Research Project Work Plan

for

TITANIUM FOR STRENGTHENING EXISTING REINFORCED CONCRETE BRIDGES

SPR 775

Submitted by

Dr. Christopher Higgins
Professor

Oregon State University
Civil and Construction Engineering
101 Kearney Hall
Corvallis, OR 97331-3212

for

Oregon Department of Transportation
Research Unit
200 Hawthorne Ave. SE, Suite B-240
Salem, Oregon 97301-5192

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1.0 Identification

1.1 Organizations Sponsoring Research

Oregon Department of Transportation (ODOT)
Planning and Research Unit
200 Hawthorne Ave. SE, Suite B-240
Salem, OR 97301-5192 Phone: (503) 986-2700

(If federal funds are used)
Federal Highway Administration (FHWA)
Washington, D.C. 20590

1.2 Principal Investigator(s)

Dr. Christopher Higgins, Professor
Oregon State University
Civil and Constr. Engr.
348 Owen Hall
Corvallis, OR 97331-3212 Phone: (541) 737-8869

1.3 Technical Advisory Committee (TAC) Members

Tanarat Potisuk, ODOT Bridge Section
Ray Bottenberg, ODOT Bridge Section
Jon Rooper, ODOT Bridge Section
Paul Strauser, ODOT Region Four
Tim Rogers, FHWA

1.4 Project Coordinator

Steve Soltesz Phone: (503) 986-2851

1.5 Project Champion

Tanarat Potisuk

2.0 Problem Statement

Oregon has many reinforced concrete bridges that were built in the 1950's. The bridges from this era commonly have poor reinforcing details such as longitudinal reinforcing bars terminating in areas under stress, inadequate bar splices, and insufficient vertical reinforcement. Consequently, these older ODOT bridges often are evaluated as deficient and require remediation. It is anticipated that on-going load rating and evolving loading requirements will uncover many deficient bridges for years to come.

Current practice and previous ODOT research provide design options for strengthening. A common option is to bond carbon fiber reinforced polymer (CFRP) strips either on the surface or just below the surface. The method relies solely on the adhesive bond to transfer stresses to the CFRP; consequently, the full strength of the CFRP is never utilized because the concrete near the bond fails first. To compensate for the relatively weak bond, more strips are installed to distribute stresses across more bond surfaces. If space is not available for more strips, a more elaborate strengthening scheme may be deployed.

In a current ODOT-funded research project, a titanium alloy bar has been developed that is lightweight and has high-strength and high ductility and is impervious to environmental degradation. The bar can be produced over a wide range of sizes. Unlike CFRP, a key feature of this material is that it can be bent. Consequently, the ends of the titanium bar can be bent to ninety degrees and embedded deep into a beam that needs strengthening. This mechanical anchorage overcomes the problem of the weak bond and allows the titanium reinforcing material to utilize its high strength. These characteristics make it both a structurally and economically effective choice over CFRP and other alternatives.

Based on the current research, a titanium retrofit was deployed on a bridge over I-84. In the strengthening design, the number of supplemental reinforcement elements per girder line was reduced from twelve for CFRP to four for titanium. The retrofit was approximately 30% less costly and is expected to have better structural performance than CFRP.

The characteristics of titanium reinforcement, particularly its ability to be bent, open up possible cost savings for a wide range of strengthening situations. Three areas listed in the Research Objectives have been identified for further research to exploit the advantages of titanium reinforcement for strengthening.

3.0 Objectives of the Study

The research has three objectives to expand the use of titanium reinforcement:

- Develop a splicing method that allows supplemental reinforcing bars to be deployed along the full length of girders including through the intermediate diaphragms that protrude from most beams.

- Develop an unbonded strengthening detail that eliminates the need to cut grooves into the concrete surface, thereby reducing labor costs, epoxy material costs, and construction time.

- Develop methods to apply exterior titanium bars to strengthen girders with inadequate transverse reinforcement.

4.0 Implementation

Meetings and workshops will be held with ODOT personnel to present research findings in-progress as well as summary findings. Presentations on findings will be made to the bridge engineering community. Background information and findings will be described in reports, papers, and peer-reviewed journals. Explicit examples will be provided for the analytical and design methods developed.

5.0 Research Tasks

<u>*Task 1*</u>*:* **Literature Review**

Review technical literature on supplemental reinforcing for splice details, unbonded strengthening approaches, and shear strengthening for reinforced concrete (RC) beams. Review of international design provisions will also be performed.

<u>*Time Frame*</u>*:* 4 month
<u>*Responsible Party*</u>*:* OSU
<u>*Cost*</u>*:* $20,000
<u>*Deliverable*</u>*:* List of pertinent references and background information for final report. Initial specimen designs for Tasks 2, 3, and 4.
<u>*TAC Decision/Action*</u>*:* Comment on specimen designs.

<u>*Task 2*</u>*:* **Splicing Methods for Titanium Reinforcing**

For positive moment regions of most RC girders, there are diaphragms located transverse to the member. These present a significant practical issue for retrofitting schemes as the interference of diaphragms precludes continuity of supplemental reinforcing bars along the web surface. Alternative details to provide continuity of supplemental reinforcing materials have not previously been developed. To develop effective alternative splice details and to quantify the performance and available strength of different details, experimental tests are proposed. Five (5) large-size girder tests are proposed to develop methods to splice titanium reinforcing bars. Parameters in the study are:

- Splice detail alternatives for T-beams (4 specimens)
- Freeze-thaw and wetting with fatigue loading of best detail (1 specimen)

Most tests will be performed on full-size girders with the splice detail located in a constant moment region to isolate the flexural demands on the splice. One specimen will be a control. Two specimens will assess alternative splice details. One specimen will place the splice at a controlled diagonal crack that intersects the flexural reinforcing steel. The diagonal-crack tip will cross the longitudinal steel within the development length region. The diagonal crack angle will be controlled by constructing the specimen with a cast-in-place “crack” at a 45^{o} angle. The last specimen will evaluate environmental durability and effects of high-cycle fatigue on the splice detail in a constant moment region.

The following test matrix is proposed:

Specimen #	Specimen Shape	Development Length	Crack Angle	Note
1	T	Ld	90	Control
2	T	Ld	90	Splice1
3	T	Ld	90	Splice2
4	T	Ld/2	45	Shear+Bending
5	T	Ld	90	Envir+Fatigue

Specimens will be instrumented to measure overall member response as well as local component stresses and deformations. In particular, titanium demands at the splice locations will be measured directly. Experimental findings will be used to develop recommendations for designing and detailing splices in supplemental titanium reinforcing materials for existing RC bridge members.

Time Frame: 12 months
Responsible Party: OSU
Cost: $100,000
Deliverable: Report on the experimental methods and results in the final report.
TAC Decision/Action: Review alternative details.

Task 3: **Unbonded Strengthening Methods for Titanium Reinforcing**

Present methods require cutting grooves in the concrete surface to bond the supplemental materials to the concrete. This task will develop new methods and details to use titanium reinforcing without having to cut grooves into the concrete. Six (6) large-size girder tests are proposed to develop methods to use unbonded titanium reinforcing bars to strengthen existing girders. Parameters in the study are:

- T- beams (4 specimens)
- Fatigue loading (2 specimens)

Tests will be performed on full-size girders under four-point bending. Four specimens will assess the approach for positive moment regions (T-specimens). One of the specimens will include haunch and taper details. Different deviators and end anchorage details will be used on the specimens. Two specimens will evaluate the effects of high-cycle fatigue on alternative deviator and end anchorage details.

In addition to the large-size girder specimens, subcomponent specimens and material tests will also be undertaken to optimize connection details, hooks dimensions, and pre-tensioning of bars. Fatigue tests of the titanium bars in air will be undertaken to assess fatigue performance. Experimental findings will be used to develop recommendations for designing unbonded supplemental titanium reinforcing bars for strengthening existing RC bridge members.

Time Frame: 12 months
Responsible Party: OSU
Cost: $120,000
Deliverable: Report on the experimental methods and results in final report.
TAC Decision/Action: Review alternative details.

Task 4: **Shear Strengthening Method with Titanium Reinforcing**

No data are available to evaluate shear strengthening with titanium reinforcing bars. This task will assess new approaches and details to use titanium reinforcing for shear strengthening bridge girders.

Six (6) large-size girder tests are proposed to produce experimental data on the behavior and capacity of RC bridge girders strengthened with titanium bars for shear. Parameters in the study are:

- Positive moment region (3 T-specimens)
- Negative moment regions (3 IT-specimens)
- Application method (NSM vs unbonded)

The following test matrix is proposed:

Specimen #	Specimen Shape	Installation Approach
1	T	NSM
2	T	Unbonded
3	T	*
4	IT	NSM
5	IT	Unbonded
6	IT	*

*To be determined based on initial results

Tests will be performed on full-size girders under four-point bending. Three specimens will assess shear strengthening for positive moment regions (T-specimens) and three specimens for negative moment regions (IT-specimens). All specimens will have well anchored flexural steel and widely spaced stirrups with 18 in. spacing, just at the minimum amount of internal stirrups as prescribed by current specifications. Two different strengthening approaches will be considered including NSM and unbonded surface application of titanium with hooked end anchorages of the titanium bars.

<u>Time Frame</u>: 13 months
<u>Responsible Party</u>: OSU
<u>Cost</u>: $110,000
<u>Deliverable</u>: Report on the experimental methods and results in final report.
<u>TAC Decision/Action</u>: Review alternative details.

Task 5: **Analysis and Design Methods**

Experimental findings will be used to develop design recommendations that will enable ODOT engineers to design with titanium reinforcing that can assure strength and long-term durability of repairs. Available methods and models will be compared with experimental results. Where appropriate, modifications to existing approaches or new methods will be developed for titanium reinforcing in strengthening RC girders, including the effects of high-cycle fatigue and environmental durability.

<u>Time Frame</u>: 4 months
<u>Responsible Party</u>: OSU
<u>Cost</u>: $30,000
<u>Deliverable</u>: Report on the analysis and design methods in final report.
<u>TAC Decision/Action</u>: Review methods.

Task 6: **Reporting**

A report detailing Tasks 1– 5 will be delivered to ODOT. The report will detail the experimental plans and test results, the evaluation of available analysis and design methods, and make recommendations for design and detailing of titanium reinforcing for strengthening RC girders. Examples will be included. A workshop will be conducted for ODOT personnel to describe the findings and the recommended guidelines.

Time Frame: 7 months
Responsible Party: OSU
Cost: $20,000
Deliverable: Final report with design examples.
TAC Decision/Action: Review report.

5.1 Reporting

All reports shall be produced in the standard ODOT Research Section report format provided to the Project Investigator by the Research Coordinator unless some other format is deemed to be more appropriate. The Project Investigator shall be responsible for submitting reports of professional-level written composition equivalent to the writing standards of peer-reviewed journals. These writing considerations include grammar, spelling, syntax, organization, and conciseness.

The Project Investigator, in consultation with the TAC and Research Coordinator, shall deliver to ODOT in electronic format the data produced during the project. The Project Investigator shall ensure the data are labeled and organized to facilitate future access. ODOT shall warehouse the data.

5.2 Safety and Related Training

All personnel (Project Investigator, students, research assistants, technicians) working in the laboratory or in the field on this project will follow the Site Safety Plan contained in the attached Appendix.

Prior to accessing ODOT right-of-way (ROW), all personnel who will work on ODOT ROW shall complete safety training appropriate to the work to be performed within the ROW. The Project Investigator shall notify the Project Coordinator in writing (email accepted) prior to the first day of work within the ROW that all project personnel who will access ODOT ROW have been trained. Until all ROW work is completed, the Project Investigator shall notify the Project Coordinator in writing (email accepted) annually that safety training appropriate to the work to be performed within the ROW has been completed by all personnel who will work on ODOT ROW.

6.0 Time Schedule

The proposed time line for completion of the project tasks is shown below.

Project Tasks	FY15 Qtr 1 Jul - Sep	FY15 Qtr 2 Oct - Dec	FY15 Qtr 3 Jan - Mar	FY15 Qtr 4 Apr - Jun	FY16 Qtr 1 Jul - Sep	FY16 Qtr 2 Oct - Dec	FY16 Qtr 3 Jan - Mar	FY16 Qtr 4 Apr - Jun	FY17 Qtr 1 Jul - Sep
Task 1: Literature Review Deliverable: Background information and specimen designs			*						
Task 2: Splice Details Deliverable: Experimental methods and results									
Task 3: Unbonded Methods Deliverable: Experimental methods and results									
Task 4: Shear Strengthening Deliverable: Experimental methods and results									
Task 5: Analysis and Design Deliverable: Methods for analysis and design									
Task 6: Reporting Deliverable: FINAL REPORT								# %	&

*TAC review of designs, # Workshop, % Draft final report to TAC, & Final Report

7.0 Budget Estimate

Task	**FY15**	**FY16**	**FY17**	**Total**
1. Literature search	20,000	0		20,000
2. Splicing Methods for Titanium Reinforcing	90,000	10,000		100,000
3. Unbonded Strengthening Methods for Titanium Reinforcing	100,000	20,000		120,000
4. Shear Strengthening Method with Titanium Reinforcing		110,000		110,000
5. Analysis and Design Methods		30,000		30,000
6. Reporting			20,000	20,000
Total OSU costs (contract amount)	**210,000**	**170,000**	**20,000**	**400,000**
ODOT project management	5,000	5,000	3,000	13,000
Total project costs	**215,000**	**175,000**	**23,000**	**413,000**