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Vibro replacement with sand and recycled aggregates

Colonnes ballastées en sable ou en agrégats recyclés

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ABSTRACT: Generally stone or gravel is used for vibro replacement, but sand or recycled aggregates may be applied as well for economic reasons. In Germany a specially designed vibro sand column skip was attached to the vibro-cat successfully first. The results were compared with a standard skip on the same site. Furthermore another system was designed and tested to install pure fly ash columns. Keller Malaysia was then employed to carry out vibro replacement treatment for the proposed East Coast Expressway which is passing through areas with soft marine deposits. Cone penetration test results yield cone resistances as low as 0.2 MPa corresponding to an undrained shear strength of only 10 kPa. Both a crane-hung S-alpha-unit and a vibro-cat were used to install vibro sand columns and further improvements were made to the system. Finally in the UK the top feed process is used traditionally because of limited depths of the upper soft layer. Quarry waste, building debris and crushed concrete was extensively tested in the laboratory before using it on site.

RÉSUMÉ : De manière générale, du gravier ou du ballast est utilisé pour les colonnes ballastées, cependant le sable ou les agrégats recyclés peuvent également être appliqués pour des raisons de coût. En Allemagne, une benne spécialement développée pour les colonnes en sable a été tout d'abord installée sur un vibrocat. Les résultats ont été comparés avec ceux obtenus pour la benne classique sur le même site. Un autre système a été également mis au point et testé pour mettre en œuvre des colonnes en cendres volantes. Keller Malaisie a de son côté exécuté un traitement par colonnes ballastées pour un projet qui couvre des zones avec des dépôts marins très mous. Un essai au pénétromètre statique a montré des résistances de l'ordre de 0,2 MPa, ce qui correspond à une cohésion non drainée de 10 kPa seulement. Un système avec une unité S-alpha ainsi qu'un vibrocat ont été utilisés pour mettre en œuvre des colonnes en sable, et des développements additionnels ont été apportés au système. Le dernier point concerne Keller Royaume-Uni, où traditionnellement le système voie humide est utilisé du fait de profondeurs limitées de la couche supérieure molle. Des essais en laboratoire sur des déchets de carrière, de chantier ou du béton concassé ont été effectués avant l'utilisation sur chantier.

KEYWORDS: vibro compaction, vibro replacement, sand columns, recycled aggregates

1 INTRODUCTION

In many areas of the world it is not easy to find gravel and stones for the installation of vibro replacement columns and in some areas sand and recycled aggregates are much cheaper than gravel. Therefore Keller developed a new hopper to enable the installation of vibro sand columns. Recycled aggregates are usually installed with the conventional top feed process because of the large size of the materials which do not fit through the stone feed tube.

2 VIBRO SAND COLUMNS IN MALAYSIA

The East Coast Expressway Phase II is 190km long and it runs from Jabur Interchange to Kuala Terengganu. The land in the project area was partly utilized as a municipal solid waste landfill during 1970s to 1990s. The bulk of the waste material found in the landfill includes plastic concrete, glass and biomedical waste.

Typically, soft ground comprises silty clay ($c_u = 10$ to 15 kPa) down to varying depth. In general, water content is $50 - 60\%$ and plasticity index $20 - 30\%$. The top layers consist of backfilled soil with average SPT $N = 11$ for up to 3m depth. This layer is followed by clayey peat with average SPT $N=2$ from 3m to 8m depth. This layer is underlain by soft clay with

average SPT $N = 3$ to 7 . This layer is followed by old alluvial silt with average SPT $N= 10$ to 30 .

Ground treatment was applied where the highway passes through areas of swampy ground and soft alluvial sediments. The objectives are to ensure embankment stability and to restrict settlements within acceptable limits. Several types of ground improvement techniques were implemented which included removal and replacement, vertical drains and surcharging, vibro sand and stone columns and dynamic replacement, to meet the stability and settlement criteria of the proposed structures.

Vibro compacted sand columns were used to improve the backfilled soil and peaty clay. Due to environmental sensitivities, all the sand columns and stone columns were installed using the "dry" method. Ground treatment was carried out from top of the working platform to the stiff to very stiff clayey silt. The embankments were fully instrumented and monitored during the filling and rest period of the embankment. Vibro sand columns accelerate the consolidation under the surcharge. The diameter of sand columns is 0.8m at spacing of 2.5m triangular centre to centre. The depth of column varies between 11.0m and 16.0m.

Vibrocats were used for sand column works with additional bucket vibrators which were fixed on the bucket skip to

increase the flowing speed of sand from the bucket skip to the air chamber.

The sand had to be sieved using a mechanical sieve before it is being used for sand column works. The sieving technique is able to segregate clay lumps and wood pieces which had the tendency to choke the air chamber and stone tube. Figure 1 shows the setup of the mechanical sieve.



Figure 1. Mechanical sieve to segregate clay lumps and wood

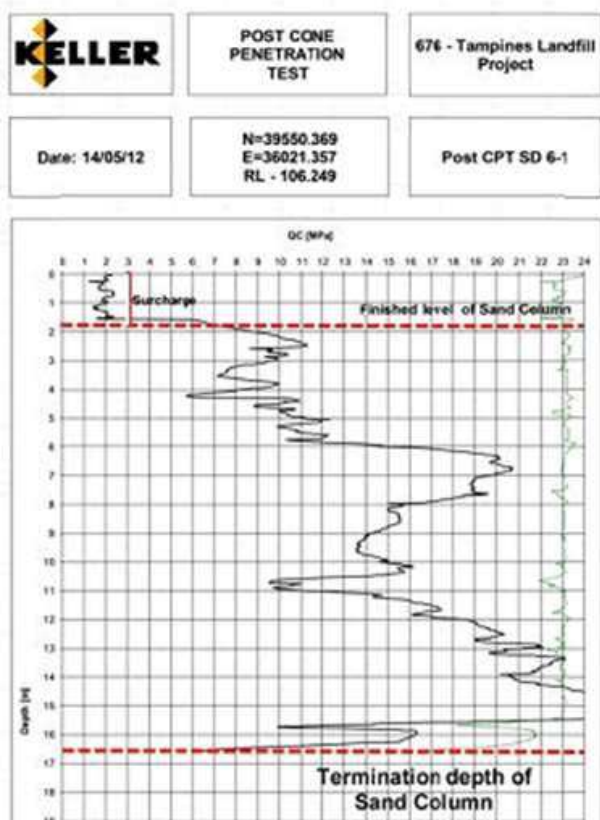


Figure 2. Post CPT in a vibro sand column

To verify the continuity and compaction of the sand column, CPT tests were carried out. When the CPT tests were executed without casing the cone has the tendency to move out of the column. The Post-CPT were carried out with a casing and the following procedure was followed: the cone is penetrated to

2.0m and it is followed by installation of 1m casing. Then the same procedure is followed until 7.0m and then the cone alone has penetrated without casing to the termination depth of the sand column. Figure 2 shows an example of a CPT test in the column. The cone resistance before ground improvement was as low as 0-1MPa.

3 VIBRO SAND COLUMNS IN GERMANY

In a first series of tests in the Renchen yard several sand and gravel mixtures were used and the time was measured to flow through the vibro-cat system. It has been found that the problem is not the material tube but the hopper itself. A new hopper was constructed with several improvements, see figure 3.



Figure 3. New sand hopper for the vibrocat

This hopper can be used for sand and gravel with a grain size distribution from 0 - 32 mm.

In the first test site in southern Germany in Rust the new hopper was successfully tested. Later the hopper was sent to the site of Obergräfenheim in Germany and the site engineer started a test programme. Sand of 0 - 4 mm diameter grain size was used to install vibro sand columns with 5 m to 6 m lengths and a diameter of 80 cm. The average time to construct a sand column was only slightly less compared to the time with an ordinary hopper and gravel 0 - 32 mm grain diameter.

Heavy dynamic soundings were executed inside and outside of columns yielding much higher blows in the columns.

4 VIBRO REPLACEMENT WITH RECYCLED AGGREGATES IN THE UK

Before the recycled materials were used for the construction of vibro columns, the mechanical characteristics of the materials had been investigated (McKelvey et al 2002). Three materials were considered: quarry waste, building debris and crushed concrete. Large shear box tests were carried out. The angle of internal friction of dry material yielded 51 degrees for crushed basalt, 46 degrees for quarry waste, 39 degrees for crushed concrete and 37 degrees for building debris. For wet materials the internal friction reduced by 0-4 degrees. The main reason for smaller values of internal friction is grain crushing.

Another recycled material, recycled glass sand, was used in the UK already. It may be even cheaper than recycled stone in certain regions. The friction angle is usually around 40 degrees. However, a low constrained modulus of 30MPa was observed

in laboratory tests. Figure 4 displays the installation of recycled glass sand.

A similar behaviour was observed testing crushed bricks (Herle 2010). The friction angle between 41 and 42 degrees is high and the constrained modulus of only 10 MPa is very low.

However, all these materials are suitable for vibro replacement as long the reduced friction angle and constrained modulus are taken into account in the geotechnical design.



Figure 4. Installation of recycled glass sand with a vibro-cat

5 VIBRO REPLACEMENT WITH FLY ASH



Figure 5. Installation of fly ash columns with a vibro-cat

Fly ash and incinerator ash have been used in Germany (Wehr and Berg 2000). An inhomogeneous coal mining deposit has been improved with vibro fly ash columns. The fill consists mainly of sand with 20% fines in average with some layers having up to 60% fines. The soil is by no means homogeneous and does not have any horizontal layers because it has been deposited with conveyor belts forming soil cones. Compaction control has been tested with crosshole measurements including different polarization of the waves to determine the earth pressure coefficient. Due to the fly ash used the columns hardened and tests on excavated columns have shown that the strength was comparable to a lean concrete.

First in situ tests were not successful because the fly ash did not flow through the air transportation system of the vibro-cat properly. Then the system was modified successfully with a separate pressurized tank as shown in figure 5. A European patent was issued for this invention.

On a site in Brazil a different fly ash was used which did not harden at all. The grain size can be described as gravel and stone, see figure 6. It was then used to install ordinary stone columns.



Figure 6. Fly ash with gravel size from Brazil

6 CONCLUSIONS

In order to be able to use sand as filling material for vibro replacement a new hopper was constructed with several modifications. Vibro sand columns were installed with this technique in several countries successfully.

Various recycled aggregates can be used to construct vibro columns: like crushed concrete, quarry waste, building debris, crushed bricks, glass sand and fly ash. However, adequate internal friction angles and constrained moduli have to be taken into account in the geotechnical design.

The top feed method currently used in the UK is suitable for larger size recycled aggregates to prevent clogging of the system.

A special device was invented to install vibro fly ash columns.

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