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DYNAMIC COMPACTION IN ASSALOUYEH, IRAN

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ABSTRACT

Dynamic compaction used as a soil improvement method for treatment of filled material in sea in Assalouyeh, Iran. Land reclamation by filling soil performed up to depth 14m and dynamic compaction used for reduction of liquefaction potential and the settlements due to static loadings. The compaction pattern and the other parameters like applied energy, compaction phases and rest periods designed in term of the characteristics of the soil to be treated and filling material deep. Final compaction pattern revised according to the results of the compaction on trial areas. Extensive trial compactions performed to optimize the compaction process with respect to the required energy for achieving specified densification criterion.

Dynamic compaction carried out in two and three passes. Using 16 patterns (combination of weight of pounder, falling height and the arrangement of the impact points) the 90 hectares area improved in 12 months. For testing of efficiency of dynamic compaction geotechnical site investigation tests performed before and after compaction. The desired tests were measurement of induced settlement, boring and Standard Penetration test, Plate load test and Field density test. The results of tests showed that the dynamic compaction was useful to increase bearing capacity up to 3 kg/cm^2 for shallow foundations and reduced mostly liquefaction potential.

INTRODUCTION

Pars energy economy specific area is located in Assalouyeh, the south of Iran and north side of Persian Gulf (Fig. 1). As the necessity of neighboring different petrochemical sites and the lack of the sufficient flat areas, land reclamation by filling soil performed up to depth 14m in an area about 300×3000m.

Regarding to high earthquake hazard in region and heavy loading due to petrochemical installations, improvement of weak filled material for reduction of liquefaction potential and settlement of footings carried out. Dynamic compaction technique was selected for treatment of filling material based on material type and geological condition.

Dynamic compaction has become a popular method worldwide for deep improvement of loose soils in last decades. The method involves the repeated application of high-energy impacts on the soil surface using tampers weighing 10-40 tones, falling from heights of 10-30m, compacting the soil strata to a considerable depth.

This paper describes the characteristic of geological site, geotechnical aspects of materials and dynamic compaction project in Assalouyeh. Moreover, the performance and efficiency of dynamic compaction for treatment of filled material is discussed.

Fig. 1. Location of project site

GEOLOGY OF SITE

Seabed dip in Assalouyeh coast is around 4% and for arriving to an area width 300m is required to be filled up to 12m depth under sea water level and about 2m above that. Ground profile under seabed consisted of up to 1m loose sandy gravel, 0.3m conglomerate and the rest layers include dense sandy gravel to gravelly sand with some cementation. This coast is located near to folded mountains in north. Existence of some faults around site and earthquake history of region is showed that the earthquake hazard is serious. Based on earthquake hazard analysis, design base earthquake magnitude is 7.2 and peak ground acceleration is 0.3g.

FILLING PROCEDURER AND LAND RECLAMATION

For preventing of erosion of filled material in sea, at first some basins with dimensions of 300×300m was made and followed by filling. In Figures 2 and 3 are showed some views of basin construction and filling operation. Some parallel and perpendicular jetties were made these basins.

Fig. 2. A view of basin construction

Fig. 3. A view of material filling in a basin

FILLING MATERIAL

Filling material consisted of alluvium deposits, which include sandy gravel with some cobbles and boulders. According to the Unified Classification System, filled soil can be classified as GW, GP and GM. Grain size distribution curves of filled material is shown in Fig. 4. There are about 15-20% fine materials, which mostly consist of non-plastic particles (silt). Coarse particles of soil often consisted of limestone.

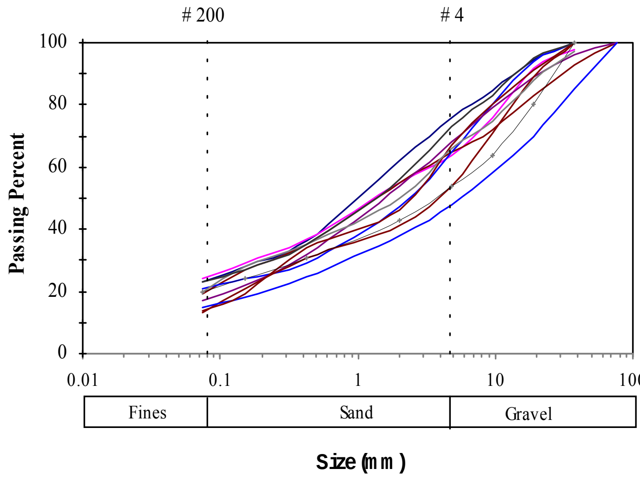

Fig. 4. Grain size distribution curve of filling materials

DYNAMIC COMPACTION PERFORMANCE

Dynamic compaction improves weak soils by controlled high energy tamping. The reaction of soils during dynamic compaction treatment varies with soil type and energy input. A comprehensive understanding of oil behavior, combined with experience of the technique, is vital to successful treatment of the ground.

In Assalouyeh project, various combinations of weight and drop height were evaluated. Desired area for treatment was divided to four zones as 2-5, 5-8, 8-11 and 11-14m according to filling material depth. In each zone some trial areas selected to perform dynamic compaction in order to get optimum pattern.

Figures 5 and 6 show some views of dynamic compaction operation in Assalouyeh. As it can be seen, a crater is formed at the impact point that may be up to 2m deep. The craters are backfilled by enddumping rockfill into the craters. Several phases or passes of tamping performed across the site, depending upon the level of improvement required. Following completion of the "high-energy" tamping, a low-energy or "ironing" phase is performed to compact the material in the craters and in the upper 2 m of the reclaimed lands. The ironing phase consists of dropping the weight 10 and 18 tones from a height of 5 to 15m as side by side.

According to the results of trial areas, 16 different patterns were selected and used as showed in the Table 1.

Fig. 5. A view of dynamic compaction in Assalouyeh

Fig. 6. Craters induced up to 2m formed at the impact points

Table 1. Used patterns in Assalouyeh site

Pattern	Main tamping						Ironing (With square pounder)		
	Grid spacing (m)	Pounder weight (ton)	Pounder dimension (m)	Fall height (m)	Impacts Phase 1	Impacts Phase 2	Pounder weight (ton)	Fall height (m)	Pounder dimension (m)
P1	3.5	15	1.95	11	5	3	10	5	2
P2	3.5	15	1.95	11	7	5	10	5	2
P3	3.5	15	2.15	11	9	7	10	5	2
P4	4	18	2.15	15	8	6	10	7	2
P5	4	18	2.15	15	10	8	10	7	2
P6	4	18	2.80	15	12	10	10	7	2
P7	5	25	2.80	20	9	7	10	10	2
P8	5	25	2.80	20	11	9	10	10	2
P9	5	25	3.25	20	13	11	10	10	2
P10	6	35	3.25	24	9	7	10	10	2
P11	6	35	3.25	24	11	9	10	10	2
P12	6	35	3.25	24	13	11	10	10	2
P13	7	30	3.25	28	8+6 *	8+6 *	18	15	2
P14	9	30	3.25	28	9+7 *	9+7 *	18	15	2
P15	11	30	3.25	28	9+9 *	9+9 *	18	15	2
P16	12	35	1.95	24	10+10 *	10+10 *	18	15	2

* Impacts number during two passes

Tamping performed in two passes in the patterns P13 to P16 that were used in the deep areas. Rest period was around 4 to 5 days between two passes to dissipate probably excess pore water pressure induced during first pass of tamping.

TESTNG

Many contracts have simply involved the measurement of depth of primary impacts and monitoring of site levels. In situ and loading tests are often performed and since the technique provides treatment to large areas very quickly, the speed at which such tests provide the necessary information is important, particularly if testing has been done between tamping passes. It is rare, therefore to recover samples for laboratory testing. For evaluating of efficiency of dynamic compaction some tests performed before and after compaction. The used tests were boring and Standard Penetration test (SPT), Plate load tests and Field density tests. Moreover, crater depth in term of impact number and induced settlements were measured in trial areas.

Figure 7, for example, shows that some crater depth- impact number curves in area with around 8m filling deep. The rate of bed settlement of crater reduces with increasing of impact numbers. Induced settlement (the average reduction in general site level as result of treatment) varies with filling material thickness and it measured around 10% of them.

Plate loading tests carried out with a circular plate 0.45m before and after treatment The results of plate loading tests show that the bearing capacity for shallow foundations increase up to 3 kg/cm^2 and deformation modulus reach to more than 500 kg/cm^2, meanwhile that was about 100 kg/cm^2 before treatment. In Fig. 8, for example, is shown some results of plate load tests. It shows that the settlement value due to loading reduce with increasing of induced energy.

Standard Penetration Test is a most useful in-situ test for assessment of density and liquefaction potential of a soil layer. Based on site seismicity studies, a liquefaction criterion was defined for DBE earthquake as shown in Fig. 9.

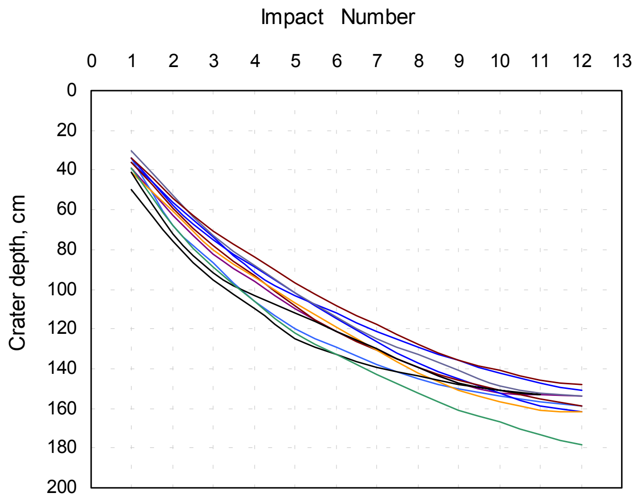

Fig. 7. Crater depth in term of impact number in area with about 8m filling deep

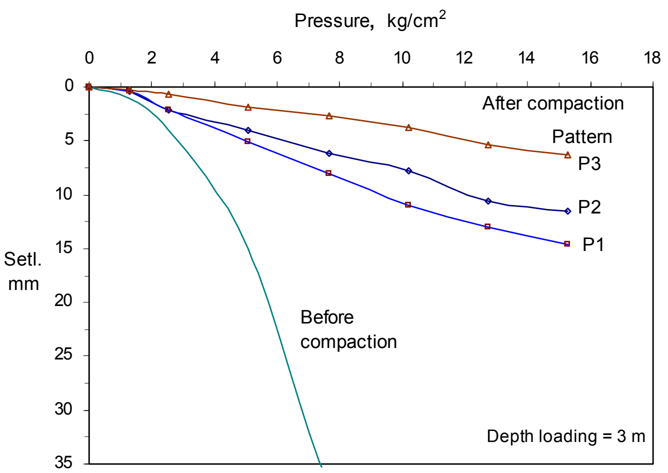

Fig. 8. Pressure-settlement curves of plate load test before and after treatment by various patterns

One of the important approach in treatment of filling material was getting to SPT values (N) that liquefaction hazard remove. In Fig. 9, for example, is showed SPT values before and after treatment.

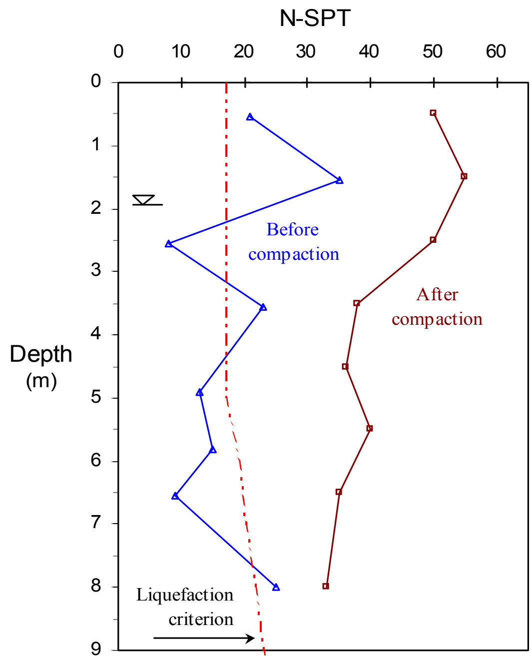

Fig. 9. Effect of treatment and reduce of liquefaction potential

Field density test was another useful test that carried out for testing of treatment. This test performed in two type, sand replacement and water replacement methods. Sand replacement type conducted on holes with dimensions 15cm diameter and 20cm deep. For water replacement method, a hole with dimensions of 100cm diameter and 100cm deep excavated and the volume of the hole is measured by filling it with water from a special calibrated cylinder (Fig. 10). Water replacement method was better than sand replacement method due to existence of some cobbles and boulders in materials.

Dry density of soils was around 1.6-1.7 gr/cm^3 before dynamic compaction and increased to about 1.9-2.1 gr/cm^3 due to dynamic compaction.

EFFECTIVE DEPTH OF INFLUENCE

Menard & Broise(1975) originally proposed that the effective depth for treatment was related to the applied energy input expression of

$$D = n\sqrt{WH} \qquad (1)$$

where W is the weight in tones, H the drop height in meters and the factor n should be determined for each site, but varies between 0.3 – 0.7. This factor was modified around 0.5 by Leonards *et al.* (1980) for relatively coarse, predominantly

Fig. 10. Some views of large in-site density test

granular soils, and factors of 0.375 to 0.7 by Mitchell and Katti(1981) for two soil types. Slocome(1993) proposed that the range of treatment depths varies with initial density, soil type and applied energy. There are many factors affecting this dimension, not least of which are the type and competence of the surface layers, position of the water table and numbers of drops at each location. Assessment of in-situ results to determine such depths also tends to be subjective and will be affected by the recovery period after treatment. Weak surface soils and a high water table can also limit the physical performance of a sufficient number of stress impulses to induce only a minor improvement to the basal layers.

In Assalouyeh site the factor *n* was determined 0.35 for areas with filling material thickness more than 8m and 0.40 for areas with thickness lower than that.

Luongo (1994) proposed the following relationship for estimating of the effective depth for treatment:

$$D = K_1 + K_2 (W.H) \qquad (2)$$

where K_1 is depth factor and K_2 is energy factor. These factors were determined 1.4 and 0.021 respectively in Assalouyeh site.

Appearance of loose silty layers between filling materials was caused to reduce effective depth of influence. These layers were formed in some area due to segregation of particles during filling process in basins. Low permeability of silty layers were caused that excess pore water pressure could not dissipate quickly so induced energy damped. Patterns with two tamping passes were used in these areas.

CONCLUSIONS

The results of tests showed that the dynamic compaction is useful technique for reaching to desired bearing capacity and liquefaction criterion in Assalouyeh site.

Performance of trial area tamping and determining of optimized pattern is vital to successful improvement of the ground.

The factor *n* of Menard and Broise(1975) expression was determined 0.35 for zones with filling material deep more than 8m and 0.40 for zones with deep lower than that in Assalouyeh site.

Appearance of loose silty layers between filling materials was caused to reduce effective depth of influence. In such areas using of two or three tamping passes was suit.

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