DAMAGE TO OIL REFINERY PLANTS AND A BUILDING ON COMPACTED GROUND BY THE NIIGATA EARTH- QUAKE AND THEIR RESTORATION

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INTRODUCTION

Two phases of aseismic foundation practice, which can be applied for the loose saturated sandy ground, are as following: first is the pile or other deep foundation reached to fairly stiff layers, and, second is the foundation constructed on improved ground by compaction. These two phases were revealed as effective by the investigation of the damage caused by Niigata earthquake, occurred on 16th in June, 1964.

The author will explain mostly the second phase or a compacted foundation in this report.

Several methods of compacting of a loose sandy ground has been proposed, however, only the vibroflotation method had been performed in the Niigata area. And the method was mostly applied to the improvement of the foundation ground of oil tanks except for one building foundation.

The general damage to oil refinery plant, with special interest upon the tanks with compacted foundation, and the design for rebuilding of damaged plant, the damage to building with compacted foundation and also the method of repairing will be explained.

At the end of this paper, the author will suggest the grain size range which is susceptible to liquefaction.

1. OIL REFINERY PLANTS

In Niigata City, two large oil refinery plants have been established, one belongs to Showa Oil Co. and the other to Nippon Oil Co.. Fig. 1 shows the location of these plants. These two plants were damaged severely by the Niigata earthquake, one of the large crude oil tanks in Showa Oil Co. began to burn immediately after the earthquake, and the damage was so severe that the most part of the plant were burned out completely.

In Nippon Oil Co., there are several new oil tanks founded on the improved ground by vibrofloatation, and they suffered almost no damage by the earthquake. However, so many tanks founded on natural ground suffered severe damage.

1) *Niigata Refinery Plant of Showa Oil Co.*

(a) General feature of damage due to earthquake

i) Heavy Equipments

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Fig. 1. Niigata City

Heavy Equipments were supported by the reinforced concrete piles of 30 cm in dia. and 7 m in length driven to the sand layer having the number of blows in standard penetration tests of about 20. After the earthquake, the maximum settlement was about 50 cm, and tilting of high structures such as chimneys were observed. Fig. 2 shows the damage.

ii) Equipment with Medium Weight

Foundation ground was stabilized by vibroflotation, and was improved to yield the allowable bearing capacity of about 10 t/m^2 . Footing foundation was used on the compacted ground. Though the depth of compaction was only 3 m, and some unequal settlement was observed, the amount of settlement was smaller than that of pile foundation.

Fig. 2. Unequal settlement of heavy equipment founded on pile foundation

Fig. 3. Settlement of tank due to earthquake

iii) Oil Tanks

Large crude oil tanks, including three 30,000 kl tanks (51.5 m in dia. $\times$ 14.5 m in height) and two 45,000 kl tanks (62 m in dia. $\times$ 16.5 m in height) were built on the compacted sand foundation, which was excavated 3 m in depth from the ground surface, then filled in each 30 cm with roller compaction. The void ratio of compacted sand was about 0.7. These tanks caught fire immediately after the earthquake. Settlements of about 20 to 30 cm were observed in these tanks.

Nine storage tanks for products having capacity of 5,000 kl (25.2 m in dia. $\times$ 10.7 m in height) were constructed on a sand mound of about 30 cm high. No compaction was performed to the ground. Considerable unequal settlements were observed and the maximum settlement was about 50 cm as shown in Fig. 3.

Showa Oil Co. had 70 tanks in total at Niigata. These tanks were located in new and old plants and both plants were constructed at very near place. The damage to tanks are listed in table 1.

Table 1. Damage of tanks in Showa Oil Co.

Damage	Number of Tanks
Burned out	40
Heavy	3
Slight	27

Fig. 4. Comparison of the results of penetration tests before and after the earthquake. (Showa Oil Co. Niigata refinery plant)

(b) Ground Conditions

The results of standard penetration tests before and after the earthquake were compared in Fig. 4. Sand deposit from surface to -15 m had coarse gradation and was considered to be the sand of dune origin, and the sand below -15 m had rather fine gradation and was considered to be the sea bed origin.

Upper sand layer of 6 to 8 m in thickness became denser by the earthquake as shown in Fig. 4.

(c) Design Principle of Reconstruction

Reconstruction work for this plant was started in March, 1965. Design principle of this reconstruction was as follows.

Heavy structures such as heavy equipment should be supported by bearing piles. The bearing capacity of piles was obtained by the results of pile loading test, in which the double tubing was used to determine the side friction and point resistance, separately. And the point resistance was considered exclusively for the design of bearing capacity of piles. Steel piles, having diameter of 355 mm and length of 17 m with shoe at the bottom, were used for this purpose. And the design load for each pile was 30 t. The reason why the side friction was disregarded was that it would become very small when the earthquake happened.

Lighter structures (load intensity of less than 4 t/m^2) were supported by stabilized ground with vibroflotation.

Oil tanks were also supported by stabilized ground with vibroflotation. However, for large tanks, the compaction by vibroflotation was limited to the neighbourhood of the periphery of each tank. A zone, between 3.5 m outwards from the side wall and 8.5 m innerwards, was compacted. Depth of compaction was 5 m from the surface, and the spacing of 1.2 to 1.5 m, center to center in triangular pattern, was decided.

2) Refinery Plant of Nippon Oil Co.

Severe damage was also observed in this plant, mostly due to the liquefaction of foundation soil. However, regarding the tanks recently built where the compaction by vibroflotation was applied, they suffered almost no damage as far as the foundation was concerned. So that we will explain, mostly, the effect of compaction in this plant. The damage to oil tanks in this plant is shown in Table 2.

Table 2. Damage to oil tanks in Nippon Oil Co.

Damage	No. of Tanks	Remarks
Settlement over 10 cm	40	Most of the tanks got some troubles such as leakage
Slight	6	
Tilting over	11	
Other Troubles	19	Mostly leakage
No Damage	37	
Total	113	

Typical example, in which the compaction work was effective, was shown by the oil tanks at Ose tank yard. Two 20,000 kl (44.58 m in dia. $\times$ 13.76 m in height) and one 30,000 kl (53.0 m dia. $\times$ 13.76 m height) tanks were constructed on the compacted ground and all of them were cone roof type. This tank yard located a few hundred meter away from the main plant near Nuttari Station. Ground condition of this area is shown in Fig. 5 (a) and (b).

Tanks constructed on compacted ground by vibroflotation had no damage except for one 20,000 kl tank in which about 19,000 kl of crude oil was stored. This tank was settled about 2 to 3 cm uniformly, however, the damage was so slight that it can be used now with no repairing work as far as the foundation is concerned.

Top layer of about 5 m deep was very loose sand containing thin silty layer, and the number of blows in standard penetration test was 1 to 10. Vibroflotation was performed through 5 m loose or soft layer for 20,000 kl tanks and 6 m for 30,000 kl tank. The spacings were 1.5 m center to center for 20,000 kl tank and 1.4 m for 30,000 kl tank in triangular pattern. Vibroflotation was applied not only in the below part of the tank base but also extended to outer 5 m from the side wall of tanks.

The standard penetration test results were shown in Fig. 5 (a) and (b). Since the upper layer of 3 m in thickness contained fine particles, the degree of compaction was not so effective. However, the underlain sand layer was compacted to $N=15$ or more.

One of 20,000 kl tanks showed slight settlement as mentioned above. Oil's level in this tank was about 12 m from the bottom, so that the pressure of about 12 t/m^2

Fig. 5 (a)

Fig. 5 (b)

was applied on the ground.

Four new oil tanks ($4 \times 22,000$ kl) are now under planning to construct at near site of these tanks. Vibroflotation was also applied for these new tanks to compact upper layer of 5 m in thickness with 1.2 m spacing.

2. DAMAGE AND REPAIRING WORKS OF A BUILDING ON COMPACTED GROUND

(a) Damage

Niigata Telecommunications Division Building of Nippon Telegraph & Telephone Public Corporation was constructed on the compacted ground by vibroflotation. The location of this building is a few hundred meters away from Kawagishi-cho Apartment House, and the soil condition of the both sites are very similar.

As Fig. 6 shows, the building has 4 stories and the total floor area of $2,901 \text{ m}^2$. Height of the building is 13.5 m, and the height/width ratio is 0.75. The raft foundation of the building which bears total weight of 3,520 t was founded on the compacted ground by vibroflotation. Intensity of design load on the raft foundation was 10 t/m^2 .

Top 2 m of the ground was very loose sand and soft clayey silt having the N-value of about 0 to 1. Below this clayey silt, loose sand layer of about 10 m thick was deposited and had the N-value of about 7. And N-value increased over 20 at the depth of about 13 to 14 m from the surface.

Compaction of the ground was performed with vibroflotation to the depth of 7 m from the surface. N-value in compacted area increased as shown in Table 3.

Results of three tests to obtain the degree of compaction during construction are shown in Fig. 7 (a), (b) and (c). When the earthquake attacked, the building settled unequally with maximum settlement of about 50 cm, and tilted about one degree. The damage was not so severe when we compared it to that of buildings around this site, for example Apartment Houses in Kawagishi-cho. The damage was represented in Fig. 8. The inclination of this building was about $1/40$ to $1/50$ in crosswise direction, and about $1/300$ to $1/400$ in longitudinal direction. No differential settlement was observed. And cracks observed in this inspection was considered to be caused not by earthquake but by shrinkage of concrete, except for the cracks at the side wall of chimney. Then,

**Table 3. Comparison of standard penetration tests
before and after compaction
(Niigata Telecommunications Division Building)**

Depth	N-value before compaction	N-value after compaction	Remarks
1 m	0	7-8	silty
2 m	0-1	6-13	
3 m	7	13-24	
4 m	7	14-21	
5 m	5-10	15-22	
6 m	7	17-22	
7 m	7	14-23	

it can be concluded that the building was displaced as a rigid body and all the damage might have been caused by the settlement of the ground.

After the earthquake, exploration work for ground was performed. The results of exploration work are shown in Figs. 9 and 10 (a), (b), (c). As these results show, the compacted ground near the edge of building was loosened by the earthquake. On the other hand, the tests performed at the middle part of the building showed rather compacted state. This would be due to the stress condition on the ground surface, since it must be constrained by the building load at the middle part.

(b) Planning for Repairing Works

So many plans for repairing work had been discussed. Finally, the following plan was decided and the repairing work has been started at the site, and preliminary excavation and plate loading test is now performing. The outlines of the plan of repairing work are the following, though some minor change of the plan will be made according to these test results and some other reasons.

First step of the repairing work is to jack up the building to make it level. For this purpose, one or two steel piles will push in about 13 m deep under each column. The depth of pile penetration will be determined by the force to push in successfully and the transmitted load by a column. Diameter of steel pile will be 406 mm or

Fig. 7 (a). Comparison of the results by plate loading tests before and after compaction.

Fig. 7 (b). Results of dynamic cone penetration tests*

Fig. 7 (c). Results of Swedish sounding tests

Fig. 8. Horizontal and vertical displacement (mm)

318 mm. Every one meter of pile will be welded at the top of penetrated pile and pushed in by several oil jacks.

When the necessary force to push in reaches over the load of column, the underpinning work will be stopped. When all piles are set, oil jacks will be used for leveling work. Pressures in oil jacks will be so applied as to raise the floor of building to level position. Then temporary support for each column will be made.

Second step is to transfer the load to new raft foundation which will be constructed below an old raft foundation. Since oil jacks should be operated under each column, new raft foundation will not be placed below each column. When the construction of new raft foundation finishes, temporary support below each column and jacks will be taken out. And new raft foundation under each column will be constructed at that

Fig. 9. Location of tests performed before and after the earthquake

part. As a new foundation is a raft type, the piles used for leveling work will only support a part of load. Cost of this repairing work is estimated about ¥32,000,000.

3. GRAIN SIZE RANGE OF SAND SUSCEPTIBLE TO LIQUEFACTION

Usually, the quicksand condition is introduced by considering the balance of weight of sand mass and hydrostatic pressure. However, in a cohesive soil, above condition can not be applied. This will be due to the cohesion of soil particles by which the soil particles can resist for separation, or the resisting force is the weight of soil mass plus cohesion. In case of sand particles, the cohesion is very small so that the resisting force is only the weight. Then, we can conclude the quicksand condition as following. First, the pore water pressure should be larger than the total weight of soil, and second, the particles can separate easily by pore pressure.

In case of Niigata earthquake, actual damage was limited to saturated sand, then, we can assume roughly that the condition of liquefaction was same to normal quicksand condition. Then the above mentioned two conditions, that is, the pore pressure increase and the particle separation might be occurred.

Particle size of soils which is susceptible to liquefaction may be expected. The first condition, which is the sudden pore pressure increase, may not happen on gravelly soils. Since the size of pore in gravelly soil is very large and the weight of each particle is too heavy to be lifted up by seepage force. The second condition, which is no cohesion, may not be satisfied by clayey or silty soils. They usually show the cohesive characteristics. So that the sand may be the soil which is exclusively susceptible to liquefaction due to earthquake. This coincides with the actual ex-

perience of earthquake damage. However, in clayey or silty soils, other kind of foundation damage due to earthquake may also be considered. Since the pore pressure within these soil can be increased and apparent strength may be decreased.

If we can obtain the grain size distribution ranges susceptible to liquefaction, it will be very useful for the design of foundation. Since vibroflotation makes sandy ground partially liquefied condition by vibration, and it is effective only for sandy ground. These tendencies can be considered as similar to liquefaction by earthquake. So that we made the suggestion of grain size range from the experience* of effectiveness of vibroflotation concerning to the grain size as a working hypothesis.

Fig. 11 shows the suggested grain size distribution susceptible to the liquefaction by an earthquake.

Susceptible range, in Fig. 11, was obtained from the experience of vibroflotation, wherein the process was effective. And the most susceptible range B should exist

Fig. 10(a) Results of standard penetration tests on natural ground. No. 1 and No. 2: Location of boring before the earthquake.

Fig. 10(b) Results of standard penetration tests (not compacted area). No. B-A and No. B-A': Location of boring after the earthquake.

* WATANABE, Takashi, "Compaction of Sandy Ground by Vibration—Vibroflotation and Related Problems—", 2nd Asian Regional Conference, May, 1963, Tokyo.

Fig. 10 (c) Results of standard penetration tests (compacted area). No. B-B, No. B-C, No. B-B', No. B-C' and No. T-1: Location of boring after the earthquake.

Fig. 11. Susceptible grain size range to liquefaction

between lower end of most effective range of vibroflotation and upper end of the limit of grain size of added materials at which the large materials than this limit could not be flown up to the ground surface in the process.

In Fig. 11, the boring results were also shown on Niigata City area. One was referred from Dr. Kishida's data who collected data on building foundation. The other was the data of borings performed by some government agencies after the earthquake. And they showed good agreement with author's hypothesis, except for zone C.

We cannot discuss the liquefaction of sand only by the particle size. Another important point will be the relative density or the critical void ratio. Since the pore pressure increase due to strain can be considered in the sand of looser state from critical void ratio. However, the critical void ratio of a sand may have the range depending on the stress conditions. Some Japanese engineers suggest the relationship between critical relative density and the depth of overburden by comparing boring data in Niigata before and after the earthquake. However, if critical void ratio depended on the intensity of vibration, we will need further research to decide such relation.

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