AN OVERVIEW OF FHWA'S BRIDGE PROGRAM STRATEGIC RESEARCH

Ian M. Friedland, P.E.[1]

Abstract

Starting in 2011, the Federal Highway Administration's bridge and structures research program was restructured and refocused to address new programs and priorities, as described in the agency's Infrastructure Research and Technology Strategic Plan. This paper provides an overview of the current bridge and structures strategic research program, and its expected impact on highway infrastructure technology.

Introduction

In the fall of 2010, the Federal Highway Administration (FHWA) initiated an effort to better integrate all elements of the agency's work related to highway infrastructure; i.e., not just research and development (R&D), but an inclusive highway infrastructure technology and innovation development and deployment program that addresses design and construction, structures and pavement, asset management and long-term infrastructure performance. The result was a new multi-year strategic plan and roadmap that describes the direction and outcomes to be pursued through FHWA's Infrastructure Research and Technology (R&T) program for the next five to ten years (FHWA, 2012). This strategic plan is founded on and informed by input from a broad array of highway stakeholders gathered through both formal and informal mechanisms.

The FHWA Infrastructure R&T strategic plan was discussed during the 27th U.S.-Japan Bridge Engineering Workshop (Friedland, 2011). The objectives of the strategic plan are to:

1. Reduce the number of fatalities attributable to infrastructure design characteristics and work zones.
2. Improve the safety and security of highway infrastructure.
3. Improve the management of infrastructure assets and advance the implementation of a performance-based program for the NHS.
4. Improve the ability of transportation agencies to deliver projects that meet expectations for timeliness, quality and cost.
5. Reduce user delay attributable to infrastructure system performance, maintenance, rehabilitation and construction.
6. Improve highway condition and performance through increased use of design, materials, construction and maintenance innovations.

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[1] Assistant Director, Bridge and Structures R&D, Office of Infrastructure R&D, Federal Highway Administration, U.S. Department of Transportation

7. Reduce the life-cycle environmental impacts of highway infrastructure (design, construction, operation, preservation, and maintenance).

This paper provides an overview of the bridge and structures R&D programs and projects that have been or will soon be initiated in support of the strategic plan and the above objectives. It highlights a few projects, but is not inclusive of the whole program. More information on the overall bridge and structures R&D program can be found on the FHWA Research and Technology website (http://www.fhwa.dot.gov/research/).

Accelerating Bridge Construction

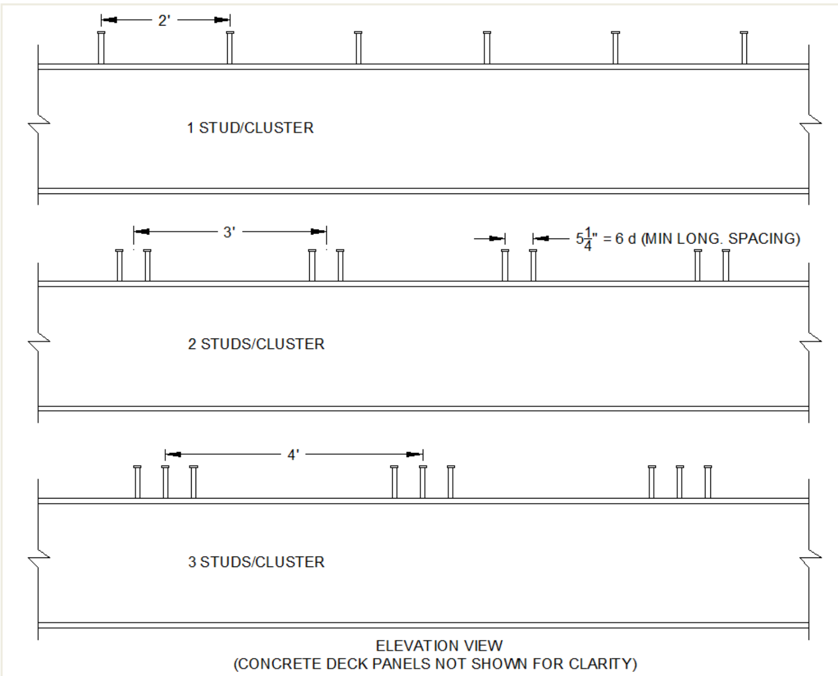
PBES Connections – Prefabricated Bridge Elements and Systems (PBES) show great promise for accelerating field-construction activities and providing increased durability in deployed components. However, the use of PBES frequently necessitates the increased reliance on field-cast connection details. The state-of-the-practice for these connections is inconsistent, with significant opportunities existing for advancement of these critical components. FHWA's Office of Infrastructure Research has a portfolio of projects aimed to facilitate innovation in this field. Conducted through the Structural Concrete Research Program, this portfolio is focused on creating field-cast connections between concrete and steel bridge elements that are simple to construct, develop appropriate strength, and exhibit better durability than the connected components. In short, the goal is to create robust connection systems that can be deployed using normal construction practices. Select projects are listed below.

This is a vertically integrated research portfolio, with projects ranging from the characterization of specific grout material properties to the full-scale structural testing of bridge systems. One project is completing a broad characterization of the mechanical and durability properties of a set of pre-packaged grouts that might be used in PBES connections. Another project is aiming to quantify the shrinkage expressed by commonly used grouts, with a focus on the variety of test methods available and the varying results that can be obtained from those methods. A third project focused on the compression response of a rapid-strengthening ultra-high performance concrete. This project was recently completed with the results published in (Graybeal and Stone 2012a, Graybeal and Stone 2012b). Another recently completed project focused on the impact of differential deflection on the bond performance of reinforcing bars in staged construction connections (Swenty and Graybeal 2012a, Swenty and Graybeal 2012b).

Full-scale connection performance assessment is underway in a project focused on deck-level connections. High-cycle fatigue tests are being completed on connections between precast concrete deck panels, with variables including grout type, reinforcement type, reinforcement lap length, and bonding interface preparation. This project also includes an assessment of a set of small-scale interface bond test methods, with the intent being to provide guidance on grout bond strength as well as the appropriateness of the test methods. Full-scale testing of adjacent box beam bridge systems has also been initiated. This research project aims to advance the state-of-the-practice for this common bridge type by demonstrating that adjacent box beam bridges can be robust, economical solutions when deployed with appropriate connection details.

Efficacy of Clustering Shear Studs for Accelerated Bridge Construction – One of the many options for superstructures to facilitate accelerated bridge construction is steel beams topped with precast concrete deck panels. However, the American Association of State Highway and Transportation Officials (AASHTO) design specifications suggest that steel beams be composite with the concrete, meaning shear studs must be welded to the beams for proper shear transfer. Therefore, pockets must be formed into the precast deck panels to accommodate grouting the studs to the beams. Experience has found that often there are fit-up issues in the field due to the accuracy of the stud placement matching that of the pocket; having more pockets leads to a higher likelihood of fit-up problems. Currently, AASHTO limits the longitudinal spacing between shear studs to a maximum of 61 cm (24 in).

This study is investigating the behavior of clustering shear studs to determine if an increased spacing can be justified. Full-scale beams will be tested in both monotonic and fatigue loading to test the validity of both the static and fatigue design procedures currently



used by AASHTO. Three stud spacings will be tested: 61, 91 and 122 cm (24, 36, and 48 in), though the number of studs will remain constant in the shear span of each specimen. This program will address four objectives: (1) examine if the 61 cm (24 in) maximum spacing limit in AASHTO can be safely extended for clustered studs; (2) examine if studs used in clusters can be placed at relaxed longitudinal and transverse spacings; (3) evaluate how using clusters of studs affects composite action; and (4) evaluate the current AASHTO shear stud specifications for fatigue and ultimate strength resistance. The results of the study will be to recommend changes, if necessary, to the AASHTO LRFD Bridge Design Specifications relevant to shear studs design.

Geosynthetic Reinforced Soil (GRS) Structural Performance Testing – Geosynthetic Reinforced Soil (GRS) is a technology which was advanced by FHWA, and has become an innovative solution which FHWA is currently actively promoting. Through the efforts of the FHWA Every Day Counts program, GRS abutments with an integrated bridge superstructure (known as the GRS-IBS bridge) are now being constructed throughout the United States.

To continue the advancement of the GRS technology, FHWA is currently conducting performance tests on GRS. A performance test (also called a mini-pier experiment) is a large element (1.4 m wide by 2 m tall) GRS load test. During the test, axial load is incrementally applied to the GRS composite structure up to failure as vertical and lateral deformations, along with reinforcement strain and vertical and lateral pressures, are measured. The results of this study are being used for several purposes: (1) to build a database of GRS material properties that can be used by designers or for design specification calibration; (2) to evaluate the relationship between reinforcement strength and spacing; (3) to study thrust against the face as a function of spacing; and (4) to validate and refine the new internal stability design method proposed by FHWA for GRS.

(with facing blocks)

(without facing blocks)

Twelve performance tests have been conducted to date. Test parameters varied reinforcement spacing (from 0.1 to 0.4 m), geotextile strength (from 17.5 to 70 kN/m), soil type (open graded and well graded), and frictionally connected facing elements (concrete masonry unit facing and no facing). Key preliminary results indicate that reinforcement spacing has a large impact on the capacity of GRS and that reinforcement strength and spacing are not linearly proportional. As expected, the impact of the facing element decreases as reinforcement spacing decreases. In fact, under working load conditions, the response of GRS is very similar whether a facing element is used or not. The results also reasonably verify FHWA's new internal stability design method.

Extreme Events and Disaster Mitigation

Unknown Bridge Foundations – Following the catastrophic collapse of the Schoharie Creek Bridge on the New York State Thruway in April 1987, national attention was focused on bridge scour. Foundation characteristics are needed for accurate scour analysis – which turned out to be inaccurate for the Schoharie Creek Bridge. Therefore, as a consequence of addressing scour vulnerability of bridges, the issue of "unknown foundations" became a national priority.

FHWA has initiated a comprehensive research program to address the unknown foundation problem. The current program builds off of prior efforts by FHWA, the AASHTO-sponsored National Cooperative Highway Research Program (NCHRP), and other programs conducted over the past 25+ years. The current FHWA program will develop or evaluate new and existing technologies for characterizing bridges with unknown foundations. In our research, the term "unknown foundation" includes unknown information relating to foundation geometry (depth, shape, type), material, and condition.

The work conducted to date on unknown foundations has focused primarily on the population of bridges over waterways in the United States that must be evaluated for their vulnerability to scour (estimated at approximately 60,000 bridges). However, many bridges built over land are also likely to have unknown foundations and the need for foundation information precludes assessments of seismic vulnerability, substructure impacts (e.g., from truck hits or blast), local soil failures, and evaluations related to load capacity when considering load increases on the bridge deck (e.g., bridge widening or double-decking, increasing maximum legal truck weights).

The unknown foundations issue remains one of the most persistent problems facing the U.S. bridge engineering community. NCHRP Project 21-5 devoted considerable effort to develop new test methods to address this issue (Olson et al., 1996). Although progress has been made since then, there are still concerns on the reliability of the available technologies and associated costs – especially when drilling boreholes adjacent to the foundation are required. At the current time, FHWA is engaging the stakeholder community to define research gaps and needs, and to prepare a multi-year research and deployment plan.

Bridge Tower Wake Turbulence Effects on Traffic and Cables – Wind turbulence in the wake of bridge towers and pylons can result in unexpected gust loadings on vehicles passing through tower portals or alongside pylons. Such unexpected vehicle loadings can cause drivers to overreact and potentially cause serious accidents or lead to bodily injuries. There have been several examples of drivers losing control of their vehicles while crossing major bridge structures during windy periods, some of resulting in fatalities. Wind turbulence in the wake of towers can also lead to buffeting loads on or galloping response of nearby cable hangers or bridge stay cables. While the effects of wind on bridge stay cables has been the subject of considerable research in recent years, this activity has focused on the influence of oncoming winds and not any impact of wake turbulence.

The objective of this study is to explore the nature of wind flow and turbulence characteristics in the wake of representative tower geometries and identify its impact on vehicle safety and the stability of bridge components such as hangers and cables. The study will involve physical modeling, in the form of wind tunnel tests on actual bridge and tower models in the Aerodynamics Laboratory at the FHWA. These tests will be complemented with numerical modeling in the form of computational fluid dynamics (CFD) simulations.

Detailed flow field studies will first be conducted around detailed models of at least two representative bridge towers. A large robotic probe support system will be used to map the 3-D flow field in detail around the models with focus on the wake. The large automated turntable will be used to vary the wind angle relative to the tower models. Following the initial round of tests, simplified models of the roadway or bridge deck sections will be added to the tower models to simulate the final bridge geometry at the tower portal areas. Flow field mapping will be repeated for the models with particular focus on the region near the intersection of the tower and roadway. Numerical modeling will be conducted as necessary to either clarify flow measurements or to augment the physical test results.

The study will provide detailed information on the characteristics of wind flow in the wake of at least two representative tower-deck geometries. The information will be evaluated for its impact on vehicle safety as well as potential for causing wind induced cable vibrations.

Development of an In-situ Bridge Scour Testing Device – Scour is the most common cause of bridge failure in the United States and contributes greatly to bridge construction and maintenance costs. Approaches to mitigate bridge scour include designing and constructing deep foundations, providing protective systems to mitigate scour, and monitoring during potential scour events. Monitoring and mitigation are essential, but information to evaluate potential scour in erosion-resistant soils is scarce. Because of time and cost constraints, most scour prediction methodologies do not account for the wide range of naturally occurring soil properties and their resistance to erosion and scour.

To address the need for more reliable and practical methodologies, FHWA is developing a device that can be used in the field to quantify soil scour susceptibility. An in-situ bridge scour testing device has been constructed and is being evaluated in the FHWA Hydraulics Laboratory. It consists of an outer circular pipe column with a concentric cutting head centered within the column. To contain incoming flow and minimize soil disturbance, the outer pipe column will advance slightly ahead of the cutting head. Inflow enters the cutting head/soil interface from around the perimeter of the head, flows horizontally inward across the soil, and exits vertically upward through an outlet in the center of the cutting head, carrying eroded material away with it. In initial testing, the cutting head has performed well. Designed to ensure a uniform horizontal shear and symmetrical pressure distribution, it was created with 3-dimensional CFD modeling.

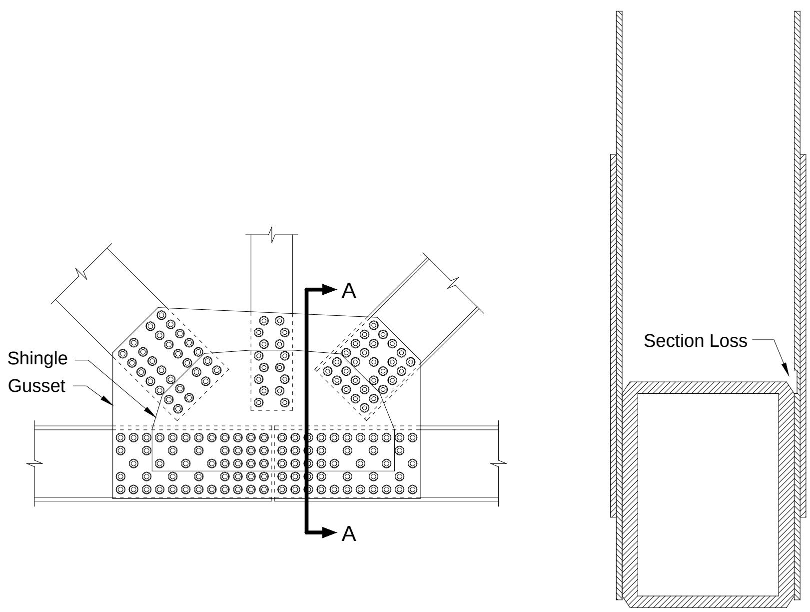
When complete, the study will determine if a practical and reliable field testing device can be developed, and will help optimize expensive bridge foundation construction.

Infrastructure Preservation and Management

Evaluation of Section Loss due to Corrosion in Single and Multilayer Gusset Plate Connections – Since the I-35W Bridge collapse in 2007, significant attention has been focused on the procedures and tools used for inspecting bridges. The National Transportation Safety Board's (NTSB) report examining the collapse (NTSB, 2008) contained five safety recommendations to FHWA and AASHTO. One of the NTSB recommendations was to "require that bridge owners assess the truss bridges in their inventories to identify locations where visual inspections may not detect gusset plate corrosion and where, therefore, appropriate Non-Destructive Evaluation technologies should be used to assess gusset plate condition." In response to this recommendation, FHWA initiated this study to enhance the inspection capabilities beyond visual inspections by using advanced NDE to improve the inspection of single and multilayered gusset plate connections with corrosion, and to transfer research findings on the capacity of gusset plates to develop new and improved inspection protocols.

For the purpose of the single layer gusset plate connection study, NDE technologies based on ultrasonic techniques are being investigated. Two NDT systems based on ultrasonic technology (UT) were used to acquire section loss data: a phased array ultrasonic system and a conventional single element ultrasonic system. Phase array leverages the technology to acquire data over a cross-sectional area by simultaneous use of 30 transducers. Conventional ultrasonic technology and uses a single element probe that is dry-coupled and eliminates the need to use any coupling during the inspection.

The primary concern with detecting corrosion damage in multilayer gusset plate connections using conventional UT sensors is how to get the ultrasonic energy into each hidden layer. It is unlikely that any ultrasonic energy introduced at the surface would be able to propagate into the multiple plate layers. Additionally, access to the boundaries at which corrosion occurs is also difficult (as illustrated in the figure below). On the other hand, there is access to each of the internal layers from the plate edges and it should be possible to generate ultrasound at this boundary and inspect the layers independently for damage. These boundaries allow for bulk wave and multi-bounce shear wave inspection techniques to be used.



Another approach for this inspection type includes advanced X-ray NDE. Advances in the both the source and the detector technology in recent years have led to radiographic images that can be obtained in much less time and lower exposure. The first change is the development of pulsed X-ray source. Pulsed X-ray sources produce radiation only when the source is activated and the X-rays are highly directional. Furthermore, the sources are battery operated with batteries equivalent to those used in electric screwdrivers. Source sizes are typically smaller than a square foot and weigh less than 6.8 kg (15 lbs). Single pulses that are 50 ns long and have photon energies of approximately

270 KVp allow for very high quality digital radiographic images that can be obtained with very low radiation exposure.

Investigation on Chloride Contaminated Grout – FHWA was recently notified by a manufacturer that one of their facilities had produced a prestressing grout which had chloride content exceeding the amounts permitted by various national and international construction and materials specifications. The chloride levels in these prepackaged grouts may be in the range of 0.2 to 0.5 percent (or higher) by weight of the cement, as compared to the specified chloride limit of 0.08 percent by weight of cement. A number of major structures, including bridges and dams, may have used this grout during construction – within the United States, it was estimated that as many as 100 bridges may be affected, including several high visibility important structures like the Woodrow Wilson Bridge and the Veterans Glass City Skyway (Maumee River Crossing).

Since the grout is intended to provide a protective barrier for the ducted post-tensioned (PT) prestressing strand in these structures, concerns were raised as to whether the excessive chloride contamination in the grout may actually accelerate corrosion, rather than protect the steel. As a result, FHWA initiated two research studies to provide systematic information to bridge owners, one focused on determining the acceptable maximum chloride level within the protective grout, and the other to design a sampling plan to determine where exactly the contaminated grout exceeding this threshold value may be located.

The first study is performing a corrosion risk assessment of the PT strands exposed to the chloride contaminated grout and evaluating overall long-term safety of the affected structures containing unacceptable grout. The main focus of this is to determine the amount of chloride required to initiate corrosion under differing conditions (temperature, humidity, segregation, and voids in grouting). The chloride concentration threshold values will provide a prediction model for the long-term performance of those bridges which inadvertently have used chloride contaminated grouts.

The study includes experimental and analytical work, with a number of full-size specimens being tested at chloride concentrations ranging from 0 to 5.0 percent by weight of cement; prestress levels from 0 to 60 percent of the strand ultimate strength, temperatures ranging from -8.3 to 40 degrees C (17 to 104 degrees F), and relative humidity ranging from 40 to 90 percent. Two large environmental chambers were constructed to provide this range of test conditions (see photograph). Temperature and humidity will be cycled to emulate many years of typical environmental exposure in this accelerated test program. At the end of 6 months, all samples will be autopsied to determine the condition of extracted strands from these chloride contaminated grouts. Based on the data, strand condition, and other variables, a chloride threshold value will be determined and the long-term risk assessment will be made based on scenarios encountered in the field.

The second study is developing guidance for bridge owners to sample the grout in both externally and internally post-tensioned bridges, in order to determine exactly where this chloride contamination may be of concern. The plan will address the number of grout samples required to be extracted in a specific bridge from various girder locations (e.g., high point, anchorage, low point deviators) to provide statistical confidence regarding chloride concentration in intact ducts and anchorage areas without harming the structural integrity of the bridge.

At the end of these companion research studies, bridge owners will have a theoretical predictive risk model. This will be based on experimentally determined chloride threshold values and actual values of analyzed chloride concentrations in the extracted grout samples from their bridges based on their field condition and periodic survey data/observations.

Contaminated Chloride Grout Study Specimens and Environmental Chambers

Summary

The projects described above illustrate the range of projects currently underway in the FHWA bridge and structures research and development program. At the current time, there are more than 50 such studies being conducted to address both short-term and longer-term highway infrastructure needs, and to develop new innovative tools and technologies that will help deliver and maintain an high-performing, cost efficient highway system within in the United States. Details on these and many other FHWA R&D studies can be found from the FHWA Research and Technology website (http://www.fhwa.dot.gov/research/).

Acknowledgements

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