Foundation Studies for Yamuna Barrage at Delhi

Etudes de fondations pour le barrage Yamuna à Delhi

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SUMMARY

The barrage is being constructed to supply cooling water to the thermal power station in Delhi and will include a four-lane national highway bridge. The paper describes the foundation investigations carried out for the design of the shallow bridge pier foundations. The field and laboratory tests indicate the existence of loose sand on which the foundations for the piers will be located. Interpretation of the test results for the design of the foundations of the barrage on this loose sand is discussed in detail in order to determine the safe bearing pressures.

SOMMAIRE

Ce barrage est construit pour alimenter en eau de refroidissement la centrale thermique de Delhi. Il comprendra un pont sur lequel passera une route nationale à quatre voies. Cet article décrit les recherches faites en vue de concevoir les fondations peu profondes pour les piliers du pont. Les recherches faites sur le terrain et en laboratoire indiquent l'existence de sable meuble dans la partie supérieure du sol de fondation. L'interprétation des résultats des essais pour le calcul des fondations dans le sable meuble est discutée en détails pour déterminer la charge admissible.

THE YAMUNA RIVER is a tributary of the Ganges. The source of the Yamuna is in the Himalayas and the river flows through the Indo-Gangetic plain which consists of alluvial deposits brought down by the rivers of northern India. Because of the alluvial bed of the river, the river channel, during the dry season, changes its course from bank to bank, and in order to steer the river channel towards the right bank, where the power station is located, a barrage will be built.

A barrage is essentially a gated diversion structure which will provide a certain water level, while taking into consideration other power stations upstream from the barrage and the problem of the pollution of drinking water because of the numerous sullage drains discharging from Delhi into the river. The barrage is built for a flood of 300,000 cusecs and a four-lane heavy traffic national highway bridge will extend over it. Because the piers will be subjected to heavy loads the foundations must be explored in order to determine safe bearing pressures. The plan of the barrage is shown in Fig. 1.

At Delhi the River Yamuna flows through an alluvial bed of sand of considerable depth and varying compactness. Earlier investigations in the vicinity of the barrage indicated that the soil profile consisted of fine silty sands at the top followed by medium sand mixed with varying proportions of kankar (hard nodules of limestone), and a final layer of fine silty sand with varying amounts of clay binder and kankar. Penetration tests carried out earlier indicated different N_c values for the same layer because the compactness of the sand varies in different locations; hence, further investigations along the axis of the barrage and at the pier position were necessary.

FOUNDATION INVESTIGATIONS

Subsoil Exploration

Drilling and sampling. Subsoil explorations along the axis of the barrage were done to study the types and engineering characteristics of the soil under the foundations. Thirteen drill holes were made using 6-in. casing and bailer to a depth of 50 to 70 feet. Disturbed samples were collected by using a flap valve bailer or split spoon sampler at five-foot intervals or as the soil strata changed.

Dynamic Cone Penetrometer Tests

In addition, since the foundation material was sandy, thirteen dynamic cone penetration tests were conducted in the area upstream and downstream of axis. A 2-in.- (50.8-mm-) diameter, 60° cone was driven by a 140-lb weight (63.5 kg) falling from a height of 30 in. (762 mm). Standard A size drill rods were used. Penetration resistance was recorded as number of blows per foot penetration (N_c).

Examination of Test Data

The analysis of the disturbed samples for particle size distribution and plasticity index (Atterberg limits) shows that the foundations consisted mostly of silty fine sand at the top and medium sand with gravel-size kankar at lower levels. The sands are mostly non-plastic. Fig. 2 shows the average grading curves for typical samples at various depths. The top 20 feet consists generally of medium sand mixed with fine sand. This layer is followed by medium sand up to 60 to 70 feet depth below the ground level, with an increase in the percentage of gravel-size kankar with depth. This is shown clearly in Fig. 2. A L-section of subsoil profile along the barrage axis is shown in Fig. 3. In general, the foundations will be resting on fine sand.

Penetration resistance N_c for each test is plotted in Fig. 4 and equal N_c contours are plotted. Variation along the axis is limited to the top strata probably caused by the movable nature of river channel. Consistent observations were obtained from reduced level 635 downwards, except where there are local pockets of kankar.

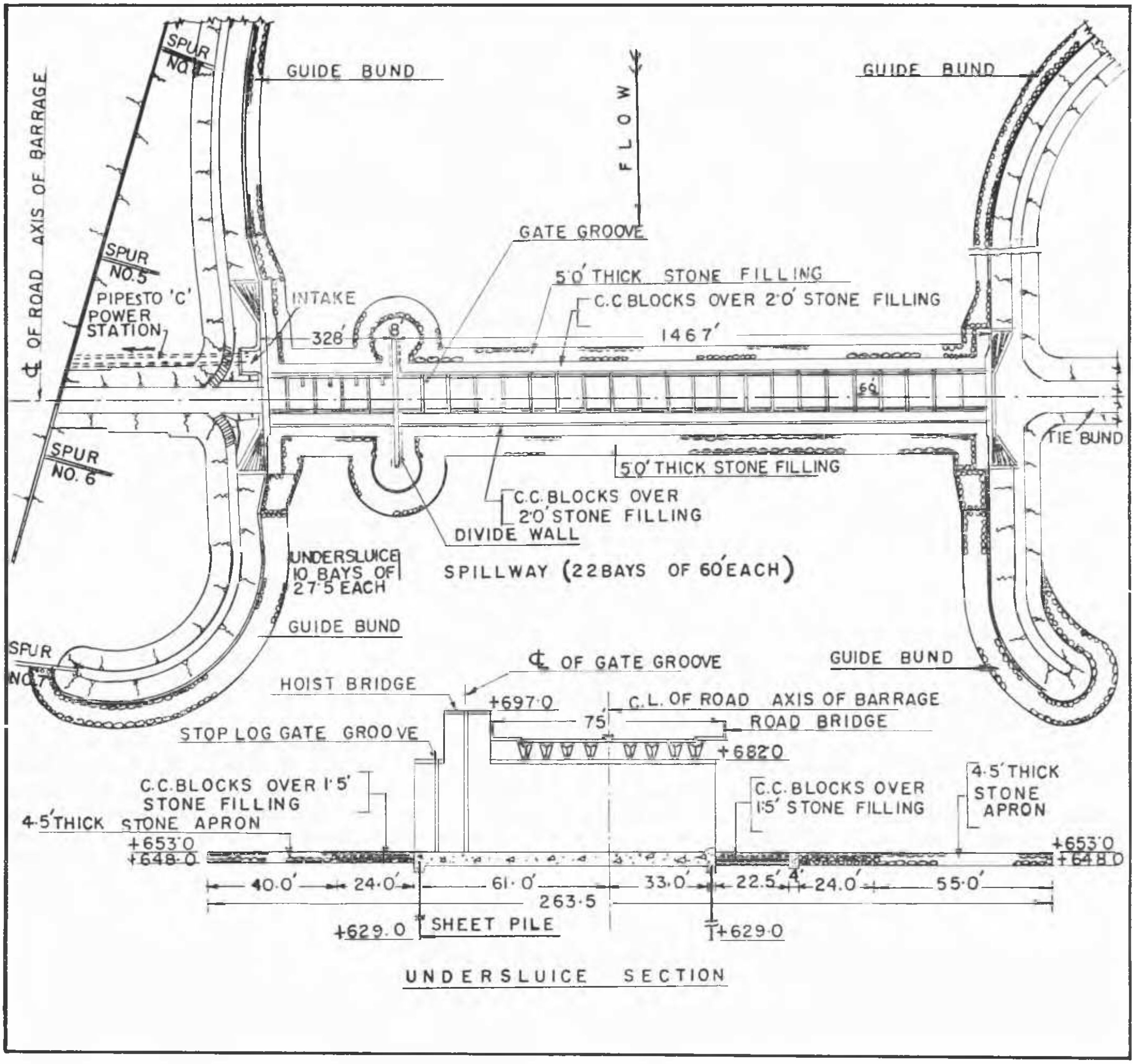

FIG. 1. Plan showing layout of the barrage.

SALIENT FEATURES OF THE DESIGN

Design of the Floor

The floor of the undersluice and spillway is treated as the gravity section. The thickness of the floor is designed to resist the uplift pressure calculated by using Khosla's theory (1936).

Design of the Right Abutment

Three penetration tests conducted below the abutment footing gave the lowest value of N_c as 34 for depth equal to width, neglecting the very high values of N_c due to the layer of kankar. The abutment is to be of coarse rubble masonry with the width of footing between 35 and 40 feet. Foundation pressures are to be determined for construction and maintenance conditions. The first condition takes into account the pressures due to self-weight (excluding the superstructure). In order to determine the safe permissible bearing pressure, two criteria must be checked—the maximum safe pressure possible to avoid failure by shearing (q_s) and the maximum safe pressure possible to limit the settlement of the structure by 1-in. total (q_n). It is essential to limit the settlement not only for the superstructure but also for the smooth working of the gates of the barrage.

The Ultimate Bearing Capacity

B = width of footing = 35 ft.

N_s = Average no. of blows/ft by standard penetration test $= N_c/2 = 34/2 = 17$ where N_c = No. of blows/ft using cone test.

The factors obtained by Meardi, Jathal and Bhrahmnalkar

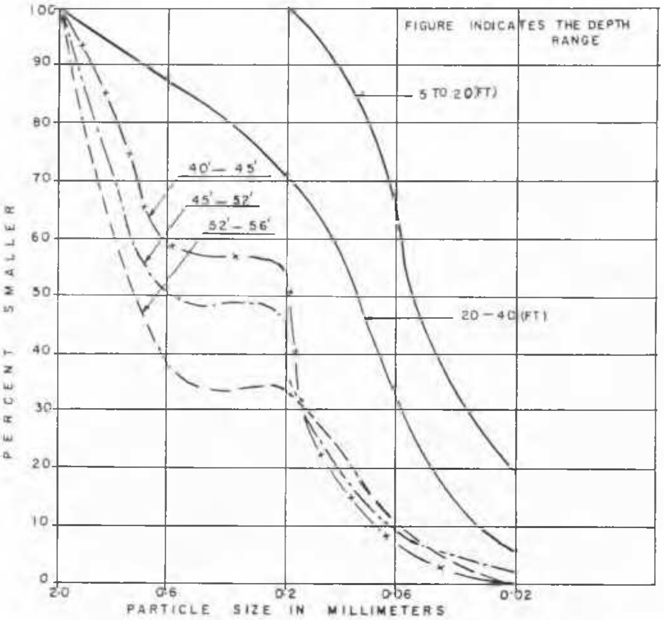

FIG. 2. Average grading curves of foundation soils at various depths.

(1964), and Meyerhof (1956) were examined and Meyerhof's correlation adopted. Therefore, for $N_s = 17$, $\phi = 35°$ (using Meyerhof's relationship) and, using Yamakado's relationship, $\phi = 22 + \sqrt{12}\ N_s = 36°$. Therefore adopt $\phi = 35°$ (average), cohesion $C = 0$, density $r_{sub} = 60$ lb/cu.ft., Depth factor $D_f = 0$, factor of safety $= 3$. Taking these data, the ultimate bearing capacity of the foundation has been worked out by two methods below.

A. Terzaghi and Peck formulae. $q_s = 1/2\ B.r.N_{r.} = 1/2\ B.\ r_{sub} \times N_r$. For $\phi = 35°$ and $N_s = 17$, $N_r = 25$. Safe bearing pressure $= q_s = 1/2 \times 60 \times 25 \times B \times 1/3 = 250\ B = (250 \times 35)/2240 = 3.9$ tons/sq.ft.

B. Meyerhof's equation. Safe bearing pressure $(q_s)_{sub} = (N_s)_{sub}/10 \times B \times 1/3 = \frac{17}{10} \times 35 \times 1/3$ tons/sq.ft. $= 20$ tons/sq.ft.

Thus the safe bearing pressures for ultimate shear failure according to Terzaghi's and Meyerhof's equations are 3.9 tons/sq.ft. and 20 tons/sq.ft. respectively. The latter is too high.

Bearing Pressure to Limit Settlement

Terzaghi and Peck (1948), and Meyerhof's (1956) methods were also used to compute safe bearing pressure to limit total settlement to 1 in.

A. Terzaghi's equation. For $N = 17$ and $B > 20$, using Terzaghi's graph, safe bearing pressure for sand to limit settlement to 1 in. total, will be 1.6 tons/sq.ft. Under submerged conditions the pressure will be reduced by half.

B. Meyerhof's equation. Meyerhof has suggested an empirical equation: $q_a = N_s/10$ tons/sq.ft. $= 1.7$ tons/sq.ft.

De Beer and Marteno (1956) suggested that submergence reduces bearing capacity by one-half, but it is equally true that the cone penetrometer test is performed below the water table and therefore no further reduction in the value is necessary. Hence the safe bearing pressure for 1-inch settlement should be 1.6 tons/sq.ft. Similarly, if the same principle is applied to Terzaghi's chart, the safe bearing pressure for 1-inch settlement will be 1.7 tons/sq.ft. This is substantiated by De Beer's experience and observation of structures in the field.

Design Criteria

In view of the previous considerations, it is proposed to use $q_a = 1$ ton/sq.ft. and $q_s = 3.9$ tons/sq.ft. for the design.

The analysis of the abutment shows that the maximum stress due to self-weight is 1.68 tons/sq.ft. Maximum stress during the maintenance condition with bridge and live load is about 2.3 tons/sq.ft. The ultimate settlement under these conditions may be more than 1 inch, therefore, the abutment will be built to its full height first before the floor is laid

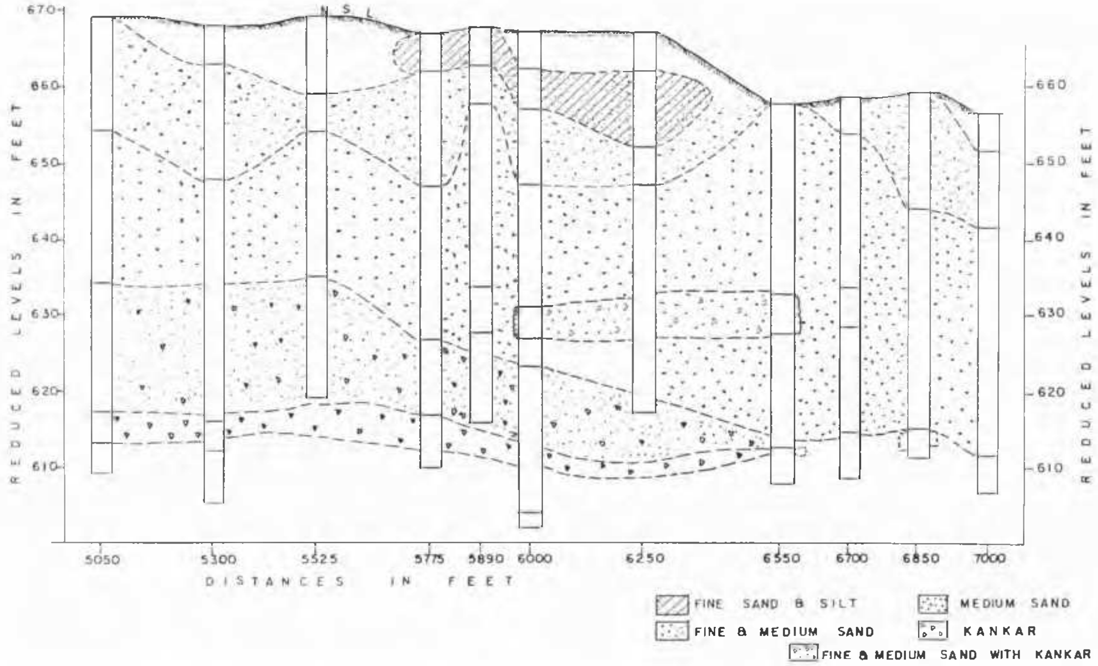

FIG. 3. Subsoil profile along the barrage axis.

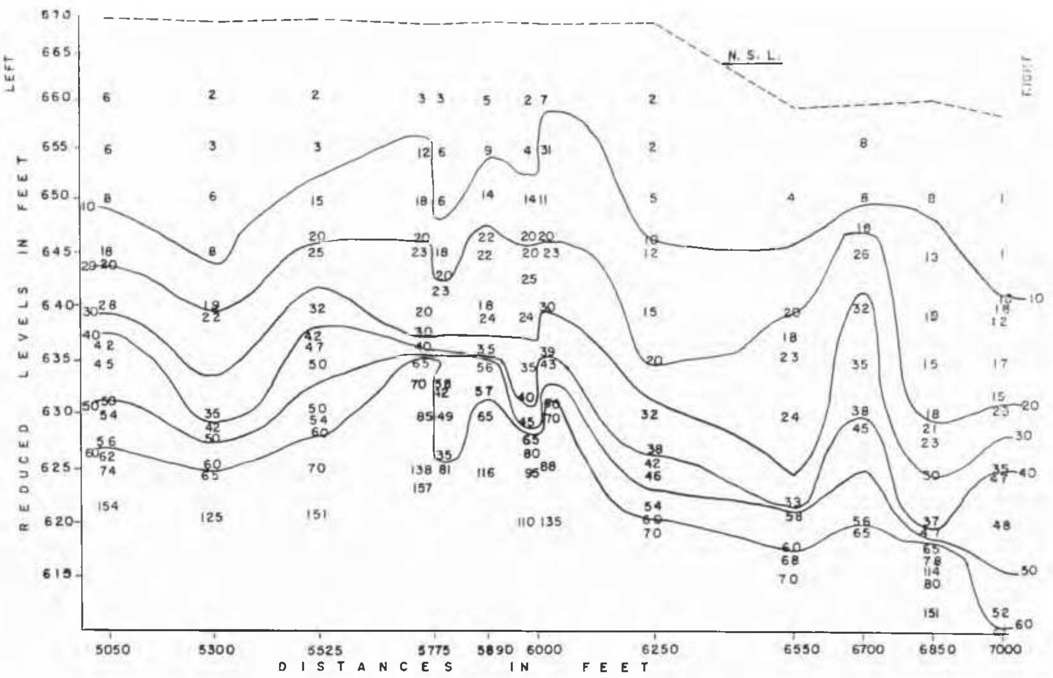

FIG. 4. Penetration resistance N_c contours.

so that initial settlement will take place. The relative settlement between floor and abutment because of the increase in stress from 1.68 tons/sq.ft. to 2.3 tons/sq.ft. at a later stage is expected to be less than 1 inch since the additional stress is only 0.62 tons/sq.ft.

CONCLUSIONS

Though the proposed structure appears safe, there are many unknown factors to be considered. The foundation is not homogeneous; there is about 10 ft. of loose sand at the top followed by medium–dense-medium sand with a varying proportion of gravel sizes like kankars. It is also difficult to visualize the nature of failure in the material in the pressure bulb. In the loose sand, the failure will be local shear and neither Terzaghi nor Meyerhof discusses this problem. A dense layer of sand will be first formed below the footing which will gradually increase in thickness as the stress is increased. During this period failure of the footing would be by settlement resulting from the plastic flow of sand. This state will continue until the sand below the footing is dense enough to undergo shear deformation. Thus even the initial settlement calculations cannot be predicted easily.

Few authors have written about the field behaviour of structures with footings of more than 20 ft. Russian field scale studies indicate that ϕ reduces for stresses more than 1.9 kg/sq.cm. for small footings but this possibility is not confirmed by field observations of large width footings and wells. It is felt that Terzaghi's equation gives very conservative values; Meyerhof, on the other hand, provides extremely high values for ultimate shear. For these reasons it is difficult to determine the problems which may arise in constructing the barrage.

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