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Improvement of Sri Lankan Peaty Clay using the Gravel Compaction Pile Method for the Construction of a Highway Embankment

Amélioration d'argile tourbeuse (Sri Lankan Peaty Clay), à l'aide de la méthode des colonnes de graviers compactés pour la Construction d'un remblai routier

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ABSTRACT: Gravel Compaction Pile method was applied as a ground improvement technique in improving the soft ground for a highway construction project in Sri Lanka. The embankment foundation soil consisted of a 5 m -12 m thick soft layer which consisted of peat, organic clay and silty clay. The vibrating compaction technique was used in the construction of Gravel Compaction Piles. Using this method, compacted gravel piles with an average diameter of 0.7 m were formed through the soft soil down to the identified bearing stratum. The spacing of the gravel piles were determined based on the stability and the settlement requirements. The average height of the embankment was around 10m and an additional surcharge load was placed to have sufficient over consolidation ratio to control the residual settlement as required in the Technical Specification. The effectiveness of the ground improvement was evaluated by comparing the field and laboratory tests conducted before and after the ground improvement and the data obtained from the field monitoring program. The results indicate that the Gravel compaction pile method is very effective for the construction of high embankments over deep peaty deposits to reduce the settlement, to increase the stability and to accelerate the consolidation.

RÉSUMÉ: La méthode « colonne en graviers compactés » a été appliquée comme méthode d'amélioration de sol pour un projet de remblai routier au Sri Lanka présentant des sols compressibles. Le sol portant la fondation du remblai se composait d'une couche de 5m à 12m d'épaisseur comprenant tourbe, argile organique et limon-argileux. La technique de compactage vibrant a été utilisée dans la construction des colonnes de gravier compacté. En utilisant cette méthode, des colonnes de 0.7m de diamètre en moyenne ont été formées à travers le sol meuble jusqu'à la couche de sol portante. L'espacement entre les colonnes a été déterminé en fonction de la stabilité et des tassements admissibles exigés. La hauteur moyenne du remblai était d'environ 10m et une charge additionnelle a été placée pour accélérer la consolidation et contrôler les tassements résiduels, tel que requis par les spécifications techniques. L'efficacité de cette méthode a été évaluée en comparant les essais de terrain et en laboratoire effectués avant et après construction et en utilisant les données obtenues par le programme de contrôle terrain. Les résultats indiquent que la méthode de « colonne en graviers compactés » est très efficace pour la construction de remblais fondés sur des dépôts tourbeux profonds avec une réduction des tassements, l'amélioration de la stabilité et l'accélération de la consolidation.

KEYWORDS: highway embankment, peat, gravel compaction pile, stability, settlement.

1 INTRODUCTION

In the Outer Circular Highway Northern Section-1 (OCH-NS1) Project, many parts of the road traverses through flood plains and marshy ground which consists mainly of very soft peat, organic and inorganic clays and loose sands. In the main highway including access ramps from Ch.8+640 to Ch.17+500, about 50 % of the area is covered by soft ground and in A1-Bypass from Ch.0+000 to Ch.1+930, the length of soft ground is more than 75% of the total length of the section. The sections of the main highway that traverse through flood plain areas were mainly built on viaducts and in other soft ground areas of about 1 km in length, the highway was built on earth filled embankments. The whole length of the highway in A1-Bypass was constructed on earth filled embankments over soft ground.

As such, extensive ground improvement work had been carried out in the construction of the embankment over the soft grounds. Depending on the ground conditions, ground improvement methods such as remove and replacement, preloading, preloading with vertical drains and Gravel Compaction Piles (GCP) were applied to improve the soft soil in order to build the embankments with heights varying from 1m to 10m. Special attention was given to the design of soft ground treatment to limit the future settlements and to ensure the stability of the highway embankment complying with design requirements in the contract. Accordingly, when high embankments were constructed on peat deposits with high layer

thickness, GCP method was used as a soft ground improvement technique. This paper presents details of the trial embankment constructed on soft ground consisting of peat and soft clay deposits which was improved by the GCP method.

2 SITE CONDITION AND THE DETAILS OF THE TRIAL EMBANKMENT

The site selected for the trial embankment was located at chainage 15+060 km to 15+117 km in Outer Circular Highway Route in Sri Lanka. The subsoil condition in the trial area was investigated by advancing 4 boreholes with Standard Penetration Tests (SPT), 2 hand auger holes, 6 Static Cone Penetration Tests (SCPT), and undisturbed samples were taken for use in the laboratory tests. The location of the bore holes, BH-160b and BH161 are shown in Figure 1. According to the investigation results the subsurface consists of a silty clay/sandy silt layer, about 1.5 m in thickness in the top. Below that a very soft peat layer mixed with organic clay of about 3 m to 5 m in thickness, was encountered. The peat layer is underlain by a loose/soft silty sand/sandy silt layer of about 3m in thickness. These compressible layers are underlain by layers of medium dense to dense silty sand. Laboratory test results indicated that the peat and organic clay layer has a high moisture content and a void ratio in the range of 75% to 237% and 3.79 to 5.69 respectively. The unit weight of the peat and organic clay layer is in the range of 11.3 kN/m³ to 12.5 kN/m³. The organic content of the peat layer was around 25%. According to the

above results, the peat found in the site can be categorized as amorphous peat mixed with clay (Karunawardena 2007). Furthermore, test results indicated that the engineering properties of the peat layer were poor with a high compressibility index of 1.95 and low undrained shear strength of 7.2 kPa to 19 kPa. According to the conventional Oedometer test results, the peat layer shows lightly over consolidation characteristics with preconsolidation pressure of 17 kPa to 32 kPa.

The plan view of the trial embankment is shown in Figure 1. The average height was around 12 m, crest width 22 m and side slope 1:1.8.

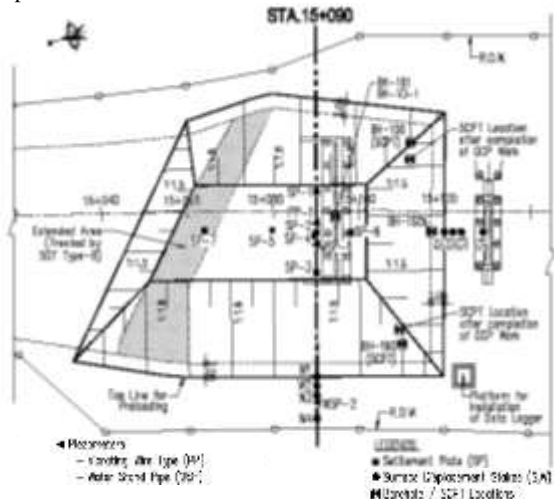


Figure 1. Plan view of trial embankment, investigation and instrumentation locations

3 DESIGN OF SOFT GROUND TREATMENT WITH GCP

The gravel compaction pile method was used in the construction of high embankments on marshy area with deep peaty soil or organic clay. These soils have very low initial strength and therefore may create stability problems in the embankments during and after construction. Also, these soils exhibit very high creep settlement during service period of the highway. In the ground improvement using gravel compaction piles, the strength of the soft soil is expected to increase and the creep settlement is expected to reduce by introducing the gravel piles into the soft soil at proper spacing according to the design. Also, surcharge load was designed to accelerate the primary settlement and to reduce the secondary settlement of the soft soil surrounding the gravel piles to limit residual settlement within the requirement as specified in the technical specification.

According to the technical specification, the embankment had to be designed and constructed by improving the soft ground in order to control the continuing settlement to 15cm limit at the road center after a period of 3 years following the acceptance of the paving. In addition, the maximum residual differential settlement had to be not more than 0.3% change in grade over longitudinally within three years after construction. Further, the embankment shall be designed to have a short term and long term factor of safety of 1.2 and 1.25 respectively.

The ground with gravel compaction piles was considered as a composite ground in the design. In the stability analysis, the properties of the composite ground were estimated with average strength parameters. In the estimation of average cohesion and the friction angle, the properties of soft ground, the properties of material used in the GCP, stress concentration effect and the area replacement ratio of GCP were considered by following the procedure outlined by Kitazume (2005). Also strength increase due to consolidation was also incorporated into the

analysis. According to the analysis results, GCP of 0.7 m diameter in a square pattern with a 1.2 m spacing together with 300 kN/m² high strength geotextile were required to satisfy the stability criteria as shown in Figure 2.

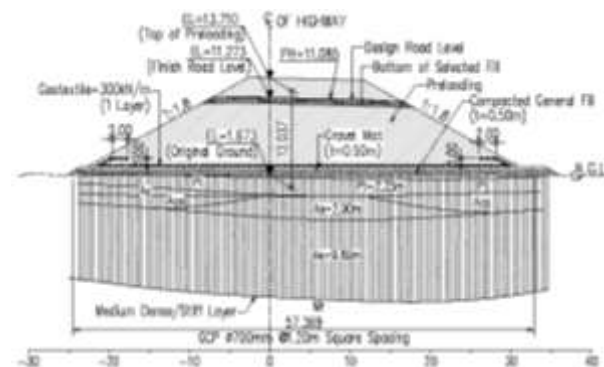


Figure 2. Typical section of GCP and preloading at Sta. 15+090

In the settlement calculation, it was assumed that the GCP and the surrounding ground settled uniformly. The settlement of the composite ground was calculated by multiplying settlement of the untreated ground by the settlement reduction factor (β) as described in Kitazume (2005). The settlement reduction factor, (β), = 0.428 was considered in the design based on the stress concentration ratio = 4 and replacement ratio of 0.267. By considering the above described design principles and the detailed soil investigation results, the settlement of the GCP improved ground due to embankment loading was estimated. Accordingly, a 2.2 m fill surcharge was required to eliminate the consolidation settlement of the GCP improved soft ground.

4 CONSTRUCTION PROCEDURE OF GCP

The vibrating compaction technique was used for the construction of Gravel Compaction Piles (GCP) for this project. The following work procedure was adopted in the ground improvement work with the gravel compaction pile method. Initially, about a 0.5 m thick fill was constructed on the original ground surface to form a working platform for the movement of GCP machine. After constructing the working platform, setting out was carried out to mark the GCP location as per the working drawing. Thereafter, the GCP machine was mobilized to the site, assembled and checked for the working condition. A trial penetration was carried out close to a borehole location, to verify the capacity of the machine and the parameters variation was calibrated with soil strength to establish the pile termination criteria. Then the installation of GCP work was started and the casing pipe was positioned vertically at the designed location and pressed into a certain depth. With the help of vertical vibrating excitation by the vibro-hammer, a casing was penetrated through soft soil to the hard stratum. In the case of penetrating relatively hard stratum, compressed air was injected from the outlet nozzles installed on the outside face of the casing pipe. During the penetration, the casing pipe was filled with the gravel material with the grading requirement shown in the Table 1.

Table 1. The gradation of the material used for the GCP.

Sieve Size (mm)	Percentage by Mass Passing the Sieve
50	100
37.5	85-100
20.0	50-80
5.0	15-40
2.0	5-25
.063	0-5

The driving of casing was terminated when the current reading reached 100 A, based on the trial penetration results. After reaching up to termination level, the casing pipe was filled with gravel material supplied through the hopper at the upper end of the casing pipe by the lifting bucket. The casing pipe was then retrieved by 1.5 m to feed the gravel in the casing pipe into the ground with help of compressed air. The gravel fed into the ground was compacted to expand to the required diameter by vibratory excitation of the casing pipe while lowering by 1.0 m to ensure that the gravel will achieve higher degree of compaction and enlarged to the required diameter of the pile. The retrieving height of 1.5 m and lowering height of 1 m was implemented at the site as the best combination to achieve the designed diameter and the compaction based on the trial work. The above procedures were repeated until the gravel compaction pile was constructed up to ground level.

5 EMBANKMENT CONSTRUCTION AND FIELD MONITORING PROGRAM

After GCP installation, the site was left for about a month allowing it to stabilize and recover the strength of the treated ground. Then the site was levelled and 0.5 m thick gravel mat was spread. After that a high strength geotextile was laid to enhance the stability of the embankment as per the working drawing. Thereafter earth filling was started and fill surcharge was applied in stages, for the stability consideration.

The improvement of the soft ground was monitored through the measurement of settlement and the excess pore water pressure during the construction period. Settlement plates were installed at the top of the soft layer or on the top of the pioneer layer and piezometers were installed at the middle of the soft layer.

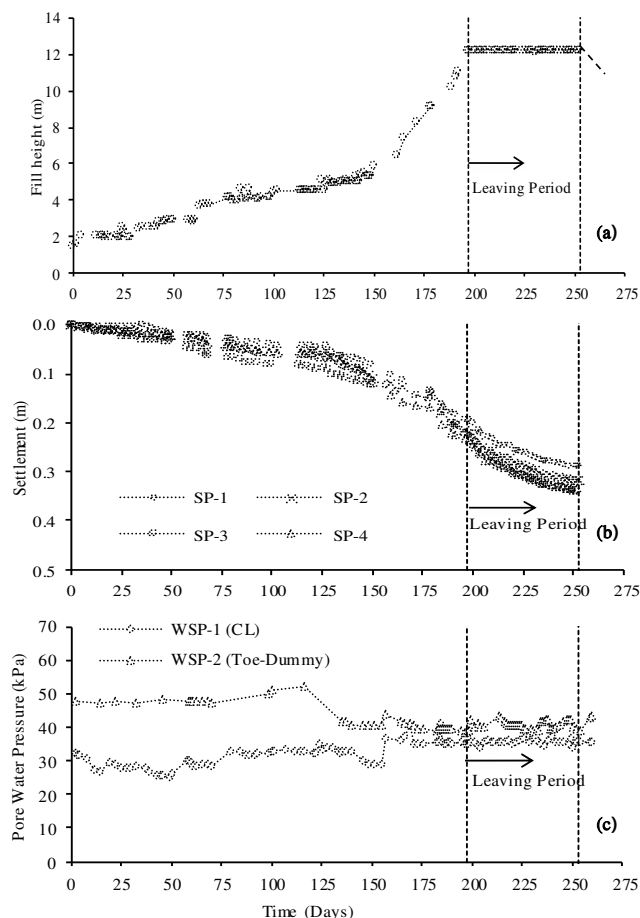


Figure 3. Loading curve and monitoring data during construction period

The settlement stakes were installed near the toe of the embankments to check the stability during the construction. The locations of the instrumentation in the trial embankment are shown in Figure 1. The loading curve that shows the placement of the fill, the settlement of the settlement gauge installed under the carriage way of the embankment and the pore water pressure (PWP) in the piezometer installed in the middle of the peat layer are shown in figures 3(a), 3(b) and 3(c) respectively. As shown in the figures the soil has been consolidated under the fill load of about 12 m and the observed maximum average settlement of the embankment was around 0.35 m. It is to be noted that in the above areas the thickness of the soft layer was around 4 m and it consists of peat, organic clay and silty clay. In most of the GCP areas the observed settlement was in the above range. As expected, low settlements were observed in the embankments that were constructed over very soft peat and clay deposits due to the GCP improvement. According to the piezometer readings shown in the Figure 3(c), the development of excess pore water pressure due to embankment loading was very low and completely dissipated within the surcharge period. It confirmed that the gravel compaction piles increases the rate of consolidation, as expected.

6 ASSESSMENT OF THE SOFT GROUND IMPROVEMENT

The ground improvement achieved was investigated by calculating the degree of consolidation using the observed field settlements before the removal of surcharge. The degree of consolidation was calculated as the ratio of the current settlement to the expected ultimate primary settlement. In the present work, ultimate primary settlement and the degree of consolidation were estimated by means of the Asaoka (1978) and hyperbolic methods (Tan et al.1991) using the measured field settlement data of the latter part of the monitoring.

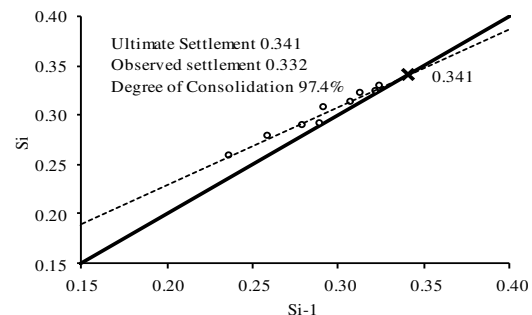


Figure 4. Graphical plot of Asaoka method (SP-4).

The calculated degree of consolidation using the Asaoka method based on the settlement data obtained from the settlement plate (SP - 4) installed at SGT section 19 area is shown in Figure 4. In the above case, the calculated degree of consolidation using the Asoka method and hyperbolic method was around 97% and 89% respectively. In general, the removal of surcharge was considered, when the Degree of Consolidation reached around 90 % under the design surcharge load. Also, the degree of consolidation was estimated based on the pore water pressure measurements at the location where the piezometers functioned.

In order to assess the secondary settlements, for each monitoring point, the long-term settlement was predicted by extrapolating the secondary settlement rate over a period of 3 years. Predictions were made by preparing a plot of displacement against log (time) for each settlement plate, with the best-fit line through the data extended to define the likely settlement after 3 years as shown in Figure 5. The surcharge was removed only after confirming the residual settlement by

considering the remaining primary and secondary consolidation settlements as described above.

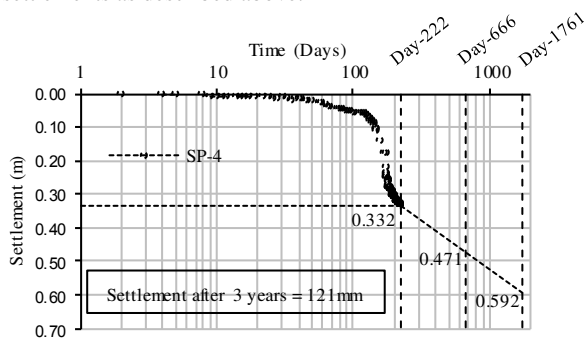


Figure 5. Confirmation of future settlement by Graphical Method.

7 INVESTIGATION PROGRAM TO CONFIRM THE GROUND IMPROVEMENT

The site investigation program was carried out to assess the actual ground improvement due to GCP method in trial sections. Investigation was carried out before the ground improvement and after the ground improvement (removal of surcharge). The investigation program comprised of advancing boreholes with SPT, performing of Static Cone Penetration Tests (SCPT), a pressure meter test, collection of disturbed and undisturbed samples and performing of laboratory tests. The investigation was carried out under the center, crest and slope of the embankment and the locations of the boreholes and the in situ tests are shown in Figure 1. The summary of SPT-N values and laboratory test results for soft soil before and after soft ground treatment works is shown in Table 2. Accordingly, it was observed that the SPT-N values of the soft soil has increased due to the soft ground treatment works and the consistency of soft soil has changed from very soft condition to soft to medium condition.

Table 2. Summary of laboratory test results

Location	Soil Type	SPT N	W _n (%)	e ₀	C _c	P _c (kPa)	Cu (kPa)
Before SGT							
BH 160b	Pt	0	236.7	5.69	1.90	17	7.2
	OH /OL	0	178	3.79	1.65	32	19
After SGT							
Center	OH/OL	2-5	44.1	1.25	0.34	120	86
	Pt	2-4	154.6	3.29	1.10	50	56
Crest	Pt	2-3	119.6	2.25	1.10	65	65
	Pt	1-2	133.6	2.35	1.10	55	21.5
Slope of Embankment	Pt	1-2	133.6	2.35	1.10	55	21.5

As indicated in Table 2 the physical properties such as moisture content and void ratio has been significantly reduced after the ground improvement. This reduction is well correlated with the reduction of the compression index which is proportional to the primary consolidation settlement. The compression index of the peat and organic clay has been reduced considerably due to the ground improvement. The comparison of results from the consolidation tests carried out before and after the ground improvement shows that the Preconsolidation pressure (P_c) of the soft soil found under the center area of the embankment has been increased from 32 kPa to 120 kPa. This increase and the vertical stress resulting from the external loading on the soil surrounding the GCP area are in the similar range. The observed increase in P_c of the peat layer under the crest area of the embankment is lower than the expected and this might be due to the inaccurate P_c value obtained from the consolidation

test as a result of sample disturbance. The Triaxial test results clearly indicated that the undrained shear strength (C_u) of the soft soil has significantly increased after soft ground treatment works.

8 PERFORMANCE OF IN SERVICE PERIOD

The performance of the embankment after pavement construction was monitored by installing the settlement markers. The observed surface settlement of the embankment constructed on the area improved by GCP is shown in Figure 6. The highway was open to traffic on September 2015, and the observed total surface settlement up to June 2016, ten months after opening to traffic, was less than 10 mm. The results of the post construction surface settlement monitoring of the embankment carried out reconfirm that the ground improvement work was very successful and the expected residual settlements are well below the allowable limit of the contract.

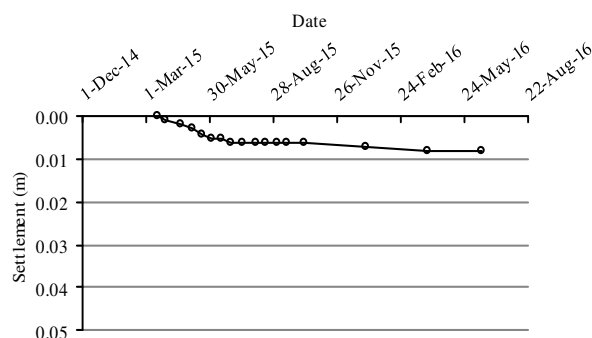


Figure 6. Surface settlement of pavement

9 CONCLUSION

A 12 m high trial embankment has been successfully constructed on a marginally stable peaty ground using Gravel Compaction Pile (GCP) technique. The field monitoring data carried out at the site indicates that the primary consolidation settlements of the foundation soil under the applied load were almost completed. Investigations carried out at the site show that both physical and mechanical properties of the peat have improved significantly. The estimation carried out based on the above information assures that the residual settlement would be less than 150 mm by the end of 3 years after construction as required in the contract and the embankment would be stable as designed.

10 ACKNOWLEDGEMENTS

The authors are grateful to the Road Development Authority of Sri Lanka, Oriental Consultants Co. Ltd of Japan, Taisei Corporation of Japan for the necessary approval and support extended towards writing this paper.

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