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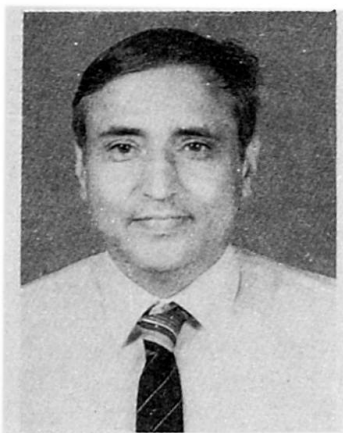
## Foundations for Deep Scour — Ganga Bridge at Varanasi

Protection contre les affouillements du pont de Varanasi

Kolkschutz der Varanasi-Brücke über den Ganges

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S.P. Chakrabarti, born in 1935, received his civil engineering degree in 1957 and has been involved in planning, design and construction of many major bridge projects in India including Varanasi bridge project.

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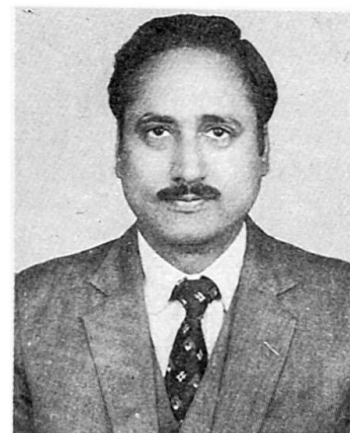
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Dr. G.P. Saha, received his degree in Civil Eng. in 1959 from Calcutta Univ. and did Post-graduate studies at Leeds Univ. England. During Post-Graduation he worked on fatigue on concrete and analysis of bridges. Dr. Saha's subjects of specialisation are reinforced and prestressed concrete and types of structures are bridges and industrial structures.

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### SUMMARY

Foundations for bridges crossing the great rivers of the Indian plains are designed to resist high floods, which cause large depths of general bed scour and local scour around them. The paper describes the salient features of analysis and design of the large diameter deep cylinder sunk by open dredging for the 920 m long monumental bridge project over the Ganga at Varanasi.

### RÉSUMÉ

Les fondations des ponts enjambant les grands fleuves des plaines de l'Inde doivent être conçues pour résister aux grandes inondations, qui causent des affouillements profonds dans les lits soit à grande échelle, soit localement autour des fondations de ponts. L'article décrit les particularités essentielles du projet et du calcul du puits cylindrique profondément foncé et de grand diamètre, réalisé par dragage ouvert pour assurer la protection du gigantesque pont de 920 m de portée, projeté pour la traversée du Gange à Varanasi.

### ZUSAMMENFASSUNG

Die Gründung der Brücken über die grossen Ströme der indischen Ebenen werden für extreme Hochwasser bemessen, die tiefe Auswaschungen des Flussbetts und Auskolkungen an den Pfeilern verursachen. Der Aufsatz beschreibt die Hauptpunkte der Berechnung und Bemessung der tiefen Brunnengründung, die mittels offener Baggerung abgesenkt wurde, für die imposante 920 m lange Varanasi-Brücke über den Ganges.



## 1. INTRODUCTION

High floods in the great rivers washing the alluvial plains of India recur frequently causing immense damage and distress. Flood plains are very wide. Bed and banks are erodible. For building highway crossings over these rivers, large investment is needed for river training into defined channels. Besides, bridge foundations have to be designed to withstand general bed scour and local scour around the foundation which are large.

## 2. PROJECT DETAILS

The new highway bridge under construction over the sacred waters of Ganga at Varanasi can serve as an outstanding example of Indian experience and practice in designing and building bridge foundations for very deep scour.

The width of the flood plains at the crossing spreads to 3 km. The design flood discharge is  $46200 \text{ m}^3/\text{s}$ . The right bank is inerodible and the flood flow will be trained into 920 m channel by an earthen guide bund forming the left bank. The location and layout of the guide bund has been determined by hydraulic model studies (fig.1).

The subsoil strata in river bed are generally silty sand for considerable depth and dense sand at founding level. Very hard clayey silt/silty clay layers have also been encountered at various levels.

The bridge on National Highway 2 is 920.5m long with an approach viaduct 349.5m long (fig.2). It carries a four lane carriageway and 1.5m wide footpaths on either side.

The main bridge consists of 6 middle spans @ 131m each and two end spans of 65.75m each. The superstructure consists of prestressed concrete two cell box girder of depth varying from 2.4m to 8.7m built in cast-in-place cantilever construction and is provided with hinge at mid span. Reinforced concrete hollow piers and single cylindrical caissons have been adopted for foundations.

## 3. ESTIMATION OF SCOUR DEPTH

General scour is estimated as per formula given in IRC:78 [1]. Design scour depth around pier is taken as twice the general scour depth to account for the local scour.

As per the model studies conducted with 920m long bridge (having 9 spans-2 end spans of 57.5m each and 7 middle spans of 115m each with 7m wide piers) and left upstream elliptical guide bund of 460m length and 30m long straight guide bund on down stream, concentration of flow near the right bank was observed. Discharge through the right 6 bays was 85% whereas through the left 3 bays was only 15% of the total discharge. Velocities of flow varied from 3 m/s to 4.1 m/s.

For the purpose of design the river is divided into two scour zones - deep and shallow. Depth of general and design scour for the two zones are given in Table.1.

**VELOCITY ALONG APPROACH EMBANKMENT**

LOCATION	Q = 32400 m <sup>3</sup> /s	Q = 46180 m <sup>3</sup> /s
A	0.81	NIL
B	0.63	0.63
C	—	0.41
D	—	—

**VELOCITY ALONG LEFT GUIDE BUND**

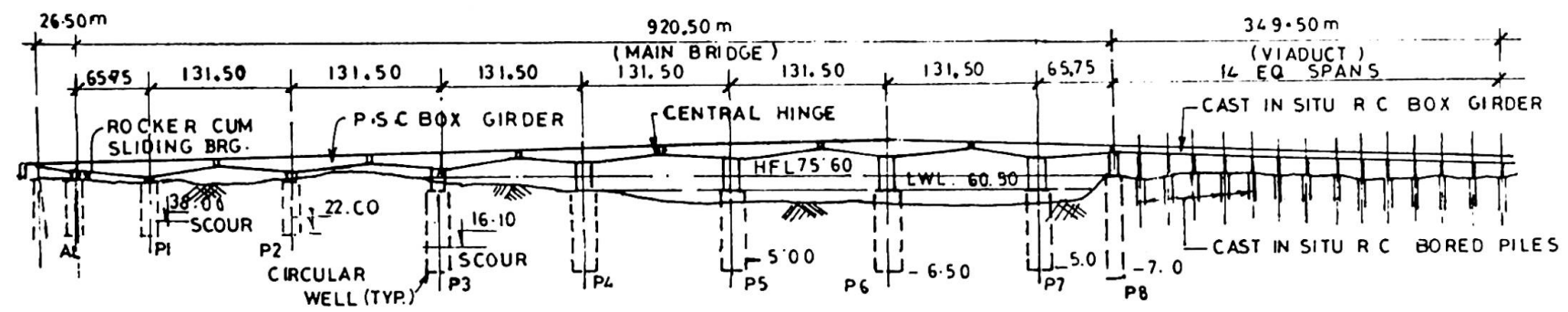
DISTANCE FROM ABUTMENT	Q = 32400 m <sup>3</sup> /s	Q = 46180 m <sup>3</sup> /s
1.8m	2.03	2.28
2.70m	2.85	3.29
3.60m	3.08	4.67
4.20m	3.35	5.05
4.60m	2.69	4.36
NOSE	1.50	3.03

φ = DISCHARGE

**PROPOSAL No. 3**

- TOTAL WATER WAY (L) — 920 m
- U/S LEFT GUIDE BUND: 460 m (05L) ELLIPTICAL CONFORMING TO THE ELLIPSE  $\frac{x^2}{460^2} + \frac{y^2}{184^2} = 1$  FOLLOWED BY THE ARC OF RADIUS 184 m AND ANGLE 30°
- D/S LEFT GUIDE BUND: 30 m STRAIGHT

**FIG. 1. SITE PLAN—MODEL STUDY**



**FIG. 2 GENERAL ARRANGEMENT OF BRIDGE**



	SCOUR ZONE	
	deep	shallow
width	720m	200m
depth of general scour	29.75m	18.80m
design depth of scour	59.50m	37.60m

**TABLE 1 DETAILS OF SCOUR ZONES**

In deep scour zone the design depth of scour (59.5m) is unusually high even for Indian conditions and require special considerations in design and construction. Salient features of the design adopted for foundations in deep scour zone are presented below.

#### 4. FOUNDATIONS

Single cylindrical caissons (wells) sunk by open dredging has been found to be optimal solution for almost all foundations of this type and the same have been adopted for Ganga bridge also.

##### 4.1 Dimensions

From the consideration of design scour depth and minimum grip length specified in IRC:78 [1] minimum depth of foundation works out to 65.5m below the lowest water level. Diameter of well has been adopted as 13m and depth of well varies from 65.5m to 67m from stability considerations. Thickness of steining has been adopted as 2.5m from considerations of sinking effort required. Guidance has been taken from other works of similar nature executed in the past.

##### 4.2 Analysis

###### 4.2.1 Service Stage

Analysis for steining stresses has been done manually for all possible critical load cases and well steining has been designed for the worst load combination. Steining stresses have also been worked out using 3DFE analysis for the critical load cases.

For 3DFE analysis quadrilateral 4 noded plate bending elements have been adopted for well steining, bottom plug and well cap. Typical plot showing variation of longitudinal stress along the well height and variation of circumferential stress along the well periphery at critical level are shown in fig.3 (a) and (b) respectively.

Longitudinal stresses obtained by 3DFE analysis compared fairly well with the results of linear analysis. Hoop stresses are found to be critical and require higher quantum of steel reinforcement than the minimum prescribed IRC:78.

###### 4.2.2 Sinking Stage

During sinking operation apart from the normal phenomenon of tilt and shift associated with kentledge, the well foundations are also encountered with the sand blow which has caused failures to a number of bridge foundations and is the most critical condition.

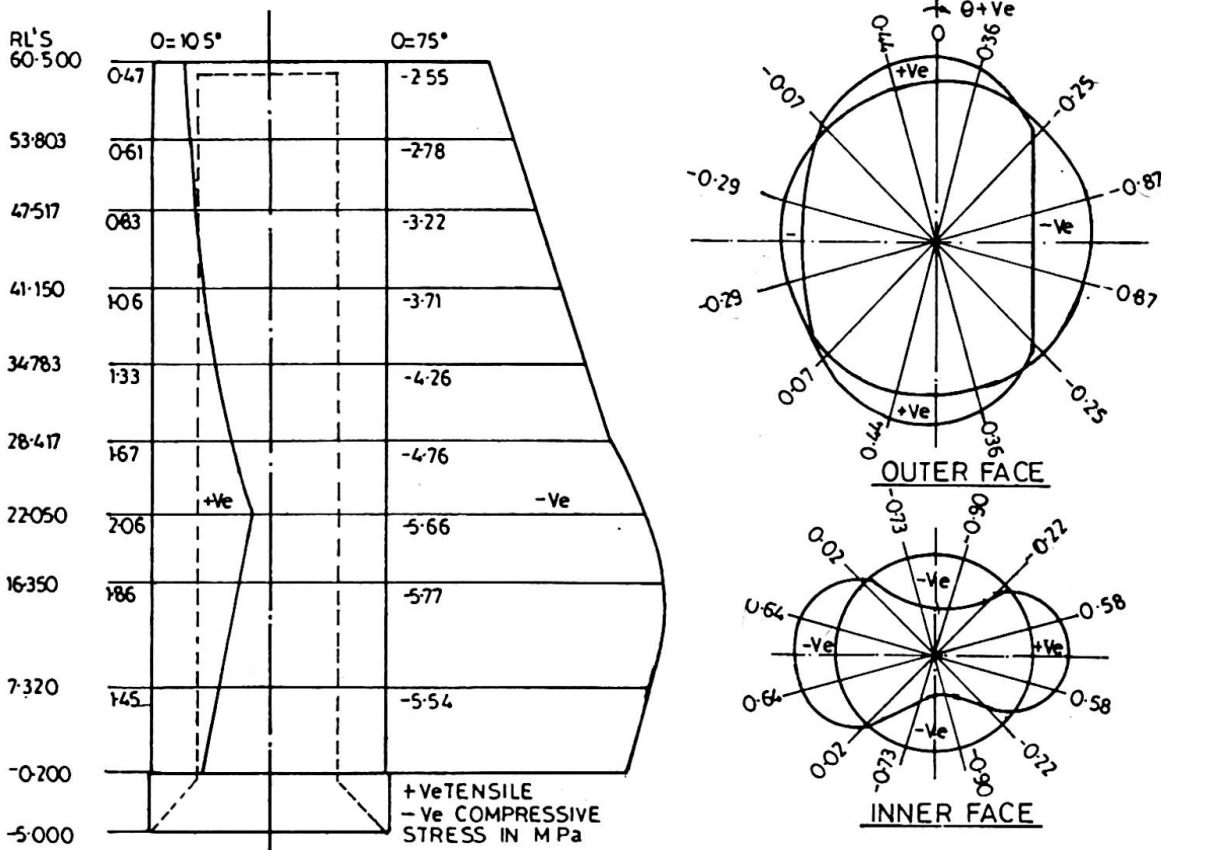


FIG-3 3D FE ANALYSIS FOR WELL P-4 SERVICE STAGE

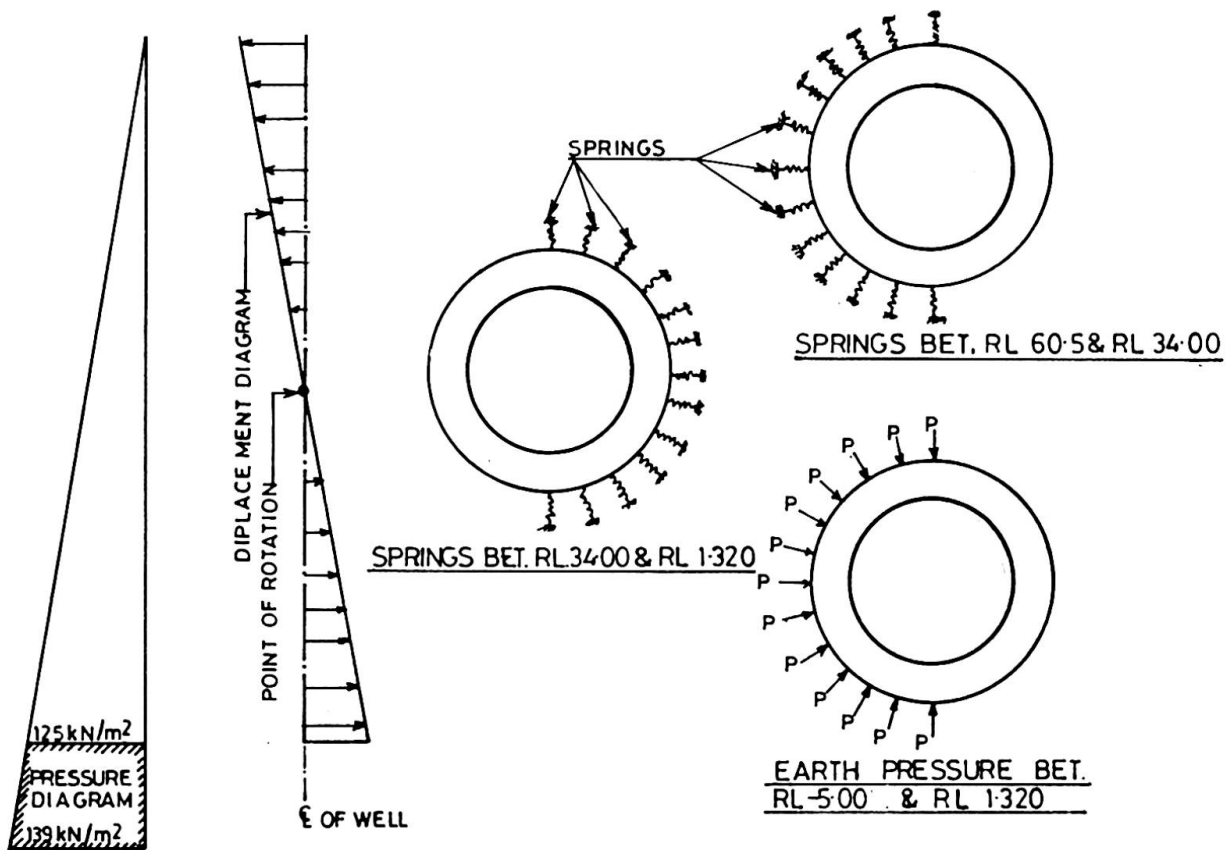


FIG-4 SAND BLOW CONDITION - APPLIED FORCES AND DISPLACEMENT MODEL



Sand blow is caused due to the difference in head of water between inside and outside the well. Though equilibrium condition is reached, in the process, the well steining is subjected to non-uniform earth pressure which give rise to transverse stresses in the steining. Detailed analysis by 3DFE method has been carried out for sand blow condition. Typical details of applied forces, displacement and springs of resistance around the periphery of well adopted in the 3DFE model for sand blow analysis are given in fig.4.

Adequacy of section has also been checked as per the model for earth pressure suggested by Santra and Ganguli [2].

## 5. INSTRUMENTATION

To assess the performance of the structure both during construction and in-service, extensive instrumentation scheme has been planned.

In the foundation earth pressure cells and reinforcement gauges are being provided to measure the earth pressure and stress in reinforcement both longitudinal and hoop actually developed at various stages. Provision has also been made to measure inclination of wells with the help of inclinometer. Pressure cells provided around the periphery at various levels along the length of well may give sufficient data to arrive at the mathematical model of earth pressure for analysis. Similarly, reinforcement gauges may help in checking the mathematical model assumed in analysis and design. Sand filling normally done in the wells has been dispensed with to facilitate inspection of steining from inside the well with the help of under water video camera. A hole has been provided in the well cap for inspection purpose.

Similarly, extensive instrumentation scheme is being planned for piers and superstructure.

## 6. STATUS

Owner : Union Government of India  
 Agency : Uttar Pradesh State Public Works Department  
 Contractor : M/s.Hindustan Construction Company Ltd., Bombay, India.

Date of Commencement : December, 1988

Work on foundations is in progress. By July 1991 out of the 9 well foundation 7 have reached the founding level. It had been possible to sink the wells without much difficulty.

## 7. CONCLUSIONS AND RECOMMENDATIONS

It is possible to sink deep wells in alluvial soil. Analysis should be done for both longitudinal and hoop stresses especially when diameter of well is more than 10m.

## REFERENCES

1. IRC:78-1983 Standard Specification and Code of Practice for Road Bridges, Section VII Foundations and Substructure.
2. Santra A. and Ganguli R.C., Design of Well Steining against Sand Blowing Condition During Sinking. Cement and Concrete, Vol 8, 1968.