Lightweight curved surface structures composed of bending-active plate units

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Abstract

This paper presents a method for fabricating reversible curved surface plate units through active bending. The original flat plates were bent by inserting braces into precut parallel slits on the plates. The bent plates were then self-stabilized with the support of braces in a state of compression. The self-stabilized plate units can be easily assembled to become a modular structure and disassembled to be transported or stored in the flat form. The curvature of the units can be controlled by adjusting the length and the spacing of the slits. The deformation of the bent units were simulated using a geometrically nonlinear analysis in SAP2000 and compared with measured results from both small-scaled and full-size models. It was found that when the self-weight was neglected, the bending deformation of a homogeneous unit was independent of the material's elastic modulus. It was also found that the bending deformation was proportional to the ratio of the slit spacing to the plate width as well as the ratio of the brace depth to the slit length. A linear function between the bent angle and the slit dimension factors for symmetric rectangular units was then derived using a regression analysis.

Two lightweight structures, including a catenary arch that spanned 4.2m and a geodesic dome with a diameter of 3.45m, were built using 3mm plywood units. 1/5-scaled models were used to study the composition and the stability of the structures. Before the construction of the structures, full-size units were tested by inserting braces at different depths to determine the maximum allowable bending deformation. Three-point bending tests were performed to measure the elastic modulus of the plywood plates. Compression tests for the bent units were performed to determine the buckling load. Nevertheless, the initial trial for the purpose of constructing the catenary arch was unsuccessful due to the scale effect. The design was modified, and the arch could be stabilized by adding out-of-plane stiffeners made of the same 3mm plywood plates. It was found that the scale effect may be diminished by changing the geometry of the structure. Therefore, a geodesic dome consisting of reciprocally connected units was proposed. The reciprocal composition enabled an efficient, simple joint design. The geodesic dome was assembled and disassembled multiple times for different purposes, including a 45-day exhibition in an interior space. It was set on an open site the last time. The deformation of the dome was monitored on a daily basis. Creep deformation accompanied by visible local breakages on the base units were found. Finally the dome collapsed due to the buckling failure of the base units after remaining outdoors for four months.

A simplified analytical model for the structural analysis of the system using SAP2000 was proposed. A comparison between the analytical and measured deformation of the constructed structures was provided. The analytical results corresponded with the observed behavior of the structures.