MPC-526
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Project Title:
Seismic Repair of Concrete Wall Piers Using CFRP Active Confinement

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University of Utah

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Research Need:

Prior to implementation of modern seismic codes, lap splicing of longitudinal reinforcement at the base of wall piers in concrete bridges was a common practice. Figure 1 shows details of lap spliced bars in wall piers; in regions of high seismicity this creates unfavorable conditions. In bridges located in high seismic regions, lap splices located in the critical hinging region of the wall pier experience bond-splitting failure of the spliced bars within the plastic hinge; this leads to stiffness and flexural strength degradation of the pier. Observations after major earthquakes show that structural damage or failure in bridges with concrete wall piers can be attributed to inferior performance of lap-spliced reinforcement at the base of the piers (Mitchell et al. 1994; Priestley et al. 1996). Figure 2 shows typical lap-splice damage from laboratory experiments that includes buckling of vertical and lateral bars (Abo-Shadi et al. 2000). Currently, AASHTO (2010, 2011) prevents splicing of pier longitudinal reinforcement at the base of the pier where plastic hinging could develop.

The most common approach for improving the bond strength of spliced reinforcement in existing bridge piers with bond-critical regions is the use of external confinement. Methods studied include the use of steel jackets (Mitchell et al. 1994; Priestley et al. 1996; Aboutaha et al. 1999); and carbon fiber-reinforced polymer (CFRP) jackets (Priestley et al. 1996; Seible et al. 1997; Hawkins et al. 2000; Harries et al. 2006; Ghosh and Sheikh 2007; Harajli and Dagher 2008; Harajli and Khalil 2008; ElGawady et al. 2010; Bournas and Triantafillou 2011; El-Souri and Harajli 2011). A technique using a combination of CFRP jackets and CFRP anchors has also been studied (Kim et al. 2011).

All of the above studies reported enhanced bond performance of the reinforcement and improved seismic response. Most of the methods used for seismic bond strengthening use passive confinement techniques - that is, techniques in which the confinement effectiveness is activated once bond-splitting cracks initiate. Because of their passive nature, most of these techniques fall short of achieving their full potential and the seismic performance of the retrofitted wall piers is inferior compared to that of wall piers designed using current codes, such as AASHTO (2011), which stipulate splice-free wall piers that are adequately confined by closely spaced transverse steel ties within the critical hinging region. Typical seismic retrofit recommendations (FHWA 2006) include steel plate encasement and bolts drilled and anchored through the thickness of the wall pier, as shown in Fig. 3; when the steel rods are tightened they provide active confinement of the lap spliced bars. A method similar to the one shown in Fig. 3 has been used with steel anchors but without the steel plate encasement with promising results (Hantouche et al. 2015).

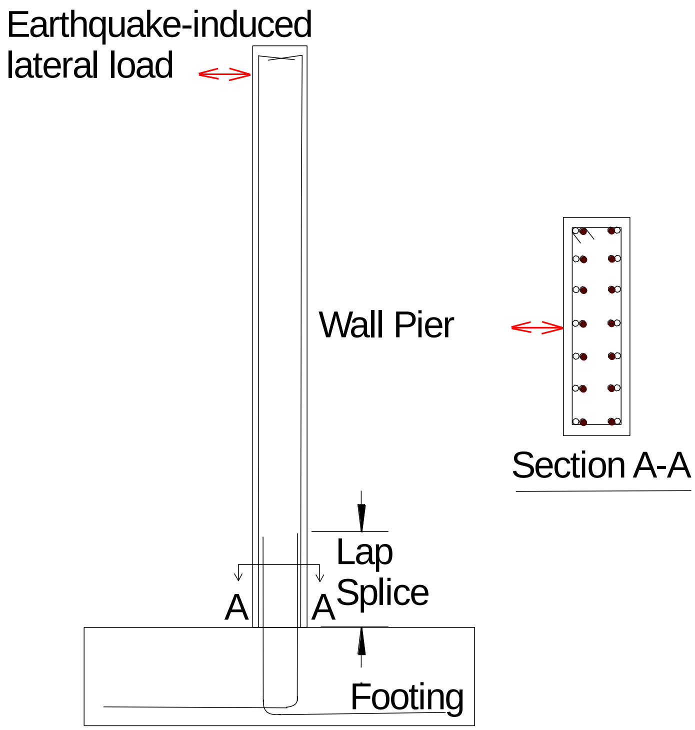


Figure 1. Typical lap splice detail in wall pier.

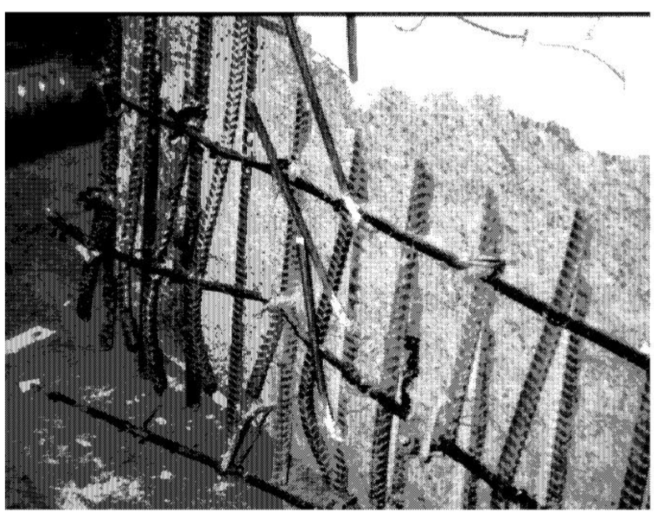


Figure 2. Lap splice failure showing buckling of vertical and lateral bars (Abo-Shadi et al. 2000).

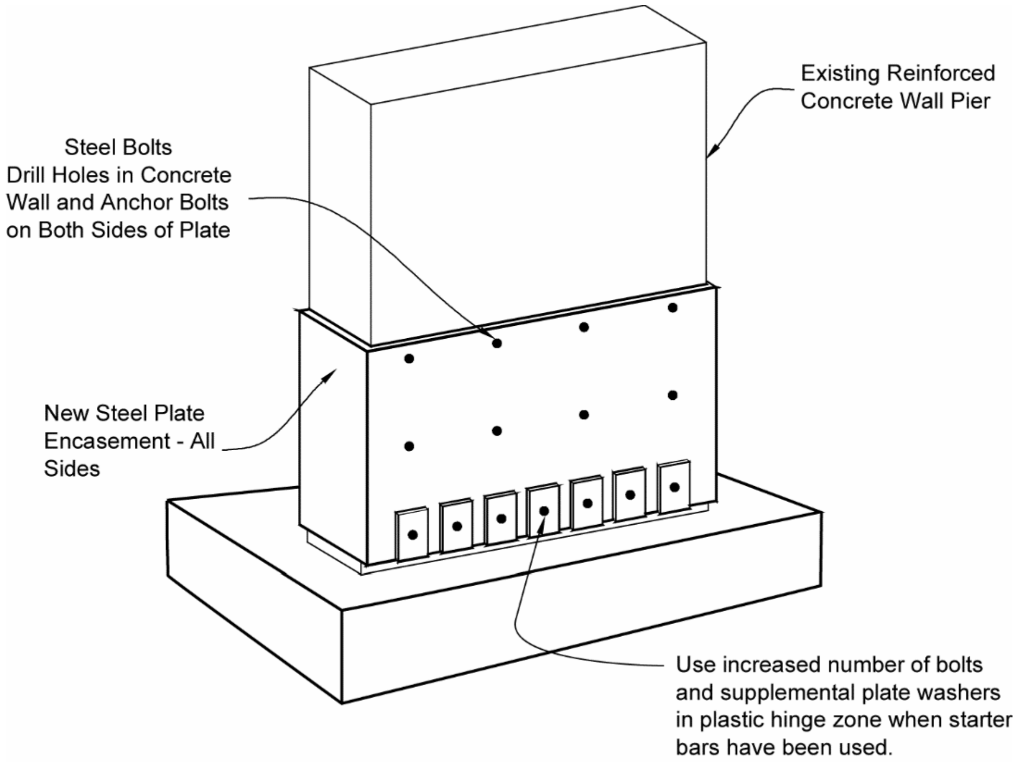


Figure 3. Retrofit for wall pier with starter bars (FHWA 2006).

The present proposal describes the concept of seismic retrofitting of lap splices in wall piers designed with inferior details similar to those shown in Fig. 1. Active confinement by means of a pretensioned CFRP jacket and CFRP anchor rods is used for bond strengthening of lap-spliced reinforcement thus improving the seismic performance of concrete wall bridge piers. Representative as-built and repaired wall pier specimens with lap-spliced reinforcement within the critical hinging region will be tested under quasi-static cyclic loads. A design approach will be developed to evaluate the active lateral pressure required for adequate bond strengthening and for designing the strengthening system.

Research Objectives:

The objectives of this project are to: (1) provide alternative methods to repair and strengthen lap splice deficiencies of concrete wall piers through the use of CFRP materials using active confinement; (2) develop an analytical model which will assist in the development of a design method for implementing the strengthening system in existing concrete wall pier bridges.

Research Methods:

The proposed research will evaluate the seismic performance of concrete wall piers in older bridges and develop a method to repair and strengthen such wall piers. The research will be performed by conducting half-scale experiments of as-built and repaired/strengthened concrete wall piers with CFRP materials. An analytical model will be developed including design recommendations for implementing the strengthening system.

Expected Outcomes:

The proposed research will provide alternative methods to repair and strengthen lap splice deficiencies of concrete wall piers in existing bridges through the use of CFRP materials using active confinement.

Relevance to Strategic Goals:

CFRP composite materials are fast becoming a method of choice for the repair and strengthening of bridges due to their light weight, high tensile strength, and the fact that they can take any shape that is required for the repair. Seismically resilient bridges improve safety and livability of the community. The State of Utah is likely to experience a strong earthquake in the next 50 years. There are approximately 250 bridges with some form of concrete wall pier in the State of Utah (Personal communication, Carmen Swanwick UDOT Chief Structural Engineer). Successful completion of the proposed project will ensure that there are alternative methods to rehabilitate existing bridges with concrete wall piers after large earthquakes and strengthen such ridges before large earthquakes occur.

Educational Benefits:

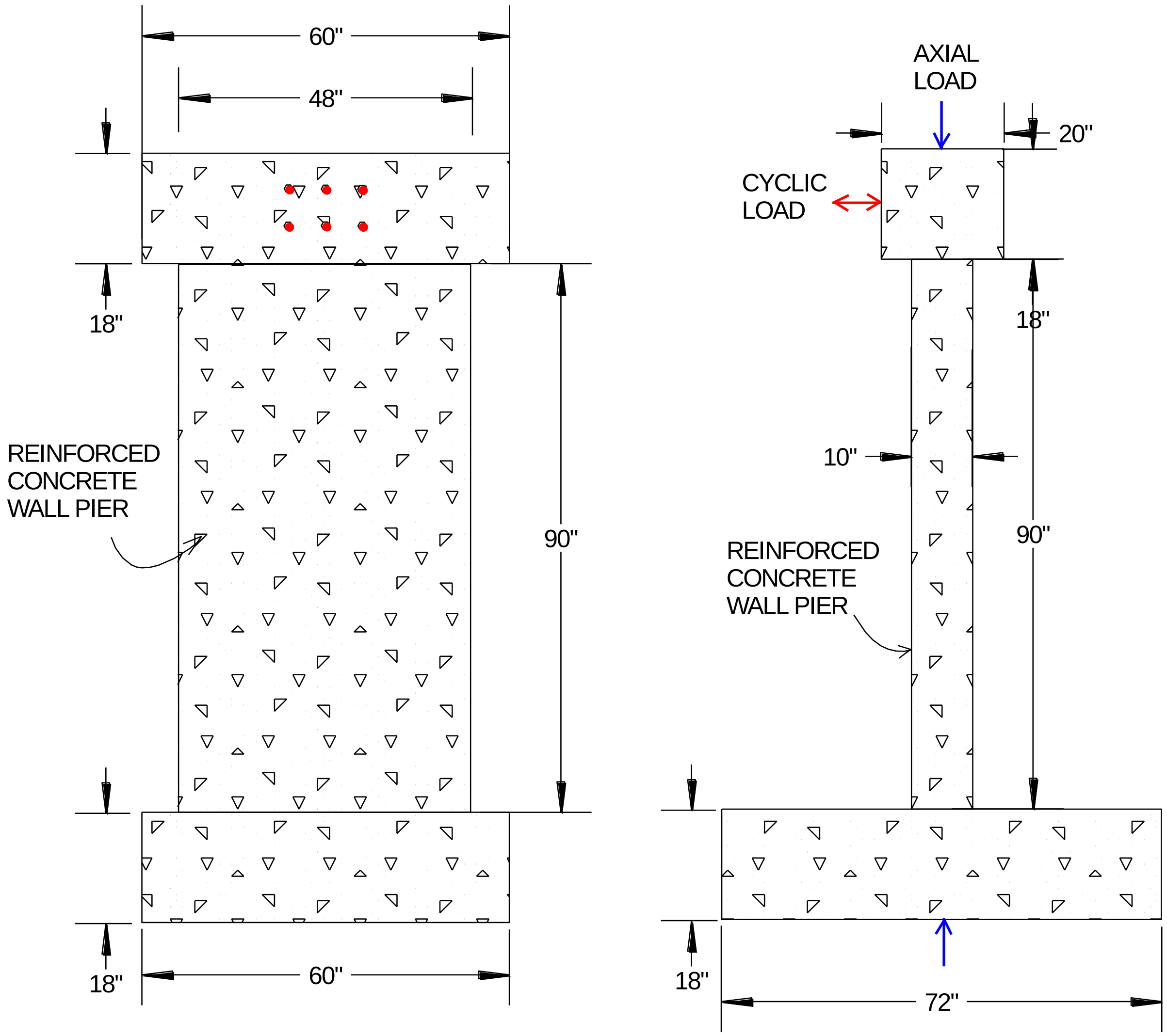
At least two university students will be involved in the project. One PhD student will be involved in the experimental portion of the work. A second student, will be funded from the Office of Undergraduate Research Opportunities program at the University of Utah. It is expected that a second phase of the project will be secured so that the PhD student will be able to complete his/her studies. At the local level, the technology transfer activity will involve high school students through an Annual Exploring Engineering Camp, during which small-scale models will be built to show details of the wall piers and how they would be retrofitted. In addition, the P.I. will make a presentation at the annual UDOT Engineering Conference and at other national conferences including Annual AASHTO Subcommittee on Bridges and Structures Meetings and the Annual Transportation Research Board Meeting.

Work Plan:

The proposed study will consist of the following tasks:

Task 1. Build three half-scale concrete wall piers with lap-splice deficiencies

Three identical specimens with the details shown in Fig. 4 will be built. The concrete will have a nominal compressive strength of 5,000 psi and the steel reinforcement will have a nominal tensile yield strength of 60,000 psi. The walls are 10 in. thick and will be subjected to a constant axial load and horizontal quasi-static cyclic load. The tests will be carried out at the University of Utah Structures Laboratory. The main reinforcement details of the as-built walls are shown in Fig. 5. The most important feature is that the vertical bars in the walls are spliced to a length of 28 bar diameters or approximately 17 in. This lap splice is the point of interest of the retrofit. A wall with the details given in Fig. 5 will likely have a similar type of failure as shown in Fig. 2, including buckling of the vertical and lateral bars. The objective of the research is to prevent such failures from occurring.



(a) (b)

Figure 4. Concrete Wall Pier: (a) elevation, (b) side view.

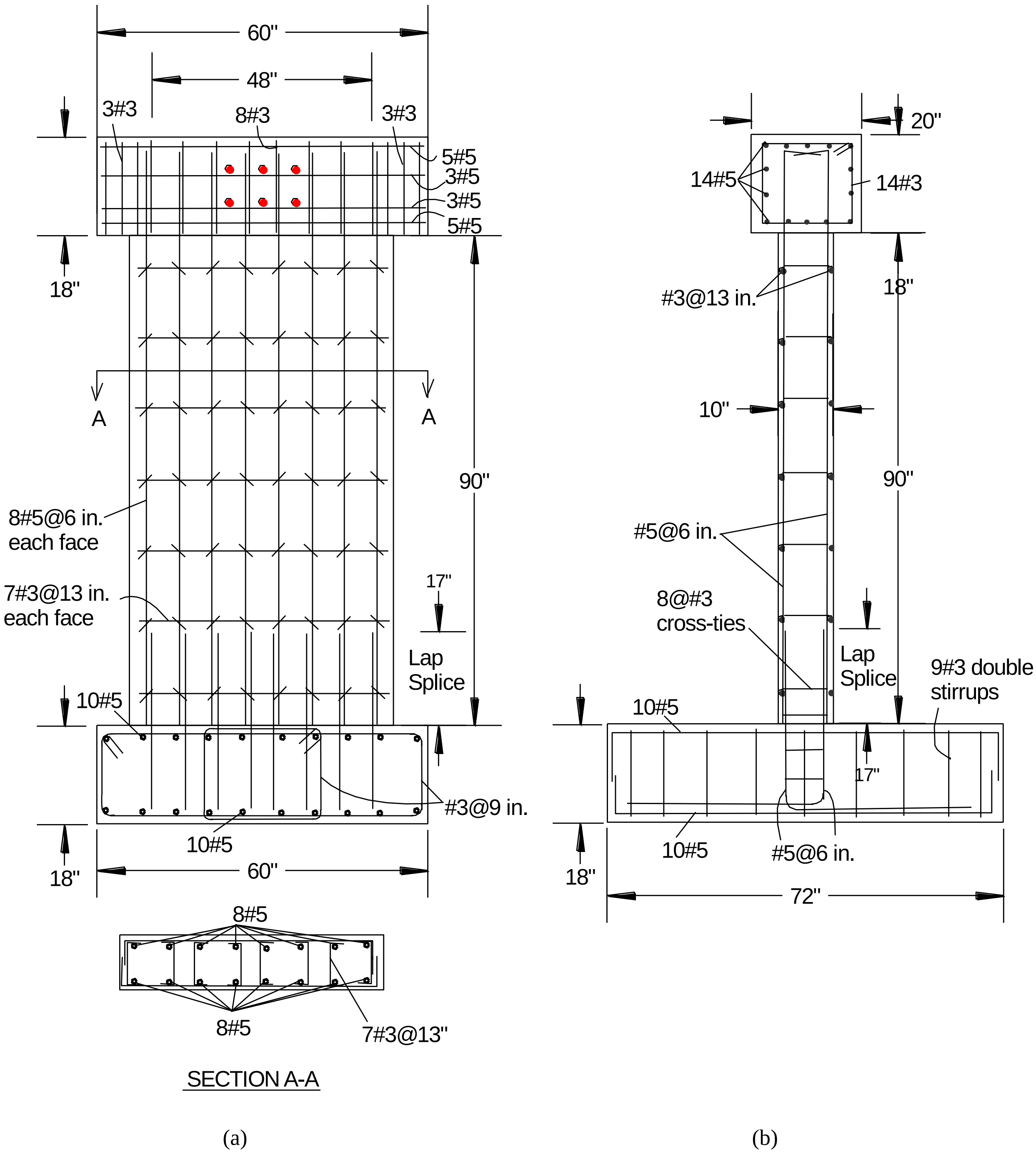


Figure 5. Concrete Wall Pier Reinforcement: (a) elevation, (b) side view.

Task 2. Perform seismic repair of the lap splice region using CFRP materials and active confinement

The seismic repair of the wall pier will be similar to the repair of bridge column-to-footing connections carried out as part of a previous MPC project (MPC-405: Seismic Retrofit of Spliced Sleeve Connections for Precast Bridge Piers. In that project, after testing as-built column-to-footing connections to failure, the damaged specimen were repaired with a CFRP donut, as shown in Fig. 6 (Parks et al. 2016). Seismic repair design for the plastic hinge zone of the column showed that four layers of CFRP composite were required and this number of layers was used in the actual repair. Each layer had a thickness of 0.04 in. and the following design properties: elastic modulus of 10,000,000 psi, and ultimate tensile strength of 100,000 psi. The four CFRP layers were part of a CFRP shell for the bottom 18 in. which included expansive grout in the gap between the CFRP shell and the column, thus forming a composite "donut" as shown in Fig. 6. The repaired specimen was tested again and its performance was found to be satisfactory.

In addition to CFRP jackets that make up the CFRP shell of the donut, the proposed research will utilize CFRP anchors. Such anchors are manufactured from a roll of CFRP strands inserted into the concrete and splayed out over the FRP material under the anchor in a fan shape, as shown in Fig. 7. In Fig. 7 the anchor is used to enhance the load transfer between two precast concrete wall panels under cyclic shear.

Figure 6. Seismic repair of a column to footing joint using CFRP composite donut.

Figure 7. CFRP anchor and application to precast concrete wall strengthening.

In the present proposal, the knowledge gained from the previous research carried out for column to footing connections (Parks et al. 2016) will be implemented for the seismic repair of concrete wall piers. The seismic repair design will follow the guidelines provided by the previous research carried out by the P.I. (Parks et al. 2016, Yan et al. 2006) as well as other researchers such as Kim et al. (2011) and Hantouche et al. (2015). The distinguishing feature of the proposed work is the use of a CFRP shell and CFRP anchors combined with the use of expansive grout; this combination of materials creates active confinement which will benefit the lap splice region. Thus, the CFRP anchors will be pre-tensioned and will not have to be activated by the initiation of bond-splitting cracks. It is expected that active confinement will result in a significantly improved performance of the concrete wall pier to high drift levels.

Task 3. Experiments and analysis of seismic repair of bridges with lap-splice deficiencies

In this task, the researchers will develop an analytical model which will assist in the development of a design method for implementing the strengthening system. The design will follow the philosophy of the AASHTO LRFD Seismic Bridge Provisions (2011) and previous research by the P.I. (Parks et al. 2016, Yan et al. 2006) and other researchers (Kim et al. 2011; Hantouche et al. 2015). Once the appropriate expansive grout mix design, number of CFRP layers and number of anchors are determined, the design will be implemented for the wall pier specimens. In this project only damaged specimens will be repaired. The damage will be inflicted by testing the as-built specimens under quasi-static cyclic lateral loads as shown in Fig. 4 and Table 1. The axial load will be 6% of the wall axial capacity and the lateral load will consist of two cycles of increasing drift as per the recommendations of ACI 374 (2013). Damage will have two levels of severity: (a) splice capacity damage, which means load is applied up to the point where bond splitting cracks appear, typically after yielding of the starter bars, and (b) splice failure where the concrete spalls off and the peak load drops but before concrete crushes. Wall Pier 1 will be repaired with the CFRP shell and expansive grout but with a minimal number of CFRP anchors. Walls 2 and 3 will be repaired with the CFRP shell, expansive grout and the required number of CFRP anchors, as shown in Fig. 8.

Based on the test results, guidelines will be developed regarding the number of CFRP layers and number and diameter of CFRP anchors to be used. In addition, an analytical model will be constructed using OpenSees (2010), which will assist in the development of a general design method for implementing the strengthening system to existing bridges.

Table 1. Pier Wall Test Matrix.

Wall Pier	Loading	Damage	Test Condition	CFRP Shell	CFRP Anchors
1	Cyclic	Splice Capacity	As-built	-	-
		To failure	Repair	√	minimal
2	Cyclic	Splice Capacity	As-built	-	-
		To failure	Repair	√	required
3	Cyclic	Splice Failure	As-built	-	-
		To Failure	Repair	√	required

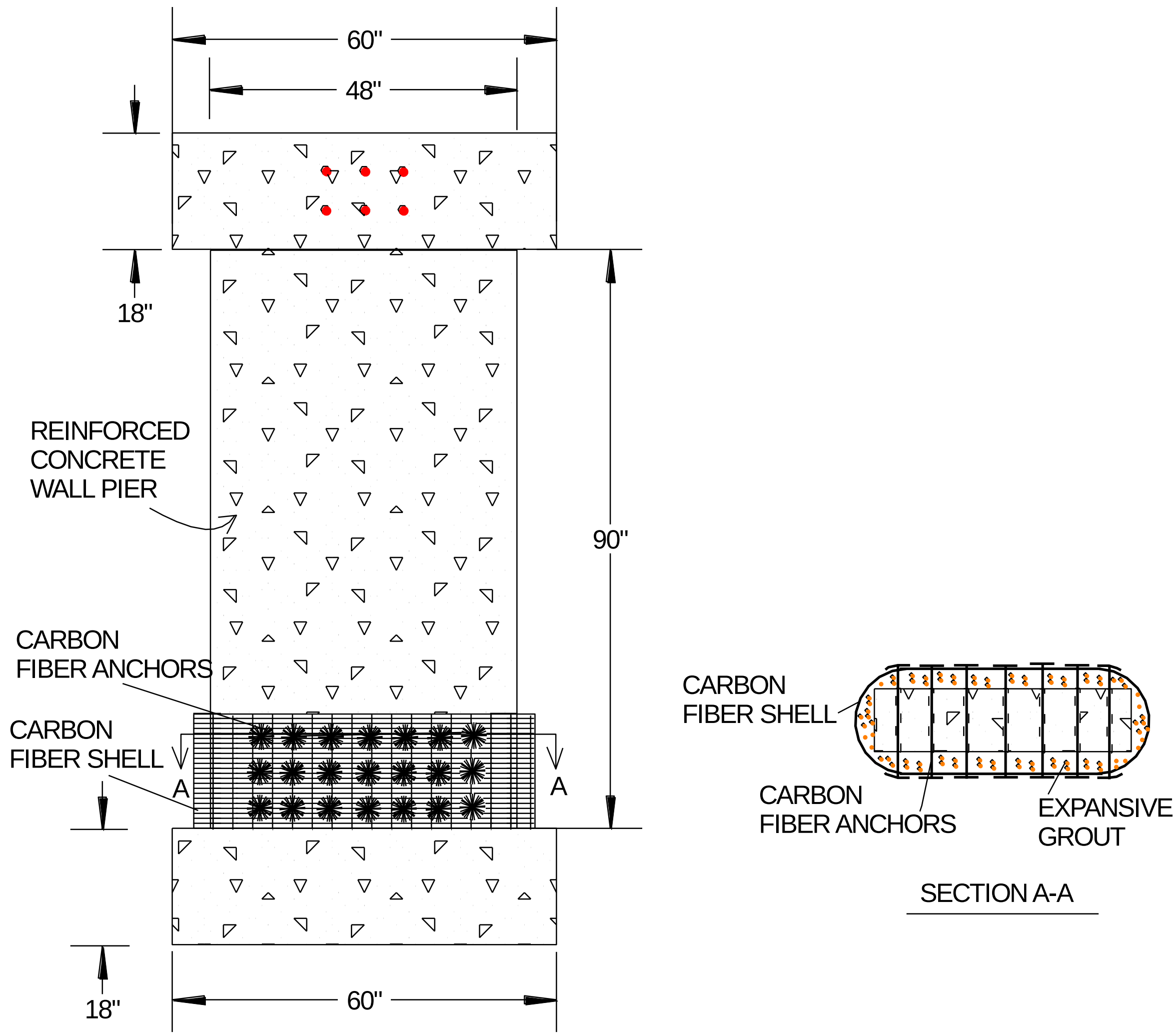


Figure 8. Seismic repair of wall pier with expansive grout, CFRP shell and CFRP anchors.

Project Cost:
Total Project Costs: $145,454
MPC Funds Requested: $70,000
Matching Funds: $ 75,454

TRB Keywords:
Concrete bridges; Expansive grout; Seismic design; Seismic repair; Wall pier; CFRP composite sheet; CFRP composite anchor.

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