# Study and Evaluation of Caltrans Bridge Seismic Design Criteria

Research Proposal Submitted


By A. El-Zeiny, Ph.D., P.E.

Faculty and Director of the Structural Testing Lab
Department of Civil & Geomatics Engineering & Construction

School of Engineering and Computer Science

California State University, Fresno


March 2001

## *Abstract:*

Bridges are important component of the transportation system in United States. Failure of bridges during seismic events has implications fare beyond the mere economic value of the bridge. It may involve loss of human life in addition to loss of property. Thus, safety of bridges is an essential goal for DOT. The continuous failure of bridges during past seismic events highlight the need for a careful seismic analysis and design of these bridges.

During the last two decades, significant research has been conducted to investigate the seismic response of bridges and to address their seismic retrofitting requirements. This research has included several analytical and experimental studies. The main purpose of the proposed project is to review existing California Department of Transportation (Caltrans) seismic design criteria for new bridges, and to recommend changes to the existing bridge design and retrofitting specifications, where appropriate, in the light of the published analytical and experimental information. This proposal contributes to the safety goal of the

# Narrative

### *Statement of the Proposed Research Project:*

Seismic design standards need to continually be upgraded to reflect latest seismological findings, most recent results of analysis and testing programs, and observations of the performance of structures during past earthquakes. A preliminary review of the current Caltrans seismic design and retrofitting specifications shows the need to upgrade these specifications by incorporating the state-of-the-art knowledge in seismic analysis and design. Such an upgrade requires a comprehensive knowledge of the conducted experimental and analytical research in the area. The following areas will be targeted in this research effort:

- Design earthquakes for both safety and functional evaluation
- Level of ductility that should be used in the analysis
- Modeling of bridge components in nonlinear inelastic dynamic analysis including modeling of joints and base isolation
- Incorporation of soil-structure interaction into current seismic analysis procedures
- Design of bridge components to ensure full ductile behavior during large earthquakes
- Simulation of stiffness degradation of bridges during major seismic events

- Revise detailing of steel reinforcement to prevent inelastic buckling of the longitudinal reinforcing bars
- Revise the column shear design criteria to include the effect of plastic hinges
- Revise anchorage provisions and specifications of splices to increase ductility

### *The need for Ductile and Energy Absorbing Design of Bridge Joints:*

A great deal of recent research has focused on aspects related to the design of various structural components and joints. Much of this research has been aimed at assuring the ductile behavior of these components and joints during large earthquakes to absorb seismic energy. This usually requires careful attention to details in the affected members. No research attention has been paid to design an energy dissipating joints that provides a passive way to control structural response during major seismic events. In this research, various schemes of joint details will be developed and an experimental testing program to assess the amount of energy dissipated by each joint will be proposed. A research proposal will be written to request funding from Caltrans to conduct the experimental work.

### *Investigation of Composite Material Applications to Retrofit Bridge Components:*

Caltrans is currently using composite materials, among other techniques, to retrofit and strengthen bridges. Nevertheless, the technology of composite materials in bridge is relatively new since it only started to be considered

al projects were pursued in the early

utilize the advantages of the composite materials. For instance, there is only very little information about the long-term durability of the composite materials exposed to the varying weather conditions taht will exist in bridge structures. Composite materials consist primarily of strong reinforcing fibers such as graphite, kevlar, or glass fibers, bonded together in a polymer matrix. Inherently, the polymer matrix is susceptible to degradation over time due to polymerization, oxidation, or UV radiation. Thus, it is debatable, that the composite materials exposed to weather conditions that include radiation from the sun, air, temperature changes, etc., can last the expected 50 or 100 year life expectancy that is associated with bridge structures. Thus, there is a need to develop accelerated testing procedures which will indicate the ability or lack thereof of the composites to last such long life.

Another issue for consideration in the application of composites in bridge retrofitting and strengthening is the bond characteristics of the composite with the existing concrete. Retrofitting of concrete structures consists on applying layers of fiber reinforced composites on the surface of selected structural elements such as columns and girders. Since it is expected that the composite material shares the load carrying condition with the existing concrete, there has to be adequate load transfer between the two materials. The load transfer is in part carried by the bonding and adhesion between the polymer in the composite and the portland cement concrete. Hence, the bond and adhesion have to be appropriate to integrate the entire strength of the composite into the existing concrete element. At the present there is no standard test to determine the bond between polymer materials and concrete. Moreover, the bond between the two materials has to be a long-lasting one since it has to endure the entire service life of the structure. There is therefore, a need to develop a simplified test to determine the bond characteristics of composite materials with portland cement concrete. Part of the effort of this research project will be focused on investigating possible ways to conduct such as test.

## *Ability to Accomplish Proposed Work:*

- **Computing Facilities:**

Part of the research proposed here will include computer analysis of bridge structures and components. The department has good computing facilities available to conduct computerized structural analysis and to analyze test data. Facilities include PCs, Unix workstations, IBM, Silicon Graphics machines and a wide variety of software.

In addition to the department's computer facilities, the lab contains its own computing facilities, including a personal computer for data acquisition and data reduction and a laser printer. The computing facilities in the structural lab are networked to the campus computing facilities, allowing use of mini-supercomputers and Unix workstations, as well as color printers and other accessories. Access to supercomputers is available through the network at national supercomputer facilities.

- **Instrumentation and Data Acquisition:**

Instrumentation and data acquisition equipment are available for monitoring specimens during testing.. A Data Acquisition System with current capacity of 16 channels, a 486 personal computer, and the MTS Test-Star software

are used to monitor and collect data.

The Structural Engineering Research Laboratory at California State University, located in the East Engineering building has the following characteristics:

- **Strong Floor and Reaction Wall:**

The strong floor is a 2 ft thick, reinforced concrete, floor slab with plan dimensions of 52 ft by 23 ft that is used for testing of large- or near full-scale building and bridge components or systems. Floor tiedowns, spaced 2 ft on center in two directions and embedded 1.5 ft into the strong floor, are used to connect test specimens to the strong floor. Each floor tiedown is capable of resisting 50 Kips of force in tension and 12 Kips of force in shear. A 5-ton capacity crane services the lab to position specimens and test equipment frames for testing.

The reaction wall is a 2 ft thick reinforced concrete wall that extends perpendicular to the strong floor to a height of 30 ft. Wall Support locations extend up a height of 18 ft and spaced 2 ft on center. The wall is L-shaped in plan with each leg extending to cover the entire strong floor plan; therefore, testing of specimens under biaxial and triaxial loadings can be readily accomplished, such as biaxial and axial loadings. The wall is capable of supporting a total load of 250 Kips applied at a height 18 ft. The wall is supported at the roof level by a tie back diaphragm to allow the support of large reactions with small deformations. The wall height of 30 ft allows for testing of large-scale components or systems, such as bridge columns or piers, or multi-column bent with bent cap.

- **Testing and Fabrication Equipment:**

Two 50 Kips hydraulic actuators are housed in the Structural Lab to apply loads or deformations to test specimens. The actuators and matching load cells have a capacity of 50 Kips of force with 10 inches stroke. One of the Actuators has a 90 gpm Servovalve enabling it to apply the 50 Kips force at a frequency up to 100 Hz. The test actuators are served by an MTS 290 service manifold. The Hydraulic system is powered by a custom-built Hydraulic pump operating at 100 gpm at 3000 psi pressure. The built-in hydraulic distribution system runs three sets of hydraulic lines at three different set up points in the lab.

Specimens can be constructed off-site and shipped to the lab for testing or specimens may be fabricated on-site. For on-site fabrication of reinforced concrete specimens, rebar cutters and bender will be available. The cutter and bender can be used to produce rebar various hooks, as well as hoops, crossties, and spirals. Welding facilities will also be available in the lab and the nearby machine shops. The nearby machine shops also house equipment, such as drill press, lathe, band saw, etc, for fabrication of precision test fixtures.

The concrete Lab is located next to the Structural Lab that has a concrete mixing and a large moist curing room. Concrete can also be obtained from local suppliers. A 12 ft x 18 ft overhead door provides direct access to the lab for the ready mix truck.

## *References:*


1. California Department of Transportation, 1998. Bridge Design Specification Manual, Sacramento, California.
2. Kawashima, K., et al, Ductility of Steel Bridge Piers from Dynamic Loading Tests, Stability and Ductility of Steel Structures under Cyclic Loading, CRC Press.
3. Proceedings of the Fourth Caltrans Seismic Research Workshop, July 1996, Sacramento, California.

**Appendix A**

## <u>PI Qualifications</u>

Vitae of PI is attached in the following pages

# Curriculum Vitae of PI

# Ali El-Zeiny, Ph.D., P.E.

---

**Education:**

- Ph.D. in Civil Engineering, December 1992 - September 1995, University of California, Irvine, Concentration on Structures.
- Core Courses in Information and Computer Science, September 1992 - March 1994, University of California, Irvine.
- M.Sc. in Civil Engineering, September 1991 - December 1992, University of California, Irvine, Concentration on Structures.
- M.Sc. Courses in Civil Engineering, September 1990 - June 1991, CU.
- B.Sc. in Civil Eng. with honor, September 1984 - August 1989, CU.

**Employment History:**

- **California State University, Fresno, August 1997 - Present**
  Faculty, Department of Civil & Geomatics Engineering & Construction
  California State University, Fresno, CA 93740-8030.
- **HARZA Consulting Engineers and Scientists, September 1995 - August 1997**
  825 Colorado Boulevard, Los Angeles, CA 90041.
  Position: Structural Engineer, Earthquake Sciences and Engineering Division.
- **University of California, Irvine, September 1991 - December 1995**
  Department of Civil and Environmental Engineering, Irvine, CA 92697.
  Positions: Instructor, Teaching and Research Assistant, and Research Project Engineer.

**Publications:**

- El-Zeiny, A., and Larralde, J., *Out-of-Plane Performance of Full-Size Un-Reinforced Brick Walls Retrofitted with Expansive Epoxy*, 9th Canadian Masonry Symposium, Fredericton, Canada, June 2001.
- Larralde, J., and El-Zeiny, A., *Horizontal Shear Performance of Full-Size Un-Reinforced Brick Walls Retrofitted with Expansive Epoxy*, 9th Canadian Masonry Symposium, Fredericton, Canada, June 2001.
- El-Zeiny, A., *Repair and Retrofit of Brick Walls using Expansive Epoxy*, Research Report Submitted to Delta Plastics, http://www.deltafoam.com, March 1998-June 2000.
- El-Zeiny, A., *Computer Simulation of the Nonlinear Liquid-Structure Interaction Problem with Free Surface*, Proceedings of the 37th Heat Transfer and Fluid Mechanics Institute, Sacramento, California, June 2001.
- Haroun, M.A., Bhatia, H., and El-Zeiny, A., *Characterization of Observed Uplift and Buckling of An Unanchored Tank During the Northridge Earthquake*, The Northridge Earthquake Research Conference, Los Angeles, CA, August 1997.
- Haroun, M.A., and El-Zeiny, A., *A Computational Technique for the Nonlinear Dynamic Analysis of Unanchored Liquid Storage Tanks*, Proceedings of the Third Asian-Pacific Conference on Computational Mechanics, Seoul, Korea, September 1996, pp. 1007-1012.
- Haroun, M.A., and El-Zeiny, A., *Simulation of Dynamic Behavior of Unanchored Tanks*, Proceedings of the 13th International Conference on Structural Mechanics in Reactor Technology, Porto Alegre, Brazil, August 1995, pp. 341-346.
- Haroun, M.A., and El-Zeiny, A., *Nonlinear Transient Response of Unanchored Liquid Storage Tanks*, Proceedings of the PVP Conference, ASME, Hawaii, July 1995, pp. 35-41.
- Haroun, M.A., and El-Zeiny, A., *Dynamic Interaction of an Uplifted Beam with the Supporting Soil*, Proceedings of the Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, April 1995, pp. 409-412.
- Haroun, M.A., El-Zeiny, A., and Bhatia, H., *Seismic Design Guidelines for Liquefied Natural Gas Tanks*, Vol. 272, PVP Conference, ASME, June 1994, pp. 43-50.
- Haroun, M.A., El-Zeiny, A., and Bhatia, H., *Seismic Qualification of Tanks for Storage of Liquefied Natural Gas*, Egyquake Proceedings, December 1993, pp. 665-674.
- Haroun, M.A., and El-Zeiny, A., *Seismic Design Considerations for Uplifted Tanks*, Proceeding of the Structures Congress, Structural Engineering in Natural Hazards Mitigation, Vol. 1, April 1993, pp. 139-144.

**Research Interests:** Structural Engineering Analysis and Laboratory Testing, Control of Structures, Risk Assessment and Reliability-Based Design. Specializing in Nonlinear Finite Element Analysis, Structural and Fluid Dynamics, Liquid Storage Tanks and Fluid-Structure Interaction

**Funded Research Project ($80,000):**

- **Seismic Evaluation of the Performance of Retrofitted and Repaired Brick Walls by Means of Expansive Epoxy Injection:** A pioneer technique to repair unreinforced masonry walls cracked during past seismic events, or to retrofit existing brick walls to meet the current code requirements, is proposed to be subjected to experimental investigation. Such walls are very common in historical buildings, such as the Los Angeles City Hall and the Alameda City Hall. The walls are injected by ceramic foaming material developed by Delta Plastics Company. After the material is shot into walls, it expands, bonds and hardens like rock. This injection technique does not affect the appearance of these historical walls and consequently it preserves their historical value. The use of Carbon fiber does not have this advantage. It is proposed to test the seismic performance and ductility of the plain brick walls first. These broken walls will then be repaired using the Ceramic Foam and tested. In addition, strengthened unbroken walls with Ceramic Foam and composite Carbon Fiber material will be tested. Performance of all walls will be studied and compared to prove the effectiveness of the Ceramic Foam material in the retrofitting and repairing of walls.

**Submitted Research Proposals:**

- **Development of Practical Design Guidelines for Unanchored Liquid Storage Tanks.** Research Proposal Written to NSF, November 1998.
- **Survivability Assessment of Current Aircraft Designs Using State-of-the-Art Technologies in Hydrodynamic Ram and Fuselage Decompression Analyses.** Research Proposal Written to Northrop Grumman Corporation, October 1998.

**Research Proposals Under Preparation:**

- **Finite Element Analysis of the Facial Skin:** The purpose of this research is to use modern numerical analysis techniques to model the biological and mechanical properties of the human face. It is an interdisciplinary project involving engineering science, computer graphics, and biology. This project will produce a software package that is capable of inputting the shape of a face, and then manipulating that face to simulate the effects of reconstructive surgery on the shape of the face.
- **Pseudo Dynamic Testing Using Active Displacement Control Techniques:** This joint proposal is under preparation and will be submitted to The National Science Foundation or to CALTRANS. The co-author of the proposal is Professor K. Mosalam from UC Berkeley. The proposal deals with the development of active algorithm to control the displacement of tested specimens. The input for the algorithm will be the magnitude of loads measured from the loading cells during the test, as well as the target ground motion. The output of the algorithm will be the displacement that should be applied on the specimen using the actuators to produce the same forces developed during a real life seismic event.

**Previous Teaching Experience:**

- More than four years of teaching experience at UC Irvine as lecturer, during which excellent teaching evaluations were received.
- Taught the following courses: AutoCAD, Statics, Dynamics, Engineering Economics, Strength of Material, Wood Design, Steel Design, Concrete Design, Seismic Design, Soil Mechanics, Advanced Structural Analysis and Finite Element Analysis.

**Student Advising:**

- Advisor of AISC Student Steel Bridge Competition.
- Advisor of AISC Student Timber Bridge Competition.
- Academic Advisor of 22 students in the Civil Engineering program.

**Professional Societies:** Member of American Society of Civil Engineers.

**Computer Skills:**

- Experienced in using the numerical object package DiffPack. The DiffPack object-oriented C++ libraries contain a wide selection of interchangeable and application-independent components, which facilitate the development of numerical simulations of partial differential equations.
- Knowledgeable in Software Engineering, Data Structures, Algorithm Analysis and various Operating Systems.
- Capable of programming in many programming language including C, C++, Java, Fortran 90, Ada, Pascal and Assembly Language.
- Proficient in finite element analysis with software packages MARC, ADINA, SAP, ANSYS and COSMOS with special experience in building research oriented Finite Element programs.
- Experienced with Unix machines and with wide variety of commercial software.

**Honors:**

- Dissertation fellowship, 1995, University of California, Irvine.
- Institute Merit Scholarship, 1984-1989.

**Registration:** Registered Professional Civil Engineer in the State of California.

**Industrial and Research Experience Highlights:**

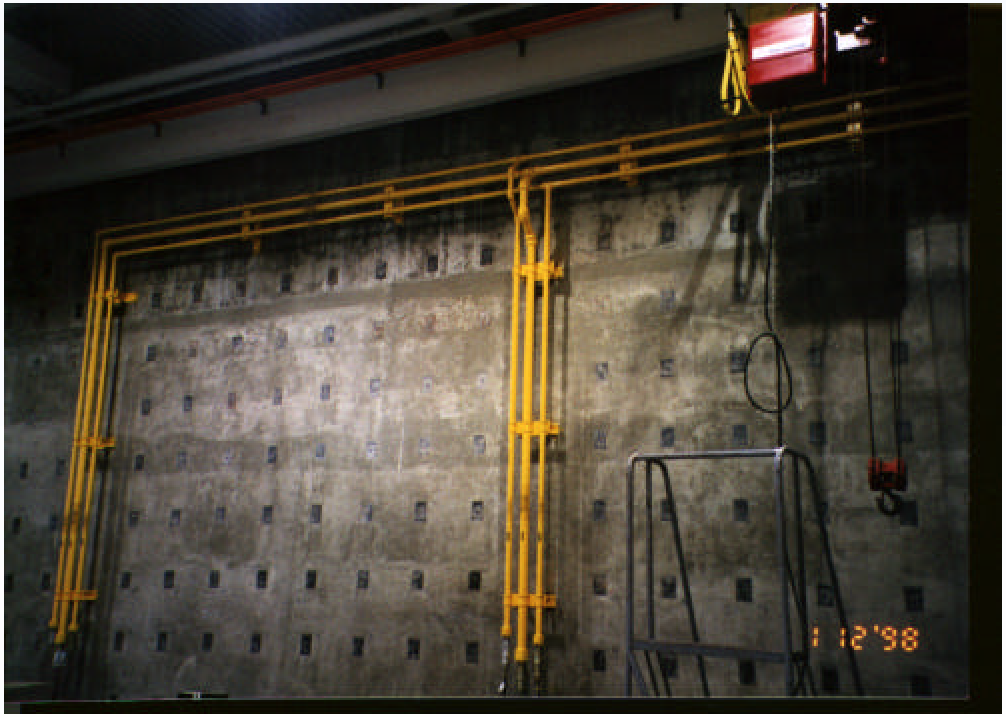
- Building a nonlinear Finite Element program capable of modeling curved shells with material and geometric nonlinearities, fluids with the nonlinear sloshing phenomenon and nonlinear fluid-structure interaction, and performs general contact analysis. The program is used to analyze and develop design guidelines for liquid storage tanks.
- Enhancing a nonlinear Finite Element program to model concrete plasticity, composite effect and cracking using the concepts of fracture mechanics.
- Nonlinear time history analysis of Big Tujunga Concrete arch dam using the finite element method. Nonlinearities arise due to concrete cracking and opening of joints.
- Project engineer on Caltrans project "Retrofit, Repair and Testing of Bridge Pier Walls". Duties included lab testing and supporting analyses.
- Performed seismic analysis of four 40 ft. wide by 30 ft. high spillway radial steel gates at Big Creek No. 7 Dam, and one 15 ft. wide by 8 ft. high radial spillway gate at Vermillion Dam to determine gate's structural integrity. Performed condition assessment of the equipment and structural analysis of each gate including finite element analyses.
- Vulnerability analysis of power transformers and bushings using Finite Element.
- Vulnerability analysis of Rockwell large steel building (250,000 $ft^2$) with gypsum concrete diaphragm.
- Author of structural finite element program to analyze static, moving and seismic loads on the Getty Museum floors. Loads include moving fork lifts, heavy statues and displays. Program written in the C language.
- Structural evaluation of Memphis Company LNG tanks, and INTEVEP oil storage tanks.
- Time history analysis of Dames & Moore MFHT unanchored liquid storage tanks. MFHT tanks are supported on building floors and used to store nuclear waste materials.
- Building data base for California faults and adapting seismic risk analysis programs.
- Project management and scheduling using Primavera systems.
- Layout and design of the 20,000 feet-long Santa Ana River pipeline and supporting structures.
- Structural engineer on the analysis and design of steel and concrete structures, bridges and various types of foundations.

**Personal Information:** Born on February 15, 1968. Married and have three children.

# *Appendix B*
# *Capabilities of the Structural Lab*
# *at*
## *California State University, Fresno*
## *Department of Civil & Geomatics Engineering & Construction*

# *Introduction*

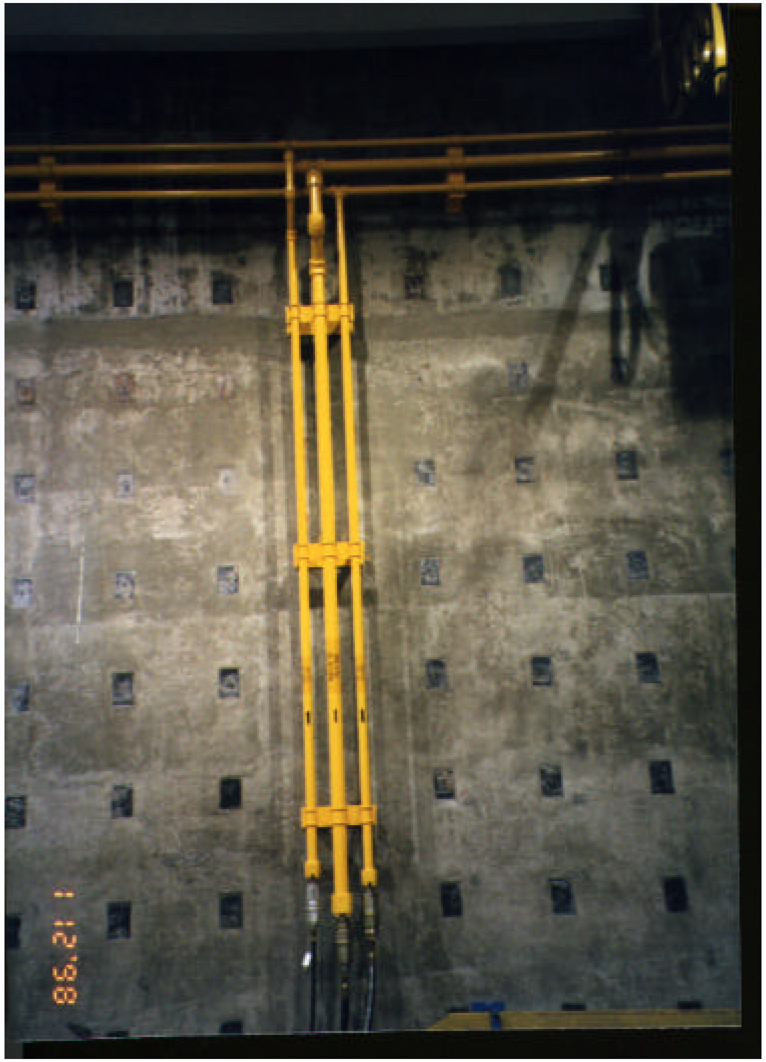
- The Structural Engineering Research Laboratory at California State University, Fresno was constructed in 1992
- The lab is housed in the East Engineering building




- This presentation shows a brief description of the components of the Structural Lab

# *Strong Wall and Floor*

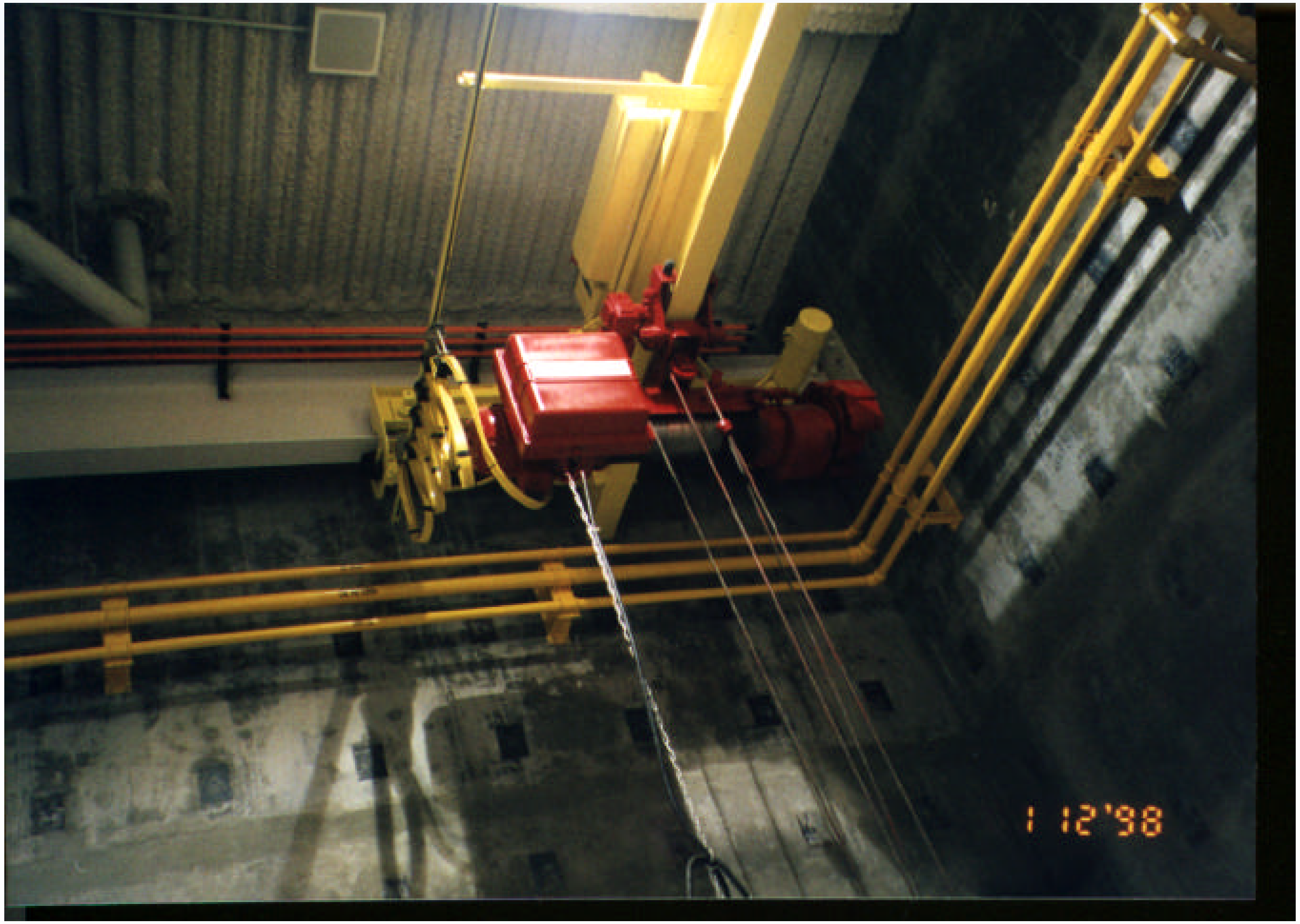
- The strong floor is a 2 ft thick, reinforced concrete, floor slab with plan dimensions of 52 ft by 23 ft
- Floor tiedowns, spaced 2 ft on center in two directions and embedded 1.5 ft into the strong floor, are used to connected test specimens to the strong floor
- Each floor tiedown is capable of resisting 50 Kips of force in tension and 12 Kips of force in shear
- The reaction wall is a 2 ft thick reinforced concrete wall that extends perpendicular to the strong floor to a height of 30 ft
- Wall support locations extend up a height of 18 ft and spaced 2 ft on center



# *L-Shaped Strong Wall*

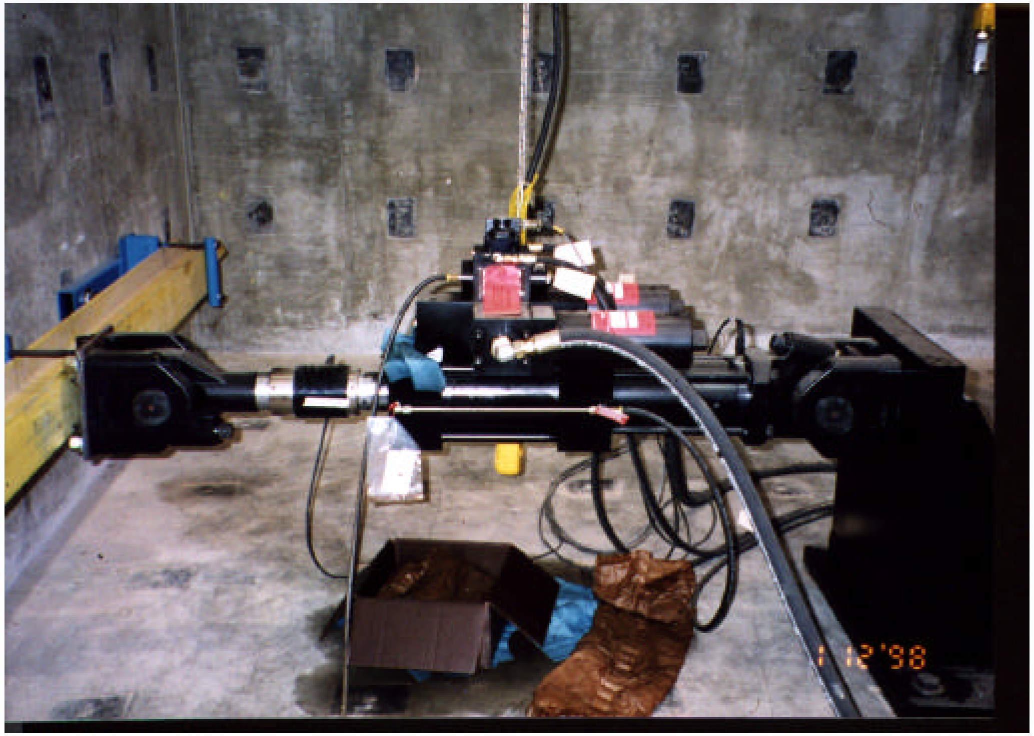
- The Wall is L-shaped in plan with each leg extending to cover the entire strong floor plan
- Thus, testing of specimens under biaxial loadings can be readily accomplished, such as biaxial bending and axial loading
- The wall is capable of supporting a total load of 250 Kips applied at a height 18 ft
- The wall is supported at the roof level by a tie back diaphragm to allow the support of large reactions with small deformations
- The wall height of 30 ft allows for testing of large-scale components or systems, such as bridge columns or piers, or multi-column bent with bent cap

# 5-Ton Capacity Crane



# *Hydraulic Actuators*

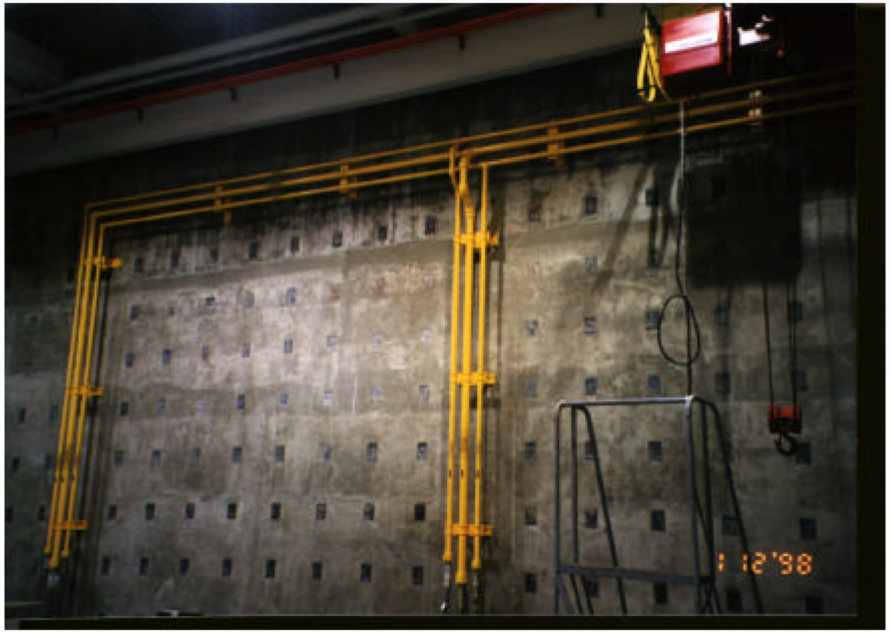
- Two 50 Kips hydraulic actuators are housed in the Structural Lab to apply loads or deformations to test specimens
- The actuators and matching load cells have a capacity of 50 Kips of force with 10 inches stroke
- One of the Actuators has a 90 gpm Servovalve enabling it to apply the 50 Kips force at a frequency up to 100 Hz



# *Hydraulic Pump*

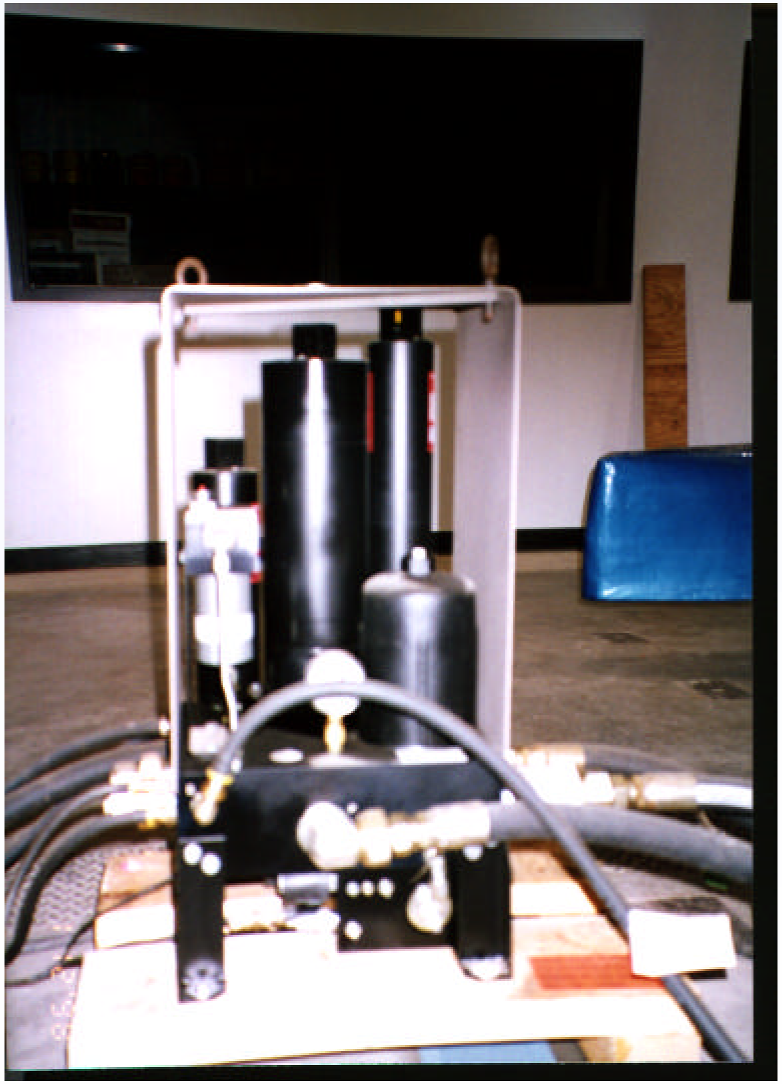
- The hydraulic system is powered by a custom-built hydraulic pump operating at 100 gpm at 3000 psi pressure
- The built-in hydraulic distribution system runs three sets of hydraulic lines at three different set up points in the lab

# *Hydraulic Distribution System*



# *Hydraulic Service Manifold*

- The test actuators are serviced by an MTS 290 Service Manifold



# *Data Acquisition*

- The Data Acquisition has a current initial capacity of 16 Channels
- The MTS Test-Star software are used to monitor and collect data
- Linear potentiometers, wire potentiometers, , pressure transducers, accelerometers, extensometers and strain gage conditioners are available for monitoring specimens during testing

# *Fabrication of Specimens*

- structed off-site and shipped to the lab for testing or specimens may be fabricated on-site
- For on-site fabrication of reinforced concrete specimens, rebar cutters, benders and various equipment will be available to produce rebar various hooks, as well as hoops, crossties and spirals
- Welding facilities will also be available in the lab
- The nearby machine shops house various fabrication equipment, such as drill press, lathe and band saw, as well as welding equipment
- The structural lab is located next to the concrete lab, which has a large room for concrete mixing and moist curing
- Concrete can also be obtained from local suppliers. A 12 ft $\times$ 18 ft overhead door provides direct access to the lab for the ready mix truck

# *Computer Facilities*

- The lab contains its own computing facilities, including a personal computer for data acquisition and data reduction and a laser printer
- The computing facilities in the structural lab are networked to the campus computing facilities, allowing use of mini-supercomputers and Unix workstations, as well as color printers and other accessories
- The department has tremendous computing facilities available to analyze test data. Facilities include PCs, Unix work stations, IBM, Silicon Graphics machines and wide variety of software
- Access to supercomputers is available through the network at national supercomputer facilities

# *Conclusion*

- Features of the Structural Engineering Research Laboratory allows the test of large- or full-scale building and bridge components or systems
- The strong floor and the L-Shape strong wall allows many types of tests to be performed
- Fabrication facilities available in the nearby machine shops and in the department allow the construction of a wide variety of test specimens
- Computer Facilities and data acquisition system allow a powerful collection and analysis of data

# *Appendix C*

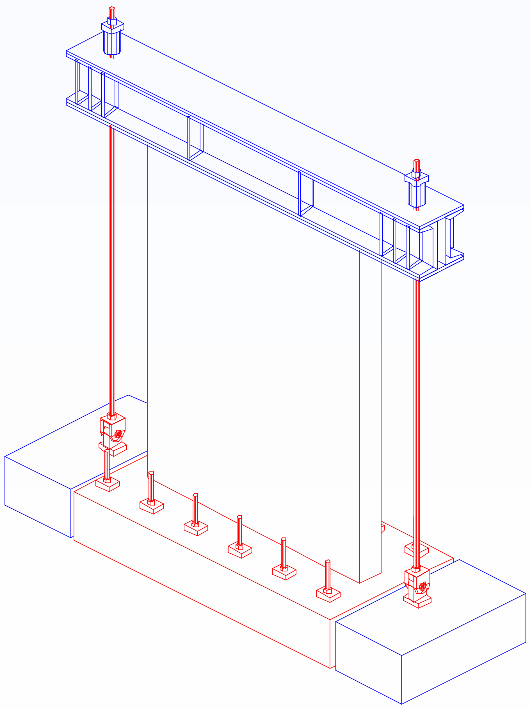
## *Previous Experience with Experimental Projects*

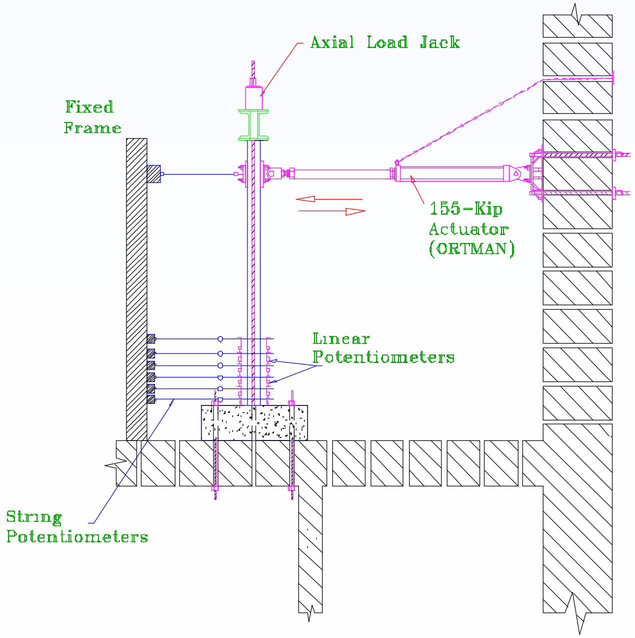
# *Retrofit, Repair and Testing of Bridge Pier Walls*

Phase I: Effect of lap splice on bridge pier wall

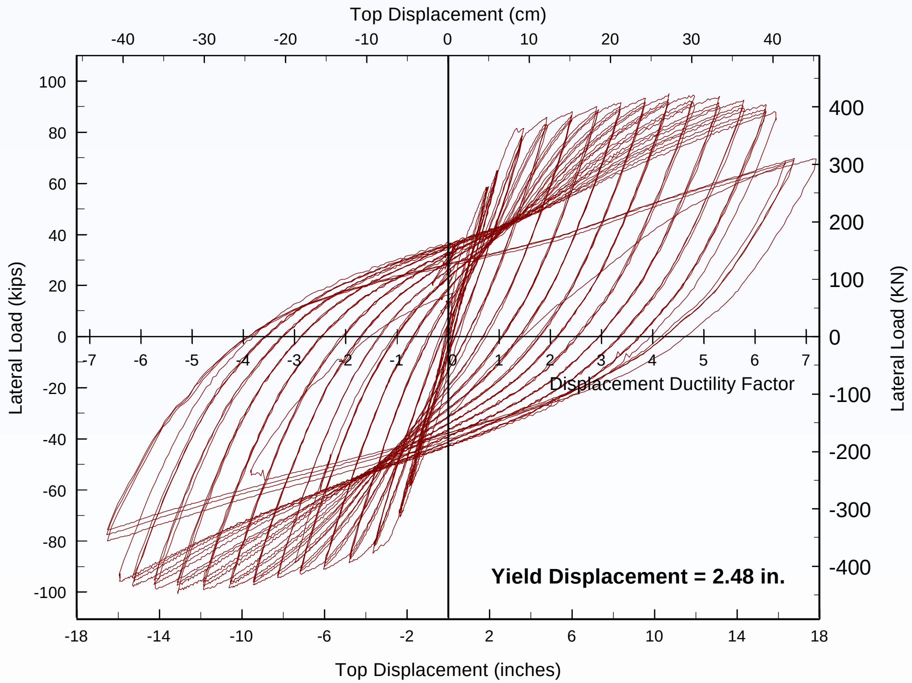
Phase II: Repair of pier walls damaged in phase I

phase III: Comparison of full scale versus half scale tests of pier walls



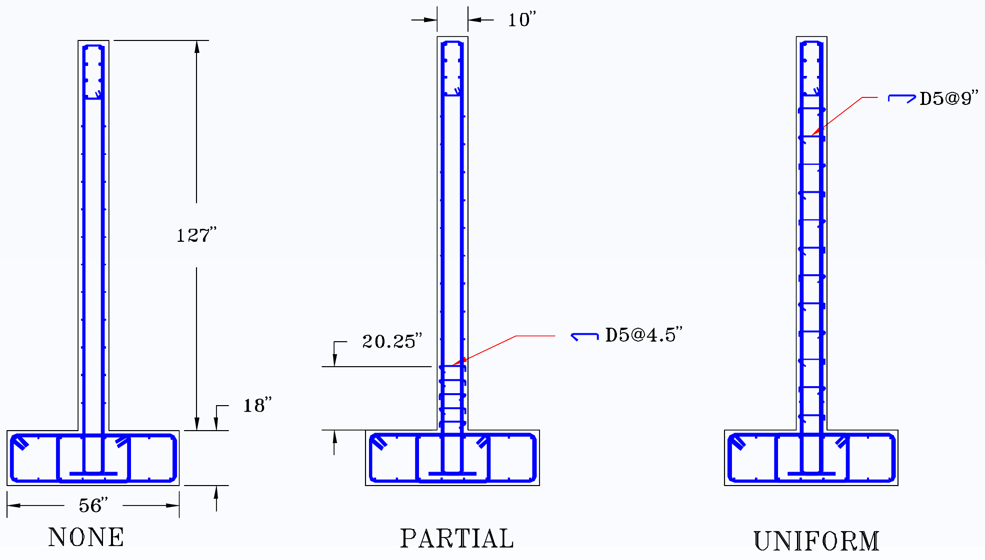


# Full Scale Walls



# *Conclusion of Phase I*

## *Testing of Bridge Pier Walls*




Lap splices at the bottom of the wall in the plastic hinge zone degrades the performance and ductility of the wall. Thus, it is recommended to avoid using splices in the plastic hinge zone, or welded splices should be used

Bars buckle under cyclic loads and cross ties fail due to the opening of their ends. It is recommended to use cross ties with improved details of their ends and longer hook length

Cross ties in the plastic hinge zone enhanced the ductility of the wall by nearly 40%

Distribution of cross ties has a minimal effect on the ductility of the wall

# *Conclusion of Phase II*

*Retrofit and Repair of Bridge Pier Walls*

Retrofit of existing pier walls designed with a lap splice:

Two confining steel columns with cross bolts may be used to confine the concrete in the plastic hinge zone

The spacing between cross bolts should be small enough to develop large ductility

Repair of damaged walls:

The following repair scheme was recommended

Demolish the damaged concrete in the plastic hinge zone with out destroying the existing rebars

Place new reinforcement (various reinforcement details were suggested)

Pour a thicker concrete wall (not thick enough to obstruct water flow)

# *Conclusion of Phase III*

*Comparison of full scale versus half scale tests of pier walls*

The Cyclic testing of six half-scale and two full scale pier walls led to the following conclusions:

Lower vertical reinforcement ratio lead to higher displacement ductilities of the pier walls when tested in the weak direction. A displacement ductility of 6 or better can be achieved by using a vertical reinforcement ration of no more than 1.3%

If the scale was done correctly in the reinforcements as well as the concrete, then pier walls built at 50% scale behave more or less in an identical fashion as full scale pier walls with the same vertical reinforcement ratios

Pier wall with the higher reinforcement ratios had more vertical reinforcement bars break than those with lower reinforcement ratios

Failure of the cross ties by the opening of their ends was prevented to a large extent by placement of double cross ties at each vertical reinforcing bar location and increasing the leg lengths