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DYNAMIC RESPONSE ANALYSIS OF SPATIAL LATTICE DOMES WITH SEISMIC ISOLATION BEARING SYSTEM

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Abstract- The objective of this study is to analyze the seismic response characteristics of 200m and 300m spanned lattice domes under both horizontal and up-down ground motion of El Centro earthquake. For the analysis of earthquake response of lattice domes, the time history analysis is used for the estimation of the dynamic response. Horizontal and up-down earthquake ground motions cause a large asymmetric vertical deformation in the large span domes. This study is to analysis the seismic characteristics of lattice domes for eigenvalue modes, displacement and acceleration response. The earthquake response of lattice domes with LRB isolation bearing by the horizontal and up-down combined ground motion is significantly reduced for the asymmetric vertical deformation and accelerations of domes.
Keywords – 100m, 200m and 300m spanned single-layer lattice dome, Earthquake ground motion, Lead rubber bearing seismic isolation system, Dynamic response

1. INTRODUCTION

The construction of spatial lattice domes is increasingly in fields of spatial structures such as theaters, botanical gardens, exhibition halls, sports facilities, bio domes. The spatial domes are aesthetically and mechanically attractive. In recent years, earthquakes have been occurring frequently throughout the world, and therefore, the various studies of building design for an earthquake is required in the dynamic response of structures. It is necessary to evaluate the combined earthquake motion for the horizontal and vertical earthquake ground motion in seismic design. Especially, the asymmetrically vertical deformation of large spatial structure is highly affected by the horizontal earthquake ground motion, but it is very sensitive to the dynamic response of large span lattice domes for the vertical ground motion. In case of actual earthquake, the up and down ground motion occurred in El Centro earthquake and Kobe earthquake. In the case of the dynamic response of large spatial structure, the influence of up and down ground motion should be evaluated. For 3-dimensional earthquake motions, it is applied to the 100% in the main ground motion, 30% of the ground motion in the perpendicular direction and vertical ground motion at the same time. Since it is very difficult to consider all the dynamic effects of earthquakes in the design of buildings, there are many damages in which structures or members are broken or collapsed when an actual earthquake occurs. Therefore, it is necessary to evaluate dynamic response of structures for applying 3 dimensional earthquake ground motions according to the system and form of the building [1, 2, 3, 4].

The seismic isolation devices used in reducing the acceleration response by the extension of period of the structure, and absorbing the seismic energy due to the damping performance of the seismic isolator, and controlling the horizontal deformation of the structure to greatly reduce the response acceleration. The lead rubber seismic system has the high vertical support capacity and the high elastic deformation to extend the period of structures, and absorb the seismic energy in the isolation system, thereby it can greatly reduce the deformation of the upper structure [1, 2, 3, 4]. In this study, the dynamic response of 100m, 200m and 300m lattice domes by the seismic ground motions of the horizontal and vertical directions was analyzed, and the reducing effect of dynamic response of the LRB isolation device installed on the support of the domes were investigated. The time history analysis was performed using Midas Gen 2019.

2. 100M SPANNED LATTICE DOMES

The seismic response of 100m single-layer lattice dome is compared with the model without installed LRB isolation device and the installed model. The structural model has a diameter of 100m and a height of 20m. 60 seismic isolation devices were installed at the support, and the device is assumed to be a bi-linear spring model. The seismic isolation system applies the data for the linear hysteresis. The vertical stiffness Kv is 1087 kN/mm, the effective stiffness Keff is 1.11 kN/mm, the yield displacement is 16 mm, the maximum displacement is 400 mm, the yield force Fy is 172 kN, maximum horizontal force is 368 kN.

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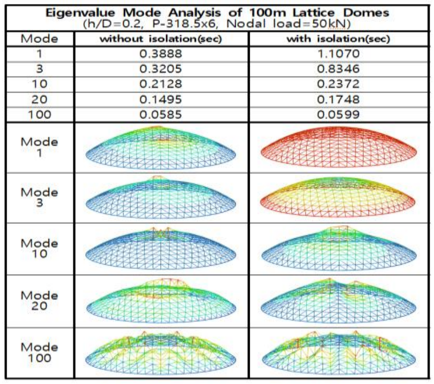


Figure 1. Eigenvalue mode analysis

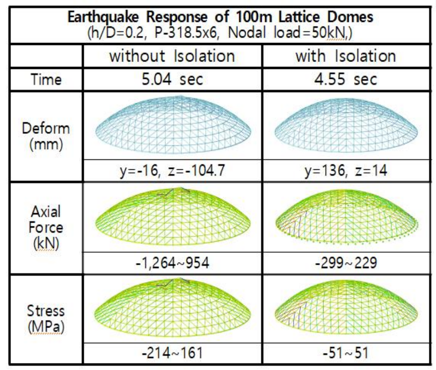
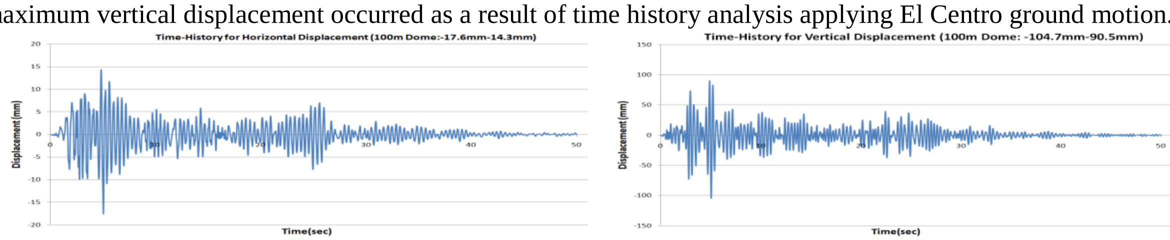


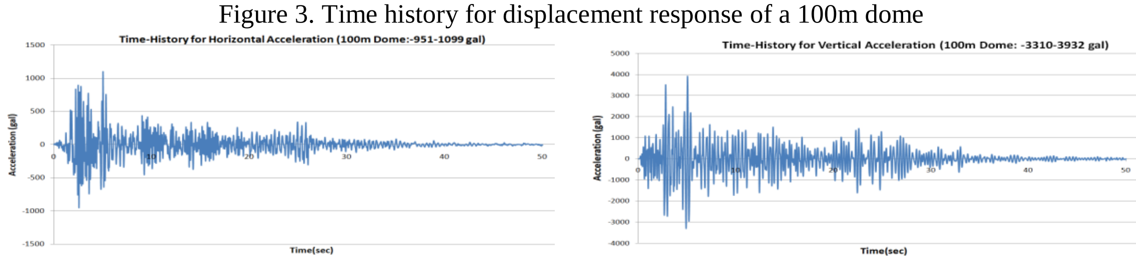
Figure 2. Earthquake response analysis

Figure 1 compares the period and mode shapes of the dome installed with and without the isolation device as a result of eigenvalue analysis from the first mode to the 100th mode. The period of the first mode was increased from 0.3888 to 1.070 by the isolation device. The 1st mode, is the S-shaped reverse asymmetrical mode, the other modes are the shape in which the central upper part of the dome vibrates up and down. When an isolation device is installed, the 1st mode has a mode shape with small deformation of the dome. The mode is a shape in which the central upper part of the dome rises up. In the 10th mode, the central part of the dome is in the shape of an S-shaped anti-symmetric vibration mode. The 100th mode is a mode shape in which the dome oscillates up and down. The LRB seismic isolator is a shape with small deformation of the dome in the 1st and 2nd modes. In this study, the dynamic response of a 100m lattice dome is analyzed through time history analysis of three dimensional ground motion (270Deg.+0.3x180 Deg.+UD) of El Centro earthquake. Since the lattice dome with an isolation device is in the elastic range, the upper structure can be assumed an elastic model. Since the upper lattice dome is less deformed, the damping constant should not be overestimated. The damping constant is about 1% in the case of steel frame (about 2% in reinforced concrete structure). The effective damping constant of the steel lattice dome applied in this study was 2%, and the damping constant of the lattice dome equipped with the isolation device was 1%. A bi-linear model can be assumed as a damper for the laminated lead rubber device. Figure 2 shows the deformation, axial forces and stress when maximum vertical displacement occurred as a result of time history analysis applying El Centro ground motion.



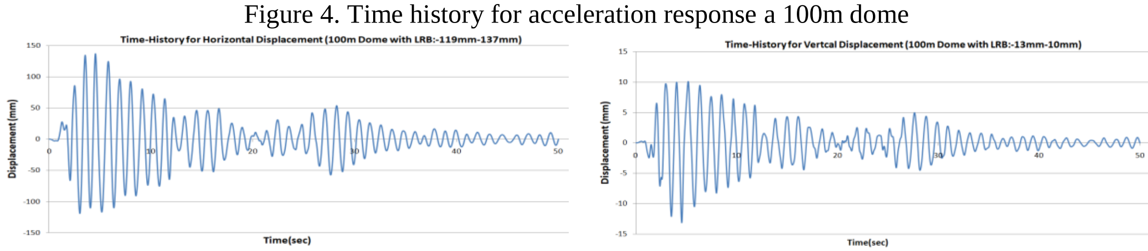
(a) Horizontal displacement (b) Vertical displacement

Figure 3. Time history for displacement response of a 100m dome



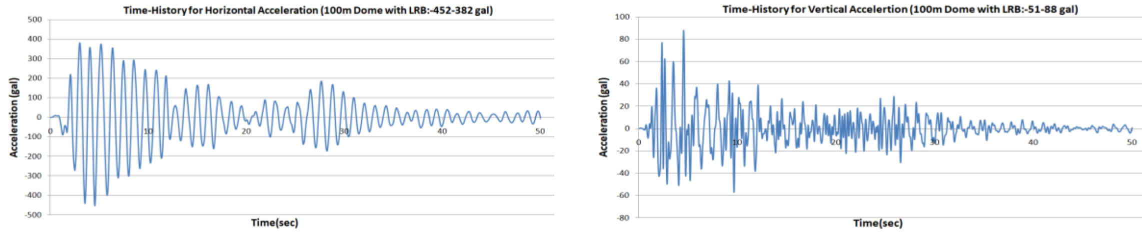
(a) Horizontal acceleration (b) Vertical acceleration

Figure 4. Time history for acceleration response a 100m dome



(a) Horizontal displacement (b) Vertical displacement

Figure 5. Time history for displacement response of a 100m dome with LRB



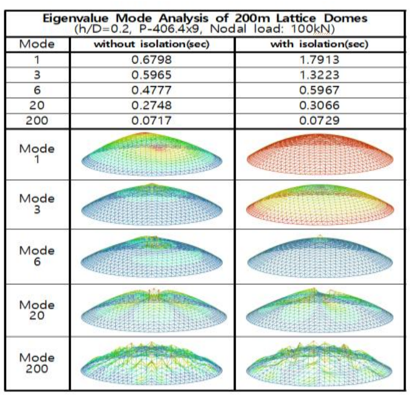
(a) Horizontal acceleration (b) Vertical acceleration

Figure 6. Time history for acceleration response a 100m dome with LRB

Figure 1, 2, 3 and 4 are the displacement and the acceleration in the horizontal direction and the vertical direction. Figure 6, 7, 8 and 9 are the responses to displacement and acceleration for horizontal and vertical directions of a dome installed with an isolation bearing. By the seismic isolation bearing the maximum horizontal displacement increased 17.6mm to 137mm, and the maximum vertical displacement decreased 104.7mm to 13mm. The maximum axial force decreased 1,264kN to 299kN, and the maximum stress decreased 214MPa to 51MPa. The vertical displacement decreased 87.6%, the maximum axial force decreased 76.3%, and the maximum stress decreased 76.2%. The horizontal acceleration decreased 58.9% (1,099gal to 452gal) and the vertical acceleration decreased 87.7% (3,932gal to 88gal).

3. 200M SPANNED LATTICE DOMES

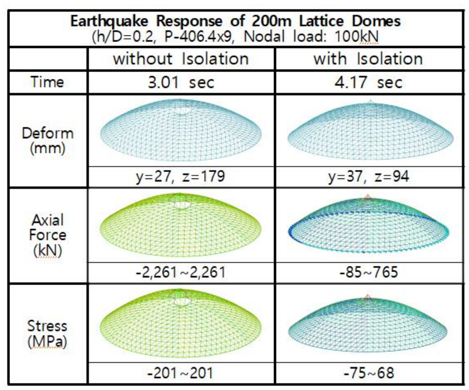
The seismic response of the 200m single layer lattice dome was compared with the model with and without installed LRB isolation bearing. The diameter of the structural model is 200m and the height is 40m. The mechanical characteristics of a lead rubber bearing are follows. The vertical stiffness is Kv=1,176kN/mm, the effective stiffness is Keff=1.28kN/mm, the maximum displacement is 400mm, the yield force is Fy=197kN, the maximum horizontal force is 427kN, and the breaking force is 512 kN. Figure 7 is the result of eigenvalue mode analysis for a 200m lattice dome with and without the lead rubber bearing. Figure 8 is the comparison of the earthquake response of 300m lattice domes with and without lead rubber bearing.



Eigenvalue Mode Analysis of 200m Lattice Domes (h/D=0.2, P-406.4x9, Nodal load: 100kN)

Mode	without isolation(sec)	with isolation(sec)
1	0.6798	1.7913
3	0.5965	1.3223
6	0.4777	0.5967
20	0.2748	0.3066
200	0.0717	0.0729
Mode 1		
Mode 3		
Mode 6		
Mode 20		
Mode 200		

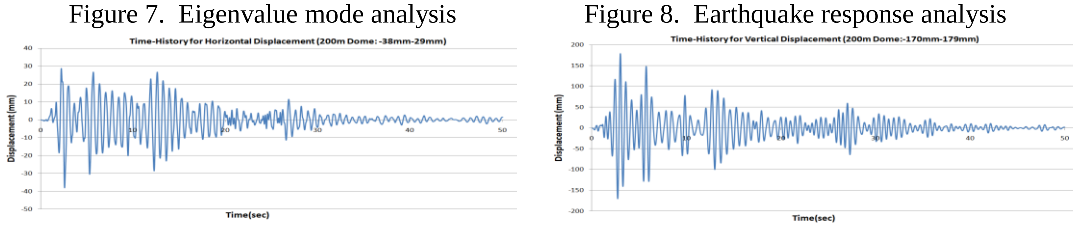
Figure 7. Eigenvalue mode analysis



Earthquake Response of 200m Lattice Domes (h/D=0.2, P-406.4x9, Nodal load: 100kN)

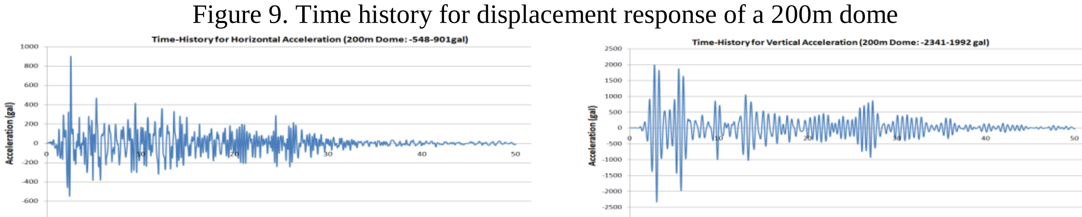
	without Isolation	with Isolation
Time	3.01 sec	4.17 sec
Deform (mm)	y=27, z=179	y=37, z=94
Axial Force (kN)	-2,261~2,261	-85~765
Stress (MPa)	-201~201	-75~68

Figure 8. Earthquake response analysis



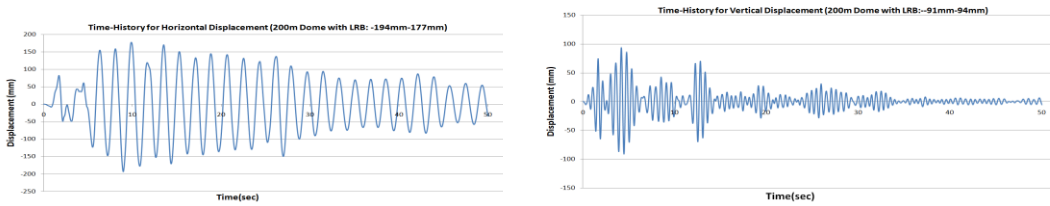
(a) Horizontal displacement (b) Vertical displacement

Figure 9. Time history for displacement response of a 200m dome



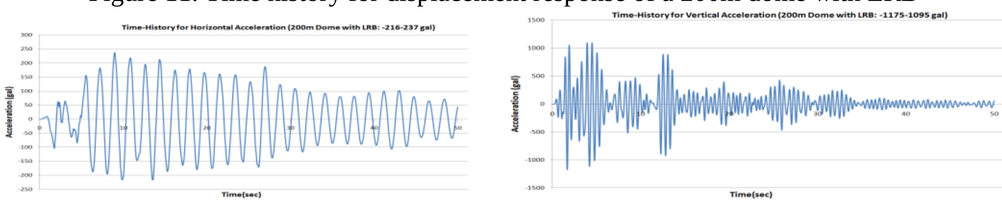
(a) Horizontal acceleration (b) Vertical acceleration

Figure 10. Time history for acceleration response a 200m dome



(a) Horizontal displacement (b) Vertical displacement

Figure 11. Time history for displacement response of a 200m dome with LRB



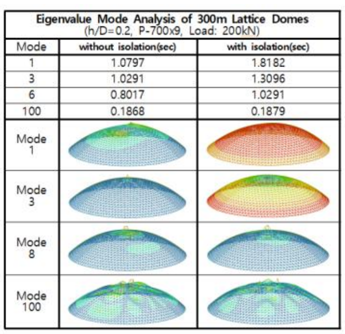
(a) Horizontal acceleration (b) Vertical acceleration

Figure 12. Time history for acceleration response a 200m dome with LRB

In Figure 9, the vertical displacement was reduced 179 mm to 94 mm and the axial force was reduced from 2,261kN to 765kN. The stress was reduced 201MPa to 75MPa. The vertical displacement was reduced by 47.5%, the axial force by 66.2%, and the stress by 64.3%. The horizontal acceleration (-548~901gal) was reduced by the isolation device 73.7% (LRB: -216-237gal), and the vertical acceleration (-2,341~1,992gal) was greatly decreased 49.8% (LRB: -1,175~1,095gal). The bottom shear force decreased 35%.

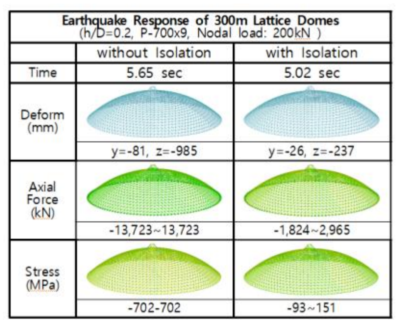
4. 300M SPANNED LATTICE DOMES

The seismic response of the 300m single layer lattice dome is compared with and without installed LRB isolation bearing. The diameter of the structural model is 300m and the height is 60m. In the lead rubber bearing system, the vertical stiffness Kv is 3,560 kN/mm, the effective stiffness Keff is 3.53 kN/mm, the yield displacement is 22 mm, the maximum horizontal displacement is 400 mm, the shear yield force Fy is 434kN, maximum shear force is 1,177 kN, and fracture shear forces is 1,412kN.



Eigenvalue Mode Analysis of 300m Lattice Domes (h/D=0.2, P-700x9, Load: 200kN)		
Mode	without isolation(sec)	with isolation(sec)
1	1.0797	1.8182
3	1.0291	1.3096
6	0.8017	1.0291
100	0.1868	0.1879
Mode 1		
Mode 3		
Mode 8		
Mode 100		

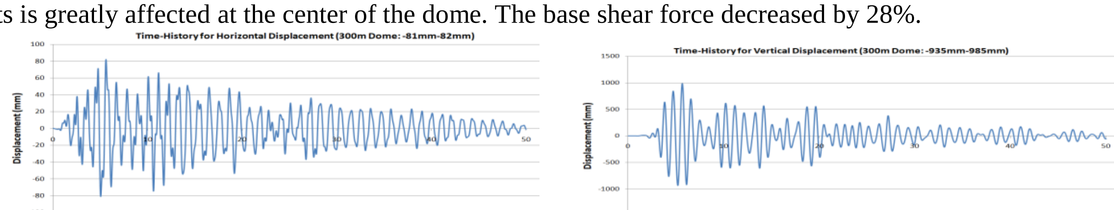
Figure 13. Eigenvalue mode analysis



Earthquake Response of 300m Lattice Domes (h/D=0.2, P-700x9, Nodal load: 200kN)		
	without Isolation	with Isolation
Time	5.65 sec	5.02 sec
Deform (mm)	y=-81, z=-985	y=-26, z=-237
Axial Force (kN)	-13,723~13,723	-1,824~2,965
Stress (MPa)	-702-702	-93~151

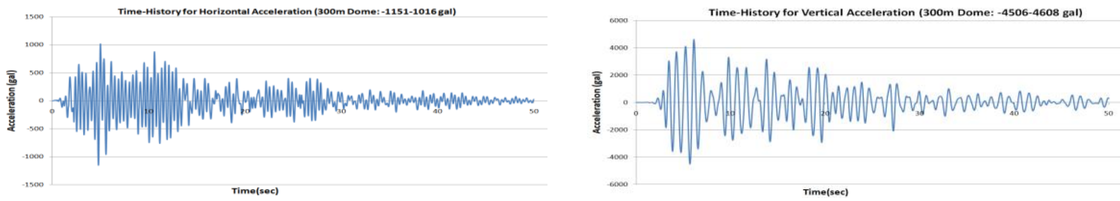
Figure 14. Earthquake response analysis

In the eigenvalue analysis of the 300m single layer lattice dome, the first mode is an S-shaped mode, the 3rd mode is an upward mode, and the 8th mode is a vertically oscillating mode. In the case of an isolation device, the first mode is an S-shaped mode, the 3rd mode is a symmetric upward shape of the lower part of the dome, and the 8th mode is an S-shaped mode. The vertical displacement decreased from 985mm to 237mm and the horizontal displacement increased 82mm to 205mm. The axial force decreased 13,723kN to 2,965kN and the stress decreased from 702MPa to 151MPa. The axial force and stress were reduced about 78.5%. The 300m single layer lattice dome shows that the response to the up and down ground movements is greatly affected at the center of the dome. The base shear force decreased by 28%.



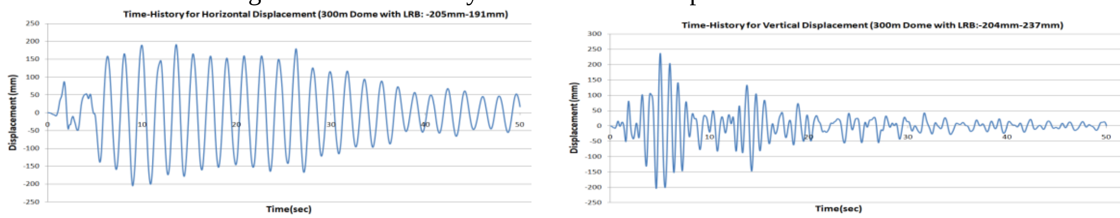
(a) Horizontal displacement (b) Vertical displacement

Figure 15. Time history for displacement response of a 200m dome



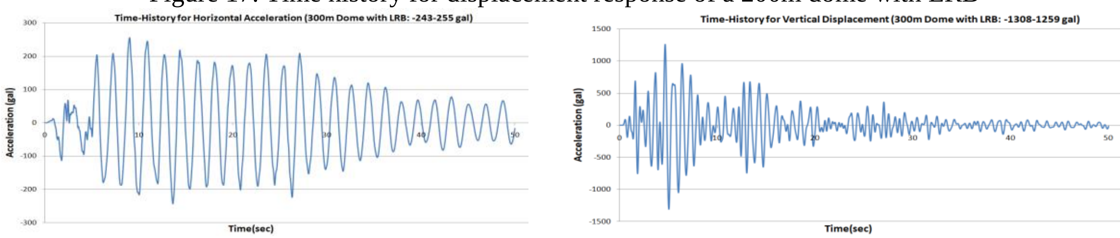
(a) Horizontal acceleration (b) Vertical acceleration

Figure 16. Time history for acceleration response a 200m dome



(a) Horizontal displacement (b) Vertical displacement

Figure 17. Time history for displacement response of a 200m dome with LRB



(a) Horizontal acceleration (b) Vertical acceleration

Figure 18. Time history for acceleration response a 200m dome with LRB

5. CONCLUSION

As a result of the seismic response analysis by time history analysis for 100m, 200m and 300m lattice domes, it can be confirmed that the installation of the seismic isolation bearing installed the lower part of the lattice dome has a great reduction effect for the asymmetric vertical deformation and accelerations against the earthquake ground motion. The LRB seismic isolator absorbed the seismic energy by increasing the horizontal displacement and greatly reduces the vertical displacement, thereby greatly reducing the axial forces and stresses of the members. In the 100m single layer lattice dome, the vertical displacement was reduced by 87.6%, and the vertical acceleration decreased by 87.7%. The 200m lattice dome showed a 47.5% reduction in vertical displacement, and vertical acceleration was reduced by 49.8%. In the 300m dome, the vertical displacement was reduced by 75.9%, and the vertical acceleration decreased by 71.6%.

6. ACKNOWLEDGEMENTS

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