International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 06 | June 2020 www.irjet.net p-ISSN: 2395-0072

Performance Analysis of Geometrical Irregularities of Integral Type Bridge: State of Art

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Abstract - *Bridges are very important structures considering the connectivity of road network. The high initial cost, seismic/wind vulnerability and maintenance play a major role in any bridge. Integral Type Bridge overcomes this by eliminating expansion joint and hence bearing too. As the structure act as a single unit there is no moisture seepage which deteriorates the materials. This bridge is proposed to provide robust configuration against earthquake shaking and increase the durability due to exclusion of joints and bearings. The portal frame disperses the loads more evenly and the resulting sections can be more economical and aesthetic. The insight is provided into the behaviour of these bridges.*

Key Words: **Integral Bridge, Temperature effect, Construction Stage, Bearings, Displacements, Soil structure interaction**

1. INTRODUCTION

The infrastructure has been on the rise in last few years that have resulted in construction of more bridges to increase the network. A bridge is a structure that permits us to cross over an obstacle. Bridges are very important special type of structures. With the increase of vehicles and freight, more road connectivity is required. Bridge is a key element structure corresponding to the heaviest responsibility in carrying a free flow of transport. They are a necessity in the congested areas to overcome the demand arisen from transportation. There are different types of bridges each serves a specific purpose and selected at different situations.

1.1 Bridges and their feasibility

Beam bridges are the common type of bridge. Normally they consist of one or more spans, supported by abutment or pier at each end. Beam bridges are usually constructed of RCC, steel, or composites. The concrete elements used in beam bridges may be RCC or PSC.

T-beam, used in bridge construction, is a load-bearing structure, with a T-shaped cross section. The top of the T-shaped cross section serves as a flange or compression member that carries compressive loads. The web of the beam below the compression flange serves to resist shear stress and to provide greater separation for the coupled forces of bending. The uses of box girder in elevated highway construction have several advantages. The highway may be curved in plan, resulting in torsion even when the loading is symmetrical, and the supports may not be disposed in best way to resist torsion. The torsional strength inherent in the closed box section, with its ability to distribute resisting moments and shears across the width of bridge is quite impressive. Along with these advantages, the box shape girder is an aesthetically pleasing structure. The design complication of warping, distortion and shear lag still occurs. Intermediate diaphragms are used to limit distortion of the box.

In suspension bridge, the deck slab is suspended using high tensile strength steel cables. The roadway hangs from these massive steel cables, which are draped over two towers and secured by anchors on both ends of the bridge. The anchors are made from solid concrete blocks. The cables transfer the loads into compression in the two towers. Cable-stayed bridges are similar to suspension bridges as they also use cables but in different form. They have fewer cables and the height of the towers is much greater than suspension bridge. An Extradosed Bridge implies in between an intermediate zone of Cable Stayed Bridge and Girder Bridge. Extradosed bridges have two different structural systems, the cable suspension system and stiff deck bending system. It is desired that the cables should have much tensile force which will give a higher compressive force in girder. Extradosed Bridge usually rely their load on only 20%-50% to cable, and remaining portion is covered by the girder as it is more stiff than the stiffening girder in a cable stayed Bridge.

1.2 Integral Bridge

An Integral Bridge (IB) is a structure where there are no bearings over the abutments and no expansion joints in the superstructure. Integral bridges are characterized by monolithic connection between the superstructure and the substructure (piers and abutments), unlike the traditional bridge construction, where the superstructure is supported on bearings and transfers all the forces to substructure and foundation through bearings. Provision of expansion joints and bearings in traditional bridges allows movement and rotation of the bridge deck, without transferring any force to abutment or pier and foundation due to thermal, creep, shrinkage induced movements. In case of lntegral Bridges, the deck carries the movement of deck to the abutment as well as to the backfill soil behind the abutment; the approach slab between the bridge end and the pavements accommodate the necessary movements.

Apart from the fully integral solutions without expansion joints or bearings, it is also possible to have structural solution, where only the expansion joints at abutments are omitted, but the bearings are provided. The back-wall portion of the substructure is directly connected with the superstructure in such case and the superstructure, back-wall and approach slab moves together 'towards' and 'away' from the backfill during the thermal expansion and contraction. Such solutions, known as 'Semi integral Bridges' are often appropriate particularly for the rehabilitation of bridges. The thermally induced cyclic movement at each abutment is restricted to + 20 mm in case of Integral bridges as per the British Advisory Notes.

2. LITERATURE REVIEW

It is unavoidable that these bridges are subjected to daily, seasonal and yearly repeated cycles of heating and cooling induced by solar radiations and surrounding atmosphere. Integral bridges are defined as bridges with monolithic joints between the substructure and superstructure. They can be visualised as single or multi-span portal frames. The increase and decrease temperatures in structural components may lead to nonlinear thermal loads that influence the behaviour of integral bridges significantly. In reality, the temperature variation affects the integral bridge structure in a complex manner. In view of the global response, uniform temperature changes cause massive expansion and contraction in bridge components.

2.1 Complexity in analysis

A complex geometry creates problems in the design of integral bridges. Irregular structures, sharply skewed structures and structures with sharp curvatures (that is, where there are abrupt or unusual changes in the mass, stiffness or geometry along the span) should be avoided.

For an integral structure, it is preferable that the spans are symmetrically placed and the adjacent pier stiffness does not differ substantially (say by more than 25 percent). Though curvature and skew can be accommodated, it would be desirable to avoid large skew (say. more than 30°) and high degree of curvature (Say R<100 m).

Bridges with tall piers are ideally suitable for integral bridges. The frame action greatly helps to reduce the lateral loads being transferred to the foundation. Preferably, abutment heights on either side shall be the same. A difference in abutment height will cause unbalanced lateral loads resulting in side sway, which should be considered in the design by balancing the earth pressure that is consistent with the direction of sway, at the abutments. This procedure is a complex, iterative process and should be avoided.

2.2 Literature Review

(Mairéad Ní Choine, 2015) Et al. developed fragility curves for two types of bridges one is integral and second is jointed bridge to draw comparisons between two design options. A same approach was used to model integral bridge with the exception that for the integral case, the abutment springs are connected directly to the deck and the column bents are connected directly to the deck with help of rigid links.

It was concluded that the integral bridges were stiffer than the jointed bridges. The PGA corresponding to a 2% probability of exceedance in 50 years is found to be 0.97 g. It can be seen that the jointed bridge is significantly more vulnerable due to seismic damage than the integral bridge. The chance of exceeding moderate damage of the joint bridge is 60% more than that of the integral bridge exceeding moderate damage. Component fragility analysis shows that the columns dominate the integral type bridge system fragility with the elastomeric bearings dominating the jointed bridge fragility.

(Justin Vander Werff & Sritharan, 2015) Et al. studies four test models of large-scale bridge and compares the results with grillage model. One test unit modelled a bridge with a four-girder pre-stressed concrete super structure using precast bulb-tee girders. The next two test units were based on bridges with four steel girders. A five-girder pre stressed concrete super structure including an inverted-tee bent cap test unit investigated by CALTRANS. Current seismic design practice allows little or no lateral seismic load to be distributed beyond the girders immediately adjacent to the column in integral bridge girder-to-cap beam connections. The, increased girder depth, unnecessarily high seismic mass, and increased construction cost due to current practice which leads to excessive girder-to-cap connection reinforcement.

It is observed that load distributions from large-scale test the girders that are not adjacent to the column also resist a significant amount of the column moment. Over estimation of the seismic load to the girders adjacent to the column by as much as 60%.

(HENG, 2018) presents an advanced bridge type with semi-continuous post-tension pre-stressing box girder, and introduces the design principles, construction procedures, and actual applications of the bridge type in Africa highway projects.

Before structural system transformation (construction stage 1 to stage 2), the bridge acts like a simple supported bridge to carry the dead load of girders. After structural system transformation (construction stage 4 to stage 6), the bridge acts like a continuous bridge to carry the loads of wearing course and attachments. Because the girders and wet joints are casted at different time, time-dependent parameters such as shrink, creep has great influence to the final inner force of the girders. The inner force of every construction stage should be added up to get the final inner force at completion stage, he found the final inner force at completion stage which was more balanced than the traditional continuous bridges.

(Sreya Dhar, June 2019) Et al. reviewed past studies on seismic behaviour of IAB's performance incorporating soil structure interaction. The abutment-backfill & soil-pile interactions were taken under consideration. The most common used piles were steel H pile, sleeved pile (steel pipe), and precast pile. They found that the variation of backfill pressure is a function of abutment displacements. The top of the abutment undergoes 'ratcheting effect'. To prevent this and the gap between abutment-backfill ground improvement techniques must be employed.

During contraction, the forces are transmitted into the backfill through abutment, adequate passive pressure resistance (shear strength of soil) is required to avoid translation and rotation of abutment. Stub abutments are recommended to eliminate the possibility of flexure failure of an abutment. They have a single row of piles, which permits abutment to move in a longitudinal direction under temperature effects.

(Brooke H. Quinn & and Scott A. Civjan, April 2016) Et al. reports results of pile orientation on single span IAB's. Two pile orientations were considered: pile web parallel with abutment centreline (weak-axis orientation) and pile web perpendicular to abutment centreline (strong-axis orientation). Pile orientation was found to have little effect on longitudinal bridge displacements. Pile orientation did effect transverse displacements. The resulting pile moment was dependent on the pile stiffness. For straight bridges, it was found that a strong-axis pile orientation resulted in a lower percentage of yield moment in the pile, although the weak-axis orientation resulted in a lower value of moment, and piles would not be expected to yield for either orientation. The latter may be preferable to minimize force transfer into the abutment and avoid the potential for concrete cracking. When skew was introduced, the critical moments were about the weak axis of the pile, even when piles were oriented about the strong axis. Significant transverse moments in the piles were introduced as a result of transverse displacements caused by plan rotation of the bridge. Therefore, the weak axis pile orientation would be more beneficial.

(Dunja Peric´, 2016) Et al. studies that the loose sand adjacent to the abutments maximizes the maximum bending moment in piles, while minimizing the maximum negative composite bending moment of the superstructure and the maximum compressive stress in the girders, for any given temperature increase and the contrary is also true. All maximum bending moments and maximum compressive stresses are further magnified by the larger temperature increases.

In summary, integral bridges experience a complex interaction with the surrounding soil. The compaction levels of the soil adjacent to the abutment and bridge temperature increases have significant effects on the internal forces in the substructure and superstructure. In particular, the presence of loose sand behind the abutments shifts critical locations from the bridge superstructure to the substructure and vice versa.

(Scott A. Civjan, Bonczar, Breña, DeJong, & Crovo, January 2007) Et al. did parametric study. A three-span bridge in Orange-Wendell, Mass. was used for a parametric study to investigate the effect of variables encountered in IAB design. The instrumentation of bridge was done to measure behaviour of bridge under different loading and temperature variation. Four-year data were collected. Bridge expansion was affected by backfill conditions, whereas contraction is influenced by pile restraint conditions. With denser backfill pile moments are minimized and lower pile restraint were provided. In bridge contraction, decrease in abutment rotation, and decrease in pile moment was seen due to lower pile restraint. During bridge expansion, denser backfill properties result in greater abutment rotation, decreased pile moment, and greater soil pressure behind the abutments.

3. CONCLUSIONS

The integral bridge behaves continuous between supports offering better riding quality and appearance. The skewed bridges would give reduced effective length and hence reduction in longitudinal force moments. However, the transverse forces and moments increase with increase in skew. At higher angles, the skewed bridges would develop moment couples and hence torsion would be produced. So, it is inadvisable to design skew angle more than 60°. Negative moment at span should be accounted for in design. So detailing of the reinforcement should be done according to the demand at the joint. This happens due to girders being continuous in integral bridges. Therefore they have critical support moments which can be tend to by providing joint reinforcement. At the support, negative bending moment is observed in integral bridge only due to live load and super imposed dead load; no negative bending moment was occurring due to dead load. The effect is the result of construction stage analysis. The sequence placement of girder on temporary supports and their accommodation of deflection caused by self-weight. The expansion and contraction experienced by the bridge because of temperature effects must be checked, as it can be governing factor in some cases of limiting spans. Maintenance cost of simply supported bridge is much high because bearing needs replacement at least twice or thrice during the design life depending upon surrounding environment conditions.

Recommendations are given to retrofit the existing multi-span bridges from free to restrained joint. This type of integral conversion practice started with Wisconsin and Massachusetts in the previous years.

Parametric study can be carried out with different deck systems like voided slabs, single cell or multi-cell box girders or curved alignment can be taken up for study.

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