Research Project Work Plan

for

HIGH STRENGTH STEEL REINFORCEMENT FOR BRIDGES

SPR 762

Submitted by

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for

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1.0 Identification

1.1 Organizations Sponsoring Research

Oregon Department of Transportation (ODOT)
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2.0 Problem Statement

High-strength steel (HSS) reinforcement, specifically ASTM A706 Grade 80, is now permitted by the AASHTO LRFD Bridge Design Specifications for use in reinforced concrete bridge components in non-seismic regions. Using Grade 80 steel reinforcement instead of Grade 60 steel reduces material and construction costs. However, state highway agencies (SHAs) only allow Grade 80 reinforcing steel in bridge structural elements that are not expected to undergo large strain reversals (low cycle fatigue) during an earthquake. AASHTO and SHAs have concerns with using Grade 80 reinforcement in elements designed for low cycle fatigue due to the lack of experimental data. In addition, using Grade 80 reinforcement is only practical if it is used in all components on a job site to prevent the risk of using Grade 60 reinforcement where Grade 80 reinforcement should be used (most reinforcement looks the same).

A PACTRANS/ODOT research project is underway investigating the capacity of columns containing Grade 80 reinforcement and subjected to earthquake strains. The results from this research are expected to provide essential information on the general performance of columns reinforced with Grade 80 reinforcement. However, obstacles to using Grade 80 reinforcement will remain because data for critical properties of the steel are not available and because some performance criteria have not yet been assessed for systems containing Grade 80 reinforcement. First, the tensile and low cycle fatigue behavior for Grade 80 reinforcing steel have not been adequately measured, which means that large safety factors need to be applied in design equations rendering the material impractical to use. In addition, little or no data are available on Grade 80 steel in resisting shearing action, which is critical for designing connections between bridge elements. Therefore, for ODOT to use Grade 80 steel in seismic regions, these key material and structural characteristics need to be quantified with reliable datasets, and design equations modified, if appropriate, to account for the high integrity input values. The proposed research will investigate low-cycle fatigue characteristics of Grade 80 reinforcement and assess the shear capacity of connections made with Grade 80 steel reinforcement. It is anticipated that this research will provide fundamental characteristics of the Grade 80 steel reinforcement and will provide critical information to design shear connectors with Grade 80 steel reinforcement.

3.0 Objectives of the Study

The first objective of this research is to generate datasets of key mechanical properties (tensile yield, compressive yield, ultimate stress and strain, and total elongation) for ASTM A706 Grade 80 reinforcing steel, to determine how these properties differ from Grade 60 reinforcement, and if appropriate, modify design equations based on the datasets so that the high strength reinforcement can be used for structures in seismic regions. The second objective is to characterize the failure mechanisms and measure the shear capacity of connections containing Grade 80 steel reinforcement. It is anticipated that the shear testing will result in modified shear capacity equations for systems containing Grade 80 steel reinforcement.

3.1 Benefits

High-strength steel bars in reinforced concrete elements can provide the following benefits: less congestion of the reinforcement cages resulting in improved constructability (easier bar and concrete placement), reduced shipping costs, reduced construction costs, improved structural performance during seismic events, and reduced environmental impact.

4.0 Implementation

If the research outcome shows Grade 80 reinforcement meets performance requirements, the product of this research will include analytical equations and procedures that will allow engineers to rationally design structures using Grade 80 reinforcement. If it is determined that Grade 80 reinforcement cannot be used in bridge columns, issues will be identified and the researchers will provide clear reasoning why the reinforcement should not be used. If results indicate that the steel can provide added value, after validation by ODOT bridge engineers, modifications to the ODOT Bridge Design and Drafting Manual will be recommended so that Grade 80 steel can be used within ODOT.

5.0 Research Tasks

***Task 1*: Literature Review**

The literature review will focus on performance characteristics of the reinforcement, appropriate testing parameters, and procedures for modifying the design equations. The researchers will conduct the literature review throughout the duration of the project to identify new knowledge related to HSS reinforcement. However, it is anticipated that the majority of the literature review will be accomplished within the first 6 months of the project.

Time Frame: July 1, 2013 – September 30, 2015
Responsible Party: OSU
Cost: ODOT cost will be $10,000.
Deliverable: The deliverable for Task 1 will be a chapter in the final report that provides background on testing, specifications, and fundamentals on the use of Grade 80 HSS reinforcement for bridge structures.
TAC Decision/Action: None

***Task 2*: Develop Experimental Program**

The team's current thinking on the experimental program follows. The program may be revised based on further review of the literature or based on preliminary test results. This task will include development and definition of the test plan, which will include variables, variable levels, and number of specimens. Currently, the testing program for low-cycle fatigue (Task 2.1) includes more than 200 reinforcing bar specimens and the shear friction tests (Task 2.2) include 12 specimens of 50 to 60 inches in length and approximately 24 inches in height.

Task 2.1: Low-cycle fatigue

For the low-cycle fatigue program, Grade 80 reinforcement will be assessed. This is important because in a seismic event, the longitudinal steel in a structural concrete member would be expected to undergo large tensile and compression strain reversal (i.e., low cycle fatigue). Mander et al. (1994) performed some of the first low-cycle fatigue testing of reinforcement and reported that it "is important to understand the fatigue characteristics of reinforcing steels for seismic applications." The authors concluded that the design codes at the time were too restrictive. However, these tests included only Grade 40 reinforcement and high-strength prestressing bars. In 2010, Hawileh et al.

reported that the low-cycle fatigue responses of ASTM A706 and A615 Grade 60 reinforcement were similar even though their monotonic ductility ratios were very different. The authors developed low-cycle fatigue relationships for the reinforcement such that the maximum permissible strains could be estimated. The authors also noted that bar fracture due to low-cycle fatigue is an important consideration in the seismic design of reinforced concrete structures. Zhou et al. (2008) assessed the low cycle fatigue behavior of high-strength reinforcement (no Grade 80 reinforcement was evaluated) and reported that the Mander model to estimate fatigue life developed in 1994 was too restrictive for newer, higher strength steels. It is clear that low-cycle fatigue testing of Grade 80 steel reinforcement is needed to ensure safe and economical design of reinforced concrete structures in seismic regions. Thus, Grade 80 steel reinforcement will be assessed to evaluate its potential use in seismic regions.

The research team's current thinking for evaluating the low-cycle fatigue characteristics of the steel reinforcement is shown in Table 1. Specifically, the research will assess the number of cycles to failure and over-strength factors for the Grade 80 steel for the variables shown in Table 1. The team will assess reinforcement with different support spacing, tensile strains, compressive strains, and. compressive-tensile strain ratios. Varying the support spacing, *s*, will provide insight on reinforcement performance for different hoop spacing (i.e., hoop spacing will likely influence stress and strain at buckling). The team will develop relationships for calculating the over-strength factors and energy dissipation for ASTM A706 Grade 80 reinforcement (while comparing it to ASTM A706 and ASTM A615 Grade 60 reinforcement). To represent the actual behavior of the bar, the team's current thinking is to test unmachined bar specimen (although equipment constraints may prevent this). Thus, in this task, the team will assess the feasibility of testing unmachined full-size actual rebar samples. The current V-shaped grips of the UTM testing machine available in the Structures Lab at Oregon State University allows for testing of reinforcing bar samples of up to #6 (5/8-inch diameter). Use of unmachined bar samples may introduce additional variability and may require that the number of samples tested for each condition be adjusted for some cases. It is also worth noting that there are reports in the literature (e.g. Brown and Kunnath, 2004) which show that fatigue life is influenced by the diameter of the bar and the geometry of the rolled bar. In this study, due to the scarcity in the market of different Grade 80 A706 bar sizes and due to constraints of the testing equipment available at OSU which is a 110 kip Universal Testing Machine, bar sizes to be tested will be either #5 or #6 bars.

Note that this is the team's current thinking and preliminary testing will provide insight on how to generate more value from the test plan. Testing will follow ASTM E606, when appropriate.

Table 1 – Preliminary test plan for assessing cyclic stress-strain performance of reinforcing steels.

Reinforcement Types	Support Spacing, s	Tensile Strain, ε_T (%)	Compressive Strain, ε_C (%)	R ($\varepsilon_C/\varepsilon_T$)	Number of Samples to Test for each Condition*
ASTM A615 G60 ASTM A615 G80 ASTM A706 G60 ASTM A706 G80	$4d_b$ and $6d_b$	0.25 to 2.5	0.25 to 2.5	1.0 to 0.1	5

* - estimated total number of specimens is more than 200

Task 2.2: Shear Capacity Testing

The team will assess the shear capacity of connectors with Grade 80 steel reinforcement. Although research has been performed to quantify the shear capacity of shear connectors based on the push-out and push-off tests, the validity of push-off tests to estimate shear transfer capacity has been questioned. Slutter and Driscoll (1965) reported that the behavior of the push-off test is not identical to the behavior of full-scale specimens subjected to flexural force and that lift-forces can adversely affect the shear capacity in shear pocket systems. Dallam (1968) reported that push-off tests can exhibit lower shear transfer capacities than full-scale test results. However, more recently Issa et al. (2003) concluded that the up-lift effect on the reduction of the shear transfer capacity can be minimized with proper specimen design and these values can be used to estimate the shear capacity of shear connector systems. The team is thus proposing to evaluate shear capacity using push-off tests as shown in Figure 1. Preliminary dimensions are shown in Figure 1. These dimensions will be finalized at the end of this task.

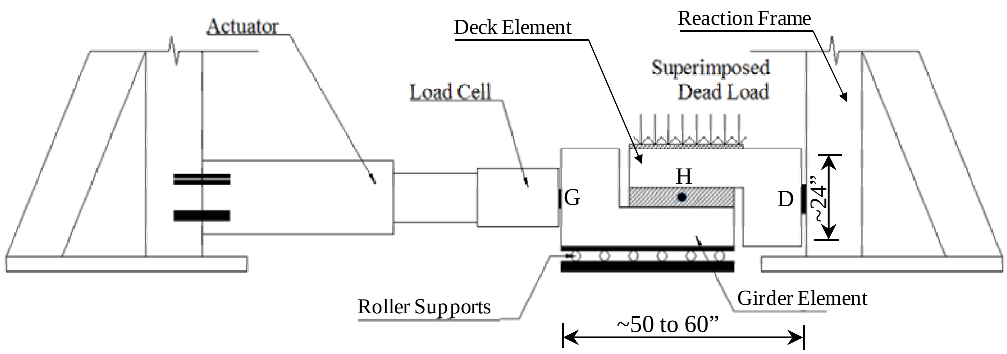

Figure 1 – Possible test layout.

Recent research has focused on the details and performance of various shear connector systems. Although this research will only assess standard shear connector systems containing high strength steel reinforcement, these recent studies will be used to better understand the methodologies used to propose modified design equations. Significant efforts have also been underway to increase shear capacity of prefabricated deck systems (Issa et al. 2003, Scholz et al. 2007, National Cooperative Highway Research Program [NCHRP] 584 2008) and this work will also be used to better understand shear capacity of non-standard systems.

The American Association of State Highway and Transportation Officials Load and Resistant Factor Design (AASHTO LRFD 2012) can be used to estimate the shear transfer capacity of girder-cast-in-place (CIP) deck systems without a haunch (typical of Oregon). The nominal shear strength, V_n, can be estimated when a CIP deck is placed on a clean concrete girder surface roughened to an amplitude of 6.4 mm (0.25 in.) as follows:

$$V_n = c \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c) .... (a)$$
$$V_n \leq \min(K_1 \cdot f'_c \cdot A_{cv} \ , K_2 \cdot A_{cv}) ...... (b) \quad (1)$$

Where:

c = cohesion factor (0.28 ksi [1.9 MPa])
μ = coefficient of friction (1.0 for roughened concrete surface)
A_{vf} = cross section of the shear reinforcement (in.^{2} [mm^2])

f_y = yield strength of the shear reinforcement or shear connector (ksi [MPa])
P_c = net compressive force normal to the shear plane (kips [kN])
f'_c = compressive strength of concrete (ksi [MPa])
A_{cv} = interface area of the concrete engaged in shear transfer (in.^{2} [mm^2])
K_1 = fraction of concrete strength available to resist the interface shear (0.3)
K_2 = limiting interface shear resistance and can be taken as 1.8 ksi (12.4 MPa) for normal-weight concrete or 1.3 ksi (8.9 MPa) for lightweight concrete

Eq. 1 is commonly used when hot-rolled round bars (R-bars) are used for the girder-deck composite system. Eq. 1 indicates that if the yield strength, f_y, increases by 33% (from 60 to 80 ksi), the cross section of the shear reinforcement, A_{vf} , can be reduced by the same percentage. Alternatively, the equation indicates that the spacing of the shear reinforcement could increase by 33% (assuming the area is kept the same). However, Trejo and Kim (2011) reported that this direct relationship is likely not applicable as there are several other factors need to be considered (such as bar yielding and concrete crushing).

This research will investigate the efficiency of four different types of shear connector materials for the girder-deck systems. The team's current thinking on testing is to fabricate specimens containing ASTM A615 and ASTM A706 with both grade 60 and 80 reinforcing steels (the four different systems will contain A615 Grade 60, A706 Grade 60, A615 Grade 80, and A706 Grade 80 – see Table 2). Triplicate specimens will be tested initially – if additional testing is needed due to large scatter, the team will test additional specimens.

Table 2 – Preliminary test plan for assessing shear friction with different reinforcing steels.

Reinforcement Types	f'_c	Number of Samples to Test for each Condition**
ASTM A615 G60 ASTM A615 G80 ASTM A706 G60 ASTM A706 G80	4,000 psi	3

** - estimated total number of specimens is 12

This research can also be useful for determining the capacity of shear keys for seismic loading. For such applications the superimposed load as shown in Figure 1 would not be applied. Although this load case could be conceived in the experimental design phase, the number of specimens would double and the current budget does not allow for this increased testing.

Characterization will include identifying the five stages of shear transfer and failure mechanisms as identified by Kim and Trejo (2013). These stages include (a) initial adhesion loss (Stage 1), (b) shear key action (Stage 2), (c) shear key action failure at peak load (Stage 3), (d) dowel action of the shear connectors at sustained load (Stage 4), and (e) final failure of the system (Stage 5) as shown in Figure 2.

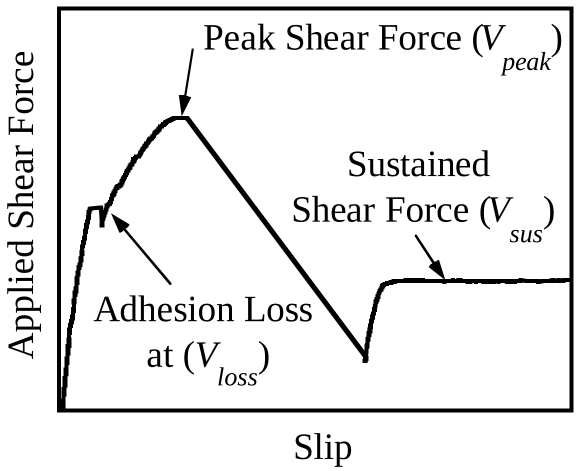

Figure 2: Typical characteristics of shear failure (Stage 5 not shown).

Time Frame: It is anticipated that the majority of this task will be completed within 6 months of project initiation. However, because results from subsequent tasks will be needed to reassess the experimental design, full completion is not anticipated until well within the testing program (~16 months after project initiation). July 1, 2013 – October 31, 2014.
Responsible Party: OSU
Cost: ODOT cost will be $5000.
Deliverable: Initial experimental program for Task 3 and revisions to initial test program when needed.
TAC Decision/Action: Review and approve experimental test design

***Task 3*: Fabricate Specimens and Perform Experimental Testing**

The experimental design developed in Task 2 will be conducted. The results will be used to develop new or modified equations and to establish appropriate safety factors in the AASHTO LRFD design equations.

Time Frame: The team will have to procure Grade 80 reinforcement. However, contacts have been established and this should occur relatively soon after the project starts. Specimens to characterize the low-cyclic fatigue of the reinforcement will be fabricated soon after project initiation. Low-cycle fatigue testing is anticipated to take 12 months. Fabrication of the shear specimens will begin after a short literature review. Fabrication is anticipated to take up to 10 months. Testing will follow after adequate concrete strength is achieved. Once initiated, testing is anticipated to take up to 12 months. Fabrication and testing of all specimens will take up to 24 months. July 1, 2013 – June 30, 2015
Responsible Party: OSU
Cost: ODOT cost will be $105,000; PACTRANS funding will provide a $95,000 match.
Deliverable: Results and analysis of testing. Presentation(s) when significant results are obtained.
TAC Decision/Action: Review outcome and provide input.

***Task 4*: Produce Final Report and Disseminate Findings**
The research findings will be disseminated through the final report, publications, and presentations. All reports will be produced in the standard ODOT Research Group report format unless some other format is deemed to be more appropriate as a supplement to the ODOT format. The research team will make recommendations to ODOT on using Grade 80 reinforcement in structures built in seismic regions. Where appropriate, recommendations will be made to update design equations.

Time Frame: The research team will document findings from the literature review and testing throughout the research program. However, the team will focus efforts on the final report within the last six months of the project. July 1, 2015 – December 31, 2015

Responsible Party: OSU

Cost: ODOT cost will be $15,000; PACTRANS funding will provide a $5000 match.

Deliverable: Final report and presentation to ODOT personnel for Review in September 30, and Final revised report by December 31, 2015.

TAC Decision/Action: Review draft report and provide input for final report.

6.0 Proposed Schedule

Task	FY14				FY15				FY16	
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
1. Literature review									R	F
2. Test design			*			*				
3. Fabricate Specimens & Conduct testing					*			*		
4. Report									R	F

*Deliverables; R – Final report submitted for ODOT review; F – Final submission of Report

7.0 Budget

The total project cost is $246,000. PACTRANS is contributing $100,000. The table below shows the ODOT costs.

Cost Source	FY14	FY15	FY16	Total
1. Literature review	$9000	$1000		$10,000
2. Test design	$5000	$0		$5000
3. Conduct testing	$30,000	$75,000		$105,000
4. Report	$1000	$4,000	$10,000	$15,000
Total for tasks (Work order amount)	**$45,000**	**$80,000**	**$10,000**	**$135,000**
ODOT support/administration	$5000	$4000	$2000	$11,000
Total project costs to ODOT	**$50,000**	**$84,000**	**$12,000**	**$146,000**

8.0 References

8.1 Brown, J., & Kunnath, S. K. (2004), "Low-cycle fatigue failure of reinforcing steel bars," ACI Materials Journal, 101(6).

8.2 Dallam, L. N. (1968), "Push-Out Tests of Stud and Channel Shear Connectors in Normal-Weight and Lightweight Concrete Slabs," University of Missouri-Columbia Bulletin, 69 (12), 1-76

8.3 Hawileh, R. A., Abdalla, J. A., Oudah, F., & Abdelrahman, K. (2010). Low-cycle fatigue life behaviour of BS 460B and BS B500B steel reinforcing bars. Fatigue & Fracture of Engineering Materials & Structures, 33(7), 397-407.

8.4 Issa, M.A., Patton, T.A., Abdalla, H.A., Yousif, A.A., Issa, M.A. (2003). "Composite Behavior of Shear Connections in Full-Depth Precast Concrete Bridge Deck Panels on Steel Stringers," PCI Journal, Sept-Oct, 1-15.

8.5 Kim, Y. H. and Trejo, D., "Shear Transfer Mechanisms and Design Equations for Shear Connectors for Full-Depth Precast Deck Panel Systems," *Accepted for Publication, ACI Structural Journal*, March 2013.

8.6 Mander, J. B., Panthaki, F. D., & Kasalanati, A. (1994). "Low-cycle fatigue behavior of reinforcing steel." Journal of Materials in Civil Engineering, 6(4), 453-468.

8.7 NCHRP Report 584 (2008). "Full-Depth Precast Concrete Bridge Deck Panel System." Transportation Research Board, Washington, D.C.

8.8 Scholz, D.P., Wallenfelsz, J. A., Lijeron, C., and Roberts-Wollmann, C.L. (2007). "Recommendations for the Connection Between Full-Depth Precast Bridge Deck Panel Systems and Precast I-Beams." Report No. VTRC 07-CR17, Virgnia Transportation Research Council, Charlottesville, VA.

8.9 Slutter, R.G., and Driscoll, G.C. (1965). "Flexural Strength of Steel-Concrete Composite Beams." Proceedings, *ASCE Journal of the Structural Engineering*, April 1965, 71-99.

8.10 Trejo, D. and Kim, Y.H., Development of Precast Bridge Deck Overhang System, Research Report 0-6100-3, July 2011, FHWA/TX-10/0-6100-R3, 74 pages.

8.11 Zhou, Y., Ou, Y. C., Lee, G. C., and O'Connor, J. S., (2008), A Pilot Experimental Study on the Low Cycle Fatigue Behavior of Stainless Steel Rebars for Earthquake Engineering Applications, Report at the University of Buffalo.