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# Structural Retrofitting of Existing Stone Siphon by Internally Concrete Lining

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***Abstract*** – Nowadays, the devastating effects of natural disasters and methods of protection from these effects are very popular. In the field of civil engineering, the issue of protecting structures against natural disasters has always been on the agenda. For this reason, research on the protection of all building types against natural disasters is of vital importance. It seems that stone siphons, especially those used for irrigation purposes, are negatively affected by earthquakes. As a result of this situation, problems are encountered in accessing water and flowing water. Post-disaster modal performance levels of stone siphons should be examined and as a result, appropriate retrofitting techniques should be applied according to the structure type, damage and regional conditions. Various retrofitting methods are available to increase the seismic performance and stiffness of stone siphons. The retrofitting method with concrete lining also stands out as an alternative, simple and popular. For all these reasons, this study focused on retrofitting stone siphon with concrete lining. A stone siphon model was created with the finite element method and modal analysis was performed. Then, the same model was retrofitted with concrete lining and modal analysis was performed. When the results obtained were compared, it was seen that retrofitting with concrete lining significantly increased the stone siphon rigidity. In light of all these findings, it is recommended to retrofit concrete lining for stone siphons.

*Keywords –Concrete Lining, Stone Siphon, Retrofitting, Modal Analysis, Stiffness*

## I. Introduction

Many types of structures are damaged as a result of natural disasters (such as floods, landslides, earthquakes). According to the degree of damage received, loss of life and property occurs with the collapse. In some structures, collapse does not occur as a result of disasters, but damage is observed [1], [2], [3], [4]. Various reinforcement methods are applied in such structures. Thus, the structures are restored to their former bearing strength and stiffness, thus avoiding possible collapse. Various proven popular retrofit methods are available to solve such problems. The use of concrete lining retrofitting is one of these retrofit methods which popular and simple method [5].

Concrete lining is one of the most conventional types of lining which has successfully been used in the world. Generally, internal cement-lining of pipe systems protects the inner steel surface from corrosion and provides excellent hydraulic properties. High purity of the cement, sand and potable water is the perfect elements for a protective lining in drinking water systems. High sulphate resistant cement types in combination with high density and low permeability of the cement-lining make cement-lining extremely suitable for conveying (sea) water that contains aggressive elements. Cement lined pipe systems, mainly used in drinking water, cooling water and firewater applications, are relatively cheap and have a very long lifetime. Shop applied cement-lining can be produced using different techniques. For straight sections of pipe, nps 3” - nps 84”, a high-capacity cement-lining machine spraying premixed cement mortar is utilized to uniformly distribute the cement mortar against the inner pipe surface. The pipe will be centrifuged on the same machine to produce a dense lining and to obtain a smooth surface of the lining. The length is limited to 18 m per pipe. Fittings and flanges of any size are lined by hand trowelling, spray gun or combination thereof. Cement concrete lining without reinforcement may be damaged due to excessive external water pressure. This situation should be taken into consideration in the design. Information about concrete lining that used to this study was obtained from [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23] theoretical, analytical and experimental studies. These studies guided the study. In addition, these reference studies not only touched upon concrete lining but also the use of concrete lining as a retrofit method.

Siphons were one of the most complex engineering solutions used by Roman engineers in their designs for aqueducts. The Romans used aqueducts extensively for supplying good quality water to towns and cities. In the case of both underground water and above-ground streams, it was necessary to ensure that the water was of sufficient quality for human consumption, and that the volume or concept us available was sufficient to meet supply needs even in times of shortage. It was therefore a decision of great social, political and economic importance, which had to be taken quickly after receiving advice from the experts. The most difficult job when using stone pipes was to drill a large circular hole through which the water would pass precisely and accurately. Little is known about the way the drills were made, except for what Vitruvio says in the last of his books De architectura [24] on the importance of scale when moving from a small scale-model to a large prototype. The manual system for perforating blocks of stone began by making a small hole with a pick. When it was impossible to go any deeper, the pick was exchanged for a long iron bar of a particular size and shape, which was used for striking and rotating until perforation had been completed [25], [26].

The aim of this study is to contribute to the retrofitting of stone siphons, which are also used in infrastructure, according to their pre-disaster and post-disaster stiffness conditions. It is known that there are many retrofitting methods available for the stone siphons to regain their former stiffness. In this study, the effects of the concrete lining method on retaining wall modal periods and mode shapes are investigated.

## II. Materials and Method

In this study, stone siphon model was created and modal analysis was carried out with the finite element method. The stone siphon model was retrofitted with concrete lining retrofitting and two stone siphon model was created for comparison. Variables on the model should be minimized in order to better see the reinforcement effects. Therefore, it was emphasized that the models should be designed simply and symmetrically. Thus, it is aimed that the only variable between both models is the retrofitting method. In the application of the finite element method, the SAP2000 software was used. In this study, [27], [28], [29] studies in which the finite element method was used for retrofit were used.

### A. *Description of Stone Siphon Model*

The model stone siphon is a cylindrical siphon with a diameter of 5 m and a height of 30 m. Wall thickness is 0.25 m. The mechanical parameters of stone material in model are; poisson's ratio: 0.2, modulus of elasticity: 2.5 GPa, density: 20 kN/m$^3$. The stone siphon finite element model was created using the SAP2000 software. The finite element model of the stone siphon is given in fig. 1.

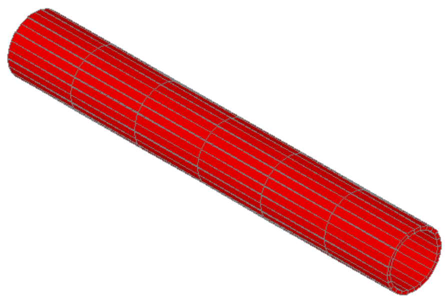

Fig. 1 3D Finite element model of the stone siphon

### B. *Description of Stone Siphon Retrofitted Model*

The existing stone siphon model is coated internally with 0.05 m concrete lining. Thus, a retrofitted model was created. Mechanical properties of the applied concrete lining materials; poisson's ratio: 0.2, modulus of elasticity: 30 GPa, density: 24 kN/m$^3$.

## III. Findings and Discussion

The stone siphon model and stone siphon retrofitted model were analysed (modal) using finite element method by SAP2000 software. The models were designed assuming there is no water in it. The period and mode shapes obtained for both models are obtained for each mode.

### A. *Modal Analysis Results of Stone siphon Model*

The modal analysis of the stone siphon model was performed. The first 5 modes were taken into account in the analysis. Obtained results are presented in figures 2,3,4,5,6 as periods and mode shapes.

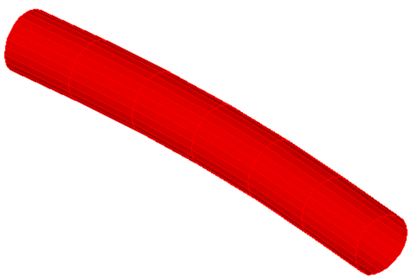

Fig. 2 1. Mode shape (Period value = 0.387 s)

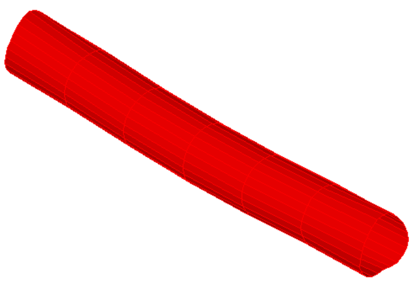

Fig. 3 2. Mode shape (Period value = 0.269 s)

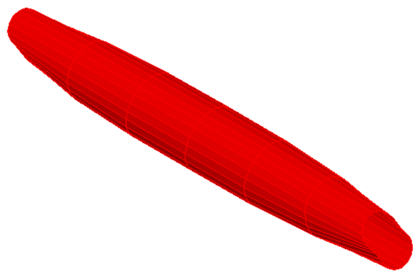

Fig. 4 3. Mode shape (Period value = 0.218 s)

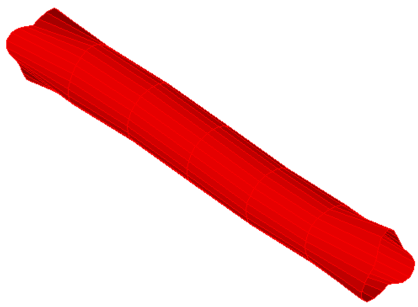

Fig. 5 4. Mode shape (Period value = 0.139 s)

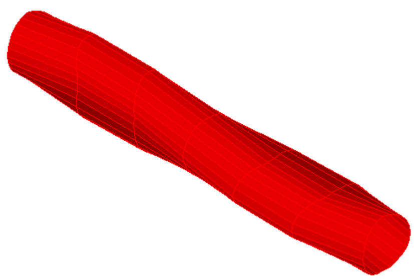

Fig. 6 5. Mode shape (Period value = 0.119 s)

*B. Modal Analysis Results of Stone siphon Retrofitted Model*

The modal analysis of the stone siphon retrofitted model was performed. The first 5 modes were taken into account in the analysis. Obtained results are presented in figures 7,8,9,10,11 as periods and mode shapes.

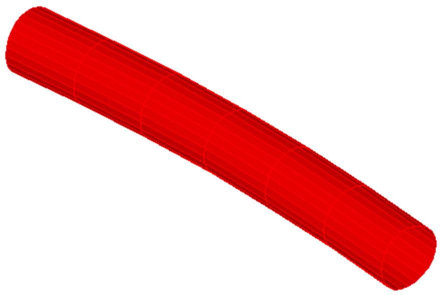

Fig. 7 1. Mode shape (Period value = 0.238 s)

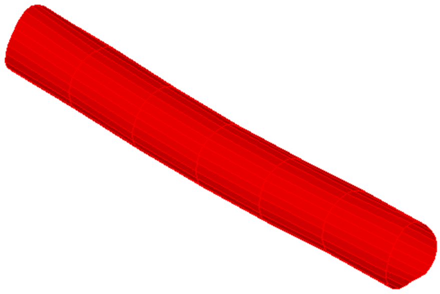

Fig. 8 2. Mode shape (Period value = 0.167 s)

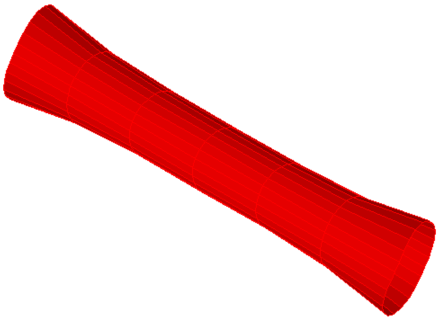

Fig. 9 3. Mode shape (Period value = 0.141 s)

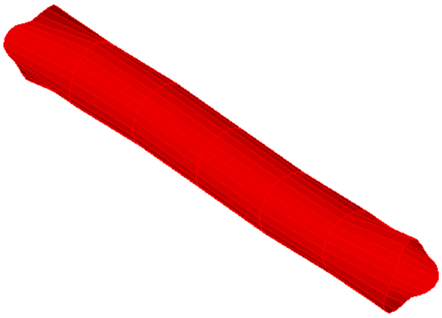

Fig. 10 4. Mode shape (Period value = 0.083 s)

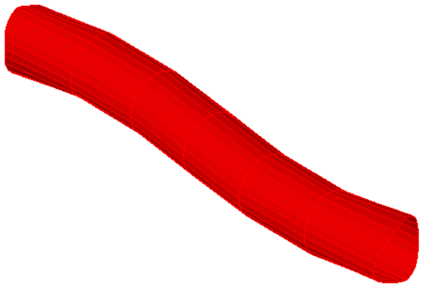

Fig. 11 5. Mode shape (Period value = 0.069 s)

### C. Comparison of Modal Analysis Results

The comparison of periods of the model non-retrofitted and retrofitted are given in Table 1.

Table 1. Comparison of period values

| Mode | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Non-retrofitted | 0.387 | 0.269 | 0.218 | 0.139 | 0.119 |
| Retrofitted | 0.238 | 0.167 | 0.141 | 0.083 | 0.069 |
| Difference (s) | 0.149 | 0.102 | 0.077 | 0.056 | 0.050 |
| Difference (%) | 38.50 | 37.92 | 26.74 | 40.29 | 42.02 |

The comparison of mode shapes of the model non-retrofitted and retrofitted model is given in Table 2.

Table 2. Comparison of mode shapes

| Mode | Non-retrofitted | Retrofitted |
|---|---|---|
| 1 | Translational | Translational |
| 2 | Translational | Translational |
| 3 | Torsional | Torsional |
| 4 | Torsional | Torsional |
| 5 | Torsional | Torsional |

In the mode 1, the period difference between non-retrofitted and retrofitted status was obtained as 0.149 s. The effect of period retrofitting with concrete lining retrofitting as a percentage was determined as 38.50.

In the mode 2, the period difference between non-retrofitted and retrofitted status was obtained as 0.102 s. The effect of period retrofitting with concrete lining retrofitting as a percentage was determined as 37.92.

In the mode 3, the period difference between non-retrofitted and retrofitted status was obtained as 0.077 s. The effect of period retrofitting with concrete lining retrofitting as a percentage was determined as 26.74.

In the mode 4, the period difference between non-retrofitted and retrofitted status was obtained as 0.056 s. The effect of period retrofitting with concrete lining retrofitting as a percentage was determined as 40.29.

In the mode 5, the period difference between non-retrofitted and retrofitted status was obtained as 0.050 s. The effect of period retrofitting with concrete lining retrofitting as a percentage was determined as 42.02.

With the retrofitting, no change was observed in the mode shapes from torsion to translation or from translation to torsion. However, some minor change in translation and torsion was observed.

## IV. CONCLUSION

As a result of this study, it is clearly seen that the stiffness of the stone siphon model increases by retrofitting the stone siphon model with concrete lining. In the 1st mode, in other words, there is a decrease of 38.50 percent in the dominant period value. The maximum decrease in period values was observed in the 5th mode with 42.02%. The minimum decrease in period values was observed in the 3rd mode with 26.47%. The maximum and minimum period value decrease was received very positively. In general, stone siphon retrofit with concrete lining, a period reduction of between 26.74 percent and 42.02 was observed. It is known that this is a very positive situation in terms of retrofit. In this case, a significant increase in stiffness can be mentioned as the effect of retrofitting. In addition, no transformation was observed in the mode shapes. In the light of all these results, it is recommended to retrofit stone siphon with concrete lining, taking into account the existing state of the stone siphon and stone siphon diameter (for adequate flow).

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