Application of Engineering Geology in Land Reclamation Project from Persian Gulf

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Summary

Land reclamation from Persian Gulf was considered in Assalouyeh region in south west of Iran due to land paucity for construction of petrochemical structures. Engineering geological studies in this project were divided into two phases. In first phase study of sea floor and available filling materials was performed before reclamation. In second phase study of suitability of reclaimed land for construction purposes before improvement and after improvement was carried out. In situ tests showed that reclaimed land is susceptible to liquefaction hazard and settlement potential. Dynamic compaction was selected for improvement of reclaimed land. Corrected standard penetration test (SPT) numbers after compaction in all of depths increased to more than 30 for which factor of safety against liquefaction increased to more than one. Engineering geological studies showed that after dynamic compaction liquefaction potential hazard has been mitigated and bearing capacity has increased.

Introduction

Land reclamation from sea is performed in projects located in coastal regions where development of infrastructures due to land paucity is restricted. Assaloyeh region in south west of Iran was considered for construction of petrochemical complexes in development of southern Pars gas resources. Due to limited land for construction of structures, reclamation of land by filling the Persian Gulf in the region was considered as a solution for the problem. Characteristics of geological structures, formations and sediments of Assalouyeh region are under control of Zagros mountain range from one end and recent sedimentary basin of Persian Gulf in other end. Engineering geological studies in this project were carried out in two phases.

Engineering geological studies in first phase

In site investigation in first phase of engineering geological studies several drill holes with depth of 20 to 30 meter were drilled on shore and off shore of the region to recognize sea floor layers (Figure 1). Standard penetration test (SPT) test with conical tip was applied in different depths to evaluate in situ properties of materials. Particle size analysis and specific weight measurement tests were performed on core samples. Tests results show that sediments are silty sandy gravel with dry density of 1.95-2.1 gr/cm^3. The SPT numbers for penetration of 30 cm of conical tip in to sea floor in different depth were more than 50 blows. From these data, sea floor materials were categorized in high to very high compacted materials group. Study of filling materials was important because it was necessary to understand the engineering geological properties of them to achieve best method of improvement like compaction. In primary studies two types of materials for filling the sea were investigated. First type which included alluvial materials located in higher parts of region was selected compared to exploitation of rock fragments from Zagros Mountains as a second type. Particle size analysis on alluvial materials showed that they are sandy gravel type with 15 percent or less silt and between 40 to 80 percent gravel. Less fine grains and more coarse grains is better suited for dissipation of ground water pressure due to compaction. Compaction tests were conducted on some samples (Table 1).

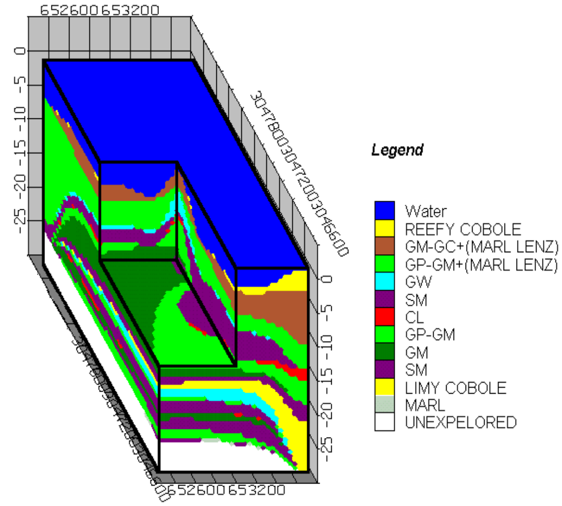

Figure 1) 3D model of sea floor layers in studied area in Assalouyeh region constructed in Rock Work software (Sheshpari 2003).

Table1) Results of compaction tests on alluvial materials in Assalouyeh region.

Sample	γ dmax (gr / cm^3)	W_{opt} (%)	Method
1	2.21	6.5	ASTM 1557
2	2.23	4.9	ASTM 1557
3	2.21	7.1	ASTM 698-C
4	2.22	6.5	ASTM 698-C
5	2.16	8.1	ASTM 698-C
6	2.21	7.2	ASTM 698-C

Engineering geological studies in second phase

With considering filling method, deploying alluvial materials in sea water, filling materials were accumulated in loose conditions in and above sea water. Also grading of filling materials contained fine grain materials like silt particles. This condition would result in low bearing capacity and settlement in static state loading and liquefaction potential in dynamic loading by earthquake. Engineering geological studies in second phase was necessary to determine applicability of reclaimed land for construction of structures. To evaluate liquefaction potential SPT test conducted at different depths in boreholes drilled in reclaimed land. The Simplified procedure proposed in two workshops (Youd, et al., 2001) was used to determine factor of safety against liquefaction potential. In this procedure cyclic stress ratio (CSR) from earthquakes is computed from equation (1) proposed by Seed and Idriss (1971).

$$CSR = \left(\frac{\tau_{av}}{\sigma_0}\right) = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_v}{\sigma'_v}\right).r_d \qquad (1)$$

In which: τ_{av} = Average shear stress CSR=Cyclic stress ratio

σ_0 = total overburden pressure

a_{max}=Maximum acceleration from earthquake on ground surface

g: Acceleration of Gravity

σv=Total vertical stress

σ' v =Effective vertical stress

Z= Depth from ground surface (m)

r_d =Stress reduction ratio related to depth can be computed from equations (2) and (3) proposed by Liao and Whitman (1986).

r_d =1- 0.00765 z for Z ≤ 9.15 (2)

r_d =1.174 - 0.0267z for 9.15< Z ≤ 23 (3)

Soil resistance against liquefaction (Cyclic resistance ratio (CRR)) is calculated from equation (4) cited by Youd, et al. (2001) from personal communication with Rauch (1998).

$$CRR_{7.5} = \frac{1}{34 - N^*} + \frac{N^*}{135} + \frac{50}{[10.N^* + 45]^2} - \frac{1}{200} \quad (4)$$

CRR $_{7.5}$=Cyclic resistance ratio for earthquake with Magnitude 7.5 Richter.

N*=Corrected SPT number. Correction is possible by equation (5).

$$N60_{cs} = \alpha + \beta(N60) \quad (5)$$

(N)60cs = equivalent clean sand value of (N)60

(N)60= the SPT blow count corrected to an effective overburden pressure of 100 kPa (1 tsf) and to a hammer energy efficiency of 60% for earthquake magnitude of 7.5.

Seed and Idriss (1971) suggested following coefficient ratios for fine content (FC) corrections.

For FC ≤ 5 %	α=0
For 5 %< FC< 35 %	α=exp (1.76-(190/FC^2))
For FC ≥ 35 %	α=5
For FC ≤ 5 %	β=1
For 5 %< FC< 35 %	β= 0.99+ ($FC^{1.5}$/1000)
For FC ≥ 35 %	β=1.2

CRR equation is valid for N*< 30. Soil has enough density and compaction not to become liquefied for N* larger than 30.

At final step of this procedure factor of safety (Fs) for liquefaction potential is calculated from equation (6).

$$Fs = CRR/CSR \quad (6)$$

For Fs< 1 occurrence of liquefaction is highly probable. Figure (2) shows results of Fs calculated for the some zones of reclaimed land in Assalouyeh region. As can be seen liquefaction potential is highly probable in reclaimed land. Bearing capacity for reclaimed land obtained from plate load test. It was evident that the bearing capacity for sustaining applied load from big structures in petrochemical complexes is not enough. For improvement of engineering geological properties, mitigation of liquefaction potential hazard and increasing the bearing capacity of reclaimed land, dynamic compaction by falling heavy weights was applied. Corrected SPT numbers for improved reclaimed land increased to more than 30 for which safety factors in all of depths increased to more than 1.It can be inferred that after dynamic compaction liquefaction potential hazard has been mitigated and bearing capacity has increased.

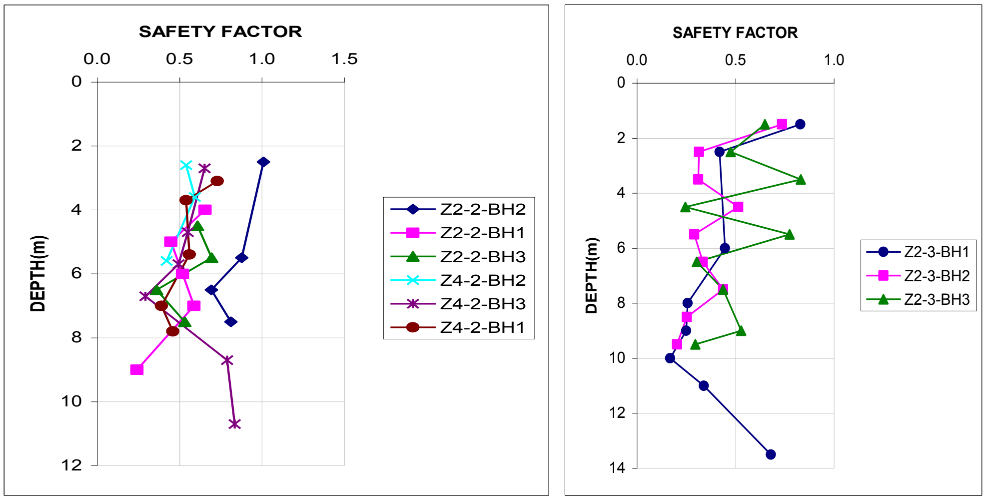

Figure 2) Factor of safety against liquefaction hazard in some zones before improvement

Conclusions

Land reclamation from sea is being done in many countries to provide required land for construction of infrastructures. Engineering geological studies is necessary for site investigation before reclamation and during improvement of reclaimed land. Engineering geological studies in two phases were carried out for land reclamation project in Assalouyeh region. In first phase different reconnaissance tests on sea floor and on available filling materials were performed to evaluate site conditions for filling the sea and reclamation. In first step of second phase engineering geological characteristics of reclaimed land were evaluated to understand usability of land for construction of infrastructures. In situ test results in this step showed that reclaimed land in Assalouyeh region is susceptible to liquefaction hazard and settlement potential. Improvement of reclaimed land was necessary due to results of this step. Dynamic compaction was selected for improvement of reclaimed land from sea. Second step of studies focused on improvement of reclaimed land to control effectiveness of dynamic compaction. Results of in-situ tests in reclaimed land showed that liquefaction hazard potential has been mitigated and bearing capacity of ground has achieved to desirable level after dynamic compaction.

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