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The Time History Analysis of 300m Single-Layer Lattice Domes

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Abstract-The objective of this study is to investigate the dynamic response of 300m single-layer lattice domes under seismic ground motion of El Centro earthquake. For the investigation of dynamic response of the large spatial lattice domes, the time history analysis is used for the estimation of the earthquake response. The spatial lattice domes cause an asymmetric deformation and maximum stresses by the horizontal and vertical ground motion, the structural stability of a 300m lattice dome can be secured by applying the rigid connection of upper part of the dome. The proposed single-layer lattice domes with a diameter of 300m have the structural capacity to resist the ground motion of the El Centro earthquake.
Keywords – 300m single-layer lattice dome, Seismic ground motion, Time history analysis, Dynamic Response

I. INTRODUCTION

Earthquakes really pose little direct danger to a person. People can't be shaken to death by an earthquake. The first main earthquake hazard is the effect of ground shaking. Buildings can be damaged by the shaking itself. Buildings can also be damaged by strong surface waves making the ground heave and lurch. Any buildings in the path of these surface waves can tip over from all the movement. The ground shaking may also cause landslides, and avalanches on steeper hills or mountains. The second main earthquake hazard is the ground displacement, the ground displacement during an earthquake can seriously damage the structures. The horizontal and vertical ground motion during an earthquake causes a large asymmetric vertical deformation of the spatial dome. The dynamic response analysis of the earthquake ground motion is most efficient through time history analysis. The large deformation and stresses are generated at the upper part of the lattice dome, which greatly affects the safety capacity of the dome. In the dynamic response characteristic of the large spatial structure, the response in the vertical direction is large due to the horizontal and vertical ground motions. Therefore, in the case of seismic design of large spatial structure, the ground motion combining the horizontal and vertical direction is evaluated for the earthquake resistance design. Therefore, it is necessary to evaluate the dynamic response of buildings by the earthquake ground motion in three directions through time history analysis.

S. Oya, Y. Hangai, K. Kawaguchi (2000) proposed the preliminary design method of single layer lattice domes for experimental study[1]. S. Kato, S. Nakazawa, M. Uchikoshi & Y. Mukaiyama (2000) investigated the response reducing effect of a seismic isolation system installed between a large dome and a lower structure under both horizontal and vertical seismic ground motions. The isolation system was effective to greatly reduce the asymmetric vertical acceleration due to horizontal seismic ground motion [2]. T. Saka, Y. Taniguchi & T. Konishi (2000) investigated the elastic buckling loads and buckling modes of double-layer domes with various lattice pattern for full loading condition and half loading condition [3]. H. Kim & J. Kang (2016) analyzed the seismic response control performance evaluation of a retractable roof with TMD mass for spatial structures. The spatial structures was analyzed the turned mass damper to control the dynamic response for the earthquake [4]. K. Park, M. Jung & D. Lee (2018) investigated the earthquake response of 300m spanned single-layer lattice domes with and without lead rubber bearing seismic isolation device [5]. J.Y. Richard Liew (2018) presented the design challenges recent innovations and the issues related to the design and construction of complex spatial structures for Garden by the Bay and Changi Jewel in Singapore. Recent trends show that steel structure is the preferred choice and increasingly being employed to produce innovative and spectacular architectural designed with complex geometrical profiles [6].

Since the large space lattice dome is very sensitive to the up and down earthquake motions, it is necessary to analyze the dynamic characteristics of the three dimensional ground motion. In this study, to evaluate the dynamic characteristics of 300m single-layer lattice dome, the time history analysis applying 3-dimensional earthquake ground motion is performed to analyze displacement response, acceleration response, member stresses and base shear forces.

II. THE BUCKLING ANALYSIS AND EIGENVALUE ANALYSIS OF 300M LATTICE DOMES

In this study, the elastic analysis, the buckling mode analysis and the nonlinear analysis is performed. When the dome of the 300m dome is composed of all hinge joints, it is structurally weak, and then the upper part of the dome is considered to be rigid connections.

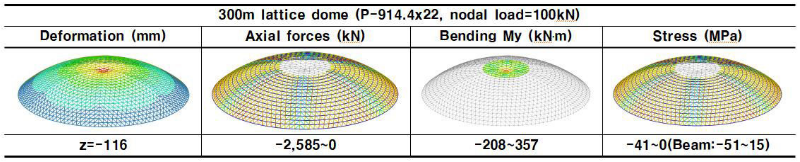


Figure 1. The static analysis for a 300m lattice dome under vertical load

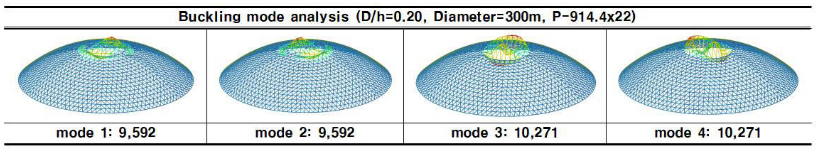


Figure 2. The buckling mode analysis for a 300m lattice dome under vertical load

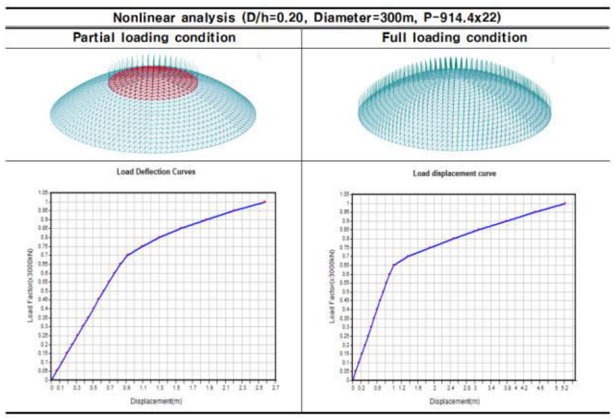


Figure 3. The nonlinear analysis for a 300m lattice dome under vertical load

Figure 1 is the results of elastic analysis for vertical loads. The maximum deflection at the top of the dome is the largest, the maximum deflection is 116mm, the maximum compression force of the member is -2,585 kN, and the maximum stress is 51 MPa. Figure 2 is the results of the buckling mode analysis, and the maximum joint load in the 1st and 2nd buckling modes is 9,592 kN. Figure 3 is the result of the nonlinear analysis assuming that the ends of the members are a tri linear elasto-plastic springs. As a result of the nonlinear analysis on two cases of the central and full load conditions, the yield load of the member is 2,100 kN, and the yield load when the vertical load acts as a whole is 1,950 kN.

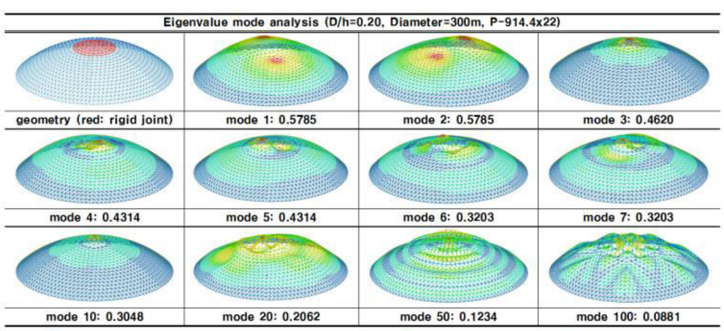


Figure 4. The results of eigenvalue analysis for 300m lattice dome

Figure 4 is the analysis results of the eigenvalue mode and period of the 300m lattice dome. In the large spatial lattice dome, the upper part of the dome is structurally weak, so that it is the rigid connection of the upper part and the other part is the hinge connection. The 1st and 2nd period are 0.5785, the 3rd period is 0.4620, and the 4th and 5th period are 0.4314. The 1st and 2nd periods are S-shaped modes in which the top of the dome is asymmetrically deformed, and the 10th period is shaped to rise upwards. The 20th, 50th, and 100th modes are the mode shape in which the top of the dome vibrates up and down.

III. TIME HISTORY ANALYSIS OF 300M LATTICE DOMES

The earthquake response analysis for the ground motion of El Centro 270 degree (PGA=0.3569gal)

Figure 5 is the result of the time history analysis of the 300m lattice dome by applying the earthquake ground motion of El Centro 270 degree. The results are deformation, axial forces and stresses at 2.80 sec. The vertical deformation was the largest at 2.80 sec. The peak vertical displacement is 212 mm, the maximum compressive force is 8,236 kN, and the maximum stress is 235 MPa (hinge member: 134 MPa). The horizontal displacement (z=212mm) is larger than the horizontal displacement (y=46mm). Figures 6 and 7 are the horizontal displacement response (-46~38mm) and the vertical displacement response (-212~187mm). Figure 8 and 9 are the acceleration response in the horizontal direction (-1,193~1,445 gal) and the vertical acceleration response (-4,232~5,532 gal). The dynamic response was greatly increased in the early part before 20 seconds and the dynamic response was gradually decreased after 20 seconds. Figure 5 shows the time history curve for the base shear forces.

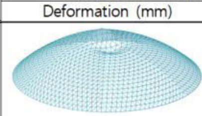
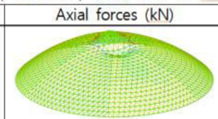
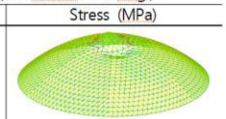
sec	300m lattice dome (P-914.4x22, nodal load=100kN, El Centro 270 Deg.)		
	Deformation (mm)	Axial forces (kN)	Stress (MPa)
2.80			
	y=36, z=212	-8,236~8,236	-134~134 (Bean:-235-235)

Figure 5. The results of time history analysis for 300m lattice dome at 2.80sec

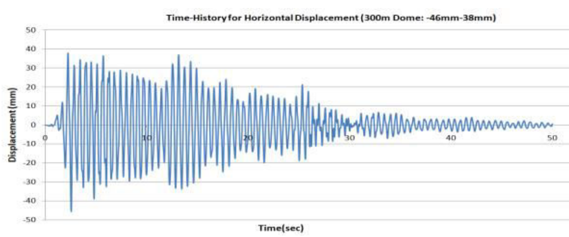


Figure 6. Horizontal displacement response

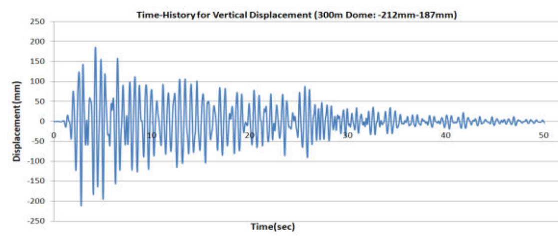


Figure 7. Vertical displacement response

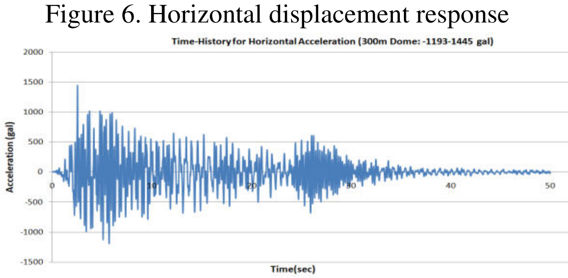


Figure 8. Horizontal acceleration response

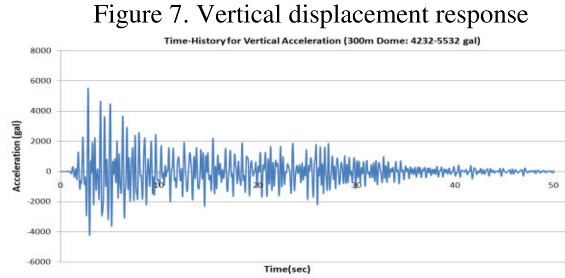


Figure 9. Vertical acceleration response

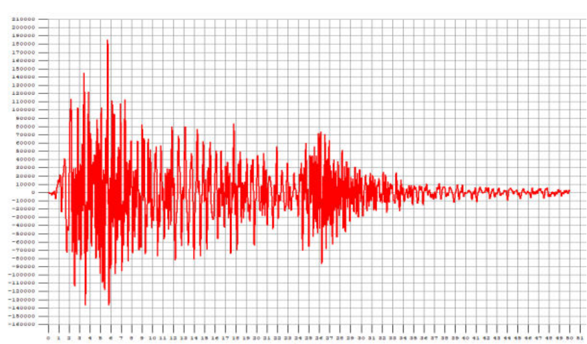


Figure 10. Base shear forces (-136,700~185,200kN)

The earthquake response analysis for the up and down ground motion of El Centro earthquake

Figure 11 shows the results of the time history analysis of the 300m lattice dome. In the analysis of the time history, the up and down ground motion of El Centro earthquake is applied. The deformation in the vertical direction is the largest at 1.26 sec. The vertical displacement at this time is 74.6mm, the maximum axial force is 2,965 kN, and the maximum stress is 48 MPa. Figure 12 is the displacement response curve in the vertical direction (-74.6~69.7mm), and Figure 13 is the vertical acceleration response curve (-5,920~6,067gal).

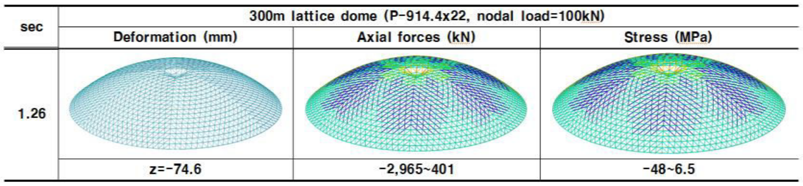


Figure 11. The results of time history analysis for a 300m lattice dome at 1.26sec

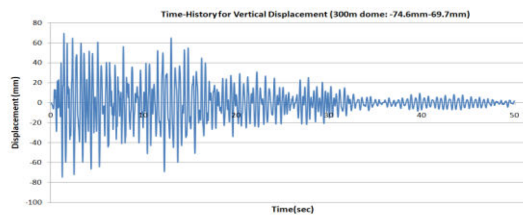


Figure 12. Vertical displacement response

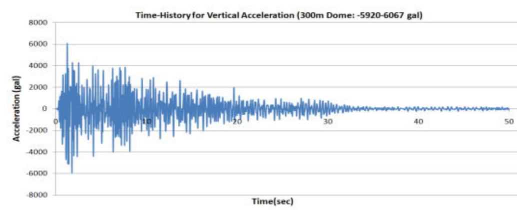


Figure 13. Vertical acceleration response

The earthquake response analysis for the 3-dimensional ground motion of El Centro earthquake

The dynamic response of the 300 lattice dome is analyzed by applying the 3-dimensional earthquake ground motion (270 Deg.+0.3x180 Deg.+UD), the peak ground acceleration is 0.3569gal. Figure 14 shows the results of the time history analysis of the 300m lattice dome. In the analysis of time history, the vertical displacement was the largest at 2.79sec. The vertical displacement at this time is 243 mm, the maximum compressive force is 7,753kN, and the maximum stress is 252 MPa. The horizontal displacement (z=243mm) is much larger than the horizontal displacement (y=45mm). Figures 15 and 16 show the horizontal displacement response (-45~37mm) and the vertical displacement response (-190~243mm) of the lattice dome. Figures 17 and 18 are the horizontal acceleration response (-1,204~1,457 gal) and the vertical acceleration response (-6,622~5,107 gal), respectively. Similar to the characteristics of the El Centro earthquake ground motion, the dynamic response occurred large before 15 seconds, and the dynamic response gradually decreased after 15 seconds. Figure 19 is the response history of base shear forces.

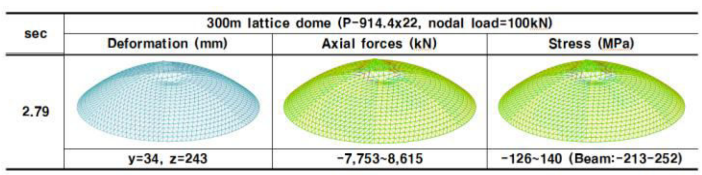


Figure 14. The results of time history analysis for 300m lattice dome at 2.79sec

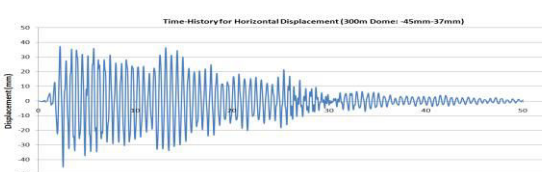


Figure 15. Horizontal displacement response

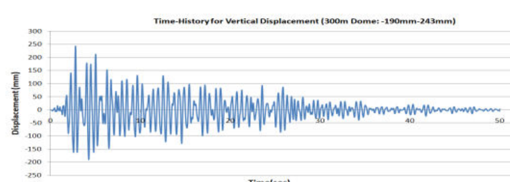


Figure 16. Vertical displacement response

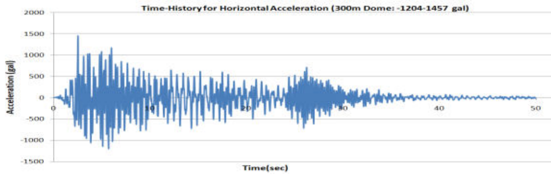


Figure 17. Horizontal acceleration response

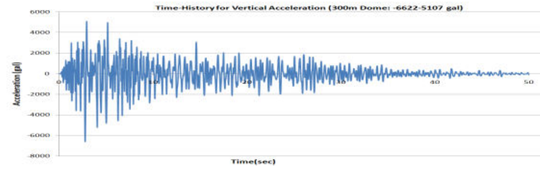


Figure 18. Vertical acceleration response

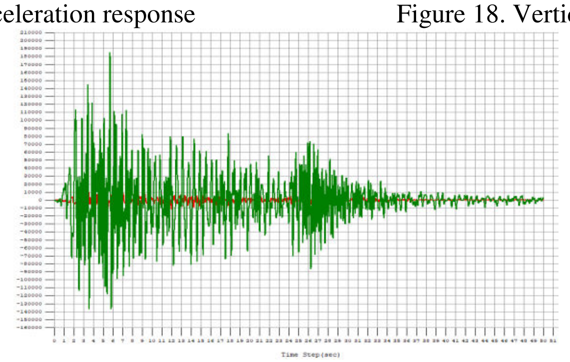


Figure 19. Base shear forces (-136,700~185,200kN)

IV.CONCLUSION

In this study, dynamic response characteristics (displacement response, acceleration response, member forces, stresses, etc.) were analyzed by performing time history analysis on a single-layer lattice dome with a diameter of 300m.

(1) In the large spatial lattice dome, the S-shaped asymmetric deformation occurred in the vertical direction at the top of the dome due to the horizontal and vertical ground motion, and the maximum stress occurred when the vertical displacement was maximum. The 300m single-layer lattice dome was structurally weak at the upper part of the dome, and the dome was mechanically satisfied with structural capacity when the connection of members made of the rigid connection at the upper part of the dome..

(2) Compared with the combined conditions of the ground motion of El Centro earthquake, the maximum vertical displacement was increased by 12.8%, and the peak vertical acceleration was increased by 16.5% due to 3-dimensional ground motion.

V. ACKNOWLEDGEMENTS

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VI. REFERENCE

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