PRECAST CONCRETE BRIDGE SUBSTRUCTURE SYSTEMS AND DETAILS FOR SEISMIC REGIONS

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ABSTRACT

This paper summarizes several precast concrete bridge substructure systems and details for seismic regions based on the 2004 FHWA/AASHTO International Scan on Prefabricated Bridges and recent California projects, and also introduces concepts to be developed through NCHRP Project 12-74, “Development of Precast Bent Cap Systems for Seismic Regions”. Systems and details include: 1) partially-precast segmental pier system; 2) continuity details; 3) precast bent cap systems, including emulative and jointed systems. All systems and details have recently demonstrated viability or potential for application and provide one or more of the following benefits over traditional cast-in-place construction: reduced traffic disruption, environmental impact, and/or life cycle cost; improved work zone safety, constructability, and/or quality.

Keywords: Bridge, Precast Concrete, Seismic, Substructure, Bent Cap, Connections, Emulative, Jointed

INTRODUCTION

The aging highway bridge infrastructure in the United States is being subjected to increasing traffic volumes and must be continuously renewed while accommodating traffic flow. The traveling public is demanding that this rehabilitation and replacement be done more quickly to reduce congestion and improve safety. Conventional bridge reconstruction is typically on the critical path because of the sequential, labor-intensive processes of completing the foundation, substructure, superstructure components, railings, and other accessories. New bridge systems and reliable connection details are needed that will allow components to be fabricated off-site and moved into place for quick assembly while maintaining traffic flow.

This paper summarizes several innovative precast concrete bridge substructure systems and details for seismic regions based on the 2004 FHWA/AASHTO International Scan on Prefabricated Bridges and the San Mateo-Hayward project recently completed by the California Department of Transportation (Caltrans). In addition, concepts to be developed through NCHRP Project 12-74, "Development of Precast Bent Cap Systems for Seismic Regions" are introduced, including system concepts, prior relevant research, research tasks, and end products.

Systems and details include: 1) partially-precast segmental pier system; 2) continuity details, and 3) precast bent cap systems, including emulative and jointed systems. All systems and concepts have potential or recently demonstrated viability for application.

2004 FHWA/AASHTO INTERNATIONAL SCAN ON PREFABRICATED BRIDGES

The 2004 Federal Highway Administration (FHWA)/American Association of State Highway and Transportation Officials (AASHTO) International Scan on Prefabricated Bridges identified various precast concrete bridge systems and connection details used in seismic regions or that emphasized continuity appropriate for seismic regions, including a partially-precast segmental pier and continuity details for superstructure-to-substructure connections.[1-3]

PARTIALLY-PRECAST SEGMENTAL PIER SYSTEM

The Sumitomo Precast form for resisting Earthquakes and for Rapid construction (SPER) system is a segmental pier system developed for rapid construction of bridge piers in seismic regions using factory-manufactured, stay-in-place precast concrete panels as both formwork and structural elements.[3,4] As shown in Figure 1(a), precast panels with pre-installed cross ties (transverse reinforcement) serve as exterior formwork for short piers. Segments are stacked using epoxy joints and then filled with cast-in-place (CIP) concrete to form a solid pier (Figure 1(b)). Figure 1(c) shows a completed pier.

Figure 2(a) shows inner and outer forms used to produce a hollow section for taller piers. To reduce segment weight for hauling, panels form two channel-shaped sections. Lateral reinforcement is embedded within the channel sections and joined together in the field using couplers. Assembling of inner and outer forms in the field is shown in Figure 2(b). After inner and outer precast forms are set around longitudinal bars, cross ties are placed, and concrete is cast within the section. Completed hollow piers are shown in Figure 2(c). Use of high strength bars for cross ties reduces congestion and fabrication time. Transverse reinforcement is anchored into the panels using a special detail that includes the use of U-bars and H-sections. Cast-in-place concrete is used to connect the piers to the superstructure. Used on four bridge projects including the Otomigawa Bridge in Ayabe City, Kyoto Prefecture (330-m (1083 ft), 4-span continuous prestressed concrete rigid frame), the SPER system has decreased construction time approximately 50% over conventional CIP construction for piers up to 11.5 m (38 ft) when a total of 200 m (656 ft) of combined pier height is used. This is attributed to the elimination of formwork and reduction in curing time. For two 50-m (164-ft) piers reduction in placement time for lateral reinforcement and cross ties resulted in a 1/3 decrease in construction time. Use of high performance concrete in the panels provides a high quality, durable external finish and an aesthetic appearance.

Experimental research of the SPER system has demonstrated that stay-in-place forms develop composite action with the CIP concrete and that piers achieve a seismic performance comparable to conventional reinforced concrete piers. Other researchers in Japan have also explored the use of unbonded post-tensioned precast segmental piers, but concerns remain regarding the suitable seismic response of such systems.[5]

CONTINUITY DETAILS

To achieve continuity and monolithic action between precast elements, various details have been developed in Japan and Europe for use with CIP pours. The following section illustrates details used for superstructure-to-substructure continuity.

In addition to Japan, Germany has used methods to accelerate construction, especially for the autobahns.[2] Although bridges in Germany are not typically designed for seismic resistance, engineers have used a conservative approach that emphasizes continuity and redundancy for prefabricated, prestressed concrete bridges on Federal highways. Based on a 1993 general circular issued by the Secretary of Transportation, prefabricated, prestressed concrete components may be used only under highly restrictive conditions such as single spans with a length less than 35 m (115 ft), skew less than 36 degrees, radius of curvature for multi-span bridges greater than 500 m (1640 ft), and not for major river or valley crossings. Connections for precast elements such as deck elements are required to be monolithic with CIP pier caps, and the number of bearings must be minimized. Continuity in the longitudinal direction for multi-span bridges must be ensured, and transverse prestressing of diaphragms or pier caps is not permitted. Tee-beams are recommended for use, as I-beams are not permitted because of corrosion and aesthetic concerns related to bird droppings and salt that may collect on the top surface of the bottom flange. In addition, all prefabricated, prestressed components must adhere to the same principles for design, accessibility, inspectability, replaceability, and durability as CIP concrete bridges.

Because of these limitations, prefabricated concrete elements are used only in special situations to accelerate construction, minimize traffic disruption, or minimize formwork and falsework use. Bridge construction cost data indicate that initial cost of bridges using precast concrete average 25 percent more than CIP concrete bridges.

Figure 3 shows a bridge example based on these criteria. Longitudinal continuity is provided by using CIP concrete decks and making the girders integral with the pier cap. Mainly to enhance apparent slenderness of the bridge, rectangular or inverted bent caps are used with the girders. Transverse continuity and evenness of the deck are also provided by the CIP deck. To provide the integral connection with the pier cap, the beams are temporarily supported on shoring, as shown in Figure 3(b). The end of the beam is then cast within the pier cap to make it integral. Longitudinal post-tensioning tendons over the pier cap may also be provided to enhance continuity. It has often been found that the optimum economic solution is to provide about 50 percent of the prestressing in the precast, prestressed concrete beams and 50 percent as post-tensioning after erection. Diaphragms are also used at abutments to minimize the number of bearings.

SAN MATEO-HAYWARD BRIDGE WIDENING PROJECT

In recent years, Caltrans has developed innovative precast substructure systems and details that have been applied on projects in highly seismic regions. The following section focuses on the San Mateo-Hayward Bridge Widening project.

BACKGROUND

The San Mateo-Hayward Bridge, originally constructed in the late 1920's, serves as a vital link on Highway 92 between the cities of Hayward and San Mateo and is a major commuter route from the East Bay Area into San Francisco (Average Daily Traffic of 81,000 vehicles). In the early 1990's, Caltrans decided to build a new bridge parallel to the existing bridge to increase the capacity from four to six lanes and add two emergency shoulders. During the initial study, the main challenge was to find a rapid and economical solution to construct the 276-span, 4.7-mile long structure over the environmentally sensitive San Francisco Bay. Conventional CIP construction using falsework was not considered viable. Rather, an "over the top" technique was preferred to keep construction out of and above the water. Caltrans designed three structure types—all of which consisted of prefabricated bridge components—as alternatives for contractors to bid, with the major goal of eliminating falsework in the waterway. The successful lowest bid for construction was \$113 M (\$73/ft^2). The design includes a superstructure that consists of precast, prestressed bulb-tee girders and partial-depth pretensioned deck panels with a CIP deck. The substructure uses a partially-precast bent cap with CIP pours and precast prestressed piles.[6]

It is important to note that, in California's bridge design and construction history, the use of precast concrete for superstructures has greatly lagged behind the use of CIP concrete. The primary reason is the uncertainty associated with seismic performance and design methods when using precast concrete, especially related to connection design. The lack of research and design experience has caused most California bridge engineers to shy away from the use of precast systems. Contractors consequently have less experience and cost incentive to use precast concrete. Therefore, this project is the first of its kind to use such a wide array of prefabricated products and is the largest precast project (in cost) in California to date.

DESIGN BASIS

When precast bridge systems are used in seismic regions, monolithic action between precast components, especially between the superstructure and substructure, is normally considered a key to achieving adequate ductility and resistance. During design of the alternatives, there were no preexisting design methods for the precast concrete system and connection details that conform to the Caltrans Seismic Design Criteria.[7] However, monolithic behavior was assumed in design and is anticipated for the San Mateo-Hayward Bridge because of the use of a major CIP pour. The superstructure is made continuous longitudinally and integral with substructure by a CIP pour at each bent cap. The superstructure elements are made integral through the use of a CIP deck.

Superstructure

As shown in Figure 4(a), the superstructure uses eight 1.1 m (3 ft 8 in) deep modified pretensioned California bulb-tee girders that span an average of 27 m (90 ft). 8-cm (3 1/8 in) thick pretensioned concrete deck panels are used to eliminate formwork for the deck pour (Figure 4(b)). The CIP concrete deck is poured directly on the deck panels to produce an 18.2-m (60-ft) wide composite deck. The deck thickness is 19 cm (7.5 in) and the total superstructure depth with deck is 1.37 m (4 ft 6 in). The superstructure depth to span length ratio is 0.05.

Substructure

Partially-precast U-shaped bent caps have been designed to provide a ledge for the girders during erection and to provide a means to construct an integral connection between the superstructure and substructure. Figure 5(a) shows the precast portion of the caps, which are 0.75 m (2 ft 6 in) deep. Figure 5(b) shows the caps in place over precast piles and supporting girders, which extend into the cap. Two or three 1.1-m (42-in) diameter precast prestressed hollow concrete piles support each bent cap (Figure 5). Completed caps have an increased depth of 2.1 m (7 ft) after a large closure pour. As shown in Figure 6(a), reinforcement from piles extends through a prefabricated hole in the bottom of the bent cap to make a fixed connection between the pile and bent cap. Deck reinforcement is continuous as well (Figure 6(b)).

Expansion joints are placed at every third bent. At fixed bents, the superstructure is made continuous longitudinally by mechanically butt splicing three #36 (#11) bars that protrude from the bottom flange of each girder (Figure 5(b)). The spliced reinforcement provides adequate flexure capacity to resist the plastic hinging moment from the piles in a seismic event. At expansion joint bents, the three #36 (#11) girder bars are hooked into the bent cap to make a fixed connection to one span. The other side of the bent cap has an expansion joint seat on which the adjacent superstructure span sits. Steel pipes are used at each expansion joint to resist both longitudinal and transverse seismic loads. Adequate seat width and seismic pipes prevent unseating of the girders.

CONSTRUCTION SEQUENCE

Most bridge components were prefabricated in the precast yard and shipped to the construction site by barge. Precast prestressed piles were shipped to the site and driven segment-by-segment into the bay mud. Then, the partially-precast U-shaped bent caps with openings for pile placement were installed over piles and CIP concrete was poured in stages in the cap region. The first pour was up to bottom of the girder ledge to seal the void of the pile/cap connection (Figures 5(b) and 6(a)). After the pile-to-cap joint reinforcement and bent cap reinforcement were installed, a second pour filled the cap. Pretensioned bulb-tee girders were erected and braced and precast deck panels were then placed on girders. After deck reinforcement was installed, a 5-in topping slab was poured. Construction of the entire bridge widening required three years.

SYSTEM ADVANTAGES

The extensive use of precast components on this project eliminated falsework in the San Francisco Bay and thus enabled the major goal to be achieved: a rapid and economical system that minimizes environmental impact. Traffic disruption was minimized by shipping precast products by water and work zone safety was also improved. The use of plant-produced precast components improved produce quality and durability. The use of a partially-precast bent cap provided many benefits: 1) Through the use of a ledge, it provided a convenient means to support the girders for rapid erection; 2) Through the use of both precast and CIP concrete, it helped reduced the reinforcement congestion that is typically encountered in bent cap construction; 3) It provided an effective connection method to achieve monolithic behavior and continuity for seismic performance. Overall, the use of precast components and innovative connection details achieved the project goal and lowered the total construction cost.

DEVELOPMENT OF PRECAST BENT CAP SYSTEMS FOR SEISMIC REGIONS

INTRODUCTION

For decades, precast concrete components have been used extensively in bridge superstructure systems. However, despite the many recognized potential benefits, precast bent caps have only recently been considered a viable alternative. Reasons for this trend include the long period over which cast-in-place design and construction practices have developed into the industry standard, as well as the lack of a design methodology, connection specification and details for precast bent cap systems. However, the growing demand for accelerated construction has spurred the development of precast substructure systems throughout the United States. Recent applications of precast bent caps include SH-66/Lake Ray Hubbard Bridge near Dallas, IH-45 Pierce Street Elevated in Houston, and Route 57 over Wolf River in Fayette County, Tennessee, and the San Mateo-Hayward Bridge, among others. However, major uncertainties exist in design and construction of such systems in seismic regions.

NCHRP Project 12-74, “Development of Precast Bent Cap Systems for Seismic Regions” is intended to address these uncertainties. The objective of this project is to develop a design methodology, connection details, and design and construction specifications for precast bent cap systems in low, moderate, and high seismic regions. Specifications will be developed in a form suitable for consideration by the AASHTO Highway Subcommittee on Bridges and Structures (HSCOBS).[8] Reference 8 summarizes the problem statement for the research, which will be conducted from approximately September 2005 to September 2008. The research team consists of researchers from University of California at San Diego and California State University, Sacramento, as well as three consultants and an industry advisory group.

The following sections introduce Project 12-74, including system concepts, prior relevant research, research tasks, and end products. This is based primarily on Reference 9.

CONCEPTS FOR PRECAST BENT CAP SYSTEMS IN SEISMIC REGIONS

Seismic Design Philosophy

To implement a precast bent cap system in seismic regions requires an understanding of seismic design philosophy and behavior of precast bridge systems.[9] The primary basis for prior AASHTO guidelines was to minimize the loss to life and limit damage in essential bridges. The following premises were accepted as the cornerstone of the seismic design philosophy:

- Small-to-moderate earthquakes should be resisted within the elastic range of the structural components without damage
- Realistic seismic ground motion intensities should be used in the design procedure
- Exposure to shaking from large earthquakes should not cause collapse of a bridge system or element, but can produce damage
- Damage should be readily visible to permit evaluation and possible repair

The AASHTO specifications still adhere to the philosophy of accepting structural damage, as long as collapse is avoided in the case of a major earthquake. With such philosophy, bridges are designed for lateral forces smaller than those required for the structure to respond elastically in a rare earthquake, which is typically assumed to be that with a 90 percent of non-exceedance in 50 years.

Design for reduced lateral forces implies the development of regions of inelastic response in a bridge. These regions are mainly flexural plastic hinges that ultimately result in the development of a plastic collapse mechanism. Plastic hinges are specially detailed to ensure ductility and provide stable energy dissipation during a seismic event. Preferred locations are parts of the bridge that readily provide access for post-earthquake inspection and repair such as column tops. Because of lack of access and difficulty of repair, plastic hinges are not designed to form in bent caps. Bent caps are generally designed to be flexurally stronger than the columns so that plastic hinges can potentially develop at one or both column ends. However, bent caps form a critical part of the load path for transfer of longitudinal and transverse inertial forces between the superstructure and substructure. In earthquakes, these elements must simultaneously transfer gravity load from the superstructure as well as inertial forces caused by the dynamic response of the bridge.

Integral vs. Non-Integral Bent Caps

Bent caps can be classified as integral or non-integral depending on the method of construction and mode of seismic response. For integral bent caps, the girders are constructed monolithically with the bent cap, resulting in framing action in the longitudinal direction of the bridge. However, for non-integral bent caps, the girders are supported on bearings on the bent cap, and therefore inertial forces in the longitudinal direction of such bridges are resisted by cantilever action of the supporting columns. Because of the longitudinal framing action for integral caps, plastic hinges are expected to develop at the column tops. In bridges built with non-integral bent caps, plastic hinges are likely to form only at the base of the columns in the longitudinal direction of the bridge.

The choice of using an integral vs. non-integral bent cap is generally determined based on seismic demands. In high seismic regions, it is unlikely that the bending moment demands and deflection limits can be achieved using non-integral bent caps. In addition, larger, more costly foundations are required. In contrast, non-integral bent caps can be efficient in bridges located in moderate and low seismic regions.

Single-column vs. Multi-column Bents

The seismic response of bridges with single- vs. multiple-column bents also differs. In many situations the use of single-column bents is preferred for aesthetic reasons. Single-column bents imply that seismic resistance provided by the column in the transverse direction of the bridge is provided by cantilever action, and a plastic hinge is thus expected to form at the base of the column. In multiple column bents, the bent cap produces framing action between the columns, producing plastic hinges in the columns. In addition, multi-column bents can limit seismic demands more than single column bents, thus providing a viable solution in high seismic regions.

Emulative vs. Jointed Behavior of Precast Systems

During the past several decades, significant seismic research efforts have been directed at cast-in-place and precast concrete systems for building structures. The implementation of innovative ideas for connecting precast elements together, and subsequent verification through experimental procedures, has resulted in significant advances for accelerated building construction in seismic regions of the world. In contrast, only cast-in-place concrete lateral force resisting systems have been developed for bridges. However, the growing impact caused by extended lane closures during bridge construction in many dense urban or environmentally sensitive areas in seismic regions has spurred the development of precast bridge systems, including substructures.

Precast concrete systems that are part of the lateral force resisting system are generally classified as either emulative or jointed. Emulative systems typically use "wet" connections, i.e., cast-in-place pours that are used to join precast elements, with the intended result that the precast structure emulates a monolithic cast-in-place structure. Emulative systems have hysteretic response characteristics that resemble those of conventional cast-in place construction, where plastic hinges develop and spread in targeted elements in the structural system. This emulative approach has been widely and successfully used in seismically active regions of the world, including the U.S., Japan and New Zealand.[10]

In jointed systems, dry connections are used between precast elements, without cast-in-place concrete. A variety of approaches have been developed, such as grouted bars and post-tensioning. Because a natural discontinuity forms between the precast elements, the non-linear response of the system concentrates at specific joints between the precast elements. Major advances in jointed systems have recently been achieved through the PRESSS (PREcast Seismic Structural Systems) research program, with results having already been implemented in practice.[11-12]

The lateral-force displacement response characteristics of jointed systems heavily rely on the gravity and prestressing restoring forces. Unbonded post-tensioning, with bars or tendons that are properly protected to meet durability requirements, is best suited to jointed systems. A comparison of the hysteric response for emulative and jointed systems reveals that a large amount of energy dissipation is associated with the traditionally reliable and stable seismic behavior of a cast-in-place or emulative yielding system. This response has traditionally been sought in bridge systems, despite the fact that a significant residual displacement is likely after a major event. In contrast, a characteristic flag-shaped seismic response results for a jointed system that is designed to self-center. Although the amount of energy dissipation is reduced in the jointed system, the system ideally returns to a zero-force, zero-displacement point at every cycle, as well as at the end of the seismic event. It has also been demonstrated that stable seismic response of buildings is achievable with much less damping than that associated with full emulative behavior.

While the principle of avoiding collapse in strong earthquakes still prevails in practice, some communities in congested areas may expect bridges to survive a moderately strong earthquake with little to no disturbance to traffic. The jointed system provides a structural system that: (a) incorporates the nonlinear characteristics of yielding structures and, thereby, limits the induced seismic forces and provides acceptable damping characteristics; (b) encompasses self-centering properties allowing the structural system to return to its original position after an earthquake; and (c) reduces or eliminates cumulative damage to the main structural elements. These factors indicate response that allows a structure to be immediately functional after a major earthquake. Application of jointed concepts to bridge piers appears to holds much promise as an alternative to emulative connections and systems.

It is anticipated that both emulative and jointed systems can provide reliable performance to satisfy a variety of performance expectations by owners.

PRIOR RESEARCH RELATED TO PRECAST BENT CAP SYSTEMS

Non-Seismic

Prior research for both non-seismic and seismic regions has been conducted and provides a basis for NCHRP 12-74. The Texas Department of Transportation (TxDOT) sponsored Project 1748, "Development of a Precast Bent Cap System" at the University of Texas at Austin.[13] Three categories of connections types were developed: grouted ducts, grout pockets, and bolted connections. The program included monotonic pullout tests and beam-column connection tests that addressed variables such as anchorage of straight and headed epoxy-coated reinforcing bars, bar size, embedment depth, and grout brand, as well as full-scale construction and testing of a precast bent cap system. End products included a design methodology, construction guidelines with a precast connection specification, and example details for a non-integral precast bent cap system in non-seismic regions. Figure 7 illustrates the implementation of the grouted duct connection on two recent Texas bridges.[14-15] Close adherence to the 1748 Precast Connection Specification helped ensure successful implementation.

For practical reasons, the scope of Project 1748 entailed only precast bent caps on cast-in-place columns or precast trestle piles. Bents subjected to seismic-induced loads were not addressed. In addition, focus was placed on systems that use simple construction operations and provide maximum reasonable construction tolerances. Post-tensioning of connections or bent caps as well as use of precast columns were not addressed. Nevertheless, many Project 1748 findings related to constructability are applicable to NCHRP 12-74. In addition, even certain aspects of connection details provide a reasonable basis for development of non-integral emulative details for seismic regions.

Seismic

Although a comprehensive research program to develop precast bent cap systems for the range of seismic regions has yet to be conducted, several pertinent research projects have been conducted. Based on the results of TxDOT Project 1748, an experimental research program was conducted at California State University, Sacramento to develop an emulative non-integral precast bent cap system for seismic regions using a grouted duct connection.[16-17] The end products of the first phase of research were the development of a feasible grouted duct seismic moment connection detail, anchorage provisions, and recommendations for design and testing of beam-column connection specimens. The moment connection that was developed with industry input is a variation of the Project 1748 grouted duct connection. While the nonseismic grouted duct connection consisted of ducts housing longitudinal bars anchored within the column core (to enhance constructability for low to moderate moment demands), the seismic moment connection uses ducts that house all column bars, which are extended into the cap. Reference 17 summarizes key findings, including bond performance of grouted bars under tension cyclic loading. Results suggest that a grouted duct connection may be an economical, effective moment connection for a non-integral precast bent cap system in seismic regions. However, experimental investigation of actual connection regions and systems is needed. In addition, References 13, 16, and 17 identified the need to further study the use and required properties of grout within precast seismic systems. Other research

Other research projects pertinent to NCHRP 12-74 have been conducted, notably at the University of California, San Diego. The study of joint behavior under seismic loading was conducted to establish a design procedure for bridge cap beam-to-column joints. The feasibility of precast fabrication of concrete bridge joint systems consisting of fully prestressed cap beams was also demonstrated.[18] Test results indicated that the performance of bridge joints incorporating prestressing and a reduced amount of reinforcement was superior to conventionally reinforced specimens. A multi-column precast bent cap system was also studied to further implement prestressing in bent cap to column joints.[19] Strut-and-tie models revealed the beneficial effect of prestressing on the seismic performance of the column-to-cap connections. Although only one specimen used precast concrete (beam segments post-tensioned to a joint region that was the extension of a column), prestressing of precast bent caps is expected to provide enhanced performance to reduce joint reinforcement and thus alleviate congestion. This may be advantageous for high seismic regions, where there is the tendency to use a heavy bent cap and extensive joint reinforcement. The use of post-tensioning provides a dual benefit: facilitating the use of lighter segmental cap components for hauling and erection as well as reducing joint congestion. However, the cost-to-benefit ratio for using post-tensioning for the various seismic regions, including high seismic regions, needs to be examined through NCHRP 12-74.

Caltrans also sponsored a research project, in cooperation with PCMAC, to investigate the feasibility of using spliced precast girders with an integral connection between girders and bent.[20] This was a first major experimental investigation of a precast bridge system for high seismic regions. It provided the necessary verification of adequate seismic performance for the innovative post-tensioned spliced girder system, and demonstrated that an integral connection was possible without beam continuity through the bent cap. However, there are several aspects of the research that NCHRP 12-74 should modify or build upon: 1) the bent cap was entirely cast-in-place, requiring a major field pour; 2) continuity was based solely on longitudinal post-tensioning; and 3) issues of constructability and speed of construction have hampered the use of this system in practice.

An increasing research focus has also developed for jointed self-centering systems as well. Priestley et al proposed the use of moment resisting frame systems prestressed with partially unbonded tendons as the primary lateral force resisting mechanism for seismic regions.[21] This concept was supported by a series of non-linear dynamic time-history analyses that showed the viability of such systems, including the advantage of minimal residual drift following a strong earthquake. Others have subsequently carried out experimental work on precast beam-column joints, walls, and bridge column components, and some have proposed a hybrid system, in which mild steel reinforcement is combined with unbonded tendons in the critical connections.[12,22] The objective of using mild steel reinforcement was to provide hysteretic energy dissipation to the system. Since then, several systems have been studied as part of the PRESSS research program on precast concrete building systems.[23] Tests have also been conducted to determine equivalent debonded length of bars grouted in metal ducts to verify that the reinforcing bars used in a hybrid frame system developed under PRESSS will be protected against premature fracture in the critical region adjacent to the beam-column joint.[24]

Based on this review of seismic behavior of bridges and distinction of different systems, as well as an overview of recent applications as well as pertinent literature, the research approach for NCHRP 12-74 is briefly summarized in the next section.

RESEARCH APPROACH

The NCHRP 12-74 research approach will encompass the following nine tasks:

1. Assemble and Review Relevant Information
2. Development of Precast Bent Cap System Concepts
3. Recommend Precast Bent Cap System Concepts
4. Prepare Detailed Work Plan
5. Submit Interim Report
6. Conduct Analytical and Experimental Work
7. Further Develop and Finalize Precast Bent Cap Systems
8. Prepare Project Deliverables
9. Submit Final Report

Connection details for both emulative and jointed systems will be developed and examined through a program that includes both experimental and analytical efforts. Further details for each task will be available as progress is made in the research, beginning in the fall of 2005.

END PRODUCTS

The research will culminate in the development of practical, validated emulative and jointed precast bent cap systems for all seismic regions, including associated design methodologies, connection details, design and construction specifications, commentary, and illustrated design examples. Because the research will be based on innovative developments and experimental and analytical investigations, with input from a Technical Advisory Group, the end products are expected to provide cost-effective seismic resistance and also facilitate accelerated, durable construction.

Connection details for low, moderate, and high seismic regions will be provided, with the goal of minimizing changes to connection details for each seismic region. Differences in design methodologies and connection details, however, are expected for emulative and jointed systems. Design methodologies will also address major system differences. Design and construction specifications will be developed in *AASHTO LRFD Bridge Design Specification* format with commentary. Design examples will demonstrate the step-by-step application of the design methodologies and thus will be immediately applicable to practice. In addition, a detailed implementation plan for moving the results of the research into practice will be provided.

SUMMARY AND CONCLUSIONS

The successful design and construction of recent precast bridges such as the San Mateo-Hayward bridge and the Sacramento River bridge[3] have helped Caltrans gain confidence in developing and implementing seismic resistant precast bridge systems. Both projects used innovative systems based on an emulative approach because monolithic behavior between the superstructure and substructure based on cast-in-place construction has been proven over many years, and is expected to conform to the current Caltrans Seismic Design Criteria.

These projects have used details that have attempted to emulate cast-in-place behavior, which is considered the most logical approach to achieve ductility and seismic resistance for precast systems in seismic regions. Alternative approaches may provide innovative solutions to substructure design and construction. However, until adequate research on alternative approaches such as jointed systems has been conducted, such approaches will be used rarely, if at all. Therefore, it is recommended that comprehensive research be conducted to develop design methodologies, construction specifications, and detailing for such innovative precast systems. The following section introduces a new research project that is intended to help provide a basis for the design and construction of a precast bent cap system in seismic regions.

NCHRP 12-74 will develop design methodologies, connection details, and design and construction specifications for precast bent cap systems in low, moderate, and high seismic regions. By addressing the major uncertainties associated with these systems, bridge designers, fabricators, and contractors will have a reliable basis upon which to design and implement precast bent cap systems in seismic regions.

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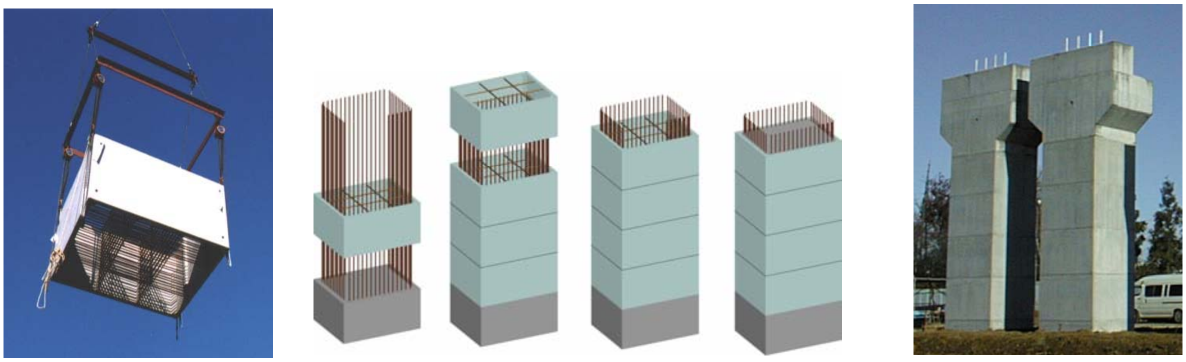

FIGURE 1 Partially-Precast Segmental Pier System for Solid Columns: (a) Exterior Precast Panels; (b) Construction Sequence; (c) Completed Piers. (Courtesy of Sumitomo Mitsui Construction Co.)

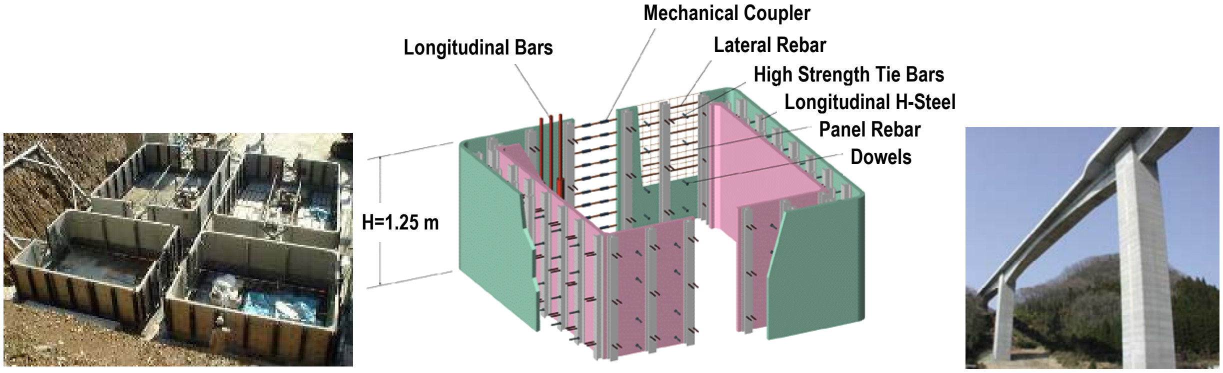

FIGURE 2 Partially-Precast Segmental Pier System for Hollow Columns: (a) Interior and Exterior Precast Panels; (b) Reinforcement Details; (c) Completed Piers. (Courtesy of Sumitomo Mitsui Construction Co.)

FIGURE 3 Precast, Prestressed Bridge on Autobahn near Munich, Germany: (a) T-Beams with Integral Bent Caps; (b) Temporary Shores for Beams.

(a) *(b)*

FIGURE 4 San Mateo-Hayward Bridge Widening—Superstructure: (a) California Modified Bulb-Tee Girders; (b) Pretensioned Deck Panels on Girders.

(a) *(b)*

FIGURE 5 San Mateo-Hayward Bridge Widening—Partially-Precast Bent Cap: (a) Cap Being Moved into Place; (b) Girder and Pile Connection at Bent Cap.

(a) *(b)*

FIGURE 6 San Mateo-Hayward Bridge Widening: (a) Longitudinal Bars from Pile Extending into Cap; (b) Continuous Epoxy Coated Deck Reinforcement.

(a) Lake Belton Bridge, TX (14) **(b) Lake Ray Hubbard Bridge, TX (15)**

Figure 7. Emulative, Non-Integral Precast Bent Cap System Using Grouted Ducts