Development of dynamic cone penetration testing in Ireland
Le développement des essais de pénétration dynamique en Irlande

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SYNOPSIS: This paper deals with the development of Dynamic Cone Penetration Testing in Ireland. Its application to a range of different soil types is discussed and correlations are indicated together with the philosophy behind them. The writer and his colleagues have found this testing approach to be particularly suitable for Irish soil conditions.

1. INTRODUCTION

Historically, soils investigation procedures in Ireland have, in general, followed U.K. practice, as set out in the various B.S.I. Codes and Standards. Shell and augur drilling methods with S.P.T. testing have been used extensively, with soil sampling in U100 tubes, where possible. These methods have not proved entirely satisfactory in the glacial soils which cover most of the country. These soils are very difficult to sample in an undisturbed condition and the testing of remoulded specimens was usually employed to estimate shear strength. This tended to underestimate the strength of the stronger tills. The inherent variability of the glacial soils was also not adequately investigated, and S.P.T. tests at intervals in a borehole were not picking up layering and weak pockets within the till. In the 1970's the author and his colleagues experimented with dynamic cone penetration testing in glacial soils, initially using light hand-held penetrometers. This identified the need for heavier automatic penetrometers and following a survey of the equipment available and the particular local requirements, Borros Automatic Ram Sounding equipment was acquired in 1981. The equipment had to be easily transportable, able to gain access to restricted areas, and be strong enough to work in stiff stony tills containing cobbles and boulders. The Swedish Standard machine was chosen as a compromise between the lighter German Standard and the heavier S.P.T. Standard machines. Experience has shown that the particular choice was a good one, providing a mobile machine capable of penetrating most soils. The equipment has resulted in a significant improvement in the ability to assess the in-situ strength of variable glacial soils and now performs a major role in the standard investigation techniques used by the writer and his colleagues. A second machine, using hydraulic power, which is more suitable for working inside buildings and in confined spaces, was acquired in 1986.

Figure 1. Ram Sound Equipment with standard rod and point. Operator holding standpipe installation.

2. TEST PROCEDURE

The Swedish Standard equipment uses a 63 Kg hammer falling 500mm and a 45mm diameter cone with a 90° apex angle and mantle length of 90mm. The number of blows is recorded for each 200mm of penetration and designated as the N_b value for that increment. Both 'fixed' and 'lost' points are used, the former for shallow work, generally above 5 metres depth. Torque measurements are taken for each metre of penetration, when using the 'lost' points though experience has shown that rod friction levels are generally very low to a depth of c. 5 metres except in soft cohesive soils. However where such soils have been encountered static cone penetration testing has usually been employed.

3. STATISTICAL CORRELATIONS

Correlations were developed initially with SPT as it was the predominant field test of this type. Early work was assessed on the basis of:

$$N_b = N$$

where N_b is the corrected penetration resistance using the Swedish Standard System. However after some time it was felt that this correlation was too conservative particularly for lodgment type till deposits and sands/gravels at shallow depths. It was then decided that separate independant correlations for cohesive and granular soils should be developed.

3.1 Granular Soils

Some initial correlation testing was carried out with different cone points in beach sand deposits at Dollymount, Dublin. In addition to the Standard Swedish point, a 50mm diameter point of similar construction and 50mm diameter point similar to the solid SPT point were also used for comparative purposes. These tests indicated that the ratio between the 50mm Swedish type point and the Standard Swedish point was 1.2 while that between the solid SPT type point and the standard Swedish point was 1.5. These ratios were in excellent agreement with ratios calculated from the formula

$$Q = N_q.p'.A_b + 0.5\ K_s p' \tan \emptyset.A_s$$

which is commonly used to determine pile capacity.

Since the calculations also indicated that the penetration resistance of the standard Swedish point was similar to that of the SPT split spoon sampler, which is the basis of all SPT correlations, it was felt that the adoption of the $N_b = N$ correlation now had some substantive corroberation. The author remained of the belief that this correlation was somewhat conservative, however. Continued research, led to a study of the energy efficiency of the various types of dynamic cone penetration test systems. Douglas (1982) had indicated that the efficiency of automatic trip hammers was much higher than the rope and cathead type, which was the basis of the original SPT test. Other authors confirmed these findings and developed energy ratios for various systems in use. Skempton (1986) quoted efficiency figures for both release and trip hammer systems which indicated that an automatic trip hammer system using a light anvil could have an overall efficiency of 70-80% as against 45-55% for the classical SPT system.

Since the ram sounding equipment used by the author is of the automatic trip hammer type and uses a light anvil system, its efficiency should therefore be of the order of 70-80% which is approximately 1.5 times that of the original SPT system which forms the basis for many of the correlations in granular soils. This would suggest that our correlation against SPT should be:

$$N = 1.5\ N_b$$

In fact, Japanese authors Ohya & Ohnishi (1981) have indicated N_b of the ram sounding to be equivalent to N of SPT. However a study of the energy efficiency of the Japanese SPT systems suggests that they deliver an overall efficiency of 65-80% which is equivalent to the ram sound system.

For correlation purposes the author feels that in relating to SPT 'N' values, therefore, comparison must be made with the original systems used and thus readings from more modern, efficient systems should be increased in relation to the ratio of the efficiencies of the systems. Skempton (1986) gives a procedure for modifying values to a standard efficiency of 60% (others have suggested 55%) but the author's view is that we should relate to the original system since this is the system from which all correlations were developed. The question as to the validity of some of the Terzaghi & Peck (1948) correlations of density to SPT 'N' values is a separate matter relating to their comparisons of 'N' values under full overburden loading with plate bearing test values with overburden load removed. If comparisons with SPT 'N' value are to be used then surely they should relate to the original base. Indeed low energy efficiency systems are still in widespread use to-day. Therefore, if we wish to relate our N_b values with SPT 'N' values for granular soils we use the following relationships

$$N = 1.5\ N_b \text{ for sandy soils}$$

$$N = 2\ N_b \text{ for gravel soils}$$

3.2 Cohesive Soils

While dynamic penetration testing is not generally considered suitable for cohesive soils, it has proved an excellent tool in assessing many of the stony till soils which occur widely in Ireland. The stony nature of these deposits precludes the taking of satisfactory undisturbed samples for laboratory testing at many locations and therefore some method of in-situ test which could penetrate such soils was considered necessary. Hand-held penetrometers were used initially but were found to be of rather limited use and heavy dynamic cone equipment was obtained as previously discussed.

In developing correlations for use in these low plasticity gravelly clays, we initially adopted the relationship developed by Stroud & Butler (1975)

$$C_u = 4 - 6 \ N \ (kPa)$$

This relationship however, was found to be rather conservative for the ram sound equipment. Following assessment tests taken in a range of cohesive soils, it was noticed that in material with an undrained shear strength of 30 kPa the cone would penetrate some distance under self-weight of the apparatus. Further site and laboratory check testing suggested that a suitable relationship might be

$$C_u = 10 \ N_b + 30 \ kPa$$

Subsequent work has confirmed this relationship to be reasonable for the majority of cohesive soils encountered in Ireland, (C_u = 30-250 kPa).

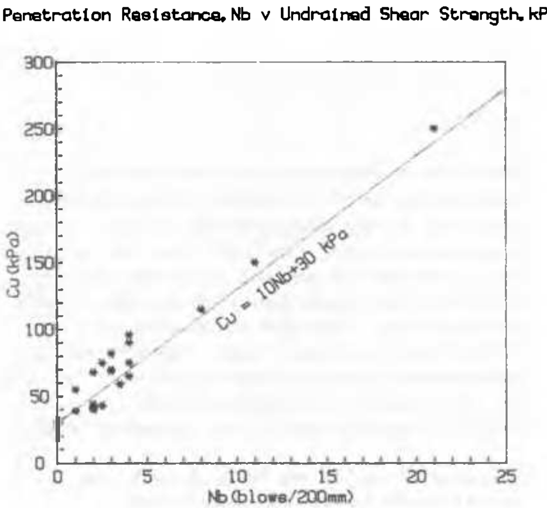

Figure 2. Correlation data for clays.

Problems arise however, where any significant depth of soft clay (C_u < 30 kPa) soils are present as friction on the rods increases significantly, with the result that soils below can appear stronger than is the case. Static cone penetration testing is always recommended for such situations, if it is feasible, though the presence of stony layers may preclude it. Our practice in assessing dynamic cone values where self-weight penetration has occurred is to increase the normal correction for friction by a factor of some 2.0 - 2.5 such that the values to be plotted as a corrected zero line are given by:

$$N_{bf} = 0.08 - 0.1 \ T$$

where T represents the measured torque on the rods in Newton metres. (The Standard correction is N_{bf} = 0.04 T). This approach provides a more realistic assessment in situations where static testing is not feasible. An example of this phenomenon is shown in Fig. Nos. 3 & 4.

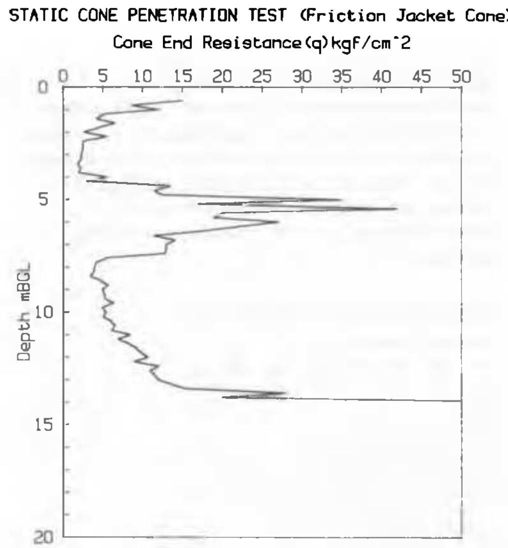

Figure 3. Result of static penetration test showing shallow and deep soft clay deposits.

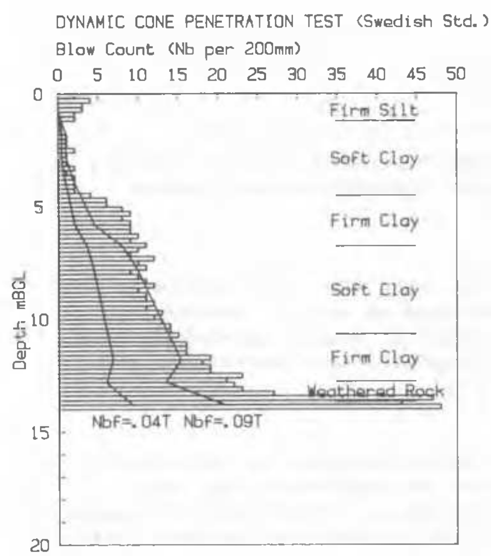

Figure 4. Result of dynamic penetration test at same location showing need for increased friction correction.

4. OTHER APPLICATIONS

4.1 Dynamic cone penetration testing also provides an excellent assessment of ground conditions with respect to pile driving and we have found the ram sound method to be a good indicator of likely pile bearing strata and driving conditions.

4.2 We have also successfully used the ram sound system for control testing on both vibroreplacement and dynamic consolidation ground treatment procedures. Recent work done in the Dublin area has proved extremely successful in determining the effective depth of stone columns formed as part of a vibroreplacement treatment program on hydraulic sand fill. Fig. No. 5 shows typical test results before and after treatment.

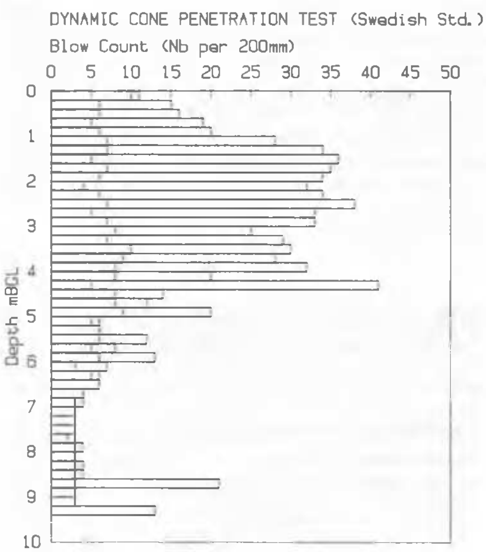

Figure 5. Dynamic penetration test results before and after vibroreplacement ground treatment.

The author feels that the test method is well suited to this type of control testing and would suggest that it should be adopted more widely as the standard test method for such assessments.

4.3 We have also established a relationship between penetration resistance, N_b, and remoulded C.B.R. value, (Road Note 29 compaction method). Fig. No. 6 shows the relevant data.

4.4 The ram sounding equipment has also proved very useful for installing standpipes for monitoring of groundwater levels and also for measurement of gas quantities present in filled sites. The system is quick and versatile and can access areas which may be difficult to service with drilling equipment.

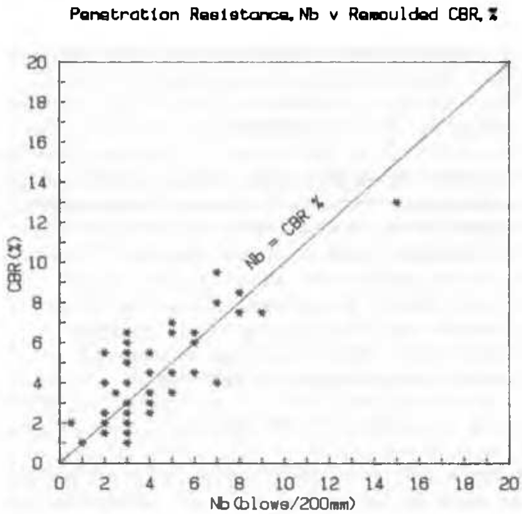

Figure 6. Correlation of dynamic penetration resistance with remoulded C.B.R. value (Road Note 29 Method).

5. CONCLUSIONS

(1) Dynamic cone penetration testing has proved an extremely useful method of assessing both granular and stony cohesive soils in Ireland.

(2) Its advantage over the SPT test is that it provides a continuous record of penetration resistance and in our experience gives much more reproducible results. Its penetrability of gravels is also much greater than the SPT method.

(3) Disadvantages are a lack of identification of soil type and shaft friction on rods, particularly for deep probing i.e. greater than 5m B.G.L.

(4) For granular soils we have found the following relationships to be reasonable.

$$N = 1.5\ N_b \quad \text{(sands)}$$

$$N = 2\ N_b \quad \text{(gravels)}$$

$$q_c(\text{kg/cm}^2) = 5\text{-}7\ N_b \quad \text{(sands)}$$

(5) For cohesive soils our adopted relationship is

$$C_u = 10\ N_b + 30\ \text{kPa}$$

(6) For road construction design purposes we use the relationship

$$N_b = \text{C.B.R. \%}$$

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