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Precast Pre-stressed Deck Slab Units

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Review Article

Abstract

The pre-stressed concrete technology was initially developed to make a concrete section of smaller size that can effectively resists the bending stresses developed due to heavy loads on them. Currently, it is being an application to make long-span bridges without any risk of failure. The prestressing technique is now used widely in the construction industry for making long-span bridges, large span slabs, Railway sleepers, precast pavements, etc. Generally, the prestressing is done in Girders (which resists the transverse moving loads) of a bridge, act as a beam for deck slab of abridge, but in recent practice, it is observed that the small block of slabs with ducts, which are further pre-stressed, can also be applied for resistance of the loads (or the bending stresses) effectively, which will further help us to reduce the number of girders and also it will lead to reducing the erection problems as they are precast units so it can be anchored easily and it will not affect the traffic flow along with the construction work.

Keywords: Prestress concrete, Bridge, Deck, Tendons, Economy, Ease-in Transportation, Erection.

1. Introduction

For the construction of medium- and long-span bridges, prestressed concrete serve as excellent constituent [1]. Since the early 1930s, when Freyssinet invented pre-stressed concrete, it has been widely used in the construction of long-span bridges, gradually replacing steel, which earlier required costly maintenance due to the inherent disadvantages of corrosion under severe weather conditions.

Solid slabs are utilised for spans of 10 to 20 metres, whereas T-beam slab decks are used for spans of 20 to 40 metres. For longer spans of 30 to 70 metres, single or multicell box girders are preferred and prestressed concrete is considered appropriate for long-span continuous bridges [1,2]. Prestressed concrete, which combines high-strength concrete and high-tensile steel, provides several advantages in bridge construction. The following are some of the most important advantages of using prestressed concrete in bridges:

(i) Apart from being cost-effective, high-strength concrete and high-tensile steel produce slim sections that are more aesthetically pleasing.

(ii) Prestressed concrete bridges can be designed as class 1 structures, which means they don't have any tensile stresses under service loads and are hence crack-free.

(iii) Prestressed concrete bridges require considerably little maintenance in comparison to steel bridges.

(iv) Precast prestressed girders support the cast in situ slab deck, making prestressed concrete perfect for composite bridge construction. This form of building is quite popular because it causes the least amount of traffic disturbance.

(v) Long-span continuous girder bridges with varied cross-sections use post-tensioned pre-stressed concrete extensively. Not only does it result in elegant structures, but it also saves money on the entire cost of construction.

(vi) In recent years, partially prestressed concrete (type-3 structure) has been favoured for bridge building because to the significant cost savings in the usage of expensive high-tensile steel in the girder.

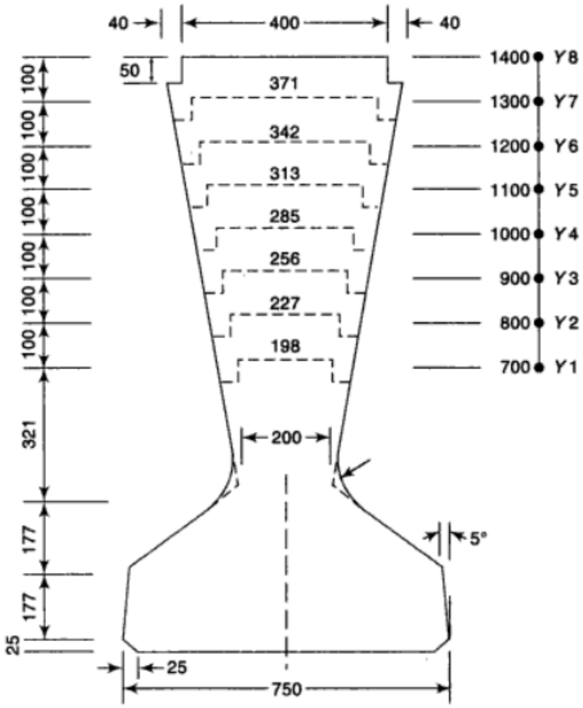

Fig.1 Cross-Section of Standard Y Beams (U.K.)

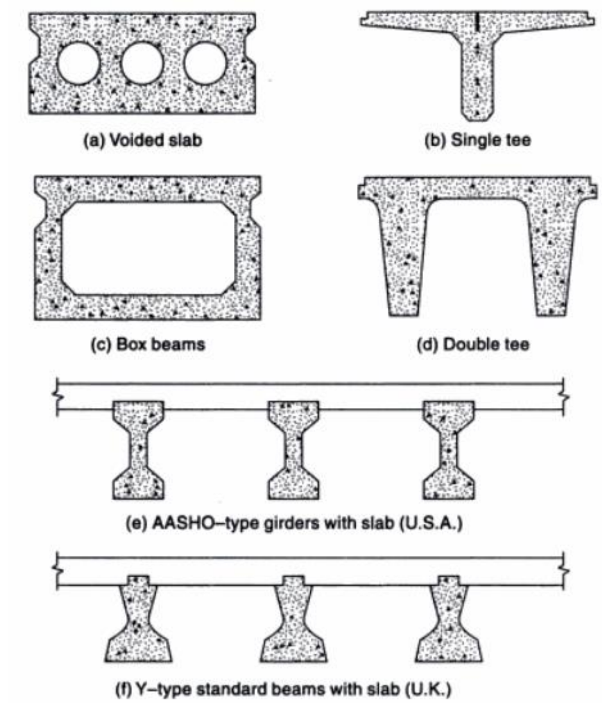

Fig. 2 Typical Cross-Sections of Pre-tensioned Prestressed

Table 1 Section Properties of Standard Y-beams [1]

Section	Depth (mm)	Area (mm^2)	Height of centroid above soffit Y_b (mm)	Section Modulus		Approximate Self-weight (kN/m)
				Top Fiber Z_t (mm^3x10^6)	Bottom Fiber Z_b (mm^3x10^6)	
Y-1	700	309202	255.24	24.85	43.40	7.42
Y-2	800	339882	298.68	35.02	58.78	8.14
Y-3	900	373444	347.12	47.88	76.27	8.95
Y-4	1000	409890	399.71	63.53	95.41	9.82
Y-5	1100	449220	455.72	82.06	116.02	10.78
Y-6	1200	491433	514.50	103.58	138.00	11.78
Y-7	1300	536530	575.54	128.15	161.31	12.86
Y-8	1400	584708	638.54	155.98	186.01	14.02

2. Literature Review

Studies are available to know the different methods of prestressing in components like I beam, Tee Beam, Post Tension slabs etc. In different manner like co-centric, eccentric (either straight, triangular or parabolic in shape) [1]. The group also analysed the type of losses in pre tensioning and post tensioning method [1].

In a Joint Highway Research Project, Purdue University and Indiana State highway commission [2], the precast post tensioned in longitudinal direction of bridge decks was studied applying 34" long and 24" wide slab having 6" thickness with key to join each block and 1" conduit for Tendons.

Sonparote & Syed [3], analysed Prestressed Precast Concrete Pavement and compared with conventional concrete road in which they observed that the precast prestressed road can resist more loads and can be erected easily and also maintain the quality of work. The parameters comparison is provided in Table 2.

Table 2 Comparison of design aspect of regular pavement and PPCP [3]

Parameter	Regular Concrete Pavement	Prestressed Precast Concrete Pavement
Grade of Concrete used	M40	M60
Modulus of Rigidity	45.16 kg/cm^2	55.31 kg/cm^2
Pavement Thickness	330 mm	210 mm
Prestressing Force (kN)	0.00	1352
Fatigue Life Consumption	0.4647	0.6574
Edge stress due to Temperature	18.26 kg/cm^2	23.04 kg/cm^2
Max. stress in the pavement	42.36 kg/cm^2	53.74 kg/cm^2

The authors [3] also reported a graphical relation between Pavement thicknesses and prestressing force as, for a lesser difference in thickness of pavement, that can provide higher prestressing forces.

El-Gharib [4], evaluated empirical deck design for automobile bridges. The steel reinforcement ratios and stress created in the reinforcing steel for the three different deck design methods were researched and compared in the study.

IRC: 5-1998 [5], Bridge, Culverts, Foot bridge, High level bridge, Channel, Clearance, Low water level, High flood level, Linear water way, Road width, Safety kerb, and other terms related to bridges are defined in this regulation.

IRC 18-2000 [6], the design aspects of prestressed concrete (Post tensioned) road bridges are covered by this regulation (Determinate structures only). These rules do not apply to members that are subjected to direct compression, such as piers.

IRC 21-2000 [7], code governs the use of ordinary cement concrete and reinforced cement concrete in road bridge structures and the other components of concrete used like aggregate, water, admixture. It also deals with Mix design used and shows the different required properties like Bond strength, anchorage, effect of loads etc.

*IRC 22-2000 [8], w*here practicable, this code will apply to composite construction of simply supported bridges; however, the requirements of this standard may be applied to other types of bridges with suitable amendments. Only when extra consideration must be given based on available information does this code apply to Box-girders.

IRC: SP 65-2005 [9], The unique design and construction requirements of precast and cast-in-situ prestressed concrete segmental superstructures of bridges are covered by these Guidelines. This will help us to find ease in erection work.

IRC: SP 71-2006 [10], standards apply to the unique design and construction requirements for precast pre-tensioned girders that may form part of a superstructure system, so that we can construct girders with precaution.

IS 1343-1980 [11] code governs the use of prestressed concrete in general structural applications. It includes both on-site work and the production of precast prestressed concrete modules; hence quality control has been checked.

IRC: 6-2000 [12], code provides the different types of loads and stresses applied in a bridge like Class AA loading, Class A loading and Class B Loading to understand the cases of load application on bridges.

IRS Concrete bridge code, 1997 [code 13], Code of Practice is applicable to the use of plain, reinforced, and prestressed concrete in the construction of railway bridges. It covers both in-situ and off-site precast unit construction. This code specifies the materials and craftsmanship required for the building of railway bridges, including concrete, reinforcing, and prestressing tendons.

Table No. 3 Load Combinations and Permissible stresses (CL.202.3) (Ref. IRC: 6-2000)

No.	G	Q	G_s	Q_{im}	F_{im}	V_c	W	F_{wc}	F_q or F_b &/or F_f			F_{ef}	G_b	F_{ep}	F_{te}	F_d	F_s	F_{er}	F_{eq}	F_{wp}	G_e	%	Remarks
	Dead Load	Live Load	Snow Load	Vehicle Impact	Impact Floating Bodies	Vehicle Collision Load	Wind	Water Current	Tractive	Breaking	Bearing Friction	Centrifugal Force	Buoyancy	Earth Pressure	Temperature	Deformation Effects	Secondary Effects	Erection Effects	Seismic	Wave Pressure	Grade Effect	Permissible Stresses	
I	1	1	*	1				1	1	1	1	1	1	1							1	100	Service condition
II A	1	1	*	1				1	1	1	1	1	1	1	1	1	1				1	115	
II B	1	(0.5)		(0.5)				1	(0.5)	(0.5)	(0.5)	(0.5)	1	1	(1)	1	1				1	115	
III A	1	1	*	1			1	1	1	1	1	1	1	1	1	1	1			1	1	133	
III B	1	(0.5)		(0.5)					(0.5)	(0.5)	(0.5)	(0.5)	1	1	(1)	1	1			1	1	133	
IV	1	1	*	1			1	1	1	1	1	1	1	1		1	1			1	1	133	
V	1					1																150	
VI	1	0.5		0.5				1	0.5	0.5	0.5	0.5	1	1	1	1	1		1	1	1	150	
VII	1	1	*	1	1		1	1	1	1	1	1	1	1	1	1	1				1	133	
VIII	1						1	1			1		1	1				1			1	133	Construction
IX	1							1			1		1	1				1	0.5		1	150	

Note:

1. * Where Snow Load is applicable, clause 224 shall be referred for combinations with Live Load.
2. Any load combination involving temperature, wind and/or earthquake acting independently or in combination, maximum permissible tensile stress in Prèstressed Concrete Members shall be limited to the value as per relevant code (IRC:18).
3. Live Load factors indicate the maximum value for the particular load combination. The structure must also be checked with no live load.
4. In load combinations with temperature where (0.5) has been adopted, it relates to the gradient effect due to temperature.
5. Seismic effect during erection stage is reduced to half in load combination IX when construction phase does not exceed 5 years.

Kumar [5], proposes a practical strategy for a major bridge with a span of 299 metres and 36 PSC and 8 RCC beams. The focus of this research is on PSC Beams, where post-tensioning parameters, rate of elongation, and behaviour may all be defined after stressing.

Ch., et al., [6], The IRC:112-2011 standard is used to analyse and design prestressed concrete bridges (deck slab, T-girder, and Box Girder). IRC:112 differs from prior codes in that it is based on limit state theory, whereas previous codes were based on working stress design philosophy.

Landge, et al. [7], used STAAD-Pro software and IRC provisions to analyse and design a longitudinal girder bridge by using I section girders. They show the different loading applied on bridge by using graphs.

AASTHO (LFRD) [17], this document explains the theory, technique, and application of highway bridge superstructure design and analysis for both steel and concrete. Loads and load factors are discussed in Chapter 3 of this book, including design criteria for common bridge loads, load factors for various LFRD load combinations, and more. Decks and deck systems are covered in Chapter 7, which includes subjects including traditional design methods, empirical design methods, deck overhang design, precast deck slabs, and bridge railings.

Rajai Al-Rousan [9], suggested use of prefabricated full depth precast bridge deck system which could be used for rehabilitation as well as for construction of new bridges with the help of high-performance concrete and post tensioned prestressing for economy & conventional use. This process will help us to save cost and time for construction and quality maintenance of slabs and parallel workings can be performed too. They show the experimental programs and used Non-linear Finite Element Analysis (NLFEA).

Huang et al. [10], presented a model updating approach which aims to assess the model, which is used in Chinese standards now a days and improving the numerical modelling accuracy for the long-term behaviour of box girder bridges with the calibrated data from another bridge which is currently serving. A three-dimensional finite element model is used for representation. To determine the realistic creep and shrinkage levels and pre-steress losses, Genetic algorithm optimization based on the response surface method is used.

Jiang et al [11], in the 70's, the study on steel and prestress concrete composite structures are started and during 1986, a prestress concrete grider bridge with corrugated steel webs have been emerged, which covers major topics of structural behaviours like Shear, torsional and flexural behaviour of bridge, Seismic and dynamic behaviour, shear buckling of corrugated steel webs etc.

In general practice, the composite beams are not checked for negative bending moments, but in their article *Saadatmanesh, et al.* [12] reported that they tested and experimentally checked the values of composite beam with negative bending moments, and the load was plotted against deflections, the strain in prestressing bars, concrete, & steel.

Parke, [13] in their manual a comprehensive overview of the basic principles which contains the concept, design, analysis, construction and maintenance of different types of bridges. Each chapter contains a different kind of topic like, Aesthetic and historic development of bridges, loads and load distribution, structural analysis, bridge dynamics, seismic response and design, Design of RCC bridge, sub structure, Design of PSC bridge, Design of steel bridge etc.

Barr, et al. [14], reported that as per AASTHO LRFD method, which predicts the avg. Prestress losses for highly stressed 2 span girder bridge is about 20% while as per NCHRP method the under predicted the avg. Losses by 16%. In this study, they used five prestressed concrete girders made by using high performance concrete, which was instrumented with vibrating wire strain gauges. They were monitored for three years and found about 28% loss of prestress of the total jacking stress.

Ca and Shahawy [55], chosen six existing prestressed concrete brides to compare and analyse different behaviour. They used the bridges of different span lengths, skew angles and number of lanes. Load distribution factors, stains and ratings were compared with AASHTO code provision and finite element analysis. The comparison reveals a significant difference between analytical and results due to effects of various field factors. Those factors affect the performance of bridges which cannot be easily quantified and they are defined as field factors. It was founded that field factors have large effect on maximum strain than on the load distribution factors.

Lee [26], As per this paper, the current AASHTO provisions gives thermal gradient across the depth of the cross section to predict the vertical thermal behaviour. This gradient is based on one directional heat flow and does not contain any provision for change of cross section, also not accounts thermal effects on sides of prestressed girders. To determine the vertical and transverse temperature gradient in PSC Girders, analytical and experimental studies were conducted on Prestressed BT-63 concrete girder segments. The analytical results are found to be good and used to determine temperature gradient in four standard PCI girder sections at selected cities of U.S.

Barr et al. [17], In this study, they monitored Precast PSC girder during fabrication and service provided the opportunity to observe temperature variation to evaluate the accuracy of calculated strains and cambers. For girders which are considered here, these effects combined to reduces the calculated prestressing stresses from designed values at release by 3 to 7% to reduce the initial camber by about 26 to 40% & to enhance bottom tension stress in service of about 12 to 27%.

Meier [18], considered utilization of different materials to make composite materials which enhances the quality of any material. This paper is based on the enhancement of bridge construction method by using those new fibrous materials like carbon fibre which are widely used now a day. As we know the fibre reinforcements are broadly used for their good bonding properties as well as for increasing the fatigue strength of concrete. This material can be used in future for bridge construction for fatigue resistance which is caused due to different loading and unloading.

Sirca Adeli [19], In this paper, a method is adopted for total cost optimization of precast, prestress I beam bridge system, by considering the cost of Deck Concrete, steel and formwork, prestressed I beams steel and prestressed concrete. This problem was formulated as a mixed integer discrete nonlinear programming problem and solved with the help of robust neural dynamics model of Park and Adeli.

Pakrashi, et al [20], This paper is basically focused on repair and monitoring of impact damaged prestressed bridge. The repair was carried out by using pre-load on the bridge in the vicinity of the damage to relieve some prestressing. After this, the preload is removed with further hardening and considerable strength gain of the repair material. Due to lack of benchmarking and inadequacy of assumed damage models, the true behaviour of damaged PSC bridge during repair is difficult to estimate theoretically. A network of strain gauges at various locations of observation has thus installed during the entire period of repair.

Jeon et al [21], considered the losses in prestressing as Friction, Elastic shortening, Slip, Anchorage loss, Shrinkage and Creep of concrete and Relaxation of steel, and analysed the problem of corrosion in steel strands which could result in loss of strength that are responsible for causing accidents too. As the pre stress wires are completely covered by grouting materials they can’t be inspected and can’t be rehabilitating easily. Also, as they are stressed too, so it is hard to work with them. In this document, the author reported the method for analysis of corrosion by using finite element method, prepared stress strain models and derived formulae. They are classified the corrosion in three types also.

3. Research Perspective

There is enormous information available to increase the speed of construction and reduce the congestion of traffic and quality confirmation problems, still there is further need to study the following

i. Study of the pre-tensioning in slabs to resist the bending and transfer the loads on girders.
ii. To study anchoring of the slabs with the girders.
iii. Conventional size of slabs from construction, transportation and erection point of view.

More focus is important for finding utilization prospectus to use precast prestress concrete long or short span slabs to serve as the deck of bridge by anchoring them with girders below?

Conclusion

The prestressing method is conventionally used now a day, even for the long span slabs of residential, commercial other public buildings. The prestressing method assures us to achieve the maximum bending stress on concrete by enhancing the tensile capacity, in which concrete is poor. The Reinforced Cement Concrete was proved to give more economical and compact sections, and we can provide more strength to concrete by doing prestressing. As the Traffic engineering technology is upgrading very early and bridges are proving solutions on level crossings and congested areas, this technology will help to make bridge construction to be easy, economical and less time taking.

Conflict of interest

The author declares no conflict of interest.

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