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Collapse Mechanism of Space Structures under heavy snow loading

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ABSTRACT

In design practice, the progressive collapse of space structures such as double grid domes are usually overlooked in the design process. This is due to the redundancy of structural members for this type of structures, it is normally considered in design practice that progressive collapse will not be triggered when the loss of individual members occurs. However, increasing number of accidents of space structure are reported when the structures are subject to heavy snow loading. To investigate the structural behavior of this type of structure, a 3D finite element model of a space structure was built by the authors using the general purpose program ABAUQS. Using this numerical model, several collapse scenarios have been investigated using both the implicit and explicit solvers available in ABAQUS. Different member or support loss situations were studied. The response of the structure and the potential of progressive collapse of this type of structure have been discussed in detail.

1. INTRODUCTION

In the design practice, the progressive collapse of double layer grid dome is not checked. It is normally considered in design practice that progressive collapse will not be triggered when the loss of an individual member occurs. This is because that they are often assumed to have sufficient redundancy, so force redistributions can be accommodated by the remaining structure. However, increasing collapse accidents of space structures have been reported. The report of O'Rourke et al (2014) describes an investigation into about 500 roof collapse incidents that occurred in the northeastern United States during the winter of 2010–2011. One of the famous examples is the collapse of Hartford coliseum. Due to the abnormal heavy snow loadings, the roof which was made of double layer grid collapsed. Therefore, the research in this area is timely.

So far, most of the research and design guidance has concentrated on assessing the collapse behavior of multi-storey buildings. Little work has been undertaken on investigating the response of space structures. In the research presented by Murtha-

Smith (1998), an analysis on hypothetical space trusses were made, it showed that progressive collapse could occur following the loss of just one of several potentially critical members when the structures were subject to full service loading. However, when the structures were evaluated using the American National Standard ANSI A58.1-1982, the structures were found to survive with a small margin of safety. Blandford (1996) performed the progressive failure analysis of inelastic space truss structures. Lew. et al (1997) discussed the advanced analysis methods appropriate for spatial structure. Shekastehband et al (2011) also performed sensitivity analysis of Tensegrity systems due to sudden member loss.

Although some research has been undertaken to investigate this problem as summarized above, the accurate behavior of double-layer grid space structures under member loss is still not quite clear. In addition, there is still no clear guidance for the design of space structure against progressive collapse. Therefore, further investigation needs to be conducted. In this paper, using the general purpose program ABAUQS (2010), a 3D finite element model of a double-layer grid space structure was built by the authors. Using this model, analysis using both the implicit and explicit solvers available in ABAQUS has been performed. Different member loss scenarios were studied in detail. The response of the structure and the potential of progressive collapse of this type of structure have been discussed in detail.

2. PROGRESSIVE COLLAPSE ANALYIS

The space structure studied here is a conventional square grid 27 meters long each side. The structure is composed of 324 square pyramids. The height of the grid is 1.5 m. The whole structure is vertically supported at selected perimeters nodes in the locations.

2.1 ANALYSIS OF THE MODEL USING CODIFIED METHOD

The structures are first assessed using the codified method by GSA (2003), which using the so called Alternate load path method: "If it is deemed that the structural element would not survive the hazard level then a structural model of the elements and its surrounding structure is developed. This structure is then assessed with the sudden removal of critical structural members such as columns to study the structures ability to redistribute the forces on the structure without progressively collapsing." Based on this method, the ability of the structure under sudden member loss is assessed using a nonlinear dynamic analysis method with the 3-D finite element technique with implicit solver.

In this study, the response of the structure is assessed under the normal full snow load. The members to be removed were forcibly removed by instantaneously deleting them, and the subsequent response of each braced frame was then investigated.

In this analysis, several center members are removed simultaneously which is to simulate the member failures scenarios. The maximum forces, displacements and rotations for each of the members or connections involved in the scenario were recorded.

Fig.1 shows the response of the axial force in the structural members located close to the removed center members. It can be observed that a dynamic response was observed for each member. However, the axial forces are still within the axial capacity of each member.

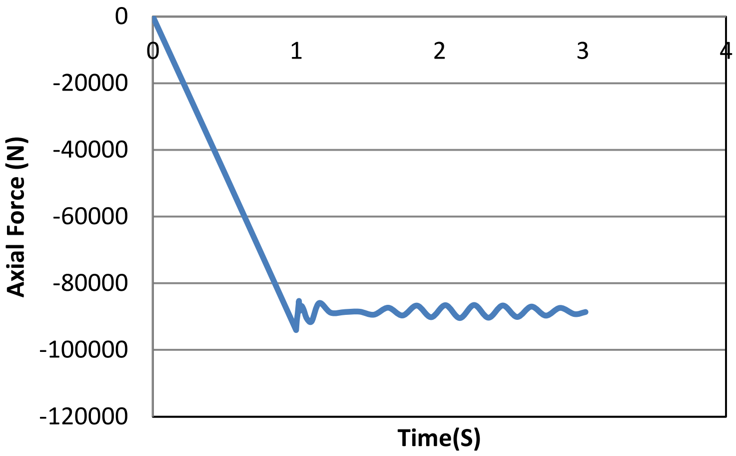

Fig. 1 Axial Force in the Top chord near the removed central pyramid.

From the investigation it can be seen that if space grid structures are designed under the current design guidance with the normal live load, the loss of certain structural members is unlikely to trigger collapse of the whole structure.

2.2 ANALYSIS OF THE MODEL USING EXPLICIT METHOD

Codified method is easy and fast, however, it cannot trace the whole failure process of the structures, more complicated explicit methods have to be used. To clearly investigate the behavior of the structure, the explicit solver was used in this part of the analysis.

In ABAUQS, the failure of a member can be assessed when using the explicit solver. Whenever the shear failure criterion is met at an integration point for a structural member, all the stress components of this member will be set to zero and that material point fails. By default, if all of the material points at any one section of an element fail, the element is removed from the mesh. Using this function, the progress of the structural failure can be modelled.

In this analysis, the middle span A is removed at the beginning of the explicit analysis, this is to simulate the support failure, which has been reported in some accidents. The value of the live load imposed was greater than the full live load used the analysis using the codified method, this is to simulate an abnormal live load condition such as a very heavy snow load.

It can be seen from Fig.2, the progressive collapse of the whole structure is trigged. The failure started and propagated first along the two lines between supports at points

A and A' and support at points D and D' (as shown in Fig 2). This indicates a typical failure mode of the structure. Consequently strengthening the support members and the structural members along these axial lines would be an effective method of mitigating progressive collapse.

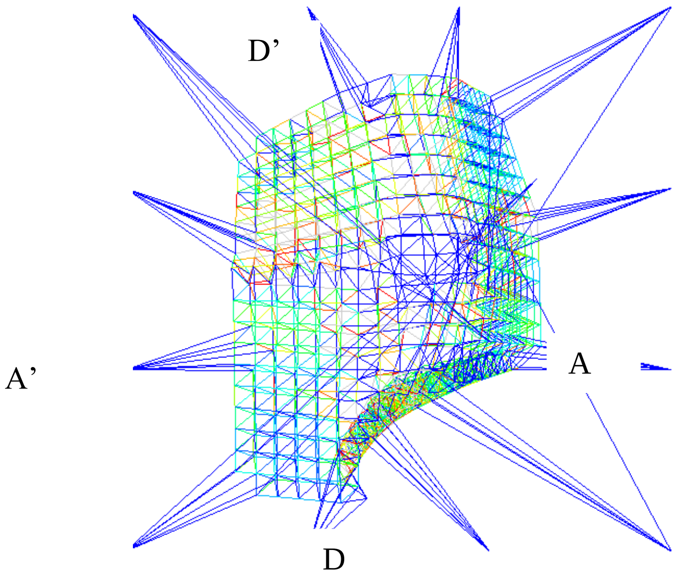

Fig.2 collapsing procedure of the double layer grid due to support loss with an abnormal live load

CONCLUSION

In this paper, the progressive collapse analysis of a double-layer grid space structure simulation was undertaken using both codified analysis method and explicit analysis method. The dome is analyzed under normal and abnormal snow load, below conclusion can be made:

1. Due to the high redundancy of the structure, for a space grid supporting a normal live load, the loss of several selected structural members is unlikely to trigger the collapse of the whole structure.
2. Under the abnormal live load condition such as a very heavy snow load a progressive collapse of the structure can be triggered, therefore, sufficient design margin should be considered.

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