ENSURING RELIABILITY OF FOUNDATION DESIGN THROUGH MODERN GEOTECHNICAL INVESTIGATION TECHNIQUES

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SYNOPSIS : *Geotechnical engineering provides the vital input for design of foundations which is of paramount importance for reliability in the performance of civil engineering structures. The paper presents a discussion on how modern field investigation techniques and in-situ testing backed up by a thorough laboratory testing programme can revolutionize foundation design. A carefully planned and properly executed investigation can result in a greater degree of confidence in the design in addition to cost effectiveness.*

INTRODUCTION

The successful prediction of foundation performance depends largely on the ability of the designer to evaluate the geotechnical parameters that control the engineering behaviour of soil. In the current scenario of fast track projects in the infrastructure and industrial sector, there is a greater responsibility on the geotechnical engineer to develop reliable and economical designs involving heavier loads and difficult soil conditions.

CHALLENGES TO THE MODERN GEOTECHNICAL ENGINEER

Multi-Disciplinary Demands

Geotechnical engineers have a vital role to play in solving some of the world's most pressing problems of space utilization, transportation sector, construction in areas with difficult soil conditions and developments in the Himalayan region (Gopal Ranjan, 1996). In doing so, they have to expand their practice well beyond traditional soil mechanics and earth sciences into newer areas and develop an understanding of related allied subjects.

The geotechnical engineer of today has to interact with professional peers of related disciplines such as engineering geologists, hydrologists, structural designers, construction engineers, highway engineers, environmental engineers etc. There is tremendous pressure on him to generate reliable engineering solutions that account for varied and diverse requirements. Interaction with professionals of these various disciplines is imperative for a greater understanding of the technical requirements. There is also a need to make other professionals aware of the numerous uncertainties that dog the geotechnical prediction of soil behaviour.

The Approach

In order to be responsive to such tough demands, the geotechnical engineer must adopt a systematic and flexible approach that caters to each specific requirement. A proper choice of investigation techniques and analytical methods to realistically model the problem is essential for generating designs that are reliable, economical and practical in addition to being amenable to speedy construction. It is also essential to ensure that the structure built performs as envisaged and designed.

Engineering decisions are also influenced by field studies, success stories and failures backed up by sound professional judgement. Peck (1980) advocates that research and practice should concentrate on investigation of non-quantifiable factors (beyond-the-text-book situations) rather than on analytical studies. Hoeg (1982) warns against excessive reliance on complex computer programs without appreciating the associated assumptions or limitations.

It is in this context that a carefully planned site investigation is an important pre-requisite for all civil engineering projects. A thorough geotechnical investigation with proper interpretation of data is the basis for safe and stable structures (Sanjay Gupta, 1993). In-situ tests, which form an integral part of a modern geotechnical investigation programme, add the extra push that is required to enhance the level of reliability of geotechnical prediction. Sufficient field tests backed up by a detailed laboratory testing programme on disturbed and undisturbed soil samples are essential to develop soil parameters that reflect the in-situ condition of the substrata.

SUBSURFACE INVESTIGATION PROGRAMME

Field Investigation

The most commonly used method of site investigation is to drill boreholes. Standard Penetration Tests (SPT) are conducted at every 1.5 to 3.0 m depth intervals in the boreholes and undisturbed soil samples are collected at every 2 to 3 m depth intervals. Fig. 1 presents a photograph shows a rotary drill rig mounted on top of a pontoon for investigating the strata beneath a lake at Gwalior.

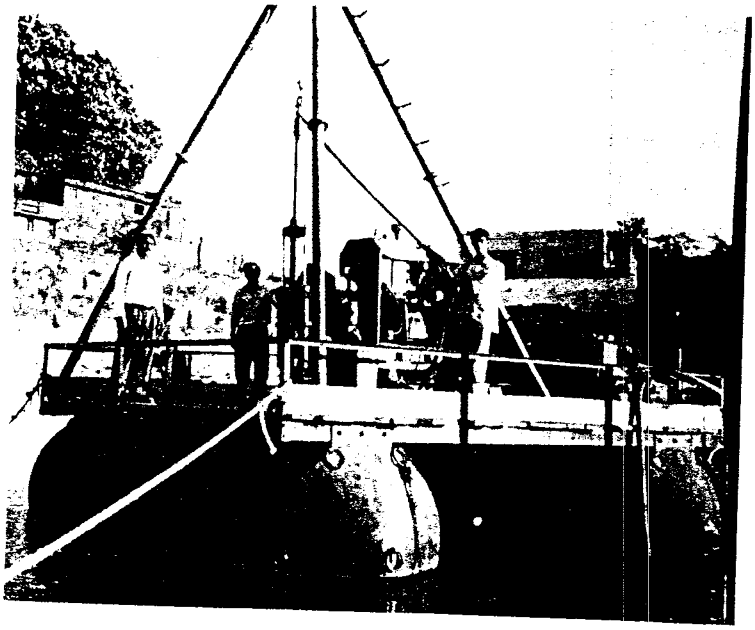


Fig.1 : Geotechnical Investigation in a Lake at Gwalior

In situ tests can provide a better insight to soil behaviour and should be relied on to greater extent. Some of the in-situ tests that can improve the quality of geotechnic prediction of foundation behaviour are discussed below :

Pressuremeter Tests: This is an advanced state-of-the-art test. A probe with a rubb membrane is lowered into the borehole and expanded under pressure. The pressur volume relationship is correlated to various engineering properties of the soils. Th prediction of soil bearing capacity and settlement from pressuremeter data is more realist than other available methods. Fig.2 presents the control panel and probe of a Menard pressuremeter.

Static Cone Penetration Tests : This test gives a continuous record of penetratio resistance with depth and is useful to identify presence of soft layers, local variations et The cone tip resistance can be correlated to undrained shear strength of clays and densit condition of sands. It can provide a better assessment of bearing capacity and settlemen pile capacities etc. Fig. 3 presents a static cone penetration test in progress.

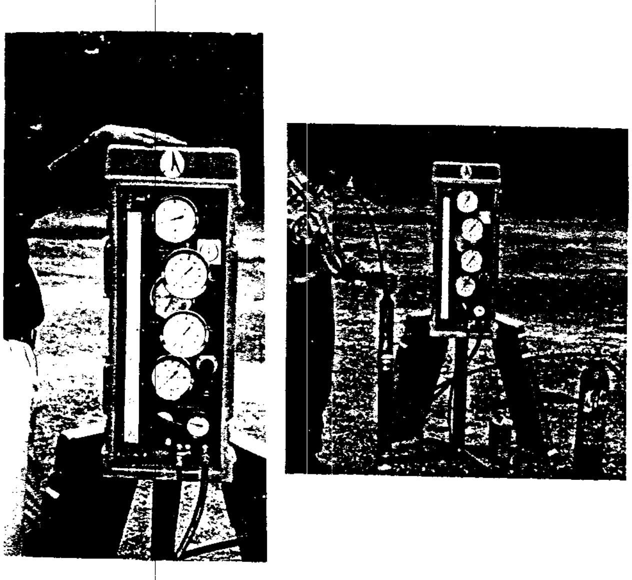


Fig.2 : The Pressuremeter Test Equipment

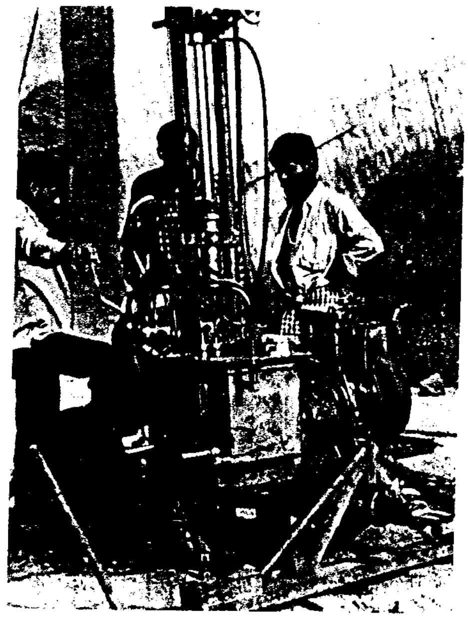


Fig. 3 : Static Cone Penetration Test in Progress at Narmada Sarovar Project

Vane Shear Tests : This test is used to determine the in-situ shear strength of the soft clays.

Load Tests: Plate load tests and pile load tests are used to evaluate in-situ load-settlement behaviour. The plate load test is a scaled down model test on prototype footings. Although its usefulness is restricted by problems of scale effects and stratification, the results may be used as an indicator of foundation performance. Pile load tests (on individual pile and pile groups) can be effectively be used to assess the load settlement behaviour of the foundation system and thus ensure reliability of foundation performance. Fig.4 presents a 800 mm diameter bored pile for a flyover in Jaipur being tested to 500 tonnes using a specially designed load frame.

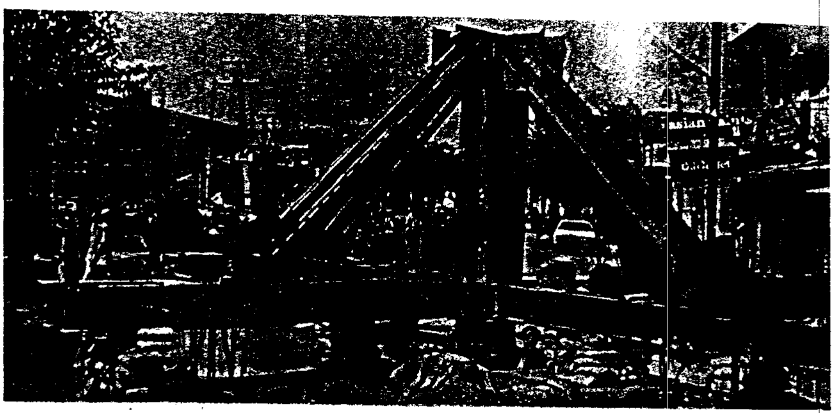
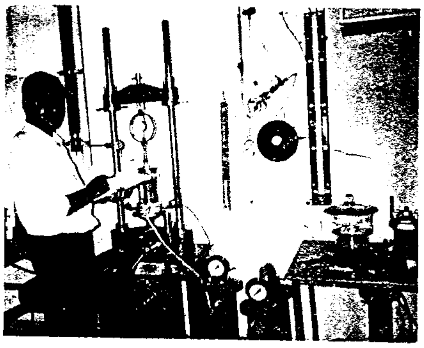


Fig. 4 : Pile Load Test in Progress for a Flyover at Jaipur

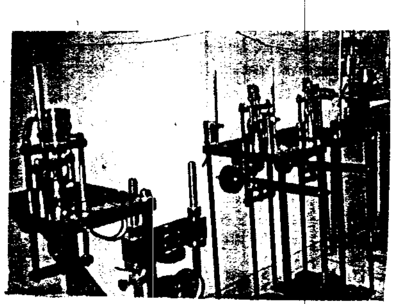
Laboratory Testing

The field investigation should be supplemented by a detailed and comprehensive laboratory testing programme. Fig. 5 presents photographs of a modern geotechnical testing laboratory. The purpose of the laboratory investigation is to :

(i) Verify field classifications
(ii) Determining strength, consolidation and permeability characteristics.
(iii) Assessing long term corrosion effects.

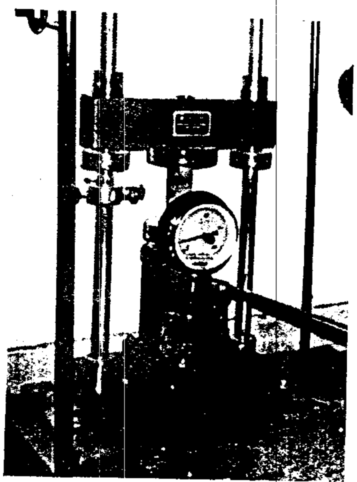


Triaxial Testing of Soils



Consolidation Tests

Chemical Analysis of Soil



Crushing Strength of Rock

Fig. 5 : Photographs of Modern Geotechnical Testing Laboratory

Depending upon the soil conditions, nature of structure being built and technica requirements, the laboratory testing should be carefully planned to generate the necessary soil parameters. This requires a proper understanding of the drainage conditions settlement behaviour, compaction, time and scale effects, etc.

CASE STUDY

General

A case study of a geotechnical investigation programme for a major monumental structure at Anandpur Sahib, Punjab is presented here. It demonstrates effèctive use of modern investigation techniques to (a) increase the reliability of the geotechnical design parameters, (b) predict foundation behaviour, and (c) save on foundation costs.

Project Details

The Khalsa Heritage Memorial Complex (also called "Ajooba"), commemorating 300 years of the Khalsa Panth is planned to be a grand massive structure replete with classical architectural features and traditional Sikh elegance. Planned on a plot of 70 acres area, the project will have about 25000 m^2 built up area. The various facilities planned include the following :

Complex A	:	includes library and associated facilities
Complex B	:	a pedestrian bridge connecting Complexes A and C
Complex C	:	Exhibition halls, theatre and related units
The Nishan-e-Khalsa	:	a tall tower structure

A lake is planned between complexes A and C. For architectural reasons and to generate the required floor space, the hills will be cut by nearly 10 to 18 m to achieve the required final finished levels. Complex D, the Nishan-e-Khalsa is planned on another hill on the northern side. A layout plan illustrating the various facilities planned and the field investigation locations are illustrated on Fig. 6.

Site Conditions

Anandpur Sahib is the bank of River Sutlej. The soils deposited in this area are alluvial deposits of this river. The river has changed course over the millennia resulting in deposition and subsequent erosion. This probably resulted in the formation of valley flanked by hills on either side. The alluvium to about 4 - 5 m depth is of Recent origin underlain by soils of Pleistocene Age.

The site is in the foothills zone of the Himalayas. The soils consist of sand mixed with pebbles / shingles (varying from 20 to 200 mm size) with intermediate clay layers.

Scope of the Geotechnical Investigation

Since the founding level at Complexes A and C were planned to the nearly 10 to 20 m below the existing ground level, it was decided to start the detailed investigation from

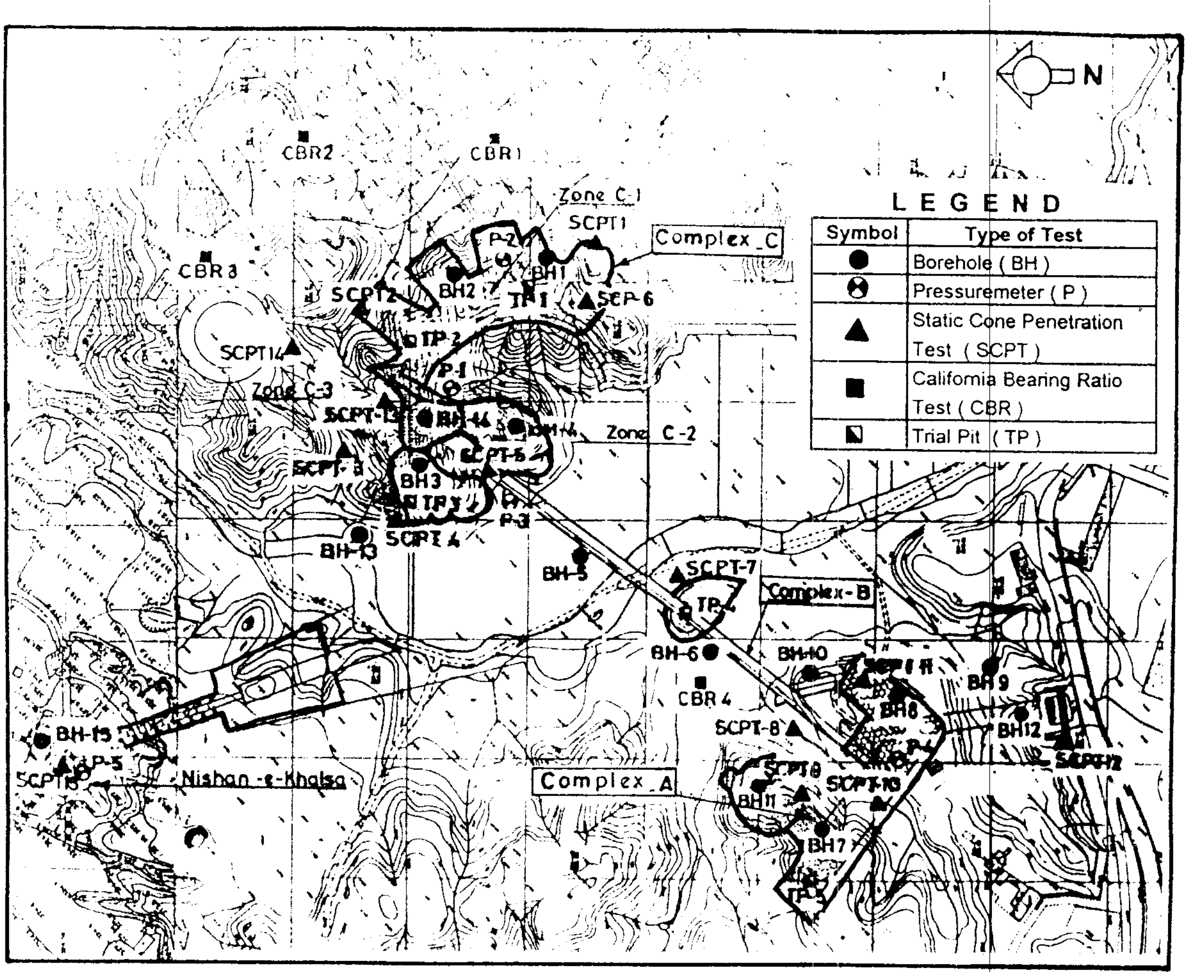


Fig. 6 : The Khalsa Heritage Memorial Complex at Anandpur Sahib Punjab

below the founding level. This meant that a blank borehole was drilled to the founding level and the various tests were started below this level. This included SPT and sample collection in boreholes, the pressuremeter tests as well as the static cone penetration tests.

After review of the site conditions and loads at foundation level for the various structures the following scope of work was finalized for the field investigation –

(i) drilling fifteen boreholes to 30 to 40 m depth in order to determine site stratigraphy and to collect soil samples for laboratory testing ;

(ii) conducting fifteen static cone penetration tests below the founding level; and

(iii) performing pressuremeter tests at different depths at five locations.

In addition, field and laboratory CBR tests, Proctor compaction tests etc. were also done for earth work and compaction control.

Presentation of Results

Typical borehole data from Complex C is presented on Fig. 7. It can be seen that the soils are primarily granular and contain pebbles / cobbles / gravel with a 1-3 m thick clay layer at about RL 304 m.

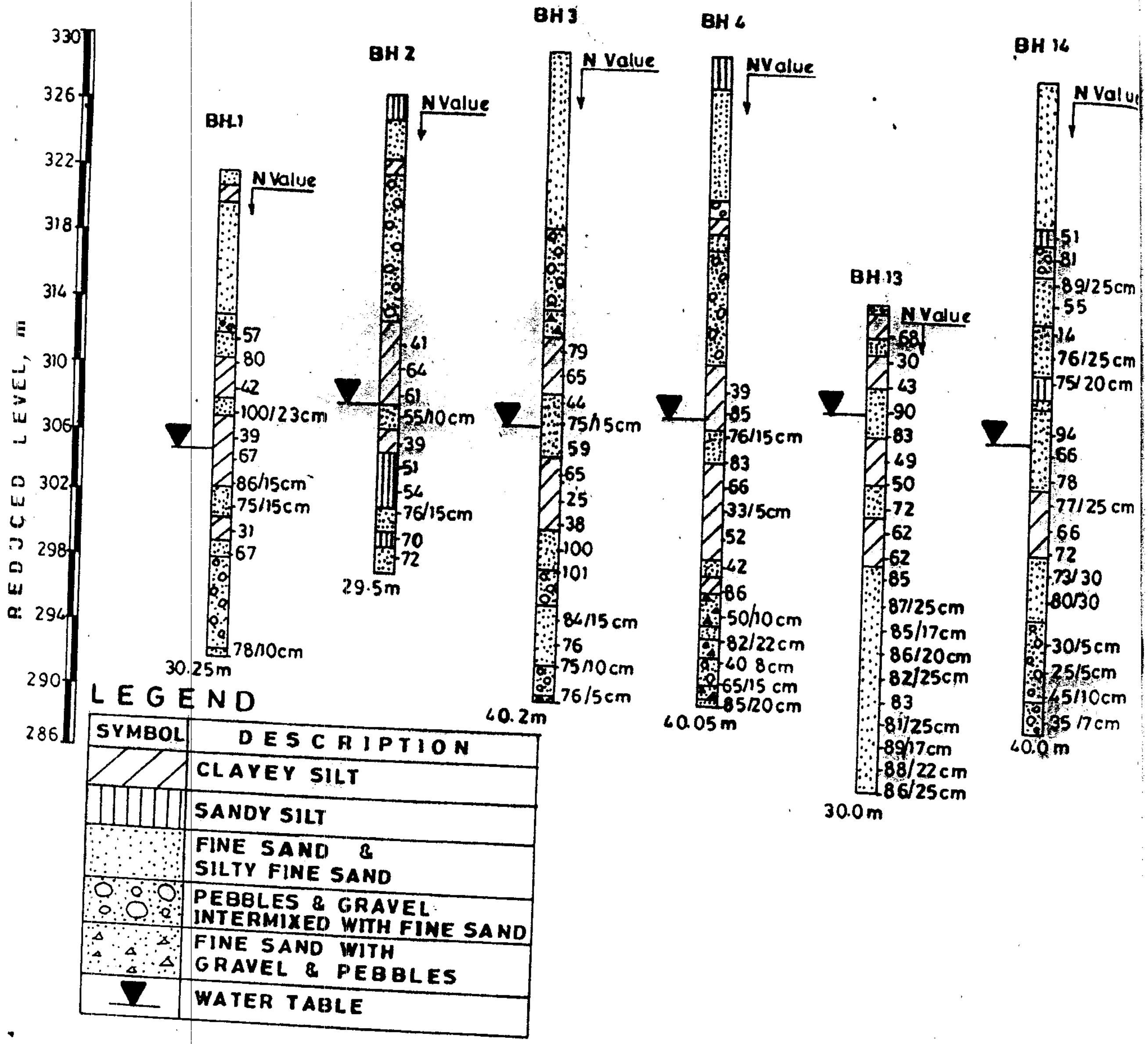


Fig. 7 : Borehole Profiles – Complex C

Typical results from a pressuremeter test showing a plot of the pressure versus volume change is illustrated on Fig. 8.

e soils
ayer at

N Value

51
81
89/25cm
55
14
76/25cm
75/20cm

94
66
78
77/25 cm
66
72
73/30
80/30

30/5cm
25/5cm
45/10cm
35 /7cm
0 m

us volume

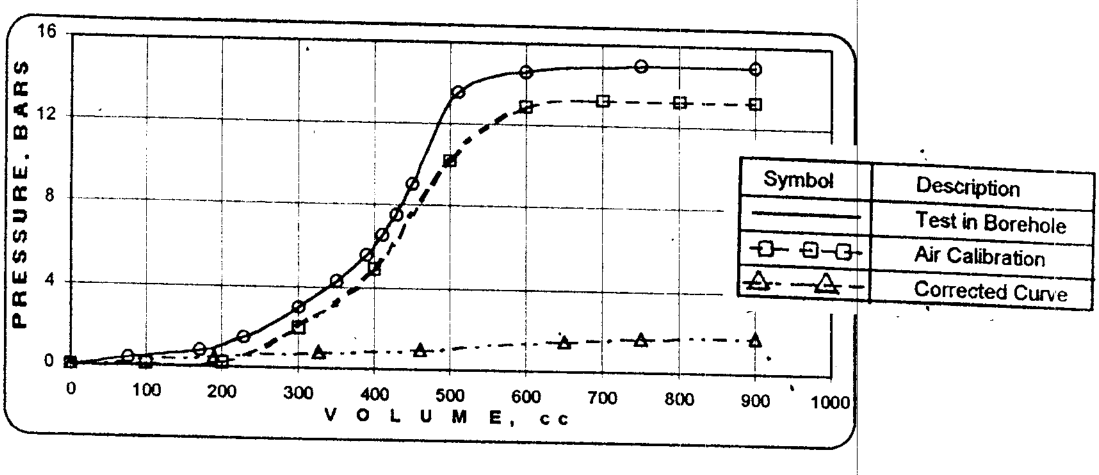


Fig. 8 : Typical Results of the Pressuremeter Test

Fig. 9 shows the interpreted profile of limit pressure and modulus of elasticity with depth based on the pressuremeter tests conducted at different depths in an NX size borehole.

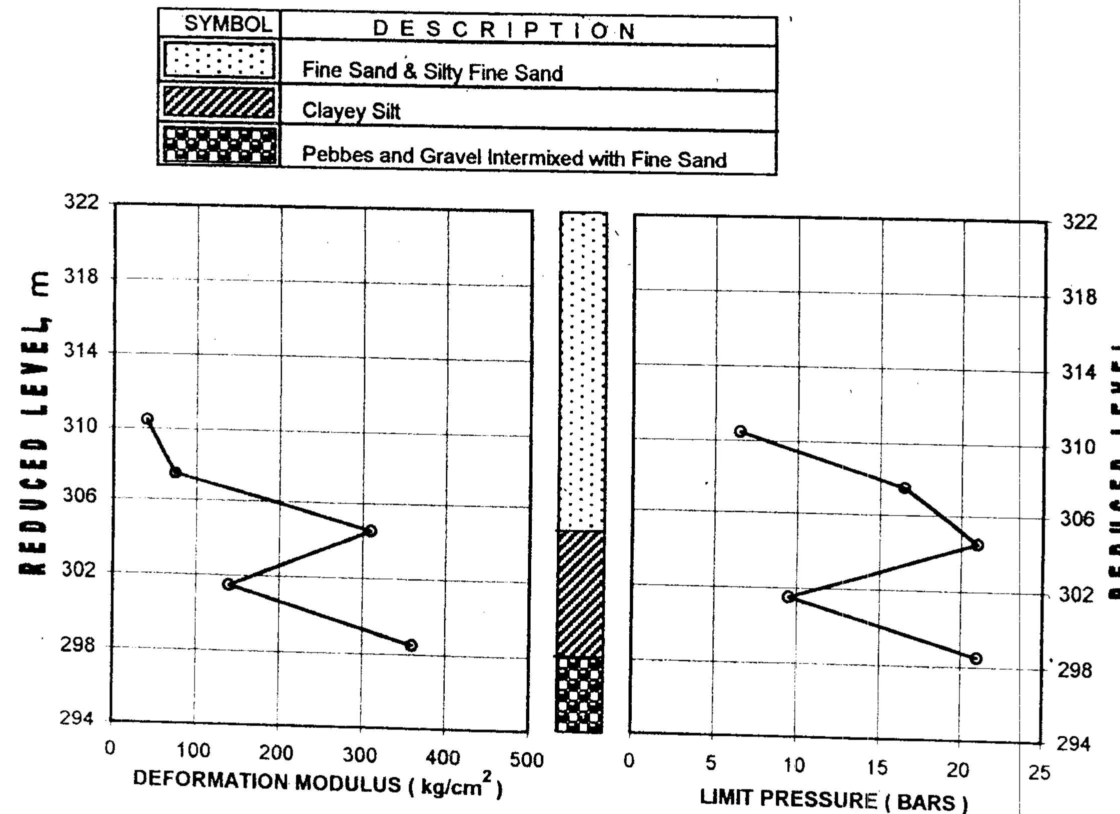


Fig. 9 : Profile of Pressuremeter Parameters

Analysis of Results and Foundation Scheme Proposed

The foundation analysis was done by four alternative methods. These include :

- N - values
- Static cone penetration test results
- Elastic theory
- Pressuremeter test results.

Based on a detailed analysis of the results, net bearing pressures for the various facilities of the project were worked out. Due to the high quality of the data, it was possible to justify a safe net bearing pressure as high as 35 to 40 T/m^2 for the various facilities. The estimated settlement under the design bearing pressure was worked out to be in the range of 20 to 40 mm which is well within the tolerable limits for adequate performance of the proposed structure.

It was demonstrated that while substantial saving was achieved in costs and time by eliminating the need for piles (as was originally planned in view of the very high column loads), a higher soil bearing capacity could be used in design as a result of the modern and reliable techniques of testing and analysis.

The settlement under the design bearing pressures were then confirmed by plate load tests at founding level. The test was conducted on a 75 x 75 cm size square plate. The evaluation of the test results matches well with the settlement predictions.

CONCLUDING REMARKS

There is a need to incorporate in-situ testing and other modern testing technologies into the specifications of major projects. The geotechnical consultant should be a part of the consultancy team right from the project inception for proper interaction to finalize the scope of the investigation. For a thorough job, a practical time schedule is most essential. The saving on time should not be at the expense of reducing on the scope of the investigation.

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