Rehabilitation, Monitoring and Strengthening of bridges

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Abstract- *This paper presents one bridge which were either rehabilitated or strengthened by using FRP composites. The resulting structure was then tested for the effect after using FRP composites for Rehabilitation and strengthening. In this paper, Structural Health Monitoring basics are covered and need for SHM in future in or India scenario. Use of FRP composites in Rehabilitation and Strengthening of structures is becoming increasingly popular and is opening new possibilities in construction and rehabilitation of structures.*

Keywords- Rehabilitation, Structural Health Monitoring, Bridge Strengthening, Repair

I. INTRODUCTION

In the recent years, rapid deterioration of exiting bridge structures has become a serious technical and economical problem in many countries, including highly developed ones. Therefore, bridge rehabilitation is one of the most important tasks in civil engineering. Bridge rehabilitation process should be preceded by assessment and evaluation of the structure to determine its actual technical condition and to select the proper rehabilitation techniques and materials. The reasons leading to deterioration of the existing bridge are more or less same in every country.

a) Increase in traffic flows and weight of vehicles, especially their axle loads, compared to the period when the bridges have been designed and constructed.
b) Harmful influence of environmental pollution, especially atmospheric ones, on the performance of structural materials,
c) Low quality structural material as well as bridge equipment elements, such as expansion joint, waterproofing etc.

Scope of work

The focus of this present work is to study the effectiveness of the bridge rehabilitation with respect to different aspect such as strain measurement, vibration measurement, deflection measurement, temperature measurement etc. The project contains two case studies, which are as follows.

A) Strengthening of Runway Bridge at Mumbai airport using FRP.

Aims and Objectives

The aims and objectives of "Rehabilitation and structural health monitoring of bridge superstructure" dissertation are as follows:

1) To study strengthening techniques of bridge rehabilitation.
2) To study the effectiveness of the FRP material and external pre-stressing in the field of bridge rehabilitation.
3) To study the different type of damages in concrete structure.
4) To study the behavior of the bridge before and after strengthening.
5) To develop a 24 x 7 bridge monitoring system for deflection, vibration and strain measurements for vehicular loading.

III. CASE STUDY (MUMBAI AIRPORT RUNWAY BRIDGE)

The bridge under consideration is the one at the Mumbai Airport, over the Mithi River. The bridge structure is a reinforced concrete structure, earlier designed for smaller aircrafts. But the bridge won't be sufficient to carry the loads of the current design of aircrafts. Hence a need for strengthening the bridge arose and considering all the available techniques, FRP laminate bonding was suggested.

Material Properties

Grade of Concrete:	M 20 (fck = 20 N/ mm^2)
Grade of Steel:	HYSD (fy = 415 N/ mm^2)
Carbon Laminates:	S&P CFK Laminates
Carbon FRP:	S&P C-Sheet 240
Glass FRP:	S&P G-Sheet 90/10
Leveling Mortar:	S&P Resin 230 leveling mortar
Primer:	S&P Resin 20 Primer
Epoxy Resin:	S&P Resin Epoxy 55/50

Design Steps

Dead load Bending moment = $\frac{wL^2}{8} = \frac{39.2 \times 19.14^2}{8}$
= 1795.06 kN.m

Dead load Shear force = $\frac{wL}{2} = \frac{39.2 \times 19.14}{2}$ = 375.14kN

The overall thickness of the slab is assumed to be 80mm per metre span of the deck.

Overall depth of the Slab = 80 × 18.7 = 1496 mm

Effective depth of the slab = 1496 – 16 - 30 = 1450 mm

Effective span is the least of

I. Clear span + Effective depth = 18.7 + 1.45 = 20.15m

II. Clear span + Bearing width = 18.7 + 0.44 = 19.14m

Effective span is therefore taken as 19.14m

Dead load of the Slab = 1.45 × 24 = 34.8 kN/m^2

Dead load of the wearing coat = 0.2 × 22 = 4.4 kN/m^2

Total load = 39.2 kN/m^2

Dead load Bending moment = $\frac{wL^2}{8} = \frac{39.2 \times 19.14^2}{8}$
= 1795.06 kN.m

Dead load Shear force = $\frac{wL}{2} = \frac{39.2 \times 19.14}{2}$
= 375.14kN

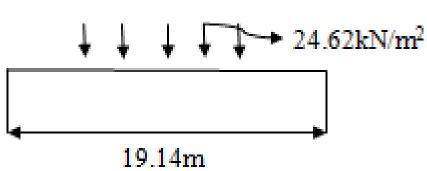
Live Load Bending Moment and Shear force

Effective width for two wheels = 7.045+7.47+6 = 20.515m

Effective length of dispersion = 15.7 + 2×(1.45+0.2) = 19m

Intensity of loading = $\frac{1.5 \times 1600 \times 4}{20.515 \times 19}$ = 24.628kN/m^2

Maximum live load bending moment occurs at the centre of the slab



Maximum Live load Bending moment =
$\frac{24.62 \times 19}{2} - 24.62 \times \frac{19 \times 19}{2 \times 4}$ = 1127.71 kNm

Design Bending moment = Dead load B.M +

Live load B.M=1795.06 + 1127.71 = 2922.77kN.m or 292.277 TN

$M_u(+)$ = 2922.77kNm> 2584.02kNm (Unsafe).

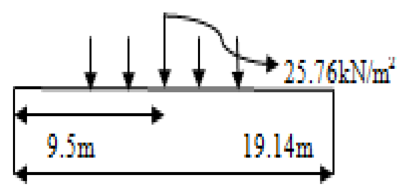
Check for Shear Stress

Distance of the center of gravity of the concentrated load from the nearest support A,

X = 19/2 = 9.5m

Effective width of dispersion = 2.248 × 9.5× (1- $\frac{9.5}{15.4}$) + 1.25 = 12.14m

Effective width for two wheels = 6.07 + 7.47 + 6.07 = 19.6m



Design Check against Demand

The maximum bending moments at support and mid span and shear force are found as
At support:
Mu(-) = 1436.83kNm>1274.82kNm (Unsafe)

At mid span:
Mu(+) = $M_u(+)$ = 2922.77kNm> 2584.02kNm (Unsafe)

Shear Force:
Vu = 621.65kN >548.15kN (Unsafe)

Thus, it is found that the beams are unsafe against both bending moments and shear forces.

Punching Shear Capacity and Design check of Slab

Let us conservatively assume a wheel contact with pavement as 150 mm by 300 mm as shown in Fig 7. The bridge deck is covered with a 200 mm layer of wearing course and a 200 mm thick concrete pavement. The load will be distributed at an angle of 45^o through the two layers to the bridge deck. Thus the load will be distributed in an area of

1100 mm (300 + 400 + 400) by 950 mm (150 + 400 + 400) and therefore the critical section for punching shear will be at a distance of d/2 (= 150 mm) from the face of distributed load area i.e. 1400 mm by 1250 mm.

Thus, the area resisting punching shear is given by,

$A_{ps} = 2*(1400 + 1250)*279 = 1478700\ mm^2$

The allowable shear stress as per IS 456 is equal to $0.16(fck)^{0.5} = 0.716$ MPa
Therefore, allowable punching shear load = 0.716*1478700/1000 = 1058.75 kN =107.93t > 54t (Hence safe).

However, in order to have better load dispersion and thus safety, it is proposed to provide 12 mm dowels at 300 mm c/c to connect the deck slab with pavement

Design of T-beam for Mid-Span Strengthening

The design moment, $Mu_{(+)} = 2922.77$ kNm

The neutral axis depth for the strengthened section (neglecting compression reinforcement) is given by

$x_{u,str} = (0.87f_yA_{st} + f_fA_f)/(0.36f_{ck}b_f)$, thus

$x_{u,str}=(0.87*415*7605.82 +2050*A_f)/(0.36*20*3300)$
$= 115.575 + 0.086A_f$

Now, the moment carrying capacity for the strengthened section is given by,

$M_{u,str} = 0.87f_yA_{st}(d – 0.42x_{u,str}) + f_fA_f(D – 0.42x_{u,str})$, thus

$M_{u,str} = 0.87*415*7605.82*(990 – 0.42*(115.57 + 0.086A_f) + 2050A_f*(1040 –0.42*(1015.57 + 0.086A_f))$

Now, for $M_{u,str} = M_{u(+)} = 2992.77$ kNm, we get,

$2992.77 \times 10^6= 2.74*10^6*(990 – -48.53-0.036A_f) + 2050A_f*(1040-48.53 – 0.036A_f)$

Simplifying, we get,

$73.8A_f^2 – 1.93*10^6 A_f – 4113.15*10^6 = 0$

Solving for A_f, we get,
$A_f = 215.848 mm^2$

Let us provide, 3 Nos. 90 x 1.4 S&P CFK laminates ($A_f = 378\ mm^2$) on the soffit of beam in the middle 6000 mm span.

Design of Beam for Shear Strengthening

The design is done as per EuroCode8 part 3. The shear contribution of FRP shear reinforcement for one ply is given by

$$V_f = 0.9d_fb_w\rho_fE_f\varepsilon_{fve}(1+\text{Cot}\beta)\text{Sin}\beta$$

$\rho_f = 2*0.234*1/600 = 0.00078$

V_f =0.9*990*600z80.0007*8*240*0.0047=470.36kN

Therefore two piles of wraps,
V_f =2*470.36=940.72kN

Thus, allowable shear capacity,
$V_{uf} = \varphi V_f = 0.85*940.72 = 799.61$ kN

Hence, total shear resistance capacity of strengthened section, $V_{u,str} = V_{uc} + V_{us} + V_{uf} = 548.64 + 470.36 + 799.61 = 1818.882$ kN > V_u (621.65 kN). Thus the beams are safe against shear.

IV. SURFACE PREPARATION FOR INSTALLATION OF FRP

Areas of the beams with visible cracking were first repaired (by removing loose concrete and replacing it with new patching concrete, and filling the cracks with a cement based grout material) and those with uneven surfaces ground to a smooth finish. Sharp edges around the beam corners were then rounded, and the bridge underneath was sand-blasted and pressure washed with water to remove any loose surface materials that could lead to de-bonding of the laminates. After the surface was dry, laminate locations on the beams and flange soffits were clearly marked. A 15 mm gap was provided between U-jackets laminates to allow an avenue for moisture to escape.

A primer was applied followed by putty at the locations where the FRP laminates were to be installed. The primer is expected to penetrate the concrete surface, increase its strength, and improve laminate bonding to the surface. After primer application, gaps and pinholes greater than 1 mm can be seen on the concrete surface.

V. CONCLUSIONS

The flexural strengthening of beams is achieved by externally applying S&P CFK Carbon Laminates.

1. S&P CFK Laminates 90x1.4 at 450 mm c/c along the length of the beam at the soffit of the slab of T-beam up to 2500 mm from the face of the support on either side.
2. S&P CFK Laminates 90x1.4 at 500 mm c/c across the length of the beam at the soffit of the slab as main reinforcement to slab up to 300 mm from the face of the beam on either side.
3. Nos. S&P CFK Laminates 90x1.4 along the length of the beam at the soffit of the beam as main reinforcement to beam in the middle 6000 mm of the beam.

The shear strengthening of beams is achieved by providing Carbon U- Wraps on the beams as shown in Fig. 10. The design recommendation is to provide 2-ply-430 gsm S&P C-240 as U-wraps on beams at L/3 from the face of the support on either side.Load tests were conducted before and after installation of the laminates to evaluate effectiveness of the strengthening system and investigate its influence on structural behavior of the bridge. The FRP techniques were easily implemented and showed satisfactory performance.

Connection of truss over main beam

Pre-stressing Mechanism in Truss

Replacement of damaged Bearings

REFERENCES

[1] Branko Glisic and Daniele Inaudi, " Fibre optic met hods for structural health monitoring",

[2] John Wiley & Sons, Chichester, **2007**.

[3] Guidelines for Structural Health Monitoring, ISIS Canada.

[4] International Society of Structural health Monitoring and Intelligent Infrastructure, www.ishmii.org

[5] "Report on Dam Safety Procedures", Government Of India, Ministry of Water Resources.

[6] Jacob Egede Anderson, "Structural Health Monitoring Systems", Cowi A/S and Futurtec OY, 2006.

[7] "Report card for America's Infrastructure", American Society of Structural Engineers, **2005.**

[8] http://memory.loc.gov/ammem/collections/habs_haer/

[9] Radomski W., Bridge Rehabilitation, Imperial College Press

[10] ACI Committee 440. State-of-the-Art Report on FRP for Concrete Structures. ACI 440R-96

[11] Manual of Concrete Practice, ACI, Farmington Hills, MI, 1996, 68 pp.

[12] G.L. Rai, "Different Strengthening Techniques for RC Columns", R&M International.

[13] B.N. Pandya, M. M. Murudi, A. A. Bage, "Seismicretrofitting of reinforced concrete buildings",

[14] Proceedings WSRR 09.

[15] Gopal Rai, Kulvinder Singh, Yogesh Singh,"External Pre-Stressing Using Carbon Fiber Laminates",

[16] Proceedings WSRR09, IIT Bombay

[17] Bambole A. N., Jangid R. S., Rai G. L., "Rehabilitati-on and Testing of the Karal Rail Over Bridge for JNPT, Navi Mumbai" , Proceedings WSRR09, IIT Bombay

[18] ACI 440-2R

[19] IS 15988:2013

[20] IS 800: 2007

[21] FIB-14

[22] IS 456:2000

[23] IS 13311 (Part- I): 1992

[24] IS: 1331 (Part 2): 1992

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