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Review on applicability of Box Girder for Balanced Cantilever Bridge

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Abstract - *This paper gives a brief introduction to the cantilever bridges and its evolution. Further in cantilever bridges it focuses on system and construction of balanced cantilever bridges. The superstructure forms the dynamic element as a load carrying capacity. As box girders are widely used in forming the superstructure of balanced cantilever bridges, its advantages are discussed and a detailed review is carried out.*

***Key Words*: Bridge, Balanced Cantilever, Superstructure, Box Girder, Pre-stressing**

1. INTRODUCTION

Bridges have always been associated with human civilization since ancient times. A bridge is an important element in a transportation system as its capacity governs the capacity of system, its failure or defective performance will result in serious disruption of traffic flow. It is therefore prudent to develop special attention in design to ensure adequate strength and durability with safety and cost. Significant traffic and congestion across urban areas creates demand for long span bridges. One of the critical considerations in the design of long span bridges is the structural adequacy and stability. Selection of most appropriate erection method is the key issue for the engineers. Planning, design and construction techniques should be revised and refined to satisfy several parameters including feasibility, ease of construction, safety and economy.

1.1 Overview

Initially naturally available materials such as stone and timber were extensively used for construction of bridges. From such ancient techniques man derived prototypes to form a structurally strong and stable structure. The efficiency and sophistication of design and construction kept pace with advances in science, material and technology. The earliest construction of permanent bridges started around 4000 B.C. Bridge construction received a spurt with the advent of reinforced and pre-stressed concrete. From 1928-1936 the development of pre-stressing system by Freyssinet gave further practical application in construction of bridges.

The next generation of bridges were made of steel and was first used in the Eads Bridge at St. Louis, Missouri, in 1874. Use of steel led to the development of cantilever bridges. The world's longest span cantilever bridge was built in 1917 at Quebec over St. Lawrence River with main span of 549 m. India can boast of one such long bridge, the Howrah bridge, over river Hooghly with main span of 457 m which is fourth largest of its kind.

Concrete cantilever construction was first introduced in Europe in early 1950's and it has since been broadly used in design and construction of several bridges. Unlike various bridges built in Germany using cast-in-situ method, cantilever construction in France took a different direction, emphasizing the use of precast segments. The various advantages of precast segments over cast-in-situ are:

i. Precast segment construction method is a faster method compared to cast-in-situ construction method.
ii. As precast segments are casted in yards they are protected from weather condition whereas cast-in-situ segment are exposed to detrimental weather condition.

Narmada Bridge at Zadeshwar is the first bridge in India to be built by balanced cantilever using precast segments. The structure spans of 96m with total length of 1347m.

1.2 Evolution of Pre-stressed concrete cantilever bridges

The cantilever construction method is a very ancient technique, in which a structure is built component by component above the ground level. Since ancient times, this method has been used for the construction of arches in Europe and in South America, and for the building of wooden bridges. In the 19th and early 20th centuries, this method was applied to the construction of arched metal bridges, such as the Gabarit and Viaur viaducts, or lattice girder designs, such as the Forth Bridge, the Bénodet Bridge or the old Pirmil Bridge at Nantes.

More recently, it has been used for the construction of cable-stayed bridges, such as the Saint-Nazaire Bridge over the River Loire and the Normandie Bridge over the Seine. As far as pre-stressed concrete is concerned, construction by the cantilever method mainly applies to bridges whose decks can be combined with straight or horizontally curving beams and which are built out from their piers, with cast-in-situ or prefabricated segments as in Fig 1. and Fig 2. respectively. This type of bridges is the focus of the study.

Fig -1: Cantilever construction of pre-stressed concrete box-girder bridge decks with cast-in-situ segments (Source: Design guide-Pre-stressed concrete cantilever bridges)

Fig -2: Cantilever construction of pre-stressed concrete box-girder bridge decks with pre-fabricated segments (Source: Design guide-Pre-stressed concrete cantilever bridges)

1.3 System of Balanced cantilever bridges

Precast segmental bridge construction was introduced in 1960. The new generation of bridges started replacing cast-in-situ segment by precast segment due to the accelerated construction while maintaining the quality of work. The precast construction process involves the segmental manufacturing of bridge components in precast yards or plants which are then transported to the construction site in order to be assembled. In pre-casting each segment is cast against the previous one so that the end face of one segment will be an imprint of the neighbour segment, ensuring a perfect fit at the erection. The two common assembly procedures for precast segmental bridge superstructures are the "incremental launching method" and the "balanced cantilever method". In the incremental launching method entire spans are constructed and then lifted into place or constructed in place on a temporary steel truss. In the balanced cantilever method, segments are installed one at a time on either side of the piers.

Balanced cantilever construction is achieved by erecting a segment on one side pier, then erecting one on the other side, then back to the original side so that moments about the pier due to the eccentric loads cancel out each other. After mid-span is reached a closure-pour connects the segments to a previous half-span cantilever from opposite pier. Immediately after the closure-pour cures the cantilever is post-tensioned to the already completed portion of the structure. The same erection process is repeated till the structure is completed. The various advantages offered by balanced cantilever method are:

i. In this method the bridge deck can be erected without any false-work or scaffolding from the ground level. Accordingly the erection is not affected by land condition (river, sea, valley, railway) surrounding the erection spot.
ii. It is suitable for a very wide range of spans (from 40 to 200 m, or even 300 m).
iii. The supported road can have any type of geometry, both horizontally and vertically.
iv. This method can be used regardless of the natural characteristics of the gap to be bridged (large depth, steep slopes, very poor-quality soils, coastal site, etc.).

1.4 Balanced cantilever construction method

The construction method consists of erecting the majority of a bridge deck without false-work or scaffolding at ground level, by working in consecutive sections known as segments, each of which is cantilevered out from the preceding segment. After a segment is built, the pre-stressing tendons fixed to the extremities are tensioned, firmly attaching them to the preceding segments and thus forming a self-supporting cantilever which serves as a support for the subsequent operations.

In this method, initially the piers are constructed and pier table is executed, the pier table is that part of span above the pier as in Fig 3.

Fig -3: Construction stage-I

(Source: Design guide of pre-stressed concrete bridge)

After the execution of pier and pier table, the traveller is installed on the pier table, the traveller is that component which takes the previously casted segment as a support and act as shuttering for the next segment to be casted as in Fig 4.

Fig -4: Construction stage –II

(Source: Design guide of pre-stressed concrete bridge)

The traveller is installed on both sides of the pier and segments are casted at a time / simultaneously on both sides, so that the cantilever span is to be executed and their respective weights get compensated as in Fig 5.

Fig -5: Construction stage –III

(Source: Design guide of pre-stressed concrete bridge)

Finally the scaffolding is used for execution of side span and two cantilever spans are attached at centre closure to complete the construction, and cantilever span are converted into continuous structure as in Fig 6.

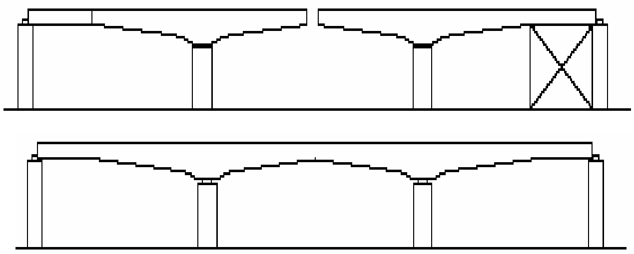

Fig -6: Stage IV-Completion stage

(Source: Design guide of pre-stressed concrete bridge)

1.5 Superstructure of Balanced cantilever bridges

Box girders are widely used in forming the superstructure cross-section of balanced cantilever bridges. Box girders, have gained wide acceptance in freeway and bridge systems due to their structural efficiency, better stability, serviceability, economy of construction and pleasing aesthetics. It can cover a range of spans from 25 m up to the largest non-suspended concrete decks built; of the order of 300 m. Single box girders may also carry decks up to 30 m wide. For the longer span beams, beyond about 50 m, they are practically the only feasible deck section. Below 30m precast beams or voided slab decks are more suitable while above 50m single cell box arrangement is usually more economic. The various advantages provided by box girders are as follows:

i. In recent years, single or multi-cell reinforced concrete box Girder Bridge have been proposed and widely used as economic aesthetic solution for the over crossings, under crossings, grade separation structures and viaducts found in modern highway system.
ii. The very large Torsional rigidity of the box girder‘s closed cellular section provides is more aesthetically pleasing than open-web type system.
iii. In case of long span bridges, large width of deck is available to accommodate pre-stressing cables at bottom flange level.
iv. Interiors of box girder bridges can be used to accommodate service such as gas pipes, water mains etc.
v. For large spans, bottom flange could be used as another deck accommodates traffic also.
vi. The maintenance of box girder is easier as interior space is directly accessible without use of scaffolding.
vii. Alternatively space is hermetically sealed and enclosed air may be dried to provide a non-corrosive atmosphere.
viii. It has high structural efficiency which minimizes the pre-stressing force required to resist a given bending moment, and its great torsional strength with the capacity this gives to re-centre eccentric live loads, minimizing the pre-stress required to carry them.

2. LITERATURE REVIEW

As box section girder is considered to be one of the suitable choices for superstructure of balanced cantilever bridges, a thorough review is carried out over the past. It's various advantages, disadvantages and its suitability is taken into account. Each and every facet should be considered for economical and safe structure. This chapter gives an overview of various studies carried out by different researchers and that are published in some of the international journals around the world. The overall goal of this chapter is to critically evaluate the different methodologies so as to identify the appropriate approach for our future work.

2.1 Review of Literature

In (2010) P.K Gupta, K.K Singh and A. Mishra carried a detailed study of box girder of different cross sections namely rectangular, trapezoidal and circular using finite element method. SAP2000 has been used to carry linear analysis of these box girders. To analyse the complex behaviour of different box girders three dimensional 4-noded shell elements have been employed for discretization of domain. The linear analysis has been carried out for dead load and live load Of Indian road congress of class 70R loading for zero eccentricity as well as maximum eccentricity at mid-span. The loads placed are in accordance with IRC: 6-2000 Standard specifications and Code of practice for

In (2013) Amit Saxena and Dr. Savita Maru carried out a comparative study of T-beam girder and Box girder superstructure. The goal of the study presented in this paper is to determine the most favourable option between T-beam and Box girder which is commonly used superstructure for balanced cantilever bridge. This study is on the basis of moment of resistance of section, shear capacity and cost effectiveness from both T-beam and Box girder. The study in this paper investigates two structural systems i.e. T-beam girder and box girder for span of 25m and detailed design analysis has been carried out with IRC loadings. The dead load calculation is done manually and for live load linear analysis is done on STAAD-PRO and then, comparison between dead load bending moment and live load bending moment is presented. Detailed cost analysis for two materials i.e. steel and concrete for both structural systems is also carried out and then the cost of superstructure is compared.

In (2014) Vishal U. Misal carried out a study on design and cost analysis on pre-stressed concrete girder. In this paper spans are subjected to IRC class AA, 70R loading to analyse the shear force and bending moment that will be induced at regular intervals along the beam. In this paper I-girder and Box girder are designed and analysed by classical old theory. These results are then analysed with the results obtained for the same by using the STAAD PRO software. The quantities of concrete and steel required for both the girder are analysed.

In (2014) Miss P.R. Bhivgade carried out a study on analysis and design of pre-stressed concrete box girder. In this paper at various span/depth ratios, the deflections and stress criteria are checked. In this study a two lane simply supported box girder made up of pre-stressed concrete which is subjected to moving loads is analysed as per Indian Road Congress (IRC:6) recommendations, Pre-stressed code (IS:1343) and also as per IRC: 18 specifications. The box girder is analysed using SAP 2014 bridge wizard and pre-stressed with parabolic tendons in which full sections is utilized. The bending moment, shear force and deflection results are calculated by considering different loading such as dead load, live load and superimposed load. The comparison of pre-stress force, deflection and stress values are obtained for various span/depth ratios. These values are calculated as per IS: 1343-1980.This paper gives the basic principles for proportioning of concrete box girder to help designer to start with the project.

In (2014) Chirag Garg and M.V.N Kumar analysed the several positions in a box girder where the pre-stressed tendons can be added. By keeping constant loading and varying the positions of tendons a comparative study has been done so as to understand the most effective positions of pre-stressed tendons. The author states several researches on box girder over the years like the development of curved beam theory by Saint Venant (1843) and thin walled beam theory by Vlasov (1965).

In this paper complete analysis of bridge section and the addition of pre-stressed tendons and loading is done on SAP2000 software. The stress tendons were added to bridge sections at various positions in different combination. Various combinations of these positions have been analysed so as to find the most effective combination. In this research tendons have been added in two parts each being over complete span of the deck section. A combination of three moving vehicle loads i.e. H 20-44 Truck load, HS 220-44 Truck load, H 20-44 Lane load in two lanes of bridge deck is considered in this study.

The conclusion of entire analysis was obtained by comparing the stress contours of the different cases. In the 1st case when tendons were added over the entire top span and the over-hanging part of the box girder, the displacement reduced considerably. In the 2nd case when the tendons were added at the bottom of the structure in addition to the top span the bridge becomes more stable compared to previous case. In 3rd case when tendons were added to the slant edges there was no considerable change in the stability of the bridge.

In (2015) Abd. El-Hakim Khalil investigated the behaviour of box beam girder under pure torsion. The author has described various methods for torsional strengthening of concrete box beams. In this paper box beam was strengthened experimentally with external pre-stressing technique using two different directions horizontally and vertically. Also a computing procedure is presented to predict torsional capacities of box beams under torsion and results are compared with the experimental one. In this study ten strengthened box beams using external pre-stressing technique with and without web opening were tested.

The study emphasizes pre-stressing direction and transverse opening dimension. The torsional capacities, failure modes, stress in external tendon and strain in internal reinforcement were studied in detail. The experimental results indicated that the contribution of external pre-stressing technique for horizontal and vertical direction to torsional capacity of box beam with and without opening is significant, with ratios ranging from 31% to 58% respectively. It was found that the presence of transverse opening decreases the torsional capacity compared to beam without opening. The result proposed and modified equation of Egyptian code and of box beam.

In (2015) Nila P Sasidharan carried the study of box girder curved in plan with rectangular cross-section. The finite element software ABAQUS is used to carryout analysis of these box girders. The analysis is carried out for the dead load, super imposed dead load and live load of IRC Class A loading. The paper presents a parametric study of curved box girders by varying span and radius of curvature and by keeping the span to depth ratio constant. The cross section adopted for the model is a single-cell rectangular type box girder having 7.5m width, 2-Lanes carriageway with overall deck width of 8.5m is considered. The thickness of top deck slab is 240mm at middle, 300mm at web and 200mm at ends. The thickness of both soffit slab and webs are 240mm. The overall Span lengths considered are 20m, 30m and 40m. Seven different radius of curvature such as 75m, 90m, 100m, 150m, 200m, 250m and 300m are considered. A span to depth ratio of 16 is adopted.

In (2014) Ms. Rubina Patil and Dr. R.S Talikoti performed a seismic analysis on balanced cantilever bridge considering time dependent properties. The author explains time required for constructing multi-span bridges are more in which the structure experiences continuous changes in the statically system due to support, loading and environmental conditions. In this paper the effect of time dependent properties on moment variation with time during construction and at various stages during the life span of the bridge is studied. The analysis is first carried out by conventional methods using Dischinger's equation, Kwak and son equation Trost and wolff equation and are then compared with the analysis carried out in SAP 2000 according to CEB-FIP code.

2.2 Abstract of Literature

i. For span up-to 30m (100ft) reinforced concrete girder require fewer man-hours than pre-stressed concrete as pre-stressed concrete girder require extra labours for fabrication, placing and anchoring cables. But for span above 30m pre-stressed girder provide the most economical choice. At span above 60m reinforced concrete girder becomes un-economical.

ii. Pre-stressed concrete girder whether continuous or simple requires much less steel than reinforced beam girder. Pre-stressed concrete girder is better over reinforced concrete girder if lower dead load is desirable however steel plate girder offers even lower dead load than pre-stressed concrete girder.

iii. Box girder shows better resistance to torsion of superstructure. The cost analysis carried out shows that box girder are costlier than I- girder but the losses are less than I- girder.

iv. As the depth increases the pre-stressing force decreases and the number of cables decreases.

v. The most effective position of the tendons in box girder to increase the stability of bridge superstructure as shown in the Fig 7. below. However adding tendons in the slant edges does not show any considerable change in the stability of the bridge but only adds weight of the bridge.

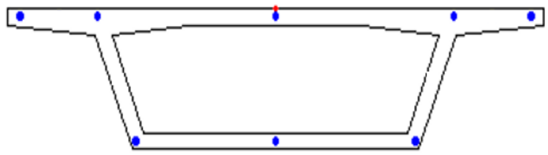

Fig -7: Most Effective Positions of Tendons in a Bridge Section
(Source: Chirag Garg 2014)

vi. The quantity of steel, dead load bending moments and shear force resistance for T-beam girder are lesser than the box girder, thus T-beam girder are more suitable than box girder for span up-to 25m span. Also T-beam girder has more capacity for moment of resistance than box girder. Thus, for 25m span, T-beam girder is more economical but if span is more than 25m, box girder is always suitable.

vii. Large differences are observed between the internal forces such as bending moment, shear forces and axial forces with and without considering construction stages. Thus, the analysis without construction stages cannot give reliable solutions.

viii. The depth of cross-sections and cross-sectional shape of girders have a significant impact on the development of deflection and stresses in different cross-sections.

ix. Strengthening of box beam using external pre-stressed technique improves ductility behaviour, torsional capacity transversely while for longitudinal strengthening it is not that effective.

x. The radius of curvature and the reactions like bending moment, shear stress are inversely proportional to each other. Hence, as radius of curvature increases the reactions are minimum.

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