CHAPTER 1

INTRODUCTION

1.1 General

Bridges have always been an integral part of human life because of their ability to connect with the communities, regions, and opportunities several times. Among all the human-made concrete structures, bridges always have critical and expensive as well. Despite both challenges, bridges have been constructed for thousands of years. Every bridge has a time limit and the ability to bear the certain designed load, but as time passed the population of the users have increased as well the frequency of load, no. of vehicle and intensity of loading on the bridge have increased exponentially and the surrounding acidic environmental also the reason of deterioration of the structure and the very unlike condition for any concrete structure is withstand in saline water or even presence of acidic water nearby. Due to these burdens over time, bridges become dilapidated, and it is not safe to use them. For these type of bridge, the authorities have three option left; first, they stop the traffic on the bridges, which is the least favorable decision as the existing connection of humanity will be ceased, second after demolishing the existing bridge or in parallel of old one make a new bridge. The second option is also harsh in terms of the economics of the state because most of the ancient bridges are out of service, and they are more than forty-five percent of the total existing bridges in number. The replacement cost of these all bridges is a significant burden on the economy for any developing country. The third option is retrofitting and/or strengthening structures of bridges, which is proved to be very emphatic and economical later because of several aspects. Like strengthening is economical, can be performed while in service, painless procedure, long-lasting etc.

Research in the retrofitting area is essential since engineers in seismic-prone regions often face the problem in designing the repair or strengthening work for damaged buildings without quantitative analysis. In such circumstances, there are two possible solutions replacement or retrofitting. Complete structure replacement might have determinate disadvantages such as high cost for material and labor, a stranger environmental impact, and Inconvenience due to interruption of the function of the structure. e. g. traffic problem. When possible, it is often better to repair or upgrade the structure by retrofitting. RC structures encounter damage even before the expiry of their service life due to improper Construction techniques, inefficient design, explosions, fires, change of usage, corrosion, flood. etc. Hence they call for immediate damage detection and a check for their integrity to estimate the remaining life span of the structure and the extent of Serviceability that can be expected from the structure. These measures also aid in determining the appropriate mitigation measures to increase the remaining life and enhance the integrity of the structures. The conventional strengthening method for structures attempts to compensate for the lost strength by adding more material around the vulnerable sections. These methods include section enlargement, polymer-modified concrete filling, and polymer granting. These methods that involve concrete in strengthening are time-consuming, dusty, and laborious. They require a long time to implement and, therefore, a more extended period of evacuation. They also increase the dead load on the structure. In some cases, especially in bridges, external post-tensioning, bonded steel plates, and steel jacketing have been used. These techniques often apply steel reinforcement that remains exposed to environmental attack. Therefore they are vulnerable to corrosion that limits their lives. Moreover, the quality of the strengthening depends heavily upon the skill of the personnel. It is difficult to strengthen complex areas such as beam-column connections using these methods. A recent development in fibre reinforced polymer (FRP) composites can solve many of these problems. These materials are extremely strong with high ultimate strain. They are chemically inert and corrosion-resistant. Moreover, they are very light and facilitate easy implementation at the site with fewer supporting structures. These methods are cleaner and material cure very quickly.

1.2 Strengthening of structures

Pre-damage rehabilitation/strengthening is known as retrofitting, while post-damage is called repairing. The Strengthening, retrofitting, and rehabilitation of structures across the world performed mainly because of two reasons:

a. Rusting of pre-stressed/reinforced bridge.
b. Increasing of the live load/traffic load over the bridges than the initially designed load

To repair the damaged structure and restoration of the cracks, two prescripts were available in the early twentieth century there-

1. using the pre-stressing cables
2. Using steel plates with epoxy glue.

The first option generally avoided due to the following reasons -

a. In the bridge generally, the precast superstructure being used and so to pre-stress these very high stressing forces will be required to do it effectively.
b. Installing the compatible anchorages will be challenging in the slab.
c. The overhead space will be minimised to an extent.

In 1982 the external strengthening using corbon fibre reinforced plastic was done in several bridges. In all the studies pre-stressing was done in tension flange using epoxy-bonded steel plates. The study intended to make the epoxy-bonded steel plates safe, economical, and efficient, and the plates were also increasing the girder's stiffness and strength. But there are several difficulties in using the steel plates, like corrosion and the beam's stability at post-tensioning in the lateral direction. The engineers wanted to enhance the load-carrying capacity of beams used as girders in the bridges of several parts of Japan, Europe, and Africa. The pros of using this strengthening system consist of the more comfortable application procedures, absence of special anchorages, repairing of girder can be performed using the bridge. Simultaneously, this method's consequences can be listed as corrosion in between the steel plates and epoxy. It is well known that deterioration in steel plates will adversely affect the bond strength between epoxy and plates. Some studies also provided some insights about the bonding of steel plates to the concrete beam in their tension flange. Both investigated the series of 4890 mm and 3250 mm long girders in bending at 4 points. They concluded that in their result that full composite support was stored by enhancing the bond properties of adhesive. The actual performance in the form of ultimate load, stiffness, and controlled crack had shown a remarkable improvement. Studies about the long-term effect of corrosion on the epoxy steel strength and conducted the durability test on R.C. beam externally bonded with epoxy steel plates. (Figure 1.1)

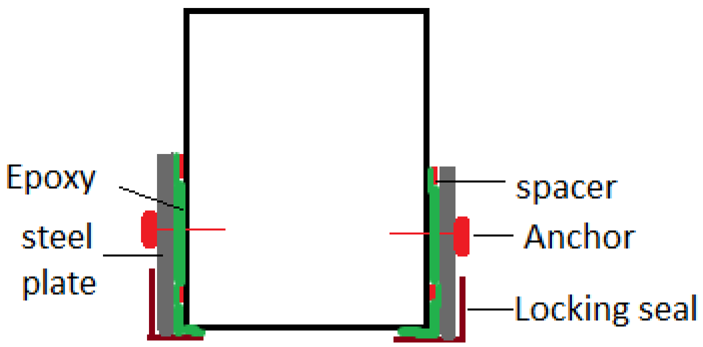

Figure 1. 1 Concrete beam strengthen using steel plate

Redistribution of stress did not take place where glue deformed or connection disruption during the fatigue analysis. In this study, the epoxy EPICOL-U was used as gluing material. The Temperature was ranging from -20°C to +90°C during loading of the sample. In this loading period, there was no evidence of shortening in the ultimate load capacity at a lower temperature while the situation was different when temperature upsurge. When the temperature risen to 60° and afterwards the epoxy shows weaker strength and seems more deformable. In lower temperatures the cracks initiated from the end of the steel plate and propagate to the concrete and epoxy transferred all the stress without failing. While in the case of higher temperature epoxy glue, it seems unable to transfer the shearing stress steel to concrete and cracks in epoxy before entering into concrete, which originated from the plate end.

All above passage can be concluded that the consequences of using the steel plates as follows

1. The heavy weight of steel plates increases a dead load of structures.
2. The corrosion rate of steel was too high.
3. The weak bond strength of steel plate with epoxy glue in the case of temperature risen.
4. Due to heavy weight, the handling at the site were not easy.

1.4 Composite material

Due to the several shortcomings of steel plates, the three types of composite material have been invented. The composite material can be classified into three categories -

A- Polymer matrix composites (PMC)-Popularly called fibre reinforced Polymer/plastic.
B- Ceramic Matrix Composites (CMC)
C- Metal Matrix Composite (MMC)

The polymer matrix composites (PMC’S) are the most used polymer in advanced composites structure strengthening. The polymer composite matrix became popular due to the following characteristics-

1. Lightweight - The fibre material is 0. 55 to 2 Kg per square feet makes the PMC's cheaper transportation cost, No structural framing and very easy as well as fast installation.

2. Noncorrosive - very high resistance to saline water, chemical and other external environmental factor.
3. Due to the ability to mould in any shape enables it to strengthen the complex structure.
4. The normal age of laminate is about 30-50 years. So very less maintenance cost.
5. High Strength to weight ratio enables it to withstand in very heavy load and contribute very little in dead weight.
6. Generally, most of the FRPs are waterproof in nature.

1.4 Fibre reinforced polymers/plastic (FRP)

Due to all these shortcomings of steel plate a new material was introduced in the market in the middle of the twentieth century. FRP (Fibre-Reinforced Plastics/polymer) has emerged as a popular retrofitting material and FRP plates as an application of the plate bonding methods are pretty reliable. In the middle of twenty century, the strengthening of the structure started using fibre plates. The FRPs employed in the construction industry are mainly of three type's viz. glass fiber-reinforced plastics (GFRPs), carbon fiber-reinforced plastics (CFRPs), aramid fiber-reinforced plastics (AFRPs).

Initially it was assumed that FRP would be a better material for retrofitting only to those structures that only need to be corrosion force or less scopes for increasing the dead load or requires better performance in fatigue. But further, this material showed a few more characteristics like better handling at the site, ease of application in structure, the reduced labor cost of retrofitting, etc., which made the FRP very popular material for rehabilitation and retrofitting of damaged and overloaded structure. FRPs are being proved to be very efficient for increasing the load carrying in the Cabo city of old structure. FRPs also help in reducing the member of the existing structure by redistribution of reaction forces strengthening using fibre wrapping dramatically reduces the corrosion intensity and other environmental losses in bridges. Also, the fibre reinforced plastic can be utilized when it is hard to rectify the small or minor design error by strengthening the structure without the major scope of the changes.

Reinforced plastic and composite fibre deliver the ultimate benefits in several usages where lineal material fails to deliver the tolerable service life. The Superb confinement to an electrochemical rusting and very high strength-weight ratio of composite allows them to become the most desirable material for strengthening and rehabilitation. The capacity to mold them in any shape, size and texture makes them attractive for any type of usage in the construction and repairing of the existing structure. Initially, the pure plastic substances are used to design any size and shape without any alignment or fibres. But these fabrics allowed creep and strength loss in long-time loading. So to eliminate these problem reinforced fibre was combined with the plastic to inhance its long and short term developments, increase mechanical Competence, decrease the shrinkage and creep, reduces the thermal expansion, to increase stability. Reinforced fibre composite are built of five fibres shackled with the resins. These fibres can be aligned in any direction to improve the potency and stiffness of composite to ensure the strength of material in that particular direction. The quality of any composite fibres depends on the thread used and its direction of alignment in the composite. The role of resin is to work as the bonding agent in the composite fibre. Some possible failures are listed here

1. In the epoxy glue, many type of cohesive failure is possible.
2. At the joint of laminate and epoxy adhesive failure also predicted
3. At the joint of epoxy and concrete, the adhesive failure is quite common.

It is much-needed quality of laminate strengthen girder or structure that laminate should only start failing when the steel begins yielding and the complete failure of concrete ocurs before the compressive failure.

The strengthening of concrete structure with carbon fibre reinforced polymer (FRP) is a well-established retrofitting method. Also, glass fibre-reinforced polymer (GFRP) can contribute to the strength of tension zone of concrete structure by increasing the flexure strength. Suppose the steel ratio is comparatively smaller in reinforced concrete structure. In that case, the flexural strength of concrete attains a good value when fixed with GFRP plate, and also, the crack size in the old structures can be reduced by application of plates in all types of loading conditions.

Concrete is the second most-consumed product after water on earth, and indeed reinforced cement concrete (RCC) comprises a majority of that consumption. A vast majority of the civil engineering structures that are being built today or had been built in the past 100 years have concrete as the dominant building material and hence these have been or will be subjected to the ravishes of time and nature. As concrete ages, it strengthens but deteriorates in a corrosive environment. RC structures encounter damage even before the expiry of their service life due to many reasons like earthquakes, improper construction techniques, inefficient design, explosions, fires, change of usage, corrosion, floods, etc. Hence, they call for immediate damage detection and a check for their integrity to estimate the remaining life span of the structure and the extent of serviceability that can be expected from the structure. These measures also aid in determining the suitable mitigation measure to increase the remaining life and enhance the integrity of the structure.

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The types of fibre widely accept for retrofitting of the dilapidated structure are-

A - Glass fibre

B- Carbon fibre

C- Aramid fibre

D- Natural fibre

(i) Silk

(ii) hemp

1.4.1 Properties of different fibre reinforced plastic (FRP)

A- Glass fibre - Glass fibre has introduced to the world in the 1930's. GFRP has become the staple in the structural rehabilitation industry. The first use of GFRP in any structure was in 1967 in Disneyland's "House of the future". The properties of carbon fibres are listed in table 1.1.

Table 1. 1 Properties of Glass fibre Laminates

Property	**E-Glass**	**S-Glass**
Density (gm/cm^3)	2.2-2.8	2.4-3.0
Strain to failure (%)	2.0-5.0	2.5-5.7
Specific Strength (kN.m/kg)	1000-2000	1500-2500
Specific modulus ($10^6\ m^2/s^2$)	20-30	30-40
Tensile Strength, (GPa)	3.0-4.0	4.5-5.5
Tensile Modulus (GPa)	70.0-80.0	80.0-90.0
Compressive Strength, Longitudinal (MPa)	500-600	600-700
Compressive Strength, Lateral (MPa)	250-350	300-350

B- Corban fibre- Carbon fibre reinforced polymer is mainly dependent on carbon fibre for stiffness and durability. The polymer inside the material enables it to provide a cohesive matrix to bind up the fibre together and increases the toughnessness. The primary beauty of CFRP is its extensively directional properties, unlike metals. The desired strength and stiffness of carbon fibre polymer can be customized according to structures as their polymer matrix is controllable. The properties of carbon fibre are listed in table 1.2

Table 1. 2 Properties of Carbon Fibre Laminates

Property	**High Modulus**	**Intermediate Modulus**	**High Strength**
Density (gm/cm^3)	1.8-2.2	1.8-2.0	1.8-2.0
Strain to failure (%)	0.4-0.7	1.3-1.6	1.7-2.4
Specific Strength (kN.m/kg)	1050-1750	1750-2200	2200-3600
Specific modulus (10^6 m^2/s^2)	190-250	130-150	135-150
Tensile Strength, (GPa)	2.0-3.5	3.0-4.5	4.5-7.5
Tensile Modulus (GPa)	350-550	250-350	250-350
Compressive Strength, Longitudinal (MPa)	900-1000	900-1200	1000-1200
Compressive Strength, Lateral (MPa)	400-500	450-500	430-500

C- Aramid and Natural fibre

The first organic fibre was invented and known as aramid fibre: This fibre showed superior chemical and physical properties at a high temperature than carbon and glass fibre. Aromatic polyamide fibres are the main Constituent of aramid fibre. These fibres are plentiful in the heat and flame resistant, by which their basic properties are preserved in the time of nearby fire also. Kevlar 49 known as for high modules, Kevlar 29 for high toughness and Kevlar 149 for Ultrahigh modulus. these are some primary types of silk fibre and other than these fibres, two other natural fibre material are silk and hemp.

1.5 Motivation

The human species are building bridges since their existence on this earth. Like other structures, bridges also have a particular predefined life, and accordingly, people plans for their new transportation mediums. In the meantime, the rapid growth of population and vehicle intensity over almost all of the bridges are overloaded and making it out-serviced. Building New bridges at every old bridge are not possible due to feasibility and economic point of view. So to strengthen them, the only option left. To enhance the strength of old structures, lots of techniques have been invented. Retrofitting using polymer matrix is also an effective way of rehabilitating the old structure, but the analysis of strengthening effect by altering the length of the girder and the no. of the layer has explored less. The real-time strengthening of bridge girders and the effectiveness of no. of the layer with the varying length of girder is not much investigated in practical use.

An attempt has been made to correlate the different parameters with strength behavior, and the same has been applied for a field study to retrofit the bridge. Finite element analysis of one road over bridge near Pusa, Muzzafarpur Bihar and two rail bridges at Ratlam, MP and real time field testing of both the bridges has been studied. The modelling of several rectangular and I section girder of size spanning from 5 meter to 30 meter using ANSYS 18.1 to correlate the parametric investigation of all the girders.

1.6 Organisation of thesis

The present study is divided into six chapters. In chapter one, a general introduction of the strengthening material, their properties are discussed. Chapter two consists of the literature review on FRP retrofitting and failure of the structural element and the scope of the study. Chapter 3 parametric analysis of a benchmark girder has been discussed, and different strengthening aspects of the different laminated girders of rectangular and I shaped have been discussed. Chapter 4 starts with the analysis of rectangular bridge girders using ANSYS, and a recommendation on the strengthening of the girder has been proposed according to the outcome of the analysis. Later the post strengthening testing result has been analyzed. In chapter 5, two different rail bridges have been analyzed using ANSYS for static and dynamic analysis of girder. Later a separate strengthening scheme is being suggested for both the bridge girders. Pre and post-strengthening real-time field testing has been conducted on the bridge using Indian rail locomotive WAGON 7. Analysis of results has been concluded in the tail of the chapter. The conclusion drawn out of the present work and the further study scope is included in chapter 6.