iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 Issue: X Month of publication: October 2017

DOI: http://doi.org/10.22214/ijraset.2017.10011

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Analysis of Soil Liquefaction using Numerical Modeling

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Abstract: ***Soil liquefaction occurs when partially or completely saturated soil is subjected to either a sudden change in load, cyclic loads or even tremors. Liquefaction is enabled when the pore water pressure transcends the contact pressure and therefore the water tends to move towards the surface of the soil. This report focuses on the instance of soil liquefaction that occurred due to the Kobe earthquake of January 17, 1995, in the southern part of Hyōgo Prefecture, Japan, known as Hanshin which was a cause for large scale wreckage claiming nearly 4,634 lives. It was measured a 6.9 on the moment magnitude Richter scale and was a 'strike-slip' type earthquake. An analysis was performed using Plaxis software in which a superstructure was subjected to Convulsion loading for a given soil. The results showed considerable settlements that could lead to the complete collapsing of the structure. In an attempt to avoid this, a Geogrid was introduced at a certain depth below the foundation of the framework. Later, comparisons between the two cases were drawn by considering the extent of settlement as the pivotal parameter. The results returned positive for decreased settlement of the structure in the case where the Geogrid was laid.***
Keywords: ***Geogrid, Kobe Earthquake, Numerical Modelling, Plaxis, Soil Liquifaction***

I. INTRODUCTION

Liquifaction is the phenomenon in which a saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress, usually earthquake shaking or other sudden change in stress condition, causing it to behave like a liquid. If the soil is saturated by water (a condition that often exists when the soil is below the ground water table), water fills the gaps between soil grains. In an attempt to flow out from the soil to zones of low pressure, water flows upward towards the ground surface. If the loading is rapid, large enough, or is repeated many times (e.g. earthquake shaking, storm wave loading) such that it does not flow out in time before the next cycle of load is applied, the pore water pressure may build up to an extent where it exceeds the contact pressure that keeps soil grains in contact with each other. This loss of soil structure causes it to lose all of its strength and it is observed to flow like a liquid.

A. Past Records

Earthquakes accompanied with liquefaction have been observed for many years. Liquefaction has been common in a number of recent earthquakes that it is often considered to be associated with them.

Some of those earthquakes are Alaska, USA (1964), Niigata, Japan (1964), Loma Prieta, USA (1989) Kobe, Japan (1995), Chi Chi, Taiwan (1999), Bhuj, India (2001)

B. Effects of Liquefaction

The effects of liquefaction are vast and may range from minor cracks to large depressions. The most prominently observed effects of liquefaction are lateral displacements, tilting and settlement of buildings and foundations, buckling of bridges, fissures in the ground, collapse of expressways, earthen dams and levees, floating of manholes and sand boiling

C. Prevention and Mitigation techniques

A number of techniques can be adopted to reduce and prevent the effects of soil liquefaction. The following mitigation techniques are widely adopted.

1) Vibro Compaction
2) Dynamic Compaction
3) Vibro floatation
4) Compaction Grouting

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue X, October 2017- Available at www.ijraset.com

II. EVALUATION USING PLAXIS

For this study, a numerical model of a 2-floored building (3m×5m×2.5m) was constructed on a soil stratum of certain properties. A foundation of 2m was provided. A Water Table at the depth of 5m from the ground surface was assigned. The Model was then subjected to Earthquake Loads based on the time-acceleration conditions of The Great Hanshin earthquake, or Kobe earthquake, Japan (1995). The response of the soil mass and structure was recorded.

The failure observed was in the form of complete sinking due to high water content, showing soil liquefaction. For another case the soil was compacted to reduce water content and a Geogrid was provided to further stabilize the soil.

A Geogrid is a geosynthetic material used to reinforce soils. Geogrids are commonly used to reinforce retaining walls, as well as subbases or subsoils below roads or structures. Compared to soil, geogrids are strong in tension. This allows them to transfer forces to a larger area of soil than would otherwise be the case.

III. RESULTS AND DISCUSSION

A. Case 1: Dynamic loading of building

The model was prepared and simulated with Dynamic loading conditions considering assigned properties of structure and soil.

On subjecting the model to Earthquake loads, liquefaction was observed and settlement of the building took place. Failure of soil mass and settlement of building due to liquefaction is evident from the figures.

A scale factor of 10 was used.

Displacement in soil below the building was observed to be 0.16 m or 16cm.

B. Case 2: Dynamic Loading of building after compacting and providing Geogrid

The same model was provided a Geogrid below the foundation and simulated with dynamic loading conditions. Water Table level was slightly lowered due to assumed compaction of soil.

The revised model was again subjected to Earthquake loads. The provision of a Geogrid had prevented potential liquefaction and reduced settlement of the building considerably.

An identical scale factor of 10 was used.

After compaction and provision of Geogrid the displacement in soil below the building was observed to be 35×10^{-3}m which is nearly 0.035m or 3.5cm. The Geogrid caused the stresses to be distributed over a larger area, thereby reducing settlement by an appreciable difference.

C. Soil Element Displacement

The software enables us to calculate the soil element displacement at nearly 4275 node points. From these node points, two critical node points – 2429 and 2797 (below the foundation on either sides) were considered for analysis. The tables below show the difference in settlement before and after providing a Geogrid and compacting the soil with respect to these two node points.

IV. FIGURES AND TABLES

TABLE 1 Properties of soil

γ_{unsat}	18 KN/m^3
$_{sat}$	18 KN/m^3
C	15 KN/m^2
ϕ	20 degrees
E	2E+04 KN/m^2
υ	0.3

TABLE II Properties of steel used in the building

υ	0.18
EA	5.1E+06 KN/m
EI	9000 KNm^2/m

TABLE III Properties of Geogrid

Material	Sand
E	3.5E+06 KN/m^2
υ	0.2
Geogrid EA	2.1E+04 KN/m

TABLE IV Soil Element Displacements

Node	X (m)	Y (m)	Ux (10^{-3}m)	Uy (10^{-3}m)
2429	10	38	66.016	-102.048
2797	15	38	66.003	-87.747

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TABLE V Sil Element Displacement after providing geogrid

Node	X (m)	Y (m)	Ux (10^{-3}m)	Uy (10^{-3}m)
2429	15.638	28.406	18.005	0.534
2797	9.608	20.402	5.159	0.458

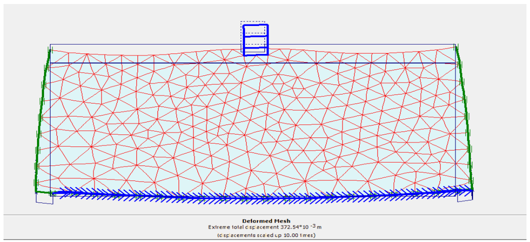

Fig. 1 Deformed mesh of model

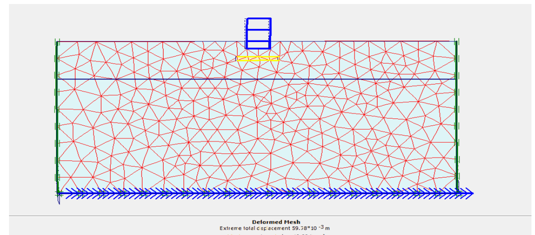

Fig. 2 Deformed mesh of model with Geogrid

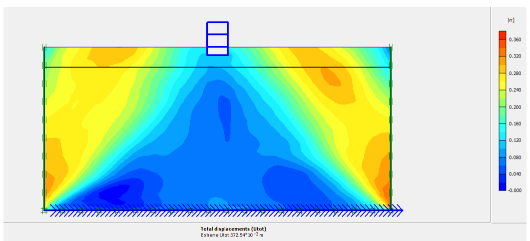

Fig. 3 Total Displacement of model

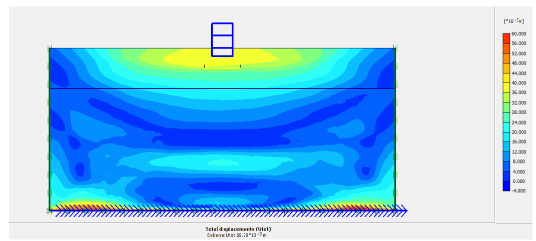

Fig. 4 Total displacement of model with geogrid

V. CONCLUSION

Studies carried out on the building founded on liquefiable soils have led to the following conclusions:

A. Liquefiable soil, if not treated, causes the soil to lose its strength and the structure to collapse. Based on the current study, the settlement of the building was observed to be 16 cm.

B. The provision of Geogrid has prevented potential liquefaction and sinking of building, reducing the settlement of the building to 3.5 cm.

C. Soil element displacement has reduced by 48×10^{-3} m and 61×10^{-3} m along X direction and 101.5×10^{-3} m and 86.5×10^{-3} m along Y direction.

D. The Geogrid transfers stresses in soil to a larger area as compared to the previous case.

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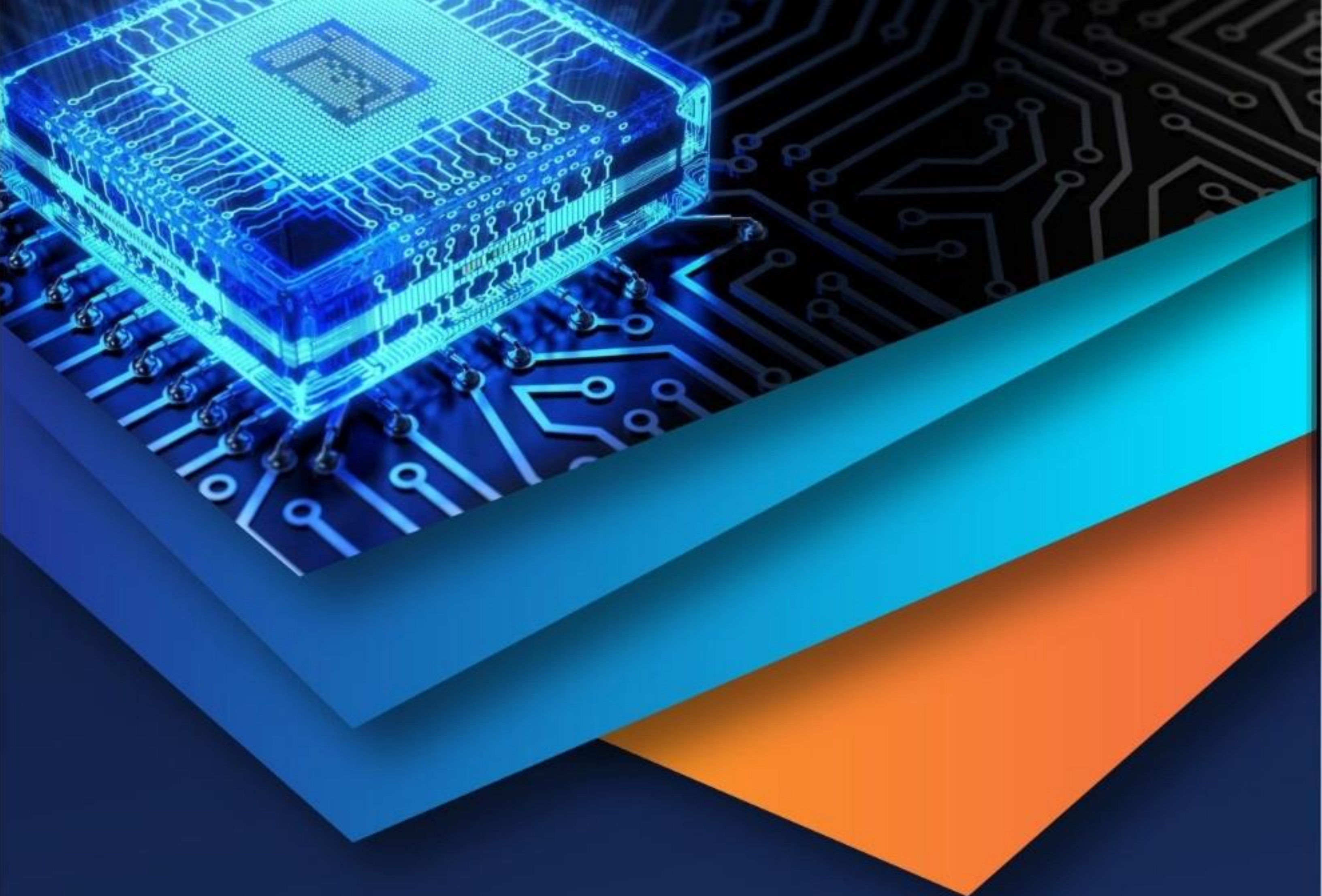

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