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Performance and protection approach of single-layer reticulated dome subjected to blast loading

Ximei Zhai [a], Yonghui Wang [b,*], Ming Huang [a]

[a] School of Civil Engineering, Harbin Institute of Technology, Harbin, Heilongjiang, China
[b] Department of Civil and Environmental Engineering, National University of Singapore, Singapore

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ABSTRACT

The elaborate finite element model of Kiewitt-8 single-layer reticulated dome with span of 40 m subjected to eccentric blast loading was established and all the process from the detonation of the explosive charge to the demolition of reticulated dome structure was reproduced. The blast performance of reticulated dome was numerically studied and two approaches to improve the blast resistant capacity of reticulated dome were discussed. Response types of reticulated dome under eccentric blast loadings were defined. Partially reinforcement of reticulated dome is found to be an effective and economical way to improve its blast resistant capacity compared with fully reinforced reticulated dome. The pre-designed openings on the wall to release blast loading were studied, which provided some guidance on the blast resistant design of such structures.

1. Introduction

Due to the increasing explosion attack on buildings for decades, many design guidelines were proposed to design buildings against potential blast loads [1,2]. Commonly, the structural members are strengthened to achieve the targeted blast resistant capacity. To simplify design procedure, equivalent Single-Degree-of-Freedom (SDOF) method proposed by Biggs [3] is adopted to predict the response of structural members. A structural member can be equivalent to a SDOF system by transformation factors which are calculated by equating the internal strain energy and kinetic energy between the structural member and SDOF system. The equation of motion for equivalent SDOF system can be solved numerically. Due to inherent deficiency of equivalent SDOF method which cannot capture the changing Dynamic Increase Factor (DIF) and Deflection Shape Function during motion, Finite Element (FE) method is increasingly adopted to predict structure' response under blast load and can give more accurate results than equivalent SDOF method. Another commonly adopted method to assess the damage level of structural members under blast loading is Pressure–Impulse (*P–I*) diagram, which was first developed in the study of houses damaged by bombs dropped on UK in the Second World War [4,5]. For a given blast scenario, the peak overpressure and impulse can be obtained and compared with *P–I* diagram to determine the damage level. However, the generation of *P–I* diagram is complex and *P–I* diagram for the same structural member may be changing with the blast load profile.

The currently design codes for blast resistance are based on structural members, such as beam, slab, column, etc., which may be attributed to the fact that the duration of blast loading is very short compared with structure's natural period and local damage is usually observed in blast event, especially for close range blast loads. Therefore, existing publications have focused mostly on the performance of steel, concrete and fiber reinforced members, as well as beam-column connections [6–13]. However, it may not be sufficient to obtain the structure's global performance under blast loads by only studying structural members. With the rapid development of computer hardware over the last decades, it has become possible to establish the whole structure model and analyze its global behavior with different blast scenarios. Hence, numerical method has been widely adopted to study the dynamic responses, failure modes and collapse mechanism of reinforced concrete and steel frame structures subjected to blast loading [14–19].

Reticulated dome is usually adopted as the roof structure for gymnasium which, as a public activities arena, is prone to terrorist attacks. Reticulated dome is composed of many tube members, and global structural analysis is usually necessary for design under static loading not only to obtain the forces in each tube member but also to capture the stability behavior of reticulated dome. Therefore, global structural analysis is also necessary for reticulated dome against blast loading. Kiewitt-8 single-layer reticulated dome is an important type of single-layer reticulated dome. It consists of six latitudinal circles and eight main radial ribs that divided the sphere into 8 axi-symmetrical fan-shaped segments. Diagonal members are

* Corresponding author. Tel.: +65 946 548 35.
E-mail addresses: wangyonghui@nus.edu.sg, yonghui_hit@163.com (Y. Wang).

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applied to link the latitudinal and the main radial members, and similar triangular grids are formed all over the spherical surface, as shown in Fig. 1 [26]. Yet research of the behavior of this kind of structures under blast load has so far been little. Zhai and Wang [20–22] conducted a series of studies to investigate the behavior of kiewitte8 single-layer reticulated dome and defined four response types of such structure under centric blast loading. Since the explosive may not detonated at the center of reticulated dome in most cases, the authors extend their study to single-layer reticulated dome subjected to eccentric blast loading.

In this paper, the elaborate FE model of Kiewitt-8 single-layer reticulated dome with span of 40 m subjected to eccentric blast loading was established and all the process from the detonation of the explosive charge to the demolition of reticulated dome structure, including the propagation of the blast wave and its interaction with structure was reproduced. Four meshing approaches were compared in order to find the optimal meshing approach which can effectively and accurately reproduce the blast loading. Blast performance of reticulated dome subjected to eccentric blast loading was numerically studied and its response types were defined. Finally, two approaches for improving blast resistant capacity of reticulated dome were discussed.

2. Computational model

2.1. Finite element model

The FE model of Kiewitt-8 single-layer reticulated dome with span of 40 m and rise-span of 1/5 is established, as shown in Fig. 2. Roof panel, rivet, purlin, purlin hanger and reticulated dome members are sequentially established from top to bottom to form the reticulated dome structure model, as shown in Fig. 2(a). Rivet is utilized to connect roof panel and purlin and purlin hanger is utilized to connect purlin and reticulated dome. The tubes are adopted for the reticulated dome member and the prulin hanger (see Fig. 2(b)) with cross section to be $\Phi 114\times 4.0$ and $\Phi 76\times 4.0$ (∅ steel tube, outer diameter in mm × thickness in mm), respectively. Channel-section member is usually adopted for the purlin in practice of single-layer reticulated dome. To simplify modeling procedure, equivalent hollow rectangular section purlin by equating the cross section stiffness is a better option and the dimensions of hollow rectangular section is shown in Fig. 2(c). The diameter of rivet is 12 mm and there are seven rivets equally distributed on each prulin. The thickness of roof panel is 1 mm steel panel. Since the reflected pressure is significantly higher than the incident

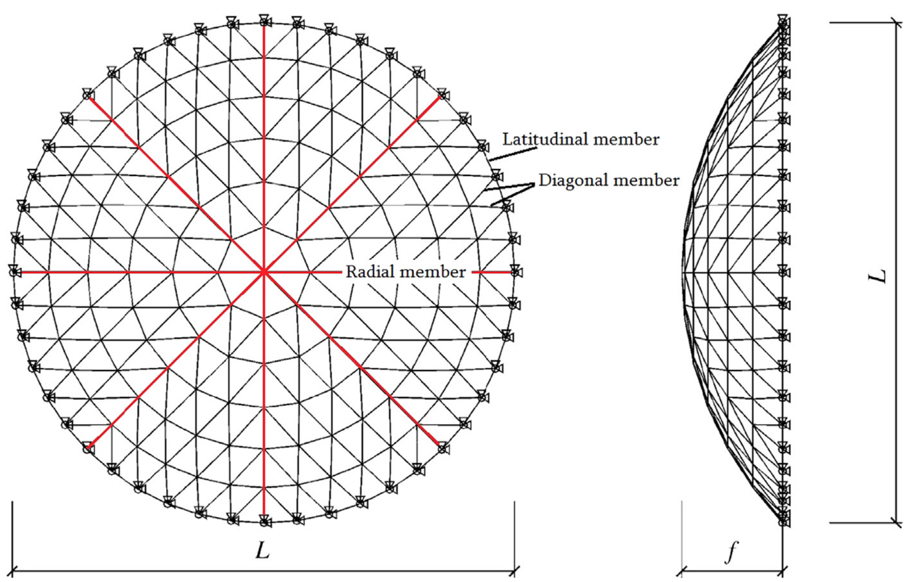

Fig. 1. Configuration of Kiewitt-8 single-layer reticulated dome.

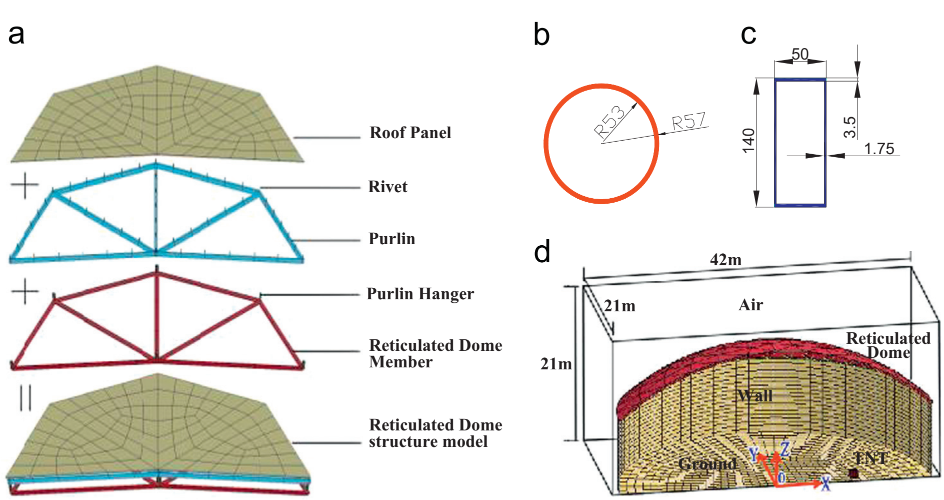

Fig. 2. Finite element model for Kiewitt-8 single-layer reticulated dome. (a) Partial reticulated dome model (b) tube (c) purlin and (d) half reticulated dome model.