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EARTHQUAKE RESPONSE ANALYSIS OF SINGLE-LAYERED LATTICE DOMES WITH AND WITHOUT SEISMIC ISOLATION SYSTEM

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Abstract- In building design, various seismic isolation systems are being increasingly applied to enhance seismic resistance. This paper is to analyse the earthquake response of single layer lattice domes with and without lead rubber bearing seismic isolation system. The seismic isolation system can greatly reduce the dynamic response of large span structures for the horizontal and vertical earthquake ground motion. The base isolation system is one of the best methods to reduce the damage of structures. The main idea is to control the period of structures against the period of earth movement to reduce the frequency of structures, this system would help in reducing the construction cost on the long time and increase the safety of structures. The comparison of deformation, compression forces and stresses of structures are carried out the time history analysis for both fixed base system and base isolation system to find the seismic response reducing effect.
Keywords –lead rubber bearing seismic isolation system, earthquake response, single-layered lattice domes, horizontal and vertical earthquake ground motion, seismic response reducing effect, time history analysis

1. INTRODUCTION

The effect of buildings on earthquakes is very complex, it difficult to consider all of them in seismic design. The damage pattern of buildings are the failure of columns, the crack of beams, the crack of walls, the failure of foundations, the overturning of structures, the fall off of exterior cladding, the fall of interior finish, etc. An earthquake is the shaking of the surface of the Earth, resulting from the sudden release of energy in the Earth's lithosphere that creates seismic waves. There are three main types of fault, all of which may cause a plate earthquake by normal, reverse and strike-slip. Many earthquakes are caused by movement on faults that have components of both dip-slip and strike-slip that is known as oblique slip. Nowadays, huge earthquakes are the main reason of damages of buildings. The base isolation system is one of very efficient tools to reduce damages by the earthquake response of buildings. Recent studies have shown that most isolation buildings are to use the multi-layer laminated rubber bearing system with steel plates. This lead rubber bearing system is very stiff and strong in vertical direction and soft in horizontal direction. The important parameters to reduce the structure response are the lengthening of the fundamental period of the buildings and deformation at the isolators. The isolation system is modeled as a bilinear hysteretic element. The isolation is assumed semi-rigid in vertical direction and has negligible torsion resistance. The seismic devices are elastomeric bearing, lead rubber bearing and friction/sliding bearing. These bearings are multilayered and laminated bearings with a circular hole. Lead plug is inserted to increase the damping of isolation device. The elastomeric lead rubber bearing systems consist of the fixing plates at top and bottom, several layers of elastomer, steel shims and a lead core. The elastomeric provides the lateral flexibility, and the steel shims provide the resisting capacity of vertical load. The lead core provides the energy dissipation and damping. During the seismic excitation of buildings, the rubber layers deform laterally by shear deformation, and allowing the building to translate horizontally and absorbing energy when the lead core yields. The lead rubber bearing system can be considered a linear viscoelastic element or a linear elastic-perfectly plastic element by bilinear model.

2. LEAD RUBBER BEARING (LRB)

Base isolation is an important device for protecting building from earthquake excitations. Base isolation is to isolate a structure from the external ground excitation. During the earthquake, the lead rubber bearing effectively reduces the ground acceleration by extending the period of structure vibration and a concentration of seismic demand at the isolation level. The lead rubber bearing composes of layers of rubber, layers of steel plate and a solid lead core in the middle of bearing, which form a bearing with strong vertical stiffness and low horizontal stiffness. During the deformation in the horizontal direction by earthquake, the lead core dissipates the energy of earthquake. The rubber acts as a spring system, it is very soft laterally but very stiffness vertically. The high vertical stiffness is achieved by the thin layer of rubber reinforced by steel plate shims.

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The lead core provides damping by plastic deformation when the isolator moves laterally in an earthquake. The building with base isolation remains its original shapes and avoids damages because the lead rubber bearing dissipates the inertial force upon the building, extends the period of building and decrease the acceleration of the building. High damping rubber bearing is composed of special rubber with excellent damping attribute and layers of steel without lead plug, which enable it to absorb large energy of earthquake, taking its high elasticity, friction damping and viscos damping. To protect the building from deformations and damages, high damping rubber bearing becomes very flexible in horizontal direction so that they can reduce the earthquake force by changing its own shape. The rubber bearing can spring back to its original shape after earthquake owing to high elastomeric property and stable bilinear behavior. The smooth hysteresis of high damping rubber bearing is reliable in the performance of safety. The lead core controls the lateral displacements of building and absorbs a part of the seismic energy. The plastic of the lead core provides an important hysteretic behavior. The hysteric behavior has the bilinear approximation expressed in force-displacement. Rubber material has different kinds of elastic modulus. The hysteretic of elasto-plastic characteristics is possible to fine adjust by varying the lead plug diameter. Elastic sliding bearing is composed of the natural rubber bearing bonded with PTFE material and stainless steel slide pate, small displacement is absorbed by the rubber and large displacements cause the rubber bearing to slide the plate. The bearing has different friction coefficient and damping.

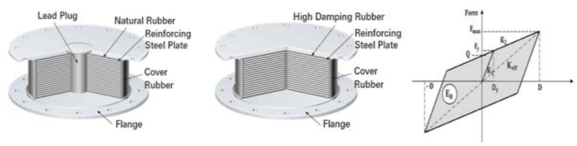


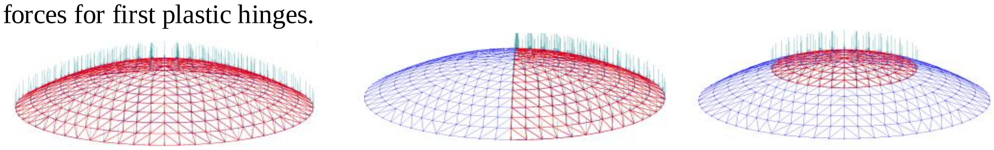
Figure 1: Lead rubber bearing and high damping rubber bearing

The lead rubber bearing assumes that the response relationship is bilinear model. K1 is the elastic shear stiffness of lead rubber bearing. K2 is post yield stiffness. Q is the zero-displacement force, Fy is the yield force, Keff is the effective stiffness. Fmax is maximum design force of the isolator. Dy is the yield displacement. D is the maximum displacement. Q depends on lead plug area. The yield strength is associated with Fy=Q/(1-K2/K1). The design recommendation for bilinear model is K2/K1=0.1.

3. 100M SPAN SINGLE-LAYERED LATTICE DOME

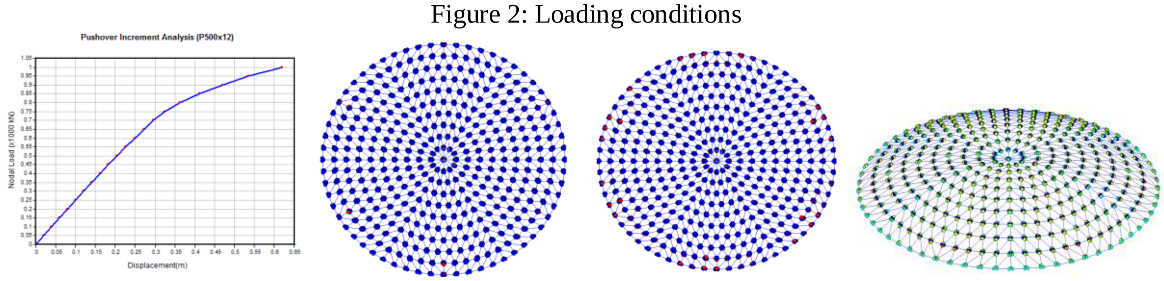
3.1. Pushover increment analysis of a lattice dome according to loading conditions

The model is single-layered lattice dome with 100m diameters. The loading conditions are three types for full loading, half loading and central loading condition. This study is to investigate the load-displacement curve, plastic hinge progressive status and axial forces for first plastic hinges.



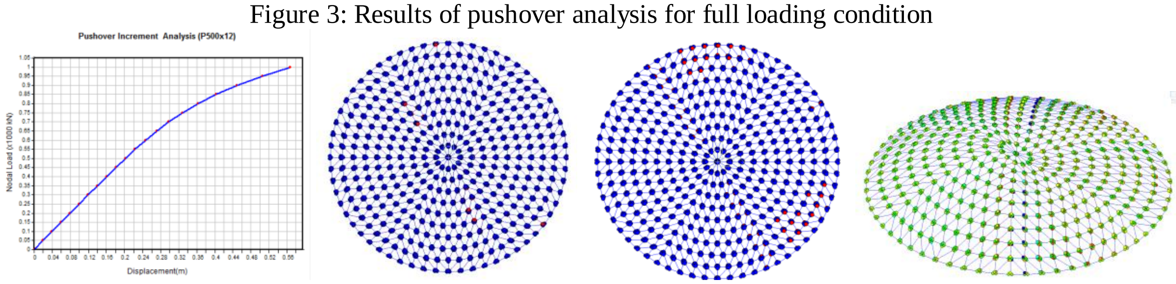
(a)Full loading (b)Half loading (c)Central loading

Figure 2: Loading conditions



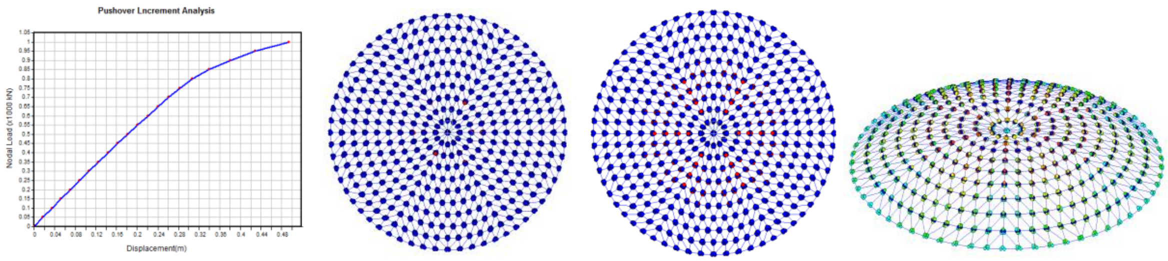
(a)Load-displacement curve (b)Step 10(500kN) (c)Step 14(700kN) (d)Axial forces(-5555kN, step10)

Figure 3: Results of pushover analysis for full loading condition



(a)Load-displacement curve (b)Step 11(550kN) (c)Step 13(650kN) (d)Axial forces(-5556kN, step11)

Figure 4: Results of pushover analysis for half loading condition

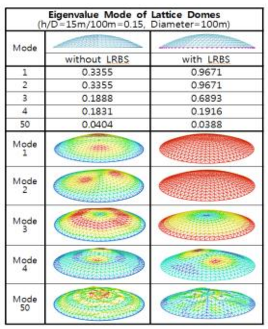


(a)Load-displacement curve (b)Step 15(750kN) (c)Step 16(800kN) (d)Axial forces(-5662kN, step15)

Figure 5: Results of pushover analysis for central loading condition

3.2. Earthquake response of a lattice dome without lead rubber bearing

This study is to investigate the earthquake response of a lattice dome without lead rubber bearing seismic isolation device. The earthquake is the combination of El Cento earthquake's ground motion. The eigenvalue mode and time history analysis are carried out the investigation of periods and seismic response of lattice dome. The results show deformation, axial forces of members, stresses at the peak response and time history for accelerations response.



Mode	without LRBS	with LRBS
1	0.3355	0.9671
2	0.3355	0.9671
3	0.1888	0.6893
4	0.1831	0.1916
50	0.0404	0.0388

Figure 6: Eigenvalue mode analysis

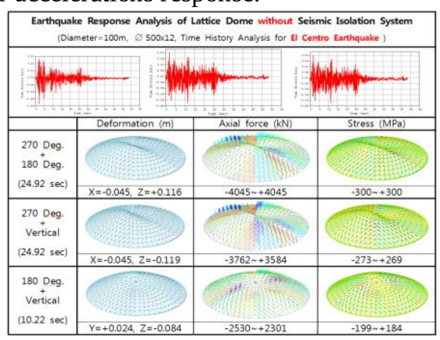


Figure 7: Earthquake response analysis

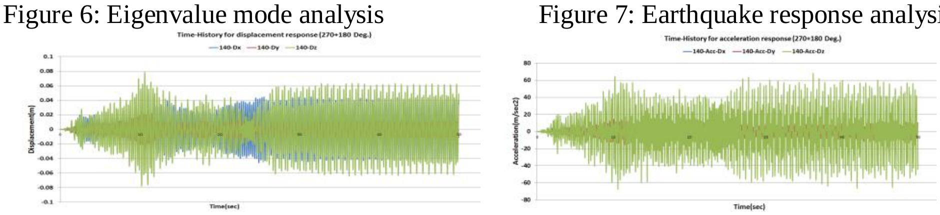


Figure 8: Response for linear time history analysis (270+180, t=24.92)

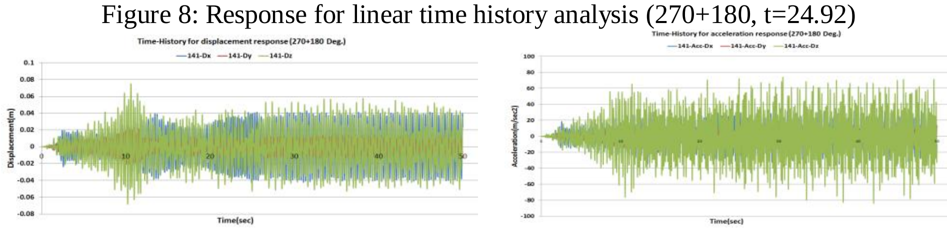


Figure 9: Response for nonlinear large deformation analysis (270+180, t=24.92)

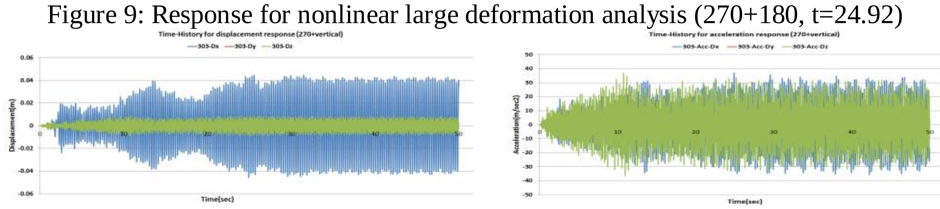


Figure 10: Response for linear time history analysis (270+vertical, t=24.92)

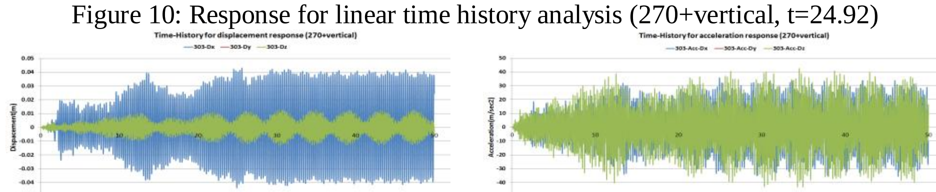


Figure 11: Response for nonlinear large deformation analysis (270+vertical, t=24.92)

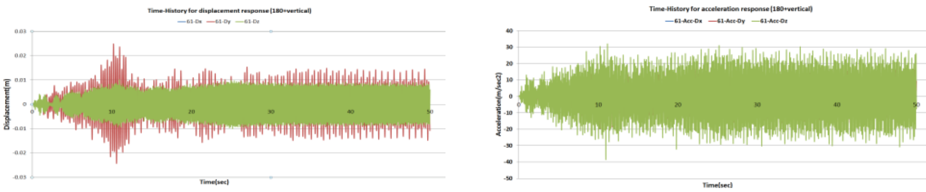


Figure 12: Response for linear time history analysis (180+vertical, t=10.22)

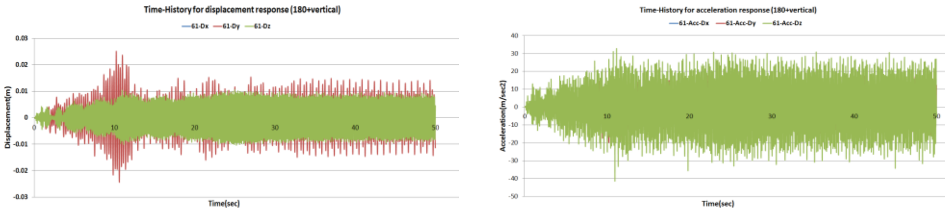


Figure 13: Response for nonlinear large deformation analysis (180+vertical, t=10.22)

3.3. Earthquake response of 100m span lattice dome with lead rubber bearing

The single-layered lattice dome with lead rubber bearing seismic isolation system is carried out the earthquake response analysis for El Centro earthquake. The results show the displacement history and acceleration response of the linear and nonlinear time history analysis. The results of the displacement and acceleration response provide different distribution for the time history curve. The horizontal displacement of the dome increases, on the other hand, vertical displacement greatly decreases by a lead rubber bearing. The maximum stress reduced from 70% to 82% by a lead rubber bearing.

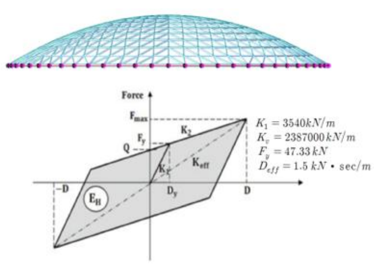


Figure 14: Lead rubber bearing system

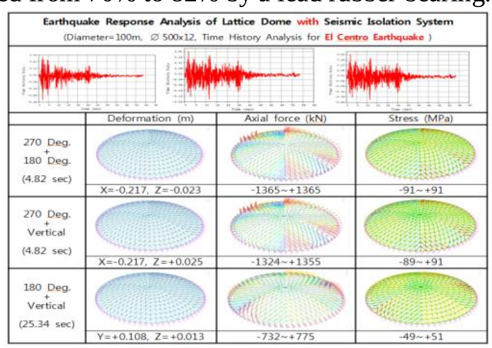


Figure 15: Earthquake response analysis

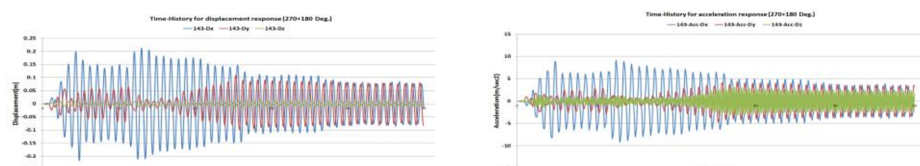


Figure 16: Response for linear time history analysis (270+180, t=4.82)

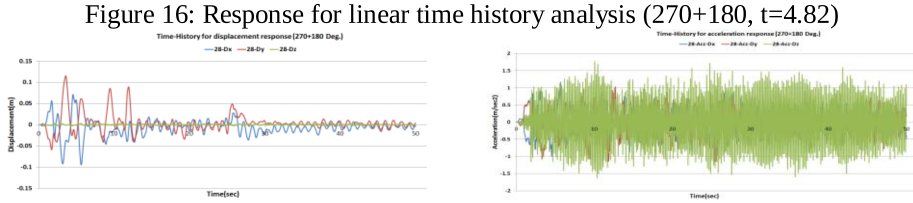


Figure 17: Response for nonlinear large deformation analysis (270+180, t=3.59)

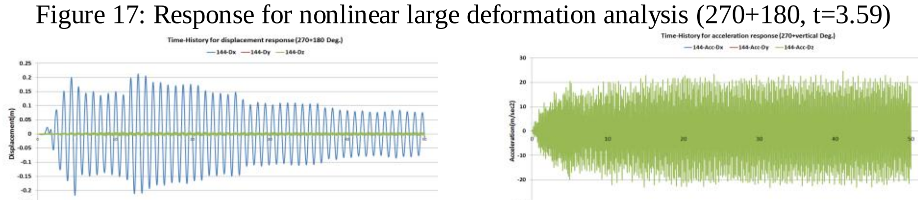


Figure 18: Response for linear time history analysis (270+vertical, t=4.82)

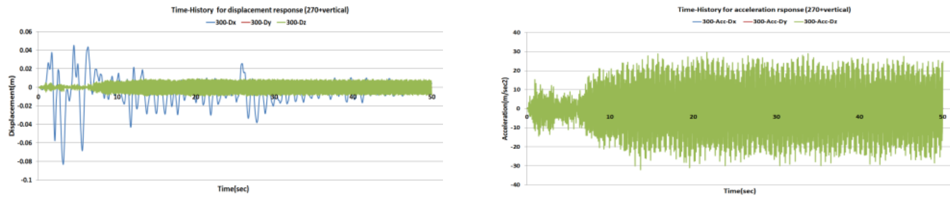


Figure 19: Response for nonlinear large deformation analysis (270+vertical, t=3.14)

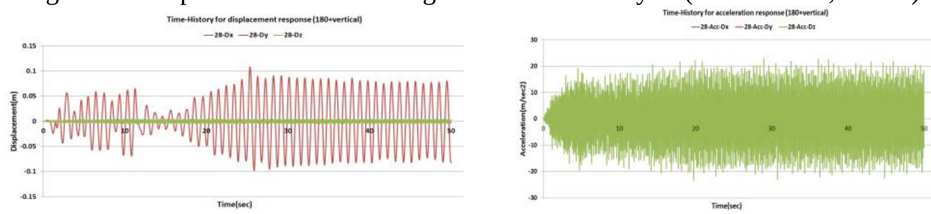


Figure 20: Response for linear time history analysis (180+vertical, t=25.34)

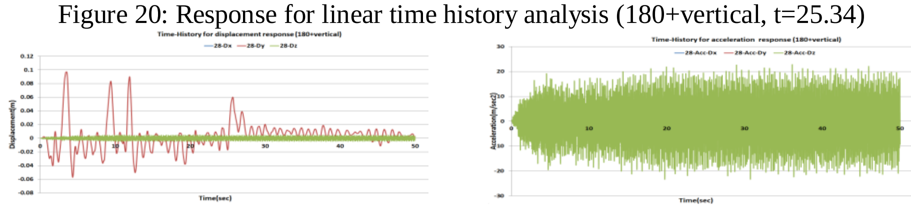
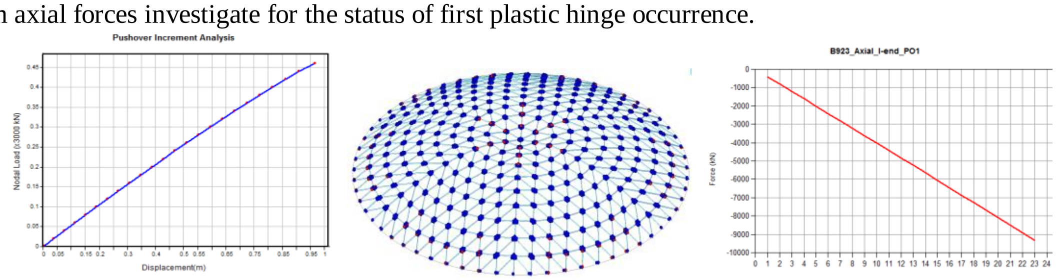


Figure 21: Response for nonlinear large deformation analysis (180+vertical, t=3.53)

4. 300M SPAN SINGLE-LAYERED LATTICE DOME

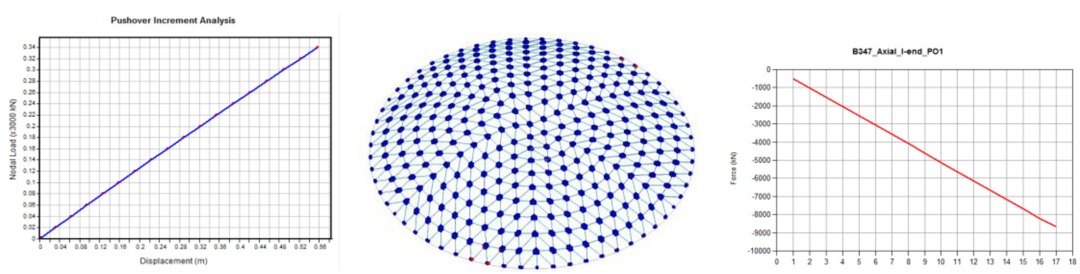
4.1. Pushover increment analysis of a lattice dome according to loading conditions

The research is to analysis the load-displacement curve and plastic hinge status of 300m span single-layered lattice dome, and the maximum axial forces investigate for the status of first plastic hinge occurrence.



(a)Load-displacement curve (b)Plastic hinge status (c)Compression forces

Figure 22: Load-displacement curve and plastic hinge progressive status for full loading condition



(a)Load-displacement curve (b)Plastic hinge status (c)Compression forces

Figure 23: Load-displacement curve and plastic hinge progressive status for half loading condition

4.2. Earthquake response analysis of 300m span dome with and without lead rubber bearing

The objective of this research is to investigate the response reducing effect of a seismic isolation system installed between 300m span dome and supports under both horizontal and vertical seismic ground motion. The time history analysis is performed to investigate the dynamic behavior of 300m span single-layered lattice domes with and without a lead rubber bearing for seismic isolation system. In order to ensure the seismic performance of lattice domes against strong earthquakes, it is important to investigate the mechanical characteristics of dynamic response. Horizontal and vertical seismic ground motions cause a large asymmetric vertical response of large span domes. One of the most effective methods to reduce the dynamic response is to install a seismic isolation system for observing seismic ground motion at the base of the dome. This research discusses the dynamic response characteristics of 300m span single-layered lattice domes under horizontal and vertical seismic ground motions.

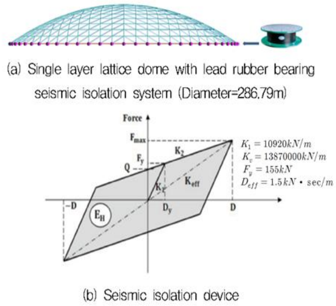


Figure 24: Lattice dome

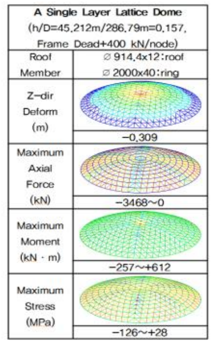


Figure 25: Results for dead load

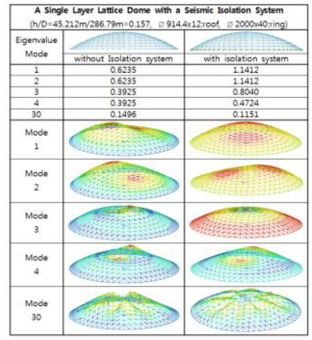


Figure 26: Eigenvalue analysis

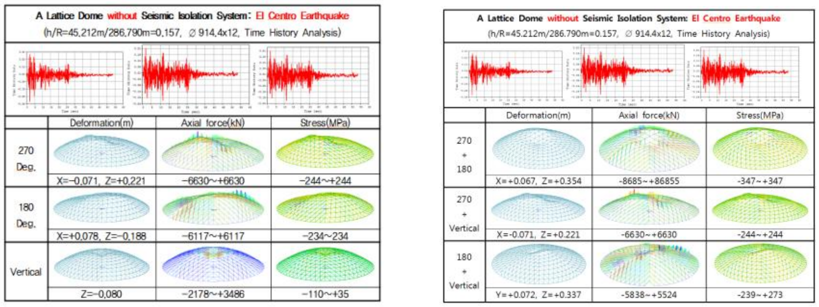


Figure 27: Earthquake response of a dome without a lead rubber bearing for seismic isolation

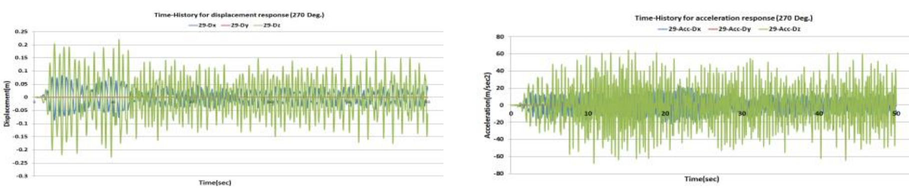


Figure 28: Response for a dome without seismic isolation system (270 Deg., t=10.77)

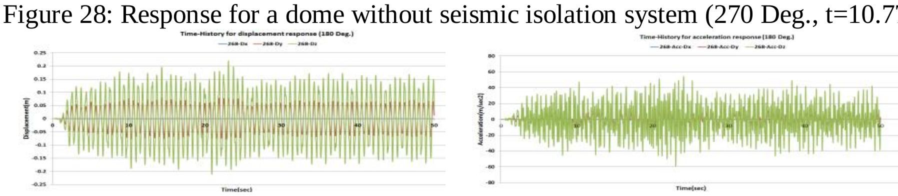


Figure 29: Response for a dome without seismic isolation system (180 Deg., t=16.49)

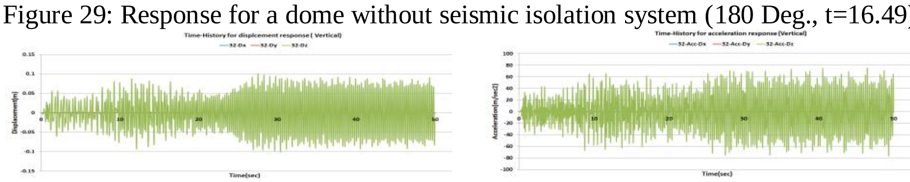


Figure 30: Response for a dome without seismic isolation system (Vertical, t=28.18)

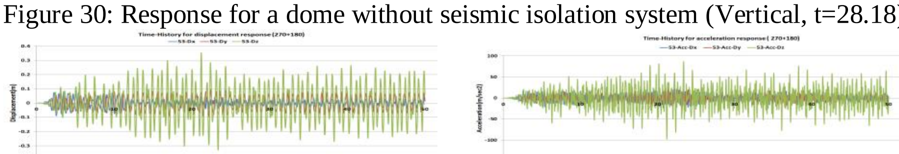


Figure 31: Response for a dome without seismic isolation system (270+180 Deg., t=21.22)

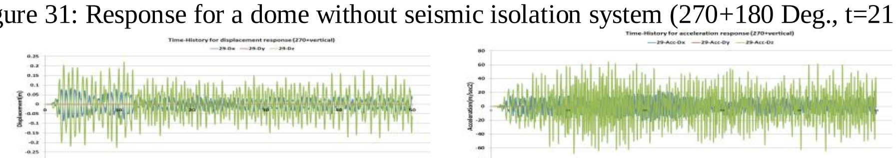


Figure 32: Response for a dome without seismic isolation system (270+vertical, t=10.77)

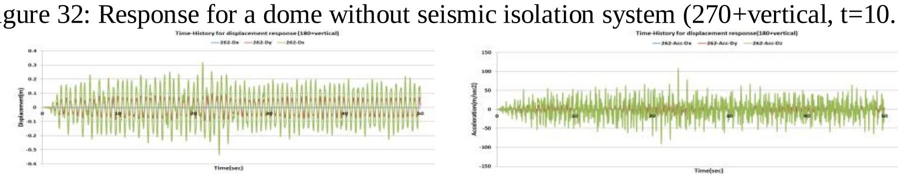


Figure 33: Response for a dome without seismic isolation system (180+vertical, t=23.39)

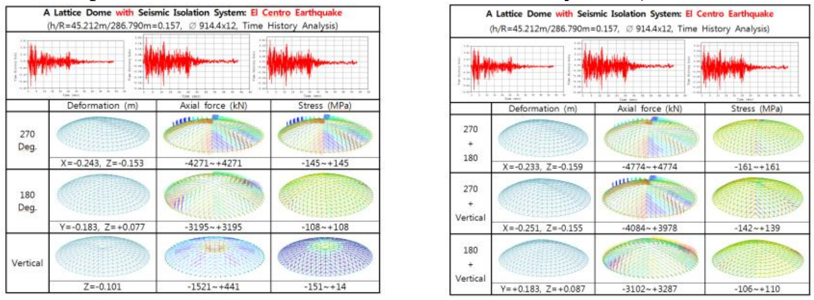


Figure 34: Earthquake response of a dome with a lead rubber bearing for seismic isolation

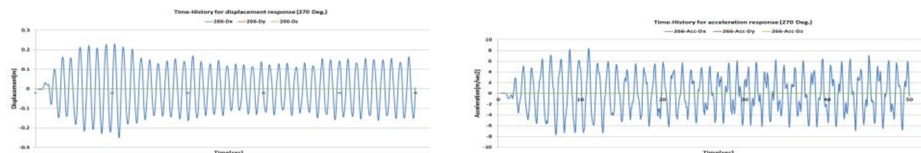


Figure 35: Response for linear time history analysis (270 Deg., t=11.04)

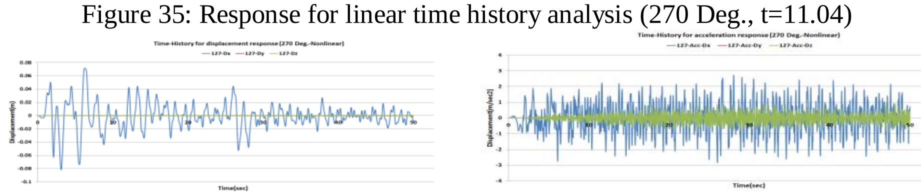


Figure 36: Response for nonlinear large deformation analysis (270 Deg., t=3.14)

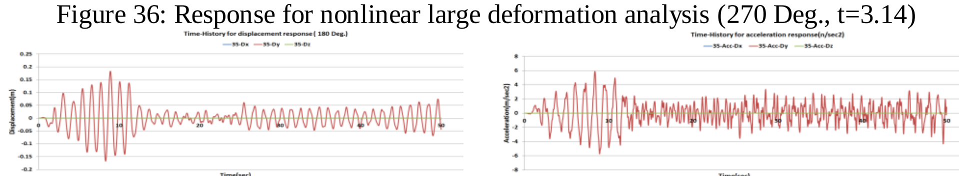


Figure 37: Response for linear time history analysis (180 Deg., t=8.92)

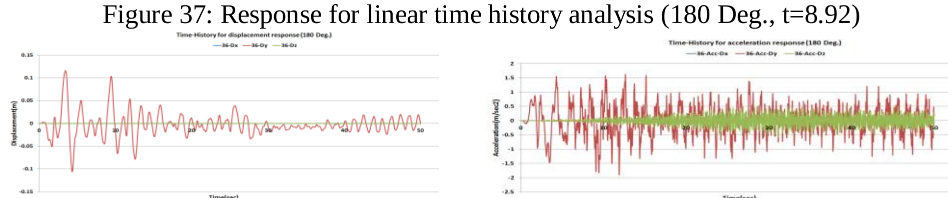


Figure 38: Response for nonlinear large deformation analysis (180 Deg., t=3.45)

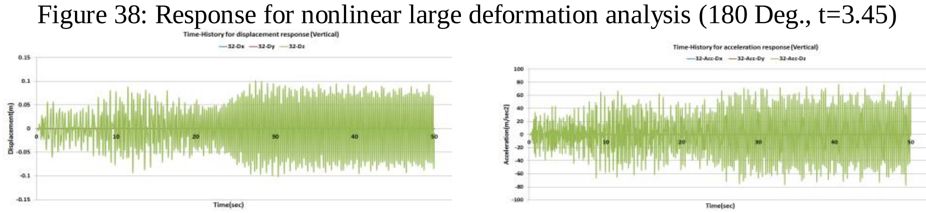


Figure 39: Response for linear time history analysis (Vertical, t=30.39)

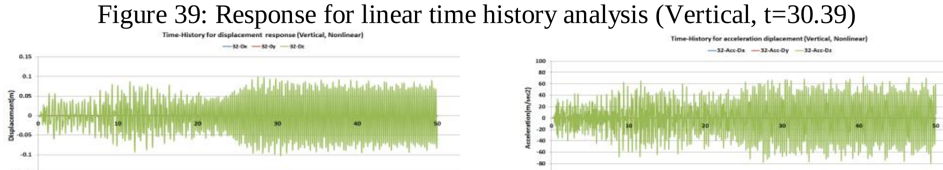


Figure 40: Response for nonlinear large deformation analysis (Vertical, t=30.39)

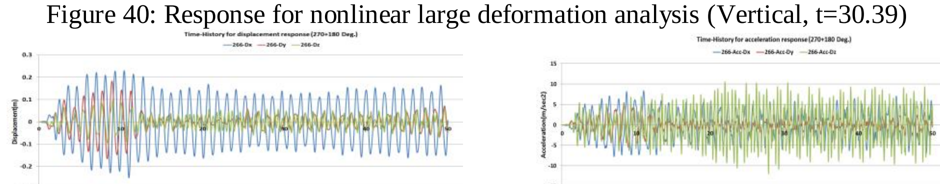


Figure 41: Response for linear time history analysis (270+180 Deg., t=11.06)

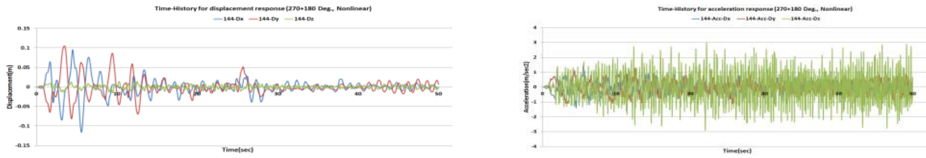


Figure 42: Response for nonlinear large deformation analysis (270+180 Deg., t=5.61)

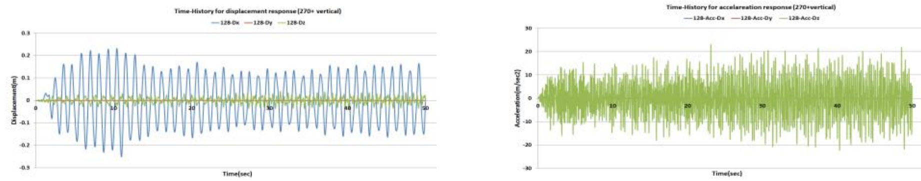


Figure 43: Response for linear time history analysis (270+vertical, t=10.99)

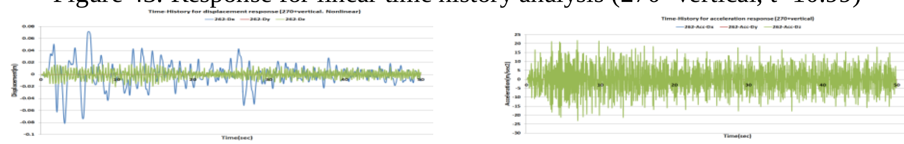


Figure 44: Response for nonlinear large deformation analysis (270+vertical, t=3.13)

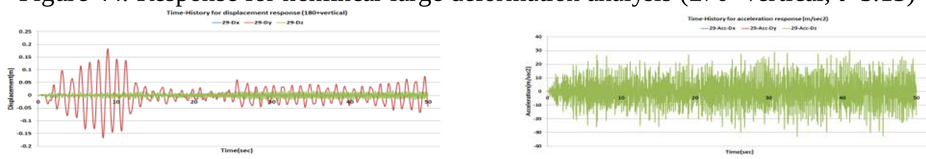


Figure 45: Response for linear time history analysis (180+vertical, t=8.92)

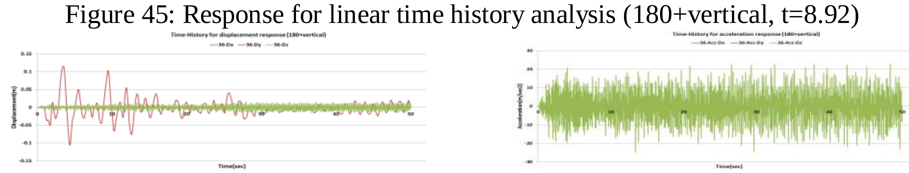


Figure 46: Response for nonlinear large deformation analysis (180+vertical, t=3.45)

5. CONCLUSION

In this study, the dynamic response of building for El Centro earthquake was analyzed for a single layer lattice dome with a diameter of about 300 m. The analysis of the dynamic response for the case with and without the lead rubber isolation system showed that the isolation device reduced the maximum stress of the dome decreased by 46%. The maximum axial force and the maximum stress were slightly larger in the case of the combination of two directional earthquakes than in the dynamic response to one directional earthquake. Dynamic responses to the combination of two direction earthquakes can be expected to have good results, because of the irregular nature of the dynamic response of structures for one directional earthquake. Large-span lattice dome caused not only horizontal deformation but also vertical deformation of horizontal earthquakes. The results of the linear analysis and the nonlinear large deformation analysis of domes without base isolation system are not significantly different in the case of the absence of the seismic isolation device. The acceleration response showed when the response of domes with the seismic device can be greatly reduced than the response of dome without the seismic isolation device. The lattice domes with base isolation remains its original shapes and avoids damages because the lead rubber bearing dissipates the inertial force upon the structure, extends the period of structure and decrease the acceleration of the structure. The lead rubber bearing effectively reduces the ground acceleration by extending the period of structure vibration.

6. REFERENCES

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