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Structural characteristics of Hagia Sophia under consideration of the ribs inside the dome

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Abstract

In this study, an analytical model of Hagia Sophia, modeled by the shell and the ribs was prepared to clarify the structural characteristics of the main dome depending on the effect of displacements and stresses of the dome with and without 40 ribs. A tetrahedral secondary elements were adopted to mesh. As the results, in displacement, the maximum amount of displacement of dome with ribs is smaller than that without ribs. Therefore, ribs is effective to prevent the deformation. In the equivalent stress of dome with ribs is smaller than that without ribs. Therefore, ribs was effective for reducing the stress of the dome between the openings.

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Keywords: Hagia Sophia; Structural analysis; Finite element; Stiffening ribs

1. Introduction

Hagia Sophia (Fig 1a) is a typical Byzantine style building in Istanbul, Turkey, which was built in the 6th century. It was registered UNESCO the World Cultural Heritage. And also it has been currently used as a museum and open to the public.

Hagia Sophia was firstly built in 360 years by Constantine Ⅱ. Then through the twice burnt down, Hagia Sophia was rebuilt from the 527 to 532 years. For construction work in the short term, it is impossible to provide sufficient strength of mortar, it was the cause of the structural problem of Hagia Sophia. Rebuilt Hagia Sophia has been partially collapsed and repaired due to repeated earthquake [1].

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The most important structural features of Hagia Sophia is a main dome of a diameter of about 31 meters. The main dome has radical 40 ribs and the same number of openings in inside. The dome is supported by four main arch.

Horizontal force generated from main dome is suppressed by a semi-dome in the east and west direction. Buttress as supports the dome in the north and south direction. And four corners are suppressed by the triangular pendentives. The material composed of Hagia Sophia was stone and marble, as well as the composite material containing the brick and mortal in even amount. Gallery level used a stone and main dome used a brick and a mortar [2].

In the previous studies, the dome has been commonly analyzed as a shell structures. However, the mechanical properties of the shell with ribs has not been considered. In this study, an analytical model of Hagia Sophia that is modeled by the shell and the ribs was analyzed to clarify the structural characteristics of the main dome.

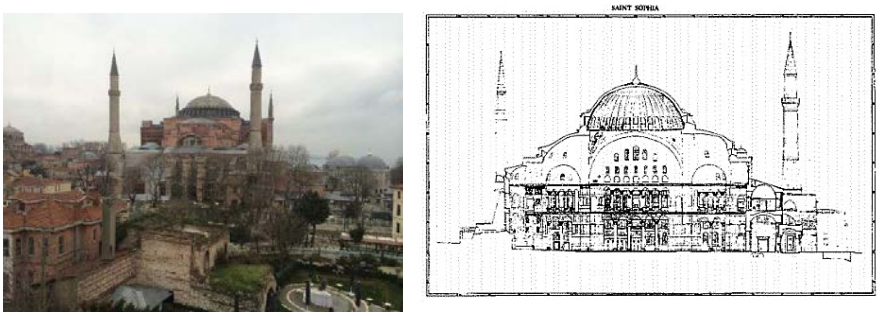


Fig. 1 (a) Photo of Hagia Sophia (b) Drawing of Robert Van Nice

2. Creation of an analysis model

2.1. Modeling of Hagia Sophia

Hagia Sophia was modeled with reference to the measured drawings of Robert Van Nice [3]. It contains all 46 sheets, Floor tiles and bricks and cracks are described in detail (see Fig. 1b). The existing drawings was the most detailed ones to determine the geometric data of the model.

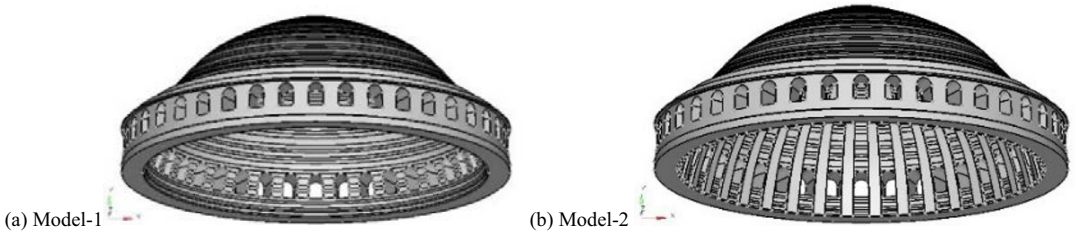
2.2. Analytical Model

To create the analytical model, “Hyper Mesh” was adopted [4]. In this study, the structural behavior of the main dome depending on the effect with and without ribs was analyzed.

Two models were defined:

In Fig. 2(a), the numerical model of the dome (Model-1) without ribs. Also Fig. 2(b) shows the numerical model of the dome (Model-2) with ribs in the main dome.

Using the two models, the investigation of the structural characteristics of the main dome was performed depending on the effect of radial ribs.



(a) Model-1 (b) Model-2

Fig. 2. Numerical model