INFLUENCE OF INTERMEDIATE PIER BEARING TYPE ON INTEGRAL ABUTMENT BRIDGE SEISMIC RESPONSE

D.L. Kozak\textsuperscript{1}, J.M. LaFave\textsuperscript{2} and L.A. Fahnestock\textsuperscript{3}

ABSTRACT

Due to the popularity of integral abutment bridges (IABs) in the United States, understanding their seismic behavior is a critical need. IABs are frequently used in the Midwestern state of Illinois, which includes regions of moderate to high seismicity in the southern part of the state due to its proximity to the New Madrid Seismic Zone. Illinois typically uses two types of bearings between the superstructure of a bridge and the intermediate pier caps – namely, elastomeric bearings and low-profile fixed bearings. In seat-type abutment bridges, at least one pier incorporates fixed bearings while the other piers and abutments use elastomeric bearings, which aid in creating a quasi-isolated seismic response of the superstructure. In IABs, the inherent fixity of the superstructure at both abutments leads to superstructure movement that is dependent on the type of bearings at the intermediate piers. This study investigates the seismic behavior of three- and four-span IABs typical to southern Illinois with either all elastomeric or all fixed bearings at the intermediate piers. The bridges are modeled in OpenSees and subjected to 1000-year return period earthquake ground motions appropriate for the region. This sensitivity study considering the use of elastomeric or fixed bearings in IABs provides new information on demands that are transmitted from the bridge superstructure into the bridge substructure, especially the piers and foundations.

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Influence of Intermediate Pier Bearing Type on Integral Abutment Bridge Seismic Response

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ABSTRACT

Due to the popularity of integral abutment bridges (IABs) in the United States, understanding their seismic behavior is a critical need. IABs are frequently used in the Midwestern state of Illinois, which includes regions of moderate to high seismicity in the southern part of the state due to its proximity to the New Madrid Seismic Zone. Illinois typically uses two types of bearings between the superstructure of a bridge and the intermediate pier caps – namely, elastomeric bearings and low-profile fixed bearings. In seat-type abutment bridges, at least one pier incorporates fixed bearings while the other piers and abutments use elastomeric bearings, which aid in creating a quasi-isolated seismic response of the superstructure. In IABs, the inherent fixity of the superstructure at both abutments leads to superstructure movement that is dependent on the type of bearings at the intermediate piers. This study investigates the seismic behavior of three- and four-span IABs typical to southern Illinois with either all elastomeric or all fixed bearings at the intermediate piers. The bridges are modeled in OpenSees and subjected to 1000-year return period earthquake ground motions appropriate for the region. This sensitivity study considering the use of elastomeric or fixed bearings in IABs provides new information on demands that are transmitted from the bridge superstructure into the bridge substructure, especially the piers and foundations.

Introduction

Integral abutment bridges (IABs) are commonly used in the U.S. and have been constructed in the Midwestern state of Illinois since 1986 [1]. The seismic behavior of IABs in southern Illinois is of particular interest due to the proximity to the New Madrid Seismic Zone (NMSZ). Furthermore, when the American Association of State Highway and Transportation Officials (AASHTO) increased the design seismic hazard for bridges to a 1000-year return period event [2], the more stringent design requirements generated new interest in the seismic behavior of IABs.

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Previous research on seat-type abutment bridges has shown that bearings between the superstructure and substructure make a large contribution to the seismic response of these non-integral abutment bridges [3]. However, IABs are much stiffer and do not incorporate bearings at the abutment-superstructure interface, but the two elements are instead connected rigidly through a monolithic concrete pour. Thus, bearings are only employed between the superstructure girders and intermediate pier caps. This study investigates differences in IAB seismic behavior when using two common bearing types at piers – Type I elastomeric bearings and low-profile fixed bearings.

Analytical Modeling of Representative IABs

Using the OpenSees [4] computational platform, two non-skew IABs are modeled with either elastomeric or fixed bearings at their intermediate piers. Both bridges use steel plate girders for the superstructures, with the major difference between the bridges being that one bridge has three spans while the other has four. The three-span IAB consists of 80 ft exterior spans and a 120 ft center span, while the four-span IAB has 145 ft exterior spans and 160 ft interior spans. Both bridges are designed for southern Illinois using the Illinois Department of Transportation (IDOT) bridge manual [5]. An elevation and OpenSees model of the 3-span bridge are presented in Fig. 1.

![Figure 1. (a) Elevation of the three-span IAB; (b) OpenSees model for the three-span IAB.](image)

The elastomeric bearings are Type I, meaning they are reinforced with steel shims and the top is vulcanized to a steel plate, which is attached to the girder. The bottom of the elastomeric bearing is in direct contact, but not attached to, the top of the concrete pier cap. The elastomeric bearings are accompanied by side retainers in the transverse direction, which are attached to the pier cap by steel anchor bolts [5]. The low-profile fixed bearings consist of two steel plates – one attached to the pier cap, and the other to the girder. Between the steel plates are pintles that act in shear to prevent movement in any direction [5]. It has been found through testing that the weak point in these bearings is at the steel anchor bolts connecting the plates to the pier cap [6].

All critical bridge components with any potential for significant inelastic response were explicitly modeled in OpenSees [4] in accordance with experimental results and established models from the literature [6-7]. The components were modeled to capture their individual nonlinear contributions to the overall behavior of the IAB. The modeled components include
superstructure, pier column, pier foundation pile, abutment pile, abutment backfill, retainer, elastomeric bearing, and fixed bearing behavior, as well as the soil surrounding the piles.

The individual component models also allow the components to be monitored during analyses to assess damage. The damage limit states observed (and their abbreviations) in the IABs include: backfill soil failure (BF); retainer engagement (RE), yielding (RY), and failure (RF); fixed bearing yielding (FY) and failure (FF); bearing unseating (BU) and sliding (BS); abutment and pier pile yielding (APY and PPY, respectively); failure of the soil surrounding the piles (APS for abutment, PPS for pier); and light (SL and CL), moderate (SM and CM), and severe (SS and CS) damage to the concrete (“C”) and reinforcing steel (“S”) of the pier columns. These observed limit states and modeled components were based in part on common damage seen in previous seismic IAB studies (including post-earthquake reconnaissance).

Dynamic Analysis Results

The IAB models have been subjected to twenty ground motion time histories in both the bridge longitudinal and transverse directions. The twenty ground motions were specifically developed for Cairo, IL at the design-level hazard of a 1000-year return period [8]. The city of Cairo was chosen because it is the most southern city in Illinois and the closest to the NMSZ. The resulting occurrences of limit states are presented in Table 1 as a percentage of the total number of analyses. Limit states not indicated in Table 1 do not occur in any of these analyses. The results are used to compare seismic behavior between the different IABs and directions at the seismic design-level hazard.

Table 1. Percent of dynamic analyses in which each limit state is observed.

<table>
<thead>
<tr>
<th>Bridge Excitation Direction</th>
<th>Three-Span Steel IAB</th>
<th>Four-Span Steel IAB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Longitudinal</td>
<td>Transverse</td>
</tr>
<tr>
<td>APS</td>
<td>70%</td>
<td>55%</td>
</tr>
<tr>
<td>APY</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>CL</td>
<td>35%</td>
<td>60%</td>
</tr>
<tr>
<td>CM</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>CS</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>FY</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>PPS</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>RE</td>
<td>0%</td>
<td>-</td>
</tr>
<tr>
<td>RY</td>
<td>0%</td>
<td>-</td>
</tr>
<tr>
<td>SL</td>
<td>60%</td>
<td>80%</td>
</tr>
<tr>
<td>SM</td>
<td>0%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Results in the longitudinal direction of the three-span steel IAB indicate there is more
damage to the piers when fixed bearings are used, as compared to elastomeric bearings. This can be observed through increased occurrences of light and moderate damage to the pier column steel and concrete (SL, CL, SM, and CM limit states). In fact, moderate pier column damage only occurs in the three-span IAB when fixed bearings are used. In the transverse direction, there are minimal changes in the occurrence of pier column damage regardless of the bearings used. However, a major observation in the transverse direction is a decrease in damage to the abutment piles (APY) and soil surrounding these piles (APS) when fixed bearings are used. The abutment piles in the transverse direction are very important due to the lack of backfill resistance in that direction, leaving the lateral load transferred at the abutment to be resisted only by the piles.

In the longitudinal direction of the four-span IAB, there is once again more occurrences of moderate pier column damage when fixed bearings are used. There is also less damage to the abutment piles and soil surrounding those piles when fixed bearings are used. In the transverse direction there are no major changes to the limit states, which occur regardless of the bearing type used. The four-span IAB analyses in the transverse direction are the only ones that experience a significant amount of severe pier column damage (SS or CS). This severe damage is related to decreased occurrences of damage to the abutment piles and soil surrounding the abutment piles.

Acknowledgments

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References