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Studying impact of reclamation technique on vibrocompaction performance

Analyse de l'impact du vibrocompactage selon la technique de remblaiement d'un terre-plein gagné sur la mer

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ABSTRACT: The process of creating new lands from seas or riverbeds is an efficient and pragmatic approach responding to an increasingly growing global demand for commercial exchanges. The material is dredged and reclaimed via dumping, rainbowing or pumping ashore. In almost all cases, the newly reclaimed site can be enhanced using soil improvement (such as Rapid Impact Compaction, Dynamic Compaction or Vibrocompaction) and consolidation techniques (such as Prefabricated Vertical Drains with a preloading surcharge). In this paper, vibrocompaction data in a reclaimed silica-based clean sand, with 12% fines maximum, and less than 2% of 2µm clay particles, has been analysed for a jobsite located in South America. On this project, unexpected difficulties were encountered. Correlating the needle's amperage with 150 pre and post-CPTs (Cone Penetration Tests), the descending and ascending phases of vibrologs have been split and studied independently. The influence of grid size and the number of passes has been investigated. The resulting in-depth data analysis identifies clear differences in soil improvement performances depending on the reclamation technique. The article also includes an analysis of the ageing effect after a 100-days resting period by means of CPTs.

RÉSUMÉ: Le processus de création de nouvelles terres à partir des mers ou des lits de rivières est une approche efficace et pragmatique répondant à une demande mondiale croissante en matière d'échanges commerciaux. Le matériau est dragué et déposé par déversement, par largage en arc-en-ciel ou par pompage. Dans presque tous les cas, le site nouvellement crée et gagné sur la mer peut être amélioré en utilisant des techniques d'amélioration du sol (telles que le Compactage par Impact Rapide, le Compactage Dynamique ou le Vibrocompactage) et des techniques de consolidation (telles que les Drains Verticaux Préfabriqués avec surcharge). Dans cet article, le vibrocompactage d'un sable à base de silice, avec 12% de fines au maximum et moins de 2% de particules d'argile (2µm) est analysé pour un chantier situé en Amérique du Sud. Là-bas, nous avons fait face à de nombreuses difficultés. En corrélant l'ampérage de l'aiguille vibrante avec 150 pre & post CPTs, les phases descendantes et ascendantes des enregistrements de paramètres ont été séparées et étudiées indépendamment. L'influence du maillage et du nombre de passes a été étudiée. L'analyse de données qui en résulte met en évidence des différences claires dans les performances d'amélioration du sol, fonction de la technique de remblaiement du sable. L'article inclut également une analyse de l'effet du temps après une période de repos de 100 jours par mesures de pénétrations statiques (CPTs).

Keywords: Reclamation technique; vibrocompaction; data mining; grid size; ageing effect.

1 INTRODUCTION

The study project is located in South America where 1,080 points were vibrocompacted. To verify the actual improvement of the ground, 150 pre- and post-CPTs were conducted. After analysis, the upper part of the sand reacted perfectly to compaction, while the lower part showed only slight improvement.

This article focusses on the used reclamation techniques (rainbowing and dumping) and compares how they influence vibrocompaction performances. Usual state-of-art parameters (such as the spacing grid, the number of passes and the ageing effect) are also studied using a statistical analysis.

2 METHODOLOGY

The study considered the following key aspects:

Needle Amperage Analysis: The descending and ascending phases of vibrologs were studied independently to correlate needle amperage with soil improvement. This analysis aimed to identify trends in amperage changes during the vibrocompaction process.

Influence of Grid size: Different grid sizes were used during the vibrocompaction process. The study examined how grid size influenced the rate of soil improvement.

Number of Passes: In some cases, a two-pass approach was utilized during vibrocompaction. The research investigated the impact of the number of passes on soil improvement.

Ageing effect: An essential aspect of the study involved analyzing the soil's response to vibrocompaction after a 100-day resting period. CPTs were conducted to assess changes in soil strength over time.

3 DREDGING AND RECLAMATION SEQUENCES

- **Step 1:** Depending on the area of the quay, the *in-situ* clay is removed using a Cutter Section Dredger (CSD) down to depths of -26.50mCD to -31.00mCD,
- **Step 2:** Sand is dredged from a borrow area by a Trailing Suction Hopper Dredger (TSHD),
- **Step 3:** The dredged sand is dumped by opening bottom doors up to -10.00mCD to -14.50mCD,
- **Step 4:** The sand is reclaimed using rainbowing up to target level,
- **Step 5:** Vibrocompaction works are performed up to -26.50mCD to -31.00mCD, depending on the area.

4 AMPERAGE

During vibrocompaction works, the needle vibrates during the entire process. The production is split into three main parts: a descending phase, an ascending phase and a stationary phase. The descending phase is done in one continuous movement while ascending and stationary phases are alternating.

Thus, the descending phase represents the soil behaviour before compaction.

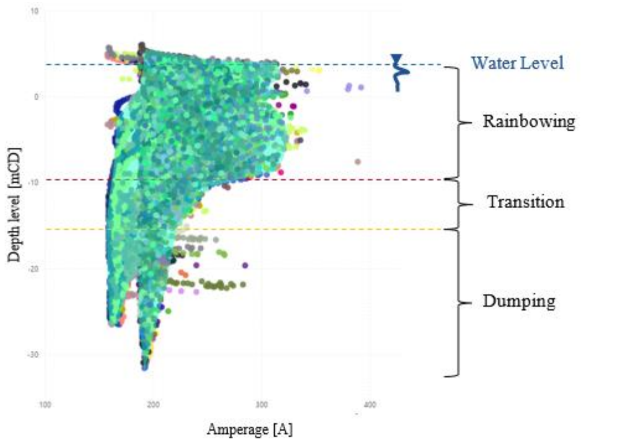

Figure 1. Descending phase compared to the reclamation technique.

As shown in Figure 1, the recorded amperage in the rainbowed sand varies significantly, ranging from 190A to 330A, whereas the amperage in dumped sand falls in the range of 190A to 230A.

This difference comes from the placement method and disposal circumstances: under water, a rainbowed sand is naturally more compacted than a dumped sand.

5 POST SOIL IMPROVEMENT ANALYSIS

5.1 Grid patterns

On site, several grid sizes were tested, including among others: a triangular grid pattern in 4.40x4.40 m² (1 and 2 passes), and a rectangular pattern in 5.00x5.00 m² (2 passes).

Comparing both patterns requires a unified geometric model. A converted axisymmetric model centred on each vibrocompaction point is applied, as defined below:

$$R = \sqrt{\frac{Area\ of\ the\ grid}{\pi}} \tag{1}$$

where R (m) is the radius of influence, depending on the Area of the grid (m²).

Table 1. Radius of influence for each grid.

Grid pattern	Radius [m]
Triangular 4.40x4.40 m² - 1 pass	2.096
Triangular 4.40x4.40 m² - 2 passes	1.632
Rectangular 5.00x5.00 m² - 2 passes	1.994

5.2 Influence of grid on the improvement degree

For each grid, we compared the average of pre-CPTs with the average post-CPTs (after vibrocompaction) after 30 days of resting period.

5.2.1 Triangular grid pattern (4.40x4.40 m² - 1 pass)

As Figure 2 illustrates, pre-CPTs show a homogeneous q_c profile apart from the first 4 m, where the ground was compacted and levelled with excavators and graders.

CPTs after vibrocompaction (also called post-CPTs) show a q_c value which is 82% higher on average. We also notice that the improvement is higher in rainbowed sand when compared to dumped sand.

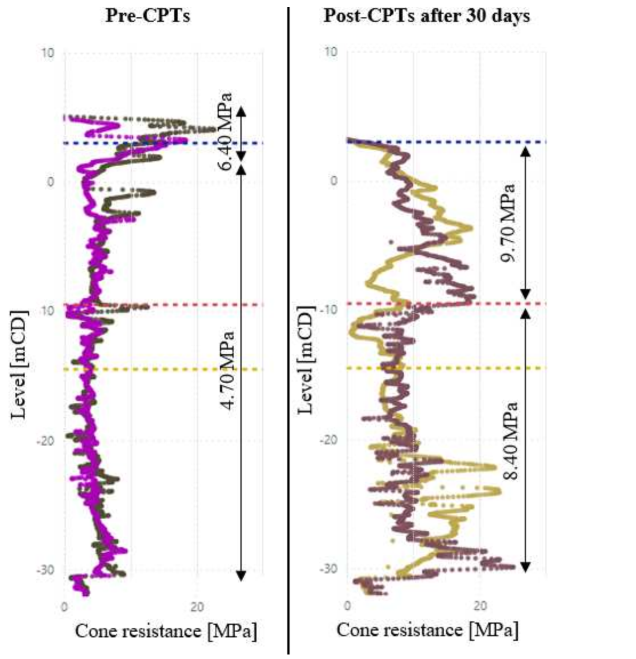

Figure 2. Triangular grid - 1 pass - R=2.096m - Pre&Post-CPTs comparison.

5.2.2 Triangular grid pattern (4.40x4.40 m² - 2 passes)

Based on pre-CPTs introduced in Figure 3, we can't see a clear difference between dumped and rainbowed sand. Over the first 3 to 4 m, the sand is more compacted.

Vibrocompaction improved the entire average profile by 108% in a homogeneous way. The hard top layer is no longer visible. There is also a clear difference between improved rainbowed sand and improved dumped sand.

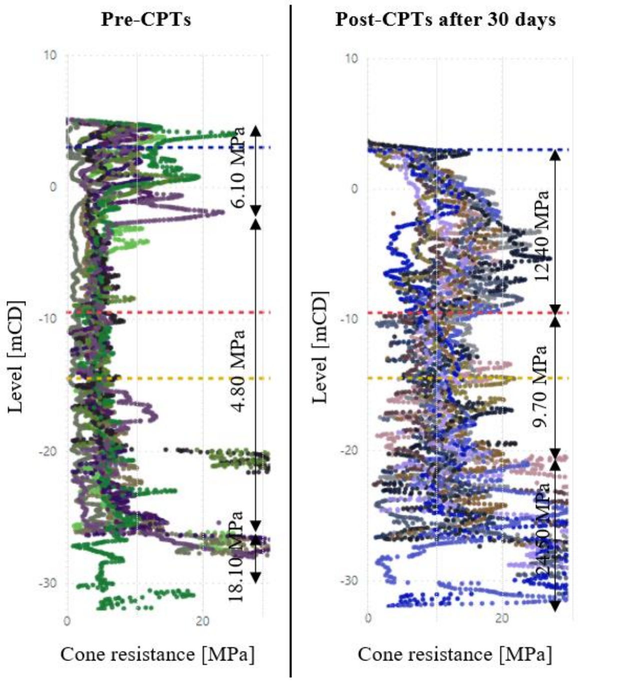

Figure 3. Triangular grid - 2 passes - R=1.632m - Pre&Post-CPTs comparison.

5.2.3 Rectangular grid pattern (5.00x5.00 m² - 2 passes)

Looking at pre-CPTs (Figure 4), we can see again the hard top layer.

The vibrocompacted soil presents a global improvement of 81% on average. Cone resistance in a vibrocompacted rainbowed sand is almost two times higher than a vibocompacted dumped sand.

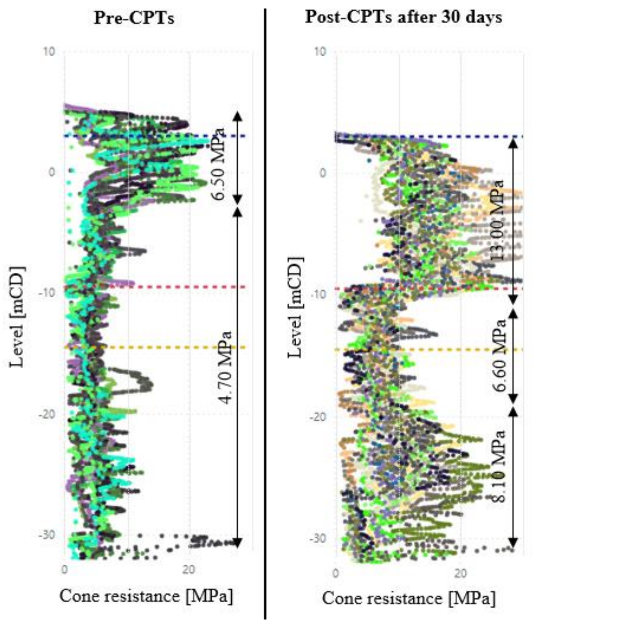

Figure 4. Rectangular grid - R=1.994m - Pre&Post-CPTs comparison.

5.2.4 Comparison of vibrocompaction performances

- (A), (B), (C): The global improvement is directly linked to the radius of influence. Thus, the narrower the spacing between each point, the better the improvement will be. The improvement is higher in a rainbowed sand as compared to a dumped sand.
- (A) & (B): The improvement increases with a second pass by 26%.
- (A) & (C): The radius of influence is near-identical, and as a result, the global improvement as well. Using either two passes or an equivalent one-pass shows equivalent result.

Table 2. Performances measured for each grid.

Reference	Grid pattern	Radius [m]	Global improvement (30 days)
(A)	Triangular 1 pass	2.096	82%
(B)	Triangular 2 passes	1.632	108%
(C)	Rectangular 2 passes	1.994	81%

6 AGEING EFFECT

CPTs performed too soon after the completion of compaction show pessimistic results due to pore water pressure, the rearrangement of particles and the possible presence of temporarily trapped release air. When CPTs are repeated after a resting period, an improvement is observed. This is called the ageing effect.

Thus, 150 CPTs where performed from 0 to 195 days after the first point compacted.

We studied the ageing effect over two approaches: by comparing grid patterns, and by comparing the improvement above, and below -10.00mCD (corresponding to the interface between rainbowing and dumping).

6.1 Influence of the grid

As illustrated on Figure 5, the improvement degree is higher with a triangular grid (the smallest radius of influence), reaching 114%.

In both rectangular and triangular grids, at least 60% of improvement is observed four days after the completion of the first pass. Then, tests performed the same day as the second pass show an effective loss of 10 to 20% in improvement.

After the second pass, the rectangular grid zone improves by an additional 30% and the triangular grid zone by 55%.

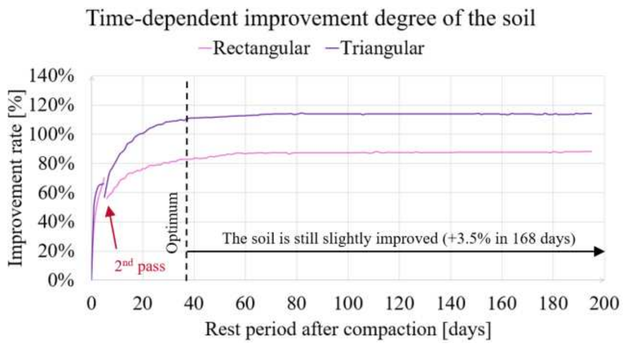

Figure 5. Time-dependent improvement rate of the soil - Rectangular & Triangular grids.

Based on these results, the optimum ageing time seems to be reached between 25 to 30 days after the second pass. Beyond this point, the soil will carry on its improvement over time but the delta between rectangular and triangular grid remains constant.

6.2 Influence of the reclamation technique

As previously shown, the measured amperage differs whether we are in rainbowed or dumped sand. In order to determine if the post-compaction results are different, we have separated the results at the -10.00mCD threshold.

Thus, above -10.00mCD refers to the rainbowed sand, while below -10.00mCD corresponds to the dumped sand. The transition zone is included in the dumping cycle, but does not influence the results.

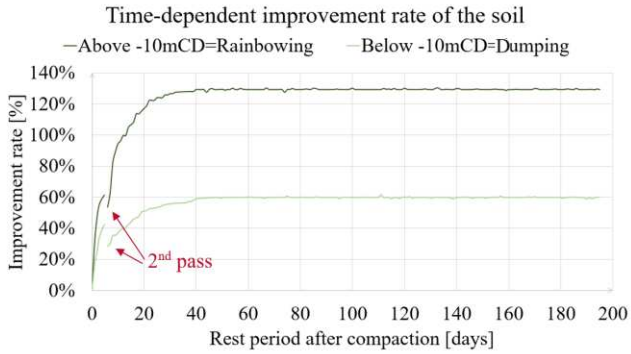

Figure 6. Time-dependent improvement rate of the soil - Above & below -10.00mCD.

Figure 6 clearly shows that the improvement rate is 70% higher in the rainbowed vibrocompacted sand as compared to the dumped vibrocompacted sand.

This difference likely arises from the dumped sand capturing sedimentation layers, which are then mixed together by vibrocompaction, resulting in a lower but consistent effectiveness of the compaction.

This phenomenon depends on the length of the dumping cycle and the presence of sediments in the water.

7 CONCLUSION

While the upper layer reacted as expected, unusual results were observed in the lower part of the fill. For the first time, we encountered difficulties in compacting the dumped layer. After analyzing the various effects discussed in this article, we believe this is likely due to fines in the sand matrix captured during each dumped load, resulting in a mixed soil layer with a high fines content.

To address these issues, a two-pass triangular approach yielded the best results. The amperage seems to be the best parameter to analyze the first soil response. Thence, a dumped soil presents lower post improvement values than a rainbowed sand. On this project, a second pass of compaction, or an equivalent narrow first pass appears to be the most efficient solution to improve the dumped soil.

Finally, depending on soil's properties, q_c values are improved by 60%, 4 days after the 1st pass. The ageing effect can improve the *in-situ* soil by an additional 25% after at least 30 resting days.