Effect of Earthquakes over Time on the Geogrid-Pile Foundation System in Loose Sand

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Abstract: Researchers and engineers have developed several means to enhance the dynamic lateral stability of civil engineering structures, such as geosynthetic reinforced earth retaining structures to resist excessive earthquake shaking. There is, however, as yet little information about using geogrids with pile foundations under earthquake loadings. This study thus linked a single embedded pile in loose sandy soil with a geogrid, with the system then subjected to two different seismic waves. The laboratory tests were carried out on single pile with a length to diameter ratio of 25 in poorly graded soil (SP) with a relative density of 30%. The geogrid used in the research was Nelton CE121 geogrid (700×700 mm), which was connected with the pile at a depth of 1/8 of the pile length. The model was then subjected to replications of both the Ali Al Gharbi and Halabjah earthquakes, which hit Iraq in 2014 and 2017, respectively.

It was found that using geogrid with pile foundation reduced the settlement in the pile by about 50% and 90% for the Halabjah and Ali Al Gharbi earthquake forces, respectively. The maximum bending moment was also reduced, with the bending moment ratio at the pile surface for the Halabjah and Ali Al Gharbi earthquakes being 70% and 50% respectively. The settlement ratio increases as magnitude of earthquake decreases.

Key wards: bending moment, displacements, earthquake, geogrid, loose sand, pile.

1. Introduction

Studying the effect of earthquakes on the behaviour of piles requires the construction of a model that simulates reality to study the causes of failure and other influences that effect such foundations (Al-Recaby [2], Al-Tameemi [4], Al-Sammaraey [3] and Salem [11]). To minimise such risks, it is important to stabilise the soil using reinforcing, which works to strengthen resistant properties and thus positively affects the foundation (Fakhraldin [9] and Taha [12]). Some researchers have thus studied the effects of adding geogrid to piles in soft soils under dynamic influences (Taha [12] and Zanzinger et al. [13]), but there is little information about such systems in sandy soil under...
real earthquake behaviours. This research thus aimed to study the behaviour of geogrid-pile foundation systems under real earthquake modelling in sandy soils.

2. Materials and Modelling

2.1 Sand

The soil used in this study was classified as poorly graded sand (SP), as shown in figure 1; the physical and chemical properties are listed in Table 1, being tested according to ASTM and BS specifications respectively.

![Particle size distribution](image)

**Figure 1.** Particle size distribution

| Soil Property                  | Loose Sand | Reference   |
|-------------------------------|------------|-------------|
| Max. Unit Weight, $\gamma_{\text{max}}$ (kN/m$^3$) | 17.77      | ASTM-D4253  |
| Min. Unit Weight, $\gamma_{\text{min}}$ (kN/m$^3$) | 13.962     | ASTM-D4254  |
| Dry Unit Weight, $\gamma_d$ (kN/m$^3$)         | 15.25      | -           |
| Total Unit Weight, $\gamma_t$ (kN/m$^3$)        | 17.16      | -           |
| Specific Gravity, $G_s$         | 2.60       | ASTM-D854   |
| Max. Void Ratio, $e_{\text{max}}$             | 0.827      | -           |
| Min. Void Ratio, $e_{\text{min}}$             | 0.434      | -           |
| Effective Size, $D_{10}$ (mm)       | 0.18       | ASTM-D422   |
| Mean Size, $D_{30}$ (mm)           | 0.30       | -           |
| Mean Size, $D_{60}$ (mm)           | 0.7        | -           |
| Friction Angle, $\varnothing$      | 33°        | ASTM-D4767  |
| SO$_3$, %                        | 2.6        | BS-1377     |
| Gypsum content, %                | 5.59       |             |
| T.S.S.%,                         | 0.74       |             |

2.2 Pile and steel box

The pile investigated was made from aluminium, with a diameter of 16 mm and a thickness of 1.4 mm, offering an L/d ratio of 25. The elastic modulus was 67 GPa. A uni-measure displacement transducer type JX-P A-50-N11-21S-31N was mounted at the pile head to measure settlement. Three strain gauges were mounted on the surface of the pile to measure the bending moment of the pile: the first was located on the head of embedded pile, the second at the mid length, while the
third was at the pile toe. The pile was placed in the centre of the steel tank where the concentrated load is 0.0365 KN (Hansen [10]). The steel box was made in the form of a parallelogram 800 mm high with base dimensions 700×700 mm, which was set up on a shaking table device as manufactured by Al-Sammaray [3] and Al-Tameemi [4]. Figure 2 shows the pile and steel box arrangement.

![Steel box, Pile and Displacement transducer](image)

**Figure 2.** (a) Steel box, (b) Pile and (c) Displacement transducer

### 2.3 Geogrid

Nelton CE121 geogrid, as tested by Fakhraldin [9] and Al-Essawi [1] was used, with dimensions 700×700 mm; this was connected with the pile using a special ring manufactured from Teflon, as shown in figure 3.
2.4 The Raining Technique

A raining technique was used in this study to generate 30% relative density. The raining box was made from steel, with dimensions 600×400×250 mm (length, width and height). It had eight mechanical gates located at its base with dimensions of 600 mm length, 50 mm width and 3 mm thickness, connected to a pivot arm that controlled opening and closing. The gates were opened once in order to drop sand into the steel box, then the sand surface was adjusted to level. The raining box was hung from the ceiling by roller (2 tons) as shown in figure 4. Several trials with different heights of fall were completed to develop the desired relative density. Figure 5 shows that the relative density (Dr) is a function of the height of fall; in order to obtain the desired 30% relative density, the height of the free fall was required to be 20 cm.
Figure 4. The raining technique (a) Sand falling, (b) Gates (c) Levelling the sand surface and (d) Using goblets to calculate density

Figure 5. Calibration of sand density
2.5 Earthquake Data

The earthquakes data used in the research is based on earthquakes in Halabjah in Sulaymaniyah city and Ali Al-Gharbi in Missan city as recorded by the Iraqi Meteorological Organization and Seismology. Table 2 presents the information for these earthquakes and Figure 6 illustrates the relationship between acceleration and time for both earthquakes.

Table 2 Halabjah and Ali AL Gharbi earthquakes data

| Earthquake | Halabjah | Ali Al-Gharbi |
|------------|----------|--------------|
| Region     | Iraq – Iran border | Iraq |
| Data (UTC*) | 12/11/2017 18:18:17 | 25/09/2015 06:10:24 |
| Magnitude, (Mw) | 7.3 Mw | 4.9 Ml |
| Modified Mercalli Intensity, (MMI) | VIII- Moderated heavy | N/A |
| Epicentre depth, (Km) | 19 | 10 |
| Shake Duration, (sec) | 300 | 160 |
| Station distance to epicentre, (Km) | 218.8 | 106.9 |
| Sampling Frequency,(Hz) | 10 | 10 |
| Acceleration direction | E-W | N-S |
| Maximum acceleration, (g) | 0.1 | 0.1 |
| Station code | BHD | IBDR |
| Reference | Iraqi Meteorological Organization and Seismology | Iraqi Meteorological Organization and Seismology |
3. Results

Figure 7 and Figure 9 illustrate the pile settlement over time in loose sand for the equivalents of the Halabjah and Ali Al Gharbi earthquakes without geogrid and with Nelton 700×700 mm geogrid at a depth of L/8. The pile settlement occurring during the simulated Halabjah earthquake was greater than the pile settlement under the simulated Ali Al Gharbi earthquake due to higher dynamic loading, as settlement is a function of loading. The settlement ratio of the Halabjah and Ali Al Gharbi earthquakes were 50 and 90%, respectively. Figure 8 shows the bending moment overtime for the same piles demonstrating that the maximum bending moment was reduced; the bending moment ratio at the pile surface for the Halabjah and Ali Al Gharbi earthquakes were 70% and 50%, respectively.
Figure 7. Settlement time curves

(a) Without geogrid
(b) With geogrid
(c) Without geogrid
(d) With Nelton CE121 Ali Al Gharbi earthquake

Figure 8. The bending moment time curves for (a) Halabjah earthquakes and (b) Ali Al Gharbi earthquake
4. Conclusions

1. Adding geogrid to soil reduces settlement and bending moment of a pile under earthquake forces.

2. The settlement reduction ratio depends on the strength of the wave. Here, the settlement ratio was 50% for the simulated Halabjah earthquake and 90% for the Ali Al Gharbi earthquake.

3. The ratio of the reduction in bending moment at the surface of embedded pile reached 70% and 50% for the Halabjah and Ali Al Gharbi earthquakes, respectively.

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