DETERMINATION OF MODAL PARAMETERS OF REINFORCED CONCRETE BOX CULVERT RETROFITTED WITH GFRP USING FINITE ELEMENT METHOD

Fouad Bakkour
Department of Civil Engineering, Ondokuz Mayıs University/Samsun, Turkey

Sertaç Tuhta
Department of Civil Engineering, Ondokuz Mayıs University/Samsun, Turkey
* stuhta@omu.edu.tr

Furkan Günday
Department of Civil Engineering, Giresun University/Giresun, Turkey
* furkan.gunday@giresun.edu.tr

ABSTRACT

This paper presents a new method for the reinforcement of concrete box culvert, which is the most common type of culvert, by applying a thin layer of glass fiber reinforced polymer composite (GFRP), the fiber glass reinforced polymer composite has a high resistance against corrosion and chemicals. Therefore, effectively eliminate corrosion problems and increase the service life of concrete culvert. In this study, the strengthening method was used (GFRP) using the finite element method. As a result of the reinforcement was made by wrapping a fabric (GFRP) with a thickness of 3 mm in the concrete structure of the culvert, which is 12.6 m long, 3.72 m high, and 3.65 m wide. The differences between typical parameters of concrete culvert and GFRP reinforced culvert were compared. These conditional parameters are period and mode forms. The first five case modes with and without GFRP were examined by a finite element method. A difference of 5% - 8% was observed in the periods of the first five modes. It has been observed that reinforcement.

Keywords: GFRP, Concrete Culvert, finite element method, Modal Parameters, Reinforcement.

INTRODUCTION

Culverts are generally made of a variety of materials including reinforced concrete, corrugated metal, and stone. In the 1970s, there has been a great boom up in culverts construction in lots of countries. Most of these culverts made of corrugated metal or strengthened concrete are already close to forty years of age and are deteriorating at a high rate. Culverts are subjected to aggressive environments (for example, exposure to excessive moisture, treatment with deicing salts, etc.). For these culverts, moisture, temperature, and chlorides boost up the corrosion of the metal pipes or internal metal reinforcement, which ultimately leads to unserviceability. [3]. In addition, earthquakes, natural disasters and adverse environmental situations damage these structures. FRP materials have low density, high mechanical properties, and are resistant to chemical substances and corrosion. In addition, it can be implemented quickly because it is flexible. [1], [4], [6], [7], [9], [10], [11], [12], [15]. Therefore, it is appropriate for the reinforcement of concrete box culverts. The project aimed toward investigating the feasibility and effectiveness of FRP reinforcement to reduce the problems related to corrosion therefore increase the service life of the culverts. In addition, the effects of the GFRP material, which has become extensive recently at the structure, will be evaluated. Glass fiber strengthened polymer (GFRP) has been studied considerably for many structures including concrete culvert.

[1], [2], [4], [5], [6], [7], [8], [13], [14], [16], [17]. The concrete culvert was strengthened with a GFRP layer, and finite element analysis was used to determine its dynamic behaviour. Dynamic parameters have been in comparison between the GFRP mode and the mode before reinforcement. The differences have been additionally revealed by analysing all of the effective variables (period, mode shape, etc.) in dynamic behaviour before and after reinforcement. For GFRP materials, proper surface preparation is very important. In this study, we aimed to make the concrete culvert more resistant and to seal it in case of any cracks or splintering on its surface by wrapping a GFRP layer on the surface. We will also obtain more balance by reducing the period. The mode figures and period values for the formulation have been given separately in both cases and in comparison. Therefore, it is intended to reveal the effect of reinforced GFRP on the modal parameters of concrete culvert.

MATERIAL AND METHOD

Description of Glass Fiber Reinforced Polymer

The reinforcement with GFRP systems is one of the methods of strengthening, repairing and strengthening various structures. The reinforcement with GFRP systems has drawn the attention of engineers as one of several FRP composites for the reinforcement and repair of concrete structures and structures. In the reinforcement with GFRP system, fiber-reinforced composite fibers are made of glass fiber that is compatible with a variety of matrices, including epoxy resin, vinyl ester resin, phenolic resin, and … to form a composite. In addition, GFRP fabrics can be produced unidirectional and bidirectional. GFRP costs less than other fibers, is also easy to install, and has high tensile strength and strong corrosion, chemical and chloride resistance. The reinforcement with GFRP system is also used in wood, steel and construction structures. If a structure is damaged under certain conditions (earthquake or debris etc.) or there is a change in the use of the building, change or increase in the size of the classes of structures, then the existing structure of safety and favourable conditions for load-bearing loads. The structure will need to be improved or repaired and strengthened. GFRP is attached to structural structures such as beams, columns, floors, walls, and in addition to structural elements such as trusses, chimneys, culverts and tunnels. GFRP was chosen to be used in this study because it is less costly and transparent than other fibers. The reinforcement with glass composite system is a viable alternative to reinforcing old structures such as steel reinforcement and concrete pavements; this result in the corrosion resistance of the structure in addition to the structural reinforcement, the weight of the structure is reduced. The most important feature of GFRP fabrics is that it offers much higher stiffness than older technologies that used only a few millimetres of material to reinforce the structure. [1], [2], [10], [11]. Figure 1 shows the materials that will be used for the expected reinforcement. The GFRP fabric to be used is designed to be 3mm thick.

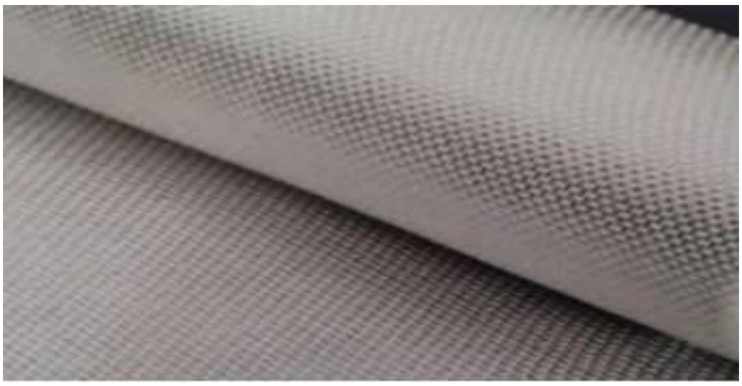


Figure 1: GFRP Fabric

The mechanical properties of GFRP are included in SAP2000 as follows.

Mass and Weight of Material:

1- Weight per Unit Volume = 1900.65 kgf/m^3

2- Mass per Unit Volume = 193.81 kgf /m^3

Mechanical Properties of Material:

1- Elasticity Module:

E1 = 4078.86 kgf/mm^2

E2 = 4078.86 kgf/mm^2

E3 = 815.77 kgf/mm^2

2- Poison Rate:

U12 = 0.25

U13 = 0.25

U23 = 0.25

Description of Concrete Box Culvert

First, the features of the concrete box culvert and the properties of the GFRP material have been entered into SAP 2000 program. In this study, GFRP material will be implemented to the entire surface. Therefore, all cracks on surface closed. The length of the culvert is 12.6 meters, while the height of the culvert is 3.72 meters, its width is 3.65 m, the thickness of the culvert is 0.15 m, and the soil height above the culvert is 0.80 m. In this study, the analysis was made using the finite element method for the current mode and the mode after reinforcement, respectively. The studies have been examined under separate titles and the data received have been presented. In both states, the mode shapes and the period values of the mode are given separately and compared. Concrete box culver and GFRP's wall thicknesses used in this studies article are given in Table 1.

Table 1. The thickness of Concrete Box Culvert and GFRP layer

Material Name	Thickness (mm)
Concrete Box Culvert	150
GFRP	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

The analysis for current state and state after reinforcement was performed using the finite element method, respectively. The studies were examined under separate headings and the resulting data were presented, mode forms and period values for mode are given and compared separately in both cases.

Analysis of Concrete Box Culvert Without GFRP

The 3D finite element model of the Concrete box culvert was created with the SAP 2000 program. Concrete box culvert's finite element model without GFRP effects is given in Figure 2.

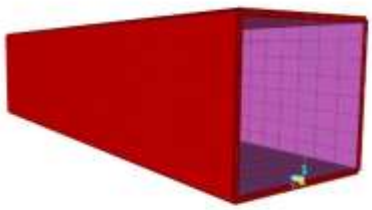
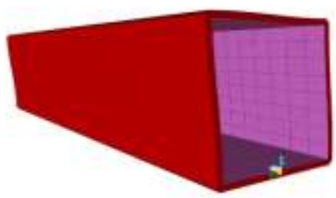


Figure 2: 3D View of Concrete Box Culvert without GFRP

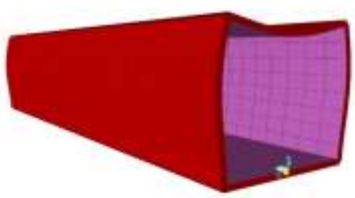
Modal analysis results before applying GFRP to the Concrete box culvert are given in Table 2 and respectively mode shapes and displacements given figure 3 and 4.

Table 2. Period of Concrete Culvert without GFRP

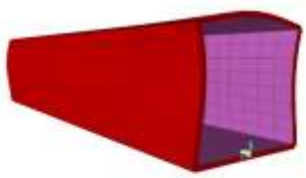
Mode No	Period (s)
1	0.1658
2	0.0413
3	0.0395
4	0.0346
5	0.0331



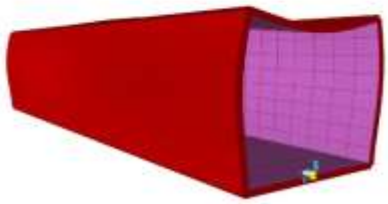
Mode-1



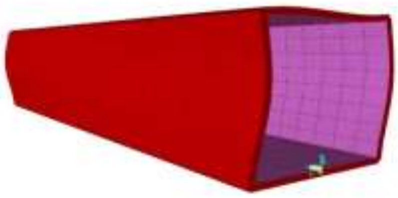
Mode-2



Mode-3



Mode-4



Mode-5

Figure 3: Mode Shapes of Concrete Box Culvert without GFRP

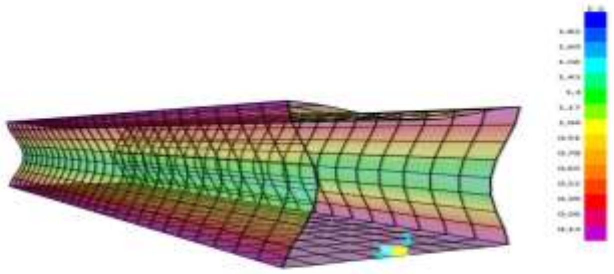


Figure 4: Displacements of Concrete Box Culvert without GFRP

Analysis of Concrete Box Culvert With GFRP

The reinforced state is depicted in Figure 5 by the finite element model of concrete culvert reinforced with GFRP layer. The GFRP material method is applied in this research. The thickness of the GFRP material is 3 mm. GFRP material is applied to the entire surface. SAP2000 program was used to obtain the results of the analysis.

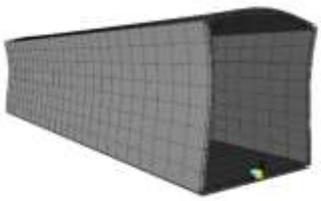
Figure 5: 3D View of Concrete Box Culvert with GFRP

Modal analysis results after applying GFRP to the concrete culvert are given in Table 3 and mode shapes and displacements given figure 6 and 7.

Table 3. Period of Concrete Box Culvert with GFRP

Mode No	Period (s)
1	0.1567
2	0.0390
3	0.0371
4	0.0321
5	0.0308

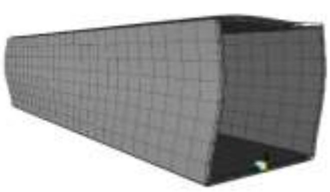
Mode-1



Mode-2

Mode-3

Mode-4



Mode-5

Figure 6: Mode Shapes of Concrete Box Culvert with GFRP

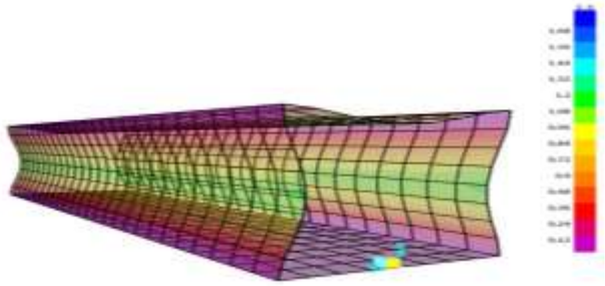


Figure 7: Displacements of Concrete Box Culvert with GFRP

Comparison of Analysis Results

The comparison of the period of the model without GFRP and the GFRP model is attached in Table 4.

Table 4. Periods comparison before and after applying GFRP

Mode No	Difference (s)	Difference (%)
1-1	-0.09100	5.48
2-2	-0.00230	5.57
3-3	-0.00240	6.07
4-4	-0.00250	7.22
5-5	-0.00230	6.94

CONCLUSIONS

In this study, as a result of the reinforcement made by wrapping 3 mm thick GFRP fabric into the 150 mm thick Concrete Box Culvert structure, the percentage changes in the parameters of the structure are listed as below.

In the mode 1, the period difference between non-GFRP and GFRP status was obtained as -0.09100. The effect of GFRP reinforcing as a percentage was determined as 5.48%.

In the mode 2, the period difference between GFRP and non-GFRP status was obtained as -0.00230. The effect of GFRP reinforcing as a percentage was determined as 5.57%.

In the mode 3, the period difference between GFRP and non-GFRP status was obtained as -0.00240s. The effect of GFRP reinforcing as a percentage was determined as 6.07%.

In the mode 4, the period difference between GFRP and non-GFRP status was obtained as -0.00250s. The effect of GFRP reinforcing as a percentage was determined as 7.22%.

In the mode 5, the period difference between GFRP and non-GFRP status was obtained as -0.00230s. The effect of GFRP reinforcing as a percentage was determined as 6.94%.

When the concrete culvert was reinforced using GFRP, the decrease was clearly visible in the periods, especially when analysing the dominant period, a decrease of 5.48% was observed.

Maximum displacements difference between concrete box culvert without GFRP and concrete box culvert with GFRP observed a -0.014 cm. The effect of GFRP reinforcement was determined to be a 7.69% reduction in displacement.

It is also known that the reduction in periods eliminates the structure from the resonance range and increases the rigidity. Also was observed that the reinforced state with the GFRP layer reduced the torsions, reinforced the strength of the structure, and became more balanced.

It is predicted that the effect of strengthening with GFRP will increase even more by increasing the thickness of GFRP. In this study, only 3 mm thickness was applied which is a single layer application. Thus, the most fundamental effects were revealed.

Through these results, it was shown that the method of reinforcement GFRP could be used to concrete box culvert.

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