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Novel cable-stiffened single-layer latticed shells and their stabilities

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ABSTRACT

The cable-stiffened single-layer latticed shell is a new structural system that aims to enhance the stability of the single-layer latticed shell. This paper compares the stability of a cable-stiffened single-layer latticed shell with that of a single-layer latticed shell using a numerical analysis to investigate the stability behaviour of the new structure. In the analysis, the following influential parameters have been taken into account: (1) layouts of the cables; (2) joint types; (3) pretension in the cables; and (4) cross-sections of the cables. The results indicate that the buckling load of single-layer latticed shells is improved significantly by the introduction of the cables. For the cable-stiffened single-layer latticed shells with different layouts of cables, both the pretension in the cables and the cross-sections of the cables have a considerable effect on their stabilities. Meanwhile, the numerical analysis also indicates that although joint types have a remarkable effect on the stability of a single-layer latticed shell, the effect on the corresponding cable-stiffened single-layer latticed shell is limited.

1. Introduction

As a common form of spatial structures, single-layer latticed shells provide a highly efficient method to span a large distance. However, because the computational thickness of single-layer latticed shells is much smaller than the span, which leads to the low bending rigidity out-of-plane, sufficient attention must be paid during the design of such structures to avoid overall buckling.

Attempts have been made to improve the stability behaviour of single-layer latticed shells. The suspen-dome, which consists of a single-layer truss dome and a tensegric system that stiffens the former by inversely loading it, is one effective method to improve stability [1]. The existing research indicates that the strength of the single-layer truss dome against buckling has been greatly increased by the use of a tensegric system [2–4]. However, the tensegric system of the suspen-dome is only suitable for domes, and is difficult to translate for use with other shapes of shells.

The cable-stiffened single-layer latticed shell is another structural system that is able to greatly enhance the stability behaviour of the single-layer latticed shell. Cables are introduced into the grids of the shell, and the shear rigidity in-plane and the bending rigidity out-of-plane of the shell are significantly improved. Compared with the suspen-dome, the cable-stiffened single-layer latticed shell is suitable for any shape of a latticed shell. In addition, there is sufficient flexibility for the layout of the cables [5]. This structural system can be found in several projects. The Neckarsulm dome is a typical use of this type of structural system: it is a two-way single-layer latticed shell, and its cables are set in directions diagonal to the grids [6]. The museum of the History of Hamburg and the Hippo House at the Berlin Zoo use the same structural system [7,8]. The Kumagaya dome uses another form of cable-stiffened single-layer lattice shell, in which the cables are replaced by tension rods [9]. The tension rods are diagonally connected in the in-plane and out-of-plane directions of the grids through posts, which effectively provide the bending rigidity out-of-plane.

Many research achievements can be found regarding the stability of the single-layer latticed shells [10–17], but less research is available concerning the cable-stiffened single-layer lattice shells. Schlaich studied the behaviour of the structure by performing a full-scale load test for the Neckarsulm indoor swimming pool project [7]; Wu analysed the pre-stress introducing process of a type of cable-stiffened lattice shell [18]. Fujimoto analysed the buckling and strength behaviours of cable-stiffened cylindrical lattice shells [19]. Umezawa analysed the increase in the buckling load of the Kumagaya dome after the tension rods were set [9]. Feng used the continuum analogy to evaluate the buckling load of an elliptic paraboloid cable-braced grid shell [20].

Unfortunately, the rigidity of the joint may affect the buckling load of the latticed shell greatly. Kato performed a second-order elastic analysis for reticulated domes with semi-rigid joints [21]. López investigated the rotational stiffness of the joints and suggested a formula to estimate the buckling loads of a single-layer spherical dome with semi-rigid joints under symmetric load [22,23]. Experimental and numerical studies were also conducted, and the behaviour of single-layer spherical domes influenced by the joint rigidity was studied [24].

Welded joints and cast steel joints are two types of joints commonly used in single-layer latticed shells. Some other joints, such as the scissor-

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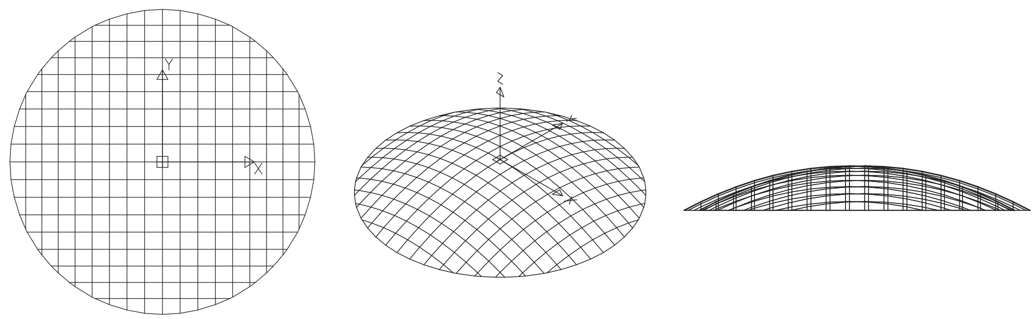

Fig. 1. The two-way single layer elliptic paraboloidal latticed shell.

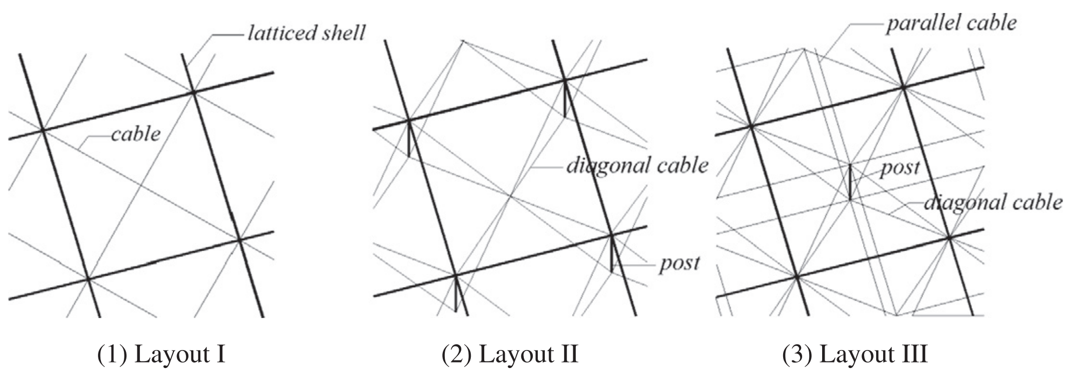

Fig. 2. Three layouts of cable-stiffened single-layer latticed shells.

type joint developed by Schlaich, are used in projects (for example, the Neckarsulm indoor swimming pool by Schlaich) to reduce the complexity of the joint fabrication and construction [7]. The rotation of the scissor-type joints is prevented by the cross cables in units.

Obviously, the stability of cable-stiffened single-layer latticed shells is influenced by the layouts of the cables. Although scissor-type joints that can rotate freely have successfully been used in Schlaich's projects, the influence of the stiffness of the joints on the stability of the new structural system has not been studied. In this paper, the stability of cable-stiffened single-layer latticed shells is analysed numerically. Three different layouts of cables and posts of cable-stiffened single-layer latticed shells are considered. In addition, three different

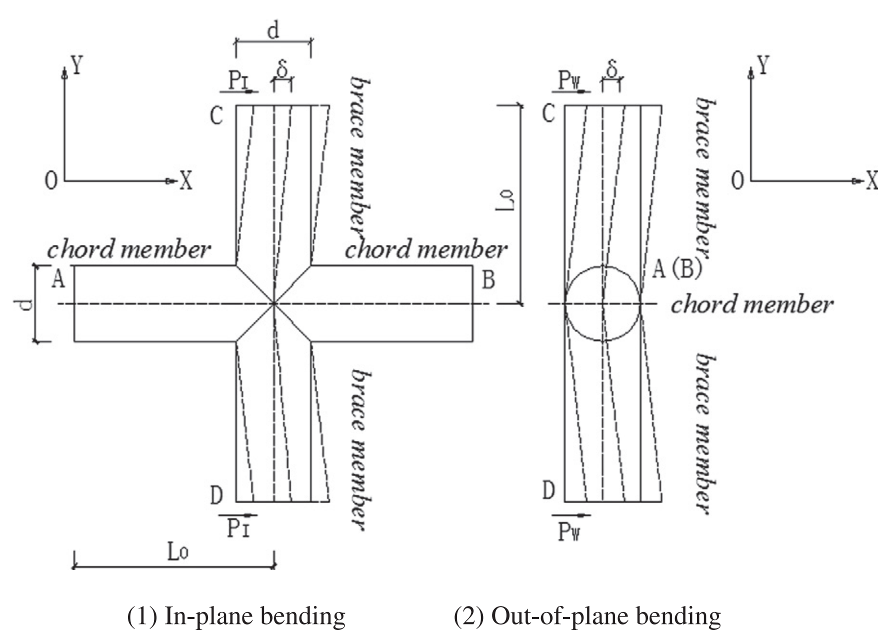

Fig. 3. The load pattern and the deformation of the tubular joint.