Analysis and Design of a Bridge at Bhoothathankettu Barrage

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Abstract - *The present project deals with the analysis and design of a prestressed concrete bridge at Bhoothathankettu barrage. It is the construction of a new bridge for diversion of traffic for safety of old barrage. The analysis of the structure is done with the help of STAAD.pro software. In this present study, design of prestressed concrete girder and reinforced concrete girder is presented.*

STAAD Pro is a powerful tool for design projects. The STAAD results will also compared with manual calculations done as per IRC 6-2000, IRC 21-2000, IS 456-2000.

1. INTRODUCTION

A bridge is a structure constructed to span physical obstructions such as a water body, valley, road etc. Design of bridge depending on the function of the bridge, nature of terrain where the bridge is to be constructed, funds available to built it etc. Prestressed concrete bridges have become much popular these days. The reason behind this is the various advantages of prestressed construction procedure over the RCC and steel bridge construction techniques. Prestressed concrete bridges are economical, durable and aesthetic solutions in most situations. Concrete remains the most common material for bridge construction around the world, and prestressed concrete is frequently the material of choice. So it is important to study about the design features of prestressed concrete bridges and to provide some relevant information regarding the design and analysis of prestressed concrete bridges. For this the bridge at Bhoothathankettu barrage was selected. The project is undertaken by Irrigation Department of government of Kerala and the contract is taken by Mary Matha construction. The bridge has a total span of 211 meters, divided into 10 spans of 21.1m each. It has a carriage way width of 7.5m.The first part consists of analysis and design of super structure PSC bridge. The second part consists of design of substructure. The grade of concrete and steel used are M30 and Fe 415 for superstructure and substructure. The live load considered is IRC Class A loading. The softwares used are STAAD Pro.V8i, AUTO CAD 2013.

The STAAD Pro.is an analysis and design software package for structural Engineering. Structural design is an art and science dealing with the design of buildings considering economy, elegance, safety, serviceability and durability. The design process starts from structural planning, so as to fulfill the functional requirements of clients. In general, functional requirements and aesthetic aspects are managed by an architect while the parameters like safety, serviceability, economy and durability of the structure for its intended use are attended by structural engineers.

1.1 Literature Review

According to Amin Akhnoukh, Large-diameter prestress strands have been used for decades in cable-stayed bridges and mining applications in the United States and post-tensioned tendons in Europe and Japan. Seven wire low-relaxation prestress strands of 0.7 inch diameter were introduced for the first time in pretensioned applications in North America in the construction of the Pacific Street and Interstate 680 highway bridge in Omaha, Nebraska.

The bridge girders were fabricated using 0.7 inch strands placed at centerline spacing in excess of 2 inch. Larger strand spacing was favored by the Nebraska Department of Roads (NDOR) engineers, structural designer, and the fabricator to avoid possible structural and fabrication problems due to the substantial increase in prestressing force associated with the large strand cross section area. The main impediments to using larger strands are: 1) lack of prestressing bed capacities, 2) lack of structural knowledge regarding the transfer and development lengths of larger strands, 3) absence The bridge girders were fabricated using 0.7 inch strands placed at centerline spacing in excess of 2 inch. Larger strand spacing was favored by the Nebraska Department of Roads (NDOR) engineers, structural designer, and the fabricator to avoid possible structural and fabrication problems due to the substantial increase in prestressing force associated with the large strand of statistical data regarding mechanical properties of large diameter strands including yield and ultimate stress, 4) the safety hazard associated with strand harping due to the absence of sufficient pull-down devices, and 5) the possibility of developing wider end zone cracks upon strand release. In a recent study, steel reinforcement was recommended to avoid splitting or excessive cracking at the interfacing surface between bottom flange and web when 0.7 inch strands are used in girder fabrication.

This paper presents a study about using 0.7 inch prestressing strands in bridge girders fabrication. The study includes two phases. An analytical phase to calculate the possible increase in flexural capacities of I-girders when 0.7 inch strands are used, and the effect of girder and deck compressive strengths on composite girder-deck capacity, and a case study to compare bridge panel design constructed using 0.7 inch and 0.6 inch diameter strands.

According to Ankit Sahu, Prof. Anubhav Rai, and Prof. Y.K. Bajpai, A couple of decades back, when pre-stressing was not commonly used in India, R.C.C. beams used to be cheaper even for 25m spans. This is because the mix design for high strength concrete used to be based on 500kg/m3 (i.e. 10

bags of cement/m3) as permitted by IS: 456-1978. With modern methods of mix design based on maximum 8 bags of cement/m3 (to minimize shrinkage & creep) the cost of high grade concrete has come down. Furthermore, the price difference between HYSD bars & high tensile steel used for Prestressing has come down to 25-30% from more than 100%. Ditto for fixtures & accessories associated with pre-stressing. These used to be very costly then but have now become affordable because of the greater demand resulting in economics of scale for the manufacturers.

According to Anupam Sharma and Suresh Singh Kushwah,

For 3 m span simply supported beam,

1) Max. displacement of PSC beam increased as compared to RCC beam against the loading conditions 1.

2) Max. displacement of PSC beam decreased as compared to RCC beam against the loading conditions 2.

3) Max. displacement of PSC beam decreased as compared to RCC beam against the loading conditions 3.

4) Max. displacement of PSC beam decreased as compared to RCC beam against the loading conditions 4.

5) Max. displacement of PSC beam decreased as compared to RCC beam against the loading conditions 5.

In this paper analyzed the RCC & PSC beams against the different loading conditions. They studied the analysis of prestressed concrete beams more effective as compared to reinforcement concrete beams in flexure using different loading conditions. The prestressed concrete is better in structural behavior, durability. The aim of this paper is to compare the structural analysis of the reinforced concrete and prestressed concrete beams using different loading conditions in flexure. Results show that overall flexural analysis of prestressed concrete beam is very good in all aspect compared to reinforced concrete beam.

2. OBJECTIVES

To design and analyse the bridge at Bhoothathankettu Dam.

The primary objectives are:

1. Creation of structural plan
2. Creation of STAAD model
3. Application of loads on the member
4. To analyse the bridge using STAAD Pro.V8i
5. To design the superstructure and substructure of the bridge

3. RESULTS AND DISCUSSIONS

Basic design datas

1) Bridge Type : Prestressed concrete bridge
2) Name of the stream : Periyar river
3) Arrangement exists for crossing the river : Barrage bridge
4) Span length : 21.1 m
5) No.of longitudinal girders : 3
6) No.of cross girders : 3
7) Grade of concrete : M30 for superstructure and substructure
8) Grade of steel : HYSD Fe 415
9) C/C distance between longitudinal girder : 3 m
10) C/C distance between cross girders : 10.55 m
11) Carriage way width : 7.5 m

Fig 1: Site map of Bhoothathankettu

Details of deck slab

Fig 2: Deck slab

Depth of slab = 300mm

Thickness of wearing coat = 80mm

Total dead load moment = 10.42 kNm

Total live load moment = 95.696 kNm

Vehicle loading

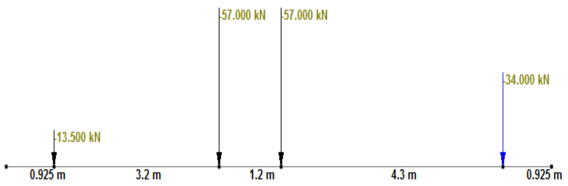

Fig 3: Vehicle loading

Total dispersion parallel to span = 9.405 m
Total dispersion perpendicular to span = 9.87 m
Total moment = 95.696KNm
Reinforcement: Provide 16mm dia bars @ 180mm spacing, Provide 8mm dia bars @ 200mm spacing as distribution reinforcement.

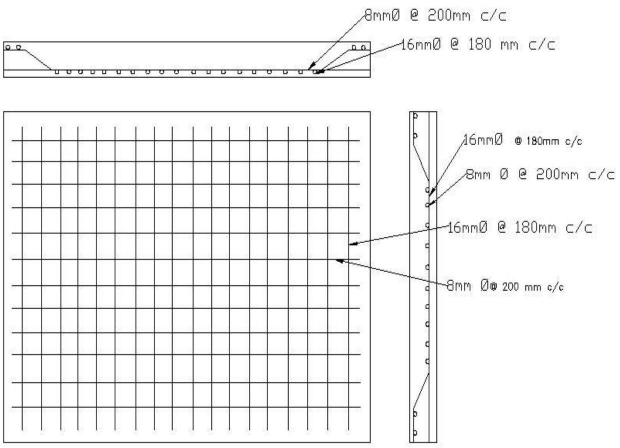

Fig 4: Reinforcement details of deck slab

Cantilever portion

Material constants

Concrete, f_{ck}=25 N/mm² since slab is M_{30} concrete.

Steel, f_y=500 N/mm²

Clear cover to reinforcement = 40mm

Thickness of deck slab = 300mm

Thickness of cantilever portion = 300mm

Depth of longitudinal girder = 2200mm

Thickness of wearing coat = 80mm

Table -1: Details of cantilever portion

Sl. No.	DESCRIPTION	LOAD (kN)	LEVER ARM (m)	Moment (kNm)
1	Parapet (0.5x1x25)	12.5	2.275	28.43
2	Wearing course(0.08x2.525x22)	4.44	1.2625	5.6
3	Slab (0.3x2.525x25)	18.94	1.2625	23.9

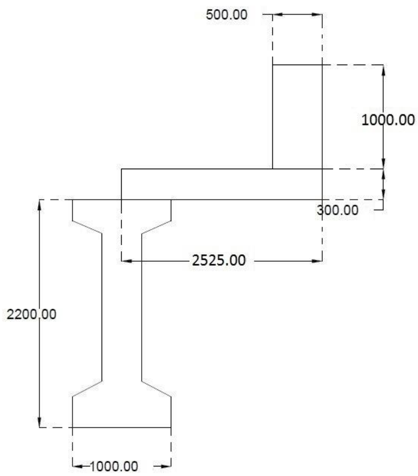

Fig 5: Details of cantilever portion

Foot path loading = 5 kN/m²
Live load moment = 15.94 kNm
Total moment = 73.87 kNm
Provide 12mm dia bars @300mm spacing as main reinforcement
Provide 8 mm dia bars @ 300mm spacing as distribution reinforcement.

STAAD ANALYSIS

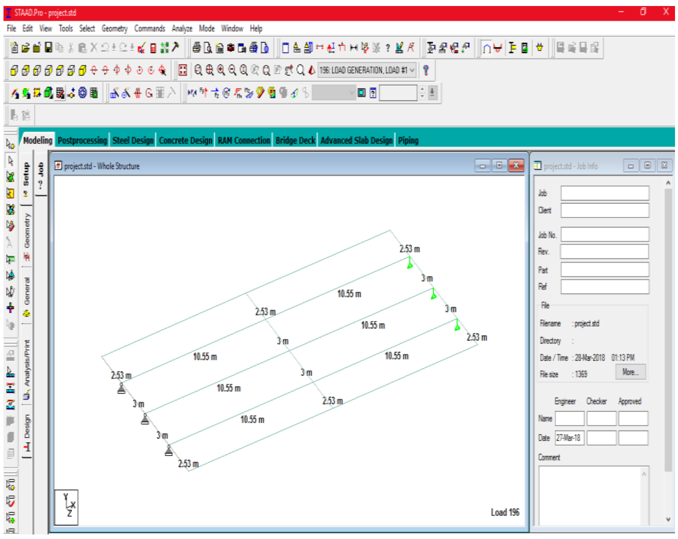

Fig 6: STAAD model

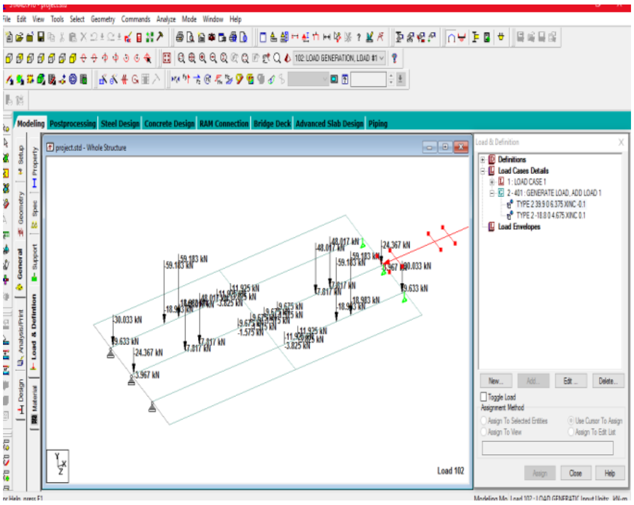

Fig 7: Moving load diagram as per IRC class A loading

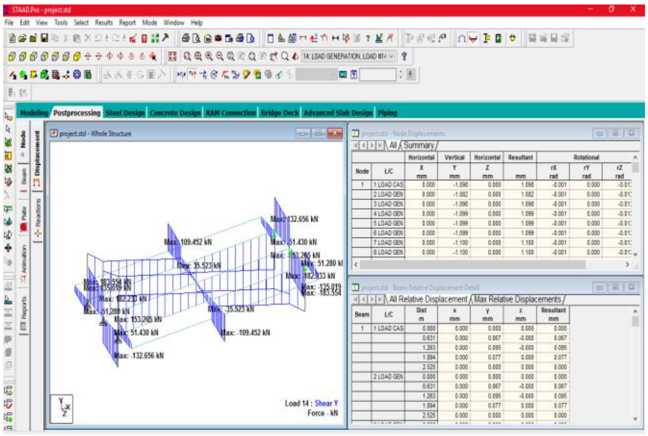

Fig 8: Shear force diagram

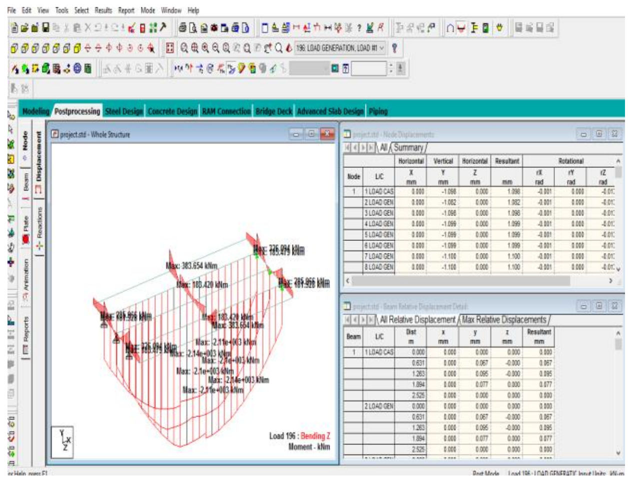

Fig 9: Bending moment diagram

Longitudinal girder

From analysis of super structure in STAAD

- Moment due to L.L = 2.23×10^3 kNm
- Moment due to D.L = 1.4×10^3 kNm
- Section modulus Zp obtained= 3.02×10^8 mm^3 > zp required=2.8×10^8 mm^3, hence safe

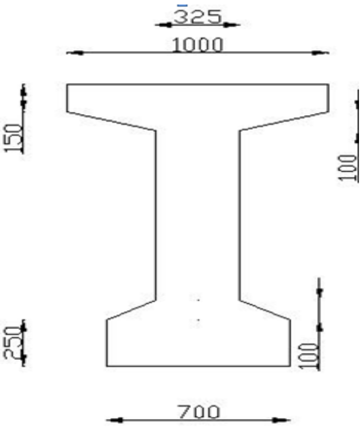

Fig 10: Details of longitudinal girder

Prestressing force (factored) =5300 x 1.5 = 7950 kN
Prestress at cable is assumed as 1200 N/mm^2
Provide 5 no.of 40 mm dia cables containing 8 no.of tendons having 16 mm diameter @ 60 mm spacing and a cover of 100 mm.
Eccentricity at support = -260.9 mm
Eccentricity at mid span = 580.45 mm
Anchorage block dimension = 300 mm x 190 mm
Distance between each block = 5mm

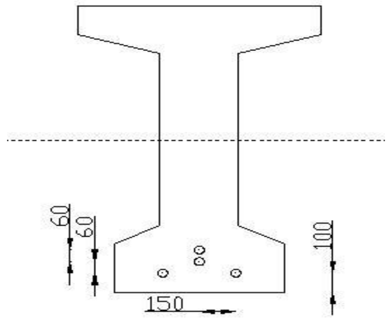

Fig 11: Mid section of longitudinal girder

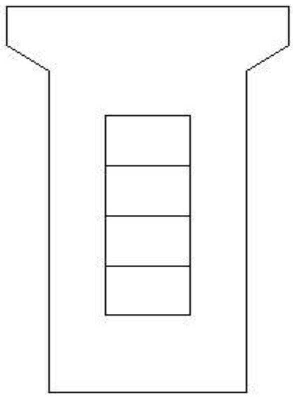

Fig 11: End section of longitudinal girder

Prestressing force = 950 kN
Area, A = 1.1575 x 10^6 m^2
Section modulus of top fiber = 3.31 x 10^8 mm^3
Section modulus of bottom fiber = 3.02 x 10^8 mm^3
Stress developed at transfer stage,
At top, σ_t = -14.374 N/mm^2
At bottom, σ_b = 24.72 N/mm^2
Stress developed at service stage,
At top, σ_t = -4.82 N/mm^2
At bottom, σ_b = 12.915 N/mm^2

CALCULATION OF LOSSES

i)First stage of prestressing

a) Loss due to friction
At mid span = 1159.5 N/mm^2
At end section = 1146.74 N/mm^2
Loss at mid span = 4.44%

b) Loss due to Elastic shortening = 3.92%
c) Loss due to shrinkage of concrete = 3.845%
d) Loss due to relaxation of steel = 2.5%
e) Loss due to creep of concrete = 8.62%
Total loss = 15.805 %
Deduction losses
Prestress available at transfer stage = 1017.25 N/mm^2
Prestress force = 6739.3 kN
Prestress available at top = 2.6 N/mm^2
Prestress available at bottom = 45.54 N/mm^2

ii) Second stage of prestressing

a) Loss due to friction
At mid span = 982.96 N/mm^2
At end section = 972.09 N/mm^2
Loss = 4.44%
b) Loss due to Elastic shortening = 2.49%
c) Loss due to shrinkage of concrete = 4.53%
d) Loss due to relaxation of steel = 2.5%
e) Loss due to creep of concrete = 15.16%
Deduction losses
Prestress available at transfer stage = 867.672 N/mm^2
Prestress force = 5748.3 kN
Prestress available at top = -0.55 N/mm^2
Prestress available at bottom = -6.77 N/mm^2

Provide 10 mm 2 legged stirrups at supports and gradually increasing the spacing to 300 mm towards the mid span as shear reinforcement

Provide 8 no.of 12mm dia bars as supplementary reinforcement

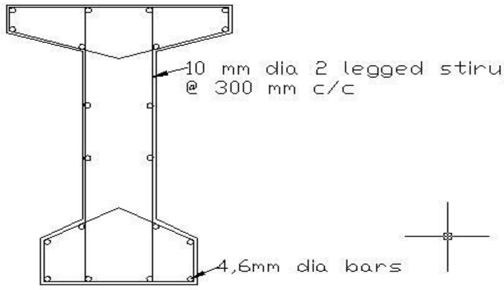

Fig 12: Reinforcement detailing of Longitudinal girder

Cross girder

Span = 3 m
Dead load bending moment = 117.138 kNm
Live load moment due to IRC class A loading = 242.25 kNm
According to IS 456-2000
$M_{u\ limit}$ = 3405.53 kNm
Min A_{st} = 0.12%bd = 1200 mm^2
Provide 4 no.of 20mm dia bars.

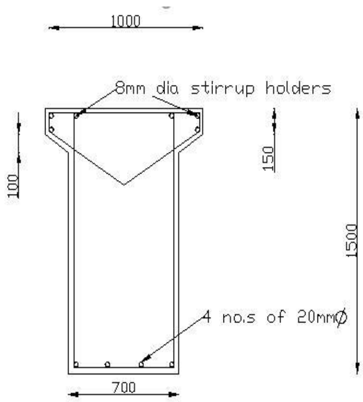

Fig 13: Reinforcement details of cross girder

Bearing

Maximum D.L reaction per bearing = 229.167 kN
Maximum L.L reaction per bearing = 427.209 kN
Vertical reaction induced by
longitudinal force per bearing = 2.27 kN
Angle of rotation, α = 0.0048
N_{max} = 658.646 kN
N_{min} = 229.167 kN
According to standard size index from IRC 83- part 2
Plan dimension = 320 mm x 500 mm
Thickness of bearing = 39 mm
Loaded area, A = 15 x 10^4 mm^2
Allowable contact pressure = 10.606 N/mm^2
Thickness of individual elastomeric layer h_1 = 10 mm
Thickness of outer layer, h_e = 5 mm
Thickness of steel laminate, h_s = 3 mm
Adopt 2 internal layers and 3 laminates
Total thickness of elastomeric in bearing = 30 mm
Side cover = 6 mm

Fig 14: Cross section of bearing

4. CONCLUSIONS

In this project, we have done the analysis and design of superstructure and substructure of the proposed bridge at Bhoothathankettu.

The analysis was done using STAAD Pro.V8i by considering the class A loading and the design was done manually using relevant codes.

Since the construction of flyovers using RCC is time consuming, PSC bridges are the solution for this. Some of the advantages of prestressed concrete bridges are:

1. The size or dimensions of structural members are reduced, which may increase the clearances or reduce storey heights.
2. It permits the use of large spans (greater than 30 m) with shallow members, even when heavy load are encountered.
3. In addition to general advantages, such as excellent fire resistance, low maintenance costs, elegance, high corrosion-resistance, adaptability etc, the prestressed concrete is found to sustain the effects of impact or shock and vibrations.
4. Because of smaller loads due to smaller dimensions being used, there is considerable saving cost of supporting members and foundations.
5. The prestressing technique has eliminated the weakness of concrete in tension and hence crack free members of structure are obtained.
6. Because of better material (i.e. controlled concrete and high tension steel) being used and nullifying the effect of dead loads, smaller deflections are caused.

The different applications and future scope of prestressed concrete bridges are

1. High span-to-depth ratios
2. They do not crack under working loads, and whatever cracks may be developed under overloads will be closed as soon as the load is removed, owing to the cambering effect of pre-stress.
3. This becomes an important consideration for such structures as long cantilevers. Under live loads the def section is also smaller because of the effectiveness of the entire un-cracked concrete section.
4. Larger spans possible with prestressing (bridges, buildings with large column-free spaces)
5. Post-tensioning allows bridges to be built to very demanding geometry requirements, including complex curves, and significant grade changes.
6. Another advantage of post-tensioning is that beams and slabs can be continuous, i.e. a single beam can run continuously from one end of the building to the other.
7. Crack control helps in constructing high performance water tanks
8. More aesthetic appeal due to slender sections
9. Applications of various prestressed techniques enable quick assembly of standard units such as bridge members, building frames, bridge decks providing cost-time savings

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