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Structural Behavior of Curved Soffit Reinforced Concrete Beams Strengthening by CFRP Strips

A Thesis Submitted to the Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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CHAPTER ONE
INTRODUCTION

1. 1 General

Many of reinforced concrete bridges in the world , are constructed a century ago, need some kind of improvement, repair or maintenance in order to work well with heavy traffic and meet current and future needs with better design calculations or make them stronger because they cannot keep up with the demands of modern traffic and vehicle weights. In these cases, improved design calculations include numerical or analytical capability assessments but some structures cannot be saved by simply making design changes, so they can only be improved by making them stronger or, at worst conditions, by substituting it. Several studies have also shown that a bridge's actual service life, up until it is torn down, is often much shorter than the life it was designed for. For example, a study of the bridges that were torn down in Sweden because of wear and tear between 1990 and 2005 showed that their average final life was 68 years, not 100 **(1).**Figure(1.1) shows a Swan Street Bridge.

Figure (1.1) Swan Street Bridge, Melbourne, Australia **(2).**

Strengthening bridges is necessary to sustain new applied loads or to enhance degraded elements. Among the methods that are used for strengthening as replace damaged items, attaching the external steel plates fixed mechanically, applying the external post-tension , use concrete or steel cranes when necessary. These techniques are time-consuming and expensive, and they could even do more harm than good by adding to the structure's self-weight and necessitating further drilling holes in it. These additions significantly reduce the aesthetic value of bridges and because the use of FRP fiber reinforced polymer materials is easier, it was used to strengthen the bridges because of its mechanical qualities, FRP allows engineers to improve significantly in use, safety, and economy of construction **(3)**.

Generally speaking, the major function of fiber reinforcement is to impart strength and stiffness in a single direction along the fiber's length. This material is often used to replace metal parts in structural applications where the ability to hold weight is important. Because FRP has good mechanical properties, it can be used in engineering to make big improvements in the functionality, safety, and cost-effectiveness of buildings. These advancements may be made because of the features of FRP **(4).**

Structural engineers have been increasingly interested in using fiber reinforced polymer (FRP) materials to reinforce structures over the past several decades due to FRP's high strength-to-weight ratio, simplicity of installation, corrosion resistance, and low maintenance needs . FRP has been used to strengthen many long span bridges. There have been a lot of studies done on the causes of failure of FRP-reinforced RC roof beams **(5, 6and 7).**

Studies have shown that the bond strength between the concrete and the FRP makes a big difference in how well it works as a strengthening material. So, most RC structural members by FRP fail because FRP separates from the concrete. The performance of the adhesives that are currently on the market has shown that they are good enough to transfer stress between FRP and concrete. But the main cause of de-bonding is cracks in places with a lot of shear because the concrete has a low tensile strength. To understand and control de-bonding, a lot of experiments have been done and a lot of theoretical models have been made. A lot of research has been done on how flat soffit RC beams have been strengthened with FRP. But we don't fully understand how curved soffit RC beams that are strengthened with FRP fail yet**(2).** Figure (1.2) Applications of FRP in buildings and other structures.

Figure (1.2) Applications of FRP in buildings and other structures (a) Glass fibre reinforced poly-mer structural shapes (b) Five-storey Eyecatcher FRP demountable building Switzerland(c) Startlink test house modular pultruded FRP concept profiles (d) Startlink—Fully composite test house (e) Pultruded FRP cooling tower (f) Duracomposites railway platforms **(8).**

1.2 Curved Beams

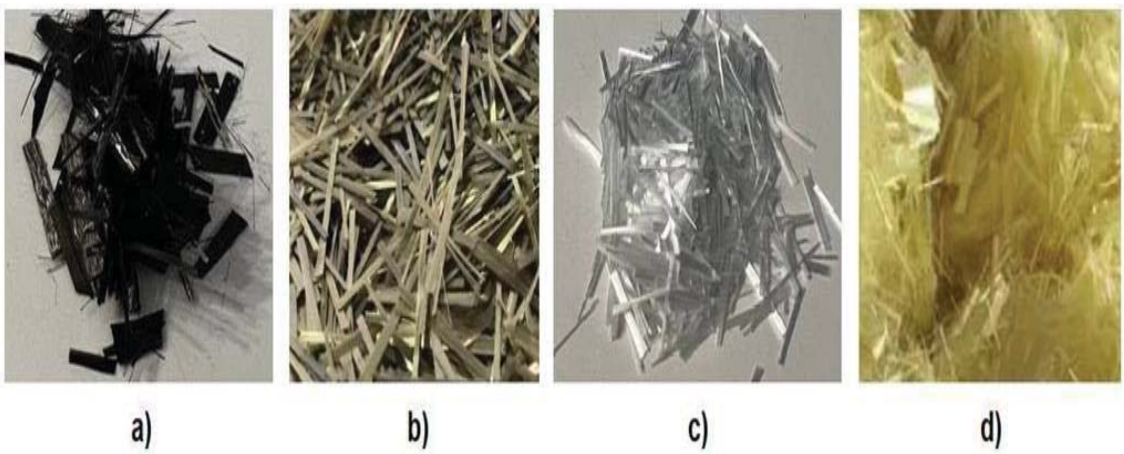
Curved beams have been frequently applied in many engineering disciplines such as civil, mechanical, aerospace, etc. Curved beams are thus widely used, in everything from bridge structures, to balconies. It is important to note that in a curved beam, unlike a straight beam, the centroidal axis and the neutral axis are not identical. In addition, stresses from the neutral axis do not vary in a linear manner **(9).**

Reinforced concrete (RC) curved beams have been somewhat increased in use in the modern world for various reasons primarily architectural, and have also been used in various structural applications. Bridges that contain a curve are called "curved bridges"**.** The curve helps to spread the force of the load outward rather than downward, which is the case on a straight bridge. This means that more weight can be put on the bridge without failure it . The basic principle of curved bridges is that it works because the load is transferred along the curve to the abutments instead of being pushed down **(10).**

1.3 Components of Composite Materials

1.3.1 Fibers

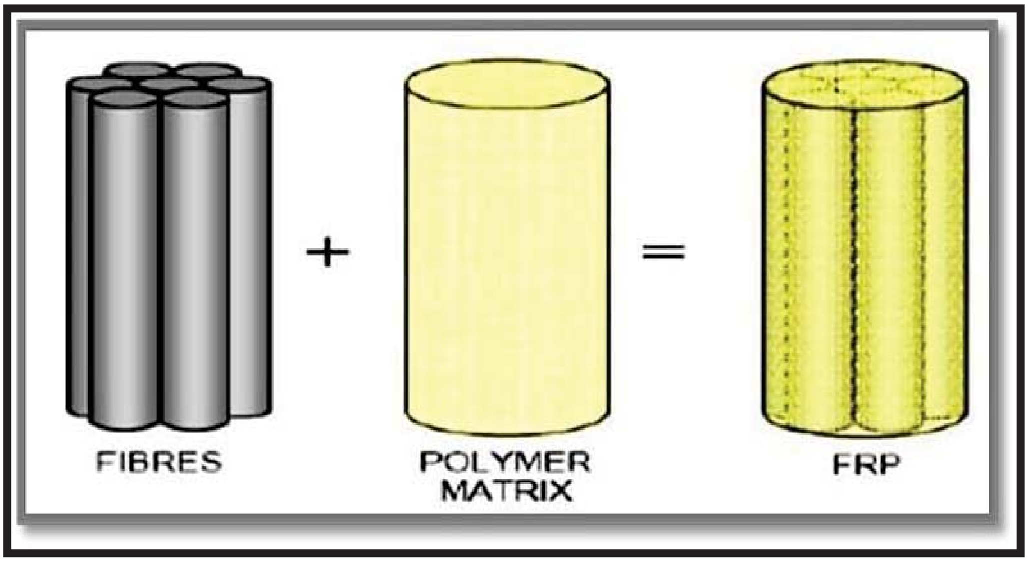
Many times, the characteristics of composite materials are determined by the fibers used to make them. Construction often makes use of carbon, glass, and aramid fibers. Carbon fiber reinforced polymer (CFRP) is an example of a common moniker for this kind of composite. Stiffness and tensile strain are the two most notable characteristics that vary greatly amongst the various fiber kinds **(11).** Figure (1.3) Main type of fibers.



Figure(1. 3) Main type of fibers: (**a**) carbon fibers; (**b**) basalt fibers; (**c**) glass fibers; and (**d**) aramid fibers **(11).**

1.3.2 Matrixes

The matrix should spread forces out among the fibers and protect them from bad things that might happen. Almost thermosetting resins (thermosets) are used. Most of the time, vinyl ester and epoxy are used as matrices. Despite being more expensive, epoxy is preferred over vinyl ester. Epoxy has a work life of about 30 minutes at 20 C^0 , however this may be adjusted with different formulae. Epoxies offer high strength, bonding, creep, and chemical resistance **(12).** Figure (1.4) Basic material components of FRP composite.



Figure(1.4)Basic material components of FRP composite**(12).**

1.4 Carbon Fiber Reinforced Polymer (CFRP)

Carbon fiber elastic modulus is high, ranging between 200 and 800 GPa. The maximum elongation is 0.2 to 2.5%, with stiffness increasing with decreased elongation. Carbon fibers are water-resistant and chemical-resistant. They have a good resistance to fatigue and do not corrode or exhibit any creep or relaxation in their structure. Figure (1.5) shows a (CFRP) (**13).**

Figure(1.5)Surface preparation and CFRP fixing(**13).**

1.4.1 Advantages of Carbon Fiber Reinforced Polymers

One of the most important features of this element is that it can easily make bonds with each other and form a chain. For this reason, carbon fibers become a suitable material for high-performance applications with materials which are necessary and have broad use like coal, oil and diamonds and these fibers can be obtained from thermal transformation of organic fibers or from polymeric precursors .Carbon fibers have low density, high strength and high stiffness properties. These fibers are usually 80–95% carbon-containing, can be in staple or filament form, have very good mechanical properties, and at the same time, they are lightweight and have a density of 2268 g/cm 3 **(14 and 15).** They can withstand temperatures up to 3000 °C with retaining their structural integrity **(16,17and18)**. They have very low coefficient of linear thermal expansion which also causes dimensional stability, high fatigue strengths and thermal conductivity even higher than copper **(19).** They are not affected by moisture or most of the solvents, acids and bases at room temperature(**20).**

1.5 Non-linear Structural Analysis

Because nonlinearity occurs in real life, nonlinear analysis of RC soffit curved beam is essential. The girder s' nonlinearity was caused by the loading they were subjected to, which resulted in elongation and axial force. In the majority of situations, the equivalent modulus of elasticity is employed in each stage of the analytical computation. Nonlinear behavior was also caused by the interplay of loads and axial forces in the girder. The extent of deflection is induced by bending and the intensity of the compressive force relative to the bucking load and it determine the degree of nonlinearity. Nonlinear behavior is also caused by the deformation of the structure, which is constantly changing(**21**).

1.6 Objectives of the Study

The general objective of this research is to understand the effect of bending on the behavior of curved RC beams reinforced with FRP.

The specific objectives are:

1- To review and summarize various experimental and analytical studies on the behavior of straight and curved RC beams using CFRP.

2- Make a comparison between the numerical and experimental work on the behavior of RC curved beams supported using CFRP, and to prove the possibility of using a finite element numerical program in Ansys 2019.

3-To carry out parametric studies to understand the influence of various parameters.

1.7 Scope of Study

The purpose of this study is to examine the behavior effect of the curvature curved beams under the static load by nonlinear finite element analysis. ANSYS2019 was used to analyze a curved beam; it helps to determine load capacity with deflection.

1.8 Layout of Thesis

This thesis is divided into five chapters so that it can complete the objectives listed below::

1- In chapter one the aim and objective of the thesis are outlined.

2- Chapter two provides a summary of the previous studies on finite elements in curved beams that have analyzed and the practical work.

3- Chapter three included FE methods, comparing FEM model predictions with experimental results and curved beam nonlinear responses.

4- Chapter four discusses the results of the parametric analysis, which considers the influence of the degree of curvature, the length of curvature, the compressive strength, the kind of curved forms, the type of applied load and the shape of the FRP strengthening.

5- Chapter five includes a summary of the most major conclusions and suggestions taken from the discussion of the overall results of the research.

Abstract

Structural Behavior of Curved Soffit Reinforced Concrete Beams Strengthening by CFRP Strips

By

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Since the tendency of architects in general and civil engineers in particular towards the construction of curved reinforced concrete structures has increased, it has become necessary to pay attention to these structures, develop them, and effects. This research is focused on investigating the performance of concavely-curved soffit-reinforced concrete (RC) beams strengthened by carbon fiber-reinforced polymer (CFRP). The objective of this research is to study the effect of the soffit's curvature on the behavior of curved beam, deformability, and load capacity of reinforced concrete beams strengthened with CFRP. This study is divided into two parts. The first part includes a numerical analysis of previous studies where a 3D nonlinear finite element (FE) analysis was performed, using (Ansys2019) 3D, to model from the program two curved reinforced concrete beams simply supported with CFRP. The beams were simulated to obtain the load & deflection curve, failure load, failure mode, crack ,stress and change at failure, in order to understand the effect of curvature on the performance and load capacity of this type of structural member; The results showed a high degree of convergence between the experimental and theoretical programs. While the second part of the research included, FE models were adopted in conducting various parametric studies, where 31 models were developed for parametric studies to study the behavior of models for simply supported curved beams with a length of 6 meters to understand the effect of curvature on the performance and capacity of these types of structural members and six groups. The first group

represented models using the following degrees of curvature: 1 mm/m, 2 mm/m, 3 mm/m, 4 mm/m, and 5 mm/m. As for the second group, it was represented by different lengths of curvature, and the third group explored the effect of different values of compressive strength on the curved beam. As for the fourth group, it was represented by different forms of stiffening with the same area, size and type. The fifth group included using different types of curvature, and the sixth group was done using different types loads.

The results of the FEM program showed that the load-bearing capacity of the curved beams reinforced with carbon fiber reinforced polymer decreases with increasing degree of curvature, whereas it was the increase in bearing force in 1mm/m degree by 42.167% compared of control beam. It was found that the strength was increased by three strips of strengthed by carbon fiber-reinforced polymer about 18.33% compared of control beam. As for the shapes in relation to the curve, it was noted that the curved shape beam is better in terms of bearing force about 5% compared control beam.