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Experimentation with the German Dynamic Probing Technique on the Great Barrier Reef

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SUMMARY Coral reefs are one of the most complex geotechnical formations. This is because ground conditions are extremely variable in both horizontal and vertical directions. Within metres, changes from hard algae-encrusted coral limestone, over rubble of coralline fragments and loose coral sand, to voids of substantial size are common. It is evident that under these conditions site investigations and engineering judgment on the likely mechanical response of coral materials to man-induced loads are very difficult indeed.

Research has demonstrated that dynamic probing, particularly a German version of it, is presently one of the best site investigation techniques on coral reefs as it is a very quick testing method which provides continuous quantitative records over the depth of penetration. Typical dynamic probing results from various areas of The Great Barrier Reef are presented from which principal features of the structure of coral reefs can be delineated. In-situ experiments were carried out with differently shaped driving points and with a slight rotation of the penetration rods. By this modification, significantly increased penetration capabilities could be achieved. Results are also presented on hole-widening experiments using a stepwise increase of the diameter of the driving points. The particular merits of this method lie in a quick production of holes which might be used for pressuremeter or other kind of down-hole testing.

1 INTRODUCTION

In recent years, coral reefs have become increasingly important for geotechnical engineers. Due to the reefs' favourable proximity to continental shore lines in certain parts of the world and to the existence of large numbers of coral islands in the Indian and Pacific Oceans, many engineered structures are being built on coral reefs or with coralline material. On The Great Barrier Reef, for instance, almost 40 lighthouses, some of them substantial structures, are serving the "Steamer Track", which is an international shipping route on the in-shore side of The Reef (Figs. 1 and 2).

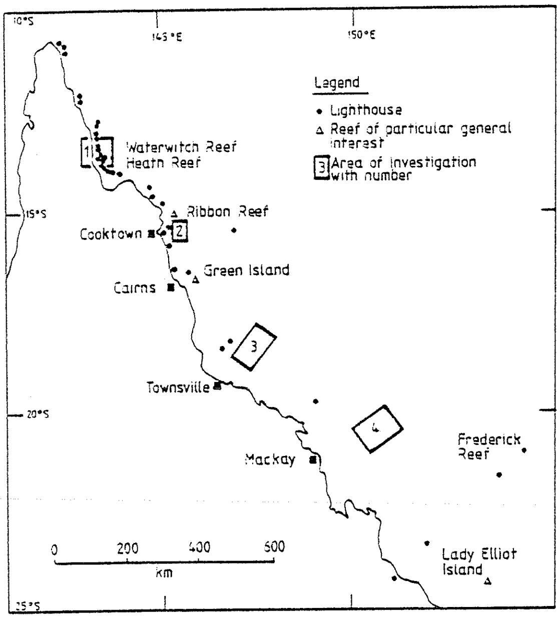

Fig. 1 Location of lighthouses on The Great Barrier Reef and areas of investigation

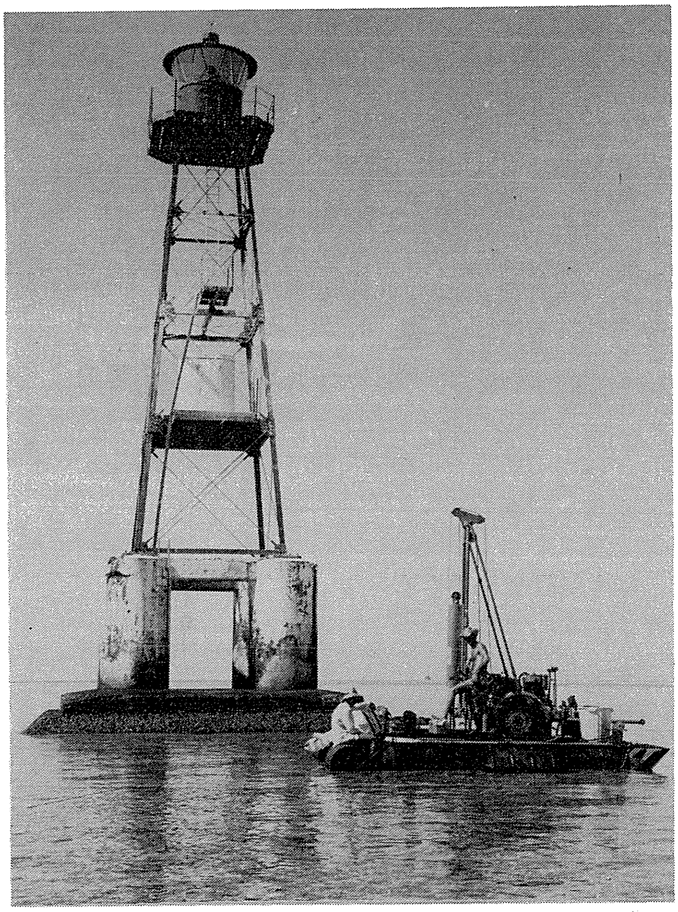

Fig. 2 Site investigation with the heavy dynamic probing technique for the foundation of a new lighthouse on Heath Reef (Area 1, Fig. 1)

Experience has shown that geotechnical engineering on coral reefs is in most cases fraught with difficulties. Core recoveries from drilling are low, running sands and hole collapses tend to cause jamming and loss of the drill string, and drilling fluid circulation may be lost. Pile-driving and grouting are also regularly attended by difficulties associated with the porous and cavernous nature and the extreme variability in both horizontal and vertical direction of the reef material. As a result, contractors' claims for compensation for extra costs incurred by "unforeseen conditions" are not uncommon. Against this background particular site investigation and construction techniques, adapted to the environment and geotechnical conditions of coral reefs, become desirable.

The Department of Civil and Systems Engineering, James Cook University of North Queensland, has a long-standing scientific and applied-technical interest in this problem. Particular logistics comprising research vessel, raft, loading and anchoring facilities, have been set up to carry out site investigations at any point of The Great Barrier Reef (BOCK and BROWN, 1980). Coral reef material was tested for its geomechanical properties both in the laboratory (FORSTER, 1974; MOSS, 1976) and in-situ (SIMMONS, 1976). Various site investigation techniques were employed, including diamond drilling (CAMERON, 1975; SIMMONS, 1976), seismic refraction (BILLINGHAM, 1979) and dynamic penetration (BOCK and MOSS, 1980; OLSEN, 1980; BOCK, 1981, 1982 and 1983; FORURIA, 1983). In essence, it turned out that both diamond drilling and seismic refraction are of rather limited value, whereas dynamic penetration is a very useful technique on coral reefs. In particular, it is a German version of dynamic probing which yielded excellent results when investigating the near-surface structure of coral reefs down to a depth of about 30 m. Experience with this probing technique and its modification to cope with the particular geotechnical conditions of coral reefs are reported herein.

2 DYNAMIC PROBING* METHOD

The principal aim of dynamic probing is to measure the effort required to force a point through soil or soft rock and so to obtain resistance values which might be related to their mechanical properties. In practice, the probing method consists of driving into the ground a rod with a drive point by means of a drop hammer and measuring the number of blows per a particular, standardized amount of penetration. It is a method which is particularly useful for exploring soils and weak rocks with an *erratic* structure of which coral reefs are excellent examples. Because of its simplicity, dynamic penetration enables many quick tests to be performed at very moderate expense. Used in combination with other geotechnical information, e.g., from exploratory drilling, from geological mapping and/or from knowledge of the regional geology, it can be a very powerful site investigation method.

In context with site investigations on The Great Barrier Reef, carried out by the author, Dynamic Probing (DP) was preferred to Standard Penetration Testing (SPT) for a couple of reasons. The main ones were as follows.

- DP yields a *continuous* penetration resistance record;
- *Simplicity* and *speed* of the DP testing are superior. Particularly on submerged coral reefs, these are very important, if not decisive factors, because of quickly changing tidal and other hydrodynamic conditions;
- On The Reef, the principal geotechnical units are known (coral reef limestone; shingle; coral sand; cavities) and mainly their horizontal and vertical distributions are of concern. Sampling, as it can be carried out with the SPT, is therefore of no crucial importance.

The German type of Heavy Dynamic Probing (HDP) (DIN 4094; Sheet 1 and 2) was employed as it is known that this type of probing has the capacity of investigating stiff and hard soils as well as soft rocks at relatively great depths. For the sake of simplicity and economy, no drilling mud or casing for decreasing friction along the extension rods were used (DPB test of the proposed European Standard). By this, the HDP tests had more the character of reconnaissance tests rather than those for (indirect) determination of mechanical properties of soils and rocks.

The main disadvantage of the HDP test is its lack of acknowledgement in international standards. However, results from different types of dynamic probing can be compared via energy considerations (cf. Section 4). This allows a correlation of the non-standard HDP test with e. g. the DPB test or with the SPT (cf. Table I).

The main piece of equipment used was a Heavy Dynamic Penetrometer, manufactured by Nordmeyer/Peine, W.-Germany (Fig. 2). Specifications are as listed in Table I.

Before its first operation on The Reef, essentially two technical questions were open concerning the usefulness of the HDP;

1. Would the HDP be in a position to penetrate through zones of hard coralline layers?
2. Would there be a tendency of jamming of the rods as common in drilling? Would there be any difficulties in pulling the string of sounding rods, particularly from a floating raft?

With respect to the first question, it was found that the HDP was generally well able to penetrate through layers of hard coral limestone (exemptions ref. Section 3). In fact, HDP was an excellent method of delineating the near-surface structure of coral reefs down to a depth of about 30 m. Hard coralline limestone, pockets of loose sand and cavities could all be identified and their respective thicknesses determined (Fig. 3).

Relating to the second question raised, surprisingly small, if any, effects of jamming of the rods were observed. One factor which reduced this effect was the diameter of the driving point (43.7 mm) which was slightly bigger than the diameter of the rods (32 mm). Due to the use of sacrificial tips, recovering the rods also proved to be feasible, even from the floating raft.

The particular advantages of the HDP in the rough environment of coral reefs result from the straightforwardness of the testing principle, the ruggedness of the machine and the speed of the operations. A 25 m deep probing requires

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*In accordance with the latest proposal of the Subcommittee on Standardization of Penetration Testing in Europe, the expression "probing" is preferred to terms such as the general expression "penetration" or the formerly used term "sounding". With the use of the expression "probing" it is indicated that a (quasi-) continuous record is obtained from the test in contrast to, for example, the Standard Penetration Test (SPT) which furnishes only one resistance value for about 1.5 m depth.

Table I Specifications of Heavy Dynamic Probing in comparison with two standard techniques

Dynamic Penetration Method	Mass of hammer [kg]	Height of Fall [m]	Dimension of Probe: Diameter Outer [mm]	Diameter Inner [mm]	Area [mm^2]	Length shaft [mm]	Apex angle [°]	Count N taken after penetration of ... [m]	Standard
HDP	50	0.5	43.7	-	1500	43.7	90	0.10	DIN 4094 Sheet 1 and 2
DPB	63.5 ± 0.5	0.75 ± 0.02	51 ± 0.2	-	2000	51 ± 2	90	0.20	European (recommended)
SPT	63.5	0.75	50.8	35	2027	≈800	(60)*	0.30	ASTM D 1586-67

*in gravelly soils only

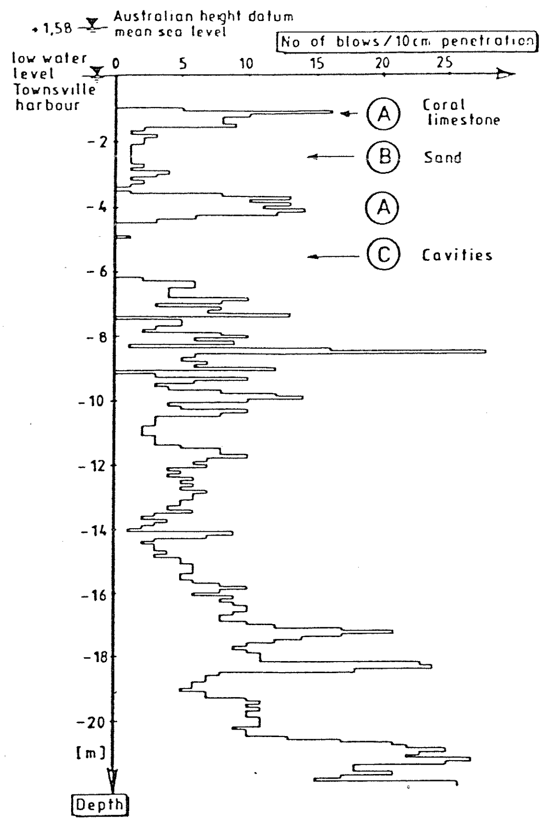

Fig. 3 Penetration diagram from testing on Keeper Reef (Area 3, Fig. 1). Note the notoriously variable ground formation, profile.

approximately 3 hours. This includes setting-up and disassembling of the equipment. In comparison, an equivalent diamond drill hole can hardly be sunk in less than 3 days.

Due to the speed of the dynamic probing method, systematic site investigations in various parts of The Great Barrier Reef became feasible (Fig. 1), which would not have been possible when relying on drilling alone. A total of more than 150 tests have been carried out till today. The broad data base of these tests made it possible to identify some systematic features behind the veil of a notoriously variable formation (Fig. 3). A probing test which represents the general trend is shown in Fig. 4. A sequence of three units could be identified as follows:

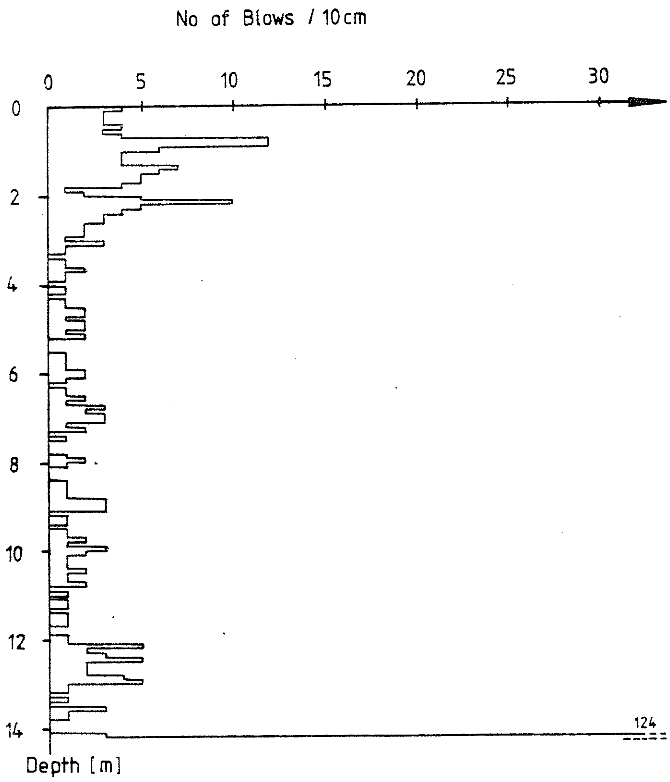

Fig. 4 Penetration diagram from Heath Reef showing general trend

Top: An about 2 m thick crust of slightly cemented debris of coralline material (up to 12 blows per 100 mm penetration)

From -2.2 m to -14.1 m a zone of extremely low penetration resistance

At -14.2 m refusal layer, which, from other investigations in neighbouring parts of the Reef, can be stratigraphically interpreted as the Holocene/Pleistocene interface

Bottom: (HOPLEY, 1982).

The result of another test, delineating similar underground conditions, is shown in Fig. 5. In this case, the relatively hard near-surface layer is approximately 8 m thick. The Holocene/Pleistocene interface is at a depth of about -21 m.

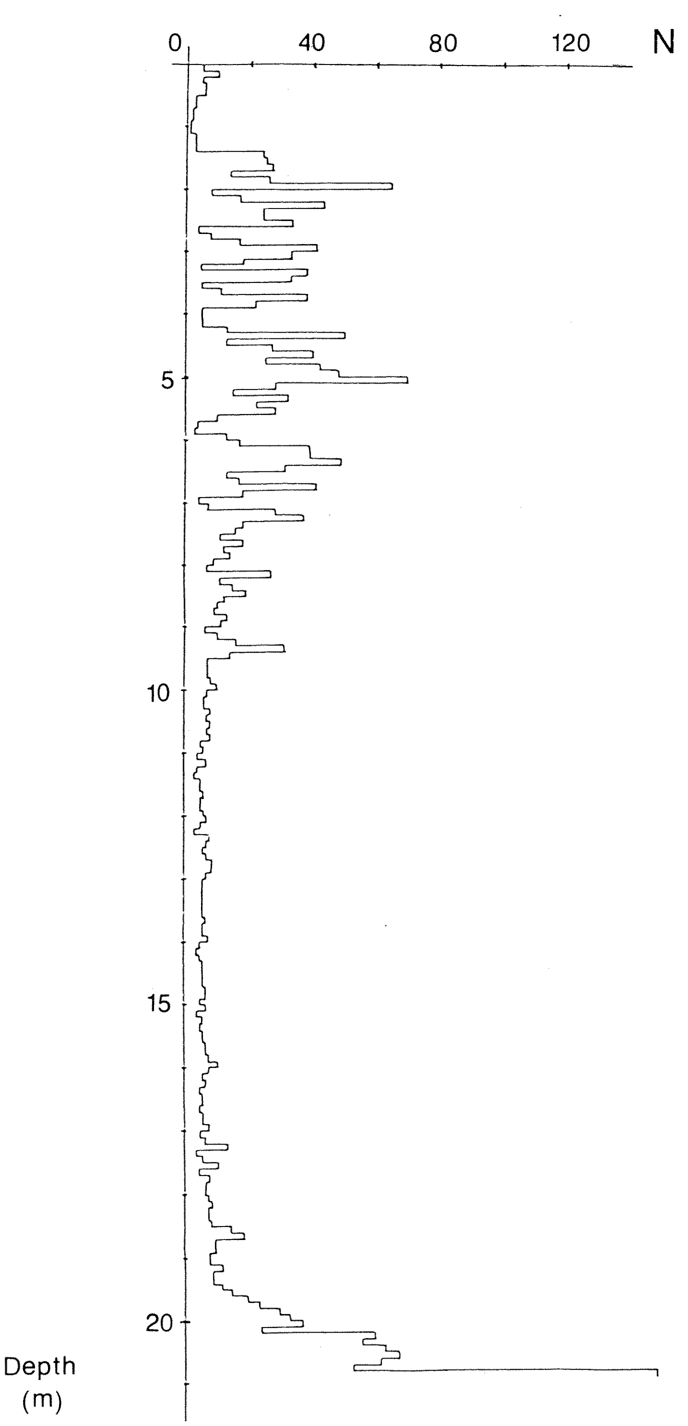

Fig. 5 Penetration diagramme from Hope Island (Area 2, Fig. 1)

3 MODIFICATIONS OF THE DYNAMIC PROBING METHOD

In some situations dynamic probing was not possible due to hard coralline layers. This happened either directly at the surface of the reef or at moderate depths of a few metres. To cope with these cases a modified probing technique has been developed. Instead of a tip with a smooth surface, a cross-chisel tip of identical dimensions was used (Fig. 6). During probing the string of rods was manually rotated by about a 1/6 revolution per blow. By this approach some elements of percussion drilling were combined with dynamic probing, yielding a significantly increased capability of penetrating through hard coral rock. The two types of tips caused differing readings for N-values higher than about 20. For lower N-values there is no recognizable effect on the readings. Quantification of this modified

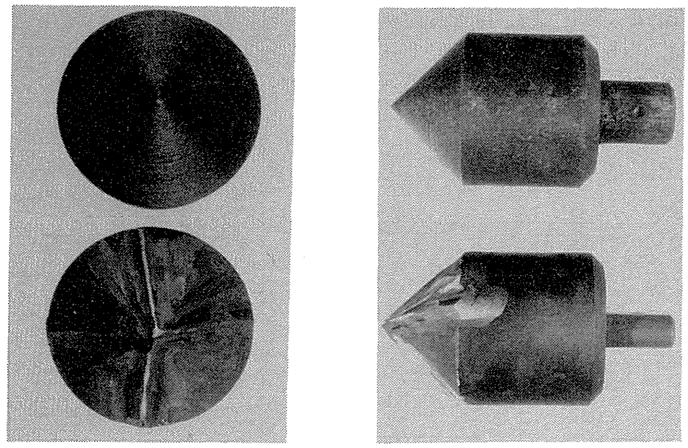

Fig. 6 Standard cone-shaped tips ∅ 43.7 mm (top) and modified cross-chisel tips (bottom)

probing method is proceeding and at the time of writing is not yet complete.

Another experiment was the widening of penetration holes by use of a series of tips with stepwise-increased diameters (Fig. 7). This experiment might

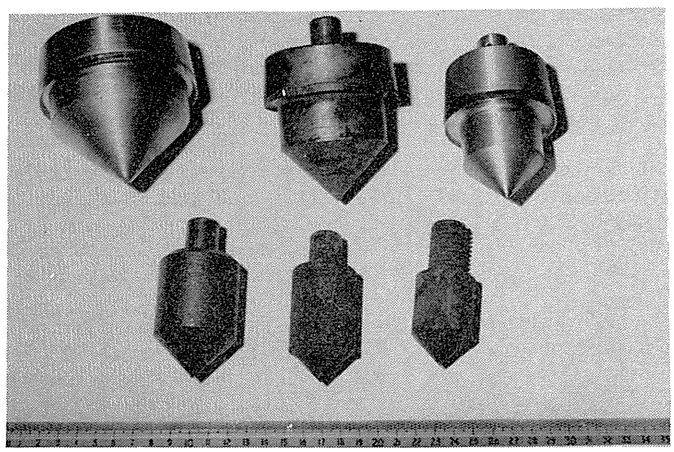

Fig. 7 Tips with various diameters, used for stepwisely widened penetrometer holes

be of some geotechnical interest, e. g. in context with the quick installation of piezometer holes or the application of some down-hole testing instruments such as a pressuremeter. Starting at the standard diameter of 43.7 mm, the penetrometer hole was widened in three steps (∅ = 60; 75 and 86 mm). Figure 8 gives an example. From the four probing logs it can be gathered that the general features of the ground are showing up in the logs in a similar fashion. In detail, however, there is a difference in so far as initial probing yielded data which scatter more than those from the widening operations. In the practice of dynamic probing testing it might therefore be advisable to perform one quick widening test after the initial test. This would help in delineating the principal structure of the ground more clearly than using initial probing records only.

4 CORRELATION OF HDP WITH SPT

Until now Dynamic Probing techniques, as mentioned in the foregoing sections, are rarely employed outside of Central Europe. Efforts to promote these techniques in countries such as Australia have been made (e.g. WIESNER,1982), whether successfully remains to be seen. Internationally, the commonly employed technique is that of the SPT. Much work has been

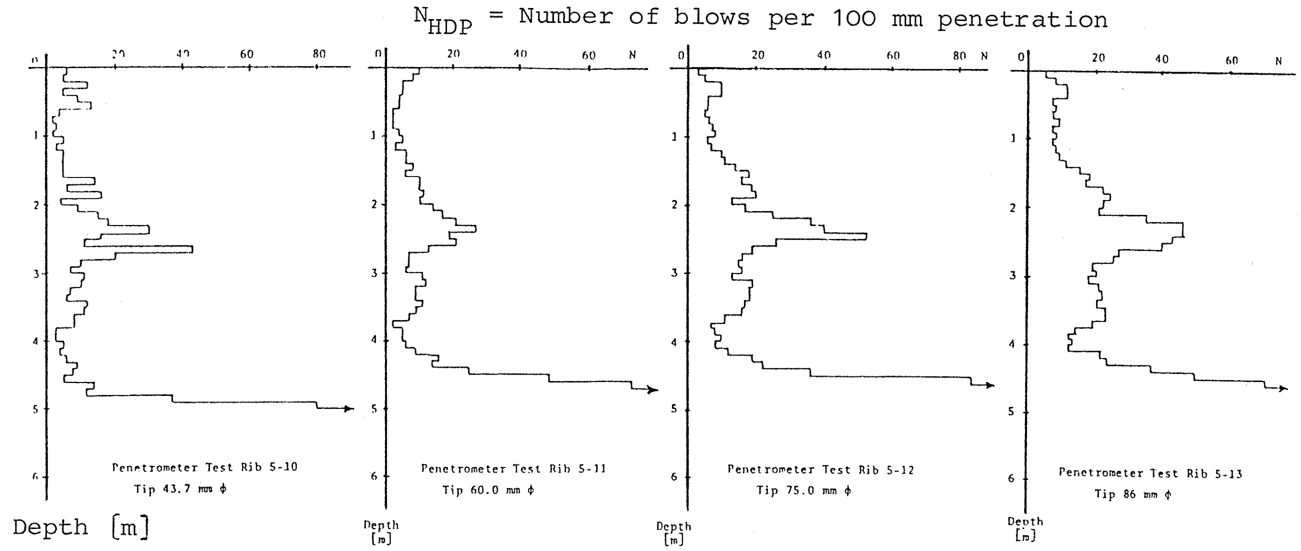

Fig. 8 Widening of penetration holes (Ribbon No. 5 Reef, Area 2 in Fig.1)

done on correlating design parameters with the "N-values" of the SPT (NIXON, 1982). Despite some fundamental methodological reservations concerning this empirical approach, one has to acknowledge the fact that those empirical methods are quite often successfully employed in foundation engineering practice. Against this background it was desirable to correlate HDP with SPT and so to connect the HDP with the existing system of empirical rules.

Such correlation can be done either theoretically or experimentally. DIN 4094 Part 2 and BOROWCZYK and FRANKOWSKI (1981) specify relationships between HDP and SPT for various soil types and index properties, however not for coral reef material.

Theoretically, the penetration resistance, q_d, is WIESNER, 1982)

$$q_d = \frac{M}{M + M'} \quad \frac{M \cdot g \cdot h}{A \cdot e}$$

with M = Mass of hammer

M' = Mass of rods

g = acceleration due to gravity

h = height of fall

A = cross-sectional area of driving point

e = average penetration per blow

Neglecting the relatively minor differences in the mass term M / (M + M'), the ratio of the number of blows N for the respective standard penetrations of 0.1 and 0.3 m (ref. Table I) is as follows.

(a) No plugging of SPT core

$$\frac{N_{SPT}}{N_{HDP}} = \frac{\dfrac{0.00107 \cdot 0.30}{63.5 \cdot 9.81 \cdot 0.75}}{\dfrac{0.0015 \cdot 0.10}{50 \cdot 9.81 \cdot 0.50}}$$

$$\frac{N_{SPT}}{N_{HDP}} \approx 1.1$$

(b) Plugging of SPT core

$$\frac{N_{SPT}}{N_{HDP}} \approx 2.1$$

Friction which develops along the outer shaft of the probes has been neglected within this analysis. While in the case of the HDP the associated energy loss is negligible because of the shortness of the probe (only about 0.04 m), such a loss may be substantial for the SPT. SCHMERTMANN (1979) reports that the percentage of applied energy consumed by friction lies between 44 % for loose sand and 85 % for highly overconsolidated clay. This would correspond to N-ratios as follows:

(c) With friction along the SPT sampler, no plugging

$$\frac{N_{SPT}}{N_{HDP}} \approx 2.0 \text{ to } 7.5$$

Experimentally determined N_{SPT} / N_{HDP} ratios, derived from parallel run actual SPT and HDP field tests, are given in Fig.9. The data is from both published (WERNICK,1982) and unpublished records, our own investigations included. The N_{SPT} to N_{HDP} ratios found experimentally for various soil and rock types are listed in Table II.

Table II Experimentally determined ratios of N-values from SPT and HDP

Soil or rock type	Coralline Rock	Sand (silty)	Silt (sandy)	Average
Number of tests	35	37	42	114
$\frac{N_{SPT}}{N_{HDP}}$	3.1 ± 0.7	3.9 ± 2.2	2.7 ± 1.2	3.0 ± 1.6

Comparing the theoretically and experimentally derived N-ratios it becomes evident that, despite large scatter, friction along the shaft of the SPT probe indeed plays a major role in consuming the applied energy. This in turn means that the commonly used penetration resistance formula, noted above, is not meaningful for the SPT but only for Dynamic Probing with squat driving points. Assuming that the experimentally found average N-ratio of 3.0 is representative for coralline material, and furthermore realizing that the standard penetration distances are 0.3 m and 0.1 m respectively (Table I) leads to the result that the *amount of penetration per blow is the same for both SPT and HDP.*

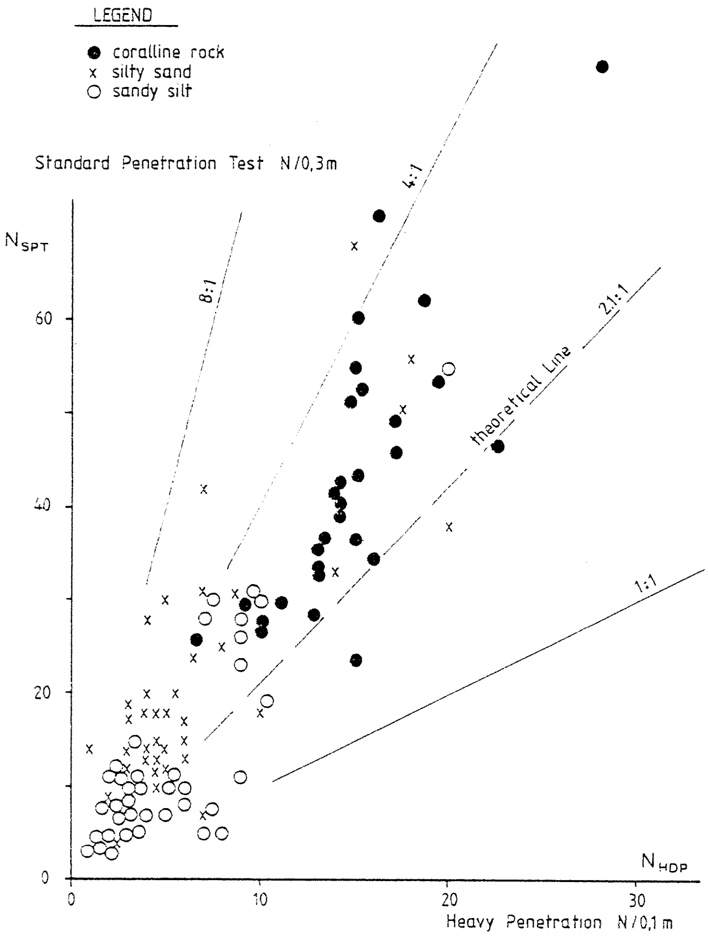

Fig. 9 Correlation of N-values from SPT and HDP

5 CONCLUSIONS

Dynamic probing is a site investigation method which is particularly useful on coral reefs. The difficult environmental and geotechnical conditions are met by a simple, relatively cheap and quick testing method. It is a method suited to the extremely variable, if not erratic structure of coral reefs. To cope with hard encrusted layers of coralline limestone, which can always occur on coral reefs, some modifications of the Dynamic Probing technique are recommended. Certain elements of percussion drilling such as the use of cross-chisel bits and the rotation of the sounding rods should be adopted. These additional elements should be implemented carefully in a step-by-step approach against the background of maintaining the fundamental mechanical principle of penetration testing.

6 REFERENCES

BILLINGHAM, S.L. (1979). The study of site investigation technique for determining the engineering properties of coral reefs. - B.E. Thesis (James Cook Univ.)

BOCK, H. (1981). Founding structures on coral reefs. - Proceed. Conf. Environm. Eng. Townsville, 51-56

BOCK, H. (1982). Engineering properties of coral reefs. - Int. Rep. to Dep. Science & Tech., 1-22 (unpubl.)

BOCK, H. (1983). Zur Ingenieurgeologie von Korallenriffen. Geologisch-geotechnische Untersuchungen auf dem Großen Barriere Riff Australiens. - Ber. 4th Nat. Tag. Ing.-Geol. Goslar (in print)

BOCK, H. and BROWN, E.T. (1980). Foundation properties of coral reefs. Site investigation techniques and preliminary results. - Proceed. Int. Conf. on Struct. Found. on Rock, Sydney, 1, 43-54

BOCK, H. and MOSS, K.H. (1980). Report on site investigations for the foundation of lighthouses on Heath, Waterwitch and Chapman Reefs. - Rep. Dept. Civil & Systems Eng. James Cook Univ. to Dept. Housing & Constr., p. 1-40 (unpubl.)

BOROWCZYK, M. and FRANKOWSKI, Z.B. (1981). Dynamic and static sounding results interpretation. - 10. Int. Conf. Soil Mech. Found. Eng. Stockholm, 2, 451-454

CAMERON, P.A. (1975). Light construction on The Great Barrier Reef. - B.E. Thesis (James Cook Univ.)

FORSTER, D.F. (1974). Geomechanical properties of coral rock. - B.E. Thesis (James Cook Univ.)

FORURIA, V. (1983). Report on site investigations for the foundation of lighthouses on Creal, Little Bugatti and White Tip Reefs. - Rep. Dept. Civil & Systems Eng. James Cook Univ. to Dept. Housing & Constr., p. 1-36 (unpubl.)

HOPLEY, D. (1982). The Geomorphology of The Great Barrier Reef: Quaternary development of coral reefs. - p. 453, New York (Wiley & Sons)

MOSS, K.H. (1976). Geotechnical studies of coral reef materials. - B.E. Thesis (James Cook Univ.)

OLSEN, W.H. (1980). An investigation into the near-surface structure of coral reefs using dynamic penetration techniques. - B.E. Thesis (James Cook Univ.)

SCHMERTMANN, J.H. (1979). Statics of SPT. - Proceed. ASCE J. Geotech. Eng., 105, 655-670

SIMMONS, J.V. (1976). Memorandum. - Dept. Civil & Systems Eng. James Cook Univ. (unpubl.)

WERNICK, E. (1982). Anwendung und Grenzen der Bodenverbesserung durch dynamische Intensivverdichtung am Beispiel einer Wohnsiedlung. - Geotechnik, 3, 125-138

WIESNER, T.J. (1982). Pile behaviour prediction at ESOPT2. - Austr. Geomech. News, 5, 20-24