Improving Shallow-Deep Foundation with Reinforcement by Geogrids for Tall Building

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Abstract. This research has studied the effect of the vertical load, it has acted at the center of the raft foundation and piled raft foundation. Stresses resistance and displacements were significant parts to examine the behavior of improving foundation. These are important parts of life the structure. The study focuses on different cases of the embedded layer in tension zone with concrete grade B20 of (MD/XMD) Tensor SS2 geogrids in raft and piled raft foundation for a tall building in Incheon Tower in South Korea, it was treated to solve those problems. Stresses resistance of raft and piled raft foundation were greater than vertical stress applied of dead and live loads, also the stress value of XMD was greater than the value of MD.

Keywords: Improvement, shallow foundation, deep foundation, reinforcement, geogrid.

1. Introduction

Shallow foundations, where feasible, are generally more economical than deep foundations if they do not have to be installed deep into the ground and extensive ground improvement works are not required. They are often used to support structures at sites where subsurface materials are sufficiently strong. Unless a shallow foundation can be founded on a strong rock, some noticeable settlement will occur. The design of shallow foundations should ensure that there is an adequate factor of safety against bearing failure of the ground and that the settlements, including total and differential settlement, are limited to allowable values. The structural design of piles should be carried out under the requirements in local structural codes and regulations. The piles should be capable of withstanding both the stresses induced during handling and installation as well as during their service life [1]. In the calculation of vertical stress, it generally assumes that the foundation of a structure is flexible [2]. In practice, this is not the case; no foundation is perfectly flexible, nor is it infinitely rigid. The actual nature of the distribution of contact stress will depend on the elastic properties of the foundation and the soil on which the foundation is resting [2].

The most common materials from which most structures are built are wood, steel, reinforced (including prestressed) concrete, and masonry. Lightweight materials such as aluminum and advanced composite materials, such as fiber-reinforced plastics (FRB) are also becoming more common in use. Plain concrete is made by mixing cement, fine aggregate, coarse aggregate, water, and frequent admixtures. The strength of concrete depends on many factors: notably the proportion of the ingredients and the conditions of temperature and moisture under which it is placed and cured. Reference to concrete strength means uniaxial compressive strength measured by a compression test of a standard test cylinder. The most important variable in determining concrete strength is the water to cement (w/c) ratio. The lower the water/cement ratio, the higher the compressive strength [3]. Geosynthetics include exclusively manmade polymeric products such as geotextile, geogrids, geonets, geomembranes, geosynthetic clay
liners, and geocomposites. Geogrids are mainly used as tensile reinforcement. In manufacturing uniaxial geogrids, circular holes are punched on the polymer sheet, which is subsequently drawn to improve the mechanical properties [4].

2. Materials Properties

2.1. Study Model

In the current study, a full three-dimensional (3D) FE model is created on Abaqus CAE v.6.14 software [5]. Two sets of the raft and piled raft foundation with geogrid embedded in the tension zone of the foundation by concrete grade B20, as shown in Figs. 1 and 2. The foundation comprises a 5.5 m thick concrete grade B20 both sets. Piled distribution of piled raft foundation was 172 piles of 2.5 m diameter with lengths below the base of the raft different from (36 m, 50 m, and 66 m) row by row gradually, without basement walls and soil properties in analysis for both sets of models.

![Figure 1. Description of raft foundation.](image1)

![Figure 2. Description of piled raft foundation.](image2)

2.2. Finite Element Model

The physical and mechanical properties of Tensor geogrid (SS2) are summarized in Table 1. Material properties for concrete with simplified concrete damage plasticity model in class B20 are listed in Table 2. The 10-node quadratic tetrahedron elements were used to mesh the raft and piled raft foundation. The 2-node linear 3-D truss was used to mesh Tensor SS2 (MD/XMD) geogrids. Boundary conditions at the base of the raft and piles at the piled raft were fixed.

**Table 1. Properties of SS2 [6].**

| Dimensional Properties | Unit | Data |
|------------------------|------|------|
| Aperture size (MD/XMD) | mm   | 28/40|
| Mass per unit area     | kg/m²| 0.3  |
| Rib thickness MD/XMD   | mm   | 1.2/1.1|
| Junction thickness     | mm   | 3.9  |
| Longitudinal rib width | mm   | 3    |
| Transverse rib width   | mm   | 3    |
| Roll width             | m    | 4    |

| Mechanical Properties  |       |      |
|------------------------|-------|------|
| Peak Tensile Strength  | kN/m  | 14.4/28.2|
| MD/XMD                 |       |       |
| Elastic modulus MD/XMD | GPa  | 0.57/0.99|
| Upper yield strength MD/XMD | MPa | 1/3 |
| Lower yield strength MD/XMD | MPa | 1/3 |
| Tensile strength MD/XMD | MPa  | 24/30.7|

| Physical Properties    |       |      |
|------------------------|-------|------|
| Property               | Data  |      |
| Mesh type              | square|      |
| Standard color         | Black |      |
| Polymer type           | PP    |      |
| Packaging              | Rolls |      |
Table 2. Properties of concrete [7].

| Material's parameters | Plasticity parameters |
|-----------------------|-----------------------|
| Concrete elasticity   | B20                   |
| Modulus of elasticity, E (GPa) | 21.2               |
| Poisson's ratio (υ)   | 0.2                   |
| Concrete compressive behavior | Inelastic strain |
| Concrete tension behavior | Inelastic strain |
| Yield stress (MPa)    | Cracking strain       |
| 10.2                  | 0                     |
| 12.8                  | 7.73585E-05           |
| 15                    | 0.00173585            |
| 16.8                  | 0.000288679           |
| 18.2                  | 0.000422642           |
| 19.2                  | 0.000575472           |
| 19.8                  | 0.00074717            |
| 20                    | 0.000937736           |
| 19.8                  | 0.00114717            |
| 19.2                  | 0.001375472           |
| 18.2                  | 0.001622642           |
| 16.8                  | 0.001888679           |
| 15                    | 0.00217358            |
| 12.8                  | 0.002477358           |
| 10.2                  | 0.0028                |
| 7.2                   | 0.003141509           |
| 3.8                   | 0.003501887           |

Table 3. Load components for Incheon Tower [8].

| Load component          | Value   | Load component          | Value   |
|-------------------------|---------|-------------------------|---------|
| Dead Load               | 6036 MN | Horizontal load x-direction | 149 MN  |
| Live Load               | 651 MN  | Horizontal load z-direction | 115 MN  |
| Moment in x-direction   | 21,600MN-m | Earthquake load x-direction | 110 MN  |
| Moment in z-direction   | 12,710MN-m | Earthquake load z-direction | 110 MN  |

2.3. Vertical Loading
The vertical load (6687 MN) was applied incrementally at the center of the raft, it computed of dead and live load from Table 3.

3. Verification Results with Program
The numerical results obtained from the FE analysis of piled raft foundation were compared with the results by [8] as shown in Fig. 3, where the vertical load applied at the center point of the raft foundation versus the vertical displacement is plotted. The percentage of the average vertical displacement of Fig. 3 was 60%. Figure 4 was plotted the vertical load versus the vertical displacement of the raft foundation,
the reduction of displacements was very small. Figs. 5 and 6 were described the comparison of vertical loads of raft foundation and piled raft foundation with [8], where vertical loads were given equal values in the middle of analysis of raft and piled raft but piled raft had taken more steps to complete his analysis to reach finally at the same value of [8]. The percentage of the average vertical load in Fig. 5 and Fig. 6 were 6.5% and 64% respectively.

![Figure 3. Vertical load versus vertical displacement of the piled raft foundation and FE model Poulos.](image1)

![Figure 4. Vertical load versus vertical displacement of raft foundation.](image2)
4. Results: Set 1 (Raft Foundation) and Set 2 (Piled Raft Foundation)

4.1 Stress Distribution
Von-Mises described that the yield surface has an open cylinder around the hydrostatic axis in the space of the principal stresses as shown in Fig. 7. The Von-Mises is the most common yield criterion for structure. It is a combination of stresses and represents very well the yielding and ultimate stresses [9]. Thus, the value was got from Abaqus CAE v.6.14 software [5] for set 1 and set 2 (1.49 MPa and 19.98 MPa) respectively. Therefore, it can easily say that magnitude of stresses obtained higher than the value of stress applied at the center of the foundation (1.2661 MPa).
The maximum value of stress was distributed in the edge of the foundation for set 1 and different places for set 2 referred to the critical region at the foundation Figs. 8 and 12, as summarized in Tables 2 and 4. The high value of stress (19.98 MPa) appeared at the connection between pile and raft foundation as shown in Fig. 12 but the result of the stress in Fig. 8 (1.49 MPa) was observed at all edges of the raft foundation. Stress resistance of piled raft is too much higher than the raft foundation. The Von-Mises stress of (MD and XMD) Tensor SS2 for raft foundation in set 1 and piled raft in set 2 were (0.001364 MPa and 0.002367 MPa) and (0.007011 MPa and 0.02862 MPa), respectively summarized in (Tables 2 and 4). The regions of the plastic deformation effect were symmetrical especially in the edge of the layer as shown in Fig.10 and Fig.11 but Figs. 14 and 15 were observed very close to the connection between pile and raft foundation. In general, XMD Tensor SS2 is given a high value of stress, it depends on mechanical properties of elastic modulus, yield strength, and tensile strength.

4.2 Displacement Effect
Displacements value for raft foundation in the set were summarized in Tables 4 and 5 approximately (0.3 mm) while they indicated in Tables 6 and 7 approximately (20 mm) of piled raft foundation in set 2, as noticed in (Figs. 9 and 13). The value of displacement of raft foundation (0.299 mm) was noticed along the foundation as shown in Fig. 9. It compares with the value of displacement of piled raft foundation that it was (19.99 mm) as shown in Fig. 13. It depends on distributed lengths of piled at the foundation.

Table 4. Summarizing table of finite element for set 1.

| Specimen                  | Case   | Aperture size (MD/XMD) | Material Properties                                      |
|---------------------------|--------|------------------------|----------------------------------------------------------|
| Raft Foundation with MD Tensor SS2 | Reinforced | 28 by 28 mm C/C | Concrete Grade B20 and One layer in Tension zone of the MD Tensor SS2 |
| Raft Foundation with XMD Tensor SS2 | Reinforced | 40 by 40 mm C/C | Concrete Grade B20 and One layer in Tension zone of the XMD Tensor SS2 |

Table 5. Results summary table for set 1.

| Specimen                  | Ultimate Stress (MPa) | Ultimate Displacement (mm) | Ultimate Stress of MD/XMD (MPa) |
|---------------------------|-----------------------|-----------------------------|---------------------------------|
| Raft Foundation with MD Tensor SS2 | 1.49                  | 0.299                       | 0.001364                        |
| Raft Foundation with XMD Tensor SS2 | 1.49                  | 0.299                       | 0.002367                        |
Table 6. Summarizing table of finite element for set 2.

| Specimen                              | Case     | Aperture size (MD/XMD) | Material Properties                                      |
|----------------------------------------|----------|------------------------|----------------------------------------------------------|
| Piled Raft Foundation with MD tensor SS2 | Reinforced | 28 by 28 mm C/C        | Concrete Grade B20 and One layer in Tension zone of the MD tensor SS2 |
| Piled Raft Foundation with XMD tensor SS2 | Reinforced | 40 by 40 mm C/C        | Concrete Grade B20 and One layer in Tension zone of the XMD tensor SS2 |

Table 7. Results summary table for set 2.

| Specimen                              | Ultimate Stress (MPa) | Ultimate Displacement (mm) | Ultimate Stress of MD/XMD (MPa) |
|----------------------------------------|-----------------------|-----------------------------|---------------------------------|
| Piled Raft Foundation with MD tensor SS2 | 19.98                 | 19.99                       | 0.007011                        |
| Piled Raft Foundation with XMD tensor SS2 | 19.98                 | 19.99                       | 0.02862                         |

Figure 8. Von-Mises stress contour plots of raft foundation with XMD tensor SS2.

Figure 9. Vertical displacement contour plots of raft foundation with XMD tensor SS2.
Figure 10. Von-Mises stress contour plots of the XMD tensor SS2 in the raft foundation.

Figure 11. Von-Mises stress contour plots of the MD tensor SS2 in Raft Foundation.

Figure 12. Von-Mises stress contour plots of piled raft foundation with XMD Tensor SS2.
Figure 13. Vertical displacement contour plots of piled raft foundation with XMD tensor SS2.

Figure 14. Von-Mises stress contour plots of the XMD tensor SS2 in piled raft foundation.

Figure 15. Von-Mises stress contour plots of the MD Tensor SS2 in piled raft foundation.
5. Conclusion

• Different values of the Von-Mises stress of (MD and XMD) Tensor SS2 referred to the mechanical properties of elastic modulus, yield strength and tensile strength of XMD tensor had bigger values than MD tensor.

• Displacements value for raft foundation in set 1 were smaller than values of piled raft foundation in set 2 because the boundary conditions of the raft foundation base were fixed and material properties of soil neglected too.

• The magnitude of stresses obtained from the piled raft foundation bigger than the raft foundation in the same value of the applied load.

• The applied load was (6687 MN) that it leads of the applied stress (1.2661 MPa) the results of resistance stresses come of Abaqus software were of raft foundation (1.49 MPa), piled raft foundation (19.98 MPa). The magnitude of resistance stresses was greater than the applied stress.

Recommendations
The strength of the foundation should be improved by embedded more layers of XMD Tensor SS2 geogrid.

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