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Retrofitting and Rehabilitation of damage footbridge over Yamuna River

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Abstract: ***Every Structure has a certain predefined age with which it has to withstand, and after that, it requires the rehabilitation/repairing to avoid any damage or collapse. The footbridge over Yamuna River in Delhi, India was constructed in 1960 adjacent to Wazirabad barrage, and this is a very important link to East Delhi and West Delhi. Due to heavy traffic plying on this footbridge, in due course of time, the signs of deterioration were visible in the bridge expansion joint assemblies in the deck slab and cantilever portion of footpath slab. There were many potholes also developed in the wearing course. It was also dilapidation observed in many portions of the footpath, and some portion of the footpath slab were collapsed. The cantilever portion of the footbridge was retrofitted with steel jacketing fixing in the main longitudinal girder of the bridge. In this study analysis of the cantilever footbridge slab retrofitted by a steel jacket was carried out to check the deflection and stress limit of the bridge and it is found that the bridge is safe and now Bridge is open for traffic.***

Index Terms: Footbridge, dilapidation, Retrofitting, Steel Jacketing.

I. INTRODUCTION

Several bridges in India are constructed few decades ago, are not serviceable and requires immediate attention due to damage and deterioration. The obvious reasons for Deterioration in the structural performance of bridges are Salinity of water, overloading, corrosion, and material ageing [1,2]. In past few years, in every part of the world a large number of failure is reported in the bridge structures. To repair and to strengthen the bridge Fibre Reinforced Polymer and steel jacketing are more effective in the straight ribbed bar than smooth bars with the hooked end in the earthquake [3]. If a simply supported beam were damaged upto yield stress and then jacketed with steel plates and compared with simple reinforced beam, then jacketed reinforced concrete beam gives little more strength and behave well than those of simple RC beam of equal dimensions [4]. Steel plates, pre-stressing strands, fibre-reinforced polymer (FRP) reinforcement, steel wire ropes and pre-painted galvanised iron, (pre-coated steel, PPGI) Sheets are the most commonly used materials in strengthening the bridge components.

The main advantages of PPGI sheet strengthening of deck slab are the low prices and convenient construction, and the disadvantage is that it cannot provide a pre stressing force [5]. Strengthening with PPGI sheets usually having lower self-weight with high-tension bearing capacity, which may prevent to local concrete damage.

The steel section is very useful as the jacketing material due to its high strength, fatigue endurance, and corrosion resistance [6]. To increase the seismic strength of bridge slab the steel diaphragm over abutments and piers replaced by specially designed ductile diaphragm and tested its yield strength. Shear panel eccentrically braced frame and triangular plate diaphragm were also developed to increase the slab resistance [7]. There are several methods of plating which is nowadays available for rehabilitation and retrofitting of bridges. Each and Every plate have different performance level and failure mechanism under similar conditions. Comparison of several aspects of plates strength like bonding and bolting, bonding between steel and FRP is necessary for deciding of plates at onsite application [8]. The link slabs are very useful for strength increment of earthquake deficient multi-span bridge of precast, pre-stressed and steel girder [9]. After retrofitting the strain in the beams were decreased because the plates were very helpful in resting the load. After some time again the beam was tested under the same loading condition and no change in strain were found. Fibre reinforced polymer, Steel plates are commonly used materials to strengthen the Structures [10]. GFRP plates performance was found satisfactory in concrete and steel member jacketing under service load condition [11]. Slacken dynamic loading of a jacketed beam not contributed much in its load reduction capacity. Shear prism & T beam were tested under static and dynamic load to verify [12]. After repairing a non-ductile damaged beam column with several retrofitting materials like epoxy mortar and grouted using low viscous polymer, steel plates jacketing and fibre reinforced polymer (FRP) wrapping in column & beam component it has been proved that specimen regain its strength and overcome the deficiencies of ductile detailing [13]. In this paper, the study of the strengthening technique used in rehabilitation of footbridge attached with 460-meter-long beam bridge adjacent to Wazirabad barrage has been done. The footbridge Slab and its cantilever beam were facing severe deterioration as well as an increment in traffic capacity and strengthening of footbridge done in two part. One is strengthening using the PPGI sheet below deck slab, and another is jacketing of a cantilever beam by steel angles and plates. The PPGI sheet will prevent slab from deterioration in future are also very light in weight and economical with ease in installation. This paper is organized as follows: first,

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In the background, the details of old footbridge and reason of deterioration is being introduced; second, the strengthening procedures with a layer of PPGI sheet with jacketing of cantilever beam has been described; third will cover the modelling and analysis of steel jacket and finally, several conclusions will be drawn.

II. BACKGROUND

The foot bridge adjacent to Concrete Bridge over Yamuna river had been 60 years old and has dependency of large population of east and west Delhi [Figure 1 and Figure 2]. This Bridge was designed for pedestrian and Bicycle, but in some part it collapsed and some cracks were visible in cantilever beam of footbridge. There are several aspects are responsible for deterioration and collapsing of bridge component in this area ranging water quality to load and age of bridge. As for as of water quality of Yamuna river in NCT Delhi is concern, it is reasonably good before Wazirabad. The fact is from Wazirabad to Okhla has only 2% of catchment area but the pollution contributed is approx. 70% due to industrial and multiple sewage line falls in this region. The Bridge has been built in 1959 along with a barrage over river, so due to age and overloading makes the bridge unserviceable. This bridge has a barrage on its upstream so the level of alkalinity is at very high. Though its stretch between Wazirabad barrage to downstream is less than 2% of the Yamuna catchment but it receives approximately 78% of the total waste (BOD) load that received by the river and which is cause of severe pollution. At the time of contract initials the following data in Table 1 was measured by Central Pollution Control Board, (Updated on November 25th, 2016) [14],

Table 1 Water quality at Bridge site

S.N.	Quality Parameters	Measured Value at site	Permissible Values*
1	Cl- Content	1700 mg/l- 3000 mg/l	≤500 mg/L
2	Free ammonia (NH_3)	1.8 mg/l	1.2 mg/l
3	SO_4 (Sulphate in SO_3)	700-1200 mg/l	400 mg/l
4	Dissolved Oxygen(DO)	5.5-15.5 mg/l	4.0mg/l
5	Bio-chemical Oxygen Demand	3 – 8 mg/l.	3 mg/l
6	Total Coliform (TC)	450 - 43000 MPN/100 ml	5000 MPN/100 ml

* IS 3025 Part17 [5] and IS 456: 2000 [15].

Figure 1 Geographic layout of Yamuna Bridge (Source: Google Map)

The footbridge has been damaged and become unserviceable (Figure 3 & Figure 4) due to overloading, material aging and salinity of water. The slab of footway was damaged at the extent from where repairing was not possible. The footbridge has been scrapped completely (Figure 5). After scrapping the damaged footbridge portion the rehabilitation of cantilever beam has been done by jacketing with steel. After jacketing the cantilever beam, the fabrication of deck slab was done by PPGI sheet as permanent shuttering and a fresh deck slab laid down (Figure 14).

A. Dimensions of Bridge:

Centre to Centre distance between Piers= 20 Meters
Total no of Span = 23

Length of total span = 23*20 = 460 Meter

Width of footbridge = 3.0 meter

Width Available for pedestrians = 2.5 meter

Total number of Piers= 23 Nos

Abutments = 2 Nos

The 23 span Bridge consisting 22 concrete piers and 2 abutments. The total length of bridge is 460 meters and total width of footbridge is 3.0 meter. It is supported on cantilever is situ cast beam. Figure 2 Present a global view of footbridge portion supported on cantilever beam. The Bridge has 2.5% Longitudinal and 0.75% of traverse slope.

Figure 2 Global Image of Yamuna Bridge

The concrete mix M25 were used in the Slab and M15 in the handrails bottom as recommended by the IRC 5: 1956. The strength of concrete mix M25 was 25.3 MPa and 16.8 MPa for M15. A layer of waterproof concrete was applied on the bridge deck pavement whose strength was 22 MPa. For wearing coarse Asphalt Concrete was used. By improving construction technology and adding admixture in the mix proportion of concrete an impermeable waterproof concrete was prepared. A steel crush barrier of 4-meter height was installed to avoid type of accident due to river. Time by time development on both side of bridge increases in the result of heavy pedestrian load including heavy motorcycle and 3 tyre small public transport. Also the day by day decreasing the water quality at Okhla Barrage was also a reason for damaging the foot bridge. The foot bridge was damaged brutally years ago and become unserviceable because of that intensity of overloaded pedestrian and vehicle could not present in this study. Damage to the foot bridge such as deteriorated Joints, cracking in the concrete, steel corrosion, scrapping of the outer layer of concrete were noticed before demolition. Figure 3 to Figure 6 shows the foot bridge damage.

As damage to the footbridge slab can be seen in the Figure 4. The covering concrete had been scrapped at some extent and reinforcement also deteriorated due to salinity of water. So it was needed to replace urgently. Surface of footbridge also got damage due to excess loading can be seen in figure 4 as it become unserviceable. Figure 6 shows the brutally damage of reinforcement and footbridge slab due to salinity of water.

Figure 3 Bottom View of footbridge slab

Figure 4 Top View of Slab

Figure 5 Scrapped potion of deck Slab

Figure 6 Deteriorated Reinforcement of slab

In the Figure 7 the cracks forms due to the Excess Loading and Aging can be easily seen. The several crack which is exceeding the standard limit can be easily observed.

Figure 7 Crack observed in the beam supported slab

III. RETROFITTING PROCEDURES

As some cracks were observed in the cantilever beam supported to slab (figure 7) and slab of foot bridge was also damaged by water quality flowing below so to prevent in future a preventive layer of PPGI sheet also provided Figure 10 and 11. The Retrofitting of the existing footbridge slab was not possible without scrapping entire footbridge slab. So first entire slab was needed to scrap carefully. The IRC 6 suggested that if the crack in the cantilever beam is greater than 1mm under service load then it need to be strengthen immediately so to strengthen the cantilever beam steel jacketing of ISMB angles and plates section has been used (Figure 5 & Figure 6). The details are given below-

A. Steel Bracketing of Cantilever beam

There were many factors because of which cantilever beam deteriorated and crack can be easily seen in Figure 7. Like Aging, Water flowing below footbridge contains So_4 and CL^- , Increased Traffic density. In this work the Steel Jacketing in both side of cantilever beam has been done Figure 8. The Modelling was done using the STAAD Pro. V8i (Figure 9).

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Figure 8. Jacketing of Cantilever beam of footbridge

Figure 9: Model of Cantilever Steel jacket

Table 2 contains the material properties which was uses in the designing and retrofitting of footbridge.

Table 2 Details of Material Used in foot Bridge Retrofitting:

Concrete Used	Steel Used
M-40 = Grade of Concrete in footpath slabs	**Angle =** ISMB 65*65*8 MM
M-30 = Handrails bottom beam and Crash Barrier	**Plate =** 460 *65*8 MM
	Bolt = φ 22 mm
PPGI sheet used	
Thickness of PPGI sheet = 1mm (IS 513-2008)	Sheet Length= 12000 mm
Yield Strength = 240 MPa	Width = 1200 mm
Thickness = 1mm	Profile = Trapezoidal
Zinc Coating = 275 GSM Both side (Conform to IS 277-2003 Including amend 3-2009)	
Sheet Length= 12000 mm	Unit weight = 7.1 kg/m^2
Width = 1200 mm	Pre-treatment= Chromate both side
Profile = Trapezoidal	
Top coat thickness= 18 microns (Regular modified polyester)	
Epoxy Primer= 7 microns thick on both side of sheet	

B. **Load Calculation (According to Clause 209.4 of IRC :6);** loading condition considered in foot bridge design as follows-

1) **Vertical Load**

Live Load = 5 kN/m^2

Dead Load

a) Deck slab load= 3*1*0.210*25= 15.75 kN/m

b) Wearing Coarse = 3*0.025*22 = 1.65 kN/m

2) Side Load

c) Wind Load= 1.37 kN/m^2

d) User leaning or Bumping and others = 150 Kg/m

C. Laying of PPGI sheet and deck slab:

As specified in table 2, PPGI sheet were drawn below the deck slab to protect the Deck slab from the corrosion and deterioration from dangerous chemical in below flowing river Figure 10 and Figure 11. The sectional line diagram of deck slab can be observed in Figure 12.

Figure 10 Laying of PPGI sheets

Figure 11 Skelton of steel for Deck slab

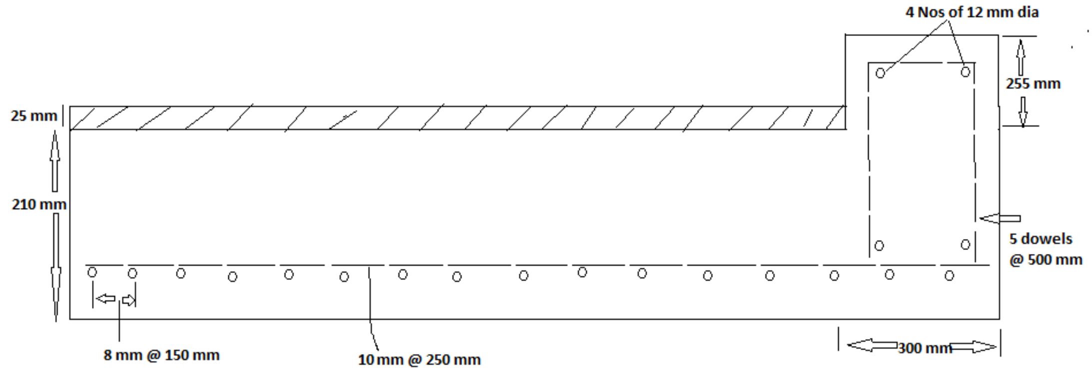

Figure 12 sectional Line diagram of Deck slab

IV. MODEL ANALYSIS:

The analysis of jacketed steel structure using STAAD.Pro V8i was carried out to check whether structure is safe or not. In Figure 13 the deflected shape of steel jacketing structure and Node displacement in Figure 13 is shown when it is loaded.

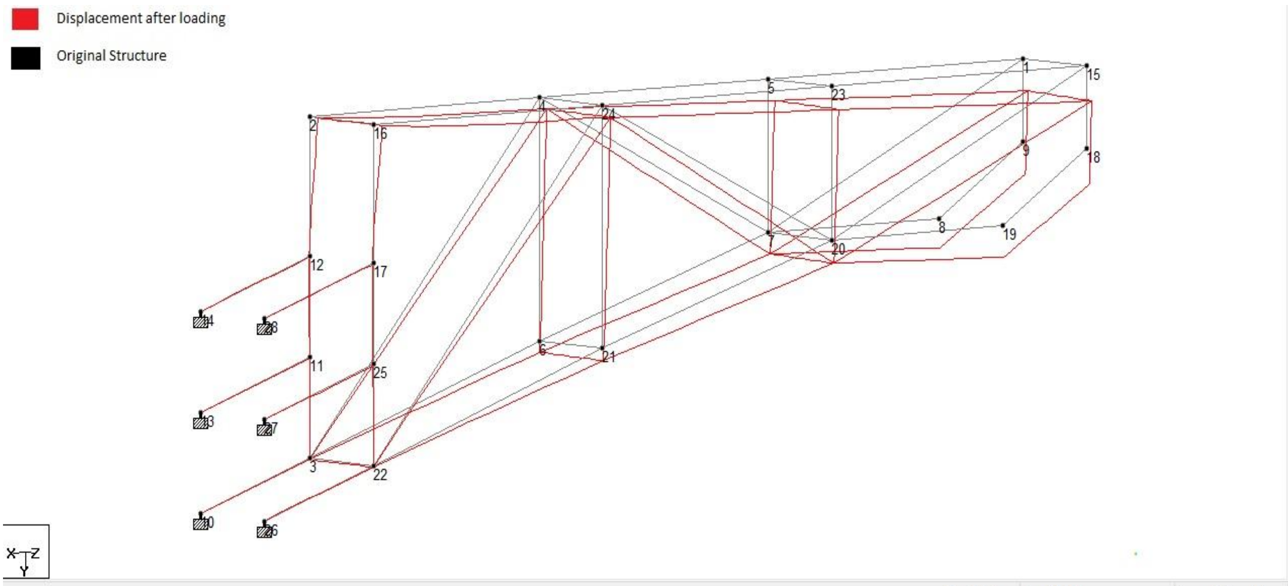

Figure 13 Deformed shape of Steel Jacketing Structures

Displacement value of different node is presented in the Table 3.

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Table 3 Node Displacement

			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX, Rad	rY, Rad	rZ, Rad
Max X	4	3 WL	1.284	-1.329	-1.939	13.071	0.003	-0.011	0.001
Min X	15	2 LL	-4.957	8.339	-4.84	-9.526	-0.016	-0.012	-0.045
Max Y	18	2 LL	-3.238	7.34	-2.789	8.168	-0.018	-0.013	-0.048
Min Y	9	3 WL	1.08	-3.04	-3.783	3.937	-0.004	-0.014	0.001
Max Z	16	2 LL	-4.338	7.369	2.759	4.76	-0.05	-0.007	-0.124
Min Z	18	3 WL	-1.452	4.688	-3.634	3.98	-0.007	-0.014	-0.001
Max rX	25	2 LL	-1.993	7.269	-3.633	8.367	0.013	0.005	-0.002
Min rX	16	2 LL	-4.338	7.369	2.759	4.76	-0.05	-0.007	-0.124
Max rY	25	2 LL	-1.993	7.269	-3.633	8.367	0.013	0.005	-0.002
Min rY	17	2 LL	-2.705	7.371	-7.209	2.659	-0.004	-0.034	-0.039
Max rZ	2	3 WL	1.278	-0.195	-2.397	2.723	0.003	-0.01	0.003
Min rZ	16	2 LL	-4.338	7.369	2.759	4.76	-0.05	-0.007	-0.124
Max Rst	15	2 LL	-4.957	8.339	-4.84	-9.526	-0.016	-0.012	-0.045

V. CONCLUSIONS:

In Table 3 the resultant and rotational node displacement have been presented. The results were obtained using the software STAAD.PRO V8i. Using Table 3 Some of conclusive data have listed below-

1. The Maximum Resultant Displacement is 9.526 mm, which is in downward side.
2. The Maximum Horizontal Displacement in X direction is 4.957 mm.
3. The Maximum Axial Compressive Stress is -9.227 N/mm^2 in both steel beam which is fix with main girder of bridge and between node 22-26 and 3-10.
4. The Maximum Axial Tensile Stress is 21.824 N/mm^2 in Both steel beam which is fix with main girder of bridge and between Node 17-28 and 12-14.
5. Retrofitted footbridge were open for the traffic (Figure 14) when analysis steel jacketing members and found all safe.

Figure 14 Final View of Retrofitted foot bridge Slab

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