Experimental investigation of reciprocally supported element (RSE) lattice honeycomb domes structural behaviour

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ABSTRACT

The honeycomb configuration of the many Diamatic dome patterns available is particularly convenient for reciprocally supported element (RSE) transformation. This is due to there being only three lattice bar elements intersecting at any apex, irrespective of the number of the bar elements used to form the crown polygon. RSE transformation effort therefore is both reduced and simplified compared to some RSE forms. To inform the understanding of the structural behaviour of honeycomb RSE lattice domes, a study comparing structural modelling predicted behaviour with monitored behaviour in the laboratory was carried out. This investigation focused on the structural behaviour of a RSE lattice honeycomb dome structure under applied static loading. The first part of the study included configuration processing, structural modelling and analysis. The second part involved manufacture, construction and monitored behaviour of the dome in the laboratory. The creation of the selected RSE honeycomb lattice structure together with the structural modelling and experimental outputs are presented and discussed. Predicted displacements and stresses are compared under varying applied loading, boundary support conditions and connection stiffnesses. The locations of the onset of local yielding is considered and discussed. The applied loading did not exceed the tube yield stress according to the von Mises ductile material failure criterion indicating that the dome behaviour observed was elastic.

1. Introduction

Element cluttering typically evident in the crowns of the Ribbed, Schwedler and the Lamella family of lattice domes, as shown in Fig. 1(a)–(c), may render their reciprocally supported element (RSE) transformation challenging. The honeycomb configuration of the many Diamatic dome patterns available [1] is particularly convenient for RSE transformation. This is due to there being only three lattice elements intersecting at any apex irrespective of the number of elements used to form the crown polygon. See Fig. 1(d) and (e). RSE transformation effort is both reduced and simplified compared to some other RSE forms [2–16]. Honeycomb configurations can be similar in appearance to geodesic domes when five lattice elements are used to form the crown polygon. See Fig. 1(d).

To augment the understanding of the structural behaviour of RSE honeycomb lattice domes, a study comparing structural modelling predicted behaviour with monitored behaviour in the laboratory was carried out. This investigation focused on the structural behaviour of a RSE lattice honeycomb dome structure under applied static loading. The first part of the study included the configuration processing, structural modelling and analysis. The second part involved manufacture, construction and monitored behaviour in the laboratory.

2. Diamatic honeycomb domes RSE transformation

The basic elemental lattice honeycomb domes considered for transformation into equivalent RSE domes were created using Formian [1,17]. In Formian, the parameters controlling the span and rise at the dome crown is the sweep angle that is defined as half the central angle at the origin of the elemental dome sphere. In the initial studies, a sweep angle range of 30–70° was considered.

The constraints of the test rig in the Engineering laboratories at the University of Greenwich, Chatham, (UOG) dictated the size of the dome that could be considered. A dome diameter of the order of 3.2 m with a rise to the crown of approximately 1.0 m could be accommodated. A sweep angle of 60° was found to provide the desired initial dome diameter and rise.

Dome construction was informed by previously acquired experience [18–20]. It was anticipated that circular hollow section (CHS) tubes of 48.3 mm diameter would be used and these would be bolted together with 12 mm diameter bolts. The bolts would pass through 13.0 mm diameter clearance (oversized) holes drilled through the CHS tubes. Saddleback washers with a minimum thickness of 0.85 mm would be utilised to enable accurate seating and location of the bolts and RSEs.

The rotation method was used for the RSE transformation [2,21,22].
This required the elementary dome lattices to be rotated about a normal vector, \( N \) passing through the dome origin and lattice elements midpoints. A rotation angle of 15° was selected as a starting point. The common perpendiculars between each pair of skew lines that were formed about each apex were used to generate the initial eccentricities. Formian [1] and Rhinoceros [23] were used to carry out the RSE transformation. Fig. 2 illustrates the transformed honeycomb lattice dome into the equivalent RSE structure.

### 2.1. Transformation optimisation

A 50 mm target eccentricity value, between the CHS centroidal axes, was selected for all the dome connection locations. This required the initial 15° rotation eccentricity values to be modified \([2,21,22]\). To keep the optimisation time required to achieve this to a minimum, the accuracy of the final eccentricity values obtained was considered sufficient at 50 mm, plus (+) 2.5 mm or minus (−) 0.5 mm. Small dimensional differences could be made up with shims in the form of parallel faced flat washers \([2,21]\). Following this optimisation process the final RSE dome span and rise was accepted as 3066 mm and 894 mm respectively. See Fig. 3 for details of the initial and optimised eccentricity values together with the required shim thicknesses and their locations.

### 3. Structural modelling

The dome structure was modelled and analysed using Oasys General Structural Analysis, (GSA) software with 3-dimensional and finite element capabilities \([24]\).

It was anticipated that it may be problematic to model some of the experimental features such as the actual support conditions and the bolted connections. A range of possible scenarios were considered therefore as, for example, welding end plates to the boundary support legs to give fixed or pinned end conditions was in this instance considered uneconomic for a structure of this scale.

The static-linear analysis of the dome under load conditions was carried out in stages. The first stage considered five different analysis models \([25]\). These five models were refined to eight analysis models in order to ensure that all of the possible variations were captured and these are now considered here.

#### 3.1. Boundary support conditions

The boundary support conditions anticipated assumed that: (i) the support legs may be free to move laterally as none would be mechanically fixed in position, and (ii) minor geometric self-adjustments would take place due to the initial loading and unloading procedure \([2,25]\).

Determination of boundary support stiffnesses was determined in stages. Stage 1 assumed that under an elastic load value all of the boundary support nodes, S1-S10, shown in Fig. 3 were fixed in position and pinned from which the reaction forces, \( F_x \) and \( F_y \) were obtained. Stage 2 assumed the same load conditions as stage 1 except node \( S_2 \) that was given a horizontal roller support from which displacements, \( U_x \) and \( U_y \) were determined. All of the remaining displacements, \( U_x \)
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