| April 2020 Research Seminar: Rapid Retrofitting Techniques for Induced Earthquakes – Phase I | | |
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| **#** | **Questions** | **Responses** |
| | **Earthquakes** | |
| 1 | What seismic response spectrum should we use for western Pennsylvania? | Some induced earthquakes have been documented in Ohio, but none I know of to date in western PA. Nevertheless, the seismic design spectrum based on AASHTO LRFD should be used in all cases. |
| 2 | Why is there induced seismicity in the central United States? | For the reasons discussed in the presentation, the induced seismicity in the central U.S. is due to wastewater disposal from oil extraction. For more information, see the USGS website https://www.usgs.gov/natural-hazards/earthquake-hazards/induced-earthquakes. |
| | **Retrofitting Techniques** | |
| 3 | What are the implications for building vulnerability and retrofit into a project? | Buildings seem to be more vulnerable to induced earthquakes than bridges. Damage is primarily nonstructural. The framework developed through this research would be straightforward to apply to residential/commercial buildings. |
| 4 | What are the techniques for bridge foundation retrofit, if any? | Chapter 6 of the ABC-UTC report "Synthesis on the Use of Accelerated Bridge Construction Approaches for Bridge Rehabilitation" [ABC-UTC-2013-C1-ISU02] discusses repair methods for abutments. Also, the University of Oklahoma project through the ABC-UTC titled "Development of Guide for Selection of Substructure for ABC Projects" [ABC-UTC-2016-C2-OU01] may have more information. |

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| 5 | Are you aware of the research dissertation entitled "Procedures to Rehabilitate Extremely Damaged Concrete Members Using Innovative Materials and Devices," by Huaco and Jirsa? | Yes, the presenter and panel are aware of this dissertation, which documents methods such as CFRP jackets and mechanical splices for buckled bar that can be used for the repair of concrete members. However, that work focuses on "extremely damaged concrete members" caused by high-intensity earthquakes as a result of low-cycle fatigue, whereas this work focuses on the cumulative effect of a large number of small-to-moderate *induced* earthquakes. |
| 6 | Less mass = less movement. How important is it to reduce the weight of structures to improve seismic response? | By reducing the weight of a structure, the inertial load generated by an earthquake is reduced. This is apparent from the AASHTO LRFD Uniform Load Method in which the seismic loading is proportional to weight. However, it should be noted that a reduction in mass will also have an effect on the period of the structure, so the elastic seismic response coefficient may increase for shorter periods associated with less mass. |
| 7 | How much have you considered/studied using lightweight concrete for high-rise projects in seismic areas (less mass = less movement)? | I cannot personally claim to have studied the use of lightweight concrete for high-rise projects in seismic areas. Less mass should translate to a lower design base shear and lower seismic loads, but this result may vary depending on the specific building and design spectra, and a detailed analysis is needed before making general claims. |
| 8 | Have you considered retrofitting structures with seismic isolation bearings as a rapid retrofitting technique? | Seismic isolation helps to diminish the load path between the superstructure and the substructure/foundation, reducing the loads on the columns/piers. This is an attractive approach in high-seismic regions, but the *rapidity* of such a retrofit needs to be assessed. |
| | **Other** | |
| 9 | Can you address change orders and resolutions? | The presenter is unaware of any changes in the scope of a construction project, either ongoing or future, to address induced earthquakes. As discussed in the presentation, the AASHTO LRFD Standards have not been revised to incorporate man-made seismicity, so the same design provisions still apply. |

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| 10 | What are the future research needs related to this project? | The presenters believe that the following three research needs warrant further exploration: (1) evaluation of existing and new rapid repair methods with the proposed framework, as proposed in Phase II; (2) development/evaluation of high-cycle fatigue curves for cover concrete for use in the proposed FDI framework; and (3) combining the effects of induced earthquakes and deterioration from other sources and years of service. |
| | **Questions during Seminar** | |
| 11 | Has hydraulic fracturing contributed to the frequency of the earthquakes? If yes, what levels of ground motions have they generated? | The disposal of wastewater produced during hydraulic fracturing (as well as traditional oil extraction) is the main source of these induced earthquakes. The largest induced earthquake on record was the M5.8 Pawnee, OK event in 2016. |
| 12 | Can you share some information on the ground motion characteristics on the time history of acceleration, and also velocity for the induced earthquakes? | This work focused on peak ground acceleration (PGA) and spectral acceleration (Sa) primarily. The high-frequency (>10 Hz) or short-period (<0.1 sec) content of induced earthquakes, as has been noted, appears in the response spectra. Velocities were not looked at in this work. |
| 13 | Now that we are seeing a decrease in intensity and frequency of induced earthquakes, do we still have to worry about retrofit? | At this point in time, retrofit would most likely not be the best use of resources, but should the induced earthquakes return, the proposed FDI framework would be a valuable tool for evaluating on which bridges retrofit would be most beneficial. |
| 14 | Is there a general policy by the Oklahoma DOT regarding how to address man-made induced earthquake? | The Oklahoma DOT and the Oklahoma Turnpike Authority are both currently using ShakeCast to determine which bridges need to be inspected following an earthquake. The PI and Co-PI of this ABC-UTC project were also involved in the Oklahoma ShakeCast project. |
| 15 | Use of Miner's rule could involve large variability. Have you been able to check the accuracy of the overall approach and, in particular, the use of Miner's damage model? It is the simplest damage model but has large variability. | Some validation has been performed comparing the damage indices calculated from the fatigue damage index (FDI) framework and from running time-history analyses of the finite element model, which showed good correspondance. No checks have been made against laboratory or field measurements/observations. |

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| 16 | Have you considered the contribution from other modes of structure to the overall damage calculation? What is the reason to neglect the vertical component of the seismic load? | This framework attempts to parallel the methodologies in the *AASHTO LRFD Bridge Design Specifications* , which consider only horizontal seismic loads and only a single mode for simple bridges. We are considering two modes (the fundamental mode in the longitudinal and transverse directions), but higher modes have not been included. This was done because the fundamental modes typically control the response. |
| 17 | Can we also apply the fatigue index to the bridge pile foundation? | Yes, this could be done by incorporating the bridge pile foundation into the finite element model used in the FDI framework. |
| 18 | Is the S-N curve only considering rebar? | The specific S-N curve used in this research was for a rebar, but other materials/members could be assessed assuming an appropriate S-N curve is known. |
| 19 | How did you account for the ties resistance to fatigue action as a confinement factor? | The ties were incorporated into the finite element model through the constitutive relations for the confined concrete, but they were not explicitly modeled. |
| 20 | So basically, if there is no fracking (fracking only ramped up in the study period), would the number of induced seismicity events go back down to a natural level prior to 1974? | This remains an open question in the seismology and geology communities. It is unknown at this time whether the seismic activity will return to historical levels or if that baseline has been shifted. Only time will tell. |
| 21 | At FDI = 1.00, rebar is fractured; however, it could be severely damaged with rebar buckling due to extensive concrete spalling. Comments? | Extensive spalling of concrete has not been observed to date due to induced earthquakes. If this is incorporated into the finite element model, then one could monitor whether or not rebar buckling occurs prior to FDI reaching unity. Multiple limit states should be considered to determine which one ultimately controls. |
| 22 | Is the use of the model only for eigenvalue analysis? Can this approach be used without any numerical modeling using the uniform load method in AASHTO? | The uniform load method in AASHTO can be used for the determination of the periods, as well as the stresses developed in the rebar (or other material) under load. In fact, this was the intention to make the framework easier to use by practitioners. See the Final Report for more discussion on this. |

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| 23 | So do you expect the concrete shell in the column to spall under this seismic activity? | Spalling of cover concrete on abutments and columns has been observed under induced earthquakes. |
| 24 | What is the number of cycles and the stress used as reference to determine FDI? | The specific S-N curve used in this study came from D'Angelo et al. (2014), but other relations could be used if compatible *in situ* conditions were used. |