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Report of Geotechnical Investigations for the site of Const. of structures at the proposed Truck Terminal at Baddi , Distt. Solan (H.P) for BBNDA.

1. Introduction :

The present report deals with the Geotechnical field and lab investigations conducted at the site for the Construction of proposed structures of Truck Terminal at Baddi , Distt Solan (H.P).

The work was taken in hand at the behest of CEO , BBNDA , Jharmajri , Baddi (H.P) vide letter no. BBNDA/Proj./06/2007-880 dated : 14th Sept. 2007.

The scope of work as per the terms of reference included the following:

(i) Reconnaissance / field trip for studying the general topography and geology of the area / terrain.

(ii) The field Geotech investigations consisted of 45 Test Pits each extended upto a depth of 2.5m / 3.0m , and 4 test bore holes explored by mechanical boring upto 20m depth , below existing NSL.The location of all the Test Pits designated as TP1 to TP45 and four test bore holes BH1 to BH4 is shown on site plan . (Figure-1).

iii)The disturbed/undisturbed soil samples were obtained at suitable intervals from the 45 Test Pits and the 4 mechanically drilled bore holes , for subsequent laboratory tests to determine various index and engineering properties of the subsoil .

iv) Conducting of Dynamic Cone Penetration Test in each test pit / Bore holes at different depths (approx. 1.0m/1.5m intervals) . The

DCPT tests were performed in place of standard penetration tests because of the generally gravelly nature of strata.

v) Conducting plate load test at one location as marked on layout plan-fig-1 (marked as PLT1) , since the plate load tests are preferred to SPT tests in case of soils having small boulders and stones which obstruct the standard penetration test.

vi) Analysis of data and estimation of safe bearing capacity for wall footings and isolated column footings of different tentative sizes and depths.

vii) A comprehensive Geotechnical investigation report embodying all the above information alongwith tables of Field / Lab tests results and bearing capacity computations.

2. Field Investigations:

After a detailed reconnaissance of the site and discussion with the clients viz CEO , BBNDA , Jharmajri at Baddi . it was decided to explore the subsoil strata by excavating 45 number open test pits upto a maximum depth of 2.5m/3.0m and additional 4 bore holes taken down to 20m depth to be excavated by mechanical drilling.

A number of disturbed and undisturbed (wherever feasible) soil samples were collected from different depths in the various test pits / bore holes .

1 Dynamic Cone Penetration Tests :

The test is conducted by driving the cone by blows of a hammer . The number of blows for driving the cone through a specified distance is a measure of the dynamic cone resistance.

The DCPT tests were performed by using the standard 50mm cone without bentonite slurry (as per IS : 4968 – 1976) . The driving energy is given by a 65kg hammer falling through a height of 75cm , the number of blows for every 10cm penetration were recorded , the number of blows required for 30cm of penetration was taken as the dynamic cone resistance (N_{cbr}) .The DCPT values of the subsoil in the different test pits / deep bore holes through mechanical drilling have been shown in the relevant col. In Tables-1 to 49

2 Plate Load Tests :

The plate load tests were performed in the one pit specially dug for the purpose at the site . The plate load test is considered useful for soils containing gravels , stones and boulders.

The test was performed as per IS : 1888 – 1982 .

To conduct the test , a pit of the size 5Bp x 5Bp (Bp being size of plate) was excavated upto the depth equal to tentative depth of footings (2.0m). The standard plate of size 30cm square and 25mm thick was used. The depth of the central hole (Dp) for the plate was kept as Dp = (Bp / Bf) x Df where Bf is width of pit and Bp is width of plate .The plate was placed in the central hole and the load applied by means of a hydraulic jack . The reaction to the jack was provided by means of kentledge i.e. platform loaded with sand bags. A sitting load of 7kN / m^2 was first applied . Thereafter the load was applied in the increments of 25% of estimated safe load or one tenth of ultimate load. The settlements were recorded on three dial gauges after intervals of 1 , 5 , 10 , 20 , 40 , 60 minutes and thereafter at hourly intervals.Each load was maintained constant until the rate of settlement on the cohesionless soil below the plate became less than

0.02mm per minute. Each plate load test was conducted until failure or at least until the settlement of 25mm had occurred.

As per IS : 1888 – 1982 , the load settlement relation is plotted on a log - log graph which normally gives two straight lines , the intersection of which is taken as yield value of soil. Sometimes when the load settlement curve does not indicate a marked breaking point , the ultimate load is taken as corresponding to settlement of one fifth of the plate width. Alternatively ultimate load may also be obtained from the point of intersection of tangents to the two curvilinear portions of the natural load settlement plot .

<u>The results of plate load tests are more valuable for predicting the settlement of cohesionless soils and for evaluating the allowable bearing pressure of sandy and gravelly soils (for specified maximum settlement) which are difficult to be sampled and tested in the undisturbed state.</u>

The plate load test data and the load-settlement plot for the plate load test are shown in Table Nos : PLT-50 and figs. 2 resp .

3 Laboratory Soil Tests and Results :

An extensive laboratory testing program was carried out over a period of two weeks for determining the index and engineering properties of the various soil samples .All the tests were conducted as per the relevant IS standards.

The following Lab tests were performed on the different soil samples collected from various pits.

i) Grain size analysis : for studying the gradation of the soil samples.

ii) Atterberg Limits : for determining the plasticity characteristics of the finer fractions.

iii) Shear strength tests (Direct shear tests) on the various soil samples for determining the shear parameters - cohesion ‘ c ‘ and angle of internal friction ‘ φ ‘

The lab test results on the soil samples for the 45 test pits and 4 bore holes are summarized in tables 1 to 49.

The Plate Load Test data (Load vs Settlement) for the plate load test is summarized in Table Nos. – 50.

4 SubSoil Profile

Based upon results of soil classification tests and using the IS soil classification system an average sub soil profile has been obtained and plotted for the 45 test pits and 4 mechanically drilled bore holes upto 20m depth in respective boring logs (Tables 1 to 49) .

Subsoil water table was encountered at a depth of about 12m to 13m from NSL explored upto 20m in the 4 mechanically drilled bore holes.

Perusal of soil profiles shows that the subsoil in the area under consideration is typically sedimentary alluvial deposit in the foot hills near Baddi , merging into the plains and consists of various layers of coarse grained silty sandy gravel (major fraction gravel) and coarse grained silty gravelly sand (major fraction sand) . In general the subsoil in the region of significant depth , is a cohesionless well graded coarse grained material in a state of medium compactness.

5 Foundation Parameters :

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Following tentative dimensions of foundation have been adopted to determine the allowable bearing capacity values.

Two cases have been taken for bearing capacity calculations.

1. Wall / Strip Footings:

   Width of footing (B) = 1.5m
   Depth of footing(D) = 1.2m

2. Isolated RC Column square footings for the frame structure units (Single Storeyed) :

   Width of footing (B) = 1.5m
   Depth of footing(D) = 1.5m

3. Isolated RC Column square footings for the frame structure units (Double Storeyed) :

   Width of footing (B) = 1.8m
   Depth of footing (D) = 1.5m

It may be seen that ,with these dimensions of the footings , the foundations shall be resting on non plastic cohesionless gravelly/ sandy soil . The nature of soil in the region of significant depth is also cohesionless coarse grained well graded silty sandy gravel / silty gravelly sand .

6 Bearing Capacity Criteria :

It is now a well known Geotechnical maxim that a foundation is likely to fail by either of two modes i.e

i) Shear Failure

ii) Excessive Settlement

Shear failure being catastrophic , an adequate factor of safety is applied to ultimate bearing capacity that can initiate this type of failure. BIS recommends a value of F.O.S = 2.5 (although sometimes a higher factor of safety 3.0 is advisable) to obtain the net safe bearing capacity ‘ qns ‘ based on physical characteristics of the foundation and relevant shear strength parameters of the soil as obtained from lab shear tests or as obtained indirectly from correlations with SPT ‘ N ‘ values.

Through settlement analysis a net loading intensity ‘ q_n ‘ is obtained on the basis of physical characteristics of the foundation and the relevant compressibility characteristics of the underlying soil.This analysis is done to ensure that foundation will not settle more than the permissible values as per BIS recommendations. The permissible settlement depends upon the type of super structure and the nature of supporting strata.

The lesser of these two computed values is adopted as the allowable bearing capacity for proportioning the foundations of superstructure.

7 Bearing Capacity computations :

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1 Estimation of Safe Bearing Capacity from shear failure criteria :

In this case ,the net safe bearing capacity values against shear failure shall be governed by the shear strength parameters of the supporting silty sandy gravel stratum.

The average values of shear strength parameters obtained through direct shear tests on disturbed sandy / Gravelly samples taken from the various test pits are $\Phi = 31.0°$.

The range of the DCPT values in various test pits is 16 on the lower side and 40 on higher side upto a depth of 3m . The DCPT values (upto 8m) in the 4 mechanically drilled bore holes have a higher range (30 to 50) , but from a depth of 8m onwards to 16m , the DCPT values further increase being in the range 40 to 60.

For bearing capacity computations on shear failure criteria for isolated footings founded at a depth of about 1.5m , the lowest average minimum value of Ncbr from DCPT has been taken as 20.

The Dynamic cone resistance Ncbr is correlated with SPT number N for coarse grained soils as follows :

Ncbr = 1.5 N for depths upto 3m

Ncbr = 1.75 N for depths between 3m to 6m

Ncbr = 2.0 N for depths greater than 6m

Based on the above correlation the N value is estimated for the depths of footings in the present case (being less than 3m) as

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$$N = Ncbr / 1.5 = 20/1.5 = 13.3$$

The corrected N value considering the small dilatancy and overburden effects at the proposed footing depths being less than 3m may be conservatively taken as

N corrected = 13.0

The angle of internal friction Φ based on N - Φ correlation given by Terzaghi and as per IS – 6403 : 1981 is estimated as

$$\Phi = 30.5°$$

and this value of Φ is used in bearing capacity calculations in the following.

The notations used in the analysis of allowable bearing capacity are appended at the end of the report.

The ultimate bearing capacity equation for footings on cohesionless soil is

$$q_{nf} = q(Nq\text{-}1)Sq\ dq + 0.5\ \gamma\ B\ N\gamma\ S\gamma\ d\gamma\ .\ W'$$

Case- 1: Wall / Strip Footings:

Width of footing (B) = 1.5m
Depth of footing(D) = 1.2m

$$q=1.7 \times 1.2 = 2.08\ t/m^2$$

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(taking the unit weight of compacted granular backfill soil as 1.7 t/m2) since backfill soil is not normally well compacted.

$\gamma = 1.82\ t/m^3$ (Field Density of supporting soil)

W′ = 1 (considering that the water table remains at or below a depth of (D + B) beneath the ground level.

For N=13.0 , Φ=30.5°
$Nq = 12.5$ and $N_\gamma = 14.0$
$sq = 1.0$; $s\gamma = 1.0$ (Wall footing)
$dq = d\gamma = 1 + 0.1\ D/B \tan(45 + \Phi/2) = 1.14$

Since the backfills are not normally well compacted the depth factors can be dropped from basic bearing capacity equation.

Substitution of the above values in the basic bearing capacity equation gives

$$q_{nf} = q(Nq-1)Sq\ dq + 0.5\ \gamma\ B\ N\gamma\ S\gamma\ d\gamma\ .\ W'$$

$qnf = 42.40\ t/m^2$

and with FOS = 3.0

$$\mathbf{q_{ns} = q_{nf} / 3.0 = 14.10\ t/m^2}$$

Case-2 Isolated RC Column square footings for the frame structure units (Single Storeyed) :

Width of footing (B) = 1.5m
Depth of footing(D) = 1.5m

$q=1.7 \times 1.5 = 2.55\ t/m^2$

(taking the unit weight of compacted granular backfill soil as 1.70 t/m2) since backfill soil is not normally well compacted.

$\gamma = 1.82\ t/m^3$ (Field Density of supporting soil)

W′ = 1 (considering that the water table remains at or below a depth of (D + B) beneath the ground level.

For N=13.0 , Φ=30.5°
$N_q = 12.5$ and $N_\gamma = 14.0$
$s_q = 1.2$; $s_\gamma = 0.8$ (Square footing)
$d_q = d_\gamma = 1 + 0.1\ D/B \tan(45 + \Phi/2) = 1.14$

Since the backfills are not normally well compacted the depth factors can be dropped from basic bearing capacity equation.

Substitution of the above values in the basic bearing capacity equation gives

$q_{nf} = q(N_q-1)S_q\, d_q + 0.5\, \gamma\, B\, N_\gamma\, S_\gamma\, d_\gamma \cdot W'$

qnf = 50.49 t/m^2

and with FOS = 3.0

$\mathbf{q_{ns} = q_{nf} / 3.0 = 16.82\ t/m^2}$

Case-3 Isolated RC Column square footings for the frame structure units (Double Storeyed) :

Width of footing (B) = 1.8m
Depth of footing (D) = 1.5m

q=1.70 x 1.5 = 2.55 t/m^2

(taking the unit weight of compacted granular backfill soil as 1.70 t/m2) since backfill soil is not normally well compacted.

$\gamma = 1.82\ t/m^3$ (Field Density of supporting soil)

W′ = 1 (considering that the water table remains at or below a depth of (D + B) beneath the ground level.

For N=13.0 , Φ=30.5°
Nq = 12.5 and $N_\gamma = 14.0$
sq = 1.2 ; sγ = 0.8 (Square footing)
dq = dγ = 1 + 0.1 D/B tan (45 + Φ/2) = 1.14

Since the backfills are not normally well compacted the depth factors can be dropped from basic bearing capacity equation.

Substitution of the above values in the basic bearing capacity equation gives

$q_{nf} = q(Nq\text{-}1)Sq\ dq + 0.5\ \gamma\ B\ \ N\gamma\ \ S\gamma\ \ d\gamma\ .\ W'$

$qnf = 53.53\ \ t/m^2$

and with FOS = 3.0

$\mathbf{q_{ns} = q_{nf} / 3.0 = 17.84\ t/m^2}$

The bearing capacity of shallow footings should be estimated considering both shear failure criteria and the settlement criteria and the lesser of the two is adopted as the design safe bearing capacity.

7.2 Estimation of allowable soil pressure based on settlement criteria:

The allowable soil pressure (q_{na}) of a shallow foundation is limited either by the net safe bearing capacity (q_{ns}) or the safe settlement pressure ($q_{n\rho}$) .The design of shallow foundation on cohesionless soils is generally governed by the safe settlement pressure , as the net safe bearing capacity for a footings of usual size is quite high . However , in the case of narrow footings on water logged sands, the net safe bearing capacity may be the controlling criteria for the design .

It is the normal practice for design of footings of usual size to use empirical methods based on N – values for the determination of the allowable soil pressure for cohesionless soils. The plate load tests are also used in the case of soils having small boulders and stones which obstruct the standard penetration test. The methods using the standard penetration test are preferred to plate load tests for homogeneous soils , as these are more economical.

7.2.1 **Safe Bearing Pressure based on DCPT cone resistance(Ncbr) / N values**:

Case-1 & 2

Footing width B = 1.5m

As per IS : 6403-1971 , the allowable soil pressure for Ncorrected =13.0 , a settlement of 40mm and width of footing B = 1.5m , is estimated as

$$q_{n\rho} = 16.8 \text{ t/m2}$$

Case-3

Footing width B = 1.8m

As per IS : 6403-1971 , the allowable soil pressure for Ncorrected =13.0 , a settlement of 40mm and width of footing B = 1.8m , is estimated as

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$$q_{n\rho} = 16.2 \text{ t/m2}$$

7.2.2 Safe Bearing Pressure estimated from plate load test :

Based on observation data Terzaghi and Peck predicted that the differential settlement $\triangle\rho$ of footings on cohesionless sands / gravels is unlikely to exceed 50% of the maximum settlement , which means that the maximum settlement of the largest footing ρ_p should be restricted to 2 x $\triangle\rho$, if $\triangle\rho$ is permissible differential settlement .

The corresponding settlement of test plate in plate load test can now be estimated from the following equation :

$$\rho_p = \rho \left(\frac{Bp\,(B + 30)}{B\,(Bp + 30)} \right)^2$$

$$= 2 \times \triangle\rho \left(\frac{Bp\,(B + 30)}{B\,(Bp + 30)} \right)^2$$

In the present investigation the permissible differential settlement of the isolated footings (as per IS : 1904 – 1986) may be taken as 0.002 L , where L is center to center distance between columns. (may be tentatively taken as 6m).

Hence $\triangle\rho = 0.002L$
$= 0.002 \times 6 \text{ m} = 12 \text{ mm}$

Now B = 2m (the width of pits for plate load test)
Bp = 30 cm

Substituting these values in the above equation

$$\text{Hence } \rho_p = 2 \times \Delta\rho \times \left(\frac{Bp\,(B + 30)}{B\,(B\,p + 30)}\right)^2$$

$$= 7.93 \text{ mm (approx.)}$$

the intensity of loading corresponding to this ρ_p may now be read from load settlement curve and is the safe bearing pressure q_ρ for the specified maximum settlement ρ

In the present investigation , the safe bearing pressure q_ρ corresponding to settlement criteria from the plate load test (load settlement curve , Fig- 2) is estimated as 15.0 t/m^2 .

11) Conclusions and Recommendations :

Based on analysis of subsoil conditions , field and lab tests and computation of bearing capacity as above , following conclusions are drawn and recommendations made :

i) the subsoil water was encountered at a depth of 12.0m to 13.0from the existing NSL in all the 4 mechanically drilled bore holes during the days of investigation Oct. / Nov. 2007.

ii) The allowable safe bearing capacity values for the three cases considered for this project are recommended as follows (

depending on Shear / Settlement / Plate load test criteria governing) :

Case-1 : Wall / Strip Footing
(B=1.5m and D=1.2m)

$(q_a)net = 14.10\ t/m^2$

Case-2 : Isolated RC Column square footings for the frame structure units (Single Storeyed) :
(B=1.5m and D=1.5m)

$(q_a)net = 15.0\ t/m^2$

Case-3 : Isolated RC Column square footings for the frame structure units (Double Storeyed) :
(B=1.5m and D=1.8m)

$(q_a)net = 15.0\ t/m^2$

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Geotechnical Investigations

Report for

Site of Construction of Structures at the Proposed Truck Terminal Site ,BADDI (H.P)

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