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Satellite Office: IDA Bulding Ground Floor, Jamnagar House, Shahjahan Road, New Delhi-110 011

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OPTIMIZING FOUNDATION DESIGN THROUGH QUALITY GEOTECHNICAL INVESTIGATION–CASE STUDY OF BRIDGE ACROSS RIVER TAPI




RAVI SUNDARAM[1] SANJAY GUPTA[2] SORABH GUPTA[3] RAJESH GUPTA[4]

ABSTRACT

The quality of geotechnical data greatly influences the foundation design. Use of the right kind of equipment for geotechnical investigations can help in optimizing the foundation design and can result in substantial cost savings. The paper presents a case study illustrating the advantage that can be achieved by using triple tube core barrel to drill through weathered rock. Initial geotechnical investigations for a bridge across Tapi River carried out using "calyx" drilling rig and single tube core barrel yielded low core recoveries and RQD values. This resulted in a very conservative foundation design with bridge pier footings bearing at nearly 7 m depth into the basalt rock. To economize the design, a confirmatory geotechnical investigation was done at the same locations using a hydraulic core drilling rig with triple tube core barrel which confirmed high recovery and RQD values. Graphical plots of recovery and RQD with single and triple tube core barrel illustrate the substantial increase in these values when in the superior equipment is used. Although there is a lot of scatter in the data, it is evident that the use of triple tube core barrel gives a more realistic estimate of the core recovery and RQD values. As a result, the design is more economical and reliable. The design was revised based on the data which confirmed higher safe bearing pressures at shallower depths. The overall impact of the exercise was a direct saving of 1.86 crores in foundation cost alone (51% of the original estimate) based on a confirmatory investigation costing less than 15 lacs- a 1200% return on investment! In addition to this, there was indirect savings in cost of blasting, dewatering and manpower. The time saving was also substantial.

1. INTRODUCTION

The importance of ensuring proper quality of work for a geotechnical investigation cannot be over-emphasized. Proper exploration methods and use of appropriate sampling tools are crucial for a thorough investigation.

Good quality samples and reliable geotechnical data can not only economize the foundation design but also help in selecting the right type of equipment for excavation of foundation pits. It also generates appropriate geotechnical design parameters and can optimize the depth at which foundation may be constructed.

The paper presents a case study of how geotechnical investigation using the right equipment/ tools can generate a realistic ground profile to help take critical decisions on foundation depth and design safe bearing capacity. It demonstrates that rational solutions to geotechnical problems are possible using realistic borehole data and can result in substantial cost savings.

2. PROJECT DETAILS

A bridge is planned across River Tapi on National Highway NH-752G in Maharashtra, upstream of the Prakasha dam/barrage. The 610 m long bridge shall have nineteen piers and two abutments (each span of 30.5 m long). The existing bridge, 8.5 m away from the proposed new bridge has 39 spans, each 15.25 m long.

Rock is encountered at the project site from the ground level. The rock classifies as basalt. A photograph showing the exposed rock along the alignment is illustrated on **Fig. 2.**

1 Director, Email: ravi@cengrs.com
2 Managing Director, Email: sanjay@cengrs.com
3 Director, Email: sorabh@cengrs.com
} Cengrs Geotechnica Pvt. Ltd., Noida
4 Sr. General Manager (Technical), H.G. Infra Engineering Ltd., Jaipur, Email: rajesh.gupta@hginfra.com

A sketch showing the bridge details is presented on **Fig. 1.**

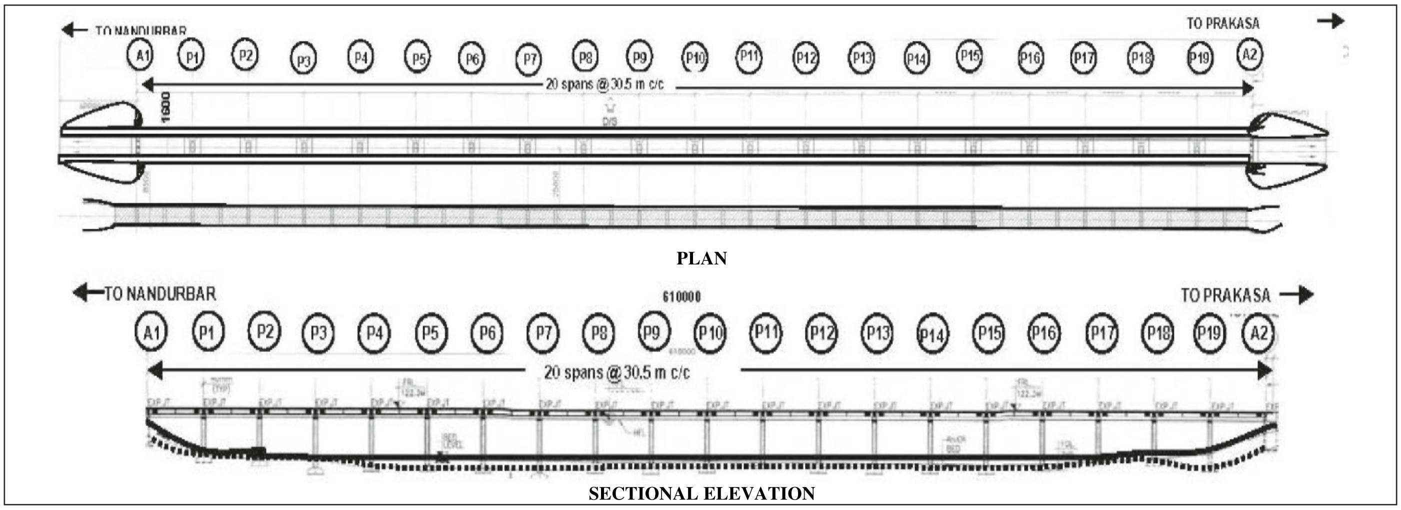

Fig. 1 Schematic General Arrangement Plan of the Bridge

Rock is encountered at the project site from the ground level. The rock classifies as basalt. A photograph showing the exposed rock along the alignment is illustrated on **Fig. 2.**

Fig. 2 Rock Exposed Along Alignment Adjacent to Existing Bridge.

Note the Barrage Spillway in the Background

3. INITIAL GEOTECHNICAL INVESTIGATION

3.1 Requirements of IRC and IS Codes

Appendix-2 of IRC: 78-2014[1] states that the extent of exploration for bridges shall be adequate enough to give a complete picture of the rock profile, both in depth and across the channel width. For sub-surface investigation in rock, double tube diamond drilling method shall be used. The standard proposes use of triple tube drilling in weak friable rocks.

IS: 1892-1979[2] states that core drilling shall be so designed that in sound 'rock, continuous recovery of core is achieved. It suggests using double tube core barrels for ensuring better core recovery. IS: 6926-1996[3] also recommends use of double tube core barrel and suggests use of triple tube core barrel in soft rocks.

3.2 Drilling using "Calyx" Rig

The agency that had been awarded the design and construction work got a detailed geotechnical investigation done from a local drilling contractor. The drilling contractor mobilized a light-weight calyx drilling rig (popularly used for drilling tube-wells)with a screw feed arrangement. Drilling was done using a single tube core barrel. A photograph showing the rig is illustrated on **Fig. 3**.

Fig. 3 Drilling using Calyx Drill Rig

The calyx drill machine does not have a hydraulic system to apply pressure on the drill-head; hence the rate of drilling is slow. Further, there is a lot of play in the drilling alignment. As a result, there is lot of vibration and disturbance during drilling with a single tube core barrel which results in grinding of the core (resulting in lower recovery) and its breakage (leading to lower RQD value).

The standard practice is to use a double tube core barrel to minimize the disturbances during drilling and core sample collection. The single tube core barrel is known to result in poor core recoveries due to mechanical fracturing of the rock cores during the sampling process.

3.3 Drilling Data Obtained and its Consequences

Fig. 4 presents borehole data obtained. Core recovery[4] and the RQD values recorded using a single tube core barrel are quite low, leading to a lower assessment of the Rock Mass Rating (RMR)[5] value. The safe bearing pressure assessed at 1-1.5 m below the top of rock as per IS: 12070-1987 RA 2010[6]ranged from 300-400 kPa (30-40 T/m^2).To achieve the desired SBC of 800-900 kPa(80-90 T/m^2), the investigation agency suggested extending the foundation depth to about 4.5-7.5 m below ground level.

This required substantial excavation through the rock in addition to a huge cost for dewatering. The design was approved, and the EPC contractor mobilized the construction team and equipment to the project site to begin foundation construction.

However, the work came to a standstill when trial excavations at some pier locations indicated that the rock was much harder than anticipated and could not be excavated using the conventional excavators mobilized for the purpose. Dewatering in the fractured rock formation was another challenge.

More than one year of precious construction period was lost on account of this as the contractor was forced to demobilize from the site and revisit his foundation design.

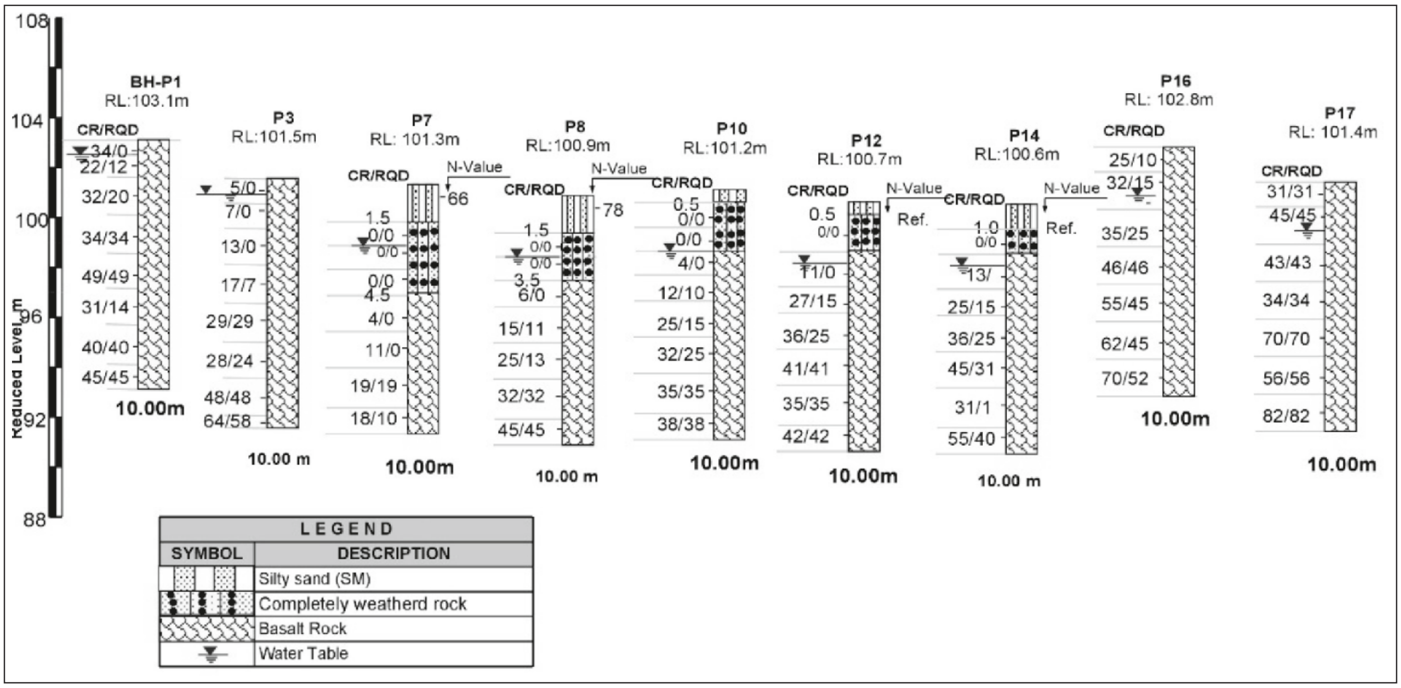

Fig. 4 Cross-Sectional Profile Along Bridge Alignment Showing Typical Boreholes Drilled by Calyx Drill Rig Using Single Tube Core Barrel

4. ADDITIONAL GEOTECHNICAL INVESTIGATION

4.1 The Need for Additional Investigation

Excavation for foundation construction indicated presence of hard rock with widely spaced joints contrary to the borehole data. Considering the problems in excavation and foundation construction, the contractor decided to perform an additional geotechnical investigation to check the apparent discrepancy between the soil report and the in-situ conditions at the site.

The intention was to use better drilling method to obtain superior quality samples that could explain the reason for difficulties faced in excavation and validate the require dsafe bearing capacity values at shallower depth. Diamond core drilling in accordance with IS: 6926 (1996) RA 2001[3] was performed.

4.2 Drilling using Hydraulic Rig with Triple Tube Core Barrel

The authors proposed that the drilling should be done using a heavy duty hydraulic rotary drill rig instead of the calyx rig. The hydraulic pressure applied on the drill string shall not only increase the rate of drilling, but also ensure verticality of alignment and avoid play and vibrations, thus minimize fracturing of the rock core. **Fig. 5** presents photograph of core drilling using hydraulic rotary rig.

Fig. 5 Drilling Using Hydraulic Rotary Drill Rig

Although double tube core barrel is a popular and somewhat more economical option (from perspective of investigation costs), the triple tube core barrel can provide a more realistic assessment of the rock characteristics. The higher drilling cost using triple tube core barrel can be justified by the substantial savings in foundation costs.

Triple tube core barrel[7] has three concentrically placed tubes. The outer tube is for cutting, middle one is for finer cutting of the core and the inner tube is for retrieving core sample with minimal disturbance or damage. **Fig. 6** presents pictorial sketch of the triple tube core barrel illustrating the three tubes, valves, etc. The innermost tube is a split stainless-steel pipe. The outer tube is hard-faced to reduce wear and tear and to act as a stabilizer.

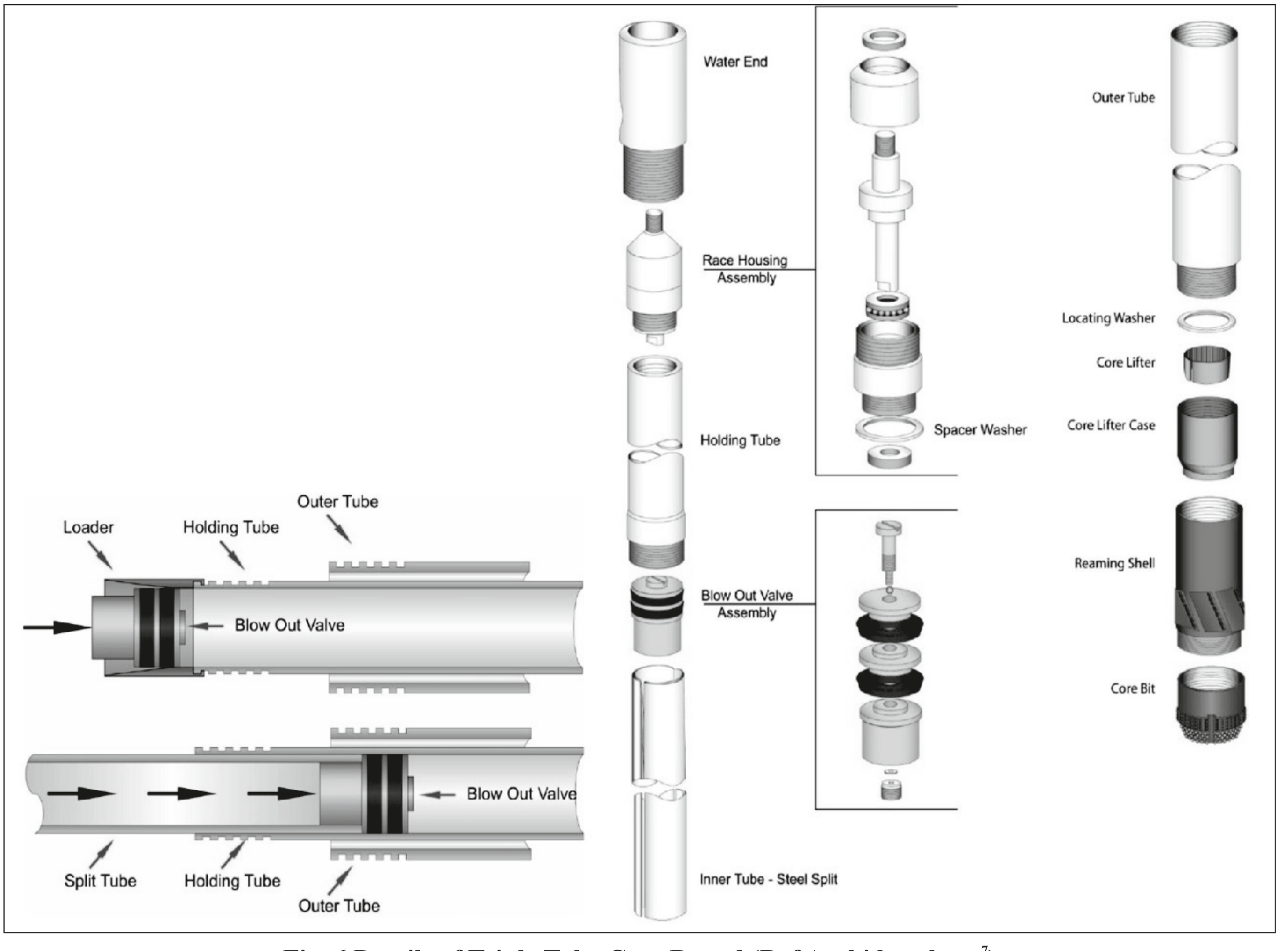

Fig. 6 Details of Triple Tube Core Barrel (Ref Asahi brochure[7])

4.3 Comparison of Borehole Data–Triple Tube Core Drilling Versus Calyx Drilling (single tube)

The additional investigation included 20 boreholes through the rock at the pier and abutment locations. The boreholes were drilled to 15 m depth.

Fig. 7 presents a comparison of drilling data at two typical pier locations (P-4 and P-8). It may be seen that while drilling with the calyx rig indicates very poor to poor recoveries and RQD, use of the triple tube core barrel ensures high recovery and superior sample quality. The RQD values are substantially higher in comparison to single tube drilling. **Fig. 8** shows selected boreholes along the bridge alignment drilled using triple tube core barrel.

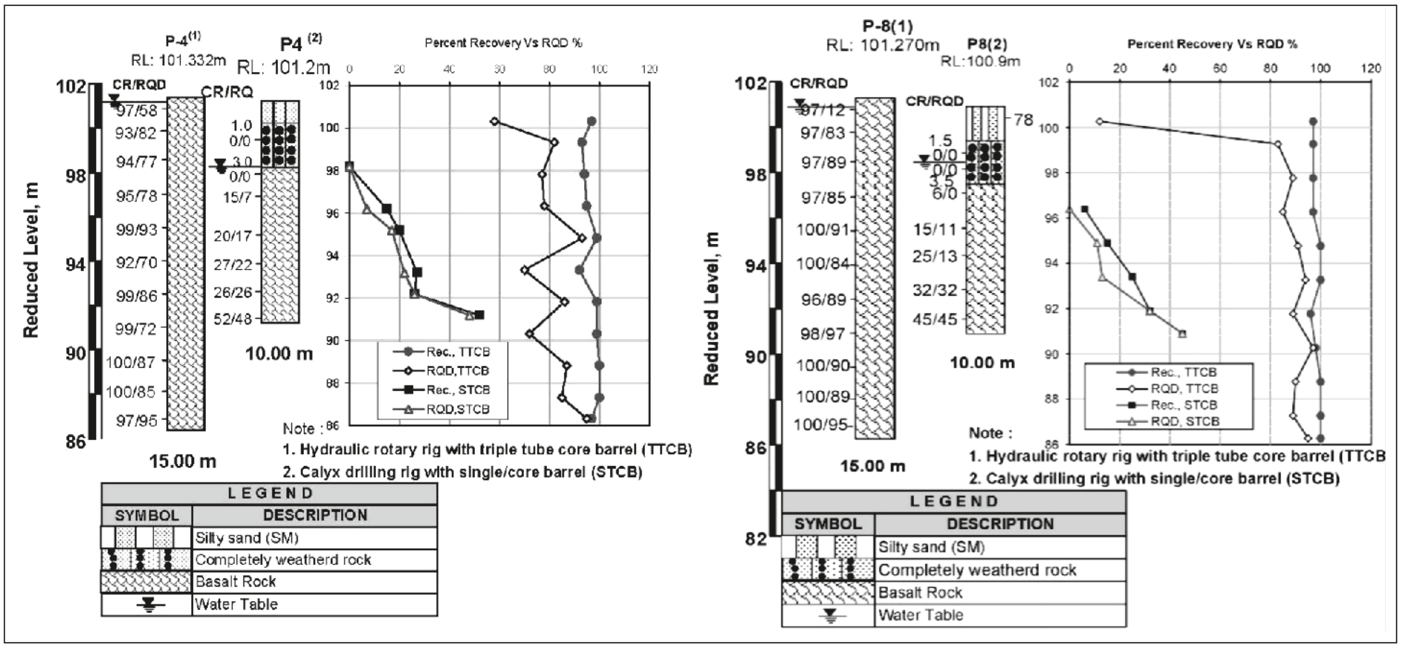

Fig. 7 Comparison of Drilling Data (recovery and RQD) of Single Tube Core Barrel Using Calyx Rig and Triple Tube Core Barrel Using Hydraulic Rotary Drill Rig.

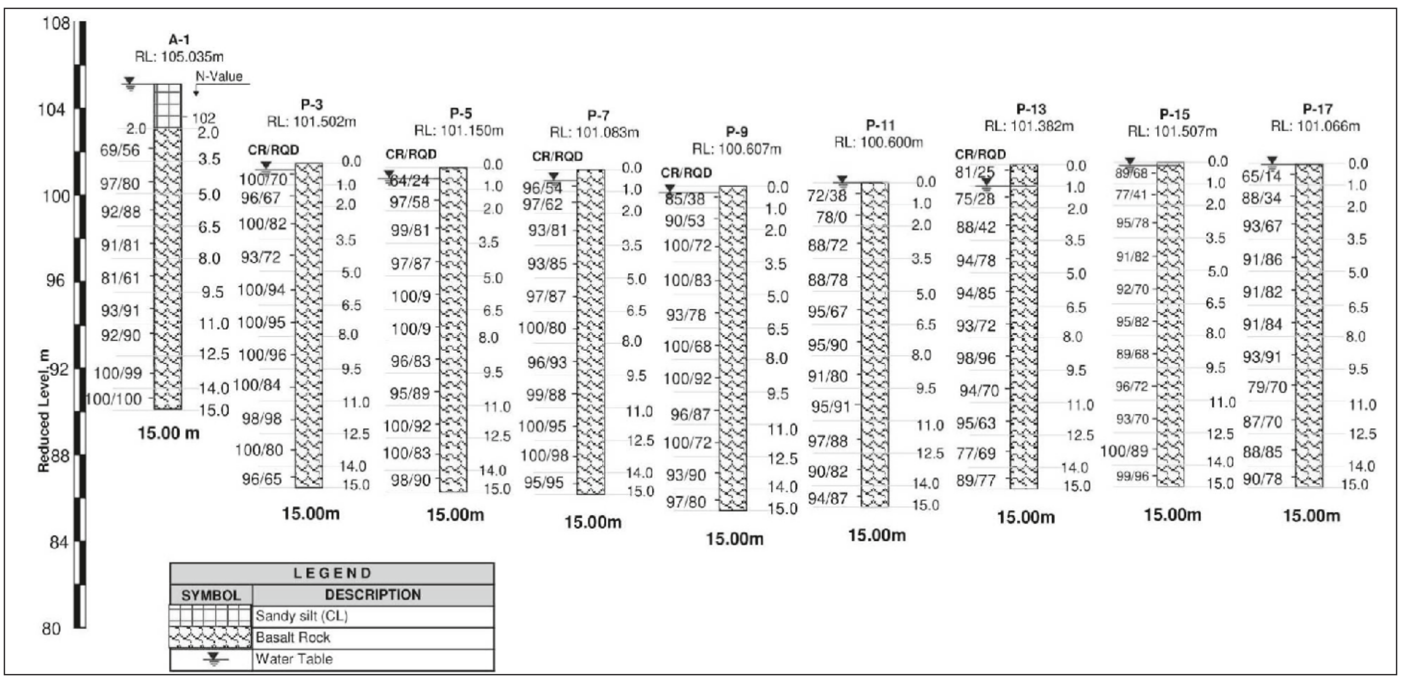

Fig. 8 Cross-Sectional Profile Along Bridge Alignment Showing Typical Boreholes Drilled Using Triple Tube Core Barrel Using Hydraulic Rotary Drill Rig

It is evident that use of triple tube core barrel yields high recovery of the rock core (> 90% in this case), as compared to core recoveries of only about 10-30% in the earlier investigation. The RQD values are also higher since disturbance/vibrations are minimized and chances of mechanical breakage of rock cores are low.

4.4 Data Analysis

Plots of core recovery versus and RQD depth for single and triple tube core barrels are presented on **Figs. 9 and 10**. It is evident that there is a substantial increase in both core recovery and RQD values when triple tube core barrel is used.

A comparison between core recoveries and RQD using single tube core barrel and triple tube core barrel is depicted graphically on **Figs. 11 and 12.** These graphs illustrate the advantage of using triple tube core barrel and demonstrate the poor quality of data obtained using a single tube core barrel and calyx drill rigs.

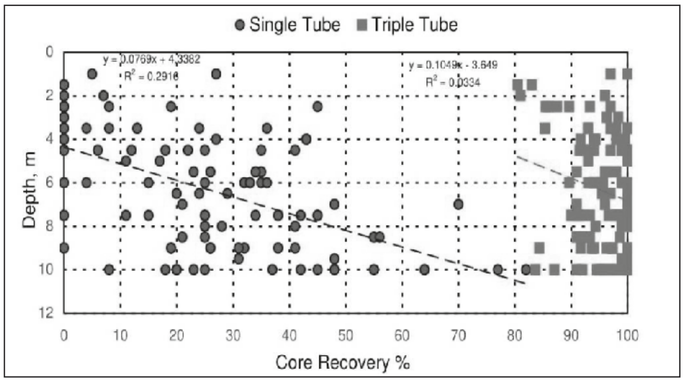

Fig. 9 Plot of Core Recovery Versus Depth Using Single Tube and Triple Core Barrel

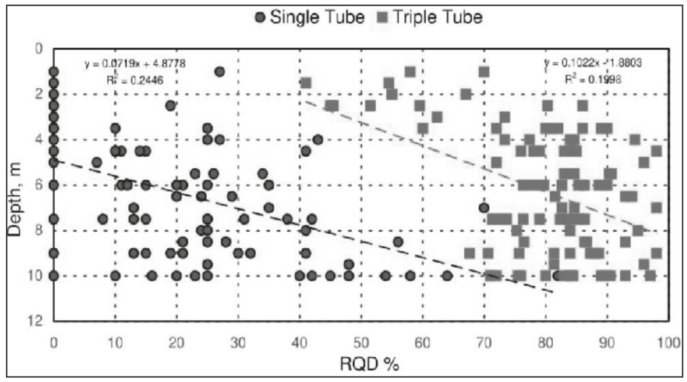

Fig. 10 Plot of RQD Versus Depth Using Single Tube and Triple Core Barrel

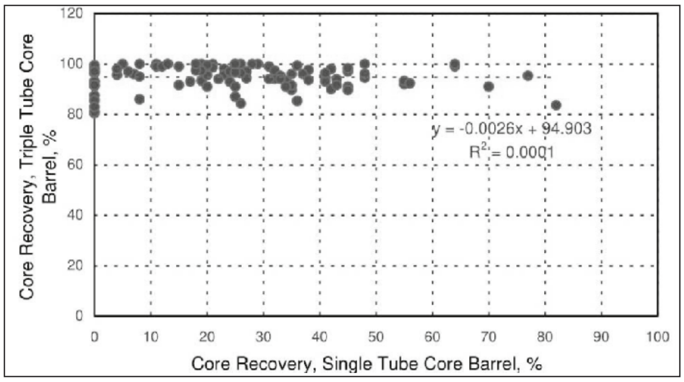

Fig. 11.Comparison of Core Recovery with Single Tube and Triple Core Barrel

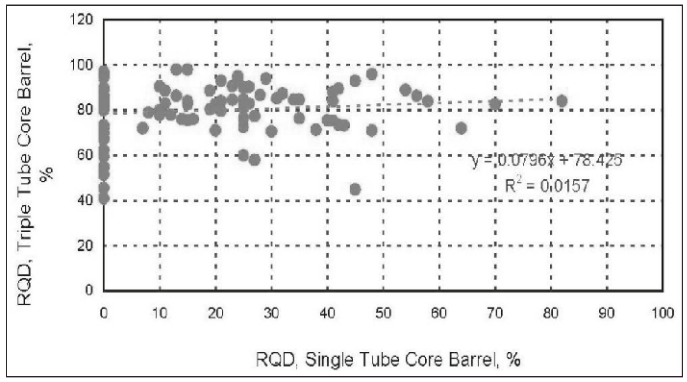

Fig. 12 Comparison of RQD with Single Tube and Triple Core Barrel

Regression analysis shows that the core recovery is generally above 90% with triple tube core barrel while the core recovery using single tube core barrel is generally in the range of 0 to 30%. The graph is nearly horizontal with a large scatter in values.

RQD plots of single and triple tube core barrel indicate RQD values generally exceeding 70% with triple tube core barrel while the RQD using single tube core barrel is generally in the range of 0 to 25%. The scatter in data points is large.

The scatter may be attributed to the vibration and disturbance during drilling with a single tube core barrel which could be variable and erratic.

5. IMPACT ON FOUNDATION DESIGN

Based on the initial investigation using single tube core barrel, the Rock Mass Rating (RMR) was assessed to be in the range of 15-20 at shallow depths, increasing to about 28-32 below 4-6 m depth. The uniaxial compressive strength of the rock cores ranged from 17.0 to 30.0 N/mm^2 at shallow depths, increasing to 30.0 to 45.5 N/mm^2 at deeper depths.

Accordingly, the investigation agency suggested a safe net bearing pressure of about 300-350kPa (30-35 T/m^2) at 2 m depth 450-550kPa (45-55 T/m^2) at 5-7 m depth. For SBC of 700 kPa (70 T/m^2), the required foundation depth was assessed to be about 8-9 m depth.

The investigation using triple tube core barrel yielded high core recoveries and RQD values. The RMR value of the rock mass was assessed to be in the range of 36 to 56. The measured uniaxial compressive strength of the rock cores ranged from 23.0 to 44.0 N/mm^2 at shallow depths, increasing to 38.0 to 52.0 N/mm^2 at deeper depths.

Analyzing as per IS: 12070-1987 RA 2010[6], safe bearing pressure of 90-100 kPa (90-100 T/m^2) could be justified at 2-4 m depth. This is because the RMR value is correlated to the safe bearing pressure. The RMR is a function of the crushing strength, RQD and spacing between the joints among other factors. The increase in RQD could justify using a higher RMR value for the calculations.

The design was done considering a safe net bearing pressure of 900 kPa (90 T/m^2) from the earlier SBC value of 300 kPa. Thus, the SBC values for design could be increased about 3 times in this case.

Since rock is met at the ground level at most pier locations, the scour is expected to be negligible.

As a result, the depth of foundation was reduced substantially, and foundation sizes were also economized. Typically, the foundation plan dimensions reduced from 8.75 m x 10.5 m to 6.5 x 8.0 m. The foundation depth could be reduced from 6.5-8 m to 2-3 m.

6. COST SAVING REALIZED

An analysis was done to assess the savings in quantities of concrete, reinforcement steel and the excavation through the rock.

The quantity of concrete per foundation reduced from 104 m^3 to 54 m^3. The reinforcement steel quantity reduced from 6.8 Tonnes per foundation to 4.6 Tonnes. In addition, there was a large saving in excavation cost and the need for rock blasting was eliminated.

The foundation cost reduced from 3.62 crores to 1.77 crores (approx.), indicating direct savings of about 51% in the material and excavation cost alone.

The indirect savings were even more substantial as given below:

i. Due to the reduced foundation depth, rock blasting was no longer required. In addition to the cost of blasting, the time and effort required in obtaining the necessary permissions for arranging explosives on site would have been quite a challenge.

ii. Cost of dewatering for 6-7 m deep excavation for a period of several months was also saved.

iii. Apart from the above, 8-10 months was saved in construction time alone, which was probably the biggest saving realized. Idling time due to flood in river and other such time losses were minimized.

iv. The saving in manpower cost (labor and personnel) was also considerable. This was not specifically assessed but is expected to be of the order of 25-30 lakhs.

v. There was substantial saving in hire charges of excavators and other equipment, disposal of excavated material, import of soil used for backfilling of foundations, etc. These have also not been specifically assessed.

Table 1 Details of Savings in Quantities at Typical Pier Locations

Pier No.	**Parameter**		**Quantity as per initial design SBC = 300 kPa)**	**Quantity as per revised design (SBC = 900 kPa)**
P-3	Foundation Dimensions		8.75 m x 10.5 m	6.5 m 8.0 m
	Foundation Depth		6.5	2.0
	Concrete Volume		104 m^3	57 m^3
	Reinforcement Steel		6.8 T	4.6 T
	Volume of Excavation		1992 m^3	212 m^3
P-7	Foundation Dimension		8.75 m x 10.5 m	6.5 m 8.0 m
	Foundation Depth		104 m^3	57 m^3
	Concrete Volume		6.8 T	4.6 T
	Reinforcement Steel		1725	235
	Volume of Excavation		1971 m^3	1092 m^3
Cumulative P-1 to P-19	Concrete Volume		130 T	87 T
	Volume of Excavation		19,863 m^3	7,808 m^3

The overall impact of the exercise was a direct saving of 1.86 crores in foundation material and excavation cost alone (51% of the original estimate of 3.62 crores), based on the confirmatory investigation costing less than 15 lakhs- a 1200% return on investment! This is in addition to the large indirect savings.

Table 2 summarizes the savings realized in the foundation costs on the project.

7. CONCLUDING REMARKS

Use of the right kind of sampling equipment and drilling methodology is the key to a proper geotechnical investigation. Conservative designs are often a result of unreliable / non-representative data resulting from use of unsuitable equipment. The money saved by cutting corners in geotechnical investigations is a pittance, as compared to what is at stake.

The use of triple tube core barrel ensures a realistic estimate of rock characteristics by minimizing sampling disturbance and ensuring good quality rock cores. This ensures optimum and safe foundation design. Substantial cost savings can be achieved in foundation sizes and excavation depth. In addition, there could be large indirect

Table 2 Cost Saving Realized

Item	As per initial design (SBC=300kPa)	As per revised design (SBC=900kPa)	Saving	Cost Saving (Rs.)
Concrete (m^3)	1971	1092	879m^3@ Rs. 5000/m^3	43.9 lakhs
Steel (Tons)	130	87	43 T @ Rs. 50000/T	21.4lakhs
Excavation (m^3)	19863	7808	12055m^3@ Rs. 100/m^3	120.1lakhs
Foundation Cost	**Rs. 362.2 lakhs**	**176.4 lakhs**	**Total Savings**	**185.4 lakhs**
Additional saving	: Cost of blasting:12-15 lakhs saved Cost of dewatering: 30-50 lakhs saved due to reduction in foundation depth			
Time saving	: 8-10 months for large quantity of excavation, permissions for blasting, time that would have beenlost due to flood in river, etc.			
Other Savings	: Savings in manpower – (personnel and labour) costs and equipment hire charges, not specifically assessed, but is expected to on the order of 25-30 lakhs.			

saving as a result of reduced construction time.

REFERENCES

1. IRC-78-2014, Standard Specifications and Code of Practice for Road Bridges, Section-VII: Foundations and Substructure, Revised Edition, Indian Roads Congress, New Delhi.
2. IS: 1892-1979, Code of Practice for Subsurface Investigation for Foundations, Bureau of Indian Standards, New Delhi, Reaffirmed 2002.
3. IS: 6926 (1996), Diamond Core Drilling – Site Investigation for River Valley Projects – Code of Practice, Bureau of Indian Standards, New Delhi, Reaffirmed 2001.
4. IS: 5313 (1980), Guide for Core Drilling Observations. Bureau of Indian Standards, New Delhi, Reaffirmed 2004.
5. Bieniawski, Z. T. (1989), Engineering Rock Mass Classifications, Wiley Publishers. Canada.
6. IS: 12070 (1987), Code of Practice for Design and Construction of Shallow Foundations on Rocks, Bureau of Indian Standards, New Delhi, Reaffirmed 2010.
7. Asahi Diamond Industrial Australia Pty.Ltd., Brochure for Triple Tube Conventional Core Barrel, https://www.asahi-diamond.com.au/

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