120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #6419

Public Works for Public Learning: A Case Study

Dr. Thalia Anagnos, San Jose State University

Thalia Anagnos is a professor in the General Engineering Department at San Jose State University where she has taught since 1984. Her research interests are in structural engineering, earthquake loss estimation and risk analysis, engineering education, and informal education. On this project she is helping to develop materials aimed at K-12 that complement the exhibits.

Becky Carroll, Inverness Research, Inc.

Becky Carroll has worked for Inverness Research since 1990. Her work has involved studies of K-12 mathematics and science education, as well as studies of exhibition and program development in the informal science field. In the informal field, her areas of interest include studies of collaboratives and networks, programs for youth, exhibition development projects, and professional development for museum professionals. In the formal field, she has participated in studies of mathematics and science program improvements and teacher professional development. Past and current projects in the informal domain include studies of the Center for the Advancement of Informal Science Education (CAISE); the TEAMS collaborative; Community Science Workshops; and the Precollege Science Collaborative and ITEST grant programs at the American Museum of Natural History; exhibit development projects at the Golden Gate Bridge, the North Carolina Museum of Life and Science and the Exploratorium; as well as the TexNET and Playful Invention and Exploration networks. On the formal side, projects include the Rapid City Math Science Partnership, the Maine Physical Sciences Partnership, the Appalachian Math Science Partnership, the Wyoming Middle School Mathematics Initiative, the Gilbert Systemic Science Plan (LSC), and the Appalachian Rural Systemic Initiative.

Ms. Shannon Weiss, David Heil & Associates, Inc.

Shannon Weiss specializes in the design and implementation of evaluation and market research projects related to DHA's core areas of emphasis in science, engineering, health, and environmental education; and institutional strategic and business planning. Her work serves a range of academic institutions, government agencies, corporations and non-profit enterprises including projects funded by the National Science Foundation and the National Institutes of Health. Prior to joining DHA, Shannon designed and conducted evaluations for Seattle's Woodland Park Zoo, Burke Museum of Natural History and Culture, and the Pacific Science Center. Shannon received a BA in Art History from the University of Evansville in Evansville, IN; an MA in Museum Studies from the University of Washington in Seattle, WA; and was a member of the initial cohort of the University of Washington's IMLS funded New Directions in Audience Research Program.

Mr. David R. Heil, David Heil & Associates, Inc.

David Heil, President of David Heil & Associates, Inc., (DHA) is well known as an innovative educator, author, and host of the Emmy-Award winning PBS science series, Newton's Apple. Active in promoting public understanding of science for over 30 years, he is a frequent conference and workshop presenter on science, technology, engineering, and mathematics (STEM) education, and his firm provides research and evaluation services for a broad range of government, corporate, non-profit and university clients. David is a co-author of Family Engineering: An Activity and Event Planning Guide, and serves as a member-at-large on the Executive Committee of ASEE's K-12 Division.

Public Works for Public Learning: A Case Study

Abstract

With the goal of educating the general public about engineering principles, outdoor exhibits next to the Golden Gate Bridge provide hands-on experiences and displays that explain concepts such as forces in the main cables and suspenders, the function of the towers and the anchorages, aerodynamics of the bridge deck, torsional resistance of the bridge deck, and bridge vibration, to name a few. As part of the dissemination plan for this project, the *Public Works for Public Learning Conference* brought together representatives from both large and small public works projects from around the world to share their successes in using these projects for raising public awareness. This paper summarizes some of the key lessons from this project.

Introduction

Large- and small-scale public works projects are important in the smooth operation of every community, yet a majority of the population has little awareness of how these projects work and what their functions are. Few non-engineers understand the engineering challenges of delivering clean water, disposing of our sewage, or changing a traditional intersection into a round-about, a project that seems quite simple on the surface. According to a 2002 National Academy of Engineering (NAE) study on technological literacy[1] few people are "aware that modern technology is the fruit of a complex interplay between science, engineering, politics, ethics, law, and other factors," and therefore they are unable to make informed personal or policy decisions about technology development, priorities, and use. Greater knowledge of the underlying science and engineering needed to design and operate public works and the impact of public works on our quality of life will contribute to the *knowledge* and *ways of thinking* characteristics of a technologically literate citizen as defined in the 2002 NAE study[1].

A consortium of public works engineers, science museums, faculty, and exhibit evaluators have been involved in the project funded through a grant by the National Science Foundation awarded to the Golden Gate Bridge, Highway and Transportation District (GGBHTD) to build an outdoor exhibition next to the Golden Gate Bridge. When completed, the exhibition will consist of an 85-foot long 1:80 precise scale-model of the bridge accompanied by about two dozen exhibits strategically placed around the site. Most of these satellite exhibits are already installed. Some are hands-on interactive exhibits, while others are more traditional informational panels. Topics range from cultural, such as the history of the bridge and the Art Deco design, to engineering, such as the design of the towers and retrofit for seismic forces. EHDD Architecture worked closely with the GGBHTD and the National Park Service to design the exhibition layout to accommodate the high visitor flow (approximately 10 million people visit annually, and in the summer up to 6,000 bicyclists alone cross the Bridge daily). The exhibits are located to take advantage of people's natural impulse to gravitate to the locations with the best views of the bridge. Exhibit design took into account the diverse ages, languages, and educational goals of the visitors as well as accommodations for the disabled and visually impaired. Exhibits are complemented by web content (in nine languages in addition to English) so that visiting school groups and the general public can explore the topics in more detail after their visit. Formative assessment was used throughout the exhibit development to incorporate public and expert feedback into the exhibit design. Summative assessment of the entire project is ongoing[2].

With the goal of increasing awareness of the potential for public works sites to deliver programming on STEM (Science, Technology, Engineering, Mathematics) topics, the *Public Works for Public Learning Conference* brought together representatives from large-scale and small-scale public works projects from around the world to share their successes in using civil engineering projects for informal public education. Strategies ranged from teaming with local arts councils to host events at public works sites, to more traditional visitors center displays and tours.

Public Works in Free Choice Learning

Science museums and science centers around the world offer exhibits that encourage visitors to explore science and engineering concepts, ask questions, and engage in discussion with the goal of increasing technological literacy. A 2008 study by the Consortium of Universities for Research in Earthquake Engineering (CUREE)[3] documents a number of museums and exhibits dedicated to informing the public about civil engineering accomplishments and history. These range from the National Building Museum in Washington DC that is "devoted to the history and impact of the built environment"[4] with exhibits about architecture, engineering and design, to an individual exhibit on water movement and water pressure (*WaterWays*) at the Children's Discovery Museum of San Jose[5]. *Tech City* is a traveling exhibit developed by the Sciencenter in Ithaca NY that allows visitors to "solve the kind of real-world problems that engineers face."[6] Some exhibits use former civil infrastructure such as an offshore oil drilling rig[7] or former research facilities such as the San Francisco Bay Model[8], to provide engaging realistic experiences for the public. Less common and to a large extent untapped as a resource for free choice learning, are existing public works projects.

Historically, public works projects have used a variety of formats for education and outreach. These include public informational meetings; flyers, brochures, and posters; informational websites; open houses and guided tours; fairs and festivals; flat panel displays; and interpretive signage[9]. Few outdoor public works exhibits on the scale of the Golden Gate Bridge museum exist. The *Public Works for Public Learning Conference* explored "how to develop effective public exhibits and educational programs based on the themes of infrastructure, construction, and engineering."[10] Presenters described how they have built and managed free choice learning experiences around large internationally recognized infrastructure including the Sydney Harbour Bridge[11], the Panama Canal[12], and the Eiffel Tower[13], as well as smaller local and regional projects such as the Hyperion wastewater treatment plant in Los Angeles[14] and the WaterWorks at Arizona Falls in Pheonix[15].

Strategies for delivering content include high-cost curated exhibits about the history of the projects, profit-making interactive experiences such as climbing to the top of a bridge, and low-cost informal gatherings, for example hosting science days at the venues. The City of Los Angeles remodeled an old administrative building on the site of the Hyperion wastewater treatment plant and turned it into the Environmental Learning Center, aimed primarily at school groups, that houses a classroom, auditorium, and exhibits to complement on-site tours. The facility is designed to LEED Gold certification, allowing visitors to also learn about construction with recycled materials, environmentally friendly landscaping, alternative energy, and the use of green roofs for environmental efficiency[14]. In addition, visitors can take a virtual tour of the facility on the LA Sewers web site[16]. A particularly creative free choice learning experience involved a partnership between the Salt River Project (SRP) and the City of Phoenix Office of Arts and Culture to bring together art exhibits and modern dance to attract visitors to the annual dry up (Figure 1). Visitors interacted with SRP staff as they relocated the white amur, a carp used to control vegetation. Staff informed visitors about silt, canal maintenance, the importance of keeping garbage out of the canal, and the use of fish for eating weeds[15].

Figure 1. Public art displays and modern dance performances at the Arizona Canal annual dry up and fish herding were used to attract visitors and discuss the importance of the canal. (source: Duncan[15])

Themes repeated throughout discussion of these projects at the conference include:

- Public works projects provide excellent settings for teaching about important current science and technology topics (global climate change, sustainability, environmental stewardship, biodiversity, etc.) as well as engineering principles and the impact of public works on society.
- Free choice learning projects and activities, particularly those that invite public comment, can result in the community being more supportive of public works projects.
- Partnerships (schools, government agencies, community groups, professional organizations, private companies, etc.) are essential to offering a variety of engaging programs and attracting a diverse set of visitors.
- Pervasive new technologies (mobile phones, Internet, video games and virtual worlds, etc.) and cyberlearning has changed visitors' expectation of their experience.
- Exhibits must speak to multicultural, multilingual, multigenerational audiences.
- Funding is one of the challenges/barriers to developing public works free choice learning experiences. Funding sources include National Science Foundation, public works agencies, environmental agencies, energy agencies, and parks and recreation, corporate and community foundations, local businesses and industries, as well as private businesses with financial interest in the project.[9]
- Using the engineering and scientific artifacts to tell stories effectively engages the public.
- Non-traditional delivery mechanisms such as art, pop culture, and music can inspire learning about public works.

Many of these themes apply to the development of the Golden Gate Bridge outdoor exhibition project.

Golden Gate Bridge Exhibit

Approximately 10 million people visit the Golden Gate Bridge each year (not counting the many more who traverse in motor vehicles). Before this project, most visitors would walk out on the bridge for a few minutes, take a photo (fog permitting!), visit the gift shop, and return to their vehicles. Informal education opportunities at the site were limited to a statue of Chief Engineer Joseph Strauss, a cross-section of the main cable, and various publications in the gift shop. Although the site has numerous historical military installations including Battery Lancaster, little information was available about what they are and why they are there. The goal of the project, led by the GGBHTD and CUREE, in collaboration with the National Park Service, the Golden Gate National Parks Conservancy, and the American Public Works Association (APWA) was to enhance the visitor experience by increasing their awareness of, and interest in, the science and engineering of the bridge while respecting the historic and scenic character of the site.

The exhibition required major renovation of the site to improve circulation for bicycles, pedestrians, automobiles, buses, and maintenance vehicles. Site renovations had to take into account endangered species, historic and cultural resources, views, and potential future expansions such as an indoor museum at the site. In addition to history, aesthetics, construction, and geology, the exhibits explain engineering concepts such as forces in the main cables and suspenders, the function of the towers and the anchorages, aerodynamics of the bridge deck, torsional resistance of the bridge deck, and bridge vibration, to name a few. A 1:80 scale replica of the bridge shown in Figure 2 provides an opportunity for people to see all of the elements of the bridge close up, and to see the structural elements of the towers that are hidden by the Art Deco coverings on the real bridge.

Figure 2. The centerpiece of the exhibit is a 1:80 precise scale-model of the bridge that will be placed in Battery Lancaster after site renovations are complete. (credit: Doron Serban)

While the exhibition includes many innovative exhibits, only those that are specifically related to engineering are described here.

How the Bridge Vibrates – Visitors learn that the Golden Gate Bridge is not a static structure, but instead vibrates in multiple modes that are excited by winds or earthquakes. Chain is used to model the cables and segmented pieces are used to model the roadway deck, with the purpose of exaggerating vibration patterns so that they are more easily seen (Figure 3). An information panel explains four modes of vibration: horizontal swaying, vertical vibration, torsional vibration, and shaking in the anchorage area. Panels explain that the Golden Gate Bridge has a 20 second horizontal period of vibration and that the bridge is designed to deflect 27.7 ft (8.4 m) horizontally at midspan during high winds.

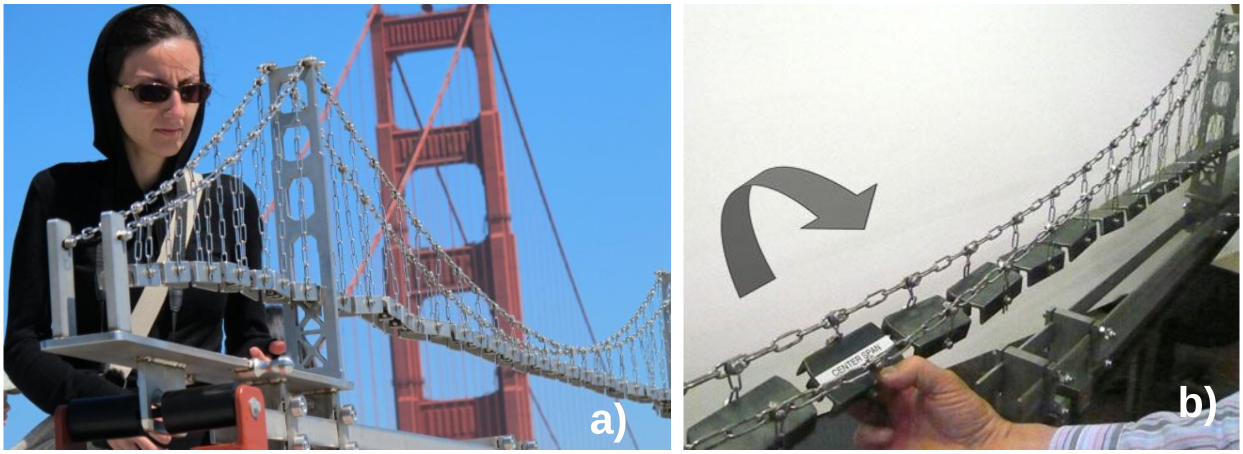

Figure 3. a) A model of the bridge constructed of chain and metal segments exaggerates the motion of the bridge. b) When a visitor twists and pulls down on the center span area, the resulting torsional vibration mode mimics that caused by the wind. (credit: S. Lani (a) R. Reitherman (b))

Tracking the Daily Movement of the Bridge – This exhibit is not currently installed. In 2013 it will be installed at base of the bridge and at the nearby Exploratorium discovery museum. A GPS device at the center span of the Bridge tracks its movements. This GPS signal is captured and plotted for visitors. Figure 4a shows the cyclical up and down movement of the bridge each day as it expands and contracts. Figure 4b displays on a mobile device the combined vertical and horizontal movement of the bridge over time. If evaluations determine that this is successful, a similar exhibit may be displayed at the Oakland-San Francisco Bay Bridge.

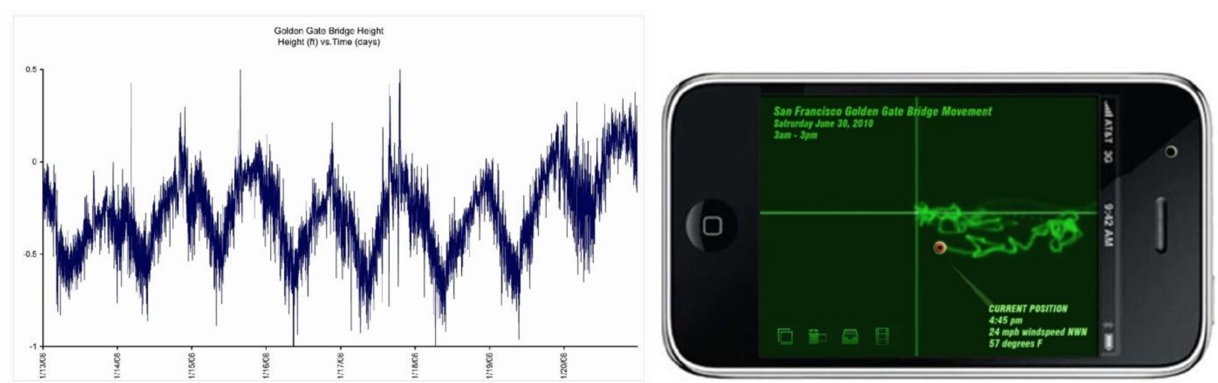

Figure 4. a) GPS tracking of the vertical motion of the center of the Bridge shows a daily cyclical pattern consistent with changed in temperature. b) A real-time display of vertical and horizontal movement will be available on mobile devices as well as at the site. (credit: S. Lani)

Suspension Cable Tension versus Tower Height - This exhibit allows visitors to explore the trade-offs between tower height and the forces in the main suspension cables. The exhibit consists of three model suspension bridges with towers of different heights, resulting in main cables with different sags. By pulling on the cables of each model the visitor experiences the phenomenon that the shorter tower results in higher tension forces (Figure 5). A companion information panel describes the relationship between cable diameter, cable force, and tower height (Figure 6). The physical nature of this exhibit makes it a favorite with kids.

Figure 5. Visitors pull on the main cable to discover that the cable force is larger when the sag is less. (credit: R. Reitherman)

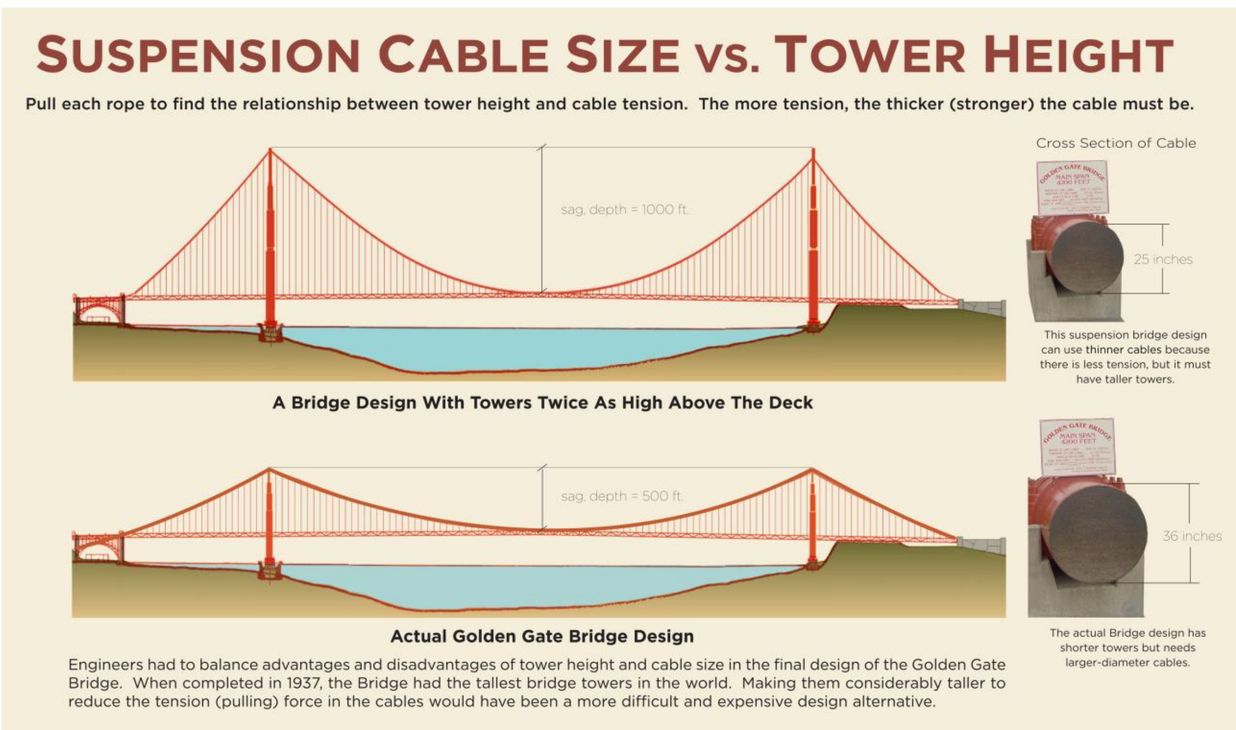

Figure 6. The informational panel that accompanies this exhibit shows how design decisions such as the tower height impact other elements of the bridge – the suspension cable diameter.

Resisting the Twisting – This exhibit teaches visitors about torsional stiffness and how a 1953-1954 retrofit in which bracing was added to connect the two trusses that support the roadway deck made the deck stiffer and thus less vulnerable to the high winds that blow through the

Golden Gate. Scale models of the pre- and post-retrofit sections of the bridge deck (Figure 7) allow visitors to compare the flexibility of the two designs by twisting them. The two sections are cantilevered out from a support structure and have handles that provide a sufficient moment arm so that children can apply enough force to see the twist. Guides with stoppers are provided on each handle to prevent strong or enthusiastic visitors from twisting the sections too far and destroying them. All exhibits need to be designed to anticipate ways that visitor can use and misuse them.

Figure 7. Visitors twist models of the pre- and post-retrofit deck sections to experience the difference in torsional resistance. (credit: left R. Reitherman, right M. Garlock[17])

Seismic Retrofit and Seismic Isolation – In 1995-96 Dr. Abolhassan Astaneh-Asl performed experimental studies on replicas of the bases of the towers of the Golden Gate Bridge to investigate buckling and post buckling behavior[18] (Figure 8a). A segment of the buckled test specimen has been mounted near the bridge so that visitors can compare the test specimen with elements that were replaced when the seismic retrofit was done. The new elements are laser cut from a single steel tube in contrast to the original lattice struts that were built up from many small riveted members (Figures 8b and 8c). The information panel describes the process of using test results to make decisions about the seismic retrofit. It also explains why the modern, one-piece steel tubes inserted to strengthen the bridge were laser-cut with openings to match the original struts they replaced, thus preserving the historic appearance of the bridge. Also related to seismic retrofit, a cutaway of an elastomeric seismic isolator is displayed near where they are mounted under the bridge deck (Figure 9). Visitors learn about the principles of base isolation and how the isolators reduce the forces the bridge experiences during an earthquake.

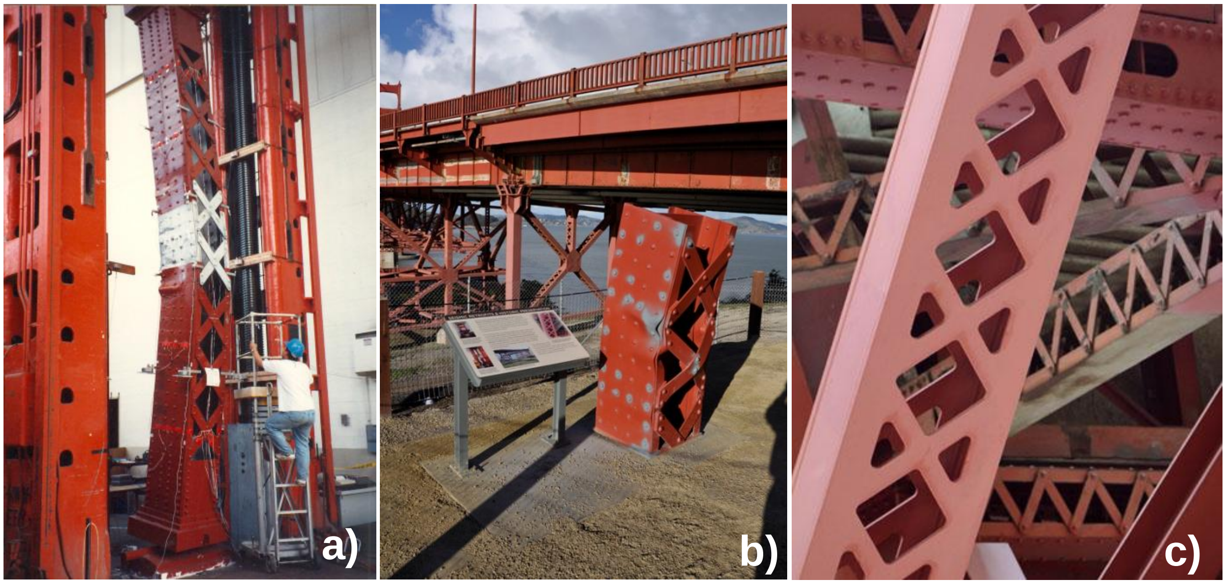

Figure 8. A replica of an element of Golden Gate Bridge was tested in compression at U.C. Berkeley (inset A, credit: A. Astaneh-Asl, Dept. of Civil & Environmental Engineering, UC Berkeley). A segment of the buckled test specimen is displayed along with a description of how the tests were used to make decisions about seismic retrofit (inset b, credit: Reitherman). Retrofitted segments are laser cut rather than riveted (inset c, credit: R. Reitherman).

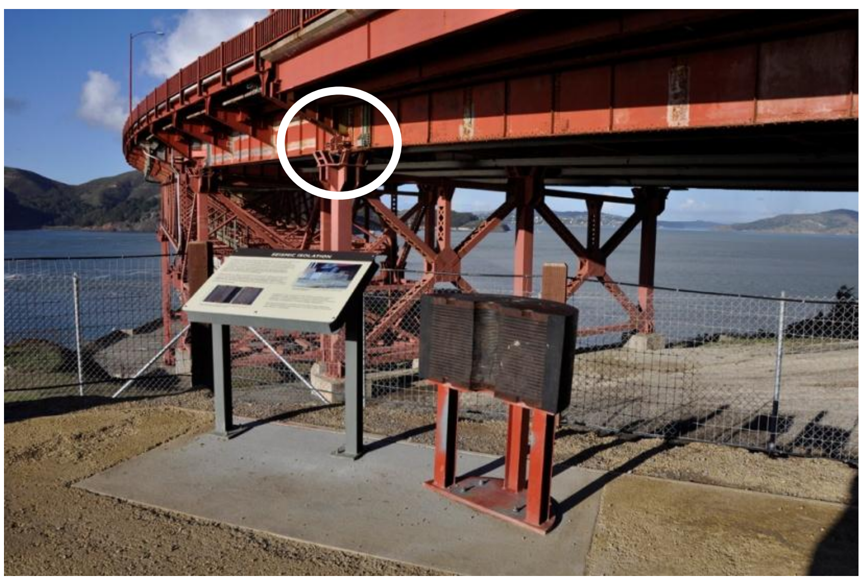

Figure 9. The cutaway of a seismic isolator is placed near where similar isolators are located on the bridge (white circle) so that visitors can make the connection between the exhibit and the seismic retrofit of the bridge (credit: R. Reitherman)

Wind Speed and Wind Pressure – The Bridge is designed to resist the forces caused by the winds blowing through the Golden Gate. Wind pressure increases with the square of the wind velocity, and this exhibit shown in Figure 10 enables the visitor to “feel” this quadratic relationship. As the visitor pushes on the display, a dial gage indicates the wind speed and the corresponding “resisting force” being applied. Note the visual cue of a hand to help the visitor understand how to interact with the exhibit.

Figure 10. Visitors push on the display to experience the forces the bridge must supply to resist the wind pressure. (credit: R. Reitherman)

Bridge Deck Aerodynamics - Two bridge cross sections are mounted side by side to demonstrate how a modern aerodynamically designed bridge cross-section performs in comparison to one similar to the Tacoma Narrows bridge deck. Concepts of torsional stiffness and the relationship between deck cross-sectional shape and deck stability are introduced.

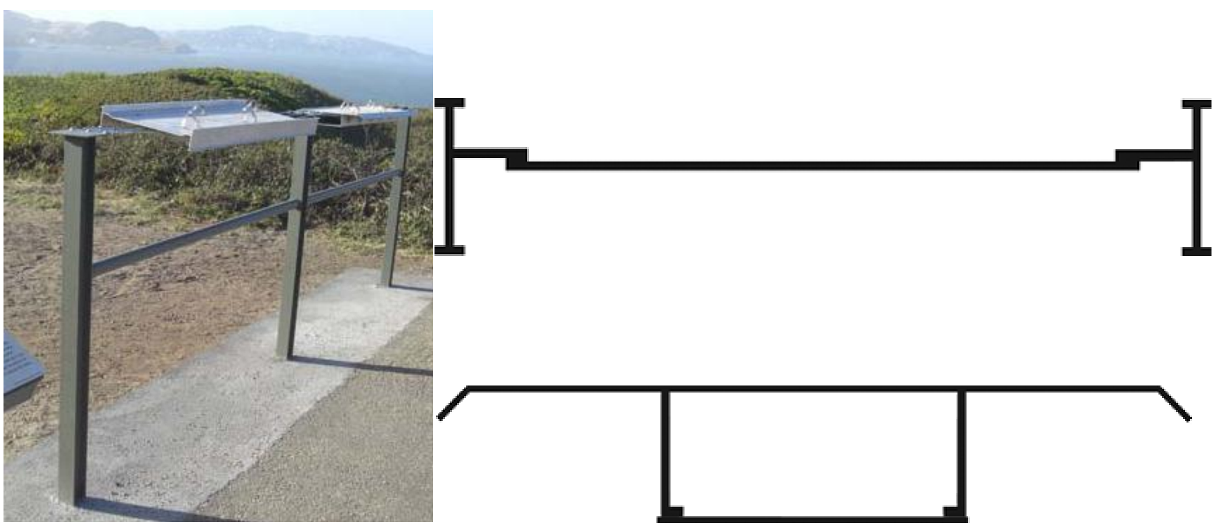

Figure 11. Visitors can compare the performance of two bridge deck designs: non-aerodynamic (top right) and aerodynamic (bottom right). (credit: R. Reitherman)

Tactile/Braille Model of Bridge –At the entrance to the exhibition area a tactile model with Braille labels allows visitors with limited vision to touch the outline of the Bridge to obtain a sense of its design and proportions (Figure 12). A non-profit organization, LightHouse for the Blind and Visually Impaired in San Francisco, advised the project on visual accessibility issues.

Figure 12. A tactile model with Braille labels is designed to meet the needs of visually impaired visitors, but all visitors find the model interesting to touch and photograph. (credit: R. Reitherman)

Exhibit Development as an Education and Research Resource

Three exhibits were developed and fabricated at Princeton University: the 1:80 model of the bridge, the deck torsion exhibit, and the Tactile/Braille model of the bridge. Eleven undergraduate students completed a thesis, independent study, or summer research project in conjunction with development of these projects[17]. A student from San José State University had the lead role in designing and constructing the wind speed/wind pressure exhibit. The exhibits themselves presented a number of challenging engineering problems. The site experiences strong winds and a corrosive salt-laden fog. Several student studies were dedicated to analyzing which materials would resist the fog-induced corrosion while having other desirable characteristics such as strength, low lead content, machinability, and compatibility to prevent galvanic corrosion. Exhibits have to be durable, accessible to visitors of different heights and strengths, and easy to assemble and maintain. Three students dedicated their research to analyzing the gravity, wind, and seismic loads on the 1:80 scale model[19]. Students had to develop finite element models of the scale model to evaluate loads (Figure 13a) and prototypes to test fabrication and assembly protocols (Figure 13b). Students prepared detailed drawings of the connections (Figure 14a), and tested the strength of full-size model elements (Figure 14b) to ensure the model meets specifications. An important lesson from this project is that the development of an exhibit should not be overlooked as an educational opportunity.

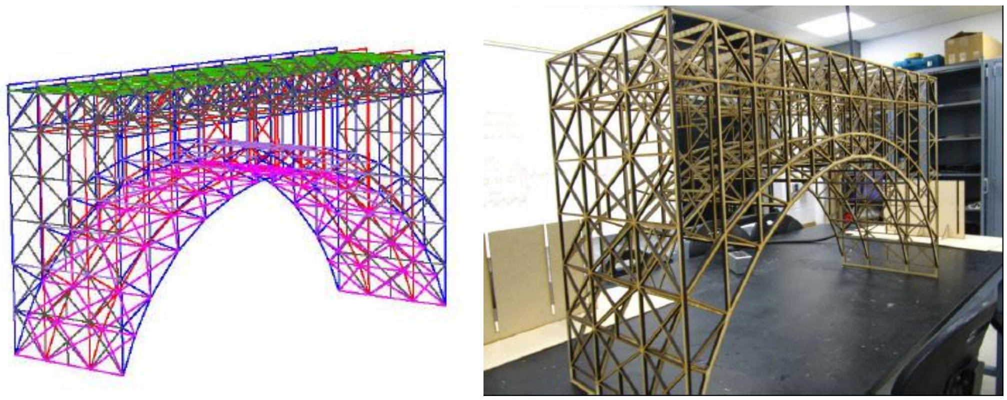

Figure 13. a) Finite element model of the arch at the south end of the bridge, and b) prototype model used to test instructions for fabrication on a laser milling machine. (source: M. Garlock[17] and S. Black[19])

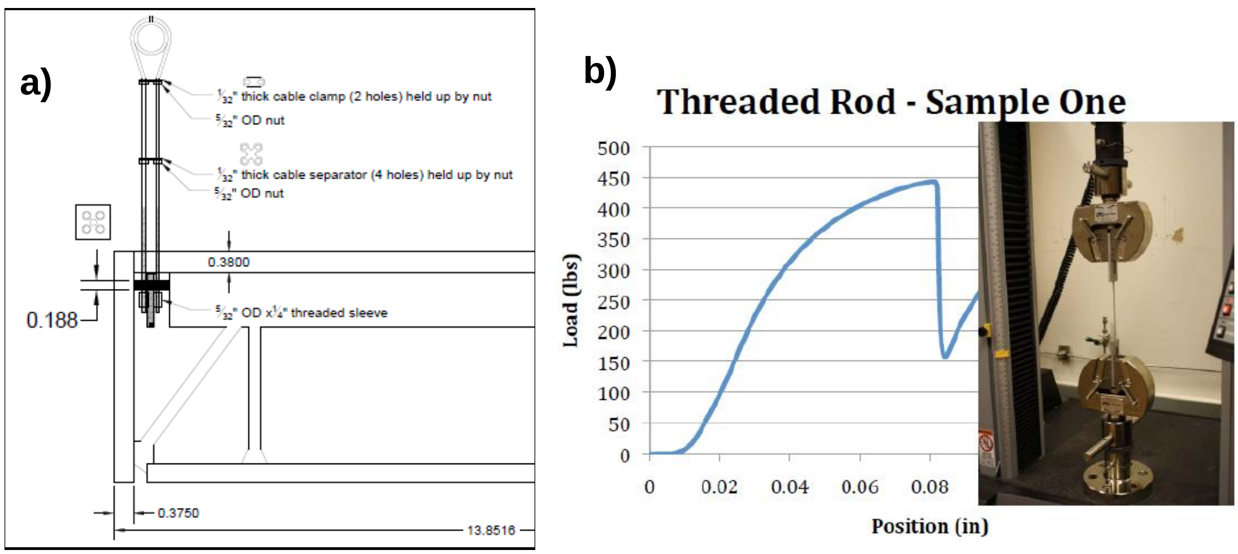

Figure 14. a) Detail of hanger-to-deck connection on 1:80 model, and b) strength testing of rod used as a hanger for the 1:80 model. (source: S. Black[19] and M. Garlock[17])

Companion Web Content

A companion web site is under development. Currently it contains information about each exhibit, a virtual bridge tour, a photo gallery, and historical fun facts. An effort is underway to translate all of the information about the exhibits to eleven foreign languages. Additional material under development includes links to science standards to help K-12 teachers use this material in their classrooms, suggested agendas for a field trip to the bridge, links to engineering material appropriate for college students, and some interactive apps for visitors to explore concepts such as the relationship between tower height and force in the main cable.

Formative and Summative Assessment

From the inception of the project two educational research organizations participated in the team to perform the formative and summative assessments. Initially evaluators focused on front-end questions that drive the formulation of the exhibits. Through interviews with GGBHTD staff and visitors to the bridge, data were gathered on common questions and interests. Interview questions concentrated on the audience, their interests, prior knowledge, conceptions and misconceptions, their reactions to the proposed exhibits, and how to best engage them in learning about the bridge. Visitors indicated that their top interest was photo opportunities, followed by more technical issues such as earthquakes, design of the bridge, its construction, wind effects, maintenance, and environmental impacts. During the formative assessment phase, evaluators used multiple methods to assess the effectiveness of the exhibits. These included expert critique by the evaluators themselves based on their previous experience with science exhibits, naturalistic observations of visitors, mediated interviews with visitors, and exit interviews[20]. Groups of advisors were asked to provide feedback on the content, layout, and language used in informational panels. Periodically evaluators and developers would hold prototyping sessions at the site to jointly interview and observe visitors.

Formative evaluation revealed that exhibit usage varied depending on whether or not the bridge was visible from the exhibit area. This reinforces the point that visitors are at the Golden Gate Bridge to see the bridge itself and are often constrained by time (if they are on a tour for example) so it was important to make seeing the bridge a priority. Many visitors are more inclined to stop at an exhibit if it provides a good photo opportunity; several of the exhibits that included models of the Golden Gate Bridge were used as stand-ins when the actual Bridge was not visible due to the fog. The few school groups observed tended to use the exhibits differently. Often school groups are visiting the Golden Gate Bridge to complement classroom curriculum and they tend to spend more time at the site and have more time to explore the exhibition. Children in school groups also used the exhibits more vigorously. One consistent behavior that was observed was one visitor in a group interpreting or explaining the exhibit to others. This included not only tour guides, but also young adult children explaining the exhibits to their parents, as well as spouses and friends explaining the exhibit to their peers.[20]

Visitors were positive about their experiences with interactive exhibits and panels. Through interviews with visitors, evaluators concluded that concepts generally were accessible to visitors. Visitors were able to understand technical concepts such as:

- the bridge moves in response to wind, temperature, gravity loads, and earthquakes
- the bridge has different types of motion – twisting, up and down, back and forth
- high towers (greater cable sag) make it easier to lift more weight
- the design of the Bridge influences how the wind interacts with it[20]

Due to the variety in ages of visitors, as well as the different languages spoken, photos, visual cues, and simple language were important elements in ensuring that visitors knew how to interact with and understand the exhibits.

The summative evaluation is ongoing to look at both short- and long-term impacts of the entire project. The summative evaluation is looking at impacts on two audiences: the general public and public works professionals. The impacts being studied are:

Public Audiences

- Increased interest in and knowledge of STEM concepts
- Increased understanding of science and engineering related to the Golden Gate Bridge
- Impact of the Golden Gate Bridge website on public audiences

Professional Audiences

- Increased awareness of public works sites' potential to provide STEM education
- Increased understanding of project design and implementation processes
- Increased awareness of funding opportunities
- Project provided a model for STEM education projects at public work sites
- Increased the public works sites' capacity to deliver hands-on science education activities[20]

As with the formative assessment, evaluation strategies include site visits, observations of visitors, surveys, and exit interviews of visitors, and informal interviews with project staff. In addition, timing and tracking studies have been piloted. Because the exhibit is free, visitors do not need to purchase or present a ticket, and there are multiple entrances and exits to the exhibit area. This makes it difficult to track the exact number of visitors to the exhibits over time. It can be said that some subset of the 10 million annual visitors to the Bridge visit the exhibit. Over three days in March 2013 an evaluator was able to collect almost 400 unique observations of visitors interacting with the exhibits. In addition, the evaluator conducted 43 interviews with exhibit users to evaluate what they had learned and how the outdoor exhibits enhance their visit to the bridge. These data are in the process of being summarized. A companion paper discusses summative assessment in more detail[2].

Conclusions

This innovative project has highlighted the potential for public works projects to serve as contexts for free-choice learning experiences. A lesson from both the exhibition at the Golden Gate Bridge and the *Public Works for Public Learning Conference* is that this framework for free-choice learning creates a win-win. The public gains new understandings of the public works projects, and the public works projects gain visibility in their communities in new ways. It provides an excellent opportunity to increase the public's knowledge about science and engineering concepts and to introduce them to the complexities of building and maintaining our infrastructure. The recommendation is to start small and experiment with a low cost, low risk effort to understand the challenges, and develop partnerships among diverse groups in the community. Build on public works events and opportunities in the community that are already underway and augment them with activities that attract people and provide educational information that is meaningful to their everyday lives. Challenges abound -- in the partnerships that need to be formed among numerous public agencies, in securing funding, in developing robust exhibit experiences that can withstand large crowds and harsh outdoor settings, in envisioning how they may be utilized differently than exhibits in a museum setting, in addressing the needs of a broad audiences, and in assessing the effectiveness of the effort -- but with a dedicated team and creativity the benefits likely outweigh the costs.

Acknowledgement

This paper is based on work supported by the National Science Foundation under Grant No. DRL-0840185 and the Golden Gate Bridge Highway and Transportation District. Any opinions, findings, and conclusions or recommendations are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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