A Review On Seismic Performance Analysis Of Integral Bridges

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Abstract : Integral bridges, also known as Integral abutment bridges or joint-less bridge or rigid frame bridges or portal bridges, are those in which the superstructure and substructure are monolithically connected, having no expansion joint and bearings. Integral bridges are advantageous due to reduced maintenance costs, enhanced structural capacity during earthquakes comparing to jointed bridges with bearings and expansion joints, lesser corrosion and material degradation at the expansion joints, riding comfort, improved durability etc. The continuity between the superstructure and substructure increases the redundancy which can allow the formation of local mechanisms at selected locations in which design detailing can be provided for large inelastic ductile deformations. Integral abutment bridges (IAB) are now becoming very popular due to various advantages over their service life. Various factors affecting the total length of the integral bridge includes the capacity of pile, type of soil and movement of abutment due to thermal stresses and earthquake load and other factors. Backfill soil properties influence the integral bridges behavior significantly. The contribution of abutments of bridge in the natural vibration behavior of integral abutment bridge is also observed to be significant. This paper aim towards the review of study of seismic performance analysis of integral bridges conducted by various authors in past. This study provides an understanding of seismic behavior and significance of soil structure interaction in integral bridges and comparison between integral and conventional bridges.

***IndexTerms* – Integral Bridge, expansion joint, soil-structure interaction**

I. INTRODUCTION

Integral bridges are gaining popularity as an alternative to jointed bridges over past decades. Conventional bridges (i.e Jointed Bridges) are designed with expansion joints and bearings. Leaking of expansion joints and seals is the most frequent problem of jointed bridges. Such bridges need to be checked and repaired at more regular intervals in comparison to integral bridges. Moreover, bearings are also troublesome, as steel bearings seizes up with time which is attributed to corrosion and elastomeric bearings getting ruptured due to large unexpected or sudden movements. Such types of problems are eliminated in integral bridges since there are no expansion joints and bearings.

II. FORMS OF INTEGRAL BRIDGES

Depending upon the abutment detail, there are four ways that a bridge can be made integral. The four forms of abutments are:

a) Frame abutments (Fully integral bridges)
b) Bank pad abutments
c) Flexible support abutments
d) Semi-integral end screen abutments

Frame abutments (Fully integral bridges)
Integral bridge with frame abutments are like portal frame where moments, shear force and axial loads are transferred directly to the substructure from deck of bridge and retains the backfill behind the abutment. Seismic response of the integral bridges is affected significantly by the dynamic forces exerted by the backfill soil on the abutments and soil pile interaction.

Integral Bridge with Bank Pad Abutments
It is an alternative to stiff portal frames in which the end supports are fully integral with the deck acting as a shallow foundation for end span. Shallow abutment is used in a condition where the foundation is very stiff and no settlement problem can occur. It should have adequate weight, and the end span have adequate flexibility, in order to avoid uplift from differential settlement or live loads.

Flexible support abutments (Sleeved Pile)
Flexible support abutments have post holes created around the piles that extend up to pile depth. The posthole should ensure adequate space for the pile to move horizontally and it will eliminate the soil and pile interaction. The buckling resistance of the pile over the length needs to be considered. This type of abutment is more suitable for short-span bridges.

Semi-integral end screen abutments
When bridge bearings are used in integral bridges, they are referred as semi integral bridges. In this type of bridge, expansion joints in the deck are eliminated but bearings are present at the abutments to accommodate superstructure movements. The girders are

integrally cast in a concrete end screen wall/backwall that is independent of the rest of the abutment. Girders and the endscreen wall are connected by an end plate and shear connectors. The endscreen wall provides lateral and torsional restraint to the girders.

III. ADVANTANGES OF INTEGRAL BRIDGES

In comparison to conventional bridges, costs of construction and maintenance are much lower due to elimination of joints and bearings (FHWA, 1986) as well as comparatively faster and simpler construction (Wasserman and Walker, 1996). Significant cost is accounted by bearings and expansion joints in comparison to traditional bridges because they need to be maintained properly as they are vulnerable to fatigue and corrosion. Integral bridges have enhanced structural capacity during earthquake events (Hassiotis et al, 2006).

IV. NEED FOR THE STUDY

A common problem in the seismic resistance of typical bridge is unseating of the superstructure from bearings, which can be eliminated in integral bridges. However, expansion joints and bearings used in conventional bridges allow superstructure movements during seismic events resulting in a decreased demand in the substructure foundation. In integral bridges, the piles and abutment must be capable of accommodating these increased demands. Integral bridges provide increased seismic resistance with respect to conventional bridges through increased redundancy in the structure and continuity. Although integral bridges have performed well in recent seismic events, a detailed research study has not yet been conducted to assess, evaluate and quantify their seismic performance. The assessment of the seismic performance of integral bridges in relation to that of jointed bridges is scarce in the literature. Moreover, the effects of soil structure interaction (abutment-backfill and soil-pile) on seismic performance of integral bridges are not known.

V. SOIL STRUCTURE INTERACTION

The behavior of integral bridges is predominantly determined by soil structure interaction as bridges are jointless and movements due to primary as well as secondary loads are catered by soil-pile and soil-abutment interaction. This phenomenon needs to be clearly understood to get insight into behavior of integral bridges.

Q Zhao et al. (2011), conducted a seismic study of a two span integral abutment steel bridge with variation in sand compaction at back of the abutment and clay stiffness of piles. A 3-D FEM of the bridge with spans 42.67m and 44.81m was developed considering soil springs around the piles and behind the abutments using Sap 2000. This study concluded several important points. When sand backfill behind abutment was compacted, dominant longitudinal frequency of the bridge increased significantly, more than increasing the stiffness of clay around the piles. Under earthquake excitation, the maximum deflection of pile and the maximum displacement of abutment were both at the abutment-pile interface and decreased when the backfill of abutment was compacted or the piles were present in firmer clay, or both. Under earthquake loading, the maximum pile moment was at the abutment-pile interface. The pile moment decreased when the backfill of abutment was compacted and increased when the piles were in firmer clay. Recommendation of densely-compacted backfill behind abutments was made, since it reduced the deflection of pile, displacement of abutment, the moments of the girders, and especially the pile moment.

Ahmad M. Itani et al. (2011), studied the seismic performance of steel plate girder bridges with integral abutments. The superstructure composed of four composite steel plate girders spaced at 11.75 feet for a total deck width of 44 feet including the overhangs. The span lengths were 105 feet, 216 feet, and 105 feet, for a total length of 426 feet. The piers were with single bent having a diameter of 60 in. and clear height of 25 feet, and supported on steel piles. A 3D model of the bridge was developed considering abutment-soil and soil-pile interaction and pushover analysis was carried out. Seismic load paths in both longitudinal and transverse directions were evaluated for translational modes that were dominant. A greater percentage (72%) of seismic force in longitudinal direction, was resisted by the abutment-backfill passive resistance. Overall response was governed by soil-pile interaction in the transverse direction. According to the study, nearly 40% of the transverse seismic force was resisted by the soil-pile interaction for each abutment. It shows that piers in integral bridges were subjected to lower seismic forces, thus limiting their damage during earthquake. Also, Integral Abutment Bridge with piles that have major axis parallel to abutment axis performed better in terms of the nonlinear response of piles.

Stergios A. Mitoulis et al. (2016), concluded that the interaction of abutment and backfill during earthquake event or thermal expansion/contraction is the biggest challenge in the application of integral bridges. This interaction causes settlement and ratcheting of backfill soil resulting in excessive and long term loading at abutment. In order to provide solution to this, a novel isolator which a compressible inclusion of reused aggregates derived from tyres was introduced between abutment and backfill soil. Laboratory tests on mechanical properties of the compressible inclusion were conducted at University of Surrey. Different sizes and thicknesses of the isolator were tested. A finite element analysis was carried out to study the aforesaid phenomenon using such an isolator. Thermal (expansion and contraction) as well as earthquake loads were considered to study the behavior of abutment backfill. It was observed that soil pressures were significantly lowered with the use of isolator as compared to conventional bridges. Soil pressures during seismic excitations were again smaller on isolated abutment as compared to conventional abutments. There was significant reduction in the backfill soil settlement for isolated bridge under thermal as well as seismic loadings. Moreover, bending moment and shear forces were significantly lesser as compared to conventional bridges. Optimal placement of isolator is required for improved performance of integral bridges.

D.L Kozak et al. (2018), studied regarding seismic modeling of integral abutment bridges in Illinois. Integral abutment bridges (IABs) are getting popular in modern design and construction of bridges due to reduced maintenance costs associated with water, dirt and chemicals that may fall into abutment seat thereby damaging bearings, girders and abutment. Due to elimination of expansion joint, behavior of integral abutment bridges is complex considering the soil-structure interaction limit states. In this study, dynamic analysis of IAB was carried out considering all critical IAB components and their response contribution to overall bridge was investigated. Seismic response of a steel plate girder IAB and a precast PSC girder IAB was computed using 20 ground motions shaking, for 1000 year return period hazard level. These analyses indicated some important limit states of IABs during earthquakes. One of the key limit states observed was yielding of piles at abutment for both steel and concrete IABs in all the dynamic analyses. Another limit state was indicated to be in pier shafts. Pier damage was found to be more in concrete IAB while light damage was experienced by steel IAB. Larger inertial forces were found to be developed in prestressed concrete IAB due to significantly heavier superstructure in comparison to steel bridge, during seismic events. Therefore, it is recommended to increase pier sizes to accommodate these increased intertial forces in prestressed concrete IABs.

Sreya Dhar et al. (2018), concluded seismic response of integral abutment bridges depends considerably on the abutment–soil interaction and soil–pile interaction in the longitudinal direction and the transverse direction respectively. In this study, modal behavior of IAB with and without soil-structure interaction was investigated. The bridge was 330m long, 10m wide and 12m in height. Models, one with effect of soil-pile and abutment-backfill interaction and other fixed base model having pier bottom fixed, were taken. The stiffness of the bridge was lower along transverse direction in comparison to longitudinal direction for both the models resulting in lower modes along transverse direction of bridge. It was seen that range of natural periods for SSI model was higher (0.8-2.1s) than that for fixed base model (0.4-0.6s). The abutment-backfill and soil-pile and interactions increased the overall flexibility of bridge in comparison to fixed base model. Thus, using fixed base model for design forces calculations may lead to unsafe and uneconomical design. Considering more realistic behavior, soil structure interaction must be taken into account in performance-based studies of bridges.

Saeed Mahjoubi et al. (2018), worked on a nonlinear FEM of integral bridge with soil model. Soil model considered both the nonlinearity of free field soil and near field soil mass and inertia. Damping due to non-linearity of soil was taken into account through hysteretic energy loss of non-linear soil springs. A parametric study was conducted to identify effect of length of bridge, type of abutment and type of soil at the back of abutments on earthquake response of integral bridges. Non-linear direct integration finite element analysis was carried out on 16 integral bridge models using 5 real seismic ground motions. It was concluded that the natural period of 1st vibration mode increased as the bridge length increased. IAB with loose soil at back of abutments showed a longer period in comparison to integral bridges with dense soil behind abutments. There was increase in maximum earthquake displacement of integral bridges with increased length. IABs with dense soil behind abutments showed lesser displacement in comparison to those with loose soil.

VI. COMPARISON BETWEEN SEISMIC PERFORMANCE OF INTEGRAL AND JOINTED BRIDGES

Mairead Ni Choine et al. (2014), presented a comparative study between the seismic performances of a fully integral three span PSC and a three span continuous concrete bridge having elastomeric bearings at piers and abutments. To create geometric variation of each bridge type, two types of bridge lengths and three pier heights were taken, making 6 geometric bridge samples for each bridge type. A probabilistic analysis using fragility approach was performed for each bridge to compute the probability of exceedance of the pre-defined damage states. The results showed that the integral bridges performed better for different bridge lengths and pier heights considered. For instance, the probability of the 52 m bridge with 6.9 m column height exceeding moderate damage, for 50-year earthquake, increased to 83% for the jointed bridge from 23% for the integral bridge. However, it was studied that the piers of the integral bridges were more vulnerable to earthquake damage than the piers of jointed bridge. It is understood by the logic that superstructure is monolithic with the supporting structure resulting in larger forces and moments (demands) getting transferred from deck to the piers under earthquake excitations. In spite of this, vulnerable structural components such as shear keys and elastomeric bearings, along with the chances of unseating of deck, results in the integral bridges being more resistant to earthquakes in comparison to jointed bridges.

Rahul M Deshnur et al. (2016), carried out a study to get insight into structural behavior of integral bridge and a conventional RC girder bridge using grillage analogy. Detailed comparison was made between both types of bridge configurations by studying their behavior in terms of bending moment, shear force and deflection. It was concluded that the reduction in bending moment was almost 60% in integral bridge as compared to conventional bridge and thereby integral bridges proved to be economical. However, the shear forces in both the bridges were having not much differences in their results. The maximum deflection in integral bridge was significantly reduced in comparison to the conventional bridge. The reduction was found to be around 70%.

Semi Erhan et al. (2014), conducted a study to assess, evaluate and quantify the seismic performance of IBs in comparison to conventional jointed bridges, particularly with respect to the differences at their abutments, one two and three span bridges were considered. The superstructure consisted of steel plate girders for one and three span bridge and PSC girders for two span bridge and substructure consisted of steel H-piles. 3-D finite element models of the bridges including nonlinear soil structure interaction effects were made. The nonlinear time history analyses of the bridge models were then conducted using seven ground motions and scaled to 0.2, 0.35, 0.5 and 0.8g peak ground accelerations for each EQ record, to study the seismic performance. Integral bridges have enhanced seismic performance compared to conventional bridges (CBs) for the range of PGAs and bridges considered. The superstructure of CBs is supported at the abutments by flexible, elastomeric bearings and is free to move due to the presence of expansion joints. Such structures produces very large deck displacements in comparison to that of integral bridges in which there is rigid connection of abutment with the superstructure and thereby preventing the free deck movement along with the resistance provided by the backfill. In integral bridges, the monolithic connection between abutments and superstructure, resulted in resistance of earthquake force in longitudinal direction by both abutments. Moreover, larger displacements and rotations of the abutment were observed in conventional bridges. These differences were primarily due to lack of restraint in lateral direction provided by the superstructure to the abutment. In a summarized form, integral bridges have better seismic performance as compared to CBs.

VII. CONCLUSION

In general, integral bridges are found to have better seismic performance in comparison to conventional bridges due to difference between configuration at abutments of integral and conventional bridges. In conventional bridges, large deck displacements are produced in comparison to integral bridges where abutment and superstructure are rigidly connected thereby preventing free deck movement in combination with the abutment backfill resistance. It was observed that when sand backfill behind the abutment is compacted, it increased the dominant longitudinal frequency of the bridge. It was observed that maximum pile deflection and abutment displacement was affected by soil stiffness behind the abutment as well as around piles and decreased when backfill is compacted, under seismic loading. Densely compacted backfill is recommended, since it will reduce the pile deflection, abutment displacement, girder moments and pile moments. A comprehensive research is yet to be conducted to evaluate the seismic performance of integral bridges. Moreover, study of comparison between integral and jointed bridges is limited in literature.

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