Getting to LRFD Together - Observations Made During the Joint TxDOT/WSDOT Development of PGSuper

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ABSTRACT

It's a 2,400-mile drive from Olympia to Austin, but the need for high-quality precast bridge girder design software has made the distance seem a lot closer.

The Texas Department of Transportation (TxDOT) is a world-leading consumer of precast products. In 2005, TxDOT designers used over a million linear feet of precast I girders in their bridges, and they needed an LRFD software solution that met their workload. After much research, TxDOT determined that PGSuper™ was the best match and offered benefits that others did not. PGSuper™, developed by the Washington State Department of Transportation (WSDOT), is a leading tool for LRFD precast-prestressed girder design. PGSuper's success is founded on its advanced feature set, reliability, and its open source license that allows modifications to exactly match the end-users' needs.

A joint TxDOT-WSDOT project was launched in mid-2006 culminating in the February 2009 release of PGSuper version 2.1. This new version meets nearly all of TxDOT's requirements. Furthermore, it is easily tailored for other agencies using LRFD. This paper highlights the benefits, as well as the complications, encountered during this collaborative project and shows the success of the WSDOT/TxDOT effort by demonstrating the new features of PGSuper™.

KEYWORDS

Bridge design, Precast Concrete, Prestressed Concrete, AASHTO LRFD, Design software

Introduction

Texas has nearly 50,000 bridges, which is about 40 percent more than any other state [1]; the girders in the vast majority of new structures are built using precast-prestressed concrete. This makes the Texas Department of Transportation (TxDOT) a world-leading consumer of precast products. For example, in 2005 TxDOT used over a million linear feet of precast I girders in new bridges [2]. TxDOT has approximately 100 in-house engineers and consulting engineers at 170 separate firms all needing LRFD precast-prestressed girder design capabilities.

In order to deal with this huge design workload, TxDOT's Bridge Division has developed many processes, tools and software to automate the design process and to encourage uniform bridge standards and best practices throughout the state. These innovative approaches have enabled TxDOT to deliver finished high-quality bridges at costs that are much lower than in most other states. In 2007 TxDOT and Wisconsin led the nation in lowest cost structures on a per-square-foot basis. [3]. TxDOT's precast track record throughout the years has been superb. However, the mandatory change to the AASHTO LRFD Bridge Design Specifications [4] in October of 2007 forced TxDOT to reexamine all design and production practices. During the reexamination process, TxDOT found that their existing precast girder design program PSTRS14 needed significant updating.

The PSTRS(1-14) series of programs has served the Bridge Division for decades. TxDOT has found that the main advantage of a tool developed in-house is that it gives designers full control over their design processes. However, their existing software lacked LRFD support and was developed with decades-old technology, making it obvious that a new software solution was required.

After extensive research into existing software solutions available from commercial sources, other states, and AASHTO; and following a thorough investigation into the development of a new program in-house, TxDOT determined that PGSuper™ best matched its requirements offering benefits other software packages did not. PGSuper™, developed by the Washington State Department of Transportation (WSDOT), is a full-featured tool for LRFD precast-prestressed bridge girder design and analysis. PGSuper's success is founded on its advanced feature set, reliability, and an open source license, which allows modifications to exactly match the end-users' needs.

Saving money was another driving factor. PGSuper is open source therefore; it can be distributed to all TxDOT staff, consultants, and producers without fees. Similar commercial programs, that are not tailored toward TxDOT's high production needs, cost $1000-$5000 annually per seat. Hence, widespread use of PGSuper has potential to save TxDOT millions of dollars in software licensing fees over a ten-year period.

TxDOT began collaborating with WSDOT in mid-2006, culminating in the February 2009 release of PGSuper version 2.1. This new version plays a significant roll in TxDOT's successful migration to LRFD.

Description of PGSuper

PGSuper™ is software for the design and analysis of precast-prestressed girder bridges. The program models simple and continuous span structures and designs in accordance with the AASHTO LRFD Bridge Design Specifications. PGSuper was developed by the Washington State Department of Transportation (WSDOT) Bridge and Structures Office. PGSuper analyzes and designs precast girders for all critical stages including prestress release in the casting yard, lifting, hauling, erection, service, and ultimate conditions. PGSuper's automated design algorithm determines the prestressing and concrete strength, verifies shear reinforcement, lifting, transportation, and slab haunch requirements. All of these features can be modified to meet the needs of the end user. PGSuper has a modern user interface that utilizes advanced Bridge Information Modeling (BrIM) capabilities, so the engineer's focus is always on modeling, designing, and analyzing real bridges.

Original development of PGSuper started in 1998. In its early stage, PGSuper was an in-house tool tailored for WSDOT's design needs. This gave it limited appeal for designers outside of Washington State. However, after a decade of development and refinement, PGSuper's reliability and well-rounded feature set now surpass other precast bridge girder design programs in many aspects [5].

Managing and Expanding Design Knowledge – Software is Key

Consistency of design practices among a bridge owner's inventory is a major driving factor in the AASHTO LRFD and LRFR Specifications. WSDOT understood during the development of PGSuper that modern design processes rely on software, and like it or not, software encapsulates and implements many of the policies and practices of an organization. Also, WSDOT approached the development of PGSuper with change in mind; bridge owners and the precast industry are continuously innovating as evidenced by the use of high performance concrete, 0.6" diameter strand, and the development of long span girder sections over the past decade. Likewise the computer technology industry is continuously changing as evidenced by the plethora of new hardware devices, software, and operating systems available in the marketplace. PGSuper provides unique features that allow owners or engineers to embed their design decisions in the software without the need for programming. This feature set allows bridge owners to configure PGSuper to reflect their policies and practices and instructs the software to enforce those standards, resulting in consistent designs.

The theories behind precast girder design are well defined and documented, but actual design practices and policies differ widely between bridge owners based on experiences, capabilities of local fabricators, physical factors (e.g., seismicity), and past practice. For instance, WSDOT has a design philosophy whereby engineers design girders for zero tension at the final service condition and consider lifting and transportation of the girder. On the other hand, TxDOT prefers to use allowable tensile stress limit prescribed by AASTHO in the final service condition and defers all lifting and transportation considerations to the fabricator and contractor. In both cases, the owner's engineers are designing precast-prestressed girders; however, each approach is different.

PGSuper's library system contains thousands of design parameters that can be configured to model the design practices of virtually any bridge owner. Library parameters describe girder shapes, design constants in the LRFD and local specifications, and many other decisions and constants used during design. The library system provides a way to specify design practices in PGSuper without the need to alter the programming instructions or reinstall the software. Library data can be published on the Internet so that bridge owners, engineers, and consultants can all use the same standardized data for consistent and repeatable designs. Both WSDOT and TxDOT publish PGSuper libraries on the Internet. Either agency can independently change and publish their library data and instantly publish the data to engineers anywhere in the world. In addition, library data from the Internet is read-only and traceable allowing plan checkers to easily verify that a correct design configuration was used.

Parameters in the library system are intentionally made generic, not WSDOT- or TxDOT-specific, allowing the software to be much more agile. An example of this flexibility is TxDOT's recent research on increasing concrete tensile stress requirements at release. TxDOT engineers were able to do the research and validate effects on new designs without the aid of programmers. Once the research is accepted as practice, they will be able to quickly disseminate a new allowable stress limit to all TxDOT designers and consultants with a few clicks of the mouse. Another powerful side effect of this parameter-based approach is that such an approach allows any agency or producer to configure its own version of PGSuper and post the configuration online - thus allowing expansion of PGSuper's precast design capabilities into new markets.

TxDOT Requirements

In 2006, PGSuper was a very capable girder design program; however, it did not fully support TxDOT's design practices. This section highlights how TxDOT's specialized needs were met with PGSuper.

Automated Design

Since WSDOT rarely debonds strands in its bridge girders, PGSuper's original design algorithm was restricted to computing optimal designs for harped strands. The debonding capabilities of the software were limited to analysis. TxDOT regularly uses debonded strands in bridge girders, so its high-production environment required automated design of harped, straight, and debonded configurations.

These new requirements necessitated a major rewrite of PGSuper's design algorithm. Nearly 100 pages of flowcharts were created and reviewed by TxDOT and WSDOT staff. Testing and refinement of the design algorithm was facilitated by over 400 bridge configurations from TxDOT, WSDOT, and other agencies. The resulting design algorithm reliably produces consistent designs satisfying WSDOT, TxDOT, AASHTO, and many other requirements.

Live Load Distribution Factors

The computation of live load distribution factors has been a hot-button issue since the AASHTO LRFD specifications were introduced. Many state transportation organizations,

including WSDOT [6] and TxDOT [7], have independently made their own modifications to the LRFD equations. PGSuper already had both AASHTO and WSDOT methods for computing the factors, so a TxDOT method was added. Compounding the problem was the need to support the 13 parametric girder shapes available in PGSuper. Also, users needed to be able to input distribution factors manually or have the program compute them using the lever rule when the designer deemed it necessary to override the AASHTO equations. Over 500 bridge configurations were analyzed to verify the distribution factor calculations.

Risk Aversion by Taking the Alternate Route

In 1999, soon after the first release of PGSuper, WSDOT launched the Alternate Route Project (ARP). The Alternate Route Project is an ongoing effort to promote the development of open source software in the government sector. Open source software is software that is licensed in such a way that end-users are free to use, share, and modify software so long as it remains open. At the time, the concept of open source software was new, and no licenses existed that protected the unique interests of government agencies. Therefore, WSDOT worked along with the Free Software Foundation [8] to draft the ARP license, which is loosely based on the Gnu Public License (GPL) [9]. WSDOT then made PGSuper, as well as its other in-house bridge engineering software, available as open source software under the ARP license.

TxDOT designers' experience with in-house engineering software taught them that software is a key factor in their bridge design process. Changes in software are directly reflected in final plans and specifications, so control over software development is an important aspect in quality control. Joining an open source software project mitigated all software ownership risk for TxDOT because open source software gives all parties protection against adverse claims of ownership and access to the source code. At any time, both parties are free to abandon the collaborative relationship and to copy the source code, modify the software, and distribute it under a new name. Such an action is known as a "fork" in the software development world and it comes with serious consequences.

PGSuper is a complex software system comprised of over 100,000 lines of source code. Maintenance of such a system is not trivial and requires specialized expertise and dedicated resources. By collaborating, TxDOT and WSDOT benefit from shared resources and expertise. The collaboration is a win-win for both agencies and for engineers around the world.

The ARP license is a sufficient agreement for a strong collaborative development effort. This agreement removes risks related to software ownership. All other agreements of the collaboration have been handled with verbal commitments, trust, and a commitment to develop software for mutual benefit.

Inside the Collaborative Development Process

TxDOT began modifying PGSuper in mid-2006. They selected BridgeSight Inc., a California based consulting firm, to provide the programming services. With the significant players separated by large geographic distances, communication was a challenge. Only two face-to-face meetings between WSDOT/TxDOT/BridgeSight occurred in Austin at the beginning of the project. BridgeSight visited TxDOT two more times yet all other communications were via telephone and the Internet. A simple web-based tracking system was set up by TxDOT to serve as a documentation hub and to facilitate project management.

Technical decision making for the project was intentionally made fluid. Ad-hoc phone conferences and emails between decision makers ranged in frequency from weekly to several times daily depending on the complexity of issues. Proper level staff was always made available to allow design decisions to be made quickly, often on the spot.

This fluid arrangement had an unexpected positive affect by creating an environment of trust. Now both agencies look out for each other's interests. WSDOT implemented many new features into PGSuper during the project and always consulted with TxDOT staff to make sure that the features were compatible, and vice-versa. New features are vetted and optimized to be useful for both agencies. Current plans for future enhancements and maintenance of the program are being shared and reviewed by WSDOT and TxDOT engineers.

A Successful Deployment

In March 2009, PGSuper version 2.1 was deployed internally at TxDOT Bridge's main offices and given to select engineers statewide. The new version meets nearly all of TxDOT's requirements. Training sessions are now being developed at TxDOT to facilitate statewide deployment. TxDOT libraries for PGSuper have been deployed over the Internet and are currently available to all PGSuper users.

Future Plans

Although the latest version of PGSuper is well adapted for both WSDOT and TxDOT precast designs, there will always be room for new features and improvements. Many new features are planned, and some of the major upcoming features are listed below.

- TxDOT precasters frequently submit design modifications using "nonstandard strand patterns". This practice is currently not easily accommodated using PGSuper's "fill-sequence" based approach. Research is currently underway to determine a streamlined approach to accommodate design modifications from precast manufacturers.
- Although the software models the entire bridge, PGSuper currently designs girders one at a time. New features will be added to aid in determination of an optimal uniform girder design for multiple girders in a bridge.
- WSDOT currently has a separate program called PGSplice used to design spliced precast-prestressed girder design alternatives. PGSplice's multi-piece splicing

capabilities will be incorporated into PGSuper, adding the ability to place post-tensioned strands into girder lines.
- The Bridge Information Modeling capabilities will continue to be refined and enhanced.
- Intrinsic capabilities to allow software extensions will be implemented, thereby further improving the ability of different agencies and private third-party developers to extend and enhance the capabilities of PGSuper.

Conclusions

The collaborative development between TxDOT and WSDOT has resulted in the successful release of PGSuper version 2.1. The process has resulted in an improved, more agile, precast design tool and the expansion of precast design knowledge in both agencies. In addition, unique aspects of the project, enabled by an open source development strategy, have allowed both agencies to retain complete control over their internal design processes and specifications.

PGSuper is easily tailored for other agencies using LRFD. It is the hope of the authors to bring more partners into the PGSuper collaboration.

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