Abstract

Integral abutment bridges (IAB) are constructed without any deck joints with abutment and pier. In a single span construction, the deck is cast integrally with abutment. In the case of a multi-span construction, the intermediate support to the deck is provided either by flexible pier with deck integrated monolithically with the pier or by rigid pier with a bearing on it supporting the deck. This practice is a significant deviation from the conventional method of bridge construction which employs deck joints at the location of pier and abutment for the release of stresses caused by the expansion and contraction of the deck due to thermal variation and vehicular action. However, in the case of IAB, the construction of the deck without joint introduces secondary stress due to thermal variation, which are required to be considered in the design. Despite this, the popularity of integral abutment bridge is recorded to be growing. This is because of the fact that the distress caused by the malfunctioning of bearing and joints along with associated damage to the components of the bridges with conventional bridge are experienced to be more than the distress caused by secondary stresses. The IAB also has an advantage over conventional bridge type as it avoids the requirement of frequent maintenance of bearing and deck joints, unseating of deck and damage of bearing during seismic excitation. Further, the redundant frame configuration of integral abutment bridge greatly improves the performance of the bridge under seismic excitation.

Considering the inherent redundancy of the bridge, IAB is preferred for adoption in construction of bridges in areas classified under high seismic risk zone. Review of literature indicates insufficient information in the seismic behavior of the integral abutment bridge with soil structure interaction to frame a detailed procedure for

seismic design and implementation of integral abutment. To adopt integral abutment bridge in areas of high seismic risk zone, a holistic study on the seismic behavior of integral abutment bridge with simulation of soil condition is required to be undertaken. Further, strategies for additional improvement in seismic performance of the bridge under seismic excitation is also required to be explored for implementation in the construction of the bridge in highly important roads and railway corridor.

With an objective for adopting a suitable method for modelling of soil pile interaction and abutment backfill interaction, the background literature on formulation of the existing approaches is studied in detail. Amongst the existing approaches available, the method which are simple to implement in modelling of soil structure interaction of integral abutment bridge but simulate the soil behavior without loss of accuracy are selected. The modelling of tip bearing interaction of pile using load settlement $Q-z$ curve, shaft skin frictional force interaction using load transfer $t-z$ curve and lateral pile soil interaction using load displacement $p-y$ curves are found to be adequate to account for the soil pile interaction in IAB. For precise evaluation of seismic response of the bridge, the far field soil reaction is also incorporated in the modelling of the pile soil interaction. The abutment backfill interaction is modelled using the hyperbolic relation between the abutment wall movement towards backfill and passive resistance mobilized.

The finite element modelling of an existing sample bridge considered for study is carried out by modelling the steel concrete composited deck using grillage model, while the pier, pier cap and piles are modelled using beam element. The abutments and the pile caps are modelled using thick shell element. Nonlinear analyses are carried out for observing the response of the bridge, where soil as well as the structural components may undergo yielding. Nonlinear plastic hinges are modelled for concrete pier and piles using results from the moment curvature analysis of the section. To identify the effect of incorporation of far field soil element in the modelling of soil pile interaction, two categories of models are developed by varying the modelling in the soil pile interaction. In the first category, the soil pile interaction is modelled using soil spring modelled by $p-y$ curve, only representing the nonlinear behavior of soil near the pile. In the second category, the far field soil element is attached in series to the soil spring modelled by $p-y$ curve to simulate the radiation damping and elastic response of soil in the vicinity of the pile but away from zone of nonlinear behavior. The modal analyses of both the models indicate that the incorporation of far field element in the modelling of soil pile interaction make IAB more flexible. Nonlinear time history analyses of both the models using ground motions compatible to design response spectrum were also carried out. The second category of model results in higher displacement and higher seismic forces in the piles supporting the pier due to the incorporation of far field soil reaction in the modelling of soil pile interaction. The drift of the pier is also observed to have increased in second category model of IAB. The precise evaluation of seismic design forces in IAB thus require detailed modelling of soil pile interaction incorporating far field soil reaction.

The analysis of IAB under cyclic thermal loading for a variation of $\pm 17^0$ C temperature of deck considered for the site is found to induce displacement in abutment which is much lesser than that of theoretically computed value of deck expansion. The forces induced in piles and abutments are also observed to be within the elastic capacity. Hence, the cyclic strain induced in the pier, abutment and piles

are expected to be within elastic limit and not susceptible to low cycle fatigue due to cyclic thermal deformation.

To explore the strategy for improving the performance of IAB under seismic excitation, sleeved pile foundation is proposed. Sleeved piles are designed and introduced to the foundation of abutment and pier. The provision of sleeved pile increases the flexibility of the IAB lengthening the vibration period of the bridge thereby reducing the seismic forces in pier. The nonlinear time history analyses of the IAB with and without sleeved pile using ground motion compatible with design response spectrum indicate improvement of seismic performance of bridge with sleeved pile. The sleeved pile is observed to be a feasible arrangement for improvement of seismic performance of IAB. Further, the provision of sleeved pile is also found to improve the thermal response of IAB.

The seismic capacity of IAB with and without sleeved pile is also assessed using incremental dynamic analysis (IDA). The IDA is a method for thorough evaluation of the seismic performance of a structure. The IDA results are presented in the form of intensity measure (IM) *vs* damage measure (DM). The IAB models with and without sleeved pile are subjected to a suite of 20 ground motions, scaling each to a different intensity (IM) to force the model all the way from elastic response to collapse. The response of IAB to each scaled ground motion in the form of drift of pier (DM) are extracted from every step of the analysis and IDA curves are developed for all the ground motions considered. The IDA curves are summarized to obtain the median seismic demand of the IAB. The seismic capacity of the bridge is estimated by interpolating the IDA curves using Ramberg-Osgood (R-O) equation using the median values of initial slope of IDA curve, critical IM, critical value of engineering demand parameter. The estimated median capacity of the bridge through interpolation using R-O equation indicates that the IAB with sleeved pile is having reasonably higher capacity than IAB without sleeved pile. The median seismic demand for the various damage states observed from the summarized value of IDA indicates a higher demand various damage states for the IAB with sleeved pile implying a higher seismic capacity.

The seismic vulnerability of the IAB with and without sleeved pile is compared by developing an analytical fragility curve. The different damage states such as yielding, cover spalling and bar buckling are assigned a quantitative value in the form of drift of pier, estimated using moment curvature analysis of section as well as using the empirical equations developed from the experiment on bridge column data set. Probabilistic median seismic demand is estimated from the summarized IDA results taking the value of IM from the corresponding $DM_{50\%}$ at different damage state. The fragility curve developed for different damage states for IAB with and without sleeved pile displays that the IAB with sleeved pile is less vulnerable as compared to that of IAB without sleeved pile.