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Geomembranes Thin Films Modeling for Wave Refraction and Absorption Toward Seismic Optimization

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Abstract: Basically it is assumed that seismic waves while passing through different layers of earth are reflected, refract, refraction and absorption and distribute and reduce energy. In this study, porosity and elastic properties of objects are used in the design of the proposed model to develop further wave refraction and absorption. In this method the longitudinal wave energy is relatively absorbed by a layer of artificial soil and has been amortized, so that seismic wave's energy is wasted for the displacement of layers and the desired structure remains with relative low movement. According to the results of laboratory model, elastic refractory materials (dense PVC) were used because the merge rate of elastic materials is more than other materials. In the damping phenomenon, the object's internal kinetic and strain energy rate quickly decrease. Therefore, for wave distribution and absorption in the earth, geomembranes were designed in very thin layers and were used in soil layers. Finally, the model defines the geomembrane related parameters and offers a schematics diagram of the plan.

Keywords: Seismic improvements, securing the building against earthquakes, seismic wave absorption and refraction

INTRODUCTION

From the behavioral and superior engineering point of view, earthquake should be considered as a phenomenon which affects the whole structural environment and soil and may also provide other phenomena. In recent decades much research has been done in the field of earthquake engineering. That result of these researches has started a new era in the design and analysis of the building quakes. Regulations such as ATC and FEMA are forming and many of researches are in this line (Mirza Gol Tabar, 2005).

Properties of seismic waves change passing through various environments. High frequencies quickly attenuate and low frequencies will be stable to farther distances. On the other hand different layers of the earth boost parts of the frequency spectrum which are the closer to the layer natural frequency. If there are layers in the ground with a frequency further than the seismic frequencies spectrum, the wave will not be strengthened and will be amortized. Therefore soil type plays an important role in the amortization of wave and energy and also stability of the structure through static and dynamic forces.

Einde *et al.* (2003) presented an overview of the research and development of applications of advanced composites to civil infrastructure renewal at the University of California, San Diego (UCSD). Dicleli and Mansour (2003) investigated economical and structural efficiency of friction pendulum bearings (FPB) for retrofitting typical seismically vulnerable bridges in the State of Illinois. Their results showed that FPB may successfully be used for economical seismic retrofitting of typical bridges in the State of Illinois or in regions of low to moderate risk of seismic activity. Su and Zhu (2005) introduced a research called by "Experimental and numerical studies of external steel plate strengthened reinforced concrete coupling beams" to develop a new method for strengthening reinforced concrete (RC) coupling beams. The numerical model developed is very useful for investigating strengthened beams with other configurations and other reinforcement details. Khosravi and Amini (2006) investigated how increasing soil depreciation for minimizing displacement of soil particles under the force of the earthquake and they introduce a structure for Achieve to this aim. Mirza Gol Tabar (2006) introduced Philosophy of soil and structure improvement against earthquake and its related phenomena. He drew a structure for Seismic retrofit ranking. Paret *et al.* (2008) present a paper called by "Using traditional and innovative approaches in the seismic evaluation and strengthening of a historic unreinforced masonry synagogue". They showed a system of tension ties in the attic that interconnect the four perimeter walls and so on. The tension ties contain super-elastic nitinol wires and were designed to be lightweight, easy to install, that enabled the structure to survive the 1906 earthquake.

The present study discusses the ways to increase soil depreciation in order to minimize the displacement of soil particles under the structures by the effect of earthquake force. Basically, seismic waves passing through different layers of soil reflect and refract waves and distribute and reduce energy. Therefore, the proposed scheme uses the porosity and elastic properties of materials such as resistant porous materials and geomembranes and has been utilized for further development of diffraction and absorption of waves. As thickness of reinforcement layers such as PVC and different types of geosynthetics are very thin, their thickness under the normal static and seismic load can be calculated regarding the tensile strength and shear strength of the fibers through the proposed relationships in this article. Finally it can be stated that the main objective of the study is to provide a model for seismic optimization through thin geomembranes layers for refraction and absorption of wave in the soil under the structure foundation.

THEORETICAL FOUNDATIONS

Iran is at risk of severe earthquake in areas such as Buin Zahra earthquake (1962), Tabas earthquake (1978), Golbaft earthquake (1981) Manjil and Rodbar earthquake (1990) Bojnord earthquake (1997) Bam earthquake (2003) and dozens of other seismic prone areas. According to records of domestic seismicity as well as methods of construction of buildings in the past years and also high potential seismicity of most domestic populated cities, it is seriously of high priority to hedge the community from the earthquake effects. Malicious destruction of national assets and human resources make it inevitably necessary to retrofit the existing buildings and structures against earthquake and the necessity of national regulations legislation to evaluate the safety and retrofit of existing buildings is highlighted. Iran is a seismic country and on the other hand considering that a large number of buildings are vulnerable due to lack of safety issues, the necessity to strengthen and repair and retrofit buildings is boosted. In addition to earthquake other factors which require the necessity of repair, retrofit and reinforcement of buildings include: design error, function switch, improper performance, damage caused over time, environmental factors, etc. Reasons to study the vulnerability and retrofitting of buildings can be expressed as follows: Changes in compilation of regulations of structural design and seismic design, changes in material conditions and the use of inferior materials or savings, lack of competent executives that leads to the non-normative construction, scientific and practical weakness of supervisory engineers and sounding as if regulations related to design and calculations and supervision of buildings are not important, economic and cultural weakness, architectural biased taste which leads problems in the designs of structures (Mirza Gol Tabar, 2005).

Improvement includes retrofitting and repair and remodeling (Mirza Gol Tabar, 2006). Improvement is a measure that can help an engineer to improve the seismic behavior of buildings and immunize the structures for a specific performance level in a specified risk level. In building evaluation, if the building fails to provide the desired performance level, the improvement must be made. In the first step of improvement, it shall be determined that the building should be improved for which level of improvement such as baseline, desirable, special, or limited or local and will be determined depending on the conditions of structure. In the second stage one of the improvement strategies should be used. Improvement strategies are aimed to increase strength, increase hardness, increase ductility and decrease the earthquake force with the help one or a combination of several methods (Fajfar, 1999):

- **Local correction of structural components:** During the evaluation of structural components with the acceptance criteria instructions, if it is specified that some of the components lack the sufficient capacity for force and transformation, then "Local correction" is the adequate strategy to provide the expected performance level.
- **Eliminate or reduce irregularities in the existing building:** If the result of evaluation is such that the building is not accepted for the expected performance due to building irregularities, it is possible to reach the desired level by amendment methods. For example correction or reduction of such irregularities in the building with soft or weak floor may be provided by adding brace and shear walls in these floors to increase the mentioned lateral stiffness with other floors.
- **Provide lateral stiffness for the entire structure:** By adding bracing or shear walls may fulfilled this goal.
- **Provide the necessary resistance for the whole structure:** If the majority of the components are not compatible with the acceptance criteria, a backer system with sufficient capacity should be created.
- **Reduction of the building mass:** By lightening the building and using details with lower mass, this target can be fulfilled. Therefore in this study for seismic upgrading of residential buildings, the motion of the earth has been relatively amortized by a layer of artificial soil, so that the wave energy is absorbed, because the energy of seismic wave is spent for the displacement of these layers and the desired structure remains with a relative low movement.

Modeling: In earthquake, the structures is under earthquake acceleration, ground motion or changed of location, thus as for Fig. 1 it can be stated that (Khosravi and Amini, 2006):

$$U = Ul + U_g \qquad (1)$$

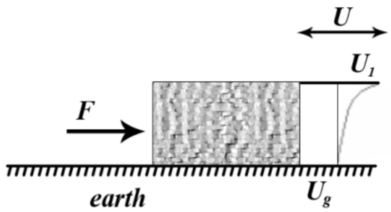

Fig. 1: Change the location of land and structures under earthquake loads

Given the amount of total displacement U is a function of the amount of U_l and U_g and also U_l which means the structure and movement of the Earth is also a function of ground motion over time, therefore it can be stated that (Khosravi and Amini, 2006):

$$U = \lambda.F\ U_g\,(t) \quad (2)$$

λ is a coefficient which depends on structural details and on the other hand the Newton's law of motion for the systematic movement under earthquake acceleration$U_g(t)$, is similar to a system with a fixed foundation under the external force F (t) and regarding the acceleration and damping parameters and the related to object properties which depends on the spring coefficient U (t), the motion equation is obtained as the relation (3). In this relation C and K are respectively the damping matrix and stiffness of the system and U is the displacement vector (Austin, 1996):

$$M \iint U(t) + C \int U(t) + KU(t) = -M. \iint U_g\,(t) \quad (3)$$

If the structure is considered as rigid, (U = -Ug) then we have:

$$C\int U\,(t) + KU\,(t) = 0$$

In which, for minimizing U, the most important parameters of stiffness and depreciation shall be examined. Furthermore the slimy depreciation always acts in the opposite direction. The earthquake coefficients depend on the design acceleration and reflection coefficient and significance and behavior of the structure. The minimum seismic coefficient (c) is 0.04, so that for soils with a bearing strength higher than one, the maximum seismic coefficient is 0.08 and for the soils with the bearing strength less than one, the maximum c value is 0.1. This suggests the energy dissipation effect in weaker soil and probably with more porous than the stiff soil (Moghadam, 2002). Also in a state that there is no external forces to the structure, after solving the above differential equation and curve and drawing the seismic wave and the tangential cover equation, the maximum wave amplitude at time t is shown as the relation (4) (Khosravi and Amini, 2006):

U/U0 = ρ . Cos (wd.t)
Wd = w . √(1 - ζ^2)
ρ = e^(-ζ.w.t) (4)

The depreciation coefficient (ζ) in the range 0.01 for a rigid structure is up to 0.2 for the elastic structure and earth materials. the angular coefficient of the L curve covering is e^(-ζ w t) which based on the experimental curve, the decreasing slope of the curve L meaning the steep depreciation wave for elastic objects (such as PVS) with a slope of about 45 - degrees and for rigid objects (Aluminum) with a slope of about -10 (Chopra, 1998). For refractory porous objects (such as dense sand) is -30 degrees, which refers to the fact that elastic objects absorb energy and porous objects distribute the source of energy.

As shown in these equations, the increase of extinction coefficient reduces the earthquake forces in the ground. Extinction coefficient is obtained of relationship (5). In this relation, w is angular frequency and E is the coefficient of elasticity and μ is the coefficient of internal friction of soil. Depreciation coefficient is different in soil materials and can vary 10 to 20%. The natural frequency of most of the soils varies 20 to 30 Hz which increases with the soil resistance (Moghadam, 2002):

$$\zeta = E / \mu\ .\ w \quad (5)$$

In granular soils, depreciation due to friction is more important than other factors. When the wave passes through the softer layers, it gets closer along the vertical axis. According to regular dynamic principle, the vibration amplitude increases. Therefore the seismic coefficient for the soft soil in higher than the firm soil. Theoretical studies show this increase gradually happens in the passage of the wave from the bed rock to the surface. Experience shows that structural damages in the soft alluvial earth can be more severe, which has been proved in numerous earthquakes (Moghadam, 2002).

Wave passes through a porous environment is along with the energy distribution and waves caused by the main input wave distribute in the porous object. The accumulation of energy within these layers is almost identical with the rigid layers (for waves moving to a single point). Basically, the seismic waves passing through different layers of soil are reflected, refract, refracted and absorbed and distribute and reduce energy. In the present study the porosity and elastic properties of the objects is used in the proposed model, to build more wave refraction and absorption. The effect of wave energy in underground structures under explosion wave energy can be expressed as follows: the

Table 1: Wave velocity and modulus of elasticity in different environments

Materials	Longitudinal wave velocity (m/s)	Seismic-explosive velocity	Modulus of elasticity (kg/cm^2)
Loose and fine sand	1300 -300	6300 -2500	250 -100
Dense sand and gravel - crushed soil	2260	8500 -3000	2000 -1000
Sandstone - very dense sand and gravel	2000 -3600	14000 -3000	5000 -1500
Limestone	5500 -3200	21000 -7000	7000 -4000

Vafayan (1997) and Bowles (1996)

maximum pressure on the wall of the structure buried deep in the earth, under the explosive charge can be considered as the following simple relation (6):

$$Pc = K * Ps \tag{6}$$

Ps is the maximum pressure at ground level above the structure and values of the coefficient K for various soils in different conditions is about:

- For fractured and seamed lands
- 1.4 for granular soil non-sticky and slightly moisturized or dry
- For the fine-grained cohesive soil slightly moisturized
- 3.4 for the fine-grained cohesive soil moisturized
- For all the saturated soil with underground water levels less than 3 meters from the natural ground level

The above set of contents specifies the seismic velocity reduce in loose soil with lower modulus of elasticity than dense materials, that can be exploited for wave extinction. Wave velocity and modulus of elasticity values in various environments are presented in Table 1.

In this study through absorption of wave energy, the relative motion of the earth has been amortized by a layer of artificial soil, so that the energy of seismic wave is spent for the displacement of layers and the desired structure remains with relative low movement. Also in order to increase the damping behavior in earth layers to reduce the change of location in the soil and foundation, according to the results of laboratory models elastic refractory materials (PVC compact) can be used. In this type of material vibration damps in a short time because the amortization speed in the elastic material is higher than other materials (the phenomenon of gradual decrease of vibration amplitude) and in the damping phenomenon, the internal kinetic and strain energy decrease over time with a high velocity.

Basically, seismic and wave motion creates shear stresses in the ground (back and forth). The shear strain materials are determined, through defining the relation $\gamma = \tau G *$ which represents the shear stress tolerance within object (Beyer, 2003) and knowing the two value of G, the shear modulus of material (in this project PVC material is added to the soil mass) and $\delta.\delta = u/l$ in which *u* is PVC material movement due to shear force and l is the thickness of energy absorbing layer and damping of the waves. Finally we can say that wave distribution in the soil depends on the following factors:

- The depth of weak layer comparing the bed rock
- Acceleration-Speed -Change of location-the external force applied
- Poisson ratio of soil and soil rigidity
- Material porosity and pore pressure
- Relation of $\zeta = E / \mu * w$ and the amount of w equals to $\sqrt{k/m}$

When materials have higher amortization coefficient and modulus of elasticity and deeper elastic layers, the damping wave force due to earthquake is much faster and higher. However, the required materials with the above specifications are not possible due to and economic reasons and foundation bearing capacity control and unauthorized leakage or non-conforming leakage controls for static and dynamic load bearing of the important structures. Therefore, the calculated mathematical models using empirical relationships and scientific resources, the thickness of soil needed to be (considered) under the foundation can be calculated by the relation (7):

$$l = 0.15\ Hb \tag{7}$$

Hb is the height of the structure and l is the thickness of the studied soil and the thickness necessary to damp the energy caused by the wave is:

$$d = \varepsilon.\delta.U \tag{8}$$

δ is the shear strain and ε is the axial strain of the ground below the foundation and the thickness of the damping object d shall be distributed between the thickness l in the deep Earth. On the other hand to distribute the damper object as very thin layers with T thickness the following project can be used. In this project each of the artificial layers shall absorb the shear force and also they shall not be able to transfer power as friction to the adjacent lower and above layers. Since the thickness of reinforcement layers such as PVC and types of geosynthetics are very thin, their

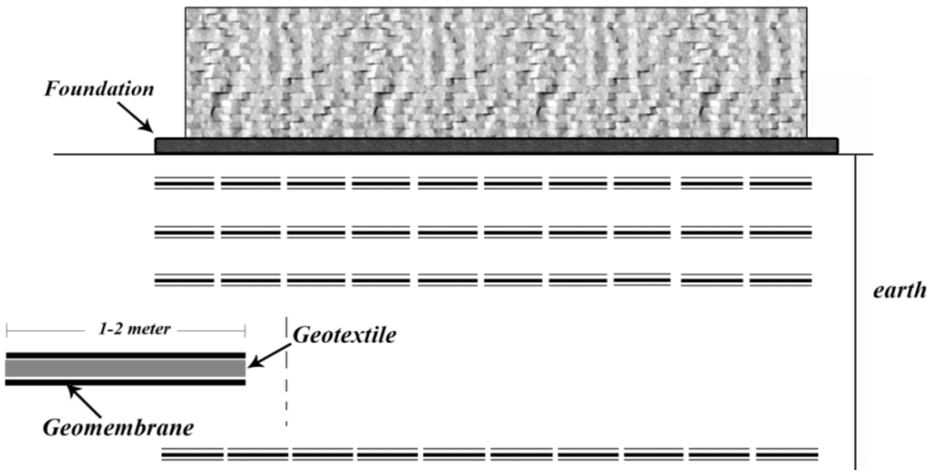

Fig. 2: Layout of geomembrane under a broad foundation

thickness can be calculated under normal static load of Ps and the maximum vertical components earthquake force of Fv according to the tensile and shear stress in the fibers.

The relations determining the thickness of geomembrane are the relation (Corbet and Peter, 1996) for static loads:

$$T = (\tan \delta u + \tan \delta l) * P * x / \cos \beta * \sigma al \qquad (9)$$

Khosravi and Clark relation for static and dynamic loads:

$$T = Eg * N * Pe / (Eg * N + 2 \sigma all) \qquad (10)$$
$$N = (1-\upsilon s2) / Es$$

Pe: effective and total pressure (including static and dynamic load).

Thus the proposed implementation of an elastic dense layer of fibers with thickness d can be implemented under a broad foundation (approximately one meter below the foundation) and, if excavation under the foundation and pouring the good soil with technical specifications is possible, it is proposed to be implemented as follows. Type of fiber arrangement under the foundation with details is recommended as Fig. 2.

RECOMMENDATIONS

About the old and aged buildings the following is recommended:

- To identify buildings with high importance such as hospitals and clinics, schools and colleges, firefighters, the fire departments, the Offices of the disaster and the halls and assembly halls and also crowded places
- To determine the buildings with medium-grade importance such as residential homes
- To determine the buildings with low-grade importance such as warehouses, etc.

After the city's zoning and specifying the desired structures the study of vulnerability and seismic evaluation with qualitative and quantitative methods is started and then if needed a plan for their reinforcement is provided and after the credit allocation the implementation process should be done.

CONCLUSION

By evaluating the performance of buildings against external and seismic and underground and up ground factors, it can be concluded that to assess the capacity of existing building, the structures capacity should be compared with the demand of desired performance level. In this line after selecting the required performance level and determining the analysis method, model building parameters have been defined and determined and comparing the results with acceptance criteria which are identified regarding the purpose of improvement, the situation of structural performance is characterized. If the capacity of structural members is less than the minimum demand, points are determined by the software and in these points or the whole structure the improvement operations must be done and for this one of the mentioned strategies is used. To evaluate the existing buildings first the essential building shall be considered and after investigation of essential building, all structures with high importance are considered such as schools, mosques, halls, etc. Finally, all buildings with the possibility of defect in the structures shall be revised and necessary steps shall be taken in terms of reviewing and evaluating and if necessary the improvement and reinforcement shall be started.

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