# Preface

Fibre-reinforced polymer has eventually become a popular choice for retrofitting and strengthening structural elements. Hence, a need arises to know the quantitative and qualitative effect of these techniques on the original integrity of the concerned structural entity. In India, most of the bridges made in the middle of the twentieth century are classified as structurally deficient or functionally obsolete. To alleviate this problem, a great deal of work is being proposed to be conducted to develop the strengthening of the existing bridge by using fibre-reinforced polymers (FRP) composites. Fibre-reinforced polymer composite materials have shown great potential as alternative bridge retrofitting materials to conventional ones. The acceptance of FRP composites in the bridge industry is mainly due to their superior properties, such as their high strength, long-term durability, and good corrosion and fatigue resistance. However, several technical issues remain and must be addressed before the civil engineering community can develop confidence in structural design with FRP composite members. These issues include the prediction of the dynamic responses of FRP bridges under static and dynamic loading. The present investigation attempted to focus on the performance of FRP retrofitted bridges.

In the present study, initially simple RC beam is analysed using ANSYS Workbench 18.1 software to obtain the maximum deflection, stress, strain energy, natural frequencies and deflections at various modes of free vibration for different design parameter such as width to depth ratio of beam, percentage of steel and loading intensity. Thereafter, the same beams were analysed after retrofitting with one layer, two layer and three layers of carbon fibre reinforced polymer (CFRP) and glass fibre reinforced polymer (GFRP) sheets. CFRP sheets were applied in the tension zone (bottom face) while GFRP was in the shear zone (side face).

At first, a RC beam was simulated for two-point loads, and the results obtained for maximum deflections were compared with manual calculation to ascertain the most appropriate settings of the simulation in the three-dimensional analysis environment of the software. After that, a number of beams were analyzed by altering the width to depth ratio, the percentage of tension steel and the loading intensity over the beam and the variation of deflections, stresses, strains, strain energies, natural frequencies of the first five modes of free vibrations are obtained without retrofitment. Then, two types prismatic and I-girder beam of different size were retrofitted with layers of FRP sheets, and the parametric analysis was carried out, and the results were observed. These results are compared, and multivariate regression analysis is performed to obtain equations to testify the observations and trends. This whole process concludes that the effect of retrofitting is insignificant for single layer FRPs while the most effective results were obtained for the case of triple-layer FRPs in the longer spans and two-layer composite FRPs in shorter spans. Deflections, stress, and strain energy with their relative change across various cases are accurately related to varying parameters through regression analysis. The equations are developed for retrofitted girders, and it may be used for the design of FRP retrofitted girders.

The concept of retrofitment of the girder was then applied for the rehabilitation of two types of bridges, one road bridge and another rail bridge of two different spans. Numerical study on beam further continues for parametric analysis of two different type of bridge girder; simple rectangular girder for a road bridge and prestressed I type girder for rail bridge using ANSYS software. For prismatic girder, three prismatic girders of spans 16.5 meter, 22.5 meter and 28.5 meter has been picked for analysis using ANSYS applying IRC vehicle loading For I-girder, the three different span 13.67 meter, 19.67 meter and 25.67 meter are analysed using RDSO train load. These spans are specifically chosen to simulate the field test of the real bridge.  All the girders are retrofitted with different FRP layers of a different combination of carbon and glass fibre and analysed for the best combination of fibre polymer. It is found that the single-layer FRP and the smallest girder in each group unwavering the least efficient while triple layer fibres and largest girder established the most efficient one.

In this study, one road bridge near Pusa Muzzafarpur, Bihar, has been analysed. The bridge girder was reported severely damaged. All the damaged girders were retrofitted using the designed thickness of fibre polymer and tested for static and dynamic loading using loaded trucks in different combinations and speeds. The finite element model of a rectangle RC girder of span 16.5m, 22.5m, and 28.5m has been addressed on various parameters with and without fibre wrapping. This study covers the potency of different layers of fibre wrapping analysed with ANSYS, and other results were discussed before and after strengthening the girder. Finally, the strengthening of the delaminated bridge girder using prescribed fibre wrapping with varying layers has been performed. Deflection, the natural frequency produced at different loading conditions using the loaded truck is being discussed. The bridge girder's plasticity has been calculated in terms of deflection recovered when the load was removed. The data of static and dynamic testing were compared before and after the strengthening of the girder. The bridge is now in-service conditions.

Two well-known rail bridge, no 114 and 54, at Ratlam, Madhya Pradesh, India was restricted for the high-speed train due to deterioration of the girder. Due to this deterioration, speed of the trains over the bridge was restricted up to 20 km/h. The first rail bridge at Ratlam was constructed on Nakdi River in the year 1958-60. The bridge is a composite PSC I-girders and supported on neoprene bearing. The primary reason for retrofitting the PSC I- girders on the bridges was to arrest the cracks on the girders. As the cracks were propagating with time, these girders' strengthening is required immediately to stop further deterioration. The pre-strengthening test was carried out using rail locomotive WAGON 7. The static and dynamic strength of the out-serviced bridge girder has been investigated numerically, and one additional hypothetical girder is also analysed numerically to correlate the results. The strengthening

scheme was designed according to the numerical result of FRP composites analysis. The girders of this bridge no 114 were retrofitted using three-layer composite fibre in the bottom and side faces. After strengthening the girder were tested using same rail locomotive WAGON 7 under static and dynamic loading condition at 20 KMPH, 75 KMPH and 100 KMPH for one layer, two layers and three layers of retrofitting. Deflections and natural frequencies of girder before strengthening and after strengthening were analysed.

Another rail bridge at Ratlam-Godhra of single-span on the Hadap River in India was studied. The dilapidation was reported in several parts of the girder of the bridge. To strengthen the girder of the bridge, fibre plates were designed and glued in the shear and tension zone of the girder. After strengthening the girder, the deflection and natural frequencies were measured by running Wagon 7 of the Indian railway after one layer, two layers of retrofitting for static and dynamic loading conditions. Again comparison of pre and post retrofitting strength in terms of deflection and natural frequency has been discussed. The results show a significant improvement in deflection and natural frequency after strengthening. As the considerable decrement in deflection was noted, by observed results, the speed limit of the train on both the bridges is recommended to increase up to 100 km/h. Now it is open for high-speed trains.

**Keywords:** Girder, Retrofitment, Strengthening, Pusa Road Bridge, Ratlam Rail Bridge