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Principles of Well-Foundations, River Training and Protection Works

BY

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1. Introduction. The note owes its origin to experiences on the 1943-45 Assam lines of communication railway doubling. When the Americans took over from the B. A. R. the operation of the metre gauge section from Parbatipur to Ledo, they also assumed directive (but not executive) charge of engineering maintenance. The use at their insistence of one-ton C. C. or solid rock blocks as scour protection round the piers of a vital bridge with wells only 50′ to 60′ deep probably accounts for its survival. These blocks were handled at source by crawler cranes, and at destination by a drag-line (mounted in a well wagon) using the crane attachment. On the other hand their adherence to river protection works which contravened the very basis of river training practice as developed in India, and the tendency of some local railway engineers to accept these methods necessitated the issue of instructions upon which this note is based.

Nowadays there is rarely time (let alone a properly indexed technical library) for collecting data whenever a river training, bank protection, or bridging problem arises. Also most of the old technical papers, including Spring's classic, are out of print. The note which follows gives in condensed form design data applicable to alluvial rivers with flood discharges between about 2,00,000 and 6,00,000 cusecs based on accepted practice in India.

2. Form of Guide Banks. The usually accepted ideal plan for these is slightly converging (see Fig. 1), though local conditions may require the parallel lay-out, or even the diverging (splayed) form with the disadvantage of encouraging formation of sandbanks at the entry, and oblique flow. The curved head (of which the angle subtended at the centre and radius depend upon local conditions) is necessary to lead the river into the bridged channel without turbulence. Although a river in flood could not attack the reverse of a curved head, dangerous whirlpools are liable to form, associated with surge waves or "breathing" which necessitate pitching-stone and apron on the reverse of most curved heads.

3. Purpose of Guide Banks. (1) To reduce the waterway in a wide and indeterminate river bed to a size which can be crossed by a bridge of depth of foundations and length commensurate with the bed conditions and flood discharge. A rough guide to the amount of waterway which may be closed may be obtained (following Spring) by allowing for about 90 per cent of the flow through the closed portion of the (entirely by scour measured below normal bed) river-passing through one-third of the bridge, with a deepening not exceeding the greatest (ascertainable) measured depth, usually at a bend.

(2) By being made sufficiently long to ensure that any embayment will attain the natural bend/chord ratio of the river (Fig. 1) and short-cut itself before the deep channel can attack the approaches. The up-stream length of guide banks for rivers of the sizes considered in this note should normally be 1 to 1¼ times the length of the bridge, but this can be reduced where local conditions, such as a swift straight river, stable bed materials, etc, allow.

(3) Protect the abutments.

(4) Promote parallel flow through the bridge.

4. **Design of Aprons.** Sir Robert Gales' rule is "deepest ascertainable scour" (greatest measured depth at a cutting bend during floods, reduced to depth below normal bed or low water plus 33 per cent for effect of unerodible face of guide bank) increased for exposure, restriction of waterway, and safety margin, by 25 per cent for body and tail and 50 per cent for head (= D), multiplied by 3/2.

$$i.e.\ D=\frac{125}{100}\left(d+\frac{33d}{100}\right) \text{ for body and tail}$$

$$D=\frac{150}{100}\left(d+\frac{33d}{100}\right) \text{ for head of guide bank.}$$

where d is the deepest measured scour below normal bed, and D is the *scour* used for calculating the breadth of apron, to which Gales suggests the addition of a 15′ berm (see Fig 2), though in most Punjab rivers this additional factor of safety is not necessary. Width of apron = 1.5 D.

The apron is laid on the river bed during the dry season and has been found to launch itself by a process of small slips into the form shown dotted in Fig. 2, thereby creating a sloping under-water protection wall. The thicknesses recommended by Gales are as given in the table. For most Punjab rivers these thicknesses could safely be reduced by 15 per cent to 25 per cent.

	Permanent Slope (on bank)			Prospective Slope (Apron after launching)					Apron
Part of guide bank	Pitching stone, T.	Soling ballast.	Thickness of Covering, T 2.	Pitching stone, T.	Add for absence of soling, 33%	For head, 22%	Thickness of under-water slope=T′.	Thickness T.′	Apron thickness 1·5×T′.
Head	3′–6″	7″	4′–1″	3.5′	1.17′	0.77′	5.44′	5′–5″	8′—3″
Body & Tail	3′–6″	7″	4′–1″	3.5′	1.17′	-	4.67′	4′—8″	7′–0″

Alternatively the dimensions given by Macrae in Vol. 237 of the proceedings of the Institution of Civil Engineers may be adopted.

On no account may the slope stone (on the guide bank) be allowed to slip as a breach would result. The ponded flood water behind the guide bank being higher than the level of the free river by the slope of the bed multiplied by the distance from the breach to the head, plus dynamic afflux, any breach in the bank is usually disastrous. Thus any apron of less width than the calculations show to be necessary is usually bad engineering. The 7″ of soling ballast or quarry spalls on the pitched slope of the guide bank is to protect the sand beneath the "rip-rap" from being sucked out by wave and surge action. Modern practice favours uniform-thickness aprons.

5. **Spurs.** These are a discredited form of construction and have led to many disasters by opposing the direct force of flow, thus causing relatively harmless kinetic energy to be changed into highly destructive turbulent eddy flow and swirls which generate scour holes in which the spur is engulfed and down stream works are endangered. Even oblique spurs should be avoided. If, however, spurs must be built they should either be permeable (*e.g.* brushwood and piles) or if of stone should have curved heads and tails of guide bank type and full-scour aprons.

6. **Bends.** Any obstruction (even a curved guide bank head) promotes scour and draws the river to the resulting deepened channel. Consequently the practice of trying to stop an embayment from reaching a vital point by stone pitching the bend should be avoided. Not only does this draw the deep channel to where it is least wanted, but by holding it there and discouraging the natural occurrence of a cut-off results in an expensive and probably losing campaign to hold the bend by expenditure of unpredictable quantities of stone.

If an embayment cannot be kept at a safe distance by building or extending a guide bank so as to promote a cut-off, some form of permeable silt-forming protection should be adopted.

7. **Permeable training works.** These are less used in India than in some other countries. In Bengal, bamboo pile and brushwood spurs called "bandels" are used. Such works have to be so designed as neither to oppose the current sufficiently to be overthrown, nor form eddies and so be undermined by local scour, but they must slow down the current sufficiently to cause deposition of silt.

In the Argentine groups of spurs or fences consisting of rails or poles driven or wobbled down into the river bed 5′ to 6′ apart are joined by three wires to which layers of brushwood are attached, the resulting silting being extended year by year.

In the U. S. A. a system known as "retards" is used in which brushwood is anchored by wires to the tops of piles jetted down to below scour-depth, or by anchoring hurdles or cages across the current.

In New Zealand pointed stakes freshly cut from the parent willow, 2″ to 4″ diameter, and of length to project some 4′ above ordinary flood level, are firmly fixed at two to three feet centres in a belt extending from the shore to a depth of up to eight feet of water in belts which may be 100′ or more wide.

The useful characteristics of the willow are :—(*a*) rapidity of growth ; (*b*) density of fibrous rooting rendering it good for holding free sand or soil against erosion, and excellence for promoting deposition of silt ; (*c*) ability, through its prolific rooting to establish contact and permanent fixation on the river bed even when suspended in the water above the bed ; (*d*) cheapness of construction. Maintenance consists of keeping the willows cut back to a height of some 8 or 10 feet above flood level. They should not be allowed to grow high and become top-heavy.

8. **Well foundations.** These are normally sunk by open dredging. Cranes (Scotch derrick type if fixed, or revolving jib type if rail mounted) are preferable to hoists and gantries. A great advantage of mounting dredging machinery on a temporary track is the rapidity with which the river bed can be cleared in case of floods, but a clear through line has to be left for material trains, rail-mounted pile driving sets (for temporary pile bridge), and girder assembly, etc. Where it is not possible to construct the well shoe (curb) on the river bed, artificial islands can be made in water not exceeding about 15′ in depth and 2′ to 3′ per sec. velocity, first constructing a double ring of light piles and brushwood to contain the filling. Where depth and velocity rule out this device, double ring steel cylinders (caissons) are built on shore, launched, floated to site, located for centre line and level by tackles fastened to pile clusters, or (alternatively) erected on pile stagings at pier site and lowered by jacks on to the river bed. Owing to bed scour set up under the cutting edge as it approaches river bottom some gravel or similar light protection to the bed may be necessary. Additional steel strakes are added to the cylinder until it is securely bedded. Sinking is by open dredging from crane or gantry rigs on floating sinking sets. Ordinary obstructions such as tree trunks can be smashed with rail chisels, or by drilling by driver and blasting with electric exploder. Wells hung up on clay are loosened by reducing skin friction and buoyancy by pumping, care being taken not to cause blows or "plunging," namely a downward plunge of the entire well. For sinking through boulders or founding on rock, etc., pneumatic sinking is employed. To a ring attached to the steel shoe is bolted a cone (called air dome) connected with a shaft to the discharge lock at the top. This apparatus can be attached or not according to strata and obstructions encountered, and can be removed or replaced at will.

To overcome skin friction wells are designed with walls as thick and heavy as possible, care being taken to leave a central hole big enough to take the dredgers to be employed. 7′—6″ thick steining for a 25′ dia. well is normal. The "sinking effort" (weight divided by outside superficial area) should not be less than 2½ cwt. per sft. 4 cwt. sft. can be attained by use of heavy-aggregate concrete. A top plug is always used, a bottom plug generally used. Although bottom plugs were not used in three wells of the Ganges bridge at Sara, and the Bally bridge over the Hooghly, they provide for medium depth wells used in Punjab rivers a factor of safety (in case of unpredicted scour) which the cautious engineer will not willingly omit. Similar reasons apply to the practice of filling the intervening space with sand.

The subject is dealt with in greater detail in Mr. T. McIntyre's " Well Foundations for Bridges " published in Railway Board Technical Bulletin, July 1945. As regards plant, hoists should be 5 tons to handle 36 cft. Priestmans grabs, and there should be surplus boiler power to deal with pulsometers, pile hammers, etc. Charges for shaking a hung-up well should not normally exceed four sticks (eight ozs.) of gelignite, for wells up to 20′ dia., increasing for larger wells. The risk in heavy charges is that the well is lifted by the explosion and is then dropped, but if it is gripped high up, the bond rods may tear out and the well split circumferentially.

9. **Depth of wells.** The first step is to ascertain the greatest depth of water which can be found from soundings in the river at active bends in the vicinity of the bridge site, reducing the soundings to depth below low water level as the most convenient datum. The greatest scour will probably be found, not at high flood when the water is following a fairly direct swift course, but on a falling river at about three quarters stage.

That portion of the well which is sunk below the scour line is known as the embedded depth or grip. Most engineers agree that the grip obtained for wells of medium depth from Graph XIII-A illustrating Chapter XI of Spring's River Training and Control (Railway Board Technical Paper No. 153) see Fig 3, is excessive. Provided that deepest scour has been carefully estimated, a grip of half the depth of the pier in water (*i.e.*, $\frac{1}{3}$ of the height from foundation level to flood level) is sufficient. If scour approaches this depth stone should be thrown in. If it continues until the grip is reduced to $\frac{1}{5}$, (*i.e.* $\frac{1}{6}$ of the height from foundation level to flood level) the bridge is in danger and trains should be piloted over.

Gales' rule for depth of scour is to add to the deepest measured scour at a bend 33 per cent for contact with a hard bank plus 25 per cent for local eddy scour, *i.e.*, $D=\frac{125}{100}\ \frac{(133d)}{100}$, as at para 4. To this he adds a grip of 50′. The following example is given to illustrate a foundation depth worked out on the $\frac{1}{2}$ (or $\frac{1}{3}$)$\frac{1}{3}$ rule mentioned above for comparison with Gales 50′ rule and Spring's Diagram, XIII-A.

(1) Greatest measured depth of water ...	50
(2) Deduct rise of flood above L. W. L. ...	14
(3) Greatest measured depth below L. W. L. ...	36
(4) Add 33 per cent ...	12

(5) Deepest probable scour below L. W. L.	48
(6) Add 25 per cent	12
(7) Total deepening below L. W. L.	60
(8) Add rise of flood	14
(9) Total depth of pier in water	74
(10) Grip at $\frac{1}{2}$ of depth of pier in water	37 (Fixed addition of 50′ by Gales).
(11) Depth of cutting edge below L. W. L. = (7) plus (10)	97 (110′ by Gales).

By Spring's diagram, see Fig 3, the depth of cutting edge below L. W. L. is 123 − 14 = 109, and grip = 49′.

10. General. A bridge designed on the foregoing principles will conform to sound practice. For rivers of exceptional size, such as the Ganges, reference should be made to Gales' paper and the discussion thereon, vide Journal of the Institution of Civil Engineers for December 1938, particularly the table on page 175.

There will nearly always be local variations which render exact application of accepted procedure inappropriate. For solution of special problems engineers have to rely on their observation, detailed study of the subject, and ingenuity.

What is needed is an Indian code of practice or bridging manual which will cover in addition to points considered in the note the whole field, including narrowing the river to bridgable size, design of wells, caissons and piers, safe load on deep well foundations, methods of sinking, girder erection, plant, floods and repair of breaches, and a historical river-training summary, with a separate section dealing with rainfall and runoff and hill torrents.

The annual loss to Indian revenues from defective engineering resulting from lack of knowledge of the behaviour of rivers and torrents is probably sufficient to pay in one average year the cost for a decade of a joint departmental engineering committee to co-ordinate and amplify the extremely valuable work which has been (and is being) done by standardisation committees, experimental laboratories, and practical engineers throughout the country.

11. New Methods. For forty years or so, since the widespread acceptance in India of the system of river training on the stone-pitched guide bank principle, development has been mainly confined to refinements of that system. There are signs that we are on the eve of a move forward, assisted by the increased use of models. Pitched islands (see Punjab Engineering Congress Technical Paper No. 275 of 1945) as an aid to river training are a case in point, whether used singly with success as above Suleimanki weir in association with guide banks, or (less effectively) in a string in the absence of other training works. The Suleimanki island perimeter is equivalent to about 550 feet of guide bank, not a light undertaking.

It is to be hoped that experience of pitched islands and of pile and brushwood protection (see para 7 above) will continue to be gained by progressive use of these methods in dealing with full-scale river-training problems.

PLATE I
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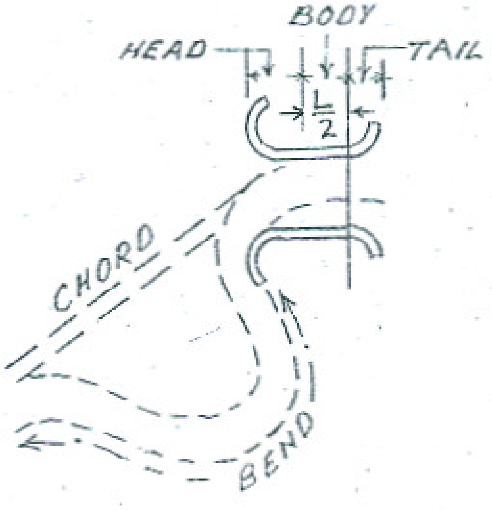

FIG. 1

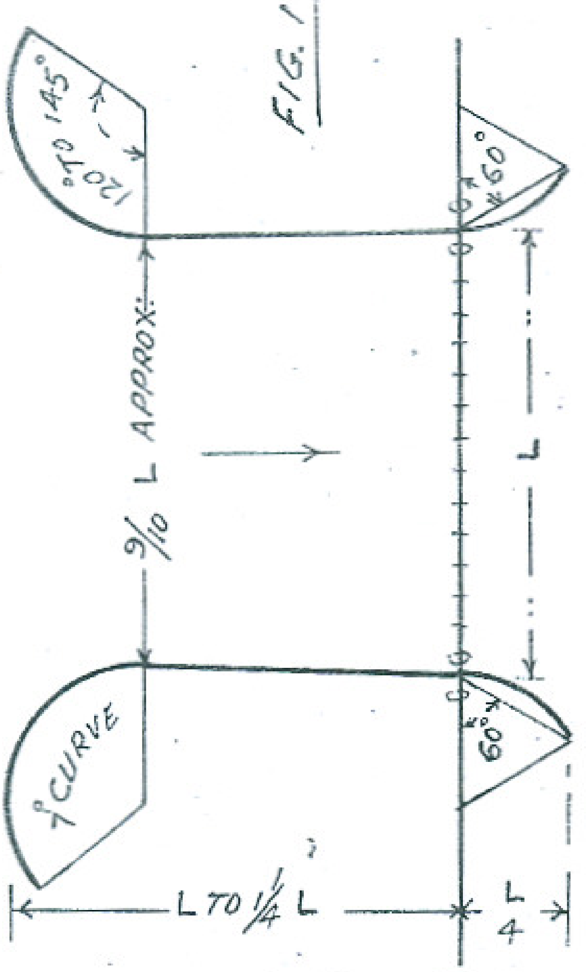

FIG. 2

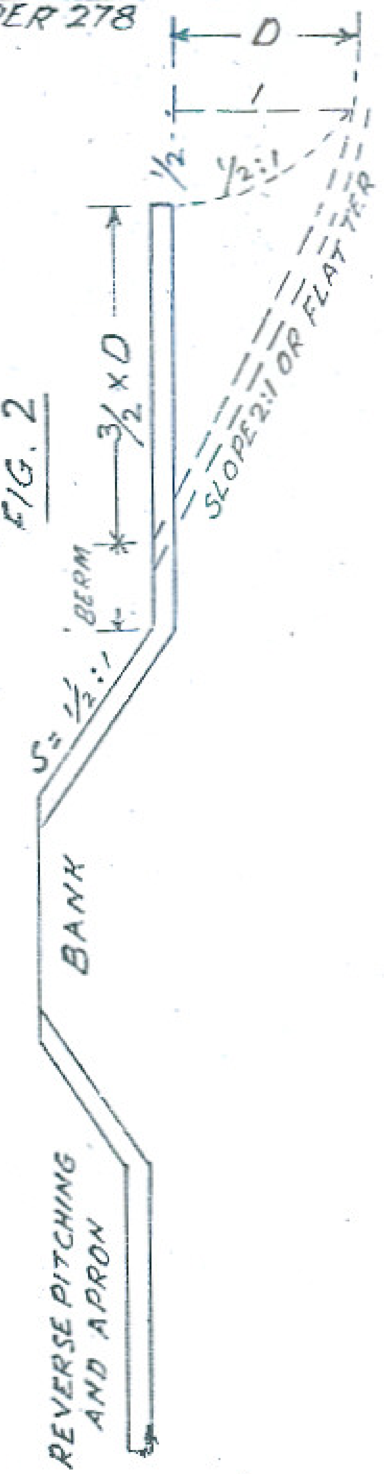

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FIG. 3 VERTICAL SCALE:- 30' = 1"

PLATE 2
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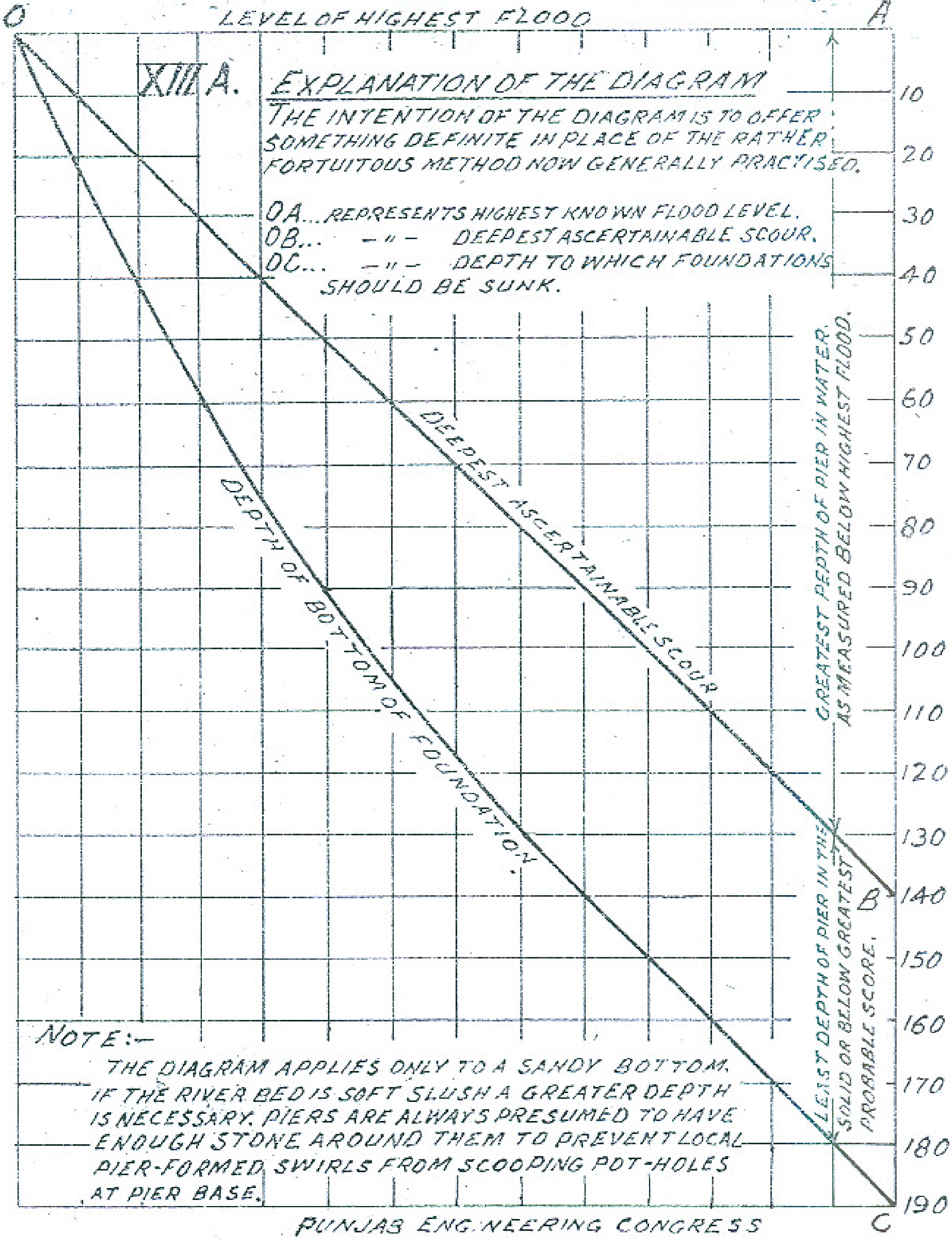

XIII A. EXPLANATION OF THE DIAGRAM

THE INTENTION OF THE DIAGRAM IS TO OFFER SOMETHING DEFINITE IN PLACE OF THE RATHER FORTUITOUS METHOD NOW GENERALLY PRACTISED.

OA... REPRESENTS HIGHEST KNOWN FLOOD LEVEL.
OB... —"— DEEPEST ASCERTAINABLE SCOUR.
OC... —"— DEPTH TO WHICH FOUNDATIONS SHOULD BE SUNK.

NOTE:— THE DIAGRAM APPLIES ONLY TO A SANDY BOTTOM. IF THE RIVER BED IS SOFT SLUSH A GREATER DEPTH IS NECESSARY. PIERS ARE ALWAYS PRESUMED TO HAVE ENOUGH STONE AROUND THEM TO PREVENT LOCAL PIER-FORMED SWIRLS FROM SCOOPING POT-HOLES AT PIER BASE.

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DETERMINATION OF RUNOFF FROM RAINFALL ON PUNJAB TORRENTS

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