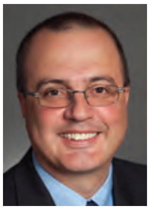
A PROFESSOR'S PERSPECTIVE

STRUT-AND-TIE MODEL

Concrete bridge design by STM



by Dr. Oguzhan Bayrak, University of Texas at Austin

Students in the Ferguson Structural Engineering Laboratory at the University of Texas at Austin observe a reinforcing bar cage being placed into a form. Photo: David Birrcher and Robin Tuchscherer.

The eighth edition of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*, with substantial revisions in regard to applying the strut-and-tie model (STM), will be published in 2017. This edition of the AASHTO LRFD specifications places an increased emphasis on designing concrete structures with STM and clearly delineating B-regions from D-regions. Article 5.7, devoted to the design of B-regions, states the following:

> *Where it is reasonable to assume that plane sections remain plane after loading, regions of components may be designed for shear and torsion using either the sectional model as specified in Article 5.7.3 or the strut-and-tie method as specified in Article 5.8.2.*

This implies that STM can be used in lieu of the sectional design provisions. It is also worth noting the introductory sentence in Article 5.8, which is devoted to the design of D-regions:

> *Refined analysis methods or strut-and-tie method may be used to determine internal force effects in disturbed regions such as those near supports and the points of application of concentrated loads at strength and extreme event limit states.*

By these excerpts, it is obvious that all components of a concrete bridge can be designed using STM. Most certainly, bridge substructure components, such as pile caps and bridge bents, are prime candidates for design by STM. The introduction of loads by bridge beams and geometric discontinuities seen in some bent caps, such as inverted-tee caps, render such bridge elements as D-regions almost in their entirety. Following this line of thought, and starting about two years ago, I began teaching bridge substructure design by STM in our concrete bridge design class at the University of Texas. My teaching efforts, in this regard, greatly benefited from decade-long STM research, development, and implementation efforts funded by the Texas Department of Transportation.[1,2]

The starting point that I use in my bridge design class relates to some field problems and performance issues encountered in designing D-regions by using sectional design methods. It is true that in many cases the use of legacy sectional methods produces reasonable bridge bent designs. It is also true that there have been a number of cases in which the use of small pot bearings and associated stress concentrations underneath those bearings have created field issues. Similarly, I am aware of cases in which large quantities of stirrups used in the bent caps were not providing the benefits calculated in sectional designs because direct strutting of the load from bearings to supporting columns was the primary load-transfer mechanism. Providing clear explanations of the observed field problems and how those problems could have been avoided by using STM proved to be a great starting point in my classes. The following excerpt, taken from the commentary of the AASHTO LRFD specifications (C5.8.2.1), serves to let the designer know about some of the aforementioned performance issues in a concise manner.

> *Traditional section-by-section design is based on the assumption that the reinforcement required at a particular section depends only on the independent values of the factored section force effects* V_u, M_u, *and* T_u *and does not consider the manner in which the loads and reactions are applied which generate these sectional forces. The*

> *traditional method further assumes that the shear stress distribution is essentially uniform over the depth and that the longitudinal strains will vary linearly over the depth of the beam.*

Perhaps the most important challenge in teaching bridge design by STM relates to shifting students' focus from the development of sectional force diagrams. Instead of having students design for those sectional effects by using legacy design methods, we want them to take a more holistic view of the element that is being designed. For example, rather than having to worry about flexural design and shear design in ways that can be viewed as being compartmentalized, the focus has to be shifted to identifying load paths that can be used in transferring loads from their respective points of application to supports/foundations. Flexural design, shear design, and reinforcing bar anchorage checks are all implicit when designing by STM, in addition to nodal stress checks under bearing pads and all other critical locations. Once a design by STM is complete, all aspects of design have been individually and collectively considered.

After overcoming the challenge outlined previously, students taking my class develop sufficient mastery of the technical aspects of structural design by STM. They work on a team project to go through a project-based learning experience, where the student teams build structural elements in our structures laboratory that they have designed by STM. Subsequently, the teams run structural tests on the elements they previously designed and fabricated such that they can observe the actual load paths, as evidenced by structural cracks and reinforcing bar strains. Ultimately, the student teams compare the experimentally observed load paths to those assumed in their original design. In this way, the circle of learning is complete.

The fact that STM forces structural engineers to think through each and every detail, as loads get transferred from their point of application to the foundations, is probably the most important attribute of this method. Carefully thought-out structural details not only help improve the load-carrying capacity of an element, but also improve the in-service performance. As we *aspire* to design bridges to last a century—while being mindful of our natural resource consumption, good structural details, and better optimized designs—structural designs by STM will undoubtedly gain increasing levels of importance. Stay well, until the next article.

References

1. Birrcher, D. B., R. G. Tuchscherer, M. R. Huizinga, O. Bayrak, S. L. Wood, and J. O. Jirsa. 2009. *Strength and Serviceability Design of Reinforced Concrete Deep Beams*. Report No. FHWA/TX-09/0-5253-1. Austin, TX: Texas Department of Transportation.
2. Williams, C., D. Deschenes, and O. Bayrak. 2012. *Strut-and-Tie Model Design Examples for Bridges: Final Report*. Report No. FHWA/TX-12/5-5253-01-1. Austin, TX: Texas Department of Transportation.