Architectural heritage and seismic retrofit of the Golden Gate Bridge

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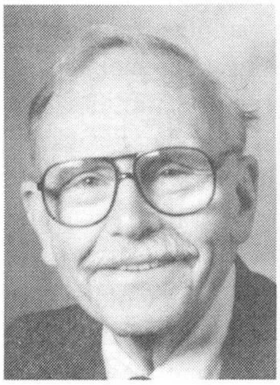
Héritage architectural et consolidation du pont de Golden Gate vis-à-vis de séismes

Denkmalschutz und Erdbebenertüchtigung der Golden-Gate-Brücke

Charles SEIM
Senior Principal
T.Y. Lin International
San Francisco, CA, USA



Charles Seim has been with T.Y. Lin for 15 years. He has been active in the design of large bridges, seismic investigations and is the Project Manager for the seismic retrofit of the suspension span of the Golden Gate Bridge. Prior to joining T.Y. Lin, he participated in the design, construction and maintenance of California toll bridges.

SUMMARY
The 58 year old Golden Gate Bridge is world renown as an example of the beauty that engineering can achieve. The crossing consists of seven structural types, including the 1280 m suspension span. All are in need of seismic retrofit to upgrade the structures to withstand a magnitude 8 event. The retrofit measures must conform to performance, design and architectural criteria to preserve the bridge's historical and architectural heritage. The paper reviews the original design and the collaboration between the engineer and the architect and presents the criteria to be used by designers to safeguard this structure.

RÉSUMÉ
Le Pont de Golden Gate, construit il y a 58 ans, a une réputation mondiale, due à sa beauté et au succès de sa réalisation technique. La traversé du Golden Gate peut être décomposé en sept parties structurales, comprenant entre autres, la partie suspendue de 1280 m. Toutes ces parties doivent être reprises et consolidées, du point de vue sismique, afin de résister à un événement de magnitude 8. Les mesures de consolidation doivent satisfaire des critères de performance, de projet et d'aspects architecturaux, afin de préserver les qualités historiques et architecturales du pont. L'article traite du projet original et de la collaboration entre l'ingénieur et l'architecte. Il présente les critères que doivent respecter les ingénieurs afin d'assurer la pérennité de cette construction.

ZUSAMMENFASSUNG
Die 58 Jahre alte Golden-Gate-Brücke ist ein weltbekanntes Beispiel für die im Ingenieurbau erreichbare Schönheit. Der Brückenzug besteht aus sieben Tragsystemen, darunter der 1280 m langen Hängebrücke. Sie alle benötigen eine Tragwerksverstärkung, um einem Erdbeben der Magnitude 8 widerstehen zu können. Die Ertüchtigungsmassnahmen müssen Leistungs-, Entwurfs- und architektonische Kriterien erfüllen, um die bauhistorische Bedeutung der Brücke zu erhalten. Der Beitrag behandelt den ursprünglichen Entwurf und die Zusammenarbeit zwischen Ingenieur und Architekt mit den denkmalschützerischen Vorgaben.

1. INTRODUCTION

The Golden Gate Bridge is one of the most famous, historical and enduring structural achievement in the world. The start of its construction culminated a decade of bridge designs that extended the world record for span length five times (1) in the United States. The Golden Gate Bridge opened on May 28, 1937 and held the title of the world's longest bridge for 27 years when it lost by only 60 ft to the Verrazzano-Narrows Bridge in New York.

Although most people think of the Golden Gate Bridge as a single structure, the 2790m overall length of the bridge actually consists of seven different structure types. The bridge's major components are the North & South steel truss approach viaducts, the Fort Point steel arch, the steel cable's concrete anchorages and concrete anchorage housings, the main span steel suspension bridge, and the art deco concrete pylons which are purely architectural motifs. All of the foundations for these structures except the northern viaduct are supported directly on rock. The design and construction of the bridge has been well documented in the Report of the Chief Engineer (2).

2. BRIDGE LIFE

The question is often asked, "How long will the Golden Gate Bridge last?". The answer, of course, is "hundreds of years", if it is properly maintained. Eliminating obsolesces, what will bring the Golden Gate Bridge down? Corrosion, fatigue, scour, wind, and earthquakes are the enemy of all bridges. But these are natural events; perhaps more bridges have been destroyed by the most evil and horrible of all - man-made events - war.

The owners and operators, The Golden Gate Bridge Highway and Transportation District's policy is to maintain the bridge in first class conditions; corrosion is not a factor. Live load stresses are low; fatigue is unlikely. The bridge is founded on rocks - scour cannot happen. But the bridge was damaged by a wind storm in 1951. The damage was repaired and a lower lateral bracing system installed in 1954.

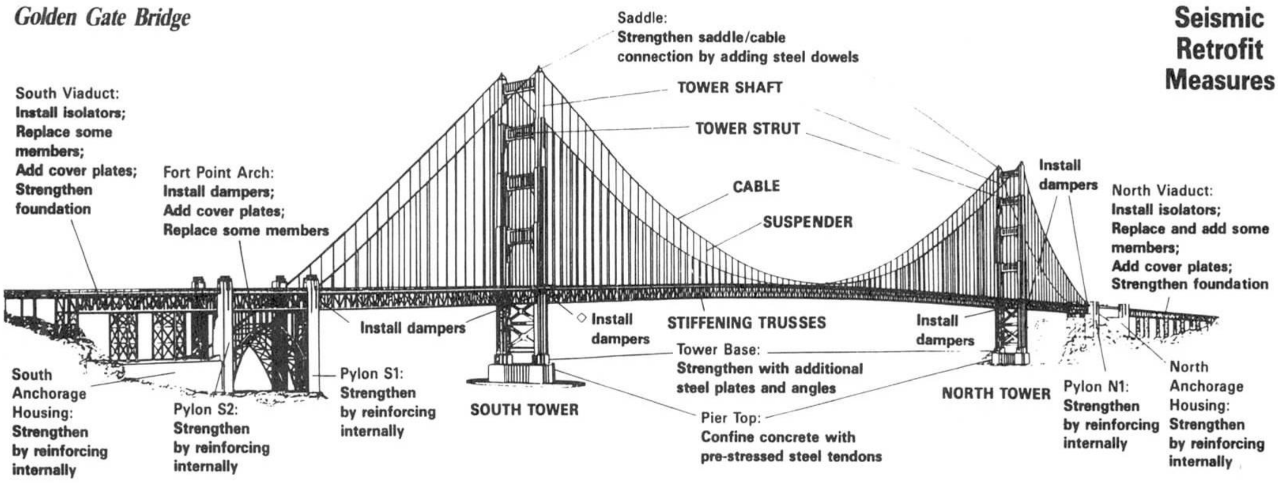
The seismic risk to the bridge was brought startling to the attention of the engineering profession by the October 17, 1989, Loma Prieta Earthquake. The Golden Gate Bridge was not damaged by this moderate and distant earthquake. The maximum acceleration near the bridge site was a modest eight percent of gravity, about its design value of seven and one half percent.

Shortly after the earthquake, the District employed T.Y. Lin International (TYLI) to perform a seismic evaluation of the entire crossing. That investigation (3) found that in a magnitude 7 event, severe damage could close the bridge for an extended period of time. In an event similar to the 1906 disaster, considered equal to the maximum credible earthquake of magnitude eight plus, portions of the bridge could be in risk of collapse.

A follow-up report (4) developed design criteria, a seismic retrofit concept for each of the 7 structures comprising the crossing, and a cost estimate for seismic retrofit of the crossing.

3. PERFORMANCE CRITERIA

Performance Criteria that controls the service and use of the bridge after a major event, were developed by the District to meet the following four requirements in a maximum credible earthquake defined as a return period of 1000 to 2000 years.



- The bridge shall not be totally closed to the public for more than 24 hours after the earthquake.
- The bridge shall provide emergency vehicle access immediately after the earthquake.
- The bridge shall be available for limited vehicular access (e.g., public transportation) within a few days after the earthquake.
- The bridge should be repairable to fully operational pre-earthquake service levels within one month after an earthquake.

Limited, repairable damage to the bridge, consistent with these four requirements, is acceptable. This criteria will allow the bridge to serve as an emergency entrance and exit for San Francisco and, within a few days, to serve the public and reduce the cost of damage repairs.

4. ARCHITECTURAL HERITAGE

The aesthetic impact of the Golden Gate Bridge was the result of a fruitful collaboration between an engineer, Joseph B. Strauss and an architect, Irving F. Morrow. Strauss wanted to create the most beautiful bridge in the world. Perhaps the considerable criticism he received for his original proposed monstrosity of a hybrid cantilever/suspension bridge convinced him to stress beauty of design for this crossing..

The project was both his and Morrow's opus magnum, an unprecedented technical challenge and achievement at a breathtaking site. Strauss wrote in (2) " It is a truism that every great bridge project in its consummation has contributed notably to the science of structural design and the technique of the builder; and in these respects the Golden Gate Bridge has been no exception. Nevertheless, its outstanding contribution has not been to these alone, but to architectonics as well, for the structure since its completion has received notable recognition because of its majestic beauty and size."

" We have seen that the design adopted was one in which the essential beauty and elemental simplicity of a conventional suspension design was obtained, a design with symmetrical shore spans supported by the cables. To this simplicity of line was added the dignity of the well-proportioned portal-braced towers, all in accordance with the original studies. A happily-selected color scheme dominated by orange-vermilion completes the picture, blending perfectly with the changing seasonal tints of the natural setting of the bridge and the surrounding land masses, sea and sky. The effect is as highly pleasing as it is unusual in the realm of engineering structures."

Within this statement by Strauss, we see his feelings of the importance of aesthetics (architectonics) to the overall impact of the bridge on the viewer. He mentions simplicity of line, well proportions, and color scheme, all of which contributes to the beautiful appearance of the structure.

Morrow's major contribution is that he viewed the Bridge as a whole, and insisted that all elements form an integral design. As Morrow himself put it: "The architectural design of the bridge is properly a single, all-inclusive problem embracing its appearance in every possible aspect. Form, texture, color, illumination, etc., are each and every one only integral parts of one general conception. To isolate as a separate detail any one of these aspects of appearance would result in disharmony, or at best in failure to realize to the full the original intention of the design. In view of the tremendous scale and dignity of the Golden Gate Bridge, the preservation of unity is of prime importance. Small effects cleverness, trickiness will prove disintegrating and unworthy. All treatment must aim at the utmost breadth and simplicity of effect."

We can see that Morrow's viewpoint harmonizes with Strauss' and emphasizes the importance of respecting and preserving the structural heritage that is so admired by the public.

Clifford Paine, the Principal Assistant Engineer to Strauss throughout the construction of the Bridge, wrote: "The architectural treatment of the bridge was carefully studied during the early stages of the design, the towers being given special attention as they constitute such a prominent feature. The size and spacing of the struts above the floor, the treatment of the strut enclosures, the location of the offsets in the shafts, the number and position of the diagonals...all received careful consideration."

Paine stresses his concern for proportion of size and spacing particularly for the two main towers which are the dominant features of the bridge, and by simple measurements, determines the size and spacing of the struts follows a logical profession. The towers are 227m high with struts above the roadway and the more structurally efficient cross-bracing used below the roadway. The shafts of the towers are tapered both transversely and longitudinally by setbacks along the height.

It is interesting to view the proportions of the towers as they were finally constructed. The four struts above the roadway vary in depth and spacing, being thinner and closer together with height. The two top struts are each approximately 6.7m deep and the lower two are approximately 9.1 ft deep, giving a ratio of about 1 to 1.36. From the tower top down to the roadway, the vertical strut spacing ratios are 1, 1.1, 1.3 and 1.4, respectively.

The importance of the architectural design and historical heritage of the Golden Gate Bridge is well documented in (5). The bridge, by every measure, is eligible for listing on the National Register of Historic Places and is a Civil Engineering Landmark. In 1994, the American Society of Civil Engineers elected the bridge as one of the "Modern Wonders of Civil Engineering."

5. ARCHITECTURAL CRITERIA

According to the U.S. Historic Preservation Act of 1966 and the Secretary of the Interior's Standards for Rehabilitation, special consideration must be given to any changes to the bridge that may affect the defining characteristics of the structure. For the Golden Gate Bridge, these include distinctive features, such as the steel arch over Fort Point, the flanking concrete pylons, and finishes such as the International orange color or concrete form marks.

If new work is required, it should not destroy historic materials that characterize the property and should be compatible with mass, size, scale, and architectural features to protect the historic integrity of the property and its environment. These issues are not binding on the retrofit measures at this time, but were used as strong guidelines for the seismic retrofit design.

In recognition of these issues, the retrofitting measures developed to upgrade the seismic performance of the bridge will meet the following hierarchical guidelines:

1. First priority shall be to meet the seismic retrofit design criteria presented in the Design Criteria.
2. Second priority shall be to maintain the current architectural appearance of the bridge and to follow as much as possible the guidelines of the U.S. Preservation Act of 1966. Care shall be taken not to radically change the structural systems and structural features of the existing bridge. Seismic retrofit measures shall preserve as much as possible the scale of member and proportions of solids to voids of the existing bridge.
3. Third priority shall be to respect as much as possible the architectural vocabulary established for each of the structural types comprising the bridge. Care shall be taken not to radically change the character defining features, materials, finishes and color of the existing bridge.
4. Fourth priority shall be to retain as much as possible of the original material that is now constructed into the structure.

6. DESIGN CRITERIA

Since no design documents existed for seismic retrofit design of long span bridges, TYLI was engaged to develop a Design Criteria for Seismic Retrofit Measures (5). The criteria was developed as a guide for designers and was printed in loose leaf notebooks so that revisions could easily be inserted. In lieu of using the criteria, the designer is permitted two alternatives (1) analysis methods which consider actual material properties and behavior, or (2) physical models or testing.

The technical issues that the Design Criteria addresses are based on meeting the Performance Criteria and Architectural Requirements noted above. Limited repairable damage that does not threaten structural safety and that can be repaired without interrupting traffic is acceptable. This does allow portions of the bridge to respond to limited inelastic action but the primary response should be essentially elastic where possible.

7. SEISMIC RETROFTI METHODS

The figure shows the final seismic retrofit methods developed for the seismic retrofit of the seven structural types of the Golden Gate Bridge crossing. Several consultants are working on the construction documents with completion schedule for mid-summer. The District plans to start construction during the summer of 1995. The total estimated cost of the construction, engineering and administration is about $165 to $175 million. This is approximately 10 to 15 percent of the replacement costs of the entire crossing.

8. CONCLUSION

The seismic retrofit methods developed for the seven structural types comprising the Golden Gate crossing has shown that all seven can be structurally upgraded to meet the Performance Criteria, the Design Criteria and the Architectural Requirements of the Golden Gate Bridge.

The design criteria and retrofit methods developed during the design of the seismic retrofit of the Golden Gate Bridge provides a methodology that can be applied to the seismic retrofit design of other major bridges and also honor the historical heritage of the structure.

9. ACKNOWLEDGMENTS

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