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# Simulation of Shotcrete in RC Tunnel Using Finite Element Method

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***Abstract* –** Nowadays, tunnels are gaining importance with the developing transportation networks. Different solutions are made in the design of tunnels according to the land structure and ground condition. Various retrofitting methods are used in damaged tunnels. Especially in recent years, natural disasters in the world have also affected the tunnels. There may be damage and collapse in the tunnels during and after the disaster. It is predicted that in the event of a possible collapse in the event of a disaster, loss of life and property may also occur. After the disaster, even if the tunnels have not collapsed, they are damaged. In this case, collapse may occur in the next disaster due to collapse or environmental vibrations. It is also known that in post-disaster situations, it is vital that the transportation network remains active in order to deliver the necessary aid to the region. For all these reasons, in this study, the shotcrete method, which is one of the retrofitting methods of tunnels, is mentioned. Thus, the effect of the shotcrete method applied on an exemplary tunnel on modal parameters has been demonstrated. In this comparative study, it was observed that the stiffness of the tunnel increased with the shotcrete method. As a result of this study, it is suggested to retrofitting the tunnels with the shotcrete method, taking into account the state of the tunnel lining or mirror and environmental factors.

*Keywords – Reinforced concrete tunnel, Shotcrete, Modal analysis, Retrofitting*

## 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. In addition to the loss of life and property that may occur with the effect of collapse in tunnels, indirect loss of life and property is seen with the damage of transportation networks. Various proven retrofit popular methods are available to solve such problems. The use of shotcrete is one of these retrofit methods which popular method.

The increase in the population living in the cities and the physical growth in the cities cause the disruption of some urban functions, especially transportation. In order to eliminate the problems in these functions, it is becoming more and more necessary to use the underground day by day. In this context, transportation-related structures such as underground car parks, subway and highway tunnels can be counted as the main urban underground structures. In addition, there are wastewater tunnels of all sizes and structures such as shopping, culture and art centers, although not too many [5]. Tunnel; railway, highway, pedestrian road, canal etc. These are the engineering structures that are applied to pass this part underground in places where it is technically impossible or economically unsuitable to pass a part of the transport routes such as During construction, each tunnel has its own unique conditions. They are underground rock structures with an inclination angle of less than 30º, open at both ends, and very small in diameter relative to their length. Arching can also be described as the ability of the gaps opened in the rocks to stand without the need for support. Arching varies depending on the geological features of the rock, the relationship between strike slope and tunnel direction, and the length of the unsupported part. The stability of the excavated rock, the thickness of the cover on the tunnel, the nature of the structures or structuring on the tunnel route and the regions where the stresses in the tunnel are particularly concentrated during the projecting phase; are the basic parameters in determining the excavation support type. In the determination of tunneling method and shoring support systems, besides the parameters of route topography, ground conditions and tunnel geometry, speed, cost, time, safety and functionality factors should also be considered. In terms of construction techniques, there are 5 groups of tunneling methods [6].

- Drilling - Blasting Method
- New Austrian Tunneling Method (NATM)
- Tunnel Boring Machine Method (TBM)
- Ground Pressure Balancing Machine Method (EPBM)
- Open - Close Method

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 [7].

Researchers have carried out many studies using both the retrofitting and the finite element method. Researchers have conducted studies [8], [9], [10], [11], [12], [13], [14], [15] about tunnels which also contributed to this study. Also, researchers have conducted studies [16], [17], [18], [19], [20], [21], [22], [23], [24] about shotcrete which also contributed to this study.

The aim of this study is to contribute to the retrofitting of tunnels, which are also used in transportation networks, according to their pre-disaster and post-disaster stiffness conditions. It is known that there are many retrofitting methods available for the tunnels to regain their former stiffness. In this study, the effects of the shotcrete method on RC tunnel stiffness and mode shapes are investigated.

## II. Materials and Method

In this study, reinforced concrete tunnel model was created and modal analysis was carried out with the finite element method. The reinforced concrete tunnel model was retrofitted with extra shotcrete and two reinforced concrete tunnel 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 package program, which is used in the field of academic and engineering applications all over the world, was used.

### A. *Description of RC Tunnel Model*

The model tunnel is designed as reinforced concrete. The tunnel model has a diameter of 5 m and a semicircular cross-section, height is 2.5 m, length is 20 m and wall thickness are 0.20 m. The mechanical parameters of the model reinforced concrete tunnel are; poisson's ratio: 0.2, modulus of elasticity: 30 GPa, density: 24 kN/m$^3$. The reinforced concrete tunnel finite element model was created using the SAP2000 software. The finite element model of the reinforced concrete tunnel is given in fig. 1.

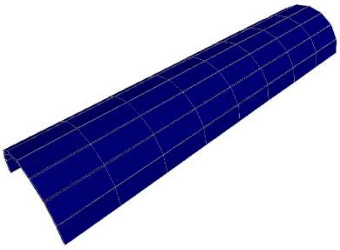

Fig. 1 3D Finite element model of the RC tunnel

*B. Description of RC Tunnel Retrofitted Model*

0.05 m shotcrete process was applied to the all-inner surface of the existing tunnel model. Mechanical properties of the applied shotcrete; poisson's ratio: 0.2, modulus of elasticity: 35 GPa, density: 23 kN/m$^3$.

## III. Results and Discussion

Reinforced concrete tunnel model and reinforced concrete tunnel retrofitted model were analysed (modal) using SAP2000 software. The period and mode shapes obtained for both models are obtained for each mode.

*A. Results of RC Tunnel Model*

The modal analysis of the reinforced concrete tunnel model was performed with FEM. 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.

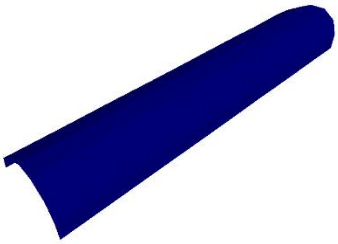

Fig. 2 Mode shape (Period value = 0.052 s)

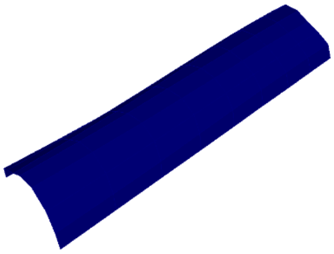

Fig. 3 Mode shape (Period value = 0.034 s)

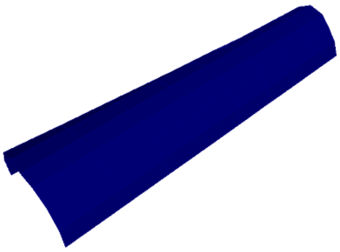

Fig. 4 Mode shape (Period value = 0.024 s)

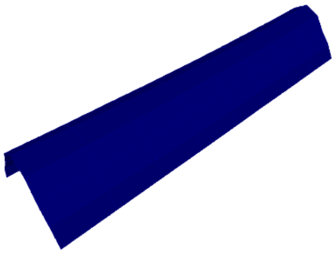

Fig. 5 Mode shape (Period value = 0.023 s)

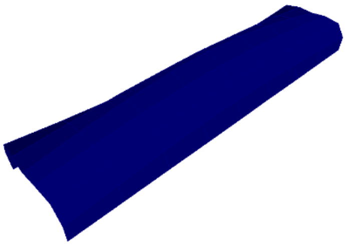

Fig. 6 Mode shape (Period value = 0.022 s)

*B. Results of RC Tunnel Retrofitted Model*

The modal analysis of the reinforced concrete tunnel retrofitted model was performed with FEM. 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.

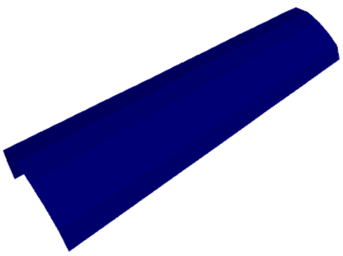

Fig. 7 Mode shape (Period value = 0.036 s)

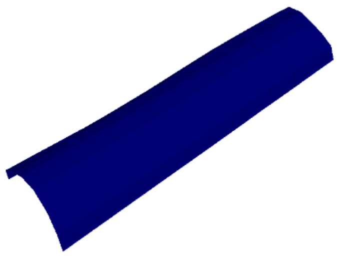

Fig. 8 Mode shape (Period value = 0.027 s)

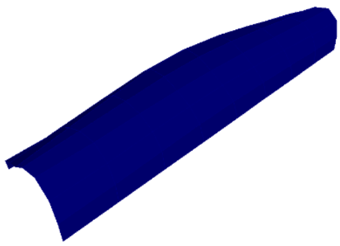

Fig. 9 Mode shape (Period value = 0.018 s)

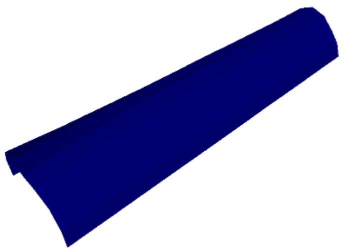

Fig. 10 Mode shape (Period value = 0.016 s)

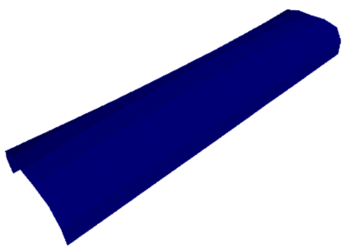

Fig. 11 Mode shape (Period value = 0.015 s)

### C. *Comparison of Modal Analysis Results*

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

Table 1. Comparison of period values

| **Mode** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Non-retrofitted | 0.052 | 0.034 | 0.024 | 0.023 | 0.022 |
| Retrofitted | 0.036 | 0.027 | 0.018 | 0.016 | 0.015 |
| Difference (s) | 0.026 | 0.007 | 0.006 | 0.007 | 0.007 |
| Difference (%) | 50.00 | 20.59 | 25.00 | 30.44 | 31.32 |

When the mode shapes are examined in general, translations are seen in the 1st and 2nd mode shapes in both models. Torsions dominate in the 3rd, 4th and 5th mode shapes. With the retrofitting, some change in translation and torsion was observed.

## IV. CONCLUSION

In the mode 1, the period difference between non-retrofitted and retrofitted status was obtained as 0.026 s. The effect of period retrofitting with shotcrete as a percentage was determined as 50.00.

In the mode 2, the period difference between non-retrofitted and retrofitted status was obtained as 0.007 s. The effect of period retrofitting with shotcrete as a percentage was determined as 20.59.

In the mode 3, the period difference between non-retrofitted and retrofitted status was obtained as 0.006 s. The effect of period retrofitting with shotcrete as a percentage was determined as 25.00.

In the mode 4, the period difference between non-retrofitted and retrofitted status was obtained as 0.007 s. The effect of period retrofitting with shotcrete as a percentage was determined as 30.44.

In the mode 5, the period difference between non-retrofitted and retrofitted status was obtained as 0.007 s. The effect of period retrofitting with shotcrete as a percentage was determined as 31.32.

With the retrofitting, some change in translation and torsion was observed.

In the light of all these results, it is clearly seen that the stiffness of the reinforced concrete tunnel model increases by retrofitting the reinforced concrete tunnel model with shotcrete. In the 1st mode, in other words, there is a decrease of 50.00 percent in the dominant period value. The maximum decrease in period values was observed in the 1st mode and it is known that this is a very positive situation in terms of retrofit. As a result of this study, the reinforced concrete tunnels can retrofit with the shotcrete method, taking into account the state of the tunnel lining or mirror and environmental factors.

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