DETERMINATION OF MODAL PARAMETERS OF REINFORCED CONCRETE TUNNEL RETROFITTED WITH CFRP USING FINITE ELEMENT METHOD

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ABSTRACT

In this paper, the effectiveness of (CFRP) fabric-reinforced concrete, as a means of increasing the rigidity of tunnel lining, was experimentally and analytically investigated. Carbon fiber reinforced polymer (CFRP) is a practical option construction material that has been utilized considerably in the reinforcement of concrete structures. Reinforcement has been implemented by wrapping 4 mm thick CFRP fabric around a concrete tunnel of 5 m in diameter and 25 m in length. The differences between modal parameters of the concrete tunnel and CFRP reinforced concrete tunnel were compared. These modal parameters are period and mode shapes. The first 5 modes of the situation with and without (CFRP) were examined with finite element method. Improvements between 7.86% - 30.24% have been observed in the periods of the first 5 modes. Accordingly, CFRP reinforcement method can be used for safety on concrete tunnels.

Keywords: CFRP, Tunnel lining, Finite Element Method, Modal Parameters, Reinforcement.

INTRODUCTION

Structural flaws of existing segmental tunnel linings require for strengthening techniques. Water infiltration is the most common reason of deterioration. Still, deficiencies could be the consequence of deficient design or construction, or the result of unanticipated or changing geologic conditions in the soil that supports the tunnel. Another common cause for repairs is the fact that numerous tunnels have outlasted their design life expectation; consequently, the construction materials themselves have deteriorated. Therefore, they need reinforcement perpetually. [5],[6]. Recently, the application of FRP composites for reinforcement to concrete elements has emerged as one of the most important and promising technologies in structure engineering. [2], [11], [13]. There are studies on the use of FRP not only in concrete and reinforced concrete, but also in steel, masonry and composite structures, with positive results. [1], [3], [4], [7], [8], [10], [12], [14], [15]. There are references [16], [17] on tunnel lining. Carbon fiber reinforced polymer (CFRP) materials are put forward for the reinforcement of concrete tunnels as a consequence of their high corrosion and chemical resistance. [18]. In this study, we aimed to make the concrete tunnel more durable by wrapping a CFRP layer on the bottom surface of the concrete tunnel and to ensure its tightness in case of any cracks on its surface. We will also obtain more stability by reduction the period. First, the tunnel analysed without CFRP and the period values shown in table 2. Then, the tunnel analysed after applying 4 mm CFRP fabric to entire bottom surface and the period values shown in table 3. The mode shapes and period values were given separately in both cases and compared in table 4. Therefore, this paper aimed to reveal the effect of CFRP reinforced on the modal parameters of concrete tunnel lining.

MATERIAL AND METHOD

Description of Carbon Fiber Reinforced Polymer

The use of (CFRP) is aimed at restoring or increasing the load bearing capacity of the building element, the application is a strengthening process rather than a repair. This method can only be used after determining the current bearing capacity of the building element and a comprehensive project. The main advantages of this composite material, which has a higher tensile strength than steel, is that it is light, does not corrode, can be stored in rolls and can be easily applied. Using CFRP fabrics (Figure 1), the outer surfaces of stone structures, arches, vaults and domes are sheathed in the appropriate direction and width to increase their bearing capacity and ductility under existing loads. Care must be taken when preparing the surface prior to applying all dust and material free to remove material between the CFRP fabric and the structure that will affect the adhesion of any dust particles. [1], [9], [10]. The most important advantage of CFRP fabrics is that they give much more stiffness with only a few millimetres of structure reinforced material compared to traditional methods. [11], [13]. The materials that will be used for reinforcement are shown in the figure 1. The thickness of the CFRP fabric that will be used is 4 mm.

Figure 1: CFRP Fabric

The mechanical properties of CFRP are included in SAP2000 as follows.
Mass and Weight of Material:
1- Weight per Unit Volume = 1600.55 kgf/m^3
2- Mass per Unit Volume = 163.15 kgf/m^3
Mechanical Properties of Material:
1- Elasticity Module:
E1 = 13766.17 kgf/mm^2
E2 = 13766.17 kgf/mm^2
E3 = 1019.7 kgf/mm^2
2- Poison Rate:
U12 = 0.3
U13 = 0.3
U23 = 0.022

Description of Concrete Tunnel

First, the concrete tunnel properties and properties of the CFRP material were entered into the SAP 2000 software. In this study, CFRP material will be applied to the entire bottom surface. Thus, all the fine cracks on the surface will be closed. The diameter of the concrete tunnel is 5 meters, the length of the concrete tunnel is 25 meters, the soil height above the tunnel is 10 meters, and the type of concrete used is C30.
The thickness of concrete tunnel and CFRP layer used in this article are shown in Table 1.

Table 1. The thickness of Concrete Tunnel and CFRP layer.

Material Name	Thickness (mm)
Concrete Tunnel	200
CFRP	3

In this study, SAP 2000, a package program that uses the finite element method, was used. The mechanical properties of concrete materials were introduced into SAP 2000 software as follows.
Mass and Weight of Material:
1- Weight per Unit Volume = 2548.49 kgf/m^3
2- Mass per Unit Volume = 259.87 kgf/m^3
Mechanical Properties of Material:
1-Elasticity Module:
E1 = 3161.07 kgf/mm^2
2-Poison Rate:
U12 = 0.2

Results and Discussion

In this part, finite element analysis was performed for current mode and mode after reinforcement, respectively. The studies were presented under separate headings and the obtained data were presented, the mode numbers and period values for the formula are given and compared separately in both cases.

Analysis of Concrete Tunnel without CFRP

The 3D finite element model of the concrete tunnel was generated using SAP 2000 software. Concrete tunnel finite element model without CFRP shown in Figure 2.

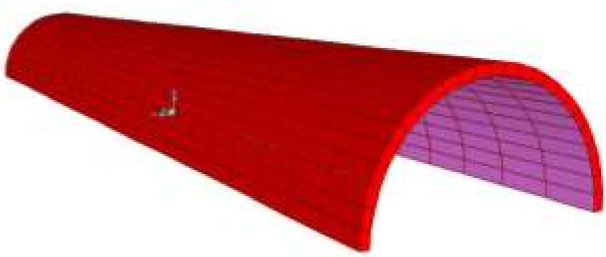
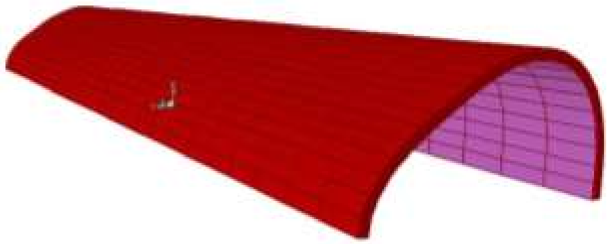


Figure 2: 3D View of Concrete Tunnel without CFRP

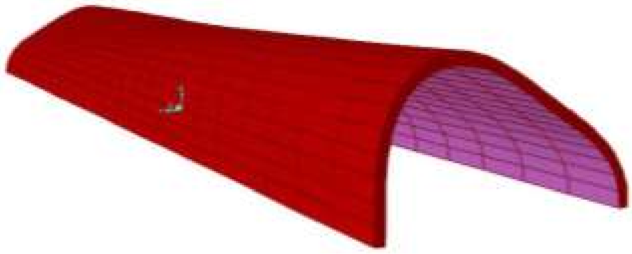
The results of the typical analysis before applying CFRP to the concrete tunnel are shown in Table 2 and the mode shapes and displacements respectively given in Figure 3 and 4.

Table 2. Period of Concrete Tunnel without CFRP

Mode No	Period (s)
1	0.0440
2	0.0318
3	0.0281
4	0.0203
5	0.0202

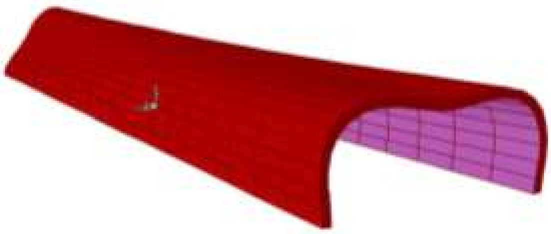


Mode-1

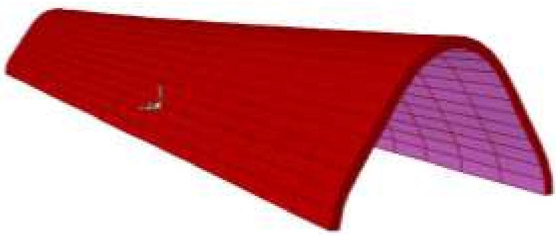


Mode-2

Mode-3



Mode-4



Mode-5

Figure 3: Mode Shapes of Concrete Tunnel without CFRP

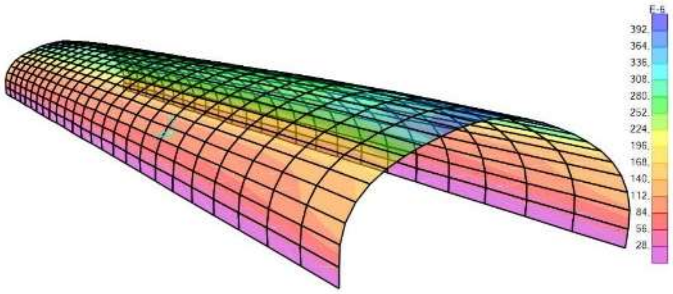


Figure 4: Displacements of Concrete Tunnel without CFRP

Analysis of Concrete Tunnel With CFRP

The CFRP-reinforced concrete tunnel model designed by the finite element method is shown in Figure 5. CFRP fabric technique is used in this study as a reinforcement method. CFRP fabric thickness is 4 mm. The bottom surface is completely coated with CFRP fabric. The analysis data was produced by the SAP2000 package software.

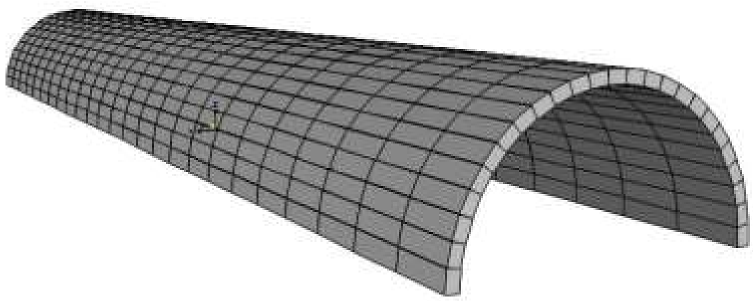
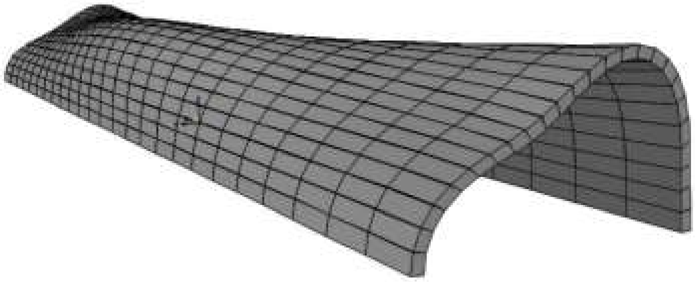


Figure 5: 3D View of Concrete Tunnel with CFRP

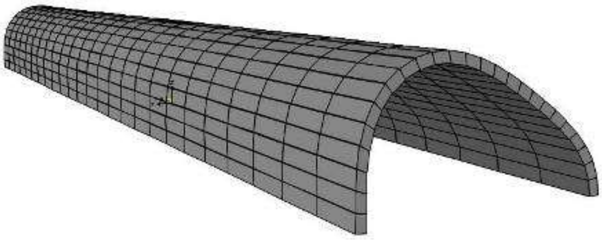
The results of the typical analysis after applying CFRP to the concrete tunnel are shown in Table 3 and the mode shapes and displacements respectively given in Figure 6 and 7.

Table 3. Period of Concrete Tunnel with CFRP

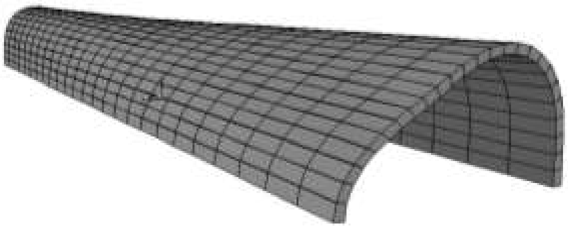
Mode No	Period (s)
1	0.0390
2	0.0293
3	0.0196
4	0.0179
5	0.0179



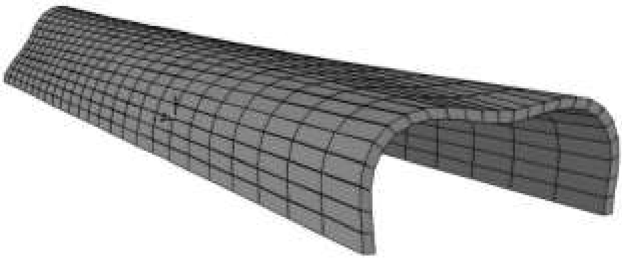
Mode-1



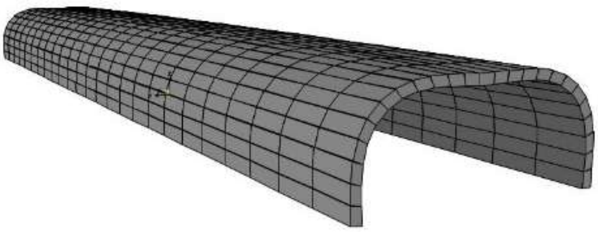
Mode-2



Mode-3



Mode-4



Mode-5

Figure 6: Mode Shapes of Concrete Tunnel with CFRP

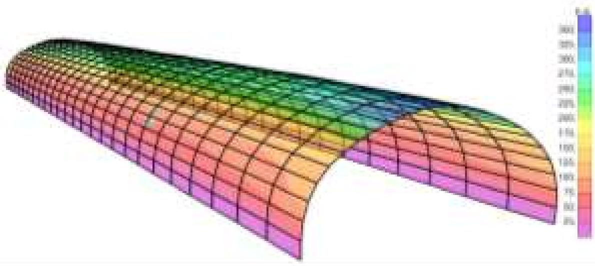


Figure 7: Displacements of Concrete Tunnel with CFRP

Comparison of Analysis Results

The comparison of period of the model without CFRP and the model with CFRP is given in Table 4.

Table 4. Periods comparison before and after applying CFRP

Mode No	Difference (s)	Difference (%)
1-1	-0.0050	11.36
2-2	-0.0025	7.86
3-3	-0.0085	30.24
4-4	-0.0024	11.82
5-5	-0.0023	11.38

CONCLUSIONS

In this study, as a result of the reinforcement made by wrapping 4 mm thick CFRP fabric to the 200 mm thick Concrete Tunnel, the ratio changes in the parameters of the structure are listed below.

In the mode 1, the period difference between concrete tunnel without CFRP and concrete tunnel with CFRP observed as

-0.0050s. The effect of CFRP reinforcement was determined to be a 11.36% reduction in period.

In the mode 2, the period difference between concrete tunnel without CFRP and concrete tunnel with CFRP observed

-0.0025s. The effect of CFRP reinforcement was determined to be a 7.86% reduction in period.

In the mode 3, the period difference between concrete tunnel without CFRP and concrete tunnel with CFRP observed as

-0.0085s. The effect of CFRP reinforcement was determined to be a 30.24% reduction in period.

In the mode 4, the period difference between concrete tunnel without CFRP and concrete tunnel with CFRP observed as

-0.0024s. The effect of CFRP reinforcement was determined to be a 11.82% reduction in period.

In the mode 5, The period difference between concrete tunnel without CFRP and concrete tunnel with CFRP observed as

-0.0023s. The effect of CFRP reinforcement was determined to be a 11.38% reduction in period.

Maximum displacements difference between concrete tunnel without CFRP and concrete tunnel with CFRP observed as

-0.0042 cm. The effect of CFRP reinforcement was determined to be a 10.71% reduction in displacement.

With the reinforcement of the concrete tunnel with CFRP, a reduction in the periods is obvious. Especially when the peak period was analysed, a 11.36% reduction is observed. Also, the decrease in periods removes the structure from the resonance range and increases the rigidity. When the analysis results are studied, it is apparent seen in this study that reinforcing the concrete tunnel with CFRP makes the concrete tunnel safer.

In the light of all these findings, CFRP reinforcement method can be used in concrete tunnel.

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