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Establishing competent ground conditions with the DPSH

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Insufficient information is currently available to fully understand the mechanism of rod friction in DPSH (Dynamic Probe Super Heavy) probing. Consequently, a method is proposed to distinguish profiles in which friction results in excessive blow counts based on normalised profiles. While friction-impacted DPSH profiles are difficult to interpret, those unaffected by friction show better equivalence to SPT (Standard Penetration Test) profiles, especially if used to screen for competent (SPT blow counts ≥ 30) ground conditions.

INTRODUCTION

MacRobert (2017) showed that a narrow range of Dynamic Probe Super Heavy (DPSH) blow counts (N_{30SB}) could be associated with very loose and loose consistencies. However, the range of N_{30SB} values associated with medium-dense and dense horizons was very large. This brings into question the usefulness of the DPSH to establish the presence of competent horizons in the ground. Standard Penetration Test (SPT) blow counts (N) above 50 are commonly taken to indicate the presence of a very dense and competent layer within the ground (Decourt *et al* 1988). For foundation design, screening foundations subject to small settlements are often based on finding the depth below which $N \geq 30$ (Lommler 2012). This research sought to re-examine the existing MacRobert (2017) data set and recently collected data to establish whether the DPSH can be used to establish the presence of a competent layer.

Table 1 Summary of test sites

Site	Description	Water table	Number of probing tests	Average consistency	Group
Predominantly sandy profiles					
Bellville, South Africa	Transported fine to medium-grained locally calcareous sand.	No water strikes	SPT: 1 DPSH: 2	Medium-dense	1
Chloorkop, South Africa	Clayey silty sand with fine gravel becoming more abundant with depth. Reworked residual granite.	No water strikes	SPT: 3 DPSH: 2	Medium-dense	1
Matutuíne, Mozambique	Medium and fine sand.	No water strikes	SPT: 5 DPSH: 19	Medium-dense	1
Dunkeld, South Africa	Clayey silty coarse sand with traces of sub-angular quartz gravel. Reworked residual granite.	No water strikes	SPT: 1 DPSH: 2	Very loose	2
Glenhazel, South Africa	Silty sand with fine gravel at depth. Fill, hillwash and reworked residual granite.	No water strikes	SPT: 1 DPSH: 3	Loose	2
Parktown, South Africa	Profile of mixed origin predominantly silt and sand.	No water strikes	SPT: 8 DPSH: 17	Loose	2
Mt Edgecombe, South Africa	Slightly clayey transported sand.	On average below 21.5 m	SPT: 1 DPSH: 7	Medium-dense	3

Keywords: site investigations, in-situ testing, dynamic penetration testing, soil classification, statistical analysis

List of notations

$\bar{d}$	Normalised depth
N	Standard Penetration Test blow count
N_{30SB}	Dynamic Probe Super Heavy blow count (over 300 mm)

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Site	Description	Water table	Number of probing tests	Average consistency	Group
Milnerton, South Africa	Transported loose to medium slightly silty fine sand.	On average below 0.6 m	SPT: 2 DPSH: 2	Medium-dense	3
Chicalla, Angola	Fine to medium-grained sand with abundant shell fragments.	On average below 14.7 m	SPT: 3 DPSH: 8	Loose	3
Gope, Botswana	Transported sand cover with a thin variable layer of poorly developed calcified pedogenic material.	No water strikes	SPT: 4 DPSH: 13	Medium-dense	3
Maputo, Mozambique	Silty fine sand dune deposit with some occasional cemented nodules.	On average below 20.6 m	SPT: 17 DPSH: 17	Dense	3
Predominantly clayey profiles					
Boksburg, South Africa	Clayey sands, sandy clay, and silty clay. Residual intrusive and shale.	No water strikes	SPT: 3 DPSH: 8	Very stiff	1
Free State, South Africa	Sandy clay to silty clay. Reworked residual sandstone and mudstone.	No water strikes	SPT: 6 DPSH: 12	Stiff to very stiff	1
Hennenman, South Africa	Sandy clay to silty clay. Residual mudstone.	No water strikes	SPT: 9 DPSH: 4	Stiff to very stiff	1
Soweto, South Africa	Clayey sand to clayey silt. Residual andesite.	No water strikes	SPT: 3 DPSH: 8	Very stiff	1
Johannesburg, South Africa	Clayey sand to clayey silt. Residual andesite.	No water strikes	SPT: 1 DPSH: 3	Firm to stiff	2

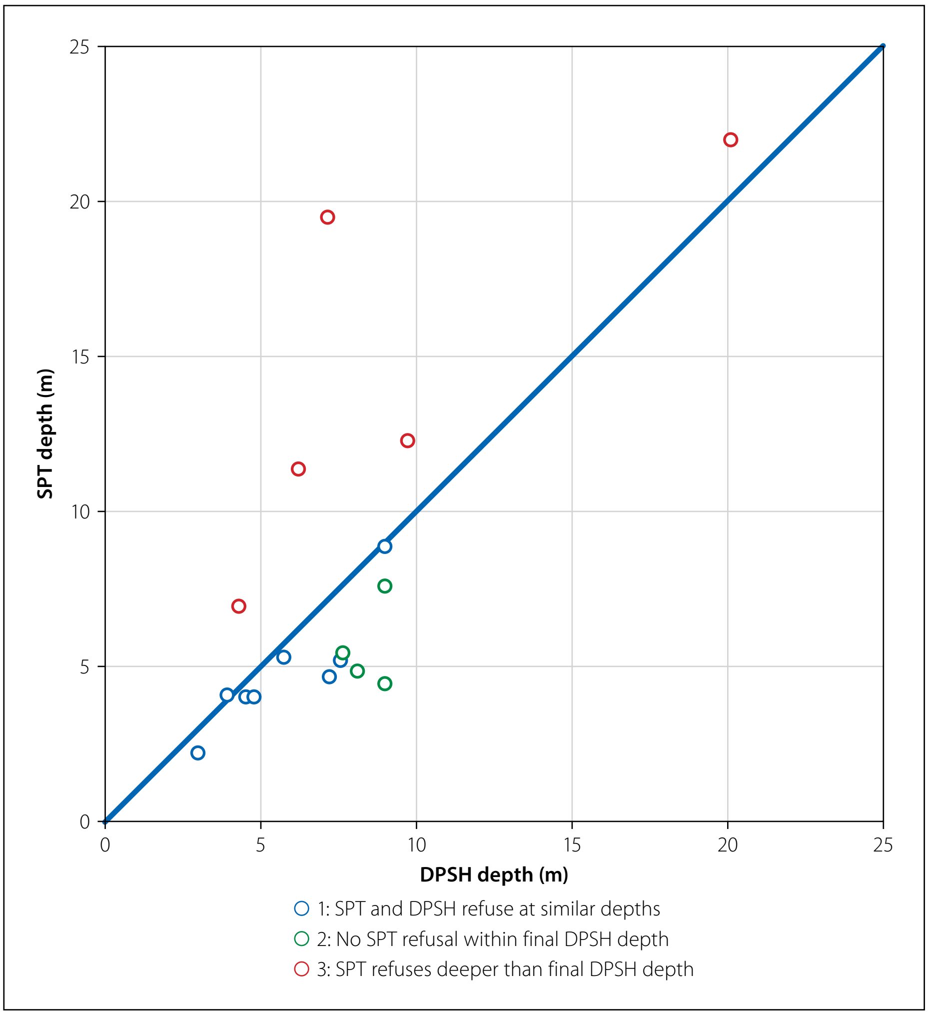

Figure 1 Average final depths

METHODOLOGY

Test sites

Table 1 summarises the various sites considered in this study. The location, soil profile, water table depth, number of respective probing tests performed, average consistency and site grouping are provided. Only DPSH and SPT testing conducted adjacent to each other, for comparative purposes in the original site investigation scope, were compared. Note that some sites and probes analysed in MacRobert (2017) have been excluded as there was insufficient information from borehole logs to interpret and predict conditions at the final DPSH depth.

Statistical approach

Table 1 shows sites divided into three groups. The sites in Group 1 were those where the average final DPSH depth coincided within a single standard deviation of the average depth at which SPT N exceeded 50. Group 2 profiles were those where no SPT exceeded 50 within the average final DPSH depth. Group 3 sites were those where the average depth at which SPT N exceeded 50 was greater than the final DPSH depth. Group 3 DPSH probings encountered significant rod friction leading to large blow counts at shallow depths. Average final depths for the three groups are shown in Figure 1. Each N_{30SB} profile was normalised by depth (i.e. depth at a given N_{30SB} divided by respective final probe depths) and a third-degree polynomial plotted through. These regression curves were used to establish bounds for the three groups. Analysis was carried out on raw blow counts, as the analysis suggested the range of blow counts was more important than a blow count for which a correction (i.e. overburden, rod length, borehole diameter, energy corrections) may be relevant.

RESULTS

While it was not possible to differentiate the three groups based on known properties of the profile (e.g. clayey vs sandy profiles, dense vs loose or water table), the shape of resulting N_{30SB} profiles could be differentiated (Figure 2). In this figure N_{30SB} values for each probing in the dataset are plotted against normalised depth (i.e. depth at which the N_{30SB} value was recorded divided by the final probed depth). Figure 2(b) shows Group 2 profiles along with a proposed lower bound (Equation 1). This lower bound was obtained by ensuring that less than 10% of Group 2 profiles had more than 50% of N_{30SB} values above the bound. Figure 2(c) shows Group 3 profiles and the corresponding upper bound (Equation 2). This upper bound was obtained by ensuring that less than 10% of Group 3 profiles had more than 50% of N_{30SB} values below the bound. Figure 2(a) shows Group 1 profiles along with the two proposed bounds. Seventy percent (70%) of Group 1 profiles had fewer than 50% of N_{30SB} values above or below the bounds. These bounds are defined by:

$$N_{30SB,LB} = 330\bar{d}^3 - 437\bar{d}^2 + 181\bar{d} - 11.1 \quad (1)$$

$$N_{30SB,UB} = 438\bar{d}^3 - 594\bar{d}^2 + 248\bar{d} - 0.45 \quad (2)$$

Where:

$N_{30SB,LB}$ is the lower bound

$N_{30SB,UB}$ is the upper bound

$\bar{d}$ is depth normalised by the final DPSH depth.

Figure 2(d) shows the proposed use of the bounds. Due to considerable overlap in N_{30SB} for $\bar{d} < 0.2$, any blow counts above this should be ignored. If more than 50% of N_{30SB} values for $\bar{d} \geq 0.2$ lie above the upper bound, then probing is considered to fall into Group 3. If more than 50% of N_{30SB} values after $\bar{d} \geq 0.2$ lie below the lower bound, that profile is considered to fall into Group 2. However, if neither of these conditions are met, probing is considered to fall into Group 1 and corresponds to reaching a competent horizon (i.e. $N > 50$). Classifying a profile as Group 1 does not necessarily mean that 50% of N_{30SB} fall between the bounds.

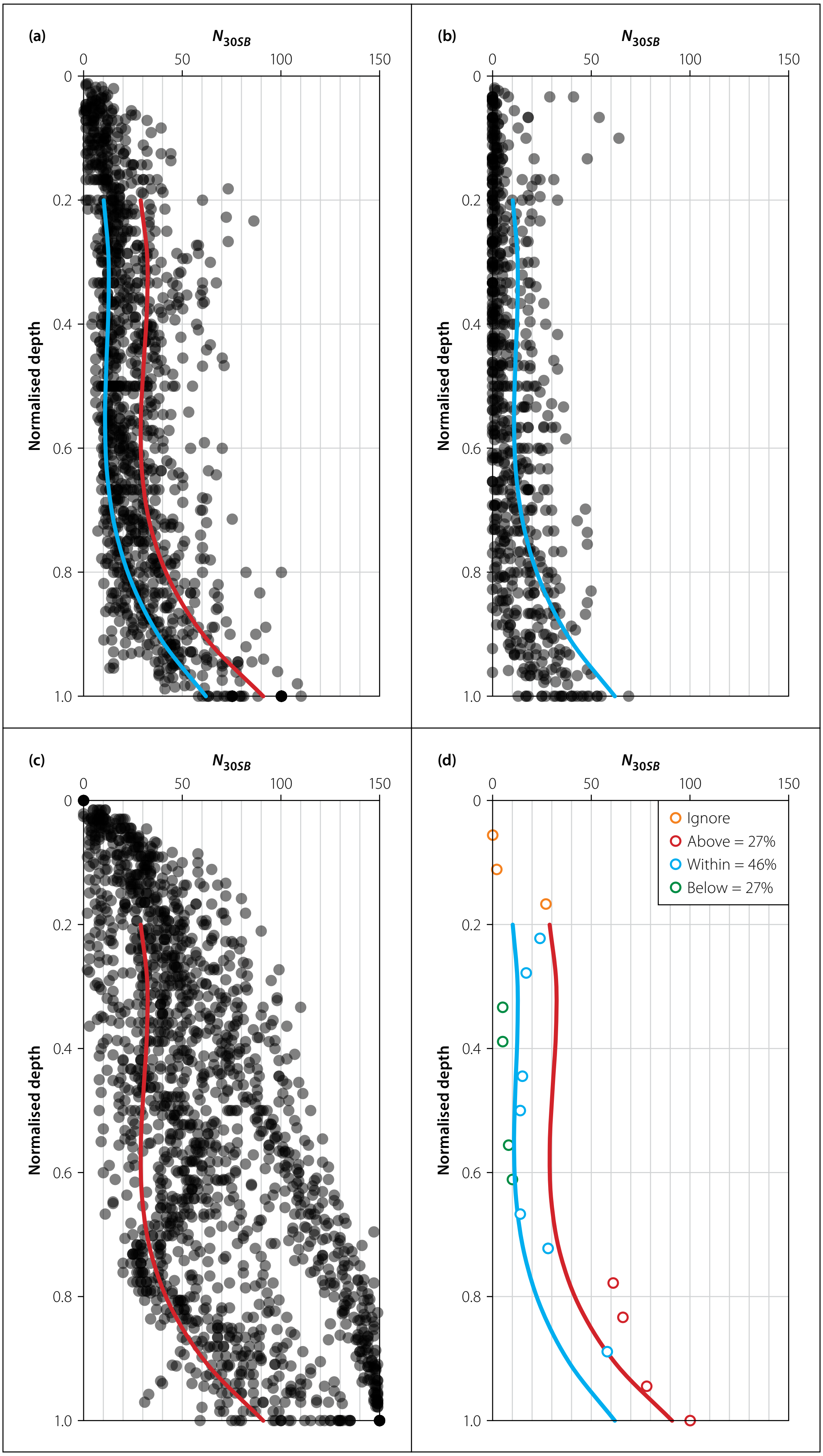

Figure 2 Normalised N_{30SB} profiles: (a) DPSH and SPT probings with similar refusal (Group 1) depths showing upper and lower bounds, (b) DPSH probings deeper than SPT (Group 2) probings showing the lower bound, (c) SPT probings deeper than DPSH probings (Group 3) showing upper bound, and (d) lower and upper bounds showing proposed usage

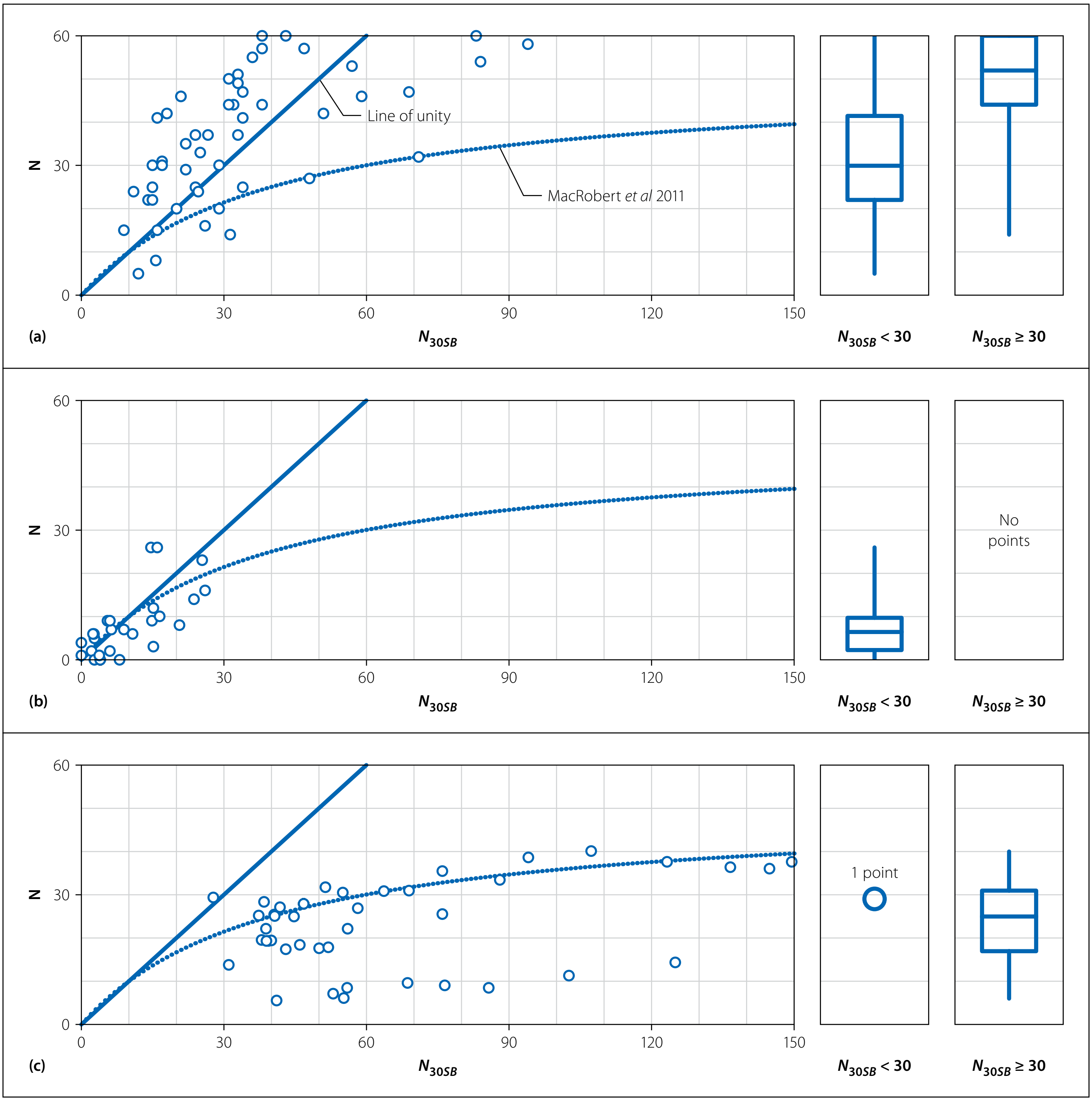

Figure 3 **Scatter plot of N_{30SB} and N values at equivalent depths, with box plots of N values for N_{30SB} below and above 30: (a) Group 1, (b) Group 2, and (c) Group 3**

It should be noted that setting these bounds so that no probings would be misassigned resulted in their overlap. Consequently, engineering judgement is required to interpret N_{30SB} profiles that plot within ± 5 N_{30SB} of the bounds. It is recommended in such situations to consider the average normalised profile for a site (based on a minimum of 5 DPSH probings on a site). Due to greater risk in failing to identify probings falling into Group 2, DPSH probing where the majority of N_{30SB} for $\overline{d} \geq 0.75$ fall below the lower bound should be classified into Group 2 regardless of whether most other points plot within the bounds.

Figure 3 illustrates correlation between N_{30SB} and N for the three groups. While Group 1 data generally trends along the line of unity (Figure 3(a)), scatter suggests superficial equivalence. On the other hand, the MacRobert *et al* (2011) correlation unnecessarily underestimates high blow counts for Group 1. A blow count of 30 is often used as a screening threshold in foundation decisions (Lommler 2012); consequently, N values for N_{30SB} above and below 30 are highlighted by box plots to the right of Figure 3. For Group 1 profiles, using this threshold will lead to similar consistency delineations. That is, for $N_{30SB} < 30$, 50% of N were below 30, and for $N_{30SB} \geq 30$, 92% of N were above 30.

Assuming equivalence or using the MacRobert *et al* (2011) correlation between N and N_{30SB} for Group 2 data (Figure 3(b)) does not result in significantly different values, although subject to scatter. For Group 2, neither N_{30SB} nor N exceeded 30; consequently delineating a profile based on a blow count of 30 would be acceptable for Group 2 profiles. Figure 3(c) shows the great difficulty in interpreting Group 3 profiles. The MacRobert *et al* (2011) correlation unfortunately overestimates many N values, and using $N_{30SB} \geq 30$ as a consistency delineation is unsafe, as 72% of equivalent N are less than 30. The only basis for rational design for Group 3 profiles is to resort to other investigation procedures (e.g. a borehole with SPT N at regular intervals).

Final N_{30SB} varied considerably within the data, reflecting little guidance on DPSH refusal criteria. The data suggests that $N_{30SB} > 75$ is an appropriate refusal criterion; however, specifying a single N_{30SB} as a refusal criterion is problematic. For instance, if $N_{30SB} > 75$ is specified as refusal, an intolerable number of Group 3 probings would terminate at a shallow depth and be classified as Group 1 when normalised. Consequently, it is suggested that if N_{30SB} exceeds 50 in the first 3 m, probing should be continued until N_{30SB} exceeds 100. Should N_{30SB} not exceed 50 in the first 3 m, probing should be continued until N_{30SB} exceeds 75. In both cases it remains to be ascertained whether the profile falls into Group 1 or Group 2, thereby providing useable information.

As mentioned earlier, there was no clear distinction in the shape of N_{30SB} profiles based on soil type (i.e. clayey vs sandy). While clayey profiles fell into either Group 1 or Group 2 (i.e. less influenced by rod friction), this is difficult to generalise, as sandy profiles fell into all three groups. This lack of a clear soil type link to rod friction is reflected in work by others (Stefanoff *et al* 1988). The approach presented here, to establish whether rod friction is present, is independent of soil type.

CONCLUSIONS

While it was not possible to link DPSH rod friction to characteristics of a profile, a method to identify profiles influenced by rod friction is presented. Large N_{30SB} values (above 50), obtained when DPSH probing in rod friction impacted profiles, are largely meaningless unless a site correlation with a more robust test is developed. For profiles unaffected by rod friction, N_{30SB} and N are roughly equivalent but subject to considerable scatter. It is recommended that even when DPSH probings are unaffected by rod friction, N_{30SB} values are best used for screening equivalent N above and below 30, to establish competent founding horizons.

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