CHAPTER 9

ABSTRACT

This thesis includes analyses that focus on the dynamic behavior of the church of Zabourda, in the district of Kozani, Greece. A first objective of this study is to examine the importance of various structural elements, such as the tympana, apses, main and secondary vaulting system, in the behavior of the whole structure. A second objective is to predict the initiation and propagation of failure at various structural elements under several load combinations.

First, a visit to the church was carried out, and the geometry, as well as the damages that the church was subjected to after the earthquake of Kozani, in 13 May, 1995, were recorded. Then, the church, with its real dimensions, was designed, using the Architectural Desktop (chapter 3) and the necessary analyses were executed.

It must be mentioned that the simulation of such structures is rather difficult, because of their geometric asymmetry and the difficulty in understanding the load transfer mechanisms though the several structural elements. For this reason, a simple investigation was carried out in order to understand the behavior of the vaulting system and their collaboration with the vertical structural elements (chapter 4). In the beginning, simple vaults that are supported by tympana and walls or domes and apses were examined. A force equal to 1Kn was applied in the top of the vault and through the displacement that the force causes to the system, its stiffness is calculated. Afterwards, simple models, similar to the church, were gradually constructed and through the process that was described before, their stiffness is calculated. In these analyses two categories of models were used: 1) symmetric models, 2) asymmetric models, with different lengths between the longitudinal and the transverse direction.

Next, models, that gradually compose the whole church, were constructed (chapter 5) and a modal analysis was performed, using the program SAP2000 as well as the program LUSAS (chapter 6). In this analysis framework, a parametric investigation was performed by studying the importance of various structural elements, such as the tympana, apses, main and secondary vaulting system, in the stiffness of the whole structure. After the end of this analysis a final model was chosen, and this one was used for the analyses that followed.

An elastic analysis was carried out, using the program SAP2000 (chapter 7). In the beginning, gravitational and/or earthquake loads were applied in order to identify the deformation of the models, which were used in the modal analysis. The

earthquake forces in doth directions, are found as a product of the masses with an assumed normalized acceleration equal to 1g (acceleration of gravity). Afterwards, for the final model, which was selected from the modal analysis, an elastic analysis using the design spectrum, specified by the Greek Seismic Code (EAK 2000), and a dynamic analysis were performed. During these analyses the gravitational loads and the earthquake forces were applied simultaneously, in order to identify certain areas of the load-bearing system that exhibit stress concentration and reaches critical tensile compressive and shear strength values for the stone masonry. The stress fields obtained in this way were combined with a Mohr-Coulomb (σ-τ) failure criterion in order to identify the failure areas.

Finally, the analysis was extended in a non-linear range, using the program LUSAS, by the inclusion of three alternative modified Von-Misses failure envelopes for the stone masonry (chapter 8). This time the combined gravitational and earthquake forces are applied sequentially.