Efficient Installation of Gravel Drains

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Proceedings: Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, March 11-15, 1991, St. Louis, Missouri, Paper No. 3.24

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SYNOPSIS : The gravel drain system aims to avert liquefaction in a sandy soil by quickly dissipating excess pore water pressure. We have developed a compaction-rod type machine which allows efficient construction of gravel drains. Main attributes of this machine are: (1) extremely fast installation of gravel drains, (2) low noise, (3) low level of vibration, (4) virtually no ground deformation during construction, and (5) densification of the surrounding soil. Large-scale model tests demonstrated that a cone-type compaction rod is most effective in densifying the surrounding soil when installing gravel drains with our machine.

INTRODUCTION

In 1964, the city of Niigata, Japan, suffered disastrous damages by soil liquefaction caused by the earthquake. Since the Niigata earthquake, various researchers started to look for effective countermeasures against liquefaction.

The conventional sand compaction method has been generally used in Japan, but its applications are often limited due to strong vibration and noise as well as the disturbance of the surrounding ground.

The idea of the gravel drain was advanced by Prof. Seed of U.C. Berkeley in 1977. The gravel drain aims to avert liquefaction in a sandy soil by quickly dissipating excess pore pressure generated during earthquakes. Since construction of gravel drains produces no serious vibration and noise, it is suitable to sites in urban areas and adjacent to existing structures.

In 1978, the first major application of gravel drain system in Japan took place in the Ohgishima man-made island as a countermeasure against liquefaction in the area behind the revetment. While effective against liquefaction, the system also would have no adverse effect on the revetment and adjacent structures.

Since then, more research and development related to this system have occurred. Field tests were performed at a site on the Ohgishima island where full size models were vibrated artificially. Three different situations were tested: One without gravel drain, another with gravel drain, and the third an empty well. These exercises positively demonstrated that the gravel drain system has a sound scientific merit.

Early on, construction of gravel drains was done with Benoto construction machine or doughnut auger construction machine. But in 1981 we began an effort to develop a machine dedicated to the construction of gravel drains and finally settled on a compaction rod type machine.

One of the important characteristics of this machine is the compaction effect of the surrounding soil. To further take advantage of the compaction effect, we undertook a research program in which the increase in the strength of the surrounding soils was tested as a function of the shape of compaction rod, the position of compaction rod, the diameter of compaction rod, the number of compaction and the stroke length of compaction. The test program has led to identification of the most suitable shape of compaction rod.

In this paper are reported the development of a compaction rod type machine dedicated to gravel drain installation and the results of the recent research program aimed at improvement of the compaction effect of this machine.

DEVELOPMENT OF CONSTRUCTION MACHINE FOR GRAVEL DRAINS

Gravel drains are driven into the sandy soil as shown in Fig.1. In our effort to develop a gravel drain construction machine, we focused

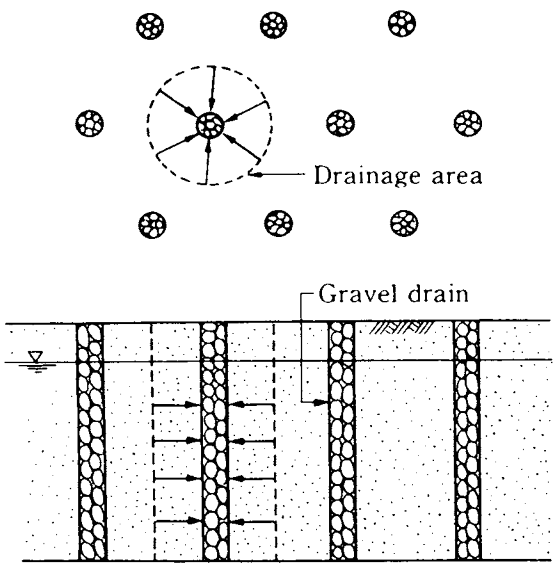

Fig.1 General view of gravel drains.

our attention on the following three points:

(1) To consider the casing auger type which has high construction efficiency as our design base.

(2) To preclude the use of compressed air as it causes the ground deformation.

(3) To compact and spread the discharged gravel in such way as to reduce the physical disturbance to the surrounding ground caused by a casing auger and construct dense gravel drains.

Developed machine and procedures

The developed construction machine, as shown in Fig.2, consists of a 3-point crawler type pile driving machine, compaction device, earth auger, casing auger and compaction rod. The hole is drilled with the casing auger. Gravel is lifted by the hopper and poured into the casing. And the compaction rod extends down the casing to strike and compact the gravel column.

The procedures for gravel drain construction, as shown in Fig.3, are as follows:

(1) Place the construction machine at a predetermined location and confirm its verticality.

(2) Screw the casing auger down into the ground to a predetermined depth, while simultaneously pouring water into the casing to prevent boiling.

(3) Pour gravel into the casing.

(4) Unscrew the casing auger and pull it up while compacting gravel with the compaction rod.

(5) Remove the casing auger out of the ground and the gravel drain is complete.

While constructing a gravel drain, it is important to preserve the continuity, length, and diameter of the gravel drain. For this purpose, sensors are developed to continuously monitor and control the state of construction, as shown in Fig.4.

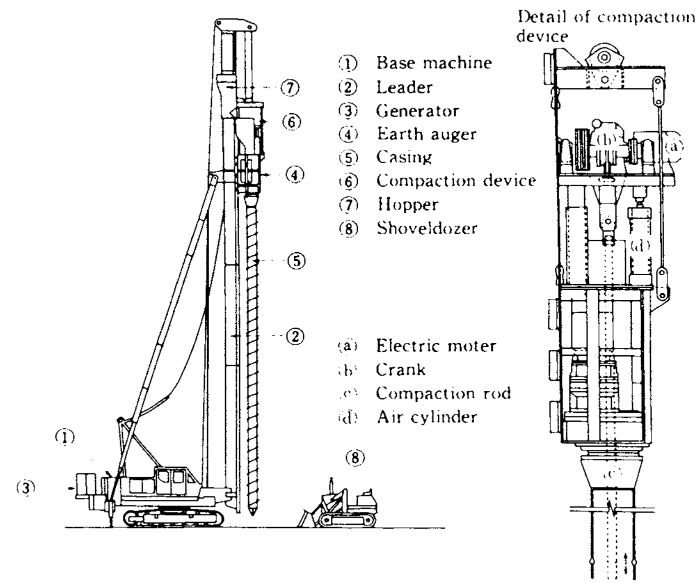

Fig.2 Developed construction machine for gravel drains.

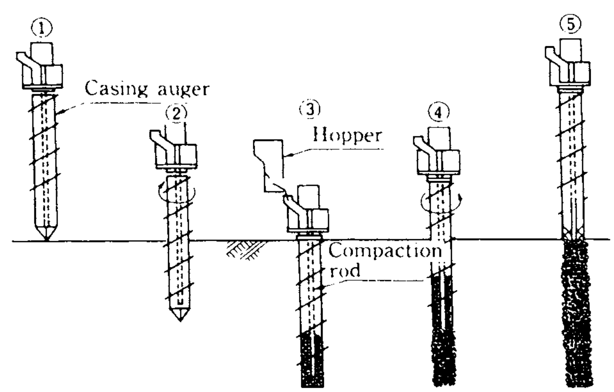

Fig.3 Construction procedures of gravel drains.

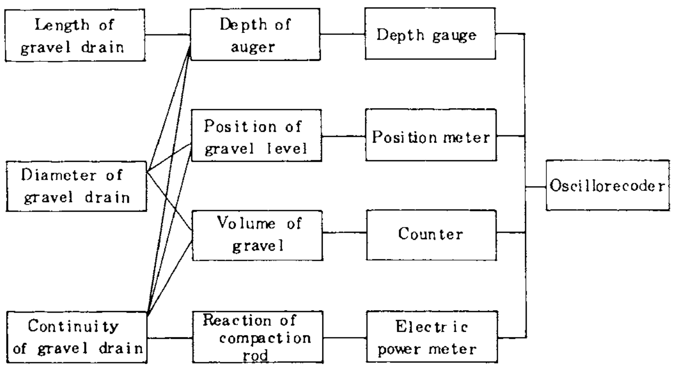

Fig.4 Construction control system.

Main characteristics of the system

In the light of construction tests and performance records, the developed gravel drain construction machine has the following characteristics and effects.

Fig.5 shows the effects of vibration caused by the gravel drain system in comparison with vibrocompaction methods like the sand compaction method and others.

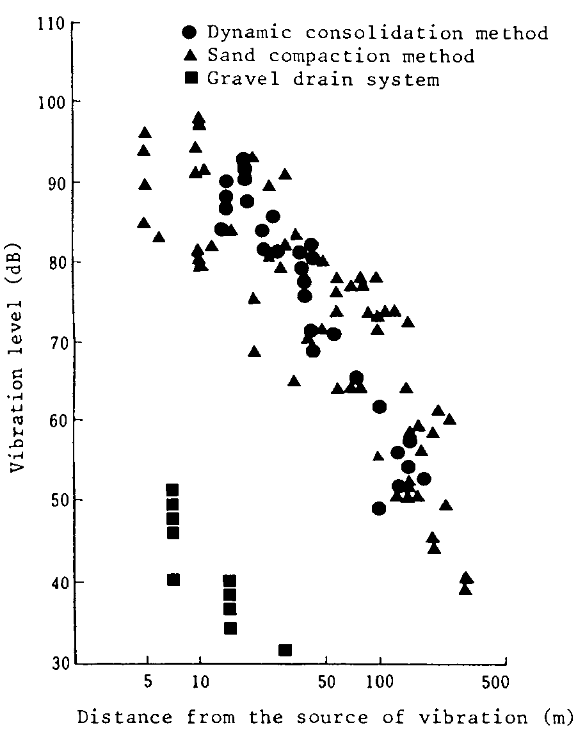

Fig.5 Propagation of ground vibration due to various foundation improvement methods.

In the case of vibrocompaction methods, the vibration higher than the specified value of vibration (less than 75 dB in Japan) extends beyond more than 50 meters away from the work site. On the other hand, by using the gravel drain system there is virtually no vibration. Also, the noise caused by the gravel drain system is very low as shown in Fig.6.

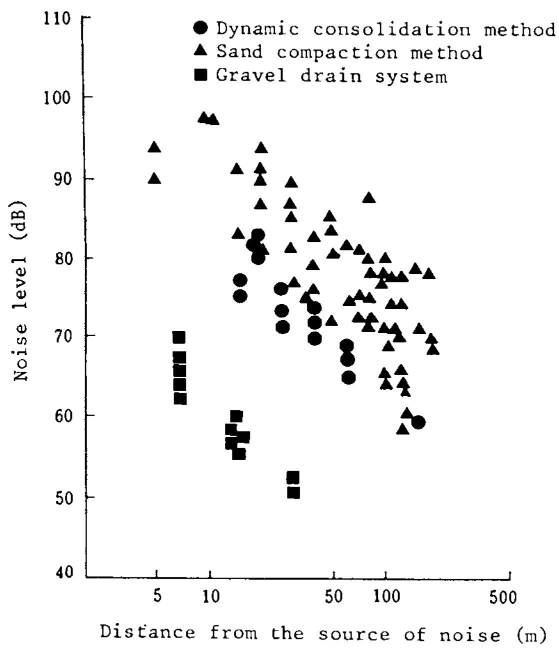

Fig.6 Propagation of noise due to various foundation improvement methods.

When reinforcing the foundation for existing structures, the ability not to disturb the surrounding ground is quite important. Fig.7 shows the test results on the disturbance to the surrounding ground with N value of 7 to 12 caused by three different method of gravel drain construction: (a) the Benoto method, (b) the casing auger was removed from the ground while applying pneumatic pressure on the gravel column; (c) our construction machine with compaction rod was applied. The horizontal displacement of the surrounding ground is essentially negligible in the case of our gravel drain construction machine. Therefore it is clear that the use of our machine with its compaction rod is superior to others in preventing ground displacement.

From a design point of view, the gravel drain's ability to dissipate excess pore pressure quickly in a sandy soil is of vital interest. To verify this critical ability, the measurement of

N values before and after construction was conducted in the ground where gravel drains were actually driven. Fig.8 shows the investigation sites which are located near the Shinano river in the city of Niigata. The comparison results of N values before and after construction at the 3 sites are shown in Figs.9 and 10. In Fig.10, the separation between the solid line and the broken line is indicative of the improvement in compaction effect due to the compaction rod. Through these investigations the compaction effect of the surrounding soil from the use of the compaction rod was ascertained.

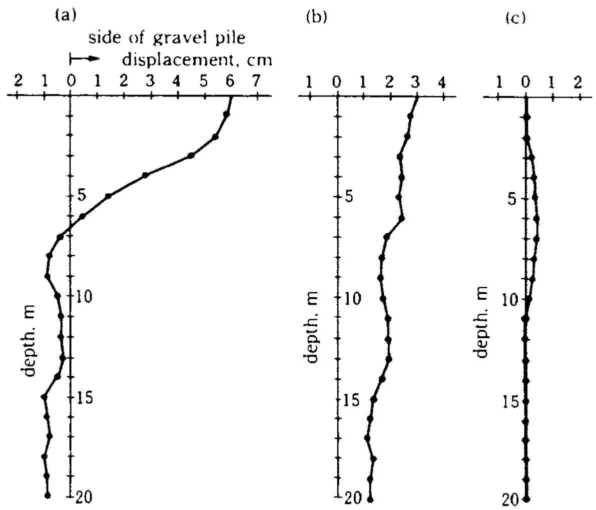

Fig.7 Disurbance of surrounding soils due to different methods of gravel drain installation.

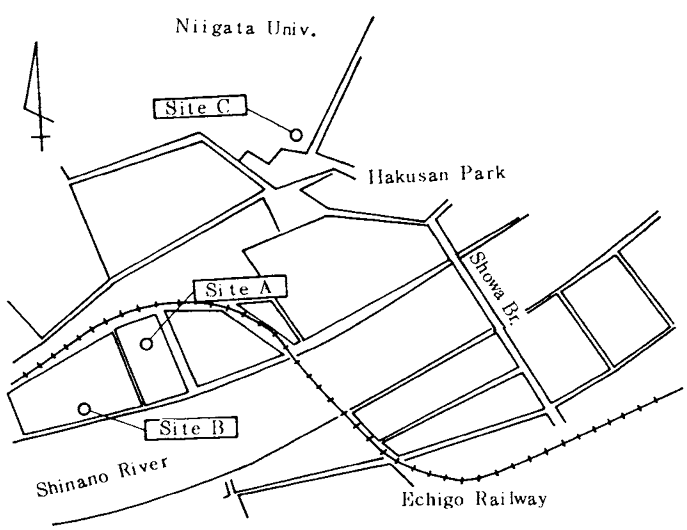

Fig.8 Investigation sites in the city of Niigata.

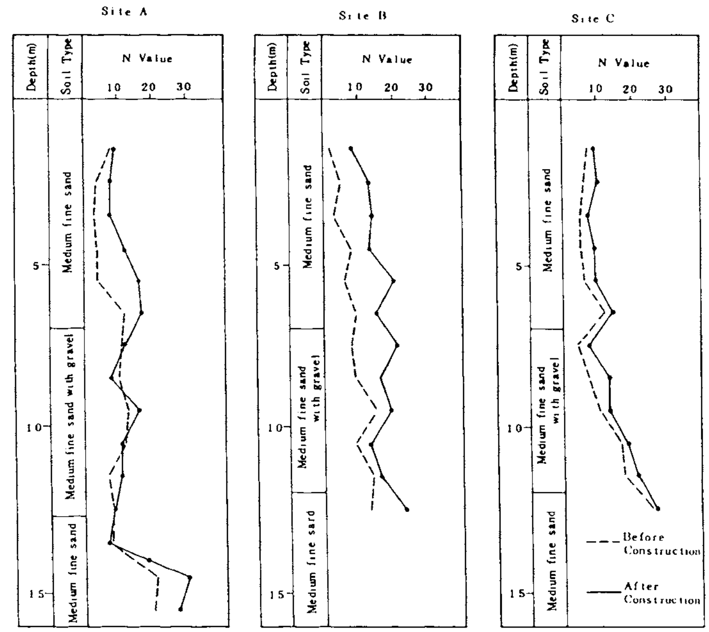

Fig.9 Compaction of surrounding soils as a result of gravel drain installation by our method at three liquefaction-prone sites in Niigata, Japan.

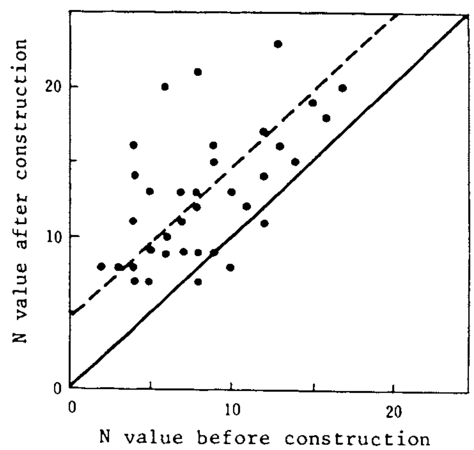

Fig.10 Improved N value in the surrounding soil as a result of gravel drain installation by our method at three field sites in Niigata, Japan.

VERIFICATION TESTS FOR IMPROVEMENT OF COMPACTION EFFECT

The compaction effect from the use of the compaction rod was shown in the previous chapter. However, only the dissipation effect by the high permeability of the gravel drain is considered in the design of gravel drains. If the compaction effect of the surrounding ground from the use of the compaction rod is confirmed quantitatively, we can consider not only the dissipation effect, but also the densification effect of the surrounding ground in designing gravel drains. Therefore, large scale model tests were conducted to quantify the compaction effect from the use of the compaction rod.

Large scale model tests

Fig.11 shows the general view of the test facilities. They consists of a compaction device, a container for the model ground, a frame and so on. The compaction device in the real construction machine was used in the tests. The container, as shown in Fig.11, is made of a stack of 6 rings each 2 meters in diameter. The height of the container is 1.8 meters and the diameter of the casing tube is 40cm. Fig.12 shows grain size accumulation curves of sand and gravel used for the tests. Sand used for the tests is derived from Mt. Sengen in Chiba Prefecture and gravel used for the tests is JIS No.7 size gravel for roads, derived from Tochigi Prefecture.

The test sequence was as follows : ① Setting of a rod and a casing in the container, ② Placing gravel and sand in the casing tube and the container, ③ Driving a gravel drain, and ④ Measuring completed shape of the gravel drain. Fig.13 shows the flow of the test procedures in detail. Note that cone penetration values were measured to examine the soil strength distribution before and after the test.

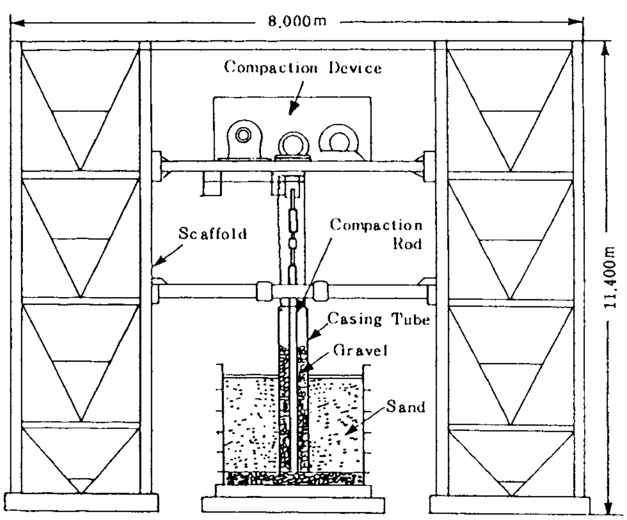

Fig.11 General view of the prototype test facilities.

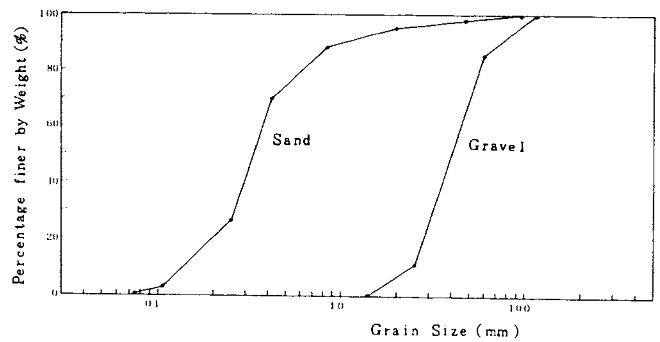

Fig.12 Grain size accumulation curves of gravel and sand for the tests.

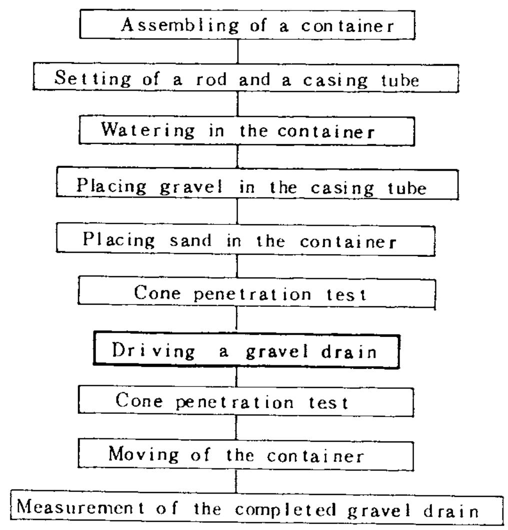

Fig.13 Flow of test procedures.

The factors affecting the improvement of the soil strength are : ① tip shape of compaction rod, ② the number of compaction, ③ the stroke length of compaction, ④ the diameter of compaction rod, ⑤ the position of compaction rod, among others. As a result of the preliminary tests, ① tip shape of compaction rod, ② the number of compaction, and ③ the stroke length of compaction were singled out as the parameters to be examined in detail in the tests, as shown in Table 1. The diameter of compaction rod is 150 mm ; two types of the compaction rod are used in these tests as shown in Fig.14.

Table 1 Conditions on model tests.

	Tip Shape	Number of Compaction(/m)	Stroke Length of Compaction(mm)
A	flat	100	200
B	flat	150	200
C	flat	200	200
D	cone	50	200
E	cone	100	200
F	cone	150	200
G	cone	100	300

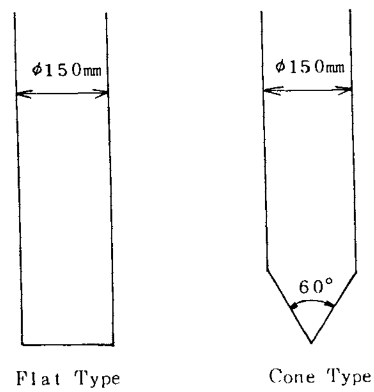

Fig.14 Shapes of the rod head.

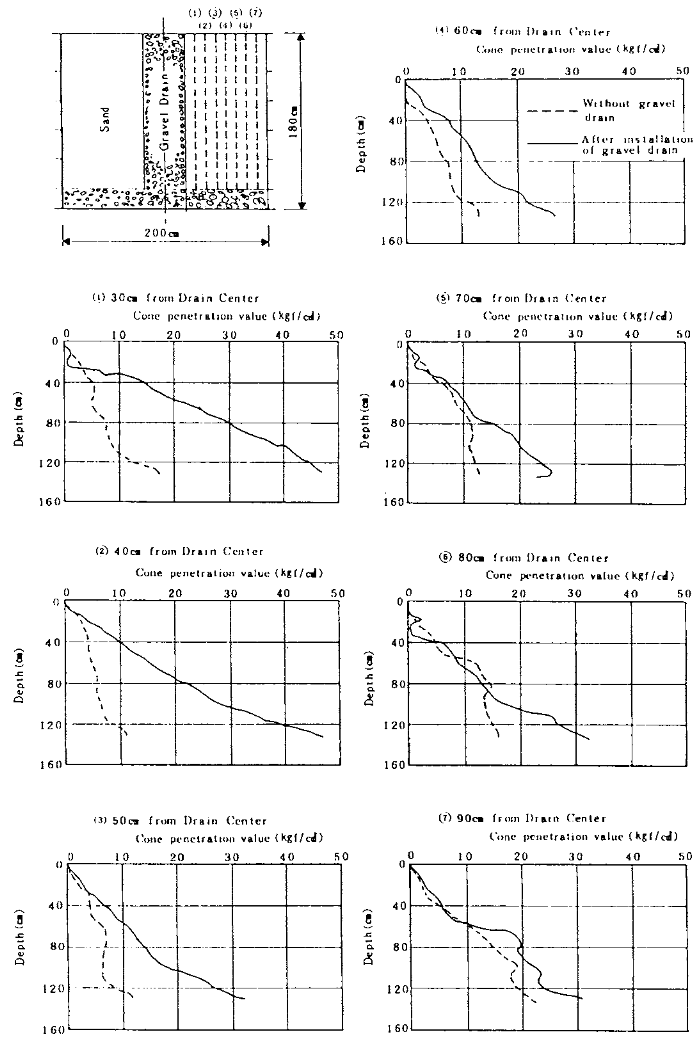

Fig.15 Results of cone penetration values before and after the test.

Results of large scale model tests

Fig.15 shows the cone penetration values before and after the test. As shown in the figure, cone penetration values were measured at intervals of 10cm from the boundary of a gravel drain and soil layers. The cone penetration values before the test are shown by the broken lines, and the values after the test by the solid lines. The separation between the solid line and the broken line is indicative of the improvement by the effect of the compaction rod. As the cone penetration values shown in Fig.15 are continuous, the average value between the depth of 60cm and 120cm is used as the representative value of penetration resistance.

Fig.16 shows the improvement of cone penetration values in the cases where gravel drains were driven with the flat-type compaction rod shown in Fig.14. The penetration resistance increases according to the increase in compaction times and so does the range of the improvement. The range in which the flat-type compaction rod is effective to improve the soil strength is within 70~80cm from the center of the gravel drain.

The results in the cases where the cone-type compaction rod was used are shown in Fig.17. Similar to the results of the flat-type compaction rod, both the penetration resistance and the range of the improved penetration resistance increase according to the increase in compaction times. Comparing the improvement between the case A and the case E in which the number of compaction is 100 times, the improvement in the case E is more than double that in the case A. And the range of improved penetration resistance by the increase of compaction times in the cases of the cone-type rod is also greater than that in the flat-type.

The influence of the stroke length of compaction rod is recognized by comparing the results of

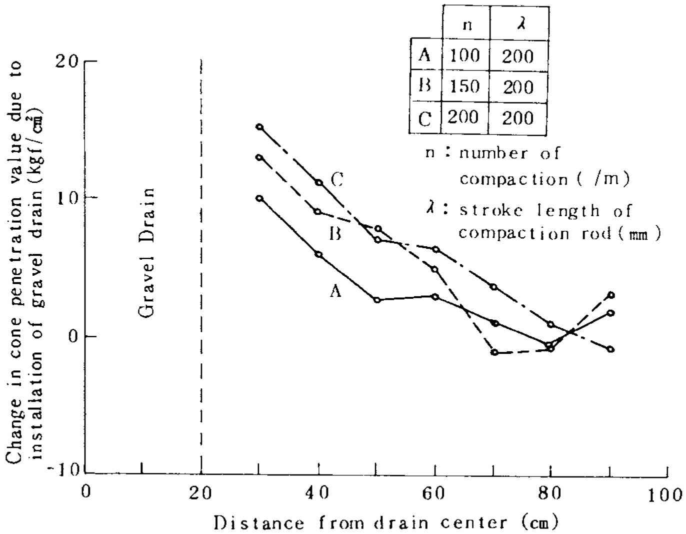

Fig.16 Improvement of soil strength due to installation of a gravel drain with a flat-type rod head.

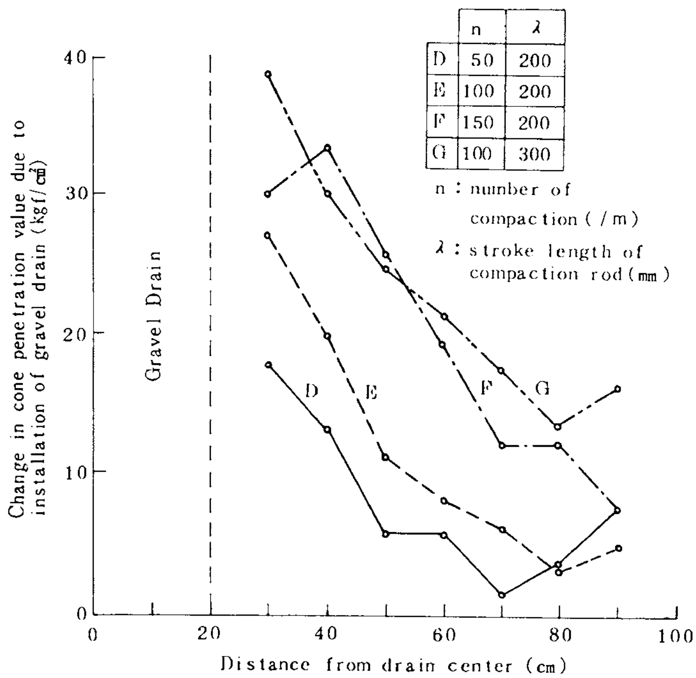

Fig.17 Improvement of soil strength due to installation of a gravel drain with a cone-type rod head.

the case E and the case G. The improvement in the case G in which the stroke length of compaction rod is 300mm is about double that in the case E in which the stroke length of compaction rod is 200mm. And the improvement in the case F in which the number of compaction is 150 times and the stroke length of compaction rod is 200mm is almost the same as the improvement in the case G in which the number of compaction is 100 times and the stroke length of compaction rod is 300mm.

Fig.18 shows the relation between the completed drain diameter and the improvement of cone penetration value. Concerning each compaction rod, the increase in the drain diameter is almost proportional to the improvement in cone penetration value. But comparing between the results of the flat-type and those of the cone-type compaction rod, even for the same completed drain diamater, the improvement of cone penetration value is different. In other words, comparing between the cases B and E which have the same completed drain diameter, the improvement of cone penetration value in the case E (with the cone-type rod) is larger than that in the case B (with the flat-type rod.)

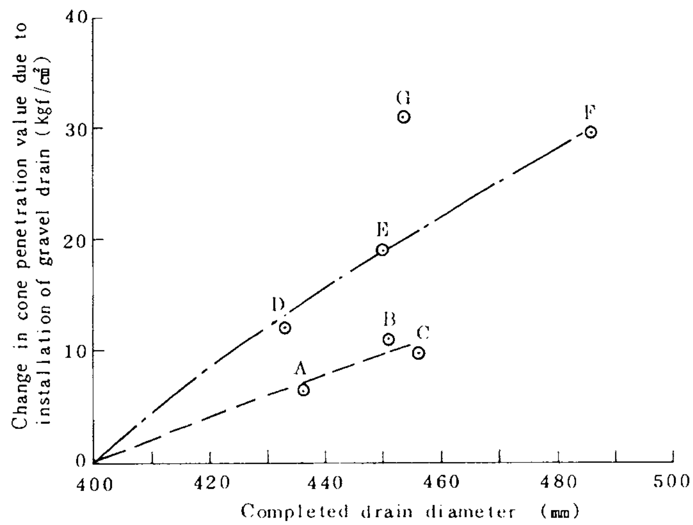

Fig.18 Relation between completed drain diamater and the improvement of cone penetration value.

Fig.19 shows the relation between a parameter representing the cumulative work done by the rod and the improvement of cone penetration value. The integrated value of rod reaction in time domain is used to represent the work done by the rod to the surrounding soil. Comparing the results in the cases A, B and C against those in the cases D , E and F, the improvement of cone penetration value from the cone-type compaction rod is about 3 times larger than from the flat-type compaction rod for the same amount of work done. This result means that the cone-type compaction rod is more efficient than the flat-type compaction rod to improve the strength of the surrounding soil.

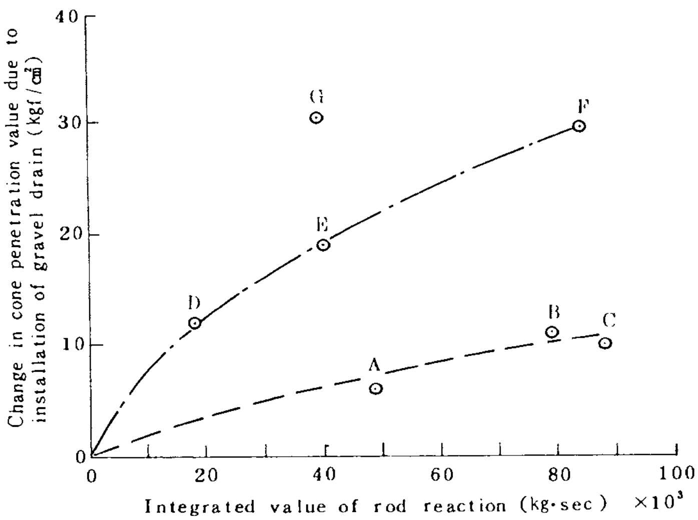

Fig.19 Relation between integrated value of rod reaction and improvement of cone penetration value.

CONCLUSIONS

The following conclusions are warrented :

(1) We have developed an extremely efficient compaction-rod type machine dedicated to construction of gravel drains, with such additional attributes as low level of vibration, low noise, and no disturbance to the surrounding ground.

(2) While the gravel drain system aims primarily to avert liquefaction in sandy soils by quickly dissipating excess pour pressure, the gravel drains constructed by our machine produce not only the dissipation effect but also the compaction effect of the surrounding ground.

(3) Large scale model tests were conducted to study various factors affecting the compaction effect by our machine. The results confirmed that the greater the number of compaction and the stroke length of compaction, the greater the compaction of the surrounding ground. The study also demonstrated that the cone-type rod head is the most effective shape for producing the compaction effect.

ACKNOWLEDGEMENTS

Prof. Ishihara of the University of Tokyo, Japan has provided invaluable guidance throughout the development of construction machine and the performance of verification tests. Dr. Sonu of TEKMARINE, INC, Pasadena, California, has kindly reviewed the manuscript.

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