CCEER

Center for Civil Engineering Earthquake Research

University of Nevada, Reno

Celebrating 25 Years of Advancing Seismic Safety

FOREWORD

The Center for Civil Engineering Earthquake Research (CCEER) at the University of Nevada, Reno was formally established in 1984. Early research efforts were devoted to testing full-scale bridges in the field. But with the completion of the high-bay structures laboratory in the Harry Reid Engineering Laboratory in 1992, recent efforts have used a set of high performance shake tables to study a range of structural and geotechnical systems.

Today CCEER comprises two research laboratories, one in geotechnical engineering and the other in large-scale structural systems. Almost 20 academic, research, and administrative faculty, research scientists, and technicians are affiliated with the Center, and about 30 doctoral and masters students are engaged in research projects under the Center's umbrella. Total research funding in 2009 was about $3.5 million. In its 25-year history CCEER has published more than 160 technical reports which describe the results of these activities. Through these and other publications, the Center has become well known for its work in advancing seismic safety, particularly in the area of highway bridges.

The Large-Scale Structures Laboratory is a member of the George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) established by the National Science Foundation in 2004. Through the Center's shared-use policies, research is carried out for federal and state agencies, the private sector and non-profit organizations. In addition to highway bridges, the Center's research efforts include the study of non-structural components in buildings and alternative building materials.

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Ian Buckle

The earthquake engineering program here at the University of Nevada Reno is one of the finest in the country and perhaps the world. Housed within the Center for Civil Engineering Earthquake Research, this program has a long history of innovative work particularly in the experimental simulation of earthquake effects. Over the years, notable advances have been made towards the goal of seismic safety, particularly with regard to our highway infrastructure.

This year the Center is twenty five years old and to mark the occasion we have published this short report, which summarizes our past and present accomplishments, lists our research grants and technical reports, and is an opportunity to acknowledge the outstanding people who have made this achievement possible.

The success we enjoy today is due to the untiring efforts of many people who range from the founding faculty to today's dedicated researchers, from first class graduate students to innovative lab personnel, from the department office to the dean's office, and from the office of sponsored projects to the president's office. It also includes our sponsors, both federal and state, who have funded the unique equipment in our laboratories and our cutting-edge research. Without the generous support of NSF, NEES, FHWA, DOE, FEMA, MCEER, Caltrans and NDOT[1] we would not be where we are today.

A 25th birthday is an appropriate moment to pause and take stock… to look back and see where we have come from and to look forward and recognize the challenges that still lie ahead. From the testing of Ramp 13 in the I-80/395 Interchange using a D-8 Tractor in 1974, to the shake table testing of a four-span bridge to the point of collapse in 2009, we have indeed come a long way.

But there is still a long way to go before we can say we are safe from earthquakes.

On behalf of the Center I am asking all our friends, colleagues, and sponsors to join with us as we move forward into the next quarter century to meet this challenge head-on.

Ian Buckle
Professor and Director
Center for Civil Engineering Earthquake Research and James E. Rogers and Louis Wiener Jr. Large-Scale Structures Laboratory

[1] NSF: National Science Foundation; NEES: George E. Brown Jr. Network for Earthquake Engineering Simulation; FHWA: Federal Highway Administration; DOE: US Department of Energy; FEMA: Federal Emergency Management Agency; MCEER: Multidisciplinary Center for Earthquake Engineerng Research; Caltrans: California Department of Transportation; NDOT: Nevada Department of Transportation.

Manos Maragakis

Amy Childress

The College of Engineering has recently set a vision to achieve, during the next five to ten years, measurable national recognition. This vision requires, among many other tasks and goals, the development of: state-of-the-art educational programs, nationally and internationally recognized research programs, and outreach programs that serve the needs of the State and the Nation. With limited resources and significant economic challenges, the accomplishment of these strategic goals requires careful planning and a successful example to study and follow. The College is very fortunate to house the Center for Civil Engineering Earthquake Research, the success of which provides an excellent example of how this vision has been, and continues to be, accomplished. The Center began with an ambitious visionary plan that required effective leadership, acquisition of key personnel, strategic focus, development of unique educational programs, successful grant writing, and outreach at the local, national, and international levels. The Center started small and steadily grew through the focused, dedicated, and hard work of its faculty and staff; over the past 25 years it has managed to achieve its vision of national and international recognition. The Center is now expanding further, and in doing so, continues to serve not only the state of Nevada, but also other seismically-active regions in the country and the world. Nevada is the third most seismically-active state in the Union and the work of the Center is vital to the safety and well-being of Nevadans as well as the millions of people around the world who live in seismically-active countries. The work of the Center has impacted the development of new seismic guidelines, has contributed to the development of new advanced seismically resistant structural designs and retrofits, and has educated engineers with key positions in academia, federal and state agencies, and private industry. As we are looking to the future, the Center continues to serve a critical need for the state of Nevada and the nation and continues to excel in all of its activities. I am grateful and proud of its success, I am confident about its bright future and I extend my heartfelt congratulations and best wishes for 25 more years of excellence.

E. "Manos" Maragakis
Dean of the College of Engineering

Designing, building, and maintaining infrastructure is central to the discipline of Civil and Environmental Engineering. Recent catastrophes have reminded us of the critical role that civil and environmental engineers have in our daily lives. Living in Nevada, earthquakes are at the top of the list of possible natural disasters that can damage our infrastructure, threaten our lives, affect our economy, and compromise our future. The recent swarm of earthquakes centered near Reno in the first part of 2008 brought earthquake risk to the forefront of our attention. The Department of Civil and Environmental Engineering is proud to be the academic home of the internationally-recognized Center for Civil Engineering Earthquake Research and to be able to make a significant contribution to the important issue of seismic safety in Nevada and around the nation and world. Through the development of guidelines for the retrofit of existing bridges and structures, the seismic design of new bridges and structures, and the careful education and outreach on the importance of seismically-safe structural design, the Center for Civil Engineering Earthquake Research has made significant contributions to the field of earthquake engineering. These contributions have made the Center recognized around the world for its high quality of work and as one of the premier programs for students to study earthquake engineering. It has brought credibility and recognition to the Department, the College, the University and the State. I want to congratulate the faculty and the staff for their achievements and wish them continued success in the future.

Amy Childress
Chair of the Department of Civil and Environmental Engineering

Pre -1984

The teaching of earthquake engineering in the Civil Engineering Department began long before the establishment of CCEER. With strong encouragement from Professor George Housner of the California Institute of Technology and founder of the modern science of earthquake engineering, Professors Bruce Douglas and Alan Ryall of the Nevada Seismological Laboratory began a collaboration in 1967 to introduce the discipline of earthquake engineering to Nevada by establishing such a program at UNR.

In 1968, a graduate course in Dynamics of Structures, including the earthquake response of structures, was initiated as a Special Projects course. This course appeared for the first time in the UNR Catalog in 1970. Also in 1968, Douglas and Ryall initiated a course in Earthquake Engineering jointly sponsored with the Geology Department. It appeared in the UNR Catalog in 1971 and has been taught regularly ever since.

In addition to establishing a teaching program, Douglas and Ryall also collaborated for more than a decade on earthquake engineering research projects. Their early work focused on engineering seismology and their later work on seismic risk in Nevada and California. They worked largely in the field because the capital cost of building and equipping a laboratory on campus could not be justified at the time.

In 1974, the first funded research contract on the earthquake performance of bridges was obtained from the Federal Highway Administration with James D. Cooper as the contract manager. The experiment was conducted on Ramp 13 in the Reno spaghetti bowl, which is the southbound exit from I-80 east to US 395. It is a six-span slab-and-steel girder bridge. Relatively high amplitude lateral vibrations were generated by the pullback and quick release method, where cables and a D-8 Caterpillar Tractor were employed to cause the initial deformation (Fig. 1). Traffic induced vibrations were used to excite the vertical motions. Relevant dynamic properties of this structure were determined by studying these motions for use in earthquake design. It was the first field test of a highway bridge undertaken by the faculty. The graduate student was Harlan Fricke.

With the cooperation of the Nevada Department of Transportation, four additional field experiments were undertaken during this period. The next field test was conducted on the Rose Creek Interchange on I-80 near Winnemucca, Nevada. That bridge was a 400 ft long five-span reinforced concrete box girder. Its in-situ earthquake dynamic properties were studied using the previously described pullback and quick release method. Around the same time, traffic induced vibrations were used to investigate a variable depth composite steel girder bridge on I-80 near Wells, Nevada. Another field experiment was conducted on the Cold Stream Interchange on US 395 near Bordertown. That bridge was a two-span concrete box with a single concrete pier. The purpose of testing that structure was to pioneer a new method of generating very high amplitude earthquake-like lateral loads using large hydraulic rams. When this was successfully completed, the new experimental technology was employed during another field experiment at Rose Creek with a large crew of graduate students.

Except for the first test, all of these early field studies were funded by the National Science Foundation (NSF) with Dr. Jack Scalzi as the program manager. Over a period of two decades Dr. Scalzi and NDOT were major factors in the success of the Center.

It was during this pre-1984 period that the Civil Engineering Department began focusing its efforts on building a critical mass of faculty in the areas of structural, geotechnical, environmental, and pavements/materials engineering. The reasons were to improve competitiveness for external research funding and expand the learning experience for the department's undergraduate students. At the time the department's structural engineering faculty included just three professors: Dr.s Bonell, Douglas, and DeAngelis. But in 1979 Dr.s Mehdi (Saiid) Saiidi and Gary Norris were hired. Dr. Saiidi was appointed from the University of Illinois at Urbana Champaign with expertise in the seismic performance of reinforced concrete structures, and Dr. Morris from the University of California Berkeley with expertise in geotechnical engineering. With the addition of these two new faculty members, the earthquake program began to grow.

Fig. 1: Setting Up A Pull Test Using a D-8 Tractor, 1974

1984-1992

Late in 1983 Dr. Douglas and Dr. Saiidi began planning the establishment of a research center in earthquake engineering to provide an organizational structure for faculty involved in earthquake research, enable the conduct of high quality research, and publish a technical report series. The result of this exercise was the Center for Civil Engineering Earthquake Research which obtained its first dedicated office space (SEM 111) and published its first technical report in January 1984.

1985 marked the Center's first cooperative international field test. At the time, NSF was interested in the work of the New Zealand engineering research community because it had a reputation for transforming research results to engineering practice quickly. The planning for collaborative research began in December of 1981 when a joint US/New Zealand Applied Technology Council workshop was held in Wairakei, New Zealand (NZ). The first cooperative project to be proposed was the large-amplitude, quick-release field testing of a set of bridges in New Zealand using the techniques develop at UNR. At Dr. Scalzi's recommendation, NSF supported the US-side with Dr. Douglas as PI. The NZ-side was supported by the National Roads Board, Central Laboratories, the Head office of the Ministry of Works, and the Auckland City Council through the University of Auckland. The PIs for the NZ side were Dr. Ian Buckle (University of Auckland) and Dr. John Wood (Central Laboratories). Field experiments were conducted in January and February of 1985 on the Dominion Road Bridge (a curved, 10-span, 910 ft long, prestressed concrete box girder bridge in Auckland, NZ), shown in Fig. 2, and the Manga-te-waiti Bridge (a base isolated structure near Dannevirke, NZ). In addition to the above structures, ten other bridges in the U.S. were field tested during this period.

In April 1984, the National Science Foundation funded a workshop at UNR to develop a set of research needs in earthquake engineering for bridges, and to identify the experimental facilities that would be required to satisfy these needs. The workshop was attended by many members of the national earthquake engineering community. The

Fig. 2: Quick-Release Testing the Dominion Road Bridge in Auckland, New Zealand, 1985

result was a strong recommendation for the construction of a "National Bridge Engineering Laboratory" located at a single site with substantial operating and research funding. The capital costs for the laboratory alone were projected at $100-$150 million. Accordingly, UNR and the State of Nevada proposed to NSF that this Laboratory be located at Stead just north of Reno and be managed, operated and maintained by the Center under a grant from NSF (Fig. 3). But NSF declined to accept the proposal and the concept of a national bridge laboratory lapsed.

Fig. 3: Artist's Rendering of the Proposed National Bridge Engineering Laboratory at Stead

This experience became one of the major factors in urging the University to move forward with the construction of an engineering laboratory building on campus. In 1987 the Nevada State Legislature appropriated $425,000 (Assembly Bill 64) for the design and planning of the new UNR engineering laboratory, provided that $1 million was raised from the private sector.

In response, the Nevada Section of AGC helped the university to raise $1.8 million from local construction and engineering companies, and UNR alumni. A 5,700 sq ft, high-bay bridge structures laboratory was planned for the building based on recommendations from visiting ten different university and government agencies that operated this kind of facility. Design of the building began in 1989 and was undertaken by Michael Blakeley Structural Engineers. That same year the Nevada legislature authorized $9.8 million for the construction of the building which is now known as the Harry Reid Engineering Laboratory. The building was completed in 1992.

Personnel changes of note during this period include the retirement of Professor De Angelis in 1984, and the appointment of Dr.s Emmanuel (Manos) Maragakis and Raj Siddharthan that same year. Dr. Maragakis came from the California Institute of Technology having done his doctoral thesis in the area of earthquake structural dynamics of highway bridges. Dr. Siddharthan obtained his doctorate from the University of British Columbia and specialized in geotechnical engineering and soil dynamics. Dr. David Sanders joined the faculty in 1990 from the University of Texas at Austin with his primary expertise in earthquake effects on reinforced concrete structures.

1993-1999

The first project to be conducted on the strong floor of the new building was the ultimate load testing of a series of 700 ft long full-scale prestressed box girders recovered from the old Wells Avenue Viaduct in Reno. This project was funded by the National Science Foundation and it was conducted under the direction of Dr.s Saiidi and Douglas. Shear, flexure, and fatigue performance of these girders was studied including their repair. The first doctoral graduate student to conduct research in the lab, Dr. Yolanda Labia, graduated shortly thereafter.

The new laboratory provided the leverage necessary to pursue additional funding to further increase the Center's research capability and infrastructure. A successful proposal was submitted to NSF's Experimental Program to Stimulate Competitive Research (EPSCoR) and funding was received in two stages (1993, 1997) for a total of $1.26 million.

Furthermore, as a direct result of the damage sustained during the 1989 Loma Prieta Earthquake in California, the Federal Emergency Management Agency (FEMA) awarded a total of $5.5 million to build a capability at UNR for simulating earthquakes using multiple shake tables. Following the advice of an External Advisory Committee, the decision was made to purchase two, 50-ton, uniaxial shake tables from MTS Corp. of Eden Prairie, MN. These custom-designed tables could be operated independently of each other, or simultaneously, with a total pay load of 100 tons (the largest in the U.S. at the time). In addition, a single 50-ton biaxial table could be assembled from the components of the two tables. The two shaking tables were delivered in 1996 and commissioned in May of 1997. The first experiment to use one of the shake tables was conducted in 1998. Funded by Caltrans, the project studied the performance of a reinforced concrete bridge column and required the development of an off-table mass rig to correctly model the inertia forces acting on the column (Fig.4 and Fig. 5). The graduate student was Patrick Laplace. The mass rig is still in use today.

Once the two shake tables were installed, it was apparent that the laboratory was too small. Up to this point in time specimens had been fabricated inside the lab but the shortage of space required this activity to be moved outside. In 1996 BJG Architecture + Engineering designed an outdoor fabrication yard with a moveable storage building; construction was completed in 1997. Once the fabrication yard was complete, BJG then designed an expansion to the existing laboratory. The floor space was increased by 50 percent to 150 ft x 56 ft.

Fig. 4: A Column under Test on a Shake Table in the Large-Scale Structures Laboratory

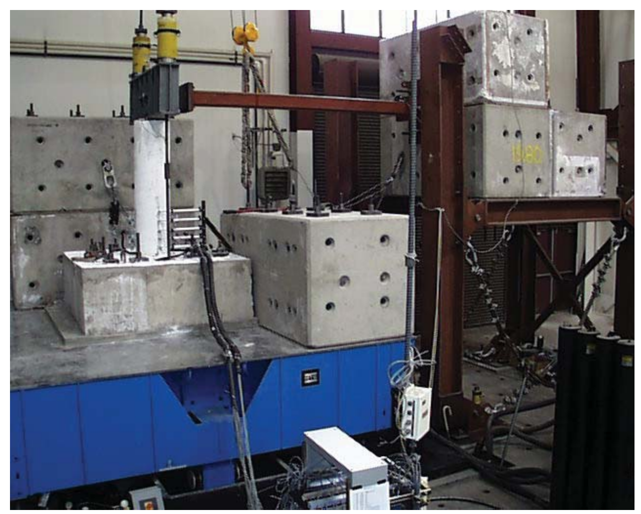


Fig. 5: The Off-Table Mass Rig Attached to a Column on the Shake Table

The concrete box test floor and the crane rails were extended southward 50 ft. The principal funding for this exercise came from Mr. James E. Rogers, the founder and owner of Sunbelt Communications Company. Construction began in 1997 and was completed in 1999, at which time the laboratory was renamed the "James E. Rogers and Louis Wiener Jr. Large-Scale Structures Laboratory."

Personnel actions in this period began with the hiring of Dr. Ahmad Itani in 1994. Dr. Itani obtained his doctorate from the University of Michigan in the area of seismic resistance of steel moment frames. In 1999 Dr. Douglas retired and Dr. Ian G. Buckle was hired as the Director of the Center. Dr. Buckle's expertise is in seismic isolation, seismic retrofitting of bridges, and code development.

2000-2009

Following a series of damaging earthquakes in California, Japan and Taiwan in the 1990s, and recognition of the need to upgrade experimental facilities in U.S. universities, the National Science Foundation called for proposals to establish a network of world class earthquake simulation sites in 2000.

In response to this solicitation, the Center successfully proposed to upgrade the two existing shake tables from uniaxial to biaxial motion and add a third identical biaxial table (Fig. 6). The total budget for this upgrade was approximately $7.2 million and comprised $4.6 million from NSF with cost sharing from the Department of Energy ($1.0 million) and the Department of Housing and Urban Development ($1.6 million). At the same time, the Large-Scale Structures Lab became a NEES Construction Site in 2000 and commenced operations as one of 15 Equipment Sites under a management, operations, and maintenance agreement with NSF in 2004.

Fig. 6: Installation of the Third Biaxial Shake Table, 2001

Known as the George E. Brown Jr. Network for Earthquake Engineering Simulation, NEES is a network of 15 (now 14) large-scale experimental sites that feature advanced experimental tools such as shake tables, wave basins, geotechnical centrifuges, dynamic load systems, and field-testing equipment for studying earthquake effects at or near full-scale. All are linked to a centralized data repository and earthquake simulation software, by the high-speed broad-band Internet2. The NEESgrid network allows the earthquake engineering user community to interact in real time with any of the networked sites and access the data repository.

In addition to the construction of the NEES Equipment Sites, NSF also established a research fund for the use of these facilities. Several faculty have been successful at winning awards under this program including two Small Group Awards (2004, 2005) related to improving the seismic performance of bridges and one Grand Challenge Award (2007) related to the performance of non-structural components in buildings. All of these awards are multi-year, multi-million dollar grants, involving multi-investigator collaboratories with leading academic institutions led by UNR.

Many of these projects pushed the state-of-the-art in earthquake engineering simulation well beyond anything attempted before. The testing of a 130 ft long, 0.3-scale, four-span bridge (2006) required three shake tables and two abutments fitted with servo-controlled actuators. This was the first time this configuration had been used and the successful synchronous control of the tables and actuators won the Laboratory the 2007 NEES Award for Innovations in Actuator Control. The number of multiple-table research projects increased during this period and perhaps the most ambitious to date is the FHWA project which involves the testing of a 145 ft long, 0.4-scale, three-span curved bridge in 2010. Under design at the end of 2009, this project will require relocating the tables to a curved alignment early in 2010. The model is expected to occupy the full length and width of the Laboratory.

Using remaining funds from the NSF-NEES Construction Award, a grant from FHWA, and a contribution from the Office of the Vice President for Research, a fourth shake table was designed, constructed, and commissioned in 2009. This 20-ton table has six degrees-of-freedom (3 translations, pitch, yaw and roll) and can be used synchronously with the other three tables or operated independently. It is expected that this table will enable the Laboratory to broaden its research activities to include, for example, the seismic qualification of non-structural components.

But just as in the mid-nineties, after the commissioning of the first two tables, the Laboratory is once again too small. Plans have been developed by BJG Architecture + Engineering for a 23,000 sq ft expansion which includes a 10,000 sq ft strong floor, 6,000 sq ft of offices for graduate students and visiting scholars and a 7,000 sq ft interactive auditorium for education and outreach activities. Estimated to cost $20-23 million, about $3 million has been received to date from the Department of Energy. Fundraising continues for the remainder.

Personnel actions in this period included the hiring of Dr. Patrick Laplace as Assistant Research Professor and Structures Laboratory Manager in 2001, and Dr. Gokhan Pekcan as an Assistant Professor in 2003. Dr. Laplace completed his doctorate in the earthquake engineering program at UNR and Dr. Pekcan obtained his doctorate at the University at Buffalo in earthquake protective systems. As a consequence of the NEES MOM and FHWA Awards, a number of other appointments were made during this period. These included Dr. Sherif Elfass as Research Assistant Professor and NEES Site Operations Manager (2005); Rodney Porter as NEES IT Systems Administrator (2008) replacing Chad Feller (2006); Kelly Doyle as CCEER Program Coordinator (2008) replacing Rita Johnson (2007); Chad Lyttle (2006), Todd Lyttle (2008) and Paul Lucas (1999, 2009) as Development Technicians; and Robert Nelson as Research Scientist (2009).

Bridges

Since the installation of the third shake table, researchers have extensively studied the seismic response of bridge systems supported on multiple shake tables. These projects have been funded by major grants from NSF, Caltrans, NDOT, and FHWA, and include studies of structural seismic response under uniform ground motions, under fault rupture, with abutment pounding, and with advanced components, materials, and details. In addition, extensive analytical studies have provided greater insight into the behavior of bridges with various geometries, including skew and curvature. Listed below are some of the projects that have been undertaken to improve the performance of bridge structural systems.

Seismic Performance of Bridge Systems with Conventional and Innovative Design

Bridges exhibit complex structural performance during strong earthquakes because they are highly nonlinear systems. Experimental models may be created to study this performance but for these models to be credible they must be built at a sufficiently large scale. The objective of the study is to conduct a comprehensive investigation of the seismic performance of a series of large-scale, four-span bridge systems including the soil-structure effects at the footings and abutments. The relative performance of the components, bridge piers, and bridge systems are evaluated relative to the current design assumptions and philosophies. In some of the models, innovative materials have been incorporated to set the stage for the next generation of earthquake resistant bridges. Two models have already been tested (Fig. 7) and the final model will be tested in 2010.

Fig. 7: Four-Span Bridge on Three Shake Tables and Two Abutments with Servo-Controlled Actuators

Seismic Performance of Horizontally Curved Bridge Systems

There are a growing number of bridges on curved alignments throughout the U.S. and little is known about their seismic behavior. As a result, large-scale experiments on a highly curved bridge are being undertaken under a project funded by FHWA. The bridge is a 0.4-scale model of a three-span, steel girder bridge, and spans four shake tables. The model has a total length of 145 ft, a length-to-radius ratio of about 2.0 and a subtended angle of about 113 degrees (Fig. 8 and Fig. 9).

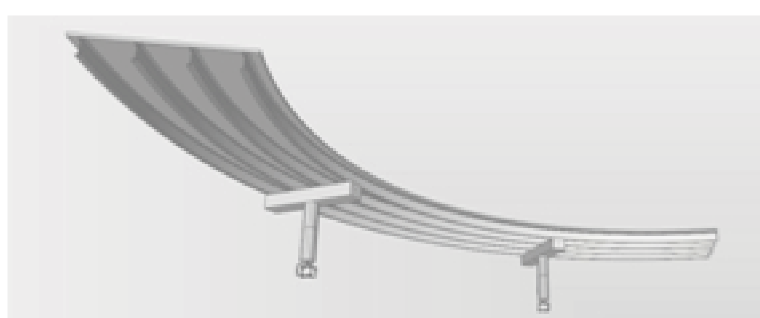


Fig. 8: Three Dimensional View of the Curved Bridge (Abutments not Shown)

The seismic load path through the superstructure is being investigated, along with column behavior subject to combined flexure and torsion, abutment interaction (pounding), and the effectiveness of response modification devices, self-centering substructures, and rocking columns. The ultimate aim is to develop a set of seismic design guidelines for this type of bridge. A secondary aim is to develop a set fragility functions for curved bridges for use in loss estimation algorithms of highway systems.

Under design at the end of 2009, this project requires relocating the tables to a curved alignment early in 2010. Testing is scheduled to begin late summer 2010.

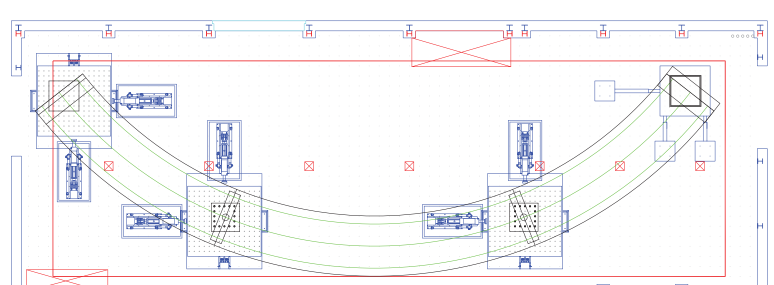


Fig. 9: Plan View of the Curved Bridge Spanning Four Shake Tables in the Large-Scale Structures Laboratory

Seismic Retrofit and Repair of Reinforced Concrete Bridge Columns

One of the active research areas at CCEER has been the seismic retrofit of bridge columns and piers with funding from Caltrans and NDOT. Methods using fiber reinforced polymers and reinforced concrete walls have been studied and recommendations have been made and implemented in bridges in Nevada and California.

Fig. 10: Applying Mortar to a Damaged Column

An ambitious project recently funded by Caltrans aims at quickly restoring bridge columns damaged during earthquakes. The objective is to minimize disruption to service for only a few days with a reliable and cost-effective repair strategy. During this study, four standard concrete columns and two substandard concrete columns were tested on a shake table and damaged. The columns were then repaired and retested to evaluate the repair performance.

The repair process consisted of straightening the column, removing the loose concrete, injecting epoxy into the damaged area, repairing the concrete using a fast-set non-shrink mortar (Fig. 10), applying CFRP wrap (Fig. 11), and accelerating the cure time using a tent and heaters. Each column was repaired in one day.

Fig. 11: Wrapping a Damaged Column with CFRP

The objective of the repair of a standard column was to restore the confinement and shear strength of the column while the objective of the repair of a substandard column was to restore and upgrade the confinement and shear strength of the column to meet current codes. Preliminary results indicate that strength was restored and the behavior of the substandard columns improved after the repair.

Fundamental Behavior of Bridge Columns and Connection Details

Fig. 12: The Bidirectional Mass Rig in the Large-Scale Structures Laboratory

It is important to have a basic understanding of how structural components behave under extreme loading to determine how they should be designed. Research has therefore been conducted on a wide range of column configurations with various connection details. Some of the different column parameters that have been studied are: shape (circular, oval/interlocking spirals, square, rectangular, flared), failure mode (flexure or shear), and high and moderate seismic detailing. Connection detailing has also been investigated for configurations such as drop bents, integral bent caps, and slab connections. Both strut-and-tie modeling as well as simple design rules have been developed to facilitate design. This research has been conducted both on and off the shake tables.

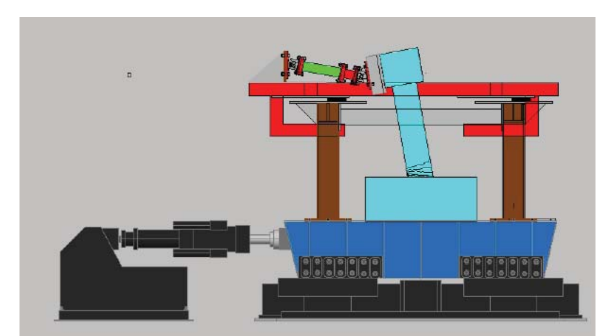


Fig. 13: Elevation View of the Biaxial Mass Rig Test Setup

In the past, shake table testing focused on single direction inertial loading. This has now been expanded to study the impact of multidirectional loading on column behavior. For example, a recent project featured the design and testing of a bidirectional mass rig (Fig. 12), which loads single cantilever columns under biaxial excitations. The aim of the test setup is to have a configuration that carries the vertical load, but allows the transfer of horizontal inertial forces to the specimen (Fig. 13). The system is composed of a platform that rests on clusters of ball bearings placed on top of a three-dimensional frame. The platform is connected to the specimen through links that transfer torsion and shear, but not axial load. Additional mass is loaded on the platform to simulate the mass of a bridge superstructure during an earthquake. The results from these tests are being used to validate analytical models, develop new inelastic models from reinforced concrete columns under combined loading, and propose new design methodologies.

Behavior of SFOBB Components

Several components for the San Francisco-Oakland Bay Bridge (SFOBB) have been tested in the Structures Laboratory to determine the need for retrofit of existing spans and help engineers design the new eastern section (now under construction). The following components have been studied:

- **Shear Links** - Large-scale experiments were conducted on the shear links and their connections to the tower legs of the proposed eastern spans of the bridge. The objectives of these experiments were to determine the deformation capacity, maximum resistance, and ultimate failure mode of built-up shear links by applying incrementally increasing cyclic plastic deformations. A variety of plate steels were used for the shear links in this investigation, such as ASTM A709 Gr. 50, ASTM A709 HPS Gr. 70, Japanese LYP Gr. 14.5, and 30 ksi. The results of these experiments illustrated the suitability of using these types of steel for seismic applications. However, the over-strength associated with the steel varied significantly. The typical failure mode for a stiffened link was at the weld toe of the stiffener to the web while the failure mode for the unstiffened web was the weld between the flange and the web.
- **Gusset Plate Connections** - Large-scale experiments were conducted on double gusset plate connections that are common in the existing spans of the SFOBB to determine the behavior of the edge buckling of these plates. The results of these experiments showed that AASHTO edge buckling equation should be modified in order to capture the observed behavior.
- **Laced Members** - Many SFOBB members are made of built-up shapes that are interconnected with lacing (Fig. 14). The axial and tensile capacities of these members depend on the interaction between the main components and the lacing elements. Large-scale experiments were conducted on laced members to establish their axial capacities and failure modes. The results of these experiments showed the AASHTO equations need to be modified to determine the axial capacity of laced members.
- **Perforated Members** - The laced members of the SFOBB proved to have inadequate axial capacity under seismic loads. Based on this finding, the laced members were replaced by perforated plates (Fig. 15) in an effort to improve the ductility and the axial capacity. Large-scale experiments were conducted on the perforated members to determine their axial capacity and failure modes. Based on these experiments, it was shown the AASHTO equations can be used to accurately determine the axial capacity.

Fig. 14: Laced Members in the SFOBB

Fig. 15: Perforated Members in the SFOBB

Cyclic Behavior of Richmond-San Rafael Bridge Components

- **Retrofitted Richmond San Rafael Bridge Tower Legs** - The tower legs of the Richmond-San Rafael Bridge are made of built-up shapes that have elements that exceed the seismic compactness ratios. In an effort to reduce these ratios, it was proposed to fill the tower legs with concrete in areas where expandable material was located between the legs. Large-scale experiments were conducted on retrofitted sections of the tower legs to determine their behavior and ultimate capacity. Figure 16 shows the test setup that was used for this investigation. The results of these experiments showed that this detail will prevent local buckling. However, it will change the failure model to the net section fracture at bolt hole locations.
- **Shear Links in Richmond-San Rafael Bridge Towers** - The towers of the Richmond San Rafael bridge utilize built-up shear links as part of the eccentric braced towers. The dimensions of the existing links are larger than available data for links that use rolled shapes. Full-scale experiments were conducted on the built-up shear links to determine their ultimate capacity and failure mode. The results of these experiments showed the over-strength factor for these links exceed 2.1 and their plastic rotation was 0.10 radians.

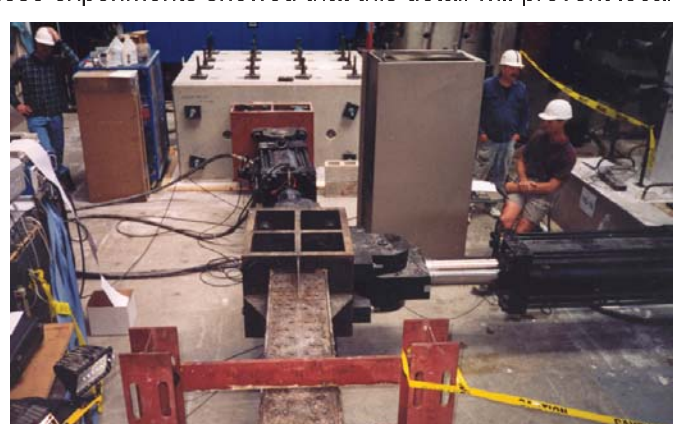


Fig. 16: End Loading on the Tower Leg of the Richmond-San Rafael Bridge

Buildings

Experimental and analytical research has been conducted on various types of buildings to determine how to design more durable structures. Much of this research has been incorporated into building codes and implemented in the field almost immediately, preserving life safety during extreme events. Some of these projects are described below.

Seismic Performance of Innovative Straw Bale Wall Systems

Modern building methods are that are seismically resistant are largely unaffordable in developing countries such as Pakistan. One solution proposed by the Pakistan Straw Bale and Appropriate Building (PAKSBAB) organization is the use of earthquake-resistant straw bale building methods that are inexpensive, energy efficient, and utilize locally resourced renewable materials.

The objective of this research project was therefore to determine the performance of earth plastered, load bearing, thin, straw bale wall assemblies under in-plane cyclic loading, and the performance of a full-scale small straw bale house (Fig. 17 and Fig. 18) using shake table simulation. The site-fabricated bales were not as wide as those used in a typical straw bale building, and the earth plaster was reinforced with fishing net. This same net anchored the walls to the gravel bag foundations. The project was funded by the EERI Endowment Fund and shared-use access to the laboratory was provided by the NEES Consortium.

Fig. 17: Construction of a Full-Scale Straw Bale House

Fig. 18: The Straw Bale House Survived Two Times the Northridge Earthquake

Strut-and-Tie Models

In portions of structures where traditional beam theory does not apply, the strut-and-tie model (STM) can be used to model the flow of forces. This flow can then be used to design reinforcement and verify concrete capacity. Research on the application of STM on deep beams and connections has been conducted. This research was used to verify and provide modification to code provisions in both the American Concrete Building Code (ACI 318) and the American Association of State Highway Official (AASHTO) Bridge Specification.

Full-Scale Two-Story Base Isolation Timber Building Test on Shake Table

Lightweight timber buildings are difficult to isolate from earthquake ground motions using conventional isolators. In this project a two-story timber structure (Fig. 19) was studied on a shake table to determine the effectiveness of an innovative device at reducing seismic forces in the building and its foundation. The building was over 20 ft high with a plan dimensions of 10 ft x 15 ft. The project led to the quantification of the benefits of using this device under different ground motions and different configurations.

Fig. 19: Full-Scale Isolated Two Story Timber Building on a Shake Table

Geotechnical Engineering

Researchers in Geotechnical Engineering have investigated the behavior of different soils and their interaction with piles, foundations, and walls during earthquakes. Analytical and experimental studies help engineers better predict soil behavior and design components to resist soil loads. Below is a summary of some of the geotechnical research conducted at CCEER.

Laterally-Loaded Pile Research

Research has been undertaken to develop a laterally-loaded pile computer program for bridge pile foundation analysis and design. The analysis method and supporting program is named the Strain Wedge Model (SWM). The basic concept is that a passive wedge of soil provides the lateral resistance to a pile or drilled shaft that is loaded at its head with a lateral force and/or moment. The analysis provides the so-called *p-y curves* of the soil with increasing depth. These curves are derived from triaxial stress-strain tests of the soil. The analysis method effectively relates a three-dimensional soil response to the desired one-dimensional p-y curve spring that was previously obtained only from back calculations of field data (from which considerable extrapolation was needed).

The SWM analysis takes several variables into account, and the following are improvements over traditional p-y curve analysis:

- **Layered Soil Conditions** - The model recognizes layered soil conditions and the effect or presence of one soil layer on the response of another (i.e. soil continuity).
- **Cross-Sectional Shape** - The method considers the influence of the cross-sectional shape of the pile, its flexural rigidity and the head condition (fixed or free).
- **Vertical Side Shear Resistance** - The analysis accounts for the additional resistance of vertical side shear as the pile or shaft deflects laterally and rotates from the vertical. This is important for drilled shafts with large diameters because they can develop considerable side shear resistance to deflection and rotation.
- **End Effects** - The analysis also treats end-effects (bottom shear and bottom moment) of short and intermediate length shafts that traditional p-y curve programs do not consider (traditional analysis assumes piles and shafts are infinite in length).
- **Nonlinearity** - The program looks at the nonlinear nature of the pile or shaft, changing the pile or shaft's flexural stiffness (EI) as a function of the moment at increasing depth.
- **Pile Groups** - The SWM method can analyze piles or shafts in groups with a given spacing. Neighboring piles develop overlap of wedges with depth and applied load (Fig. 20). Therefore, each pile has a unique response, depending upon its location within the group. This approach is valuable because the traditional p-y method applies factors to each individual pile p-y curve (which are constant with depth and load). These factors are taken as a function of the row where the pile is located, and have been determined from a very few field tests with little consideration of the other variables (i.e. soil layering and pile properties) that might affect group interference.
- **Liquefaction** - Since SWM analysis is based on tested soil stress-strain behavior, the undrained response of sands that experience liquefaction can be accurately analyzed with characterized stress-strain behavior of the soil. Conversely, the traditional p-y approach produces a curve with an incorrect shape for completely liquefied soil, and empirical corrections are suggested for that analysis method.

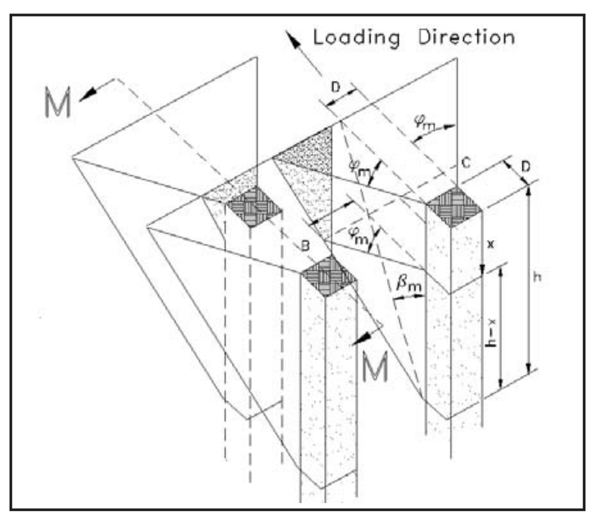


Fig. 20: Overlap of Wedges in a Pile Group

Both Caltrans and Washington DOT have sponsored this research.

Post-Grouted Pile Research

Since it takes a great deal of movement for a drilled shaft to develop end-bearing in supporting soil, many engineers ignore end-bearing and design drilled shafts only with side shear resistance. A model of a drilled shaft segment was therefore tested in the laboratory to determine whether or not end-bearing should be a significant design parameter for these components. Several specimens were tested with and without post-grouting of the shaft tip. Post-grouting the tip of a drilled shaft is analogous to loading a shaft and eliminating a considerable amount of the plastic deformation of the supporting soil. Thus, upon reloading of the post-grouted shaft, only elastic deformation is required of the soil. Consequently, a significant load can be achieved from end resistance with deformation or movement similar to that required for skin or shaft support.

This Caltrans-sponsored research consisted of testing nine 12 in diameter shafts in a soil tank (8 ft in diameter and 9 ft high) filled with sand. The tank had a cover plate that was tightened down with rods (Fig. 21) to simulate the effect of overburden to an equivalent depth of 35 ft at the level of the tip. Preliminary results indicated a seven-fold increase in tip resistance over the value allowed in current design for a tip movement of 5 percent of the diameter of the shaft.


Fig. 21: Post Grouted Pile Test Setup

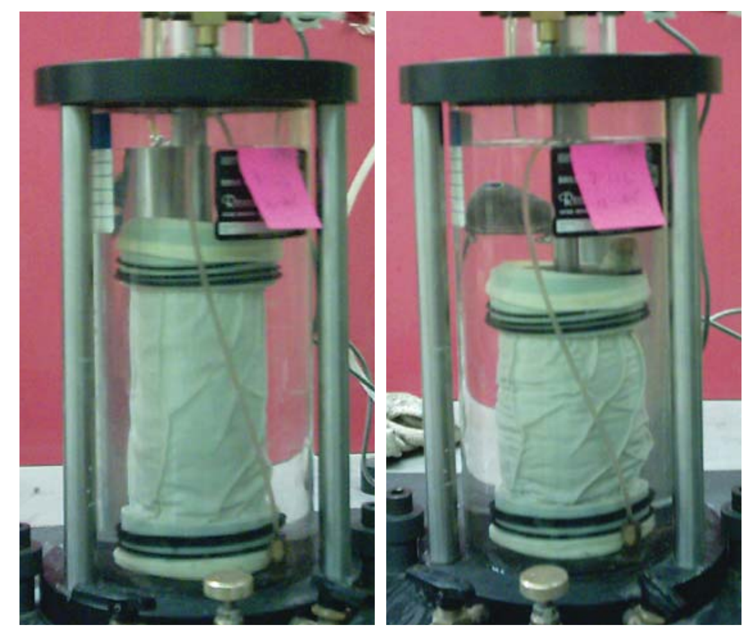


Fig. 22: Soil in a Liquefied Condition in Extension (left) and Compression (right)

Liquefaction Research

The Army Corps of Engineers and NSF has sponsored laboratory research on the liquefaction of sands (Fig. 22). The result was the development of a methodology for predicting and assessing undrained stress-strain and strength behavior of sands from standard drained triaxial test response. Further, the development of drained formulation then precludes the necessity of performing the drained tests in order to predict undrained behavior. Such formulation has been incorporated in the Strain Wedge Model program to assess, in turn, the p-y curves appropriate for either developing or complete liquefaction of the sand. Such formulation used in the analysis of the response of laterally loaded piles in liquefied soil in the Treasure Island tests has been remarkably successful. Such understanding of undrained stress-strain response of completely liquefied soil has also been used to evaluate pile response in soil experiencing lateral spread after complete liquefaction.

Nonstructural Systems

Nonstructural components and systems in buildings are not part of the structural load-bearing system, but are subjected to the same dynamic environment experienced by a building in an earthquake. Damage to nonstructural systems occurs at ground motion intensities much lower than those required to produce structural damage. Recent earthquakes have demonstrated that poor performance of nonstructural systems and components can result in significant damage. Since these systems almost always represent a major portion of the total investment in a building (Fig. 23), damage to non-structural components is very costly.

The *ceiling-piping-partition* system is a very widely used nonstructural system that consists of piping, partitions, ceilings, and other similar components. All of these subsystems have suffered significant damage in recent earthquakes, which is a main contributor to both seismic damage and associated property damage. Such damage has resulted in property loss, loss of function, increased fire hazard and loss of life. Below are summaries of two major studies on subsystems and components of the ceiling-piping-partition nonstructural system conducted in the Large-Scale Structures Laboratory.

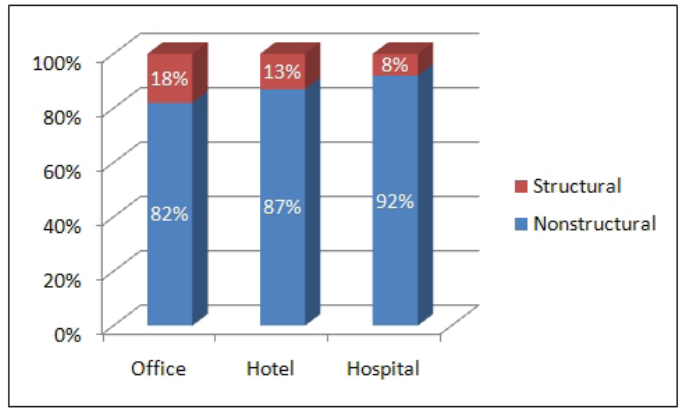


Fig. 23: Typical Investments in Building Construction (after Miranda, 2003)

Hospital Piping Subassemblies

A series of drift experiments have been conducted on welded and threaded hospital piping subassemblies to identify their characteristics with and without seismic bracing. Each specimen was made up of approximately 100 ft of 3 in and 4 in diameter, schedule 40, ASTM A53 grade A black steel pipe. They included two water heaters, one simulated heat exchanger, one y-strainer, one check valve, and two gate valves. The water heaters and the heat exchanger were anchored to a shake table and the pipes were braced and hung from a stationary frame, which rested on the lab floor. The pipes were filled with room temperature water under normal hydrostatic pressure. Results showed that the braces limited the displacements, but they did not significantly reduce the accelerations of the subassembly. There was no significant damage to the welded subassembly, and leaks began at a drift ratio of 5.0 percent. However, the threaded piping subassembly suffered minor leaks at a drift ratio of 2.2 percent and experienced failure level damage at a drift ratio of 4.3 percent. Similar experiments were conducted using copper piping subassemblies.

NEESR-GC: Simulation of the Seismic Performance of Nonstructural Systems

In August 2007 NSF funded a Grand Challenge (GC) project at UNR that is integrating multidisciplinary system-level studies. The goal is to develop, for the first time, a simulation capability and implementation process for enhancing the seismic performance of the ceiling-piping-partition nonstructural system. A comprehensive experimental program will be undertaken with the University at Buffalo to conduct subsystem and system-level full-scale experiments.

The system-level experiments that will be conducted in the Structures Lab include the design and construction of a large-scale test-bed with tunable frequencies and yielding characteristics. This frame will be mounted on three shake tables (Fig. 24), allowing the simulation of different structural dynamic environments. It will be used to study the seismic response of full-scale ceiling-piping-partition nonstructural systems and their interaction with the structure.

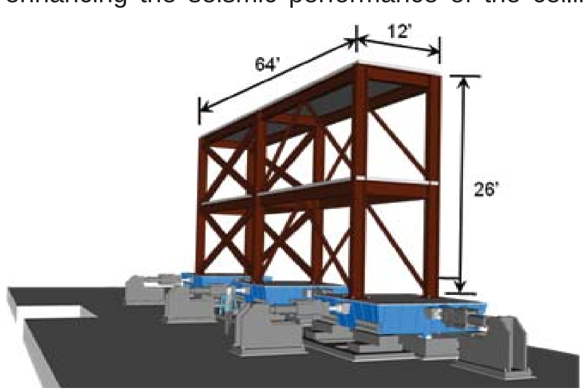


Fig. 24: Concept of System Level Experiments in the GC Nonstructural Project

Service-to-Industry

Recent changes in design codes and regulations (such as the 2006 International Building Code) require seismic qualification of mechanical and electrical equipment and their mounting systems before installation in hospitals and other critical or essential facilities. Over the past ten years there has been an increasing demand for special seismic certification and response assessment of nonstructural systems and components. Seismic qualification via shake table testing has become a standard requirement for these systems in industry.

Fig. 25: Lifting an Electric Power Generator onto a Shake Table

The Structures Laboratory has the equipment to perform this qualification work and is able, for example, to meet requirements of AC156, GR-63-CORE, and IEEE 344/693. Over fifty seismic qualification tests of various nonstructural components and systems have been completed successfully since 2000 and CCEER has published over 30 reports with a special report series "Civil Engineering and Nonstructural Testing." These tests include wall-mounted TV monitor arms, mobile shelving units, radiography and fluoroscopy systems and components (e.g. patient tables, control units, ceiling-mount tube suspensions), CT scanners, gantry, surgical lighting, main frame servers, monitoring panels, battery boxes, antenna extrusions, generators (Fig. 25), chillers, and air handling units. In addition, various mitigation strategies such as isolated floor implementations for nonstructural systems have been experimentally evaluated using the shake tables. Other static tests have also been conducted in the laboratory, as noted below.

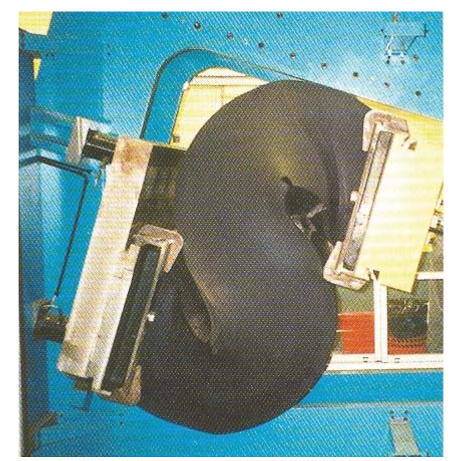


Fig. 26: Testing a Column-Type Rubber Fender

Marine Fender Testing

Testing has been conducted to determine the energy absorbing characteristics of marine fenders for Maritime International Inc. (MII) in Lafayette, LA. One type of fender manufactured by MII is buckling column-type dock-pier rubber fenders (Fig. 26). These fenders are extensively used world-wide in the berthing of large maritime vessels such as container vessels and oil tankers. Both static and cyclic tests of full-scale fenders were carried out. About 100 tests were conducted in the Structures Laboratory, and the test data was analyzed to evaluate the energy absorbing characteristics of the fenders. The test results were compared to a three-dimensional finite element model that included large deformation and viscoelastic/viscoplastic modeling. Since different sizes of fenders with the same rubber material were tested, the calibration of the viscoelastic/viscoplastic material properties was possible. Results showed that such an investigation was well-suited for extending the analytical modeling capabilities to much larger fender sizes with confidence.

Performance of an Unprotected Steel Structure Subjected to Repeated Fire at a Firefighter Training Facility

A single-story unprotected steel structure was evaluated after repeated exposure to fire at a firefighter training facility (Fig. 27). Temperatures were monitored on the structure using resistance detectors connected to a data acquisition system. Temperatures of up to 384° C were measured in the structure, which are below levels likely to cause excessive degradation in stiffness or strength. Uniform heating of the columns resulted in minimal stresses in the structure because the columns were relatively free to deform axially. However, it was found that differential temperatures of the opposite sides of the members resulted in strains up to 16 times the yield strains.

Fig. 27: Unprotected Steel Structure during Firefighter Training

Graduate Program

Fig. 28: Graduate Students Working on a Project in the Large-Scale Structures Laboratory

The University of Nevada, Reno has excellent opportunities for graduate research in Civil and Environmental Engineering. The department offers both Masters of Science (M.S.) and Doctorate of Philosophy (Ph. D.) degrees in four main areas: Structural & Earthquake, Geotechnical, Transportation, and Environmental Engineering. Students interested in the structures and geotechnical tracks have the opportunity to conduct research in the Large-Scale Structures Laboratory (Fig. 28).

To find out more information about applying for graduate school, contact the director of graduate studies or visit www.unr.edu/cee/students/grad. Graduate courses in structural and geotechnical engineering include the courses below (note that not every course is offered every year). In addition students may take graduate-level courses from outside the Department, such as in Mechanical Engineering, and Geological Sciences and Engineering, with the consent of the advisor.

CEE 642 Fundamentals of Geotechnical Engineering
CEE 643 Geotechnical Engineering: Foundations
CEE 645 Geotechnical Engineering: Retaining Structures
CEE 646 Geosynthetics
CEE 679 Earthquake Engineering
CEE 680 Concrete Structure Design
CEE 681 Structural Steel Design
CEE 682 Design of Timber Structures
CEE 683 Prestressed Concrete Design
CEE 684 Bridge Engineering I
CEE 686 Structural Analysis II
CEE 687 Reinforced Concrete Design II
CEE 688 Advanced Structural Steel Design

CEE 750 Graduate Seminar
CEE 771 Special Engineering Problems

CEE 704 Applied Finite Element Analysis
CEE 722 Limit Design in Structural Steel and Concrete
CEE 723 Advanced Reinforced Concrete
CEE 724 Applied Elasticity I
CEE 725 Advanced Topics in Structural Analysis
CEE 726 Theory of Plates and Shells
CEE 727 Matrix Methods in Structural Analysis
CEE 728 Bridge Engineering II
CEE 729 Seismic Isolation of Structural Systems
CEE 730 Dynamics of Structures
CEE 731 Advanced Dynamics of Structures
CEE 741 Geotechnical Engineering: Seepage, Slopes, Embankments
CEE 742 Advanced Soil Mechanics
CEE 745 Geotechnical Earthquake Engineering
CEE 746 Advanced Foundation Engineering
CEE 748 Advanced Geotechnical Laboratory

Fig. 29: Students Visiting the San Francisco Oakland Bay Bridge with the EERI Student Chapter

Graduate students have the opportunity to join many student groups and participate in seminars, attend software training classes, and take field trips to local construction sites (Fig. 29). The College has student chapters sponsored by the American Society of Civil Engineers, the Earthquake Engineering Research Institute, Engineers without Borders, and the Society of Women Engineers. Participating in these organizations allows students to network with their peers and enhance their graduate school experience.

Fig. 30: Reno REU Students at the Tsunami Wave Basin at Oregon State University, 2009

Fig. 31: REU Students and Advisers at the Geotechnical Centrifuge at the University of California, Davis, 2007

REU Program

The Large-Scale Structures Lab was a host site for the 2007, 2008, and 2009 NEES Research Experiences for Undergraduates (REU) Program. Several junior to senior level undergraduate students from four-year institutions explored earthquake engineering during a 10 week program, funded by NSF-NEES. Working under the supervision of a faculty advisor, students were also able to network with student and graduate advisors from other universities and present their work at a Young Researchers Symposium. The Office of Undergraduate Research at UNR offered these students essential classes such as workshops on graduate school application, poster presentation techniques, and ethics in research. In addition to participating in weekly webcast meetings with REU students at other NEES Sites, these students also participated in (1) the NEES Annual Meetings in Snowbird, Portland, and Honolulu, (2) a visit to the Tsunami Basin at Oregon State (Fig. 30), (3) a tour of the geotechnical centrifuge at the UC Davis site (Fig. 31), (4) a visit to the UC Berkeley Richmond Field Station, and (5) a Caltrans boat tour of the new East Span of the San Francisco-Oakland Bay Bridge with its innovative design featuring state-of-the-art seismic safety elements.

Earthquake Camp

Fig. 32: Students Making Notes During an Exercise on One of the Shake Tables

Education of students of all ages is one of the priorities at CCEER. One of the annual highlights is the five-day Earthquake Engineering Summer Camp which gives a unique opportunity for middle school students to explore earthquakes and their effects on man-made structures. Funded by NSF-NEES and run in coordination with the College of Engineering, the camp introduces students to seismology, soil liquefaction, principles of earthquake design of structures including base isolation, and construction techniques of wood structures. It encompasses lectures by engineering faculty, hands-on experiments designed to provide the students with a realistic and engaging experience (Fig. 32) and field trips to local projects under construction and of a significant engineering value. Students are divided into groups to carry out the various camp activities in a team environment. Guest speakers from the Nevada Department of Transportation (NDOT) and a local structural firm are invited to familiarize the students with current industry design practices. A bridge design and construction competition is integrated into the camp activities to foster creativity and reward the group with the most efficient engineering design. Additional activities such as constructing of canoes made of lightweight concrete are usually introduced by UNR local chapters of the American Society of Civil Engineering and the Society of Women Engineers. The camp concludes with students' presentations on experiments of their choice and an award ceremony.

Large-Scale Structures Laboratory


Fig. 33: The James E. Rogers and Louis Wiener Jr. Large-Scale Structures Lab

The Large-Scale Structures Laboratory (Fig. 33) is directed by Dr. Ian Buckle and managed by Dr. Patrick Laplace assisted by Chad Lyttle, Robert Nelson, Todd Lyttle, and Paul Lucas. The laboratory is equipped with a state-of-the-art servo-hydraulic system for simulating dynamic loads in general, and earthquakes in particular. The lab features four shake tables, a strong floor, a strong wall, two high-capacity bridge cranes, and an advanced hydraulic distribution system. Below is a description of these facilities.

Main Test Floor: The main test floor is a heavily reinforced concrete slab with 8,400 square feet of usable test area. It features 2,000 tie-down holes that are spaced on a 2 ft x 2 ft grid. The slab was designed as a one-way slab supported by the north and south basement walls. The principal reinforcement includes top and bottom mats of #14 Gr. 60 bars spaced at 12 in on center in both directions. The monolithic slab-wall and wall-footing joints create a box girder that is 15 ft deep, 56 ft wide, and 150 ft long. The floor also acts as the seismic mass for the shake table system.

Shake Tables: The laboratory is equipped with three biaxial MTS shake tables and one six-degree-of-freedom (6DOF) shake table. All of the shake tables are relocatable on the laboratory floor and can be controlled to act together as a single large table or operate individually with independent motions. Each biaxial table measures 14 ft x 14.6 ft with a stroke of +/- 12 in and a peak velocity of 40 in/sec at 1g acceleration under a 50-ton payload. The 6DOF shake table measures 9 ft x 9 ft. The x, y, and z axes support strokes of 6 in, 24 in, and 8 in and peak accelerations of 2g, 4g, and 1g respectively with a nominal 20-ton payload.

Strong Wall: A 20 ft x 19 ft x 2 ft post-tensioned wall is located on the east side of the laboratory. It is perforated with tie-down holes on a 2 ft x 2 ft grid and is used for static and cyclic load testing. It can be configured in conjunction with the modular reaction blocks to accommodate a variety of loading systems.

Bridge Cranes: Two overhead bridge cranes span the laboratory. Each crane has a 25-ton capacity main hook with a smaller 5-ton auxiliary hook. The cranes have a clear height of 29 ft and travel in the longitudinal and transverse directions. They are remotely controlled and can operate in unison or independently of each other.

Hydraulic Distribution System: Hydraulic hard lines feed the laboratory from an external pump house. Four pumps with a total flow rate of 605 gpm supply the hydraulic "spine" in the basement at 3,000 psi. Seven ports along the centerline of the laboratory floor provide access to feed, return, and drain lines. The MTS load frame is supplied by a separate 40 gpm hydraulic pump located in the basement. Three blowdown banks each provide 1,600 gpm of additional oil flow to the shake table system.

Hydraulic Actuators: In addition to the hydraulic actuators in the shake tables, the laboratory has another eight actuators that are available for testing. The specifications of each actuator are shown in Table 1. The laboratory has an eight-channel MTS Flex Test IIM system, a two-channel MTS STS system, and two MTS 458 analog controllers.

Table 1: Hydraulic Actuator Specifications

Quantity	Actuator Model	Load Capacity	Stroke (in)	Servovalve (gpm)	Rating
2	244.22	22k Compression; 22k Tension	20	90	Dynamic
2	244.41	110k Compression; 110k Tension	22	90	Static
1	244.51S	220k Compression; 220k Tension	30	90	Dynamic
1	243.8	450k Compression; 320k Tension	40	15	Static
1	243.9	600k Compression; 450k Tension	20	15	Static
1	243.100T	945k Compression; 700k Tension	48	30	Static

Data Acquisition: The laboratory features more than 400 channels of high speed data acquisition. Each conditioner allows "plug and play" instruments to be connected using the IEEE 1451.4 standard. All of the instruments contain their calibration information on a onboard chip which is read by the data acquisition system.

Fabrication and Staging Area: An 8,000 sq ft fabrication, staging, and storage area is adjacent to the building. Two concrete beds are used for specimen fabrication. Four forklifts are used to transport specimens, equipment parts, and tools between the fabrication area and the laboratory.

Video and Computer Systems: Test data is stored on local servers with a two terabyte data capacity. This data includes video that is captured by any of the four Sony High Definition cameras and four digital video recorders. The laboratory is also equipped with six flexTPS telepresence cameras that enable real-time activities in the laboratory to be viewed at http://tpm.ce.unr.edu/perl/portal.pl?section=local_video.

Geotechnical Engineering

The Geotechnical Laboratories are directed by Dr. Raj Siddharthan and managed by Dr. Horng-Jyh Yang with assistance from Dr.s Gary Norris and Sherif Elfass. The laboratories have facilities for testing the fundamental properties of soil and investigating its engineering behavior. The undergraduate soils laboratory contains standard soil mechanics laboratory testing equipment, and the graduate soils laboratory, shown in Fig. 34, houses specialized research equipment for advanced testing such as direct shear, flexwall permeability and stress path triaxial tests. Table 2 lists equipment unique to UNR and the appropriate tests that can be performed in the geotechnical laboratories.

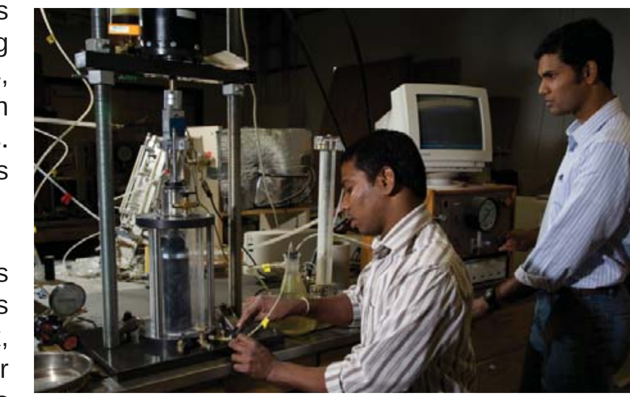


Fig. 34: Graduate Geotechnical Laboratory

Laminar Soil Box: The laminar soil box (Fig. 35) has dimensions of 10.3 ft x 10.3 ft x 6.2 ft. The walls consist of alternating sections of aluminum and rubber glued together over the height of the box, and the rest on a stiffened steel base plate. Because of the rubber sections, the box is flexible under horizontal shear and deforms laterally when shaken. An inflatable air bag and stiffened top steel plate can be placed over the box and the entire box completely sealed. By this arrangement, an air pressure of as much as 29 psi can be applied to simulate overburden pressure on the soil retained within the box.

The box is made of four individual laminated segments and all interfaces between segments are provided with gaskets. In addition, there are twelve tie rods to vertically compress the gaskets and seal the segment interfaces. The segmented nature of the box allows the soil deposit to be built up from the bottom, allowing uniform sample preparation. When completely loaded, the soil box has a maximum payload of about 120 kips.


Fig. 35: Laminar Soil Box on a Shake Table

Table 2: Unique Geotechnical Laboratory Equipment

Quantity	Equipment	Test
2	Computer Controlled Triaxial System	User-Defined Stress Path Triaxial Tests, Drained and Undrained Triaxial Tests, and Cyclic Tests
3	Flex Wall Permeameters	Hydraulic Conductivity Tests
3	GDS Volume Control Devices	
1	10.4 ft x 10.4 ft x 6 ft Laminar Soil Box	Large-Scale Shake Table Foundation and Soil Liquefaction Tests
1	8 ft Diameter x 9 ft Tall Soil Tank	Large-Scale Static Foundation Tests

CCEER PUBLICATIONS

No.	Publication
84-1A	Saiidi, M., and R. Lawver, "User's Manual for LZAK-C64, A Computer Program to Implement the Q-Model on Commodore 64."
84-1B	Douglas, B., Norris, G., Saiidi, M., Dodd, L., Richardson, J. and Reid, W., "Simple Bridge Models for Earthquakes and Test Data."
84-2	Douglas, B. and T. Iwasaki, "Proceedings of the First USA-Japan Bridge Engineering Workshop."
84-3	Saiidi, M., J. Hart, and B. Douglas, "Inelastic Static and Dynamic Analysis of Short R/C Bridges Subjected to Lateral Loads."
84-4	Douglas, B., "A Proposed Plan for a National Bridge Engineering Laboratory."
85-1	Norris, G. and P. Abdollaholiaee, "Laterally Loaded Pile Response: Studies with the Strain Wedge Model."
86-1	Ghusn, G. and M. Saiidi, "A Simple Hysteretic Element for Biaxial Bending of R/C in NEABS-86."
86-2	Saiidi, M., R. Lawver, and J. Hart, "User's Manual of ISADAB and SIBA, Computer Programs for Nonlinear Transverse Analysis of Highway Bridges Subjected to Static and Dynamic Lateral Loads".
87-1	Siddharthan, R., "Dynamic Effective Stress Response of Surface and Embedded Footings in Sand."
87-2	Norris, G. and R. Sack, "Lateral and Rotational Stiffness of Pile Groups for Seismic Analysis of Highway Bridges."
88-1	Orie, J. and M. Saiidi, "A Preliminary Study of One-Way Reinforced Concrete Pier Hinges Subjected to Shear and Flexure."
88-2	Orie, D., M. Saiidi, and B. Douglas, "A Micro-CAD System for Seismic Design of Regular Highway Bridges."
88-3	Orie, D. and M. Saiidi, "User's Manual for Micro-SARB, a Microcomputer Program for Seismic Analysis of Regular Highway Bridges."
89-1	Douglas, B., M. Saiidi, R. Hayes, and G. Holcomb, "A Comprehensive Study of the Loads and Pressures Exerted on Wall Forms by the Placement of Concrete."
89-2A	Richardson, J. and B. Douglas, "Dynamic Response Analysis of the Dominion Road Bridge Test Data."
89-2B	Vrontinos, S., M. Saiidi, and B. Douglas, "A Simple Model to Predict the Ultimate Response of R/C Beams with Concrete Overlays."
89-3	Ebrahimpour, A. and P. Jagadish, "Statistical Modeling of Bridge Traffic Loads - A Case Study."
89-4	Shields, J. and M. Saiidi, "Direct Field Measurement of Prestress Losses in Box Girder Bridges."
90-1	Saiidi, M., E. Maragakis, G. Ghusn, Y. Jiang, and D. Schwartz, "Survey and Evaluation of Nevada's Transportation Infrastructure, Task 7.2 - Highway Bridges, Final Report."
90-2	Abdel-Ghaffar, S., E. Maragakis, and M. Saiidi, "Analysis of the Response of Reinforced Concrete Structures During the Whittier Earthquake 1987."
91-1	Saiidi, M., E. Hwang, E. Maragakis, and B. Douglas, "Dynamic Testing and the Analysis of the Flamingo Road Interchange."
91-2	Norris, G., R. Siddharthan, Z. Zafir, S. Abdel-Ghaffar, and P. Gowda, "Soil-Foundation-Structure Behavior at the Oakland Outer Harbor Wharf."
91-3	Norris, G., "Seismic Lateral and Rotational Pile Foundation Stiffnesses at Cypress."
91-4	O'Connor, D.N. and M. Saiidi, "A Study of Protective Overlays for Highway Bridge Decks in Nevada, with Emphasis on Polyester-Styrene Polymer Concrete."
91-5	O'Connor, D.N. and M. Saiidi, "Laboratory Studies of Polyester-Styrene Polymer Concrete Engineering Properties."
92-1	Straw, D.L. and M. Saiidi, "Scale Model Testing of One-Way Reinforced Concrete Pier Hinges Subject to Combined Axial Force, Shear and Flexure," edited by D.N. O'Connor.
92-2	Wehbe, N., M. Saiidi, and F. Gordaninejad, "Basic Behavior of Composite Sections Made of Concrete Slabs and Graphite Epoxy Beams."
92-3	Saiidi, M. and E. Hutchens, "A Study of Prestress Changes in A Post-Tensioned Bridge During the First 30 Months."
92-4	Saiidi, M., B. Douglas, S. Feng, E. Hwang, and E. Maragakis, "Effects of Axial Force on Frequency of Prestressed Concrete Bridges."
92-5	Siddharthan, R., and Z. Zafir, "Response of Layered Deposits to Traveling Surface Pressure Waves."
92-6	Norris, G., and Z. Zafir, "Liquefaction and Residual Strength of Loose Sands from Drained Triaxial Tests."
92-6A	Norris, G., Siddharthan, R., Zafir, Z. and Madhu, R. "Liquefaction and Residual Strength of Sands from Drained Triaxial Tests."
92-7	Douglas, B., "Some Thoughts Regarding the Improvement of the University of Nevada, Reno's National Academic Standing."
92-8	Saiidi, M., E. Maragakis, and S. Feng, "An Evaluation of the Current Caltrans Seismic Restrainer Design Method."
92-9	O'Connor, D.N., M. Saiidi, and E. Maragakis, "Effect of Hinge Restrainers on the Response of the Madrone Drive Undercrossing During the Loma Prieta Earthquake."
92-10	O'Connor, D.N., and M. Saiidi, "Laboratory Studies of Polyester Concrete: Compressive Strength at Elevated Temperatures and Following Temperature Cycling, Bond Strength to Portland Cement Concrete, and Modulus of Elasticity."
92-11	Wehbe, N., M. Saiidi, and D.N. O'Connor, "Economic Impact of Passage of Spent Fuel Traffic on Two Bridges in Northeast Nevada,"
93-1	Jiang, Y., and M. Saiidi, "Behavior, Design, and Retrofit of Reinforced Concrete One-way Bridge Column Hinges," edited by D.N. O'Connor.
93-2	Abdel-Ghaffar, S., E. Maragakis, and M. Saiidi, "Evaluation of the Response of the Aptos Creek Bridge During the 1989 Loma Prieta Earthquake."
93-3	Sanders, D.H., B.M. Douglas, and T.L. Martin, "Seismic Retrofit Prioritization of Nevada Bridges."
93-4	Abdel-Ghaffar, S., E. Maragakis, and M. Saiidi, "Performance of Hinge Restrainers in the Huntington Avenue Overhead During the 1989 Loma Prieta Earthquake."
93-5	Maragakis, E., M. Saiidi, S. Feng, and L. Flournoy, "Effects of Hinge Restrainers on the Response of the San Gregorio Bridge during the Loma Prieta Earthquake."
93-6	Saiidi, M., E. Maragakis, S. Abdel-Ghaffar, S. Feng, and D. O'Connor, "Response of Bridge Hinge Restrainers during Earthquakes-Field Performance, Analysis, and Design."
93-7	Wehbe, N., Saiidi, M., Maragakis, E., and Sanders, D., "Adequacy of Three Highway Structures in Southern Nevada for Spent Fuel Transportation."

No.	Publication
93-8	Roybal, J., Sanders, D.H., and Maragakis, E., "Vulnerability Assessment of Masonry in the Reno-Carson City Urban Corridor."
93-9	Zafir, Z. and Siddharthan, R., "MOVLOAD: A Program to Determine the Behavior of Nonlinear Horizontally Layered Medium Under Moving Load."
93-10	O'Connor, D.N., Saiidi, M., and Maragakis, E.A., "A Study of Bridge Column Seismic Damage Susceptibility at the Interstate 80/U.S. 395 Interchange in Reno, Nevada."
94-1	Maragakis, E., B. Douglas, and E. Abdelwahed, "Preliminary Dynamic Analysis of a Railroad Bridge."
94-2	Douglas, B.M., Maragakis, E.A., and Feng, S., "Stiffness Evaluation of Pile Foundation of Cazenovia Creek Overpass."
94-3	Douglas, B.M., Maragakis, E.A., and Feng, S., "Summary of Pretest Analysis of Cazenovia Creek Bridge."
94-4	Norris, G.M., Madhu, R., Valceschini, R., and Ashour, M., "Liquefaction and Residual Strength of Loose Sands from Drained Triaxial Tests."
94-5	Saiidi, M., Hutchens, E., and Gardella, D., "Prestress Losses in a Post-Tensioned R/C Box Girder Bridge in Southern Nevada."
95-1	Siddharthan, R., El-Gamal, M., and Maragakis, E.A., "Nonlinear Bridge Abutment , Verification, and Design Curves."
95-2	Ashour, M. and Norris, G., "Liquefaction and Undrained Response Evaluation of Sands from Drained Formulation."
95-3	Wehbe, N., Saiidi, M., Sanders, D. and Douglas, B., "Ductility of Rectangular Reinforced Concrete Bridge Columns with Moderate Confinement."
95-4	Martin, T., Saiidi, M. and Sanders, D., "Seismic Retrofit of Column-Pier Cap Connections in Bridges in Northern Nevada."
95-5	Darwish, I., Saiidi, M. and Sanders, D., "Experimental Study of Seismic Susceptibility Column-Footing Connections in Bridges in Northern Nevada."
95-6	Griffin, G., Saiidi, M. and Maragakis, E., "Nonlinear Seismic Response of Isolated Bridges and Effects of Pier Ductility Demand."
95-7	Acharya, S.., Saiidi, M. and Sanders, D., "Seismic Retrofit of Bridge Footings and Column-Footing Connections."
95-8	Maragakis, E., Douglas, B., and Sandirasegaram, U., "Full-Scale Field Resonance Tests of a Railway Bridge."
95-9	Douglas, B., Maragakis, E. and Feng, S., "System Identification Studies on Cazenovia Creek Overpass."
96-1	El-Gamal, M.E. and Siddharthan, R.V., "Programs to Computer Translational Stiffness of Seat-Type Bridge Abutment."
96-2	Labia, Y., Saiidi, M. and Douglas, B., "Evaluation and Repair of Full-Scale Prestressed Concrete Box Girders."
96-3	Darwish, I., Saiidi, M. and Sanders, D., "Seismic Retrofit of R/C Oblong Tapered Bridge Columns with Inadequate Bar Anchorage in Columns and Footings."
96-4	Ashour, M., Pilling, R., Norris, G. and Perez, H., "The Prediction of Lateral Load Behavior of Single Piles and Pile Groups Using the Strain Wedge Model."
97-1A	Rimal, P. and Itani, A. "Sensitivity Analysis of Fatigue Evaluations of Steel Bridges."
97-1B	Maragakis, E., Douglas, B., and Sandirasegaram, U. "Full-Scale Field Resonance Tests of a Railway Bridge."
97-2	Wehbe, N., Saiidi, M., and D. Sanders, "Effect of Confinement and Flares on the Seismic Performance of Reinforced Concrete Bridge Columns."
97-3	Darwish, I., M. Saiidi, G. Norris, and E. Maragakis, "Determination of In-Situ Footing Stiffness Using Full-Scale Dynamic Field Testing."
97-4	Wehbe, N., and M. Saiidi, "User's manual for RCMC v. 1.2 : A Computer Program for Moment-Curvature Analysis of Confined and Unconfined Reinforced Concrete Sections."
97-5	Isakovic, T., M. Saiidi, and A. Itani, "Influence of new Bridge Configurations on Seismic Performance."
98-1	Itani, A., Vesco, T. and Dietrich, A., "Cyclic Behavior of "as Built" Laced Members With End Gusset Plates on the San Francisco Bay Bridge."
98-2	G. Norris and M. Ashour, "Liquefaction and Undrained Response Evaluation of Sands from Drained Formulation."
98-3	Qingbin, Chen, B. M. Douglas, E. Maragakis, and I. G. Buckle, "Extraction of Nonlinear Hysteretic Properties of Seismically Isolated Bridges from Quick-Release Field Tests."
98-4	Maragakis, E., B. M. Douglas, and C. Qingbin, "Full-Scale Field Capacity Tests of a Railway Bridge."
98-5	Itani, A., Douglas, B., and Woodgate, J., "Cyclic Behavior of Richmond-San Rafael Retrofitted Tower Leg."
98-6	Moore, R., Saiidi, M., and Itani, A., "Seismic Behavior of New Bridges with Skew and Curvature."
98-7	Itani, A and Dietrich, A, "Cyclic Behavior of Double Gusset Plate Connections."
99-1	Caywood, C., M. Saiidi, and D. Sanders, "Seismic Retrofit of Flared Bridge Columns with Steel Jackets."
99-2	Mangoba, N., M. Mayberry, and M. Saiidi, "Prestress Loss in Four Box Girder Bridges in Northern Nevada."
99-3	Abo-Shadi, N., M. Saiidi, and D. Sanders, "Seismic Response of Bridge Pier Walls in the Weak Direction."
99-4	Buzick, A., and M. Saiidi, "Shear Strength and Shear Fatigue Behavior of Full-Scale Prestressed Concrete Box Girders."
99-5	Randall, M., M. Saiidi, E. Maragakis and T. Isakovic, "Restrainer Design Procedures For Multi-Span Simply-Supported Bridges."
99-6	Wehbe, N. and M. Saiidi, "User's Manual for RCMC v. 1.2, A Computer Program for Moment-Curvature Analysis of Confined and Unconfined Reinforced Concrete Sections."
99-7	Burda, J. and A. Itani, "Studies of Seismic Behavior of Steel Base Plates."
99-8	Ashour, M. and G. Norris, "Refinement of the Strain Wedge Model Program."
99-9	Dietrich, A., and A. Itani, "Cyclic Behavior of Laced and Perforated Steel Members on the San Francisco-Oakland Bay Bridge."
99-10	Itani, A., A. Dietrich, "Cyclic Behavior of Built Up Steel Members and their Connections."
99-10A	Itani, A., E. Maragakis and P. He, "Fatigue Behavior of Riveted Open Deck Railroad Bridge Girders."
99-11	Itani, A., J. Woodgate, "Axial and Rotational Ductility of Built Up Structural Steel Members."
99-12	Sgambelluri, M., Sanders, D.H., and Saiidi, M.S., "Behavior of One-Way Reinforced Concrete Bridge Column Hinges in the Weak Direction."
99-13	Laplace, P., Sanders, D.H., Douglas, B, and Saiidi, M, "Shake Table Testing of Flexure Dominated Reinforced Concrete Bridge Columns."

CCEER PUBLICATIONS

No.	Publication
99-14	Ahmad M. Itani, Jose A. Zepeda, and Elizabeth A. Ware "Cyclic Behavior of Steel Moment Frame Connections for the Moscone Center Expansion."
00-1	Ashour, M., and Norris, G. "Undrained Lateral Pile and Pile Group Response in Saturated Sand."
00-2	Saiidi, M. and Wehbe, N., "A Comparison of Confinement Requirements in Different Codes for Rectangular, Circular, and Double-Spiral RC Bridge Columns."
00-3	McElhaney, B., M. Saiidi, and D. Sanders, "Shake Table Testing of Flared Bridge Columns With Steel Jacket Retrofit."
00-4	Martinovic, F., M. Saiidi, D. Sanders, and F. Gordaninejad, "Dynamic Testing of Non-Prismatic Reinforced Concrete Bridge Columns Retrofitted with FRP Jackets."
00-5	Itani, A., and M. Saiidi, "Seismic Evaluation of Steel Joints for UCLA Center for Health Science Westwood Replacement Hospital."
00-6	Will, J. and D. Sanders, "High Performance Concrete Using Nevada Aggregates."
00-7	French, C., and M. Saiidi, "A Comparison of Static and Dynamic Performance of Models of Flared Bridge Columns."
00-8	Itani, A., H. Sedarat, "Seismic Analysis of the AISI LRFD Design Example of Steel Highway Bridges."
00-9	Moore, J., D. Sanders, and M. Saiidi, "Shake Table Testing of 1960's Two Column Bent with Hinges Bases."
00-10	Asthana, M., D. Sanders, and M. Saiidi, "One-Way Reinforced Concrete Bridge Column Hinges in the Weak Direction."
01-1	Ah Sha, H., D. Sanders, M. Saiidi, "Early Age Shrinkage and Cracking of Nevada Concrete Bridge Decks."
01-2	Ashour, M. and G. Norris, "Pile Group program for Full Material Modeling an Progressive Failure."
01-3	Itani, A., C. Lanaud, and P. Dusicka, "Non-Linear Finite Element Analysis of Built-Up Shear Links."
01-4	Saiidi, M., J. Mortensen, and F. Martinovic, "Analysis and Retrofit of Fixed Flared Columns with Glass Fiber-Reinforced Plastic Jacketing."
01-5	Saiidi, M., A. Itani, I. Buckle, and Z. Cheng," Performance of A Full-Scale Two-Story Wood Frame Structure Supported on Ever-Level Isolators."
01-6	Laplace, P., D. Sanders, and M. Saiidi, "Experimental Study and Analysis of Retrofitted Flexure and Shear Dominated Circular Reinforced Concrete Bridge Columns Subjected to Shake Table Excitation."
01-7	Reppi, F., and D. Sanders, "Removal and Replacement of Cast-in-Place, Post-tensioned, Box Girder Bridge."
02-1	Pulido, C., M. Saiidi, D. Sanders, and A. Itani, "Seismic Performance and Retrofitting of Reinforced Concrete Bridge Bents."
02-2	Yang, Q., M. Saiidi, H. Wang, and A. Itani, "Influence of Ground Motion Incoherency on Earthquake Response of Multi-Support Structures."
02-3	M. Saiidi, B. Gopalakrishnan, E. Reinhardt, and R. Siddharthan, A Preliminary Study of Shake Table Response of A Two-Column Bridge Bent on Flexible Footings."
02-4	Not Published
02-5	Banghart, A., Sanders, D., Saiidi, M., "Evaluation of Concrete Mixes for Filling the Steel Arches in the Galena Creek Bridge."
02-6	Dusicka, P., Itani, A., Buckle, I. G., "Cyclic Behavior of Shear Links and Tower Shaft Assembly of San Francisco – Oakland Bay Bridge Tower."
02-7	Mortensen, J., and M. Saiidi, "A Performance-Based Design Method for Confinement in Circular Columns."
03-1	Wehbe, N., and M. Saiidi, "User's manual for SPMC v. 1.0 : A Computer Program for Moment-Curvature Analysis of Reinforced Concrete Sections with Interlocking Spirals."
03-2	Wehbe, N., and M. Saiidi, "User's manual for RCMC v. 2.0 : A Computer Program for Moment-Curvature Analysis of Confined and Unconfined Reinforced Concrete Sections."
03-3	Nada, H., D. Sanders, and M. Saiidi, "Seismic Performance of RC Bridge Frames with Architectural-Flared Columns."
03-4	Reinhardt, E., M. Saiidi, and R. Siddharthan, "Seismic Performance of a CFRP/ Concrete Bridge Bent on Flexible Footings."
03-5	Johnson, N., M. Saiidi, A. Itani, and S. Ladkany, "Seismic Retrofit of Octagonal Columns with Pedestal and One-Way Hinge at the Base."
03-6	Mortensen, C., M. Saiidi, and S. Ladkany, "Creep and Shrinkage Losses in Highly Variable Climates."
03-7	Ayoub, C., M. Saiidi, and A. Itani, "A Study of Shape-Memory-Alloy-Reinforced Beams and Cubes."
03-8	Chandane, S., D. Sanders, and M. Saiidi, "Static and Dynamic Performance of RC Bridge Bents with Architectural-Flared Columns."
04-1	Olaegbe, C., and Saiidi, M., "Effect of Loading History on Shake Table Performance of A Two-Column Bent with Infill Wall."
04-2	Johnson, R., Maragakis, E., Saiidi, M., and DesRoches, R., "Experimental Evaluation of Seismic Performance of SMA Bridge Restrainers."
04-3	Moustafa, K., Sanders, D., and Saiidi, M., "Impact of Aspect Ratio on Two-Column Bent Seismic Performance."
04-4	Maragakis, E., Saiidi, M., Sanchez-Camargo, F., and Elfass, S., "Seismic Performance of Bridge Restrainers At In-Span Hinges."
04-5	Ashour, M., Norris, G. and Elfass, S., "Analysis of Laterally Loaded Long or Intermediate Drilled Shafts of Small or Large Diameter in Layered Soil."
04-6	Correal, J., Saiidi, M. and Sanders, D., "Seismic Performance of RC Bridge Columns Reinforced with Two Interlocking Spirals."
04-7	Dusicka, P., Itani, A. and Buckle, I., "Cyclic Response and Low Cycle Fatigue Characteristics of Plate Steels."
04-8	Dusicka, P., Itani, A. and Buckle, I., " Built-up Shear Links as Energy Dissipaters for Seismic Protection of Bridges."
04-9	Sureshkumar, K., Saiidi, S., Itani, A. and Ladkany, S., "Seismic Retrofit of Two-Column Bents with Diamond Shape Columns."
05-1	Wang, H. and Saiidi, S., "A Study of RC Columns with Shape Memory Alloy and Engineered Cementitious Composites."
05-2	Johnson, R., Saiidi, S. and Maragakis, E., "A Study of Fiber Reinforced Plastics for Seismic Bridge Restrainers."

No.	Publication
05-3	Carden, L.P., Itani, A.M., Buckle, I.G, "Seismic Load Path in Steel Girder Bridge Superstructures."
05-4	Carden, L.P., Itani, A.M., Buckle, I.G, "Seismic Performance of Steel Girder Bridge Superstructures with Ductile End Cross Frames and Seismic Isolation."
05-5	Goodwin, E., Maragakis, M., Itani, A. and Luo, S., "Experimental Evaluation of the Seismic Performance of Hospital Piping Subassemblies."
05-6	Zadeh M. S., Saiidi, S, Itani, A. and Ladkany, S., "Seismic Vulnerability Evaluation and Retrofit Design of Las Vegas Downtown Viaduct."
05-7	Phan, V., Saiidi, S. and Anderson, J., "Near Fault (Near Field) Ground Motion Effects on Reinforced Concrete Bridge Columns."
05-8	Carden, L., Itani, A. and Laplace, P., "Performance of Steel Props at the UNR Fire Science Academy subjected to Repeated Fire."
05-9	Yamashita, R. and Sanders, D., "Shake Table Testing and an Analytical Study of Unbonded Prestressed Hollow Concrete Column Constructed with Precast Segments."
05-10	Not Published
05-11	Carden, L., Itani., A., and Peckan, G., "Recommendations for the Design of Beams and Posts in Bridge Falsework."
06-01	Cheng, Z., Saiidi, M., and Sanders, D., "Development of a Seismic Design Method for Reinforced Concrete Two-Way Bridge Column Hinges."
06-02	Johnson, N., Saiidi, M., and Sanders, D., "Large-Scale Experimental and Analytical Studies of a Two-Span Reinforced Concrete Bridge System."
06-03	Saiidi, M., Ghasemi, H. and Tiras, A., "Seismic Design and Retrofit of Highway Bridges," Proceedings, Second US-Turkey Workshop.
07-01	O'Brien, M., Saiidi, M. and Sadrossadat-Zadeh, M., "A Study of Concrete Bridge Columns Using Innovative Materials Subjected to Cyclic Loading."
07-02	Sadrossadat-Zadeh, M. and Saiidi, M., "Effect of Strain rate on Stress-Strain Properties and Yield Propagation in Steel Reinforcing Bars."
07-03	Sadrossadat-Zadeh, M. and Saiidi, M., " Analytical Study of NEESR-SG 4-Span Bridge Model Using OpenSees."
07-04	Nelson, R., Saiidi, M. and Zadeh, S., "Experimental Evaluation of Performance of Conventional Bridge Systems."
07-05	Bahen, N. and Sanders, D., "Strut-and-Tie Modeling for Disturbed Regions in Structural Concrete Members with Emphasis on Deep Beams."
07-06	Choi, H., Saiidi, M. and Somerville, P., "Effects of Near-Fault Ground Motion and Fault-Rupture on the Seismic Response of Reinforced Concrete Bridges."
07-07	Ashour M. and Norris, G., "Report and User Manual on Strain Wedge Model Computer Program for Files and Large Diameter Shafts with LRFD Procedure."
08-01	Doyle, K. and Saiidi, M., "Seismic Response of Telescopic Pipe Pin Connections."
08-02	Taylor, M. and Sanders, D., "Seismic Time History Analysis and Instrumentation of the Galena Creek Bridge."
08-03	Abdel-Mohti, A. and Pekcan, G., "Seismic Response Assessment and Recommendations for the Design of Skewed Post-Tensioned Concrete Box-Girder Highway Bridges."
08-04	Saiidi, M., Ghasemi, H. and Hook, J., "Long Term Bridge Performance Monitoring, Assessment & Management," Proceedings, FHWA/NSF Workshop on Future Directions.
09-01	Brown, A., and Saiidi, M., "Investigation of Near-Fault Ground Motion Effects on Substandard Bridge Columns and Bents."
09-02	Linke, C., Pekcan, G., and Itani, A., "Detailing of Seismically Resilient Special Truss Moment Frames."
09-03	Hills, D., and Saiidi, M., "Design, Construction, and Nonlinear Dynamic Analysis of Three Bridge Bents Used in a Bridge System Test."
09-04	Bahrami, H., Itani, A., and Buckle, I., "Guidelines for the Seismic Design of Ductile End Cross Frames in Steel Girder Bridge Superstructures."

MEMBERSHIPS & AFFILIATIONS

The Center is a member of the following organizations:

- Consortium of Universities for Research in Earthquake Engineering, headquartered at University of California, Berkeley
- Asia-Pacific Network of Centers for Earthquake Engineering Research, headquartered at Tokyo Institute of Technology, Tokyo, Japan
- George E. Brown Jr. Network for Earthquake Engineering Simulation, headquartered at Purdue University
- Nevada Earthquake Safety Council

The Center also enjoys a working relationship with the following organizations:

- Multidisciplinary Center for Extreme Events Research, University at Buffalo
- Nevada Bureau of Mines and Geology
- Nevada Seismological Laboratory

Listed below is a sample of the research grants and contracts acquired by the faculty and staff of the Center for Civil Engineering Earthquake Research. This list includes contracts exceeding $10,000 over the past ten years. They are listed by sponsor name and year.

American Iron and Steel Institute

2008	Development of LRFD Code Language for the Seismic Analysis and Design of Steel Plate Girder Bridges	$ 20,000

California Department of Transportation

1999	Pile Group Program for Full Material Modeling and Progressive Failure	$ 150,000
1999	Shake Table Testing of Flared Columns	$ 283,946
1999	Cyclic Behavior of Plate Girder Bridges and their Components	$ 251,000
2001	Shake Table Studies of RC Columns with Interlocking Spirals	$ 283,904
2000	Cyclic Behavior of Shear Links and their Connections in the New San Francisco-Oakland Bay Bridge (with UC San Diego)	$ 888,142
2003	Seismic Retrofitting of Column/Bent Cap Joints by Hinge Shifting and Supplement	$ 328,564
2002	Experimental Studies on the Seismic Performance of Hinge Restrainers at Intermediate Hinges (Phase II)	$ 42,135
2002	Effect of Loading History on Shake Table Performance of Bridge Bents with In-fill Wall Retrofit	$ 46,636
2002	Analysis of Laterally Loaded Intermediate and Long Drilled Shafts	171,330
2004	Seismic Response of Flared Columns with Vertical and Horizontal Gaps	$ 59,939
2004	Investigation of Flange Failures in Falsework Cap and Sill Beams	$ 175,506
2004	Bridge Seismic Analysis Procedure to Address Near-Fault Effects	$ 372,955
2005	Seismic Response, Assessment, & Development of Recommended Design & Analysis Guidelines For Skewed Post-Tensioned Concrete Box Girder Highway Bridges	$ 345,076
2005	Development of Improved Column Pin Connection Details and Design Procedures	$ 265,386
2005	Develop and Assess Post-Grouting Methods to Increase the Load Capacity of Deep Foundations	$ 268,509
2006	Guidelines for Seismic Design of Steel Girder Bridge Superstructures	$ 359,532
2006	Testing of Pile Extension Connections to Slab Bridges	$ 315,742
2006	Emergency Repair of Damaged Bridge Columns Using Fiber Reinforced Polymer (FRP) Materials	$ 251,070
2007	Precast Bridge Columns with Energy Dissipating Joints	$ 300,000
2008	Stability of Rebar Cages in Bridge Columns	$ 240,000
2009	Effect of Live Load on Seismic Response of Bridges	$ 310,875

Carrier Corp.

2009	Seismic Qualification Testing of Cooling Systems	$ 40,254

Caterpillar / HOLT of CA

2009	Shake Table Testing of Caterpillar Generators	$ 28,026

Chinese National Science Foundation

1999	Substructure Performance under Earthquake Loading	$ 30,000

Convergence Engineering Corp., Gardnerville, NV

2002	Shake Table Testing of Battery Box Assemblies	$ 28,725

Da-Lite Screen / Advance Products Division

2004	Shake Table Experiments (AC156) of Da-Lite Assemblies	$ 19,215

Ease, Inc., Los Angeles, CA

2002	Shake Table Testing of Hospital Components	$ 56, 573
2003	Shake Table Testing of Non-structural Assemblies	$ 46,819
2005	Shake Table Qualification Testing of Non-structural Systems	$ 42,917
2009	Seismic Response Characterization of Nonstructural Systems for Critical Facilities	$ 72,855

Ergotron, Inc.

2003	Shake Table Testing of Ergotron Wall Mount Assemblies	$ 21,830

Ever-Level Foundation System

2000	Shake Table Testing of A Two-Story Wood Frame on Ever-Level Foundation System	$ 51,394

Federal Highway Administration

2000	Seismic Retrofit of Flared Bridge Columns with Fixed Base (with Nevada Department of Transportation and Applied Research Initiative)	$ 55,962
2003	Feasibility of Bridge Design for Near-Fault Ground Motions	$ 100,000
2007	Seismic Response of Near-Fault Bridges	$ 422,386
2007	Improving the Seismic Resilience of the Federal-Aid Highway System Federal Highway Administration	$ 3,652,614
2008	Seismic Response of Near-Fault Bridges	$ 110,700
2008	Seismic Behavior of Steel Bridges with Integral Abutments	$ 65,000
2010	Field Tests of Post-Grouted Drilled Shafts (with Caltrans)	$ 260,000

International Business Machines Corp. (IBM)

2004	Shake-table Seismic Qualification Testing of IBM Products using IBM and NEBS Requirements	$ 215,991

John A. Martin and Associate, Los Angeles, CA

1999	Seismic Evaluation of Steel Joints in the UCLA Hospital	$ 54,496

Maritime International Inc., Lafayette, LA

2001	Marine Fender Testing and Failure Analysis	$ 12,197
2002	New Generation of Energy Dissipation Devices	$ 18,415

Modjeski and Masters (with UNR)

2006	Verification and Implementation of Strut-and-Tie Model in LRFD Bridge Design Specifications	$ 111,779

Multidisciplinary Center Earthquake Engineering Research

1999	Experimental Facilities Network	$ 34,955
2000	Experimental Facilities Network	$ 31,963
2000	Technical Direction of TEA-21 and106 Highway Projects	$ 127,218
2000	Seismic Design and Retrofitting Manual for Highway Bridges (Phase II)	$ 17,413
2000	Earthquake Protective Systems Manual (Phase II)	$ 52,382
2000	Second International Workshop Seismic Effects Transportation Structures (Taipei)	$ 18,240
2001	Technical Direction of TEA-21 and106 Highway Projects (Phase II)	$ 88,819
2001	Earthquake Protective Systems Manual (Phase III)	$ 12,502
2001	Seismic Performance of Bridges with Steel Superstructures	$ 108,912
2001	18th U.S.-Japan Bridge Engineering Workshop	$ 59,984
2002	Technical Direction of TEA-21 and106 Highway Projects (Phase III)	$ 92,253
2002	Seismic Performance of Bridges with Steel Superstructures (Phase II)	$ 174,634
2002	Third Intl Workshop on Seismic Design and Retrofit of Transportation Facilities	$ 19,333
2003	Experimental Data for the Seismic Performance of Piping Distribution Systems	$ 78,000
2003	Networking of Experimental Facilities	$ 26,000
2003	19th US-Japan Bridge Engineering Workshop	$ 50,000
2004	Technical Direction of TEA-21 and106 Highway Projects (Phase IV)	$ 57,378
2004	Seismic Performance of Bridges with Steel Superstructures (Phase III)	$ 189,723
2005	20th and 21st US-Japan Bridge Engineering Workshops	$ 80,000
2005	Innovative Bracing Systems for Nonstructural Piping Systems (Phase I)	$ 79,989
2005	Non-Structural Portfolio	$ 78,000
2006	22nd and 23rd US-Japan Bridge Engineering Workshops	$ 79,000
2006	Innovative Bracing Systems for Nonstructural Piping Systems (Phase II)	$ 37,951

National Academies, Transportation Research Board

2008	Update of the AASHTO Guide Specifications for Seismic Isolation Design	$ 84,916

GRANTS & CONTRACTS

National Cooperative Highway Research Program IDEA

2003	Fiber-Reinforced Plastics for Seismic Bridge Restrainers (with Nevada Department of Transportation)	$ 97,685
2005	Seismic Response of Bridge Columns With Engineered Cementitious Composites and Shape Memory Alloys in Plastic Hinge Zone	$ 77,861

National Science Foundation

1999	Instructional Shake Table (through Washington University)	$ 12,000
2000	Seismic Fragility and Retrofit of Non-Ductile Reinforced Concrete Structures Using New Technologies	$ 75,000
2001	Development of a Biaxial Multiple Shake Table Research Facility and Supplement	$ 4,683,457
2003	Teachers Integrating Engineering into Science	$ 99,654
2003	Collaborative Research: Demonstration of NEES for Studying Soil-Foundation-Structure Interaction and Supplement	$ 301,111
2004	US-Turkey Workshop on Seismic Retrofit and Post-Earthquake Evaluation of Highway Bridges	$ 34,995
2004	Real-Time Control and Simulation Network and Five Degree-of-Freedom Table Upgrade	$ 41,614
2004	Seismic Performance of Bridge Systems with Conventional and Innovative Design	$ 2,024,000
2005	Seismic Simulation and Design of Bridge Columns under Combined Actions, and Implications on System Response	$ 1,419,998
2007	FHWA/NSF Workshop on Future Directions for Long-Term Bridge Performance Monitoring, Assessment, and Management	$ 55,000
2007	Joint US-Slovenia Study of Simple Modeling of Bridge Seismic Response	$ 23,270
2007	Simulation of the Seismic Performance of Nonstructural Systems	$ 3,600,000

National Science Foundation / Network for Earthquake Engineering Simulation

2004	Management, Operation and Maintenance of NEES Equipment Site at University of Nevada, Reno	$ 888,370
2005	Management, Operation and Maintenance of NEES Equipment Site at University of Nevada, Reno	$ 928,284
2006	Management, Operation and Maintenance of NEES Equipment Site at University of Nevada, Reno	$ 1,031,570
2007	Management, Operation and Maintenance of NEES Equipment Site at University of Nevada, Reno	$ 1,154,612
2008	Management, Operation and Maintenance of NEES Equipment Site at University of Nevada, Reno	$ 1,048,000

Nevada Department of Transportation

1999	Review of Seismic Retrofit Design for Bridges at I-80/US-395 Interchange	$ 10,712
1999	Creep and Shrinkage Prestress Losses in Nevada Aggregates	$ 178,715
1999	Seismic Performance of Bridge Bents with Unretrofitted Footings	$ 58,483
1999	Cracking in Newly Placed Concrete Deck Slabs	$ 73,808
1999	Replacing Bridge Decks on Post-Tensioned Concrete Bridges in Nevada	$ 50,678
2001	Seismic Evaluation and Retrofit of Las Vegas Downtown Viaduct (with UNR and UNLV)	$ 450,600
2001	Filling of the Structural Tubes in the Galena Arch and Supplement	$ 39,974
2003	Performance, Design, and Detailing of Two-Way Column Hinges (with FHWA)	$ 197,526
2003	Seismic Retrofit of Bridge Hinges with FRP Restrainers	$ 15,000
2004	Instrumenting the Galena Creek Bridge and Supplement	$ 168,037
2007	Seismic Performance of Integral Connections between Substructures and Precast Concrete Structures and Supplement	$ 369,886
2009	Unbonded Prestressed Columns for Accelerated Bridge Construction and Earthquake Resistance	$ 191,615

PC Bridge Co., LTD Japan

2004	Shake Table Testing and Analysis of a Prestressed Segmental Concrete Column	$ 25,723

SC Solutions / TCI, Santa Clara, CA

2001	Behavior of TCI/BR Antenna Under Dynamic Vibrations	$ 32,905

Seismic Isolation Engineering

2005	Quasi-static Cyclic Testing of Nippon Steel Corporation Unbonded Braces	$ 37,577

South Carolina Department of Transportation / South Carolina University

2009	Behavior of Pile to Pile-Cap Connections Subjected to Seismic Forces	$ 121,597

Slovenian Research Foundation

2001	Innovative Methods for Seismic Protection of Bridges	$ 15,000

Spacesaver, Inc

2003	Seismic Qualification Testing of Spacesaver Mobile Shelving	$ 26,866

State of Nevada Applied Research Initiative

2003	Innovative Reinforcement to Reduce Earthquake Damage in Concrete Bridge Column Plastic Hinges	$ 50,000

Structural Design Engineers, Inc., San Francisco, CA

1999	Cyclic Behavior of the San Francisco Moscone Moment Frame Connections	$ 61,161

TCI, Fremont, CA

2001	Behavior of TCI/BR Antenna Under Dynamic Vibrations	$ 32,905

UNI System, Inc., Houston, TX

2001	Behavior of Reliant Stadium Urethane Bumper Under Dynamic Loading	$ 10,912

University of Nevada, Reno

2005	Structural Integrity of Steel Framing System at UNR Fire Science Academy	$ 32,036

U.S. Department of Energy

2000	Upgrade of Earthquake Simulation Facilities	$ 1,000,000
2004	Expansion of the Earthquake Engineering Facility at the University of Nevada Reno (Phase I)	$ 966,000
2008	Expansion of the Earthquake Engineering Facility at the University of Nevada Reno (Phase II)	$ 1,967,992

U.S. Department of Housing and Urban Development

2000	Upgrade of Earthquake Simulation Facilities	$ 1,618,750

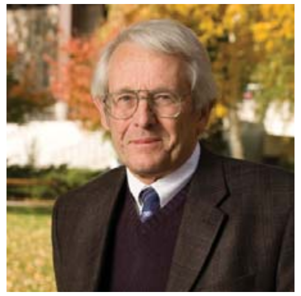
VMC Group

2009	Shake Table Testing of Three Genset Units	$ 49,362

Westbrook, Inc.

2003	Shake Table Testing of Westbrook Assemblies	$ 18,464

CENTER PERSONNEL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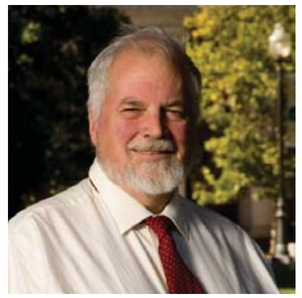
Director of CCEER

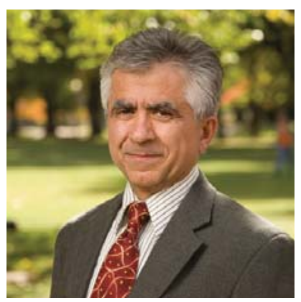

Bruce Douglas
Emeritus Professor


Ahmad Itani
Professor


E. “Manos” Maragakis
Professor and Dean


Gary Norris
Emeritus Professor


Gokhan Pekcan
Professor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Professor


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CCEER Program Coordinator


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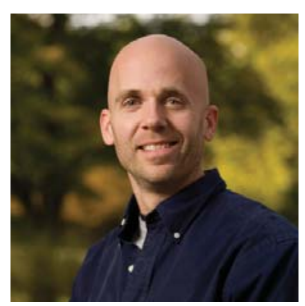
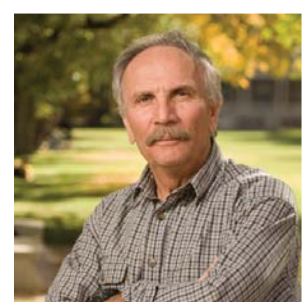

Patrick Laplace
Lead Laboratory Engineer


Paul Lucas
Development Technician


Chad Lyttle
Development Technician


Todd Lyttle
Development Technician


Robert Nelson
Research Scientist


Rodney Porter
NEES System Administrator

DOCTORAL STUDENTS

Since the establishment of the Center for Civil Engineering Earthquake Research, 34 students have earned their doctoral degrees in the earthquake engineering program. Listed below are the names of these students, their year of graduation, and research topic.

1988	James Richardson	Dynamic Response Analysis of the Dominion Road Bridge Test Data
1992	Yang Jiang	Behavior, Design, and Retrofit of Reinforced Concrete One-Way Bridge Column Hinges
1992	Zia Zafir	MOVLOAD: A Program to Determine the Behavior of Nonlinear Horizontally Layered Medium under Moving Load
1993	Saber Abdel-Ghaffar	Evaluation of the Response of the Aptos Creek Bridge During the 1989 Loma Prieta Earthquake
1994	Spiros Vrontinos	A Simple Model to Predict the Ultimate Response of R/C Beams with Concrete Overlays
1995	Yolanda Labia	Evaluation and Repair of Full-Scale Prestressed Concrete Box Girders
1995	Qiudong Wu	Dynamic Response of Steel Fiber Reinforced Concrete
1997	Ihab Darwish	Determination of In-Situ Footing Stiffness Using Full-Scale Dynamic Field Testing
1997	Nadim Wehbe	Effect of Confinement and Flares on the Seismic Performance of Reinforced Concrete Bridge Columns
1997	Mahmoud El-Gamal	Programs to Computer Translational Stiffness of Seat-Type Bridge Abutment
1997	Jeff Palmer	Drained and Undrained Lateral Compression Response from Drained Axial Compression Tests
1997	Barbara Blasey	Development and Application of a Drought Index for Northwestern Nevada
1997	Patrick Pilling	The Response of a Group of Flexible Piles and the Associated Pile Cap to Lateral Loading as Characterized by the Strain Wedge Model
1998	Mohamed Ashour	The Prediction of Lateral Load Behavior of Single Piles and Pile Groups Using the Strain Wedge Model
1999	Nagi Abo-Shadi	Seismic Response of Bridge Pier Walls in the Weak Direction
2001	Sherif Elfass	A New Approach for Estimating the Axial Capacity of Driven Piles in Sand up to True Soil Failure
2001	Claudia Pulido-Collantes	Seismic Performance and Retrofitting of Reinforced Concrete Bridge Bents
2002	Tung Nguyen	Sand Behavior from Anisotropic and Isotropic Static and Dynamic Triaxial Tests
2002	Patrick Laplace	Experimental Study and Analysis of Retrofitted Flexure and Shear Dominated Circular Reinforced Concrete Bridge Columns Subjected to Shake Table Excitation
2003	Hisham Nada	Seismic Performance of RC Bridge Frames with Architectural-Flared Columns
2003	Ronald Meis	Behavior of Underground Piping Joints Due to Static and Dynamic Loading
2004	Khaled Moustafa	Impact of Aspect Ratio on Two-Column Bent Seismic Performance
2004	Lyle Carden	Seismic Load Path in Steel Girder Bridge Superstructures
2004	Peter Dusicka	Cyclic Response and Low Cycle Fatigue Characteristics of Plate Steel
2004	Magdy El-Desouky	Further Developments of 3DMOVE and its Engineering Applications
2005	Horng-Jyh “Tigra” Yang	Extension/Compression Test Stress-Strain-Volume Change Characterization under Drained Condition
2006	Juan Correal	Seismic Performance of RC Bridge Columns Reinforced with Two Interlocking Spirals
2006	Nathan Johnson	Large-Scale Experimental and Analytical Studies of a Two-Span Reinforced Concrete Bridge System
2007	Zhyuan Cheng	Development of a Seismic Design Method for Reinforced Concrete Two-Way Bridge Column Hinges
2007	Hoon Choi	Effects of Near-Fault Ground Motion and Fault-Rupture on the Seismic Response of Reinforced Concrete Bridges
2008	Hamid Bahrami	Guidelines for the Seismic Design of Ductile End Cross Frames in Steel Girder Bridge Superstructures
2008	Kevin Almer	Seismic Continuity Performance of Precast U-Girders Integrally Connected to a Cast-in-Place Substructure
2009	Arash Zaghi	Seismic Design of Pipe-Pin Connections in Concrete Bridges
2009	Ahmed Abdel-Mohti	Seismic Response Assessment and Recommendations for the Design of Skewed Post-Tensioned Concrete Box-Girder Highway Bridges

Editorial Kelly Doyle and Rita Johnson

Layout Kelly Doyle

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