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Seismic Performance Detection in Retrofitted Concrete Spillway by FEM

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Abstract – Earthquakes damage not only buildings but also infrastructure and superstructure facilities. Therefore, the seismic performance of all structure types is of vital importance. It is known that seismic performance losses occur in various types of structures due to the earthquake effect. Various retrofitting methods are available for such structures to regain their former seismic performance. Appropriate retrofitting techniques should be applied according to the type of structure, its damage and the conditions of the region. In addition, the retrofitting process can be done to the entire structure or to some sections or parts of the structures. It is known that environmental and forced vibrations, especially in spillways, increase the destructive effects by activating the water in the spillway. In this type of situation, stiffness losses for spillways increase even more. Their collapse becomes inevitable under the influence of the next forced and environmental vibrations. For this reason, this study focused on the technique of retrofitting concrete spillways with shotcrete. A sample concrete spillway model was created using the finite element method and modal analysis was performed. Then, the same model was retrofitted with shotcrete and modal analysis was performed. When the results obtained were compared, it was seen that retrofitting with shotcrete had a positive effect on the rigidity of the concrete spillway. In light of all these findings, shotcrete can be an option for retrofitting concrete spillways.

Keywords –Shotcrete, Retrofitting, Modal Analysis, Concrete Spillway, Seismic Performance

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. It is known that the destructive effects of natural disasters also damage structures, thus damage may occur much more than expected. Concrete spillways are also exposed to these destructive effects. Various proven retrofit methods are available to solve such problems. The use of shotcrete is one of these retrofit methods.

Shotcrete; concrete consisting of cement, aggregate, water and some necessary additives; It is a type of concrete coating obtained as a result of spraying the concrete on the surface to be coated at a certain speed with the help of a special hose and equipment. Shotcrete is a working method based on very fast freezing. When looking at the usage phase in the tunnel, it is excavated immediately after the steel shoring and steel mesh are thrown away. A dense-cement design concrete (injection as it is known in the field) and the instant setter are held in two same positions, then poured with the help of machine pumps to the place where the steel shoring and steel mesh are laid. The thinnest point in spillage; is that the instant setter and the injection come in separate channels up to the mouth of the pump that makes the injection. Their complete mixing occurs at the mouth point of the concrete pump. The sprayed concrete solidifies within seconds and interrupts the interaction of the ground and the air in the gradual tunnel construction. In cases where shotcrete is used and the interaction of the ground and air is not interrupted, the mirror dries as the day progresses, spills, bursts and collapses may occur [5], [6]. Researchers have conducted experimental and theoretical studies [7], [8], [9], [10], [11], [12], [13], [14], [15] about shotcrete which also contributed to this study.

A spillway is a structure used to provide the controlled release of water downstream from a dam or levee, typically into the riverbed of the dammed river itself. Spillways ensure that water does not damage parts of the structure not designed to convey water. Spillways have been used for over 3000 years [16]. Despite being superseded by more modern engineering techniques such as hydraulic jumps in the mid twentieth century, since around 1985 [17] interest in stepped spillways and chutes has been renewed, partly due to the use of new construction materials (e.g., roller-compacted concrete, gabions) and design techniques (e.g., embankment overtopping protection) [18], [19]. The steps produce considerable energy dissipation along the chute [20] and reduce the size of the required downstream energy dissipation basin [21], [22]. Research is still active on the topic, with newer developments on embankment dam overflow protection systems, [22] converging spillways [23] and small weir design [24].

The aim of this study is to contribute to the strengthening of concrete spillways used for many purposes according to their modal conditions. In this study, the effects of the shotcrete retrofit method on concrete spillway modal periods and mode shapes are investigated.

II. Materials and Method

In this study, concrete spillway model was created and modal analysis was carried out with the finite element method. The concrete spillway model was retrofitted with shotcrete retrofitting and two concrete spillway 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, which is used in the field of academic and engineering applications all over the world, was used. In this study, [25], [26], [27] studies in which the finite element method was used for retrofit were used.

A. *Description of Concrete Spillway Model*

The model concrete spillway is dimensions; width is 5 m, wall heights are 2 m and length are 25 m, wall thickness is 0.20 m. The mechanical parameters of concrete spillway in model are; poisson's ratio: 0.2, modulus of elasticity: 30 GPa, density: 24 kN/m^3. The concrete spillway finite element model was created using the SAP2000 software. The finite element model of the concrete spillway is given in fig. 1.

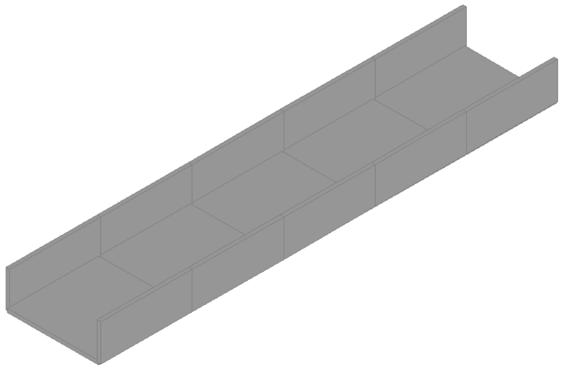

Fig. 1 3D Finite element model of the concrete spillway

B. *Description of Concrete Spillway Retrofitted Model*

The inner surface of the existing concrete spillway model was coated with 0.05 m of shotcrete to create retrofitted model. Mechanical properties of the applied shotcrete materials; poisson's ratio: 0.2, modulus of elasticity: 35 GPa, density: 23 kN/m^3.

III. Findings and Discussion

The concrete spillway model and concrete spillway retrofitted model were modal analysed using SAP2000 software. The period and mode shapes obtained for both models are obtained for each mode.

A. *Modal Analysis Results of Concrete Spillway Model*

The modal analysis of the concrete spillway model was performed with finite element method. 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.

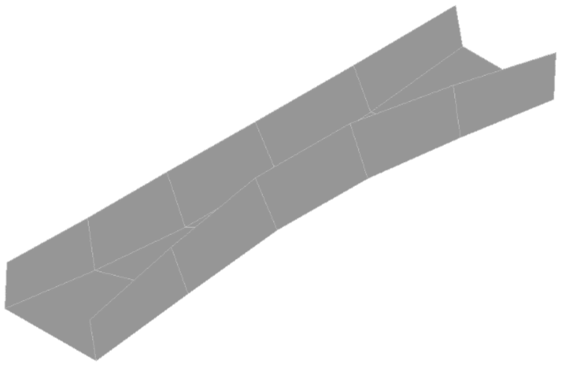

Fig. 2 1. Mode shape (Period value = 0.165 s)

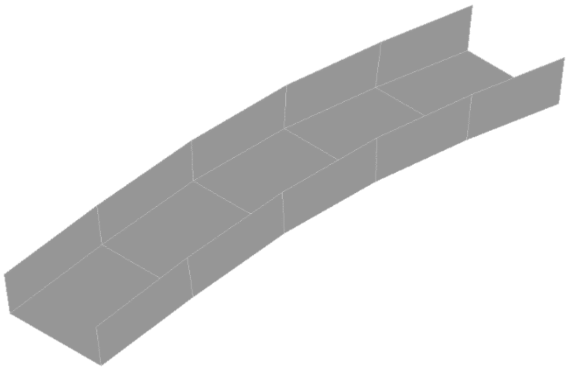

Fig. 3 2. Mode shape (Period value = 0.149 s)

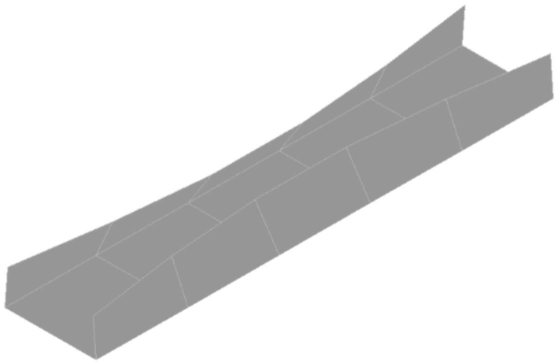

Fig. 4 3. Mode shape (Period value = 0.103 s)

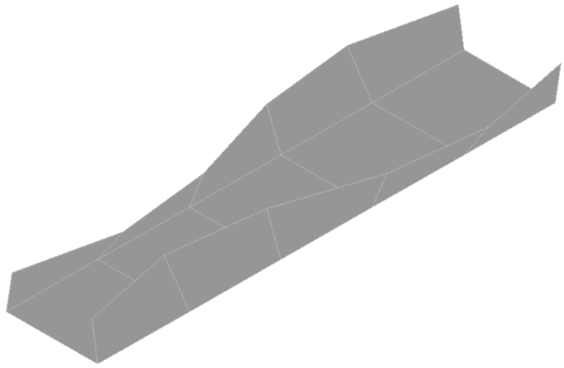

Fig. 5 4. Mode shape (Period value = 0.093 s)

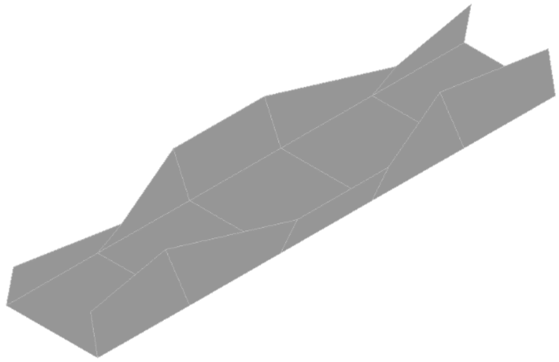

Fig. 6 5. Mode shape (Period value = 0.080 s)

B. *Modal Analysis Results of Concrete Spillway Retrofitted Model*

The modal analysis of the concrete spillway retrofitted model was performed with finite element method. 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.

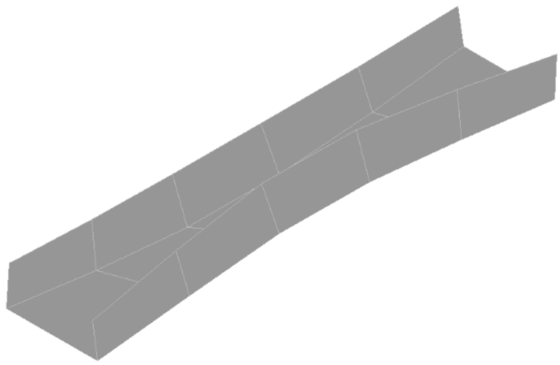

Fig. 7 1. Mode shape (Period value = 0.155 s)

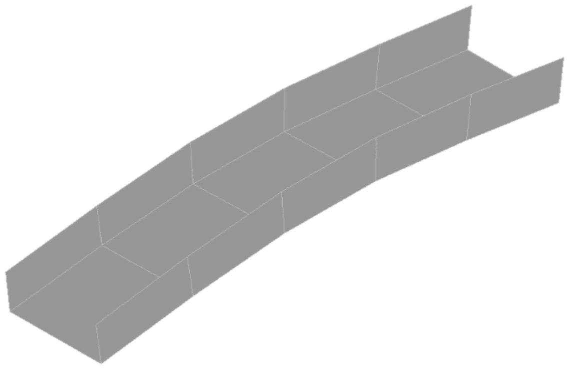

Fig. 8 2. Mode shape (Period value = 0.144 s)

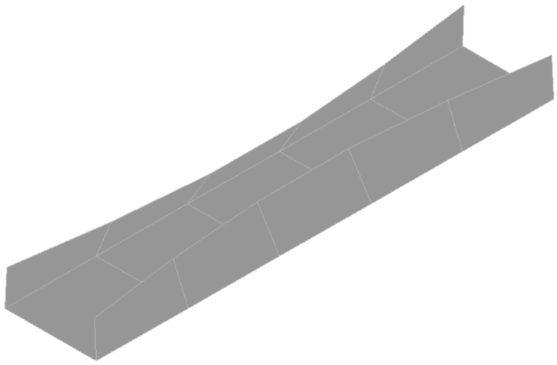

Fig. 9 3. Mode shape (Period value = 0.077 s)

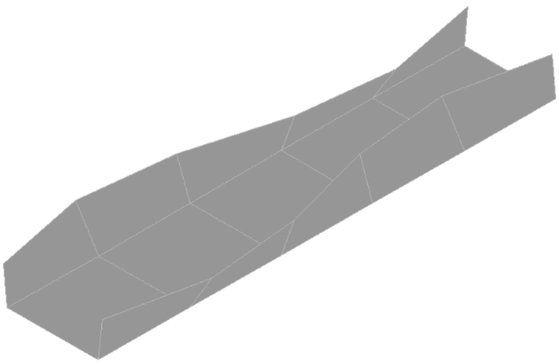

Fig. 10 4. Mode shape (Period value = 0.069 s)

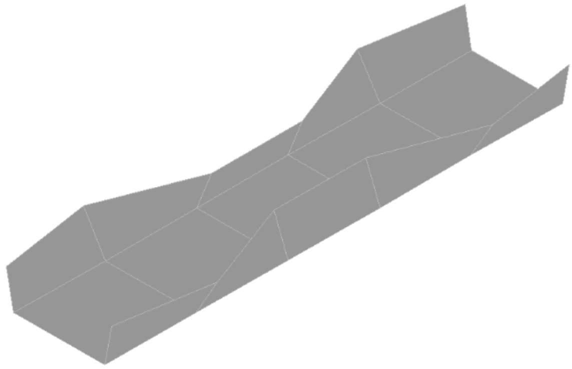

Fig. 11 5. Mode shape (Period value = 0.058 s)

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	0.165	0.149	0.103	0.093	0.080
Retrofitted	0.155	0.144	0.077	0.069	0.058
Difference (s)	0.010	0.005	0.026	0.024	0.022
Difference (%)	6.06	3.36	25.24	25.81	27.50

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	Torsional	Torsional
2	Translational	Translational
3	Torsional	Torsional
4	Torsional	Torsional
5	Torsional	Torsional

IV. CONCLUSION

In the mode 1, the period difference between non-retrofitted and retrofitted status was obtained as 0.010 s. The effect of period retrofitting with shotcrete retrofitting as a percentage was determined as 6.06.

In the mode 2, the period difference between non-retrofitted and retrofitted status was obtained as 0.005 s. The effect of period retrofitting with shotcrete retrofitting as a percentage was determined as 3.36.

In the mode 3, the period difference between non-retrofitted and retrofitted status was obtained as 0.026 s. The effect of period retrofitting with shotcrete retrofitting as a percentage was determined as 25.24.

In the mode 4, the period difference between non-retrofitted and retrofitted status was obtained as 0.024 s. The effect of period retrofitting with shotcrete retrofitting as a percentage was determined as 25.81.

In the mode 5, the period difference between non-retrofitted and retrofitted status was obtained as 0.022 s. The effect of period retrofitting with shotcrete retrofitting as a percentage was determined as 27.50.

With the retrofitting, some minor change in translation and torsion was observed. It is thought that these changes are not very important. No negative change was observed in terms of retrofit in mode shapes.

As a result of this study, it is clearly seen that the stiffness of the concrete spillway model increases by retrofitting the concrete spillway model with shotcrete retrofitting. In general, it is seen that the decrease in the periods is between 3.36% and 27.50%. In the 1st mode, in other words, there is a decrease of 6.06 percent in the dominant period value. It is known that this is a somewhat positive situation in terms of retrofit. The reason for this situation can be shown as the single layer application of shotcrete and long of spillway model. It is estimated that with the thicker application of shotcrete, the period decrease will be greater in 1st and 2nd mode. It can be said that the period declines in the 3rd, 4th and 5th modes are quite positive. The maximum decrease in period values was observed in the 5th mode %27.50 and the minimum decrease in period values was observed in the 2nd mode %3.36. In the light of all these results, the concrete spillway can retrofit with the shotcrete, taking into account the existing state of the spillway and environmental factors.

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