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# PRESERVATION OF HISTORICAL BRIDGES IN USA: THE GOLDEN GATE BRIDGE AND THE ALBION RIVER BRIDGE CASES

**Abolhassan Astaneh-Asl***

* University of California, Berkeley, USA
e-mails: Astaneh@Berkeley.edu

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**Abstract**. *The Golden Gate Bridge opened to traffic in 1937, is located between two major and active seismic faults, the San Andreas Fault, capable of creating an M8.3 earthquake, and the Hayward Fault capable of creating an M7.3 earthquake. The bridge is only 16 km from San Andreas and 11 km from the Hayward faults. The main challenges in seismic retrofit of this iconic and historical bridge were: (a) to establish the strengths of the critical components of the bridge; (b) to design seismic retrofit concepts that will enable the bridge to withstand its maximum credible earthquake, and; (c) most importantly, to ensure that the historical appearance of the bridge is preserved. The author of this keynote paper, who has been closely involved with the project, discusses critical aspects of these three important items. The Albion River Bridge has a length of 302 meters, opened to traffic in 1944, and is a fine example of a historical timber bridge and one of the last remaining engineered timber bridges in California. The bridge is located in Northern California about 10 km to the east of the San Andreas Fault capable of creating M8.3 earthquakes. The bridge is currently in very fine condition, however, since 2013, the State Department of Transportation has intensified its efforts to demolish the bridge and replace it with a reinforced concrete bridge. The majority of local residents opposing the demolition invited the author to investigate the condition of the bridge and to assess its seismic safety and needs for retrofit. The paper discusses the results of this investigation and how the efforts helped to register the bridge as a U.S. National Historic Place with the Federal Government.*

## 1 INTRODUCTION

In the United States, the main vehicle to preserve historical buildings, bridges, and other structures is through the use of National Register of Historic Places (NRHP) [1], which is a Federal program of National Park Service of the Department of the Interior [1]. The NRHP is based on the 1966 National Historic Preservation Act passed by U.S. Congress as Public Law 102-575 [2]. In the United States, the National Register of Historic Places is *the official list of the Nation's historic places worthy of preservation. Authorized by the National Historic Preservation Act of 1966, the National Park Service's National Register of Historic Places is part of a national program to coordinate and support public and private efforts to identify, evaluate, and protect America's historic and archeological resources.*[2]."

In order for a property in a State to be on the list of National Register of Historic Places, it has to be nominated by property owner, an agency, a historical society or by any individual by filling out a standard form available at [2, 3] and submitting it to the Office of Historic Preservation of the state that the property is located in. Then the SHPO notifies the property owner of the filing of the application and asks for input and comments. Regardless of how the property owner responds or replies at all, the State Office of Historic Preservation proceeds with the review of the application and solicits public comments on the registration and prepares a case for consideration of the State Historic Preservation Commission. After the nomination is approved by the State Commission, the recommendations are submitted by the state to the National Park Service in Washington, D.C. for final review and listing by the Keeper of the National Register of Historic Places [2].

Currently, there are 95214 assets such as sites, buildings, bridges, and other properties listed as U.S. National Historic Places, 2670 of them being bridges. The Golden Gate Bridge, Figure 1(a), a major steel suspension bridge, is currently eligible for the National Register of Historic Places in U.S. However, the bridge is a privately owned structure owned by the Golden Gate Bridge Highway and Transportation District and the owner had not applied for historical registration. The recreational area around the Golden Gate Bridge, which includes the historical Civil War era Point Fort, which is now located under the Golden Gate Bridge, is registered as a National Historic Place and is considered a U.S. Landmark. Due to historical and engineering significance of the Golden Gate Bridge, one of the marvels of bridge engineering, the case of historical preservation of this bridge is included in this paper.

One of the bridges that were just registered as a U.S. National Historic Place is the Albion River Bridge also discussed in this paper. The Albion River Bridge, Figure 1(b), is primarily a timber truss structure with timber braced towers. The main river crossing consists of two steel riveted trusses supported on two 4-legged concrete moment framed towers. The bridge is the last remaining well-engineered timber bridge in California, and maybe in the U.S.

Photo: Abolhassan Astaneh-Asl

Photo: Abolhassan Astaneh-Asl

Figure 1: (a) the Golden Gate Bridge, and (b) the Albion River Bridge

For a bridge or building to be registered as a National Historic Place, it has to satisfy one or more of the evaluation criteria listed in [2], which states that National Register criteria for evaluation is to consider *"The quality of significance in American history, architecture, archeology, engineering, and culture is present in districts, sites, buildings, structures, and objects that possess integrity of location, design, setting, materials, workmanship, feeling, and association* [2]." In addition, there are seven specific criteria that can be used to justify National Registration as a Historic Place. The criterion that is often applied to the bridges is *"(c) that embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction* [2]."

## 2 GOLDEN GATE BRIDGE HISTORICAL PRESERVATION EFFORTS

The construction of the Golden Gate Bridge started in January 1933 and it opened to traffic in May of 1937. The bridge spans the Golden Gate Strait which has a width of about 1.6 kilometers. The total length of the bridge is 2742.3 meters (8,997 ft.) while the length of the total suspension bridge is 1280 meters (4200 ft.) with a main span length of 390 meters (1280 ft). The structure has six lanes of car and truck traffic with two pedestrian lanes one on each side of the bridge. Although Joseph Straus was the Chief Engineer of the bridge in charge of its design and construction, Leon Moisseiff is credited with the most graceful aspect of the bridge which is its single suspension span. Charles Alton Ellis was the main engineer of the bridge and Irving Morrow designed the architectural aspects of the main towers. The stunning suspension concept of the bridge designed connecting the north side of the San Francisco to the Marin County to the north.

Even before the design of the Golden Gate Bridge started, historical preservation was a major consideration. The alignment of the bridge was passing over the Fort Point, which is a fort built before the Civil War between 1853 and 1861, more than 70 years before the construction of the Golden Gate Bridge started. Currently, the Fort Point is a U.S. National Historic Landmark. At the time of design of the Golden Gate Bridge, an arch bridge was designed over the Fort Point, Figure 1(a), to cross over the historical building.

### 2.1 Structure of the Golden Gate Bridge and its current condition

The Golden Gate Bridge, shown in Figure 1(b) on the previous page, consists of three distinct segments: the San Francisco approach structures, the Marin approach structure and the main suspension bridge. The two main towers of the suspension spans consist of two multi-cell steel tower legs connected to each other by horizontal trusses above the deck and cross bracings below the deck. The cross-section of the towers is formed with 1 meter (3-1/2 ft) square cells and the base of each leg is 15 cells long and nine cells wide. The cell walls at the base of the tower are 22mm (7/8 inch) thick silicon steel plates. As the tower approaches the top, the cross-section is reduced by reducing the number of cells until only 21 cells remain at the top. At the top of the towers, the suspension cables pass through a cable groove on the saddle. The cables are tied down to the concrete pylons at each end and are connected to the anchorages. The suspended bridge is connected to the shore by two approach structures. The Marin approach has a series of five 53.4-meter (175 ft.) deck truss spans supported on high, four-legged steel towers. The San Francisco approach has one two-hinged arch over the historical fort, two 38.1-meter (125 ft.) deck truss spans supported on two steel towers, one 53.4-meter (175 ft) deck span, and three 21.7-meter (71 ft.) plate girder spans.

### 2.2 Seismic response of the Golden Gate Bridge and seismic retrofit needs

The Golden Gate Bridge being a long period structure is particularly sensitive to two phenomena: (a) the near-field velocity pulse [4], and (b) the long period component of the far-field strong motions [5]. The first phenomenon, the near-field velocity pulse, results in permanent displacement at the site of the structures located near the ruptured fault. Due to velocity pulse, larger forces and displacements can be generated in the structures [4]. However, this phenomenon is not currently considered in the seismic design of bridges. The second and equally important phenomenon is the effect of long distance earthquakes on long period structures, such as the Golden Gate Bridge. This phenomenon also is not generally considered in the seismic design.

In recent years, the author has undertaken several projects [5], focusing on studying the effects of long-distance earthquakes on long-span bridges and tall buildings, both having long periods of vibration. When a fault ruptures, the ground motion moving away from the ruptured fault becomes weaker but its period of vibration is elongated. When the long period surface waves arrive at the site of a long period structure such as the Golden Gate Bridge, even though the amplitude of the ground motion is relatively small, because of its period is close to the period of the structure, the response of the structure can be quite large. Figure 2 shows first two modes of vibration of the Golden Gate Bridge with a fundamental period of vibration of 17.5 and 9.5 seconds respectively [5]. The structure was subjected to two ground motion records, one, the 1994 Northridge Newhall records, Figure 3(a), which was a strong ground motion, with maximum peak ground acceleration (MPGA) of 0.6g, and the other the 1999 Chi-Chi-002 ground motion, with an MPGA of only 0.08g, recorded at a site relatively far from the epicenter. Figure 3 shows time history of acceleration for one of the horizontal components of each earthquake.

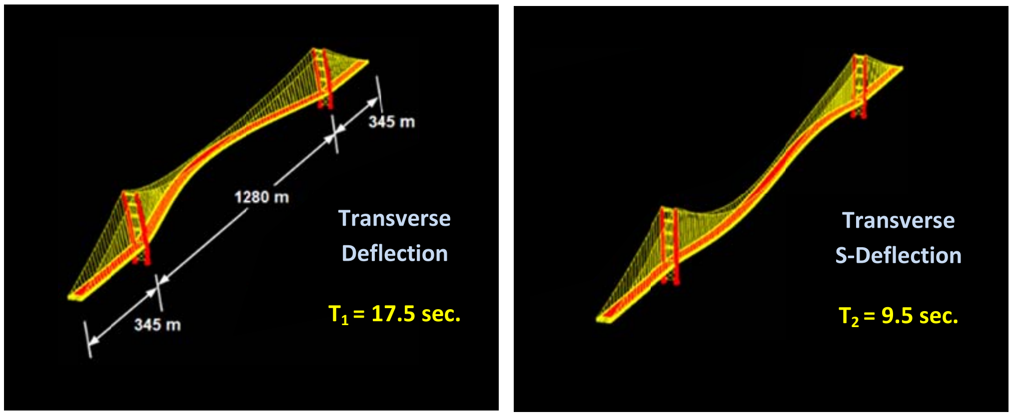
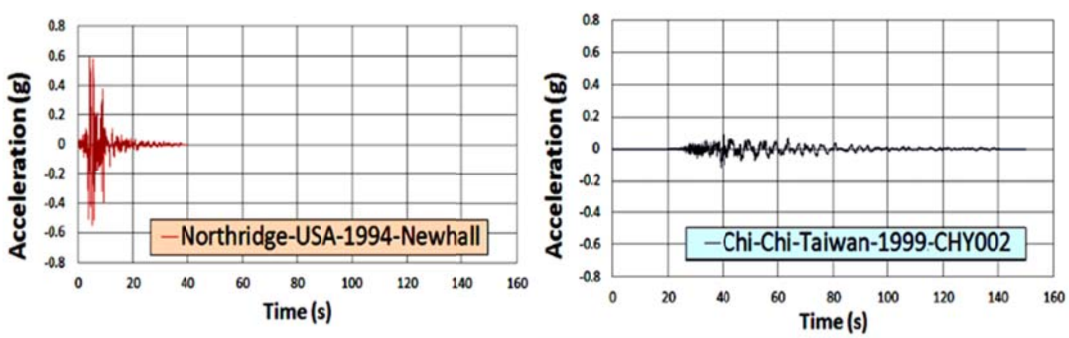


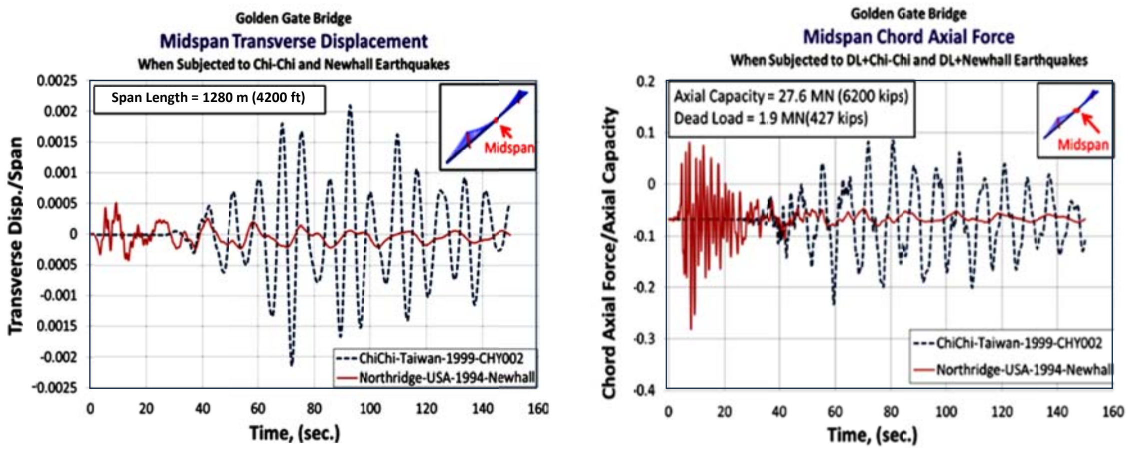

Figure 2: (a) Two higher modes of vibration, and
(b) ground motions used in the analysis[5]




(a) (b)

Figure 3: Acceleration record of a horizontal component of (a) 1994
Northridge Newhall, and (b) the 1999 Chi-Chi-002 earthquakes.[5]

Figure 4 shows the response of the Golden Gate Bridge to the strong but short period quake (Northridge –Newhall) and the weak but long-period earthquake (Chi-Chi-002). The left plot shows that the transverse displacement of the bridge midspan, when subjected to the weak Chi-Chi earthquake, is about four times the displacement generated by the much stronger Northridge earthquake ground motions. The larger displacement due to Chi-Chi earthquake indicates that this relatively weak earthquake, with an MPGA of 0.08g, can cause far more damage in the bridge especially in the expansion joints than what the much stronger Northridge earthquake, with MPGA of 0.60g can cause. The time-history plot on the right side of Figure 4 shows the axial force generated in the truss chord at midspan. The much weaker Chi-Chi quake creates almost the same axial force in the chords as the much stronger Northridge earthquake. The study of the Golden Gate Bridge (5) and other long-span bridges indicated that in design and evaluation of these bridges, in addition to traditional seismic design procedures, the response of these long-period structures to long distance earthquakes should also be considered.




**(a)** **(b)**

Figure 4: (a) The displacement response, and (b) the force response of the Golden Gate Bridge to Northridge and Chi-Chi ground motions [5]

The Golden Gate Bridge is located about 80 kilometers north of the epicenter of the 1989 Loma Prieta earthquake. During this earthquake, the bridge sustained no significant damage and continued its service after the initial inspection. The author's investigation of the damage due to Loma Prieta earthquake indicated that the damage was in the form of two separate segments of the bridge deck impacting each other in the longitudinal direction and causing some damage to the expansion joints, which easily was repaired.

In the aftermath of the 1989 Loma Prieta earthquake, the Golden Gate Bridge, Highway and Transportation District, which is a non-governmental agency and owns the bridge, commissioned seismic evaluation and retrofit studies of the bridge. As part of the seismic retrofit studies undertaken by a joint venture of T.Y. Lin International and Roy Imbsen and Associates [6], it was necessary to establish the post-buckling behavior of critical elements of the bridge.

The critical elements were identified to be the chords of the two main stiffening trusses, typical column legs of the approach structure towers and the legs of the main towers of the suspension spans. The main reason for the need for actual testing of these elements was that at the time of design and construction of the Golden Gate Bridge, our knowledge of local buckling of steel plates was relatively limited. Many elements of the cross sections of steel bridges built prior to 1960's, such as the Golden Gate Bridge, are sufficiently strong to carry their applied compression load but have limited *post-buckling compressive ductility.* The limit of width-to-thickness, b/t ratio, in most of these old bridges satisfies only the elastic limit, which means the elements are expected to *locally buckle* prior to reaching their compressive yield capacity and cannot reach their yield capacity after buckling. The post-buckling ductility is needed to ensure desirable cyclic behavior during a strong earthquake.

### 2.3 Tests of Critical Members of the Golden Gate Bridge

To investigate the post-buckling ductility of critical elements of the Golden Gate Bridge, the author, as the Principal Investigator, led a 2-year test program to fabricate realistic riveted full-scale and ½-scale components of the main truss and the towers of the Golden Gate Bridge and test them under monotonic compression load. In the following sections, a summary of these two test programs is provided. The full reports of the studies are in [7,8].

### 2.3.a Test of Chord Members of the Main Trusses of the Golden Gate Bridge

The stiffening truss chord specimen was a 7/8-scale model of a segment of the side span truss from joint to joint as shown in Figure 5. The latticed member specimens were tested with pinned end condition and according to the procedures outlined in the Technical Memorandum No. 4 of the Structural Stability Research Council. After all, instrumentation was installed, calibrated and tested for proper operation, the axial load was applied. The specimens were loaded by a Southwark-Emery 17,800 KN (4,000,000 lb.) hydraulic-based universal testing machine located in the Structural Research Laboratory of the Department of Civil and Environmental Engineering of the University of California at Berkeley. The loading rate was relatively slow; therefore, the tests can be regarded as a static load test.

During the main loading, there were a number of intentional unloadings and reloading at certain load levels to record the elastic unloading behavior of the specimens. The specimens were loaded until buckling occurred and load dropped. The specimens were loaded further after buckling to observe the post-buckling behavior and ductility. The truss chord specimen failed abruptly at 8,675 KN (1,950 kips). This failure initiated by local buckling of the cover plate, Figure 4, at a location of about a quarter of the length from the top. After buckling, the capacity suddenly dropped to about 50% (4,450 KN) of the initial buckling load.

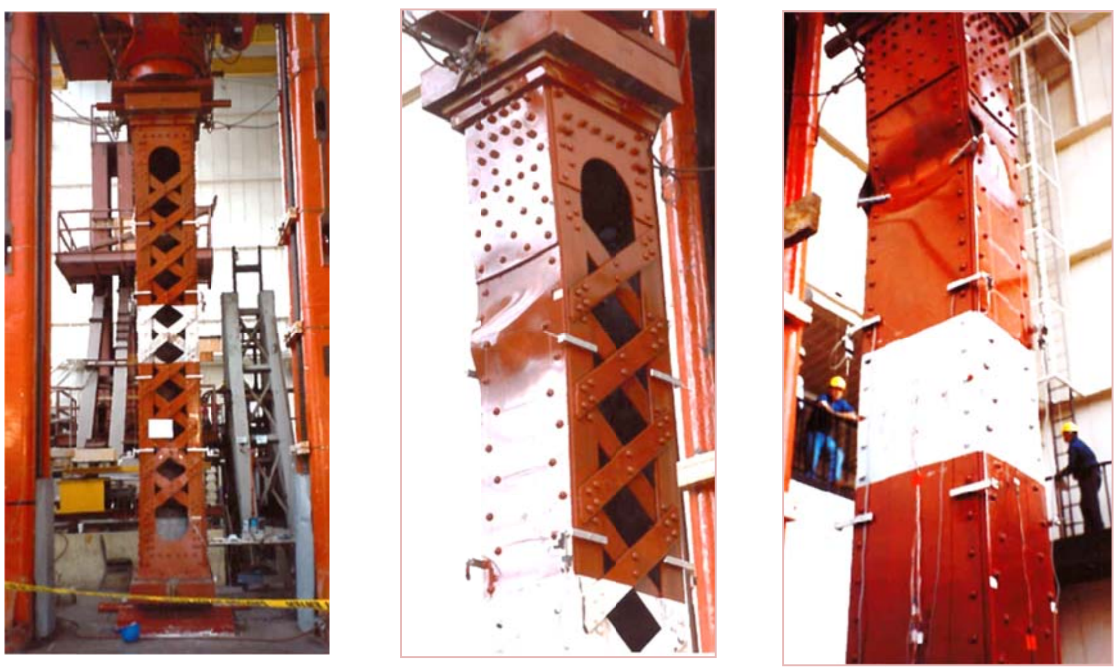


Figure 5: Truss chord specimen and its local buckling during the test [7]

The behavior of specimen indicated that it does not have any ductility and as soon as local buckling occurs in an *elastic* manner, the load suddenly drops. Since there was no economic way to retrofit the truss members to increase their ductility, the seismic retrofit strategy that was followed was to add hydraulic dampers between the main trusses and the tower legs in the longitudinal direction to prevent the development of large axial forces in the truss chords.

**2.3.b Historical Preservation of Golden Gate Bridge Latticed Test Specimen**

Currently, Golden Gate Bridge on its south end has an exhibition area that shows the history of design and construction as well as seismic retrofit. The permanent exhibit has a place to exhibit a piece of the lattice members we tested with a poster board that explains the test program. Figure 6 shows the exhibit area, where our test specimen is exhibited.

Figure 6: The Golden Gate Bridge specimen tested by Astaneh-Asl et. Al. [7]
at the Golden Gate Bridge permeant exhibit site.

**2.3.c Test of the Components of the Main Tower of the Golden Gate Bridge**

The seismic retrofit studies conducted by T. Y. Lin Int. [6] showed that during the strong earthquakes, the tower legs can actually uplift up to 5 cm ( 2 inches) on one side. The other side of the tower leg will be under very large compression and can locally buckle. It was necessary to test the behavior of the plates at the base of the towers and to establish their buckling strength and post-buckling ductility. The full-scale main tower base specimens consisted of a 22 mm (7/8") thick plate and a similar plate retrofitted by adding a vertical wide flange at mid-width to stiffen it. There were also two 1/2-scale main tower cruciform specimens, which consisted of four cell wall plates connected to each other by angles and rivets to form a cross. One specimen represented the existing condition while the second specimen had wide flanges added to it as vertical stiffeners to reduce the width-to-thickness ratio of the plates. Material for the components of the specimens was selected to simulate the actual material in the bridge which was Silico steel with a yield strength of 345MPa (50ksi.)

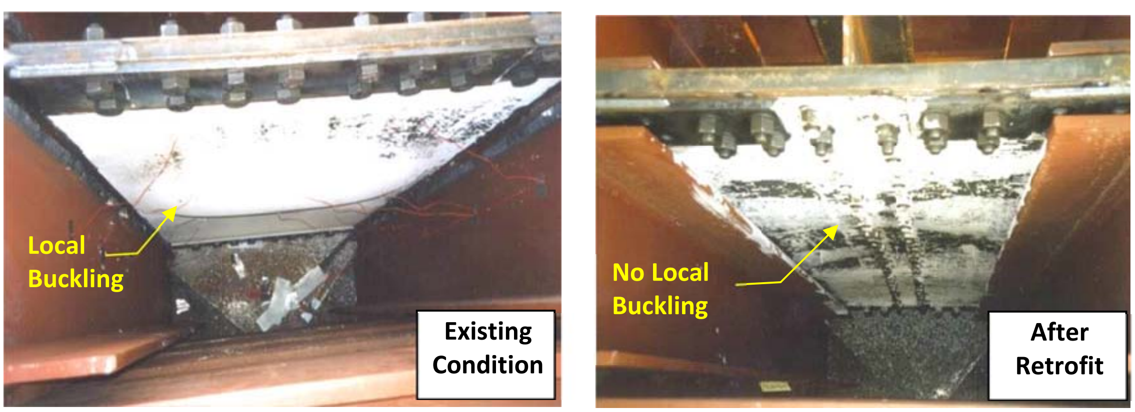



Figure 7: Non-ductile buckling of full-scale tower specimens
of the Golden Gate Bridge

Figure 7 shows the two full-scale specimens of the base of the tower legs after completion of the monotonic compression tests. The specimen representing the existing condition of the cell walls, Figure 7 (left), failed with limited yield lines visible on the specimen. The buckled waves consisted of about 2.5 waves in the vertical direction and one wave in the horizontal direction. The amount of yielding appeared to be limited. In contrast, the specimen representing the retrofitted condition, Figure 7 (right) yielded significantly and after the test showed very small if any buckling deformations. Figure 8 shows the axial stress-strain curves for the two specimens with retrofitted specimen showing no drop in compressive capacity and significant ductility.

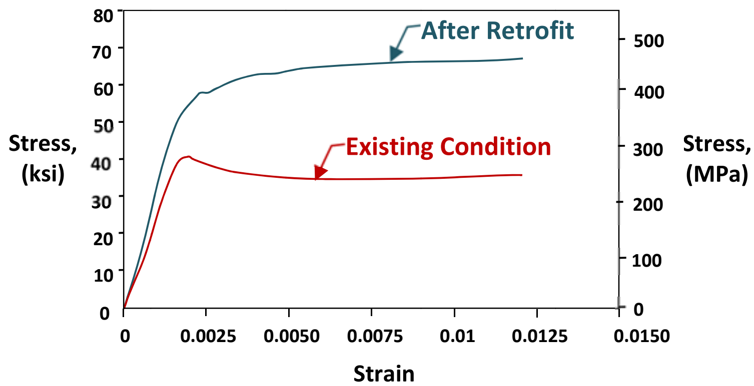



Figure 8: Axial stress-strain curves for the two full-scale tests

Figure 9 shows existing and retrofitted cruciform specimens after the tests. The behavior of 1/2-scale cruciform specimens representing four cell walls was very similar to the behavior of full-scale specimens summarized above. Again, the specimen, Figure 8 (left), representing the existing condition buckled abruptly in an elastic manner dropping the compressive force without much ductility. But, the retrofitted specimen, Figure 8 (right), was able to develop higher strength and yield considerably before minor local bucklings occurred.

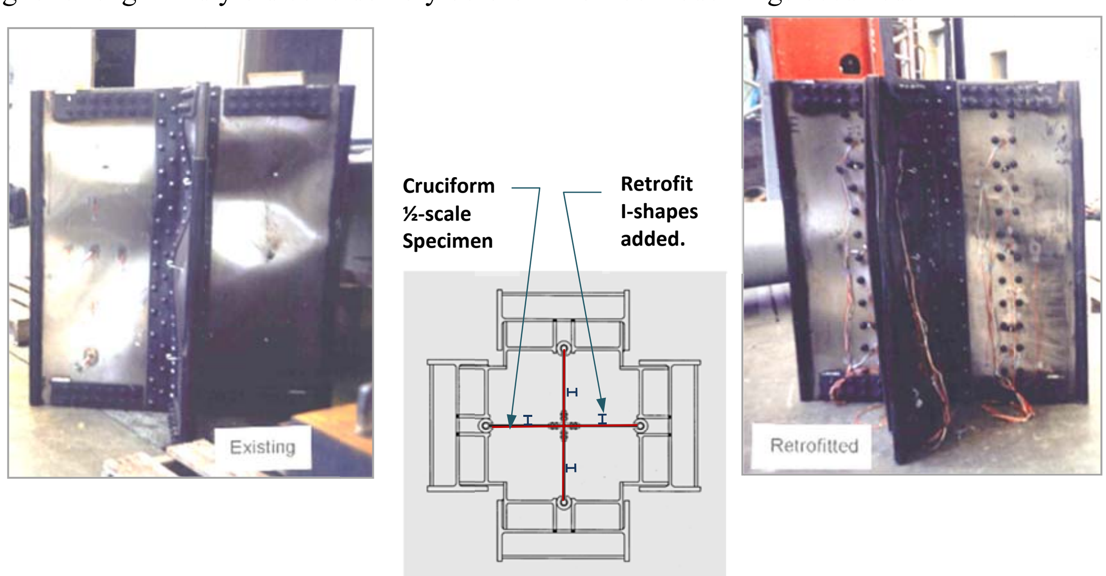



Figure 9: Non-ductile buckling of existing plates (left), and ductile yielding of the retrofitted specimen (right)

## 4 THE ALBION RIVER BRIDGE

The Albion River Bridge is located in northern California near the town of Albion. It carries the two-lane scenic California Highway-1, officially called Shoreline Highway, over the Albion River, which flows into the Pacific Ocean after passing under the bridge. The coordinates of the bridge are 39° 13' 34" N, 123° 46' 09" W, respectively. The bridge was completed and opened to traffic in 1944. Figure 10 shows a general view of the Albion River Bridge with the main structural parts of the bridge identified. The total length of the bridge and the width of the roadway (curb-to-curb) are 295.4 m (969 ft) and 7.9 m (26 ft), respectively.

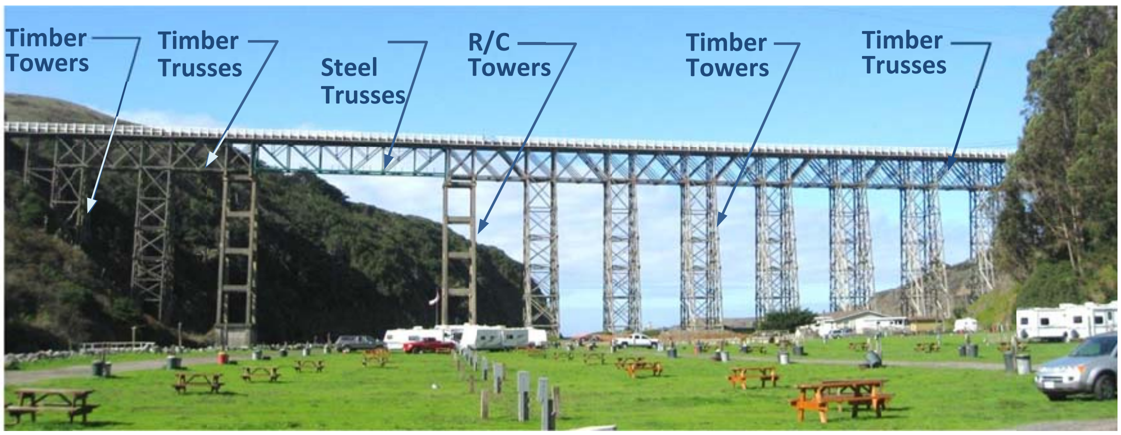



Figure 10: A view of the Albion River Bridge

The deck of the bridge, which has a layer of asphalt overlay on it, is a timber deck made of two layers of planks supported on longitudinal timber joists. The wood joists, in turn, are supported on two longitudinal steel trusses comprising the main span (over the river) and the two timber trusses in the north and south approach spans. The main span consists of two parallel 39.6 m (130ft) long riveted steel trusses supported on four-legged reinforced concrete towers.

The north and south approach spans consist of 11.6 m (38 ft.) span timber trusses supported on ten-legged braced timber towers. The wood trusses and towers are connected using galvanized bolts. The bridge is an excellent historically significant example of a well-preserved, aesthetically pleasing timber bridge. Figures 11 shows typical close-ups of the timber, steel, and concrete elements of the Albion River Bridge. The photos indicate that all components of the bridge are in very good condition. The most recent "Load Rating" report of the bridge indicates that the bridge, after more than 72 years of service, still has the same load carrying capacity that it had when it was built. This is a testimony to the excellent design and proper selection of material as well as good maintenance.

As for seismic condition, in 2016, the California Department of Transportation added Interim Seismic Retrofit to the bridge, which consisted of extending the bearing supports of the main steel trusses and adding "Cable-Restrainers" to the bearings of this span to prevent the two steel trusses from dropping off their support in the event of future strong earthquakes. This type of seismic retrofit has been done for other steel truss bridges in California since the 1989 Loma Prieta Earthquake to prevent the collapse of the spans. There was no seismic retrofit of timber trusses or towers of the Albion River Bridge.

Figure 12 shows a SAP Model of the Albion River Bridge. Seismic Analysis of the Bridge indicated that there is a need to conduct a thorough investigation of seismic behavior of this historically significant bridge, at the level of what was done for the Golden Gate Bridge to find out exact seismic retrofit needs of the bridge and to develop proper and economical seismic retrofit to ensure that the bridge survives future earthquakes without noticeable damage to its historical appearance.

Figure 11: Close-up Views of Typical Timber, Steel and
R/C Parts of the Albion River Bridge

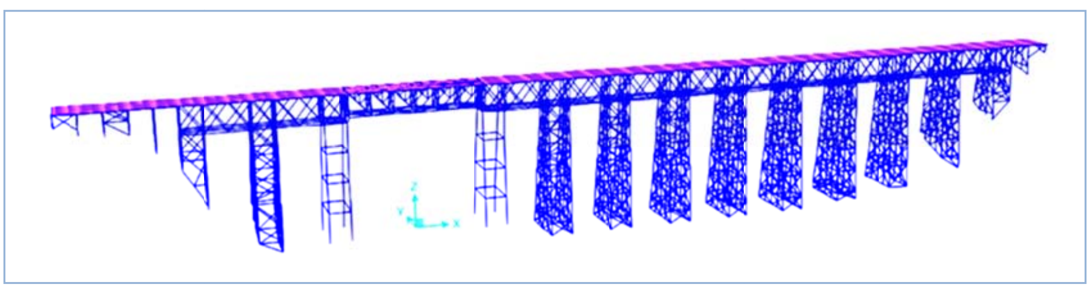


Figure 12: Analysis model of the Albion River Bridge

**4.1 Historical significance of the Albion River Bridge**

The bridge has two very important historical significance that have made it eligible to be listed on the U.S. National Register of Historic Places by the U.S. National Parks Service of the Department of Interior. The two criteria in the National Register of Historic Places [2] that applies to the Albion River Bridge are: (a) The structure is "*associated with events that have made a significant contribution to the broad patterns of our history*; and (b) the structure embodies "*the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction* [2].

The Albion River Bridge was constructed during World War II. At the time, the steel usage in U.S. was controlled by the War Department and was used mostly to construct war equipment such as tanks and ships. When the War Department was asked by the State of

California to supply steel for the bridge, the only items they received was two steel trusses, recovered from an old railroad bridge and some railroad rails and a limited amount of rebars. The steel trusses were used in the main span over the river. The rails were used as longitudinal rebars in the columns and rebars were used in various concrete elements. This connection of the Albion River Bridge to World War II has made the bridge significant as far as the U.S. history is concerned and satisfies the Criterion (a) mentioned in the previous page. The bridge also satisfies the Criterion (b) of the National Register of Historic Places as given in the previous page since it is one of the last remaining "well-engineered" timber bridges in California, and probably in the U.S. and represents a *type, period, or method of construction* that is no longer used.

### 4.2 Historical Registration of the Albion River Bridge

In 2015, a National Register Form was filed by John Johansen, a local architect, to register the Albion River Bridge as a United States National Historic Place. After more than one and a half year review of the application, the California Office of Historic Preservation [3] placed the case of the Albion River Bridge historical registration on the May 10, 2017 meeting agenda of the State Historical Resources Commission and asked for public comments. The author prepared a 14-page letter in support of the application and submitted it to the Commission, attended the meeting of the Commission and made in-person public comments in support of the application. At the meeting, the Commission unanimously approved the Albion River Bridge to be listed in the U.S. Register of National Historic Places and forwarded its recommendations to the Department of the Interior for final approval.

### 4.3 Challenges faced in historical registration of the Albion River Bridge

The efforts to register the Albion River Bridge as a National Historic Place has been quite challenging, though at the end, very rewarding when the bridge was registered. The main challenge and difficulty was that the California Department of Transportation (Caltrans),the state agency that owns, maintains, and operates the Albion River Bridge, not only was not supporting the historical registration efforts but appeared to be determined to push for demolition and replacement of this perfectly fine historic bridge in a very good condition and replace it with a reinforced concrete bridge. Caltrans was giving numerous reasons for replacement in its reports, such as, "the timber deck is rotten and crushing", "the bolts are corroding", "the steel truss has corrosion", "the treatment material of the timber is releasing arsenic to the environment", "the tsunamis can collapse the bridge", "the cost of maintenance justifies spending more than $50 million to replace the bridge ", and several other reasons. The author using the results of his 3 years of investigation of the condition of this bridge, in his letter to the Historical Preservation Commission showed that none of the above-mentioned reasons are true and the bridge is in very good condition.

The main reason for demolition was given by Caltrans was that the timber deck of the Albion River Bridge "was rotten and crushing". Under pressure from the Albion Community members and the author, in 2015 Caltrans materials laboratory did conduct actual in-situ tests and laboratory tests of the deck core samples and concluded that the deck, in fact, is in very good condition and is not rotting nor crushing. The corrosion of steel elements also proved to be not true and not a justifiable reason to demolish a perfectly fine historical bridge. The corrosion of galvanized bolts can be managed by proper maintenance of the bridge and by replacing the corroded bolts with better galvanized modern bolts that resist corrosion better.

## 5 CONCLUSION

1. The tests reported in this paper formed the basis of the seismic retrofit of the critical elements of the Golden Gate Bridge, which were the main stiffening truss and the base of the main towers. In both cases, the problem was that the truss chords and the base of the tower had relatively high width-to-thickness ratios, resulting in a very brittle local buckling of these elements under compression.
2. The local buckling problem of the main truss chords of the Golden Gate Bridge could not be retrofitted with the economy. Therefore, by using hydraulic dampers between the main trusses and the tower legs, the seismic forces expected during the future strong earthquakes were reduced and the local buckling of the truss chords prevented.
3. The tower legs of the Golden Gate Bridge do not have anchor rods to connect them to the foundations. As a result, during a major earthquake, the tower legs of the bridge are expected to uplift and compress down on the caisson foundations. Under the compression, the plates at the base of the tower legs can buckle locally prior to ductile yielding. The towers were retrofitted to prevent the local buckling by bolting vertical wide flange stiffeners to the mid-width of the plates. The tests summarized in this paper showed that the retrofit measure was able to prevent local buckling and enable the plates to reach their capacity in compressive yielding and have sufficient ductility.
4. Registering the Albion River Bridge as a U.S. National Historic Place was very challenging although eventually successful. The State Department of Transportation, the owner of the bridge, was not supporting the historical registration. The State Department of Transportation was and still is pushing for the demolition of this perfectly fine historically significant bridge and wants to replace it. This case showed that through the efforts of the Community and fact-based data supplied by the author, it was possible to stop the transportation agency from the demolition of a valuable historical bridge.

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