PRECAST, PRETENSIONED, RECTANGULAR BENT CAPS

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ABSTRACT

Rectangular bent caps are predominantly cast-in-place and reinforced with Grade 60 steel. The quality of cast-in-place concrete is highly variable, and the concrete cracks at service loads, leaving reinforcing steel susceptible to corrosion. Cast-in-place construction is also a time consuming process that puts construction workers in hazardous work environments for extended periods of time. Casting concrete on-site delays construction as the concrete must cure before construction can continue. The process of casting bent caps in place is also dangerous as workers must perform various functions off the ground, often times above roadways or waterways. In light of these concerns, the Texas Department of Transportation (TxDOT) is analyzing the use of standardized precast, pretensioned, rectangular bent caps as an alternative to conventionally reinforced, concrete bent caps. Precast concrete is generally a more consistent, higher quality product than cast-in-place concrete, and pretensioning caps improves structural performance, especially with regards to crack control. Construction times can be reduced by casting the caps off-site and allowing them to cure during the early phases of construction. Certain construction steps, such as formwork and curing, will be eliminated by casting the caps off-site, reducing the amount of work conducted off the ground and increasing worker safety.

Keywords: Precast, Pretensioned, Rectangular, Bent, Cap, Concrete

INTRODUCTION

The Texas Department of Transportation is constantly seeking innovative solutions to modern structural and transportation problems. In recent years, the focus in the bridge industry has increasingly centered on accelerating bridge construction and improving worker safety while also enhancing structural performance. With current constraints on funding at all levels, accelerated bridge projects are becoming a popular method of reducing the cost of bridges. Reducing the construction time of bridges also benefits the economy as a whole, creating a freer flowing transportation network. Although accelerated bridge construction is becoming more and more popular, it is important that worker safety not be sacrificed in exchange for time. Safety has become as much a focus in the engineering and construction industries as accelerated construction, and neglecting safety to reduce construction time could have dire consequences.

TxDOT is always concentrating on finding new and innovative methods of enhancing the structural performance of bridges. With the largest bridge inventory in the nation, it is important that these innovations increase the service life of a bridge. Increasing the service life of newer bridges will reduce the amount of repair work needed on these bridges, and will shift that work further out into the future. Delaying the need for repairs on newer bridges will allow more of the older bridges to be repaired or replaced. Focusing repair work on the older bridges and increasing performance of newer bridges will improve the overall bridge network. In an effort to address all three of these challenging issues, TxDOT has designed a precast, pretensioned bent cap. This new structural member is believed to be superior to its cast-in-place equivalent in each of the areas mentioned above.

CAST-IN-PLACE BENT CAP

Currently, bent caps are predominantly cast-in-place structural elements that are reinforced with Grade 60 steel. Though these bent caps are the most prevalent, they present a number of issues for engineers and contractors alike. Cast-in-place caps present problems in each of the three areas discussed in the introduction: construction time, worker safety, and structural performance. These problems are all major factors in the decision to design a precast, prestressed alternative.

CONSTRUCTION

Casting concrete members in place is a time consuming process, particularly for bent caps. The casting process involves setting up formwork and placing reinforcement within the form (Fig. 1), placing concrete (Fig. 2), curing concrete, and finally, removing forms. Each of these individual tasks represents a time investment that, when combined, can add a lot of time to the overall construction process. Curing of concrete and removal of formwork can also add time to the process as the contractor must either wait a prescribed amount of time or until certain conditions exist to perform these steps[1]. Typically the contractor must allow a minimum of four days for the concrete to cure. Additionally, the contractor must also wait to remove the forms until the concrete reaches a compressive strength of 2,500 psi. Once the concrete has been placed and the formwork removed, the contractor must continue waiting until the concrete has reached a compressive strength of 3,000 psi before they can begin placing superstructure elements on the cap.

Fig. 1: Formwork for cast-in-place bent cap

Fig. 2: Cast-in-place concrete placement

In addition to delays that occur during the construction process, cast-in-place construction can be limited by accessibility. Depending on where the construction is taking place, it may be difficult to transport concrete from a batch plant to the job site. TxDOT typically limits the amount of time between batching and placing concrete to less than one hour[1]. If the job site is not located near a concrete plant, the contractor must perform additional tests or alter their mix design so that it will still perform properly after transportation. Accessibility also applies to transporting the concrete to the particular location on the job site where it is needed. On long stretches of water, the contractor may need to use slick-lines or barges to get the concrete from the shore to the location of the bent cap.

SAFETY

In addition to being time consuming, the cast-in-place construction process places workers in hazardous work environments. Bent caps are cast atop columns or piles that can extend many feet above the ground and/or water surface. Construction workers must perform tasks such as placing and removing formwork, placing of steel and concrete, etc. off of the ground, typically with small, congested work platforms to maneuver. These workers are exposed to fall hazards that can be from great heights or over underlying roadways (Fig. 3) and waterways. Construction work can also present safety hazards to the traveling public as debris could potentially fall onto the underlying roadway or vehicles. While the use of precast, prestressed bent caps will not completely eliminate these hazardous, the number of workers and amount of time needed to install these caps are much less than those associated with cast-in-place construction. By reducing the number of workers and amount of time exposed, the overall safety can be greatly increased.

Fig. 3: Substructure adjacent to underlying roadway

STRUCTURAL PERFORMANCE

Cast-in-place concrete presents several issues with regards to structural performance. The quality of the concrete used during cast-in-place construction can vary widely in quality. Compressive strengths of this concrete can be inconsistent between batches. These inconsistencies in concrete quality can lead to subpar performance on an essential structural element. Cast-in-place concrete also experiences cracking at service loading levels. When the bent caps crack, the reinforcing steel will be exposed and thus subject to corrosion. Inconsistent material properties, cracked concrete, and corroding steel all lead to reduced service life of the bent caps.

FIRST GENERATION PRECAST CAP

TxDOT began using precast bent caps as an alternative to conventional cast-in-place bent caps in the early nineties. The use of precast caps helped address certain issues such as time constraints, limited accessibility, etc. in each of the projects for which they were chosen. TxDOT designed a variety of different precast caps, ranging from rectangular bent caps to Inverted-T's, to be employed for a variety of different bridge applications.

In 1994, TxDOT chose to use precast caps on the US 290 Ramp G Project in order to minimize traffic disruption. This portion of US 290 consists of a ramp supported on an Inverted-T straddle bent above a lower roadway (Fig. 4). During the early stages of construction, it was determined that cast-in-place construction of the bent cap would require closing of the lower roadway for an estimated 41 days. In order to minimize road closures, the contractor instead chose to precast the bent cap. The use of a precast cap in place of the cast-in-place cap resulted in the ramp being closed for only 6 hours[2].

Fig. 4: US 290 Ramp G Straddle Bent

Also in 1994, TxDOT was posed with the issue of constructing a half-mile long bridge, supported by forty four identical bent caps, over Redfish Bay. This project presented the challenge of performing construction over the Gulf Coast. Instead of casting the caps over the water, the contractor instead proposed the use of precast caps[2]. By precasting the caps, the contractor was able to barge the finished caps out to their locations and lift them into place (Fig. 5), thus eliminating much of the work that would have had to be completed over the water.

Fig. 5: Crane placement of precast bent cap

SECOND GENERATION PRETENSIONED CAP

Recently, TxDOT has begun analyzing the use of prestressed, precast bent caps as an alternative to conventionally reinforced, cast-in-place bent caps and as an advancement upon the conventionally reinforced, precast caps developed in the nineties. Reinforcing precast bent caps with pretensioned strands instead of grade 60 rebar will improve the structural performance of the bent cap while providing the construction time savings and worker safety advantages the precast caps have over the cast-in-place caps. As was the case with the first generation precast caps, casting the caps off site and lifting them into place instead of casting in place, large amounts of time will be saved in the construction process. By casting the caps at the precast yard, time consuming processes such as formwork, concrete placement, and curing can be done beforehand so that the caps will already be finished before the reach the site. Worker safety will also be improved as the amount of work that must be performed in hazardous locations will be reduced.

DESIGN CONCEPT

In order to provide a superior performing structural element, certain decisions were made early in the design process. As a starting point, the pretensioned caps are being designed as alternatives to TxDOT's standardized, rectangular bent caps (Fig. 6). These standardized bent caps are used extensively on a variety of different bridge types throughout the state of Texas and providing a pretensioned alternative for these caps allows for the opportunity to use the pretensioned caps on a wide range of bridge projects. The choice to design alternatives to the standardized, rectangular bent caps also aids in narrowing certain options such as cross-section design, where the decision was made to match the cross-sections currently present in TxDOT's Bridge Standards.

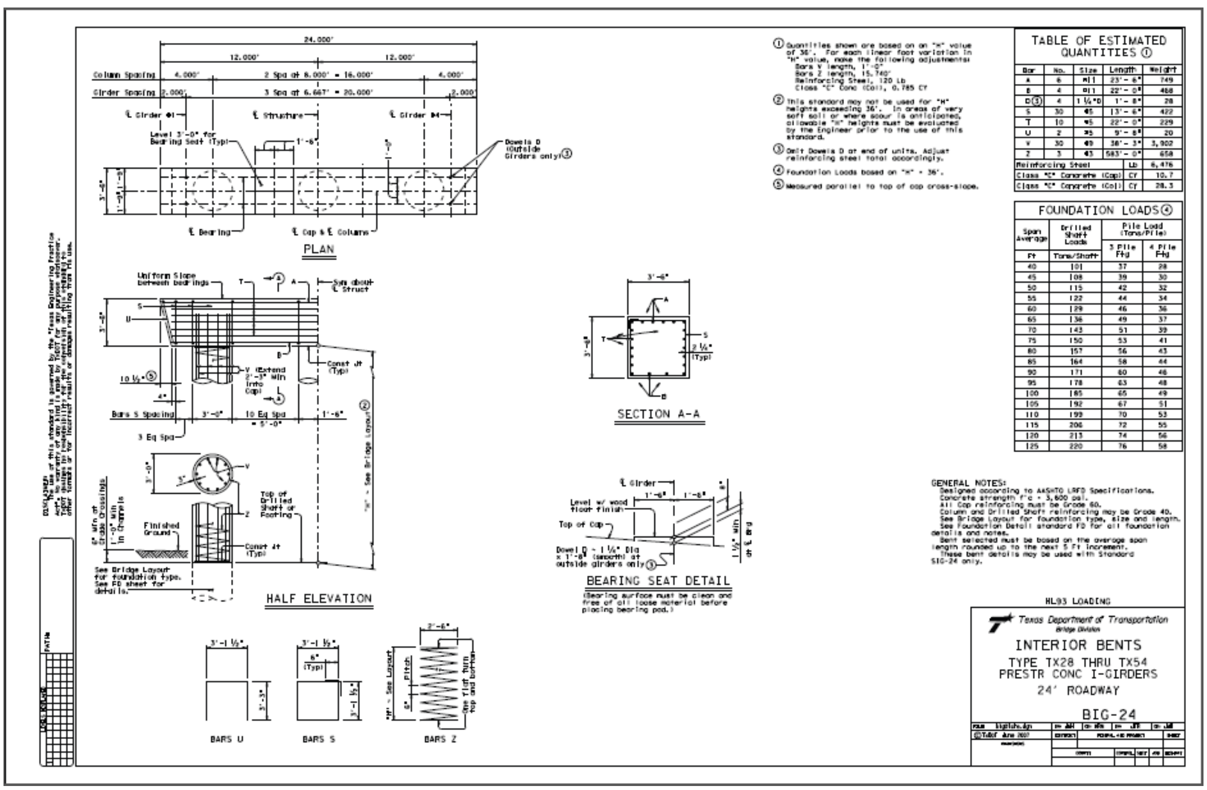

Fig. 6: Typical TxDOT standard bent cap[3]. ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/big01ste.pdf

In order to ensure that these new caps are structurally comparable to their cast-in-place counterparts, the caps were designed to provide at least as much ultimate moment capacity as is present in the conventionally reinforced cap. The moment capacity of the prestressed cap was calculated using the strain compatibility method. In order to optimize the capacity of the prestressed cap, the amount of strands and, more importantly, the strand pattern had to be selected. The decision on how to arrange the strands was important because the strand pattern will affect more than just the ultimate moment capacity. Since these bent caps will be prestressed, the orientation of the strands within the cross section will not only affect the moment capacity of the section, but also the camber, and the ease of fabrication.

After careful consideration, it was determined that a symmetric strand pattern (Fig. 7) would best address each of these issues. The strand pattern consists of an equal number of strands in the top and bottom faces to provide sufficient moment capacity, and two additional strands placed symmetrically on each side face to prevent cracking on the sides. By using the symmetric strand pattern displayed in Figure 7, there should be minimal to no camber in the cap, making it easier for the contractor to install. This strand pattern mimics the grid-like patterns used for TxDOT's standardized girders, which should help the fabricator be more familiar with setting up the section for fabrication. The two inch grid system and consistent cross-section design mentioned above should also make fabrication easier as it will cut down on the formwork and anchor plates a fabricator would need to have.

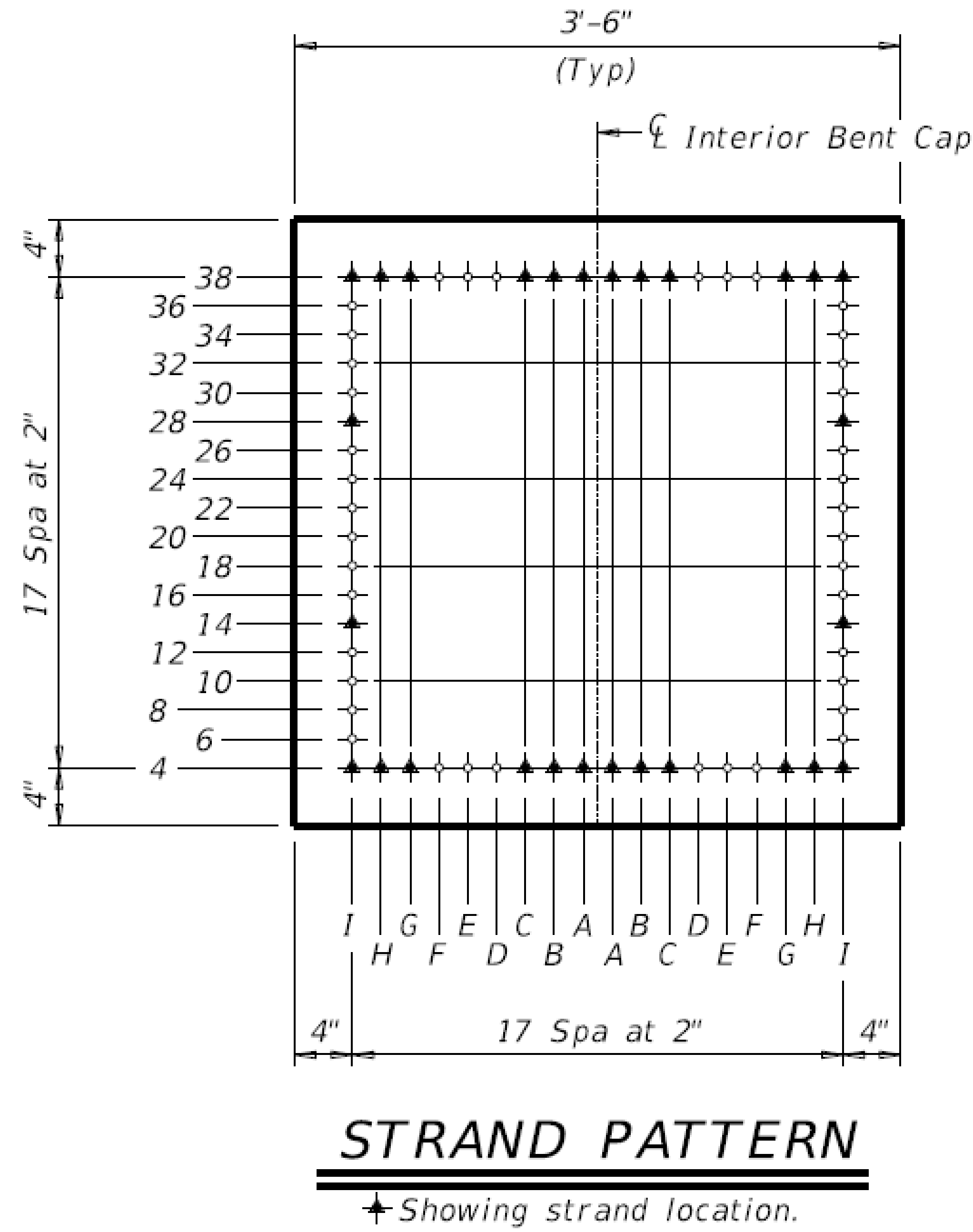

Fig. 7: Example Strand Pattern for 3'- 6" Cap[4]

After selecting the strand pattern, the amount of strands needed to provide sufficient moment capacity was then determined using an iterative strain compatibility approach. A trial number of strands was selected, analyzed, and then increased until the resulting cross section had at least as much moment capacity as the corresponding conventional cap (Fig. 8). Once the moment capacity of the prestressed cap was sufficient, other design checks were carried out according to AASHTO LRFD Bridge Specifications. Shear capacity was provided with proper stirrup sizing and spacing. Because these bent caps are prestressed, it is also important to provide adequate confining reinforcement to prevent the section from bursting. This is accomplished with tighter spacing of stirrups in the end regions.

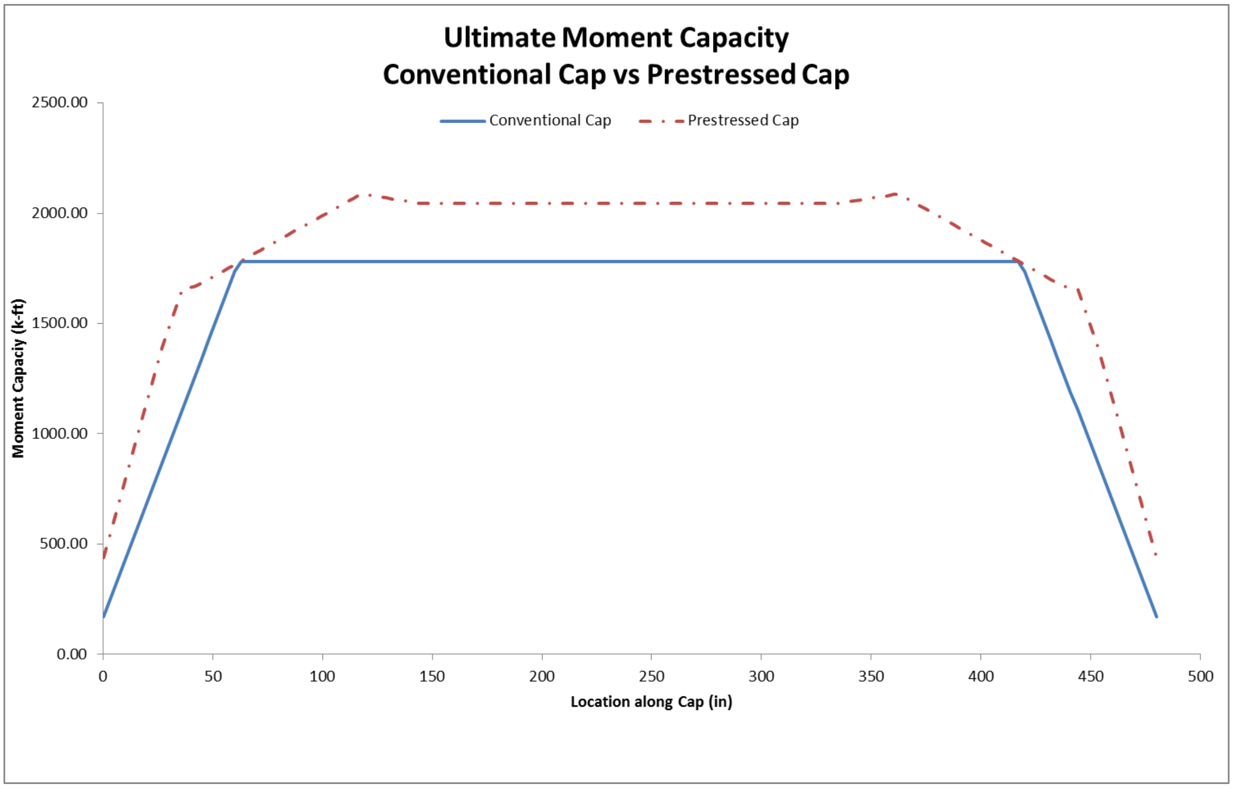

Fig. 8: Example comparison of ultimate moment capacity between conventional cap and prestressed cap

Finally, it was important to check the stress levels of the section at different limit states. Two important limit states to check are the temporary stresses before losses and stresses at service limit states after losses, as per AASHTO LRFD section 5.9.4[5]. First, the stresses in the section were checked immediately after release of the strands. This limit state is also useful in checking the stress in the section during storage and lifting of the bent cap to ensure that storage/lifting locations will not distribute the stresses throughout the section in a manner that will compromise the integrity of the cap. Then, the stresses at the service load level were checked to ensure they again did not violate allowable stress limits.

Another important design consideration that had to be considered was the connection details between the cap and the column or pile. This issue was addressed by using the connection details present in the precast cap details currently in TxDOT standards. The cap to concrete column connection consists of ducts cast into the cap at column locations. The columns will have reinforcement extending from their tops that will extend through the ducts (Fig. 9). Once the cap has finished being placed, the ducts will be grouted.

Fig. 9: Cap to column connection

For cap to concrete pile connections, voids will be cast into the cap at column locations. The cap will then be placed over the piles and the remaining void space will be grouted. The cap to concrete column detail did not need to be changed for the pretensioned bent, however, the cap to concrete pile detail needed a minor adjustment of increasing the section width by six inches (three inches on either side of the void at the bottom face) to enable sufficient number of prestressing strands to be placed on the bottom face (Fig. 10). In both cases, care needs to be taken to ensure that placement of the strands within the section is both symmetric and does not interfere with duct or void locations. Cap to steel pile connections will remain the same as they currently are in the standards, with the pile welded to a plate that is embedded in the cap.

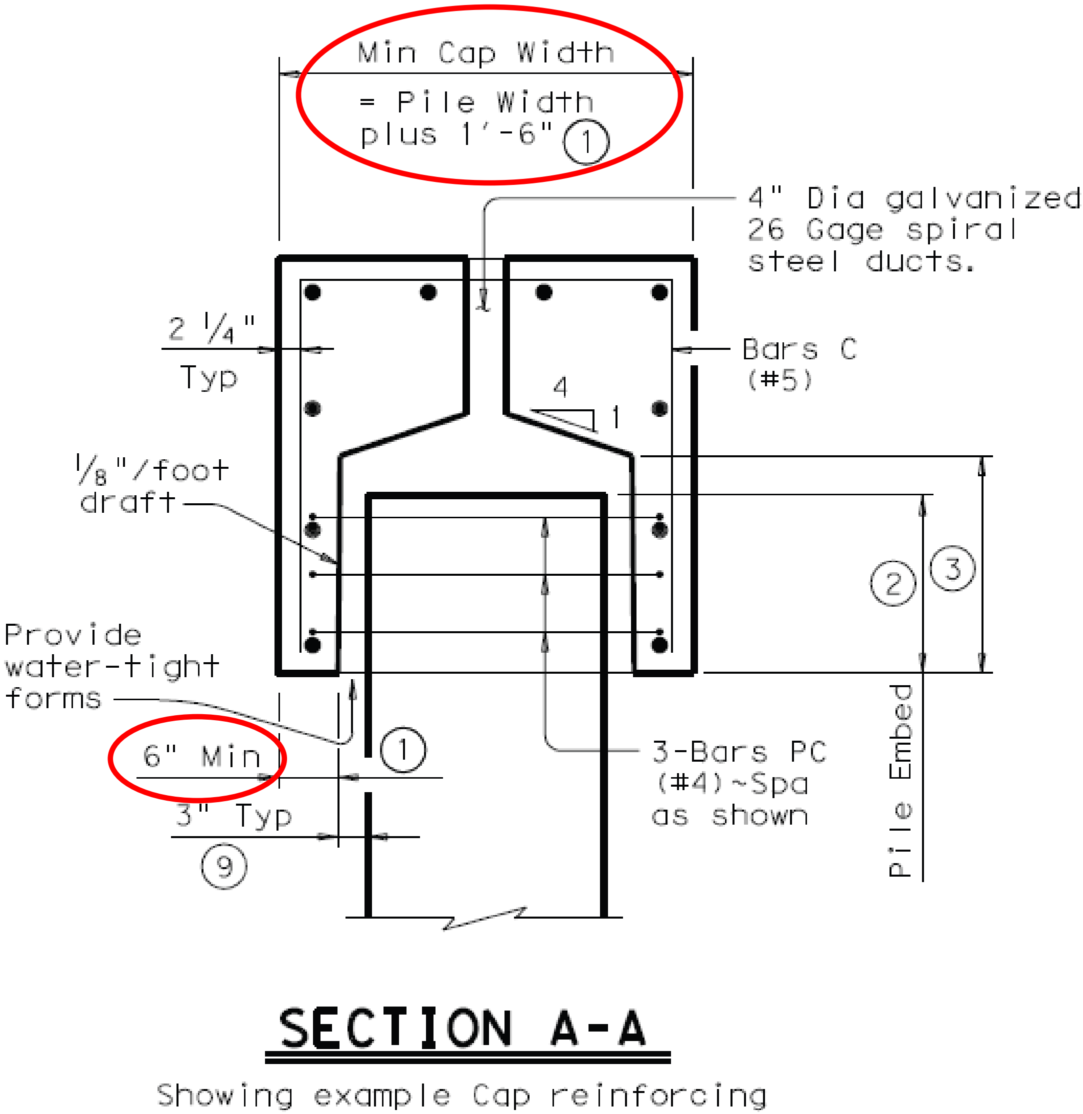

Fig. 10: Cap to pile connection[6]

STRUCTURAL ADVANTAGES

The use of pretensioned, precast bent caps provides several advantages to a cast-in-place bent cap with regards to structural performance. Precast structural elements are typically higher quality products than cast-in-place elements for a number of different reasons. Firstly, the concrete used in precast construction is typically much higher quality than the concrete used in cast-in-place construction. The concrete used for prestressed elements is usually high performance concrete that has much tighter restrictions on its composition and must go through more rigorous testing than cast-in-place concrete to be approved. In addition to being higher quality, the concrete specified for the pretensioned cap will have a compressive strength of 5,000 psi, whereas the conventional caps have a compressive strength of only 3,600 psi. This increase in compressive strength is necessary to enable the concrete to withstand the prestressing forces but also provides benefits to the bent cap such as enhanced moment and shear capacities.

The biggest advantage of pretensioning the caps is the improved crack control. Firstly, the superior quality concrete inherently controls cracking better than the concrete used in cast-in-place construction. Prestressing also improves crack control, as the concrete is precompressed. By prestressing the concrete, the stresses in the concrete will remain in compression at higher load levels. All of the cap sections analyzed so far have been designed to remain below the cracking limit at the service load limit state. By keeping the bent cap crack free at service loads, the service life of the cap will be extended. Reduction in cracking improves structural performance and durability of the cap and also helps prevent moisture from reaching the reinforcement and causing corrosion.

APPLICABILITY/LIMITATIONS

Currently, the use of precast, pretensioned bent caps has only been analyzed as an alternative to TxDOT’s standardized rectangular bent caps. Further analysis is needed for bridges requiring non-standard, aesthetic, or non-rectangular bent caps. The applicability of pretensioned bent caps must also be assessed for each bridge project. Pretensioned bent caps will typically be more feasible on longer bridges with repetitive cap geometry where the fabricator has the opportunity to mass produce caps.

Care must be taken when analyzing the structural capacities of a pretensioned bent cap, especially with regards to development of reinforcement and confining steel. Prestressing strands develop at a slower rate than conventional grade 60 reinforcing. Therefore, depending on the moment demand, it may be necessary to add supplemental steel in the end regions to enhance moment capacity in underdeveloped zones. Confining reinforcement must also be carefully analyzed to ensure proper bursting resistance. TxDOT has addressed this concern at the cap to column connection by providing confining hoops on either ends of column ducts.

The majority of the state of Texas has no seismic activity, and the areas that do have a very small level of seismic activity. Because of the low seismicity in Texas, the cap to column/pile connection details are not designed for seismic effects. Further consideration must be given to these details if the caps are to be used in seismic regions.

IMPLEMENTATION

At this time TxDOT has designed precast, prestressed bent caps for two separate bridge projects. The bridges for both of these projects were identified as favorable candidates for the implementation of precast, prestressed bent caps. The first project consists of two bridges, each 2,100 feet long, on Texas State Highway Loop 1604 in north eastern San Antonio. The bridges contain a total of thirty six bent caps that are all forty feet long and require the same amount of reinforcement. The consistency of the caps' geometry and reinforcement favors precast construction because of the precast fabricator's ability to quickly cast all of the bent caps. The precast fabricator will be able to cast multiple caps at a time on a given stressing line, and will not have to make major changes between casting sequences. By precasting the thirty six bent caps for this project, the contractor will save a large amount of time that would have been spent on casting those caps in place.

The second project selected is a pair of bridges in south eastern Austin that spans the Colorado River. This project only contains a total of eight bent caps, but does have a short construction timeline. Because of this short time line, the contractor expressed an interest in using precast bent caps instead of cast-in-place caps. By casting the caps off site in advance, when the construction reaches the bent cap phase, the contractor will simply have to install the caps instead of having to spend time with the cast-in-place process.

Currently, the first generation precast bent caps are provided as an alternative for all standard bridge designs. Standard details are being developed for the second generation precast, prestressed bent caps and, once completed, will also be provided as an alternative to the conventional, cast-in-place caps. In some instances, such as near the coast where corrosion is a major issue, the prestressed caps will be required as a means of limiting cracking and reducing the risk of corrosion. It is TxDOT's belief that these precast, prestressed will eventually be the primary design option, as they provide a better overall product than their cast-in-place counterpart.

CONCLUSION

As the owner of the nation's largest inventory of bridges, the Texas Department of Transportation is always seeking innovative solutions to modern engineering problems. With the bridge industry increasingly focusing on accelerated bridge projects, it has become more important to find methods of speeding up bridge construction. Increased regulations on worker safety have also emphasized the need to improve worker safety. An ageing transportation infrastructure and limited access to funding make increasing the service life of bridges an essential goal of any innovation.

TxDOT believes that the implementation of precast, pretensioned bent caps can be an effective solution to each of the problems stated above. The use of precast elements as an alternative to cast-in-place elements can reduce the construction time of bridge projects by eliminating time consuming construction steps such as formwork and curing. Worker safety is improved by limiting exposure to hazardous work environments, such as construction over waterways or underlying roadways. The superior quality concrete used during precast construction and the improved structural performance of prestressed concrete serve to enhance the overall structural performance of the bridge and increase the service life of both the bent cap and the bridge. Implementation of precast, prestressed bent caps requires careful analysis but is a viable method of addressing modern engineering problems.

REFERENCES

1. "Item 420: Concrete Structures." *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*. TxDOT, 2004.
2. Hyzak, Michael, Ronnie Medlock, and Lloyd Wolf. "Innovative Prefabrication in Texas Bridges." *Spring Meeting, Texas Section of American Society of Civil Engineers* (2002).
3. “Interior Bents: Type Tx28 thru Tx54 Prestr Conc I-Girders 24’ Roadway.” TxDOT, June 2007.
4. “Pretensioned Interior Bent Option.” TxDOT, March 2014.
5. "Section 5.9.4." *AASHTO LRFD Bridge Design Specifications*. American Association of State Highway and Transportation Officials, 2012.
6. “Precast Concrete Bent Cap Option.” TxDOT, January 2012.