A Study on the Structural Analysis and Design of A Post-Tensioned Girder Bridge Proposed Near Khangaon Village Across Ballari Nala on SH-54 in Belagavi District

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Abstract- **This paper focuses on understanding the concept of analysis and design of post-tensioned concrete bridges. For the study, an existing reinforced concrete bridge near Khangaon village, Belagavi, which is in structurally poor condition, is identified. Work has been carried out to propose a new post-tensioned prestressed concrete girder bridge with an increased height for the above mentioned site. A post-tensioned girder bridge is designed by working stress method referring to IRC – 6, IRC – 18, IRC – 21 and IS: 1343. Two cases have been studied and a parametric study has been carried out by altering the effective span of the post-tensioned girder, one with an effective span of 30m and the other with 45m. The analysis and design are carried out manually, by preparing analysis and design calculation sheets in MS Excel. The results from the two cases are compared to study the girder forces, structural element sizes and usage of construction material to ultimately propose a cost effective design.**

Keywords- Bridge Engineering, Post-Tensioned Prestressed Concrete Girder Bridge, Working Stress Method, MS-Excel

I. INTRODUCTION

During the past thirty years, rapid developments in the field of bridge engineering has resulted in the widespread use of several new types of reinforced and prestressed concrete bridge decks, which are structurally efficient and aesthetically superior besides being economical and catering to the needs of the fast moving highway traffic. Beam or girder bridges are the simplest structural forms of bridge spans supported by an abutment or pier at each end. More complex beam bridges are built using many beams lined-up side by side with a deck across the top of them. In a girder bridge, the beams are the primary support for the deck and are responsible for transferring the load down to the foundation. In these bridges, no moments are transferred throughout the support, hence their structural type is known as simply supported. The simplest beam bridge could be a log, a wooden plank or a stone slab laid across a stream. But bridges designed for modern infrastructure will usually be constructed of steel or reinforced concrete, or a combination of both. The concrete elements may be reinforced, prestressed or post-tensioned. Posting-tensioning is a method of strengthening concrete or other materials with high-strength steel strands (tendons). Concrete is very strong in compression but weak in tension. It will crack when forces act to pull it apart. Steel reinforcing bars are typically embedded in the concrete as tensile reinforcement to limit the crack widths. However it does not carry any force until the concrete has already deflected enough to crack. This is ‘passive reinforcement’. Post-tensioning tendons, on the other hand, are considered ‘active reinforcement’ because the steel is effective

as reinforcement even though the concrete may not have cracked. Post-tensioning structures can be designed to have minimal deflection and cracking, even under full load. A properly engineered post-tensioned beam can span longer distances than a reinforced cement concrete (RCC) beam and it is thinner and lighter in weight, it uses less concrete without cracking or breaking.

II. LITERATURE REVIEW

Numerous studies have been reported on the analysis and design of bridges. The literature pertaining to the concept of post-tensioned girder bridge relevant to the present work has been reviewed and presented below.

Dr. Sudhir S Bhadouria et al. (2017) worked on the cost comparison between two bridge forms, reinforced cement concrete (RCC) girder and Prestressed Concrete (PSC) girder. A repetitive process of analysis and design for various spans (30m, 35m, and 45m) was carried out for the comparison. A detailed cost estimation was presented and thus based on the economic criteria the best bridge was finalised. It was concluded that a PSC girder bridge was economical compared to a RCC girder bridge over spans more than 25m.

Mary Beth D., Hueste et al. (2012**)** worked on the design of typical highway bridge structures as simply supported using standard precast, pretensioned girders. The objective of the study was to evaluate the current state-of-the-art and practice relevant to continuous precast concrete girder bridges and recommend suitable continuity connections for use with typical Texas bridge girders. Continuity connection details used for precast, prestressed concrete girder bridges were investigated. Several methods were reviewed that have been used in the past to provide continuity and increase the span length of slab-on-girder prestressed concrete bridges.

Mohammad Omar Faruk Murad et al. (2016) studied long span box Girder Bridge with pre-tensioned inverted T-girder using splicing technique. A full scale 3D analysis of post-tensioned box section and pre-tensioned inverted T-girder section was carried out by considering only vertical loading. Post-tensioned box section flexure, shear, torsion and stress in both longitudinal and transverse analysis showed lower values when compared to pre-tensioned inverted T-girder section. Phani Kumar et al. (2016) carried out analysis and design of prestressed concrete bridges using IRC: 112-2011. The study aimed at comparing the design with the IRC:112-2011 and the earlier code IRC:21. IRC:112 is based on limit state theory while the earlier codes were based on working stress design philosophy. Wagdy G. Wassef et al. (2003) have documented their work on comprehensive design example of a prestressed concrete girder bridge. The superstructure consisted of two simple spans made continuous for live loads. The substructure consisted of integral end abutments and a multi-column intermediate bent. The document also included instructional commentary based on the AASHTO-LRFD Bridge Design Specifications which along with the design example served as a guide to aid bridge design engineers. Detailed design computations for the following components were included: concrete deck, prestressed concrete I-girders, elastomeric bearing, integral abutments and wing walls, multi-column bent and pile and spread footing foundations.

III. OBJECTIVES AND METHODOLOGY

A. Objectives

For the present study an existing bridge near Khangaon village located on SH–54 towards Gokak from Belagavi city is identified. The bridge was built for the flow of traffic over the Ballari Nala. The topographic survey and detailed study of this existing bridge showed that the bridge was in a structurally poor condition and high flood level (HFL) was above the deck slab level leading to submergence of the bridge and inconvenience to the traffic flow during high floods. The existing bridge is a RCC bridge consisting of seventeen spans of 5.3m each. The present study aims at proposing a new post-tensioned prestressed concrete girder bridge with increased height for the same site.

The objectives of the present study are-

1. To understand the concept of design of post-tensioned concrete girder bridges.
2. To plan, analyse and design a post-tensioned concrete bridge using the standard codes and principles.
3. To carry out parametric study by altering the effective span of the post-tensioned girder and comparing the results.
4. To optimize the design to achieve cost effectiveness.

B. Methodology

For the present study, a post-tensioned girder bridge is designed by working stress method referring to IRC–6, IRC–18, IRC–21 and IS:1343-2012. Two cases have been studied by altering the effective span of the post-tensioned girder, one with an effective span of 30m and the other with 45m. The analysis and design have been carried out manually by preparing calculation sheets in MS-Excel. The outer and inner girder forces like dead and live load bending moments, shear forces and prestressing force for the two cases are studied and compared.

C. Site Details and Structural Design

Details regarding the site are mentioned in Table 1 below.

TABLE 1: DETAILS OF THE SITE

Location	Khangaon Village
Project Proposed on	SH - 54
Name of the River/Nala	Ballari Nala
Width of the River/Nala	75m
Total length of bridge	90m
Reduced Level of Temporary Bench Mark	590.850m
High Flood Level	590.850m
Bottom Level of Deck Slab (Existing Bridge)	589.965m
Height of Existing Bridge	2.2m
Ground Slope	1 in 207.5
Bearing Strata	Hard Rock

DESIGN OF DECK SLAB AND GIRDERS:

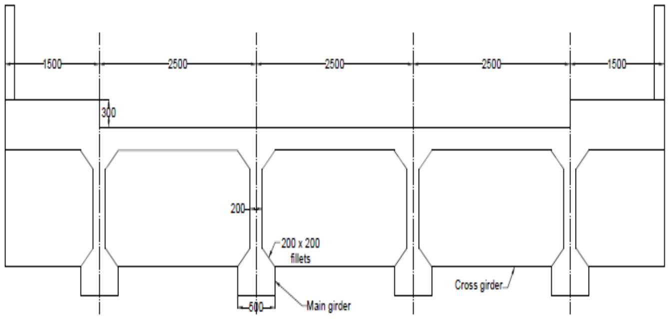

Fig. 1: Cross section of the bridge deck

Following specifications are considered for the design of deck slab-

- Width of road = 7.5m
- Grade of concrete = M-20
- Thickness of deck slab = 250mm
- Thickness of wearing coat = 80mm
- Footpath = 1.5m wide on each side
- Kerbs = 600mm wide and 300mm deep on each side
- Live load = IRC Class A-A tracked vehicle loading
- Impact factor for class A-A tracked vehicle is 25% for 5m, decreasing linearly to 10% for 9m span

Following specifications are considered for the design of girder-

- Grade of concrete = M-50 (prestressed concrete girders)
- Loss ratio = 0.85
- Spacing of main girders = 2.5m
- Spacing of cross girders = 5m

Adopting Fe-415 grade high yielding strength deformed (HYSD) steel bars and Freyssinet system, anchorage type, 7 strands of 15.2mm diameter in 65mm diameter cable ducts.

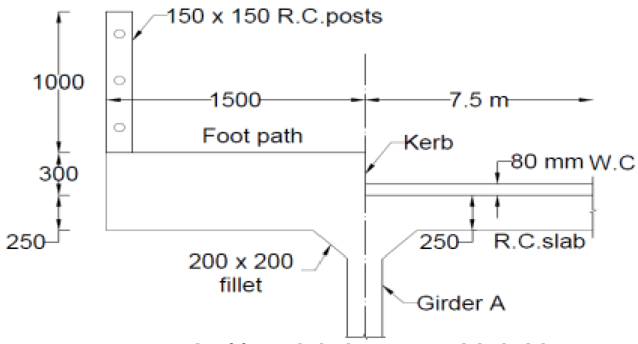

Fig. 2: Details of footpath, kerb, parapet and deck slab

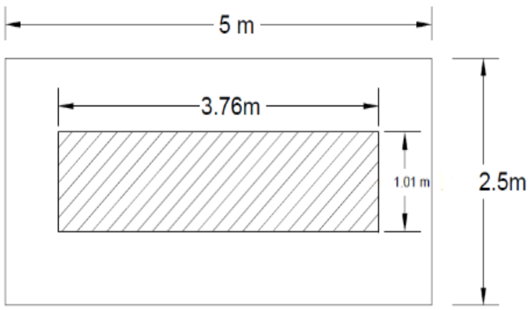

Fig. 3: Position of wheel load for maximum bending moment

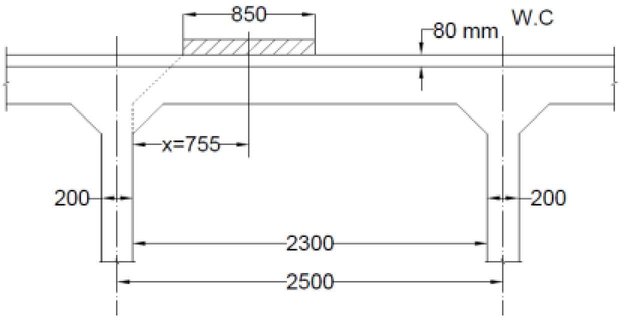

Fig. 4: Position of wheel load for maximum shear force

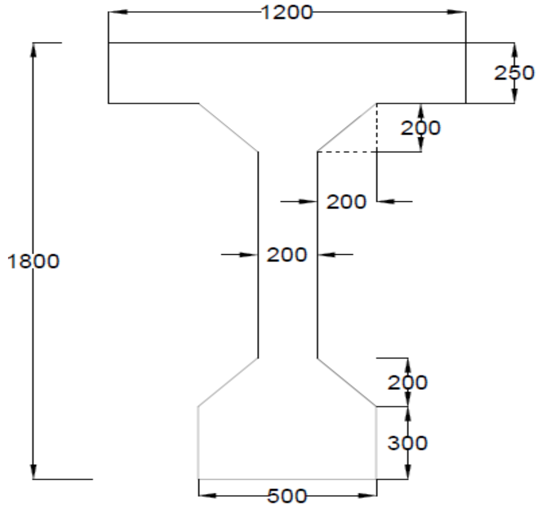

Fig. 5: Cross section of main girder (for effective span 30m)

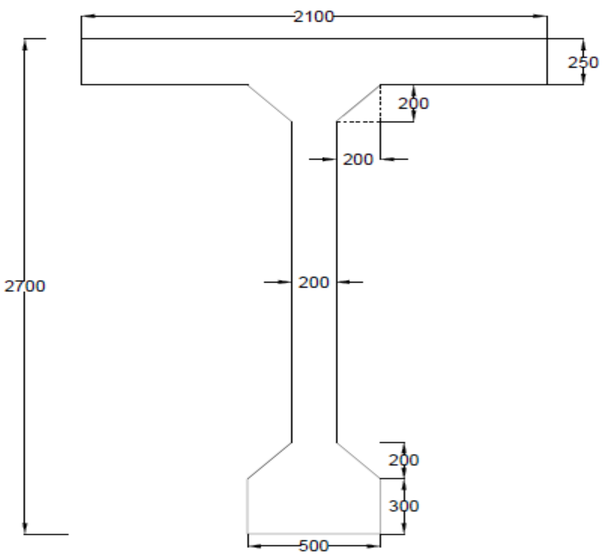

Fig. 6: Cross section of main girder (for effective span 45m)

The overall depth of main girder is decided at the rate of 60mm for every metre span. Using Courbon's theory, the live loads are arranged for maximum eccentricity. When the live loads are positioned near to the kerbs the centre of gravity of live load acts eccentrically with the centre of gravity of the girders. Due to this eccentricity, the load shared by each girder is increased or decreased depending upon the position of the girders. The live load bending moments and shear forces are computed for each of the girders. The cross girders are assumed to be rigid so that the reactions due to dead and live loads are assumed to be equally shared by the cross-girders.

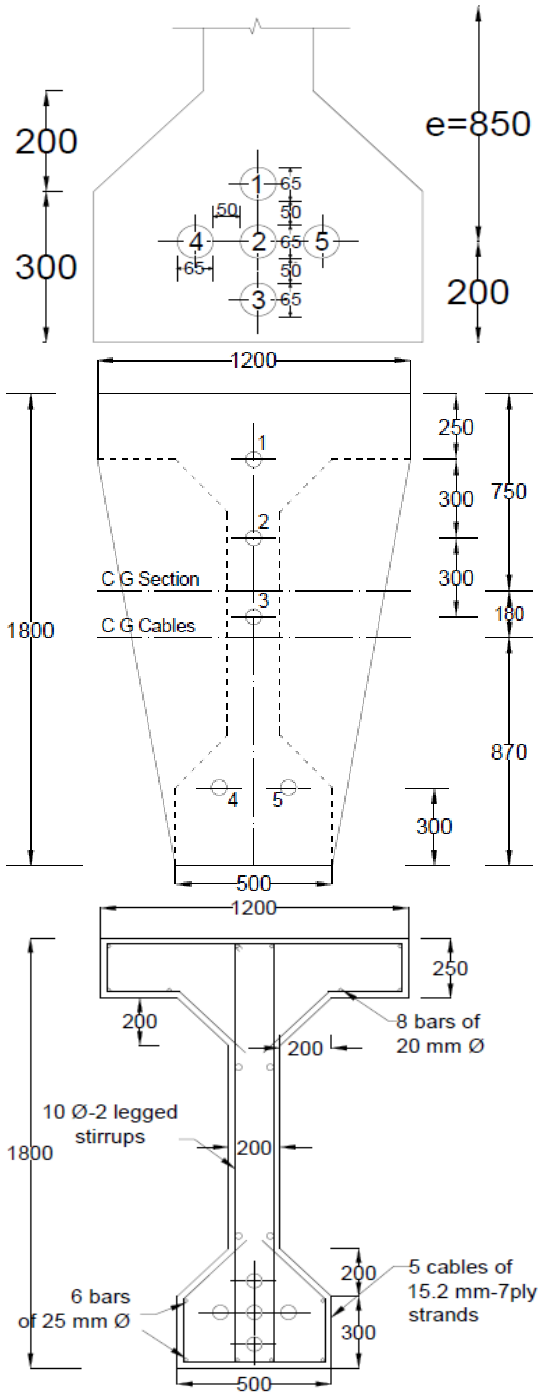

Fig. 7: Arrangement of cables at centre of span and support section and reinforcement at centre of span (for effective span 30m)

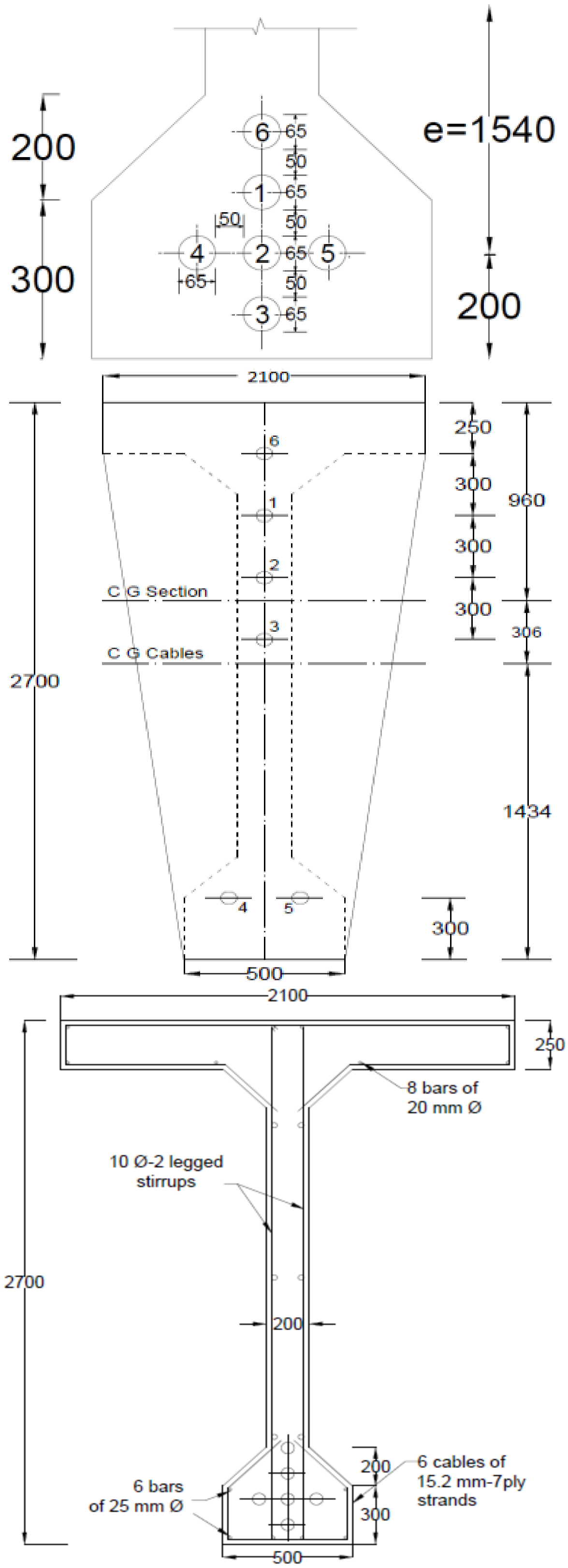

Fig. 8: Arrangement of cables at centre of span and support section and reinforcement at centre of span (for effective span 45m)

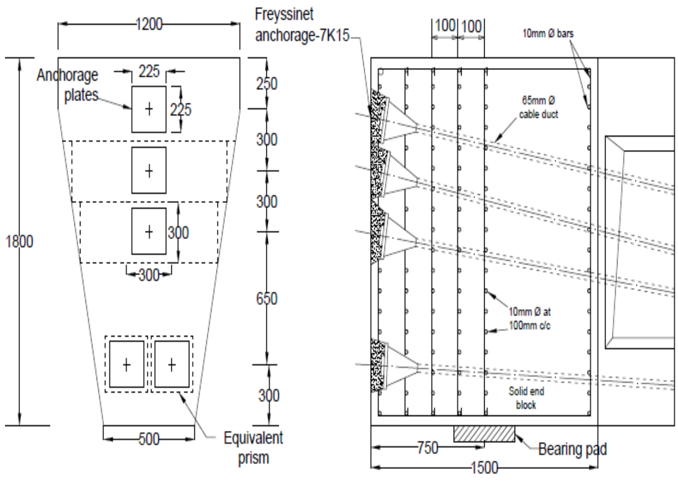

Fig. 9: Equivalent prisms and anchorage zone reinforcement (for effective span 30m)

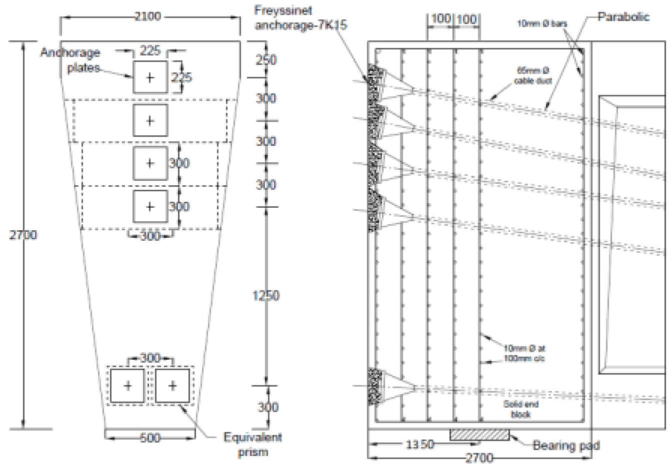

Fig. 10: Equivalent prisms and anchorage zone reinforcement (for effective span 45m)

DESIGN OF BEARING: Following specifications are considered for the design of bearing-

- Type of bearing = Elastomeric rubber pad bearing
- Thickness of individual elastomer layer (h_i) = 10mm
- Thickness of outer layer (h_e) = 5mm
- Thickness of steel laminates (h_s) = 3mm
- Side cove = 6mm
- Adopting 3 laminates with 2 internal layers of elastomers; Total thickness of pad (h_o) = 39mm

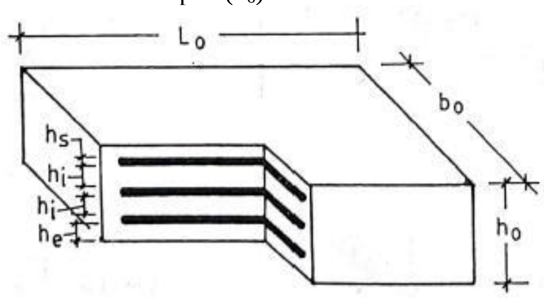

Fig. 11: Elastomeric rubber pad bearing

DESIGN OF PIER: Following specifications are considered for the design of pier-

- Material = 1:3:6 cement concrete
- Total Height = 4m

- Height above HFL = 1m
- Height below HFL = 3m
- Length = 8m
- Top width = 2m
- Bottom width = 2.5m

The material of the pier being 1:3:6 cement concrete, the maximum permissible compressive stress in concrete is 2N/mm^2 or 2000 kN/m^2. Hence the stresses developed at the base of the pier are within safe permissible limits.

DESIGN OF ABUTMENT: Following specifications are considered for the design of abutment-

- Material = 1:3:6 cement concrete
- Height = 4m
- Length = 8m
- Top width = 3m
- Bottom width = 4.4m

The maximum stress σ_A is less than the safe bearing capacity of the soil. Hence the stresses are within safe permissible limits. Also the abutment has sufficient factor of safety against sliding.

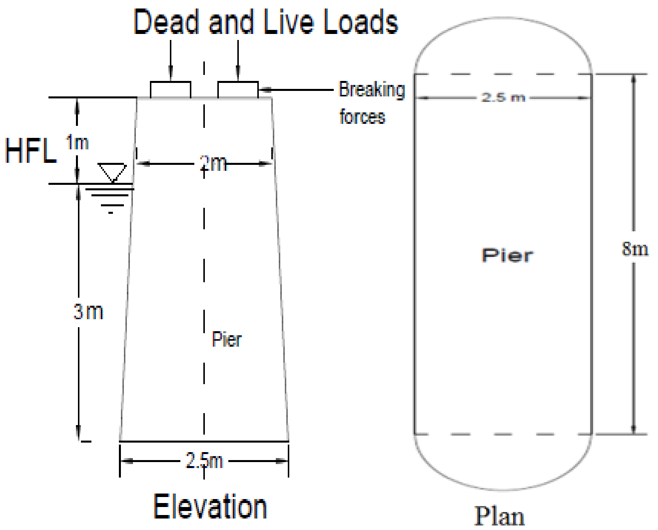

Fig. 12: Elevation and Plan of Pier

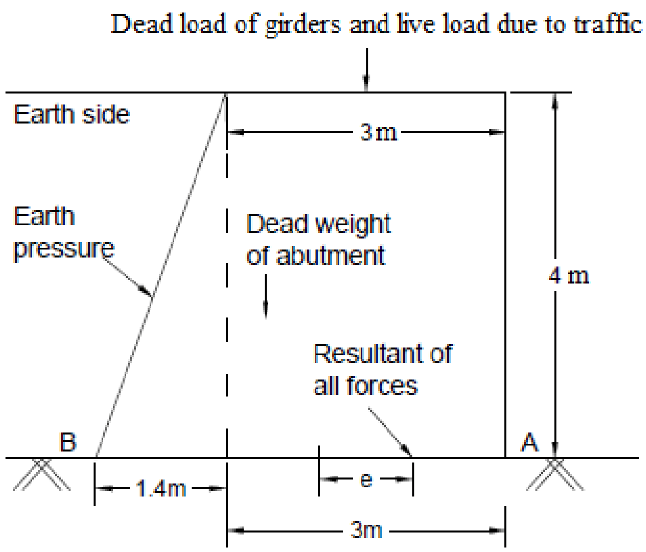

Fig. 13: Elevation of Abutment

DESIGN OF FOUNDATION:
Following specifications are considered for the design of foundation for pier-

- Grade of concrete = M-40
- Size of footing = 10m×4m
- Depth of footing = 600mm
- Providing 16mm diameter bars @100mm c/c both ways.

The design is safe against one-way shear and two-way shear.

Following specifications are considered for the design of foundation for abutment-

- Grade of concrete = M-40
- Size of footing = 10m×6m
- Depth of footing = 600mm
- Providing 16mm diameter bars @100mm c/c both ways.

The design is safe against one-way shear and two-way shear.

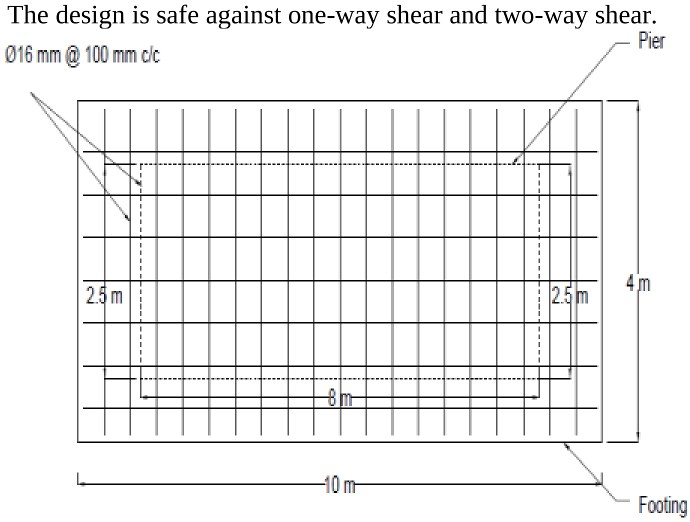

Fig. 14: Footing for Pier

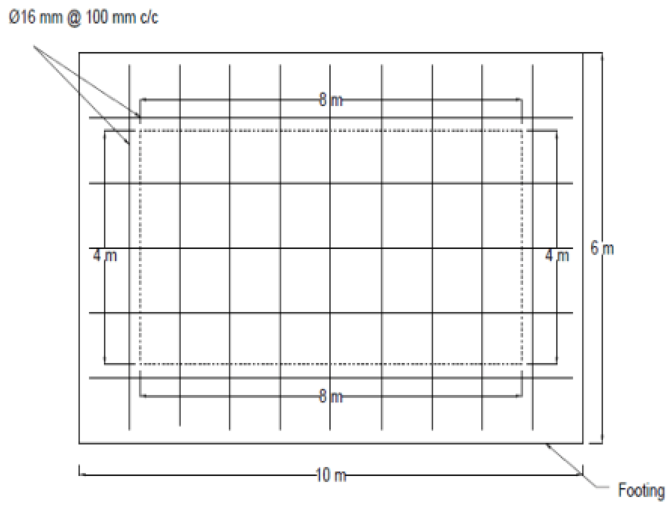

Fig. 15: Footing for Abutment

IV. RESULTS AND DISCUSSIONS

Post-tensioned Girder Bridge was analysed and designed for dead load, moving live load and the prestressing effects using the working stress method. Two cases were studied by varying the effective span of the main girders. First case was with an effective span of 30m and the second case was with an effective span of 45m. For the design of piers, abutments and foundation, the main governing criteria for finalizing the height was that the overall height of the bridge should be above the HFL.

A comparative study between the two cases considering bending moments (BM), shear forces (SF) and prestressing force (PSF) has been carried out to better understand the effect of variation of the effective span of girder. The girder forces are summarised in tables 2 and 3 below.

TABLE 2: ABSTRACT OF DESIGN BENDING MOMENT AND SHEAR FORCE IN MAIN GIRDERS (FOR EFFECTIVE SPAN 30M)

Bending Moment	**Dead Load B.M**	**Live Load B.M**	**Total Design B.M**	**Unit**
Outer Girder	4300.9	2073.7	6374.6	kNm
Inner Girder	4300.9	1596.0	5896.9	kNm
Shear Force	**Dead Load S.F**	**Live Load S.F**	**Total Design S.F**	**Unit**
Outer Girder	565.95	296.8	862.7	kN
Inner Girder	565.95	427.0	993.0	kN

TABLE 3: ABSTRACT OF DESIGN BENDING MOMENT AND SHEAR FORCE IN MAIN GIRDERS (FOR EFFECTIVE SPAN 45M)

Bending Moment	**Dead Load B.M**	**Live Load B.M**	**Total Design B.M**	**Unit**
Outer Girder	11043.1	3176.7	14219.8	kNm
Inner Girder	11043.1	2444.9	13488.0	kNm
Shear Force	**Dead Load S.F**	**Live Load S.F**	**Total Design S.F**	**Unit**
Outer Girder	993.075	303.1	1296.1	kN
Inner Girder	993.075	436.1	1429.2	kN

It was observed that the forces in the girders, both outer girders and inner girders, with effective span 45m are higher than that of 30m span. Subsequently the size of girders with effective span 45m also turned out to be much bigger than that of 30m span to resist these higher forces. A depth of 2700mm was needed for the girders with 45m span whereas depth of 1800mm was sufficient for the 30m span girders.

TABLE 4: ABSTRACT OF TOTAL USAGE OF MATERIALS- CONCRETE AND STEEL FOR THE BRIDGE

Material	**For Effective Span 30m**	**For Effective Span 45m**	**Unit**
Concrete	652.78	647.2	m^3
Steel	29521.3	31543.16	kg

It was observed that the amount of concrete required in both the cases came out to be nearly equal. This is because in the case of bridge with 45m girder span even though the girder size is large, there is reduction in the number of piers required and subsequently in the number of footings required to support the piers. The amount of steel required is more for the case of 45m girder span due to larger forces to be resisted. Furthermore, a total of 6 cables to achieve the prestressing effect were required for the girder with 45m span as against 5 cables in the case of 30m span girder.

V. CONCLUSIONS

The main aim of the study was to learn and understand the concept of analysis and design of post-tensioned concrete bridges. For this study, an existing bridge near Khangaon village on SH-54, Belagavi was identified. The bridge was designed for the traffic over the Ballari Nala. From the results and comparison, following points are concluded-

1. The forces in the girder with effective span 45m were higher than that of 30m span.
2. Subsequently the size of girder with effective span 45m also turned out to be much bigger than that of 30m span to resist these higher forces.
3. For the usage of material to consider the economy of the project, the amount of concrete required in both the cases came out to be nearly equal but the amount of steel required was more for the case of 45m girder span due to larger forces to be resisted.
4. Furthermore, a total of 6 cables were required to achieve the prestressing effect for the girder with 45m span as against 5 cables in the case of 30m span girder.

The heights of pier and abutment were finalised in order to avoid the submergence of the bridge (causing inconvenience to the traffic flow during high floods). The total pier and abutment height proposed was 4m, thus being 1m above the HFL against the present height of 2.2m. To finalize the height of piers and abutments, the governing criteria was that the overall height of the bridge was required to be above the HFL. With the datum being 588m and the HFL being 590.850m, a pier and abutment of height 4m is proposed (590.85–588 = 2.85m) with nearly 3m height below the HFL and 1m above the HFL, the top of the pier and abutment would be at 592m. This is the minimum height desirable from the point of view of both the safety as well as economy.

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