A PROFESSOR'S PERSPECTIVE

STRUT-AND-TIE MODEL

How did we get here and where do we go next?

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Since the strut-and-tie model (STM) originated in Europe in 1899, much has happened in the way of developing and refining this technique. Benefiting from about a century's worth of development, the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications* included its first set of STM design provisions for bridge elements in 1994. *Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)* included its first STM design guidance as an appendix to the code in 2002. It was not until 2007 that the use of the AASHTO LRFD specifications were mandated for use in federally-funded projects.

With much to learn from our European colleagues and their century-old experience with STM, several efforts in the United States took place to develop design guidance on STM. For example, the National Cooperative Highway Research Program (NCHRP) recently funded two 20-07 projects: Task No. 217 to develop design examples and Task No. 306 to offer improved guidance. Subcommittee A of ACI's Committee 445 prepared two special publications (SP-208, *Examples for the Design of Structural Concrete with Strut-and-Tie Models*, and SP-273, *Further Examples for the Design of Structural Concrete with Strut-and-Tie Models*). The Portland Cement Association also published an STM guidance document entitled *AASHTO LRFD Strut-and-Tie Model Design Examples* in 2004.

Within the context described previously, Ferguson Structural Engineering Laboratory (FSEL) researchers started their investigations toward the use and further development of this technique in 2002. Over the span of 12 years, and largely funded by the Texas Department of Transportation (TxDOT), a team of researchers remained steadfast in their quest to improve the understanding of STM. During this period, FSEL researchers mined data from nearly all research projects conducted in the twentieth century, augmented knowledge by testing some of the largest test specimens in history, and improved our knowledge of STM. Four research projects, five doctorate students, six master's students, and 21 undergraduate students contributed to this development effort that ended in 2013. Equally important, nine staff members of FSEL were instrumental in supporting this ambitious multi-faceted project. This culminated in the STM design provisions developed at the University of Texas that are included in the reorganized Section 5 of the *AASHTO LRFD Bridge Design Specifications*, which will be published in 2017.

Many students who contributed to this effort are currently practicing or teaching structural and bridge engineering in Arizona, California, Washington, Indiana, Illinois, Texas, Massachusetts, Colorado, and Florida. Internationally, some have moved on to practicing and teaching in Mexico, Panama, and France. The human-resource-development aspect of the STM projects is equally as important as the technical objectives and this fact has to be recognized in view of the credit that has to be distributed to many brilliant minds. In summary, this is what AASHTO codified as the STM provisions in the latest *AASHTO LRFD Bridge Design Specifications*.

The 7th edition of the *AASHTO LRFD Bridge Design Specifications*, specifically the 2015 Interim Revisions, emphasizes the delineation of D-Regions from B-Regions and recommends the use of STM for D-Regions. For all practical purposes, the design of a great majority of substructure components will be done through STM. That is, the empirical/legacy methods will gradually retire and make way for designs by STM in the upcoming years.

Embracing this change quickly will pay dividends and will help produce better-performing bridge substructures. Like all change, there will be challenges that the bridge design community will face and addressing those challenges will certainly be possible. None of those challenges will be greater than the overall reluctance that many engineers possess for change. After all, we have been designing bridges for quite some time by using the legacy design methods.

As the thinking goes, at some level, all of us feel that "if ain't broke, don't fix it." The fact is, certain aspects of the legacy designs were "broke" and thus we really needed to "fix it." Those of us who leave our offices to take a look at the performance issues encountered in some bridges know all too well that some inverted-tee straddle bents and some hammer heads supporting reasonably long spans have some performance issues we do not commonly encounter in other bridge components. So, the notion that everything is just perfect and things cannot possibly be improved is open for debate.

All of us have to remember that shrinking resources drive the necessity to do more with less. To me, that is another way of stating that we need to improve our efficiency and the precision with which we design. The Precast/Prestressed Concrete Institute (PCI), among other organizations, has been emphasizing sustainability and efficiency. What better way to do that than to remove excess fat in our designs while adding additional design margin where we need it.

One of many full-scale specimens tested at Ferguson Structural Engineering Laboratory at the University of Texas at Austin. Photo: Ferguson Structural Engineering Laboratory staff.

What do I mean by this? I mean more refined design techniques, better design procedures, reduction of empiricism in our design expressions, and design provisions calibrated with more representative data are bound to help us improve the state of the practice. Does that sound like a tall order? If it does, so be it. With that said, how are we to improve the state of the art without challenging the status quo?

Challenging the status quo in 2017 requires more effort than it did in the 1960s. This statement should not be taken as a criticism of the development efforts that took place after the Second World War. In contrast, we should be giving the highest praise to the forefathers of structural engineering and those engineers and researchers who contributed to the development of design codes during that difficult time when they had to develop structural design codes of practice with limited funding. To improve upon "what's good" requires extraordinary efforts. That is really and truly the future of structural engineering research.

So, where do we go next? As far as STM is concerned, training will be the most important aspect in the implementation of the new STM provisions of the *AASHTO LRFD Bridge Design Specifications.* The good news is that such developments are underway. In this way, we can build the best bridges of the twenty-first century within our country and beyond. That is what we should all *ASPIRE*™ to do. Stay well, until the next article.

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