GEOTECHNICAL EXPLORATION: COST AND TIME OPTIMIZED PROGRAM FOR RELIABLE PREDICTION OF SBC, SBP, ABC & DEPTH OF FOUNDATION

Tailor Ravin M.
Lecturer, Civil Engg. Dept.,
S.V. National Institute of Technology,
Surat - 395007, Gujarat.

Desai Hitesh H.
Research Scholar,
Applied Mechanics Department, S.V.N.I.T.,
Surat – 395007.

Dr Mahesh D. Desai
Visiting Professor,
PG (SMFE) Section, AMD, S.V.N.I.T.,
Surat – 395007.

Note: The first part of this article appeared in the Jan-Mar issue. This issue contains the remaining part of the article.

Authors' suggestion:

1.0 For large plots evolve 3 to 5 DCPT (IS - Part I, 4 corners & centre) which will indicate need for additional tests. The profile of Nc vs depth will be used to evolve:

a) Homogeneity of subsoil with depth

b) Plan zoning at plot for similar subsoil stratification.

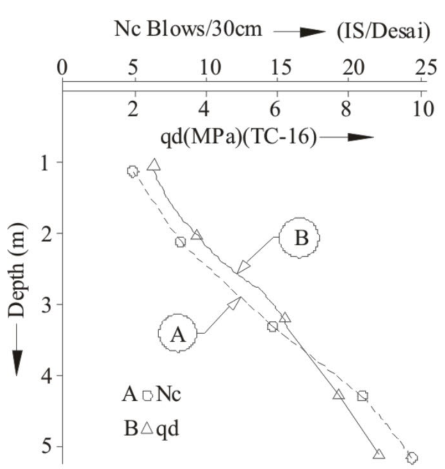


Fig. 1: Comparison of Trends of N_c and q_d for a site (Desai M. D.).

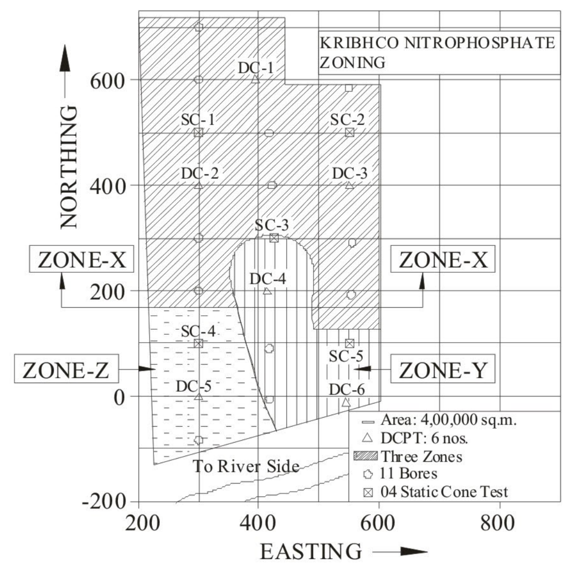
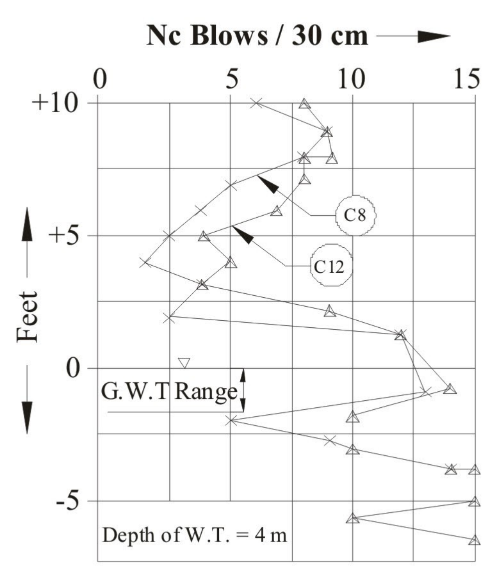


Fig. 2: Typical Zoning Plan by DCPT to Plan Detail Exploration (Desai M.D.)

2.0 Using proposed interpretation (Desai M.D.) estimates G.W.L. at site to be cross checked with available nearby bore / well data.



Delhi Area (Desai Cone)

Fig. 3: Predicted and Actual Water Table (Desai M.D.)

1.0 Compute R = ΔN_c/depth for slopes of data Nc vs depth and log the soil probability using local experience & recommendations.

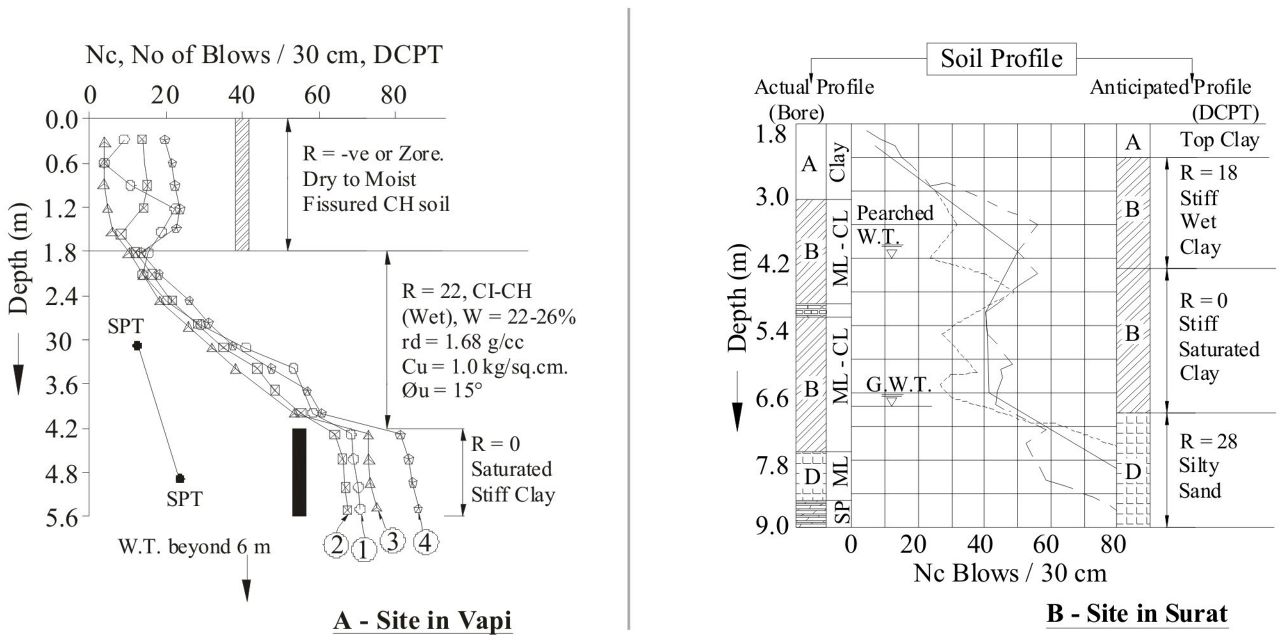


Fig. 4: Sol Profiles Developed by DCPT

4.0 For each strata in model profile depending on cohesive & non cohesive subsoil, predict the engineering parameters (Desai M.D., 2005).

a) Saturated cohesive soil (R = _), Nc vs Cu, Øu = __, CBR = __, E = __.

b) N.C. soils (R = __), avg. Nc, P_0', R_d, C – Ø, for type of sand fine and coarse.

5.0 The data (Nc > 10) indicate depth to found (D_f) the 6 storied common type or medium span structures. Consider the D_f + 4 to 6 m as stressed zone.

Note: Soil below shows improving / decreasing Nc / strength.

6.0 Considering soil type, water table and Nc – P_0' derive SBC, PBC for settlement safe for structure and allowable bearing capacity.

e.g.

<u>(1) Soil: Saturated Clay, Øu = 0,</u>

As per Dr. M.D. Desai(2005) interpretation ,

Cu = 8 x Nc < 150 kPa, E = 600 x Nc kPa upto depth 5 m

Observed: average or representative Nc = 10,

This gives Cu = 80 kPa, E = 4800 kPa, SBC = 250 kPa (F.S. = 2),

<u>(2) Soil: Silty fine sand (SM)</u>

Nc=10	Rd	Ø	E	SBC	PBC, St=25mm	Liquefaction
P_0=0	80%	> 30º	15 MPa	NA	400 kPa	Low
P0=50 kPa	50%	28º	-	NA	250 kPa	Medium

7.0 If capacity of soil is inadequate marginally examine going deeper, feasible ground treatment for soil (such as raft, pile, dynamic compaction, static compaction, sand wicks, geo-fabrics / grids reinforcing etc.)

8.0 Plan bore two per zone with specific critical parameters. (Personally supervised)

e.g. Subsoil saturated clay with sand strata below 7 m, D_f = 2 m, require C_u, E_u from proper UDS at foundation level and 2 & 4 m below (only one SPT for check). UDS not reliable if N_s > 25, adopt pit block or other method for UDS or N.D. test insitu. Soil density ρ_d (Dry density) – water content profile with depth (with note of season) will be required.

If the strata is clay to 2 m overlaying SM – ML non plastic silt and sand above W.T. model average N_c at proposed depth of foundation (N_c > 10), plan bore hole with SPT at 2.0, 3.0, 4.5, 6.0 m depth conducted carefully keeping personal supervision for drop, piping in borehole etc. UDS do not provide any reliable data. Two samples may give some range of ρ_d, water content. Shear and compressibility are sensitive to ρ_d – w and remolding. The strata could be dilatant in sampling. Data needs careful analysis before testing as UDS and recommended for engineering properties.

9.0 Compare model data with bore, after scrutiny and digesting data to derive final reliable design parameters. In case of marginal design bearing capacity and stress for the structure additional check test vane / static cone / pressurometer can be adopted.

10.0 In case of large gap between predicted design parameters a prototype model test can be conducted on 1.0 to 1.5 m square footings to get non challengeable parameters.

This aspects and its economics, time to construct have been illustrated by 2 case studies.

Case studies:

Case – I:

Soil exploration for building at West Delhi - Case study of significance of experience based judgement. (2008)

1.0 **Introduction:**

Building: Seven stories building on approx. 6000 sq.m. plot area.
Soil exploration: 5 boreholes for geotechnical profile.
Soil profile 0 – 10 m of SM, Silty fine sand, SPT values shown in Fig. 5.N_s is corrected as per IS code.

2.0 **Analysis:**

2.1 Main structure:

SPT at, 2.0 m, varies 13 to 30,
9.0 m, ” 19 to 40,
Up to 25 m, ” 38 to 41.

Depth for foundation: 9 to 10 m below G.L., dictated by the planning.

Design report:

Isolated footings:
Soil below 9 m – CL, depth: variable 2 to 3 m thick,
$N_{SPT} > 30$, C = 0.9 kg/cm^2, Ø = 5º, W_L = 27, PI = 9, W = 9 – 10 %, ρ_d = 1.5,
Net allowable bearing capacity = 25 T/m^2, Sub-grade modulus, k = 2.2 kg/cm^3, F.S. = 2.5, S_t < 50 mm

Authors' Interpretation: (Based on Ref: 2)

a) All soil data above 9.0 m: not required if foundation depth 9.0 m prescribed.
b) Based on UDS, SBC = 25 T/m^2,
c) Based on $N_{SPT} > 30$, $C_u > 12$ T/m^2, SBC > 33 T/m^2, recommended.
d) Soil is low to non plastic silt & fine sand in behavior

2.2 **Light structure:**

Design report:

D_f = 1.2 m on SM, Allowable bearing capacity = 10 T/m^2 as per exploration report.

Authors' interpretation: (Based on Ref: 2)

D_f = 2 m, Minimum N_{SPT} = 13, N_{avg} = 15, P_O = 30 kPa, R_d = 70 %, Ø = 35º, Permissible bearing capacity for S_t 40 mm = 50 T/m^2 (No Water Table)
Net design bearing capacity = 30 T/m^2.
Liquefaction not likely…

3.0 **Foundation Cost aspects:**

As per exploration report:

100 T column load / 10 T per sq.m. bearing capacity = 10 sq.m. foundation base area,
Concrete volume = 10 sq.m. area x 0.7 m depth = 7 m^3 per column

Based on authors' interpretation:

100 T column load / 25 T per sq.m. bearing capacity = 4 sq.m. foundation base area,
Concrete volume = 4 sq.m. area x 0.7 m depth = 2.8 m^3 per column

Saving of Concrete per column: 7.0 – 2.8 m^3 = 4.2 m^3 per column.

Assuming Rs 4,000/- per m^3 cost of concrete, total savings per column = Rs 16,800/-

Total saving for the Project = Nos. of column x Savings per column!!!!

4.0 **Conclusion:**

For seven stories framed structure with foundation at 9 m, only classification at 2 m interval with moisture density profile at 2, 4, 6, 8 m could optimized exploration. The bearing capacity of Delhi top soil – non cohesive, SM has been recommended as $^1/_3$ rd of value estimated by modified N value interpretation. Confirmatory model test could be economical in total cost if bearing capacity as per authors' chart is adopted. Even judgment, local experiences to review codal, over-safe parameters is justified.

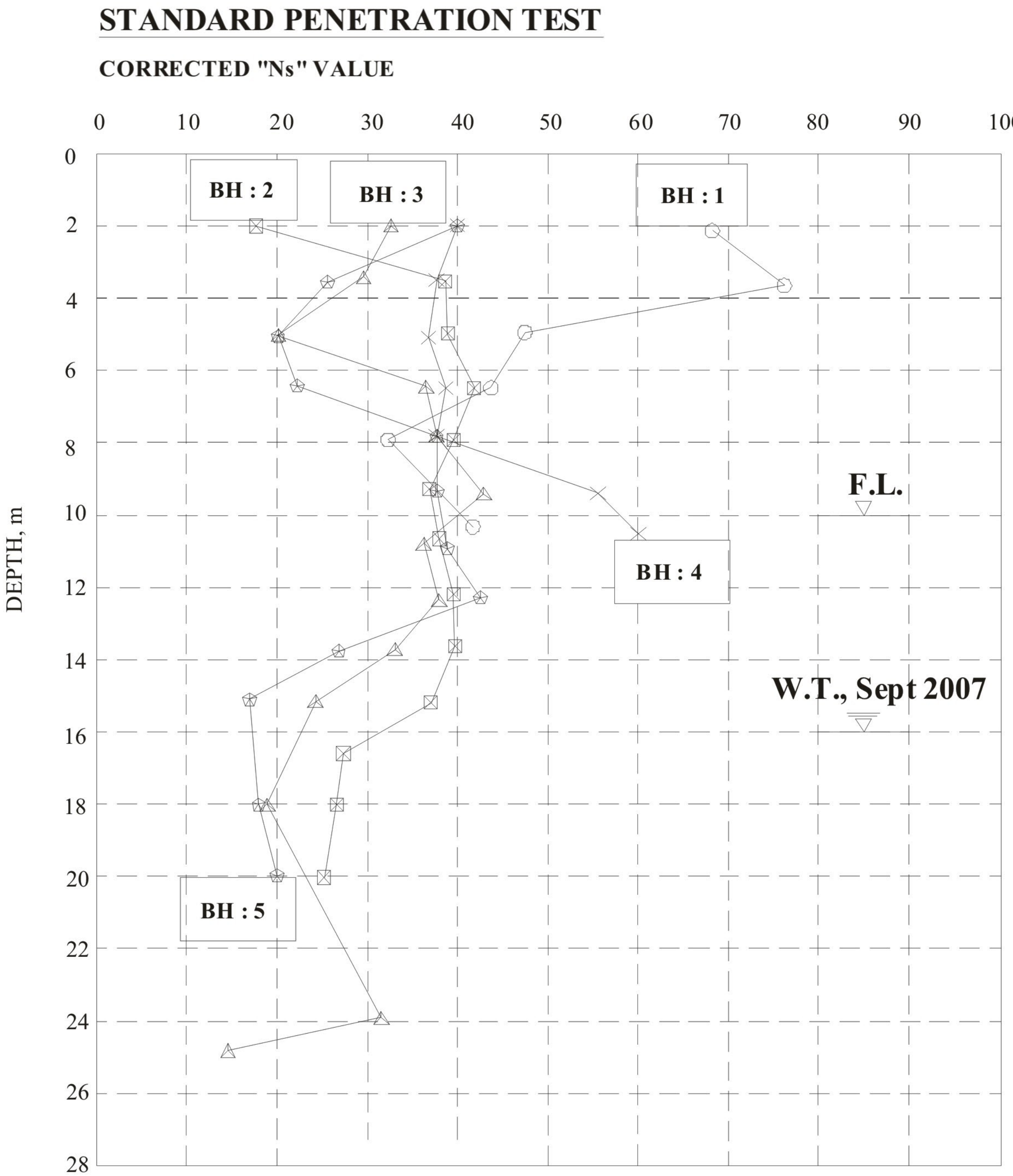


Fig. 5: Standard Penetration Test Data for the Building at Dwarka, Delhi.

Case - II:

Preliminary Exploration of Plot, for Foundation of proposed Housing Colony at Surat.

1. Conventional geotechnical exploration of year 2007 comprised of 8 bores. The exploration aimed at studies for foundation design for 13 storied towers.

   The analysis of data showed 1.5 to 4.0 m cohesive (CH) soil with $N_{s\,avg} = 10$ overlaying 2.0 m thick ML soil layer ($N_{s\,avg} = 14$), 6.0 to 10.8 m strata is SM group of silty fine sand $N_s > 25$ increasing with depth. Ground Water Level is at 3.0 m below G.L. (RL 4.0 m). The depth at which non-plastic SM - SP soil is encountered is variable. The report recommended shallow footings at 3.0 m depth with SBC of 225 kPa. The estimated settlement was 70 mm.

2. The report was reviewed by authors on client's request. The G.W.L., in well around, was at 9.0 m. The observed water table at 3.0 m is due to ponds & 2006 flood water. The overall ground at RL 7.0 m has 6.0 m top cohesive soil overlying sand strata. The flood level is RL 8.5 m where as high tide in river is at RL 4.5 m.

3. To review the data, 6 nos. of 50 mm DCPT tests were planned in the plot for quick, economical investigation. The data is shown in Fig. 6. The analysis as per Desai M.D. (2005) shows:

   a) The top 6.0 m strata and below 8.4 m are fairly homogeneous in plan & section.
   b) The N_C of insitu soil is consistently showing higher values than vary low SPT values, presumably due to its sensitivity to drilling, boiling and suction in drilling bore at such a site. The SPT & UDS were not representing field conditions (stratified layers deposits)
   c) Top 3.0 m is cohesive soil with N_C varying from 6 to 20 blows / 30 cm against $N_{SPT} = 5$, w = 28 % to 38 %. The C_u varies from 50 to 100 kPa against $C_u = 30$ to 40 kPa on UDS.
   d) Soil strata below proposed foundation level 3.0 m shows stratified silty sand, saturated by flooding & ponds with $N_C > 20$. For average $N_C > 25$ blows / 30 cm, $C_u > 100$ kPa, $E_s = 10{,}000$ kPa by empirical correlations. Substantial heaving recorded in excavation.
   e) Ground Water Level could be at 4.8 m or so but non flood periods water table could be 6.0 m below G.L.
   f) If soil is cohesive, safe bearing capacity for minimum design of footings will be 300 kPa with factor of safety 2.0.
   g) Estimated settlement of strata for width of 3.0 m, change of stress 250 kPa, thickness of compressible strata = 3.0 m, stiffness factor 0.8 will be 60 mm or so.
   h) Provision of sand with Geo-textile fabric below P.C.C., and light compaction design baring capacity of 30 T/m^2 is feasible subject to check on model footing test. This reduces combined footing & raft for high rise structure economizing the cost of foundation.

4.0 The case study illustrates, the quick DCPT exploration (3 days for 6 tests / team), one bore to check soil profile proved better insitu characteristics, economy in exploration and foundation cost and saving of time in exploration. If case studies are not available to reject SPT & UDS sampling, a model test is desirable.

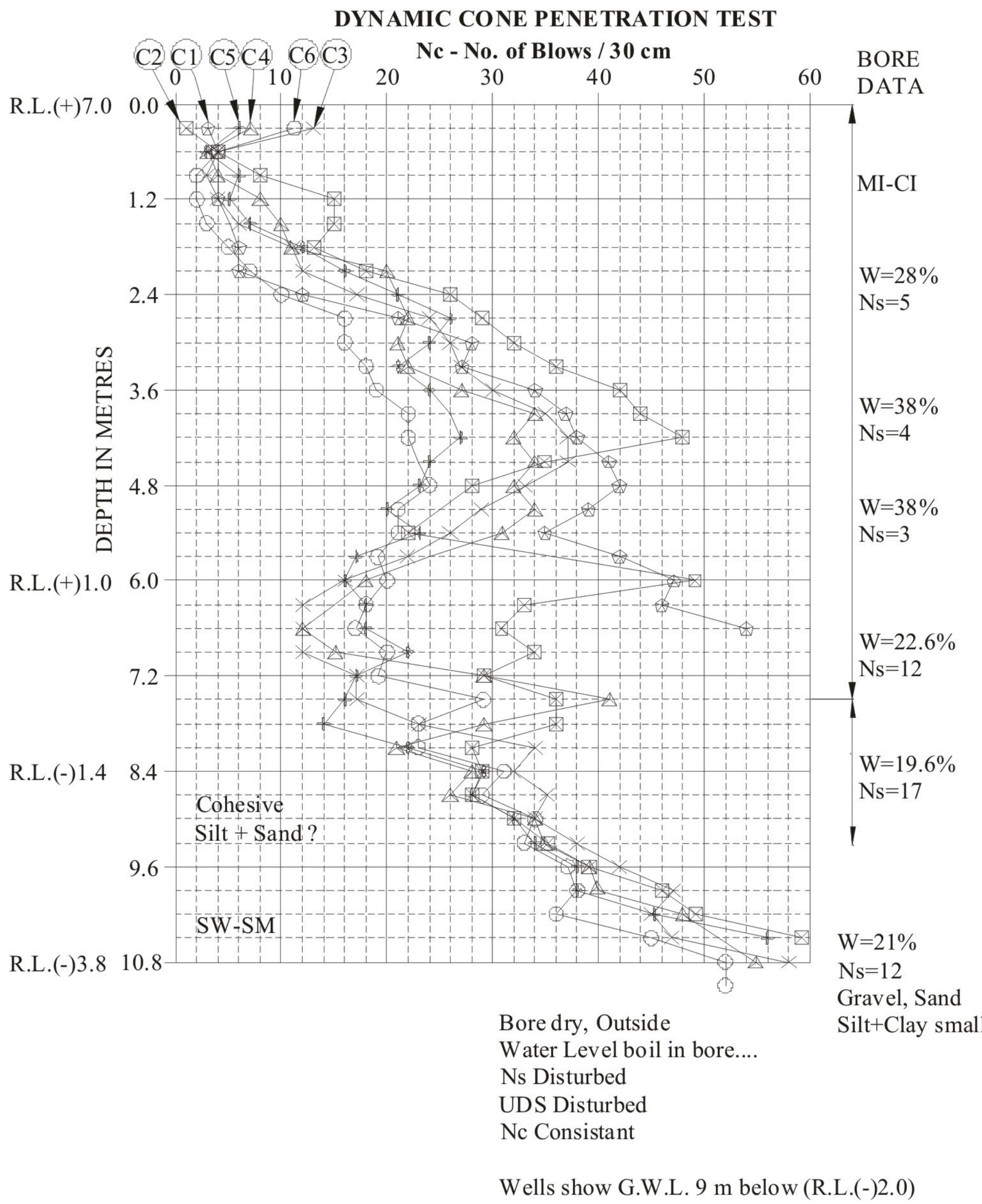


Fig. 6 Chart showing DCPT tests result for foundation of high-rise building at Surat.

1.0 Thus the case study has brought out the justification of judgment on experience, checking of bore data by sounding test quickly. The design discussions led to adoption of Geo-reinforced footings saving cost & time.

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