Closure to "Evaluation of Vibratory Compaction by In Situ Tests" by K. Rainer Massarsch and Bengt H. Fellenius

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We appreciate the discusser's constructive discussion and the opportunity to emphasize a few aspects of the paper.

Vibratory Compaction Methods

The distinction between different vibratory compaction methods mentioned by the discusser is important. In order to distinguish between different vibratory compaction methods, the authors applied the term *deep vertical vibratory compaction* (DVVC) for methods where a vertically oscillating compaction probe is used to densify granular soils (Massarsch et al. 2019a).

Site Investigations

The initial investigations were carried out in order to meet the design requirements of the project; therefore, as recognized by the discusser, the timing and sequence of testing were not in control of the authors. However, it is important to keep in mind that at the time of the project (1988), the flat dilatometer test (DMT) had only been recently introduced in North America and the cone penetration test (CPT) was still not widely used outside the research community. A major objective of the paper was to examine whether, and to what extent, changes in horizontal stresses did occur as a result of vibratory compaction.

Standard penetration tests (SPTs) were carried out before and after treatment as mentioned in the paper [cited from Neely and Leroy (1991)]. However, similar to the increase in cone resistance, increase in SPT *N*-index only indirectly reflects changes in horizontal stress. Nevertheless, for the convenience of the reader, the SPT data reported by Neely and Leroy (1991) are shown in Fig. 1. The data indicate a significant increase of *N*-values following compaction. However, the soil profile is rather simplistic compared to the detailed representation of CPT results.

The authors agree that CPTs with water pressure measurements can in some cases provide additional information regarding soil density and stress conditions. Detailed CPT results including pore water pressure measurements have been reported by Massarsch and Fellenius (2017). These measurements identified the existence of fine-grained layers (silt and clay) in the soil deposit. In the opinion of the authors, the excess pore water pressure can be expected to have dissipated rapidly (within a few days) after treatment.

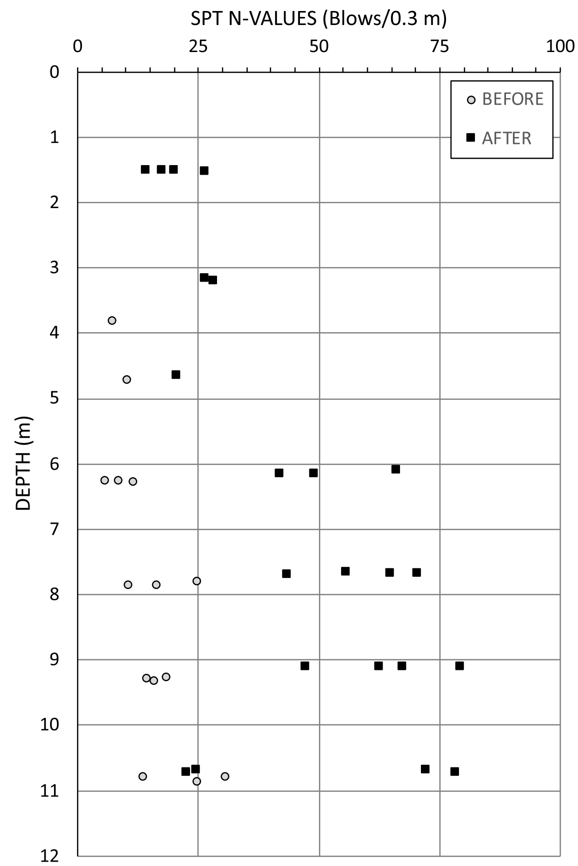

Fig. 1. Comparison of SPT *N*-values before and after compaction. (Data from Neely and Leroy 1991.)

We agree that in the case of soil compaction projects, there is a limited benefit of plotting and studying the CPT data in soil behavior type (SBT) charts. The friction ratio, which is a normalization of the sleeve resistance, disguises the actual change in sleeve resistance. The authors' SBT diagrams were added in response to the comments by one of the peer reviewers.

Time Effect

The discusser points out an important aspect that may not be immediately apparent to the reader. Vertical effective stress does not change markedly following conventional vibratory compaction (unless a fill is added). However, independent of compaction method, vibratory treatment does cause a change in horizontal stress. The authors have investigated five different compaction projects where horizontal stress changes were monitored by CPT sleeve friction, f_s, and DMT horizontal stress index, K_D (Massarsch et al. 2019b).

In all cases, changes in horizontal stress were observed after compaction. No doubt, horizontal stresses will vary immediately after vibratory compaction. Typically, horizontal stress is highest in the vicinity of the compaction point and decreases with increasing distance. Therefore, as soil compaction is carried out in a grid pattern, significant variations in horizontal stress can be expected within the treated soil volume.

The data presented in the paper suggest that an equalization of horizontal stresses will occur. It can be assumed that horizontal stress will decrease close to the compaction point but can increase in between. In the authors' opinion, this stress equalization process can at least partly be responsible for the gradual change (time effect) observed from penetration resistance (CPT or SPT) (Mitchell 2008).

An important question is whether the increase in horizontal stresses could disappear with time. The CPT and DMT reported in the original paper and results by Massarsch et al. (2019a) suggest that horizontal stresses remain after compaction, similar to the case of static preloading.

References

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