FHWA Strategy to Increase Use of Refined Analysis

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Engineering practitioners of today, with the aid of ever-advancing computer technology, are able to solve engineering problems of great complexity, and produce designs/evaluations that are more refined and more reliable than in the past. However, our nation's governing bridge design specifications and the profession as a whole have not yet fully exploited the capabilities of this new generation of analytical tools. Many bridge engineers and owners appear to favor a general philosophy of keeping analyses as simple as possible to minimize errors or to remain true to the accepted, proven engineering practices. Consequently, they have avoided embracing regular use of refined analysis methods.

In 2009, an international technology scan sponsored by Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and the National Cooperative Highway Research Program (NCHRP) determined that engineers in the United States significantly lagged behind their European counterparts in the use of advanced modeling tools and procedures to design and assess bridges. The scan team recommended increased use of refined analysis for bridge design and evaluation, and encouraged the use of refined analysis to avoid unnecessary posting, rehabilitation, or replacement. Unfortunately, practical implementation of these recommendations has been limited.

What is Refined Analysis?

The generic term "refined analysis" is often used to describe a more-detailed, sophisticated structural modeling approach, which typically involves computerized finite-element analysis (FEA). A significant number of references to refined analysis are made in the *AASHTO LRFD Bridge Design Specifications*, however no formal definition is provided. These references are typically along the lines of "in lieu of a refined analysis, the following can be used," implying that the provided approximate (simplified) analysis procedure is deemed sufficient for most cases, but refined analysis should be considered if more complexity is involved. The AASHTO LRFD specifications also acknowledges and specifies limits of applicability for many approximate procedures indicating that in some cases refined analysis is required.

Therefore, using the AASHTO LRFD specifications as the governing bridge analysis specification, one could define refined analysis as: Any analysis that provides more accurate results or addresses complex structural components/systems or behaviors that fall outside the limits of the AASHTO LRFD specifications' approximate procedures.

Based on the previous definition, analytical procedures that would not be considered refined would include the following:

- Line girder analysis using distribution factors
- Moment magnification procedure for compression elements
- Strut-and-tie models of concrete elements
- Strip method of deck analysis and design
- Cross-sectional frame analysis for box girders
- Equations for effective flange width of composite decks

Conversely, analytical procedures that would be considered refined (Figures 1-3) include the following:

- System modeling that accounts for load distribution to girder lines
- Sectional modeling that accounts for shear lag, local stresses, or distortion
- Models explicitly defining diaphragms/cross frames or the deck as a surface (rather than a grid) in two dimensions
- Models using plastic hinges, such as by pushover analysis

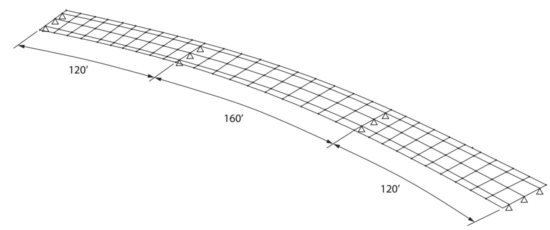

Figure 1. Grillage model. All Figures: Federal Highway Administration.

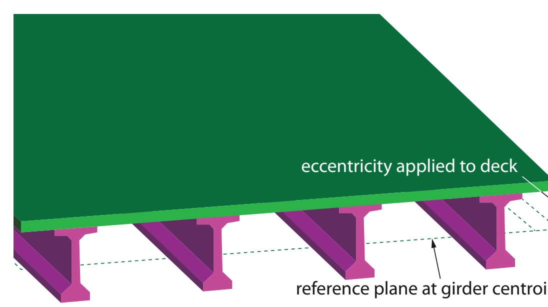

Figure 2. Plate with eccentric beam model.

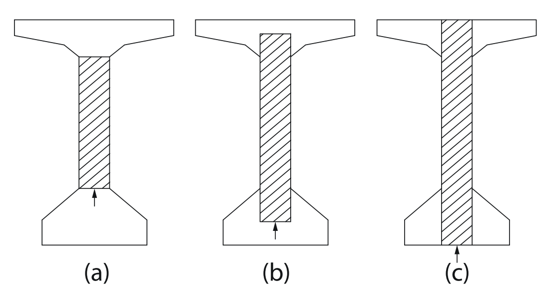

Figure 3. Finite-element analysis web-depth modeling options.

Why Use Refined Analysis?

In some cases refined analysis is *required* to complete the design verification according to the AASHTO LRFD specifications. These are instances for which the code-specified approximate methods do not apply. Furthermore, there are reasons why using a refined analysis might be advantageous, such as capturing behavior not adequately accounted for by approximate methods and/or outside the limits of the AASHTO LRFD specifications.

A properly and efficiently executed refined analysis can provide substantially better information on bridge behavior and performance and allow for more cost-effective and reliable design. Conservatism imbedded in our code-specified approximate methods can add unnecessary cost, which may have serious implications for owner-agencies with limited budgets. At the same time, the AASHTO LRFD specifications encourage designers to expend effort on developing and using complex automated calculation tools to execute the necessary code checks rather than performing meaningful structural modeling to better understand behavior. This often hides the controlling factors and hinders the development of new bridge innovations in general.

Practitioners indicate that refined analysis of most bridge structures can be done for only a small premium over conventional, simplified techniques with currently available computer technology. The practice of bridge engineering in the future is expected to take a more holistic approach, where the design, fabrication, construction, inspection, and management will be much more integrated by digital information exchange. Refined analysis is expected to become routine as software vendors develop "translator" and "wizard" tools to communicate with database records and generate detailed structural models for engineering analysis.

Refined analysis in bridge engineering has the potential to provide the following benefits in the engineering design and evaluation of our nation's infrastructure:

- Improved structural safety by more rigorous assessment of limit states
- Increased economy by going beyond use of approximate, conservative design formulae
- Increased safety and economy by accurate modeling of system or local behavior
- Improved safety evaluation by full consideration of condition data such as section loss or as-built geometry
- Increased sustainability by more frequently allowing the continuing use of existing infrastructure
- Accelerated innovation development as industry gains a deeper understanding of bridge behavior

A New Manual

FHWA has concluded that there is insufficient technical guidance in the literature on the proper application of refined analytical techniques for bridge engineering. A credible resource is needed that will establish and demonstrate the requirements for proper application and define an industry standard of care. In an effort to address this gap, FHWA is working on a manual that will provide standard modeling procedures and benchmark solutions to guide engineers and provide a consistent set of results for verification.

This manual will fill a very important void and provide the necessary guidance for engineers and owners to consider and apply refined analysis. Volume 1 (covering general procedures) is available now, and Volume 2 (covering material-specific details) is scheduled for completion in late 2016. A preliminary version of this manual is available on line at www.fhwa.dot.gov/bridge/refined_analysis.pdf.

Going Forward

The AASHTO LRFD specifications clearly recognizes refined analysis as a needed tool for our nation's bridge designers. FHWA will continue to promote the expanded use of refined analysis for bridge design and evaluation through development of technical guidance and training and implementation in projects. FHWA is looking forward to working with our nation's bridge design community to advance our current state-of-practice to take advantage of the vast capabilities that refined analysis can provide.