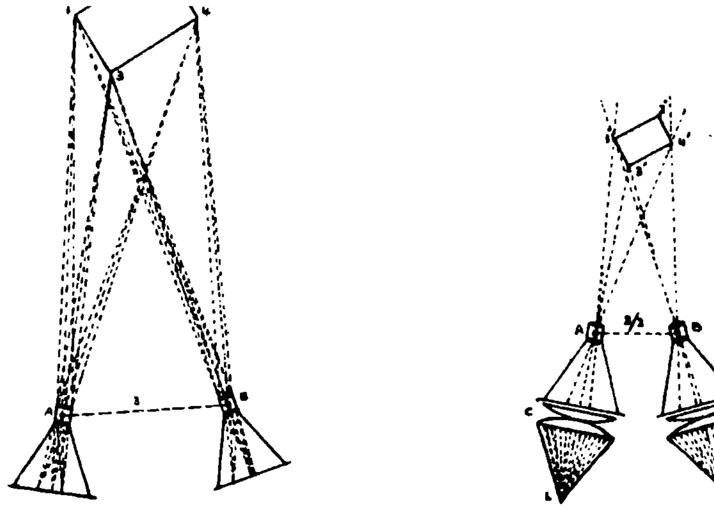

Fig. VIII.2

Scheimpflug's experiment

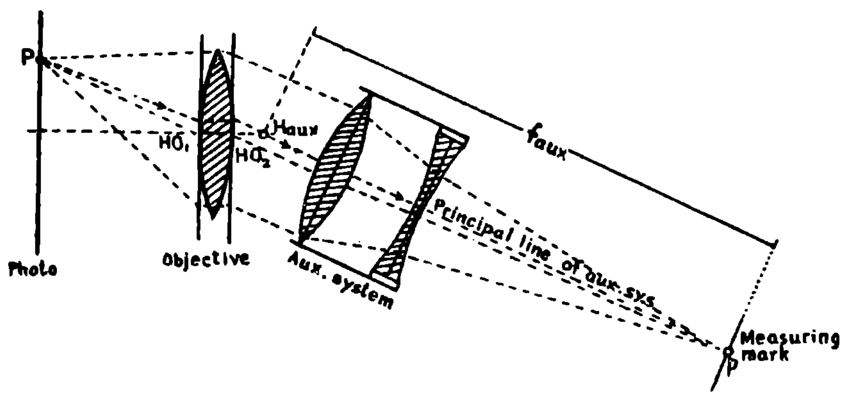

Fig. VIII.3

Auxiliary lens system

No. 3959 P.Z.D.'72-4000'73.

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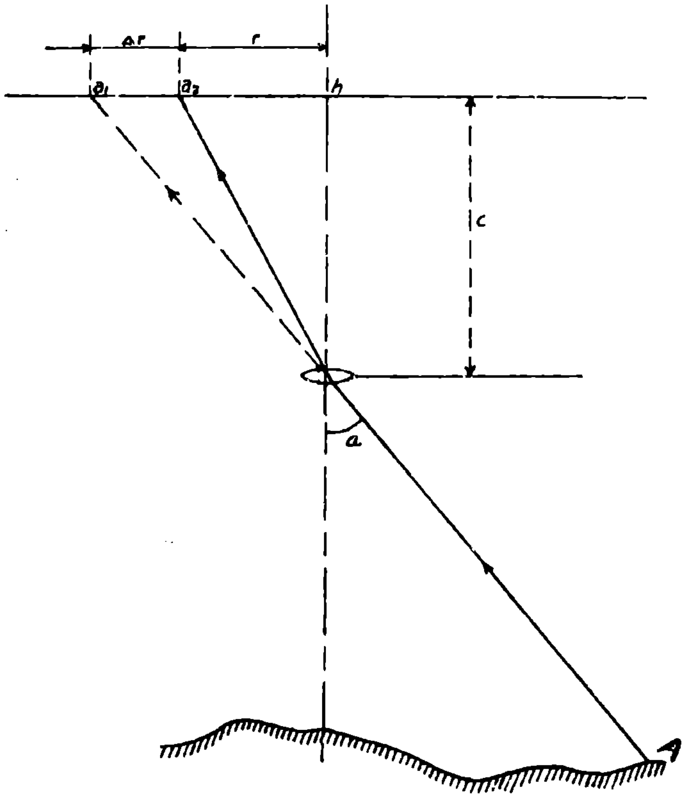

Fig. VIII.4
Lens distortion

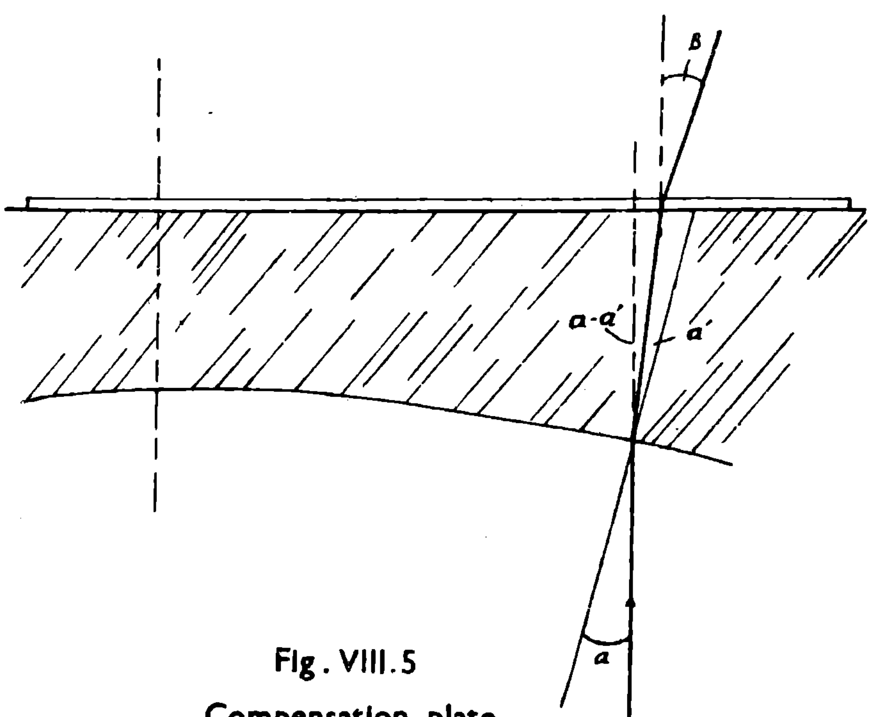

Fig. VIII.5
Compensation plate

Reg. No. 3959 P.Z.D.'72-4000'73.   PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

Parallelogram of Zeiss

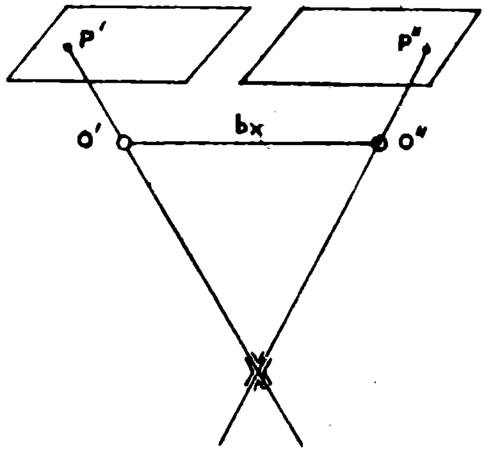

Fig. VIII.6

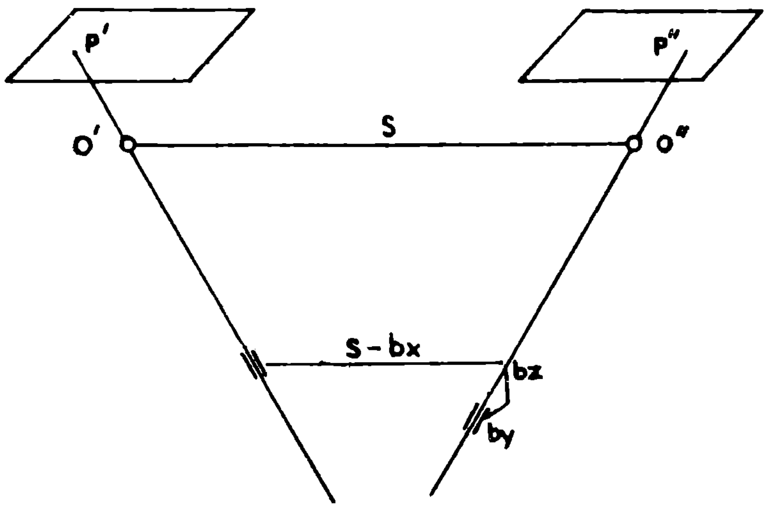

Fig. VIII.7

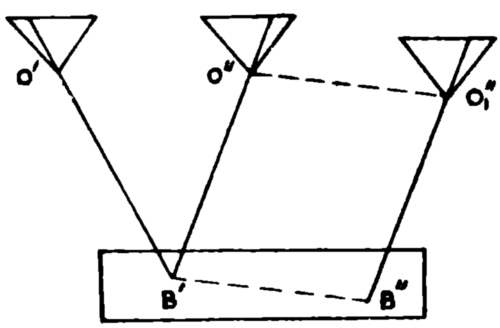

Fig. VIII.8

Reg. No. 3959 P.Z.D.'72-4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF I

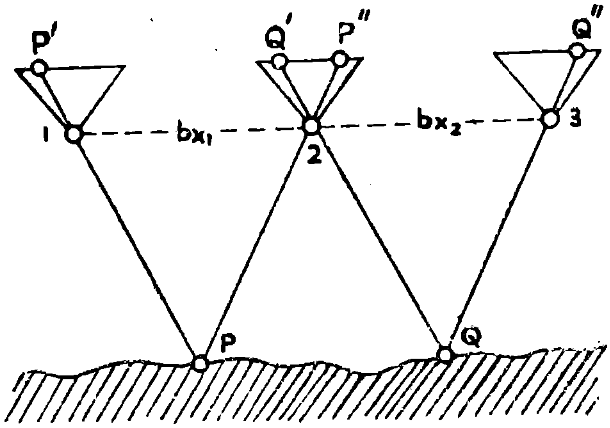

Fig. VIII.9

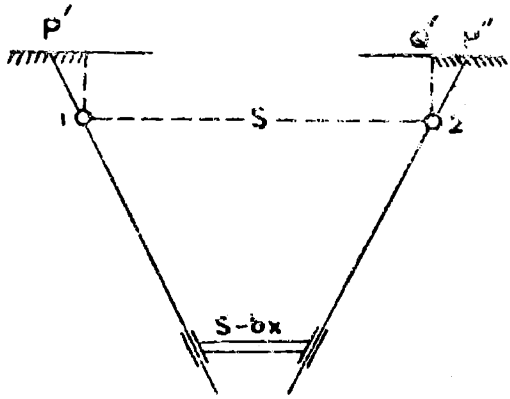

Fig. VIII.10

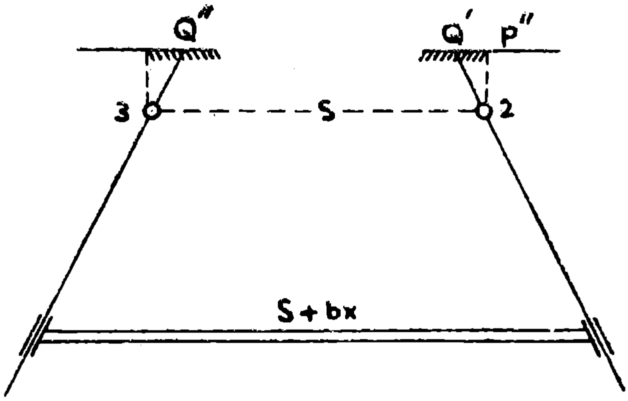

Fig. VIII.11

Reg. No. 3959 P.Z.O.'72-4000'73.

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Dove prism

When dove prism is rotated through 90°, the image is rotated through 180°

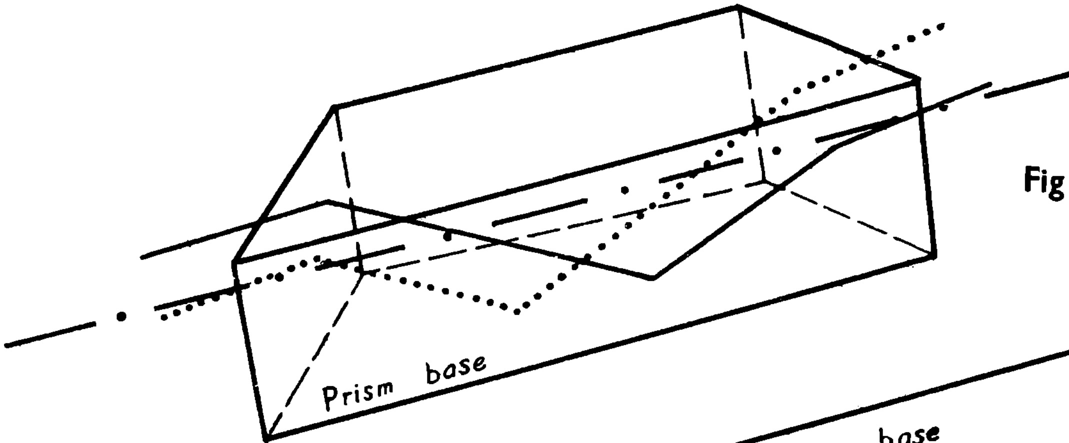


Fig. VIII.12

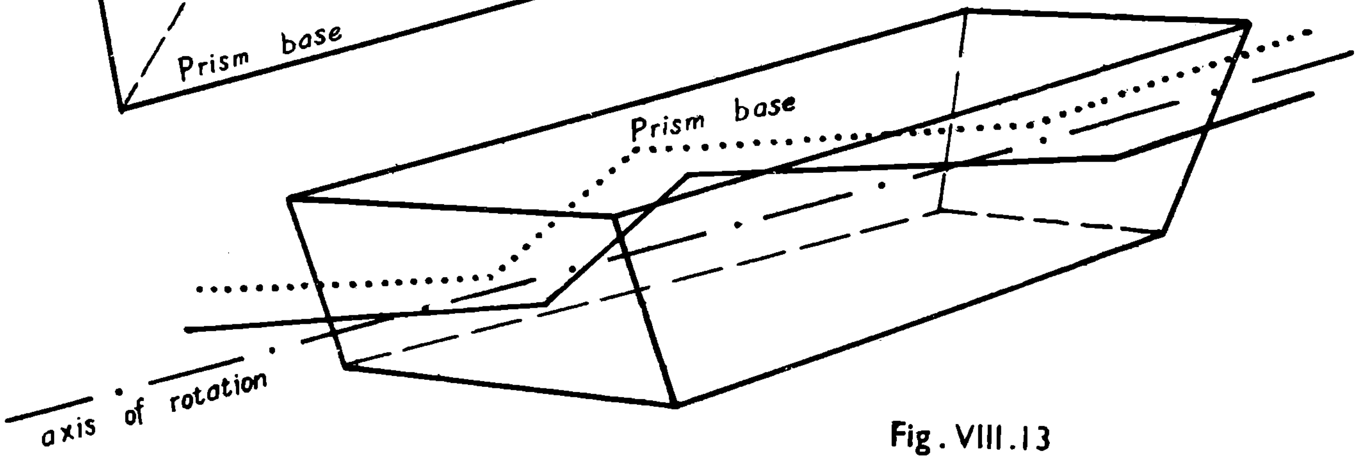


Fig. VIII.13

No. 3959 P Z.D.'72-4000'73.
PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

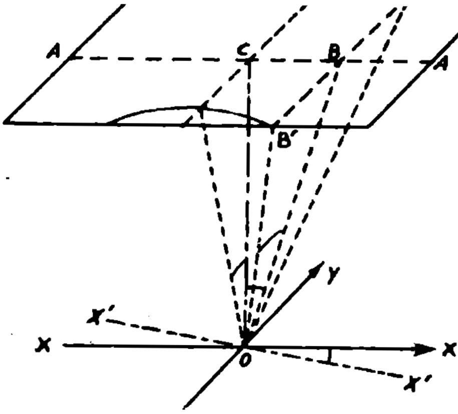


Fig. VIII.14

Influence of the position of primary axis

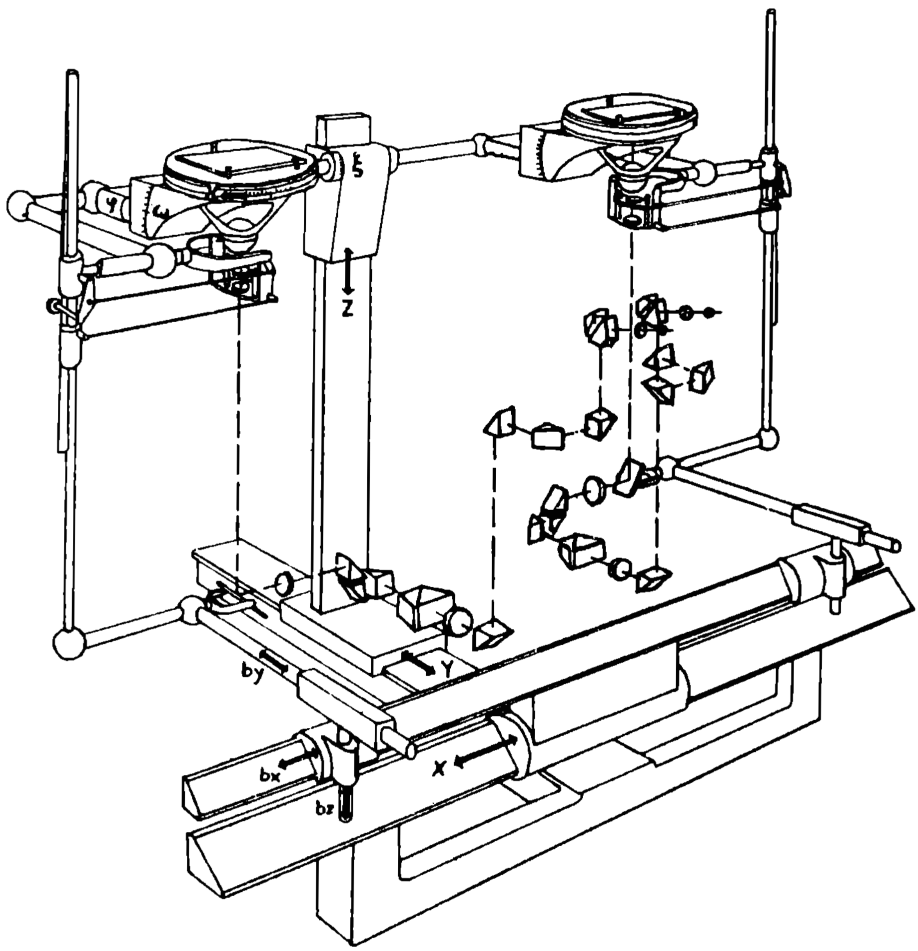


Fig. VIII.15

Schematic diagram of Stereoplanigraph C 8

3959 P.Z.D.'72-4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

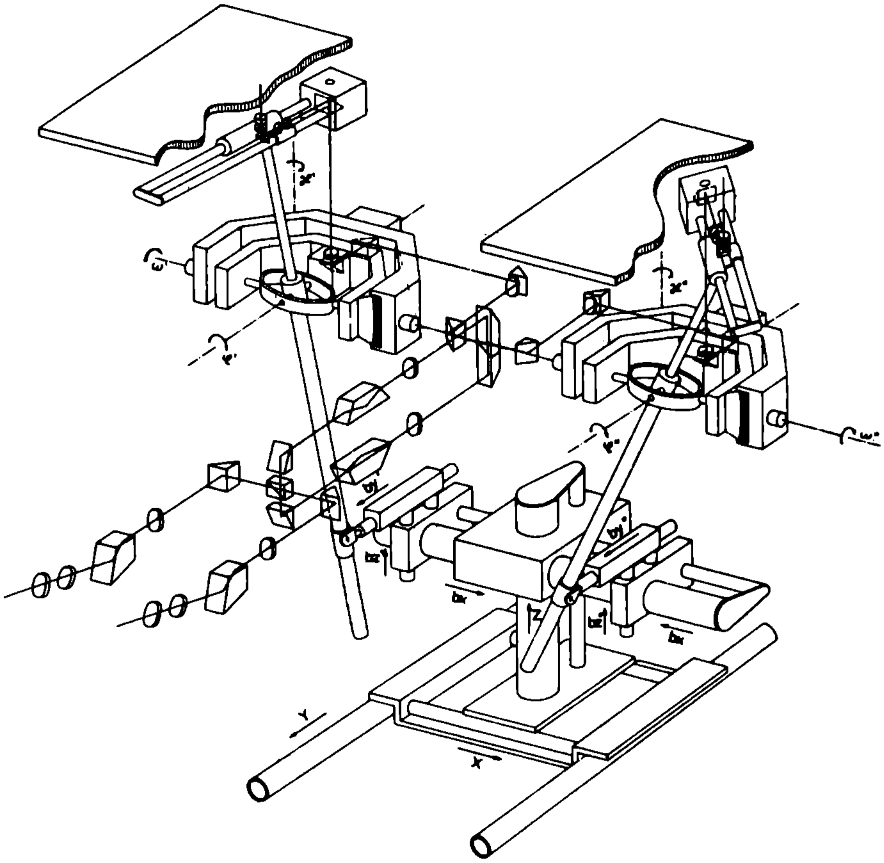
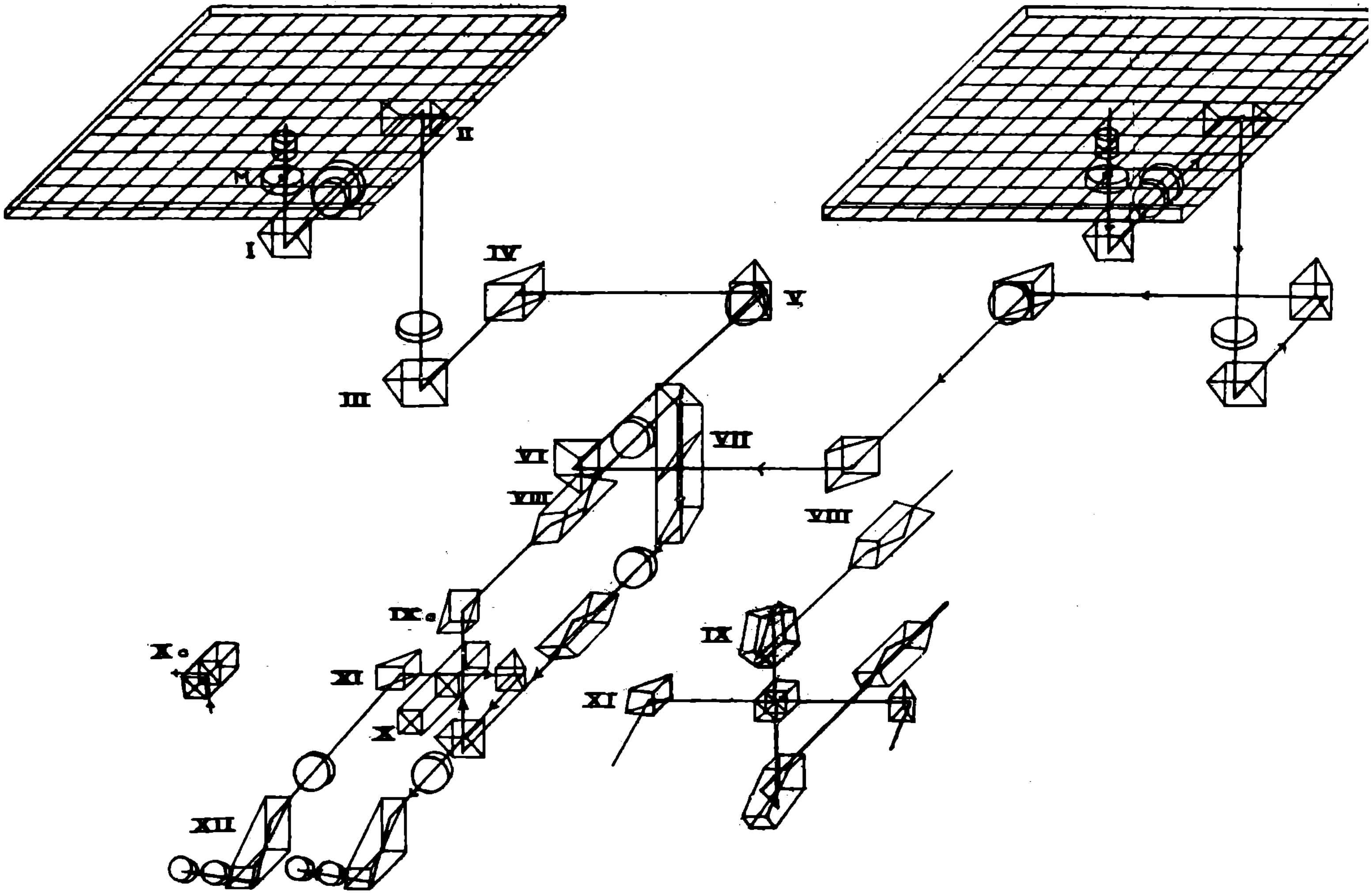


Fig. VIII.16
Schematic diagram of Wild Autograph A 7

Reg. No. 3959 P.Z.D.'72-4000'73.

Printed at the 103 (P.Z.O.) Printing Group of Survey of



Optical path from right photo........
Optical path from left photo..........

Fig. VIII.17
Optical train in A 7

Reg. No. 3959 P.Z.D.'72-4000'73.
PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

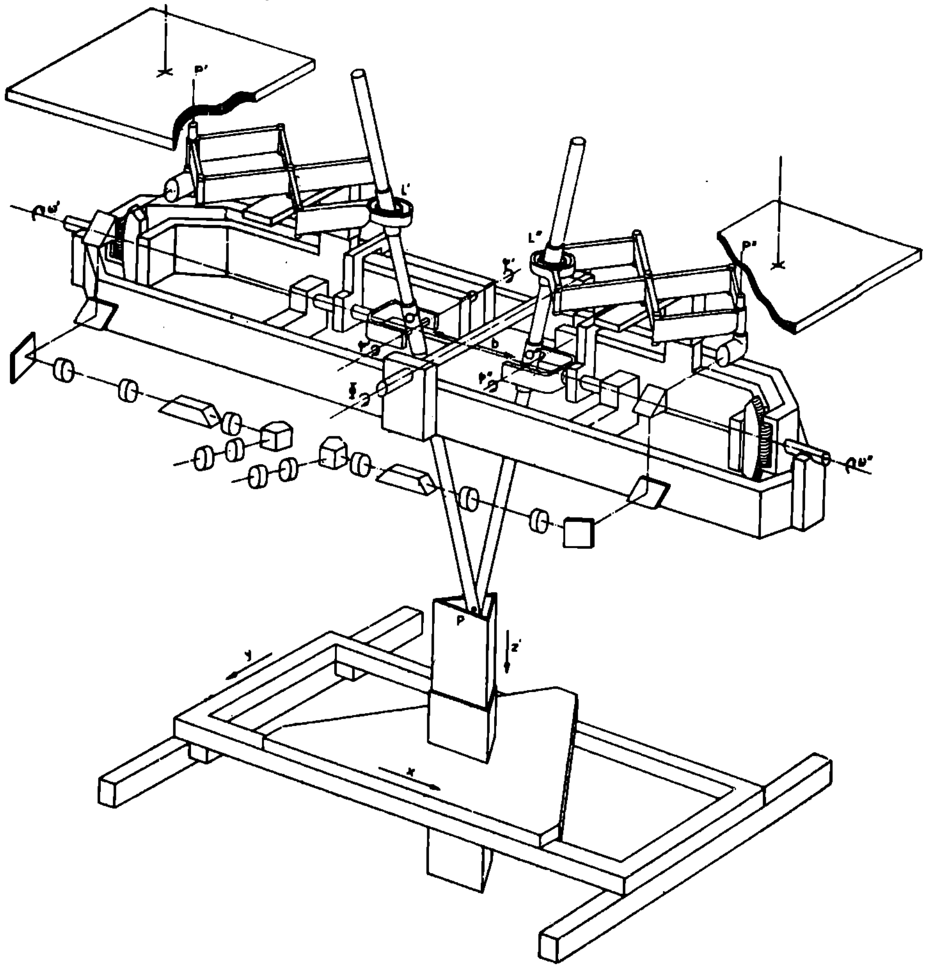


Fig. VIII.18

Schematic diagram of Wild Autograph A 8

Reg. No. 3959 P.Z.D.'72-4000'73.

PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

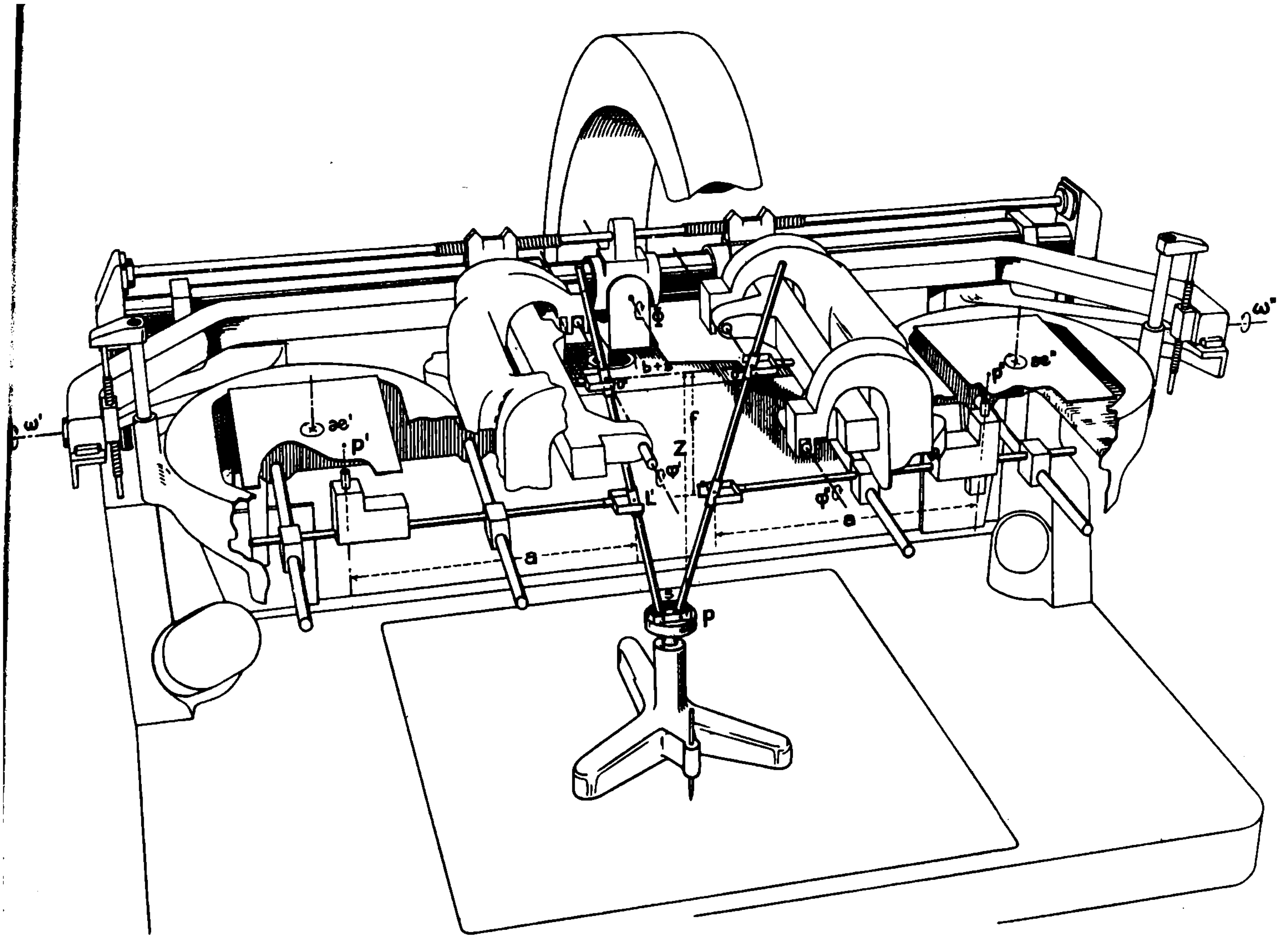


Fig. VIII.19
Schematic diagram of Wild B 8

Reg. No. 3959 P.Z.D.'72-4000'73.   Printed at the 103 (P.Z.O.) Printing Group of Survey of India.

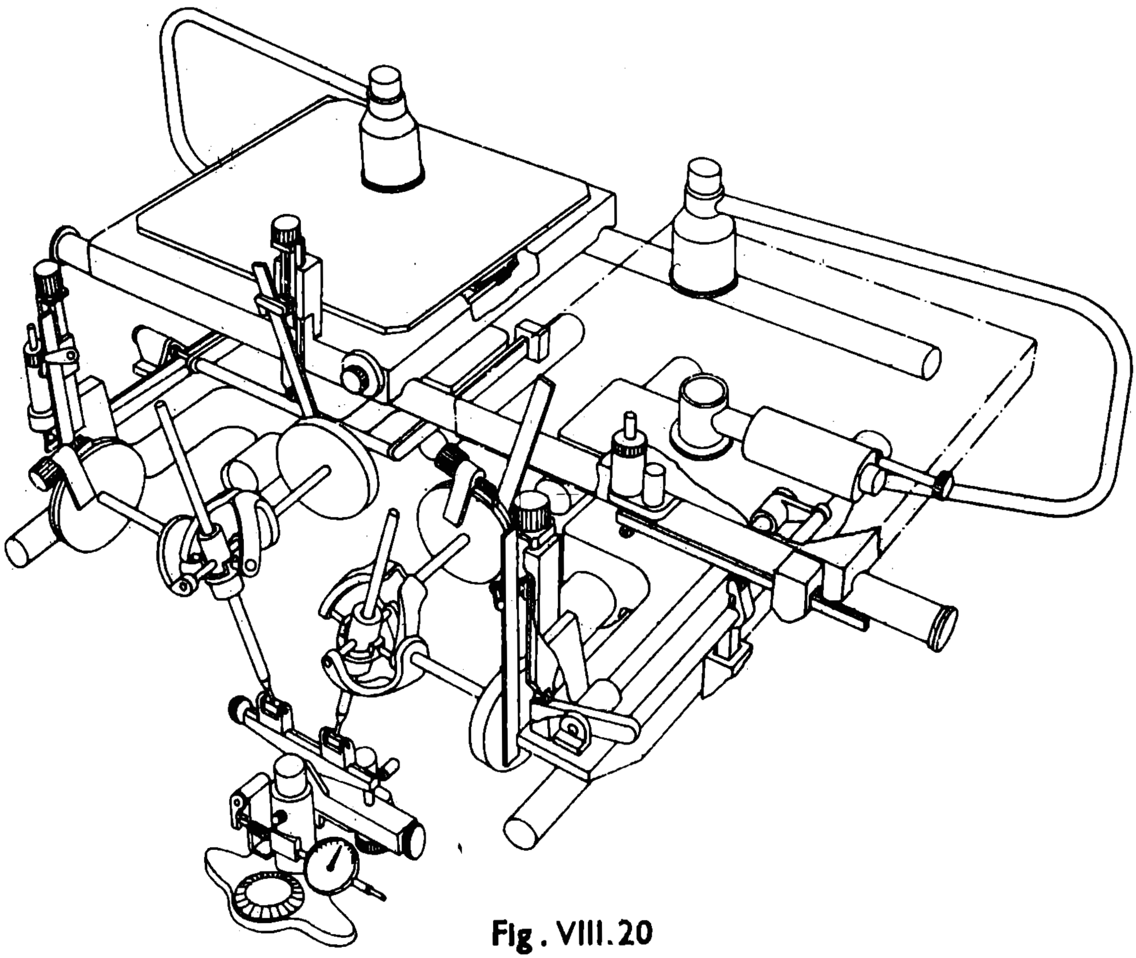


Fig. VIII.20
Schematic diagram of Kern PG 2

No. 3959 P.Z.D.'72-4000'73.   PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

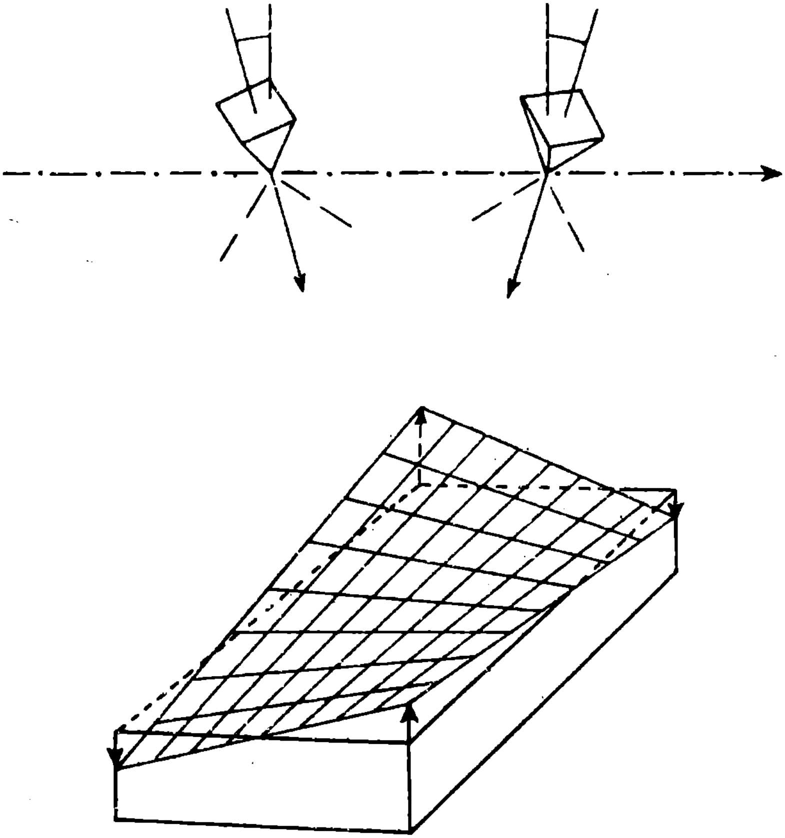


Fig. VIII.21
The deformed model

No. 3959 P.Z.D.'72-4000'73.

PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

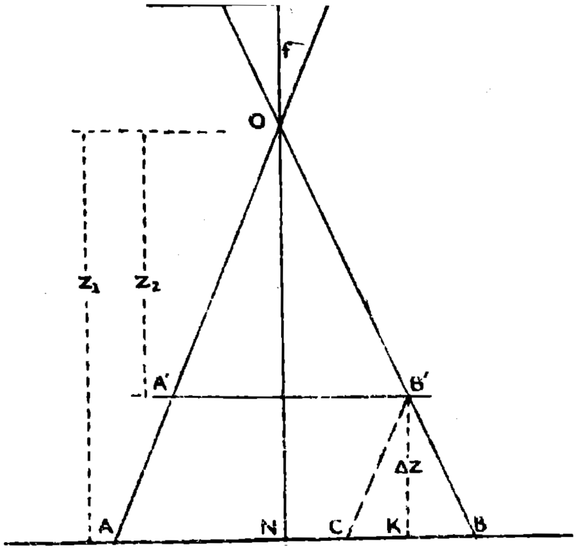


Fig. VIII.22
Calibration of z and f

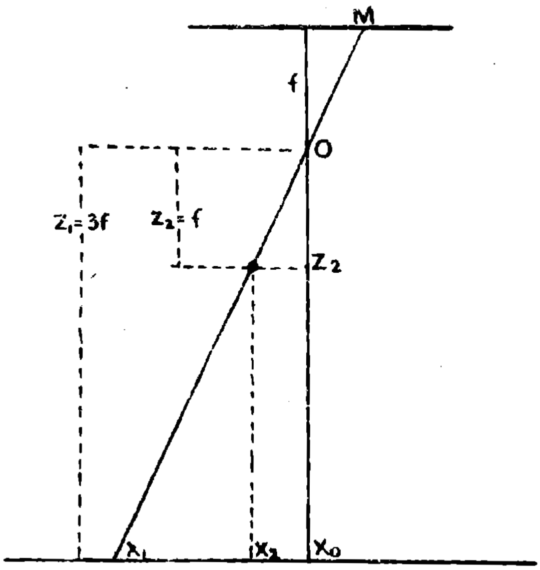


Fig. VIII.23
Verticality of space rods

Reg. No. 3959 P.Z.D.'72-4000'75.

PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA

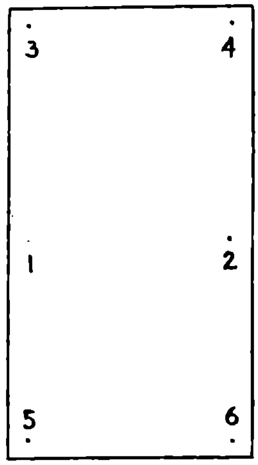


Fig. IX.1
Six points of the neat model

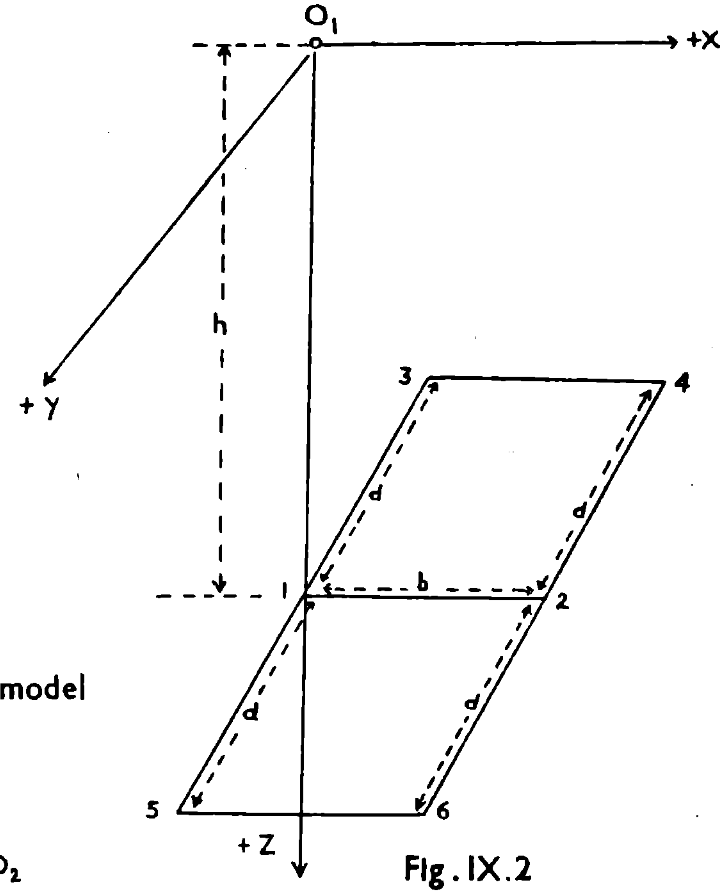


Fig. IX.2
Numerical rel. orientation

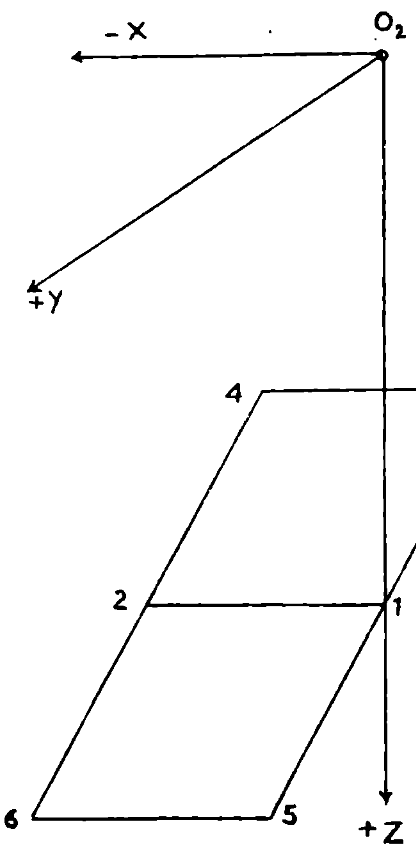


Fig. IX.3
Numerical rel. orientation

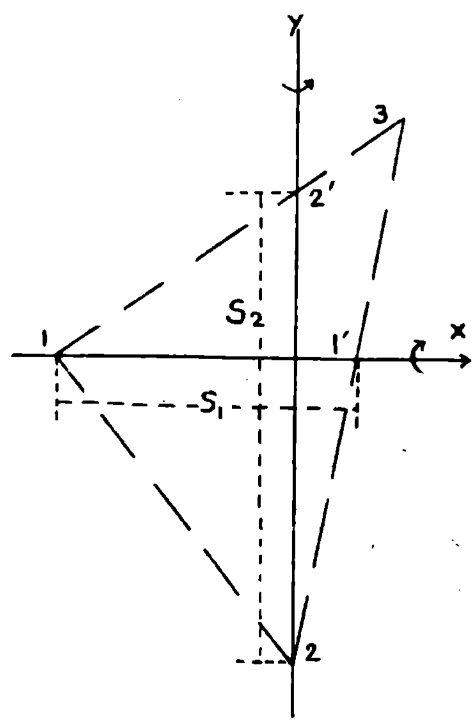
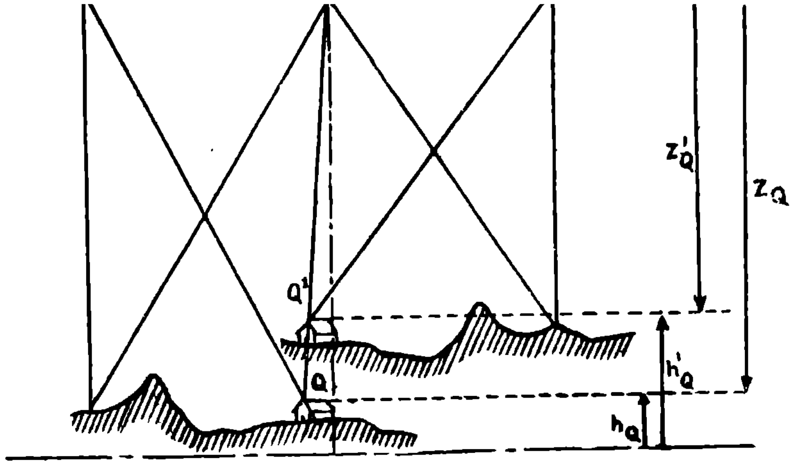


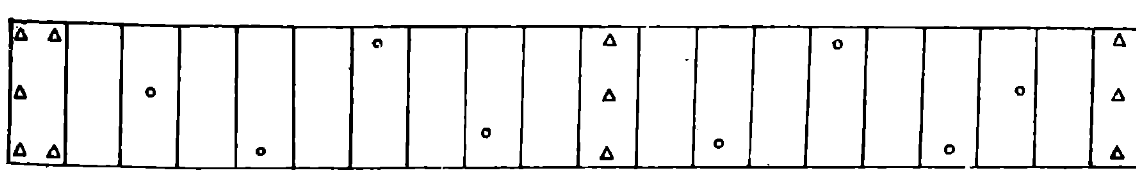
Fig. IX.4
Horizontalisation

Reg. No. 3959 P.Z.D.'72-4000'78. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.



$$\frac{\Delta bx}{b} = \frac{Z_Q - Z'_Q}{Z'_Q} = \frac{-h_Q + h_Q}{Z'_Q}$$

Fig. X.1
Base setting



Δ Ideal positions of control points required for strip adjustment by graphical method.

○ Random positions of check points.

Fig. X.2
The 3-band Control for strip adjustment

Pg. No. 3959 P.Z.D.'72-4000'73.

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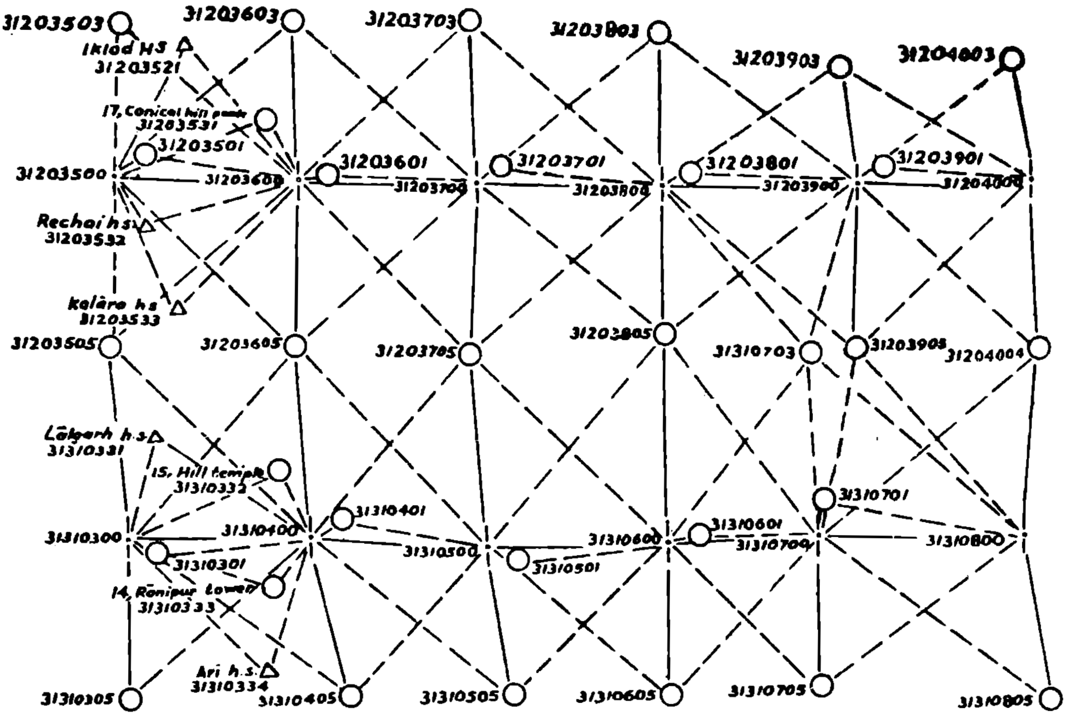
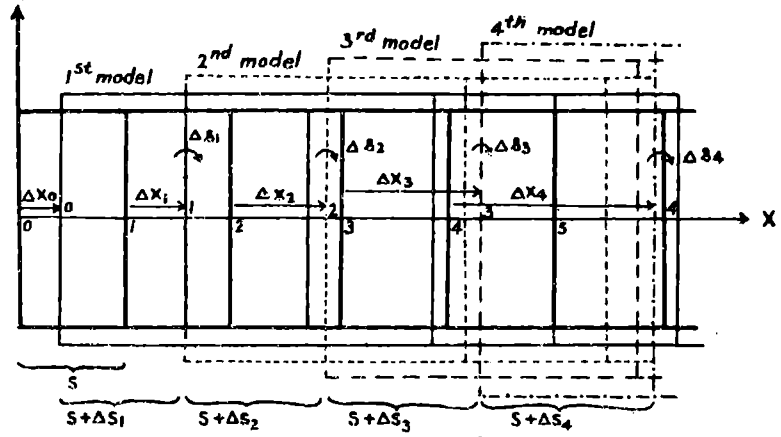


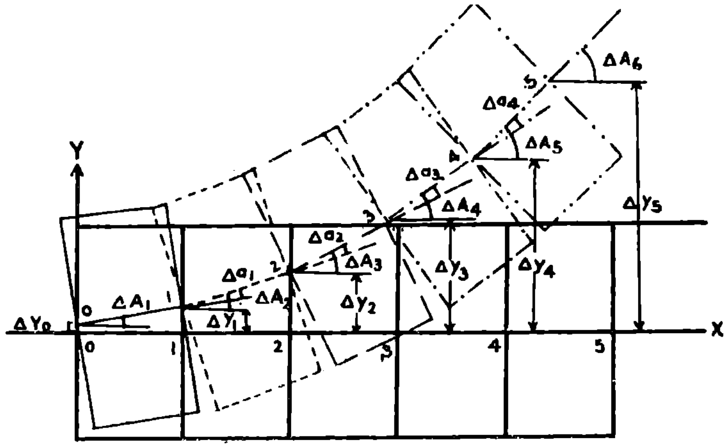
Fig. X.3
Planning index

No. 3959 P.Z.D.'72–4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF

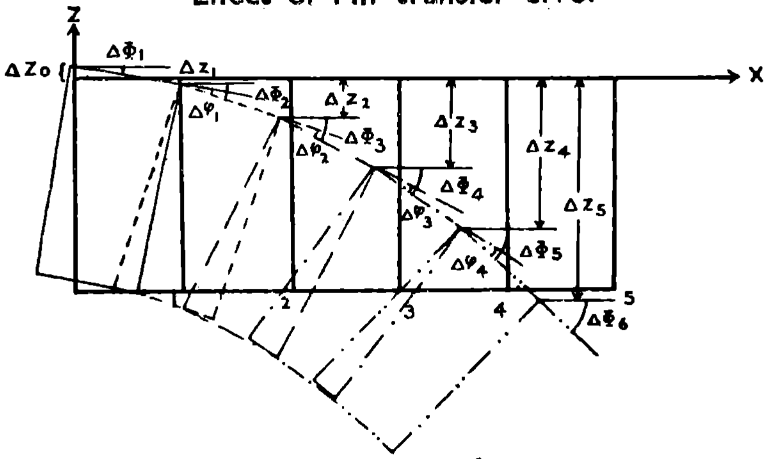
Effect of Scale transfer error



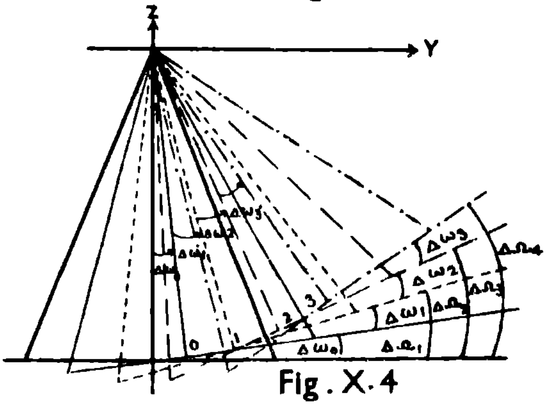
Effect of Azimuth transfer error



Effect of Phi transfer error



Effect of Omega transfer error



Idealised model without any error is shown by thick line. (Upper two figures are in plan and the bottom two are in sections.)

Fig. X.4

Reg. No. 3959 P.Z.D.'72–4000'73.

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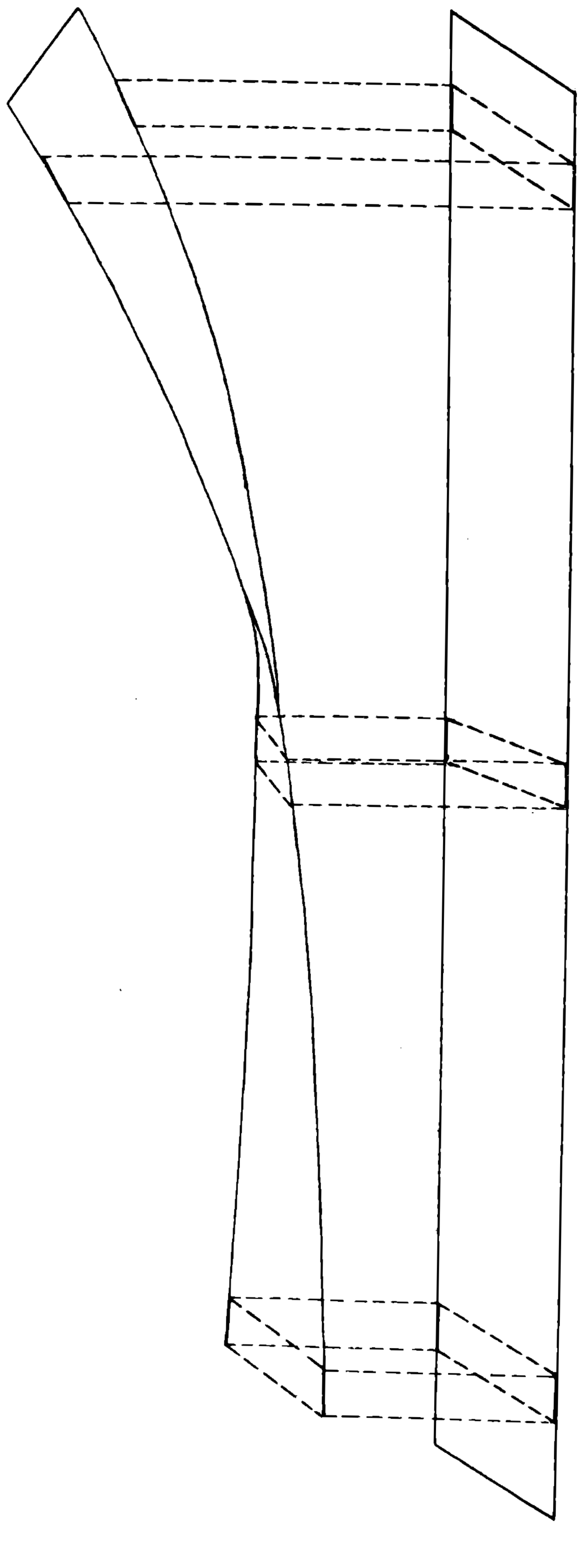
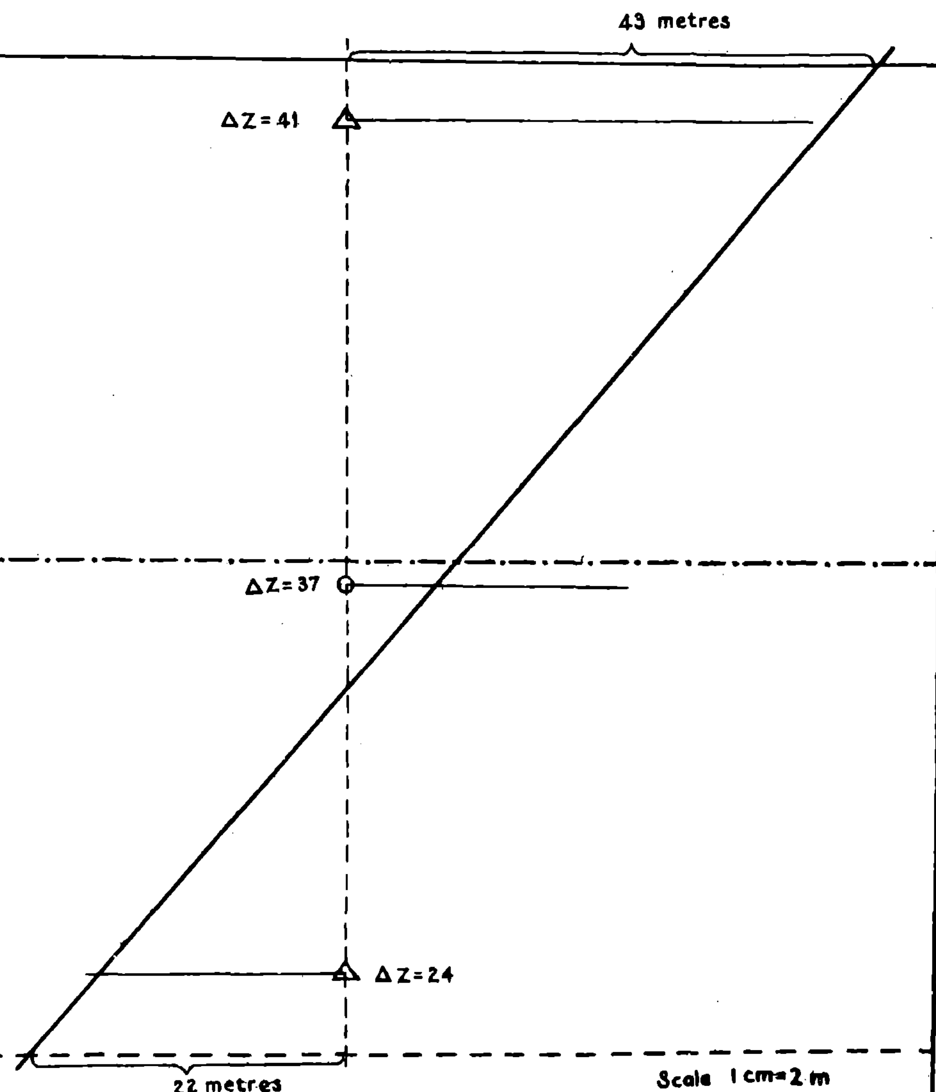


Fig. X.5
Correction surface

Reg. No. 3959 P.Z.D.'72 – 4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.



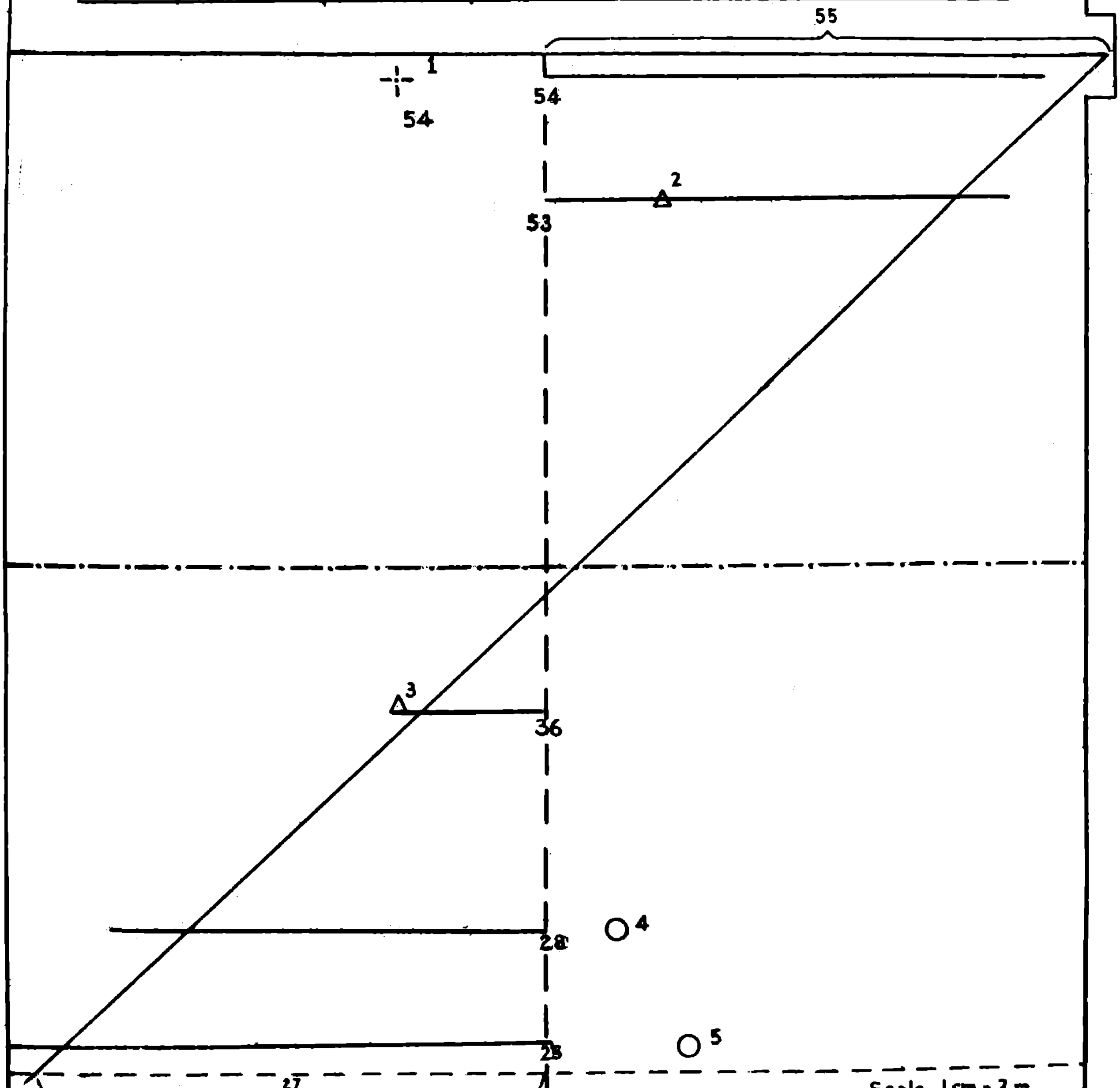
When control points lie on a line at right angles to the strip axis.

Fig. X.6 (a)

Datum correction graph

Reg. No. 3959 P.Z.D.'72-4000'73.   PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.

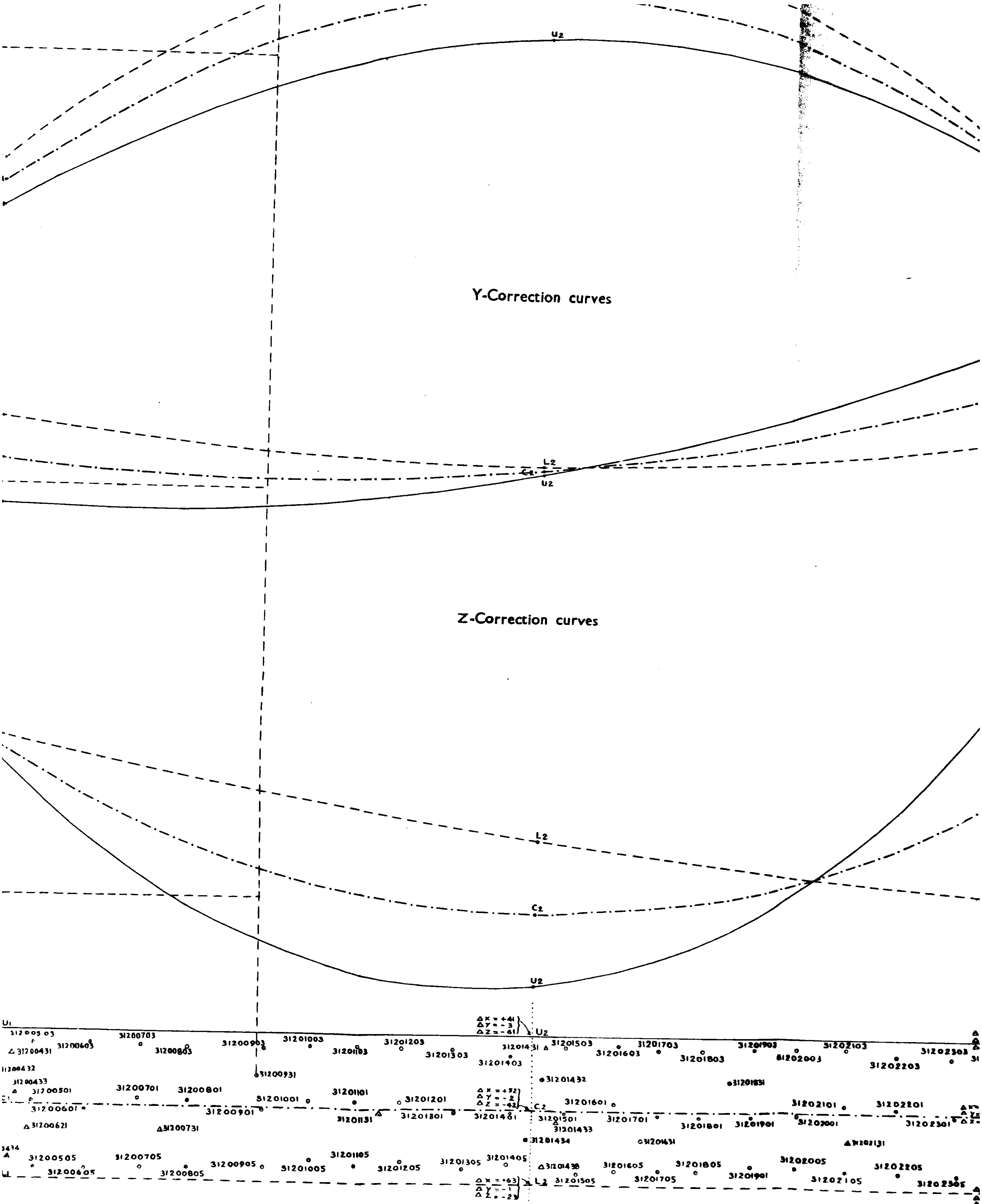
				the cross section.
1	B.M.	47	+ 7	54
2	H.S.	49	+ 4	53
3	h.s.	30	+ 6	36
4	clino	20	+ 8	28
5	I.P.	22	+ 3	25



When control points do not lie on a line at right angles to the strip axis.

Fig. X.6 (b)
Datum correction graph

Reg. No. 3959 P.Z.D.'72-4000'73. PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.



The above diagram is one-fifth of the original size

Fig. X.7

Graphical strip adjustment

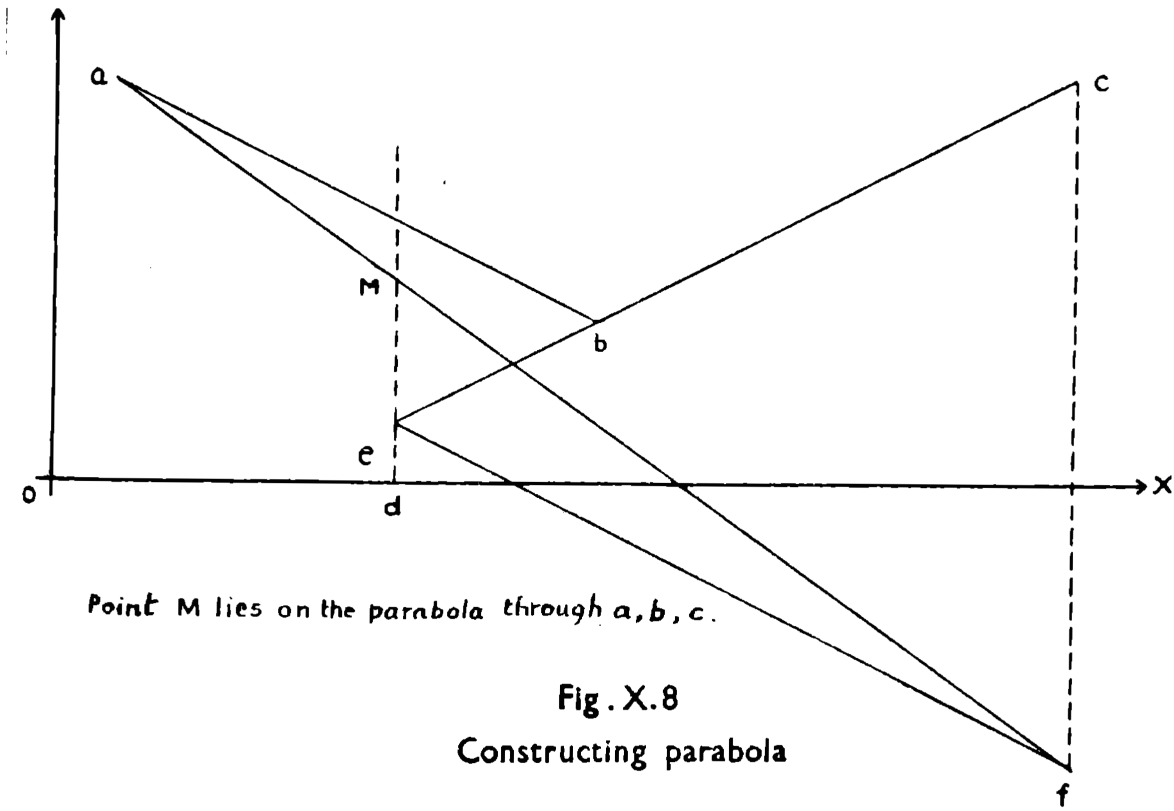


Fig. X.8
Constructing parabola

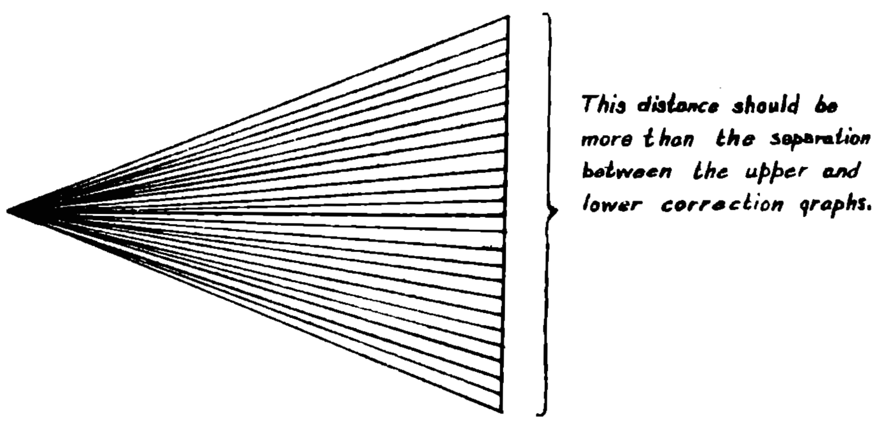
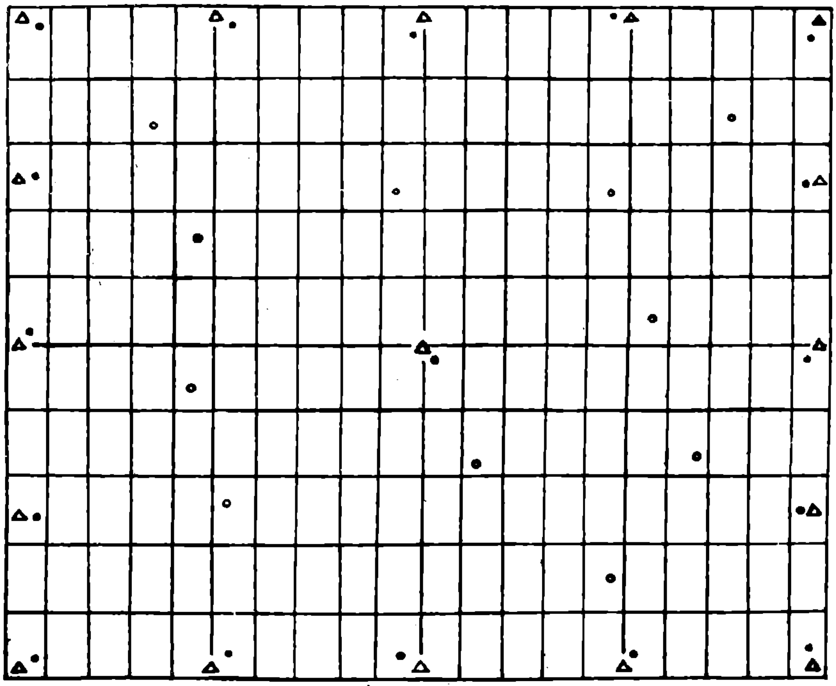


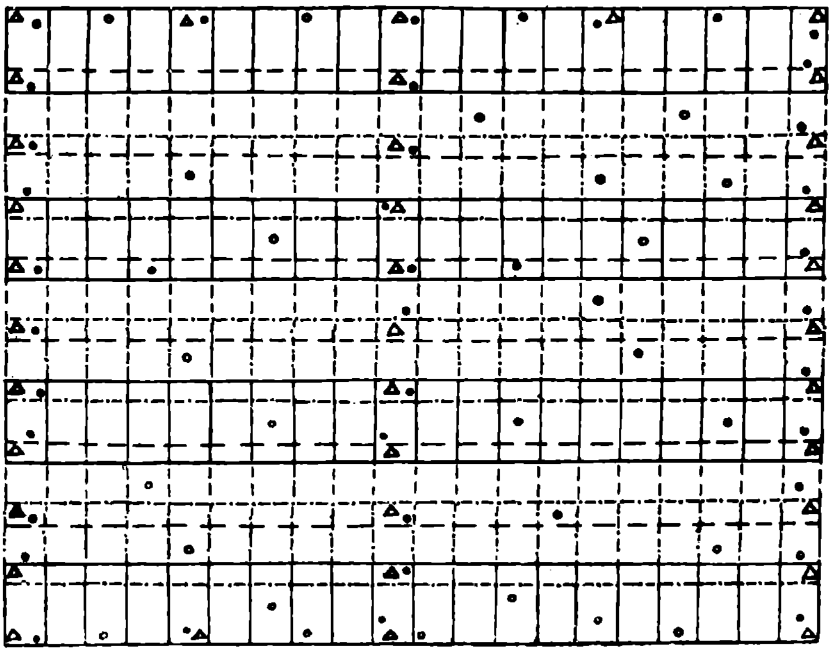
Fig. X.9
Interpolator

Reg. No. 3959 P.Z.D.'72- 4000'73.   PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA



▲ Planimetric control points required for adjustment.
• Planimetric control points to check the reliability of used points.
∘ Planimetric control points to check the accuracy of adjustment

Fig. X.10



▲ Height control points required for adjustment.
• Height control points to check the reliability of used points.
∘ Height control points to check the accuracy of adjustment.

Fig. X.11

Z.D.'72- 4000'73.

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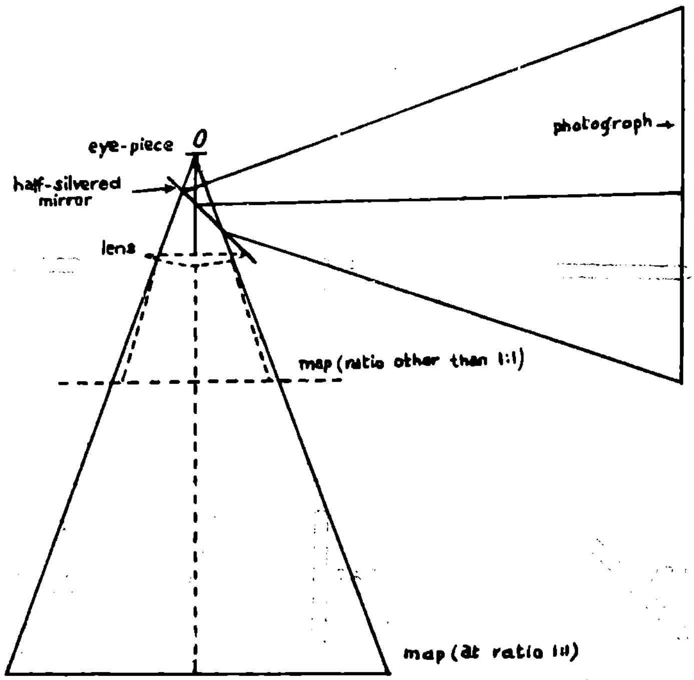

Fig. XI.1
Sketch-master – Schematic diagram

1959 P.Z.D.'72–4000'73.   PRINTED AT THE 103 (P.Z.O.) PRINTING GROUP OF SURVEY OF INDIA.