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Effects of support positioning on thermal behaviour of double layer space truss domes

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This work is dedicated to the first author's late son, M. Hassan Alinia

Abstract

This paper presents the follow-up of a study on the influence of the type and properties of support conditions on the thermal behaviour of spherical double layer space truss roofs. The earlier papers were about the effects of support flexibilities on the behaviour of space trusses subjected to uniform, gradient and partial loadings. In this paper, the effects of columns' spacing and positioning on the thermal behaviour of space structures are considered. These parameters are defined by the distance between two opposite columns (radial distance), and the space between two adjacent columns (circumferential distance).

Keywords: Double layer grids; Space structures; Domes; Thermal loading; Column positioning

1. Introduction

Space truss structures are becoming increasingly popular for covering large areas such as sports centres, halls and other wide span roofs. Covering spans of up to 100 m have been constructed worldwide. The main advantages of these structures are that they are light in weight, have a high degree of indeterminacy and thus have a great stiffness, have simple production and fast assembly, are totally prefabricated, do not need site welding, are easily formed into various attractive geometrical surfaces, have the ability to cover large areas with widely spaced column supports, have good response against earthquakes and are cost effective.

These advantages and other related points about large span space truss domes are fully discussed by the present authors [1, 2], where a literature review of other research works [3–12] was presented. Marsh [11] commented on the thermal expansions and specified that space trusses are normally single structural assemblies, and are thus required to be free to expand and contract without restraint. He also emphasized that should there be a high temperature change across the structure, as is possible in large roofs, internal stresses would be developed and might require some attention.

The first two papers published by the present authors [1,2] studied the effects of flexibility of substructures upon thermal behaviour of spherical double layer space truss roofs subjected to either uniform, gradient or local temperature rises. It was observed that the forces induced by thermal expansion of truss members on substructures and supporting frames were very significant, and that their magnitudes depended on the amount of temperature rise, and the dome's span and height. It was also mentioned that the key point in the partial thermal loading is the unsymmetrical deformation in the behaviour of the dome; whereas in the gradient loading case; it is the rotational deformations of truss members. Last, but the most important point was that the use of rigid supports should be carefully examined in the design procedures.

The main aim of the present work is to study the effects of column spacing and positioning on the thermal behaviour of dome type space truss roofs. In other words, the effects of the number of supporting columns, i.e. the circumferential space between two adjacent columns; and also the radial distances between them, i.e. the distance between two opposite columns are considered and discussed.

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Nomenclature

D_r	Radial distance of columns
D_p	Circumferential distance between two adjacent columns
E	Modulus of elasticity
H	Thickness of double layer dome
h_c	Height of columns
I_c	Second moment of area of columns
K_c	Lateral stiffness of columns
R_t	Top layer's radius of curvature
R_b	Bottom layer's radius of curvature
T	Temperature rise in degrees Centigrade
V	Shear force exerted on columns
α	Coefficient of temperature expansion
α_c	Open angle in degrees
σ_y	Yield stress
υ	Poisson's ratio

2. Method of study

2.1. Modelling and method of analysis

Modelling of space structures is carried out by the special software FORMIAN [13–15]. Wire frame models are then analysed by the structural analysis programme software, SAP2000 [16]. A typical model frame considered in this research is shown in Fig. 1.

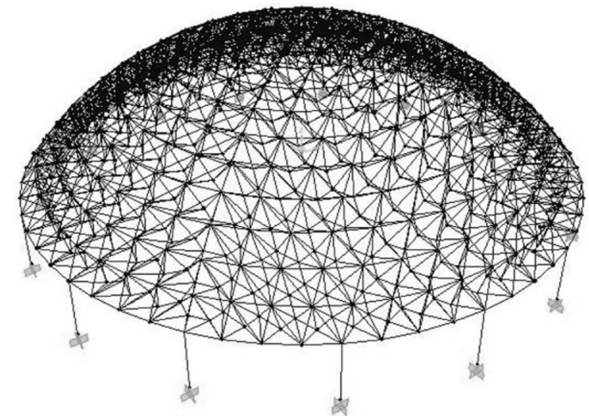

Fig. 1. A typical space truss model and its supporting columns.

2.2. Geometrical properties

Six double layer space truss domes, having either 'diamatic' or 'square' member arrangements, are modelled and analysed in this research. All models have spherical surface skins, and their geometrical parameters and properties are shown in Fig. 2 and Table 1.

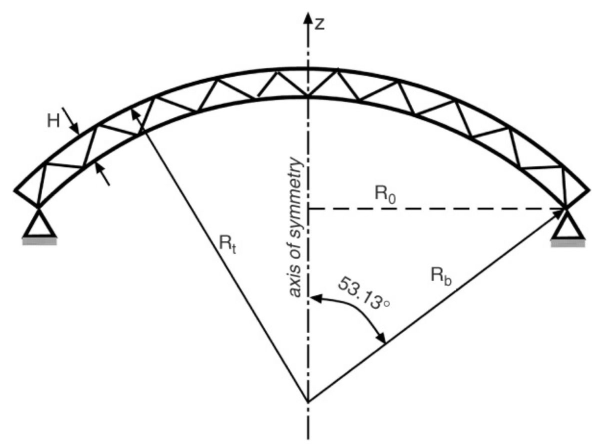

Fig. 2. Geometrical parameters of models.

2.3. Mechanical properties

Mild steel tubular members with outside diameters of 25–200 mm are used and the following properties are assumed:

$E = 200{,}000$ MPa
$\sigma_y = 240$ MPa
$\upsilon = 0.3$
$\alpha = 1.2 \times 10^{-5}/°\text{C}$.

2.4. Support conditions

The substructure of a space frame dome may be composed of a reinforced concrete ring, a 3D framed structure or just simple columns. The substructures of space frame roofs can be either 'rigid' or 'flexible'. In the first category, the truss roof is positioned either directly on the ground, as in Fig. 2; or on a relatively rigid structure compared with the space structure itself. In other words, the space frame is almost fully restrained against any vertical and horizontal displacements. In the second category, the columns may experience horizontal displacements and allow widening of the dome. To cover a full range of support conditions, 15 different hollow circular sections of steel columns with different heights and flexural stiffness are selected and applied to the models; the properties of columns are defined in Table 2. The flexural stiffness of columns is denoted by the parameter K_c, where:

$$K_c = \frac{3EI_c}{h_c^3}. \tag{1}$$

Fig. 3 illustrates the distances D_p and D_r incorporated as the variable parameters in this research. D_p is the circumferential distance between two adjacent columns, which is directly related to the central angle β; and D_r is the radial distance between the axis of revolution of the dome and columns.

2.5. Thermal loading

A wide range of uniform thermal loadings are applied to the models. Thermal loadings are applied to all members by means of exerting temperature rises of 20, 40, 60 and 80 °C.

3. Analysis and discussion of results

All models are preliminarily and conservatively designed for dead loads according to rules and regulations of Eurocode