100 YEARS TRB
MOVING IDEAS: ADVANCING SOCIETY

CENTENNIAL PAPERS

Standing Committee on Seismic Design and Performance of Bridges (AFF50)
Elmer M. Marx, Chair

Seismic Design of Transportation Structures: Setting the Stage and a Vision of the Future

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HISTORY - SETTING THE STAGE

The past century of advancement in the seismic design of transportation structures is viewed in two parts, 1) setting the stage for advancement and 2) the advancements that TRB has helped along.

Setting the stage, we begin with the 1906 San Francisco earthquake, which devastated the Bay Area with both shaking-induced destruction and a subsequent massive fire. In the wake of this event, a professor of engineering at the University of California, Charles Derleth, said "An attempt to calculate earthquake stress is futile. Such calculations could lead to no practical conclusions of value" (1). This statement is a great starting place, because in the last century, we, as a profession, and TRB, as an organization have shown it is not true. Calculating earthquake stresses is not a futile exercise and practical conclusions are the foundation of modern seismic design.

The early part of the century brought scientific advancements that later enabled the development of transportation-related earthquake engineering, of which TRB has been a central part. Earthquakes themselves became better understood and the acceptance of plate tectonic theory in the 1960s helped set the stage for quantification of the ground shaking hazard. Structural dynamics techniques were developed, and they led to analytical and calculation tools that have enabled the effects of seismic hazard on transportation facilities to be quantified.

Techniques such as the development of response spectra, response history analysis, and finite element analysis, all supported by the emergence of, first, the analog and later the digital computer, have opened doors in the engineering world that Professor Derleth could not anticipate. These doors were also opened by experimental techniques that were not available at the dawn of TRB in 1920. The emergence of the large-scale testing and the electric strain gage allowed the development and understanding of inelastic structural behavior, which when coupled later with capacity design principles, gave rise to the design approaches used in the latter part of the TRB first century.

The structural and geotechnical community took these new developments to heart and put into place building codes establishing a minimum standard of care that would ideally prevent loss of life should a large earthquake occur. In 1940, Caltrans and later AASHTO (American Association of State Highway and Transportation Officials) adopted the simple lateral force design approach outlined in the Uniform Building Code for buildings. This approach lived until the early 1970s in the AASHTO specifications.

Along the way, notable earthquakes provided refinement of the understanding of seismic risk, and the industry began developing mitigation strategies that made their way into the early building codes, which as the name implies were largely focused on buildings, not transportation facilities, such as bridges and highways. In the transportation realm, earthquake damage was primarily related to permanent ground movements induced by instabilities and loss of strength in the soil supporting bridges, as experienced by the 1964 Good Friday earthquake in Alaska. Bridge damage did not seem to be related to vibration effects of the bridge itself, unlike the experience of the building industry. However, it was not long before this observation proved unwise, and transportation structures soon caught up to buildings, both in damage type and mitigation approaches.

With the stage set, the second part of the story begins. 1971 brought the now infamous San Fernando earthquake in California. At the time Caltrans was developing new, dynamics-based design methods, but these were yet to be widely deployed. The temblor was a seminal event in transportation structure seismic design. Many bridges, some brand new, were destroyed, and the industry realized that something drastic needed to done to improve seismic design. In fact, the entire built environment suffered in this event, and development of improved design procedures and improved codes began in earnest. We are still enjoying the benefit of the work that began in 1971.

Additionally, the liquefaction-induced failure at the Van Norman Dam during the San Fernando Earthquake of 1971 was a major example re-illustrating the importance of earthquake-induced ground failures. As a result, efforts to appropriately characterize the likelihood of ground failures led to the development of modern methods for evaluating soil deformation subject to liquefaction and the performance-based design of transportation assets subject to geoseismic hazards. The use of more advanced tools than the conventional and widely used Standard Penetration test (SPT), such as CPT (Cone Penetration Test), have provided a major step forward in improving both quantitatively and qualitatively prediction of liquefaction potential and other associated geoseismic hazards affecting our transportation structures. We are now better able to predict a wide range of earthquake-induced ground deformations.

The 1971 San Fernando earthquake began the era of modern seismic design specification development, and prior to that event bridge seismic design, particularly on a national level, was largely undeveloped. The poor performance of bridges in this event led to an expansion of the seismic provisions in the AASHTO bridge design specifications in 1975 and to development of an optional AASHTO guide specification for bridge seismic design in 1983. The 1989 Loma Prieta earthquake re-emphasized the need for rigorous seismic design of bridges, and the guide specification became mandatory, and was adopted into the AASHTO bridge design specifications as “Division I-A” (2). However, the elapsed time from first development of that document to full adoption meant that there was already a need for updated design guidance, and so began the current era to further enhance the AASHTO seismic design documents. This activity also set the stage for the emergence of the TRB seismic committee.

BACKGROUND OF THE COMMITTEE

The TRB seismic committee, AFF50, grew out of the Dynamics and Field-Testing Committee (A2C05 and later AFF40), which covered seismic issues until the 1994 Northridge and 1995 Kobe, Japan earthquakes demonstrated the potential need for a separate committee devoted to seismic design. (*See also the Centennial paper for AFF40, which also provides complementary historical background to this paper for AFF50.*) The first new step was establishment of a Task

Force on 'Seismic Design of Bridges' (A2C52), which was formed in 1994. This group acted like a regular committee, held annual meetings, sponsored sessions, and put forth research needs statements. The task force was successful enough that in the year 2000 the Seismic Design of Bridges Committee (A2C08) was formed; then in a TRB overhaul that committee became the AFF50 committee in 2003. The committee has had strong leadership over its short life with capable chairs from a blend of academic and practice backgrounds. The AFF50 committee chairs have been:

- Manos Maragakis, University of Nevada Reno
- Ian Buckle, University of Nevada Reno
- Michael Keever, California Department of Transportation
- Elmer Marx, Alaska Department of Transportation and Public Facilities

The committee has continued to be well supported with strong participation from throughout the transportation and bridge industry. The current scope of the committee since 2015 has been (3):

This committee is concerned with the performance of transportation structures during earthquakes and development of improved seismic design and retrofitting practices.

Prior to 2015 the more detailed and descriptive scope (4) was as provided below. This version is recalled here because it provides more color regarding the actual focus and activities of the committee.

This committee is concerned with the performance of bridge systems during earthquakes and with the application of that knowledge to developing improved seismic design and retrofitting standards. This knowledge includes the overall performance of bridge structural and geotechnical systems including the superstructure, substructure and foundations. The committee is concerned with studies that are specifically related to the assessment of the seismic resistance and behavior of bridges. In addition, the committee is interested in the sharing of practices which could help enhance the seismic performance of other transportation infrastructure structures such as tunnels and wharves, and the safety and reliability of bridges from a national security standpoint.

TRB is a place for researchers to share the knowledge they develop, then practitioners and owners help take that knowledge and improve the standard of earthquake engineering practice through the development of new design guidelines that AASHTO can adopt and put to use in day-to-day practice.

This is also true of seismic design of bridges and transportation facilities. As additional U.S. earthquakes occurred the pace of innovation and best practice development accelerated. The TRB seismic committee was there to help researchers, practitioners, and owners take the next step to improve earthquake engineering practice across the U.S. and abroad. Many participants in TRB come from around the world, bringing their experiences and skills and sharing them with other TRB participants. The composition of the AFF50 committee reflects the broad constituency of TRB, itself, and the committee currently has 13 members from academia, seven (7) from public agencies, and eight (8) from practice. This composition has remained similar over the history of AFF50.

Through the evolution of the TRB seismic committee, the process for development of new seismic design techniques and seismic design codes became an integral part of the TRB process and was implemented through NCHRP. The AFF50 committee has long had a close association and has provided support for the AASHTO Committee on Bridge and Structures (COBS), formerly Subcommittee on Bridge and Structures (SCOBS), in particular the Technical Committee for Seismic Design, T-3, along with other technical committees. The current AASHTO seismic design specifications have their roots in projects and initiatives that TRB and AFF50 helped conceive, fund, and execute.

The AASHTO T-3 technical committee has also fostered this process in that several chairs of AFF50 committee have also been from the so-called "T-3 States", and these chairs include Mike Keever, from Caltrans, and Elmer Marx, the current chair from the Alaska DOT & Public Facilities. The close cooperation between the AFF50 committee and the AASHTO T-3 technical committee is a prime catalyst for advancement of transportation facility seismic design.

In 2006, the Geoseismic Joint Subcommittee (AFF50(1)) was formed to shepherd the development and deployment of best practices for site and foundation effects on transportation facilities. This joint subcommittee between AFF50 and the Standing Committee on Foundations of Bridges and Other Structures (AFS30) provides much needed collaboration between the geotechnical community and the structural community. This collaboration has always been necessary with transportation facility design because many such facilities are built on sites with challenging and often poor soils.

The AFF50(1) geoseismic subcommittee has had two very capable geotechnical engineering chairs over its short existence:

- Ed Kavazanjian, Arizona State University
- Sharid Amiri, California Department of Transportation

CURRENT STATE OF PRACTICE AND COMMITTEE ACTIVITIES

The seismic committee and geoseismic subcommittee have helped provide platforms for people to share their knowledge through podium and poster session presentations, papers in the Transportation Research Record: A Journal of the Transportation Research Board, and participation directly with the committees. Popular topics for podium and poster sessions at the Annual Meeting include:

- reconnaissance reporting for significant earthquakes world-wide and their effects
- common-themed emerging technologies, both structural and geotechnical
- newly developing analytical techniques, both structural and geotechnical
- case histories in seismic design

Since 2013, the two seismic-focused committees have hosted six workshops at TRB Annual Meetings and hosted seven webinars through TRB to reach even broader audiences. A winning formula has been to first put on a workshop and then follow that up with a webinar to reach people who could not attend the Annual Meeting. These webinars have been very popular and typically have participation levels several times larger than the live TRB workshops, themselves.

Workshop / Webinar topics have included:

- Soil-Foundation-Structure Interaction of Bridge Systems (2013 workshop / 2016 webinar),

- Seismic Pushover Analysis: Using AASHTO Guide Specifications for LRFD Seismic Bridge Design (2014 / 2015),
- After an Earthquake and Extreme Event Assessment of Bridges (2015 workshop only),
- Direct Displacement-Based Seismic Bridge Design (2016 / 2017),
- Seismic Design and Accelerated Bridge Construction (2017 /2018),
- Improving the Earthquake Performance of Bridges Using Seismic Isolation (2016 webinar only), and
- Static and Seismic Design of Piles for Downdrag (2018 / 2018).

The AFF50 committee meetings have been attended by many “friends of the committee”, and to a lesser extent the same is true of the AFF50(1) geoseismic committee meetings. The mid-year meetings of the committees are also well attended, though often by only the committee members. As such, the meetings, themselves, have been a valuable venue for additional presentations beyond the podium and poster sessions. In fact, often more than half of the entire committee meeting is usually occupied with invited presentations or short 3-minute “research nuggets”, brought over from AFF40 by Bob Sweeney.

Topics of presentations at the committee meetings have a wide range and include:

- overviews of experimental work in-progress,
- new concepts for seismically resilient bridge components
- seismic issues and developments with accelerated bridge construction, ABC,
- AASHTO T-3 committee updates
- Updates on USGS’s seismic mapping developments
- Updates on agency specific criteria (e.g. Caltrans, WSDOT)

A central function of the AFF50 and AFF50(1) committees is to solicit, prioritize and help develop Research Needs Statements (RNS) that can be advanced through the TRB and AASHTO processes to select and fund research important to the transportation community. This is one of the most valuable functions and contributions of the committees. If funded, contractors are sought and selected to execute NCHRP projects that often are adopted into AASHTO design specifications. There have been many products from these seismic-focused committees that have influenced AASHTO by providing Synthesis documents and NCHRP research reports, some of which have been adopted into the AASHTO specifications.

Synthesis documents are often used to pull together existing information and knowledge on a given topic to help map a strategy to address a given topic. Synthesis documents serve as a point-in-time compendium of the state-of-practice and state-of-research for a topic, and as such are usually extremely valuable in helping both practitioners and research understand emerging topics. These syntheses often then lead to a formal NCHRP research project to address a topic and typically also provide draft guidance for specification language to be considered by AASHTO. The AFF50 and AFF50(1) committees have been relatively successful in proposing and facilitating synthesis documents.

Example synthesis documents include:

- NCHRP 20-05 Topic 12-88 *Application of Accelerated Bridge Construction Connections in Moderate-to-High Seismic Regions* (NCHRP Report 698)
- NCHRP 20-05 Topic 43-07 *Performance Based Seismic Design* (NCHRP Synthesis Report 440)

- NCHRP 20-05 Topic 46-11 *Post Extreme-Event Assessment of Infrastructure Damage to Highway Bridges* (NCHRP Synthesis Report 497)
- NCHRP 20-05 Topic 49-12 *Seismic Design of Non-Conventional Bridges* (in press)

Formal NCHRP projects are the prime goal of the committees, as these documents are ones that directly impact practice in the profession. Example NCHRP documents that the committees have helped bring to fruition include:

- NCHRP 12-49 *Recommended LRFD Guidelines for Seismic Design Specifications for Highway Bridges* (MCEER/ATC-49. This effort was helped along by predecessor Task Force A2C55 and Committee A2CO8.)
- NCHRP 20-7 Topic 193 *Recommended AASHTO Guide Specifications for Displacement-Based Seismic Design of Bridges*
- NCHRP 20-7 Topic 262 *Update of the AASHTO Guide Specifications for Seismic Isolation Design*
- NCHRP 12-101 *Seismic Evaluation of Bridge Columns with Energy Dissipating Mechanisms* (NCHRP Report 864)
- NCHRP 12-105 *Proposed AASHTO Seismic Specifications for ABC Column Connections* (in progress)
- NCHRP 12-106 *Proposed Guidelines for Performance-Based Seismic Bridge Design* (in progress)
- NCHRP 12-114 *Guidance on Seismic Site Response Analysis with Pore-Water Generation* (in progress)

The Structures Section seismic (AFF50) and geoseismic (AFF50(1)) committees are helping advance earthquake engineering and are doing exactly what Professor Derleth said was futile to do and of no practical value. TRB has closed out its first century with a very strong finish in terms of contributing to bridge and transportation structure seismic safety. This is especially impressive given the slow and late start to putting transportation earthquake engineering on a truly rigorous basis.

TOMORROW - VISION FOR THE FUTURE

In the near future, and certainly in the next century, we expect that earthquake engineering of bridges and transportation facilities will shift away from simple life-safety based specifications and move towards preserving functionality following a major earthquake. Known as performance-based engineering, this approach will not only help protect the lives of the traveling public but also preserve the economic viability of geographic regions impacted by major earthquakes. Work is currently underway in this arena, but this work is incremental. Much data, many new design techniques, new decision-making approaches, and technical training are required. Thus, it will take many years for the full benefit of performance-based seismic design to be realized. The benefits will be worth the wait, because one day we may be able to better predict damaging earthquakes, design bridges to withstand their effects without damage, and by doing so, help communities avoid the physical, social and economic costs that large damaging earthquakes impose. Professor Derleth threw down a metaphorical gauntlet with his statement in the wake of the 1906 San Francisco earthquake, and subsequent generations of engineers from around the world and from all walks of life have, 100-year-plus years out, risen to the challenge of calculating response and designing highly resilient transportation systems. There is no reason to doubt that engineers in the next 100 years will achieve any less than those of the last century.

Much remains to be done and TRB and the AFF50 Committee and AFF50(1) Joint Subcommittee are helping achieve these goals today and they, along with the other TRB committees, will help produce transportation systems that are indeed resilient in many ways: resilient to heavy use, resilient to extreme events and most of all, safe and available for the communities they serve.

REFERENCES

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3. Triennial Strategic Plan (TSP), 2012 to 2015, Standing Committee on Seismic Design and Performance of Bridges (AFF50), Transportation Research Board.
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