DEVELOPMENT AND REFINEMENT OF ILLINOIS' EARTHQUAKE RESISTING SYSTEM STRATEGY

Daniel H. Tobias[1], Jerome F. Hajjar[2], Ralph E. Anderson[1], James M. LaFave[2], Chad E. Hodel[3], Larry A. Fahnestock[2], William M. Kramer[1], Joshua S. Steelman[2], Patrik D. Claussen[1], Kevin L. Riechers[1], and Mark D. Shaffer[1]

Abstract

An important aspect of newly adopted American Association of State Highway and Transportation Official's (AASHTO) bridge design code provisions is a design earthquake with significantly increased accelerations. The Illinois Department of Transportation (IDOT) has recently developed and implemented an Earthquake Resisting System (ERS) strategy for all bridges in the state in order to accommodate the increased AASHTO seismic design hazard. This paper provides a short history of the development of IDOT's ERS strategy as well as an overview of a recently established research program aimed at refinement and calibration at the University of Illinois at Urbana-Champaign (UIUC).

Introduction

Background

In 2008 and 2009, the American Association of State Highway and Transportation Officials (AASHTO) published modernized codified standards for the design of highway bridges to resist earthquake loadings. The revised and updated provisions are contained in the *AASHTO Load and Resistance Factor Design Bridge Design Specifications* (*LRFD Code*) (AASHTO 2009b) and the 1st edition of the *AASHTO Guide Specifications for LRFD Seismic Bridge Design* (*LRFD Seismic Guide Specifications*) (AASHTO 2009a). These two documents reflect the culmination of several years of effort by the bridge engineering community in the United States (MCEER/ATC 2003; NCHRP 2006). Both the *LRFD Code* and the *LRFD Seismic Guide Specifications* have incorporated a design earthquake with a 1000 yr. return period (Leyendecker et al. 2007). Prior to 2008, the codified design return period earthquake was 500 yrs. (FEMA 1988; AASHTO 2002). The methods and soil parameters used to determine design earthquake response spectra (BSSC 1995) along with numerous other aspects of seismic bridge design philosophy were also modernized in the recently published AASHTO documents.

Traditionally, the philosophies and need to address typical bridge configurations in western states within the United States have driven advancements and codified provisions for seismic design of highway bridges nationwide. Seismic considerations have been a primary concern in these states for many years due to the

---

[1] Illinois Department of Transportation, Springfield, Illinois, USA.
[2] University of Illinois at Urbana-Champaign, Urbana, Illinois, USA.
[3] WHKS & Company, Springfield, Illinois, USA.

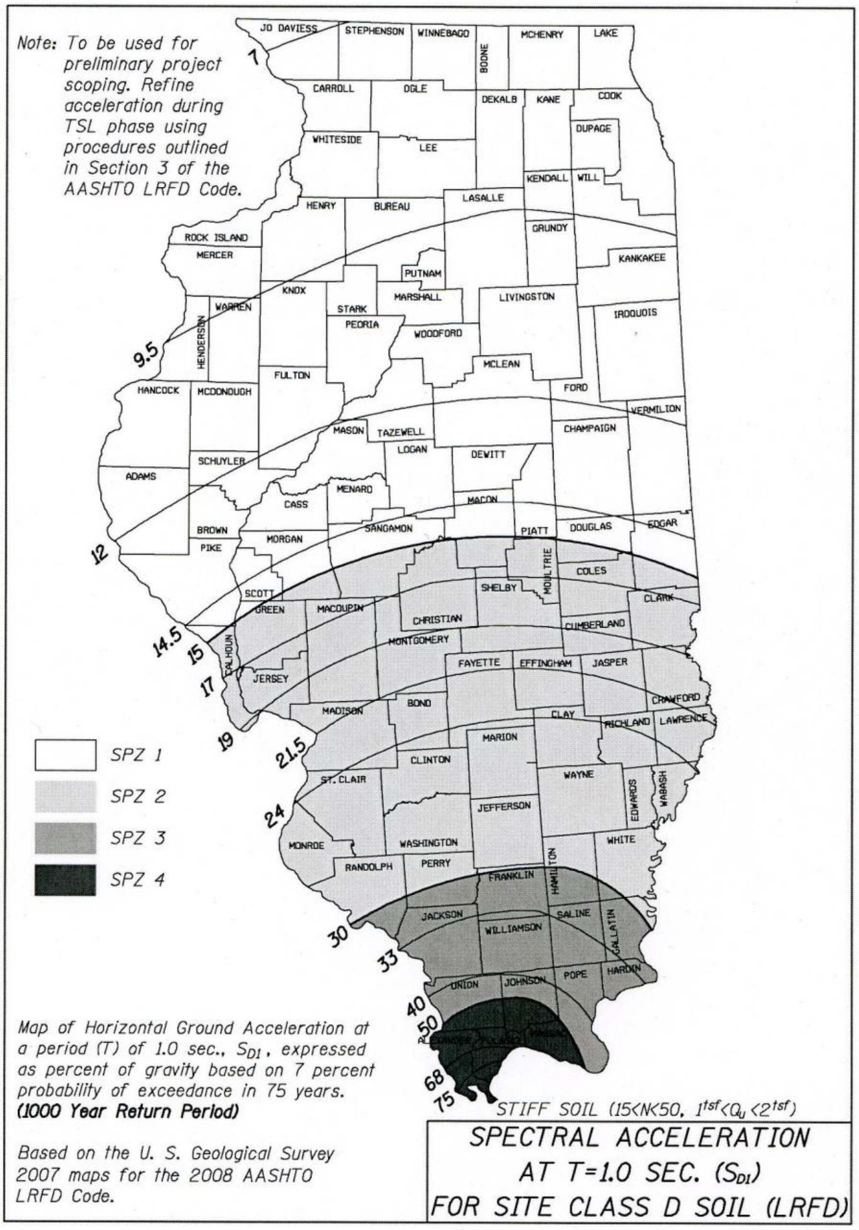
region's widely recognized high risk for large damaging earthquakes. With the advent of the newly adopted 1000 yr. design return period earthquake, though, there is a keener recognition of the risk for a large seismic event happening in some mid-western and eastern states. Significant earthquakes in these regions of the United States are known to have occurred, but the frequency of recurrence can be quite long. In the last several years, many states east of the Rocky Mountains, including Illinois, have made significant strides with regards to seismic design, retrofitting and construction methods for highway bridges. The modernization efforts in Illinois have focused on seismic design philosophies and methods that are the most appropriate for typical bridge configurations constructed in the state.

Scope of Increased Design Hazard

Designing bridges for a 1000 yr. earthquake, which primarily affects approximately the southern half of Illinois, represents a significant increase in design accelerations from the 500 yr. event. Fig. 1 presents an approximate 1000 yr. spectral acceleration map for Illinois at a period of 1.0 sec. assuming all the soil is classified as Soil Site Class D according to the definitions contained in the *LRFD Code* and the *LRFD Seismic Guide Specifications*. Site Class D is a common soil type in southern regions of Illinois. The figure gives a generalized idea of the seismicity of Illinois for the 1000 yr. design seismic event. Spectral accelerations at 1.0 sec. are used to delineate between Seismic Performance Zones (SPZ) in the *LRFD Code* and Seismic Design Categories (SDC) in the *LRFD Seismic Guide Specifications*. As the SPZ (and SDC) increases in number (letter), so do the seismic design requirements. For the 500 yr. design earthquake, there were no parts of Illinois in SPZ 4 and only a small portion was in SPZ 3. Furthermore, the design accelerations within each SPZ are significantly greater for the 1000 yr. earthquake as compared to the 500 yr. earthquake.

Development and Refinement

In late 2006 and mid 2008, after several years of development, the Illinois Department of Transportation (IDOT) published and implemented initial versions of a comprehensive strategy or framework for the design, retrofit and construction of bridges to resist seismic loadings in the *IDOT Bridge Manual* (IDOT 2008a) and the *IDOT Seismic Design Guide* (IDOT 2008b). The strategy is comprised of a set of core concepts and structural details which, when implemented together, form a generalized Earthquake Resisting System (ERS). Illinois' ERS strategy is flexible enough to be applicable to all common bridge types built in the state, and for any past or future codified hazard level. Pertinent aspects of recently adopted seismic provisions in the *LRFD Code*, the *LRFD Seismic Guide Specifications,* the *Federal Highway Administration Seismic Retrofitting Manual for Highway Bridges* (*FHWA Retrofit Manual*) (FHWA 2006), and several other sources (ICC 2000; AASHTO 2000) were used to formulate and tailor a viable ERS framework for the state. R-factor or forced based concepts (from the *LRFD Code*) are used as a primary basis for design.



Note: To be used for preliminary project scoping. Refine acceleration during TSL phase using procedures outlined in Section 3 of the AASHTO LRFD Code.

Map of Horizontal Ground Acceleration at a period (T) of 1.0 sec., S_{D1}, expressed as percent of gravity based on 7 percent probability of exceedance in 75 years.
(1000 Year Return Period)

Based on the U. S. Geological Survey 2007 maps for the 2008 AASHTO LRFD Code.

STIFF SOIL ($15<N<50$, $1^{tsf}<Q_u<2^{tsf}$)

SPECTRAL ACCELERATION
AT T=1.0 SEC. (S_{D1})
FOR SITE CLASS D SOIL (LRFD)

FIG. 1. APPROXIMATE SPECTRAL ACCELERATIONS AT A PERIOD OF 1.0 SEC. FOR SITE CLASS D SOIL IN ILLINOIS

Initial modernization and improvement efforts by IDOT in the state coincided with those of AASHTO over the last several years (Hodel et al. 2004; Tobias et al. 2006a; Tobias et al. 2006b; Tobias, et al. 2008a; Tobias, et al. 2008b). The processes of updating the *LRFD Code* and formulating the *LRFD Seismic Guide Specifications* were undertakings in which Illinois played an important role as a contributing member of the AASHTO Technical Subcommittee on Seismic Bridge Design (T-3). The involvement by IDOT at the national level helped to greatly enhance the locally developed Illinois ERS strategy. IDOT had the opportunity to garner experience and expertise from other contributing states, and also played a role in crafting some of the key provisions that pertain to states with typical bridge configurations and seismicities which are similar to Illinois.

A research program initiated in early 2009 by IDOT at the University of Illinois at Urbana-Champaign is primarily focused on refinement and calibration of the currently implemented forced based approach for areas in Illinois with moderate to moderately high seismicity. In time, for areas in Illinois with higher seismicity, additional aspects of the recently developed displacement based approach (from the *LRFD Seismic Guide Specifications*) are also anticipated to be incorporated into Illinois' ERS strategy through the results of the ongoing research effort.

The first part of this paper provides a brief overview of the initial development of Illinois' ERS strategy over the last 5 to 6 years, while the second part provides a description of the ongoing research program aimed at calibration and refinement.

ERS Strategy

Range of Applicability

Illinois' ERS strategy is primarily intended for common bridge types built in the state that normally can be designed assuming the first mode of vibration is the dominant response to a seismic loading (i.e., are regular as defined by the *LRFD Code* and the *LRFD Seismic Guide Specifications*). Superstructures of these bridge configurations generally include those with a concrete deck on steel or precast prestressed I-beams, or a wearing surface on precast prestressed deck beams (box beams). The abutments include non-integral and integral stub. The piers can be of various types including multiple column concrete bents, several variations of drilled shaft bents, and solid walls. Foundation types include spread footings, HP and metal shell piling, and drilled shafts. Various combinations of these elements make up the vast majority of Illinois' inventory at present and for the foreseeable future. For bridges that are irregular, the general principles of the Illinois ERS strategy are also applicable, and required to be followed. Irregular bridges typically require multi-modal design and analysis methods.

Seismic Structural Redundancy Levels

The underlying philosophy of Illinois' ERS strategy is to allow certain levels of damage during a seismic event at planned locations in a structure such that loss of span is prevented. Loss of span directly impacts critical public transportation facilities, and can potentially lead to loss of life. Optimally, prevention of span loss is achieved through what can be termed "levels or tiers of seismic structural redundancy" that dissipate energy from an earthquake in key components of bridges in succession as they fail (fuse) or engage, and alter the response of a structure. These key bridge components include weak or fuse-like connections between superstructures and substructures of bridges, conservative beam seat widths (support lengths) on substructures, an allowance for plastic deformation in superstructure components such as steel diaphragms, an allowance for plastic embankment deformation at abutments, and an allowance for plastic hinging in selected parts of substructures and foundations (when necessary).

The first tier or level of seismic structural redundancy, and theoretically weakest fuse in Illinois' ERS strategy, is the connections between superstructures and substructures. These connections are designed to fail at a nominal level of dynamic excitation while still meeting the strength requirements for normal or service loads (non-extreme event). Fig. 2 presents a typical fusible elastomeric bearing and superstructure-to-substructure connection with side retainers for steel I-beams used in Illinois, and Fig. 3 illustrates the details of the side retainer design. Most non-integral connections between superstructures and substructures for typical bridges in Illinois are designed to nominally carry 20% of the tributary dead weight of a superstructure in the restrained direction regardless of the Seismic Performance Zone of the structure. In 2008, AASHTO updated and clarified the provisions for the seismic design of connections between superstructures and substructures. The notion that, at the discretion of owner, bearings and their connections may be designed as sacrificial elements (i.e. fusible) is now fully endorsed alongside the historical concept which required connections between superstructures and substructures always be designed to stay elastic during a design seismic event.

For Illinois, it is much more economical and logical to embrace the fuse concept between superstructures and substructures in order to adapt to increased design accelerations. The benefits of energy dissipation and an increased chance of substructure/foundation survival (possibly beyond the 1000 yr. seismic design event) outweigh the cost of modifications to typical bridge configurations in Illinois that would be required to keep these connections elastic during a large seismic event.

Once superstructure-to-substructure connections have fused during an earthquake, adequate seat widths for beams on substructures are provided such that superstructures can "ride out" the remainder of a design seismic event (or possibly greater). Conservatively designed seat widths are the second tier of seismic structural redundancy in Illinois' ERS strategy. The empirical relationship for determining required support length, N (m), used by Illinois is given by Eq. 1.

$$N = \left[0.10 + 0.0017\,L + 0.007\,H + 0.05\sqrt{H}\,\sqrt{1 + \left(2\frac{B}{L} \right)^2} \right] \frac{1 + 1.25 F_v S_1}{\cos\alpha} \qquad (1)$$

where L = typically length between expansion bearings (m); H = tallest pier between expansion bearings (m); B = out-to-out width of superstructure (m); B/L = ratio not to be taken greater than ⅜; α = skew angle (°); and $F_v S_1$ = one second period spectral response coefficient modified for Site Class. The required seat widths calculated using Eq. 1 are typically about 25 to 30% greater than that required by the *LRFD Code* and the *LRFD Seismic Guide Specifications*.

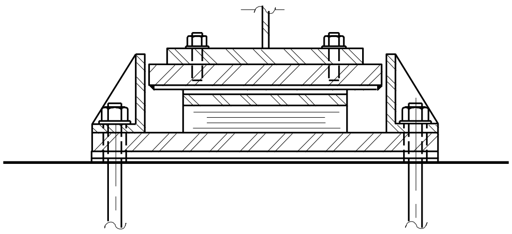
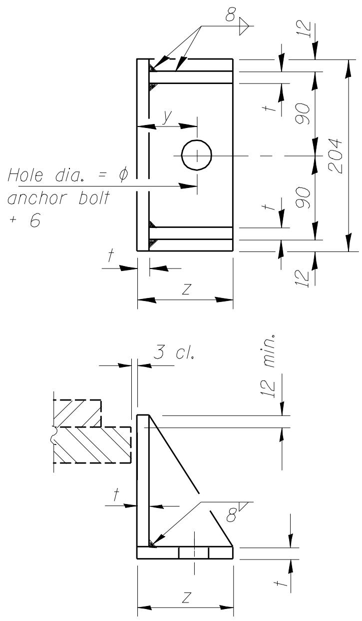


FIG. 2. TYPICAL FUSIBLE ELASTOMERIC BEARING AND CONNECTION DETAIL WITH SIDE RETAINERS FOR STEEL I-BEAMS



Dimensions in mm.
(Note: 25.4 mm = 1″)

FIG. 3. TYPICAL FUSIBLE SIDE RETAINER DESIGN FOR STEEL I-BEAMS

The third tier of seismic redundancy in Illinois’ ERS strategy generally encompasses plastic hinging of elements in substructures such as reinforced concrete columns and, when necessary due to a bridge’s configuration, substructure/foundational elements such as piles and drilled shafts. Figs. 4 and 5 provide some typical seismic details used in Illinois for multiple round columns piers and drilled shafts. Embankments at abutments are generally considered sacrificial elements as part of the third tier of seismic structural redundancy. The “amperage level” for fuses in substructures and foundations is generally somewhat greater than those of the first tier of seismic redundancy. Failure of the connections between superstructures and substructures along with plastic deformations in superstructure diaphragm elements helps to provide an enhanced probability that the third tier of redundancy may not become fully engaged or fuse during a moderate to significant seismic event (but probably will during a major seismic event without causing span loss). The concept is analogous to comparing the primary electrical fuse for an entire house to the many secondary individual fuses that are connected to it.

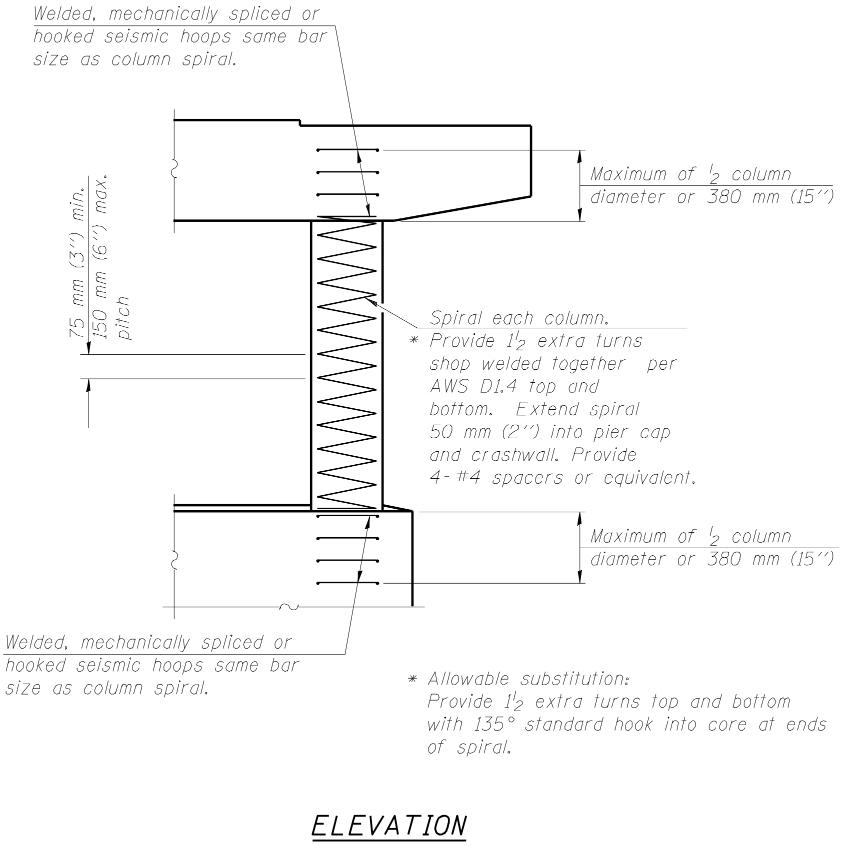


FIG. 4. SEISMIC CONFINEMENT DETAILING OPTIONS FOR CIRCULAR COLUMNS

ϕ and R-factors

Depending on the specific situation, varying degrees of isolation between superstructures and substructures are likely provided after fusing occurs primarily because friction may be the only mechanism of seismic force transfer at these interfaces. If elastomeric bearings are employed on a structure, some isolation is also provided before fusing. Since there are several sources of seismic energy attenuation in the load path from superstructures down to their interfaces with substructures, IDOT permits an increase in some ϕ or strength reduction factors for the 1000 yr. design return period seismic event from those prescribed by the *LRFD Code*. These increases primarily apply to reinforced concrete pier construction (usually from 0.9 to 1.0) for combined moment and axial force resistance. R-factors are primarily used in the design of substructures/foundations to promote ductile structural response during an earthquake by reducing design moments. The recommended R-factors in Illinois'

ERS strategy for substructure and foundation design generally follow the guidance and bounds of the *LRFD Code*. However, interpretation and judgment was required to develop and clarify for practitioners values that should be used for design which are applicable to specific pier and abutment types built in Illinois. Refinement and calibration of the ϕ and R-factors currently used in Illinois' ERS strategy are one of the primary focuses of the research effort that is currently ongoing at the University of Illinois at Urbana-Champaign.

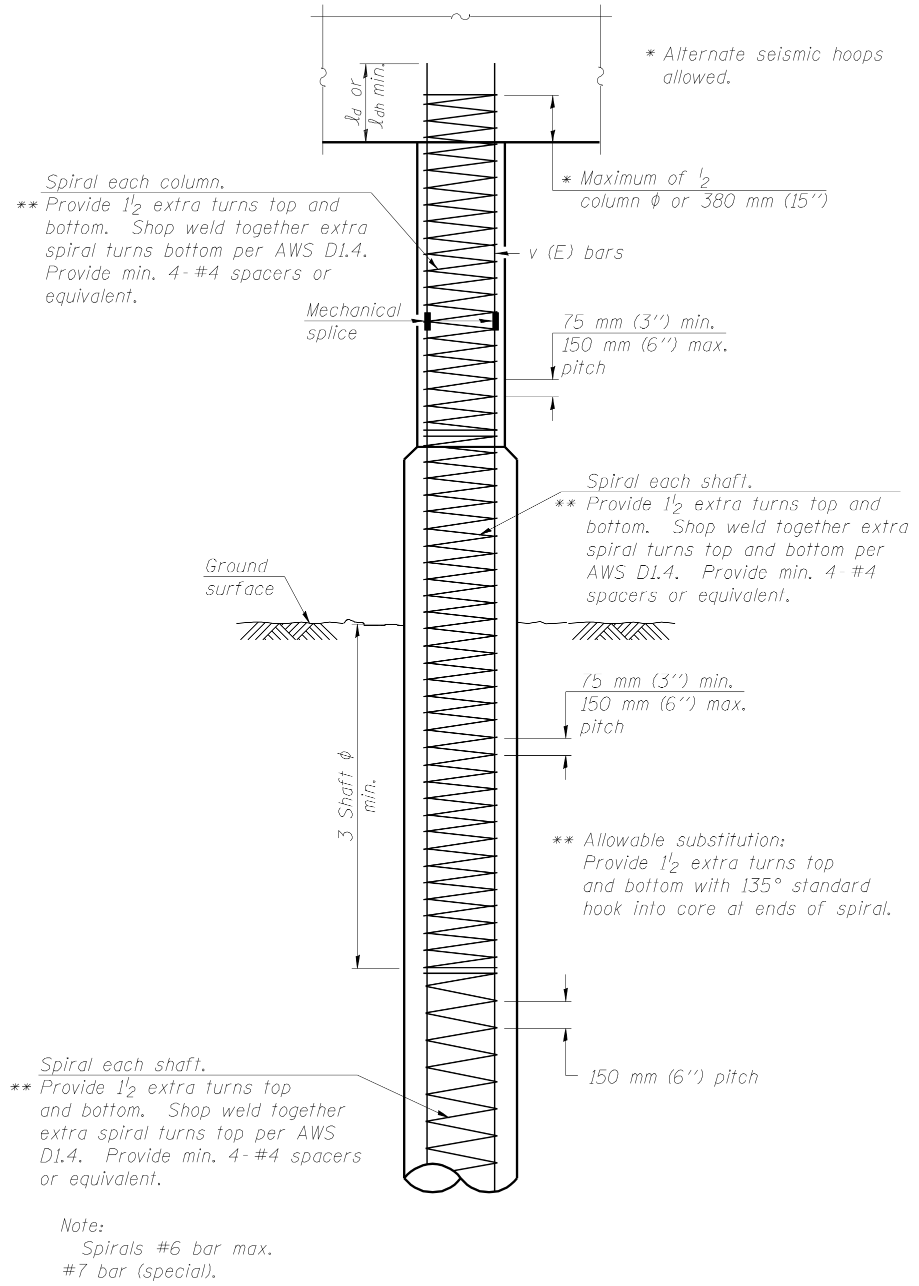


FIG. 5. SEISMIC DETAILS FOR INDIVIDUAL COLUMN DRILLED SHAFT PIERS

Calibration and Refinement of ERS Strategy

General

IDOT has teamed with the University of Illinois at Urbana-Champaign to obtain assistance with furthering the enhancement of Illinois' ERS strategy. There are some theoretical methods and assumptions embedded in the strategy that lack full verification as well as significant areas which can be targeted for refinement and calibration. An experimental university testing program that also includes the employment of sophisticated analytical computer models can provide each of these to IDOT. In recognition of the variability and uncertainty inherent in seismic design, Illinois' ERS strategy was initially formulated as a fairly conservative framework of relatively straightforward design and detailing methods primarily intended to economically streamline seismic bridge design efforts. The changes to the AASHTO bridge design provisions (primarily the adoption of the 1000 yr. design return period earthquake) have substantially increased the population of structures in Illinois requiring seismic analysis and design. In order to fully realize the economic benefits of Illinois' recently established ERS strategy, it is in the state's best interest to make improvements such that it will be less costly and time consuming to obtain a similar and heightened level of seismic resistance for new bridges. In the long term, it will also be much more economical for Illinois to achieve some level of uniformity in seismic resistance for its full population of bridges (new and retrofitted).

University of Illinois researchers are employing the current documentation of Illinois' ERS strategy, an oversight panel comprised of IDOT and Federal Highway Administration engineers, information from prior research on bridge behavior in Mid-America, as well as any other ongoing national and international initiatives related to seismic analysis and design to provide key background for the project. It is expected that the research effort will lead to a more rational and consistent bridge design approach that balances structural safety with design methodologies, construction practices, and construction costs appropriate for Illinois. In addition to more realistic analytical models, static and dynamic testing of bridge components and foundation elements should provide IDOT with a clearer picture of how to refine its ERS strategy. The aspects of the strategy that are probably somewhat more conservative than required should be able to be refined because the uncertainty surrounding the differences between actual behavior under seismic loading and that assumed in the current simplified design models can be better quantified.

Stage 1: Refinement and Calibration of Seismic Structural Redundancy Level 1

A series of laboratory tests are in the planning stages, and computational simulations are ongoing. The tests and simulations are planned to document the force-deformation relationship, cyclic energy dissipation, and deformation capacity during loading of bearing assemblies that are commonly used in the areas of Illinois which are prone to seismic activity. These bearings are intended to constitute a seismic fuse, so they are desired to be the first primary elements to fail (i.e. are sacrificial elements) within the structural system. Horizontal shearing combined with the effects from gravity load on side retainers and other bearing elements are under investigation. The experimental and computational results are expected to produce better quantified "fuse capacities", as well as provide information for assessing the response of the superstructures and substructures as the fuses breach their capacities.

The computational work in this stage includes a two-tiered analysis approach for simulating the local structural response of bridge bearing fuse assemblies. The first set of analyses is using component modeling concepts to characterize the likely range of response of the bridge bearings. The formulation utilizes a combination of coarse-mesh continuum elements and beam or spring elements that allows for parametric bracketing of the likely variables which govern the response of bridge bearing assemblies and neighboring components of a bridge's superstructure. These parametric studies are helping to highlight the details of what needs to be assessed in the experimental study. The second set are more detailed continuum type analyses of the test specimens that allow for both prediction and corroboration of the experiments, and to enable exploration of a wide range of parametric variables than can be assessed in the tests. Both types of analyses include nonlinear constitutive response of the bearing and, as needed, the bridge superstructure, geometric nonlinearity based on the anticipated deformations, and gap/contact/friction response (where appropriate).

The experiments in this research stage are planned to focus on the three bridge bearing types most commonly used in current IDOT design and construction practice:

1. Standard Illinois "Low-profile" fixed bearings
2. Standard Illinois "Type I" steel reinforced elastomeric expansion bearings
3. Standard Illinois "Type II" steel reinforced elastomeric expansion bearings with a slider surface

All bearing types are planned to be experimentally evaluated at full-scale for longitudinal, transverse and bi-directional (skew) horizontal loading conditions. Figs. 6, 7 and 8 illustrate the preliminary rig configuration for the testing of bearing fuse capacities at the University of Illinois' Newmark Structural Engineering Laboratory. Fig. 6 presents a plan view, and Figs. 7 and 8 present elevation views.

Stage 2: Computational Simulation of Response of Bridge Systems

Based on calibrations of the fuse responses determined from Stage 1, a series of parametric computational analyses are planned for a suite of typical bridge systems in order to investigate the response of the superstructure and substructure to appropriate seismic excitations. Specific issues to be addressed in these analyses include: a) Documentation of the progression of damage (sequence of fusing) in the bridge, to ensure that proper fuses typically fail first (rather than other portions of the superstructure or substructure); b) Investigation of the required seat widths to ensure adequate bridge performance; c) Documentation of anticipated peak forces that will be transmitted to the substructure, and; d) Evaluation of changes in stiffness or strength characteristics (such as period) after a seismic event. Fig. 9 illustrates a typical preliminary bridge system model. Parameters that will be varied in the global bridge system modeling include: bearing type; superstructure type (steel girder and prestressed concrete girder); single vs. multi-span (with the strong focus being especially on continuous multi-span systems); and selected, common substructure types (including pier and wall assemblies, integral abutments, appropriate soil and embankment conditions, and related parameters). Of particular interest in these system studies is addressing concern about vertical accelerations unseating the girders on the pintles of low profile fixed bearings in construction typical to Illinois, as well as assessing appropriate seat-widths for damage due to dynamic loading.

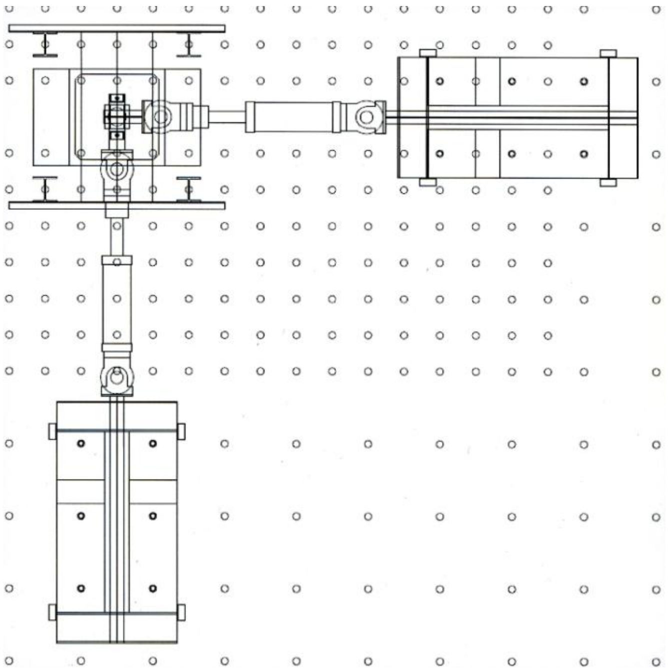


FIG. 6. PRELIMINARY PLAN VIEW OF BEARING TEST SETUP

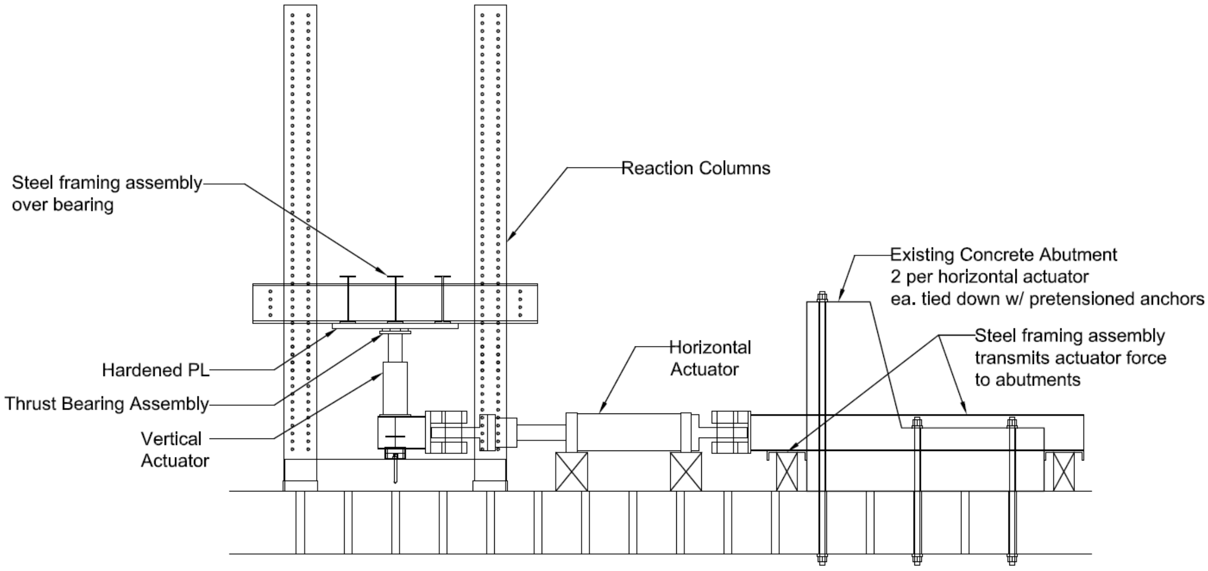


FIG. 7. PRELIMINARY ELEVATION VIEW #1 OF BEARING TEST SETUP

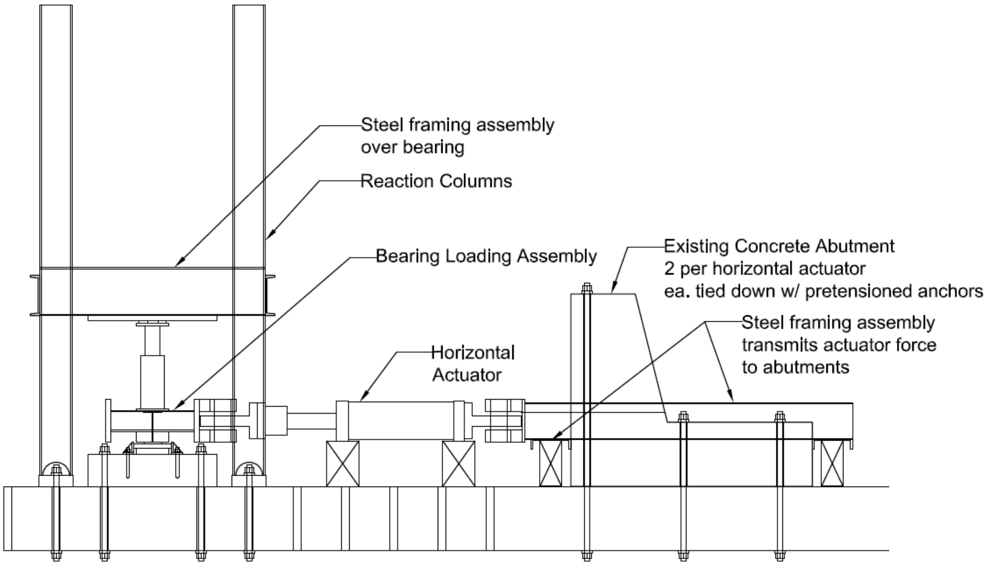


FIG. 8. PRELIMINARY ELEVATION VIEW #2 OF BEARING TEST SETUP

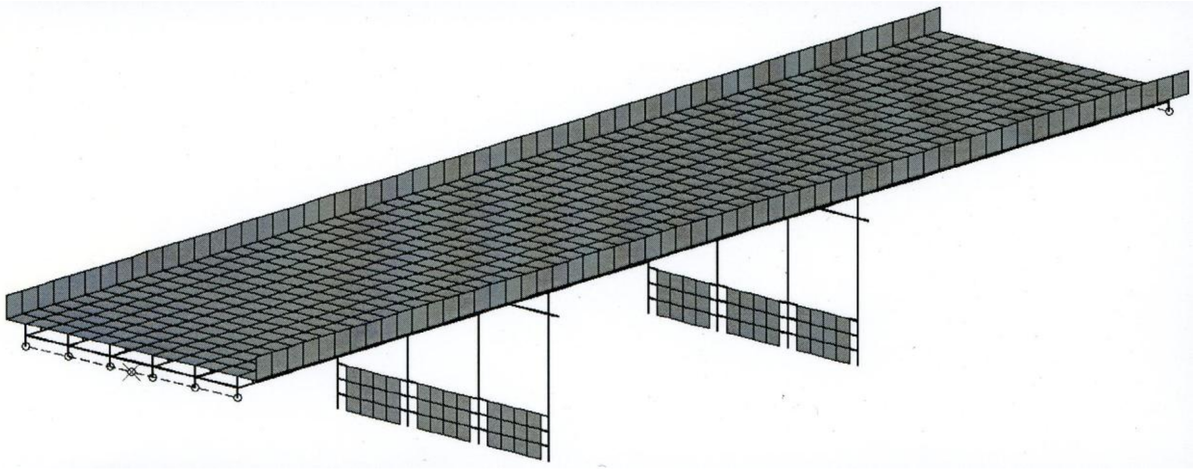


FIG. 9. PRELIMINARY TYPICAL SYSTEM ANALYSIS MODEL

The modeling strategies will typically include detailed macro-level component models of the bridge, where the girders, deck, bearings, and substructure components are modeled explicitly. Model components outside the scope of testing in this research will be calibrated in part based on existing seismic experimental studies of appropriate components available in the literature. Both equivalent static and dynamic analyses will be included in these studies. The equivalent static (pushover) will be used to assess monotonic strengths (system capacity), whereas the dynamic analyses will be used to corroborate the monotonic strengths as well as to determine estimated seismic demands. Seismic records appropriate for Mid-America have been reported in the literature and will be utilized for this study.

Stage 3: Refinement of Strength Reduction Factors (ϕ) and R-factors

Plans for the final stage of the project include adequately processing the system analyses from Stage 2 in order to assess appropriate and calibrated seismic strength reduction factors (ϕ) and design values for R-factors, and to begin development of an appropriate simplified method for pushover analysis for use as part of the typical design procedure in highly seismic regions of Illinois. Simplified pushover analysis in the *LRFD Seismic Guide Specifications* is not well developed for many typical bridge systems used in Illinois.

Acknowledgements

The funding for the ongoing research project described in this paper, *ICT R27-70: Calibration and Refinement of Illinois' Earthquake Resisting System Bridge Design Methodology*, provided by the Illinois Center for Transportation (ICT), is gratefully acknowledged.

The authors also acknowledge the contributions of Mr. Thomas J. Domagalski, Mr. Michael A. Mossman, Mr. Greg D. Farmer, and Ms. Rebecca M. Leach. Mr. Domagalski, Unit Chief of Design in the Bureau of Bridges and Structures at IDOT, contributed valuable advice and guidance during development of the IDOT ERS strategy. Mr. Mossman, Mr. Farmer, and Ms. Leach produced the detailed drawings in the initial part of this paper.

References

American Association of State Highway and Transportation Officials (AASHTO). (2000). *Guide specifications for seismic isolation design with interims*, Washington, D.C.

AASHTO. (2002). *Standard specifications for highway bridges*, Washington, D.C.

AASHTO. (2009a). *Guide specifications for LRFD seismic bridge design*, Washington, D.C.

AASHTO. (2009b). *LRFD bridge design specifications and interim specifications*, Washington, D.C.

Building Seismic Safety Council (BSSC). (1995). "1994 edition NEHRP recommended provisions for seismic regulations for new buildings and other structures." *Rep. Nos. FEMA-222a and FEMA-223a*, prepared by BSSC for Federal Emergency Management Agency (FEMA), Washington, D.C.

Federal Emergency Management Agency (FEMA). (1988). "NEHRP recommended provisions for the development of seismic regulations for new buildings." *Rep. Nos. FEMA-95 Part 1: Provisions and FEMA-96 Part 2: Commentary*, FEMA, Washington, D.C.

Federal Highway Administration (FHWA). (2006). “Seismic retrofitting manual for highway structures, Part 1 – Bridges.” *Pub. No. FHWA-HRT-06-032*, FHWA, Washington, D.C.

Hodel, C. E., Trello, M. J., and Tobias, D. H. (2004). “Seismic retrofitting in Illinois: bridge population implementation.” *Proc., 4th Nat. Seismic Conf. and Workshop on Bridges and Highways*, Federal Highway Administration, Washington, D.C.

Illinois Department of Transportation (IDOT). (2008a). *Bridge Manual*, Springfield, IL.

IDOT. (2008b). *Seismic Design Guide*, Springfield, IL.

International Code Council (ICC). (2000). *International Building Code*, Birmingham, AL.

Leyendecker, E., Frankel, A., and Rukstales, K. (2007). “AASHTO guide specifications for LRFD seismic bridge design.” AASHTO, Washington, D.C.

Multidisciplinary Center for Earthquake Engineering Research (MCEER)/Applied Technology Council(ATC). (2003). “Recommended LRFD guidelines for the seismic design of highway bridges.” *Special Pub. No. MCEER-03-SP03,* MCEER, Buffalo, NY.

National Cooperative Highway Research Program (NCHRP). (2006). “Recommended LRFD guidelines for the seismic design of highway bridges.” *Draft Rep. NCHRP 20-07 Task 193*, TRC Imbsen and Associates, Sacramento, CA.

Tobias, D. H., Anderson, R. E., Hodel, C. E., Kramer, W. M., and Wahab, R. M. (2006a). “Implications of future seismic bridge design provisions for Illinois.” *Proc., 5th Nat. Seismic Conf. and Workshop on Bridges and Highways*, Federal Highway Administration, Washington, D.C.

Tobias, D. H., Anderson, R. E., Kramer, W. M., Hodel, C. E., and Wahab, R. M. (2006b). “Standardized seismic bridge design in Illinois.” *Proc., ASCE Structures Congress 2006*, American Society of Civil Engineers, Reston, VA, 1-8.

Tobias, D. H., Anderson, R. E., Hodel, C. E., Kramer, W. M., Wahab, R. M., and Chaput, R. J. (2008a). “Implementation of 2008 AASHTO Seismic Bridge Design Provisions for Illinois.” *Proc., 6th Nat. Seismic Conf. and Workshop on Bridges and Highways*, Federal Highway Administration, Washington, D.C.

Tobias, D. H., Anderson, R. E., Hodel, C. E., Kramer, W. M., Wahab, R. M., and Chaput, R. J. (2008b). “Overview of Earthquake Resisting System Design and Retrofit Strategy for Bridges in Illinois.” *Pract. Per. on Structural Design and Constr.,* American Society of Civil Engineers, Reston, VA, Vol. 13, No. 3, 147-158.