Investigation of Post Tensioned Segmental Bridge by Limit State Method

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Abstract:

For development of industrial society and global economic expansion, the construction of long span bridges nowadays has rapidly increased. Besides, the construction methods have undergone refinement and they have been further developed to cover many special cases such as progressive construction of cantilever bridges, span-by-span construction of simply supported or continuous spans, balanced cantilever method etc. Currently, among these construction methods, the segmental construction of post-tensioned bridges has been recognized as one of the most efficient type for bridges. This method has great advantages over other kinds of construction, particularly in urban areas where temporary shoring would disrupt traffic and services below, in roadways and over waterways where falsework would not only be expensive but also a hazard. The use of precast segmental construction for concrete bridges has increased in recent years due to the demand for shorter construction periods and the desire for innovative designs that yield safe, economical and efficient structures.

In this explorative study, a span of 25 m of a post-tensioned segmental bridge has been designed using limit state method in correspondence to IRC: 112-2011, considering the ultimate limit state of strength and serviceability as specified in the code. At Chinchwad, Pune, a bridge is under construction which is designed by using working stress method. The aim of this study is to analyses and design a 25 m span of the same segmental bridge having a width of 8.4 m using limit state method i.e. IRC 112:2001. A two lanned road carrying live loads IRC Class 70R and IRC Class A as per IRC 6:2014 is designed. Internal type of prestressing system is adopted and precautionary provisions will be given for external prestressing as per SP-65. The minimum dimensions of the segments are in accordance with clause 9.3 of IRC: 18-2000 and the final dimensions are according to the parameters of design. The prestressing losses are also considered as specified by IRC 112:2011. The manual structural analysis is compared by taking aid of midas-civil, a software for analysis and design of post tensioned bridges.

Keywords: **Post tensioned segmental bridge, limit state method, working state method, prestressing losses, midas civil software.**

I. INTRODUTION

Segmental construction is a method of progressive construction of segments, stitching them to the segments already placed, by prestressing. In accordance with the development of industrial society and global economic expansion, the construction of long span bridges has increased. Moreover, the construction methods have undergone refinement, and they have been further developed to cover many special cases, such as progressive construction of cantilever bridges, span-by-span construction of simply supported or continuous spans, balanced cantilever method etc. Currently, among these construction methods, the construction of post tensioned segmental bridges has been recognized as one of the most efficient type of bridges without the need for extensive false work. This method has great advantages over other kinds of construction, particularly in urban areas where temporary shoring would disrupt traffic and the services below, in roadways and over waterways where falsework would not only be expensive but also a hazard. The use of precast segmental construction for concrete bridges has increased in recent years due to the demand for shorter construction periods and the desire for innovative designs that yield safe, economical and efficient structures.

1.1 OBJECTIVE

- The aim of the dissertation is to analyze and design a span of a post tensioned segmental bridge using limit state method.
- Confirming to IRC: 112-2011.
- Also compare with working stress method.
- Compare the design of span of segmental bridge by limit state method confirming to IRC: 112-2011 with the midas-civil software.
- To compare the results.

II. LITERATURE REVIEW

Michele Fabio Granata and Antonino Recupero stated that in current engineering practice, safety checks on serviceability and determinations of ultimate limit states of segmental bridges are generally performed, either considering separately the contributions of axial force, bending moment, and shear force or considering the interaction effects through approximate expressions recommended by building codes. During construction stages and service life, the interaction between internal forces can be of fundamental importance in establishing the actual degree of structural safety and, for this reason, a different philosophy for performing checks in segmental bridges is proposed, plotting N-M and M-V interaction domains for cracking, construction stages, and serviceability as well as M-V interaction domains for ultimate limit states. Delayed deformations as a result of creep are considered, as are bonded and unbounded prestressing. A model is developed for plotting M-V domains at the ultimate limit state, underlining the strength reduction that occurs in concrete sections with external prestressing versus beams with full internal prestressing. A numerical application on an actual segmental bridge built by cantilevering was performed to show the proposed methodology, based entirely on strength domains, for safety checks. The load and stress paths in the construction stages are highlighted by considering the effects of creep in concrete, whereas bending-shear interaction is evaluated in the two cases of fully bonded prestressing and partially unbounded prestressing. The results show that safety checks which are performed based on approximate assumptions and expressions that do not explicity.

Prof. Dr. Ing. G. Rombach studied the segmental box girder bridges and stated that externally post tensioned are one of the major new developments in bridge engineering in the last years. In contrast to classical monolithic construction a segmental bridge consists of small precast elements stressed together by external cables. The many advantages of this type of structure like fast and versatile construction, no disruption at ground level, high controlled quality and cost savings have made them the preferred solution for many long-elevated highways and bridges. Emphasis is given on the design of joints. As in AASHTO specifications the joint is designed considering the effect of shear key only. In German codes, only frictional forces are considered. The load bearing of the shear key is neglected as only epoxy joints can be used. But the author has included both dry and glued joints. After conduction nonlinear finite element analysis, a new equation is formed by the author.

M. A. Algorafi, A. A. A. Ali, I. Othman, M. S. Jaafar and R. A. Almansob stated that externally prestressed segmental concrete beams are generally used in the construction of bridge structures. In external prestressing technique, the cables are placed completely outside the concrete section and attached to the concrete at anchorages and deviators only. Segmental bridge is a bridge built in short sections. Segmental bridge applies smart technique that is a part of an engineering management. Externally prestressed segmental bridges are affected by combined stresses i.e. bending, shear, normal, and torsion stresses especially at the segments interface joints. Previous studies on these bridges did not include the effect of torsion in the load carrying capacity and other structural behavior. This study included an experimental investigation of the structural behavior of an externally prestressed bridge under combined bending, shear, normal, and torsion stresses. The aim of this study was to improve the existing equation to include the effect of torsion in estimating the failure load of externally prestressed bridge. A parametric study was carried out to investigate the effect of different external cable layouts and different levels of torsion. The expressions that best predicts the load carrying capacity of these bridges were theoretically mentioned by Turmo (2005) and Aparicio (2002) which was recommended by the AASHTO [2].

Aimin Yuan, Hangs Dai, Dasong Sun and Junjun Cai stated that precast segmental prestressed concrete box beam bridges have become the preferred construction method for many elevated highway projects in recent years. These beams, which have internal and external cables, are increasingly popular because the internal cables can improve the ductility of the beam and the external cables are convenient for maintenance. This study experimentally investigates the behaviors of segmental concrete box beams with hybrid cables. Three scaled specimens with different ratios of the number of internal cables to the number of external cables were tested in detail. The experimental results showed that the ratio had a significant effect on the load carrying capacity, ductility and failure mode of the beams. The opening of gaps between the segments could not be avoided, and the joint nearest to the applied load was determined to be the critical joint. The assumption that a plane section remains plane under bending was suitable for a crack joint produced by the load. The stress increment rule of the external cables and internal cables, as well as the variation of the plain bar strain, were determined [1].

Olivier Burdet and Marc Badaux presented an analytical comparison of the amount of prestressing required of two similar bridges, one with internal and other with external prestressing. This comparison shows that bridges with external prestressing can become economically competitive for large girder depths. The Detrimental effect of the smaller stress in the prestressing steel at the ultimate limit state is more than compensated by the thinner webs made possible by the absence of ducts. External prestressing perhaps has advantages over internally prestressing structures but it is a misconception that switching from internal to external prestressing will reduce the amount of reinforcement and the overall cost. The main parameters considered in this study were span and depth on which the comparison is based upon. It is inferred that generally up to a span of 40 m internal prestressing proves economical and effective, but above 60 m external prestressing proves advantageous considering economy and effectiveness. Depth considered as one of the main parameter for design is same for almost both the prestressing types. But an important change is in the cable layout i.e. for external the profile is trapezoidal and for internal the profile is parabolic.

Chirag Garg and M. V. N. Siva Kumar performed various studies so as to develop a more stable structural design by varying the shape of the bridge structure. Their aim was to understand the effects of changing the basic shape, on the stability of the bridge. By varying the thickness of the joints and the length of the overhang, the variation in the stability of the bridge structure is studied. SAP 2000 software was been used to apply moving loads and the deflections are studied by plotting stress contours. The shape of the box of a modified box girder bridge has some peculiar features like the increased thickness at the fixed end of the cantilever beam, increased thickness at the bottom most portion of the box structure and sloping edges. Longer the cantilever, thicker is the entire section from free end to fixed end. This provides more thickness at the fixed portions and also helps reduce the stress acting on the entire span of the beam. The benefit of this is, the bending moment acting at the fixed end is reduced and the beam becomes more stable. The bottom flange thickness proves to be useful because the stress transferred through the sloping edges from the bridge deck to the bottom of the box is easily distributed.

P. R. Bhivgade proposed that the box girder shows better resistance to torsion. Analysis for different *l/d* ratios of the superstructure was carried out for the box girder bridge. Deflection and stress criterions were satisfied well within the permissible limits. As the depth increases, the prestressing force decreases and the number of cables reduces. Because of prestressing, more strength of concrete is utilized, which well governs the serviceability criterion.

Hardik R. Trivedi stated that by using segmental box type superstructure aesthetics with economy can be achieved as curtailing of prestressing cables becomes possible. Many times, it is the only option left for construction of bridge in difficult climate regions and construction of flyovers without disturbing traffic. Analysis and design of cantilever segmental bridges are more complicated and is always a challenging task. Hence an attempt was made to accommodate procedure for three-dimensional analysis and design of the same, with an illustrative example. The objective was to spread knowledge of the atomization of the design of prestressed segmental box type superstructure. Efforts made in this study to enhance the understanding of how to make the design process easy by providing atomization with the use of the programming languages and by interlinking the same manually.

III. RESEARCH METHODOLOGY

1. To study the design parameters, specifications and conditions in which the design is to be carried out, by Pimpri Chinchwad Municipal Corporation.
2. The bridge comprises in 3 parts viz. a portion on the Pawana River, over bridge on railway and a flyover over on National Highway 4. In this dissertation, the span for which design is carried out is a part of the flyover on National Highway 4.
3. In this study, considering the functional and structural aspect as per Indian standards a superstructure span of 25 m has been designed.
4. The bridge has a two lanned carriage way.
5. The width of the segment is 8.4 m.
6. The internal type of prestressing is to be used and provisions are made for external prestressing as a safety measure for further strengthening of the bridge throughout its life. The material used for the deviators for the external prestressing is concrete.
7. The loading is as per the IRC 6:2014, IRC class 70R and IRC class A.
8. The cables used for prestressing are standard steel cables having 19 strands of 12.7 mm diameter each.
9. Finally, the bridge is being designed for the ultimate limit state and serviceability limit state and is checked for the ultimate strength considering bending and shear. The design procedure adopted is as follows: [18]

A. Loads: The following are the loads, whose effects are analyzed to estimate the prestressing force, moments, shear etc. at all critical sections in the structure. The structure is designed for these load combinations to decide the section size, reinforcements, prestress etc. so as to resist these forces for the specified strength and serviceability criterions.

   a. Dead load of the structure
   b. Live loads on the structure
   c. Wind load
   d. Impact load
   e. Longitudinal force

B. Dead Load: It includes the self-weight of the structure along with the super imposed dead loads which includes the weight of the noise or crash barrier, kerbs, footpath etc.

C. Live load: The following classes of live loads are to be considered for the design as per IRC 6:2014:

   a. IRC Class 70R loading: This loading is to be normally adopted on all roads on which permanent bridges and culverts are constructed. Bridges designed for Class 70 R loading should be checked for Class A loading also, as under certain conditions heavier stresses may occur under Class A loading.

   b. IRC Class A loading: This loading is to be normally adopted on all roads on which permanent bridges and culverts are constructed.

D. Live load and Dead load moments: The working and design moments are to be worked out according to the calculated loads and stresses. These moments are to be considered for the further calculations.

E. Equivalent moment and shear due to torsion: 20% increase in moments is considered as compensation for the effect of torsion which generally varies designer to designer.
F. Prestressed cables are to be designed including the losses due to prestress.
G. Stresses are to be calculated in concrete and steel at critical locations of the segment and at their respective centre of gravity and checked with permissible limits.
H. Structural strength criterion, for all combinations, is to be checked as per IRC 6:2014.
I. Ultimate strength analysis: The design moments and moment carrying capacity of the members have been checked for the crushing of concrete and yielding of steel criterions, for all combinations as per IRC 6:2014.
J. All Stresses have been checked for satisfying the permissible limits as per the serviceability criterion prescribed by IRC 6:2014.
K. Transverse analysis is to be performed and reinforcement is provided according to the steel required and ductile detailing clause as mentioned in IRC 112:2011.

IV. SCOPE FOR FUTURE WORK

1. The moments in the longitudinal and transverse directions are considered separately in conventional design procedures. But they also have a combined impact on the structure which can be considered for design.
2. The construction stage analysis can be done, which includes the consideration for cable by cable prestressing. This will give an exact behavior of the structure corresponding to deflections, considering long term effects of creep and shrinkage of concrete, which is approximated in the conventional design.
3. The segment dimensions can be reduced and an economical segment can be redesigned according to the limit state method as per IRC 112:2011.

V. PROBLEM FORMULATION AND METHODOLOGY

Up to 2005, there were no special guidelines, in India, for the design of segmental bridges, as it was designed using IRC 18 and IRC 21 published in 2000 which covers the design aspects for prestressed concrete post tensioned girder bridges. In 2005, a special publication SP 65 was published viz. Guidelines for design and construction of segmental bridges, which then became the base for segmental bridge construction and design using working stress method. The guidelines cover the specified design and construction requirements of precast and cast-in situ prestressed concrete segmental superstructures of bridges In 2010, at the 192nd IRC meeting at Nagpur, IRC 112 was drafted and was published in 2011 which consists the limit state design of post tensioned segmental bridges. The objective of this code is to establish a common procedure for design and construction of road bridges in India based on the limit state method. This code serves as a guide to both designers and construction engineers, but compliance with the provisions therein does not relieve them, in any way, of the responsibility for stability, soundness, durability and safety of the structures designed and constructed by them. This code consists of the basis of design of concrete road bridges with respect to limit state method. Also it contains the conditions for ultimate limit state of strength and serviceability along with the design detailing of bridges. Recently, in 2013, guide lines has been passed by the Indian Road Congress that from 2015 all post tensioned segmental bridges are to be designed using limit state method only and hence the working stress method for post-tensioned segmental bridges are being obsolete.

VI. CONCLUSION

1. The dominant criterions of limit state method are the ultimate limit state and the serviceability limit state as described in IRC 112:2011. The analysis results show that both these criterions are satisfied.
2. The values of ultimate moment and shear force confirms that by designing the same span by limit state method as per IRC 112:2011, the moments and shear forces are on the lower side as compared to working stress method.

3. The revised design of the segment shows that by using limit state method for the design of segmental bridges, the segment dimensions are reduced and an economical segment is designed.
4. The new load combination criterions, as specified in limit state method i.e. IRC 6:2014 are more appropriate and practically suitable as compared with working stress method of segmental bridges.
5. The prestressing force counteracting the stresses, in limit state method, is less and hence a smaller number of cables are required, making the section economical.
6. The analysis results by manual calculations and midas-civil software are approximately parallel. This proves that the software can be used for the analysis and design of segmental bridges.

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