Developed and or Deployed Products or Services

2009

California Department of Transportation

Division of Research and Innovation

An Evaluation of the Consequences and Effectiveness of Using Highway Changeable Message Signs for Safety Campaigns

Changeable message signs (CMS) on highways are now commonly used to alert motorists to downstream accidents and guide them to alternate routes as well as for Amber Alerts. In addition, in some areas of the state, CMS are used to inform travelers about their expected travel times to key destinations. More recently, in California and throughout the nation, CMS have been used as part of public campaigns to promote roadway safety by posting messages that encourage motorists to use seat belts, not drink and drive, and not speed. The California Department of Transportation (Caltrans), however, has a number of concerns about the consequences and effectiveness of these non-traditional CMS applications. This study employed multiple research methods to address these concerns including focus groups, telephone and in-person surveys, as well as analysis of California Highway Patrol data. This research examined a range of resources and evaluated the following questions about displaying safety campaign messages on CMSs: (1) How attentive is the public to messages displayed on CMSs? (2) Is there a public safety benefit from displaying safety campaign messages on CMSs? (3) Do travelers slow down to read CMS messages and, as a result, interrupt traffic flow?

The outcome obtained from the project activities provided robust understanding of the consequences and values of using CMS for public safety campaigns. The results are essential to maintain safe and operable state highways, local streets and roads. This contract offered the opportunity to advance the state of the art in the recent studies of CMS with route guidance messages. Potential benefits of these technologies include: reduced fuel consumption, traffic congestion relief, enhanced quality of road service and safer vehicle travel. California transportation engineers and planning officials will better understand various infrastructure investment and policy options.

This project provided a clear and comprehensive understanding of the consequences and effectiveness of using CMS for public safety campaigns, and thus informs their decisions about future use of CMS for public safety campaigns. The study showed significant benefits and suggested the following: (1) driver inattention to CMS messages does not appear to be a significant problem among California drivers; (2) positive safety effects may be derived from public safety campaigns messages on CMSs when the public is familiar with and understands the messages displayed; and (3) a small percentage of drivers may slow in the presence of safety campaign messages displayed on CMSs, but this does not appear to cause disruptions in the overall flow of traffic.

Based on the findings of this study, Caltrans should continue display of safety campaign messages on CMSs; however, the display of these messages should have a lower priority than messages related to traffic advisories, advance

notices, AMBER Alerts, and severe weather notices. Safety messages should be evaluated to ensure a high level of public familiarity and understanding, and priority for display should be based on message evaluations. Specific guidelines that prioritize messages for display on CMSs to optimize comprehension and positive behavioral change should be developed by relevant state agencies. Research on CMS messaging should be monitored and guidelines should be updated accordingly.

Development for the GPS-Automated Travel Diary (GPS-ATD) in Preparation for the 2010 Statewide Travel Behavior Survey

The Global Positioning System-Automated Travel Diary (GPS-ATD) was developed to collect information used to analyze day-to-day travel behavior useful for transportation planning and modeling. The GPS-ATD software is a specially designed survey tool to capture trips by vehicle and non-vehicle travel modes and other vital transportation information.

The Global Positioning System-Automated Travel Diary (GPS-ATD) is easy to use and provides increased data quality and information. The improvements in data quality and enhanced information will have a ripple effect on products such as travel behavior models, trip generation models, land use planning, and information affecting commute behavior. The benefits then flow from these products to provide sustainability, improved mobility, enhanced safety, and reduced environmental impact.

While the GPS-ATD was developed for the Statewide Travel Behavior Survey, it is quite flexible and reprogrammable. It is well-suited for similar travel surveys by Metropolitan Planning Organizations and other agencies. In particular, the approach used for implementing user menus will allow easy revision for other agencies, or similar Caltrans applications.

The Global Positioning System-Automated Travel Diary (GPS-ATD) minimizes user burden during household travel surveys, while providing accurate, reliable, and spatially dense traveler behavior information at a significantly reduced cost. This improved information will enhance travel demand modeling, transportation management, and land use planning. Basing the system on a commercially available platform removes risks associate with commercialization and deployment.

The Global Positioning System-Automated Travel Diary (GPS-ATD) software runs on a GPS cell phone. Combining off-the-shelf GPS cell phones with the GPS-ATD software provides a tailored solution for travel behavior surveys, in a form that can be easily procured by an agency.

The GPS-ATD provides an intuitive user interface to capture the trip activity information (trip purpose, travel mode, etc.), with minimum user input. Each

survey participant interacts with their own GPS-ATD. The system captures and logs data from the GPS receiver, allowing identification of corridors, route lengths, and regional / inter-regional trips.

The GPS-ATD will produce large and complex sets of data. Analysis of this data will require development of techniques and tools to support and facilitate extraction and reporting of useful survey data. Future work is recommended to research and develop these techniques and tools, which will enable planners to effectively search and query the large set of data to generate general statistics, share data, and automate reporting.

Liability, Regulation and Autonomous Vehicle Technologies

Autonomous vehicle technologies and advanced driver-assistance systems, such as crash warning systems, adaptive cruise control, lane-keeping systems, and autonomous parking technology, and, ultimately, full-scale driverless cars, have the potential to significantly improve transportation safety, efficiency and cost. Moreover, in the last decade, these technologies have advanced dramatically and many systems are poised for implementation in the real world. As these technologies increasingly perform complex driving functions, they also shift responsibility for driving from the driver to the vehicle itself. The United States is leading research and development efforts in this arena, but little of the available technology has been used, in part because of concerns and uncertainty about safety, liability, and social issues associated with crashes that will inevitably occur. This motivates a new look at liability and regulatory regimes because of the increasing uncertainty about what should happen when a crash occurs and the implications for the adoption of these technologies.

This research identifies the controlling legal principles for crashes involving autonomous vehicle technologies; evaluates how the existing liability regime would likely assign responsibility in crashes involving such technologies; and examines the implications for their adoption. The project team also reviews the existing regulatory environment for autonomous vehicle technologies, examines where standards and regulations might fall short, and suggests general principles and guidelines for future standard setting and rulemaking.

In a highly litigious country, in particular, tort law and safety regulations have enormous implications for the development and implementation (or lack thereof) of these technologies. This is a preliminary study to conduct research on the appropriate liability and regulatory regimes and their effect on the adoption of autonomous vehicle technology.

The research finds that while the existing liability regime does not present unusual liability concerns for owners and drivers, the liability of manufacturers is expected to increase, and this may lead to inefficient delays in the adoption of this technology. One potential approach to this problem is to more fully integrate

a cost-benefit analysis into the standard for liability in a way that accounts for the consideration of the benefits associated with this technology; another approach would be for policymakers to issue a uniform set of regulatory standards that would preempt state tort suits. Other recommendations include standardization of technology performance and system interfaces, consumer education and future empirical research.

This research is a much-needed first step towards developing coherent safety and liability regimes to meet the needs of both consumers and manufacturers as they begin to use autonomous vehicle technology. This will lay the foundations for more in-depth work in this area. The collective results will have significant implications for transportation technology and transportation policy, and will therefore be of interest to automobile manufacturers, consumers, the courts, local and national lawmakers, and highway and transportation administrators as they begin to grapple with the promise of autonomous vehicle technology.

In the immediate future, this work will raise awareness of safety and liability issues, encourage more fact-driven debate, and lay the foundations for further, large-scale research. In the longer term, it will:

- Provide lawmakers with the relevant research on the existing legal regime to allow an informed decision on whether to modify it.
- Reduce liability uncertainty for manufacturers.

Eventually the emergence of a mature body of regulation and tort law will enable consumers to make informed decisions about autonomous vehicle technology and will enable manufacturers to accurately assess liability.

In sum, this work will pave the way for us to reap the many social, economic, and environmental benefits promised by autonomous vehicle technology.

The final research report contains evaluation and analysis of the liability regime and regulatory environment for autonomous vehicle technologies, policy suggestions and opportunities for future work in this area. This report is available at: http://www.dot.ca.gov/research/researchreports/reports/2009/prr-2009-28_liability_reg_&_auto_vehicle_final_report_2009.pdf

(S3.P304) Improved Bridge Construction Methods

This project is an umbrella for tasks aimed at general improvements to the bridge construction practices. It involves development and testing of new equipment, designs, materials, and procedures that offer potential for faster, lower cost, or safer construction operations or which provide immediate or long-term performance improvements of the bridge system and/or reduced impacts to the surroundings. Some example topics include improved shoring and falsework systems, improved fabrication methods, improved materials placement strategies, and investigations of notable construction case histories (successes

and failures). Tasks completed under this project will contribute to faster, lower cost, and safer bridge construction practices or produce higher-performing bridge systems.

The state and public will benefit from improved construction operations that increase worker and public safety, yield cost savings, increase the speed of construction, reduce adverse environmental impacts, or provide performance enhancements over existing approaches.

(LEC) Erosion Control & Storm Water Pollution Prevention - Identify ways to protect roadsides and improve storm water quality

Erosion of disturbed roadsides increases maintenance costs and staff exposure to traffic, introduces loose gravel to the traveled way, degrades water quality, and puts the Department out of compliance with mandates to prevent erosion. This project seeks to expand our Departmental toolbox of strategies to meet environmental requirements by exploring ways to use landscape technology to prevent erosion and improve storm water quality.

Tasks include:

- Exploration of adding symbiotic fungus to soil as a way to enhance plant establishment in harsh environments.
- Development of a process and methods to grow and plant native grass sod in an economically viable and commercially available way.

Multiple combinations of grass species were tested to determine blends that could produce commercially viable native grass sod. The performance of various blends of grass species was identified for both sloping and flat situations. Successful native sod watering regimens, planting methods and soil pre-treatments were identified. The prevention of erosion on slopes and the filtration of runoff water at flat places was demonstrated. Research on mycorrhiza demonstrated the importance of these soil enhancements for establishing native plants in harsh environments.

By developing tools for roadside erosion control with planting methods, the Department benefits in many ways, as follows:

- Safety is improved by reducing slope failures, reducing the amount of gravel on the road, and reducing the time that workers are exposed to traffic.
- Environmental mandates and permit requirements can be met by reducing discharge of pollutants to storm drainage systems.
- Communities are enhanced through context sensitive storm water treatment facilities incorporating plantings.
- Soil structure is improved for sustainability and maintainability.
- Reduced storm water runoff leads to cleaner water ways.

In support of conformance to environmental and safety requirements, this project produced specifications for installing and establishing native sod on disturbed roadsides prone to erosion. A separate task produced guidelines and specifications for incorporating locally specific mycorrhizal fungus into degraded soil on roadside areas as a way to establish new plantings of native species. In addition to successful development of specifications, training materials and published reports, this project led to commercialization of native sod products by our research partners. A report on the native sod task can be found at: http://www.dot.ca.gov/research/researchreports/reports/2008/08-0623.pdf

(LEC) Weed and Pest Control - Develop integrated best practices to prevent and control invasive and noxious species

Vegetation control along the roadsides requires significant maintenance effort and time. Develop integrated best practices to prevent and control invasive and noxious species, in progressively more focused efforts, evaluated methods that reduce the need for restricted herbicides and reduce labor costs to control weeds along the roadside. The first task broadly evaluated alternatives to herbicides as an effort to reduce roadside vegetation maintenance. Natural materials such as corn gluten, vinegar, and others were evaluated as a means of vegetation control.

The second task evaluated having native vegetation along roadsides as an effort to reduce maintenance. Native species may provide a way of reducing maintenance along the roadsides while maintaining erosion control, so the study determined effective ways to convert existing annual non-native vegetation to native perennial species.

The third task addressed Caltrans's need to control yellow starthistle and Russian thistle while reducing herbicides by 80% by 2012. Because California is not their natural environment, there are no small animals that will keep their numbers in check. Recently identified biological controls (insects and pathogens) offer a potential solution but must be tested to obtain approval from State and Federal agencies. The most promising agents were evaluated in quarantine laboratory to determine their host plant specificity, with a goal of releasing them in the wild.

The development of integrated best practices to prevent and control invasive and noxious species provides a means for design and maintenance crews to work together in a coordinated fashion to improve the quality of the environment while reducing long term maintenance efforts. The effectiveness and relative cost of many commercially available weed control products as well as some novel techniques were explored. Controlling weeds on a long term basis is easier if robust desired species of plants cover the ground, rather than leaving bare earth. This finding led to the task to find ways to convert non-native annual weeds to low growing native perennials.

Sustained weed control for several years is shown to be required for vegetation conversion to native species. No single treatment was sufficient, but each provided different weed control characteristics. Burning provides control of non-native seeds and plants and stimulates native perennial plant growth. Tillage prepares the seed bed, stimulates germination of weed seed and provides soil volumes for root penetration. Herbicide use was important to selectively reduce non-native annual plant species. After vegetation conversion, herbicide use is shown to be reduced or eliminated except for occasional weed control. After three years of cultural and chemical management, native perennial grasses were most abundant in sites that had been burned once and sprayed at least twice. In established roadside stands of native perennial grasses, a combination of spraying, mowing and/or burning for two consecutive years is required to reduce or eliminate non-native, invasive species, such as yellow starthistle. Once established, native perennial grass stands can persist for more than a decade and remain relatively weed resistant.

The especially noxious nature of some weed species requires additional effort to attempt controls. Such plants include yellow star thistle and Russian thistle, which both grow abundantly in disturbed soils throughout California. Species that eat these plants in their original Eurasian homes were tested on native California plants and commercially grown plants. Four arthropods that appeared to be sufficiently specific to the weeds were identified and permission to release them into the wild was sought. That effort is ongoing; however the research contract between Caltrans and the United States Department of Agriculture has ended.

Controlling unwanted vegetation along the roadsides requires significant maintenance effort and time. Maintaining roadsides with live plants, instead of herbicide induced bare earth, leads to reduced long term maintenance costs, improved environment and safer less fire-prone roadsides.

Development of integrated best practices to prevent and control invasive and noxious species helps identify and control noxious weeds, reduces herbicide use, and reduces recurrent maintenance activities while preserving roadside landscaped areas. Additional benefits are reduction of dry annual plants that intensify seasonal fires, preservation of roadside habitat and native plants, and development of stakeholder partnerships.

Using biological controls reduces maintenance labor needed to control imported noxious thistle plants on state right of way. Guidelines for alternative means of vegetation and pest control. A table presenting the effectiveness of controlling known problem species of roadside plants using any one of ten materials and methods. A summary in layman's terms can be found at: http://www.dot.ca.gov/research/researchreports/two-page_summaries/res_notes_alternative_vegetation_control.pdf

Methods for converting weedy areas to native species, a report can be found at: http://www.dot.ca.gov/research/researchreports/reports/2008/07-0103.pdf

Identification of 4 species of arthropod that can be used in California for controlling imported thistle weeds. Information of the ongoing activities by our research partners can be found at: http://www.ars.usda.gov/pandp/people/people.htm?personid=5242"

Deployable products will include revised bridge design details/specifications as well as guidelines documents regarding appropriate use of emerging bridge construction techniques.

Marbled Murrelet Research

The marbled murrelet is a small bird that feeds at sea but nests in old-growth forests along the coast. Over the last 30 to 50 years this bird's population has declined due to human activities, especially the loss and fragmentation of nesting habitat. Because of the decline the marbled murrelet population of California is listed under both the federal and state Endangered Species Acts. Several California state highways are in habitat for the marbled murrelet. Little is known about the impact of human disturbance on this bird. So, to expedite important project development and maintenance activities Caltrans needed to develop high quality information about the marbled murrelet for use in Endangered Species Act consultations and for determining the appropriate actions for mitigating potential negative impacts. This task was part of a cooperative effort on the part of a number of affected organizations and government agencies including the National Park Service, U. S. Fish and Wildlife Service, and Caltrans to describe Marbled Murrelet nesting habitat, measure the bird’s reproductive success, and understand the behavioral responses of nesting Marbled Murrelet adults and chicks to human-caused disturbance. The objective of Caltrans portion of the research was developing information on the potential for roads and highways to impact the murrelet. The information was gathered and analyzed by a research team from Humboldt State University through capturing and radio-tagging birds and by human observation of nesting sites. A research team operating from Humboldt State University and including Percy Hébert, Richard Golightly and Dennis Orthmeyer performed the research.

The research consisted of four phases: evaluation of human-caused disturbance on the breeding success of marbled murrelets, breeding biology of marbled murrelets, at-sea distribution and movements of marbled murrelets, and temporal patterns of marbled murrelets flying to inland forest sites. This research description focuses on the portions of the study of most interest to Caltrans. During three nesting seasons the researchers captured a total of 102 marbled murrelets at sea and outfitted them with radio transmitters and later located nesting birds by aerial surveys using radio telemetry. Actual nesting trees were

located on foot or ascending a neighboring tree to locate the nest. Successful nesting and hatching with marbled murrelets was compared to anthropogenic noises, such as chainsaws, trail users, and road noises. The behaviors of birds were monitored using video cameras.

The research team studied the potential effects of trail use and vehicular traffic on marbled murrelet reproductive success by measuring the proximity of nests to paved highways and park trails using GIS. They plotted the nest tree locations on a map of Redwood National and State Parks and calculated the distance of the nest site to the nearest hiking trail (± 1 m) and the nearest road (± 10 m). The proximity of roads and trails was compared with hatching success. Tree nests located by aircraft telemetry and nests located in specific trees were statistically analyzed separately due to differences in precision of location. The team developed recommendations for the protection, recovery, habitat enhancements and future research for marbled murrelets."

Disturbance from trails or roads may reduce nesting success in some bird species. A major source of highway noise in the study area was large trucks using engine retarder brakes. Traffic volumes in RNSP, particularly on U. S. 101, were greater during the nesting season due to summer tourism. However, they were low compared to other areas. The research did not detect a statistically significant relationship between marbled murrelet hatching success and nest proximity to roads and trails. Nests that successfully hatched were at a similar distance from roads and trails as nests that did not produce hatching. This finding is similar to a finding in a previous study.

The findings have to be evaluated carefully. It is possible that the study was unable to detect an affect from highway related noise, because the murrelets avoided nesting near highways. Additionally, application to sites outside of RNSP must carefully consider all aspects of highway noise generation and transmission including traffic volume and terrain features.

The researchers determined that corvid predation on eggs and chicks is an important source of mortality for marbled murrelets in RNSP. Human activities that increase corvid populations or concentrations may therefore negatively impact marbled murrelets.

Adult marbled murrelets did not flush from nests when exposed to noise from an operating chainsaw. These birds appear to rely on camouflage for protection. They are cryptically colored and are generally quiet and still while on the nest. Additionally, incubation exchanges and chick feeding are done during twilight. Both adults and chicks exhibited more head raised, or bill up behavior when exposed to chainsaw noise than when not exposed to the noise. The change is statistically significant for adults but not for chicks. This change of behavior may be a response to the noise from the saw and may draw the attention of predators to the nest and increase energy use by the birds.

The researchers recommend continued measures to avoid supporting corvid populations and avoiding disturbances to adults when incubating; and chicks during the twilight feeding periods of early mornings and evenings.

The information developed during this study helps Caltrans meet its obligations under the Federal Endangered Species Act by providing criteria for housekeeping at project sites in marbled murrelet habitat, and by providing windows for activities during the incubation and feeding periods.

This project provided information to Caltrans on the biology of the marbled murrelet that can applied in project development and during maintenance activities. The information helps facilitate work in marbled murrelet habitat while protecting this listed bird. The information developed during this study helps Caltrans meet its obligations under the Federal Endangered Species Act by providing criteria for housekeeping at project sites in marbled murrelet habitat, and by providing windows for activities during the incubation and feeding periods.

The final research report containing information on marbled murrelets and recommendations for operations in murrelet habitat. This report is available at: http://www.dot.ca.gov/research/researchreports/translabreports/2002-2006_res_reports.htm

Implementation of Integrated Land Use/Economic/Transportation Model

The development of a Statewide Integrated Land Use and Transportation Model for California will help to better understand if integrated models might improve the ability of Caltrans HQ and district staff to better address their goals for congestion reduction, environmental justice and the promotion of livable communities. In addition, the set-up model will assist in understanding how other State agencies might pursue their mandates such as affordable housing and environmental quality, by using an integrated model. This is a functional version of a set-up prototype version of a Production, Exchange, and Consumption Allocation System (PECAS) model depicting future land use scenarios based on simulated micro-economic factors. It will have customization features to include appropriate representation of transportation demand-supply interaction, and congested conditions on relevant transportation modes at relevant locations.

The development and implementation of a Statewide Integrated Land Use and Transportation Model will provide robust analyses regarding a number of interactive effects among transportation, economic, and land use changes over time. It will also improve the ability of Caltrans HQ and District staff to better address and meet their goals for congestion reduction, environmental justice and the promotion of livable communities. In addition, the model will assist Caltrans in understanding how other State and local agencies pursue their mandates such as affordable housing and environmental quality. California transportation

engineering and planning officials will better understand various infrastructure investment proposals and policy options.

An integrated interregional model will improve the evaluation of various infrastructure investment proposals and policy options. For example, the model can be used to evaluate economic, land use, environmental, and other potential benefits and impacts of various major transportation investments. It can also be used to assess the potential effects of various types of large-scale policies, programs, and strategies.

Effectiveness of Cooperative Adaptive Cruise Control System

The scope of this project addresses the impact of Adaptive Cruise Control (ACC) and Cooperative Adaptive Cruise Control (CACC) on traffic flow, from the point of view of driver gap choices. Driver gap choice is the key element for which to gather information in order to obtain the best simulation result as possible. The objective of this project is threefold: (1) Develop and implement a CACC on two Infinity FX45 that we will be able for use in real traffic conditions; (2) Use these vehicles for collecting data on drivers, time-gap choices and use of ACC and CACC; and (3) Integrate the results of the data collection within the PATH tool simulation.

The results of this research support decision makers in evaluating the effectiveness of Cooperative Adaptive Cruise Control for congestion mitigation and safety enhancement. This research is important for decision about whether to provide public incentives for use of the systems, such as priority access to High Occupancy Vehicle (HOV). The collected data will support other research in California concerning driver behavior and the technologies implemented for this system, e.g the vehicle-to-vehicle communication

The final report describes the Cooperative Adaptive Cruise Control system implemented, the protocol and results of the data collection, and the results of the simulation.

Non Destructive Testing of FRP Composite Bridge Decks

FRP composite emerged as the new material for bridge construction at the end of the cold war. Previously, this material was primary used in the aerospace industry for its high strength/weight ratio. After 1989 Loma Preita Earthquake, Caltrans has heavily in looking for new materials for seismic retrofit. FRP composite column jackets have been used at a number of bridges. Since 2000, two bridges in California were built with decks that were made of FRP composite as a demonstration for possible future usage. Even though this material is well known for its non-corrosive nature, other environmental conditions will affect its load term performance. The main objective of this project is to evaluate and identify efficient and practical non-destructive test processes, such as real-time

Reverse Geometry X-Ray digital imaging (RGX) or acoustic emission testing of composite bridge decks. The proposed research effort will focus on developing a reliable, yet cost effective technique for NDE testing of composite bridge decks for maintenance deck inspections and post-earthquake damage assessments. This will be accomplished by evaluating different commercially available techniques such as real-time reverse X-Ray digital imaging, acoustic emission (AE), microwave evaluation, ultrasonic, radiography, thermography, and others. However, due to the fact that the RGX proprietary Reverse Geometry Digital X-Ray (RGX) imaging is emphasized in Caltrans problem statement, this system will be evaluated in addition to other reliable state-of-the-art acoustic emission (AE) techniques.

At the end of project, the possibility and feasibly of using the real-time reverse X-Ray digital imaging process or acoustic emission testing of composite bridge decks for maintenance deck inspections and post-earthquake damage assessments can be accessed. Methods and guidelines over using these NDE devices to access bridge deck integrity and safety can be developed and deck inspection procedure can be updated for bridge safety evaluation.

The state and public will be benefit from improved bridge maintenance practices on inspection methods and tools used that keep our bridge safe for traveling public."Non-Contact Ultrasonics with through transmission (interior) successfully identified the delaminated areas. However, there are several limitations to using this technique in that the interior of the panel will not be accessible in the field and current testing does not account for the wearing surface.

The RGX® was able to detect delaminations in the composite deck components, cracks in the foam core and the top and bottom flanges of the deck sample which some of them were not to be detected by visual inspection. However, the use of X-ray inspection in field inspection imposes a significant health hazard due to the high level of radiation induced by the X-ray source.

Both the microwave imaging and ground penetrating radar techniques were used but the trials were not successful because of the presence of the hollow core as well as carbon/epoxy laminates in the composite bridge deck.

Expanding the MITTENS software use throughout the State

Providing accurate travel times to traveling public takes away confusion and lets the travelers plan their trips better. This project helps general public by providing accurate real-time travel times to the traveling public by posting them on Changeable Message Signs (CMS). The project helps traveling public by providing travelers/commuters with real-time information that is useful and widely understandable.

Caltrans implemented a system that provides travelers with travel time messages on Changeable Message Signs (CMS). This system is able to calculate real-time highway driving time as well as train trip time for pre-defined trip itineraries and displays related messages on a network of CMS in Stockton, San Francisco Bay Area, San Luis Obispo and Sacramento/Marysville area with various messages. The real-time travel times helps traveling public in making better decisions about their trips.

Displaying accurate travel times on CMS helps commuters assess traffic, alleviates driver stress, and allows drivers to make better decisions. Knowing the driving times to popular destinations, travelers may choose a less-congested route or a different form of transportation. In addition, displaying transit information on changeable message signs is a winning proposition, providing valuable traveler information to the public and encouraging modal shift to reduce traffic congestion on highways.

Deployed products are a network of changeable message signs (CMS) that are capable of disseminating a variety of information for different purposes. These signs broadcast information about downstream corridor delays, traffic incidents, as well as estimated highway and transit travel times. Stockton, San Francisco Bay Area, San Luis Obispo and Sacramento/Marysville area are now displaying various types of traffic information on these signs.

Monitoring of Prestressing Cables in Segmental Box-Girder Bridges

In this project a health monitoring system for pre-stress (PS) tendons will be designed, assembled and tested. The system will use an array of embedded sensors (applicable to new structures) and externally-attached sensors (applicable to new and existing structures) to probe the tendons with ultrasonic waves. By monitoring certain features of the waves (amplitude, attenuation, velocity and frequency), it will be possible to detect and locate defects in the tendons (corrosion and broken wires) and, simultaneously, measure the level of applied pre-stress. These outcomes would enable maintenance engineers to identify critical tendons and detect any loss of pre-stress as it occurs. The study will extend to embedded tendons the basic results on free tendons obtained in a previous UCSD research funded by the National Science Foundation.

The work in this project indicates that ultrasonic probing of PS strands can indeed be effective for the detection of defects as well as the monitoring of PS forces in post-tensioned concrete structures. Based on the findings of this research, strategies for both real-time health monitoring and routine-based inspection of post-tensioned bridges are outlined. These strategies will need to be validated in a follow-on project focusing on additional large-scale laboratory tests and testing of bridges in-service.

The successful deployment of a non-destructive damage detection procedure to evaluate the condition of a bridge (such as a post-tensioned box-girder structure) will allow bridge maintenance inspectors to assess the safety and reliability of the structure while in-service, and identify potential problems before closure of the bridge is the only option.

Geotechnical/Structures

End-User Interest in Geotechnical Data Management Systems

Report CA07-0057: http://www.dot.ca.gov/research/researchreports/reports/2008/07-0057.pdf

Geotechnical site investigations generate large volumes of subsurface information and associated lab test data. Conventional practice within Caltrans at the onset of this project relied completely on paper-based filing systems that were often difficult and cumbersome to access by users. Misplaced files, deteriorated paper records, incomplete documentation, and a lack of awareness that certain data even exists have all contributed to inefficient or incomplete utilization of existing data. This task performed initial investigations into developing more efficient geotechnical data management practices and more productive field data collection methods to enable Caltrans to maximize the value of existing data, minimizing drilling costs and expedite project delivery.

Figure 1: Conventional paper-based geotechnical data archives used within Caltrans and overall project vision for a web-based data management system to enable users to conveniently locate, retrieve, disseminate, share, and integrate geotechnical data from both field and laboratory tests and from documents developed by geo-professionals.

The initial task in this project examined potential improvements to Caltrans data management practices for field data collection, laboratory testing, and boring log creation. It specifically assessed and developed prototype systems for three critical components of an effective data management system: (1) data modeling, (2) data collection, and (3) data exchange and dissemination.

The initial research task produced several pilot tools that demonstrated to end users the benefits of an integrated set of web-based data exchange and dissemination technologies. These pilot technologies have been embraced by management of Caltrans Office of Geotechnical Services (OGS) and have either been deployed and/or are now being refined through follow-on research tasks. Specific examples of pilot tools stemming directly from this task along with the current status of extensions to the pilots include:

- A prototype web-based repository for Caltrans' Cone Penetration Test (CPT) data was unveiled as part of this project in early 2002 and remains in use today. Until that time, CPT data files were handled and transferred individually on floppy disks. The web-based system provides a central archive of CPT data, allows operators to upload data files over the web, and allows clients to browse, preview, print, or download data going back ten years. A web-based map interface and on-demand plotting are central features to the system. The CPT data is currently served as part of a broader suite of data through the emerging 'GeoDOG' system discussed below.
- A pilot Geotechnical Laboratory Data Management System (GLDMS) that uses a network of touchscreen workstations to enter and share laboratory data that previously had been handled using redundant paper processes.
- Ruggedized tablet PCs were test deployed to evaluate their use in electronic field logging. With off-the-shelf logging software and an integrated GPS receiver, staff could generate near-complete borehole logs before leaving the field, thus minimizing subsequent transcription errors.
- An important broader impact of this research initiative has been to drive an internal consensus-building and policy development process within OGS to standardize geotechnical logging practices, nomenclature, and data management processes required to enable use of the technologies. Logging practices based on this effort have been disseminated in the *Soil and Rock Logging, Classification, and Presentation Manual* that establishes standards for projects completed both internally and by consultants.

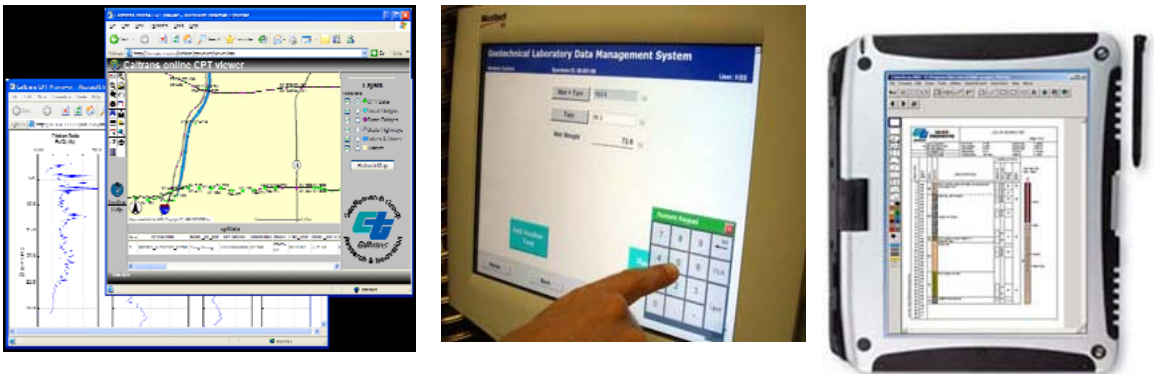


Figure 2: Pilot *data collection tools* developed and evaluated under th[illegible] web-based CPT repository (left), laboratory data management system (center), and field logging system (right).

- The initial research task also supported Caltrans test deployment of the pilot Geotechnical Virtual Data Center (GVDC) as part of participation in a broader multi-agency partnership conducted under auspices of the Consortium of Strong-Motion Observation Systems (COSMOS) and the Pacific Earthquake Engineering Research (PEER) Lifelines Program. The pilot GVDC established prototype data-center architecture, data standards and enabling technologies that demonstrated the ability to electronically share geo-data with multiple partners in public and private sectors, thus maximizing existing information and minimizing redundant drilling. Work toward refinement of the Data Interchange Standard for Geotechnical and Geo-environmental Specialists (DIGGS) has turned into a major ongoing pooled-fund project involving international partners (see http://www.diggsml.com/). Further development of GVDC demonstration applications is now occurring under the PEER-Lifelines program (see http://geodata2.usc.edu:8084/).
- The pilot web-based data management technologies developed under the initial research task (0057) and the parallel GVDC initiative have served as key building blocks for the current development of the much more powerful "GeoDOG" application which serves to provide clients access to a full range of both electronic data and scanned documents through a single geotechnical data archive (see Fig. 3). GeoDOG will be described in future reports.

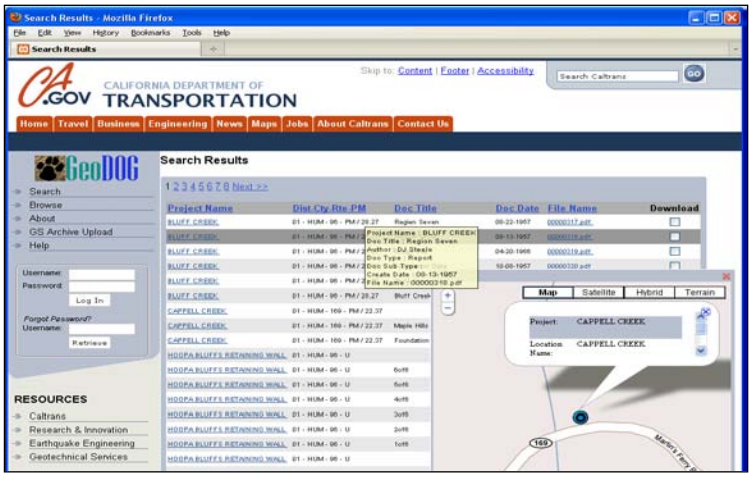


Figure 3: Sample screen from current "GeoDOG" technology that provides client's convenient means to upload, archive, and access a full range of geotechnical data and documents using web-based interfaces. This emerging application is based on experience and technologies piloted under task 0057.

- Similar to the development of the data archives application, task 0057 piloted the development of a web-based Geographic Information Systems (GIS) tool for display and simple analysis of seismic hazard map information. The initial pilot completed in 2003 presented the 1996 Caltrans California Seismic Hazard Map in a web-based interface and allowed the user to capture a PGA value used to select appropriate deterministic design response spectra from design manuals. This pilot capability was substantially upgraded in 2009 with the release of "ARS Online" (http://dap3.dot.ca.gov/shake_stable/) which uses similar web technologies but allows the user to interactively calculate a site-specific design response spectrum using recently developed "Next Generation Attenuation" relationships that incorporate effects of near-surface velocity, basin depth, and near-source directivity (see Fig. 4).

.

Figure 4: Pilot GIS-based tool for display and simple analysis of seismic hazard map developed in 2003 (left) and more sophisticated production "ARS Online" tool released in 2009 (right) that evolved from the initial pilot.

The project developed a suite of pilot technologies for improved geotechnical data management within Caltrans that are now being fully implemented in a production environment. The tools continue to evolve and have been enthusiastically embraced by Caltrans' end users and management as providing improved efficiency and accuracy in accessing and handling of valuable geo-engineering data. The public realizes benefits from reduced drilling and data-handling costs, increased inter-agency utilization of valuable existing data, more consistent design practices and faster project delivery.

Post Earthquake Bridge Inspection Maps and Tools
Reports CA09-0579 and CA09-0734: In Preparation

Following a major earthquake, one of Caltrans most critical tasks is to assess the condition of all potentially impacted bridges and roadway corridors in the state highway system. Timely response is important to ensure public safety, guide emergency vehicle traffic, and re-establish critical lifeline routes.

Prior to this project, Caltrans responders identified likely areas of bridge damage using a simple 'epicenter-outward' strategy involving target impact zones created within concentric rings surrounding the earthquake epicenter. However, patterns of intense ground shaking in real earthquakes often deviate substantially from this ring pattern due to a number of well recognized seismological phenomena. Further, the performance of individual bridges subjected to similar levels of strong shaking depends upon its design details. The goal of this project was to change the way that Caltrans responds to major earthquakes by providing better information regarding likely bridge damage by better accounting for site-specific ground motion and bridge-specific design details.

In 2005, Caltrans initiated a research contract with the United States Geological Survey (USGS) to develop and implement a Caltrans-specific version of "ShakeCast", a postevent software analysis tool. ShakeCast is a web-based application that automatically retrieves measured earthquake shaking data and analyzes the data in relation to individual bridge performance characteristics. Within minutes of an event, the program generates a simple, hierarchical list with maps of the structures and facilities most likely affected, and distributes this information in e-mails to decision makers and responders.

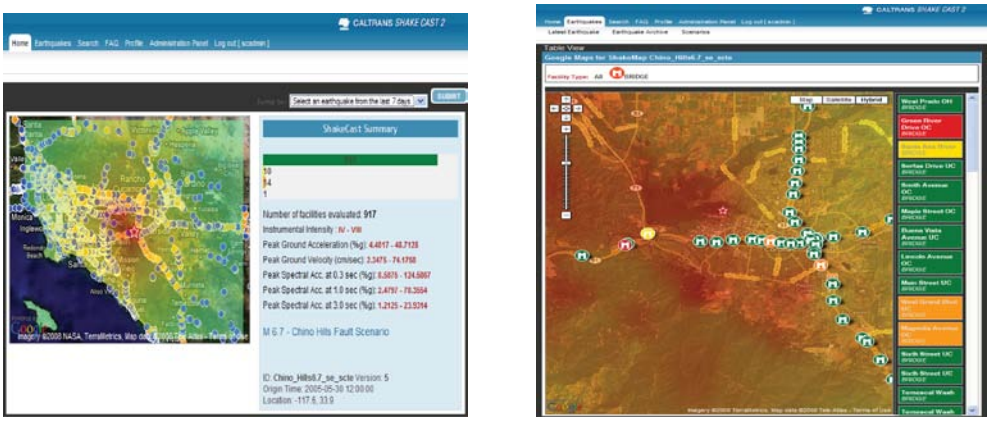


Figure 5: Example ShakeCast output provided to decision makers and emergency responders including a regional overview of earthquake impact (left) and bridge-specific information regarding inspection priority (right).

Through a combination of the external USGS contract research task and a companion internal research task, the ShakeCast software has been successfully test deployed within Caltrans and is in operation today. The software developed features internet-based account management and system administration, incorporates GoogleMaps visualization tools, and automatically generates products for that can be directly used in Google Earth®, ArcGIS®, and Excel®. Caltrans operates ShakeCast on two redundant servers at the Transportation Laboratory in Sacramento which operate 24 hours a day, 7 days a week, and rely on a robust system of Caltrans e-mail servers to distribute the notification messages.

The prototype ShakeCast system is now an integral component of Caltrans' response protocol and currently supports a group of over 300 responders and decision makers within Caltrans involved in post-earthquake bridge inspections and emergency management. This user group has received both individual and on-line training on system features and has been fully involved in identifying desirable future enhancements. By focusing inspection efforts on the most critically shaken areas, ShakeCast has drastically reduced Caltrans' response time required to assess potentially damaged structures after an earthquake.

ShakeCast has already proved to be a valuable tool for Caltrans in both post-earthquake response during real events and in scenario planning exercises. ShakeCast issued notices for the M5.4 Diamond Bar earthquake in Los Angeles that reasonably predicted observed low levels of damage within 15 minutes of shaking, well before on-site or news accounts could provide information. ShakeCast results were also used to establish likely damage conditions on the LA transportation network for the M7.9 San Andreas scenario used in the highly-successful multi-agency "2008 Golden Guardian" emergency management exercise. Caltrans has been recognized by its partners for its inter-agency leadership role in deploying ShakeCast, and Caltrans has aided marketing and deployment of the tool within other public-interest organizations.

The development, deployment and ongoing operation of ShakeCast within Caltrans assures post-earthquake situational awareness in the minutes and hours following a damaging earthquake, and allows Caltrans responders to make informed decisions and take quick actions to ensure safety, restore system functionality, and minimize losses.

Visual Inspection & Capacity Assessment of Earthquake Damaged Reinforced Concrete Bridge Elements

Report CA08-0284: http://www.dot.ca.gov/research/researchreports/reports/2008/08-0284.pdf

California's reinforced concrete (RC) bridges are periodically exposed to earthquake shaking having the potential to cause structural damage and loss of bridge function. Shortly after an earthquake, field engineers are dispatched to

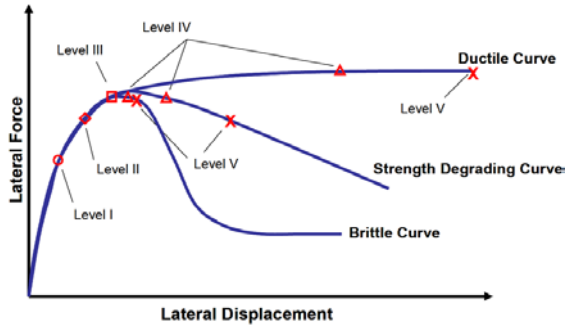
perform rapid visual inspections to establish both service level and safety of affected bridges. Visual indicators of damage, such as locations and patterns of concrete spalling and cracking, can represent vastly different levels of reserve safety margin depending upon the design details of the original bridge and any retrofit measures. The project aimed to develop guidance materials to aid field engineers with their rapid visual assessment of RC bridges after an earthquake.

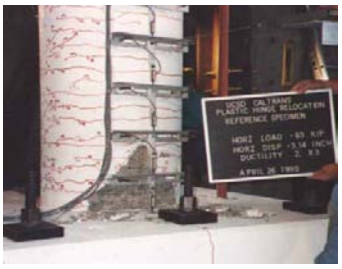
An extensive research program of large-scale proof tests that has been conducted since the early 1990's on a range of standard Caltrans bridge components has established a detailed understanding of the engineering behavior of RC bridges that has led to vastly improved seismic design practices in California. These component testing programs produced extensive archives of photographic documentation showing visual damage indicators associated with various levels of remaining structural capacity (reserve safety margin).

This research project focused on harvesting and organizing the archives of photographic information for reinforced concrete bridges, both from prior large-scale laboratory experiments and from historic earthquake bridge damage in the field, to produce a visual guide and associated training materials to assist field engineers with post-earthquake bridge damage assessment.

This project delivered a range of useful products and serves as an excellent example of the complete end-to-end research-to-deployment process. The work was accomplished through a unique and effective collaboration between researchers at the University of California San Diego (UCSD) and end-users within Caltrans Division of Structures Maintenance and Investigations (SM&I).

Fundamental research products, developed largely by UCSD researchers, consist of a bridge-inspection methodology summary report and an extensive visual catalog of RC bridge damage from both laboratory tests and field observations; all characterized using a consistent engineering terminology tied to bridge performance. Figure 6 illustrates the conceptual engineering framework for classifying damage and typical imagery from the visual catalog.





Level III

Level V

Figure 6: Generalized engineering framework (top) for classifying damaged RC columns that is used as the basis for field inspection decisions. Examples from the visual catalog illustrating typical column appearance for different damage states correlated to the engineering framework.

Products developed jointly by UCSD researchers in collaboration with Caltrans SM&I staff consist of a training manual for visual capacity assessment, an inspection manual with detailed procedures for post-earthquake inspection, and associated slide sets used for training. SM&I has used these materials since 2007 for training of hundreds of Caltrans' staff so they are well prepared to conduct effective and consistent visual evaluations of damaged bridges after an earthquake. .

A spinoff benefit of this research is that the bridge categorization framework developed under this project for bridge inspection procedures is being incorporated into an upcoming research project focused on development of improved fragility relationships to be used in the ShakeCast application for emergency-response alerting and damage prediction.

The research has produced new standard procedures and training materials for rapid visual inspection of damaged RC bridge columns based on a new, fundamentally sound, engineering framework for estimating remaining capacity of damaged bridges from visual cues. The new protocols will allow Caltrans staff to more confidently close those bridges having potentially dangerous levels of damage, and quickly re-open bridges having sufficient reserve capacity. This research will contribute directly to public safety and improved mobility as Caltrans responds to future destructive earthquakes.

Snaplock Fiber Reinforced Composites Technology Applied to Overhead Signs: Design, Construct, and Test a Fiber Reinforced Composite Overhead Sign Truss

Report CA07-0246: http://www.dot.ca.gov/research/researchreports/reports/2008/07-0246.pdf

This project aimed to develop a prototype advanced lightweight overhead sign truss that is fatigue and corrosion resistant, offers extended service life and reduced maintenance, and can be installed rapidly using light duty and less expensive lifting equipment, thus reducing construction cost and worker exposure. Key features of the design concept are the use of fiber-reinforced polymer (FRP) composite, a lightweight high-performance material, and development of innovative "snaplock" connections for easy and rapid assembly on site.

A composite overhead sign bridge was designed and analyzed; key snaplock components were developed; and two 90-ft span trusses were fabricated and tested at both the component and system level under laboratory conditions.

The traditional profile shapes used for steel sign bridges were not copied for the composite sign. Instead two types of "lineals" with a special rectangular cross sections for functionality were designed. The cross-sectional shape and fiber architecture of these tubes is dominated by the requirement for a "snap fit" (fastenerless) assembly. The complexities in geometry and fiber architecture can easily be handled by an automated "Pultrusion" process. However, since Pultrusion-dies are expensive, the "lineals" were first manufactured by hand lay-up and resin infusion on wood tooling. The snap-fit joint created by both parts was subsequently assembled and tested in order to provide proof-of-concept without expensive Pultrusion-dies or the added cost of die modifications. The most extensively loaded joint area in the sign bridge structure was assembled from the two Pultruded tubular sections and subject to the loads which were derived from the analysis as a means to establish load factors and failure modes.

Final products of this task are detailed designs and the fabrication of two 90-ft span trusses for use in future field evaluations. The design of the composite sign structure meets both Caltrans and AASHTO requirements for structural supports for highway signs. The FRP composite material allows the truss to weigh less than 1/3 of the weight of a steel structure, and it can be installed using light duty and less expensive lifting equipment.

The research has produced an innovative prototype overhead sign truss ready for field evaluation. The lightweight snaplock system can be installed rapidly using light duty and less expensive lifting equipment, thus reducing construction cost and worker exposure. The FRP material eliminates corrosion and fatigue concerns, thus providing for an extended service life, reduced maintenance, and reduced hazard to the driving public.

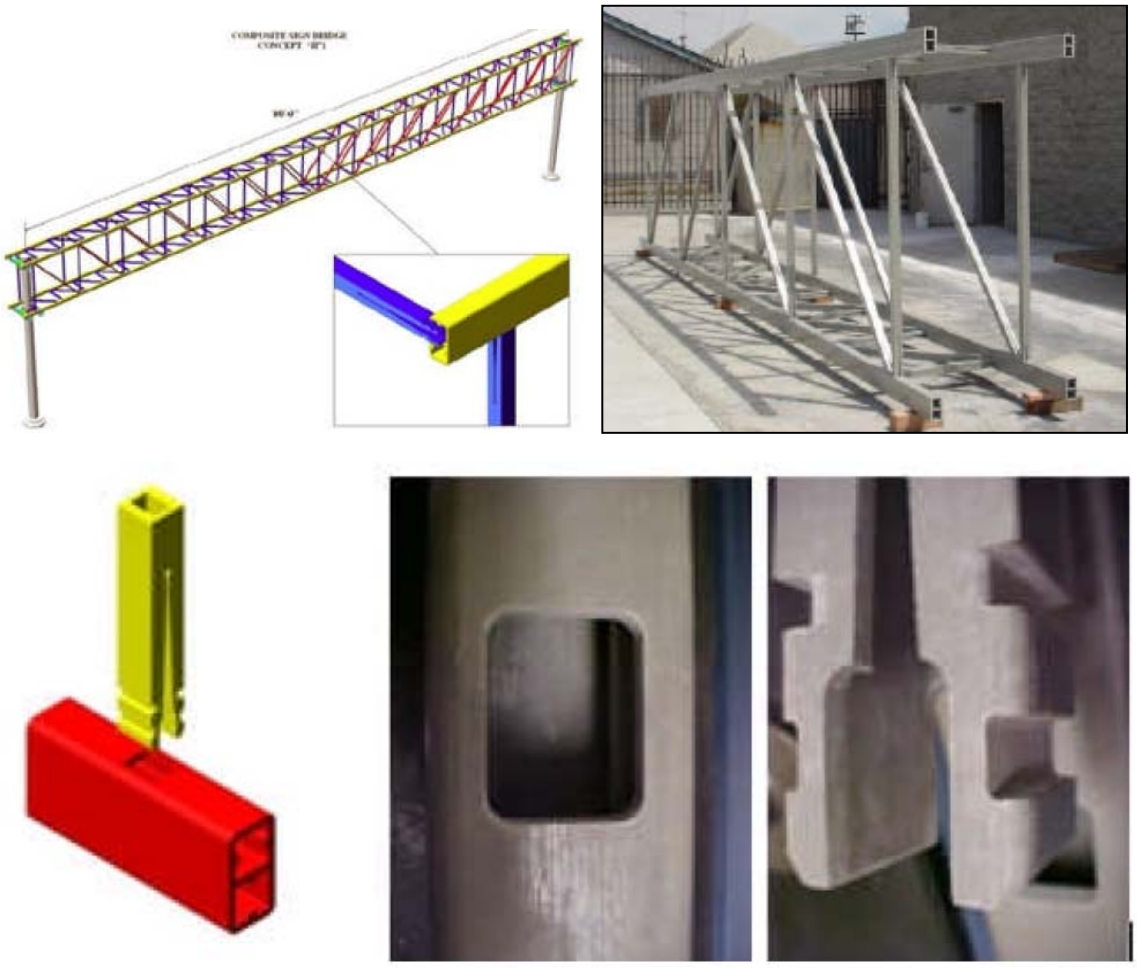


Figure 7: Innovative overhead sign truss design (top left) and center section of 90-ft-span prototype (top right). Detail of critical 'snaplock' design detail (lower left) and close-up of fabricated components (lower center and right).

Effects of Fabrication Procedures and Weld Melt-Through on Fatigue Resistance of Orthotropic Steel Deck Welds

Report CA08-0607: http://www.dot.ca.gov/research/researchreports/reports/2008/08-0607.pdf

This project aimed to resolve uncertainty in the fatigue resistance, and thus service life, of steel orthotropic bridge decks associated with fabrication processes. A common practice in the US for the fabrication of such deck involves using 80% partial-joint-penetration groove welds (PJP) to join closed ribs to a deck plate. Avoiding weld melt-through with the thin rib plate can be difficult to achieve in practice because a tight fit may not always be achievable. When weld melt-through occurs, which is difficult to inspect inside the ribs, it is not clear how the geometric discontinuities affect the fatigue resistance. Furthermore, a distortion control plan, which involves heat straightening or even pre-cambering, is also typically used for the fabricated orthotropic deck in order to meet flatness requirements. It is unclear how repeated heating along the PJP weld line affects the fatigue resistance. A program of laboratory testing was conducted to examine these issues.

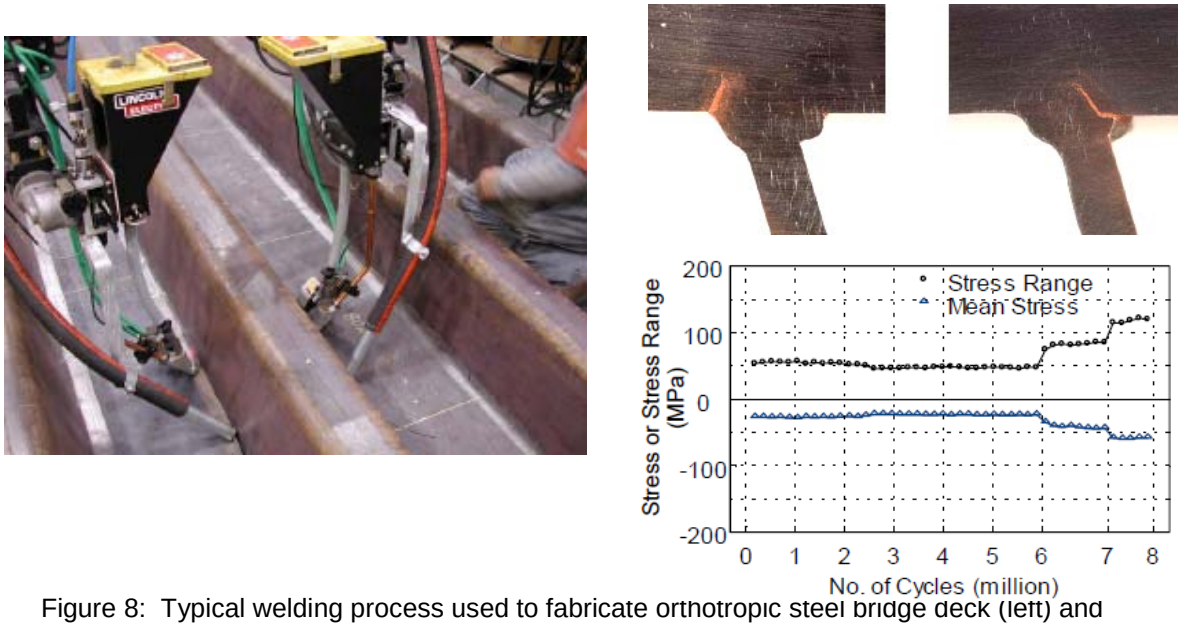


Figure 8: Typical welding process used to fabricate orthotropic steel bridge deck (left) and example fatigue test specimens and data for evaluation of partial-joint-penetration welds (right).

A series of six 2-span, full-scale orthotropic steel deck specimens (10 m long by 3 m wide) were fabricated and tested in order to study the effects of both weld melt-through and distortion control measures on the fatigue resistance of the deck-to-rib PJP welded joint. Three of the specimens were only heat straightened, and the other three were pre-cambered to minimize the need for

subsequent heat straightening.

For each of the two distortion control schemes (i.e. heat straightened, pre-cambered) one of three weld conditions [80% PJP weld, 100% PJP weld with evident continuous weld melt-through, and alternating the above two weld conditions every 1 m] was used for each specimen. Testing involved up to 8 million cycles of loading, which simulated the expected maximum stress range corresponding to axle loads of 3×HS15 with 15% impact, were applied at the mid-length of each span and were out of phase to simulate the effect of a moving truck. The load level and boundary conditions were modified slightly based on the observed cracks that occurred in the diaphragm cutouts in the first specimen.

Observations from the experimental program were used to understand the most critical fabrication parameters that affected fatigue resistance. Based on the loading scheme applied and the test results of the remaining five specimens, it was observed that three specimens experienced cracking at the rib-to-deck PJP welds at seven loaded locations. It was thought initially that weld melt-through, which creates geometric discontinuities at the weld root, was the main concern. However, only one of the seven cracks initiated from the weld root inside the closed rib, and all the other six cracks initiated from the weld toe outside the closed rib. Therefore, based on the loading pattern applied, it appears that these welds are more vulnerable to cracks initiating from the weld toe, not the weld root. For the single crack that developed at the weld root, the crack initiated from a location transitioning from 80% PJP weld to 100% PJP weld. This type of geometric discontinuity may be representative of the effect of weld melt-through in actual production of orthotropic steel decks. Two of the five specimens did not experience PJP weld cracks, and were the ones that were effectively pre-cambered; a third panel was insufficiently pre-cambered and the resulting distortion and heat straightening were the same as required for the un-cambered panels. Therefore, it has been concluded that effective pre-cambering is beneficial to mitigate the crack potential in rib-to-deck PJP welds.

The research has examined fabrication factors that affect the fatigue resistance of steel orthotropic bridge decks. Findings are being used to refine fabrication specifications for new bridges of this type that will lead to longer service life, lower maintenance costs, and reduced maintenance-related traffic congestion.

Investigation of Flange Failures in Falsework Cap and Sill Beams: Recommendations for the Design of Beams and Posts in Bridge Falsework
Report CA06-0629: http://www.dot.ca.gov/research/researchreports/reports/2008/06-0629.pdf

Falsework is the temporary system of structural elements used to support permanent bridge components during the construction process. This research investigation was initiated in response to field observations which identified potential deficiencies in the standard design of falsework that resulted in component failures, specifically localized bending in sill and cap beam flanges and lateral buckling in other beams. The research focused on possible limits

states associated with the bearing of timber and steel posts on cap and sill beams.

A program of analytical and experimental testing was conducted to establish critical limit states and develop recommendations for revised falsework details and specifications. The critical limit states identified were related to flange bending, post crushing or yielding, web yielding, web crippling, lateral web buckling and corbel crushing. Different analytical modeling methods were investigated for predicting the capacity of the flange. The first assumes a uniform stress distribution resulting in bending of the flange. This was found to be adequate for timber posts, but not as accurate as a second, more elaborate, modeling method that accounts for an interaction between flange bending and post compression strength. The third method used an effective bearing area of the post, which was found to be more appropriate for cases with steel posts.

Key findings, design equations and design examples are presented in the project report. For beams with relatively thick webs, such as those typically used in bridge falsework, the web is found to have a greater capacity than the flange and posts. The critical web limit state is web yielding (referred to as web crippling in the Caltrans Falsework manual) and variations of existing equations are found to be appropriate for predicting the capacity. Web crippling (as defined by ASCE) is found to generally not govern the design, particularly when two sill beams are stacked on top of each other. Blocking may be used to increase the flange bending and web yielding capacity, although lateral bracing or stiffeners are recommended to increase lateral buckling capacity. Design equations are presented in allowable stress design format for the consideration of the critical limit states in a falsework bent. These are compared to current Caltrans design practice and other relevant specifications. Two design examples are also provided to demonstrate the application of these equations, one using timber posts and a second using steel posts.

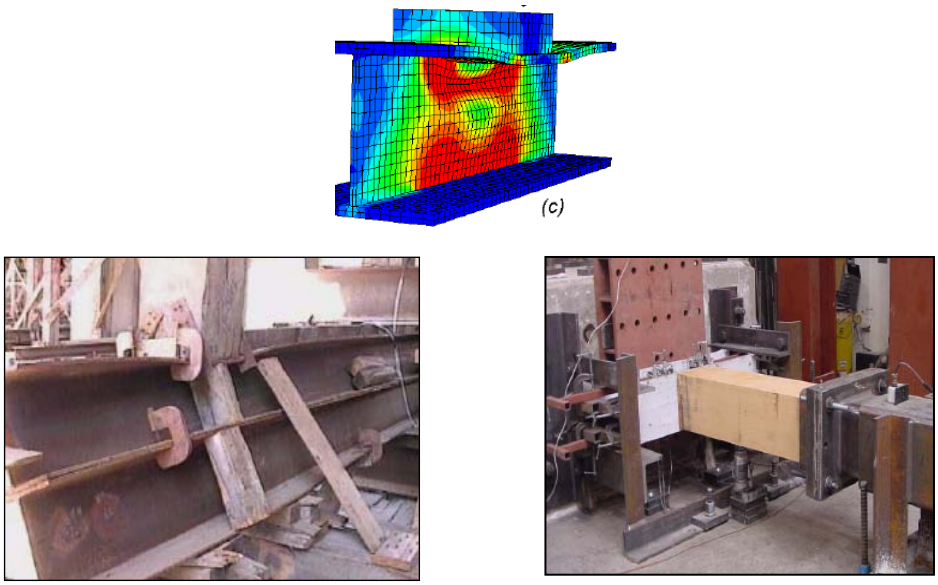


Figure 9: Field example of localized failure of falsework beam (left) and illustrative analytical and experimental investigations (right) conducted to develop recommendations for improved design practice.

The research has produced recommendations for improved falsework design that are being considered for implementation as revisions to the Caltrans Falsework manual. Improvements to these guidelines will improve the safety and performance of falsework at bridge construction sites, thus translating into higher-quality bridge construction delivered faster and with fewer claims.

Load Capacity, Failure Mode and Design Criteria Investigation of Sand Jacks: Full Scale Load Testing of Sand Jacks
Report CA06-0633: http://www.dot.ca.gov/research/researchreports/reports/2008/06-0633.pdf

A “sand jack” is a simple but essential component of falsework used in the construction of cast-in-place bridges. It consists of a sand-filled wooden box held together with steel bands. The sand filler facilitates the removal of the false-work by allowing slow and controlled unloading and lowering of the falsework bracing that becomes wedged beneath the new bridge structure. Though commonly used, a clear understanding of engineering design

Figure 10: Example of “sand jacks” used to support bridge falsework during construction.

requirements was lacking, and no guidance documents existed. The risk is that failed sand jacks can cause a catastrophic falsework collapse and loss of the bridge during construction. Research was needed to establish clear guidelines and standards for use of sand jacks.

This project completed a series of laboratory experiments needed to establish design guidelines. In the first phase, a circular sand-jack made of steel was tested to isolate the response of the two different sand fillers and the effects of the gap between the sides of the sand-jack and the application of the load. It was shown that the finer sand and a larger plunger both caused a stiffer response in the steel cylinder.

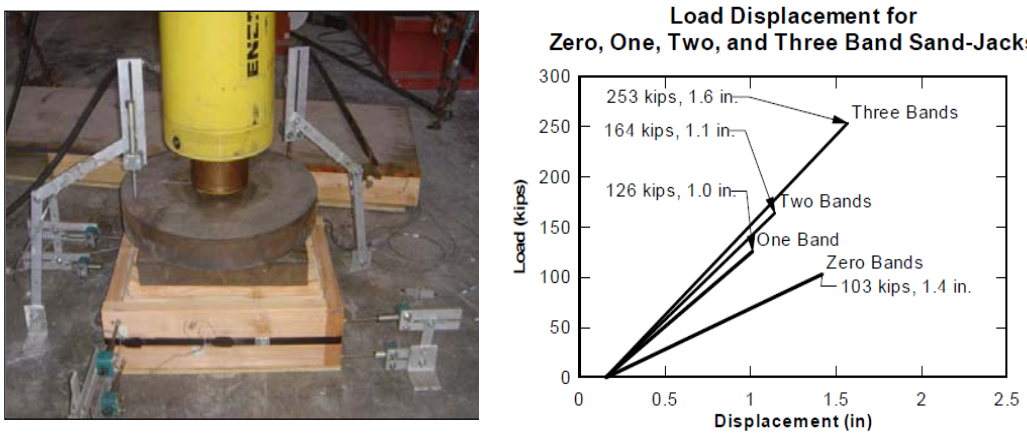


Figure 11: Example of laboratory setup for testing of sand jacks (left) and typical experimental results (right).

The second phase involved testing of several alternative configurations of wood sand jacks commonly used at job sites. For banded jacks undergoing vertical displacements of less than 1-inch, it was shown that a sand-jack with no banding had a stiffness approximately half that of a sand-jack with banding. The number of bands, the spacing of the base nails, location of the banding, and the number of crimp connections on each band had little or no effect on the response. However, the ultimate capacity was found to be significantly affected by the number of steel bands and the spacing of the base nails. Additionally, test results demonstrated no benefit to lining the sand-jack with plastic. The use of a 12-inch wide corbel under a 15-inch wide sand-jack resulted in no adverse effects.

The research has produced a clear understanding of engineering performance of typical sand jack configurations used in bridge construction practice. Results are being used to prepare engineering guidelines and standards. The improved understanding will prevent failures of sand jacks and the consequent catastrophic falsework collapse and loss of the bridge during construction. This will mitigate risks to worker safety, of delayed project delivery, and of increased project claims and costs.

Placement of Mass Concrete for Cast-in-Place Concrete Piling: The Effects of Heat of Hydration of Mass Concrete for Cast-in-Place Concrete Piles
Report CA07-0936: http://www.dot.ca.gov/research/researchreports/reports/2008/07-0936.pdf

Significant heat is generated during the concrete curing process, and too much heat can lead to degradation of the quality of the concrete. The potential deleterious effects of high curing temperatures include cracking (due to strains resulting from differential temperatures), corrosion, and an undesirable chemical process called “delayed ettringite formation (DEF)” which causes a material-related distress or deterioration of the concrete at a later date. DEF potentially occurs when internal concrete temperature exceeds a critical value (e.g. 70°C (158°F)) during the initial hydration period. The probability for DEF increases as the curing temperature exceeds the threshold by greater values.

To control the deleterious effects of high curing temperatures in large-diameter cast-in-place concrete piling, Caltrans has required contractors to use expensive and time consuming mitigation measures. However, it was recognized that the soil surrounding a pile soil is capable of acting as a heat sink, reducing heat buildup in the pile, and thus making it possible to reduce or eliminate the Department's mitigation requirements. This project conducted the numerical modeling research needed to establish engineering guidelines for cost-effective control of curing temperature for large-diameter cast-in-place concrete piling.

This project completed a series of numerical analyses using two different models, ABAQUS and the ACI 207 Schmidt model, to predict the peak temperature in the center of cast-in-place concrete piling. Five idealized concrete piles with varying diameters and made up of concrete mixes with different percentage of fly ash were used. The temperature profiles predicted using the finite element program, ABAQUS, were compared to temperatures predicted by the step-by-step method, ACI 207 Schmidt model. The results show that the ABAQUS model correlates better to experimental results and yields better predictions of the temperature profiles than the Schmidt model. The latter is faster to run but overestimates the peak temperature. Using the results from the ABAQUS model, a specification can be recommended that will result in acceptable concrete for large CIDH piles in the range of 6 to 14 feet in diameter.

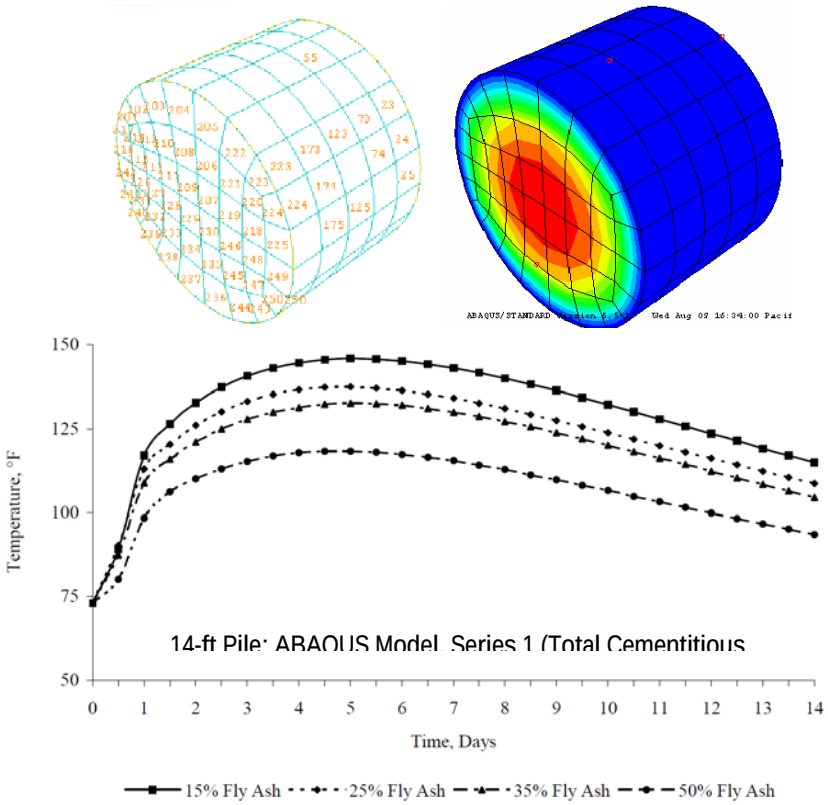


Figure 12: ABAQUS finite element mesh (top left) and graphic showing computed heat distribution (top right). Example ABAQUS results for a 14-ft diameter concrete pile having different proportions of flyash additive for temperature control (bottom).

The research has produced findings needed for Caltrans to establish engineering guidelines for cost-effective control of curing temperature for large-diameter cast-in-place concrete piling. Reduction or elimination of temperature mitigation requirements reduces bridge foundation construction costs and speeds project delivery.

Assessment and Prediction of Long-Term Durability of Fiber Reinforced Polymer Composite Bridge Structures to Rehabilitate Bridges

Report CA08-0248: To Be Posted

Fiber reinforced polymer (FRP) composites have been successfully used in the industrial, automotive, marine and aerospace sectors; however, their use in civil applications is lagging due in part to insufficient understanding of critical differences in loading, environment and even the types of materials and processes used in these applications. Some successful civil applications of FRP composites include pipelines, underground storage tanks, building facades, and architectural components. While the long-term durability of these materials is often stated as being the main reason for their use in civil applications, their durability depends intrinsically on the choice of constituent materials, method and conditions of processing, and surrounding environmental conditions throughout

their service lives. Anecdotal evidence provides substantial reason to believe, if appropriately designed and fabricated, these systems can provide longer lifetimes and lower maintenance costs than equivalent structures fabricated from conventional materials. However, actual data on durability is sparse, not well documented, and in cases where available – not easily accessible to the civil engineer. This project addresses several key knowledge gaps in the long-term engineering performance of FRP composites for common environmental conditions encountered in bridge rehabilitation applications.

System	Composite System	Fabric Weight (g/sq. m)	Matrix System	Process	Fiber Volume Fraction in Composite Layer
S1	Unidirectional E-glass fabric with hot melt adhesively bonded bicomponent thermoplastic thread in the transverse direction	913	High-tack, low VOC, 2 component 100% solids epoxy resin with a resin viscosity of 2500 cps at 23°C	Wet Layup	28%
S2	Unidirectional carbon fabric with hot melt adhesively bonded bicomponent thermoplastic thread in the transverse direction	618			33%
S3	Unidirectional tow based carbon fabric	300	Two component epoxy resin formulated for summer application (15-35°C) with a viscosity of 2700 cps at 23°C and a 120 minute pot life	Wet Layup	27%
S4			Two component epoxy resin formulated for winter application (5-15°C), by addition of acrylate, with a viscosity of 3500 cps at 23°C	Wet Layup	32%
S5	Unidirectional carbon fabric with aramid cross fibers	644	2 component epoxy resin with a viscosity of 600-700 cps at 23°C	Wet Layup	29%
S6	Prefabricated unidirectional carbon /epoxy pulformed strip		Paste form, two component, solvent free, epoxy adhesive	Adhesive Bonding	62%
S7	Unidirectional carbon fabric with stitch-bonded transverse epoxy coated glass yarn	300	Two component, 100% solids, epoxy resin with a viscosity of 700-900 cps at 23°C	Wet Layup	26%
S8		600			34%
S9	Prefabricated carbon pultruded strip		Paste form, two component epoxy adhesive	Adhesive Bonding	61%
S10	Prefabricated carbon pultruded strip		Two component, 100% solids, non sag paste form epoxy adhesive	Adhesive Bonding	69%

System	Type	Modulus				Strength			
		Immersion in Deionized Water at 22.8°C	Immersion in Deionized Water at 37.8°C	Immersion in Salt Water (5% NaCl solution) at 22.8°C	Immersion in Concrete Based Alkali Solution at 22.8°C	Immersion in Deionized Water at 22.8°C	Immersion in Deionized Water at 37.8°C	Immersion in Salt Water (5% NaCl solution) at 22.8°C	Immersion in Concrete Based Alkali Solution at 22.8°C
S1/S2	Resin	0.83	0.84	0.90	0.89	0.93	0.95	0.93	0.90
S3	Resin	0.88	0.75	0.9	0.88	0.86	0.82	0.86	0.86
S4	Resin	0.20	0.17	0.18	0.22	0.17	0.17	0.17	0.14
S5	Resin	0.78	0.77	0.75	0.77	0.87	0.84	0.84	0.86
S6	Adhesive	0.90	0.86	0.97	0.90	0.95	0.88	0.88	0.77
S7/S8	Resin	0.80	0.64	0.83	0.87	0.82	0.72	0.84	0.86
S9	Adhesive	0.59	0.49	0.66	0.62	0.61	0.53	0.62	0.59
S10	Adhesive	0.57	0.54	0.63	0.45	0.55	0.53	0.62	0.46

Figure 13: Range of FRP systems evaluated (top) and example results for normalized retention of tensile characteristics from long-term testing of FRP systems under environmental conditions typical for bridge rehabilitation applications (bottom).

Laboratory test results are provided for a representative range of FRP composite systems applicable for bridge rehabilitation. More specifically, this report provides: (a) pull-off test results to assess bond-strength between concrete and the FRP system; and (b) long-term material properties (e.g., modulus, strength and glass transition temperature) of FRP composites when subjected to environmental factors such as moisture, temperature, and salts that leach from concrete. Results are presented in a format that follows MIL-HDBK-17 in part, while preserving the primary requirements of ease of use by the civil design and owner communities.

The study also identified the need for additional work to: (a) assess and characterize the effects of incomplete cure and under cure, especially for

ambient temperature cure systems; (b) develop standardized solutions and conditions for laboratory studies that closely simulate actual field conditions; and (c) develop appropriate resin systems, gel coats, and coatings that would serve as protective layers for the bulk composite against external influences including environmental conditions, intended and accidental damage.

The testing program addressed key gaps in engineering data for use of a range of alternative advanced FRP composite materials in bridge rehabilitation applications. These data are being used to develop design specifications and engineering guidance documents for use of these materials in long-lasting bridge repairs. The public will realize savings from reduced long-term bridge maintenance costs and increased mobility from fewer repair-related traffic interruptions.

Monitoring of Prestressing Cables in Segmental Box-Girder Bridges
Report CA09-0938: To Be Posted

Prestressing (PS) tendons are the main load carrying component of post-tensioned structures including box-girder bridges. In California, post-tensioned box-girder bridges constitute 90% of all bridges built today. Material degradation of the tendons may result in a reduced load capacity of the structure that can lead to poor performance and even collapse. Degradation of the tendons is usually initiated by corrosion that, if not detected early, can lead to cable breakage. The loss of prestress associated to the tendon breakage can be catastrophic. Loss of prestress can also result from inelastic seismic response in the bridge superstructure such as concrete cracking. Unfortunately, today there is no well-established method for the monitoring of PS tendons that can provide simultaneous information on the levels of applied prestress and tendon damage (grout cracking, wire breaks, etc.) in a continuous, real-time manner.

This project aimed to develop and demonstrate a health monitoring system for prestressing (PS) tendons in post-tensioned concrete structures, including the popular segmental box-girder bridges. The technique under investigation was based on ultrasonic guided waves and embedded sensors. The goal was to provide both detectability of defects in the tendons such as corrosion and broken wires, and measurability of applied prestress levels.

The project completed a literature review and a coordinated series of numerical analyses and laboratory experiments. The literature review broadly examined alternative techniques available for health monitoring of concrete structures, particularly for cables and PS tendons. The majority of the work develops results from both numerical simulations and experiments of wave propagation in unloaded and loaded seven-wire strands, both free and embedded. Of particular interest is the identification of certain linear and nonlinear ultrasonic wave properties which were sensitive to the level of prestress applied to the strands. Those features were exploited, in combination with acoustic emission technique, to monitor the stress level in strands and to detect and localize defects during testing of large-scale post-tensioned concrete joints.

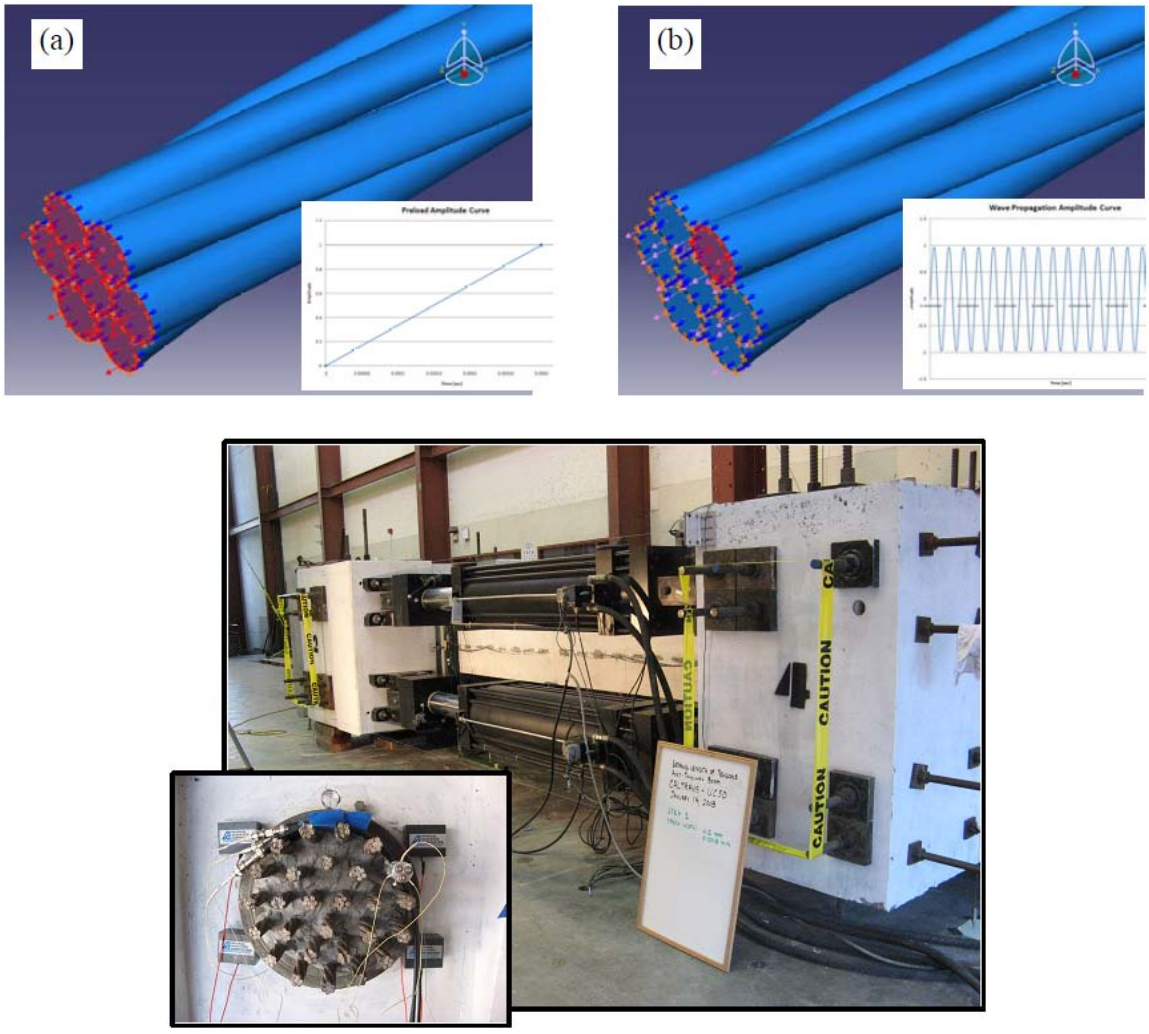


Figure 14: Example illustration from numerical simulation showing static and dynamic loading applied to 7-strand PS strand (top) and large-scale laboratory test setup used for evaluating the potential of proposed ultrasonic monitoring strategy for both monitoring prestress forces and detection of damage in cables (bottom).

The research has demonstrated that ultrasonic probing of the PS strands can indeed be effective for the detection of defects as well as for the monitoring of PS forces in post-tensioned concrete structures. The study recommends exploiting a combination of linear and nonlinear ultrasonic features for monitoring prestress levels in PS strands, and an Acoustic Emission monitoring capability to detect and locate the evolution of damage caused by a prestress loss or other factors. These techniques would require the installation of a limited number of small piezoelectric sensors in a loaded portion of critical PS strands and/or in the concrete soffit of the PT bridge. The proposed approach is applicable to both new structures and existing structures.

The research has demonstrated the basic viability of new methods for sensing the condition of embedded prestressing cables that are essential to bridge function of carrying load. With further validation under field conditions, the proposed strategy could be implemented by Caltrans maintenance engineers to detect any loss of tendon load or capacity, and would serve as clear warning of deteriorating capacity of a bridge. Such warning would facilitate timely repair and maintenance that would assure bridge safety and load rating, and would ultimately extend bridge life and thereby reduce long-term operation costs.

Assess Post Grouting to Enhance the Capacity of Foundations

Pile axial load-carrying capacity is derived from two components: tip bearing and shaft friction. Both resistances are developed as a function of downward displacement of the pile under load. While shaft friction develops at very low values of pile displacement (i.e. bridge foundation settlement), the displacement normally required to develop tip resistance is typically too large to be considered in design as it would lead to distress within the bridge structure. However, compaction post grouting at the tip of pile foundations is recognized to substantially reduce the displacement required to develop tip resistance, thereby allowing engineers to design shorter and/or smaller-diameter systems having lower cost.

This project aimed to develop recommended engineering design parameters and specifications for compaction post grouting as a means to increase the capacity of bridge foundations. The work consisted of the development of an analytical methodology and validation of the methodology through a series of large-scale laboratory tests conducted for a model pile placed into various soils.

The testing program required development of a new large-scale test apparatus (“calibration chamber”) and associated instrumentation capable of modeling field conditions. A total of four pairs of test specimens were prepared and tested. A ‘pair’ consisted of an ungrouted and grouted pile installed in an identically-prepared soil. Two different sand soils were used, each prepared at two values of relative density considered representative of a range encountered in the field. Load tests were performed on each pair, and results were compared and used for calibration of the proposed analytical methodology. The test apparatus and

typical results are shown in Fig. 15.

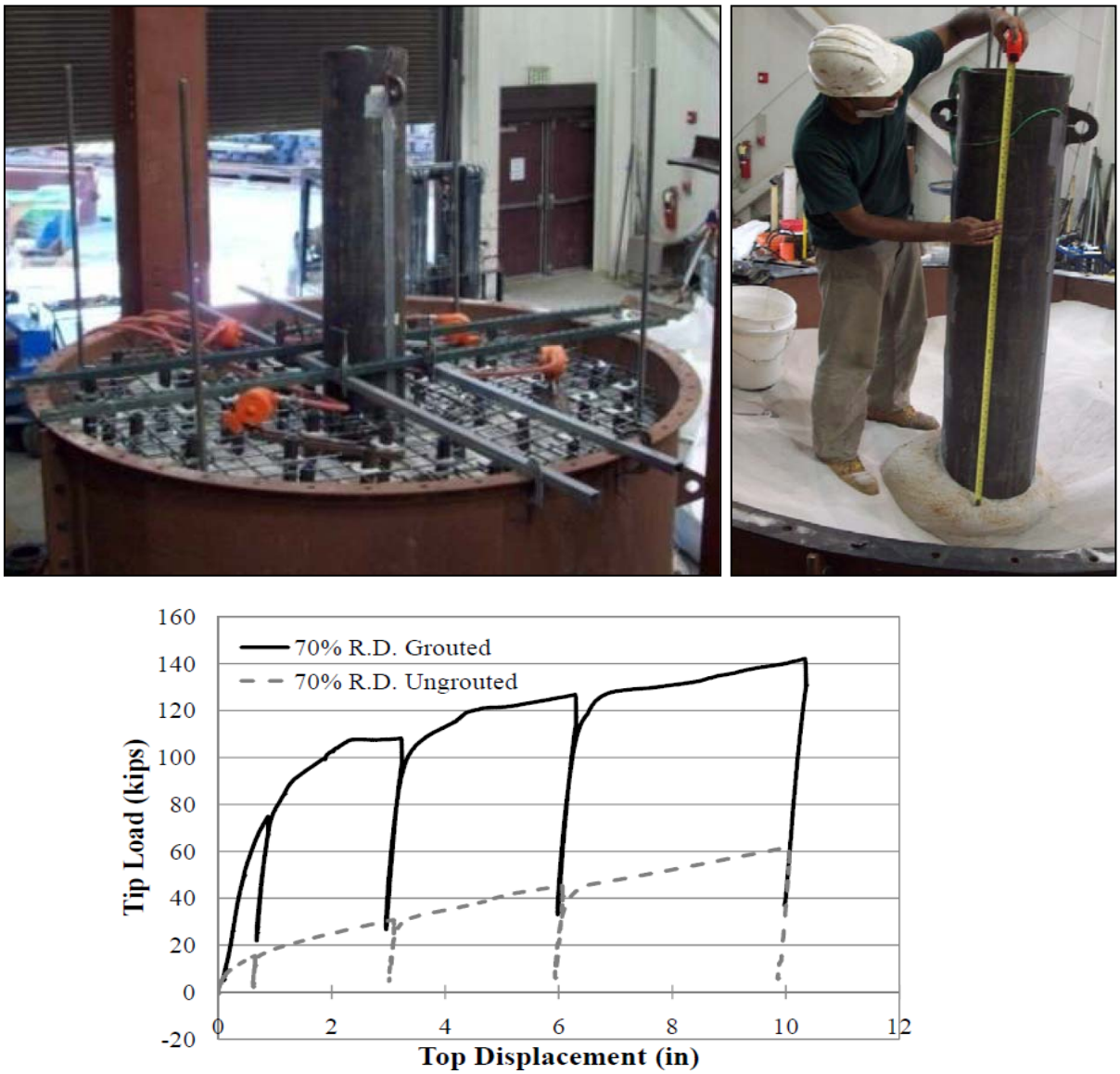


Figure 15: Laboratory test setup showing model pile in sand-filled calibration chamber before test (top left) and exposed grout bulb at pile tip after testing (top right). Example load test results (bottom) showing large increase in tip capacity and initial stiffness resulting from post-grouting technique.

This task completed initial laboratory phases of a project to develop a reliable engineering design methodology for compaction post grouting as a means to increase the capacity of bridge foundations. A subsequent task is now underway to verify laboratory results under field conditions. When complete, the recommended methodology will allow engineers to design more efficient deep foundations to support bridges, thus reducing construction costs.

Concrete Bridge Deck Crack Sealing/Filling: An Overview of Research
Report CA07-0634: To Be Posted

Cracking in concrete bridge decks is a long-term durability and maintenance problem. Cracks propagate through the deck allowing rapid ingress of moisture and chloride ions into the concrete interior, thus leading to excessive deterioration due to rebar corrosion. It occurs in most geographical locations and climates, and in many types of bridge superstructures. Common mitigation measures are to apply surface treatment sealers, which decrease the permeability of concrete, and/or to seal/fill the cracks to prevent the direct intrusion of chloride-bearing water. Caltrans spends in excess of $100 million annually on crack sealing of state-owned bridges, and most commonly uses High Molecular Weight Methacrylate (HMWM) as the filler material.

This project aimed to review the literature as well as experience and best practices of other state DOT's regarding use of crack sealers on concrete bridge decks to ensure the Department is using the most effective bridge treatment methods. Particular attention was focused on use of HMWM and the development of guidelines concerning the use of HMWM along with alternative successful sealers.

A literature review was conducted to provide broad context to the classification, function and application of various sealers and crack fillers. DOT practices regarding use of sealers were captured through a nationwide survey. Parametric studies examining the effects of sealers on the service life of bridge decks were conducted for case studies patterned after conditions in three California locations. Findings and specific recommendations regarding most effective types and application of sealers for various bridge conditions and environments are summarized.

Type of Sealant	Caltrans	# of DOTs[1]	Percent,[2] %
HMWM	x	17	42.5
Epoxy		21	52.5
Polyester		3	7.5
Other[3]		15	37.5

1 Other than Caltrans
2 Some DOTs reported using more than one sealer
3 Include Urethanes, Silanes, Siloxanes, Linseed Oils and Bituminous membrane.

Surface Prep.	Caltrans	# of DOTs[1]	Percent,[2] %
Bower Broom		6	15.0
Forced Air		11	65.0
Pressurized Water		2	12.0
Other[3]	x (sand blasting)	5	12.5

1 Other than Caltrans
2 Some DOTs reported employing more than one technique
3 Include sand blasting, shot blasting, and follow manufacturer instruction

Figure 16: Example nationwide DOT survey findings for type of sealant used (top) and surface preparation technique employed (bottom).

The project produced a practical compilation of knowledge and nationwide experience regarding the application of crack sealers and fillers to reduce the rate of concrete bridge deck deterioration. The product is allowing Caltrans bridge maintenance engineers to evaluate and update their standards, specifications and practices to more effectively use these materials to extend bridge service life and reduce long-term costs and traffic disruptions associated with bridge or bridge-deck replacement.

Validation of Coaxial Cable Sensors for Dynamic Crack Detection in RC Columns Under Blast Loads

Report CA09-1096: To Be Posted

This low-cost ($25k) project was approved as part of the 2006 “New and Innovative” research solicitation. Detection of concrete damage (spalling and cracking) in relatively inaccessible structural components such as piles or jacketed (steel or FRP) bridge columns is difficult or impossible using conventional nondestructive evaluation techniques. The project aimed to conduct proof-of-concept tests for using recently-developed (“topology-based”) cable sensors and Electrical Time-Domain Reflectometry (ETDR) measurement for real-time detection of the location and time of cracking within structural concrete members subjected to dynamic loading

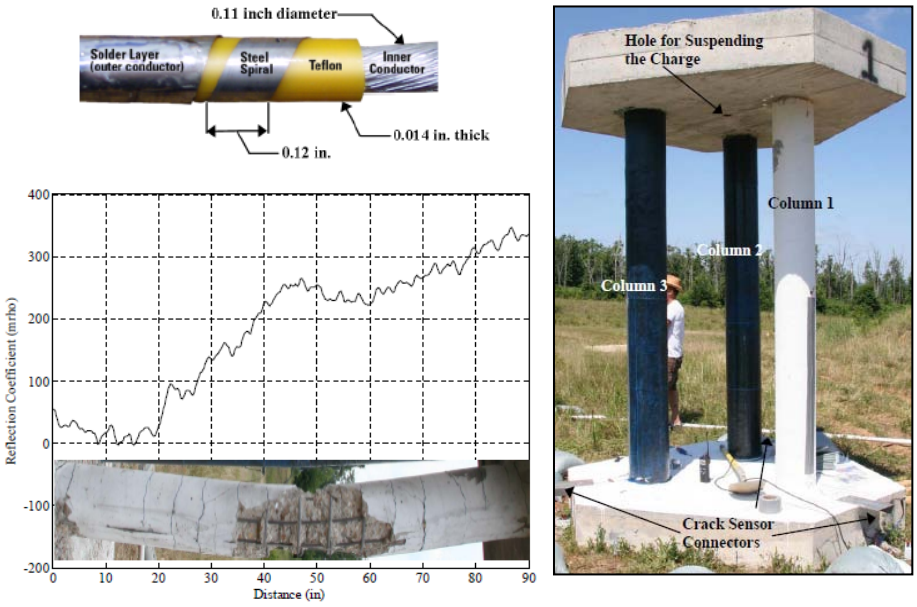


Figure 17: Cable sensor (top left) used with ETDR measurement for detecting damage to concrete columns subjected to blast loads (right). Example test results superimposed on damaged column (bottom left).

Proof-of-concept objectives were achieved by testing three columns under blast loads: one control specimen and two retrofitted specimens. One cable sensor was installed on the rear (tension) face of each column prior to any strengthening. Results indicated that the sensor and ETDR measurement instrument used during the tests shows the correct overall distribution of cracks and the location of plastic hinges. The sensitivity of the sensors for crack detection is high in comparison with the noise level; however, the local peaks were not observed for individual cracks due to the limited spatial resolution associated with the measurement instrument used during the blast tests. In the plastic hinge area, the time history of crack opening and closing corresponds well with the strain change measured from the nearby steel reinforcing bar.

The project successfully demonstrated proof-of-concept of this emerging technology to remotely and non-destructively detect damage to reinforced concrete structural members. Further research is needed to fully develop the potential of this technology for production bridge maintenance and/or structural health monitoring applications. If successfully deployed, bridge maintenance engineers will be able to quickly assess the location and extent of hidden damage caused by dynamic events such as earthquakes, blasts, or impacts, and thus allow for faster and more effective bridge repair and faster restoration of traffic.

Improvement of Caltrans Pile Design Methods through Synthesis of Load Test Results

Report CA03-0004: In Preparation

Bridge foundations represent one of the most costly and uncertain elements of Caltrans' bridge design. Field proof tests have shown that current ‘desktop’

design procedures used to predict axial pile capacity can differ from actual field capacity by a factor of two or more, frequently resulting in unnecessarily conservative designs. To overcome this deficiency, Caltrans conducts full-scale field load tests for many important bridge projects (see fig 18). Over the last 50 years Caltrans has performed over 300 load-tests on driven test piles at over 75 bridge locations. These test data represent an investment of tens of millions of dollars, and are among the most extensive archives of its kind in the world. The primary objective of the project was to evaluate existing pile capacity procedures against this test data, and to recommend adjustments to these procedures that better reflect California soils and Caltrans foundation types.

The project effort initially focused on systematic collection and organization of existing data that existed in various paper and electronic formats dispersed within Caltrans project archives. Upon close review, it was determined that the majority of load-test site locations were insufficiently characterized to meet research-quality standards. To address these shortcomings, the project performed an additional 50 borings and 58 cone soundings at select load-test locations. Undisturbed sampling and laboratory testing was also performed to complete the site characterization.

This data was combined with existing data and analyzed to evaluate common 'desktop' design procedures for estimating pile capacity. Initial analyses found that pile capacity estimates have the highest uncertainty in sandy soil conditions and that methods that rely on SPT blow counts to estimate capacity seemed to perform best. Additional analyses are now being performed under a subsequent task.

Figure 18: Typical Caltrans setup for full-scale field load test of the axial load-carrying capacity of a large pile foundation. Test pile and loading mechanism located beneath center of load frame and four reaction piles located at perimeter.

The project has successfully organized and enhanced a valuable data asset, and

initial refinements to ‘desktop’ pile design procedures have been developed. Subsequent tasks under this project will complete a more comprehensive set of analyses, evaluate proposed LRFD resistance factors, and the data will be made broadly available. Improved procedures for estimating pile capacity will reduce the occurrence of unnecessarily conservative and costly bridge foundation designs.

Enhanced Pile Load Test Instrumentation and Testing

Report CA07-0717: In Preparation

Current foundation load-test practice within Caltrans is aimed at determining the ultimate capacity of the pile and verifying that the installed pile meets design load requirements. Load and deformation measurements are typically limited to the top of the pile, and no instrumentation is normally included that would allow isolation of tip loads or how load is shed with depth through shaft friction. In many circumstances, significant benefit could be realized at only minor additional cost if supplemental instrumentation and testing were included in the load-testing program. This internal project focused on practical evaluation of alternative pile load test instrumentation that would provide the designer with a much more complete understanding of foundation load transfer.

Figure 19: Four types of strain sensors (top) being evaluated for use in enhanced pile load test instrumentation setup. Instrumentation being mounted to reinforcing cage of large-diameter CIDH foundation (bottom left) and cage being installed into drilled hole (bottom right).

This project investigated the effectiveness and practical challenges of using supplemental load test instrumentation on two large-diameter CIDH pile load tests. Four types of off-the-shelf strain gauges were evaluated including both vibrating wire and fiber-optic systems. Strain measurements at various instrumentation levels are compared and general observations are made regarding the utility of enhanced load test instrumentation.

Key findings include: 1) vibrating wire instrumentation exhibited greater ease-of-use, versatility, and lower initial cost than fiber optic based instrumentation, 2) fiber-optic instrumentation is preferred if higher accuracy and sampling rates are important, and 3) installation of the supplemental instrumentation is labor intensive and additional time must be built into the testing schedule.

Practical experience has been gained in fielding a successful enhanced instrumentation array in a CIDH static pile load test. The added effort required to install the enhanced instrumentation will limit its application to key projects. Nevertheless, for such projects, the added knowledge gained could be used to effectively reduce foundation costs or economically remedy a foundation system that does not meet design requirements, thus providing substantial project cost savings.