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Experimental and numerical studies on single-layer reticulated shells with aluminium alloy gusset joints

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ABSTRACT

Single-layer reticulated shells with aluminium alloy gusset (AAG) joints have a significant application prospect in spatial structures. To investigate their buckling behaviour, a single-layer reticulated shell with AAG joints subjected to a concentrated load at central joint was tested. The tested shell was a K6 shell with 5 rings, 8 m span and 0.5 m height. Its failure mode, buckling behaviour, internal force distribution of members, stress distribution of plates and joint stiffness were discussed. Finite element (FE) method implemented in the non-linear code ANSYS was adopted for the further investigation of single-layer reticulated shells with AAG joints. The FE procedure was accurately calibrated on the basis of the available experimental results. To develop a deep understanding, parameter studies considering the influence of joint bending behaviour on the buckling behaviour of single-layer reticulated shells were conducted.

1. Introduction

Compared with traditional constructions, single-layer reticulated shells with aluminium alloy gusset (AAG) joints provide some outstanding advantages of attractive appearance, lightness, high strength and corrosion prevention. Nowadays, the single-layer reticulated shells with AAG joints have been widely used in the space latticed structures, such as the Shanghai International Gymnastic Center (China) [1], the Sea World of Texas (America) and the Festival South Bank Exhibition (UK). Observations from extensive studies confirmed that the joint bending stiffness plays a key role in the buckling behaviour of single-layer reticulated shells [2–8]. Recently, Guo et al. [9] have conducted the experimental investigation on the bending behaviour of AAG joints, and indicated that the AAG joint stiffness exhibits a significant semi-rigid response. Therefore, the influence of the joint bending stiffness is required in the design of the single-layer reticulated shells with AAG joints.

To study the influence of the joint bending stiffness on the buckling behaviour of single-layer reticulated shells, some experiments have been carried out. Lopez et al. [4] have conducted experimental tests on two structures possessing very different features related to geometry and rigidity of ORTZ joints. In both cases the proposed model has given a good estimation of the experimentally observed behaviour of the structures. Hiyama et al. [3] discussed the buckling behaviour of aluminium alloy single layered reticular domes, composed of tubular truss members and ball joint connections, through loading tests and numerical simulations on three 1:5 scaled test structures. Ma et al. [2] carried out an experiment on a 5×6 m single-layer cylindrical reticulated shell with semi-rigid bolt-ball joints, examining the influence of joint-rigidity on the mechanical performances of shells. For the further investigation, extensive finite element (FE) simulations and theoretical studies on the buckling behaviour of single-layer reticulated shells with semi-rigid joints have been accomplished [10–14]. Fan et al. [6] established FE models of single-layer reticulated domes with bolt-ball joints using nonlinear beam element with end spring elements in software ANSYS. Based on the FE results, they proposed formulae for direct estimation of critical loads of semi-rigidly jointed single-layer reticulated domes. Lopez et al. [5] deduced a new formula which allows designers a rapid estimation of buckling loads for semi-rigid jointed single-layer latticed domes under symmetric loading conditions. Kitti [15] indicated that the influence of the joint stiffness on the buckling behaviour of shells increases with the increase of the span. However, the research on the buckling behaviour of single-layer reticulated shells with AAG joints is limited.

Recently, more and more researchers have paid their attention to the mechanical behaviour of aluminium alloy buildings [16,17]. The single-layer reticulated shells with AAG joints have a wide application prospect. For the time being, Guo et al. [9,18,19] have obtained systematical achievements of the mechanical characteristics of the AAG joints. In order to investigate the influence of the AAG joint stiffness on the buckling behaviour of single-layer reticulated shells, this paper reported experimental and FE studies. The experiment

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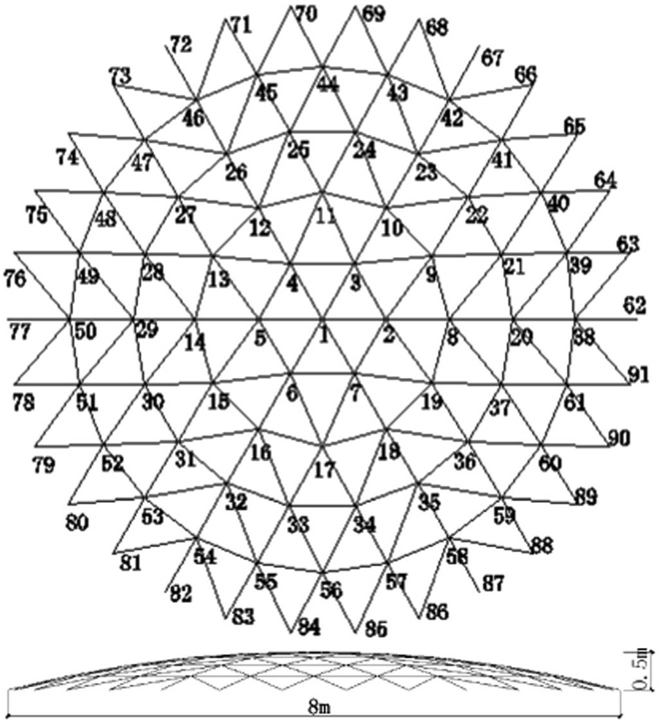

Fig. 1. Experimental single-layer reticulated shell.

presented the whole load-displacement curve and failure mode of the single-layer reticulated shells with AAG joints. According to the experimental results, the availability of the proposed FE models could be verified. Based on the parameter studies, a further understanding on the buckling behaviour of the single-layer reticulated shells with AAG joints was summarized. The achievements could serve for the practical engineering design and further theoretical analysis.

2. Experimental program

2.1. Description of the test shell

Table 1
Detailed information of I-shaped members.

No.	Quantity	L1 (mm)	L2 (mm)	No.	Quantity	L1 (mm)	L2 (mm)
G1	6	636	742	G12	12	894	1000
G2	6	629	735	G13	12	649	755
G3	6	628	734	G14	12	756	862
G4	12	816	922	G15	12	644	750
G5	12	648	754	G16	12	650	756
G6	6	622	728	G17	6	609	715
G7	12	872	978	G18	12	894	1000
G8	12	686	792	G19	12	625	731
G9	12	647	753	G20	12	783	889
G10	6	646	752	G21	12	698	804
G11	6	617	723	Total	210		

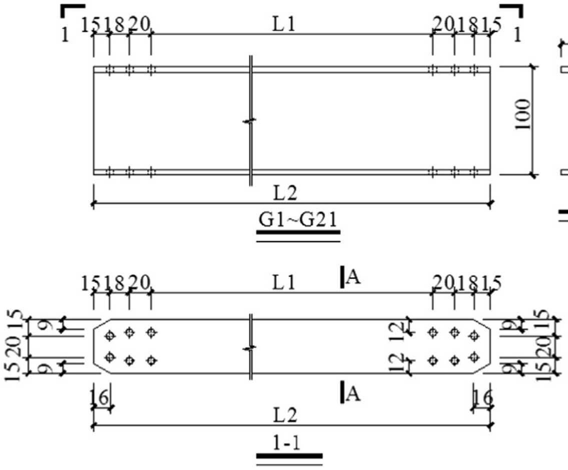

Fig. 3. I-shaped members.

The experimental single-layer reticulated shell with AAG joints was a Kiewitt-6 shell. The layout of this shell is shown in Fig. 1. The shell which had five rings was 8-m-spanned. Its height was 0.5 m. There were a total of 210 I-shaped members and 91 AAG joints (Fig. 2). There were twenty-one types of members and nine types of plates. All the I-shaped members had the same cross-sectional dimensions of 100 × 50 × 4 × 5 mm. The details of the members are listed in Table 1 and Fig. 3. The thickness of all the plates was 5 mm. Six Hand tightened stainless steel M6 bolts in 6.5 mm drilled holes were used to connect one flange to the plate.

The I-shaped members, plates, connected devices and supports were prefabricated in the factory, and the experimental shell was assembled in the Structural Laboratory in Tongji University, as shown in Fig. 4. The installation of the experimental shell was divided into six steps: (1) M24 chemical anchor bolts were placed at the design positions. Therefore, the positions of supports were determined. Each support was fixed to the ground by four M24 chemical anchor bolts, as shown in Fig. 5. (2) The supports were fixed by the chemical anchor bolts. To make sure that all the supports were located at the same elevation level,

Fig. 2. AAG joints.

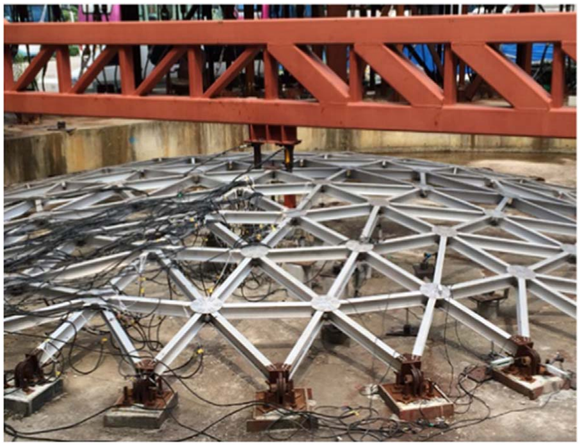

Fig. 4. Experimental shell.

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