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FREE node for a single layer free-form envelope subjected to bending moment

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ABSTRACT

For free-form structures with a single layer envelope, the node is subjected to axial load, as well as moment. The purpose of this paper is to develop and evaluate a new hollow spherical connector, termed the FREE (Flexible, Resilient, Efficient, Economic) node, for single layer free-form spatial envelopes. Reducing material and efficient shape are important points in the space structure node. Therefore, hollow spherical node sections with different holes were proposed and finite element analysis was performed, to determine the prototype among these parameters. The parameters are the size and shape of the hollow sphere. Bending experiments were also performed, to evaluate the structural capacities of the proposed node; and the corresponding test results were compared with finite element analysis. As a result, it may be said the proposed FREE node satisfied the required capacities.

1. Introduction

Complex-shape envelopes or free-form spatial structures have become a new trend in architecture. Many architects and engineers, and also building contractors, are expressing interest in realizing this extraordinary kind of structure. Due to recent industrial development, their design ideas have been built on site, as shown in Fig. 1 [1]. In contrast with typical double layer space structures, the single layer grid shell shows many beneficial features, such as saving structural materials, and the aesthetic form of the entire structure [2]. The structural design of a single layer space structure, however, requires a special approach. As the ratio of thickness in the structural member to the entire span is very large, the general stiffness of the structure mainly depends on the form of the structure. In the phase of structural design, therefore, the analysis should be dominated by membrane stress, so that the entire structural behavior can be regarded as shell behavior. Nevertheless, under the design load, bending moments can easily occur; so each member has to provide enough strength for bending moment, as well as axial forces. This means that the node in the joint must be designed for compressive and tensile forces, and bending stresses, as well [3].

Many researchers and engineers have developed various types of nodes. For example, a German engineering company, Schlaich Bergermann und Partner (SBP), developed SBP-1, in 1988. The end of the beam is fabricated as half of a fork-shaped flat plate, to be connected with a splice by two or more bolts, so that it has a single shear plane in the node. The horizontal angles between beams that are connected at the node can be adjusted [4]. In 2007, Knippers Helbig Consulting Engineers, Stuttgart and the fabricator Seele cooperated on the development of a node system. The jointing principle is a bolt connection of a hollow steel beam to the node, where the end faces meet perpendicularly. The node consists of twenty-six elements, to create a perpendicular surface, and different connection geometries [5].

Of course, the fixed-joint node in a double layer space structure is also assumed to require moment capacity. But the importance of moment capacity in the joint, which may bring global or local buckling of the whole structure, is less than for the single layer structure. For the single layered free-form structure, it would be very hard to adjust various angles on-site, which would increase the total construction cost.

In this study, a hollow sphere shaped node was proposed for the free-form structure. The prototype of a node was found by finite element analysis. In addition, the moment capacity was found by monotonic and cyclic loading test. As a result, the proposed node provided the required moment capacity.

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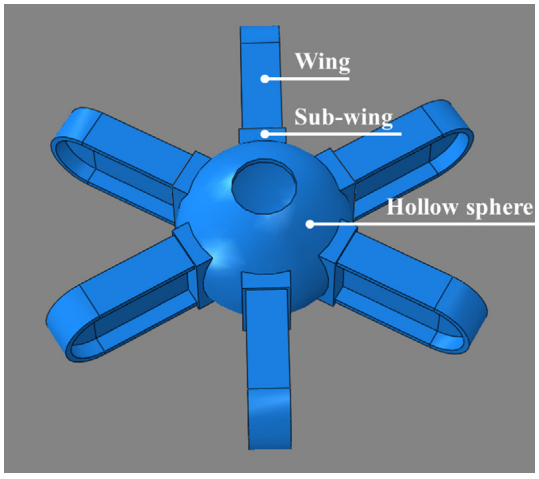
Fig. 1. New trade fair in Milan (Italy, 2005).

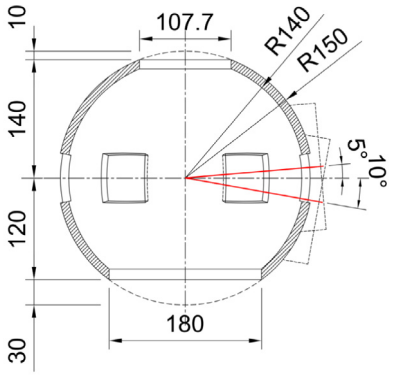
2. FREE node system

Fig. 2 shows details of the new hollow spherical node system. A sphere shape node was designed, to accommodate the angle between diagonals that are connected at the node. It is termed the FREE (Flexible, Resilient, Efficient and Economic) node. The system consists of three parts: a hollow sphere, six sub-wings, and six wings [6,7].

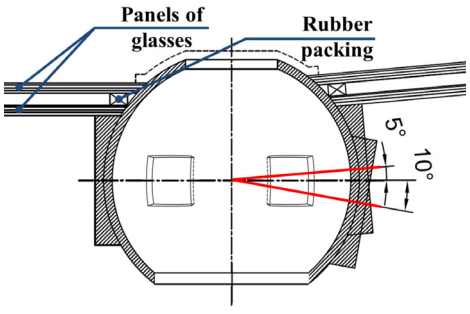
Hollow sphere is required at least 300 mm diameter due to be adjusted as up and down at an angle of 15°. To express spherical shape and holes, the hollow sphere made of cast steel. Manufactures with cast steel must have minimum 10 mm thickness because of pouring molten metal into a cast. Therefore, diameter and thickness of the hollow sphere are 300 mm and 10 mm, respectively. Two holes are made in the top and bottom parts. The top hole diameter is 107.7 mm, and the bottom one is



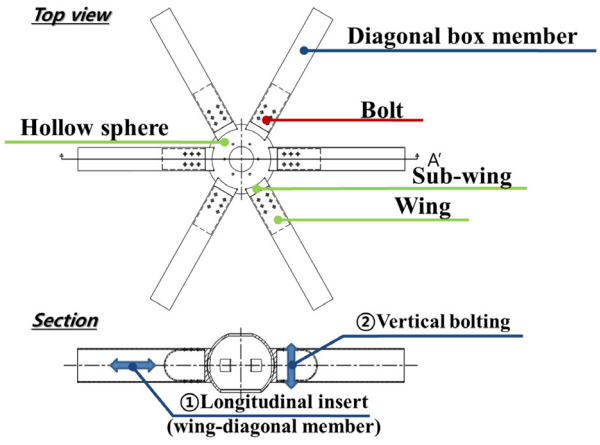
(a) Assembly of connection



(b) Spherical node ball



(c) External facing system



(d) Longitudinal and vertical assembling system

Fig. 2. Details of the spherical node system.