Research Project Work Plan

for

DEVELOPMENT OF TITANIUM SEISMIC RETROFITS FOR DEFICIENT CONCRETE COLUMNS

SPR 784

Submitted by

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for

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1.0 Identification

1.1 Organizations Sponsoring Research

Oregon Department of Transportation (ODOT)
Research Section
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Federal Highway Administration (FHWA)
Washington, D.C. 20590

1.2 Principal Investigator

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1.3 Technical Advisory Committee (TAC) Members

Tanarat Potisuk, ODOT
Albert Nako, ODOT
Ray Bottenberg, ODOT
Paul Strauser, ODOT
Tim Rogers, FHWA
Bert Hartman, ODOT

1.4 Project Coordinator

Tony Knudson, ODOT Research Phone: 503-986-2851

1.5 Project Champion

Craig Shike, Bridge Engineering Section

2.0 Problem Statement

Hundreds of bridges in the Oregon bridge inventory are supported on seismically deficient reinforced concrete columns. These columns are expected to perform poorly during a seismic event. To prevent bridge collapses and ensure disaster response and recovery after an earthquake, the deficient structural details need to be effectively retrofitted.

2.1 Background and Significance of Work

Reinforced concrete (RC) columns designed prior to the mid-1970's have details which make them susceptible to premature failure during earthquakes (Lynn et al. [1996]). In particular, lap splices and widely spaced transverse reinforcement are insufficient to develop and maintain strength under repeated loading. Splices are typically located just above the footing elevation in hinge regions where there is significant ductility demand. Transverse reinforcement is often too widely spaced and insufficient to adequately confine the core area, prevent buckling of the longitudinal reinforcement within the flexural hinge region, and provide sufficient shear strength. A typical column is shown in Fig. 1.

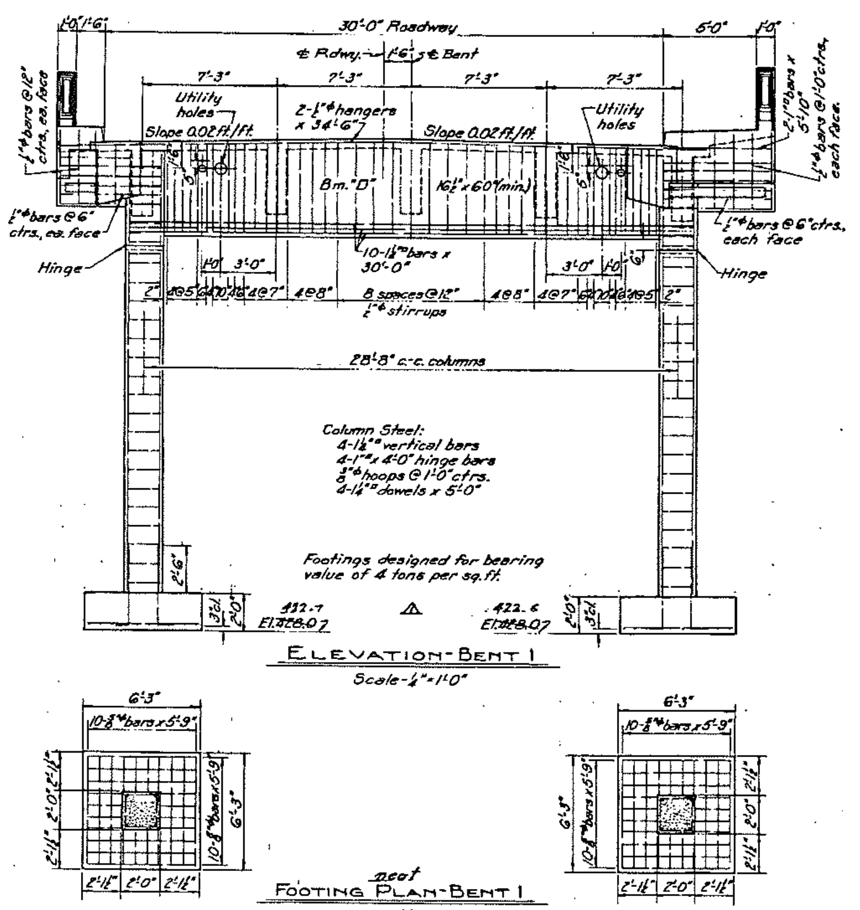

Fig. 1) Typical nonductile reinforcing details for square columns (short splice length and inadequate confinement).

These deficiencies have led engineers and researchers to develop different retrofitting methodologies to improve their seismic performance. The most common techniques use steel jackets or carbon-fiber composites (for example Aboutaha et al. [1996], Chai et al. [1990, 1994], Valluvan et al. [1993], Ersoy et al. [1993], Xiao and Ma [1995], Saadatmanesh et al. [1995,1997], Saatcioglu and Yalcin [2003]). Work on circular columns has been done using shape-memory alloy bars [Andrawes, 2010].

Most retrofit methods rely on confinement to improve the seismic performance of nonductile RC columns but have complicated installations, require specialized labor, need significant column preparation, and are expensive. New retrofit methods are proposed which employ a novel use of continuous spirals of a high-strength titanium alloy bars, supplemental longitudinal titanium alloy bars, and are combined with low shrinkage concrete or grout to externally protect nonductile rectangular RC columns. The proposed method relies on an innovative application of new high-performance materials and common construction methods which will provide an economic solution for retrofitting the many nonductile RC columns in Oregon. It will provide both ductility and strength and allow conventional inspection methods to assess the integrity of the retrofit over the bridge lifetime and allow evaluation of the column condition after a seismic event.

3.0 Objectives of the Study

A research program is proposed to develop seismic retrofits for nonductile rectangular RC columns using high-strength titanium alloy bars. The objectives of the proposed research project are to:

(1) Establish the structural effectiveness of titanium alloy bars for seismic retrofitting RC columns

(2) Determine the economic feasibility of the retrofit methods

(3) Develop analytical models to describe the behavior and performance of retrofitted nonductile RC columns

(4) Develop design methods that can be used to achieve desired seismic performance for nonductile RC columns

3.1 Benefits

The research aims to develop a new suite of seismic retrofit solutions that are structurally effective, economical, and environmentally durable with very long expected service life. The strengthening approaches will be experimentally validated. The results will effectively extend the service life of existing bridges by enabling them to provide adequate seismic performance. This will help ensure continued operation of bridges after an earthquake thereby minimizing replacement costs. Bridges with seismically vulnerable details continue to remain in service due to lack of resources. If economical and structurally effective strengthening methods can be developed, such as those proposed, it will be possible to upgrade more seismically deficient bridges in the inventory with less money.

4.0 Implementation

Meetings and workshops will be held with ODOT Bridge section personnel to present research findings in-progress as well as summary findings. Background information and findings will be described in reports, papers, and peer-reviewed journals. Design examples will be provided for the methods developed. Web-based access to in-progress test data and images, analytical methods, and summary findings will be available on-line where appropriate. The results of the research will be presented at conferences and workshops both regionally and nationally.

5.0 Research Tasks

Task #1: TAC Meeting #1

Project kick off meeting.

Time Frame: 1-3 Months after NTP
Responsible Party: C. Higgins, ODOT Research Coordinator, TAC
Cost: $0.
Deliverable: TAC meeting attendance, TAC meeting presentation, TAC Meeting Minutes
TAC Action: Review and understand project research problem statement, research questions, the limits of the research, and the project schedule. Advise ODOT Research Coordinator regarding any critical issues with the project's scope or schedule. Advise PI's regarding related professional practices, standards, methods and context for the project.
ODOT Action or Decision: Review TAC advice, discuss with PI, and if necessary direct PI to make changes to project documents.

Task #2: Literature and Design Drawing Review

A literature review will be performed to collect information related to rehabilitation and strengthening of anchorage of flexural bars. CFRP and metal alloys will be investigated for possible inclusion in the study. Performance requirements for the strengthening material will be developed and will be used as part of a review of possible alternative materials. A review of drawings for bridges constructed prior to 1970 will be conducted on three of ODOT's proposed phase I lifeline corridors (I-5; US 97; OR 58). The substructure reinforcing details, materials, column axial load levels, and footing/pile cap dimensions will be collected and organized into a database. Recommendations will be made to the TAC on the key features to be studied in subsequent tasks.

Time Frame: 6 months
Responsible Party: C. Higgins

Cost: $25,000
Deliverable: Literature review, summary of state-of-knowledge, column properties, and retrofit alternatives
ODOT Action or Decision: Review plans for testing

Task #3: Laboratory Tests of Seismic Retrofits

To evaluate the effectiveness of the retrofit methods and provide essential test data for development of analytical models and design recommendations, laboratory tests are proposed. Ten (10) specimens will be tested to failure under reversed cyclic loading. Of these, eight (8) will be column specimens on well detailed footings and two (2) will be columns with vintage footing details to assess column/footing interactions. Retrofit effectiveness will be evaluated by comparing the behavior of retrofitted columns against control specimens. The most common column details, identified in Task I, will be used in the test program. An example specimen (at the footing) is shown in Fig. 2 and the proposed test setup is shown in Fig. 3. The column axial compression stress will be held constant for all specimens. Parameters to be included in the study are:

- Square nonductile column dimensions and details (worst case lap lengths and ties)
- Amount of longitudinal titanium reinforcing
- Bonded vs unbonded titanium reinforcing
- Amount of transverse titanium reinforcing
- Shear/moment ratios
- Column-Foundation interactions

For the last parameter, it should be noted that the in-situ foundation footings have limited reinforcing steel and were not detailed for lateral forces. Thus, retrofitting a column could cause unintended damage to the foundation. To investigate this influence, two (2) specimens are proposed that include the full column-footing assembly. The soil/pile interactions will be included at the footing base and the entire assembly will be compressed onto the structural laboratory strong floor. One specimen will have a spread footing and the other will have timber piles (using simulated pile stubs). The final details will be based on the design drawing review conducted in Task 2.

Near-surface mounting of the titanium alloy bars will be considered for bonding the reinforcing to the sections and allow comparisons of performance with unbonded titanium alloy bars. In addition, it may be advantageous to cut the internal reinforcing bars to prevent bond failure at the poorly detailed lap splice and this will be considered in the study. One (1) square specimen will be tested by loading the column at a 45 degree bias rather than orthogonal to the face.

An anticipated advantage of titanium is the well-controlled material properties and low variability which can precisely fuse the column forces so as to minimize ancillary damage to other components. Two specimens will be used to consider the combined behavior of the vintage column and footing details and the ability to protect the footing from seismic damage. The specimens will be supported on the laboratory floor using elastomeric bearing pads. The column/footing will be squeezed onto the "soil" by applying axial load to the column top and thus simulating gravity load induced soil pressure across the footing. Lateral force will be applied at the column top and the column/footing interactions will be studied.

In addition, reversed cyclic low-cycle fatigue tests will be conducted to evaluate the cyclic ductility of the titanium alloy bars.

The experimental data will be used to support Task 4.

Time Frame: 15 months
Responsible Party: C. Higgins
Cost: $275,000.
Deliverable: Test data and status report at midway point
ODOT Action or Decision: Review report and comment

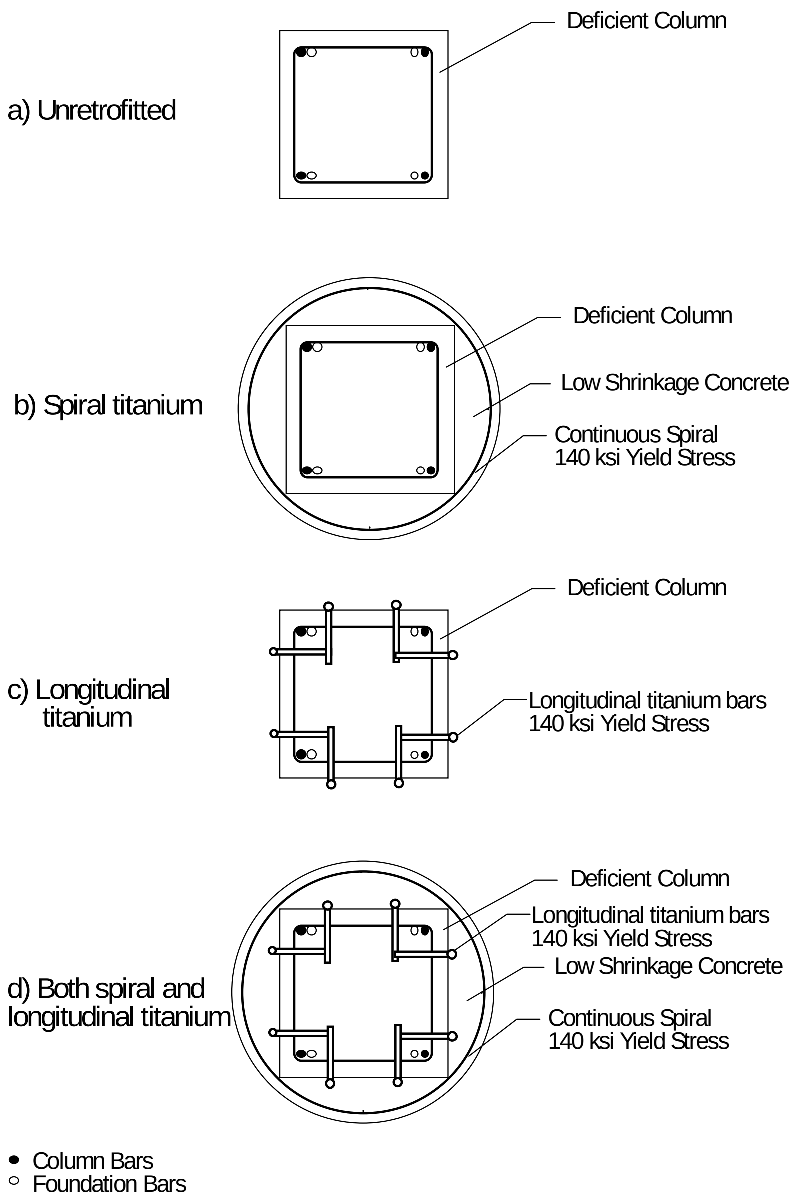

Fig. 2- Example specimen cross-sections at splice location above footing elevation.

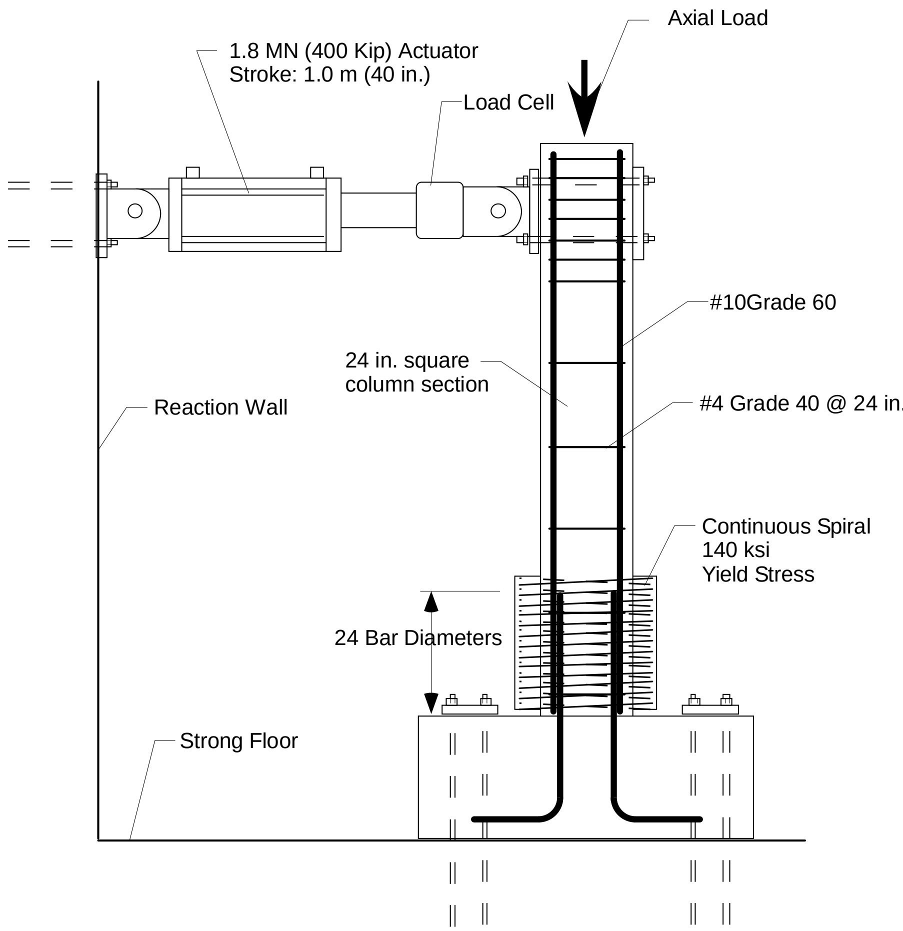

Fig. 3- Schematic of proposed test setup for full-size column tests.

<u>Task #4 : Analysis and Design of Seismic Retrofits</u>

Experimental findings will be used to develop analytical models that can predict the overall seismic response of the retrofitted columns as well as the localized demands on the reinforcing steel, and concrete, and titanium alloy bars. The results of the control and retrofitted specimens will be compared with FHWA-HRT-06-03 Seismic Retrofitting Manual for Highway Structures: Part 1-Bridges (2006) and AASHTO Guide Specifications for LRFD Seismic Bridge Design (2011) so that ODOT engineers can make immediate use of the results. A prototype model bridge will be used to compare the overall bridge responses and possible damage scenarios under different ground shaking conditions and considering different seismic retrofit strategies. The analytical and experimental results will then be used to develop design recommendations that will enable ODOT engineers to design economical and effective seismic retrofits of nonductile columns using titanium alloy reinforcing bars.

<u>Time Frame</u>: 9 months
<u>Responsible Party</u>: C. Higgins

Cost: $75,000.
Deliverable: Example problem and design methods for final report
ODOT Action or Decision: Review section in report

Task #5 : Reporting

A publication ready draft report covering all aspects of Tasks 1 – 4 will be delivered to ODOT for review. Included in this report will be a cost benefit analysis for the proposed and alternative retrofit approaches. The report will detail the experimental methods, data, results, analysis methods, and design guidelines. A workshop will be conducted for ODOT personnel to explain the research outcomes.

Time Frame: 3 months
Responsible Party: C. Higgins
Cost: $25,000.
Deliverable: Final report
ODOT Action or Decision: Review report and comment

5.1 Safety and Related Training

No field work is anticipated. The laboratory experiments will be conducted in the Structural Engineering Research Laboratory located in the Hinsdale Wave Research Laboratory. All research personnel working on this project will follow the "Site Safety Plan" developed for the Hinsdale Wave Research Laboratory.

6.0 Time Schedule

Task	FY15	FY16				FY17				FY18
	May-June	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep
1. TAC Meeting	X									
2. Literature review			X	X*						
3. Laboratory Tests of Seismic Retrofits				X	X	X	X	X		
4. Analysis and Design of Seismic Retrofits							X	X	X	X
5. Reporting								X	X	X*

*TAC review comments and PI revisions for final

7.0 Budget Estimate

Task	**FY16**	**FY17**	**FY18**	**Total**
1. TAC Meeting	0			0
2. Literature review	25,000			25,000
3. Lab testing	175,000	100,000		275,000
4. Analysis and Design		75,000		75,000
5. Reporting		20,000	5,000	25,000
Total OSU costs (work order amount)	**200,000**	**195,000**	**5,000**	**400,000**
ODOT project management				
Total ODOT costs				

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