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Study of the ground behaviour during deep excavation of a hydropower project

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ABSTRACT: The study of behaviour of the ground, during deep excavations, cannot be overemphasized. This leads to an appropriate adjustment in the design of foundations, if so dictated for the reasons of safety or economy.

The authors have drawn an interesting comparison between the predicted and the monitored rebounds of a 24 meters deep excavation for the power house of a hydroelectric project, in a thick alluvium of fine to medium sands, present in a medium-dense to a dense condition. The prediction of the rebound has been made by the analytical procedure given by Perloff and Baladi, based upon the analogy of a strip excavation. The subsequent rebounds have been measured with a system of the magnetic probe extensometers, having a series of embedded spider magnets.

1 INTRODUCTION

During the construction of the powerhouse of 184 MW Chashma Hydropower Project over river Indus in Pakistan, (Fig. 1), 24 meters deep excavations were carried out in thick alluvium of medium–dense to dense sands.

The excavations were carried out in two stages. The first stage excavations ran from El. 192 (at the ground surface) to El. 181 i.e. 11 meters deep. The second stage excavations were carried out from El. 181 to El. 168 i.e. 13 m deep (Ref. 1).

The groundwater table at this site was present almost close to the surface. Therefore elaborate dewatering with a system of well points was also implemented during the excavations.

2 EXCAVATIONS

The 62 m x 202 m base area was required to be obtained at 24 m depth below the top of the ground (Fig. 2), for laying the foundations of powerhouse.

The first stage excavations were completed in September 1995, involving 11m deep excavations in sands below the top of ground. The excavation pit at the ground was kept as 158 m x 298 m which was tapered to 114 m x 254 m at IV:2H slopes at 11 m depth.

Thereafter, the second stage excavations were taken up, which continued from September 1995 to December 1995. The excavations were carried out with the conventional mechanical excavators. Fig. 3 defines the stages of excavation.

3 MAGNETIC PROBE EXTENSOMETERS

Six magnetic probe extensometers of Geotechnical Instruments, U.K., were installed at the selected places at El. 181, upon completion of stage I excavations in September, 1995. These were generally concentrated in the central 2/3rd area of excavation (Ref. 2).

The installation of extensometers comprised drilling of 180 mm diameter boreholes. Drilling of boreholes was done by YBM straight rotary drilling machine using fishtail bit. A casing pipe of 150 mm diameter was lowered up to the bottom of the borehole to ensure safety of borehole before and during the

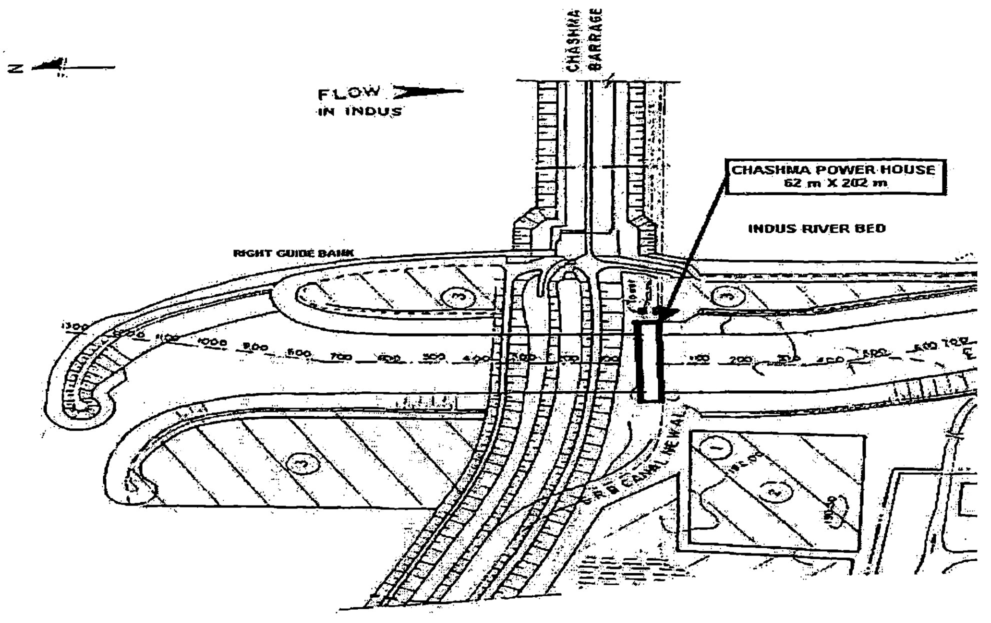

Fig. 1: Project Layout Plan.

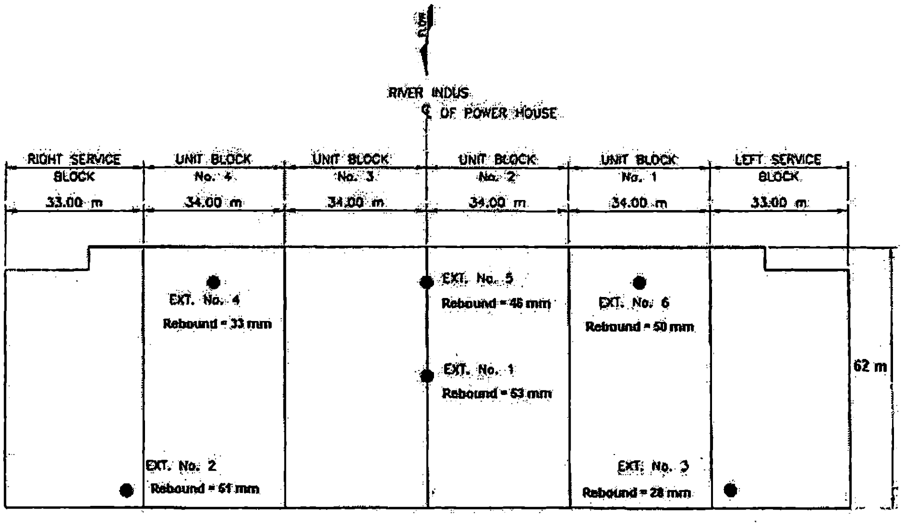

Fig. 2: Power House Rafts, Extensometers & Monitored Rebounds

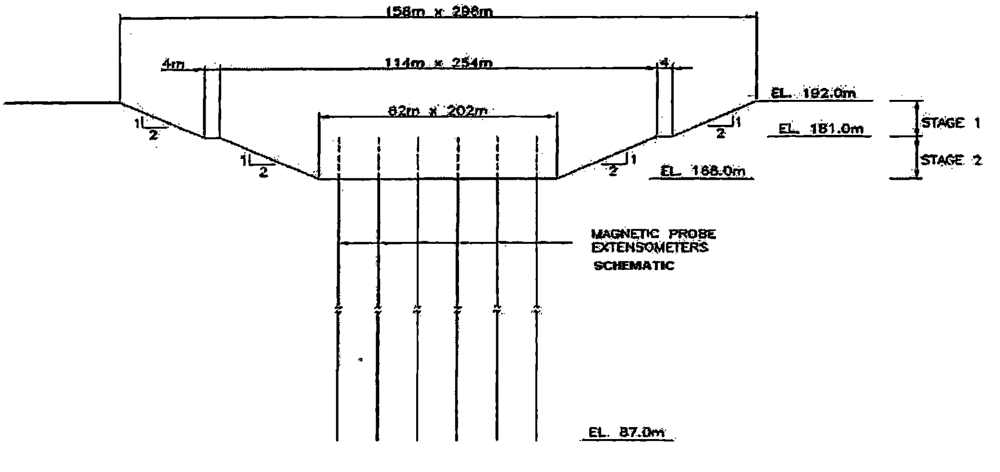

Fig. 3: The Stages of Excavation

replacement of drilling fluid with the grout mix against any collapse.

A tremie of 65 mm internal diameter was lowered inside the casing. Grout slurry (bentonite + cement) was pumped in the borehole, which due to its higher specific gravity, displaced bentonite. Immediately afterwards, the installation of extensometers started.

Each extensometer has carefully-placed ten spider magnets, along the depth of the hole at EI 177, 167, 157, 147, 137, 127, 117, 102 and 87 m. The spider magnets undergo movement with the movement of the ground. During the measurements, a torpedo sensor hung with a cable is lowered down the hole. The embedded position of the spider magnets in the ground is picked by the sensor to 0.0005 m accuracy.

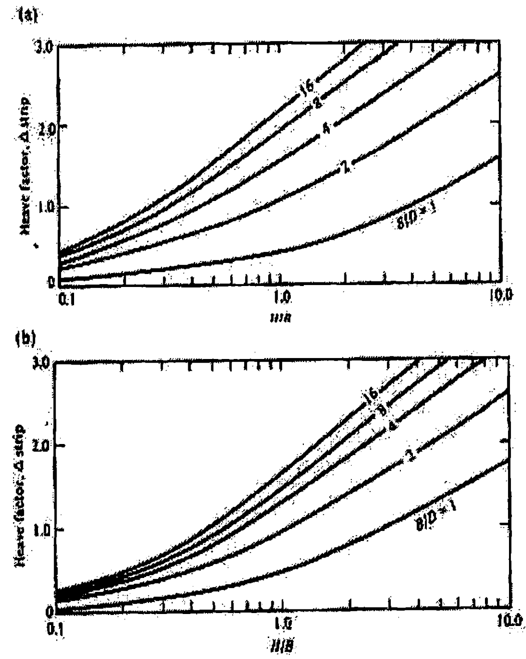

Fig. 4: Heave Factor Δ_{strip} at base of strip excavation in linear elastic medium. (a) Heave at center line. (b) Heave at edge. (Based on analysis of Baladi, 1968.)

4 PREDICTION MODEL FOR EVALUATION OF HEAVE

A long-hand method based upon the work of Perloff and Baladi (Ref. 3) was used to estimate the magnitude of heave due to the two excavation stages.

This solution for the estimation of heave is based upon obtaining elastic rebound at the base of a strip excavation in a linear elastic medium. An approximation of the expected heave has been made with the assumption that a limited depth of deformable material overlies a rigid base.

The magnitude of heave or rebound r_d, at the base of strip excavation of rectangular cross-section is given as:

$$r_d\,(\text{strip}) = \Delta_{strip}\ \frac{\gamma D^2}{E}$$

Where γ = Bulk density of the soil
D = Excavation Depth
E = Elastic modulus of the material below the excavation base

Δ_{strip} is a dimensionless heave factor whose magnitude is determined by the geometry of the excavation and the position for which the rebound r_d is being calculated. The heave factors Δ_{strip} at the centerline and at the edge of the excavation are given in Fig. 4.

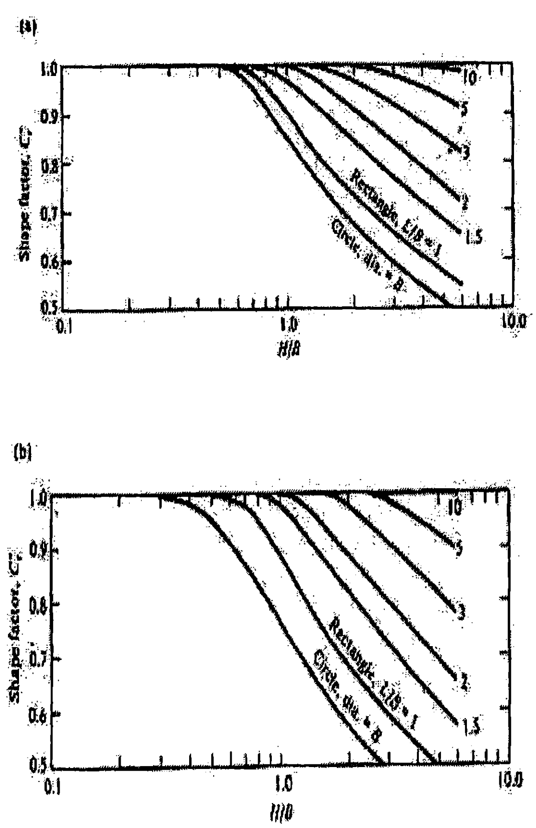

Fig. 5: Correction Factor C_γ" for correcting heave of strip excavation for shape of excavation. (a) Shape factor for heave at center line. (b) Shape factor for heave at mid point of long side. (Data from Egorov, 1958, as cited by Harr, 1966.)

When the length to width ratio of the excavation is less than 5, the adjustment is made by considering that the heave of a rectangular excavation is similar to the settlement of a uniformly loaded area. The adjusted heave has been calculated as follows:

$$r_d = C_\gamma'' \Delta_{strip} \frac{\gamma D^2}{E}$$

Where C_γ'' is determined on the basis of shape and rigidity factors, as shown in Fig. 5.

For 24m deep excavation, equivalent elastic moduli (E) of 75 & 85 MPa were evaluated for Stage I & Stage II respectively, using the elastic method proposed by Thenn de Barros (Ref. 4). The baseline data for evaluation of the elastic modulus was generated by carrying out a series of cone penetration and pressuremeter tests. A bulk density of subsoils was adopted as 2.0 g/cm3.

C_γ'' was picked as 0.83 & 0.98 whereas Δ_{strip} was picked as 2.6 & 2.1 for Stage I & Stage II respectively, as an average value between the centre line and the edge of excavation.

The maximum heave upon excavation has been predicted as 29 mm and 48 mm, in the two stages, respectively (i.e. a total heave of 77 mm), on the basis of the above considerations. This comes out to 2.6 mm and 3.7 mm of heave per meter of excavation depth in the two excavation stages, respectively.

5 MONITORED HEAVE

The heave of the excavated base (El. 168) was read corresponding to magnet No. 2 (El. 167) of magnetic probe extensometers (Fig. 6). The six extensometers indicated the rebounds as given in Table 1. The measurements indicate rebound following Stage II excavation only as the extensometers were installed upon completion of Stage I excavation. (Ref. 5):

Table 1: Rebounds indicated by extensometers (End of Stage II excavations)

Extensometer No.	Measured Heave (mm) at Magnet # 2
1	53
2	51
3	28
4	33
5	46
6	50
Ave. Heave	43.5 mm

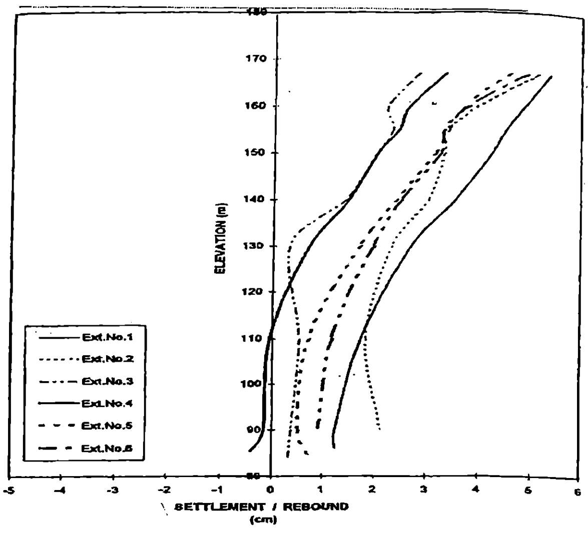

Fig. 6: Rebounds indicated by extensometers (End of Stage II excavations)

For the 13m depth of Stage II excavation, an average heave of 3.3 mm per meter of excavation was measured. Extrapolating this trend of heaving for the 24m deep excavation, a total rebound of 80.3 mm is postulated. Interestingly, this inferred value of heaving could have resulted, had the extensometers been installed before start of Stage-I. This is fairly close to the total predicted heave of 77 mm.

6 CONCLUSIONS

The simple procedure for prediction of heave (proposed by Perloff and Baladi) as explained in this paper, gives fairly good estimate of the heave of the ground in a 24 m deep excavation in sand. For the 13 m deep Stage II excavation, an average elastic rebound was predicted as 3.7 mm/m compared to the average measured value of 3.3 mm/m. Thus the predicted heave has been about 12 % higher than the actual measured value.

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