THE EFFECT OF CFRP REINFORCED SQUARE STONE CHIMNEY ON MODAL PARAMETERS USING FINITE ELEMENT METHOD

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Abstract: There is a growing concern with worldwide deterioration of traditional materials such as concrete, steel, and timber. Recently, attention has shifted to the use of fiber reinforced polymer composites (FRPs) as alternative materials. As FRPs are non-corrosive, high strength and modulus values compared to their density, light weight, acceptable deformability, tailored design and excellent formability enable the fabrication of new elements and the structural rehabilitation of the existing parts made of traditional materials. Furthermore, the resistance of FRP materials to corrosion means that they can be used to replace steel and reinforced concrete in situations when they would be exposed to corrosion. FRP therefore has wide application prospects in civil engineering ranging from reinforcing rods and tendons, wraps for seismic retrofit of columns and externally bonded reinforcement for strengthening of walls, beams, and slabs, to all-composite bridge decks, and even hybrid and all-composite structural systems. The method of strengthening with CFRP has been used in many studies recently. Therefore, this study was conducted. In this study, as a result of the reinforcement made by wrapping 2 mm thick CFRP fabric into the 15 m height stone chimney structure. The differences between modal parameters of the stone chimney and CFRP reinforced stone chimney 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. A difference of 4.99% - 13.52% was observed in the periods of the first 5 modes. Reinforcement with CFRP has been observed to be positive for safety on the stone chimneys.

Keywords: CFRP, Square Stone Chimney, FEM, Modal Parameters

Introduction

Industrial chimneys are vertical structures that allow hot toxic gases to be released into the atmosphere. It is not always possible to withstand the chimney dead loads, wind loads, effects of temperature change and seismic loads. Therefore, they need to be reinforced from time to time. Carbon fiber reinforced plastic (CFRP) materials are preferred in the reinforcement of industrial chimneys due to their high corrosion and chemical resistance. Strengthening the structural members of old buildings using advanced materials is a contemporary research in the field of repairs and rehabilitation. Many studies [1], [8], [10], [11], [12], [14] used Carbon Fiber Reinforced Polymer (CFRP) for strengthening Reinforced Concrete (RC) chimneys. Industrial reinforced concrete chimneys were reinforced with CFRP layer and their dynamic analysis was performed with finite element method. Dynamic parameters were compared between the CFRP amplified state and the state before reinforcement. The differences were revealed by examining all the effective parameters (frequency, mode shape, etc) in the dynamic behaviour before and after the reinforcement.

Masonry structures such as stone chimney is an important part of cultural heritage and contain the sociological, economic, cultural and political elements of the place and the past and offer us the opportunity to research the past. In addition, it is known that the use of stone chimneys is quite common today. Earthquakes, natural disasters and adverse environmental conditions damage these structures. Therefore, strengthening of these systems should also be done within the framework of important and specific rules.

In this study, the analysis was made using the finite element method for the current state and the state after reinforcement, respectively. The studies have been examined under separate titles and the data obtained have been presented. In both cases, the mode shapes and the period values of the mode are given separately and compared. Thus, it is aimed to reveal the effect of CFRP reinforced on the modal parameters of square stone chimneys.

Material and Method

Description of Carbon Fiber Reinforced Polymer

There are many advantages in favour of the use of CFRP materials for repair and rehabilitation of bridges, chimneys and structures. Cost savings may be realised through labour savings and reduced requirements for staging and lifting material. The dead weight added to a structure is minimal due to the high strength to weight ratio of CFRP materials. Application of bonded CFRP materials results in reduced stress-concentrations as compared to mechanical fastening. Despite the high material costs associated with CFRP materials, when overall costs for a strengthening project are determined, overall project costs are typically reduced.

With CFRP fabrics (figure 1), the outer surfaces of Stone structures, arches, vaults and domes are wrapped in appropriate direction and width to increase their carrying capacity and ductility under existing loads. Preparation of the surface before the application of all dust and free of material to remove the material between CFRP fabric and structure that will affect the adherence of any dust particles should be careful. [6], [7], [14].

Figure 1: CFRP Fabric

The most important advantage of CFRP fabrics is that it gives a much more rigidity than conventional methods with a few millimetres of material reinforced to the structure. [6], [7], [14].

The material to be used for the planned reinforcement is given in figure 1. The thickness of the CFRP fabric to be used is designed as 2 mm. The parameters of the material are given separately under "Mechanical Properties of Stone Material" and “Mechanical Properties of CFRP Material”.

Mechanical Properties of Stone Material

In this study, SAP 2000, a package program that uses finite element method, is used. The mechanical properties of the stone material were entered into the SAP 2000 program as follows.

Mass and Weight of Material:

1- Unit Volume Weight = 2162.49 kgf / m^3,

2- Unit Volume Mass = 2158.75 kgf / m^3.

Mechanical Properties of Material:
1- Elasticity Module:
E1 = 1265.53 kgf/mm²
2- Poison Rate:
U12 = 0.2

Mechanical Properties of CFRP Material
The mechanical properties of the CFRP material were entered into the SAP 2000 program as follows.
Mass and Weight of Material:
1- Unit Volume Weight = 1600.55 kgf / m³,
2- Unit Volume Mass = 163.15 kgf / m³.
Mechanical Properties of Material:
1- Elasticity Module:
E1 = 13766.17 kgf/mm²,
E2 = 13766.17 kgf/mm²,
E3 = 1019.7 kgf/mm².
2- Poison Rate:
U12 = 0,3,
U13 = 0,3,
U23 = 0,022.

Description of Square Stone Chimney
First, the features of the stone chimney and the properties of the CFRP material were entered into the SAP 2000 program. Choosing a square section aims to evaluate the effects in two directions without any doubt. In this study, CFRP material will be applied to the entire surface. Thus, all cracks on surface will be closed. The area of square stone chimney is 0.75×0.75 cm, while the height of stone chimney is 15m, Stone size of the chimney is 25×25×20 cm.
The stone chimney wall thickness and CFRP thicknesses to be used are given in Table 1.

Table 1. Thickness of Square Stone Chimney and CFRP Layers

Material Name	**Thickness (mm)**
Stone Chimney	250
CFRP	2

Results and Discussion
In this section, the analysis was made using the finite element method for the current state and the state after reinforcement, respectively. The studies have been examined under separate titles and the data obtained have been presented. In both cases, the mode shapes and the period values of the mode are given separately and compared.

Analysis of Square Stone Chimney Without CFRP
The 3D finite element model of the square stone chimney was created with the SAP 2000 program. Square stone chimney finite element model without CFRP is given in figure 2.

Figure 2: Square Stone Chimney Finite Element Model without CFRP

Modal analysis results before applying CFRP to the square stone chimney are given in Table 2 and respectively mode shapes given figure 3.

Table 2. Period of Square Stone Chimney without CFRP

Mode Number	Period (s)
1	0.43045
2	0.07108
3	0.04480
4	0.01525
5	0.01494

Figure 3: Respectively Mode Shapes of Square Stone Chimney without CFRP

Analysis of Square Stone Chimney With CFRP

The finite element model of the square stone chimney given in Figure 4 is the reinforced situation. In other words, it is CFRP reinforced. CFRP fabric technique is used in this study as this reinforcement method. CFRP fabric thickness is 2 mm. CFRP fabric is applied to the entire outer surface. SAP2000 package program was used to obtain the analysis data.

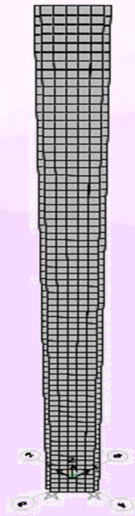

Figure 4: Square Stone Chimney Finite Element Model with CFRP

Modal analysis results after applying CFRP to the square stone chimney are given in Table 3 and mode shapes given figure 5.

Table 3. Period of Square Stone Chimney with CFRP

Mode Number	**Period (s)**
1	0.40895
2	0.06653
3	0.04173
4	0.01418
5	0.01291

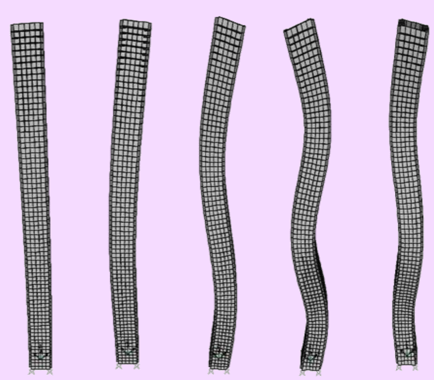

Figure 5: Respectively Mode Shapes of Square Stone Chimney with CFRP

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

Table 4. Comparison Period of without CFRP Model and with CFRP Model

Mode Number	Difference (s)	Difference (%)
1-1	-0.02150	4.49
2-2	-0.00455	6.40
3-3	-0.00307	6.86
4-4	-0.00107	7.01
5-5	-0.00202	13.52

Table 4 illustrates the effect of CFRP on the period.
When the mode shapes are examined, the modal shapes are slight differences. With CFRP reinforced, mode shapes with more balanced displacements in 3 directions are seen instead of large displacements in one direction

Conclusions

In this study, as a result of the reinforcement made by wrapping 2 mm thick CFRP fabric into the 250 mm thick stone chimney structure, the percentage changes in the parameters of the structure are listed below.
In the mode 1, the period difference between non-CFRP and CFRP status was obtained as -0.02150s. The effect of CFRP reinforcing as a percentage was determined as 4.99%.
In the mode 2, the period difference between CFRP and non-CFRP status was obtained as -0.00455 s. The effect of CFRP reinforcing as a percentage was determined as 6.40%.
In the mode 3, the period difference between CFRP and non-CFRP status was obtained as -0,00307 s. The effect of CFRP reinforcing as a percentage was determined as 6.86%.
In the mode 4, the period difference between CFRP and non-CFRP status was obtained as -0,00107 s. The effect of CFRP reinforcing as a percentage was determined as 7.01%.
In the mode 5, the period difference between CFRP and non-CFRP status was obtained as -0,00202 s. The effect of CFRP reinforcing as a percentage was determined as 13.52%.
With the reinforcement of the square stone chimney with CFRP, a decrease in the periods is clearly visible. Especially when the dominant period is analyzed, a 4.99 percent decrease is observed. It is also known that the reduction in periods removes the structure from the resonance range and increases the stiffness.
With CFRP reinforced, more balanced displacements in 3 directions are seen instead of large displacements in one direction.
In addition, it is thought that it contributes to adhesion in masonry structures.
In the light of all these findings, CFRP reinforcement method can be recommended for square stone chimneys.

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