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Survey of India

LEVELLING IN INDIA, PAST AND FUTURE

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1. INTRODUCTION: A knowledge of precise elevations of points in a country is indispensable for all survey and engineering operations - be they development of an aerodrome, topographical mapping, planning of projects, drainage of land or laying of a new railway track. Of the various methods of determining heights levelling is the most important. It consists of various categories depending upon the precision desired. These are (i) Levelling of High Precision, (ii) Precise Levelling, (iii) Secondary Levelling, (iv) Double Tertiary Levelling and (v) Single Tertiary Levelling.

Of these, the Levelling of High Precision forms the fundamental frame work for the whole country and the tertiary levelling which rests on it via the intermediary of the secondary levelling provides the bulk of the data for preparing accurate large scale contoured maps. These enable the engineers to proceed with their projects and planning operations.

This paper gives an account of the information available about elevations, the methods by which levelling of various categories is executed and the facilities that exist at the Geodetic & Research Branch of the Survey of India for instrumental and other training in all matters relating to levelling.

Levelling progress in India needs acceleration as there are vast areas where no data exists. With the coming in of projects, this sparseness of vertical control is already being keenly felt and as the country develops, the vast gaps in the levelling will become more and more glaring and uncomfortable. As a long term policy, the object should be to cover the whole country with a network of level lines so that there is no place which is more than say 20 miles distant from a stable levelling bench-mark. This is difficult to achieve without the active cooperation of the local governments, P.W.D., Railway and other outside engineers. It is hoped that they will take a keen interest in the matter and will refer to Survey of India for advice and for the training of their personnel. It is most desirable that the engineers should be able to run level lines for their own purpose according to certain standards of accuracy. Their work should be based on the existing bench-marks fixed by the Survey of India, otherwise there will be considerable confusion and much of the work would be wasted in the long run.

2. LEVELLING IN INDIA AND ITS DATUM. The only economically sound system of levelling is that which is based on a common national datum.

There is always a difficulty in choosing a suitable datum which can serve as zero of elevation for all time. An obvious course is to choose a rock cut bench-mark but there are two risks involved - it may either disappear in course of time through human interference and natural causes or it may change its elevation on account of general subsidence or elevation of the area round it, which can be brought about by a severe earthquake and several other causes. A better datum is provided by a precise value of mean sea level determined from hourly observations extended over a number of years. This has its own difficulties as it is not readily reproducible. It will not do just to take an observation of High and Low tides and take their mean. Even for ordinary military mapping observations, mean sea level has to be determined from observations extending over one lunar month. For precise scientific and geophysical work, 19 years' observations are required to eliminate annual and other cyclic tidal fluctuations. The M.S.L. at a port is determined by installing a tide-gauge at it which gives a record of the fluctuations of the water there. Zero of this tide gauge is connected by levelling to fixed rock cut bench-marks on land and this is subjected to frequent checks.

In India, on account of the vastness of the country, the datum for levelling data has been chosen as the Mean Sea Level at a group of nine tidal observatories selected with due regard to their configuration. Observations at these ports were carried out for a number of years and it was assumed that the mean sea level at these ports belonged to the same level surface. All these ports serve as issue points for the level net.

The first levels in India were started as early as 1858 and the skeleton precision net covering the entire country with a linear extent of 18000 miles took over half a century to complete. By about 1912, improvements in technique and knowledge led to the need of a type of levelling called Levelling of High Precision and the Survey of India made a start with it in 1914. This net which will comprise about 16000 miles covers some common areas of the first net and also runs through some entirely new areas. This class of levelling requires special skill and entails considerable eye strain on the observer. Due to the two World Wars and lack of trained personnel, only 75% of the second Level net is complete yet, although it was scheduled to have been completed by 1938.

In general, the secondary and tertiary levellings are done by the Survey of India for extra departmental agencies as paid for work. The progress of levelling in India has been slow as the country was comparatively undeveloped. The situation has altered considerably now and levels are greatly in demand on account of important developments in the country.

In order to avoid confusing the engineers, so far the policy has been that the Second Level net wherever it is common to the First Level net is adjusted on to it, although it is more accurate of the two. Sufficient progress has now been made with the Second Level net and an endeavour is being made now to compile 35 years of levelling results, to bring them all to one datum, to disperse their closing errors and to publish a list of about 20,000 bench-marks with final and correct values of height allotted.

The data of levelling of precision and high precision is published in a series of pamphlets. Each pamphlet contains the data of an area covering 4 degrees of latitude and 4 degrees of longitude, and is known by a number, and the name of the principal town in the area e.g. Sheet No.63 (Allahabad). Internally each pamphlet is divided into 16 degreessquares, corresponding to the degree sheets of the ¼ inch map. The degree sheets are lettered from A to P as shown on a chart at the end of the pamphlet, and are known by the combined number and letter e.g. 63D. The bench marks have been numbered according to the degree sheets in which they fall, the numbering in each sheet being quite independent of that in the surrounding sheets. Consequently, when a line passes from one degree sheet to another, the consecutive numbering of the bench-marks on the line is broken. To indicate a particular bench-mark, therefore, it is necessary to give its number and the degree sheet in which it falls, e.g., bench-mark number 85 in degree sheet 53B.

The Secondary levelling is printed in a series of gestetnered pamphlets. The list of all these pamphlets is given in "List of Publications of the Survey of India" which is obtainable gratis from the President, Geodetic & Research Branch, Dehra Dun.

On all Survey of India maps the heights fixed by levelling and triangulation are shown in upright type. The heights fixed by spirit-levelling are preceded by the letters B.M. The trigonometrical heights are shown close to the position of the triangulation station or point shown on the map by a triangle or dot. The trigonometric heights are derived by observation of vertical angles and due to uncertainties of refraction and other factors are seldom accurate to better than 5 feet. It is important that the terms spirit-levelled height and trigonometrical height should be clearly understood by all who use them.

3. PRECISION OF VARIOUS CATEGORIES OF LEVELLING. For levelling of High Precision, the limits laid down are that Probable Systematic error after M miles must not exceed $\pm$ .00106 M ft and probable accidental error must not exceed $\pm .00416\sqrt{M}$ ft.

For Secondary Levelling, the probable accidental error has generally been about $.004\sqrt{M}$, but no limit has been laid down. Similarly no hard and fast tolerances have been laid down for tertiary levelling but experience shows that an accuracy of $0.05\sqrt{\text{distance in miles}}$ should be obtainable without difficulty.

4. TYPES OF LEVELS. Research on kinematical design of instruments, production of light alloys, and development of new types of optical glass have brought in radical changes in the design of the modern Levels as compared with its older prototype. The Engineer's lusty friend the Dumpy-level was a model of solidarity, but it entailed three adjustments:

(a) The axis of collimation and the mechanical axis of the telescope had to be made parallel.

(b) The mechanical axis of the telescope had to be made perpendicular to the vertical axis of rotation, and

(c) The main bubble had to be made at right angles to the vertical axis of rotation.

The instrument could not be relied upon to maintain its adjustments for long and as these were quite clumsy, the next advance was the evolution of a Reversible Level in which the adjustments could be checked very easily. These were carried out by taking a normal sight on a staff, then giving the telescope a half rotation round its mechanical axis, another sight was taken and finally another reading was taken by reversing the telescope end for end in its cradle. Apart from its bulk, this model also suffered from certain handicaps. For instance, the axis of rotation had to be made truly vertical and in the course of this levelling, one had to move round the instrument with the possibility of disturbing the ground near the tripod legs.

A modern surveyor's level of the Zeiss pattern introduces several new features such as internal focussing telescope, a rigid body made from a new light alloy, object glass made of borosilicate crown and dense flint, improved footscrews and so on. All this has permitted the focal length of the telescope to be reduced without any loss of optical qualities, and the weight of the instrument with its box is only 13 lbs.

The most important innovation is, that certain of the adjustments that used to be essential for the older types of levels are dispensed with, for instance the collimation axis of the telescope can be levelled even if the axis of rotation of the level is not itself vertical. This makes for increased precision and outturn as the bubble can be set with the greatest possible accuracy without wasting time on obtaining exact verticality of the axis of rotation of the level.

These instruments were previously designed for precision work only, but they are now-a-days coming more and more into vogue for all kinds of levelling. The Survey of India uses Zeiss Type 3 for Levelling of High Precision, Medium Type 2 for Secondary work and small type 1 for Tertiary. To get the maximum benefit out of such instruments, it is important to be acquainted with the significance of the various improvements that have only been rendered possible by modern developments in new types of optical glass and in processes of production and correct kinematical design. Engineers should realise that quite a large amount of labour and cost can be saved by these new models.

5. <u>PROGRESS OF LEVELLING IN INDIA AS COMPARED WITH U.S.A.</u>

The charts at the end showing the levelling so far executed in India and U.S.A. respectively form an interesting study. This brings home forcibly the backwardness of India in this respect despite the early start made. As has been already mentioned, the first Primary Level net of India was started in about the middle of the 19th century and was completed in 1909. It had a linear extent of about 18,000 miles and comprised 68 standard, 1559 embedded and 13920 other bench-marks.

The second net which has been in operation since 1914 has covered about 11,000 linear miles.

In comparison, U.S.A. level net (in 1936-38) consisted of more than 150,000 bench marks distributed along about 106,950 miles of first order and 154,980 miles of second order level lines.

A glance at our levelling chart would reveal that there are wide gaps in the levelling of India. There are only 617 standard bench-marks covering the whole country, the policy being to establish them about 50 miles apart in big towns. Even this is not achieved and in any case it is not enough. For supplying data for any project, levelling has to be brought from the nearest primary line which is often at an uncomfortably long distance away. Our objective should be to aim at such a density that bench-marks along main roads are available at such convenient distances as 15 to 20 miles throughout the extent of the country for the use of local engineers and surveyors, who would base their local work on them.

As an example of what can be achieved with concerted effort may be mentioned that in the two years 1933-35, over 37,000 miles of First order levelling and 152,000 miles of Second order levelling were run in U.S.A. They realised its extreme importance and raised emergency funds for the purpose.

6. THE STABILITY OF VARIOUS TYPES OF BENCH-MARKS AND THE NEED FOR THEIR PRESERVATION: The various types of B.M's in use with levelling executed by the Survey of India are described in the preface of any Levelling pamphlet. Of these the so called "Primary Protected Bench Marks" are built and maintained by the Survey of India as they serve as control points for Secondary levelling. All other Bench-marks are built and maintained by the local governments although they are connected and the heights are published by the Survey of India. The exact significance of the various types of Bench-marks and their preservation is not so widely

recognized in Engineering and even Survey circles as it should be. Bench-marks along a levelling line are the only tangible record of levelling and if adequate steps are not taken to preserve them, relevelling will have to be done if vertical control is needed in that area at some future date. A levelling bench-mark needs much more care than a triangulation station for two reasons. Firstly it is more vulnerable as it is in a more accessible place. Secondly, a change of a foot or so is immaterial in the height of a trig-station but a change of even 0.01 feet is inadmissible in a levelling mark. This is why trig-stations are entrusted to local authorities for repairs and maintenance but the reports on bench-marks are called for from local P.W.D. Engineers of the place as they are likely to appreciate their technical significance better. It is far better for a levelling bench mark to be completely destroyed rather than that it should be allowed to change its height for the important reason that if it is destroyed, it cannot be utilized for any work while if it changes its elevation, it will falsify all further work based on it. Too often, however, routine repairs are undertaken unintelligently and the marks are subjected to displacements in doing so. The existing arrangements for the upkeep of the levelling marks cannot be described as entirely satisfactory and the intense cooperation of the Engineers and their staff is required in this connection.

The Survey of India has no regular inspection parties and it has to depend mainly on the reports of the Engineers and local officials. It is very desirable that the information supplied by these agencies about bench-marks is so reliable that it should be possible to decide on the basis of these reports when renewals of bench marks and revision of levelling should be undertaken in a particular locality. The reports received often betray a considerable ignorance in this respect. Too often it is forgotten that it is more important to protect the markstones rather than to rebuild towers or pillars surrounding them. Thus a set of special bench-marks was built by the Survey of India along the Ganges Canal from Roorkee to Hardwar and then through the gorge to Dehra Dun in 1908. Their spirit levelled heights were carefully determined and it was the intention to relevel them at regular intervals to get information about the rise of the Siwalik axis. The B.M's were handed over to the irrigation authorities, but their special importance was lost sight of by the local engineers and when re-levelling was undertaken last year, most of the marks were found to have been tampered with in the course of plastering and repairs.

Some further general remarks about the bench-marks may not be out of place here.

No bench-mark erected upon alluvium can be trusted to keep its original height. A number of points in alluvial plains may not be as good as a single rock cut bench-mark, because an alluvial area can sink as a whole and consequently the relative heights of the bench-marks in the area may stay unchanged. Some bench-marks from the very nature of their construction are very ephemeral. Milestones are a notorious example. They are dangerous marks to base work upon. The most reliable form of bench-mark is on solid ground rock; next to that are the standard bench-marks built on unconsolidated ground. Embedded bench-marks are very reliable and least likely to be interfered with. Marks on and embedded under railway platforms are always to be treated as suspect as they can change due to constant vibration.

This explains why new levelling should always be commenced from a permanent bench-mark, but before starting, check levelling should be done to 3 or 4 other bench-marks to make sure that the height of the starting bench-mark has not changed. If this value agrees with two other bench-marks within limits of .02 ft for distances below one mile and .02 M ft for distances greater than one mile, where M is distance between bench-mark in miles, the bench-mark may be considered to have retained its old heights. Wherever a mark has been disturbed, it should not be repaired without observation.

7. HELP AND ADVICE OBTAINABLE FROM GEODETIC BRANCH OF THE SURVEY OF INDIA: The Geodetic and Research Branch of the Survey of India, located at Dehra Dun is the repository of all data of High Precision, Precision and Secondary levelling and should be addressed for all requirements of this class of levelling. For any project, the usual practice is first to lay down a net of levelling of Secondary precision, covering the whole area and then to run tie lines of tertiary levelling to fill up the area to the density required. It would be advantageous for the engineers concerned with this work for their projects to seek the advice of this Branch as to the best form of the Secondary net and the tertiary mesh.

There are several important scientific and practical problems associated with levelling. To mention but a few one scientific aspect is to determine how far mean sea level at various ports deviate from an equipotential surface. Thus, the old level net of India showed the Bay of Bengal to be one foot higher than the Arabian Sea but accuracy of levelling was not enough to warrant a sure conclusion.

Stable bench-marks suitably emplaced can be used for testing the bending of the earth's crust due to dams and other heavy structures.

It has been mentioned above that M.S.L. at a port as determined by tide gauge is perpetuated by reference to fixed rock cut B.M's on land. Since both land and M.S.L. are subject to fluctuations any change in their relation evidenced after a number of years may be due to either variation of sea level or elevation or subsidence of land. To decide which is the active agent requires a lot of experience and judgment.

So far as the practical aspects of levelling are concerned, a surveyor generally requires absolute heights of points above sea-level for his topographical maps, whereas the Engineer is more interested in the relative difference of height between two bench-marks.

All observations are susceptible to two types of errors - accidental and systematic. The former can be minimised by repetition of observations, but the latter are not so tractable. Their causes must be discovered and eliminated. It so happens that levelling is susceptible to inexplicable systematic errors and great caution and experience is needed in interpreting levelling results. Furthermore levelling during different hours of the day is subject to large variations of refraction and at certain periods of the day there are large discontinuous changes which can lead to significant error in the difference between back-sight and fore-sight at a station. Special precautions are necessary when the air is boiling and the graduations on the staff viewed through the telescope appear jumpy. There are important fallacies associated with levelling which Engineers must understand. Too often they are prone to argue that heights of even secondary precision (not to speak of primary) are a luxury and of no immediate use to them; an accuracy of 1 or 2 feet would meet most of their needs. It must be emphasised that even if this were true, it is still necessary to fix a certain number of permanent bench-marks with precision in any area where projects are contemplated to serve as issue points for future extension purposes.

The Geodetic and Research Branch possesses a mass of other useful information about heights and will be glad to furnish advice about the above and other cognate problems such as the dispersal of circuit misclosures in levelling and the interpretation of levelling results. Arrangements are also in train to provide intensive instrumental training in all grades of levelling and it is hoped that Provincial Governments and Engineering Departments will make full use of them and get some of their personnel trained to organise their own field parties. It is only with the active cooperation of these agencies that India can catch up with the progress made in other advanced countries. The most important point that has to be kept in mind is, that all work carried out by any agency in India should be in terms of the National Datum, tied on to the National framework of High Precision Levelling and should conform to uniform standards of accuracy. Quite often harbour Engineers adopt a very rough determination of mean water level as a basis for their local levelling and the P.W.D. engineers assume an arbitrary bench-mark. In one instance, one P.W.D. Datum when connected to the Survey of India framework gave a difference of as much as 300 feet. Local levellings based on local datums and not carried out according to any well defined standards are to be deprecated. They may serve the immediate purpose in certain cases but are wasteful in the long run in that they cannot be utilised for any future extension work and are apt to present considerable difficulties of adjustment when joined to other lines.

8. CONCLUSION. India is in its infancy as regards vertical control and geodetic engineering when compared with advanced European countries. To extend the First and Second order level net over the one and a quarter million square miles of its area is a tremendous problem. This levelling has to conform to certain standards of accuracy which will meet the requirements of science and engineers. For such a large amount of work, cooperation of other departments is necessary and it is hoped that this note will stimulate levelling effort in India and that various departments will take advantage of the facilities provided by the Survey of India and will get some of their staff technically qualified by intensive training at Dehra Dun.

The time has come for a great expansion of levelling progress in India and an increased concentration of effort is needed. Levelling by its very nature is a slow process, its outturn varying considerably with the nature of the country. On an average in flat country experienced observers can produce 3½ miles of levelling of High Precision, 5 miles of Secondary levelling and 6 to 8 miles of tertiary levelling per day. In mountainous and wooded areas, the progress is about 60% of the above. To attain this outturn along with the necessary precision requires special intensive training, otherwise a considerable number of repetition relevelments become necessary. Modern instruments if used with a proper sense of proportion can produce considerable economy of time and labour which is very necessary in these days of inflation. To accomplish the target of having heighted points at reasonable intervals for local surveys, it is very necessary to have planned cooperation between the Geodetic & Research Branch of Survey of India and other interested Departments. It should be ensured that the personnel employed produce proper outturn.

To conserve whatever has been done already, it is imperative that the public and engineers in particular should have a fuller appreciation of the importance and utility of bench-marks and should cooperate wholeheartedly in their preservation. Much education in this respect is needed. In U.S.A. each B.M. carries the inscription that a fine of $250 or imprisonment will be imposed on any one found tampering with it.

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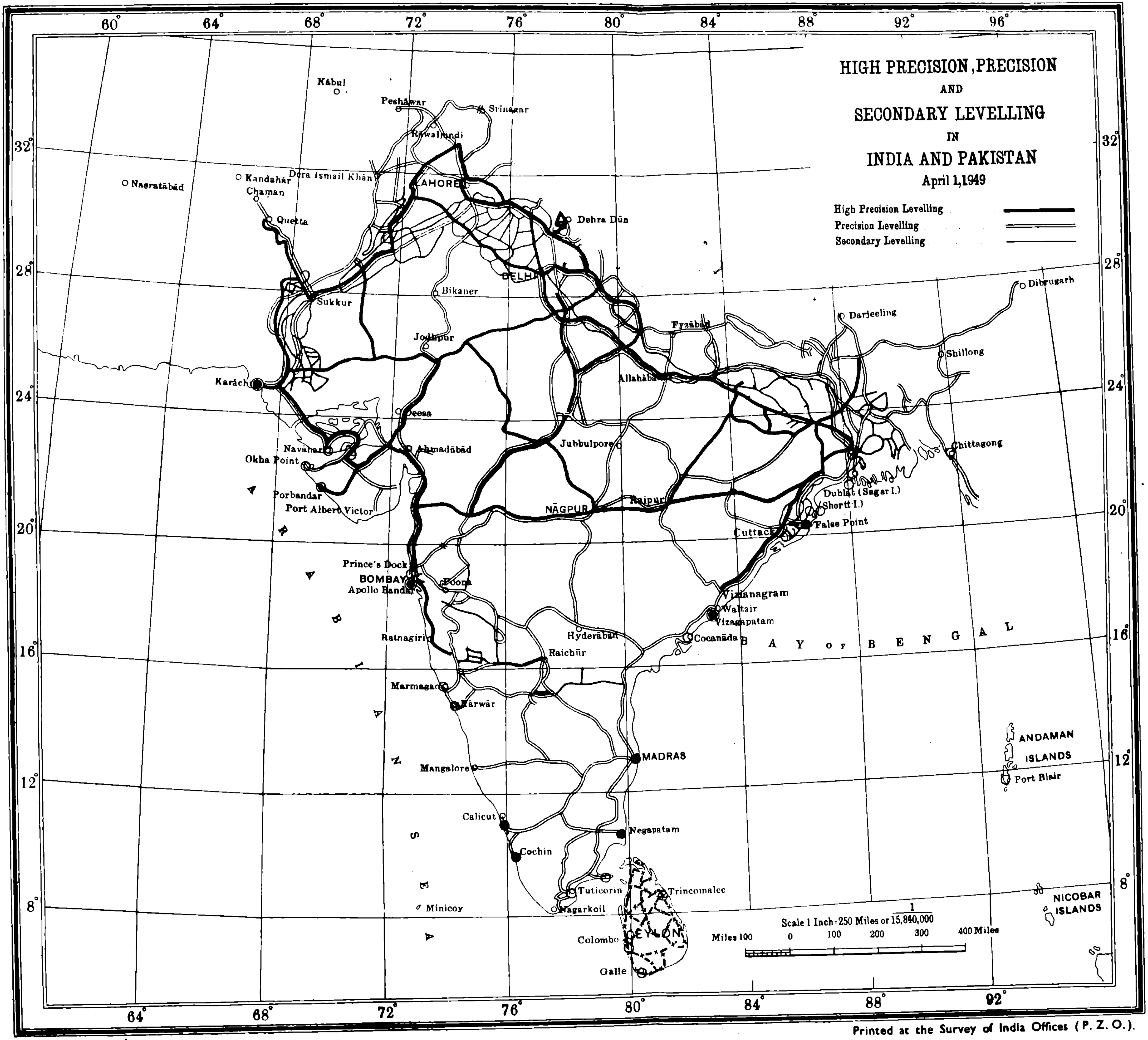

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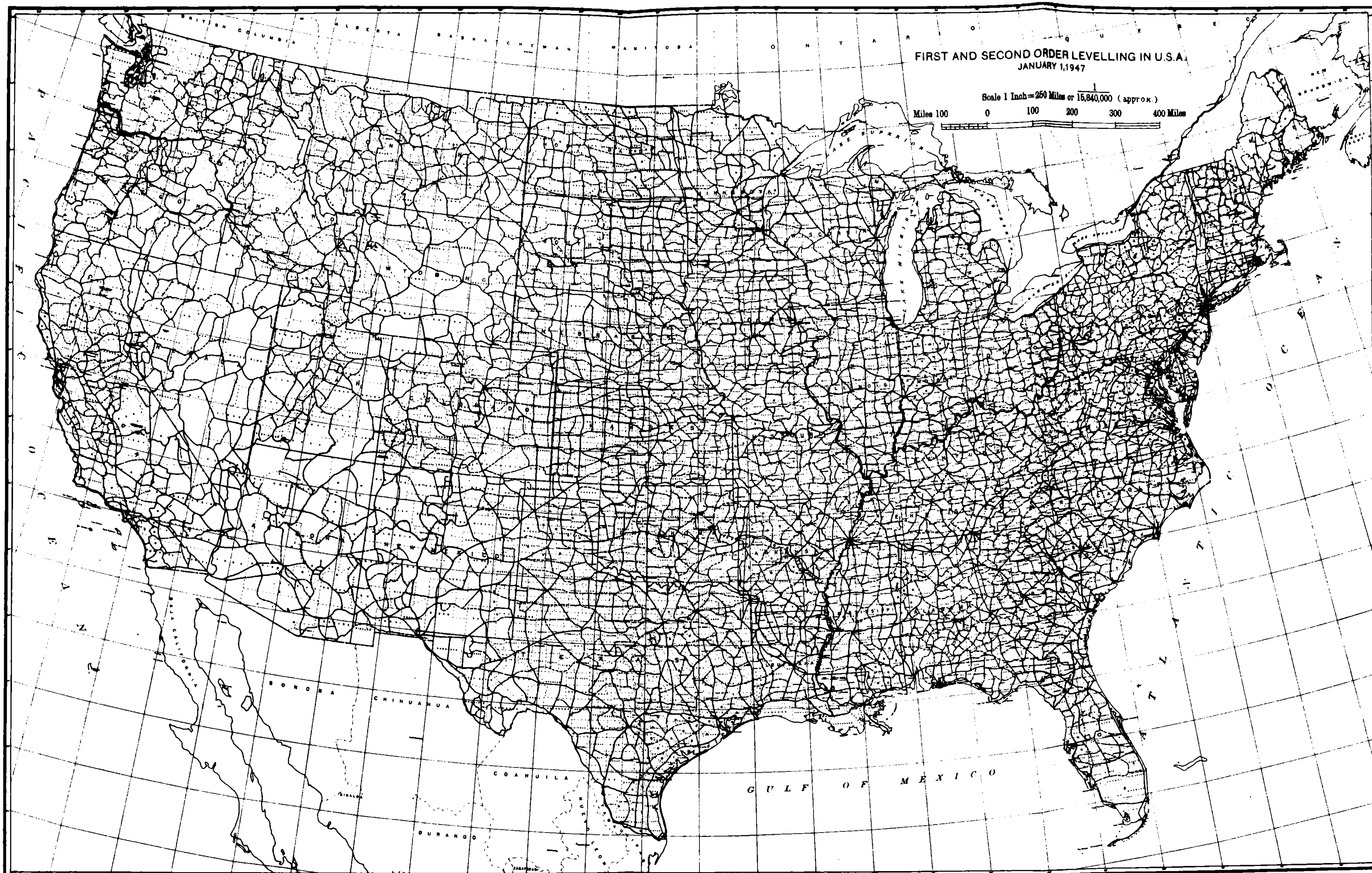
FIRST AND SECOND ORDER LEVELLING IN U.S.A.
JANUARY 1,1947
Scale 1 Inch=250 Miles or 1/15,840,000 (approx.)
Miles 100 0 100 200 300 400 Miles
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
NEW BRUNSWICK
LAKE SUPERIOR
LAKE MICHIGAN
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
BAJA CALIFORNIA
SONORA
CHIHUAHUA
COAHUILA
DURANGO
NUEVO LEON
NEW MEXICO
TEXAS