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Structural characteristics of ancient dome in Jerash

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ABSTRACT

Jerash is the remains of a Roman ancient city and is located 48km north from Amman, Jordan. In the heritage site constructed in mid second century, the stately agora, colonnaded streets and the building beside them have been constructed. In this paper, firstly, the structural characteristics of the main dome were analyzed numerically based on the shape surveying and the structural characteristics of the total structure were studied as well. Then, secondary, assuming uneven settlement of the pier due to soil flowage and foundation cutting, the structural behavior was assessed by FE analysis. From the numerical analyses, the stress concentration of total structure was detected by pier uneven settlement and the portion of stress concentration coincides with the portion of cracking and the opening between stone joints. The numerical results show well the existing structural behavior and provide us the knowledge of restorations.

1. INTRODUCTION

Jerash is the remains of a Roman ancient city and is located 48km north from Amman, Jordan. In the heritage site constructed in mid second century, the stately agora, colonnaded streets and the building beside them have been constructed. In case of space structure, the arch and the vault structures are still partially remained. Also, there are some semi domes that represent the ancient structural components and are useful to study the structural systems in this period. Within these heritage structures, the dome structure constructed from stone bricks has survived so far almost in complete shape as one of the western bath structure. From the reconnaissance around the west bath, a lot of problems, such as soil flowage and foundation cutting, were detected. Therefore, precise investigations were required. In this paper, firstly, the structural characteristics of the main dome were analyzed numerically based on the

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shape surveying and the structural characteristics of the total structure were studied as well. Then, secondary, assuming uneven settlement of the pier due to soil flowage and foundation cutting, the structural behavior was assessed by FE analysis.

2. OVERVIEW OF WEST BATH

Fig. 1 shows the layout of west bath in Jerash (Browning 1982, Kraeling 1938). The dome remained here is the northern part of the structure (A1). Considering the symmetry of the plan, the same dome existed past at southern part but only the vault remains here now. There are several stone bricks that may represent the large dome B (approximately the double diameter of A) at western part. The photo from the western view is represented in Fig. 2.

To investigate the structural characteristics of the west bath, the existing northern dome (A1) is inspected and analyzed numerically. FE analysis of heritage structure was done previously to investigate the structural characteristics (Kaneshige 2007, Yamasaki 2012).

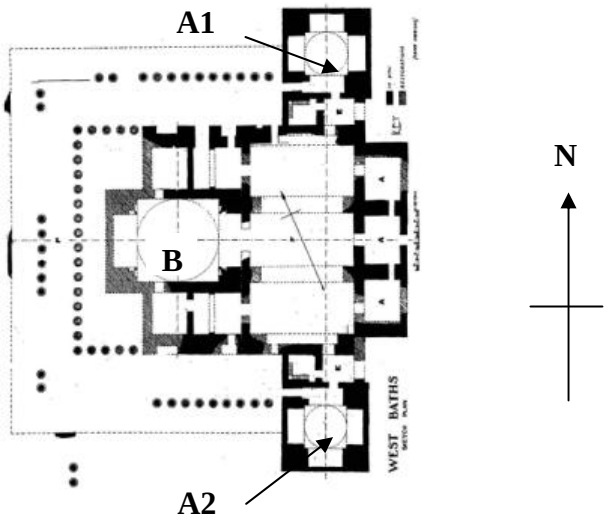


Fig. 1 The plan of west bath

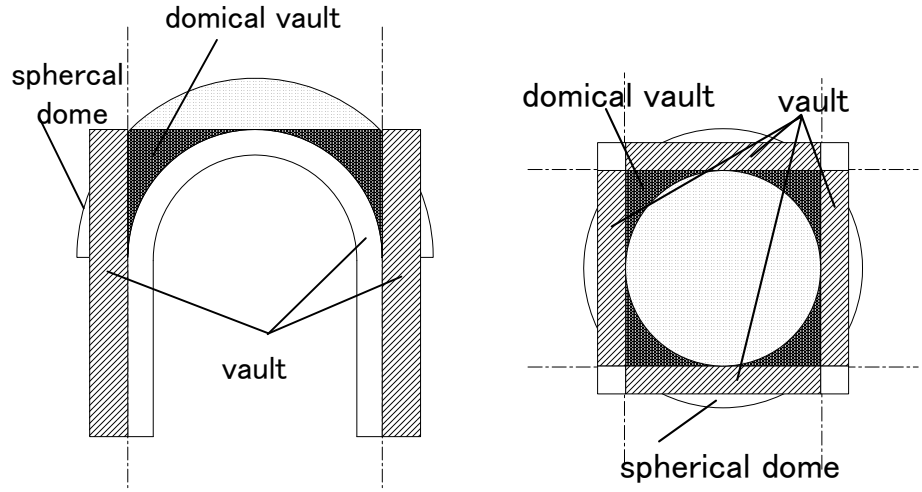
A1 B A2

Fig. 2 West view of west bath

3. STRUCTURAL CHARACTERISTICS OF NORTHERN DOME

From the inspection, the northern dome (A1) has almost the same curvature from dome top to pier top. Therefore, the dome is not a pendentive type but a domical vault type. As shown in Fig. 3, the dome is cut out from the spherical dome along the dot dash line (see Fig. 3 (b)) and the wide vaults are attached to it. The vaults resist against the horizontal loading. The domical vault is supported on the thick piers arranged at four corners.

The diameter of the dome is 6.9 m. The outer height of the dome is 9 m. The width of the structure is a square, 13.8 m on a side. The pier is also a square, 3.5 m on a side.



(a) elevation (b) plan

Fig. 3 Configuration of the dome

4. STRUCTURAL PROBLEMS AND NUMERICAL ANALYSES

The dome of the west bath is supported by four piers. Therefore, stable foundation is required. The west bath is located on the gentle slope from west to east. The west bath also has two foundation problems to support a heavy dome. One is the cutting the foundation close to the structure and represents the narrow boundary between dome and new residential buildings on the eastern side. The other is the slope instability due to the soil flowage at the road pavement on western side. Therefore, piers are prone to show an uneven settlement.

The structural problems mentioned above are inspected and are analyzed numerically. In numerical investigations, FE analyses are adopted and three dimensional analyses are performed.

4.1 Deformation of vaults

Fig. 4 shows the northern view of the vault. The right side shows the west that is the street side. From Fig. 4, the vault shows gaps between bricks because the left side of a vault settles down and the shear crack occurs on the main piers. Especially, the deformation of each brick appears at the bottom of the pier on the eastern view (Fig. 5).

Fig. 6 shows the numerical analysis of the dome models. When a pier settles unevenly, the same deformations and the same stress condition arises.

Fig. 4 Northern view of the dome

Fig. 5 Eastern view of the dome

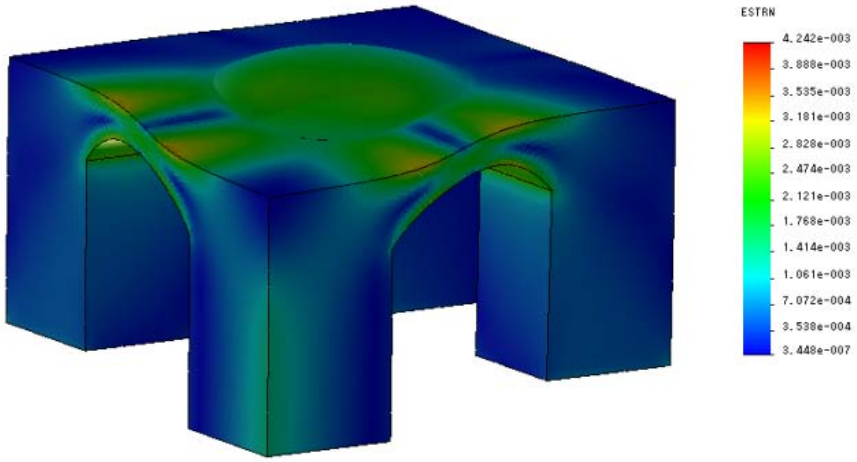


Fig. 6 FE analysis with a pier settlement

In numerical analysis, an isoparametric elastic analysis with solid element was conducted (Hinton 1984) because of finding the structural characteristics of the dome structure. Color contour shows the equivalent stress distributions.

4.2 Wall deformation surrounded by the vault

Fig. 7 shows the southern wall from the northern view. The right side of the figure also shows the street side. As the same as Fig.4, the vault incline to the eastern side.

Therefore, the large gaps arise between the vault and the wall and the opening due to a shear deformation exists.

Fig. 7 Brick wall on southern end

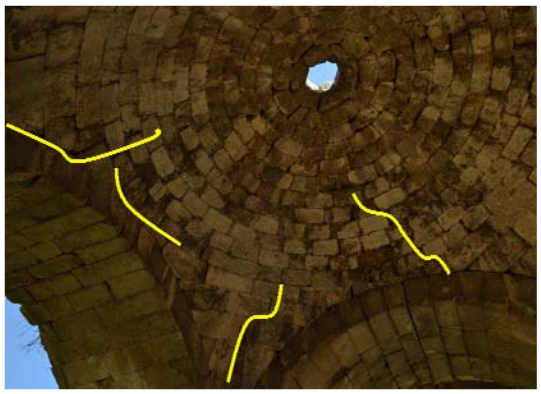


Fig. 8 Inner surface of the dome

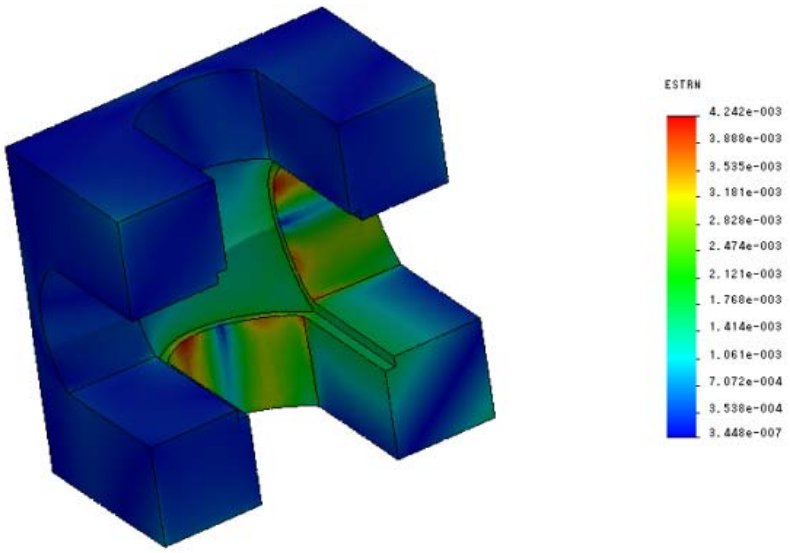


Fig. 9 Stress analysis of the dome by FEM

4.3 Deformation of the dome

Fig. 8 shows the inner roof of the west bath. The dome consists of regular stone masonry and it does not show any problems itself. However, the cornice of the dome has gaps. Also, the cracks occurred in each brick element due to the tensile stress in the bricks. In case of a spherical dome, compressive and tensile stresses arise in the portion of top and bottom of the dome, respectively. Therefore, the dome itself cannot hold its shape.

Fig. 9 shows the stress distribution of the inner surface of the dome when the one piers is subjected to uneven settlement (see Fig. 6). Color contour shows also the equivalent stress distributions. The stresses in the dome concentrate around the top of the piers and the crown of the vault.

5. CONCLUSION

In this paper, the structural characteristics of the stone dome at west bath in the Jerash heritage site are inspected and numerically analyzed. The domes B and A2 shown in Fig. 1 were collapsed. The remained vaults and piers may be collapsed due to the aging effects and the foundation conditions. Therefore, the fundamental investigation was performed.

From the inspection and the numerical analyses, following conclusions are obtained.

1. The structural deterioration and the structural deficiency were detected caused by the uneven foundation settlement from the inspection.
2. Based on the uneven settlement of a pier, the numerical investigation represents the possibility of structural failure as the same manner as the existing structure..
3. As the remained A1 dome represents the same structural characteristics as other B and A2 domes, the precise measurement of the structure will be required and the precise numerical investigation based on the measurement will be also required to maintain the historical heritage structure in Jerash,

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