193

PRB-1-318 (N)
800

Government of India
Railway Department
(Railway Board)

HISTORY

OF THE

HARDINGE BRIDGE

UP TO 1941

by

T. S. N. Rao, Engineer-in-Charge, Hardinge Bridge,
B. A. Railway

Technical Paper No. 318.

Delhi
Manager of Publications
1946

Price: Rs. 7/8/- or 11s. 6d.

BOOKS AND TECHNICAL PAPERS PUBLISHED BY THE RAILWAY BOARD.

Books

(1) Report by the Railway Board on Indian Railways. Published yearly. Price: Vol. I—Report, Rs. 2-2-0 or 3sh. 6d. Vol. II, Rs. 10-12-0 or 17sh. [1944-45].

(2) Classified List of State Railway Establishment and Distribution Return of all Railways, corrected up to 31-12-44 Price Rs. 5-0-0.

(3) History of Indian Railways, constructed and in progress, corrected up to 31st March 1939. (Published sexennially. Price Rs. 4-10-0 or 7sh. 3d.

Technical Papers

(4) Over 317 Papers have been published by the Railway Board's Office.

The Papers comprise:—

(a) Original descriptions of railway works and studies of railway problems in India and elsewhere.

(b) Reprints of articles from foreign engineering magazines.

(c) Reprints of abstracts of reports received by the Government of India on subjects connected with Railways.

A complete list of the Papers can be obtained *gratis* from the Chief Controller, Standardization, Central Standards Office for Railways, New Delhi.

The prices of the papers vary from Annas Three to Rupees Fifteen.

The books and papers can be bought from
The Manager of Publications, Civil Lines, Delhi, and his Agents.

Government of India
Railway Department
(Railway Board)

HISTORY
OF THE
HARDINGE BRIDGE
UP TO 1941

by

T. S. N. Rao, ENGINEER-IN-CHARGE, HARDINGE BRIDGE,
B. A. RAILWAY.

Technical Paper No. 318.

Delhi
Manager of Publications
1946

DH 14 251 H, NH 6
NH 6

DH 14 or 251
NH 6

List of Agents in India and Burma from whom Government of India Publications are available.

ABBOTTABAD—English Book Store.

AGRA—
English Book Depot, Taj Road.
Indian Army Book Depot, Dayalbagh.

AHMEDABAD—H. L. College of Commerce Co-operative Stores, Ltd.

AJMER—Banthiya & Co., Ltd., Station Road.

AKOLA—Bakshi, Mr. M. G.

ALLAHABAD—
Central Book Depot, 44, Johnstonganj.
Kitabistan, 17-A, City Road.
Ram Narain Lal, 1, Bank Road.
Superintendent, Printing and Stationery, U. P.
Wheeler & Co., Messrs. A. H.

BOMBAY—
Co-operators' Book Depot, 9, Bakehouse Lane, Fort.
International Book House, Ash Lane, Esplanade Road.
Joshi, Mr. V. G., News Agents, Devgad Baria, via Piplod.
Kothari Book Depot.
Lakhani Book Depot, Bombay, 4.
New Book Co., Kitab Mahal, 188-90, Hornby Road.
Popular Book Depot, Grant Road.
Superintendent, Govt. Printing & Stationery, Queen's Road.
Taraporevala Sons & Co., Messrs. D. B.
Thacker & Co., Ltd.
Tripathi & Co., Messrs. N. M., Princess Street, Kalbadevi Road.
Wheeler & Co., Messrs. A. H.

CALCUTTA—
Book Company.
Chatterjee & Co., 3, Bacharam Chatterjee Lane.
Chukerverty, Chatterjee & Co., Ltd., 13, College Square.
Das Gupta & Co., 54/3, College Street.
Hindu Library, 137-F, Balaram De Street.
Lahiri & Co., Ltd., Messrs. S. K.
Macmillan & Co., Ltd., 294, Bow Bazar Street.
Newman & Co., Ltd., Messrs. W.
Roy Chowdhury & Co., Messrs. N. M., 72, Harrison Road.
Sarcar & Sons, Messrs. M. C., 15, College Square.
Sarkar & Sons, Ltd., Messrs. S. C., 1/1/1-C, College Square.
Standard Law Book Society, 79/1, Harrison Road.
Thacker, Spink & Co. (1933), Ltd.
Wheeler & Co., Messrs. A. H.

CAWNPORE—
Advani & Co., P. O. Box No. 100.
Indian Army Depot, Juhi.

CUTTACK—Press Officer, Orissa Secretariat.

DEHRA DUN—
Jugal Kishore & Co.
Ideal Book Depot, Rajpur Road.

DELHI—
Imperial Book Depot and Press, Near Jama Masjid (Machhliwalan).
Income-tax Law Publishing House, Chandni Chowk.*
Indian Army Book Depot, Daryaganj.
Jaina & Bros., Messrs. J. M., Mori Gate.
Oxford Book and Stationery Co.
Sharda Mandir, Ltd., Nai Sarak.
Young Man & Co. (Regd.), Egerton Road.

DUM DUM CANT.—Bengal Flying Club.†

FEROZEPORE—English Book Depot.

GWALIOR—Jain & Bros., Messrs. M. B., Sarafa Road.

HYDERABAD (DECCAN)—Hyderabad Book Depot, Chaderghat.

JAIPUR—Garg Book Co., Tripolia Bazar.

KARACHI—
Aero Stores.
English Bookstall.
Standard Bookstall.

KARACHI (SADAR)—Manager, Sind G Book Depot and Record Office.

LAHORE—
Kansil & Co., Messrs. N. C., 9, Commercial The Mall.
Malhotra & Co., Messrs. U. P., Post Box No. 9.
Minerva Book Shop, Anarkali Street.
Punjab Religious Book Society.
Rama Krishna & Sons, Anarkali.
Superintendent, Govt. Printing, Punjab.
University Book Agency, Kacheri Road.

LUCKNOW—Upper India Publishing House Literature Palace, Aminuddaula Park.

LYALLPUR—Lyall Book Depot.

MADRAS—
Higginbothams.
Superintendent, Govt. Press, Mount Road.
Varadachary & Co., Messrs. P.

MHOW—British Book Depot.

MOGA—Army Musketry Stores.

NAGAPATAM—Venkataraman, Mr. B.

NAGPUR—
Khot & Sons, Messrs G. G. Sita Burdi, 3rd Mo Lane.
Superintendent, Govt. Printing, Central Provinces.

NEW DELHI—
Bawa Harkishen Das Bedi, Ferozeshah Road.
Bhawanani & Sons.
Delhi and U. P. Flying Club, Ltd.†
Jainai & Bros., Messrs. J. M., Connaught Place.
Ramesh Book Depot & Stationery Mart, Connaught Place.
Saraswati Book Depot, 15, Lady Hardinge Road.

PATNA—Superintendent, Government Printing, Bihar, P. O. Gulzarbagh.

PATNA CITY—
Lakshmi Trading Co., Padri-Ki-Haveli.
Raghunath Prasad & Sons.
Sinha & Bros., Messrs. R. P., Guzri Bazar

PESHAWAR—
British Stationery Mart.
London Book Co. (India), Arbab Road.
Manager, Govt. Printing & Stationery, N.-W.F. P.

PESHAWAR CANT.—Faqir Chand Marwah.

POONA—
Deccan Bookstall, Fergusson College Road.
Dastance Bros., Home Service, 456, Rawiwar Peth.
International Book Service.
Ram Krishna Bros., Opposite Bishram Bagh.

QUETTA—Standard Bookstall.

RAJKOT—Mohanlal Dossabhai Shah.

RANGOON—
Burma Book Club, Ltd.
Curator, Govt. Book Depot, Burma.

RAWALPINDI—Ray & Sons, Messrs. J., 43, K. & L. Edwardes Road.

SHILLONG—Superintendent, Assam Secretariat Press.

SIALKOT CANT.—Modern Book Depot, Bazar Road.

SIALKOT CITY—
Buckingham & Co., Booksellers & Stationers, Greenwood Street.
Clifton & Co.

TRICHINOPOLY FORT—Krishnaswami & Co., Messrs. S., Teppakulam.

TRIVANDRUM—
Booklovers' Resort, Taikad.
P. R. Bros., Main Road

VELLORE—Venkatasubban, Mr. A., Law Bookseller.

*Agents for income-tax, Law and allied Publications only.
† Agents for Publications on Aviation only.

This Technical Paper, which issues from the office of the Railway Board, India, is not an official publication. Neither the Government of India nor the Railway Board are responsible for statements made or opinions expressed in the paper.

W. S. BENTON,
Director, Civil Engineering,
Railway Board.

New Delhi,
1st May 1946.

FOREWORD.

At the time of its completion, the Hardinge Bridge over the Ganges at Sara was rightly considered to be one of the greatest achievements of the bridge-builder in India, and a great asset to the E. B. Railway, as it provided a vital all-rail route for the important tract of country served by the railway north of the Ganges. Naturally the anxiety caused in regard to the safety of the bridge, as a result of the damage done to its training works, was correspondingly great and has, for the last ten years, strained the best energies and resources of the Engineering Department of the railway.

2. It is so easy to be wise after the event and say at this distance of time what should and should not have been done at the time of the construction of the bridge, but even its worst critics will have to acknowledge that the behaviour of the river, particularly in regard to the scours caused near the training works, has been most unexpected and quite different to what could reasonably have been assumed at the time of the construction of the bridge.

3. Though working on another railway at the time, I was privileged to visit the construction works during two short periods of leave in 1913 and 1914. These contacts naturally created for me a special interest in the bridge which could not, however, be kept up in later years, with the result that on my appointment to the E. B. Railway in 1939, I found myself quite out of touch and wanted to have some idea of what had been during the last twenty years. As the success of the works undertaken for the protection of the bridge had not till then been fully established, I decided to pay before joining my duties a hurried visit to the Hydro-dynamic Institute at Poona and see for myself the experiments made for the safety of the bridge and the stabilization of the river above it, but this visit could not give me a connected picture of the developments which had taken place, nor could I find time to wade through the number of thick and uninviting files put up to me to study. In sheer despair I had to request Mr. Rao to compile a short history of what the Railway Engineers and the river had been doing to outwit one another at this bridge. I feel particularly indebted to him for acceding to my request and compiling a comprehensive note on the subject which, I am sure, will be found useful and interesting not only by those joining the B. A. Railway for the first time, but by the profession in general. The note, apart from being a narrative of events leading up to the present, is an intelligent resume of the measures taken to meet them. It contains many interesting observations by the author. The suggestions in Chapter XV for securing an even flow of the river through the bridge provoke thought. They could not be accepted at the time. The interests at stake were too great to be left to innovations or experiments. This chapter does, however, contain ideas which are bound to come up for consideration by future engineers in some form or other.

4. I commend this technical paper to all who are interested in this branch of engineering, in the hope that the information contained therein will be of some use and help to them in their own spheres of work.

L. P. MISRA,
General Manager,
Bengal Assam Railway.

Calcutta,
8th July, 1943

PREFACE.

For some years past it has been my intention to attempt to write a complete history of the Hardinge Bridge from the time the bridge was conceived to be built across the Lower Ganges down to the present date. For I have found that all the records in connection with the bridge were filed in different files,—which are sometimes not readily accessible,—and that too, somewhat at haphazard ; and it seemed that a collection of what had been done up to date and of the experience that had accumulated if definitely set forth for easy reference, would be a great help for future engineers. But the opportunity of writing such a book did not present itself until July, 1941, when I was told by the General Manager of the Eastern Bengal Railway to do so. Accordingly, I began the task and the result is the following chapters.

It is hoped that this work will not only prove of great practical value and interest in times of danger, but will also serve as a helpful guide to the best ways of maintaining the training works and the bridge by recognizing and understanding warning symptoms and summoning proper assistance in good time where ignorance might cause delay and aggravate the trouble. To know all about the Lower Ganges is a duty of the Engineers-in-Charge of the Hardinge Bridge.

In writing this book, I am very much indebted to Mr. R. W. Taylor, Chief Engineer, Eastern Bengal Railway for giving me encouragement and advice, and I acknowledge the courtesy and kindness of those who have helped in the collections of information.

Paksey,
December, 1941.

T. S. N. RAO.

CONTENTS.

INDEX OF PLANS.

HISTORY OF THE HARDINGE BRIDGE

by

T. S. N. RAO, Engineer-in-Charge, Hardinge Bridge,

B. A. Railway.

CHAPTER I.

THE GANGES.

(i) **The river Ganges, its tributaries and its effluents.**—The river Ganges rises in the Garhwal State, in lat. 30°—50′-4″ N and long. 79°—60′-4″ E and falls into the Bay of Bengal after a course of 1,557 miles. Under the name Bhagirathi, it issues from an ice cave at the foot of an Himalayan snow bed above Gangotri, 13,800 feet above the level of the sea. At this point it is only 27 feet broad and 15 inches deep. Ten miles lower down, at the elevation 10,319 feet, it is still only 43 feet broad and 18 inches deep. At Deo-Prayag, its junction with the Alakananda, 133 miles from its source, its elevation is 1,953 feet; and at Hardwar, 180 miles, 1,024 feet. At mile 668 where it reaches Allahabad, it is well over a mile wide and here it is reinforced by Jamuna. Thence to Benares its fall is about 6″ to the mile and thence to the sea anything between 6 and 2 inches, while its flood which is anything from 2 to 10 miles. The total length of river above given, 1,557 miles, is measured to the mouth of the Megna, where the combined waters of the Ganges, and Brahmaputra fall into the sea.

The catchment area of the Ganges and its tributaries is bounded on the north by about 700 miles of the Himalayan Range, on the south by Bindhya Range and on the east by the ranges that separate Bengal from Assam. The river basin thus enclosed has an area of 391,000 square miles. The flood discharge at Rajmahal, after the Ganges has received all its tributaries, has been estimated at two million cusecs, which works out to more or less 5 cusecs per square mile of the drainage area. A large share of the flood discharge of the Ganges consists of snow melted by the fierce heat of June, July and August. This supply is greatly enhanced by the rains which prevail all over the hills and plains of Northern India at the rate of 80 to 150 inches in the season, between June and September.

Below the point, Hardwar, of the emergence of Ganges into the plains, its principal left bank tributaries are, successively, the Ramganga, Gumti, Gogra, Gondak, Kosi and Mahananda; and on the right bank the Jamuna and Son. Besides these there are numerous minor tributaries, all of which go to swell the discharge of the main Ganges during the rainy months (vide Plate I).

When it has arrived 300 miles from the sea as measured along the river's winding, the Ganges begins to form its delta, branching out at several mouths and reaching the sea at places situated many miles apart. The chief of these channels that which is practically considered to be the Ganges proper—takes the name of Padma or Padda, and proceeds in a south-easterly direction to Goalundo where it is joined by the main stream of Brahmaputra. From the right bank of the Ganges take off the three Nadia rivers, the Bhagrathi, the Jalangi, and the Mathabhanga, which combine to form the Hugli on which stands the city of Calcutta. On the left bank, Boral leaves the main stream at Sardah and flows into and through the depression of the Chalan Beel to join the Brahmaputra. Below Sara, the Gorai, an important off-shoot, leaves the main river near the town Kushtia on the right bank (vide Plate II). All these rivers increase or diminish in size in accordance with local changes in the course of the main river. They have, however, all diminished in size since the preparation of Major Rennal's maps.

(ii) **Character of the Lower Ganges.**—The whole of the Ganges valley is practically river bed. In the early days of its formation, the changes must have been vast and rapid. Even, within the memory of man and since surveys are commenced there have been some great changes.

For almost their whole length from where they leave the hills, the Ganges and its Himalayan tributaries pass through a country composed of the finest sand and soft alluvium. Here and there for short lengths, it may come in contact with hard original ground as at Sahebganj, Godagari and Rajmahal or find small bits of hard stratum up to 80 or 100 feet thick. These latter are probably old river beds which have been suddenly deserted, and which have been filled by gradual silting of the lightest form of alluvium, mostly composed of vegetable matter. In course of time, this forms a hard bed of dark coloured tough clay, which if deep and wide enough, is capable of resisting erosion for many years. The bank at Sara, Raita and Goalbathan is a good example of this.

The Ganges changes its course in two ways; the first by "short circuiting" or leaving long bights or bends of its bed, and occupying and enlarging others, and perhaps old disused channels; the second by cutting its banks by scour parallel to its current. The first is often sudden, in a day or a week the change may be affected. Occasionally the river in the course of years, makes enormous the loops, the channel of which may close together at their bases and the river short circuits or cuts through the neck and thus flows once more direct. This may be taken as a combination of the two ways of changing course.

The changes in the river's courses are continuous, the soft character of the soil through which it cuts its way, makes changes easy and enable the river to sway to one side or the other. It is impossible to fix any limit of time or distance of the extent of its meanderings. If only the discharge of the river were constant throughout the year and in successive years, a time would doubtless arrive where bed, banks and current would have so far adjusted their deficiencies as to arrive at stability of "regime." But such a state of thing is rendered impossible by the periodic changes of discharge volume which are the consequence of rainfall and of the melting of the Himalayan snows. The result of this instability of conditions is that permanency of regime is never attained; and so, in process of time, the river is found occupying, in turn, each and every part of an area bounded by a certain pair of lines beyond which it never ordinarily wanders. Plate III shows how the river has wandered from bank to bank and changed its course between Sardah and Pabna during the last 170 years.

During the floods, erosion is very rapid. On one occassion at Goalundo it amounted to a mile in one season from the end of July to the middle of September, and on several days it cut 600 feet per day measured at right angles to the bank. Of course, there being great erosion, there is also great silting. At first low sand banks form, these increase in height and become covered with tall grass and jhow jungles. This assists the deposit of suspended matter, and gradually a "chur" forms capable of cultivation.

The river also varies greatly in depth. It may be said that the channel consists of deeps and shallows. Where the bank is hard enough to resist the current, the scour may extend to an immense depth. When the river runs through sand banks, it seldom exceeds a depth of 30 feet below low water level.

The velocity of the river in the shallows during the floods is about 4 to 6 miles per hour. In the deep it sometimes exceeds 10 miles per hour. The average gradient of the water over long stretches is about three inches per mile. But in the floods and when the river current is concentrated it amounts to from 8″ to 12″ per mile over short distance of about half-a-mile to a mile.

For short periods of half-an-hour or so when the floods are at their highest, the water often passes down in rushes. These rushes cannot be accounted for by any sudden additions to the contents of the river from its tributaries or otherwise. They are more likely due to the bodily swaying of the current from side to side. They are most noticeable where the river is checked in its course by a bend too sharp for the easy movement of the mass.

In its width the river varies as greatly as in its depth. In its narrowest parts at high flood level it will be less than a mile wide, but on one side here it may be over 150 feet deep in the floods, and have a velocity of 10 to 12 miles an hour. It is remarkable in what a narrow channel it then flows; 90% of the water may pass down in a width of 2,000 feet or less with an average depth of 100 feet or more. In such places the scour action of the water does not follow the rules usually applied to water placidly flowing in open channels. Considering that the bed is almost pure sand of the finest kind, it is difficult to understand why the water does not bore to depths even greater than those found, especially in places where some hindrance, such as a justing piece of hard bank, or a very sharp bend exists. Generally, however, the Ganges during the floods is from two to four miles wide. In such places it often flows through two or more channels of which the deepest is used by steamers.

Such are the characteristic of the Lower Ganges. They differ very greatly from those of the Indus or other of the North Indian rivers. The changeable character of the river, the instability of the banks, and the great rise and fall of the river at the beginning and end of the rains all these, combined with the traffic considerations, had made the task of choosing a bridge site a formidable one. The determination of the precise site depended on several considerations and they are dealt with in detail in the following chapter.

No. 318.

CHAPTER II.

GANGES BRIDGE LOCATION QUESTION.

(i) **Need for a permanent crossing over the Lower Ganges.**—From the time the railways first came to India down to the beginning of the present century there was no bridge on the 740 miles between Benares and the sea. Between Benares and Hardwar there were some railway bridges. All traffic from districts north of the Ganges which failed to find its way across the river at or above Benares had got to cross by one or another of several more or less efficient ferries. The whole of the great tract of country that is bounded on the north and south by the Himalayas and the Ganges, east by the Kosi and west more or less by the Gogra and the Benares—Faizabad Section of the old O. & R. State Railway—a tract of country which may fairly be said to have an area of 33,000 square miles—is served by the network of railway worked by the Bengal and North Western Railway Company. East of the country just referred to there is another greater tract about 25,000 square miles in area which is served by the Eastern Bengal State Railway.

During that period practically the whole of the import and export Calcutta trade of this latter tract of 25,000 square miles crossed the Ganges at the Sara Ferry of the Eastern Bengal Railway, while that of the former, the 33,000 square miles tract, mainly crossed the Ganges by several ferries of which the chief one, at Mokameh, was a well-equipped wagon ferry. Naturally, if there had to be only one bridge across the Ganges between Benares and the sea, the choice of the bridge site must depend on the claims of the two great tracts of country.

The traffic to and from the northern section of the Eastern Bengal Railway so largely increased during the years 1884 to 1889 that every year there was block of traffic in the busy season which commenced in August, soon after which the floods begin to fall and expose large stretches of sand—half land and half water—over which it was neither possible for boats to approach nor to lay rails. Although great efforts were made for transhipping about one thousand tons daily of goods downwards, besides the upward traffic, there was serious hindrance to the trade, both in tea and jute, which required the whole crop to be brought to market as soon as it was ready. On account of the heavy cost incurred by the railway administration in laying down miles of sidings on the sand and taking them up again yearly when the river rose, and in order to meet successfully the growing traffic, a demand for a permanent crossing was acute. Accordingly, a proposal for bridging the Ganges at Sara was first put forward officially by the administration of the Eastern Bengal State Railway in 1889.

(ii) **Sir F. L. O'Callaghan's report on the location of a bridge site near Sara.**—This reference resulted in the appointment of a committee consisting of Sir (then Mr.) F. L. O'Callaghan, C.S.I., C.I.E., President, and Mr. J. R. Bell and Mr. W. Nicholson, Members, to consider the question. The committee met during the first week of March, 1891 and reported in a brief note outlining the dangers to be feared that the construction of a permanent bridge across the Ganges reach between Damukdia and Sara was perfectly feasible at a cost of Rs. 80 lakhs for bridge and training works.

In their opinion the dangers to be feared were—

(*a*) The Ganges might abandon its channels by evulsion over its left bank, and join the Brahmaputra by the line of the Baral or other spill channel.

(*b*) It might abandon its channel to the right by re-opening the more or less half closed deltaic creek that feed the Hooghly such as the Mathabanga which takes off a few miles above the proposed site.

(*c*) By erosion, its channel, without entirely abandoning its present locus, might enter the bridge so obliquely as to endanger the stability of the piers, abutments, etc.

(*d*) Local irregularities in the channel might endanger the structure.

Regarding (*a*), the committee observed that as long as the main line between Poradah and Natore continued to be efficiently protected against possible spills from the Ganges towards the Brahmaputra and special care was devoted to the maintenance of the floor and flank protection of all spill bridges, there would not be any serious danger. Should such a left bank evulsion occur in future, its results would not be less threatening in the then existing condition of things than it would be after the bridge was built.

As to (*b*) it seemed to the committee that in the course of nature the efflux of the Ganges by the Hooghly feeders was lessening and would continue to lessen and that no serious risk would occur in that direction.

On points (*a*) and (*b*) the committee desired that the opinion of the Irrigation Department might be taken, as the interests at stake were very great and they were regarded as the most serious dangers to which the bridge would be exposed.

As to (*c*) and (*d*), the committee attached supreme importance to the straight alignment of the reach which practically had been constant for at least 110 years, being maintained; and attributing the stability of this reach to the permanence of the clay head-land at Raita, they considered it essential to protect this head-land from further erosion by a stone revetment and apron. In order to uphold this vital work the railway siding to Raita should be held permanently. To avoid dangerous irregularities in the channel bed, the committee's opinion was that the bridge itself should be neither so short, nor so hampered with piers as to obstruct the channel in a sensible degree, nor so long as to admit of a deep channel occupying a sinuous course in or near the bridge; and the river flanks should be embanked and revetted with stone to a length of at least one mile above and half-a-mile below the bridge site. A bridge of 11 spans of 450 feet between centres of piers and piers going down to 150 feet below low water level were held essential.

In June 1891 Mr. O. W. Olding, Superintending Engineer, Public Works Department, Government of Bengal, to whom the committee's report was sent for his opinion regarding items (*a*) and (*b*) stated above, remarked that the most important matter appeared to be to prevent any interference with the natural tendency of the river, that the course of the river was all in favour of the closing of the minor channels on either bank and that persons interested in the adjacent lands should not be permitted to construct embankments or other works likely to check this tendency. He was of opinion that it would be necessary to prohibit, under Section 6 and 76, Clause (*b*) of Act II.B.C. of 1882 the construction of any embankment, or the obstruction or diversion of any water course, within a tract of country between Rampur Boaliah and the proposed bridge extending for two miles on either bank of the river Ganges—a tract to be named "Controlled" or "Prohibited" area—to ensure the course of the river not being interfered with unless by proper authority, and advised that it would be desirable to appoint the Superintendent of Way and Works, Eastern Bengal Railway, to be the Engineer under the Act, so that periodical inspections might be made by an officer having a strong interest in the prohibition not being lost sight of.

On Mr. Olding's advice, the Government of Bengal, under the Notification No. 134 dated 16th May, 1893, gave powers to the Eastern Bengal Railway to watch their interest within the "Prohibited Area".

(iii) **Sir Francis Spring's report on the choice of site for a bridge across the Lower Ganges.**—During the next eleven years nothing came out of the proposal made by the administration of the Eastern Bengal Railway. In the year 1902, the preparation of a detailed project was entrusted to Sir Francis Spring. He was asked to investigate—

(1) the relative merits of the various sites suggested for bridging the Ganges,

(2) to prepare and submit a report and estimate which would enable the Government of India to judge whether a bridge was practicable and if so, at what site, and

(3) to report on how neighbouring railways might best obtain full benefit from the bridge.

Accordingly in 1903, he with Mr. W. R. Haughton and Lt. Watt Smith, R.E., examined the Ganges on a length of about 165 miles between Manihari and Sara with the intention of determining whether there were any places on the reach where the Ganges might be bridged with any chance of stability by the use of one or a pair of guide banks, suitably designed and maintained. Proceeding down the river in a steamer and making such enquiries as proved feasible, he came to the conclusion that it would be possible to brdige across the Ganges between Manihari and Sara at the sites shown in Plate IV.

Site No. 1 was about 3 miles below Sara. On account of the sharp rectangular turn of the river from an east and west to a north and south direction and to a certain rather severe erosive action on the right bank between Raita and Damukdia—an erosion which seemed likely to bring the rectangular bend of the main-stream dangerously near the suggested bridge

site, downstream from Sara, Sir Francis Spring was not in favour of recommending this site, much as it had in its favour in the form of cheap and easy approaches and a narrow river bed.

Site No. 2 was about 3 miles upstream from Sara. It was located below Raita point, the permanency of which was well known. This site suffered from the somewhat expensive disability of requiring a very heavy approach bank on the north site of the bridge and it involved the construction of more new miles of railway than were needed for the alternative site downstream from Sara. However, the estimate of the bridge and its training works was made by Sir Francis Spring on the basis of data collected for this site.

Site No. 3 was at a place called Mirganj which is about 24 miles upstream from Sara. This site was an ideal one from the mere bridge building point of view. It suffered, however, under the disadvantage of being too far east to be convenient for the Eastern Bengal Traffic and not east enough for the requirements of the Bengal and North Western Railway. Moreover, it would require that a larger mileage of new railways should be constructed, to bring it into connection with other lines, than would be justified by its constructional merits. Therefore, after some hesitation, Sir Francis Spring was compelled to reject it.

Site No. 4 was at Isabpur about 35 miles upstream from Sara. Practically this site had no advantages either in constructional facilities or in adaptability for successful training.

Site No. 5, viz., Godagari site, which undoubtedly was the most serious competitor with the Sara site, was situated about 60 miles upstream from Sara. Unfortunately this site suffered from the drawback of being too far to the west for use by the heavy traffic which would seek to cross the Ganges if a broad-gauge branch was made to Sirajganj. For, if the river was bridged so far to the west as Godagari, it would be necessary still to keep the Sara Ferry open—a state of things to put an end to which was one of the chief objects of the projected Lower Ganges Bridge.

Sir Francis Spring, then having thoroughly discussed the following considerations which governed the choice of the bridge site, viz. :—

(*a*) the engineering considerations,

(*b*) whether inability of the East Indian Railway to carry the traffic of the Bengal and North Western Railway Company, makes it necessary to give the latter separate access to Calcutta,

(*c*) distance as a factor affecting the choice of bridge site,

(*d*) relative cost of new routes and alterations of old routes and the cost of bridge itself according to its localities,

(*e*) the weight of traffic and ton-mileage consideration, came to the conclusion that the site No. 2 was by far the best from every point of view. He estimated the cost of a bridge—of 15 spans of 350 feet centre to centre of bearing, with piers going down to 150 feet below L.W.L.—and of training works at Rs. 130 lakhs.

(iv) **Formation of other committees and their recommendations.**—A controversy then arose as to the best site for the bridge from a commercial point of view. In order to advise on this point a committee under the presidentship of Mr. G. Moyle, was formed in 1907. This committee recommended the bridge should be built at Raita.

Some doubt, however, still remained as to the suitability of the Raita site from a technioal point of view and an engineering committee consisting of the Hon'ble Mr. W. A Inglis, C.S.I., President, Mr. F. Palmer, C.I.E., Mr. W. A. Johns, Mr. J. Adam and Mr. R. R. Gales, Members, was appointed in 1908. They stated their opinion that the Sara sites were as good as any other proposed. They approved the general design of bridge and scheme of training works, elaborated by Sir Francis Spring, but suggested the provision of additional training works. They were of opinion that the estimates were insufficient and proposed an addition to the cost of the bridge and of the training works roughly based on Sir Francis Spring's figures making the estimated cost of a single line bridge and training works Rs. 170 lakhs and of a double line bridge and training works to Rs. 200 lakhs. They suggested that the choice of the exact site should be left to the engineer entrusted with the actual construction of the bridge having regard to the then existing conditions.

(v) **Site selected for the bridge.**—Sir (then Mr.) Robert Gales was appointed Engineer-in-Chief of the project in November, 1908 and His Majesty's Secretary of State for India sanctioned the construction of the Lower Ganges Bridge at or near Sara in December, 1908. On receipt of the sanction a survey of the river from Raita to opposite Bhairamara was put in hand and a thorough examination of the river above and below these points was undertaken. The site selected for the bridge was site AA (vide Plate V) which is 3 miles below Sara. The alternative upper site BB, 2½ miles below Raita, was exhaustively considered and rejected for the following reasons :—

Firstly, if the main river returned, as it had then done, to the right bank above Raita, there was danger of the formation of a sand bank below Raita point which would tend to throw the whole force of the river against the left guide bank thereby subjecting it to a far severe test than could in all probability be incurred at the lower site.

Secondly, if the main river cut into the left bank above the bridge there was a probability that the upper end of the left Guide Bank would be subjected to a greater test than it could be made capable of standing without excessive expenditure and that the left approach would also be expected to attack.

Thirdly, that the cold weather channel at the upper site was then 6,400 feet wide and could not be bridged by means of a bridge 5,542 feet in length which was all that was required at the lower site and that it seemed probable that the width of the upper site would still further increase before the guide banks are constructed.

Fourthly, it was conceivable that a bridge at the upper site might in certain positions of the main river tend to throw a considerable body of water down the Govindpur channel which might eventuate in heavy expenditure to keep the river in its course through the bridge.

The advantages of the site selected were :—

Firstly, that its position below the Sara clay on the left bank practically insured immunity from the dangers to which the left guide bank at the upper site would have been exposed as described above, whilst the existence of the Raita point and the course of the river below it, appeared to provide similar security for the Right guide bank.

Secondly, that the shorter guide banks necessary at the lower site in view of the above considerations afforded greater probability of successful construction in one season, with saving in cost which however was partly counterbalanced by the need of strengthening the only semi-permanent Sara clay with a proportionate amount of stone pitching.

Thirdly, less probability of and in fact practical immunity from, disturbance of existing conditions in respect of the Railway Ghats at Sara and Damukdia any interference with which would paralyse the Eastern Bengal State Railway.

Fourthly, a shortening of the Serajganj Branch by which an important addition of jute traffic would be secured.

It was believed that the possibility of the left approach being attacked would be obviated by the projected strengthening of the Sara clay and the retiring of the alignment from the river as far as the configuration of the country permitted. It was also believed that so long as the discharge passing the bridge site remained what it was, the river would not again attain the extreme curvature, shown on Major Rennel's maps above Raita on the right bank and above Sara on the left bank. Nevertheless, as the river might again work into the Lalpur Bight and threaten the line between Ishurdi and Abdulpur it would be necessary to raise the formation level of the line of the vicinity by at least 2′-6″ above high flood level.

From the foregoing it may be seen that the decision of the Government of India to build the bridge had not been hastily arrived at ; from its conception in 1889 until its construction was sanctioned 19 years elapsed. That a bridge on the lower reaches of the Ganges had become a necessity might be judged from the fact that the goods traffic crossing the river by the railway ferry had increased in 10 years from 244,000 to 446,000 tons, and the passengers in a 5-year period from 236,000 to 310,000. Indeed as long ago as 1884, the question of the congestion of the Ganges ferry at Sara was already becoming serious.

CHAPTER III.

THE HARDINGE BRIDGE OVER THE LOWER GANGES AT SARA.

The Hardinge Bridge connects the standard 5′-6″ gauge system of the Eastern Bengal Railway south of the Ganges with the metre-gauge system north of the river. The bridge comprises fifteen spans of 345 feet 1½ inches, with three land spans of 75 feet at each end. It carries a double line of standard gauge between the girders and a foot-way 5 feet in width bracketed-off the downstream girder. The extension to the northern bank of the standard gauge has necessitated the conversion thereto of portions of the metre-gauge system.

The bridge, which was opened for goods traffic single-line working on the 1st January 1915, *i.e.*, 3 years and five months from the commencement of the erection of the first well curb, was formally opened for double line working and all classes of traffic on the 4th March, 1915.

(ii) **Main features of the bridge.**—A maximum high flood level at the site of 50 feet above mean sea level at Karachi was established after thorough investigation. Although this level is unlikely to be reached in the existing circumstances it was realized that a sufficiently high maximum should be taken to ensure sufficient free board at bridge approaches and at the training works especially where pondings or afflux could take place. The maximum high flood level recorded at the site was 47·8 feet above mean sea level at Karachi in the year 1910 (vide fig. 1). The maximum, minimum and the fair average water levels during the year are shown in fig. 2.

As the surrounding country is of very low formation, it was considered preferable to add 200 feet to the datum values and thus avoid any of the working levels being in minus figures ; consequently highest flood level in relation to the mean sea level at Karachi is R. L. 250. All the reduced levels mentioned hereinafter refer to the new datum.

In order to get a reliable estimate for the maximum flood discharge of the Ganges, twelve discharge observations were made at a site 1·32 miles below Sara in the year 1903. From these observations, vide fig. 3, the conclusion arrived at was that although before reaching Sara the Ganges has thrown off several not unimportant deltaic effluents, yet, in spite of this, a highest flood discharge of about two million cusecs might still pass at Sara. Seven years later another discharge observation by the Mississippi method, taken on the 22nd August, 1910, with a flood level of 47·8 feet, showed a discharge of 1,926,080 cusecs. This is probably one of the largest discharges hitherto gauged by exact methods in the main channel of any river. Four gaugings in all were taken in that year and a curve drawn through them showed a probable discharge of 2,500,000 cusecs at maximum high flood level.

The maximum rise of flood is 31 feet. The surface slope in flood at the bridge was found to be 0·36 feet per mile and at low water 0·10 feet per mile. The maximum velocity in flood recorded before the construction of the bridge was 12·8 feet per second with a mean velocity 9·34 feet per second. The sectional area of the river in maximum flood excluding spill over high banks was 254,750 square feet.

Although the Ganges in many places has a flood width of several miles, it was at the site selected, for all practical purposes contained in a single channel the old channel on the Bhairamara side having silted up at its head to within a few feet of high flood level. The width of this single channel, from the steep bank on the Paksey side to a definite rise on the right bank which afforded reasonable prospect of the construction of the right guide bank in one season was about 5,400 feet ; and a bridge of 15 spans of 359 feet from centre of the piers or 5,385 feet in length of main spans, being assumed, it remained to be ascertained if this amount of waterway was sufficient, allowing for the obstruction of piers and guide banks. Deducting from 5,385 feet 180 feet for slopes of guide banks and 518 feet for fourteen wells, a clear waterway of 4,687 feet is obtained. A width of 4,687 feet marked off on the remarkably even section at the bridge site of 1910, showed a mean depth of 50 feet at maximum high flood. Assuming for the purpose of calculation, an even depth of water across the bridge at high flood, and a depth and velocity due to a surface fall of 4½ inches per mile, it will be found that a depth of 70 feet and a mean velocity of 8 feet per second will rather more than pass the maximum dicharge. No such even distribution of water can be expected and even in 1910, on the 22nd August with a flood level of 47·8 feet and maximum depth of 51 feet a surface velocity of 12·8 feet per second was recorded.

So long as the river maintained its straight alignment above the bridge no great variation in depth and velocity seemed probable but if the course of the river should be changed so as to impinge in a bend on the guide banks, a similar depth of 100 feet below low water level might result, as was recorded at Sara when conditions existed. It seemed desirable, however, to bridge the river for normal conditions in a straight reach where it was practically confined in one channel, in preference to attempting by construction to force it to great depths, although the possibility of great depths of water would need to be provided for throughout. A bridge of 15 spans of 345'-1½" from centre to centre of bearings was therefore adopted, with three land spans of 75 feet at each end, so as to pass the track on the guide banks and to relieve the abutments of the thrust of the bank. The overall length of the bridge is accordingly 5,894 feet.

A maximum depth of bend scour of 100 feet below low water level having been observed at Sara, and borings showing nothing but fine micaceous sand in the river bed, a depth of 150 feet below low water was accepted as sufficient in the open river for well foundation surrounded with pitching stone. For the two foundations Nos. 2 and 15, immediately outside the guide banks, where the greatest scour might be expected a depth of 160 feet was prescribed. A headway for navigation of 40 feet above high flood level was adopted in consultation with the steamer companies.

It was originally intended to construct the piers for a double line and to erect at first girders for a single line only. The cyclone of the 17th October, 1909, however, demonstrated that the bridge was within the cyclone area, and in view of its exposed position, it was then decided owing to the greater stability which could be obtained with the greater width of span, to design the bridge for a double line in the first instance. This also appeared to be justified by the traffic prospects.

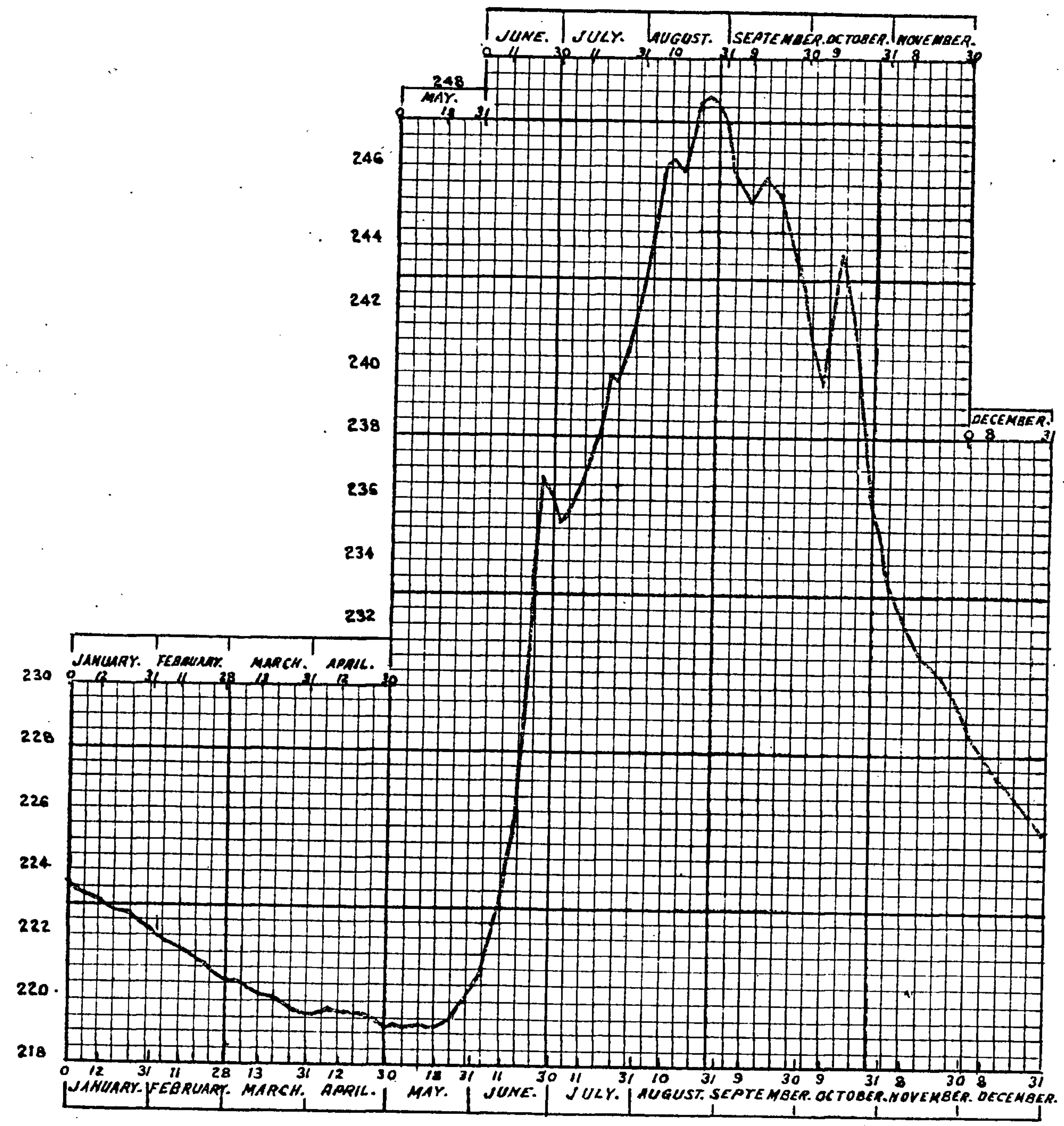
Training Works.

The training works were designed to prevent lateral movement of the river at the bridge, and to obviate any considerable change in the course of the river in its vicinity. Since 1868 the Ganges had slowly moved eastward at the bridge site about 1¾ miles, and before the construction of the training works this movement was proceeding at the rate of about 200 feet a year. Since Major Rennel's Survey in 1764 there had been erosion of the Sara clay amounting to an eastward movement of the river there of about ⅞ miles. At Raita the clay had been almost entirely eroded, and it was evident that as soon as its removal was complete there would be nothing to prevent the rapid erosion of the Raita peninsula and the advance of the great bend of the river upon the right approach of the selected bridge site. The works undertaken to arrest these movements and to restrict the river to the oscillations above Sara and Raita, which had occurred in the past, consisted of a pair of stone-pitched guide banks at the bridge and the revetment with pitching stone of the clay at Sara and Raita. The works were connected with the main line by suitable branch sidings for purposes of inspections and maintenance.

The pair of banks flanking the bridge (vide Plate VI) were aligned at right-angles to the bridge and were termed the right and left guide banks. They were each 4,000 feet in length, extending for 3,000 feet above and 1,000 feet below the bridge with suitable curved ends. They consisted of a core of sand protected on the river face with 1,250 c.ft. of pitching per lineal foot of bank. The stone was arranged as a revetment ranging from 2 feet thick at the top to 3½ feet thick at the toe of the bank, on layers of quarry chips and clay. The remainder of the stone was deposited in an apron extending outwards from the toe for a distance of 150 feet in three belts of 50 feet, respectively 4'-6", 6'-6" and 8'-6" in thickness. The guide banks were designed in such a way that, as the river cut away the sand from under the outer edge of the apron, the stone would fall in and automatically pitch a slope in continuation of the slope of the bank to a depth of 100 feet below low water level, the then maximum known depth of bend scour. At the upper and lower ends of the guide banks the pitching was carried round to the back of the bank. The banks were originally 18 feet above high flood level, and their upper part was pitched with the heaviest stone available, as a protection against very considerable waves which might be expected in a cyclone blowing upstream.

The clay at Sara has been proved by borings to extend from Dhapari north of Sara, to Paksey about 3/8 mile above the left guide bank. The clay, which is not of uniform strength, is found to a depth of about 90 feet below high flood level at the bank of the river, thinning off to 40 feet at a distance of a mile inland, vide Plate III. The clay is eroded by the action of the river on the sand beneath it, and falling in, is washed away. The revetment provided at Sara extended for a length of 3,650 feet and consisted of 650 c. ft. of pitching per lineal foot

WATER DIAGRAM OF THE RIVER GANGES
(AT THE BRIDGE SITE)
1910



HORIZONTAL SCALE 60 DAYS = 1 INCH ←→ VERTICAL SCALE 5 FEET = 1 INCH.

FIG. 1

GANGES HYDROGRAPH NEAR SARA.

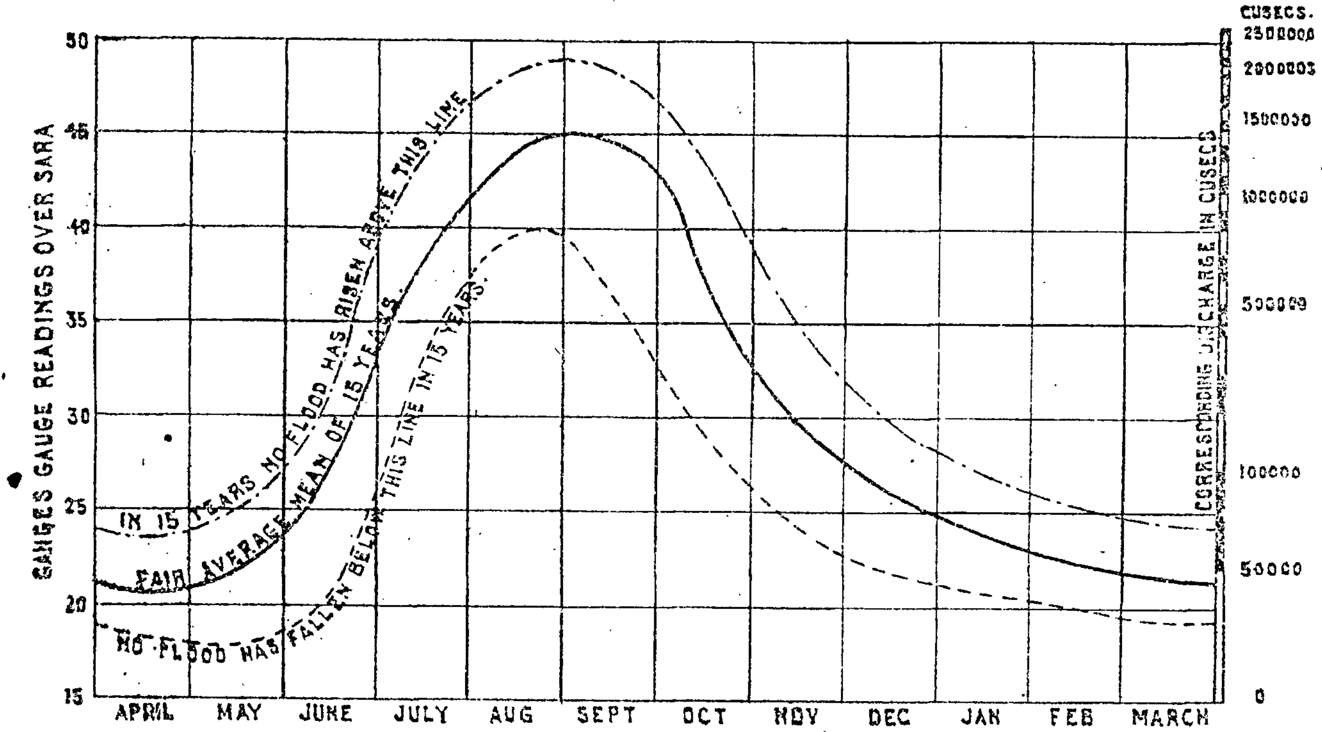
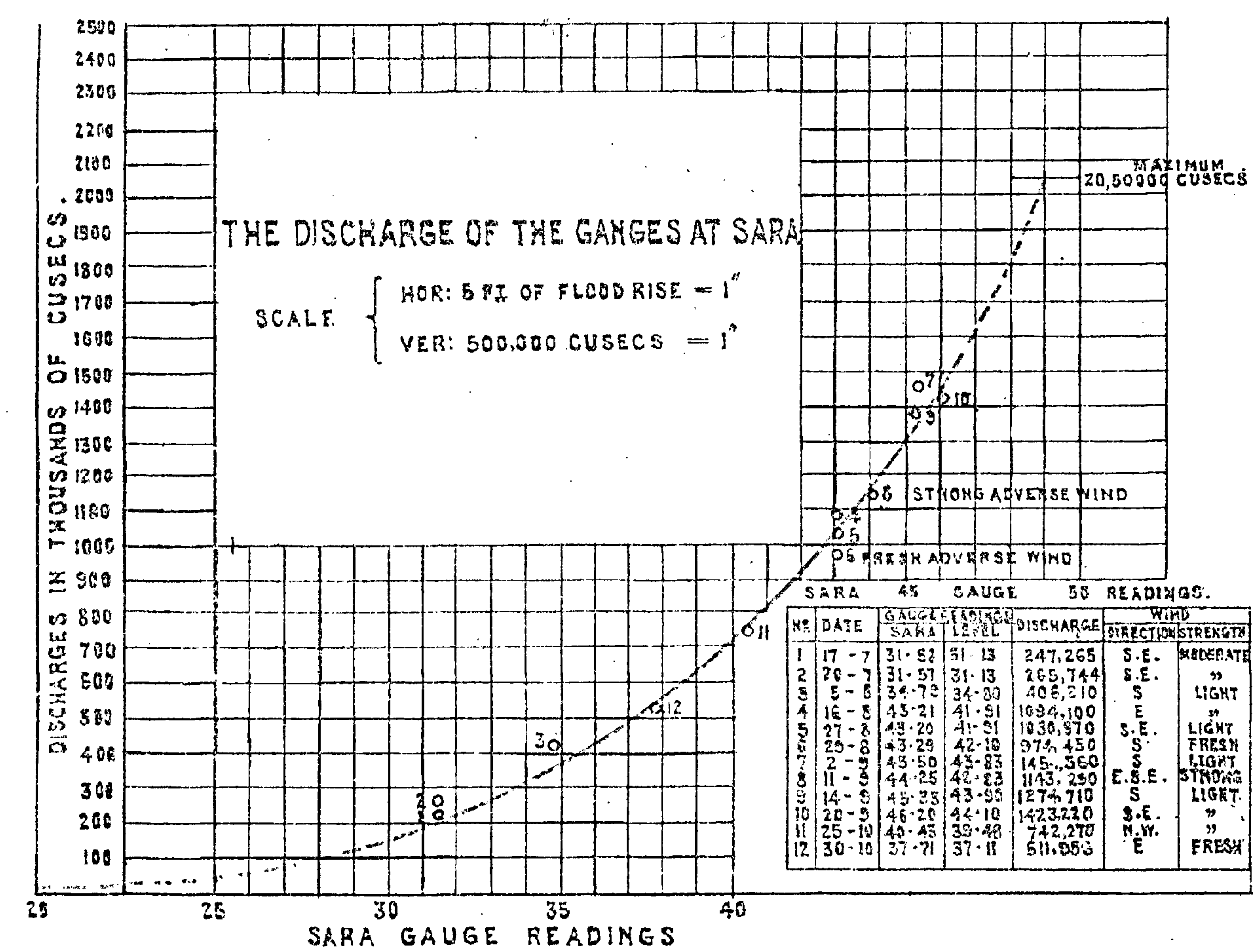


FIG. 2



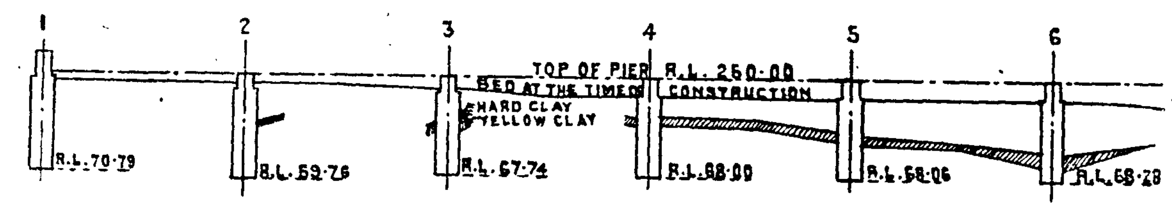
No.	DATE	GAUGE READINGS SARA	LEVEL	DISCHARGE	WIND DIRECTION	STRENGTH
1	17 - 7	31·52	31·13	247,265	S.E.	MODERATE
2	20 - 7	31·57	31·13	265,744	S.E.	"
3	5 - 8	34·79	34·80	406,210	S	LIGHT
4	16 - 8	43·21	41·91	1094,100	E	"
5	27 - 8	43·20	41·91	1030,970	S.E.	LIGHT
6	29 - 8	43·29	42·18	974,450	S	FRESH
7	2 - 9	43·50	43·83	145.,360	S	LIGHT
8	11 - 9	44·25	42·23	1143,290	E.S.E.	STRONG
9	14 - 9	45·25	43·95	1274,710	S	LIGHT.
10	20 - 9	46·20	44·10	1423,220	S.E.	"
11	25 - 10	40·45	39·48	742,270	N.W.	"
12	30 - 10	37·71	37·11	511,053	E	FRESH

FIG. 3

deposited in the water to overlap the foot of the clay and arrest the eroding action described above. The clay at Raita, vide Plate III, is of comparatively small extent and the headland was revetted for a length of 4,000 feet 2,000 feet on the northern and 2,000 feet on the western face, connected by an easy curve, to protect the clay from attack from the westward should the river again occupy the Sonaikundi Bight, and from the north should it retain the 1910 course.

(iii) **Construction.—Guide Banks.**—It was obligatory to construct in one season a continuous guide bank at least 20 feet wide on top and 5 feet above high flood level for the whole length of the approaches and to protect the slope with pitching stone in order to obviate the possibility of the river outflanking the bridge site, although at the location selected there was little danger except on the right bank, where the old Bhairamara channel formed a deep depression. It was also necessary to construct enough of the guide banks to secure the site. These works were completed during the working season of 1910-11.

Wells and well-sinking.—The bridge site having been secured by the partial construction of the flanking guide banks, bridge work was started in the early part of working season of 1911-12 on the abutment wells Nos. 1 and 16. The wells are rectangular in plan, with semi-circular ends, and measures 63 feet in length 37 feet in breadth, with two dredging hole 18′-6″ in diameter. In the first season five wells, in the second, seven, and in the third four wells had been sunk. Two of these had been sunk 160 feet and the remainder 150 feet below low water level. Except the bands of hard clay in Nos. 3 and 4 wells no obstacles of any kind were met with (vide Fig. 3A). The wells on completion, having regard to their depths, were all in good position. The greatest error at the top of the wells being in No. 6, which was 8 inches west and in No. 10 which was 11 inches north of true position. At the bottom of the wells, No. 2 was 25 inches west and No. 7 was 22 inches north of true position. The total quantity of masonry in the wells and piers was 299,000 tons.



NOTE :—

HATCHED PORTION INDICATES CLAY BELT AS FOUND AT THE TIME OF CONSTRUCTION

FIG. 3 A

All the wells were protected from scour by stone pitching to the extent of about 100,000 c.ft. except Nos. 3 and 4, which passed through clay bands. For these 50,000 c.ft. was considered sufficient. The outer ring of stone was enclosed in wire nets and in some cases surplus concrete blocks were used.

Girders.—The main spans are simple girders of the modified Petit type 345′-1½″ from centre to centre of bearings. They are 52 feet deep and weigh 1,250 tons per span. They are designed under the Government of India rules to the following scale of loading, Chord members, standard B+33 per cent. web members, standard B +40 per cent. floor members, standard B +50 per cent. This is equivalent in respect of the main girders to a train of vehicles weighing 1·6 ton per foot, hauled by two eight-coupled locomotives with 20 ton axle loads at each pair of the coupled wheels, and in respect of the floor system to an eight-coupled locomotive with 23 tons axle-loads at each pair of the coupled wheels.

Track over the Bridge.—The track consists of British Standard flat-footed 90 lbs. rails on bearing plates laid on teak cross sleepers. The sleepers are bolted to the bridge stringers. Each track is provided with inner guard rails and outer guard timbers. The bearing plates are of two kinds, ordinary bearing plates and creep plates. The former are fastened to the sleeper by square dog spikes, the head of which also holds the rail to gauge. These offer no resistance to creep or expansion movements. The creep-plates are provided with lugs between which the rail is firmly held by a steel key. The friction is sufficient to prevent longitudinal movement of the rail. The plate is independently fastened to the sleeper by screw spikes.

Rail creep is prevented from extending on to the bridge by laying the rails for ten rail lengths at each end of the bridge on creep plates. The girders were erected from both sides of the river with a fixed and rocker bearing on each pier, except where the girder erection met where there are two rocker bearing on the one pier. At this pier, viz., Pier No. 6 where temperature movements due to a length of 718 feet occur, rail-expansion joints are provided. At all other spans the rails are secured to the girders at the centre of the span by laying two rail lengths with creep-plates. All other rails are laid on ordinary bearing-plates and with the usual allowance for expansion. The rails move freely under the heads of the square dog spikes as required by the temperature movements of the girders, and no expansion troubles of any kind have been experienced.

Approaches.—The length of the line included in the project was 14·21 miles. It was built throughout for the double track, but single track only had been laid from Ishurdi onwards. The main features are the approach banks, which are 50 feet in height at the abutments of the bridge and contain 180,000,000 cubic feet of earthwork, a station at Paksey at the north end of the bridge on a 50-feet bank, and a large junction station at Ishurdi for the Sara-Sirajganj Branch. The gradient rises to the bridge from both sides, that on the north side against the load being 1 in 500, and that on the south 1 in 400.

Cost.—The cost of the complete project was about $3\frac{1}{2}$ crores of rupees :—

	Rs.
Main spans	1,80,54,796
Land spans	5,13,849
Training works	94,08,346
Approaches	71,55,173
Total	3,51,32,164

To have bridged a river, which is more or less one mile wide and 50 feet deep at an average velocity of 8 miles an hour, in $3\frac{1}{2}$ years between the laying of the first well curb and the running of the first train was, indeed, a wonderful feat. However, Sir Francis Spring's prophetic words in this connection should always be borne in mind. They were :—

> " The conclusion to which I have come is that the task of bridging the Lower Ganges flowing is an exceptionally formidable one. Of this class of work nothing approach-ing it in difficulty has been attempted in India, or indeed, so far as I know, anywhereelse. The difficulty to which I refer is not in the buildnig of thebridge, which is the usual straight ahead bridge work, but in the training of the river so that it may not desert the bridge when built ".

The control of the Baral and of all spills between Sara and Santahar is of the first importance. For if the Ganges broke through by way of the Baral or of the low land on either side of it into the Chalan Beel depression, the bridge would not only be rendered useless, but a new one would have to be built. An increase in any of the Nadia rivers would not be so serious. For if the whole Ganges took this route, although the bridge at Sara would be rendered useless, no fresh bridge would be required to connect North Bengal with the port of Calcutta, always provided the port of Calcutta in such a contingency could be retained at the present site, or rebuilt at other inlet eastward. Therefore, it would be the imperative duty of the Engineers of the Eastern Bengal Railway to recognize these contingencies and by paying close attention to the places where the Baral and other spills passed across the railway, and by never allowing these potential great rivers to destroy their bridges or to get out of hand to prevent the occurrence of what, for lack of such attention, might conceivably involve the loss of some crores of rupees.

CHAPTER IV.

HISTORY OF THE BRIDGE FROM 1915 TO 1933.

The changes that have occurred in the regime of the river in the vicinity of the bridge and within the " controlled area " (vide Fig. 3B)—the area over which the railway have been given powers by the Government of Bengal to prevent any works in the nature of the obstruction or the diversion of a watercourse, should those be considered by them as likely to react detrimentally on the protection works of the bridge or on the bridge itself, and is defined in Government of Bengal's Notification No. 134, dated 16th May, 1893, and Notification Nos. 1 and 2, dated 20th January, 1920—are contained in the records of the Special Officer, Hardinge Bridge at Paksey. A history of the important features abstracted from these records are given below :—

1917.—The first observation of any importance that has been recorded was in 1917 when a pot-hole was found below Pier No. 15. This was dealt with by removing stone from the apron between Pier No. 15 and the guide bank and depositing it in the pot-hole.

July 1919 to June 1920.—In 1919-20 cutting was observed at the Raita and Sara Protection banks. It was apparently not serious. In this year the Paksey Marginal Bund between Sara and Paksey was attacked.

1920-21.—In 1920-21 the river continued to work its way back into its old channel, *i.e.*, Govindapur Bight, above Raita, and the Lalpur Bight, above Sara. Erosion continued between Paksey and Sara.

1921-22.—In 1921-22 the Raita Head was extended round the back to meet any embayment that might occur from the Govindapur Bight (vide Fig. 3C). The erosion between Sara and the bridge continued and, in places, into the " Danger Line "—a line fixed between the Left Guide Bank and Sara beyond which erosion of the left bank of the river was considered dangerous to the Railway Colony at Paksey.

1922-23.—In 1922-23 the river developed an attack at Sara and strong eddies were noticed right up against the apron which fell in at several places, and there was noticeable cutting between chains 10 and 14 of the protection bank. The river continued to work into the Lalpur Bight and Govindapur channel.

1923-24.—In 1923-24 eddies developed at Raita and parts of the apron fell in, and at Sara a portion of the protection bank slopes also fell in. These were duly repaired during the winter.

1924-25.—In 1924-25 the apron at Raita continued to fall in and at Sara severe attacks developed on the head owing to the river having got well into the Lalpur Bight. The erosion between Sara and the bridge continued, but to a lesser extent.

In this year the Reserve Stone was reduced from 31 lakhs to 17 lakhs for the reason that it was unlikely that more than one of the protection works would be attacked in any one season and it was considered undesirable to keep as much money as the cost of 31 lakhs of stone tied up in capital suspense. The 17 lakhs was arrived at by allowing 8 lakhs for each bank for protection works and 1 lakh for replacement of pitching each year round piers.

1925-26.—In 1925-26 the river having got well into the Lalpur Bight a very severe attack developed on the Sara head and the river nearly got behind this head. A portion of the apron at the north-west corner of the head, where the attack was most severe, was carried away.

After the rains the upstream end of the protection bank was realigned for $3\frac{1}{2}$ chains, which length was remade on a curve of 330 feet radius—this retirement gave the added advantage of a wider apron.

In this year also a very severe attack developed above the Raita Protection Bank. The current flowed from the site of Raita Station along the face of the protection bank and eddies were observed at chain 32 to 15 and a big whirl-pool at chain 15.

Erosion continued between Sara and the bridge, especially at the village of Bamangaon.

The river by this year had moved towards the right bank and the main current flowed through span No. 5.

1926-27.—In 1926-27 again the river attacked both the Raita and Sara Protection Banks, the latter having the more severe attack.

At Raita a very strong current along the face of the protection bank caused a considerable falling in of the apron and the toe of the slope was also attacked, for, when prickings were taken later, no stone was found at the toe. The station site was again attacked and the removal of the station buildings was seriously contemplated.

At Sara this year there were two serious attacks during the two rises of the river. The first was easily withstood in spite of a very strong current impinging on the new head. The second, however, after impinging on the head developed a reverse current and formed a heavy embayment above the head. About half way to the end of the protection bank there was some slipping but this was most probably due to the seepage that occurred on the surface of the Sara clay.

The river this year flowed through spans 5 to 10, but no severe current was observed along the Right Guide Bank though of course the water at high flood reached this bank (vide Fig. 3 D). Pricking round piers at low water showed that there was stone at all piers except No. 9, as was also found in the previous year.

1927-28.—In 1927-28 there was a very low flood season and not much has been recorded except continuance of erosion, though slight, in the embayment above Sara and a continuance of an attack on the apron at Raita where again the toe was lost.

1928-29.—In 1928-29 once again there were attacks on the Raita and Sara Protection Bank. Strong eddies were noticed at Raita from chainage 40 to chainage 37 and chainage 29 to chainage 24 and after the flood no stone was found by prickings between chains 32 and 21, and about 2½ lakhs c.ft. of stone were used in repairs to the head and apron this season. At Sara a similar attack developed on the head and 160 feet of apron between chains 37 and 35 slipped into a deep scour hole at the toe; this scour hole was 107 feet deep and was 140 feet from the edge of bank.

The river this year flowed through spans 7 to 10 and the stone at No. 9 pier, which was pitched in the previous year was once again washed away.

1929-30.—In 1929-30 for the first time since the construction of the Bridge there was an attack on the apron of the Right Guide Bank at and near chain 15 (vide Fig. 3E). No damage was, however, done this season.

At Sara a deep scour hole about 400 feet from the centre of the bank opposite chainage 37 to chainage 35 was found to be about 135 feet deep. The usual attacks developed at the Sara and Raita heads but no serious damage to either has been recorded, but deepening of the channel at the toe of the apron at Raita occurred.

1930-31.—In 1930-31 an alarming embayment formed above the Sara head and the deep hole of the previous year moved to opposite chainage 33 of the protection bank. After repeated attacks the river got behind the new head and the protection bank between chains 33 and 32 slipped into the hole and left an isolated head. It was not a very serious slip and the bed of this pitched and used as an apron for the second retired head which was constructed not far behind the isolated head which was removed and converted into an apron.

Nothing important is recorded as having happened at Raita this season.

There was, however, an attack on the Right Guide Bank again—the main current this year flowing between spans 2 and 6. The guide bank was attacked at chainage 22, though not seriously, and only a few boulders were displaced. A chur in front of this bank was washed away but between the apron and No. 2 pier the chur existed and a channel was cut through it to induce a flow. This, however, proved ineffectual.

1931-32.—In 1931-32 the attack by the river was directed against three out of the four protection banks.

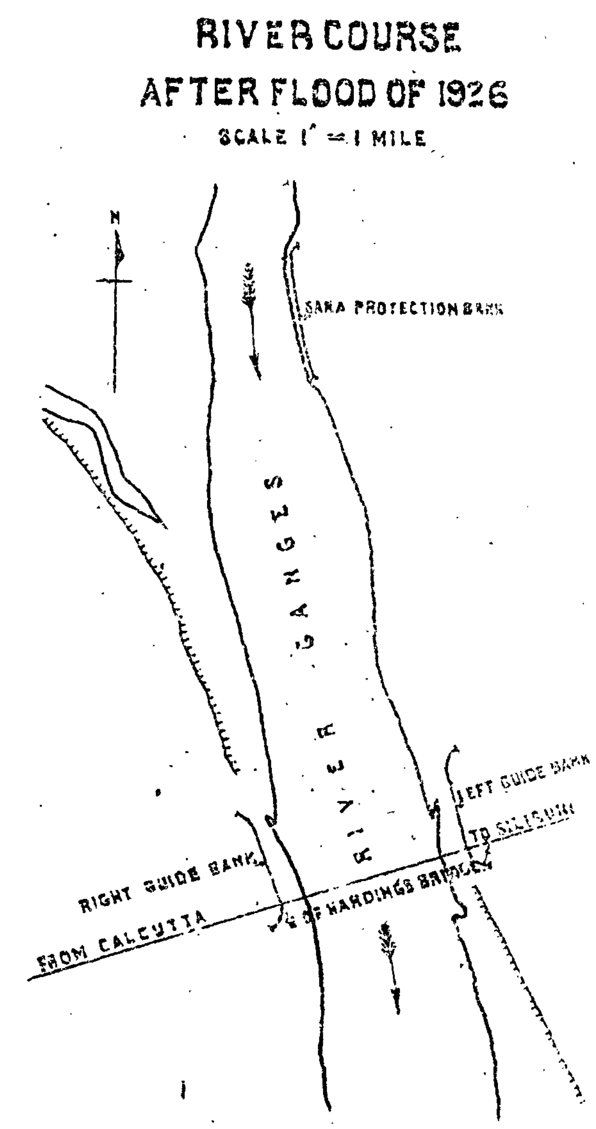


FIG 3 D.

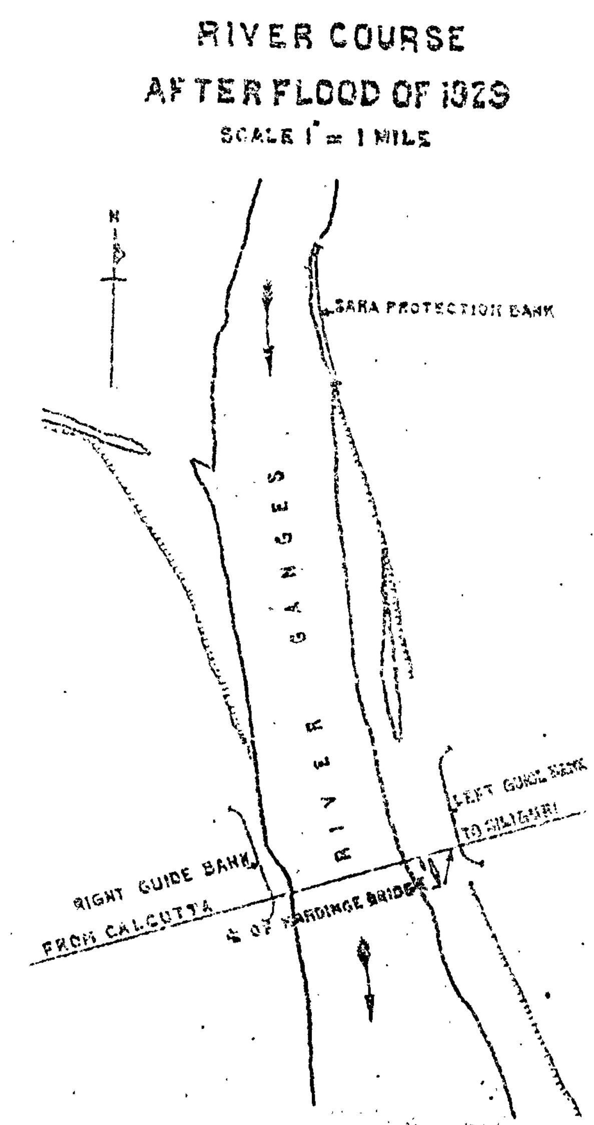
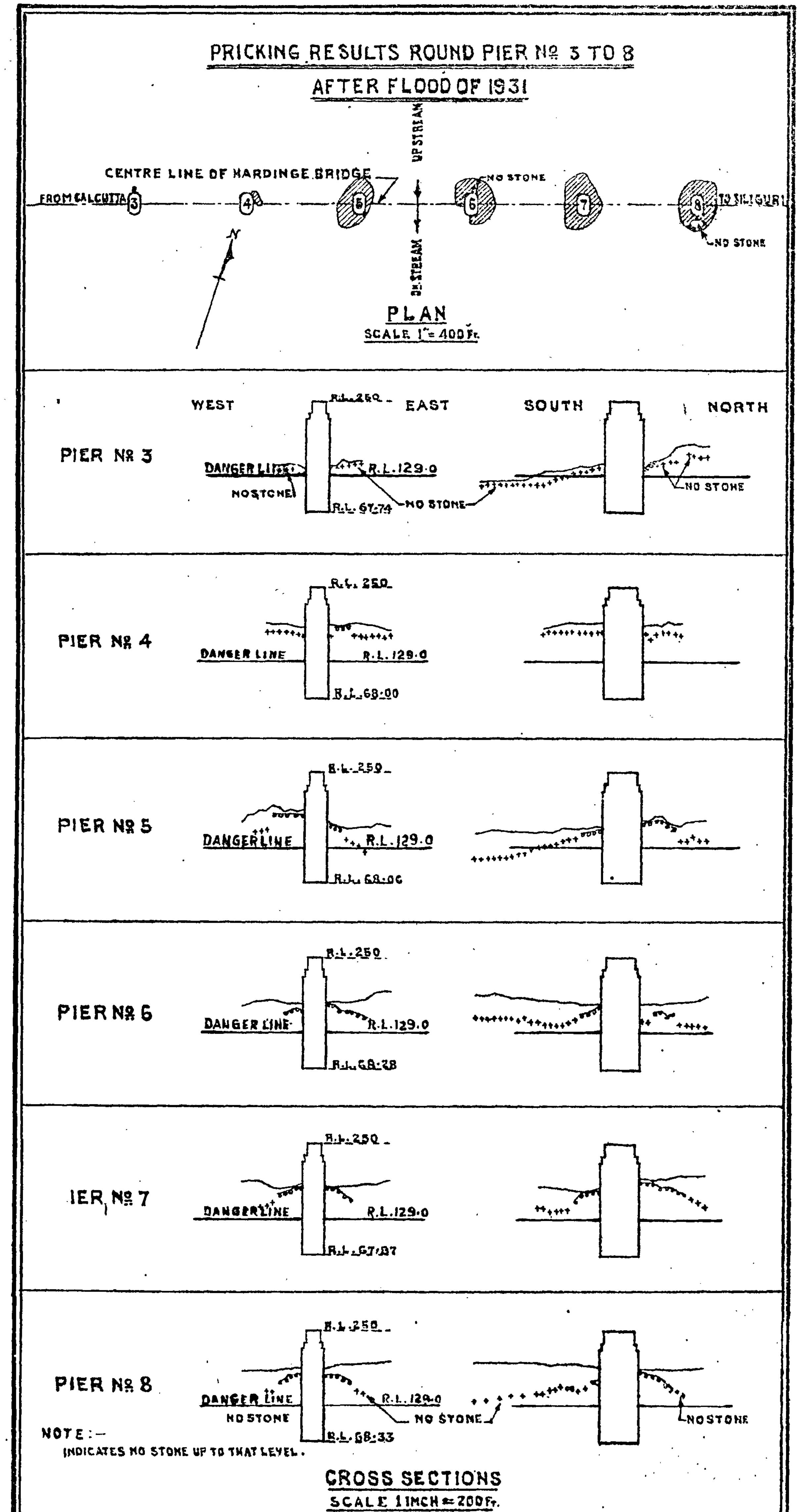


FIG 3 E.


PRICKING RESULTS ROUND PIER No 3 TO 8
AFTER FLOOD OF 1931
CENTRE LINE OF HARDINGE BRIDGE
FROM CALCUTTA
TO SILIGURI
NO STONE
UP STREAM
DN STREAM
N
PLAN
SCALE 1" = 400 Ft.
WEST
EAST
SOUTH
NORTH
PIER No 3
DANGER LINE
NO STONE
R.L. 250
R.L. 129.0
R.L. 67.74
NO STONE
PIER No 4
R.L. 250
DANGER LINE
R.L. 129.0
R.L. 68.00
PIER No 5
R.L. 250
DANGER LINE
R.L. 129.0
R.L. 68.06
PIER No 6
R.L. 250
DANGER LINE
R.L. 129.0
R.L. 68.28
PIER No 7
R.L. 250
DANGER LINE
R.L. 129.0
R.L. 67.87
PIER No 8
R.L. 250
DANGER LINE
NO STONE
R.L. 129.0
NO STONE
R.L. 68.33
NO STONE
NOTE :-
INDICATES NO STONE UP TO THAT LEVEL.
CROSS SECTIONS
SCALE 1 INCH = 200 Ft.
FIG 3 F
12 C.

At Raita a severe attack developed on the bank about 800 feet above the bank and there was heavy erosion. From here the current passed tangentially along the bank, developed eddies, leaving an exposed vertical face as near as 45 feet from the centre line of the track on the protection bank.

At Sara the results of the attack were more serious. A severe attack developed in the embayment above the Sara head—trees were anchored in anticipation of the attack, but the flood of July was so severe that these were washed away and the attack moved down to chains 33 to 27 of the bund. Between these points the strongly armoured head subsided and then disappeared in the flood of August. Soundings taken after the floods showed a scour hole of 164 feet deep below low water level, extending for a distance of 1,000 feet only 300 feet from the centre of the original bund.

In January, 1932 a new alignment of guide bank was set out and constructed with an apron for protection against scour down to 160 feet below low water level.

The Right Guide Bank was attacked all along its face from chainage 10 to chainage 30 and a deep scour hole 80 feet to 100 feet deep below low water level resulted along the whole of this length at the toe of the apron. This attack appeared to come as a repercussion from Sara, as from Sara it shot across the mouth of the Damukdia Channel, and then having eroded 1,000 feet of chur went straight to the Right Guide Bank—the current eventually passing through spans 2 to 7 of the bridge.

An embayment was also formed at the head of this guide bank showing the tendency of the river to revert to the old Bhairamara channel.

Prickings showed that the stone along the Right Guide Bank had subsided at a slope of 2 to 1, but as deep scour had occurred outside the apron it was decided to widen this apron to withstand 160 feet of scour instead of 100 feet. The apron was widened between chains 15 to 30, 8 lakhs of stone being utilised in this pitching.

The chur on the left bank of the river having widened so considerably this season, the whole of the discharge of the river was confined to 5 spans, *i.e.*, between piers 2 to 7, and consequently the channel was deepened very considerably. Prickings showed no stone at No. 3 pier and very little at Nos. 4, 5, 6, 7 and 8 piers (vide Fig. 3F). Heavy pitching was, therefore, done round these piers especially round No. 3 where a deep scour hole 17 feet below the "danger level" was discovered only 300 feet south of this pier.

1932-33.—In 1932-33 the Damukdia Protection Bank 4,000 feet in length was constructed with its tail 4,200 feet upstream of the head of the Right Guide Bank (of this more in the next chapter).

During the same working season the head of the Raita bank was heavily armoured to resist a scour of 160 feet. The face of the protection bank at chainage 23 to chainage 26 was also repaired and reinforced. Considerable work was done at Sara, the old head having been demolished to below low water level and a new alignment of the third retired head with a reverse face to the apron was constructed—this new head was further armoured to withstand 179 feet of scour.

Piers Nos. 2, 3 and 5 were again pitched at low water season. A deep scour hole 104 feet below loco water level was found to exist opposite chains 17 to 22 of the Right Guide Bank.

Plate VII shows the courses of the river between Raita and the bridge during the years 1915, 23, 26, 29 and 1932.

CHAPTER V.

THE DAMUKDIA PROTECTION BANK.

At the close of the monsoons in 1931, the approaches to the Hardinge Bridge suffered a very severe attack on the right bank immediately above the Right Guide Bank resulting in an erosion of more than 800 feet width of the bank and seriously threatening the head of the guide bank. This was caused by the river tending to occupy its old channel in the Lalpur Bight and swinging across from above Sara impinging on the right bank at about 1½ miles above the bridge and showing further tendency of endeavouring to enter its old Bhairamara Channel.

It was realized that any further development of this nature must be prevented at all cost and a proposal was made for the construction of what was then termed a ring bund of 1,500 feet in length, which was to be placed at the top of the embayment, solely with a view to preventing any extension of the erosion.

It was also realized that no work on the construction of the proposed bund could be carried out in the season 1931-32, as these developments were fully gauged very late in the year 1931, and that another attack by the river must be experienced before any actual protection work could be done. The one fear was that the floods of 1932 might be so severe that further heavy erosion would take place and any protection work would have to be sited several hundred feet back from the edge of the river as then existing. Fortunately the most sanguine hopes were fulfilled. The monsoon, in 1932, was exceptionally quiet one. Rainfall was considerably below normal and there was no heavy floods whatsoever. The highest level for the year was 243·8 and the greatest velocity was not more than 6 miles per hour. Silting occurred round several piers of the bridge and there was no heavy scouring. The deep hole below pier No. 3 silted up by a few feet. Erosion of course continued in the embayment but not as seriously as was anticipated, the maximum being just over 200 feet at a point 1,500 feet above the head of the Right Guide Bank. The embayment then, however, was definitely in behind the head of the Right Guide Bank.

A report on the situation with an outline of the protection proposed was sent to the Consulting Engineers Messrs. Render, Palmer and Tritton in London for their opinion.

The Consulting Engineers expressed their views as agreeing in general with the proposals made but stressed the opinion that the bund should be at least 4,000 feet in length possessing a definite directional quality. It would, therefore, become a protecting guide bank instead of a pure ring bund. A plan was received showing a tentative position of such a guide bank sited on a curve, bordering the old Damukdia Channel, joining Raita and the right abutment of the bridge; its direction being to the centre pier of the bridge.

There were other factors also to be considered. The lower end of the bund must be as close as possible to the existing river edge at the point where the main stream impinged and at the limit of the embayment. It was necessary that the apron should start falling and the bund become operative the moment that erosion recommenced so that further embayment would be minimized. The higher up the bund was sited and the further from the point of impingement the greater would be the embayment before the bund would commence to function. On the other hand, the lower down, *i.e.*, the closer to the bridge the bund was sited the greater must be the angle of its line of direction with the stream from the Lalpur Bight if its direction must pass through the centre of the bridge.

As bund in question, although it should be on a curve as stated above, was not intended in any way to be a guide for the Damukdia Channel its sole object being to meet an attack when the stream is in the Lalpur Bight, to prevent embayment above the Right Guide Bank and to cover the entrance to the old Bhairamara Channel—it was thought that to being protective and directional it must be as little obstructive as possible and to effect this, it must be clearly sited at as small an angle as feasible with the main current, consistent with deflecting the stream fairly through the bridge openings.

When the course was through the Damukdia Channel or on that side of the kadir the main stream was expected and did flow through spans 10 to 15 of the bridge. When the course of the river has crossed over to the Lalpur Bight the stream through the bridge has

swung over correspondingly and was expected naturally to flow through spans 1 to 6 of the bridge. But the trouble was that the main-stream showed a tendency to force itself still further westwards.

The Right Guide Bank was considered to be perfectly sound and strong enough to perform its own duty, that of controlling a stream flowing parallel to its face. As the proposed new bund at Damukdia was in no way intended to strengthen the Right Guide Bank—it was intended only to protect that bank from an unfair attack—it seemed unnecessary to site the new bund at such an angle as to attempt to coerce the stream to take a course through the middle third of the bridge.

In October 1932, a discussion was held on the selection of the final position of the new bund. At this discussion it was eventually thought that the position shown in Plate VIII would be the most effective. The bund in this position appeared to follow all the required conditions as closely as they could be reconciled.

The Damukdia Protection Bank was aligned to the middle of the fourth span of the bridge and was made 4,000 feet long; its apron was designed to meet a scour of 160 feet below low water level for the downstream half of its length and 100 feet scour for the upper half of its length. The work was commenced in November 1932 and was completed in seven months. The quantities involved in the work were nearly 2 crores cubic feet of earthwork and 90 lakhs cubic feet of boulders. The cost of this protection bank was approximately Rs. 16,73,000.

After the construction of this bank a feeling prevailed that all was well with the bridge and the danger of its isolation by the river advancing further westwards in this vicinity had passed for ever. But this feeling lasted only for a short time; within four months after the completion of the bank a major disaster to the bridge followed.

CHAPTER VI.

THE BREACH IN THE RIGHT GUIDE BANK AND WORKS DONE IN 1934 FOR THE IMMEDIATE SAFETY OF THE BRIDGE.

Early on the morning of the 26th September, 1933, on a rising river following heavy rains during the previous week in the upper reaches of the Gangetic Valley, the Right Guide Bank of the bridge was breached between chains 19 and 21. At the moment when this happened, the river was very turbulent and appeared to come into the embayment in rushes like exhalations at intervals of about two minutes creating a sudden afflux of about 2 feet. This "wave" rushed across the embayment, dashed against the eroding bank, expended its force there and then, as if with each inhalation, carried away large tracts of land covered with jungles and small trees in strip of 10 to 20 feet wide and 30 to 50 feet long. This continued till mid-day and then commenced to ease gradually until it stopped entirely at 4 p.m. The surface then became dead calm and there was no movement in the embayment whatsoever, except for that of a trickling stream over the apron at the back of the upstream end of the guide bank, which had been topped by the river. This phenomenon of flow lasted over a period of about 12 hours, when the breach extended to 1,000 feet.

During the succeeding days the river continued to rise and by the 2nd October had over-flowed the river bank upstream of and behind the guide bank. The narrow neck of land connecting the head of the guide bank, above the breach, with the main land was soon eroded by a process of retrogression to a width of 500 feet, giving the river a clear flow behind the head and thence, through the breach in the guide bank out into the river, thereby entirely isolating the head into an island. (This isolated portion of the guide bank is hereafter referred to as the "Isolated head"). This gap widened slightly daily and ceased at a width of 1,000 feet.

On the 5th October 1933 the river started falling and on the 7th October after a fall of 14 inches in one day, the breach extended another 600 feet in spite of the heavy emergency pitching which had been done in the intervening fortnight. Plate IX shows the progress of the breach from its start on September 26th to its final state after October 7th 1933.

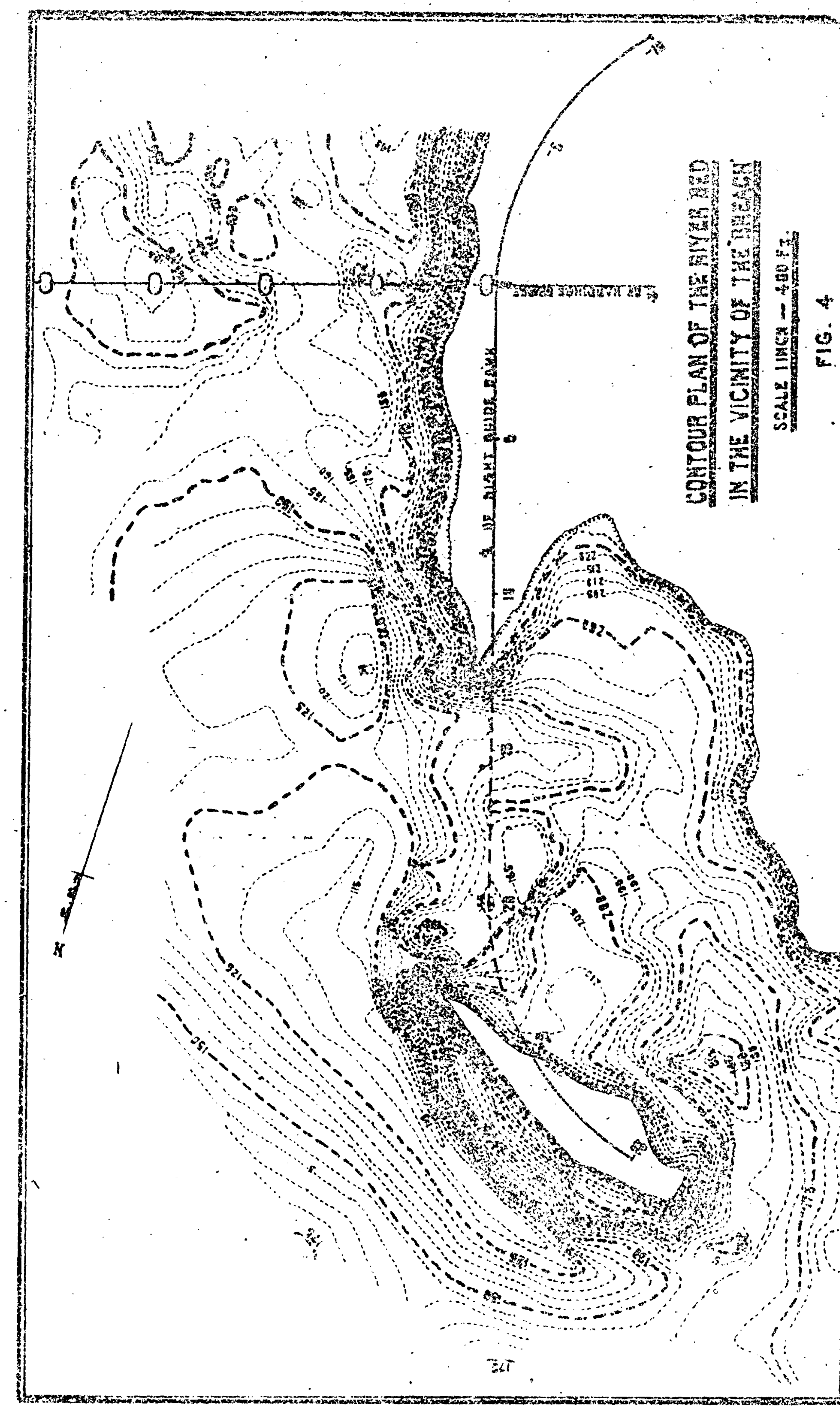
It has been said that steps should have been taken immediately the breach occurred to throw a bank of some kind across the apron at the back of the isolated head to prevent the river establishing contact with the embayment from the north. But at the rate at which things were occurring, the danger of the whole isolated head being washed away was so imminent that the then Officer-in-Charge who landed on the isolated head to consider this problem, had to abandon it both because it appeared hopeless of accomplishment against the rising river in full flood, without any steamers or barges for carrying stone, and also because of the great risk of life it would involve to a large number of workmen.

(ii) **Scheme for the safety of the bridge.**—As soon as the flood season ended and there was no further changes in the conditions, a contour plan of the river bed in the vicinity of the damage was prepared. This plan (vide Fig. 4) showed that heavy scour had taken place round pier No. 2 and that a deep pot hole had formed just below the stump of the guide bank, about 1,000 feet upstream of pier No. 2 and its depth was below the danger level of the pier. This and the whole situation showed that the bridge was left in a very vulnerable condition and as such vast issues were involved the Railway Board cabled to the High Commissioner for India requesting him to procure the services of Sir Robert Gales to come to India and advise them as to what should be done to save the bridge.

Sir Robert Gales arrived in Paksey on the 3rd December 1933, and after a searching preliminary enquiry a scheme as shown in Plate X was drawn up by him which not only dealt with the measures to be adopted for the immediate safety of the bridge through the flood season of 1934, but included recommendations for works to be carried out against future developments and changes in his report to the Railway Board, dated 31st January 1934. This report was accompanied with appendices and plans, and are available for reference in the offices of the Railway Board and of the Chief Engineer, Eastern Bengal Railway.

Sir Robert Gales's scheme for immediate safety of the bridge was evolved by the following considerations :—

Owing to the excessive depths of fast flowing water over a length of 1,600 feet, the possibility of closing the main breach itself was abandoned.



CONTOUR PLAN OF THE RIVER BED IN THE VICINITY OF THE BREACH

SCALE 1 INCH — 400 Ft.

FIG. 4

That the stump of the standing portion of the Right Guide Bank should be carried down round in some form as a defence against the river and to remove its presence as a spur was of course essential and to make construction possible within the time by keeping along the shallowest depths this defence should go round to the main land on the sharpest curve that it was possible for a broad-gauge track to be laid on it. It was, therefore, decided that the first item of repair work should be this and it was called "Mole".

The 'Mole' is a revetment consisting of a stone dyke built up from the bed of the river to slightly above low water level, with an earth bank behind. The earthwork is prevented from spreading over the remainder of the embayment lying south of it (because it was impossible to fill the large lagoon that had been made there by the breach in the time) by a temporary barrier made of piles driven 5 feet apart forced down to the bed with a frame work of treble matting and bamboos and strutted behind with heavy timbering. Above low water level the Mole is an ordinary bank faced with a covering of boulders 3′-6″ thick. The east end of the 'Mole' at the stump of the breach is in as much as 80 feet of water; this reduces gradually to a minimum depth of 20 feet at the west end, the radius of the 'Mole' is 400 feet and its total length is about 1,100 feet. (A typical section of the 'Mole' is shown in fig. 5.)

Although "The Mole" would protect the immediate approach bank at the west end of the bridge and would prevent the stump of the standing portion of the guide bank acting as a spur, it was found essential to do some sort of work which would not only block the flow through the northern gap between the main land and the isolated head but also direct the course of the stream behind the guide bank round the isolated head into the river. So, Sir Robert Gales, after investigating various schemes including that of a submerged weir of boulders, decided upon what is considered the key to the success of the scheme carried out in 1934, and that was to construct the "Backwater Bund". This bund connects the downstream end of the isolated head with the main land, and is on an alignment following more or less the most convenient shallow contours of the bed.

The Backwater Bund consists of two dykes of boulders built up from the bed of the river to R.L. 223, with earth filling between, and faced above this level, as in the Mole, with boulders. In order to prevent seepage through one dyke and thence easily through the narrow wedge of earth and out again through the second dyke a line of sheet piles was driven between the two dykes over a length of 800 feet where the dykes come nearest to each other at their base. Universal steel sheet-piling of 15″×6″ R. S. joists were used and driven an average of 20 feet into the bed. Fig. 6 shows a typical section of the Backwater Bund.

(iii) **Other works carried out as recommended by Sir Robert Gales.— Jackson's Spur.**—To control the width of the gap between the isolated head and the main land and to give a directional flow if the river cut in below the Damukdia Protection Bank, the temporary apron which was thrown out, during the emergencies in the previous October, was completed in the form of a protection bank with an access line running westwards to join with the Damukdia Branch of the Eastern Bengal Railway. This is called Jackson's Spur after Mr. L. F. Jackson, the Chief Engineer of the railway under whose orders it was thrown up as an emergency measure. It is 1,600 feet long, has an apron of 1,100 cubic feet of stone per foot run and is aligned 175 feet upstream of the tangent to the curved isolated head.

Marginal banks.—To hold up the spill from the river between the three major works, a marginal bank was constructed connecting Jackson's Spur with the Backwater Bund, and thence along the western end of the mole. This was protected with boulder facing and was given a shallow apron varying from 100 to 400 cubic feet of stone per foot run to prevent damage to the slopes.

Damukdia Protection Bank.—In view of the state of the river and the development of an attack at the upstream portion of the Damukdia Protection Bank, the apron which had been constructed in 1933 to meet 160 feet scour below low water level at its lower end and 100 feet below low water level at its upper end was widened to meet 160 feet scour below low water level throughout its length and also that the bank was slightly re-aligned and extended against this attack down from Raita in the Damukdia channel.

The Sara Protection Bank.—The upstream half of the Sara Protection Bank was realigned and extended so that no further embayment eastward in the vicinity of the Protection Bank should be permitted under any circumstances.

In this position the Sara bank is capable of extension in a straight line and the embayment eastward can be arrested at a known maximum, so long as the bank is held whenever threatened and extended whenever necessary.

Raita Protection Bank.—At Raita, as there were indications of an embayment developing similar to what had occurred at Sara, it was decided to take timely action and extend the head of the protection bank before the embayment had time to set up their dangerous conditions.

Borings.—Borings were put down round the piers to discover whether the large quantities of pitching that had been placed there when the bridge was built, and the stone which had been added since, was really washed away completely as had been suggested, or had only sunk to deeper levels round the piers when scoured.

Borings showed at what level the stone existed if it was there at all. In most cases it was proved that pitching placed round piers at a reasonable depth was not washed but sank almost vertically as scour occurred ; some stone on the other hand was washed away and some was carried downstream of the piers to a distance where it was too far to be helpful in supporting the pier. On the result of these borings it was decided that the piers exposed to attack by scour, viz., piers Nos. 2 and 3 should be pitched heavily with boulders weighing from 1/2 to 1 ton each.

In addition to the borings for locating the pitching, borings were put down over a large area upstream and over a smaller area downstream of the bridge to locate a clay patch which was struck at the time of construction of the bridge, as it was felt that the existence of this clay, might be responsible for the deepening at the adjoining piers for creating the dangerous large holes which were located downstream of the bridge. Fig. 8 shows the position of clay as located by borings in 1934-35. Clay was found to exist between piers Nos. 4 and 5 and to extend about 1,000 feet north. The clay round piers Nos. 3 and 6 was also located but has scoured away in the floods of 1935. Most of the clay patch round piers Nos. 4 and 5 has scoured away in the floods of 1936 (vide fig. 7).

The following are the costs of the various works done in 1934 :—

Mole	Rs. 20,96,800
Backwater Bund	Rs. 13,93,800
Damukdia	Rs. 2,35,000
Sara	Rs. 5,57,800
Raita	Rs. 87,000
Pitching piers with heavy boulders	Rs. 1,81,300
Jackson's Spur, Marginal Banks, &c.	Rs. 5,14,100
Miscellaneous expenditure	Rs. 2,67,000
Plant and General charges	Rs. 4,88,600
Emergency pitching during flood season	Rs. 3,93,600

The average inclusive cost of boulder works was Rs. 20-15-0 per % c.ft. and of the earthwork Rs. 13-15-0 per % c.ft.

The works undertaken in the vicinity of the bridge which had to be completed before June 1934, the ways and means adopted to get the work done within the limited period, the magnitude of the work itself and the experience and knowledge gained in carrying it out are fully described in Mr. B. L. Harvey's paper No. 5045 published by the Institution of Civil Engineers, London (session 1936-37).

TYPICAL SECTION OF "MOLE"

SCALE 1 INCH = 60 FEET

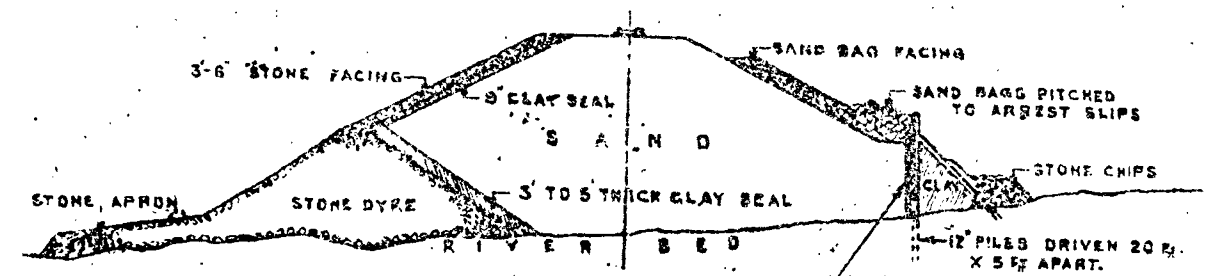


FIG 5

TYPICAL SECTION OF "BACKWATER BUND"

SCALE 1 INCH = 80 FEET

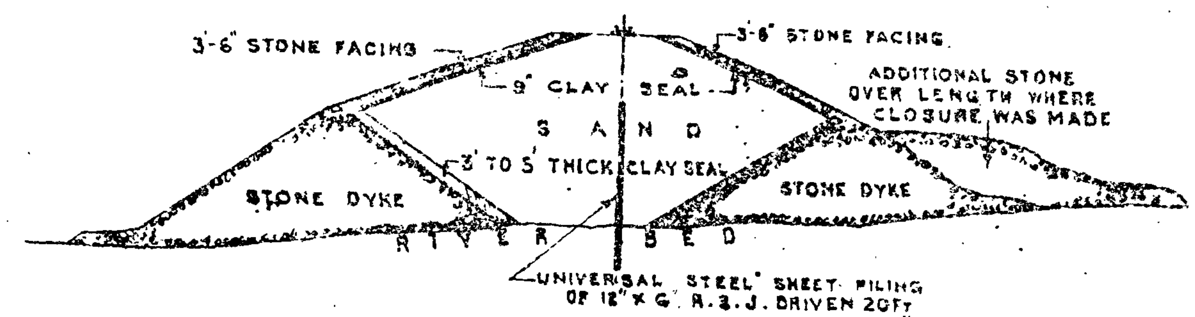
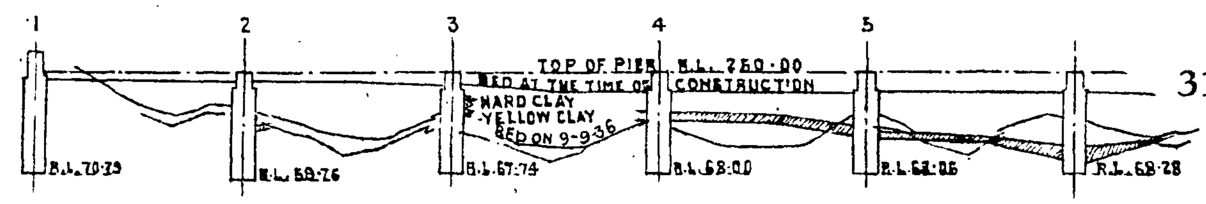


FIG 6

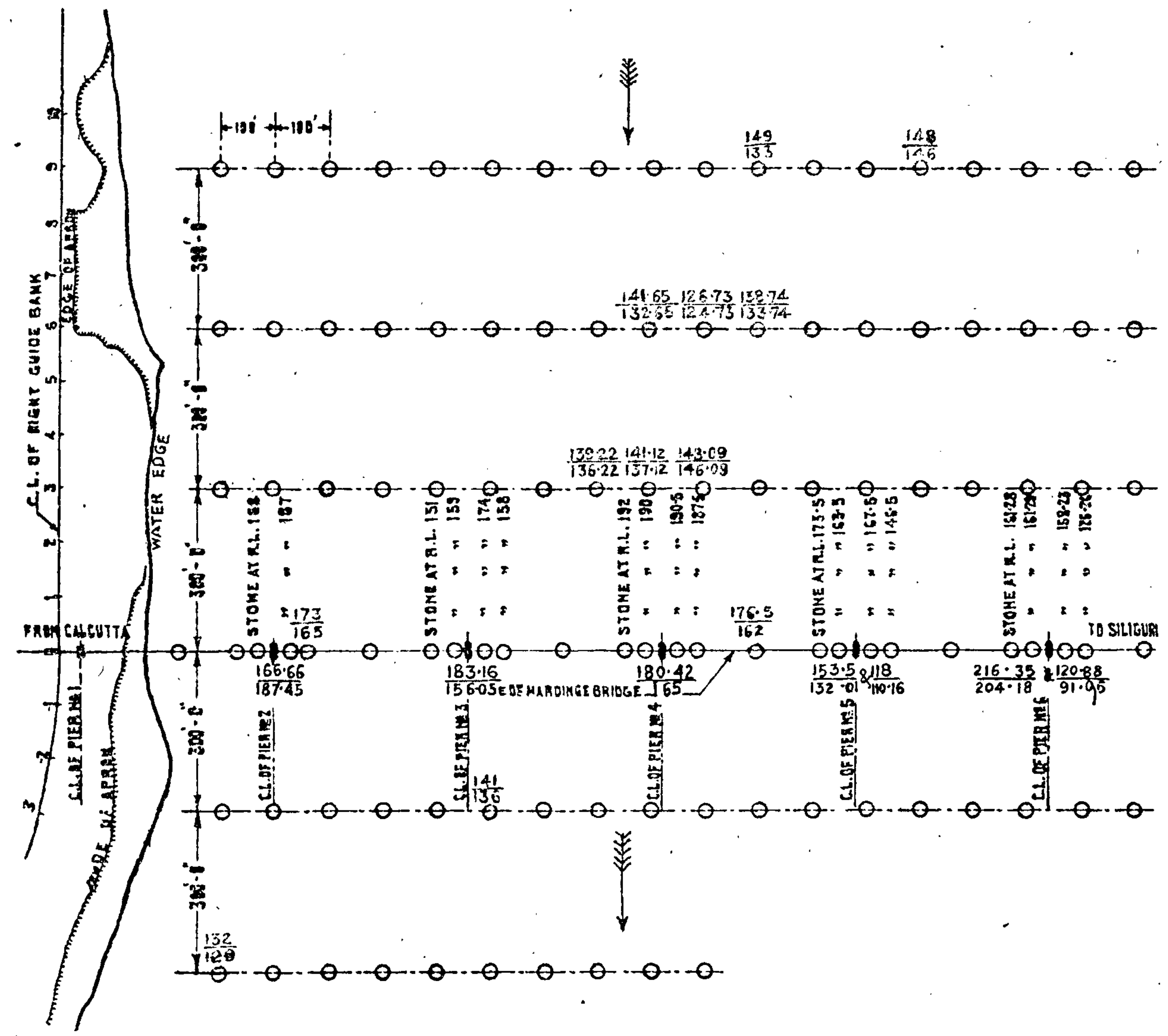
FIG.8
18 b



NOTE:—
HATCHED PORTION INDICATES CLAY BELT AS FOUND AT THE TIME OF CONSTRUCTION
BLUE LINE " CROSS SECTION ON 9-9-36
RED " " " " OF RIVER BED SHOWING THE DEEPEST SCOUR EVER REACHED SINCE THE CONSTRUCTION OF THE BRIDGE.

SECTION ALONG
CENTRE LINE OF HARDINGE BRIDGE
SCALE 1 INCH = 330 FT.

FIG. 7.



NOTE:—
CLAY FOUND BY BORING IN 1934-35 SHOWN THUS .. O
NO CLAY " " DOWN TO R.L. 100 IN 1934-35 " " ...O
TOP & BOTTOM LEVELS OF CLAY FOUND BY BORING IN 1934-35 " " ... $\frac{141}{136}$
" " " " " " DURING WELL SINKING " " ... $\frac{183·16}{166·08}$

PLAN
SCALE 1 INCH = 330 FT.

FIG. 8
18b

CHAPTER VII.

FLOOD SEASON, 1934.

All works were completed, some only just ahead of the rise of the river and although there was a feeling of security that the bridge was now quite safe there was no certainty that the new protection works and the scheme would stand up to the flood. Every known precaution was therefore taken to preserve the guide banks and the bridge through the flood. Chosen inspectors and assistants were detailed for a day and night patrol of 1,000 feet of the guide bank each in shifts of four hours on and eight hours off. By night the banks were lit by flood lights to make any movement of stone easily detectable. Pier soundings were taken by special staff, in shifts night and day at 4-hourly intervals. An elaborate system of alarm signals were introduced so that at the first sign of trouble or damage action could be taken. A nucleus of 600 coolies were paid a daily wage with nothing to do except to be available night or day, if required.

In addition, arrangements were made for the reintroduction of the ferry service for passenger and goods traffic, if the bridge had to be abandoned. New stations were constructed on the two banks of the river at the old transhipment sites of Damukdia and Sara.

The floods started more or less to schedule, the middle of June, and by the middle of August, normal high flood level was reached. The river then commenced to fall gradually till the end of August when floods occurred in the upper reaches of the Gangetic Valley. This was a warning for the Hardinge Bridge and on the 3rd September the river at the bridge reached the highest level it has since the days of its construction with a discharge of 17·5 lakhs cusecs and a surface velocity of 13·2 feet per second. The flood then commenced to fall from this peak rapidly and by the middle of October the river reached the stage of a gradual and regular fall which continued down to its lowest water level in the following April.

The main stream of the river followed a course which swung across from Sara to Damukdia, and thence almost normal to the bridge but directed straight at the isolated head of the Right Guide Bank. Here the stream appeared to be divided, a small part flowing behind the head and into the embayment above the Backwater Bund from where it turned past the head of Jackson's Spur and flowed upstream along the right bank of the river to just below the tail of the Damukdia Guide Bank; the major portion of the main stream was, however, deflected from its straight course and flowed round the curved end of the isolated head after which it straightened up again and flowed nearly parallel to the guide bank passing through spans 2 and 3 of the bridge.

Throughout the flood season a large eddy persisted outside the 'Mole' extending from opposite chainage 12·5 of the 'Mole' to within 200 feet of the lower end of the isolated head. Within this eddy a sounding of 212 feet (at water level 244-0) was recorded at a distance of 600 feet from the 'Mole' opposite chainage 12·5. A large pot hole formed in the river bed where this eddy was active, and this hole remained till the end of the flood season.

Owing to the danger to the 'Mole' and to the bridge by the existence of this deep scour hole so close, it was decided that piers Nos. 2 and 3 should be pitched as an emergency measure. The stream was too fast for barges of stone to be towed to the piers and consequently the pitching was done down improvised chutes which were speedily fixed to the girders on the upstream side at about rail level. By this process 8,000 cubic feet of one-man-rock was pitched round pier No. 2 and 59,000 cubic feet at pier No. 3. Later in the month of September No. 6 pier gave indications of scour approaching the "Danger Level" and about 46,000 cubic feet was pitched here off barges as the stream at this pier was not so fast or turbulent.

The works carried out at Raita, Sara, Damukdia withstood the attack of the river very successfully throughout the flood period of 1934, and only very petty repairs were found to be necessary at these protection banks after the flood had subsided.

At the Right Guide Bank, however, although the protection works generally served their purpose very satisfactorily in safeguarding the bridge, there were periods of anxiety during the flood season when three serious slips occurred at different points along the river front of the guide bank, and prompt emergency action was found necessary in order to arrest the slips and to prevent them from developing into actual breaches through the guide bank. All these slips were in the form of a bodily slide of the pitching stone lying either in the apron or on the slope below water and taking with them the whole of the stone on the slope of the guide bank standing above water, leaving only an exposed face of sand.

The first of these slips on the isolated head of the guidebank occurred on September, 3rd, when the river was at its highest flood level for the year, viz., at R. L. 247. The slip was repaired by throwing up a berm of stone at water level. About 6 lakhs cubic feet of stone was used.

The second slip also occurred on the "Isolated head" on the 16th October. The result of this slip might have been very serious as the junction of the "Isolated head" with the Backwater Bund was left unprotected and was liable to be breached. The slip was repaired very promptly with about 7 lakhs cubic feet of stone.

The third slip occurred on the Right Guide Bank on the 25th October, commencing from chainage 10·5 and working downstream to chainage 5·5. It was repaired by throwing up a berm at water level using about 4 lakhs cubic feet of stone.

CHAPTER VIII.

RESTORATION OF THE BREACH.

The main work in the season 1935 was the restoration of the guide bank across the original breach.

This restoration is of the same design as the 'Mole', namely, a dyke of stone, sealed behind with clay and backed with earth which is held from spreading by a pile and matting barrier. The quantities of earthwork and boulders were, however, considerably greater than in the 'Mole'; for the bank was 1,600 feet long and the average depth of water at low water level over the length was 65 feet. The bank of earth and stone has at its maximum section a base of 450 feet wide standing 105 feet high and this reduced only very slightly over the greater part of its length of 1,600 feet. Fig. 9 shows a typical section of the restored bank.

The bank was completed and the track linked thereon by the 1st of June, 1935. This work, the repairs to the previous flood season's slips and other subsidiary works carried out between December 1934 and June 1935 cost approximately Rs. 40,00,000.

TYPICAL SECTION OF "RESTORED GUIDE BANK"

SCALE 1 INCH = 160 FEET.

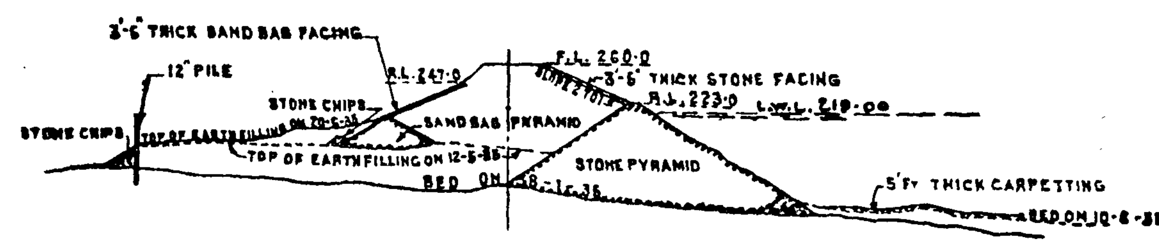


FIG. 9

CHAPTER IX.

FLOOD SEASON, 1935.

The flood season of 1935 may be considered to have commenced on the 1st July, as from this date the river rose steadily and rapidly from the abnormally low level of R. L. 226·5 to reach R. L. 243 on the 31st July.

In August the rise continued, but was very gradual and the river reached its highest level for the year, R. L. 246·5 on the 22nd.

A fairly steady and sharp fall then commenced and continued down to R. L. 241·5 on the 7th September. Thereafter a small rise followed, lasting four days, to R. L. 243 and then a fall over a period of a week to R. L. 241·5. The river again rose very rapidly from the 23rd September reaching the high level of R. L. 245·8 on the 26th. A steady fall then commenced which continued down to the low water level.

The highest surface velocity recorded in this flood at the bridge was 13·6 feet per second with a discharge of 15 lakhs cusecs.

Although there were changes, almost from day to day, in the course of the river above the bridge, there was only one prominent alteration in the main course of the river since the flood season started, and that was in the channel across the Katlamari chur which carried considerably more water this year than it has in the last three years. In fact, the indications of this channel opening in the near future as a main channel of the river were most pronounced. The Katlamari chord channel became the main stream route of the river and the entrance to the Sonaikundi Bight at the north was almost closed.

During a short period in September when there was a sharp rise in the river level the direction of flow between the Damukdia Protection Bank and the Right Guide Bank was changed to some extent. The main current attacked the head of the guide bank and a fairly strong flow appeared behind the head towards the Backwater Bund and then upstream towards Jackson's Spur.

Frequent cross-sections of the river bed taken opposite the Right Guide Bank above and below the bridge showed that the level of the bed during the flood season was changing constantly, in fact, almost daily.

During the first steady rise of the river, the bed opposite chainage 18 to 3 of the guide bank and upstream of spans 2, 3 and 4 of the bridge was scoured steadily and a depression down to R. L. 90 formed in front of chains 16 to 12. Later on, during the latter part of August, heavy silting occurred adjacent to the guide bank, 50 feet of silt having been deposited opposite chain 16 to 12. Simultaneously with this silting the bed was scoured gradually opposite spans Nos. 5, 6, 7 and 8. At this time the main river was flowing over a bed which was nearly level from the toe of the guide bank slope for a width of 1,000 feet outstream. During the fall of flood, however, " gulletting " from chainage 18 to chainage 3 again developed with a depression down to R. L. 80 opposite chainage 16 to chainage 12 and upstream of span No. 2 of the bridge. During the whole flood season there was very little variation in the level of the bed in front of the guide bank above chainage 18.

During the flood season the patch of clay in span No. 3 disappeared completely right across the span. In span No. 4 the clay resisted scour very thoroughly throughout the rise of the river, but on the fall clay at the centre of the span was washed away and it appeared to remain intact only across about a third of the span adjacent to pier No. 4.

A slip occurred at chainage 22 of the restored portion of the Right Guide Bank on the 14th August and extended rapidly to chainage 23. The slip was caused merely by subsidence on the river face of the guide bank resulting in the displacement of the slope pitching down to a few feet below low water level then leaving an earth face exposed which was immediately attacked by the river. The slip was repaired by the following evening without much difficulty.

Piers Nos. 5, 6 and 7 all scoured deep and though not to " danger " limit, they had shown a tendency towards it, and in each instance emergency pitching with one-man-rock was done from barges towed through the turbulent water and moored at the piers.

The emergency and patrolling arrangements which was first introduced in 1934, was again enforced during this flood season. A labour force of 400 coolies was employed, so that labour might be continually available for any emergency that might arise during the floods. They were employed in filling deep depressions which existed behind the Right Guide Bank.

CHAPTER X.

THE HARDINGE BRIDGE COMMITTEE AND THEIR RECOMMENDATIONS.

In April 1934, in a note dealing with the situation at the bridge, the Chief Engineer, Eastern Bengal Railway, recommended to the Railway Board that a committee of engineers be appointed " to review the whole situation and draw up a definite programme for the execution of such works as are necessary at once and those that can be thrown forward ". The Railway Board approved of this proposal and formed the Hardinge Bridge Committee (consisting of six eminent engineers in India under the chairmanship of Sir James Williamson, Agent of the Bengal and North Western Railway) to investigate the problems at the Hardinge Bridge and to submit a report on the following terms of reference :—

1. To examine the training and protection works of the Hardinge Bridge, in the light of recent events and of the committee's observation during the 1934 flood season and report on their suitability for the purpose intended.
2. To consider, in the light of the effect of the works carried out during the last working season on the regime of the river and also of the river in flood on the works in question, the recommendations made by Sir Robert Gales in his report regarding further works which should be carried out in the future, and to prepare a comprehensive scheme, with a programme of the sequence of execution, which will ensure that the existing training and protection works of the Hardinge Bridge, supplemented by the proposed works, will function so as to ensure the safety of the bridge, and the approaches thereto and will, at the same time, cause the least interference with, and risk to, navigation.
3. To report on any relevant features that may arise out of the above in connection with the design thereof.

This committee met twice at Paksey, once during the floods and the next immediately after the floods of 1934, before giving their final recommendations. In these two meetings, they confirmed the recommendations made by Sir Robert Gales that the main breach in the Right Guide Bank should be closed as early as possible, but considered that, before further works are undertaken experiments should be carried out in the Irrigation Department's Experimental Laboratory at Poona (with the permission of the Government of Bombay) by Mr. C. C. Inglis, Superintending Engineer, Deccan Irrigation Circle, with a working model of the River Ganges, to see whether any of a series of proposals, which they supplemented Sir Robert Gales's recommendations, would afford a scheme of permanent safety of the bridge.

These experiments were carefully carried out by Mr. Inglis and a note which was prepared by him on the Model Experiments was read out in the final meeting of the committee which was held in New Delhi on November 1st and 2nd, 1935.

The main conclusion drawn from the results of experiments were the following :—

(1) Water tends to adhere to guide banks and leaves them with reluctance.

(2) A guide bank pulls the river round its nose but there is a limit to the embayment caused thereby.

(3) Erosion upstream of a guide bank must occur and should be allowed for; but this erosion is definitely limited.

(4) The development of the Sara protuberance was the direct cause of the aggravated attack on the Right Guide Bank and that the Damukdia protection Bank definitely intensified this attack, though it prevented further embayment above the latter.

The committee again considered the various schemes for training the river in the light of the results of experiments made at Poona and also the proposals contained in Sir Robert Gales's Note, on the minutes of the first and second meetings of the Committee, and finally recommended.

(I) That the Raita Protection bank must be held.

(II) That the protuberance at Sara should be removed, either by cutting it back or by assisting the river to erode it. The best method of removing the protuberance should be investigated on the working model.

(III) That the guide banks at the bridge should be lengthened to approximately the length of the bridge, and if possible the Left Guide Bank should be extended far enough to protect the railway Colony at Paksey, but not to such a length as would greatly outbalance the lengthened Right Guide Bank. These guide banks should be maintained as the permanent defences of the bridge.

(IV) That the Damukdia Guide Bank should be removed.

NOTE.—As regards Final Recommendations (III) and (IV), the magnitude of the work and the expense involved in lengthening the right guide bank, under present conditions, will render it impossible until silting of the embayment between Damukdia and the right guide bank takes place; as soon as this does take place the guide bank should be extended; in the meantime the Damukdia Guide Bank must be retained and held.

(V) That, should the Lalpur Bight embayment extend and threaten the Eastern Bengal Railway Main Line, this should be retired between Ishurdi and Abdulpur on to an alignment 1½ to 2 miles to the east of the present alignment, and such realignment should, if necessary, be extended even south of Ishurdi, joining the approach to the bridge at about mile 122. The formation level of the retired alignment should be kept well above extraordinary high flood level, and all bridges in it should be controlled with sluices or other means of checking any strong flow of Ganges spill water through them.

(VI) That the model experiments should be continued, in accordance with the recommendations, with regard to the extension of the Right and Left Guide banks, the removal of Sara and Damukdia guide banks, &c. and the results of these experiments communicated to the Eastern Bengal Railway Administration for their guidance.

NOTE.—The committee are impressed with the utility of the method of investigating hydraulic probelms by means of model experiments and recommend that this method should be utilized in suitable cases in connection with the new river works and maintenance problems of the railways of India.

(VII) That pending the completion of the experiments, the Eastern Bengal Railway should prepare schemes for the retirement of the main line and other works which might become necessary, in accordance with the above recommendations, so that should it ever become necessary to do so, everything might be in readiness to start work at short notice.

The land and contours north of Sara should be surveyed in detail and the "Danger Line" of embayment and the limits of attack should be fixed by the Eastern Bengal Railway Administration, so that it may be definitely on record at what stage action must be taken.

(VIII) That no major works are necessary before the flood season of 1936. The pitching of piers, dressing of slips, etc., are however normal annual works and should receive the usual attention; they consider it advisable that the deep depressions which now exist behind the Right Guide Bank should be filled, and agree with the Eastern Bengal Railway that this work should be spread over five years and be carried out during the flood season, so that labour might be continuously available for any emergency that might arise during the floods of the next five years.

(IX) That there should be continuity of supervision of the Hardinge Bridge, that a special Officer-in-Charge of the bridge and the protection works should be selected and posted for a long period, and that comprehensive duties should be outlined for his guidance.

That during the next flood season, and probably in subsequent years until all danger is past, a selected senior Executive Engineer and an additional junior engineer be posted to the bridge during the flood season, and that the patrol and emergency arrangements for watching the protection banks during the flood season adopted during the last two years, be continued in the future.

CHAPTER XI.

CAUSES OF THE BREACH OF THE RIGHT GUIDE BANK.

Much has been written on the cause of the breach, investigations have been exhaustive and although various reasonable and probable theories have been suggested the actual and definite cause of what happened on the 26th September, 1933, the day damage was done, will probably remain obscure.

Ever since the completion of the bridge there have been watchmen at each of the guide banks whose duties were to patrol it and report any unusual occurrence to the Officer-in-Charge of the bridge. It might be their patrol had developed into a rather superficial observation of the slopes of the bank, but as no special report was received from the watchmen, it is fair to assume that all was well on the evening of the 25th and that the damage really started late on the night of the 25th or early on the 26th September. Also three days before the breach occurred the Excutive Engineer, Paksey, accompanied the Chief Engineer, Eastern Bengal Railway, on an inspection of the river and all the protection works and they felt satisfied that there was no reason for alarm.

But for this, there is no record to show what condition of flow existed at the time and immediately before the breach occurred. Lack of this evidence had led to the belief that the breach had been caused by extraordinary circumstances and when all convincing explanations had to be deduced from the facts reported after the breach occurred, it is not surprising that eminent engineers who attempted to solve the problem differed in their conclusions.

In the opinion of Sir Robert Gales, the breach of the Right Guide Bank was not due to normal causes, namely, slipping at the toe of pitching. As the breach had not occurred by some catastrophic slip when the water level passed R. L. 240·2 on the fall, he could not believe why a slip should take place at this level on the rise. He claimed that the breach arose from the core-exposure of the surface wash-out variety due to surge waves set up immediately above the guide bank head, that it was owing to the unusual character and intensity of the waves that the core-exposure was converted into a breach before it was discovered and that its occurrence at an early hour and during the Poojah Holidays had turned a simple core-exposure into a disaster.

Late Mr. B. L. Harvey, the Deputy Chief Engineer, Hardinge Bridge, who was in charge of the works undertaken immediately after the breach, suggested that the breach probably started not by a slide into a hole made by the eddy at the toe, but high up on the slope of the bank, at or just below water level.

Mr. Inglis, the Director of Hydrodynamic Research Station at Poona, who had reproduced the breach in detail in a large geometrically similar model of the Right Guide Bank differed from the views expressed by Sir Robert Gales. In his opinion the breach was caused by toe-scour resulting from diving flow. The damage originated just below the surface and that was due to all the available apron stone having launched so that when a further slip occurred at the toe stone from above rolled down the slope to make good the shortage, leaving a bare patch just below the surface which extended rapidly.

Mr. Trench, the Chief Engineer, Public Works Department Sind, disagreed with Sir Robert Gales's theory of surge waves as a cause of breach and pointed out that as there was no direct evidence that a breaking wave travelled down the guide bank before the breach nor down the "isolated head" after the breach (as would have been expected, at any rate for a time thereafter, or until the river broke through the back) the existance of a wave was only a conjecture from the fact that a surge wave was observed in the breach. He suggested that instead of a surge-wave (which could not fail to have been seen had it existed) there probably was a rhythmic alteration in the level of the river in the form of "breathing", and that this rhythmic rise and fall, at intervals of two minutes, would not be in any way dangerous to a heavily pitched bank and would certainly escape notice unless the gauges were being closely watched. As his explanation covered all the reported facts and as there was no evidence of any other sufficient cause, he came to the conclusion that the breach was caused by toe-scour.

The Hardinge Bridge Committee were of opinion that the breach of Right Guide Bank was due to under-cutting of the stone protection caused by "diving flow" of the water.

There is yet one more explanation for the failure of the Right Guide Bank and although this explanation does not lead to any positive conclusion as to the true nature of the cause of breach, it undoubtedly shows that the failure was due to defects in the design of apron which were unsuspected then and which were brought to light only by the failure under severe attack.

The original apron of the Right Guide Bank was designed for a scour 100 feet deep below low water level. During the floods of 1931, when the upstream portion of the guide bank was attacked and the river bed along the apron between chainages 10 and 30 scoured to a depth of 80 feet to 100 feet below low water level it was apprehended that the original protection was inadequate. Precautions were immediately taken and the Right Guide Bank was reinforced from chainages 15 to 30 by pitching in water about 400 cubic feet per foot run in continuation of the apron stone already launched. This additional pitching was supposed to protect the guide bank against scour down to 160 feet below low water level but actually, according to Spring's principles, it was sufficient to withstand a scour 140 feet below low water level. Also the thickness of this pitching was 4 feet and it appears to be inadequate for the purpose intended. The pitching was done at a level which was about 40 feet higher than the final position the stone was expected to take when launched and no allowance for dissipation was made. It has been found from experience at Raita that a " carpetting ", of thickness less than 6 feet, accurately laid through grids, is liable to be washed away when the bank is attacked severely by the river. The inherent defects in the method of this sort of pitching necessitates a thickness of 6 feet " carpetting " at least, so as to ensure a minimum thickness of 4 feet on the entire area pitched; otherwise the risk of sand beneath the carpetted area being sucked out and of stone being washed away by the fast flowing current, should be incurred.

Another defect in the apron of the Right Guide Bank was at its inner belt. This portion of the apron being only 4'-6" thick was not thick enough to provide on the developed 2 to 1 slope a minimum thickness of stone required to prevent the mixture of Ganges sand and silt from being washed out. So long as the horizontal inner belt of the apron remained intact there might not be danger to the bank but when once it launched to a slope of 2 to 1 slips on the face of the slope might be expected.

The floods of 1932 was not very severe. Yet, in December 1932, the condition of the river bed along the right guide bank caused considerable anxiety as a scour 103 feet deep below low water level was found at a distance of 350 feet from the centre line of the bank at chainages 17 to 19. It was, however, considered unnecessary to take any action as the prickings proved that the additional pitching done in the previous year was intact.

Now coming to the flood conditions of 1933, it was on record that during the rise of flood up to 9th September, the main-stream, after leaving the Sara Protection Bank at an angle of 60° impinged on the Damukdia Protection Bank at chainage 11 and appeared to be deflected on to the head of the Right Guide Bank at chainage 27. From 9th to 16th September, when the river was falling, the main-stream leaving Sara was so directed, perhaps due to the erosion of clay at the upstream end of the protection bank, that it left Damukdia Protection Bank and was impinging directly on the curved head of the Right Guide Bank. It was at this time, the right bank of the river between the tail end of the Damukdia Protection Bank and the Right Guide Bank appeared to have been heavily eroded forming a deep embayment, which, a few days later, became the direct cause of formation of the rhythmic alteration in the level of the river mentioned by Mr. Trench. Such phenomena of flow at the curved head of the Right Guide Bank were noticed during the subsequent flood seasons.

It has been found by experience that when the river attacks a curved protection bank and subsequently leaves it, the maximum depth of flow along the bank generally occurs about 600 feet below the point where the stream leaves the bank. At the Right Guide Bank, the main-stream, after impinging on the curved head, left the bank at chainage 25, and so, it might be expected that the pot-hole which existed at chainage 19 in 1932 (vide fig. 10) had deepened, before the breach, to a level which was lower than that recorded opposite chaniage 22 in November, 1933, viz., R. L. 107. How deep the bed scoured, whether the scour reached a level below R. L. 80, the level to which the guide bank was actually reinforced in 1932, will never be known; and to what extent the additional pitching of 4 feet thick did, or did not help to protect the guide bank is impossible to say. Lack of these informations, therefore, makes it difficult to assign the cause of breach to toe-scour. Had the scour hole been really too deep and the pitching been inadequate, the breach would probably have occurred during the fall of flood when the scour hole was formed. However, it seems certain that the scour hole made the stone protection at chainage 19 to slip further, causing a portion of, if not all, the inner belt of the apron, which was 4'-6" thick, to take a slope of 2 to 1 with a covering of stone not greater than 3 feet thick.

All this appears to have happened during the first fall of flood, *i.e.*, from 9th to 24th September, 1933. Had the river continued to fall further, probably the guide bank would have remained safe. The river, however, rose suddenly, and at the beginning of the rise when the stream was leaving the guide bank at chainage 25, the resulting eddy between the edge of the main-stream and the bank appears to have washed out sand through the interstices of a 3 feet covering mentioned above and caused the breach.

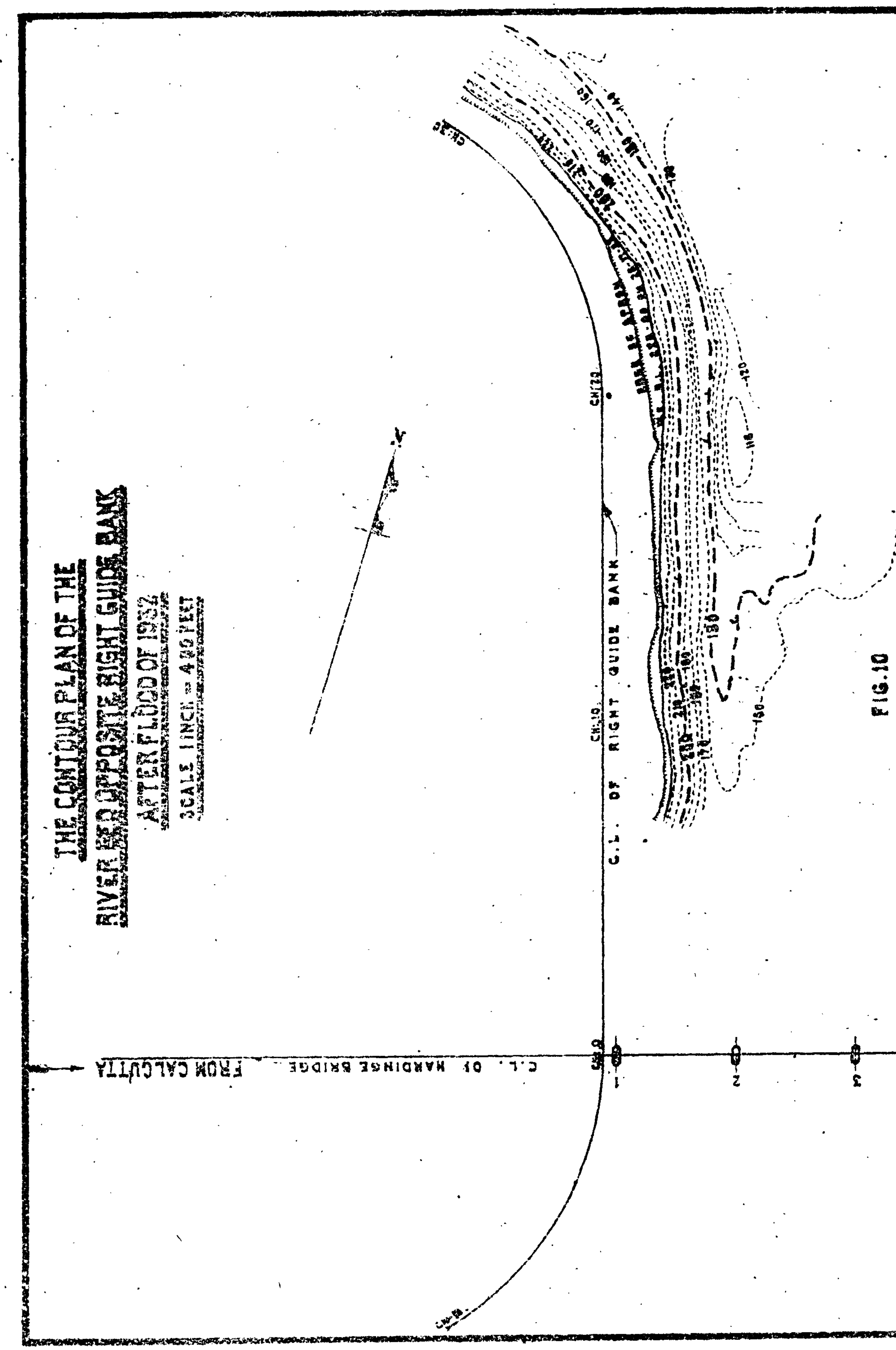


FIG. 10

CHAPTER XII.

ABANDONMENT OF THE SARA PROTECTION BANK.

In March 1936, the Railway Board decided to abandon the Sara Protection Bank and to recover as much pitching stone as could be removed from the bank above water level. This work was started in March and completed in June, 1936, and about 24 lakhs cubic feet of stone was recovered from the protection bank.

Before proceeding to give reasons that led the Railway Board to abandon the Sara Protection Bank it may be well to narrate in brief the history of the protection bank since its construction.

In the course of the Ganges, between Sarda and Pabna, the mainstream at places finds itself flowing past a comparatively unerodible clay bank. Sara is one such place and the existence of clay there was a decisive factor in the selection of a site for the bridge across Ganges below Sara. This clay in the past always had turned the river down the reach below and it was expected that it would continue to do so if further erosion could be prevented. Accordingly, in 1915, after the bridge was opened to traffic, the bank at Sara, where the clay was most resistant, and which was protruding slightly-in-stream beyond the line drawn normal to the bridge at its left abutment, was reveted with pitching stone for a length of 3,650 feet. At this time the main channel of the river was hard up against the left bank and the left abutment of the bridge. During the period 1915 to 1921 there had been no appreciable movement of the river to cause any alram and the north end of the Sara Protection Bank was well inland from the water's edge. From the year 1921 it was seen that the river was making a definite movement into the Lalpur Bight above Sara and in 1925 when the river severely attacked its upstream end the head of the Sara Protection Bank was slightly retired on a curve, in the hope that the resistant clay at and above Sara would hold the river from developing further eastward above the protection bank. This hope, however, was not realized and by 1931 the embayment increased to such an extent that, in spite of large quantity of stone having been pitched at the head, the river cut in sufficiently for the main-stream to come out crossing the head more or less at right angles and formed eddies—both on the land side and on the river side of the newly formed head—which engulfed it and diverted the main-stream abruptly across to the right bank, where trouble began. After this, the Sara Bank was realigned on a new curve and extended in the winter of 1931. At this time the matter was referred to the Consulting Engineers who recommended that in order to save further erosion of the Sara clay and to introduce smooth flow in place of eddies, the protection bank should be curved back at the best curve available and extended and that the sunken head should be cut away and removed as far as practicable. This was done after the flood season of 1932. In the winter of 1933, after the Right Guide Bank breached, the Sara Protection Bank was again realigned and extended as described before. Plate XI shows the successive alignments of Sara Protection Bank. In 1934 the Sara Protection Bank stood in that position without giving much trouble, but during the flood season of 1935 the face of the protection bank slipped at two places forming two large bights. Prickings to locate the under-water stone at these places revealed that very little stone existed and that too in isolated patches. As the river bed along the protection bank had been scoured down to 145 feet below low water level the utter futility of attempting to protect the bank against this depth of scour or even to restore the face of the protection bank where there had been erosion in the form of two bights was realized. Accordingly, the Eastern Bengal Railway Administration applied for and obtained the approval of the Railway Board in March, 1936, to abandon the Sara Protection Bank.

Thus the Sara Protection Bank came to a tragic end. During the second half of the period of its existence, the protection bank gave continuous and very serious trouble and most of the trouble, however, could have been averted had the engineers at the time foreseen the possible consequences of the erosion of the bank above it while the river was gradually translating towards Lalpur Bight. This movement of the river commenced in 1921 and the protection bank was first attacked in 1925. In 1921, there were two courses open—either to extend the pitching of the revetment upstream on the regular line of the bank or to construct a curved back extension similar to the curved back upper end of the bridge guide banks without any final head; by 1925 the latter alternative only was possible. If either of the measures had been adopted there would probably have been no eddy scours of alarming proportions at the site, and no abrupt throwing over the current to the right bank.

However, the position at Sara worsened rapidly since 1931, and threatened the safety of the Right Guide Bank and the bridge. Even in 1936, a couple of years after the Sara bank was finally realigned and extended, the position there did not improve and the danger to the bridge remained. At last, Railway Board, considering that the local engineers found it exceedingly difficult and expensive to hold a protection bank constructed on clay against a severe attack, decided to abandon the Sara Protection Bank. By abandoning the bank they expected to see whether or not a modified alignment of the river edge could be obtained which would give smooth flow up to the bridge. To a certain extent their expectation has been fulfilled. During the next five flood seasons the clay at Sara was rapidly cut away to an extent of about 1,000 feet in all. This erosion together with the gradual improvement in the Damukdia Channel had made the condition of the river in the vicinity of the bridge better and in 1941, when this report is written, the river is well away from the Right Guide bank, the stream is more or less evenly distributed through spans Nos. 2 to 6 of the bridge and the river bed opposite the Right Guide Bank and above the bridge has considerably silted, the maximum depth of water there being not more than 57 feet below low water level.

This improvement, perhaps, has led some Engineers to suggest that the whole cause of trouble at Sara started by the original abortive attempt to protect the Sara clay. They said that the clay had been scoured back very slowly for at least 200 years but that it had kept a straight alignment during that time and consequently there was no reason to anticipate that action would not have gone on at the same slow pace. There were, however, evidences to show that this probably would not have been the case. The erosion of the bank upstream of the last remnant of the resistant Sara clay, which was visible as a shelf just above low water level and projecting beyond the line of the erodible bank, would have proceeded more rapidly than the erosion of the remnant and the conditions which developed during the years 1931—35 would have occurred even at the natural bank at Sara, though not to the same extent. The Sara Protection Bank was originally constructed on the assumption that an unprotected erodible clay bank would erode more rapidly than a protected erodible clay bank. But, this assumption was, later, proved wrong, and experience has taught the lesson that the guide bank built on clay on Spring's principles does not function as intended.

Nevertheless, the importance of the Sara Protection Bank will be realised from the fact that as soon as it was abandoned, it was found necessary to do more training works for the permanent safety of the Hardinge Bridge. This protection bank, so far from having been a detached work, was an integral part of the training works and it could never have been out-flanked. It, in fact, formed the head of an "interrupted" guide bank connected with the Left Guide Bank. The natural bank of the river between Sara and the bridge was high and well consolidated and it had been raised above the maximum high flood level by means of a marginal bank. Now, with Sara Bank no longer available to control the river both the Guide Banks of the bridge became too short in length and they would have to be extended sooner or later.

The Hardinge Bridge Committee were unanimous of opinion that, in order to avert the danger to the Right Guide Bank, it was essential to get rid of the "Sara Protuberence". Whereas, Sir Robert Gales vehemently opposed the demolition of the Sara Protection Bank, and pointed out that the commanding position of the Sara Bank had hitherto been able to ensure that any bend of the river above Sara would cut off before the safety of the main line was threatened. In his opinion the price to be paid for the demolition was the cost of the proposed retirement of the main line between Ishurdi and Abdulpur.

Sir Robert Gales's view of the situation appears to be a little exaggerated. With an erosion of only 1,000 feet of clay at Sara during the last five years and with the probability of further erosion being much less, due to the improvement in the Damukdia Channel, which carries about 30% of the total discharge of the river, it is difficult to conceive how the commanding position of Sara was entirely lost. On the other hand the Railway Board's decision of 1936 appear to be right for the reasons that the shape of the Sara site during the year 1931—35 was such that it was positively harmful to the safety of the Right Guide Bank, that it was found impossible to hold a Protection bank built on stiff clay, that there has been considerable improvement in the condition of the river at the bridge since last five years, and that, if necessary, it is possible to build a new bank on sand at the correct position opposite Sara later on when the bed silts up.

CHAPTER XIII.

WORKS DONE DURING THE YEARS 1936 AND 1937 AND FLOOD SEASON REPORTS.

In addition to the abandonment of the Sara Protection Bank, the main item of work done in this year was the reinforcement of the tail end of the Right Guide Bank. Although there was no suggestion put forward by the Hardinge Bridge Committee for this work it was observed, during the course of an experiment on the working model at Poona in January 1936, that a very considerable embayment formed on the model at the tail end of the Right Guide Bank. As it was considered that there was danger of a similar embayment forming in the proto-type it was decided to reinforce the tail end of the Right Guide Bank by the addition of 12·25 lakhs cubic feet of stone from chainage 5 to the tail and round it behind the bund, and to stack a reserve of 200 cubic feet per foot run on top of the guide bank from chainage 5 to the tail. During the flood season of 1936, however, no alarming embayment was formed at this place as was noticed in the working model and, in fact, the reinforcement was found in the same position as laid.

Also, before the flood season of 1936, the protection around piers 4, 5 and 6, was increased by the addition of 138,300 cubic feet of heavy boulders (1/2 to 1 ton each) and 137,200 cubic feet of one-man-rock, as the borings revealed shortage of stone at these piers.

The system of patrols for the purpose of exercising constant vigilance at the Right Guide Bank was again brought into operation and the condition of the river bed at the piers of the bridge was carefully and regularly watched. Steps were also taken as in previous two seasons for the prompt introduction of a passenger ferry service across the river in case the Hardinge Bridge should become unsafe for traffic.

The flood in the Ganges during 1936 was remarkable for the abnormally high water level of 247·4 recorded on the 16th August which was also an exceptionally early date for this river level. The level was the highest recorded since 1915, the year in which the Hardinge Bridge was opened for traffic.

During the flood season the Right Guide Bank and the piers of the bridge withstood remarkably well the severe attack to which there were subjected by the river, but on the 10th of September a length of about 300 feet, commencing from chainage—2 of the guide bank slipped into the river. The slip extended back to about 20 feet behind the original shoulder of the guide bank and the stone protected slope of this bank completely disappeared into the river leaving the sand core exposed from water level to top of formation. Emergency repairs were taken in hand immediately throughout the remainder of the flood season. At the piers, excessive scour, which necessitated emergency pitching with stone, occurred only at piers 4 and 7.

It is worthy of describing here the method of arresting slips and preventing their rapid extension adopted as the result of experience gained during the flood season of 1934, 1935 and 1936. When a slip is detected—if it is detected early and is probably over a length of not more than 20 to 50 feet, besides the pitching which is normally done on the exposed face of earth to cover it, it is essential to prevent lateral expansion. The most efficacious way of doing this is found to be to pitch boulders speedily over a length of say 15 feet beyond the slip, at both ends, at water level, for it is at these points that slips extend and a mass of stone speedily deposited here prevents or at least slows up, not only their extension but the depth which they erode into the bank. This added stone feeds the action of the slips and preserve the original slope and it does not, therefore, remain to form a dangerous protuberence on the bank.

The following were the main works done after the flood season of 1936:—

(*a*) Due to excessive scour having occurred in the river bed along the entire upstream half of the protection bank at Raita this portion of the bank was protected against scour down to 170 feet below low water level—a depth to which scour can possibly occur as a result of the most unfavourable conditions of flow which are likely to prevail. Also the protection bank was extended upstream on a suitably realigned curve.

(*b*) Owing to the progressive development of the Damukdia Channel and the occurrence of considerable erosion along the right bank of this channel down to within only a short distance above the protection bank, the Damukdia Protection Bank was extended upstream on a slightly realigned curve, as proposed by Sir Robert Gales, as far as the old bank of 1880.

(*c*) The Right Guide Bank was reinforced throughout its length to withstand scour down to R. L. 60 wherever the existing protection was found to be inadequate.

The slip which occurred between chainage —2 and —5 during the flood season was repaired.

(*d*) As it was found that the entire pitching which existed round the upstream half of Pier No. 4 together with clay patch in a portion of Span No. 3 had disappeared during tne flood season, this pier was again protected by pitching 1·18 lakhs cubic feet of additional stone. This quantity was calculated to be adequate for protection against scour down to 120 feet below low water level.

Additional stone was also pitched round the upstream half of Pier No. 7 where the protection was found to be inadequate.

The flood in the Ganges during 1937 was less severe than it had been in any year since 1933, but the duration of the flood period was longer than usual owing to a late rise in river level having occurred in October, when it is usual for the river to be in the final falling stage.

During the flood season the Right Guide Bank and the Damukdia Protection Bank suffered no damage and no anxiety was experienced on account of excessive scour at the pier. At Raita, however, the conditions in the river developed so unfavourably at the upstream end of the protection bank in the length where no reinforcement was carried out in the previous season that this portion of the bank was in imminent danger of being destroyed. It was, therefore, considered essential to reinforce this length by the addition of a quantity of stone which would be requisite for protection against scour down to 170 feet below low water level and to carry out this reinforcement in such a way that it would fit in with a scheme for extending the protection bank on a realigned face. This work was completed by June 1938.

The other important work taken in hand after the flood season was the reinforcement and longitudinal extension of the Left Guide Bank and this work is fully described in the next chapter.

CHAPTER XIV.

THE LEFT GUIDE BANK.

With the embayment which had formed above the site of the old Sara Protection Bank and with the gradual translation of the stream away from the right bank above Raita, the indications in the year 1938 were that the river would soon short circuit through the Damukdia Channel. When this occurs the left bank of the river upstream of the original Left Guide Bank would probably be attacked heavily. The original length of the Left Guide Bank upstream from the centre line of the bridge was approximately only half the length of the bridge and as this bank was, since the Sara Bank was abandoned, the only protection on the left bank of the river, this length was entirely inadequate. So it was found necessary to take precautions while there was time and to extend the Left Guide Bank.

It was easy to realize that; but, how far the bank should be extended and what should be the shape of it so as to give the current the best directional effect at the bridge were questions which could not be answered off-hand. Various schemes were suggested. Some engineers desired that the Left Guide Bank should be designed according to standard practice, viz., the upstream length of the guide bank should be equal to the length of the bridge and that its upstream end should be terminated with a curzon head. The Hardinge Bridge Committee recommended that Left Guide Bank should be extended far enough to protect the Railway Colony at Paksey and should be maintained as a permanent defence of the bridge. But they did not specifically lay out in what manner it should be extended. They only pointed out that in designing any additional training works great care should be taken to place them in easy curves in order to encourage stream line flow, which besides the other advantages, would ensure beneficent effects on the navigation of commercial and other vessels through the bridge, and considered that the most effectual and economical method, would be to revert to Spring's design for guide banks at the bridge and to extend the original guide banks to approximately the length of the bridge, terminating their ends with a splayed head. Sir Robert Gales, however, would not agree to this alignment. He considered that a splayed head would be less efficient than a straight guide bank with Sara bank head, because owing to the retirement of the splayed head by at least half-a-mile, the margin between the main line and any future embayment of the river above the head would be reduced by not less than ¾ mile, which might be sufficient in some circumstances to make all the difference between to retire the main line or not. He said that it would be also less safe, because the downstream part of the original Sara Protection Bank is still inerodible by smooth flow—although no doubt erodible by eddy action—and this would give any new aligned Sara Bank a security which cannot be hoped for in splayed position. He, therefore, advised that the best alignment for the Left Guide Bank would be to extend the original guide bank on a line joining chainage 20 of the bank with the tail end of the abandoned Sara Protection Bank and finishing it off with a suitable head at Sara.

The Railway Administration, after a careful study of the problem, decided to extend the Left Guide Bank on an alignment as shown in Plate XII. This alignment runs at right angles to the bridge to a length approximately equal to the length of the bridge and then turns inland on a half degree curve so that the tangent to the curve drawn from the point at chainage 92 of the extended guide bank passes through the centre of Pier No. 10. They also decided to extend the guide bank for the present by 5,500 feet only which with original Left Guide Bank would give a total length of protection bank of 8,000 feet. This length would be sufficient to protect the Railway Colony at Paksey.

The apron of the original Left Guide Bank was designed for amaximum scour of 100 feet below low water level; but from observations made since 1934 it was found to be found entirely inadequate. It was, therefore, decided to widen the apron so that it would be able to withstand the maximum probable scour which might occur, *i.e.*, 160 feet below water level, as was done in the case of the Right Guide Bank. The original apron which had been put down at the Left Guide Bank had served its purpose and acted in the manner in which it was designed to act, but, during the period when the river gradually translated towards the right bank considerable amount of silt was deposited over the original apron, which had launched partially. The reinforcement of an apron was covered with sand to a maximum depth of 100 feet, at places, was not practicable in the ordinary way. This would have to be done either by laying a completely new apron designed for the greater scour at low water level or else by waiting till the sand over the fallen apron was scoured away, and extending the apron by dropping boulders through grids from barges. The former method was decided to be adopted at the Left Guide Bank using as much of the old apron as had not launched in the design. Fig. 11 shows typical section of the reinforcement of the apron as was actually carried out.

During the year 1937 borings in the river bed were put down both for the purpose of ascertaining whether any clay exist underlying the area which would be covered by the stone pitched apron of the extended portion of the guide bank and for the purpose of locating the position and extent of the launched apron of the original guide bank.

The borings showed that clay exists between chainage 53 and chainage 80 of the extended guide bank vide fig. 12. Although this clay was not of the type of Sara clay which was noted for its toughness and hardness, it was found to be at the level at which it was proposed to lay the apron of the extended guide bank. In what manner the apron laid on this clay would function, and whether it would function as intended, are questions which should be studied carefully when the river attacks this portions of the guide bank.

The borings also showed that between the guide bank apron and the pitching ground pier No. 15, stone exists right across the apron and that too at a very high level, thus forming a stone weir. When the river sets across from the Damukdia Protection Bank into this corner, a clear flow of full depth between the guide bank and pier No. 15 is essential and should be attained at any cost. Otherwise there is every likelihood of getting a scour hole downstream of pier No. 15 as deep as, if not deeper than, the scour hole formed below pier No. 2 during the last few years. This matter was considered and no additional stone was pitched between chain plus 2 and minus 1 of the Left Guide Bank. In this connection it should be mentioned that the inner belt of the original apron of the Left Guide Bank being only 4′-6″ thick—a thickness which is insufficient to give a minimum covering on the developed two to one slope required to prevent sand from being washed out through the interstices—needs additional pitching at those places where the unlaunched portion of the original apron was taken into calculation in designing the reinforcement of the apron. This was not done and it should be done either now by removing the silt over the apron and laying a layer of, at least 1′-0″ thick, stone over it, or later on when the silt is washed away.

The extension of the Left Guide Bank was done in three stages. In the year 1938 the apron of the old Left Guide Bank was reinforced and the extension of the bank was completed up to chain 40, while only the earthwork in bank was completed in the remaining portion, viz., between chain 40 and chain 80. In the year 1939, the apron between chain 40 and chain 60 was completed and the curved head of the old guide bank was abandoned. In 1940, the guide bank was extended up to chain 80. About 371 lakhs cubic feet of earthwork and 148 lakhs cubic feet of pitching were done in the total extension up to chain 80 and in the reinforcement of apron of the old guide bank. The cost of these works amounted to Rs. 26,24,000 approximately.

During the course of reinforcing the apron of the original Left Guide Bank an incident occurred which requires mentioning. A considerable amount of silt deposited over the apron originally laid had to be removed before additional pitching was done. The local engineers found no space to dispose of the spoil earth and they dumped the earth over the chur land beyond the apron edge and upstream of pier No. 15. The Steam Navigation Company who used to ply their steamers through the Paksey Channel during the high floods objected to this on the ground that the river bed lower down might silt up and hinder navigation. They represented the matter to the Railway Administration who finally decided to remove the earth thrown over the chur above the top level of stone pitching, and this was done. It appears strange how a couple of lakhs cubic feet of earth thrown over the chur could silt up lower down to such an extent as to prevent navigation. It is true that the Paksey Channel has been gradually silted up and the rate of silting rapidly increased since 1936. The cause of this, however, is to be found in the abandonment of the Sara Protection Bank. So long as there was a "protuberence" at Sara, an off-shoot below the "protuberence" found its way through the Paksey Channel. As soon as the clay at Sara eroded and the spur disappeared, the flow through the Paksey Channel gradually dwindled and whatever silt it carried during high floods was deposited there.

TYPICAL SECTIONS SHOWING REINFORCEMENT OF THE APRON OF LEFT GUIDE BANK

SCALE 1 INCH = 80 FT.

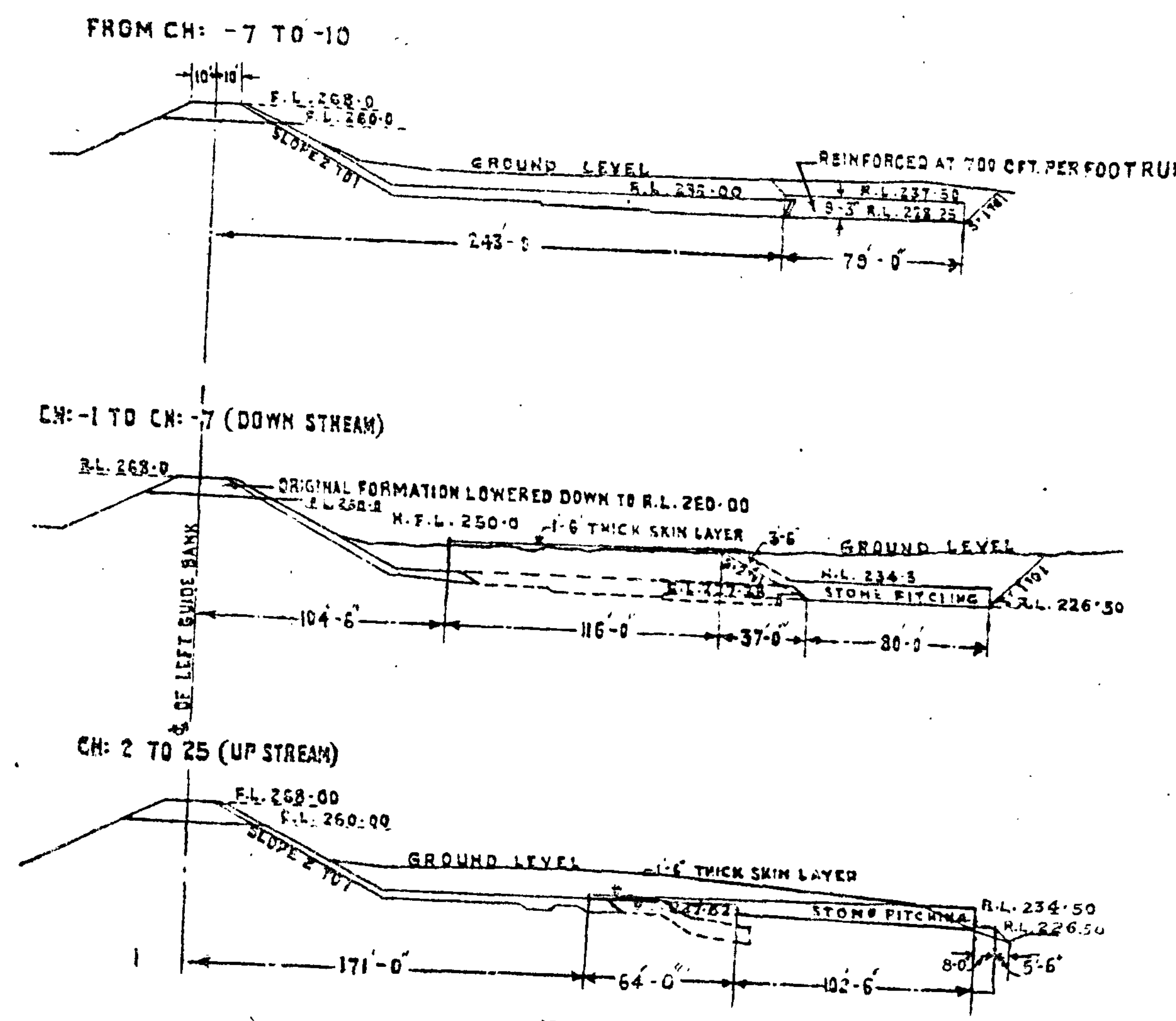


FIG 11.

32 A.

CLAY STRATA OPPOSITE LEFT GUIDE BANK AS LOCATED BY BORINGS

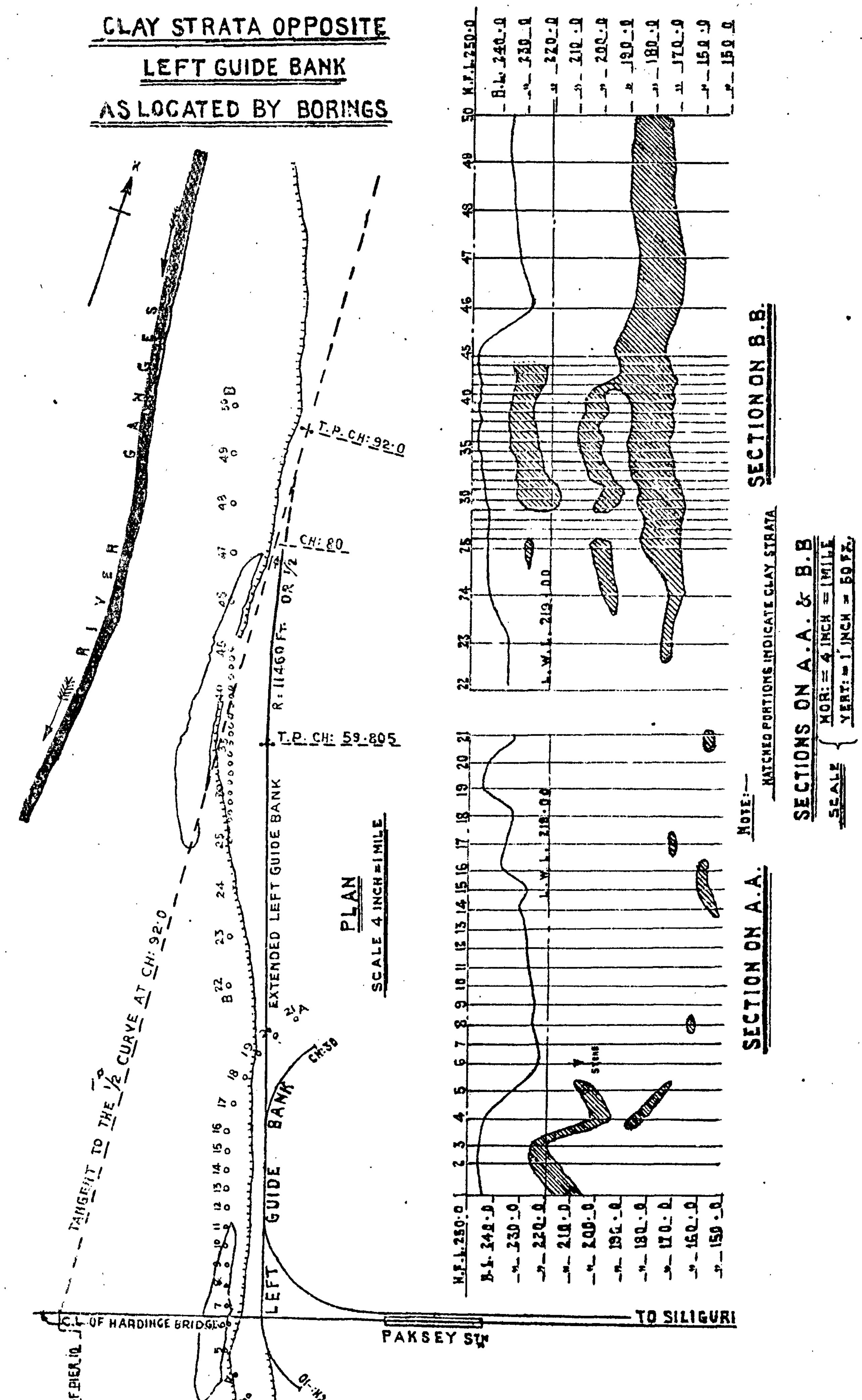


FIG. 12

CHAPTER XV.

AN ALTERNATIVE SCHEME FOR THE PROTECTION OF THE HARDINGE BRIDGE.

Since the construction of the bridge, it has been observed that whichever course the river had taken between Raita and Sara, namely, through the Damukdia Channel or round the Lalpur bend or any course between these two extremes, the river at the bridge always passed through not more than 7 spans, 4 to 5 spans out of the 7 carrying as much as 85% or more of the total discharge of the river. This means that the river not only scours deep in 4 and 5 spans to such an extent as to cause anxiety for the safety of the piers, but also get sufficient space to oscillate from one bank to the other with an amplitude of about 3,000 feet. The problem before us, therefore, is to control the oscillation of the deep channel within less amplitude than it has hitherto assumed and to guide the channel to spread through as many spans of the bridge as possible, if not all.

But the conservancy of the river flowing over alluvial soil is a matter which cannot be dealt with satisfactorily until the problem of the cause and extent of the meandering of the river are fully understood. This branch of science has not developed very far on account of the practical difficulties involved in collecting various hydraulic data for the purpose. No rule of thumb procedure can, therefore, be laid out for devising the means of controlling the river. Each case must be judged on its own merits.

Nevertheless, various schemes have been suggested for the permanent protection of the Hardinge Bridge; but none of them, including those recommended by the Hardinge Bridge Committee and by Sir Robert Gales, deal with the problem of controlling the oscillation of the river mentioned above and of distributing the flow uniformly throughout the length of the bridge. With a view to achieve this end, the following scheme is devised.

It often happens that in the case of a great river, which in places may be anything from one to five miles wide, we find the stream passing through a gorge with a cross-section not a fourth part of that exhibited elsewhere, and yet with no abnormal velocity. At such places a form of channel stability in alluvium exists in the bars thrown down when the river leaves a gorge and spreads out on a plain. The bar is formed with the material released as the velocity diminishes. Also there exists in the course of the river another form of channel stability which is the bell mouth formed above the gorge and the expansion cone below it that complies with the angle adduced by venturi. The flow of the river Brahmaputra below Amingaon and Pandu Hills and of the river Ganges just below (1) Mirganj, (2) the Raita Protection Bank, and (3) the Sara Bank are admirable examples of this form of channel stability vide figs. 13 to 16). Many great rivers furnish such instances. When no natural gorge is found within a reasonable distance from the bridge site the engineer is obliged to copy Nature and to make such a gorge artificially. He undertakes to construct a pair of banks at a certain distance apart which will pass the entire flood discharge of the river with no abnormal conditions of flow arising from them, but with a greatly improved cross-section. Mr. Bell, the original exponent of the guide bank system recommended that the guide banks should be brought closer together at their upstream ends than at the bridge site. He thought that the narrowing of the artificial gorge at its upper end improved the current's chances of flowing straight instead of obliquely through the bridge. Doubtless he was quite right. Some experiments made in this connection have proved the truth of Mr. Bell's reasoning. It is the detailed design of the "artificial gorge" that is described below.

In the design of the pair of gorge walls or guide banks it has to be considered first their shape in plan so that they may not of themselves set up dangerous swirls to their own destruction and detriment and second their cross-section so that they may be proof against erosion which may occur due to the effect of the impingement of current upstream of the banks or of deep scour. It will be necessary to consider the design of such a pair of guide banks from the successive points of view of—

(*a*) their width apart,

(*b*) their length,

(*c*) their form on plan,

(*d*) their form in section,

(*e*) the effect on the depth of the bridge pier foundations,

(*f*) the effect of the narrowing of the river on marginal lands upstream.

From Lacey's theory of flow of rivers in aluvium the regime width of Ganges, which has a maximum discharge of two million cusecs and a silt factor of 0·90, works out to 3,776 feet. If the river is restricted just upstream of the Hardinge Bridge to a width less than that required for the river to flow in regime condition, the stream on emerging through the " gorge " will expand and silt up the river bed below the gorge.

But the question is : Can we venture to narrow the river to such an extent trusting to its providing for itself a sufficient large cross-section to carry its full discharge without undue scour and afflux. The answer is yes, we can do so. Within fifteen miles of the river upstream of the bridge there are places where the width of the river has been less than the regime width.

A careful study of the flow of the river at Raita shows that the shortest distance between the centre line of the Raita Protection Bank and the natural left bank of the river is 3,200 feet (vide fig. 15). Similarly a study of the river at and below Sara before the protection bank was abandoned points out that the shortest distance between the centre line of the protection bank and the natural right bank was 3,250 feet (vide fig. 16). Therefore, without detriment to the natural behaviour of flow, the river can be safely restricted to say 3,300 feet *i.e.*, the shortest distance between the guide banks should be 3,300 feet at high flood level.

The next thing to be considered is at what position above bridge the river is to be contracted so as to give a fairly uniform flow at the bridge. This position should be neither too far from the bridge in which case there is a tendency for the river to split into two channels at the bridge, which is not desirable, nor too close to the bridge, in which case the stream will not expand and flow through the full width of the river at the bridge site. It is not easy to determine the exact length as it is not known in what manner the stream conically expands on emerging through the gorge. The expansion cone depends on the velocity with which the current leaves the gorge and the velocity in turn depends on the direction of the stream flowing above the gorge ; both these factors are unknown. However, the restriction of the river at a distance of 6,000 feet above the bridge, which is about 1/10th longer than the length of the bridge and about 1·75 times the width at the restriction, appears to give the desired result.

Regarding the form, on plan, for the guide bank, it is always desirable to have a pair of guide banks disposed symmetrically at either side of a straight line drawn normal to the centre of the bridge. The reason for this is that the current should in the long run find no such, even small, difference between the two sides of the artificial gorge as might induce them to make greater use of some spans at one side of the bridge rather than of corresponding spans at the other side. This completely fixes the position of the gorge. Now the shape of the entrance to the gorge is to be considered. In order to get the stream line flow the best shape for the entrance appears to be that of a bell mouth. On these considerations a pair of protection banks is designed to meet the oscillations of the river above them, as shown in Plate XIII. It will be seen from the plan that the proposed protection banks do not join with the existing guide banks of the bridge. There is no need to join them. The protection banks have been sited in such a way that the space between the protection bank and the guide bank is insufficient for the river to form a loop between them. Any free eddy that may be created below the gorge on account of the shape of the protection bank at its tail will be quite harmless and will have no ill effect on the training works.

The next thing to be considered — and perhaps the most important thing of all — is the proper section for the protection banks. As the width of the apron depends on the depth of the worst ascertainable scour it is necessary to know to what depth the river can scour at the proposed protection works under severe attack. The most severe attack and the resulting maximum scour would occur only when the stream in a bend is constrained to take the curvature of the bank at the restriction. When this happens the radius of the curvature of the bend will be equal to 4,220 feet, *i.e.*, 3,820 feet (the radius of curvature of the bank say 400 feet allowance for the slope of the potection bank). Mr. Furgueson in his treatise on the recent changes in the Delta of the Ganges has stated that when the surface fall is 3" per mile and less the radius of curvature of the stream is found to be four times the width of the stream. This can be reasonably assumed in our case as the surface fall above the gorge will be flattened consequent to the severe bend ; and the width of the mainstream at the restriction will then be equal to $\frac{4220}{4} = 1{,}055$ feet. From this the extent of maximum scour can be determined by the application of Lacey's theory of flow of rivers in alluvium.

RIVER BRAHMAPUTRA
AT AMINGAON

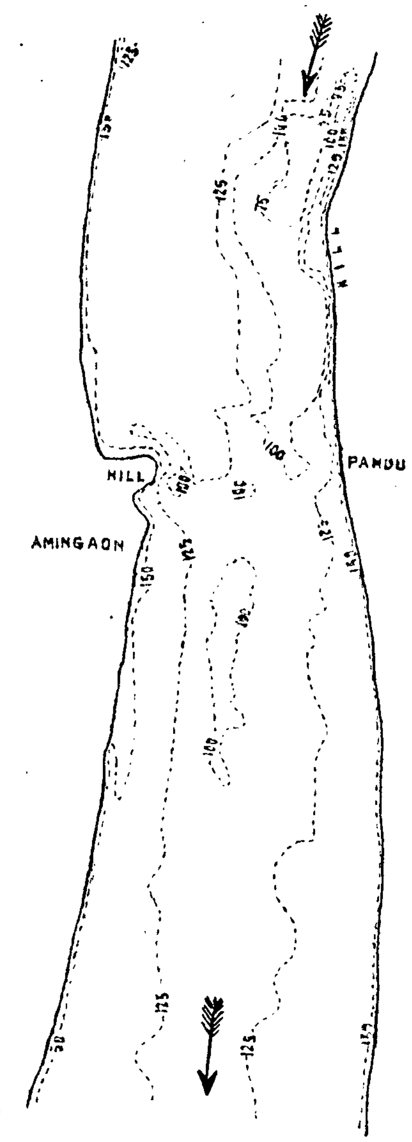


FIG. 13

RIVER GANGES
AT MIRGANJ

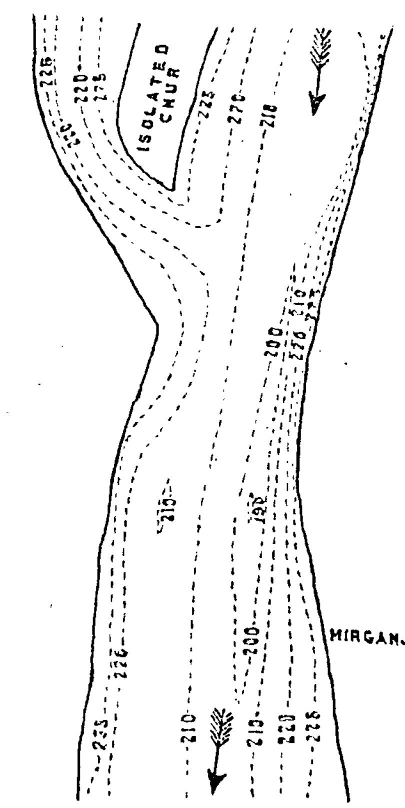


FIG. 14

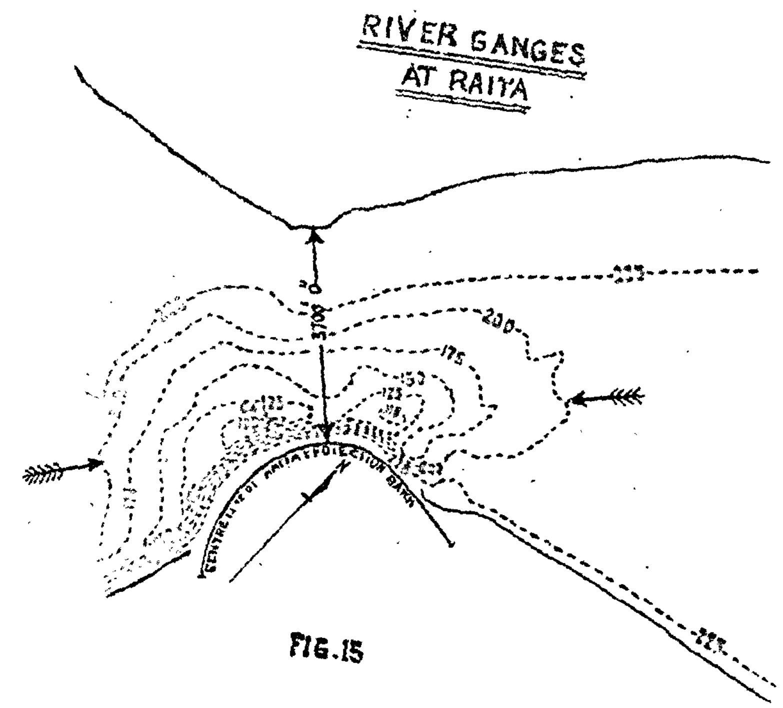

RIVER GANGES
AT RAITA

FIG.15

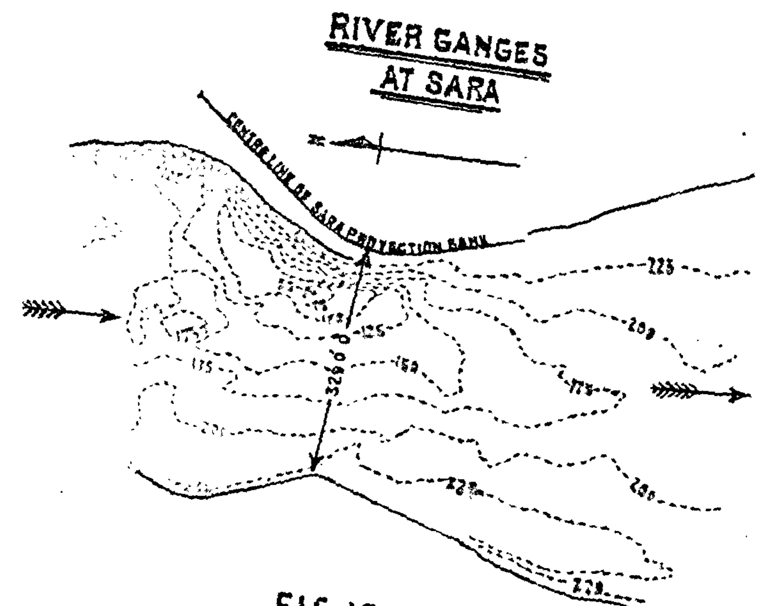

RIVER GANGES
AT SARA
CENTRE LINE OF SARA PROTECTION BANK

FIG 16

Using Lacey's formulae, the regime width (W) for the Ganges (Q=2,000,000 cusecs and f = 0,90) works out to 3,776 feet and the hydraulic mean depth R to 61·1. From these figures the probable scour in a restricted section can be estimated. The formulae used for this purpose is $\frac{R}{R_1} = \left\{\frac{W_1}{W}\right\}^{2/3}$

where R = hydraulic mean depth in regime condition.
R_1 = do do worst condition.
W = width of the stream in regime condition.
W_1 = do do at the worst condition.

$$R_1 = 61{\cdot}1 \times \left\{\frac{3776}{1055}\right\}^{2/3} = 143 \text{ feet.}$$

Assuming a semi-elliptical section the maximum depth works out to 143 × 1·273 = 182 feet approximately; *i.e.*, scour down to R. L. 67 (high flood level being assumed at R. L. 249). If the proposed protection bank is designed on Spring's principles to stand against scour down to R. L. 50 (as was done in the case of Raita Protection Bank) that would meet all contingencies.

The effect of the proposed protection work as regards scour at the bridge site may then be considered. The effective water way at the bridge is 4,230 feet. Hence R_2, the hydraulic mean depth at the bridge, will be equal to $61{\cdot}1 \times \left\{\frac{3776}{4230}\right\}^{2/3} = 56{\cdot}7$ feet and assuming only a moderate bend at the bridge the maximum depth of scour there would be not more than 1·5×56·7 feet, *i.e.*, 85 feet approximately below the high flood level. This means, with the proposed training works there would be no alarming depth of scour round the piers, no deep pot-hole below piers Nos. 2 and 15, and no need to pitch heavily round the piers. Considering the depths of scour round the piers and in the pot-hole below pier No. 2 reached in the year 1938, viz., 150 feet and 220 feet respectively below high flood level the proposed works appear to be a great improvement.

The next and the last thing to be considered is the effect of the proposed training works on marginal lands upstream. It will be seen from the plan that the proposed left protection bank does not protrude far into the river but lies on a line drawn in continuation of the curve of the high bank of the river from Dhapari to Sara. Therefore, the effects of narrowing the river at the position shown in plan will not materially differ from the effects which resulted when the river flowed through a similar width opposite Sara. In fact the effects under the proposed training works would be less on account of the position of the restriction being about two miles below Sara. Also the proposed restriction will in no way increase the embayment round the Lalpur Bight down to Sara—a limit to that embayment appears to have been reached—but it will hasten the cut off through the Damukdia Channel.

The alternative scheme detailed above appears to be the only solution for the troubles at the Hardinge Bridge. It is based entirely on established principles and natural facts, and is devised for the permanent protection of the Hardinge Bridge. It has all the advantages; it defends the bridge approaches and protects the Paksey Colony; it distributes the flow at the bridge and causes no alarming scour round the piers; it controls the river between Raita and Sara. Its protection works will be built on sand—and not on clay—and hence they can be easily maintained and held. Its cost will not be greater than that required for works recommended by the Hardinge Bridge Committee.

This scheme was proposed by the Author in the year 1938 when the Left Guide Bank was being extended. He suggested that before the scheme is approved an experiment should be made on the model at Poona and the results arrived thereat may be compared with those deduced by calculations. No experiments have been made as yet in this connection and it is doubtful whether anything will be done in view of the work already done in extending the Left Guide Bank to 8,000 feet. However, it must be mentioned here that the only time the proposed left protection bank can be constructed is before the river takes a cut-off through the Damukdia Channel.

CHAPTER XVI.

RETIREMENT OF THE MAIN LINE BETWEEN ISHURDI AND ABDULPUR.

In para. (*v*) of their Final Recommendations the Hardinge Bridge Committee recommended that should the Lalpur Bight embayment extend and threaten the Eastern Bengal Railway main line, this should be retired between Ishurdi and Abdulpur on to an alignment 1½ to 2 miles to the east of the present alignment.

During the high floods of 1938, the Lalpur Bight embayment extended by about 1,000 feet and the spill from the Ganges nearly over-topped the main line between Gopalpur and Abdulpur and almost all the bridge in this section were very heavily stressed. Therefore, it was decided to prepare and keep ready the scheme for the retirement of the main line as recommended by the committee as early as possible.

The survey works commenced on March, and was completed in June 1939. Plate XIV shows the location of the retired alignment.

As the proposed alignment has to pass through a number of villages where the acquisition of land is likely to take a long time, it was decided to start the land acquisition proceedings immediately after the flood season of 1939, so that possession of land could be obtained in time immediately after the flood of 1940, should this be found necessary.

The floods of 1939, however, were not very severe and the floods of 1940 brought about some salutary changes in the regime of the river in the vicinity of the bridge. It was, therefore, considered better to keep the Land Acquisition proceedings in abeyance till after the floods of 1941. The estimate is, however, being kept ready so that the work may be taken in hand without delay should the necessity arise. The estimated cost of this work is Rs. 27,00,000.

A general description of the proposed scheme is given below :—

(i) **Formation.**—The width at the formation level will be 35′-6″ with side slopes 2 : 1. The average formation level is at R. L. 253, which is about 3 to 4 feet higher than the formation level of the existing line between Ishurdi and Abdulpur.

(ii) **Bridges.**—There will be 14 spans of 40 feet and 15 spans of 20 feet girder bridges providing a total waterway of 865 R. ft. All the bridges will have open foundations. A special type of flooring has been designed to reduce scouring action of the flow downstream of the bridges, as illustrated in fig. 17. It will be seen from the figure that a " lip wall " is palced at the end of floor on the downstream side and its effect is to reverse the current along the bed for some distance downstream by introducing a long positive vortex. This device would effect economy in reducing the width of the floor, would result in the minimum scour, and would remove much anxiety as to the safety of the wing walls.

Girders of loading standard M. L. of 1926 have been provided for.

(iii) **Permanent-way.**—New 90 lbs. F. B. B. S. R. rails will be linked with new fittings on new wooden sleepers (N +3). Rail anchors at the rate of 4 pairs per rail length will be provided.

(iv) **Ballast.**—During the first two monsoons after construction, the track will be maintained with cinder ballast after which stone ballast at the rate of 30 cubic feet per foot run of double track will be provided.

(v) **Station and offices.**—The new Gopalpur Station will be almost midway between Ishurdi and Abdulpur. Earth for the station yard will be obtained by excavating two tanks. The earth will be carried in tip wagons.

The station building will have pucca plinth, wall and cast iron sheet roofing with an attached third class waiting shed and an Indian ladies waiting-room.

SECTION OF THE BRIDGE FLOORING

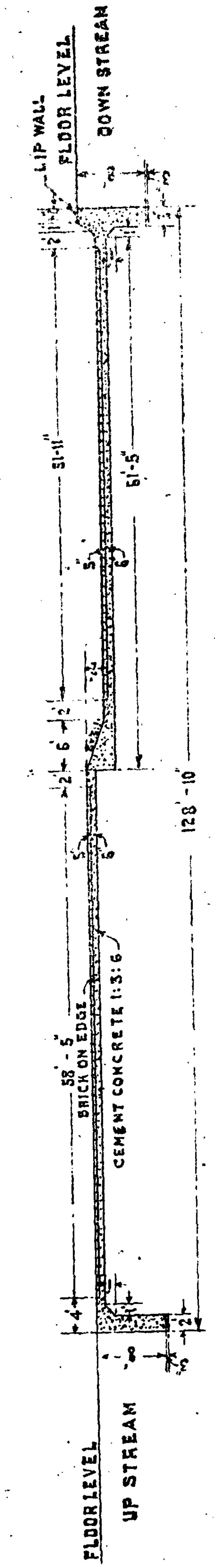


FIG 17.

The existing goods shed and parcel godown at Gopalpur will be shifted to the new station.

There will be a foot overbridge connecting the two high level passenger platforms. The platform walls will be made of cement concrete blocks.

A layer of moorum 6″ thick will be laid on the platforms.

(vi) **Residential Buildings.**—The staff quarters will be built of mat and thatch because they will be on filled up ground.

(vii) **Signalling and Interlocking.**—These arrangements will be controlled from two cabins at the two ends of the yard.

The approval of the Bengal Government to the proposed head-ways and waterways has not been obtained yet. It may be necessary to revise the estimate if any alteration is necessary in the sizes of the bridges to meet the Bengal Government's approval.

CHAPTER XVII.

FLOOD SEASON REPORTS AND WORKS DONE AFTER THE FLOODS DURING THE YEARS 1938 to 1940.

The floods in the Ganges during 1938 was remarkable from the fact that the river level started rising very quickly from the beginning of June and that although the maximum level reached at the Hardinge Bridge (namely R. L. 247·1) was about four inches lower than the highest level recorded in the year 1936, the flood levels reached at several places upstream of the bridge, viz., at Raita, Rajshahi and Lalgola Ghat, were higher than those recorded in 1936. No convincing explanation could be given for the abnormal rise in the river level between Lalgola Ghat and Raita.

During the high flood the river straightened its course above Raita and attacked the upstream portion of the protection bank with full force ; the whole river appeared to have concentrated there. Due to this change, the river level at Raita headed up to such an extent that the difference in water levels between chainage 45 of the Raita Protection Bank and the Hardinge Bridge gradually increased, until it became as much as 7·4 feet, which was very much above normal. This resulted in a decrease of slope above the head of the protection bank and was responsible for excessive bed scour at and above the head. A deep " gullet " was formed along the upstream half of the protection bank where a sounding of 195 feet below low water level was recorded opposite chainage 32 and only 500 feet away from the bank. The same depth was also recorded at a distance of about 700 feet from the bank opposite chainage 36. This bank was protected against scour down to R. L. 50, *i.e.*, about 170 feet below low water level. If the " gullet " opposite chainage 32 had moved towards the protection bank by about 30 feet only, the slope of the bank would have been in danger. The river bed, however, silted up slightly on the fall of flood and the danger was averted.

During the flood there was no marked improvement but at the same time there was no deterioration in the condition of flow through the Damukdia Channel. But there were clear indications pointing towards its development in the near future. Had the mainstream at Raita straightened and pressed against the protection bank about 400 feet further downstream before the flood subsided in all probability the Damukdia Channel would have opened during the flood season.

The left bank between Bangalpara and Dhapari was completely submerged and heavily eroded during the flood. The spill water passing over the Lalpur Bight inundated the country before flowing through the main line culverts and the water level on the upstream side of the main line between Gopalpur and Abdulpur reached the formation level.

At Sara heavy erosion of clay had taken place during the flood opposite chainage 10 to 50 of the abandoned protection bank, the maximum erosion being 400 feet opposite chainage 16.

At the Right Guide Bank the river flowed in a deep " gullet " along the bank, the deepest parts of the bed being at R. L. 83 (*i.e.*, 137 feet below low water level) opposite chainages 26 and 18 at about 500 feet from the bank. Below span No. 2 of the bridge and opposite chainages minus 8 of the guide bank, the river bed scoured to R. L. 29, *i.e.*, 190 feet below low water level during the fall of flood. This level is about 30 feet below the bottom of the foundation of pier No. 2.

At the bridge the river continued to flow mainly through spans Nos. 2 to 6 which carried about 90% of the total discharge of the river; spans 2 and 3, however, took nearly 57% of the total flow. A sounding of 123 feet below low water level was recorded at the centre of span No. 3 on 20th September 1938. That was the maximum depth recorded up-to-date at the centre of a span of the bridge. Piers Nos. 3 and 5 of the bridge were severely attacked and some emergency pitching had to be done from barges round the latter pier during the flood.

During the two previous working seasons the protection bank at Raita had been reinforced to stand against scour down to R. L. 50 between the head and chainage 16. Due to the straightening of the river above Raita during the floods, the portion of the bank between chainage 16 and chainage 10 became exposed to heavy attack by the current. This portion of the protection bank was, therefore, strengthened against scour down to R. L. 50. In addition the protection bank was realigned between chainage 26·33 and chainage 40 and extended to chainage 45.

1939 Flood season and works done after the flood.—The flood in the Ganges in 1939 was normal and less severe than that of the previous year since 1933. Durineg the flood season none of the protection works suffered any damage and no great anxiety was experienced on account of excessive scour round the piers.

The left bank of the river was eroded by an average width of 350 feet for two miles at Dadpur and by an average width of 175 feet for two miles at Lalpur Bight. At Sara, the clay opposite chainage 7 to chainage 17 of the abandoned protection bank was eroded, the maximum extent of erosion being about 190 feet at chainage 10. The right bank of the Damukdia Channel was also eroded by an average width of 400 feet to a distance of about $1\frac{1}{2}$ miles above the upstream end of the Damukdia Protection Bank. Between chainage 20 of the Damukdia Protection Bank and about a quarter of a mile upstream of the Jackson's Spur a vast chur was formed adjoining the protection bank, the left edge of the chur being on a line normal to the bridge at the centre of span No. 1. In the vicinity of the Raita Protection Bank and of the upstream end of the Right Guide Bank the river bed silted up by about 50 feet. At the bridge the river continued to flow mainly through spans Nos. 2 to 6 which carried about 90% of the total discharge of the river. These were the main effects of the flood during the year 1939.

At Raita, it was found necessary to extend the protection bank from chainage 45 to chainage 48 as the embayment formed above the head of the protection bank during the floods of 1938 was showing signs of development during the floods of 1939.

At Damukdia, it was found necessary to extend the protection bank from chainage 48 to chainage 51·5 in order to prevent the bank being outflanked by the river during the next flood season.

1940 Flood season and work done after the floods.—The flood in the Ganges during 1940 was not very severe. The following are the most noticeable effects of the flood on the regime of the river upstream of the Hardinge Bridge and on the training works :—

(*a*) Heavy erosion along the left bank of the river between Markoti and Dadpur (by an average width of 500 feet).

(*b*) Formation of a vast chur in continuation of the left bank of the river opposite the Raita Protection Bank protruding far into the river opposite chainage 34 of the bank with a change in the current direction—in the form of a subsidiary channel flowing past the upstream end of the protection bank and consequent deep scour along the bed of the river—in this reach.

(*c*) Comparatively less erosion along the left bank of the river in the Lalpur Bight between Bangalpara and Dhapari than in previous years.

(*d*) Erosion of clay at Sara (opposite chainage 6 to chainage 20 of the abandoned protection bank, the maximum extent of erosion being about 75 feet at chainage 7). The extent of erosion after the bank was abandoned is shown in fig. 18.

(*e*) Heavy erosion along the right bank of the Damukdia Channel immediately upstream of the Damukdia Protection Bank (by an average width of 450 feet for a distance of $1\frac{1}{2}$ miles above the upstream end of the protection bank) with a deepening of the channel, throughout its length, and a gradual improvement of the percentage discharge through this channel.

(*f*) Considerable silting up of the bed of the river opposite the Right Guide Bank during the fall of floods (for the first time since the year 1934) and movement of the right bank chur, which was formed during the fall of 1939 floods, further downstream resulting in a more or less even distribution of the flow of the river through spans Nos. 2 to 6.

Early in the flood season, the erosion along the right bank of the Damukdia Channel upstream of the Damukdia Protection Bank was so heavy that at one time it was thought that the Protection Bank might be outflanked. As an emergency measure stone had to be pitched on the ground level for a length of 300 feet in conflnuation of the apron at chainage 51·5 of the protection bank in order to arrest further erosion taking place immediately upstream. After the floods subsided, this protection bank was regularly extended from chainage 51·5 to chainge 60.

During August and September, a portion of the apron between chainage 51·5 and chainage 25 of the Damukdia Protection Bank launched heavily. When the apron between chainages 43 and 42 launched, the river attacked the bank and a part of the slope stone slipped into the river. This occurred on two occasions once on 20th August 1940 and again on 4th September 1940. The damages were repaired at once. Soundings taken immediately after the slips occurred, revealed no deep scour hole at the site, the maximum depth at the toe of slope being 69 feet below low water level at a distance of 400 feet from the bank. Prickings taken in November 1940 between chainage 30 and 51·5 revealed that the average slope taken by the launched apron varied from 2·5 : 1 to a little flatter than 4: 1 between chainage 31 and 44 and again from 1·5 : 1 to 2 : 1 between chainage 45 and 51·5.

It is necessary to mention here that if the apron after launching takes a slope very much flatter than 2 : 1, the protection bank will not be protected against scour down to 160 feet below low water level as originally designed. The maximum scour recorded to date in front of this protection bank was only 69 feet below low water level and with this scour at a distance of 400 feet from the bank, the face of the bank at chainage 42 and 43 slipped on two occasions, vide fig. 19. No convincing explanation was found for this strange occurrence. It was thought at first that the apron at chainage 42 and 43 launched to a flatter slope than 2 : 1 due to the fineness of sand and silt existing there. This was subsequently proved wrong by borings, which revealed no difference between the quality of soils beneath the apron at these chainages and at other chainages where the apron launched to a slope steeper than 2 : 1. The flatter slope taken by the apron at chainage 42 and chainage 43 appears to be only due to the peculiar conditions of flow existing at the time.

Whatever may be the actual cause of this, the fact, that the existing width of the apron between chainage 30 and 44 wasinadequate to protect the bank under the condition of flow and scour observed during the floods, cannot be doubted. With the gradual improvement of flow through the Damukdia Channel, it was apprehended that during the next flood season similar conditions of flow might occur and the river bed would deepen further in this reach. So, it was found imperative to redesign the apron between chainage 30 and chainage 44 for protection against scour down to 120 feet below low water level on the assumption that the apron would launch at an inclination of 3 : 1 instead of 2 : 1. This was done by widening the apron to the requisite width by pitching stone through grids in water.

Between chainage 0 and chainage 48 of the Damukdia Protection Bank the first 64 feet width of the apron was laid by 3′-6″ thick on the horizontal. This was decidedly weak, because when this portion of the apron launches the thickness of stone covering on the developed slope would be much less than the minimum 3′-4″ allowed by Sir Francis Spring. Therefore, it was found necessary to reinforce the inner belt of the apron by laying a two feet thick layer of stone on top of the existing apron.

During the fall of floods, a subsidiary channel formed round an island chur upstream of the Raita Protection Bank and it flowed past the head of the bank. In the event of the mainstream finding its course through this subsidiary channel during the flood season there would have been a severe attack on the upstream end of the protection bank with the danger of this bank being outflanked by the river. So, as a preventive measure against future attack, the protection bank was extended from chainage 48 to chainage 51.

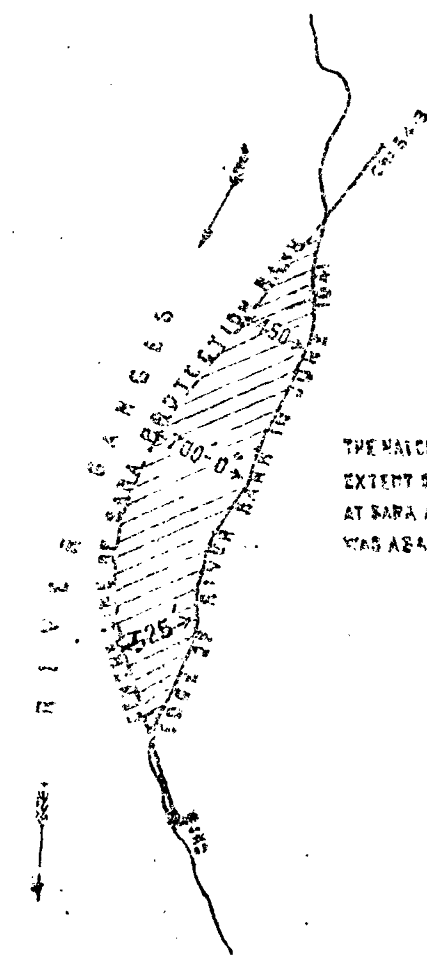
During this flood season the system of patrolling and of taking soundings was introduced in order to exercise constant vigilance at the Right Guide Bank, the Damukdia Protection Bank, the Raita Protection Bank and on the river bed round the piers. Complete arrangements were also kept ready for the prompt introduction of ferry services, both for passengers and goods, should the Hardinge Bridge become unsafe for traffic. These arrangements were made year after year since 1934 on the strength of the committee's recommendation that the protection banks should be watched carefully during the flood season until all the danger is past. The danger to the bridge was considered to exist so long as the " gullet " in front of the Right Guide Bank and the " Pot-hole " downstream of the bridge continued to persist. In the meantime the deep depressions which existed behind the Right Guide Bank were filled up. This work was spread over a period of six years and carried out by the labour engaged for any emergency that might arise during the floods.

During the fall of floods, the regime of the river in the vicinity of the Hardinge Bridge considerably improved. The Damukdia Channel carried about one-third of the

EXTENT OF EROSION

AT SARA

SCALE 4 INCH = 1 MILE.



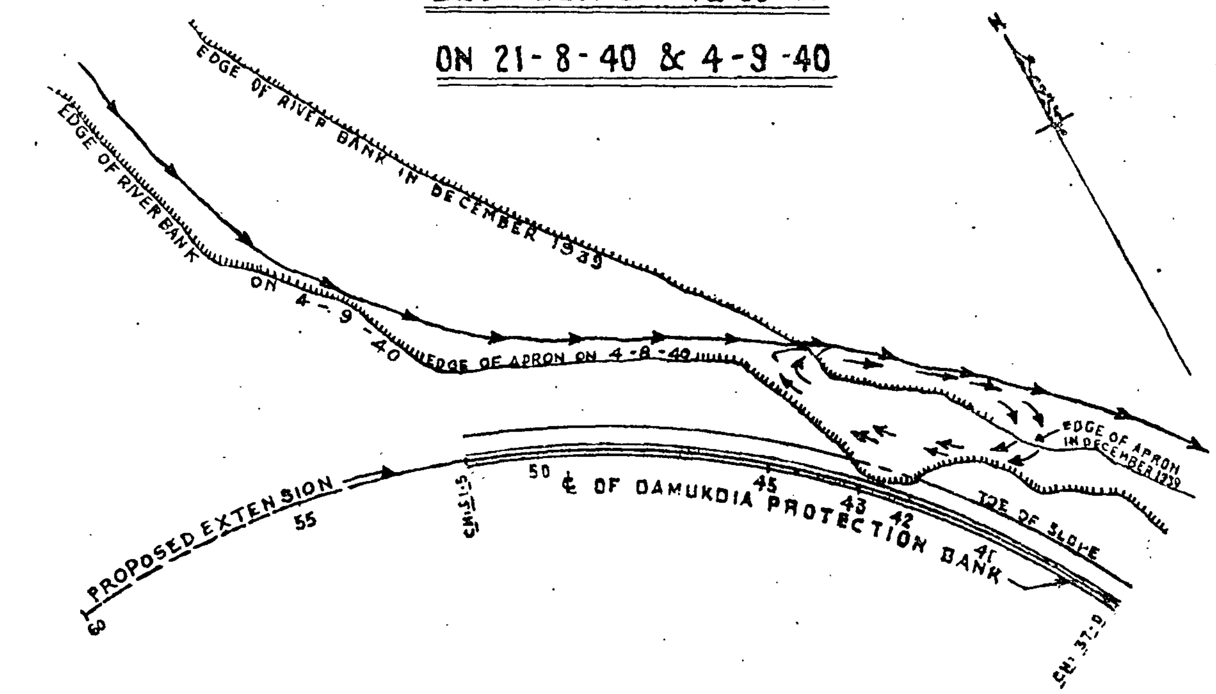
THE HATCHED PORTION INDICATES EXTENT OF EROSION OF THE LEFT BANK AT SARA AFTER THE PROTECTION BANK WAS ABANDONED.

FIG. 18

SLIPS AT DAMUKDIA PROTECTION BANK

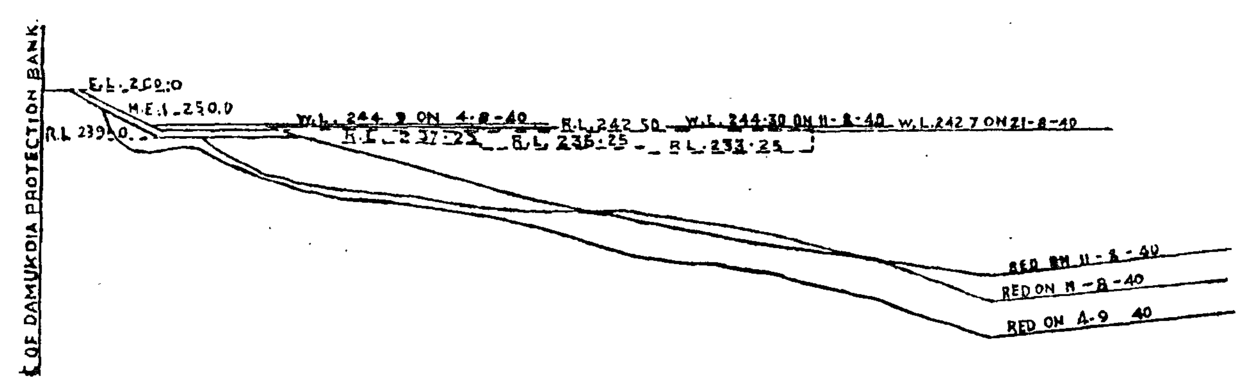
BETWEEN CH: 42 & 43

ON 21-8-40 & 4-9-40



PLAN

SCALE 1INCH = 400FT.



SECTION AT CH:43

SCALE 1INCH = 80 FT.

FIG. 19.

40 b

total discharge of the river. The combined flow of the two streams emerging from Sara and Damukdia Channel flowed down in a direction almost normal to the bridge and spreading out its course passed down the bridge through spans Nos. 2 to 6. For the first time since 1934, the " gullet " and the " pot-hole " opposite the Right Guide Bank had silted up by more than 50 feet. At the bridge, the stream, instead of running deep through two or three spans was more uniformly distributed through spans Nos. 2 to 6.

All these factors indicated that there would be no more severe attack on the Right Guide Bank; that the river would very likely move towards the left bank during the next few years and that the bridge would be out of danger. Accordingly, the Railway Administration decided to discontinue the " Traffic Emergency Arrangements" and to curtail the engineering emergency arrangements from the next flood season.

CHAPTER XVIII.

DESIGN OF A GUIDE BANK APRON.

A falling apron is a covering of stone laid on a river embankment to protect it from the erosive action of the current. Briefly, the protective covering consists of stone, usually "one man" stone weighing 60 to 120 lbs. laid during low water on the slope of the bank and in a horizontal "apron" on sand or silt deposited by the river. The stone on the slope is intended to remain in position but the apron is intended to launch or subside, when attacked by the river current, to form a continuation below water level, of the upper slope and so provide a complete protection against erosive action from top to toe.

Sir Francis Spring in his Technical Paper No. 153 on "River Training and Control" on the guide bank system has left on record a most valuable contribution to this question. His observations were worked out after very considerable experience. His note is full of warnings, his principles are sound and there is absolutely no reason why his methods and advice should not be followed almost blindfold; always provided, of course, that his ideas are thoroughly understood and also that there are methods ascertaining the deepest scour that is probable.

Nevertheless, the apron designed by Sir Francis Spring has a weak point. The weakness lies not in the principles of design but in the method of distribution of stone in the apron. This requires revision.

Revision of Sir Francis Spring's design of Guide Bank Aprons.—A copy of Spring's recommended dimensions of Guide Bank Aprons, is shown in Fig. 20.

SPRING'S DIMENSIONS OF GUIDE BANK APRONS

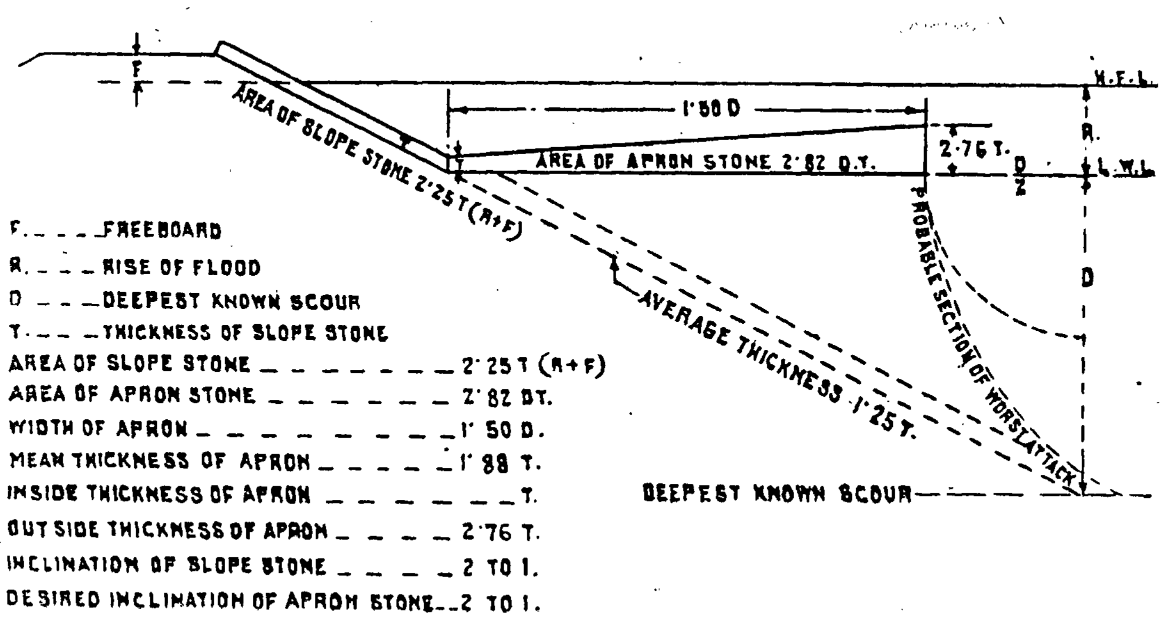


FIG 20

This design is based on the assumption that the apron launches itself in such a manner that, commencing from the outer edge of the apron and working back to the actual toe of built-up guide bank, the "probable section of worst attack" is such that the point of deepest scour is on a line drawn at a slope of 1/2 to 1 from the outer limit of the apron (throughout its progress of launching) and that every section of launched apron assumes a 2 to 1 slope down to the point of deepest scour.

If this assumption is correct then it becomes necessary to ensure that a sufficient quantity of stone is laid in every section of the apron in order that this stone, when it is launched, should protect the 2 to 1 sub-surface slope of river bank (which it will cover) from being eroded by the fastest current running past it. The thickness of stone which is adequate for preventing the maximum velocity to be effective in washing out the sand from amongst the interstices of the loose stone varies according as the sand is very coarse, coarse, medium,

fine, or very fine, and also according to the maximum velocity of current which is likely to flow past the guide bank. On the Ganges at the Hardinge Bridge reach this thickness of stone has been fixed at 3′-6″, and this is represented by the letter T in Spring's diagram.

Spring, in his treatise, has recommended that in calculating the total quantity of stone requisite for laying a complete apron an additional thickness of 0·25 T. should be provided for in the launched apron in order to allow for irregular launching which might result in the stone launching itself in places and going thin in other places. He considered that this additional provision of 0·25 T in the thickness of the launched apron would ensure that the thickness, after irregular launching, would be adequate to cover the sub-surface sand slope with *at least* as good a layer of stone as was laid on the over-water slope, down to lowest depth of scour. The quantity of stone per foot of apron calculated on this basis, and indicated in his diagram, comes to 2·82 D. T. cubic feet and no revision of this figure appears to be necessary.

Regarding the method of distribution of the stone in the laid apron it will be seen from Spring's diagram that he has commenced his apron at the guide bank end with a thickness of T and has increased this thickness uniformly to 2·76 T at the outer edge so that the mean thickness, viz., $\frac{T + 2\cdot76\,T}{2} = 1\cdot88\,T$ is correct for the purpose of obtaining the requisite area of stone ($1\cdot8\,T \times 1\cdot5\,D$), viz., 2·82 D. T. which the 2 to 1 protected slope should receive for a mean thickness of 1·25 T.

This method of distribution of stone in the laid apron appears to be incorrect and needs to be revised. The reason necessitating this revision becomes clear when one is led to consider only the inner half of the apron as recommended by Spring. The stone contained in this half of the apron is required to protect half the total length of 2 to 1 slope of sub-surface river bank down to lowest depth of scour, and therefore the area of stone required is half that calculated for the entire apron, viz., $1/2 \times 2\cdot82$ D. T. Therefore, the mean thickness of stone in this half of the apron should be $\frac{\frac{1}{2} \times 2\cdot82\,D.\,T.}{\frac{1}{2} \times 1\cdot5\,D}$ *i.e.*, $= 1\cdot88$ T. But actually the mean thickness in Spring's diagram is $\frac{T + 1\cdot88\,T}{2}$ *i.e.*, $= 1\cdot44$ T. *and hence his apron is too thin at the inner half of its total width.*

The revised method of distribution of stone in the laid apron now proposed is indicated in fig. 21:—

REVISED DIMENSIONS OF GUIDE BANK APRONS

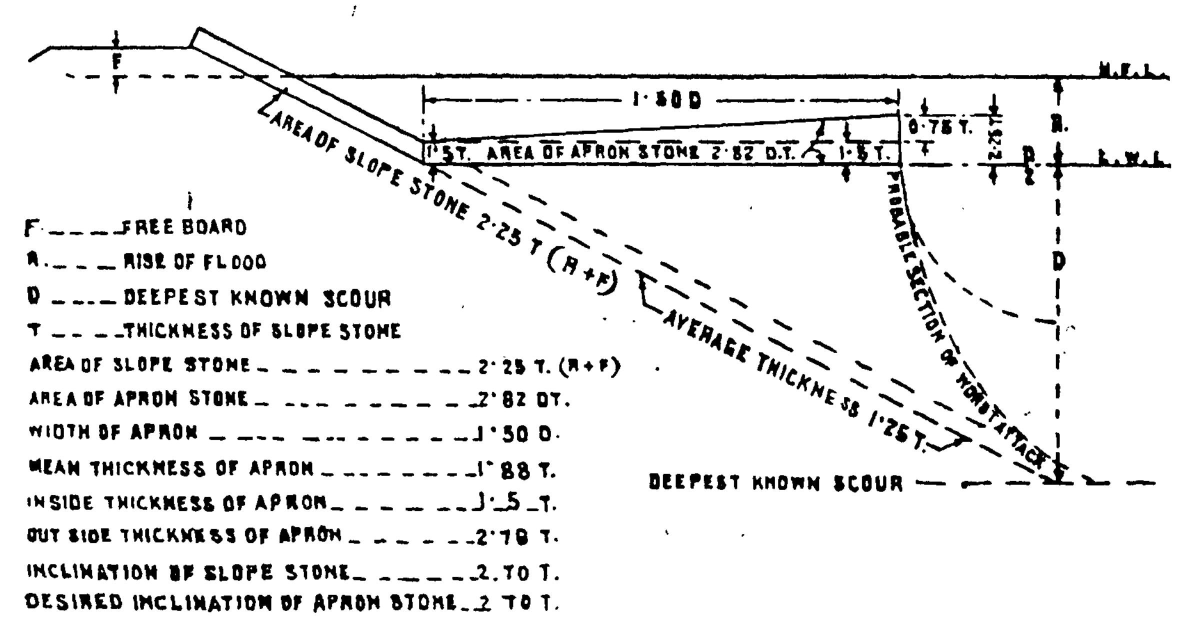


FIG 21

This method of distribution has been arrived at by, in the first instance, disregarding Spring's recommendation of providing an additional thickness of stone in the launched apron of 0·25 T to allow for irregular launching, and by calculating the area of stone required for protecting a to 2 to 1 slope down to lowest depth of scour with a thickness of stone equivalent to T. This area works out to 2·25 D. T. and it is now proposed, in order to ensure that every section of launched apron should, in theory, be covered with a thickness of stone equal to T, that the thickness of stone in the laid apron should be uniform $\frac{2{\cdot}25\text{ D. T.}}{1{\cdot}5\text{ D.}}$ viz., 1·5 T throughtout its width.

Now, in order to provide for irregular launching of stone in the laid apron, and if Spring's additional allowance of 25 per cent is adhered to, it is necessary to increase the area of apron stone arrived in the previous paragraph, viz., 2·25 D. T. by 25 per cent, which comes to 0·57 D. T. and brings the total area to 2·82 D. T. as in Spring's design.

But the method of distribution of this aditional area of stone of 0·57 D. T. requires to be considered and, in consideration of the fact that this quantity of stone is provided for irregularity in launching, and that this irregularity will vary in proportion to the depth to which each section of the apron is required to launch, it is necessary that this additional stone be distributed so as to provide uniformly increasing thickness from inner to outer edge of the entire width of apron.

This method is indicated on the diagram and, as the area of the triangular section of this additional stone is 0·57 D. T. and the width of the apron is 1·5 D the mean thickness of stone works out to $\frac{{\cdot}57\text{ D T}}{1{\cdot}5\text{ D}} = 0{\cdot}375$ T and gives an additional thickness to the apron of $2 \times 0{\cdot}375$ T $= 0{\cdot}75$ T at its outer edge.

The final result of this proposal is that all aprons on the Ganges at the Hardinge Bridge reach, irrespective of the lowest depth of scour for which they may have to be designed, should be laid so that the thickness increases uniformly from 1·5 T (viz., 5·25 feet at the inner edge to 1·5 T + 0·75 T (viz., 7·875 feet) at the outer edge.

Application of Principles of Design of Apron.—In order to understand how the apron works on launching, it is necessary to know clearly the principles on which the apron is designed and they are vividly described in the "River Training and Control" by Spring. Herein, an attempt is made to explain the application of the theories in an effort to prevent in future any disaster to a guide bank. Fig. 22 is a sketch reproduced from Sir Francis Spring's recommended dimensions of Guide Bank Apron. In place of the letters in the sketch figures are substituted to make it more self-explanatory.

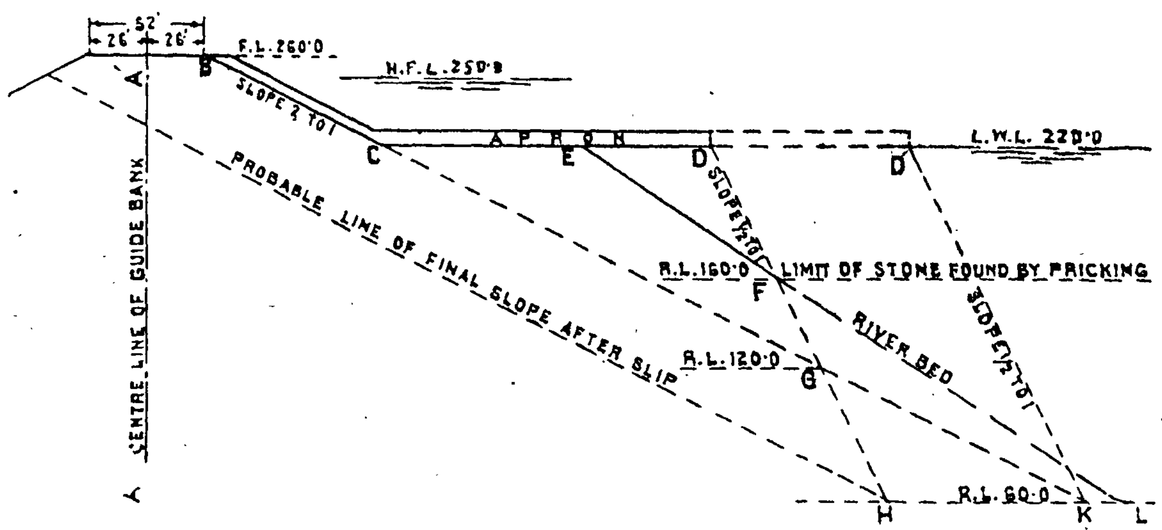


FIG. 22

A guide bank with centre line AA¹ and top width = 52 feet (½ width = 26 feet) is protected by a stone apron laid at a low water level (R. L. 220) for a scour of 100 feet below low water level, *i.e.*, a bed level of R. L. 120.

In this case the apron C D will be $\frac{3 \times 100\text{ feet}}{2} = 150$ feet long. When this apron launches itself it will eventually protect the river bank at a slope of 2 : 1 below water levels from C to G and there will eventually be one protected slope from B to G.

This slope has an assumed value of 2 : 1. Although the slope which stone assumed when undermined has been found to vary from 1·5 : 1 to 3 : 1 or flater at a few places, in most cases probings have proved to show the stone dropped more or less to a slope approximating to 2 : 1.

Spring also assumes that the end of the apron will fall on a line at an angle of $\frac{\text{D}}{2}$: D or ½ : 1, *i.e.*, from D to G on the sketch. All the pricking results have proved that this is safe and fair assumption.

From these data it may be reasonably assumed—

(*a*) That if the apron is partially launched, *i.e.*, to R. L. 160 or F in the sketch, the point F will be on the line D G and the river slope will be F E and this will leave the portion C E of the apron unlaunched.

(*b*) That if deeper scour than 100 feet below low water level occurs the apron will launch itself to finish up at a point on D G produced and assuming a scour of 160 feet below low water level *i.e.*, a bed level, of 60, this point will be H.

From assumption (*b*) above the river bed should now assume a 2 : 1 slope from H; if this line is drawn, it intersects the bank. Therefore, the bank is unsafe and must slip.

Now if the apron had been designed for 160 feet of scour below low water level it would have been laid from C to D a distance of $\frac{3 \times 160}{2} = 240$ feet.

From Spring's plan it may be found that this apron would launch at ½,1 down to R. L. 60 at K and 2 : 1 slope from K would give a protected bank from K to B *without any slip or damage to the guide bank.*

What is to be done then when it is found that the maximum probable scour will be 160 feet and the original apron designed for 100 feet of scour is partially launched?

There are two alternatives—

(*a*) To pile more stone on the launched part of the apron to meet this scour.

(The sketch will show that this would not be the solution to the problem. There is a grave doubt that the stone would do what was required of it and any doubt should not be allowed).

(*b*) To lay stone beyond the toe of the launched apron in deep water so that this stone will act as if it had originally been placed as an extension of the apron when laid at low water level. This appears to be the correct and the only solution.

The way to tackle this problem is :—

(*i*) Prickings and soundings must be taken carefully immediately the flood season is over. These must be plotted and the deepest scour probable must be ascertained and the previous figures revised if necessary.

(*ii*) On these pricking results continue the 2 : 1 slope of the bank above low water level downwards to the ordinate showing the maximum possible scour.

(*iii*) From this point draw a line up to low water level at an inclination of ½ to 1.

(*iv*) Pitching must be done between the toe of the launched apron and the point where this ½ : 1 slope cuts the river bed.

Amount of stone to be laid is then to be determined. Spring says 1·25 times the thickness of the slope stone above low water level will be required in a normal smooth running river to protect the bank below low water level but that for turbulent and fast water this figure should be increased to 1·5

For the Ganges which is liable to sudden and great alterations of depth, this figure of 1·5 must be used and the thickness of slope stone above low water level must be accepted as 3′-6″.

This gives a thickness of launched apron of 5′-3″.

The amount of extra stone required per foot run of guide bank over the area now to be covered will be $\sqrt{5} \times (160-100) \times 5'\text{-}3'' = 704$ cubic ft. per foot run.

This quantity must be distributed between the toe of the launched apron found by pricking and the point where the ½ to 1 line meets and bed of the river.

NOTE.—Should this quantity give an average thickness of less than 6 feet then the quantity required should be arrived at by multiplying the distance to be covered by 6, as it is considered that less than 6 feet thick will be inadequate to ensure the minimum thickness over the area pitched especially when the pitching is to be done in deep water.

It must be laid before any silt is deposited on the apron. If any considerable quantity of silt has been deposited on the apron then the original apron should be ignored where it has launched below low water level and a new apron laid in extension of the unlaunched portion if any.

Of course if the river bed found by prickings already goes down to the maximum depth expected the whole slope must be pitched irrespective of where the ½ : 1 line cuts the bed, *i.e.*, the slope F to L in the fig. 22 must, be pitched 5′-3″ thick. Likewise should the bed below F slope down to a point outside the ½ to 1 line (vide fig. 23) then it is advisable to carry pitching beyond the ½ to 1 line down to the bottom of the river to ensure that the pitching thrown in is not rolling away.

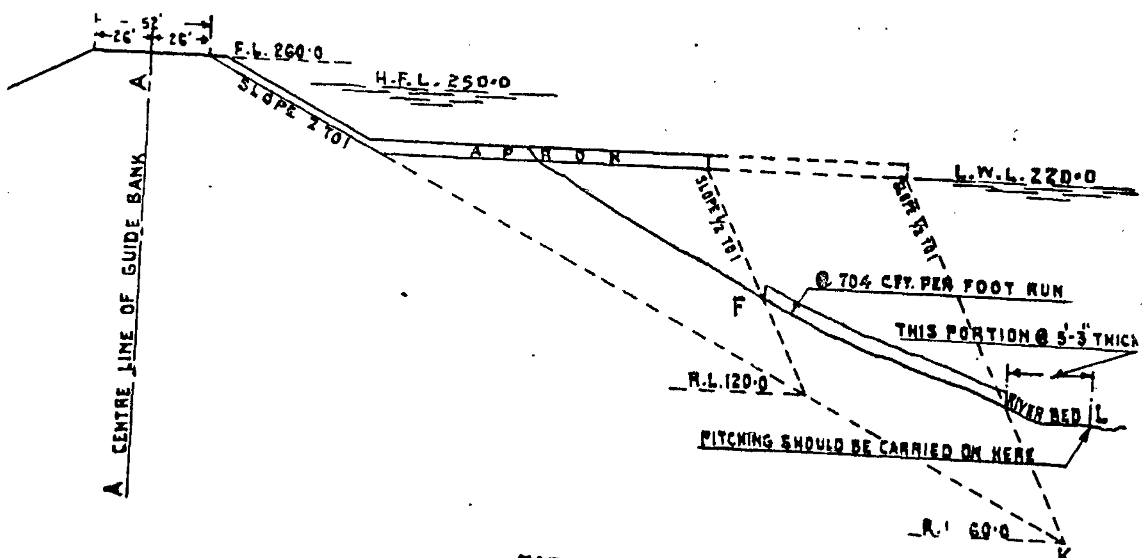


FIG. 23.

Scour opposite the Guide Bank Apron.

It is most important that the maximum probable depth of scour should be ascertained; and that it should not be underestimated lest the apron should not suffice in breadth to cover the exposed sand of a scour attack, nor overestimated, lest money should be wasted. It is the duty of the engineer designer of training works to endeavour to find out what is the deepest part of the river within, say, ten miles of the site of the work. For this purpose there should be proper means to ascertain bed scour *during high floods*, when the river deepens to its maximum. Soundings taken by line and lead after the flood subsided do not generally give the maximum scour as the river silts up to a certain extent when the flood subsides. The Echo sounding Gear is an invaluable instrument to ascertain the deepest scour in the vicinity of a structure. Care, however, must be taken to discriminate between scour due to eddy, smooth flow and turbulent flow.

Before proceeding further it is well to have a clear understanding as to the nature and cause of the different kinds of flow that may usually be found in the vicinity of a structure.

As eddies are of different sizes and have names which are used in different senses by different people a rough differentiation is suggested below :—

(a) **Whirl pool.**—An eddy of large diameter and high velocity such as caused by the main stream of the Ganges running approximately at right

angles across the end of a spur, which may be above water, submerged or partly submerged. These whirlpools have been noticed at Sara as 800 feet in diameter and 170 feet in depth below low water level. There is no reason why they should not be larger and deeper.

(b) **Eddy.**—An eddy is the term applied to water in circulatory motion, it may be of large size and slow motion or of smaller size but swifter motion. The capacity of eddies for damage depends on their size and intensity and on their position in relation to works. It will be sufficient to consider only large eddies of considerable intensity and to recognize two classes as (1) " confined " and (2) " free " . A " confined " eddy is one confined in contact with a work, such as a guide bank, by outside forces, and such eddies are very destructive. A " free " eddy is one which will be free to move away from immediate contact with a work such as a guide bank which will otherwise hinder its developement.

The eddy at Sara, which had eventually become a whirlpool might be cited as an example of a confined eddy. The eddy had been caused by the mainstream or in earlier stages, by the fringe of the mainstream, issuing from an embayment above the upstream end of the original Sara Protection Bank and thereby crossing the end in such a manner as to cause the formation of an eddy, in the acute angle between the centre line of the protection bank and the direction taken by the current. That eddy, which formed over the shelf of resistant Sara clay, was naturally not very deep, but it soon showed its character by cutting through and destroying the upstream end of the protection bank, of which it left remaining a spur at ground level and beyond that the sunken spur, which was the original end of the protection bank. The eddy was at first held in position and pressed into the protection bank by the part of the mainstream which was trying to run straight down its old channel, but the whole mainstream was engaged in cutting its future channel in the direction of the upper part of the Damukdia Protection Bank. To that it was urged by the increase in the depth of embayment, by the deflexion caused by the sunken spur, and by the thrust of the eddy, which, with its back to the protection bank and increasing in size, was adding the lateral movement. Later, as soon as the lateral movement of the main channel had released the eddy, it moved further out and by the time its diameter had increased to 800 feet and the depression at the centre had become noticeable there was no reason to doubt that it was extending downwards towards the river bed. By that time it had become a free eddy and as such could do no danger.

The development of a free eddy, having its origin at a Curzon head, may be described in the following way. As soon as the mainstream attempts to leave the head on a tangent, there is a reduction in pressure and a lowering of the surface level between the guide bank and the mainstream, which induces a return current running upstream along the guide bank. That current, at its origin a purely surface current, restores the pressure and releases to some extent the tension or tendency to cling to the guide bank and allows the mainstream to run a little further out. The water of the return current, being caught and carried down by the mainstream, is the immediate origin of the eddy, which releases the surface water of the mainstream to take its tangential course. The eddy energized by the mainstream, then increases in diameter and depth, and there being nothing to prevent it, moves downstream and takes up a position suitable to its increasing size between the guide bank and the mainstream. The axis of a stationary eddy being necessarily vertical, it appears that, as an eddy extends downwards a fully developed apron, the lower part of the eddy is interfered with the stone protected slope, and the disturbed condition and the diving flow is then introduced ; alternatively, the eddy may move down to a position where, whether by eddy action or diving flow, it will not damage the guide bank. An example of a free eddy was the large eddy which formed at the tail of the Damukdia Protection Bank and took up a position where it was quite harmless to the protection bank which caused it.

Cases of a river running tangentially to a curve and forming an eddy where the river leaves the curve have occurred on the Ganges at the Right Guide Bank and at the Raita Protection Bank. In both the cases the eddy has scoured the bed very deep.

Swirl.—A swirl is a term applied to moving eddies the digging effect of which is naturally limited.

Smooth flow.—Smooth flow is water in motion without whirlpools, eddies or even swirls and it is only to be found alongside a stone faced guide bank of which the apron is evenly subsided or in the open river. The cutting of a natural bank of sand or loam is always accompanied by eddies which may be of considerable size and deep water may, therefore, be expected alongside of a natural cutting bank. But as the friction between stone and the flowing water appears to be greater than the friction between sand and the flowing water greater depth of water may be expected alongside a properly constructed guide bank than alongside a natural cutting bank.

Turbulent flow.—Turbulent flow may be described as an on-flowing current, without whirlpools and eddies, caused by the sudden deflection of the stream from its natural course, due to obstructions of a fixed structure such as a protection bank. Very deep scour may be expected alongside such a bank especially when the stream of greater curvature is compelled to take the curvature of the protection bank. The extent of scour in such a case appears to depend on the direction of the stream impinging on the bank with reference to the alignment of the protection bank and also on the discharge of the river.

Scour, therefore, is of three kinds (a) *Normal*, caused by straight and unobstructed currents; (b) *abnormal*, caused by deflected but nevertheless on-flowing currents and by the river running tangentially to a curve and forming an eddy where the river leaves the curve of the protection bank, and (c) *extraordinary*, caused by whirlpools set up in non-forward moving water. Normal scour must in any case be provided for. Abnormal scour which will certainly occur occasionally, especially in the vicinity of fixed structure ought to be provided in the design of such structures. Extraordinary scour ought not to happen if works are well designed.

It is apparent that the guide bank apron should be designed for protection against "abnormal scour". But, how is the engineer designer to arrive at a correct judgment as to the greatest likely depth of scour that may occur opposite the training works. It is really a very difficult question to answer, as various changeable and unknown factors come into consideration. Experience and observation are the only criterions to ascertain the maximum probable depth of scour.

During the last few years, the maximum scour recorded by the Echo Sounding Gear opposite the protection works under the head "abnormal scour" is tabulated below:—

ABNORMAL SCOUR.

	Year.	Scour.	
		Due to direct attack at a distance of about 500 feet from the bank.	Due to current leaving tangentially the protection bank.
Raita Protection Bank 3° curve ..	1936	142 feet below low water level..	92 feet below low water level.
	1937	152 do* ..	122 do.
	1938	182 do† ..	188 do.
	1939	132 do ..	126 do.
	1940	141 do ..	137 do.
	1941	153 do ..	150 do.
Right Guide Bank 5° curve ..	1936	128 feet below low water level..	123 feet below low water level.
	1937	112 do ..	127 do.
	1938	148 do ..	148 do.
	1939	118 do ..	136 do.
	1940	80 do ..	108 do.
	1941	72 do ..	89 do.

* A depth of 192 feet below low water level was found at a distance of 600 feet from the bank.
† A depth of 194 feet below low water level was found at a distance of 900 feet from the bank.

The Raita Protection Bank has been designed to stand against scour down to 172 feet below low water level and the Right Guide Bank to 160 feet below low water level. It will be seen from the above table that these two banks have been adequately protected and that the deepest scour likely to occur has not been overestimated. It is needless to say that if at any time in future a scour is recorded in the vicinity of the work deeper than what is known at present, the protection works will have to be reinforced to withstand against that scour.

Once the judgment shall have been formed as to the greatest likely depth of scour, the protection works may be designed with a fair hope of being able to bid defiance to it by using Spring formulae. However, it must be remembered, that if the cross section of the apron on the curved ends is the same as on the straight the quantity per foot run will vary with the degree of curvature. In order to give the protection bank the same protection on the curve as on the straight, additional thickness of stone over and above the cross-sectional area is required to allow the falling forward of the apron to cover an increasing area on the curved portion. This additional thickness can be obtained by calculation.

Also, owing to the severity of the attack of the current on the upstream head of a guide bank, it would be advisable to have that part of the slope and apron stone made 25% thicker than elsewhere, and the breadth of the apron at that place made double, instead of 50% more than, the greatest depth of scour. In this way the head of the guide bank can be made to approximate to the ideal impregnable head. Similarly it would be desirable to have the apron of the upstream half of a curved protection bank made thicker and wider. This advice was given by Sir Francis Spring and owing to severe attacks experienced at the Hardinge Bridge Training Works, it is absolutely necessary to take his advice and design the apron of the guide banks and protection works accordingly.

Results of experiments with falling aprons.

At the request of the Railway Board in connction with the protection of the Hardinge Bridge some experiments were carried out on the falling apron at the Hydrodynamic Research Station, Poona. The experiments were concerned with (*i*) launching of an apron, (*ii*) the cause of failure of apron protection, (*iii*) the best design of aprons laid on sand and an alternating strata of sand and clay and (*iv*) the best method of reinforcing aprons already launched.

A summary of conclusions drawn from these experiments is given below:—

Summary of conclusions.

An apron of loose stones on incoherent sand launches to a slope which is the angle of repose of the stones rolling or sliding on sand under the flow conditions prevailing.

The concentration of stone on the slope is such that adequate protection is given to the sand beneath. If the scouring action becomes more severe, stone falls and the slope recedes, bringing down more stone from above thus strengthening the protection and automatically adjusting itself to the attack.

The lateral position of the slope is determined by the initial disposition, the quantity of stone in the horizontal layer per foot width, and the depth of scour, and the slope recedes until sufficient stone is brought down to protect the toe and face of the bank.

Normally the reinforcement of an apron is automatic and all that is required is to lay sufficient stone in the horizontal layer, but in order to avoid recession of slope or to provide protection consisting of larger stones at the toe, it may be advantageous to drop stone from barges.

An apron does not launch satisfactorily unless—

(*i*) the angle of repose of the underlying material is flatter than that of the stones, and (*ii*) the material scours easily and evenly.

A loose apron protection is not suitable for a bank of alternating layers of sand and

The danger of slips due to a steep hydraulic gradient or to a heavy super-imposed loading is negligible with Ganges sand; but when the river is falling quickly a slip may occur due to the bank being saturated.

An apron protection over incoherent sand may fail on account of—

(*a*) Insufficient stone being provided for the protection of the slope,

or (*b*) the stone at the toe being carried away by the current resulting in stone sliding down until all the available stone is launched, when a further slip exposes part of the bank face; after which though attack is most severe near the toe of the bank, the failure occurs through the exposed upper portion of the slope being scoured by the current, wave action and river breathing.

(*a*) can be prevented by providing sufficient stone and

(*b*) by providing stone of sufficiently large size.

A graded mixture is more resistant than stones of a single grade and when large stones are used it is advisable to provide smaller stones to protect the sand beneath; turbulence is a major cause of the removal of stone by the current and this was intensified in the case of the Hardinge Bridge by the manner of approach of the main current, *i.e.*, directed at the head of the guide bank.

In general it appears that stone of the size normally used would not be washed away, when laid on incoherent sand, unless :—

(*i*) the rise of the river, or increase of velocity, were rapid, as otherwise the apron would have time to adjust itself by launching more stone,

or (*ii*) the turbulence is present to a high degree, as this results in rapid fluctuations in velocity and direction of flow,

or (*iii*) the river were opposed by restriction in such a way that it would not develop natural channel so that velocities were unnaturally high,

or (*iv*) the guide bank were incorrectly designed, as for example a head designed too short or with too sharp a curve.

Apart from these, the falling apron would appear to be impregnable, if supplied with sufficient stone, and self-adjusting to resist all possible attack.

———

PLATE XIV.

PLAN SHOWING THE PROPOSED RETIRED ALIGNMENT OF THE MAIN LINE

SCALE 1 INCH = 1 MILE.

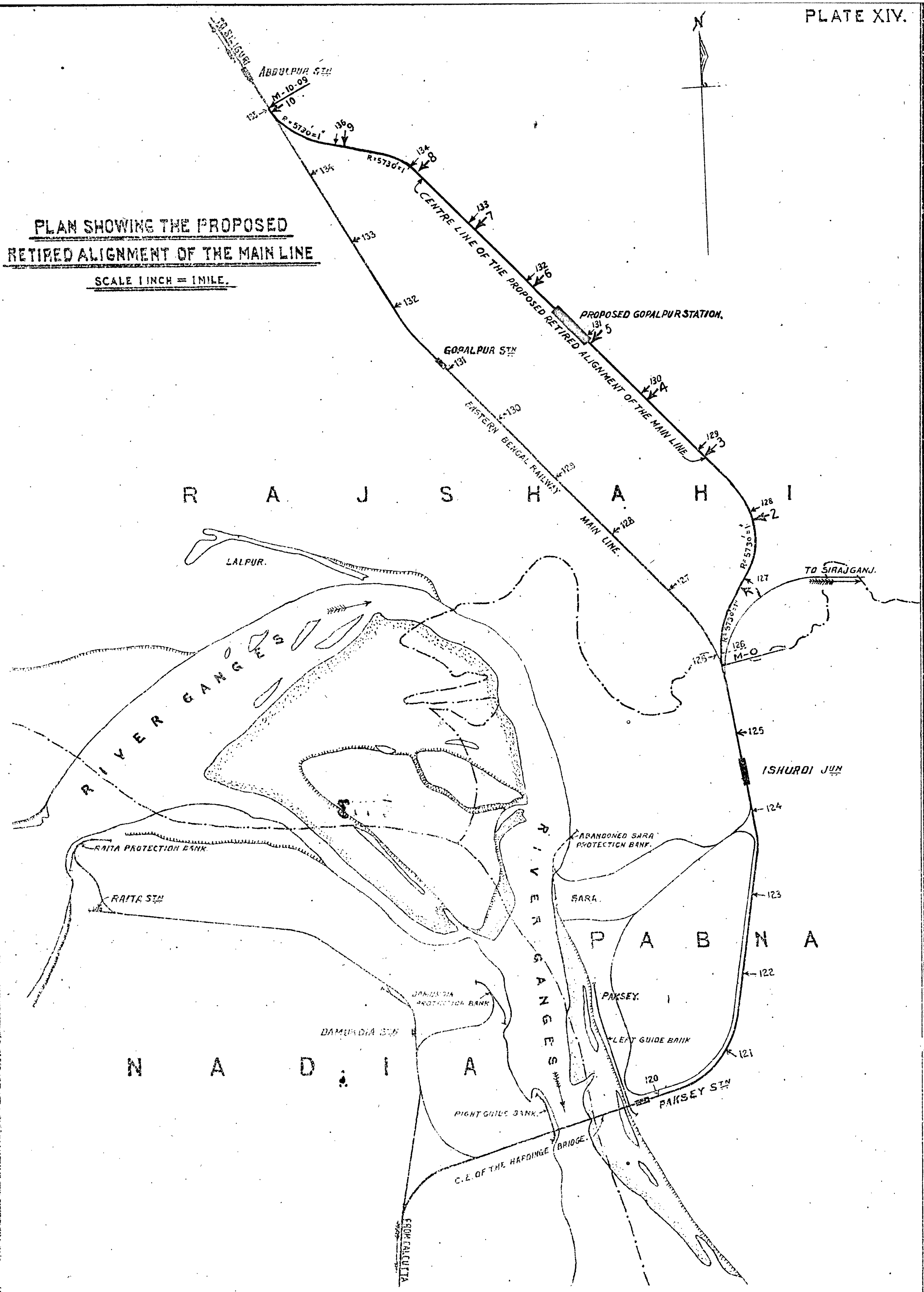
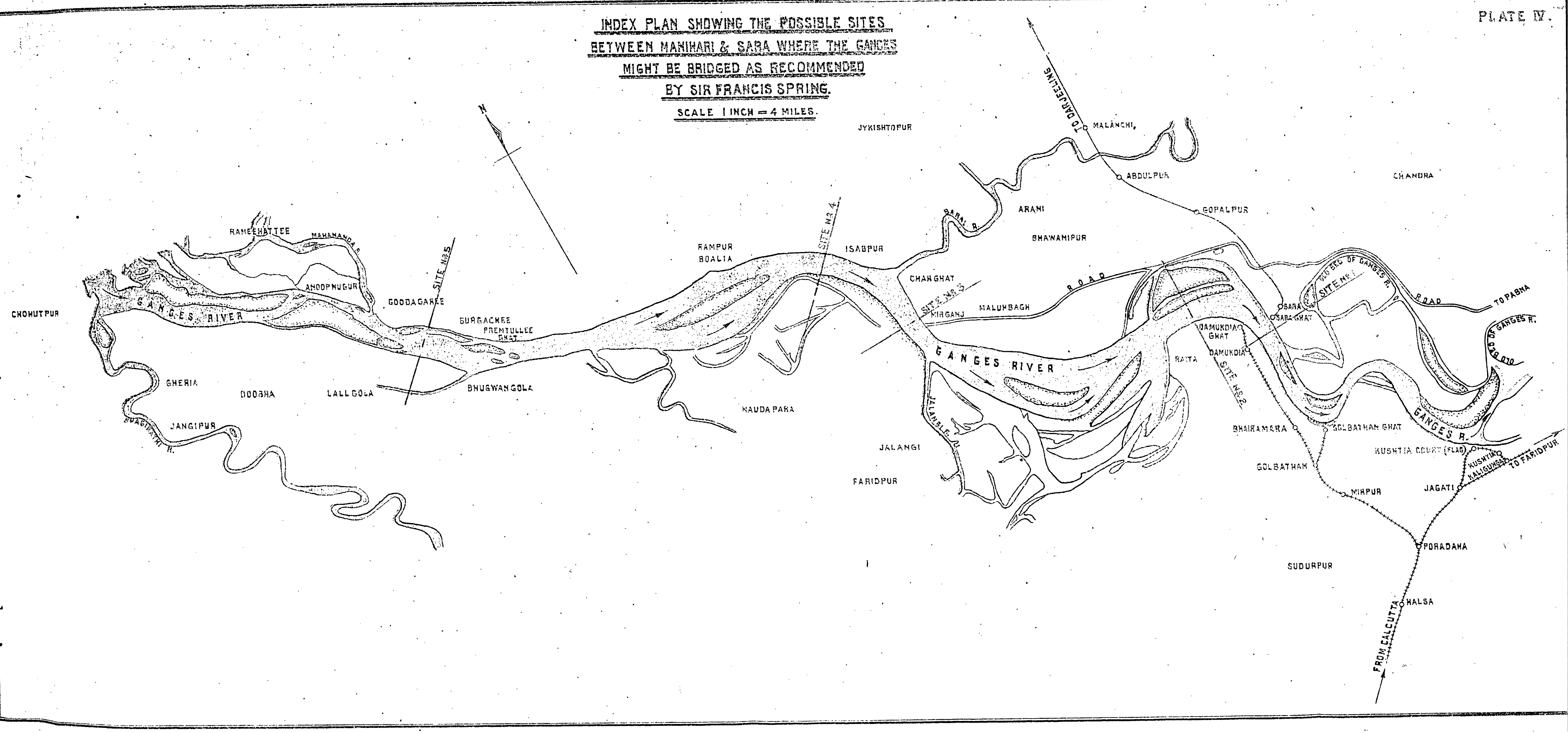


PLATE IV.

INDEX PLAN SHOWING THE POSSIBLE SITES BETWEEN MANIHARI & SARA WHERE THE GANGES MIGHT BE BRIDGED AS RECOMMENDED BY SIR FRANCIS SPRING.

SCALE 1 INCH = 4 MILES.



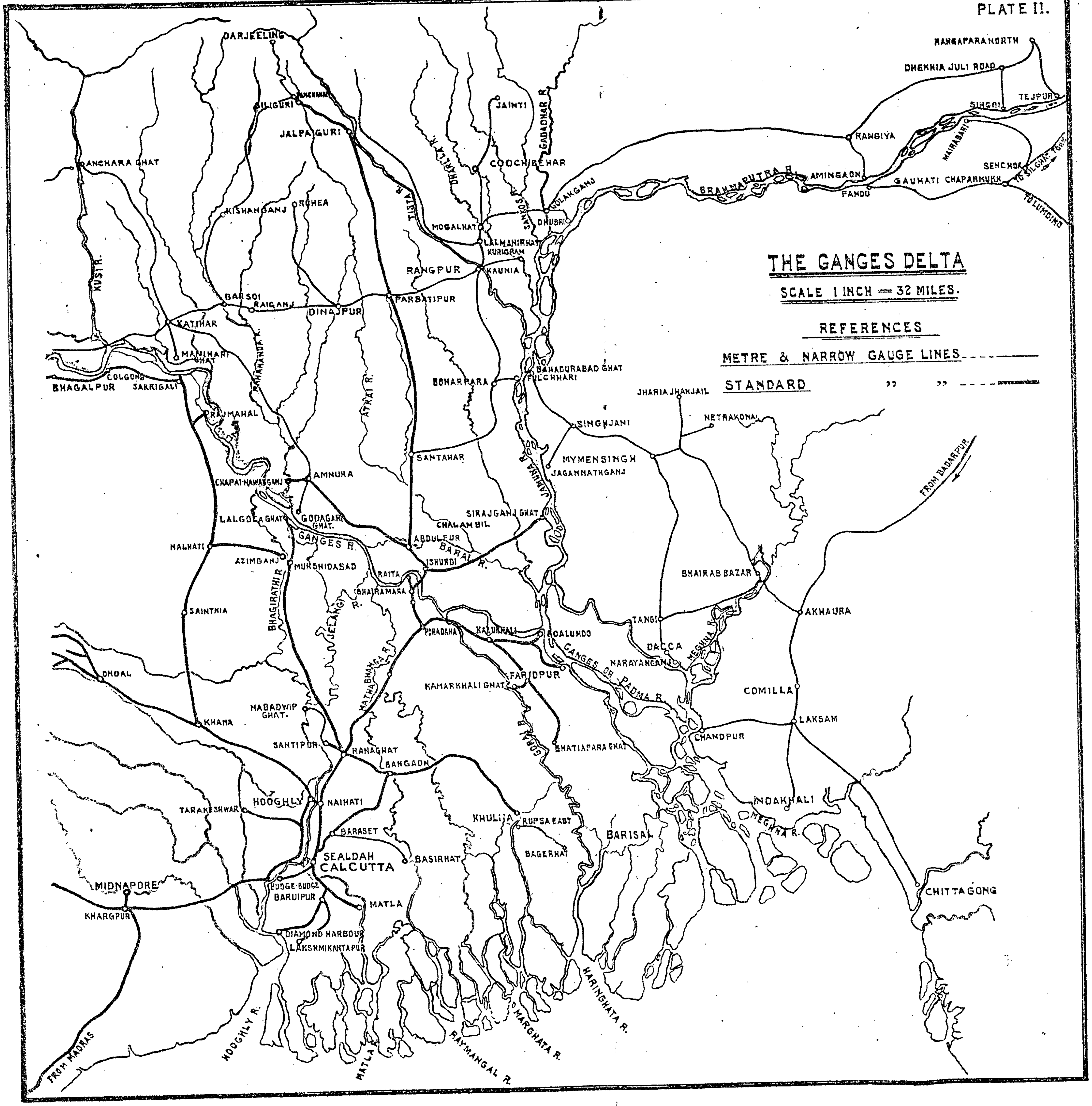
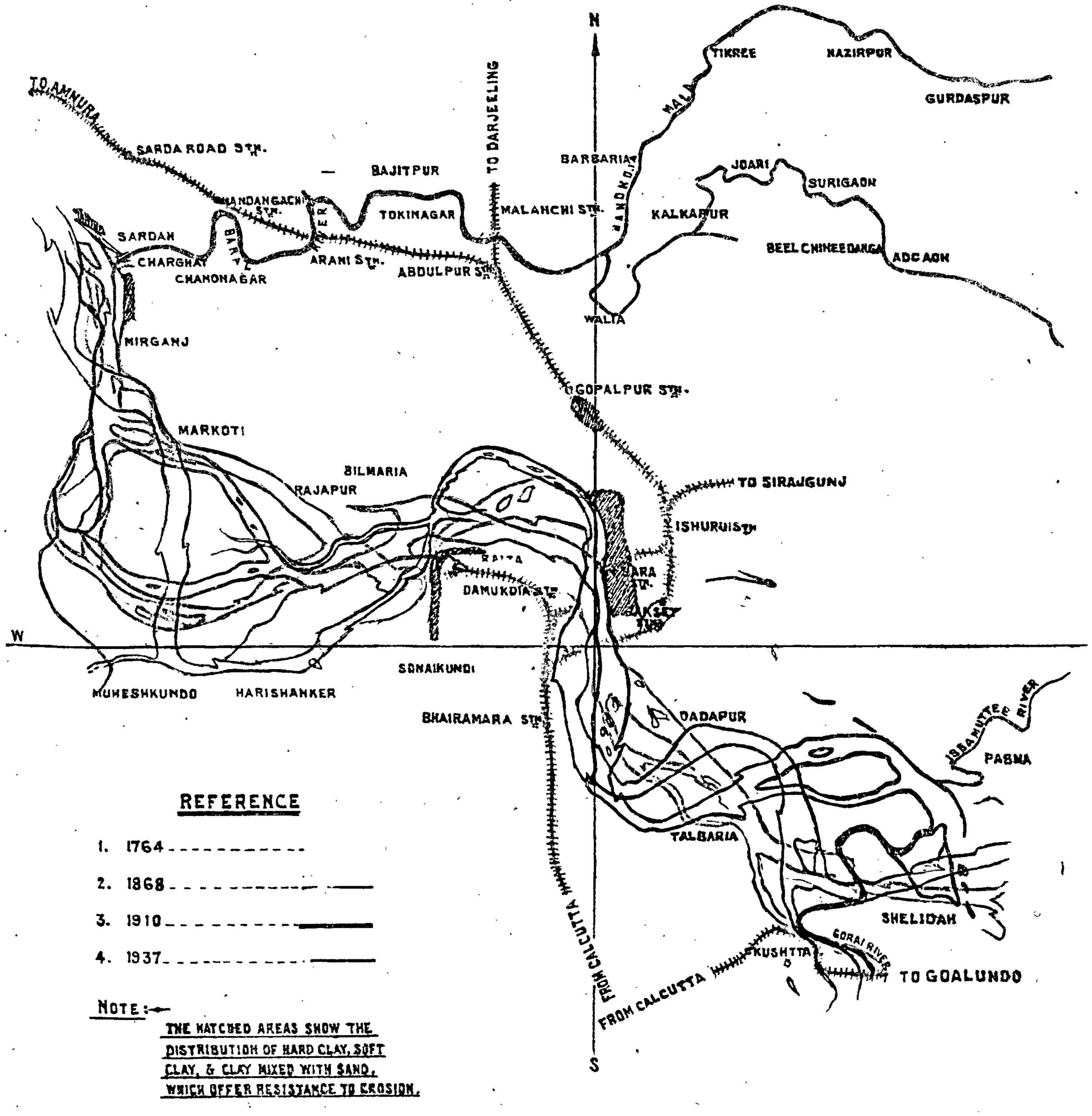


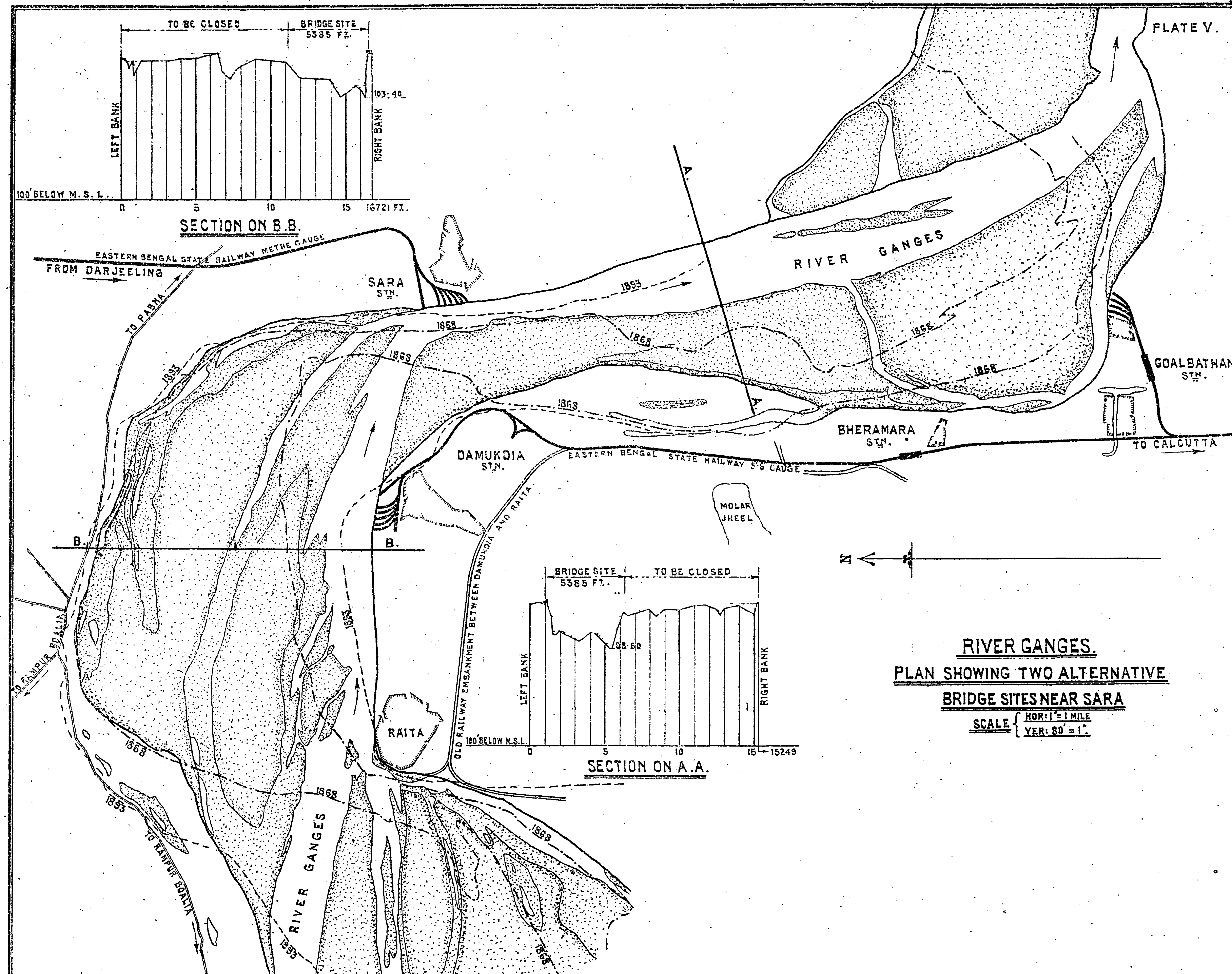
PLATE II.
THE GANGES DELTA
SCALE 1 INCH = 32 MILES.
REFERENCES
METRE & NARROW GAUGE LINES
STANDARD " "
DARJEELING
SILIGURI
JALPAIGURI
JAINTI
COOCH BEHAR
GADADHAR R.
DHARLA R.
TISTA R.
SANKOS R.
GOLAKGANJ
DHUBRI
MOGALHAT
LALMANIRHAT
KURIGRAM
KAUNIA
RANGPUR
PARBATIPUR
DINAJPUR
RAIGANJ
BARSOI
KISHANGANJ
ROHEA
ANCHARA GHAT
KUSI R.
KATIHAR
MANIHARI GHAT
COLGONG
BHAGALPUR
SAKRIGALI
RAJMAHAL
MAHANANDA R.
ATRAI R.
BONARPARA
BAHADURABAD GHAT
FULCHHARI
SANTAHAR
AMNURA
CHAPAI NAWABGANJ
GODAGARI GHAT.
LALGOLA GHAT
NALHATI
AZIMGANJ
MURSHIDABAD
GANGES R.
ABDULPUR
CHALAN BIL
SIRAJGANJ GHAT
BARAL R.
ISHURDI
RAITA
BHAIRAMARA
JAMUNA R.
SINGHJANI
MYMENSINGH
JAGANNATHGANJ
JHARIA JHANJAIL
NETRAKONA
BHAIRAB BAZAR
TANGI
DACCA
NARAYANGANJ
MEGHNA R.
AKHAURA
COMILLA
LAKSAM
CHANDPUR
NOAKHALI
MEGHNA R.
CHITTAGONG
FROM BADARPUR
RANGAPARA NORTH
DHEKHIA JULI ROAD
TEJPUR
SINGRI
RANGIYA
MAIRABARI
SENCHOA
TO SILGHAT
TO LUMDING
AMINGAON
BRAHMAPUTRA R.
PANDU
GAUHATI
CHAPARMUKH
SAINTHIA
BHAGIRATHI R.
JELANGI R.
MATHABHANGA R.
PORADAHA
KALUKHALI
GOALUNDO
GANGES OR PADMA R.
FARIDPUR
KAMARKHALI GHAT
GORAI R.
BHATIAPARA GHAT
BHOAL
KHANA
NABADWIP GHAT.
SANTIPUR
RANAGHAT
BANGAON
HOOGHLY
NAIHATI
TARAKESHWAR
BARASET
SEALDAH
CALCUTTA
BASIRHAT
KHULNA
RUPSA EAST
BAGERHAT
BARISAL
MIDNAPORE
KHARGPUR
BUDGE-BUDGE
BARUIPUR
MATLA
DIAMOND HARBOUR
LAKSHMIKANTAPUR
HOOGHLY R.
MATLA R.
RAYMANGAL R.
MARGHATA R.
HARINGHATA R.
FROM MADRAS

PLATE III.

THE RIVER GANGES BETWEEN SARDA & PABNA IN THE YEARS 1764, 1868, 1910 & 1937

SCALE 1 INCH = 5 MILES





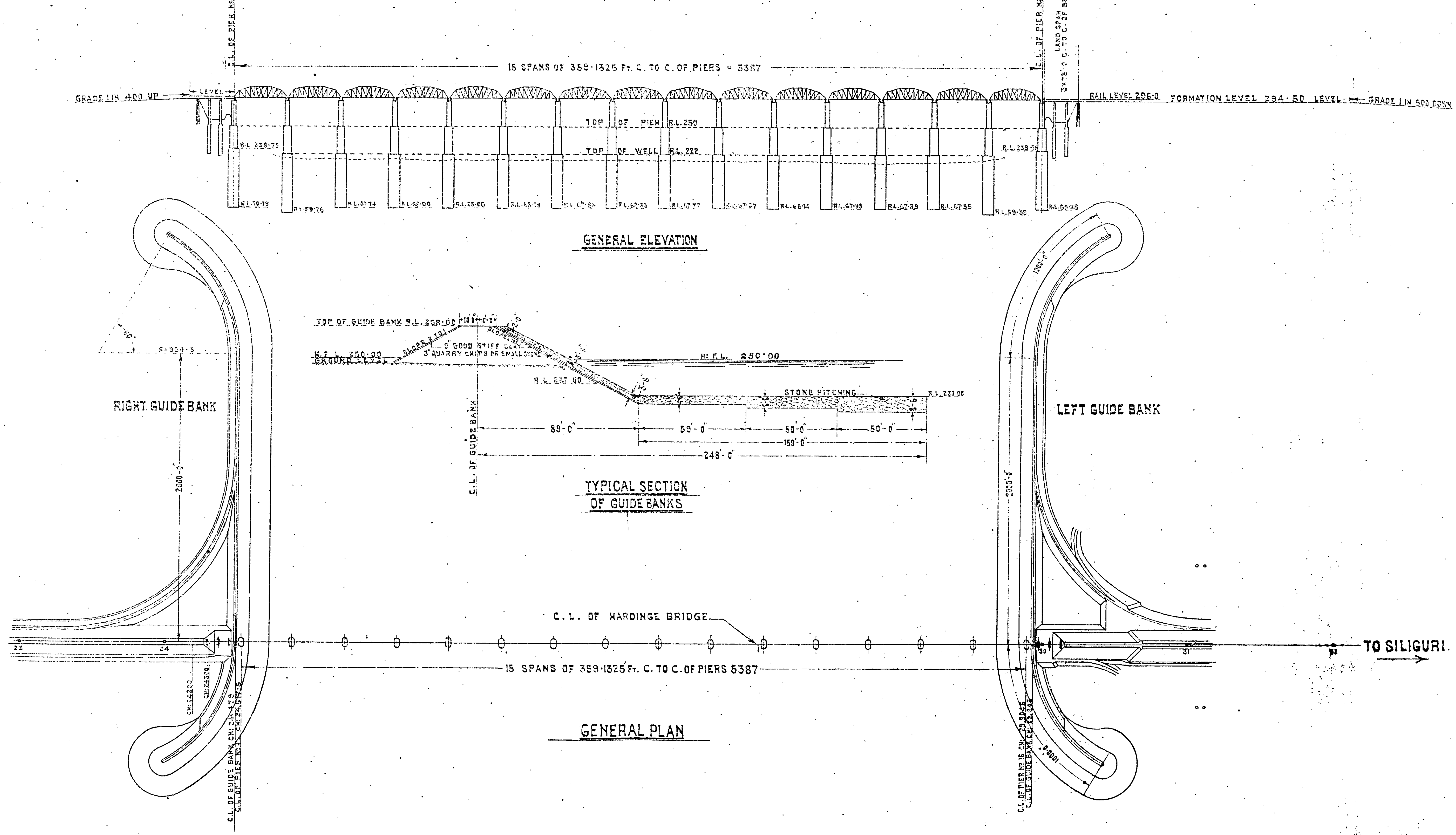
RIVER GANGES.

PLAN SHOWING TWO ALTERNATIVE BRIDGE SITES NEAR SARA

SCALE { HOR: 1" = 1 MILE; VER: 80' = 1". }

PLATE VI.

THE FLANKING GUIDE BANKS OF THE BRIDGE



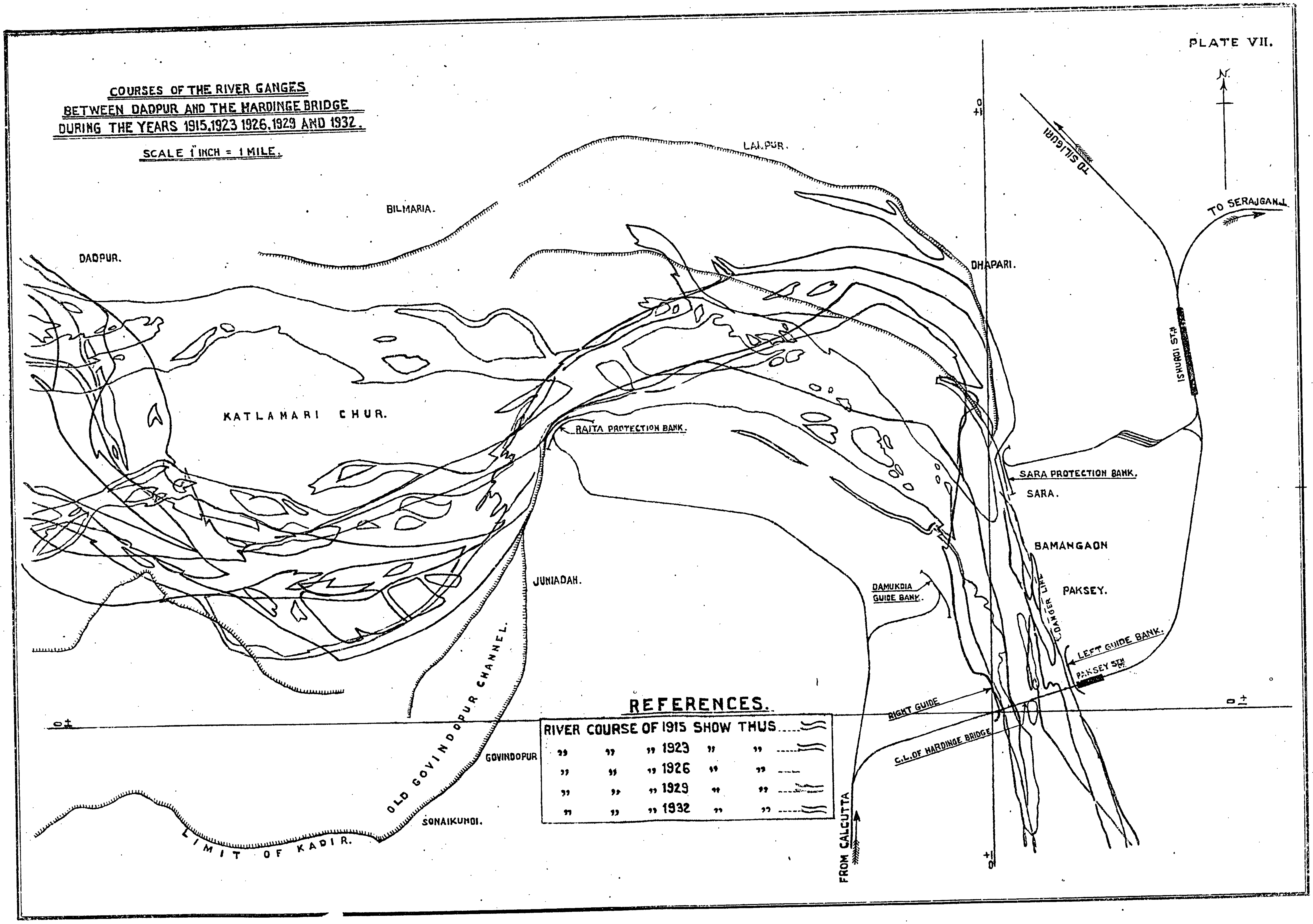


PLATE VII.
COURSES OF THE RIVER GANGES
BETWEEN DADPUR AND THE HARDINGE BRIDGE
DURING THE YEARS 1915, 1923 1926, 1929 AND 1932.
SCALE 1" INCH = 1 MILE.
N.
LALPUR.
BILMARIA.
DADPUR.
TO SILIGURI
TO SERAJGANJ
DHAPARI.
ISHURDI STN.
KATLAMARI CHUR.
RAITA PROTECTION BANK.
SARA PROTECTION BANK.
SARA.
BAMANGAON
PAKSEY.
JUNIADAH.
DAMUKDIA GUIDE BANK.
DANGER LINE
LEFT GUIDE BANK.
PAKSEY STN.
RIGHT GUIDE
C.L. OF HARDINGE BRIDGE
OLD GOVINDOPUR CHANNEL.
GOVINDOPUR
SONAIKUNDI.
LIMIT OF KADIR.
FROM CALCUTTA
REFERENCES.
RIVER COURSE OF 1915 SHOW THUS
" " " 1923 " "
" " " 1926 " "
" " " 1929 " "
" " " 1932 " "

CONTROLIED AREA

SCALE 1" = 20 MILES.

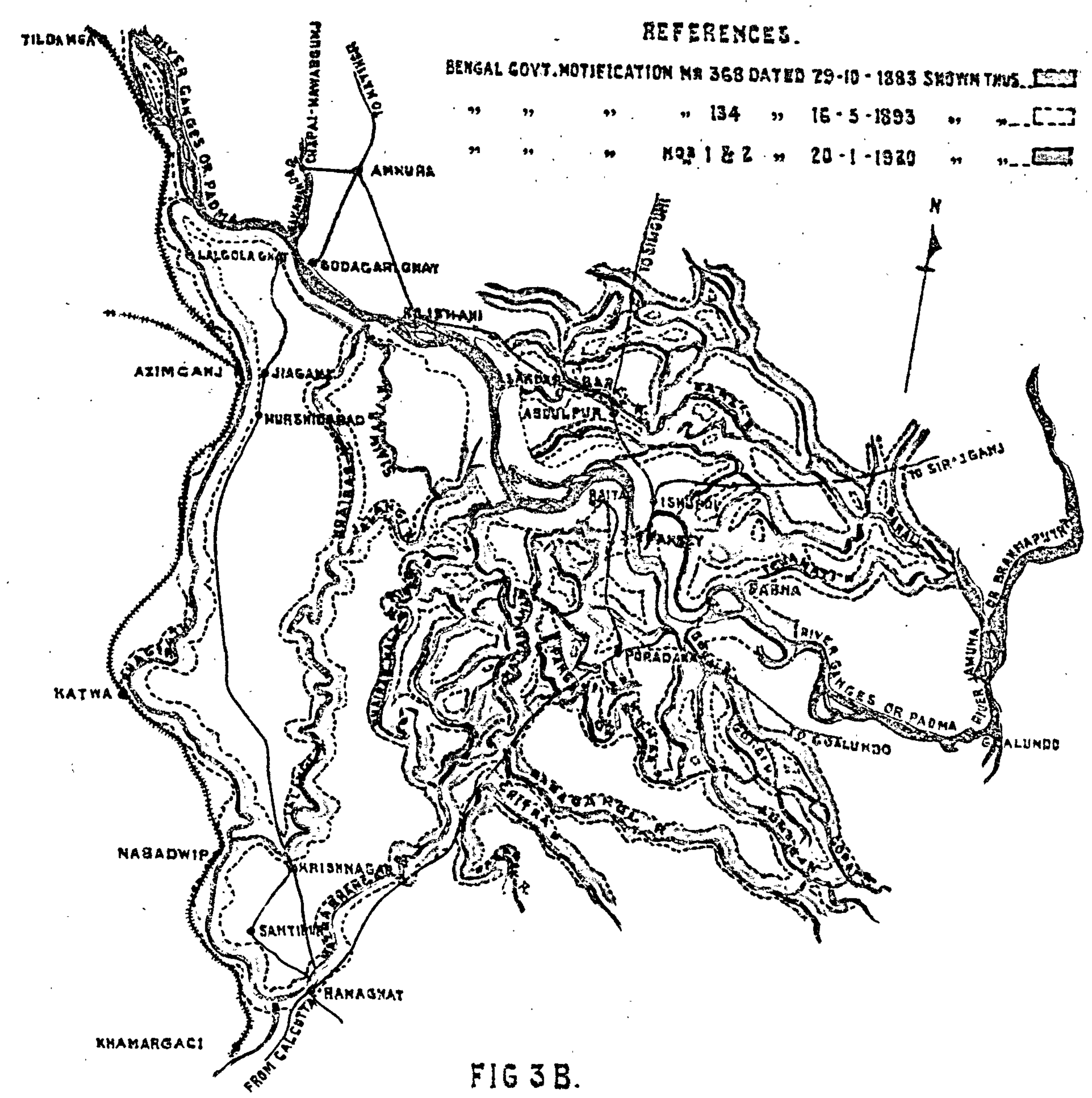


FIG 3B.

RAITA PROTECTION BANK

WORK DONE IN 1921 – 22

SCALE 4 INCH = 1 MILE.

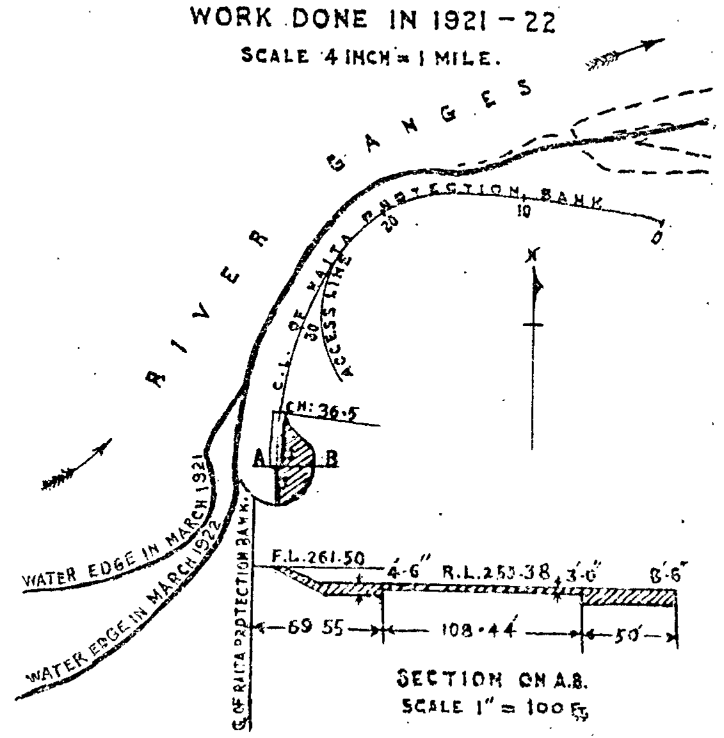


FIG 3C

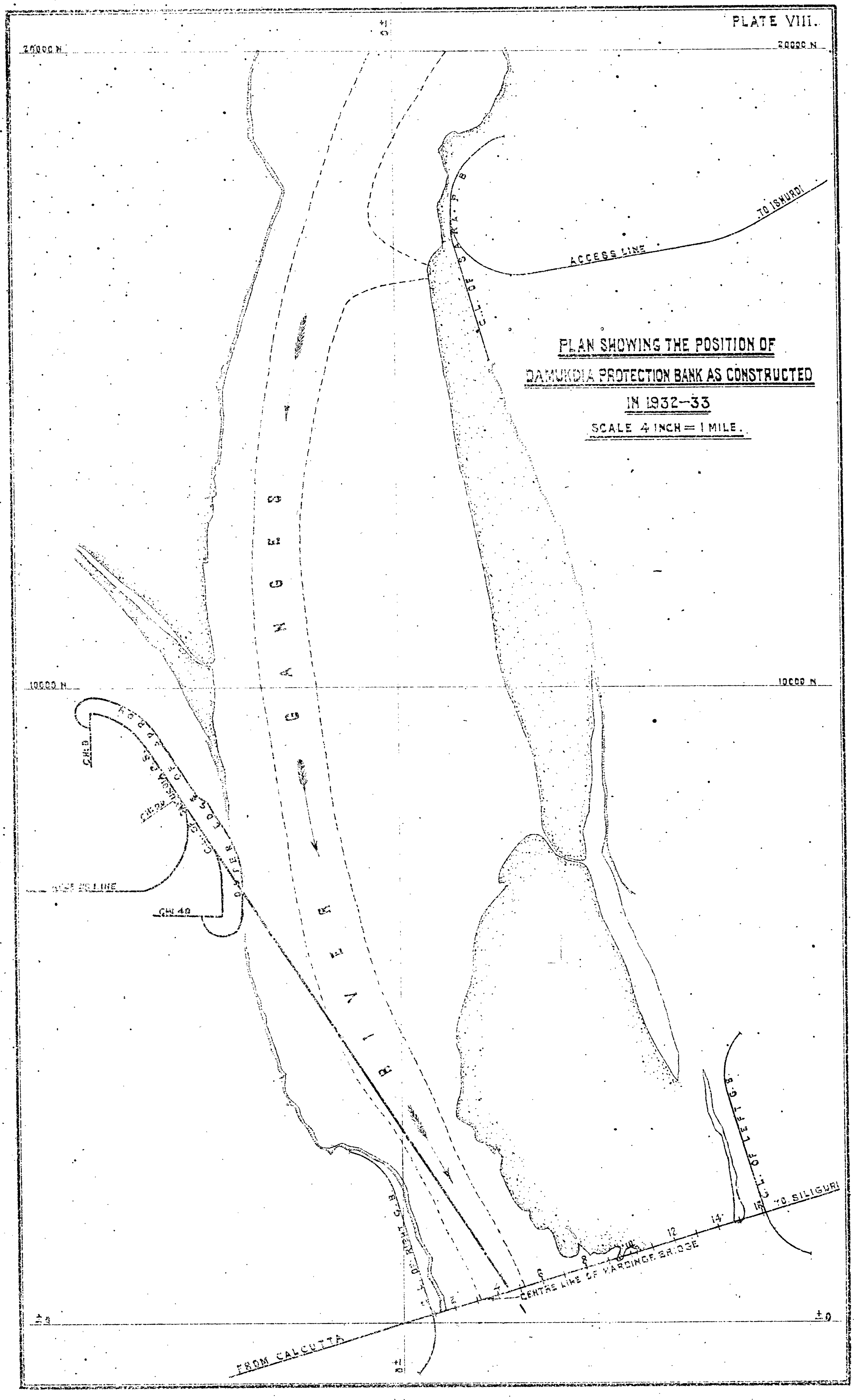


PLATE VIII.
PLAN SHOWING THE POSITION OF
DAMUKDIA PROTECTION BANK AS CONSTRUCTED
IN 1932-33
SCALE 4 INCH = 1 MILE.
20000 N
10000 N
ACCESS LINE
TO ISHURDI
RIVER GANGES
CENTRE LINE OF HARDINGE BRIDGE
FROM CALCUTTA
TO SILIGURI
C.L. OF LEFT G.B.
C.L. OF RIGHT G.B.

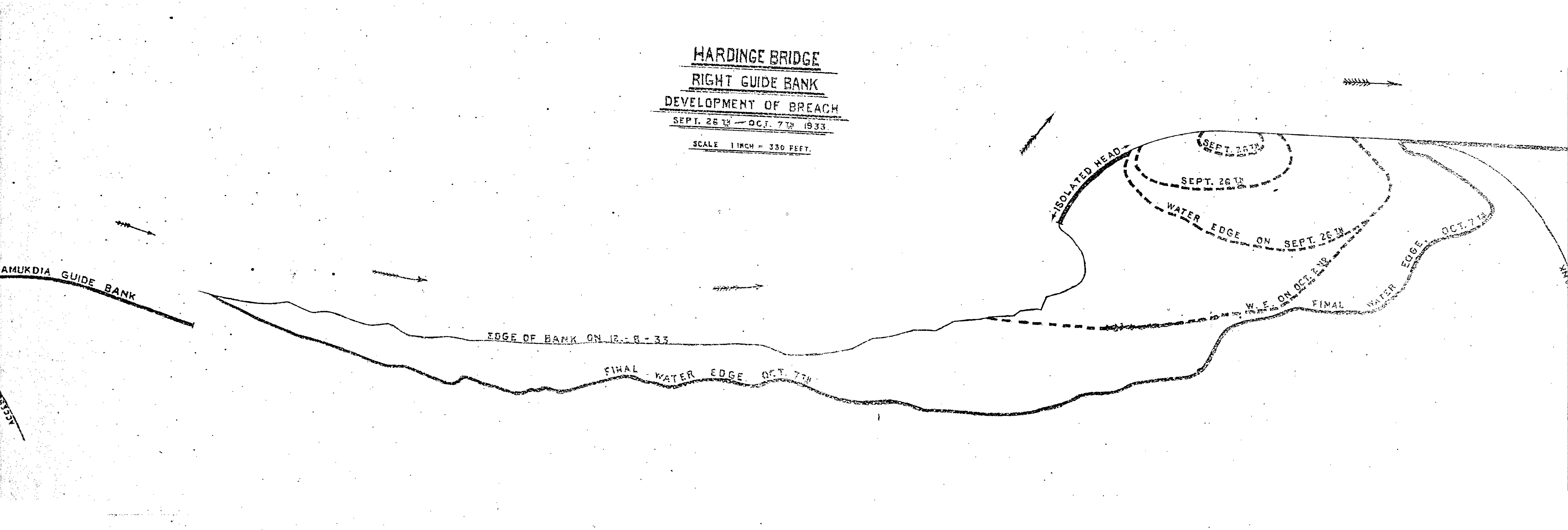

HARDINGE BRIDGE
RIGHT GUIDE BANK
DEVELOPMENT OF BREACH
SEPT. 26TH — OCT. 7TH 1933.
SCALE 1 INCH = 330 FEET.
AMUKDIA GUIDE BANK
EDGE OF BANK ON 12-8-33
FINAL WATER EDGE OCT. 7TH
ISOLATED HEAD
SEPT. 26TH
SEPT. 26TH
WATER EDGE ON SEPT. 26TH
W. E. ON OCT. 2ND
FINAL WATER EDGE. OCT. 7TH

PLATE X.

PLAN SHOWING SIR R.R. GALES'S SCHEME FOR IMMEDIATE SAFETY OF THE BRIDGE

JANUARY 1934

REFERENCES.

MARK	DESCRIPTIONS	YEAR WORK WAS DONE
A	MOLE	1933-34
B	BACKWATER BUND	,,
C	JACKSONS SPUR	,,
D	MARGINAL BANK	,,
E	DAMUKDIA PROTECTION BANK	,,
F	SARA ,, ,,	,,
G	PIER PITCHING	,,
H	RESTORATION OF RIGHT GUIDE BANK	1934-35
J	RAITA PROTECTION BANK	1938-39

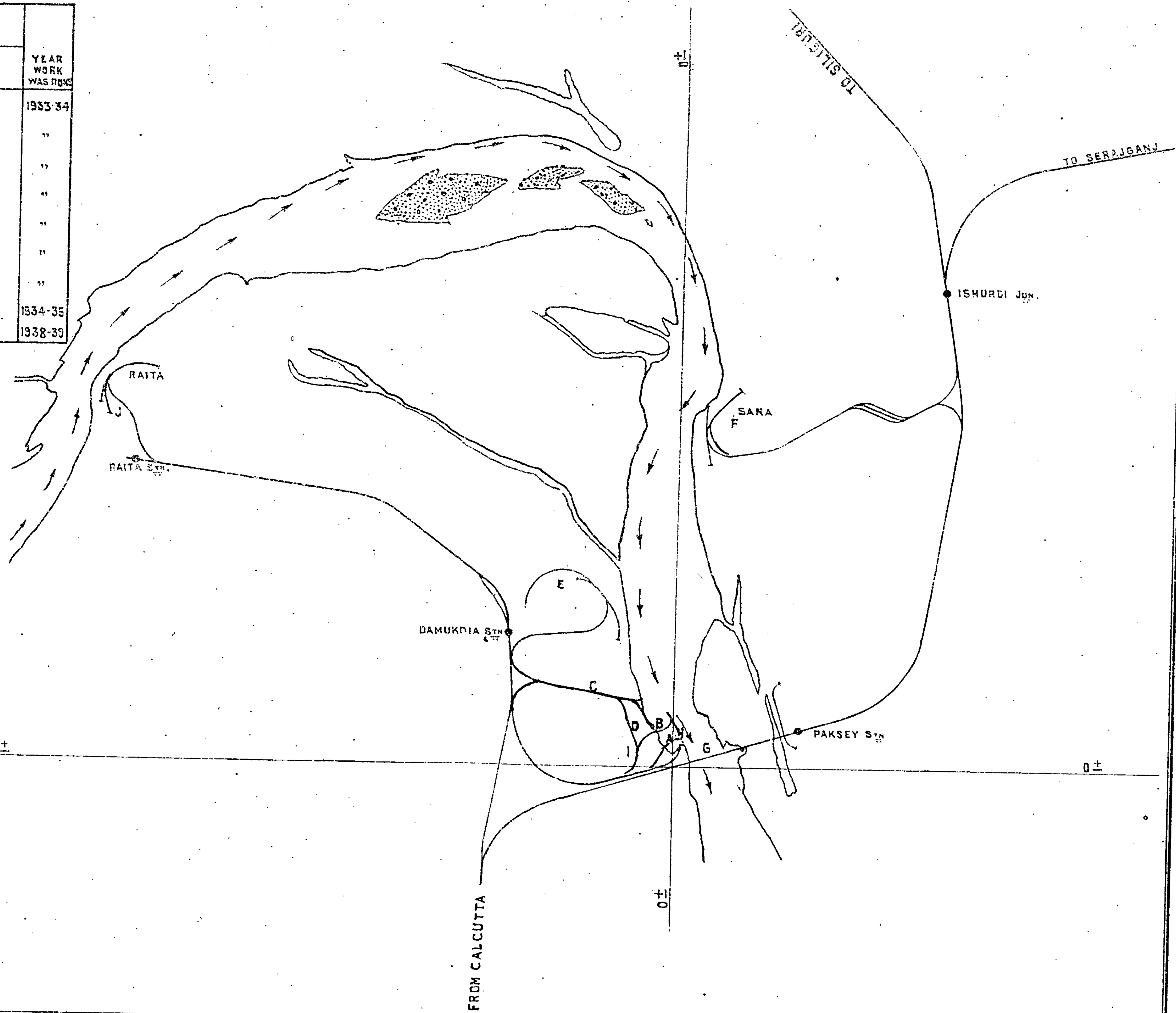


PLATE XI

PLAN SHOWING SUCCESSIVE ALIGNMENTS OF SARA PROTECTION BANK

SCALE 1 INCH = 200 FEET.

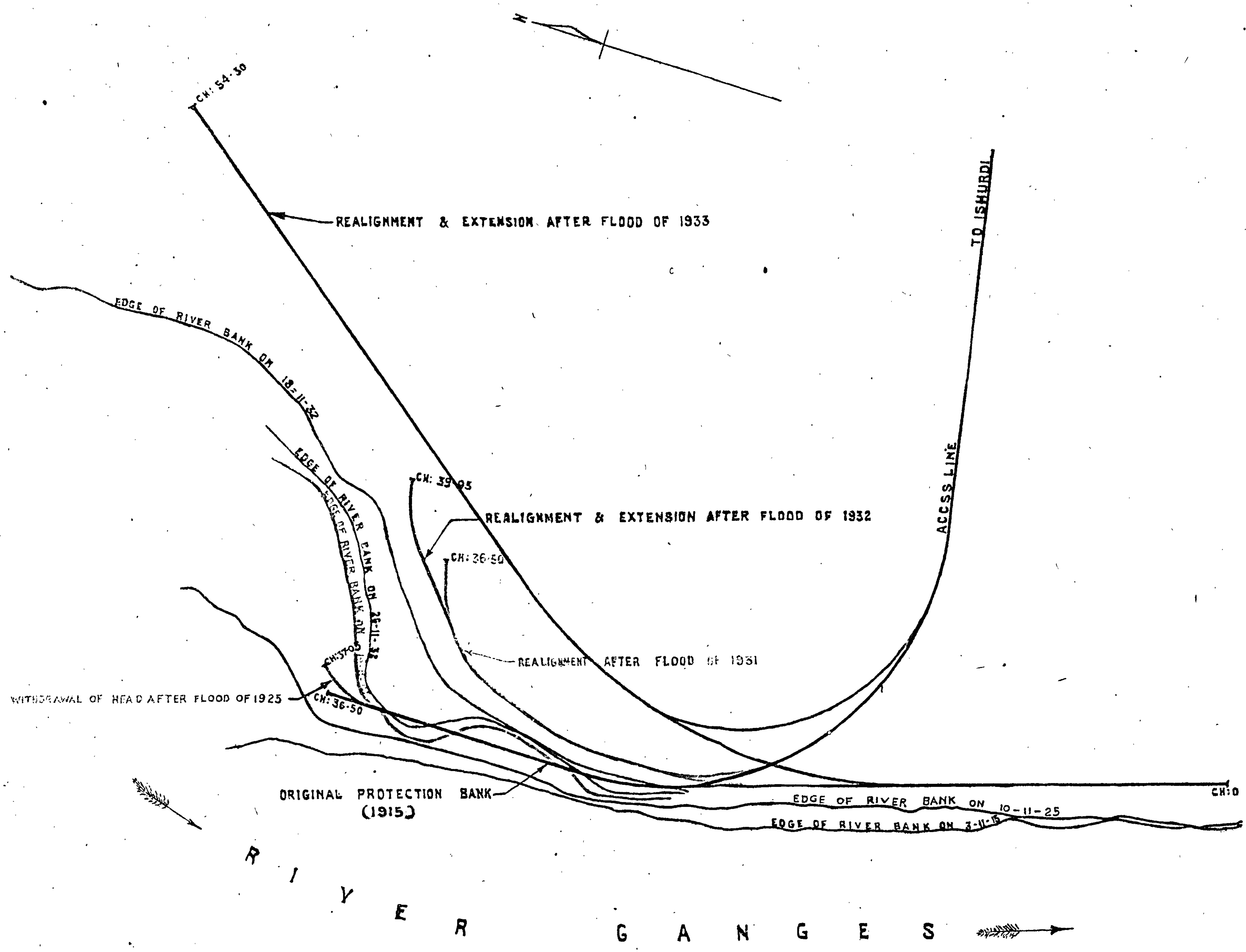


PLATE XII.

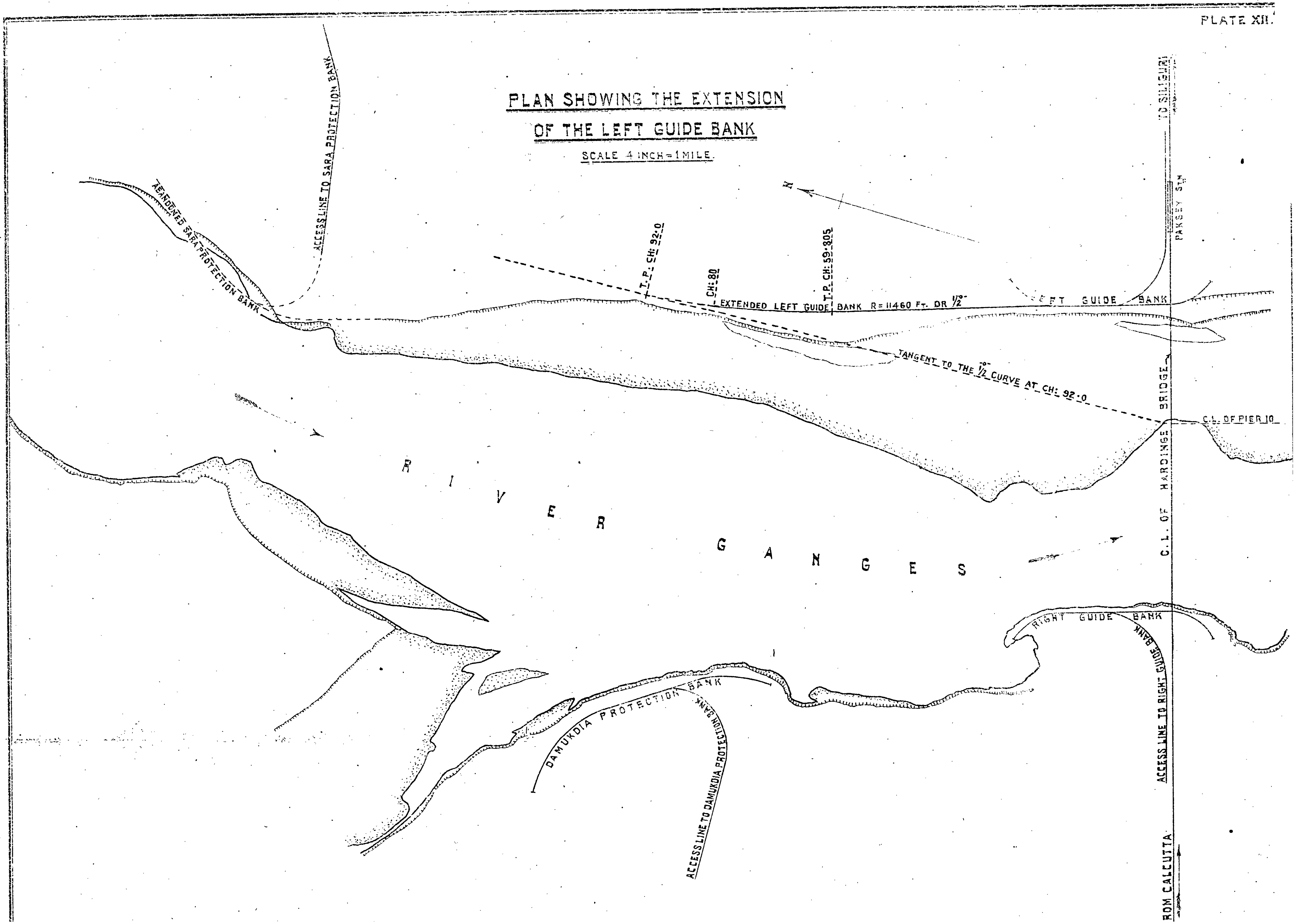
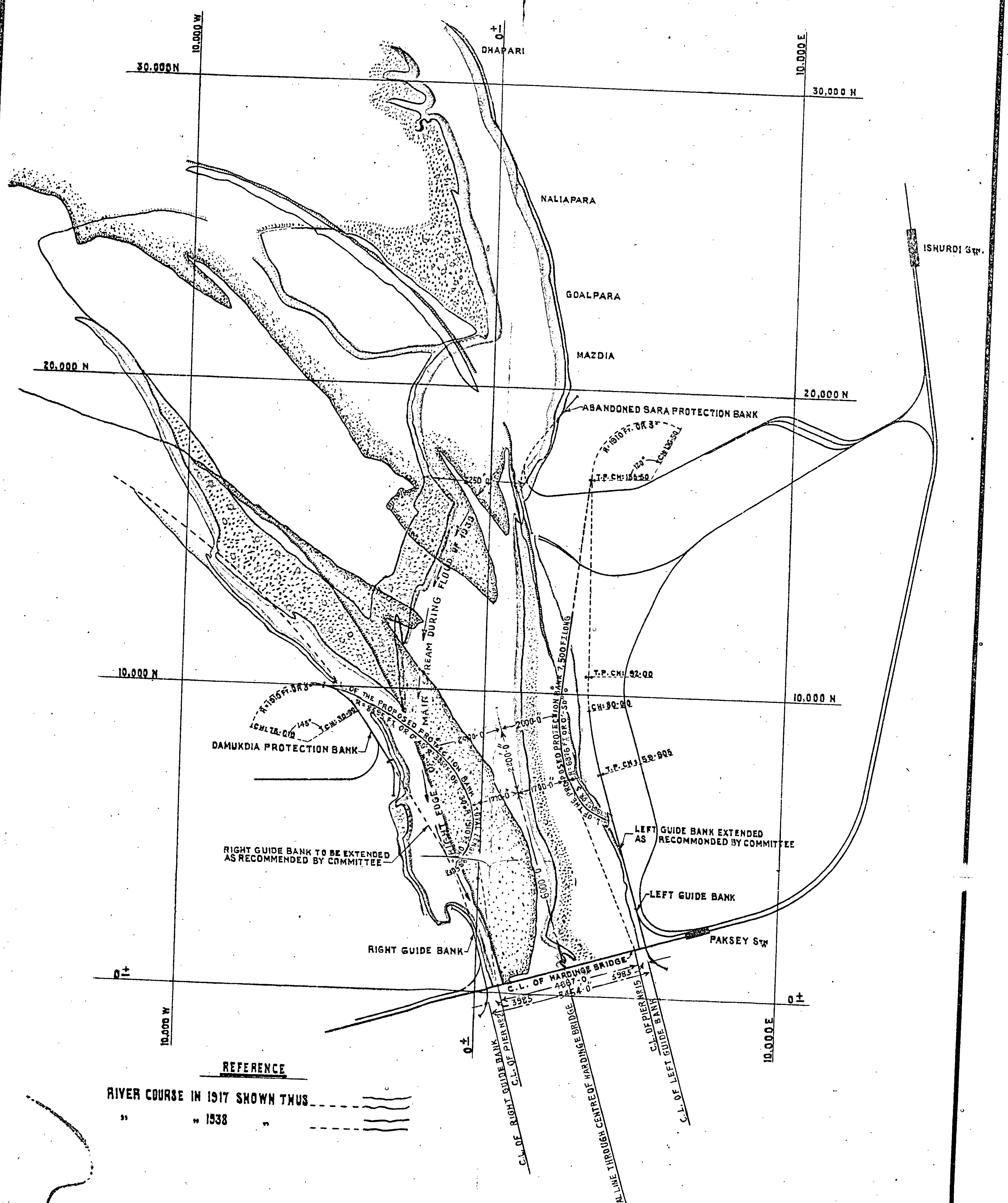

PLAN SHOWING THE EXTENSION
OF THE LEFT GUIDE BANK
SCALE 4 INCH = 1 MILE.
ABANDONED SARA PROTECTION BANK
ACCESS LINE TO SARA PROTECTION BANK
N
T.P. CH: 92·0
CH: 80
T.P. CH: 59·805
EXTENDED LEFT GUIDE BANK R = 11460 FT. OR 1/2°
LEFT GUIDE BANK
TO SILIGURI
PAKSEY STN
TANGENT TO THE 1/2° CURVE AT CH: 92·0
C.L. OF PIER 10
C.L. OF HARDINGE BRIDGE
RIVER GANGES
RIGHT GUIDE BANK
ACCESS LINE TO RIGHT GUIDE BANK
DAMUKDIA PROTECTION BANK
ACCESS LINE TO DAMUKDIA PROTECTION BANK
ROM CALCUTTA

PLATE XIII.

PLAN SHOWING AN ALTERNATIVE SCHEME FOR PROTECTION OF HARDINGE BRIDGE.

SCALE 2 INCHES = 1 MILE



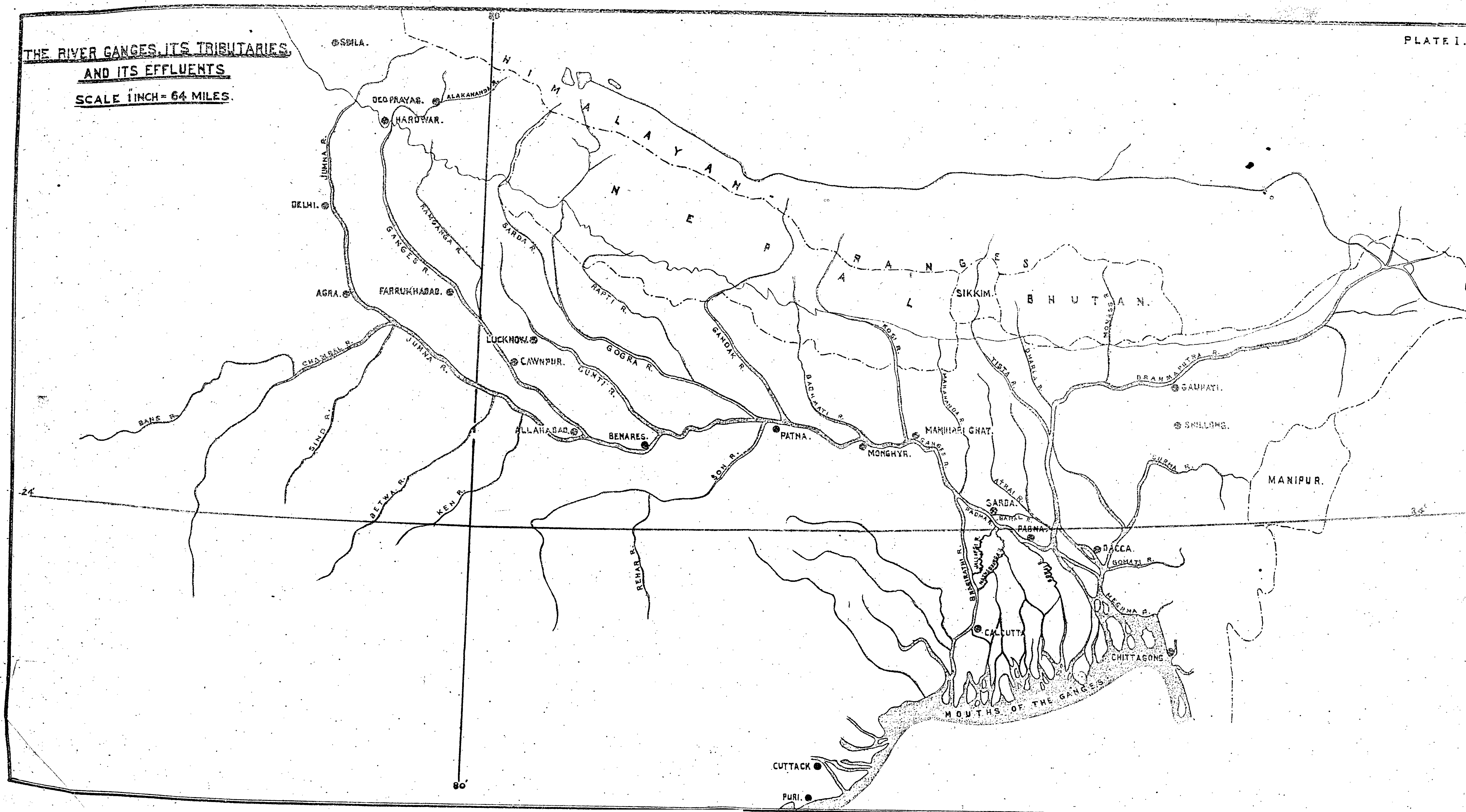


PLATE I.
THE RIVER GANGES, ITS TRIBUTARIES, AND ITS EFFLUENTS
SCALE 1 INCH = 64 MILES.
HIMALAYAN RANGES
NEPAL
SIKKIM.
BHUTAN.
MANIPUR.
SIMLA.
DEO PRAYAG.
ALAKANANDA R.
HARDWAR.
DELHI.
JUMNA R.
GANGES R.
RAMGANGA R.
SARDA R.
AGRA.
FARRUKHABAD.
LUCKNOW.
CAWNPUR.
CHAMBAL R.
BANS R.
SIND R.
BETWA R.
KEN R.
ALLAHABAD.
BENARES.
RAPTI R.
GOGRA R.
GUMTI R.
GANDAK R.
SON R.
REHAR R.
PATNA.
BAGMATI R.
KOSI R.
MAHANANDA R.
MONGHYR.
MANIHARI GHAT.
TISTA R.
DHARLA R.
MONASS R.
BRAHMAPUTRA R.
GAUHATI.
SHILLONG.
SURMA R.
ATRAI R.
SARDA.
PADMA R.
PABNA.
DACCA.
GOMATI R.
MEGHNA R.
BHAGIRATHI R.
CALCUTTA.
CHITTAGONG.
MOUTHS OF THE GANGES.
CUTTACK.
PURI.
24°
80°