Fast healers
Caltrans develops seismic bridge strategy that works with accelerated bridge construction

California’s history of seismic events has shown how earthquake-induced forces have resulted in significant damage to transportation structures.

Large-magnitude ground motions tend to inflict major damage to highway bridges and reduce or even sever the movement of goods and services in a metropolitan region. California is one of the most seismically active regions in the world. The state has experienced more than 20 significant earthquakes (magnitude ≥6.0) since the 1906 San Francisco earthquake. Recent seismic events, particularly the 1971 San Fernando, 1989 Loma Prieta and 1994 Northridge earthquakes, have led to the development of ductile details and better seismic performance criteria for concrete bridges. The examination of bridge failures and damages, especially those constructed prior to 1971, indicates that the failures are largely attributed to the design philosophy adopted at the time, coupled with the use of relatively nonductile design details. This led to a significant increase in research efforts in developing new seismic design philosophy for new bridges and retrofit strategies for existing structures.

Since the 1970s, the California Department of Transportation (Caltrans) has been a leader in the field of seismic research, design and construction of transportation-related structures. Caltrans has a vested interest in ensuring that the state’s roads and bridges are not undermined, threatened or destroyed by natural hazards, such as earthquakes. To this end, Caltrans has been conducting, sponsoring or otherwise participating in extensive research to identify the failure mechanism in an earthquake event and developing new philosophy, criteria and technologies in bridge seismic design.

Over the last decade, the nation’s economic and population growth, coupled with decaying infrastructure, have led to the omnipresent need to rapidly replace, widen and build new highway infrastructure and thus bridge structures. Transportation agencies are under increasing pressure to improve highway and bridge systems using accelerated bridge construction (ABC) techniques: a construction approach that can reduce onsite construction time and mitigate long time impacts to the public and...
environment. In 2009, Caltrans began to develop the Next Generation Bridges (NGB) for ABC that will meet or exceed current seismic performance standards. The NGB system mainly utilizes prefabricated structural components, because the components can be assembled quickly on site with reduced impact to the site environment and public. Prefabricated structural components also allow for easy repair and replacement. However, using prefabricated components requires a solid understanding of the systems’ seismic performance from moderate to large earthquakes.

**Prevent defense**

Since the 1990s, Caltrans’ seismic design philosophy has been to use a deformation ductility approach on bridges to achieve a collapse-prevention performance level. Ninety-nine percent of the state-owned highway structures in California are designated as ordinary bridges, and they are designed to adhere to the seismic collapse-prevention philosophy. The collapse-prevention philosophy allows the bridge elements to experience inelastic ductile response but remain standing and resilient after a major earthquake. This approach is based on the relatively low probability that a major earthquake will occur at a given site, offset by the potential need to absorb the repair cost incurred by a future major earthquake.

The seismic collapse-prevention philosophy prescribes ductility in the bridge columns, while the superstructure (girders and bent caps) and foundation (footing, piles, abutments) systems remain elastic during a seismic event. Inelastic ductile behavior is limited to columns, because they can be readily and easily inspected and repaired following an earthquake. Superstructures and foundations are protected from inelastic response and damage because they are difficult to repair or replace.

Ductility allows the columns to deform inelastically in hysteric force-deformation cycles without significant degradation of strength or stiffness under earthquake demands. The primary type of ductility response is generated by forming flexural plastic hinges in well-confined column sections. The displacement capacity relies on a bridge column’s ability to undergo dependable deformation in plastic hinge regions without experiencing brittle failure.

The displacement ductility approach ensures that the structural system has enough capacity to withstand the deformations imposed by the design earthquake. Furthermore, current seismic design and details do not explicitly guarantee that the damaged column component can be expeditiously repaired or replaced so that the bridge structure can be put back into service, enabling quick recovery of the transportation infrastructure.

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**This is important**

The San Francisco-Oakland Bay Bridge consists of two major structures separated by Yerba Buena Island. The West Bay Crossing goes from San Francisco to Yerba Buena Island and the East Bay Crossing from Yerba Buena Island to Oakland.

The West Bay Crossing consists of a twin suspension structure and the East Bay Crossing consists of a series of simple span trusses and a number of simple span deck systems.

Following the Loma Prieta earthquake, Caltrans designated the San Francisco-Oakland Bay Bridge as an “important” bridge: a transportation structure that needs to provide lifeline service to limit economic loss after a major earthquake. To provide lifeline service, an important bridge needs to adequately serve emergency vehicles and equipment after a major earthquake and thus needs to meet stringent seismic performance criteria.

The seismic risk to the new San Francisco-Oakland Bay Bridge comes mainly from the Hayward fault, which is capable of generating an 8.1 Richter-magnitude earthquake. The important bridge requirements and the high seismicity in the Bay Area required innovative seismic mitigation design solutions, allowing inelastic deformation in clearly designated structural components that were specially designed for this purpose.

The Skyway consists of two parallel segmental precast concrete viaducts located across the joints separating each frame, the hinge pipe beams were designed to form plastic hinges under extreme load cases.
beams were designed to form plastic hinges under extreme load cases. The expansion joints separating the frames had two hinge pipe sections, which contained a weaker mid-section to facilitate a fuse. The hinge pipe beam also allows longitudinal and earthquake loads, due to centric vertical movement, due to centric vertical tower walls in the transverse vertical walls, with legs in the transverse vertical tower walls allowing for the tower legs. The shear links were designed to be replaceable after a major seismic event. The shear links and the hinge pipe beams are good examples of details developed to control the locations of the damage and repair after a seismic event.

Fast forward in the future

In California, cast-in-place (CIP) construction has been the preferred practice for over 30 years. Typical CIP operations include lead-off, casting and finishing time and also requires a complex falsework system that affects the moving traffic during construction. Since 2009, Caltrans has been developing Next Generation Bridge (NGB) systems to meet or exceed current seismic performance standards and the ABC needs. The main objective for the NGB system is to facilitate rapid on-site construction that reduces traffic impacts to the surrounding environment and provides for a faster recovery from a major seismic event.

Recognizing that prefabricated elements can reduce overall on-site construction time and also eliminate the falsework requirement and mitigate impacts to the moving traffic, Caltrans has designated Next Generation Bridge systems to employ prefabricated elements in the research and development efforts. The move also will help accelerate bridge maintenance when needed.
The existing San Francisco-Oakland Bay Bridge will be demolished as soon as the new span is complete. Earthquakes in the San Francisco region led to the development of ductile details and better seismic performance criteria for concrete bridges.

Post-tensioned segmental columns have been conducted in the U.S. and other nations, and favorable seismic performance was observed and noted. The column segments were connected by longitudinal rebars from the bent cap to the footing. Subsequent tests indicated that the longitudinal rebars provided considerable energy dissipation during seismic motions and thus mitigated damage to other structural components.

In efforts to advance the development of NGB details, Caltrans sponsored two different new details of segmental prefabricated columns. In the first detail, the segments are connected by a single post-tensioning rod or tendon. The post-tensioned rods are prestressed, and they would serve as a self-correcting mechanism to minimize seismic displacements.

The post-tensioned column segments were seismically tested on a shake table using a simulated large-magnitude earthquake motion. The tests showed that the post-tensioned columns exhibited good seismic performance, although the behavior differed from that of cast-in-place columns. The research results showed that the post-tension rods possess a good self-centering mechanism that can significantly reduce the seismic residual displacement of the column and exhibited excellent displacement ductility capacity. Furthermore, because of the relatively slight damage induced from the earthquake, the precast column can be rapidly retrofitted by installing fiber-reinforced polymer wrap or steel shell to confine the damaged plastic hinge regions.

The second details focus on the seismic performance of precast column connections to footings, pile shafts and bent caps using special longitudinal steel couplers without any post-tensioning. The steel couplers provide workers a fast assembly process and they serve an important engineering role by providing moment resistance continuity to the column foundation joint regions. If the test showed favorable performance, the use of steel couplers could lead to innovative repair technologies.

A recommended repair technique can be employed by engineers to remove the heavily damaged column segments and install new sections by connecting the reinforcement bars with steel couplers. To test the performance of the steel-coupler connections, Caltrans has sponsored a research study that will consist of analytical and experimental research. The experimental task will test each column connection component on a shake table using a simulated large-magnitude earthquake motion. The test models will be approximately a 0.4 scale representation of the Caltrans details. The performance of the fixed and pinned test columns will be evaluated based on data obtained in previous shake-table tests of fixed and pinned columns. These data, along with detailed analytical models, will help shed light on the adequacy of the precast column footing connections. These research projects are currently under way, and the final results are scheduled to be released for detailed design development in late 2011.

The new structural details and the research will address an essential need of ABC and the NGB that will minimize delay in the operation and repair of bridges. The outcome of the research could be used in partial or total bridge replacement on existing highways or could be used in construction of new bridges in future highways.

Running rapid

The seismic design of next-generation ABC bridge details poses some significant challenges to bridge engineers. Caltrans, as a world-leading government transportation organization, has made efforts in developing new seismic design criteria to meet increasing demands for rapid replacement.

ABC is a crucial effort in Caltrans, for it serves to improve mobility and reduce travel delays. Caltrans engineers must not only be cognizant of the impacts their planned works have on traffic, but also must find solutions to minimize such disruptions. Such solutions can improve mobility with minimum time and traffic delays as a basic parameter in the transportation improvement equation across the nation.

ABC has been a leading focus of national and international research, with numerous funded projects in academia and industry. Recently in the U.S., programs have been developed to investigate viable solutions in terms of economics and constructable details to meet increasing elements of rapid construction and reduced traveler delay. The need for accelerating transportation construction is not limited to North America; European and Asian countries have embraced the idea and in many senses are leading the innovations.

In the end, widespread implementation of ABC will greatly serve the public by benefiting commerce, the traveling motorists and the economy of the region and society. DI

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