REPORT

ON THE

TRIGONOMETRICAL RESULTS OF THE EARTHQUAKE IN ASSAM

BY

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G. I. C. P. O.—No. 11 S. G.—14-10-98.—25.—G. C. R.

Report on the Trigonometrical Results of the Earthquake in Assam.

The following report on the triangulation carried out in Assam during the winter of 1897-98 for the purpose of measuring the displacements caused by the earthquake is submitted :—

2. The party employed was the levelling detachment of the tidal and levelling party, the observer was Mr. J. Bond, Extra Assistant Superintendent, and the instrument was a seven-inch micrometer theodolite. The programme, which was drawn up in conjunction with Mr. R. D. Oldham, Geological Survey of India, consisted of a revision of the principal triangulation of the eastern frontier series from Cherrapoonji north to the Brahmaputra, and of that of the Brahmaputra series south from Dhubri.

3. It was somewhat difficult to devise a programme of operations, because the geological and trigonometrical requirements were different: the geological aim was to discover the core of the earthquake, whilst the trigonometrical aim was to determine the displacements of all principal stations, whether hill or alluvial. The trigonometrical requirements confined the revisionary work to principal series only, because the topographical stations had not been fixed originally with sufficient accuracy to admit of our determining their exact displacements: the geological requirement placed the programme in the interior of the Garo-Khasia Hills, where no principal triangulation existed. The geologists required rapid work over a large area, and were content with two angles per triangle, whilst the geodesists placed accuracy before area and demanded three angles per triangle. The geologists were only interested in the displacements of hill stations, but to the geodesists the alluvial stations were as important as the hill.

4. In an interview which I had with Mr. Oldham in November 1897, the following programme was agreed upon: Mr. Bond was to commence on the Eastern Frontier Series near Cherrapoonji (*vide* chart attached) and work northwards, observing at the principal stations of Rangsanoba, Mopen, Mosingi, Laidera, Mautherrichan, Maonai, Dinghei, and Maupâni.

If, as he proceeded northwards, he found great or increasing displacements, he was to continue on this series, until he reached the Brahmaputra, but if he met with only small or diminishing changes, he was to move to Dhubri and work south.

5. In the above programme the trigonometrical requirements were subordinated to the geological. It would have been useless to attempt to carry revisionary triangulation across the Garo Hills from Cherrapoonji to Dhubri, because the stations of the topographical triangulation, with which this area was covered in 1872, had not been properly described, and could not now be traced or identified. Mr. Bond was instructed to refix all the old secondary trigonometrical points, that lay to the west of the Eastern Frontier Series, and to the east of the Brahmaputra Series.

6. Mr. Oldham required so much triangulation to be revised, that I deemed it advisable for the acceleration of the work to accept two angles in certain triangles as sufficient. But even then it would not have been possible for Mr. Bond to visit in one season all the principal stations, that were included in the geological list, and the Assam Longitudinal Series had to be omitted. Colonel Gore approved the programme generally, but added to it the station of Mun in order to secure the observation of the third angle in more triangles.

7. Mr. Oldham will explain the geological deductions that might expectedly result from the above programme. From the trigonometrical point of view the instrument was too small and the work too rough for the attainment of final data, and Mr. Bond's observations were only expected to show the approximate area that had been affected and the degree of displacements that had

occurred in stations (whether (say) 3 inches or 3 feet or 30 feet), and to thus enable a decision to be formed as to the necessity of a real revision of the principal triangulation.

8. Mr. Bond observed on the Eastern Frontier Series at the principal stations enumerated in para. 4, and fixed the secondary points at Somullon, Shillong, Suair, Rableng, Laitbli, Larjmarkham, Nongsingri, Marskuin, Sniang, Kollong Rock and Maopani Rock.

In February he moved to Dhubri, but the haze prevented any work being done on the Brahmaputra Series. The computations have been carried out by Mr. Bond under Lieutenant Crosthwait, R.E., and the results are exhibited in the following tables: the original values of the angles were probably correct at the time of measurement to within 0″·3; Mr. Bond's angles may be regarded as within 2″·5 of the present truth.

Angles.

At	Between	1860. Value.	1898. Value.	Difference.
		° ′ ″	° ′ ″	
Rangsanobo . H.S.	Taramun Tíla . H.S. Mopen . . „	68 40 41·32	68 40 45·99	+4″·67
„ . „	Mopen . . „ Mosingi . . „	41 38 32·87	41 38 19·52	−13·35
„ . „	Mun . . „ Thanjináth . „	43 20 12·69	43 20 4·05	−8·64
„ . „	Mosingi . . „ Mun . . „	87 23 17·64	87 23 20·44	+2·80
„ . „	Taramun Tíla . „ Khandigaon . T.S.	55 2 14·44	55 2 10·29	−4·15
„ . „	Thanjináth . H.S. Thandigaon . T.S.	63 54 59·93	63 55 10·00	+10·07
Mopen . „	Taramun Tíla . H.S. Rangsanobo . „	48 3 13·00	48 3 3·82	−9·18
„ . „	Rangsanobo . „ Mosingi . „	33 24 46·60	33 24 42·42	−4·18
Mosingi . „	Rangsanobo . „ Mopen . . „	104 56 40·53	104 56 58·06	+17·53
„ . „	Rangsanobo . „ Mun . . „	53 1 35·01	53 1 33·75	−1·26
„ . „	Mun . . „ Laidera . . „	47 31 30·09	47 31 18·75	−11·34
„ . „	Laidera . . „ Mautherrichan „	56 35 29·73	56 35 37·80	+8·07
Mun . . „	Rangsanobo . „ Mosingi . „	39 35 7·35	39 35 5·81	−1·54
„ . . „	Rangsanobo . „ Thanjináth . „	59 59 38·12	59 59 43·17	+5·05
„ . . „	Mosingi . „ Laidera . . „	48 52 35·70	48 52 34·55	−1·15
„ . „	Laidera . . „ Dinghei . . „	49 52 10·89	49 52 11·83	+0·94

Angles—contd.

At	Between	1860. Value.	1898. Value.	Difference.
		° ′ ″	° ′ ″	
Laidera . . H.S.	Mosingi . H.S. Mun . . ,,	83 35 54·21	83 36 6·70	+12·49
,, . . ,,	Mosingi . ,, Mautherrichan ,,	75 29 10·19	75 28 59·17	—11·02
,, . . ,,	Dinghei . ,, Mun . . ,,	73 20 47·62	73 20 60·89	—13·27
Mautherrichan ,,	Mosingi . . ,, Laidera . . ,,	47 55 20·08	47 55 23·03	+2·95
Dinghei . ,,	Laidera . . ,, Mun . . ,,	56 47 1·49	56 46 47·28	—14·21

Sides.

Side.		1860. Value.	1898. Value.	Difference.
		feet.	feet.	feet.
Taramun Tíla H. S.	Mopen . . H.S.	99101·5	99106·3	+4·8
Rangsanobo ,,	Mopen . . ,,	95013·1	95018·0	+4·9
Rangsanobo ,,	Mosing . . ,,	54152·5	54154·8	+2·3
Rangsanobo ,,	Mun . . ,,	67892·7	67895·9	+3·2
Rangsanobo ,,	Thanjináth . . ,,	60421·3	60424·7	+3·4
Mopen ,,	Mosingi . . ,,	65344·6	65344·6	0·0
Mosingi ,,	Mun . . ,,	84893·2	84897·6	+4·4
Mosingi ,,	Laidera . . ,,	64350·8	64353·4	+2·6
Mosingi ,,	Mautherrichan . ,,	83931·8	83933·0	+1·2
Mun ,,	Thanjináth . . ,,	47884·1	47884·0	—0·1
Mun ,,	Laidera . . ,,	63007·7	63007·4	—0·3
Mun ,,	Dinghei . . ,,	72154·3	72156·7	+2·4
Laidera ,,	Mautherrichan . ,,	72373·1	72377·0	+3·9
Laidera ,,	Dinghei . . ,,	57583·0	57584·1	+1·1
Mautherrichan ,,	Landau Modo . ,,	50746·7	50755·3	+8·6
Dinghei ,,	Umter . . ,,	75209·0	75211·3	+2·3

Azimuths.

At		Of		1860. Value.	1893. Value.	Difference.
				° ′ ″	° ′ ″	″
Taramun Tíla	H.S.	Mopen	H.S.	132 12 22·20	132 12 17·69	—4·51
Rangsanobo	"	Mopen	"	84 10 48·05	84 10 52·72	+4·67
"	"	Mosingi	"	125 49 21·18	125 49 12·51	—8·67
"	"	Mun	"	213 12 39·11	213 12 33·24	—5·87
"	"	Thanjináth	"	256 32 52·02	256 32 37·51	—14·51
Mopen	"	Taramun Tíla	"	312 6 42·59	312 6 38·05	—4·54
"	"	Rangsanobo	"	264 3 29·03	264 3 33·68	+4·65
"	"	Mosingi	"	230 38 42·16	230 38 50·99	+8·83
Mosingi	"	Mopen	"	50 42 37·43	50 42 46·27	+8·84
"	"	Rangsanobo	"	305 45 56·63	305 45 47·94	—8·69
"	"	Mun	"	252 44 21·33	252 44 13·90	—7·43
"	"	Laidera	"	205 12 50·93	205 12 54·84	+3·91
"	"	Mautherrichan	"	148 37 20·84	148 37 16·68	—4·16
Mun	"	Mosingi	"	72 50 40·32	72 50 32·90	—7·42
"	"	Rangsanobo	"	33 15 32·67	33 15 26·80	—5·87
"	"	Thanjináth	"	333 15 54·33	333 15 43·41	—10·92
"	"	Laidera	"	121 43 16·33	121 43 7·77	—8·56
"	"	Dinghei	"	171 35 27·50	171 35 19·87	—7·63
Laidera	"	Mautherrichan	"	100 44 9·94	100 44 2·85	—7·09
"	"	Mosingi	"	25 14 59·39	25 15 3·32	+3·93
"	"	Mun	"	301 39 4·86	301 38 56·30	—8·56
"	"	Dinghei	"	228 18 16·96	228 17 55·13	—21·83
Mautherrichan	"	Mosingi	"	328 33 55·85	328 33 51·69	—4·16
"	"	Laidera	"	280 38 35·42	280 38 28·31	—7·11
"	"	Landau Modo	"	161 26 11·33	161 26 11·36	+0·03
Dinghei	"	Laidera	"	48 21 39·61	48 21 17·76	—21·85
"	"	Mun	"	351 34 37·85	351 34 30·21	—7·64
"	"	Umter	"	146 15 41·28	146 15 22·09	—19·19
Thanjináth	"	Rangsanobo	"	76 37 25·43	76 37 10·92	—14·51
"	"	Mun	"	153 17 34·84	153 17 23·93	—10·91
Landau Modo	"	Mautherrichan	"	341 24 55·01	341 24 53·18	—1·83
Umter	"	Dinghei	"	326 12 23·13	326 12 5·71	—17·42

Displacements of Principal Stations.

Station.		Displacement in Latitude.		Displacement in Longitude.		Total Displacement.	
		Amount.	Direction.	Amount.	Direction.	Amount.	Direction.
		Feet.		Feet.		Feet.	
Mopen . . .	H. S.	2	N.	5	W.	5	N. W.
Mosingi	„	0	...	3	W.	3	W.
Mun	„	4	N.	0	...	4	N.
Thanjináth . .	„	6	N.	2	E.	6	N.
Laidera	„	2	N.	0	...	2	N.
Mautherrichan . .	„	1	N.	5	W.	5	W.
Dinghei	„	8	N.	4	W.	9	N. W.
Landau Modo . .	„	9	N.	7	W.	12	N. W.
Umter	„	7	N.	8	W.	11	N. W.

Heights of Principal Stations.

Station.		1860. Value.	1898. Value.	Difference.	
				Subsidence.	Upheaval.
		Feet.	Feet.	Feet.	Feet.
Mopen . . .	H. S.	2,581	2,577	4	...
Khandigaon . .	T. S.	35	41	...	6
Mosingi . . .	H. S.	5,794	5,798	...	4
Mun	„	6,212	6,214	...	2
Thanjináth	„	4,440	4 443	...	3
Taramun Tíla . . .	„	144	150	...	6
Laidera	„	6,180	6,186	...	6
Mautherrichan . . .	„	6,288	6,312	...	24
Dinghei	„	6,067	6,074	...	7
Landau Modo . . .	„	5,160	5,177	...	17
Umter	„	3,367	3,370	...	3

9. The above results go to show that all Mr. Bond's triangulation lay within the area affected by the earthquake: no reliable base is consequently forthcoming for the computation of his observation. Whatever side or height we start from, we find that all other sides and heights have altered, but the errors

of our initial side and height pervade the calculations, and the movements caused by the earthquake are given differently whenever we change our basis.

For the results tabulated above the side Rangsanobo—Taramun Tíla was adopted as the initial base for the triangulation, and the height of Rangsanobo as the initial height, Mr. Oldham being of opinion that these southerly stations are least likely to have been affected.

The results of the work may be summed up as follows:—

(i) The whole of the triangulation executed by Mr. Bond lies within the area affected by the earthquake.

(ii) All principal stations visited by him have apparently suffered displacement.

(iii) The average horizontal displacement is 7 feet, and the maximum 11·7 feet.

(iv) The changes in height vary from a subsidence of 4·3 feet to an upheaval of 24 feet.

(v) The general apparent effect is that the Eastern Frontier Series has been both widened and raised. Mopen and Thanjináth are further apart than formerly, as are also Mun and Mosingi and also Dinghei and Mautherrichan.

10. As to whether it is advisable to continue the secondary work in Assam or to rigorously revise the principal triangulation, I beg to submit the following recommendations for your consideration:—

(i) That the Director of the Geological Survey of India be consulted as to the geological requirements.

(ii) That secondary triangulation be continued until the limits of the affected area have been discovered.

(iii) That the principal triangulation of Burma be placed on an equal footing with that of India.

(iv) That no real revision of the principal triangulation of Assam be attempted.

11. The continuation of secondary work is recommended, in order that the trigonometrical effects of the earthquake may be discovered and recorded; the principal stations of India are being preserved for the use of the future, records of their condition are being maintained, and money spent on annual repairs, and it is only consistent that we should now note down all stations rendered unreliable in Assam. At present we do not know the absolute displacements suffered nor whether the maximum effects have yet been brought to light. We do not know to what extent the Assam Longitudinal Series, the Assam Valley Series, the Brahmaputra Series, the Cachar Series, the Sonakhoda Base-Line or the triangles on which the new Lushai Survey is being based, have been disturbed. By carrying the triangulation beyond the affected area and calculating back from a reliable side, we may possibly find that the results of Mr. Bond's work are misleading, that they have been vitiated by the adoption of an erroneous base, and that some of his stations have, after all, been left unmoved.

12. The most serious trigonometrical result of the earthquake is the severance of the connexion between the Indian and Burmese systems of triangulation. The chart shows that Burma was joined to India by a weak chain of single triangles running from Calcutta to Chittagong, and that another series running through Manipur is to complete the connexion. The principle of the Gridiron-System of triangulation is that every portion must enter into a circuit, and that, however well executed triangulation may appear, it must be tested by closing on itself. Until the Manipur Series has been completed, the triangulation of Burma will not have been subjected to a closing test.

13. The bridging of the Manipur gap will probably be completed during the coming winter, and it will then be determined whether the stations on the western side of the gap have been displaced: if unfortunately they prove to have been moved, the test by circuit will not be possible without expensive revisions on the Eastern Frontier Series, that will serve no topographical purpose, and the alternative plan of dividing the great Burmese circuit by partition series, that will fulfil at once the double object of a ground-work for topography, and a test of the whole triangulation will have to be considered.

14. Whether or not the stations round Manipur prove reliable, the fact will remain unaltered, that the Indian and Burmese triangulations have been severed, and that no future extensions into Burma will be of use. The damage could be rectified by a revision of the principal triangulation throughout Assam, but no revisionary triangulation is worthy of its cost, unless it is required for early topography. I therefore beg to suggest for your consideration, whether we cannot remedy the evil effects of the earthquake, not by restoring the old stations to their old positions perhaps for them to be displaced again, but by carrying new series over the north and east, that will not only consolidate Burma into one trigonometrical whole and obviate the immediate necessity of revision, but will also be available and valuable for new topography.

15. In proposing extension of principal triangulation over Burma, I am following the precedent of India. Five topographical parties are now employed in Burma, the character of their work is not what it was in India of old, and very few trigonometrical points are available: the areas under survey are not enclosed by trigonometrical circuits, and there are no means of correcting the errors that are being generated outwards towards our frontiers.

16. Differences of opinion exist as to the degree of accuracy necessary in the trigonometrical basis of topography, and it has been argued, that our principal triangulation is more scientific than practical. An understanding on this question must precede any discussion of proposals for future work, and I therefore ask your permission that I may state the reasons that have convinced me of the *practical* necessities of principal work.

17. Principal Triangulation is executed to serve:—

(i) As a basis for present topography and mapping.
(ii) As a means of fixing the area mapped by topography in its correct position on the Earth with reference to other surveys.
(iii) As data for determining the Figure of the Earth for the use of our own topographers.
(iv) As a perpetual record for the use of posterity.

18. These are its principal objects and I will discuss the question from the four corresponding points of view, but before doing so I must premise that the difference between principal and secondary triangulation is only a matter of degree: as the secondary is made more refined, it more nearly approaches the principal in both accuracy and cost, and the true cost of principal triangulation is never an additional cost, but merely its apparent excess over what the secondary triangulation employed in its stead would cost. I say "apparent" excess, because though in direct expenditure there would appear an excess, indirect savings both immediate and future always result from Principal work.

As a basis for topography.

19. Very accurate results are sometimes claimed for rough triangulation, but in view of the errors to which even the best work is liable, such results must be fortuitous or picked for exhibition. The errors generated over a large area of secondary triangulation will not be such as obtain in the best topographical work, nor such as are selected for instructional specimens, but will be composed of every grade from nothing to enormity. In every collection of surveyors there will be a certain number dishonest and careless, and in the Great Trigonometrical Survey of India extraordinary precautions have been introduced to guard against manipulations and blunders which might go undetected in secondary network.

20. Apart from carelessness and dishonesty, the general tendency of observers is to sacrifice accuracy to speed: the history of the Great Trigonometrical Survey shows a constant tug-of-war between the field observers and the Superintendent: the observers place local needs before general uniformity and never lose an opportunity of escaping from control. The Superintendent has been ever engaged in holding them in and endeavouring to maintain traditional accuracy. It is not uncommon to find our ablest observers impatiently criticising observational refinements, as though they were the relics of an ignorant past, or the useless fads of Science. Mr. Hennessey once showed me a letter—though I have been unable to trace it since—in which Sir Andrew Waugh explained to a querulous subordinate, that although our observational niceties may be unnecessary, yet they are *deliberately* retained, not only to create habits of accuracy, but to serve

as a reserve of force, a factor of safety: if the niceties were to be abandoned, the refinements would follow, and finally there would be no reserve of protection for essential accuracy. When a constant struggle is maintained against uniformity, accuracy and tradition by trained trigonometrical observers, what conditions would obtain, if accuracy were opposed to tradition, if observers were not specially trained, if uniformity were not considered essential, and if no real control existed?

21. The Topographical Hand-Book states that the average linear error of good secondary triangulation should be less than 3 inches per mile. What is the precise meaning of this extract? Does it mean that after a chain of triangulation has been carried 1,000 miles, the geographical position of the terminal station should be correct to within 3 000 inches, or does it mean that when two chains emanating from the same base join again on a common side, the two values of that common side should agree to within 3 inches per mile? If the second suggested meaning is correct—and from the context it is clearly the meaning intended—how long are the two chains supposed to be? If two chains started from Cape Comorin, and closed again in the Punjab, a discrepancy of 3 inches per mile in the values of the common side would be phenomenal.

22. In dealing with *great* areas the error of triangulation cannot be stated in inches per mile of closing side: the two values of the length of a closing side may be identical, whilst the values of latitude, longitude and azimuth, differ widely: it is the geographical position of the terminal points that we require to find, and not their mere distance apart.

23. The accuracy of a foundation affects the whole tone of subsequent operations, and if the Indian Survey had been based on rough triangulations, emanating from different origins, bases and azimuths in Madras, Bombay, Bengal and Sind, with no uniformity, no single control, no systematic dispersion of errors, no common spheroid, I am of opinion that the several triangulations would never have joined; boundary difficulties would now pervade the Empire, and the time would assuredly come when the whole would be rejected and revised.* When the East India Company decided to throw a Principal Triangulation of a greater accuracy than had ever been attempted in Europe, over a larger area, than had ever been pivoted on one origin, they saved their successors' endless trouble and much expense. What the Company did for India, ought not we to do for Burma?

After 80 years of operations the survey of Ceylon is still in chaos, with boundary disputes all over the island, because its foundations were not carefully laid. A small area, moreover, like Ceylon does not require the same degree of accuracy that India does.

The survey of Rhodesia is now about to be undertaken by the British South Africa Company, and the Directors have decided to base it on a Principal Triangulation of the highest accuracy attainable.

In the recently published History of the Survey of South Africa, an account is given of the preliminary discussion that took place amongst the high officials at the Cape upon the degree of accuracy that it was advisable to introduce: the following sentence is extracted:

"Sir Bartle Frere was then Governor of the Cape Colony and High Commissioner for South Africa: from his experience of Indian administration His Excellency thoroughly realised the advantages and the necessity for accurate survey, and the true economy of basing all future surveys upon a Principal Triangulation of such accuracy that its results might be considered definitive for all future time, and he gave the recommendations his strongest and most cordial support."

As a means of fixing the Area on the Globe.

24. The second purpose served by Principal Triangulation (*vide* paragraph 17) is to fix the area of the survey on the Globe. We have started from an origin in Central India and worked outwards in all directions. In all directions we have generated errors, and though it may be argued that they are of no practical importance, and that they only interfere with geodetical faddists, yet

* It has been recently proposed on the Continent to request the British Government to revise the triangulation of England which is now inferior to that of Europe.

those errors are there, secretly cumulative, ready to confront us some day in a considerable aggregate, when we join on to a foreign survey.

The different sources of error may be classified as follows :—

(i) Of Observation.
(ii) Of Standard.
(iii) Of the adopted Figure of the Earth.
(iv) Of initial Azimuth
(v) Of initial Latitude.
(vi) Of initial Longitude.

Our triangulation in Upper Burma is now 1,600 miles from our origin : what geographical displacements may be expected to exist at Mandalay?

Errors of Observation.

25. Dr. Gill, F.R.S., whose experience commands respect, states that even in the very best triangulation the errors of observation which accumulate range from 1 in 20,000 to 1 in 50,000, or from 1 inch to 3 inches per mile. By this estimate the positions of our trigonometrical points near Mandalay are possibly wrong by 200 to 500 feet.

26. The best triangulation in India is in the North-West Quadrilateral; in one of its circuits, Ferozepore—Sukkur—Karachi—Neemuch—Ajmere, containing 250 triangles, the closing discrepancy in the position of the terminal station is 50 feet, and in azimuth 3″. In the South-East Quadrilateral, in the circuit of 109 triangles, Jubbulpore—Warangal—Bilaspur—Sohagpore, the disagreement in position is 29 feet, and in azimuth 5″.

In the North-East Quadrilateral the error of position generated in 44 triangles, between Saugor and Dehra, a distance of 400 miles, was 140 feet, or 1 in 15,000, or 4 inches per mile. The error in the azimuth of the closing side was 11″·5, or 0″·25 per triangle.

In the Southern Trigon the error of position generated in 107 triangles in the circuit Madras—Bangalore—Tuticorin was 50 feet, and in azimuth 9″ or 0″·09 per triangle.

In the South-West Quadrilateral the error generated in the 30 triangles of the Khanpisura Series, between Neemuch and Ahmednagar, a distance of 350 miles, was 85 feet, being 1 in 21,000, or 3 inches per mile. The error in azimuth was 8″, or 0″·27 per triangle.

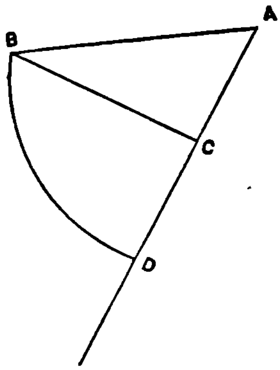
There are 14 circuits separating Mandalay from our origin, and if the above examples are taken as typical, a displacement may be expected at Mandalay of 250 feet in position and 16″ in azimuth.

27. We can arrive at another estimate as follows :—

	In position.	In azimuth.
Average error generated per triangle in the North-West Quadrilateral, South-East Quadrilateral, and Southern Trigon	3 inches	0″·03
Average error generated per triangle in the North-East Quadrilateral and South-West Quadrilateral	9 inches	0″·11
Average error per triangle for all India . .	6 inches	0″·07

There are 186 triangles between Kalianpur and Mandalay, and if we assume them to be affected by the average error only, we may expect an ultimate displacement of 93 feet in position and 13″ in azimuth.

28. The above figures show the effect of *observational* errors on Principal work, and the following give some results of Secondary work. As an example of good Secondary work I have chosen the Quetta-Kalát Series, because it is the only circuit of secondary triangulation shown on the Index Chart to the Great Trigonometrical Survey of India: it was executed by chosen observers working with 14 inch Theodolites, and the triangular errors and linear errors are as small as the Hand-book requires.



In the accompanying diagram A to D is the Great Indus Series, C to B is Captain Rogers' work, A to B is Mr. McNair's Secondary triangulation, and D to B is Mr. Claudius'.

Captain Rogers' mean triangular error— from C to B is 0″·34,	
Mr. McNair's .	. from A to B is 1″·1,
and Mr. Claudius'	. from D to B is 1″·7.

Mr. McNair's linear error of closing side is 4 inches per mile, and Mr. Claudius' 6 inches.

A real test of work, as stated before, is only to be obtained by comparing the values of geographical position, and azimuth, and the Secondary work on A B, and D B can be proved at B, firstly, by comparing the results with Captain Rogers' results on C B, and, secondly, by omitting Captain Rogers' and comparing the results of A B and D B against each other.
Firstly, accepting Captain Rogers' results at B as the standard :—

Mr. McNair's error in position is 91 feet, and in azimuth 17″ : Mr. McNair's length of chain was 17 triangles: his average error generated per triangle is therefore 64 inches in position and 1″·0 in azimuth. (For a comparison with principal work, please see para. 27.) Mr. Claudius' error in position is 30 feet, and in azimuth 47″·0 : Mr. Claudius' length of chain was 24 triangles : his average error generated per triangle is therefore 15 inches in position, and 2″ in azimuth. Secondly, omitting Captain Rogers' chain and comparing Mr. McNair's work against Mr. Claudius' : the discrepancy in position at B is 76 feet, and in azimuth 31″·0 : the average error generated per triangle is then given as 23 inches in position and 0″·8 in azimuth.

Apart from the magnitude of these azimuthal errors it is disquieting to meet with results that do not admit of mathematical explanation : in Mr. McNair's secondary chain the average triangular error is 1″·1, and the average error generated in azimuth per triangle is 1″·0 : in Mr. Claudius' secondary chain the average triangular error is 1″·7, and the average error generated in azimuth per triangle is 2″·0 : such inexplicable anomalies never occur in principal work.

It is not possible to calculate what the probable final error of such secondary work would be if it were continued to Mandalay, as the results defy all the laws of probability. When errors attain to such magnitudes, their aggregate accumulates more rapidly than in proportion to distance travelled.

Error of Standard.

29. The error in our standard foot is 0·000004341 foot. In the 1,600 miles separating Mandalay from Kalianpur, this error has accumulated to the amount of 36 feet.

Error of Axes.

30. The most probable value of the earth's axes at present known are Clarke's, and according to them the errors of the Indian Survey are as under :—

Peshawar	is shown	300 feet	too far	to the	north.
Karachi	,	600 feet	„	„	west.
Cape Comorin	,,	250 feet	„	„	south.
Mandalay	„	1,050 feet	„	„	east.

Initial Azimuth.

31. The error in the initial azimuth has given a twist to the Indian Survey on Kalianpur as a pivot. Mekran is too far north, Gilgit too far east, Mandalay too far south (by about 270 feet perhaps), and Cape Comorin is too far west.

32. The error of the initial latitude is affecting the whole Survey : its amount cannot be stated until we know more of latitude variation, but is probably under 200 feet.

33. The error of the initial longitude has placed India $2\frac{1}{2}$ miles too far east.

34. It is a reasonable presumption that the Indian Survey will at some future time be contiguous on all sides with external systems of triangulation; our own triangulation will have then to be fitted on, and it is well that we should take steps to minimise the errors that will present themselves for elimination.

35. We have already had some experience, in the case of the longitude of India, of the trouble caused by these so-called theoretical errors; in that instance, as in every other, it was argued that an error of (say) 1,000 feet can be of no practical importance in 1,000 miles, and that $2\frac{1}{2}$ miles cannot matter in 7,000. In this argument the unwarranted assumption was made that the error was distributed over the whole distance, whereas such errors are *not* distributed and will assuredly have to be faced some day. The longitude error has come in with its full force along our North-West Frontier, and it is the topographer and not the geodesist who is complaining of it. The proposal in 1894 to re-determine the longitude of India emanated from topographers, not from geodesists: the proposal to change the meridian of Indian mapping came from topographers and not geodesists. From a geodetical point of view no present advantage is to be gained by changing the longitude of the Indian Survey: such a change would indeed be better deferred, until the variation of latitude has been determined, and the figure of the earth re-calculated, when we shall be able to change our longitude, latitude, azimuth, standard and axes at the same time. But this is but one point of view only; our topographers and explorers on the North-West Frontier are those who feel the shoe pinch.* Sir T. Holdich, Colonel Wahab, and Captain Mackenzie advocate, I believe, the adoption of Greenwich terms for all frontier mapping, and would thus transfer the longitude error from their front to their rear, and insert it between India and Afghanistan: it is possible if this is done, that the shoe may then pinch others, but these others again will not be geodesists.

Just as the longitude error is now causing trouble on the North-West, the accumulation of theoretical errors will confront us some day on the North-East.

Figure of the Earth.

36. The third use of principal triangulation is (*vide* para. 17) to determine the Figure of the Earth. When Everest determined the Figure of the Earth from the Indian Triangulation, his object was topographical, though his sympathies may have been scientific. In plotting our triangulation we have to convert our distances and directions into latitudes and longitudes, an operation dependent on the axes of the Earth, and errors in the adopted values of the axes produce errors in the plotted points on our maps. If Everest had regarded axial errors as of no practical importance, and had adopted Lambton's spheroid as "quite near enough," Peshawar would now be 700 feet too far north, Karachi 1,340 feet too far west, Cape Comorin 550 feet too far south, and Mandalay 2,600 feet too far east.

As a perpetual record.

37. The only purpose served by Principal Triangulation, with which I have not dealt, is that of forming a perpetual record for posterity. We are so accustomed to the presence of our Trigonometrical Survey that we fail to appreciate the advantage of being able to commence a new survey of some enormous area, like Sind, at any moment without having to trouble about a basis, about graticule, or about connexion with neighbouring surveys. Even now-a-days when our Forest Surveys, and Forest parties, and our Topographical parties, and our Traverse parties meet in mutual contact, there frequently appear large discrepancies in the details of the overlaps, and whilst each party is maintaining its own superiority and questioning the correctness of others, they all accept without demur the infallibility of Great Trigonometrical work. Had our triangulation not been rigorously controlled, the sites of its stations, if even worthy of preservation, would not have ... preserved, and at every re-survey a re-triangulation would have been ...essary.

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*The following extract is from a letter received last week from an officer exploring in Tibet :—

"I am embarrassed by not knowing whether the longitudes of the Kuen Lun Peaks are in Greenwich or Indian terms."

38. To consolidate the Principal Triangulation of Burma, and to place it on a footing commensurate with that of India, it would be necessary:—

(i) To prolong the Mandalay Meridional Series north from Katha to Sadiya.

(ii) To execute a Frontier Series along our eastern boundary.

(iii) To measure base-lines near Toungoo, Katha, Sadiya and the Salween.

(iv) To take astronomical observations at our base-lines and on the principal series of triangulation.

The base-lines could be measured in one or two years by Nos. 22, 23 and 24 Parties, the astronomical observations would occupy No. 22 Party for four or five years, the triangulation would occupy No. 24 Party for six years.

39. The earliest operation of Indian Survey was the measurement of a base-line at Bangalore in 1800, when Colonel Lambton proposed to test his triangulation by making it emanate and close on this base. Lord Clive,—afterwards Earl Powis—the Governor of Madras, pointed out to Colonel Lambton that his proposal would not test the correctness of the base itself; "it will be expedient," he wrote, "that a base of *verification* should be measured, which may afford you the means of judging of the accuracy of the original base. It being of importance that the fundamental principles of your survey should be established with the greatest practicable degree of precision, the measurement of the base-line should be supported by observations for ascertaining the latitude and direction of the meridian."

On the principles enunciated by Lord Clive, the Great Trigonometrical Survey of India has been based; what Lord Clive did for India, should we not do for Burma?

40. On the Great Arc of India there are base lines at every 350 miles, and there are additional base-lines at Vizagapatam, Calcutta, Sonakhoda, Attock and Karachi; no point of the Indian triangulation is 400 miles from a base-line.

In Lower Burma there is one base-line at Mergui, and in Upper Burma there is no base-line at all. The distance between the Calcutta and Mergui base-lines is 1,000 miles, Sadiya and Katha are 600 miles from a base-line, Prome is 550 miles, and our eastern frontier is 800 miles; there is no base-line on the meridional arc of Burma.

In view of the errors that even the best triangulation is liable to, it has been decided in the United States of America to introduce base-lines at every 200 miles. In the new survey about to be thrown over Rhodesia the triangulation is to be verified by a base-line at every 200 miles.

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DEHRA DUN;
5th September 1898.