Regional Symposium on
Infrastructure Development
in Civil Engineering

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in cooperation with:

Japan Society for the Promotion of Science
Department of Science and Technology
Japan Society of Civil Engineers
Philippine Institute of Civil Engineers
Eastern Asia Society for Transportation Studies
MESSAGE

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Manila, Philippines

It is a great pleasure to extend to all the participants and the members of the organizing committee a hearty message of congratulations from the Japan Society for the Promotion of Science at the successful opening of the "Regional Symposium on Infrastructure Development in Civil Engineering.

Scientific cooperation between JSPS and DOST in the field of Engineering commenced in 1986 under the Core University Program. Over the past ten years, we have worked together closely and vigorously to support this highly innovative program. Tokyo Institute of Technology and the University of the Philippines, the Core Universities in Japan and the Philippines, have devoted their efforts to successfully implement this program. It is upon the achievement of harmonious research collaboration between the universities participating in this Core University Program that this symposium is being held.

We are looking forward to an active and productive exchange of views and information among all the participants gathered here from a wide variety of associated disciplines. Your contributions will help to advance research in Civil Engineering both in Japan and in Southeast Asian countries.

Successful infrastructure development is one key in solving several urban problems which the developing countries are now facing. This symposium’s pursuit of advancement in the field of Civil Engineering is sure to be both timely and highly meaningful for the participants. We hope that the fruitful result of this symposium will facilitate further research activities and cooperation.

JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE (JSPS)
MESSAGE

It is with distinct pleasure that we extend our heartfelt welcome to the participants of the "Regional Symposium on Infrastructure Development in Civil Engineering".

Despite the current setback experienced by the tiger economies, it is a fact that the Asia Pacific region is fast becoming an economic force to reckon with. Coupled with this development is the need for efficient and effective infrastructure to support thriving economy and commerce.

This symposium has been conceived as a venue for exchange among researchers and engineers from the Philippines, Japan, and other Asian countries. It is hoped that an exchange of experiences and ideas would ensue during the discussions. Despite the oceans and mountains that divide us, we share a common heritage. When we share expertise and experience, we unify our truths to form a reality that will propel the region into economic viability.

May the spirit of cooperation and generosity reign supreme during the Symposium.

Again, welcome to the Philippines and Mabuhay!

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Abstract: Ground improvement technology has played an important role in the development of reclaimed lands and soft soil coastal regions in Indonesia. This paper elaborates the author past experiences of the ground improvement techniques that has been implemented in various part of Indonesia. Case studies on dynamic compaction, vibro-compaction and pre-loading are presented.

1. INTRODUCTION

In the last 25 years Indonesia has been experiencing an average Gross Domestic Product of not less than 7 percent, an industrial growth of 10 percent, an increase of urban population growth from 10 to 30 percent. Great percentage of the development taking place in Jakarta, the capital city. In the next 20 years, expert estimates Jakarta will be dwelled by 32 million people from the current population of 8 million! The fast increasing rate of population and the dynamic economic development has forced the people to utilise marginal land for the development of buildings, industrial and their subsequent infrastructures. Nowadays, we even go toward the sea. The city has started reclaiming 32 km long coastal line covering of 2,700 hectares area in the Jakarta Bay (see Fig. 1).

As we all know that most of man’s construction is done on, in or with soil. Developing a geotechnically marginal land, such as reclaimed land on poor marine soil, is certainly a big challenge for an engineer. To mitigate the marginal land into a safe ground for construction, ground improvement technology is one of the alternative solutions. This paper tries to elaborate the ground improvement technology that has been put into practice in Indonesia for improving reclaimed lands and soft marine clay.

2. SOIL DENSIFICATION

Cohesionless soil (sand) obtained from sea is commonly used as a backfill material for the reclamation work. Hydraulic filling method, either by pumping the sand from its source and spreading it over the reclamation area or by dumping the sand directly from a barge is normally employed. Such filling methods will generate saturated and relatively loose soil.
deposits. This soil deposit has great potentials to undergo excessive settlement and to experience liquefaction under earthquake or dynamic loading.

Dynamic compaction and vibro-compaction has been implemented in many occasions to eliminate or reduce the above risks. Due to the restriction of explosive usage, to the author knowledge, blasting has never been applied.

2.1 Dynamic Compaction

The dynamic compaction (DC) is performed by repeatedly and systematically dropping a massive heavy weight ranging from 10 to 200 ton from a height of 5 to 40 m onto the ground surface (Fig. 2). This technique, pioneered by a French engineer, Louis Menard, has been applied in a number of coastal regions in Indonesia. Among others are: Balikpapan in Kalimantan Island; Arun and Tarahan in Sumatra Island. This technique has also been applied in a highland area, i.e. Porsea in North Sumatra, where the ground water table is very deep.
(up to 70 m depth). Two of the cases where the dynamic compaction is applied in the coastal area, i.e. Arun and Tarahan, shall be presented. The locations of the projects taken for case studies are shown in Fig. 3. The two sites were chosen for the reason that at Arun the sand layer relatively have small fines content and no significant coral fragment, while at Tarahan site there is significant percentage of fines content and coral fragment. These two distinct soil conditions provide good comparison to be made on the effectiveness of the dynamic compaction method.

**a. Arun Project (1986)**

The project is located in a LNG plant. The site was originally tidal flatlands adjacent to the beach, with small tidal rivers flowing through the area. During the year of 1977 to 1978 sandy material dredged from the harbour was pumped to fill the project site. The grade in this area was, thus, raised from near mean sea level to a level approximately 4 m above sea level. The soil investigation revealed that up to about 30 m depth, the soil is primarily poorly-graded sand which is generally medium to fine grained in the upper 10 m then grades to only fines with increasing depth. Thin clayey sand layer of about 1 m thick is found at a depth of about 3 to 6 m depth (Fig. 4). At this depth the fines (% passing #200 sieve) content is around 30%, whereas at other depths the fine content is generally in the order of 5-15%.

The site average SPT corrected blow counts (i.e. the blow counts were normalised to an energy ratio of
60% and an effective overburden pressure of 1 kg/cm². N₁₀₀ is in the order of 15 blows/ft where the corresponding relative density, Dr, is in the order of (see SKEMP-TON, 1986):

\[
Dr = \left( \frac{N_{100}}{60} \right)^{0.5} = \left( \frac{15}{60} \right)^{0.5} = 50\% \quad \text{............. (1)}
\]

The problem with this medium relative density for the type of the structure that the soil has to bear, i.e., a tank of 70 m wide and 26 m high, is the differential settlement problem. Apart from that, liquefaction analysis by using the procedures derived by SEED et al (1984) also shows that under the expected earthquake acceleration of 0.18g the site is prone to liquefaction. Figure 5 shows the result of the analysis (the line marked with 5% and 15% is the borderline of the liquefaction potential for 5% and 15% fines content, respectively). Based on the case record of Niigata Earthquake of 1964 where no liquefaction occurred at depth deeper than 15 m (ISHIHARA, 1985), it was decided to densify the soil up to 16 m depth. Dynamic Compaction was chosen. A 16 ton tamper with a base area of 4 m² was systematically dropped from a height of 25 m by a 165 ton crawler crane. The compaction was carried out in a 8 m square pattern. The main tamping procedure was performed in two phases as shown in Fig. 7. In order to compact the upper surface where unimproved soil existed between the main print point, upon completion of the main tamping the whole area was tamped uniformly for finishing. In this ironing tamping, the same tamper was used but with lower height of drop of 15 m. A cumulative compaction energy of 200 ton m/m² was applied. Surface measurement before and after each compaction phases showed that the enforced settlement for the above said compaction energy varied around 22 to 28 cm. The pre and post compaction SPT N values shown in Fig. 7 indicated that the treated

an effective overburden of 1 kg/cm²), $N_{160}$ is in feet of 15 blows/ft where the relative density, $D_r$, order of (see SKEMP-[6]):

$$N_{160} = (15/60)^{0.5} \times (1 - 15/60)^{0.5}$$

= 50%                      \( \text{(1)} \)

Fig. 8 Degree of Improvement by DC - Arun

The degree of improvement, defined as the ratio of Post Compaction SPT against Pre Compaction SPT, is plotted against the pre-compaction SPT N values (Fig. 8). The plot shows that when the pre-compaction corrected SPT N values, $N_{160}$, is above 30, the degree of improvement will be practically become one. That is no further improvement can be achieved.

b. Tarahan Project (1985-86)

Tarahan is a coal terminal where the coal mined from South Sumatra is transported to Java Island. The subsoil consists of 0.5-4.0 m thick fill material, composed of a mixture of cobble, gravel, sand and silt, overlying 12-16 m thick coraline soil (Fig. 9). The coraline soil consists of loose silty sand with substantial amount of coral fragments throughout the depth. The upper 5 m, in average, containing about 30% coarse coral fingers (% retained in sieve no. 4) while the lower part has about 20%. This coraline soil is underlain by stiffer strata of clayey soil followed by conglomerate in the northern area and stiff to hard clay in the southern area. The water table varies from 1.5 m to 2.5 m depth from the northern to the southern part. Owing to its high water table and the practically loose cohesionless coraline soil, the risk of seismic damage at this site is primarily related to liquefaction. The
Fig. 10 The SPT N Values before Treatment and Its Liquefaction Potential - Tarahan

results of the liquefaction analysis (SEED et al., 1984, procedures), for an earthquake acceleration of 0.25g, showed that the majority of the pre-compaction SPT N$_{160}$ values fall below the required values to prevent liquefaction (Fig. 10). Dynamic Compaction was considered as an alternative to improve the subsoil and to reduce the liquefaction potential. Field trials were carried out at certain location where the thickness of the fill material was less than 0.5m. A 15 ton tamper with a contact area of 4.3 m$^2$ falling from 20 m high was used to deliver the compaction energy into the ground. The trials were performed in a square grid pattern and were carried out in four phases. The first phase was started with 11 m print spacing, each subsequent phase was then carried out right at the centre of the previous phases (Fig 11). The last phase is the ironing phase, the drop height of this ironing phase is 12.5 m. A cumulative energy of 295 ton m/m$^2$ were applied.

Fig. 12 Pre and Post Compaction SPT at Tarahan

Fig. 11 The Tamping Pattern of DC at Tarahan

Surface measurement before and after each compaction phases showed that the enforced settlement for the above said compaction energy varied around 70 to 90 cm. The pre and post compaction SPT N values are presented in Fig. 12. It can be seen that the effective improvement depth is only around 5 m. Below that depth the soil remains unimproved and remains liquefiable. ISHIHARA (1985) shows that the required thickness of non-liquefiable soil surface layer for a ground acceleration of 0.25g should be more than 4.5m in order not to induce damage to the upper structure. Therefore, the improvement of 5 m is important of the site, the yard area and the other area, also defined is plotted against the pre-compaction corrected practically become one compared to Arun site.

Fig. 13 Degree of Improvement

Fig. 14 Fines Content proportionally same. Th compartments (also see GOUW, 1991) energy was wasted for cr
improvement of 5 m is considered adequate. However, considering the high risk and the important of the site, the dynamic compaction method was only employed at coal stockyard area and the other area was improved by vibro-compaction method. The degree of improvement, also defined as the ratio of Post Compaction SPT against Pre Compaction SPT, is plotted against the pre-compaction SPT N values (Fig. 13). The plot shows that when the pre-compaction corrected SPT N values, \( N_{10d} \), is above 20, the degree of improvement will practically become one. That is no further improvement can be achieved. Note this is lower compared to Arun site.

![Fig. 13 Degree of Improvement by DC - Tarahan](image)

The depth of the improvement that can be achieved by a dynamic compaction method is normally determined through the following empirical formula,

\[
D = n (W H)^{0.5} \quad \ldots \quad (2)
\]

Where \( D \) is the anticipated improvement depth in meter, \( W \) is the weight of the tamper in metric ton, \( H \) is the height of fall of the weight in meter, and \( n \) is an empirical coefficient ranging from 0.3 to 0.8 depending upon the soil type. At Arun site where the sand is relatively clean and no significant coral fragments, back calculation shows that \( n = 0.8 \), and at Tarahan where significant coral fragments is found the coefficient \( n \) is as low as 0.3.

Now, the question is: despite its larger energy why it gave much smaller improvement compare to Arun site? A further study shows that the fines content at this Tarahan site increases after compaction. Comparison of the fines content, Fig. 14 indicates that in the upper 5 m the fines content increases whereas below 5 m depth the fines content remain practically the same. This is due to the crushing of the coral fingers in the coralline soil (also see GOUW, 1991). This means instead of improving deeper soil layer, part of the energy was wasted for crushing the coral fragments.

![Fig. 14 Fines Content before & after DC - Tarahan](image)
2.2 Vibro-compaction

Vibro-compaction refers to a process of deep soil densification, both above and below the ground water table, through the insertion of a vibrating poker. The insertion of the poker to the desired depth is achieved by the self-weight of the poker and the vibration, sometimes supplemented by simultaneous water or air jets at the bottom tip of the poker to facilitate penetration to greater depth. Very often granular backfill is introduced into the ground, so that compacted granular material is formed within a volume of soil compacted. When sand is used as backfill, the product is named as sand (compaction) piles and when gravel is used, it is usually named as stone columns or stone piles or granular piles. The techniques, either the dry process (no water jetting) or the wet process (with water jetting) have been applied in Indonesia since the 1980s. Four case studies shall be presented here, two wet process applied at Arun and Batam, and two dry process applied at Tarahan and Baliarpahan.

![Fig. 15 The Vibroflot (after Mitchell, 1981)](image)

Adjacent to the above-explained dynamic compaction, vibroflotation was applied for improving the adjacent tank foundation. The subsoil was found to be very similar with the dynamic compaction site (see Fig.4). A 30 HP vibroflot mounted on a 35 ton crawler crane was used. The vibroflot (Fig. 15) is essentially a cylindrical metal assembly, 1.8 ton in weight, 381 mm in diameter and 1.86 m long, equipped with eccentric weights driven by electric motor operating at 1800 revolutions per minute to create horizontal vibrations. The centrifugal force developed during vibration is 10 ton. Two sets of water jetting valves, one at the bottom and one at the upper part of the vibroflot, are provided. The lower jetting valve is used during insertion and the upper valve during backfilling.

The vibroflot was inserted to a depth of 16 m and was arranged in a triangular pattern with 2.4m spacing. The trian-
gular compaction pattern was adopted since experiences indicate this pattern give a more uniform result compared to the square pattern. At each point of compaction the vibroflot was inserted with the aid of water jets, vibration and its own weight, by moving it up and down to the specified depth. The vibroflot was then held at that level while vibrating as the sand backfill material was placed in the hole around the vibroflot. To help the flow of the backfill to the bottom of the hole, once the required depth is achieved, the water jets was switched from the bottom valve to the upper one. The vibroflot was raised in increments of 30 cm in one minute or after equilibrium stress between the vibroflot and the surrounding soil was reached whichever comes first. During the process, backfill material was continuously added. The gradation envelope of the backfill material is shown in Fig. 16. The average consumption of the backfill material is 0.8 m³ per m depth treated.

The SPT blow counts before and after compaction is presented in Fig. 17. It can be seen that the vibroflotation is very effective. All the post-treatment SPT N values, N₁₀₀, are beyond the liquefaction boundary for 5% fines where the required N₁₀₀ is 15 blows/ft. The overall mean of the post-treatment N₁₀₀ is around 35 blows/ft that is much higher than required. Comparing the results of the dynamic compaction method at the adjacent site (Fig. 17), the results are much more uniform. The degree of improvement is shown in Fig. 18. As in the dynamic compaction results, the degree of improvement also becomes lower as the pre-compaction SPT blow count increases. As in dynamic compaction results no improvement is obtained when the pre-compaction SPT N₁₀₀ is higher than 30 blows/ft.

Fig. 17  SPT Blow Counts – Before & After Vibroflotation

Fig. 18  Degree of Improvement by Vibroflotation - Arun

The site locates on a completely reclaimed land. The sea bed was first dredged to remove the soft marine clay that overlain stiff clay layer. It was then hydraulically filled with sand up to a level of 3 m above the mean sea level. The thickness of the sand fill varied from 4 to 17 m. The cone penetration tests (CPT) performed before improvement revealed that the upper 3 m of the fill was in a medium dense condition. The cone resistance in this layer was vary from 50 to 200 kg/cm². This hard layer was formed due to unintentional surface compaction induced by the movement of heavy equipment, which were operated when the fill had reached above sea level. Below 3 m up to about 18 m depth the sand was in loose condition. It was required to densify this loose sand fill up to a relative density of not less than 65%. Figure 19 shows the grain size distributions of the fill material. It can be seen that the grading is located inside the best suitable range (range B as indicated in the figure) for vibroflotation as defined by BROWN (1977). Therefore, vibroflotation technique was adopted. A new 113 HP hydraulic vibroflot (40 tons centrifugal force at 3000 rpm) was employed.

Since the vibroflot has a great power, a trial of 4 x 4 m grid was performed and the reclaimed sand material was used as the backfill material. It has to be noted here that the vibroflot did not have the upper jets system and also the jetting pump had a capacity of only 900 l/min (at Arun site a pump of 3000 l/min discharge rate was used). Therefore, no column of water could be maintained during the insertion and the compaction process. This made backfilling procedure became very ineffective. Due to this reason, the compaction

![Graph showing grain size distribution](image)

**Fig. 19** Grain Size of The Reclaimed Land Material - Batam

![Diagram of vibroflotation process](image)

**Fig. 20** Pre and Post treatment

![Diagram of equipment](image)

**Fig. 21** The Dry Process
first dredged to remove vertically filled with sand sand fill varied from 4 feet. It was revealed that the resistance in this layer to unintentional surface were operated when the sand was in loose effective density of not less

![Graph showing Penetration Resistance in kg/cm²](image)

**Fig. 20 Pre and Post Compaction CPT - Batam Site**

![Diagram of Vibro-Compaction Equipment](image)

**Fig. 21 The Dry Process Vibro-Compaction Equipment**

...procedure was arranged as follows: The vibroflot was withdrawn quickly at an interval of 1.5 to 2.0 m. This was intended to let the hole collapse an filled with the surrounding sand. The vibroflot was then reinserted for about 2 minutes to compact the sand. Despite of this modified compaction procedure (the normal procedure is the one applied at Arun Site), the after treatment CPT cone resistance did not give an improvement. Only after bringing the compaction to a closer distance of 2m grid and applying higher pressure and longer time, the compaction showed reasonable results (see Fig. 20). This fact suggested that two sets jetting system and strong pump capacity, as in Arun site, have to be utilised to obtain good compaction results.

c. **Tarahan Project (1985-86)**

This site is the same site as the dynamic compaction site elaborated above. The soil profile can be seen in Fig. 9. A dry process vibro-compaction method was employed. A top mounted vibrator similar to those used for pile driving was used. In this type of vibrator two counter rotating eccentric weight is placed in a horizontal axis to produce a

vertical vibration. The vibrator was fixed on top of a 0.4 m diameter casing. The casing was equipped with a shoe that automatically open upon withdrawal and close upon re-penetrating. Two small pipes, each placed inside and outside the steel casing. The outer pipe was used to supply air jetting to help penetration of the casing to the desired depth. The inner pipe was used to blow compressed air to break the suction, which might occur during extraction of the casing. A hopper was also installed to feed backfill material into the casing. Figure 21 shows the arrangement of the device.

The casing was driven to the desired depth of 18 m, upon completion the casing was partially filled with backfill material. It was then raised about 3 to 4 m to allow its shoe to open and the backfill flow into the hole. Compaction was then carried out by re-penetrating of the casing. After re-penetration, the casing was refilled, raised and re-penetrated again until the compaction pile was completed. A triangular pattern of 1.8 m spacing was adopted and the compaction was carried out in two phases, i.e. the compaction was done in an alternate rows. The odd rows were done first, the even rows were done after all the odd rows completed. The grain size distribution of the subsoil and the backfill material are shown in Fig. 22.

The compaction results are shown in Fig. 23. It can be seen that significant improvement is achieved although the corrected SPT blow counts below 11 m are still below the liquefaction boundary line. However, below this depth, the original soil had a fines content greater than 50%, therefore, liquefaction might not occurred. Compared to the dynamic compaction applied at the site, this method achieved greater improve-

Fig. 22 The Grain Size of Subsoil & Backfill Material - Tarahan

Fig. 23 Pre and Post Treatment SPT of The Compaction Piles Method - Tarahan Site
meter casing. The casing was 1 m in diameter and closed upon re-stake casing. The outer casing, which might occur, was backfill material into the casing.

The casing was then carried out by retraction of the casing. After penetration, the casing was refilled, raised and re-penetrated again until compaction pile was completed. A triangular plan of 1.8 m spacing was used and the compaction carried out in two layers, i.e. the compaction done in an alternate layer. The odd rows were done first, the even rows done after all the odd rows were completed. The grain distribution of the subsoil and the backfill material is shown in Fig. 22.

The compaction results are shown in Fig. 23. It can be seen that significant improvement is achieved at high the corrected SPT n values below 11 m are below the liquefaction index line. However, at this depth, the original soil had fines content greater than 50%, therefore, compaction might not occur. Compared to the dynamic compaction applied at this site, this method showed greater improvement depth. Just like the case with the dynamic compaction, at a greater extent, crushing of the coral fragment also took place. The degree of improvement is presented in Fig. 24.

Comparing the results of this dry process vibro-compaction piling method with the wet process of vibroflotation applied at Arun site (compare Fig. 17 and Fig. 23), it can be seen that vibroflotation gives more uniform degree of improvement. This is due to the fact that the vibroflot applied uniform forces regardless of the depth, this is possible because the vibrating device is put at the tip of the vibrating poker. In dry process vibro-compaction method, the energy of the top mounted vibrator diminishes with depth due to the soil friction.

d. Balikpapan Project (1990)

At this site, the improvement was carried out for a 44 m oil tank foundation. The subsoil was mainly composed of loose silty fine sand for approximately 12 m depth from the ground surface with a cone resistance of 15 to 35 kg/cm². Hard layer was found at 12 to 13 m depth. The grain size distribution shows the silty content was less than 10% (Fig. 25).

Fig. 24 Degree of Improvement of Compaction Piling - Tarahan Site

Fig. 25 The Grain Size Distribution of Subsoil and Backfill Material - Balikpapan Site
Figure 25 shows that the grading of the sand was practically uniform and located between the B and C range as defined by BROWN (1977). The dry process vibro-compaction piles were adopted to improve the subsoil to get a relative density of not less than 65%. The gradation of the backfill material is also shown in Fig. 25.

The equipment employed was similar to the one used in Tarahan. A triangular pattern of 1.7m spacing (10 cm shorter compared to Tarahan site). Instead of a normal practice to feed the backfill material step by step into the ground. In order to speed up the construction time, the contractor tried to feed the material in only one step. This was carried out by making a big hopper to contain 5 to 6 m³ backfill material on the top of the casing. A lot of difficulties arise due to the weight of the backfill material in the system. The equipment often got damage. Apart from that the results also not satisfactory as showed in Fig. 26. It can be seen that practically no improvement was obtained at 2 to 6 m depth. This might be due to the non-uniform distribution of the backfill material that flow into the ground. Failing all this difficulties, it was finally decided to carry out the job by partial feeding method where the results proved to be good as in Tarahan site.

![Graph](image)

**Fig. 26 Pre and Post Compaction CPT - Balikpapan Site**

### 3. PRECOMPRESSION

When the foundation soil and/or the backfill material is a clayey material, either the existing soft marine clay or clay backfill material brought in from land. The soft clayey deposit will normally have a low shear stress and high compressibility. A structure could not be directly built on top of such a soft ground, as it will suffer intolerable settlement. A pre-compression combined with a vertical drain has been widely adopted since early 1985 to improve the settlement characteristic of the ground (GOUW, 1992)

The application of vibro-compaction is generally aimed to increase the cohesion between individual soil particles so that the soil can transfer its weight into cohesive soil. However, it is not the vibro-compaction itself which increases the cohesion, but the repeated surcharge load acting on the soil. The compacted soil is then consolidated by the repeated surcharge load, increasing the resistance to shear. This is the basic principle of the vibro-compaction technique, which is based on the concept of soil-structure interaction.

In these clayey soils, in-situ preloading can be achieved by the use of surcharge load, i.e. load is applied to the ground to increase the vertical stress. This increases the load-bearing capacity of the soil. Preloading and surcharging are often used as a combination for larger structures, but they can also be used separately for smaller structures, such as piles. In this case, the surcharge load is often applied by the use of water, which is then drained away from the ground. The water may be used to increase the load-bearing capacity of the soil, or to increase the load itself. The water may also be used to increase the load-bearing capacity of the soil, or to increase the load itself.
The application of vibration techniques, be it dynamic compaction or vibro-compaction, in cohesive soils does not produce the same results as in cohesionless soils. In cohesive soils cohesion between individual particles cannot be eliminated by vibration and, therefore, these soil particles are not separated, even temporarily, during the vibration process. As a consequence the soil cannot be compacted by vibration techniques. Introducing granular material into cohesive soil can be done and the results are granular piles (stone columns). However, it is not the vibration that makes the soil characteristics improved. It is the composite action of the granular piles and the existing soil that act together to bear the load exerted on it. The improvement of the clay characteristics can be achieved through the consolidation process where the excess pore water pressure dissipates through the high permeability of the granular pile arrangement.

In these clayey soils, improvement is normally performed by pre-compression or preloading technique, i.e. applying a preload to the compressible soil until a certain degree of consolidation be achieved. The preloading time is the governing factor and it is very often surcharge load, i.e. load in excess of the final design load, is applied to accelerate the consolidation process. To accelerate the consolidation further, vertical drains may be used to shorten the time required provided the compression is of the primary consolidation type.

Preloading and surcharging can be performed by: placing earth fill material, filling storage tanks with water, lowering the water table and use of vacuum pumping. The first two are self-explanating. The preloading by lowering the water table can take place because when the water table is lowered effective overburden pressure increases because the buoyant weight becomes the total weight in the drained layer. This results in a linear increase of pre-compression with depth. Vacuum pumping from beneath an impervious membrane placed over the ground surface can produce a pressure in excess of 60 kPa. Among these preloading techniques, the placement of the earth fill material is the one commonly adopted in Indonesia.

The preloading combined with prefabricated vertical drains has been widely implemented to overcome the consolidation problem of soft clay in various part of Indonesia. Among others are at Balikpapan, Banjarmasin, Belawan, Riau, Jakarta, Semarang, Balongan, Sumbawa and Paiton. A total of not less than 20,000,000 linear meters of prefabricated vertical drains have been installed. The majority being applied on reclamation area or in marine clay environment.

The theory of the settlement and the design of the vertical drain has been widely known and elaborated elsewhere (see: MITCHELL, 1981; DAS, B.M. 1985; GOUW, 1995). In principle, the vertical drain can accelerate the primarily consolidation by providing shorter drainage pathway for the dissipation of excess pore water pressure and by using the generally higher horizontal (radial) coefficient of consolidation.

The currently available types of vertical drains on the market consist of composite geo-synthetic material (geotextile filter wrapped around a synthetic core), monolithic geosynthetic material (non-woven geotextiles or plastic/poly-olefine) and jute fibre drains. The manufacturer and the supplier, sometime supported by laboratory test data, always claim that their drain is the best one, whereas the others have drawbacks in their resistance.
against clogging, small discharge capacity, etc. Despite of this exhaustive and everlasting argument, the author experiences showed that as long as we know the properties of the drain, have adequate information of the subsoil characteristics, design and execute the pre-compression scheme properly; all the drain can perform well in the field. The results presented in this paper show the effectiveness of a plastic monolithic vertical drain (brand name: Desol) despite of its said low discharge capacity as obtained from laboratory test.

<table>
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<th>Depth in (m)</th>
<th>Borelog Symbol</th>
<th>%C</th>
<th>%H</th>
<th>%W</th>
<th>%F</th>
<th>Y</th>
<th>t/m³</th>
<th>Cc</th>
<th>Cv ³</th>
<th>e₀</th>
<th>C</th>
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Fig. 7. Soil Profiles and Engineering Properties of a Vertical Drain Site at Balikpapan

Figure 27 shows the soil profile and the engineering properties of a vertical drain site at Balikpapan where Desol drain was installed in 1985. The vertical drain was installed in a 1.5 m triangular spacing in order to achieve 99% consolidation within 6 months time since the application of full 6.5 m high fill. Figure 28 shows the typical time settlement curve. It can be seen that at the end of the application of full preload of 6.5 m height fill (day 164) the settlement observed at settlement plate B.2 and B.4 were 1560 mm and 1595 mm, respectively. The end of primary settlement derived from the observed data by using Asaoka Method for plates B.2 and B.4 were 1610 mm and 1660 mm, respectively (Fig. 29). These means about 96% consolidation had been achieved in 164 days counting from the end of the installation of the drain and only 107 days since the application of full preload of 6.5 m high fill. The piezometer data also showed that not less than 95% of excess pore water pressure had been dissipated at the end of 164 days (Fig. 30). After the completion of the structure (an oil tank of 24 m diameter and 10.5 m high), until the end of 1992, no further
haustive and everlasting how the properties of the design and execute the pre-
are field. The results predict a vertical drain (brand from laboratory tests.

<table>
<thead>
<tr>
<th>$e_0$</th>
<th>C</th>
<th>$g^*$</th>
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<tr>
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<td>6</td>
<td>-</td>
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</tbody>
</table>

Fig. 28 The Time Settlement Curve of Preloading Scheme at Balikpapan

of a vertical drain site at drain was installed in a
thin 6 months time since time settlement curve. It
5 m height fill (day 164) 0 mm and 1595 mm, re-
ed data by using Asaoka respectively (Fig. 29). These
ounting from the end of
a of full preload of 6.5 m
% of excess pore water
er the completion of the
end of 1992, no further

Fig. 29 The End of Primary Settlement Derived by Asaoka Method
settlement was observed. This proved the drain performed well. The cone resistance also increases by a factor of three (Fig. 31). Detail of the analysis from available monitoring data has been presented in a paper titled ‘Satisfactory Performance of Monolithic Prefabricated Vertical Drain’ (GOUW, 1992).

4. CONCLUDING REMARKS

The above elaborate the use of vertical drain, flotation, compaction piles, and prefabricated vertical drains. Other ground improvement has also been implemented.

Finally, the above discussion should show how to design and construct the project to ensure the success of the improved ground. The design, construction technique, and practice are both important to ensure the success of the project.

5. ACKNOWLEDGEMENT

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GOUW, T.L., 1992, Drain, Prefabricated Vertical Drain, Flotation Piles and Vertical Drain, Asia, Proceedings of 1992 Asian Geotechnical Society Symposium, the authors, University of Philippines for infrastructure development.
4. CONCLUDING REMARK

The above elaborate the author past experiences in applying dynamic compaction, vibroflotation, compaction piling and preloading for improving reclaimed land or soft marine clay. Other ground improvement technology, such as: compaction grouting and jet grouting has also been implemented recently in a marine environment in West and East Java.

Finally, the above discussion shows that the knowledge of local soil condition as well as the know how to design and apply the ground improvement work is very important for the success of the improvement scheme. It is also important not to blindly trust a statement on a performance of a system, tools or materials. Good geotechnical theoretical knowledge and practice are both important.

5. ACKNOWLEDGEMENTS

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