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Seismic Retrofit of the South Approach Viaduct of the Golden Gate Bridge

Consolidation parasismique du viaduc sud du pont de Golden Gate

Erdbebenertüchtigung der Südzufahrtsrampe der Golden-Gate-Brücke

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SUMMARY

This paper examines the thinking behind the Golden Gate Bridge South Viaduct seismic retrofit. It discusses the analytical and design issues involved and explains the current retrofit strategy and the reasons behind it. It presents a broad overview of the analysis results and a prediction of the south viaduct's structural behavior. The paper exposes the design bases and assumptions involved. It also illustrates the importance of integrating analysis, design and detailing with other design criteria such as reliability, aesthetics, constructibility, serviceability, and economics.

RÉSUMÉ

L'article présente les réflexions qui ont conduit à la consolidation parasismique du viaduc sud du pont du Golden Gate. Il présente des questions de projet et d'analyse et explique la stratégie actuelle de la consolidation et les raisons qui y ont conduites. Les résultats de l'analyse sont présentés de façon générale, ainsi qu'une prédiction du comportement structural du viaduc du sud. L'article expose les bases du projet et les hypothèses faites. Il illustre également l'importance de la considération globale de l'analyse du projet et des détails constructifs en fonction d'autres critères de projet tels que fiabilité, esthétique, possibilité de réalisation, aptitude au service et aspects financiers.

ZUSAMMENFASSUNG

Der Beitrag untersucht das Konzept für die Erdbebenertüchtigung der südlichen Golden-Gate-Vorlandbrücken im Hinblick auf Berechnungs- und Bemessungsfragen. Nach einem Ueberblick über die Ergebnisse der analytischen Vorhersage des Brückentragwerkverhaltens werden die Bemessungsgrundlagen und -annahmen dargelegt. Dabei wird deutlich, wie wichtig die Integration von Berechnung, Bemessung und konstruktiven Detaillösungen mit anderen Kriterien wie Zuverlässigkeit, Aesthetik, Bauvorgang, Gebrauchstüchtigkeit und Wirtschaftlichkeit ist.

1. INTRODUCTION

The majestic Golden Gate Bridge guards the only entrance to the beautiful San Francisco Bay in Northern California. This historical landmark is bounded by Marin County in the north and San Francisco in the south. The 9151 foot long - six lane bridge is composed of four main structures, namely the South Approach Viaduct, the Fort Point Arch, the Main Suspension Span, and the North Approach Viaduct. The bridge joins San Francisco and Marin County and spans the only entrance into the San Francisco Bay. This paper concentrates on the South Approach Viaduct retrofit strategy from its initial development to final PS&E.

The South Approach Viaduct is a 700 foot long bridge consisting of three 70'-0" long girder spans and three truss spans (2@125'-0" & 175'-0") supported on pin steel bearings (See Figure 1). It lies between the south abutment on the San Francisco side to the south face of Pylon S2. The south viaduct supports a 62'-0" roadway with 11'-6" sidewalks on either side. The girder spans are simply supported by the south abutment, two steel planer bents 9 and 10, and bent 8 which is integral with Tower 1. The three truss spans are simply supported on three steel Towers 1,2, & 3 and Pylon S2. Bents 9 & 10 and Tower 1 are supported on concrete pedestals with no piles. Similarly, towers 2 and 3 rest on concrete frame towers which are housed within the Main Suspension Cable south housing structure. During the 1980's, the original concrete deck was replaced with a lighter and stronger orthotropic steel deck system supported on the original floorbeam pedestals. This new steel orthotropic deck system dramatically reduced the overall weight of the structure as a whole.

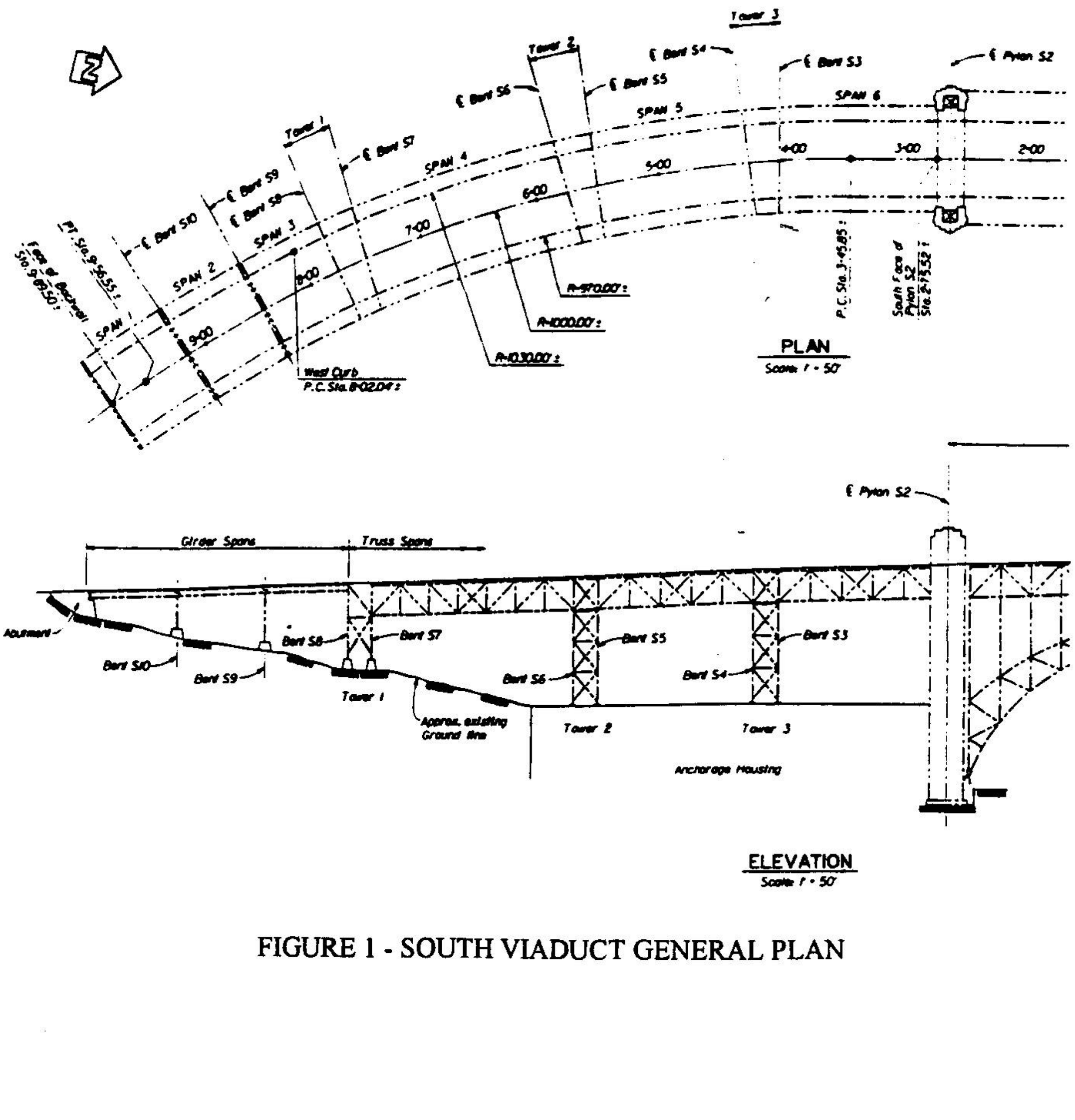

FIGURE 1 - SOUTH VIADUCT GENERAL PLAN

In the early 1980's, the Golden Gate Bridge District performed a preliminary and less thorough seismic retrofit of the Golden Gate bridge which included the installation of uplift tiedown cables at all supports, a supplementary bearing seat extension at the Pylon S2 interface, and tying all adjacent spans together with restrainer rods. These retrofit items proved beneficial as demonstrated during the 1989 Loma Prieta earthquake. However, it is believed that such a simple retrofit would not suffice should the bridge be subjected to an earthquake of much larger magnitude. The lessons learned from this retrofit did however provide some insight into how the structure behaves and what benefits certain retrofit improvements can provide.

The current retrofit scheme involves incorporating a series of improvements to help maintain serviceability before and after a large quake. The scheme includes replacing all the existing pinned steel rocker and fixed bearings with isolation bearings, installing additional shear connectors between the deck and floorbeams, linking all adjacent spans together to provide axial continuity, providing isolation joints at the south abutment and at the Pylon S2 interface, replacing the existing towers 2 and 3, and additional joint and member strengthening as deemed necessary.

2. ANALYSIS AND RETROFIT SCHEME

The intent of the Golden Gate Bridge Seismic Retrofit Project is to ensure that the bridge maintains its function after a major earthquake, termed the maximum credible earthquake, registered as 8.3 on the Richter scale. This is comparable to the infamous 1906 San Francisco earthquake. To gain a more realistic insight into the bridge behavior, site specific ground motion time histories were developed along the bridge based on the maximum credible events at the San Andreas fault.

Extensive linear, longhand, and nonlinear analysis was used to adequately predict the overall behavior of the existing structure. Initial runs showed high demand forces in the superstructure resulting in extensive strengthening and increased retrofit costs. Also with the existing bearings, a large uplift force developed resulting in a global overturning problem. For this reason, the concept of brute force strengthening was abandoned as a possible retrofit scheme. In order to reduce these high demands and the overturning problem, all the existing bearings were replaced

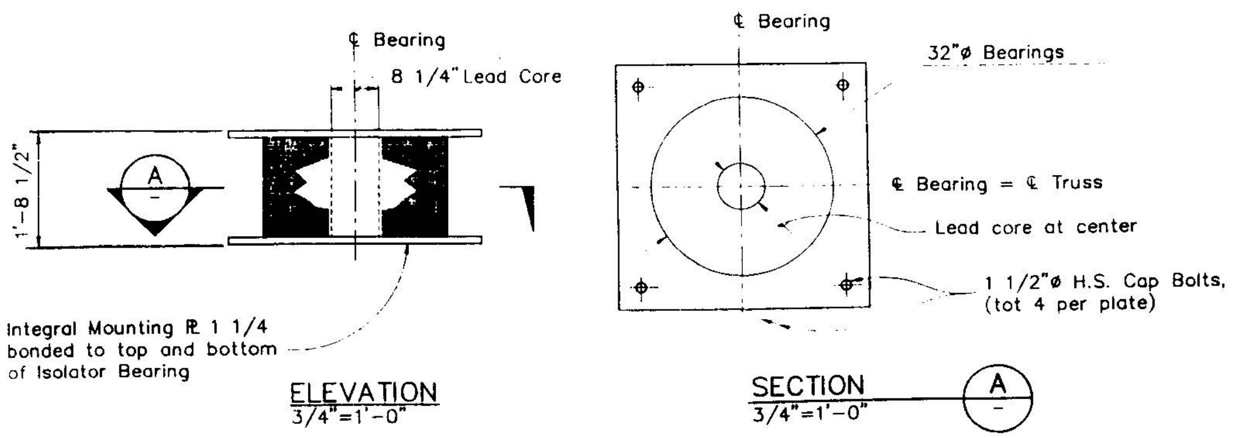

FIGURE 2 - ISOLATION BEARING DETAIL

with isolation bearings (See Figure 2). By doing so, the superstructure force acceleration was dramatically reduced to 0.3g, and the amount of strengthening required was reduced as well. With this lower force acceleration, overturning was no longer a problem. However, the benefits of reduced seismic forces through isolation bearings does have one disadvantage. Large displacements in the order of 15", characteristic of isolator bearings, occurs which will need to be accounted for at the boundary ends. The existing structure currently has only 1" temperature joints at the abutment and at the Pylon S2 interface.

Although the ground motions used in the analysis were thoroughly researched and investigated within the limits of present day technology, it is rather uncertain to predict the type and magnitude of earthquake that will occur and where. In fact, no one can predict with any degree of certainty what type or strength of earthquake will occur or how the structure will actually behave. With this in mind, secondary safety measures were incorporated into the retrofit design to provide backup safety measures in the event the primary system were to fail. A good example of this is the isolation bearings. Although the bearings were designed and sized for the design earthquake, there is a possibility that the bearing will be pushed beyond its ultimate displacement capacity resulting in failure of the bearing and support as a whole. Therefore, supplemental catcher/support blocks are added to the structure at all bearing locations that serve to support the superstructure and prevent complete span failure should the isolators fail. These blocks are positioned to allow free movement of the isolators and provide secondary support in both the transverse and longitudinal directions. This provides a much needed additional level of protection for such an important bridge.

Like all bridge structures, the majority of the structure mass is in the deck. Therefore, it is essential that the deck mass have an adequate load path in order to safely ground the seismic forces. In depth analysis showed that the existing deck supporting pedestals are inadequate to transfer the deck mass shear to the floorbeams. Therefore, a series of shear connectors were added between the deck and the floorbeams to ensure full mass transfer.

Currently, the individual girder and truss spans are independent with no continuity between adjacent spans. Retrofit analysis found that linking all the spans together proved more beneficial from a seismic standpoint. For one, linking adjacent spans together reduces the possibility of a drop span condition similar to what occurred on the San Francisco-Oakland Bay Bridge during the Loma Prieta Earthquake of 1989. In addition, linking spans allows the bridge to behave as one unit resulting in improved behavior during strong out of phase seismic movements. With the use of isolation bearings, temperature movement is accounted for in the bearings. Therefore, linking adjacent spans does not cause a concern from a thermal standpoint.

Interaction between adjacent structures has always been a concern when performing analysis. For this particular situation, the interaction with the adjacent Pylon S2 was a concern. With this in mind, the computer model was modified to include Pylon S2. Pylon S2 is a massive 240 feet tall lightly reinforced concrete hollow structure with a narrow 32'-0" base longitudinally and a 120'-0" base transversely. The current Pylon retrofit strategy calls for partially tying down the base while allowing some minimal amount of uplift to reduce the seismic forces. The approach viaduct rests on pedestals built within Pylon S2 and is therefore influenced by the Pylon behavior. With its narrow base, the pylon longitudinal displacement is relatively large. This displacement coupled with the viaduct's longitudinal displacement warranted the need for a relatively large isolation deck joint since out of phase movements could result in the two structures moving away from each other or together. The joint was designed and detailed for both longitudinal and transverse movements since the isolator bearing acts in both directions (See Figure 3). At the abutment, a similar size and joint type was necessary. These large deck joints will ensure free movement of the structure and thus make full use of the isolation bearings.

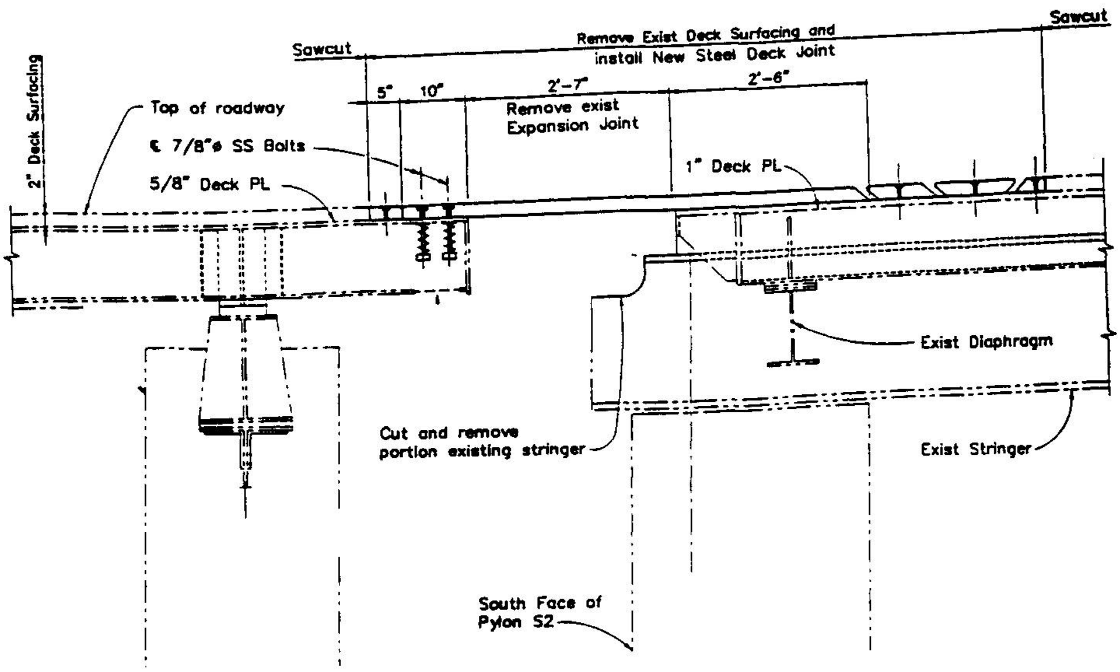

FIGURE 3 - TYPICAL ISOLATION JOINT SECTION

As discussed, the isolation bearings aid in reducing the seismic input into the structure, but there is one limitation. The limitation is that isolation bearings can resist little or no uplift force. The project specific criteria mandates that the vertical acceleration be included in the analysis and accounted for in the design. This creates a dilemma in that the superstructure must be tied down to reduce the vertical seismic force component while at the same time allowing full longitudinal and transverse cyclic isolator displacement. A detail involving standard restrainer cables with lengths that will permit the required horizontal displacement was devised. These cables were prestressed to the required uplift force to ensure their effectiveness immediately without any initial elongation.

Analysis of the viaduct demonstrated that the existing towers 1,2, and 3 remained elastic throughout the design earthquake. With this in mind, it seems logical to keep the existing towers and make strengthening provisions where necessary. However with the close proximity to the harsh salt water spraying environment, the original 1935 constructed towers 2 and 3 are severely corroded with rust. Therefore, the validity of using the original net section was in question. Continued use of these towers would result in on-going steel deterioration as well as a reduction in overall tower strength. A detailed life cycle cost comparison was performed on whether it would be more economical in the future to keep, upgrade, and maintain the existing towers or to replace them altogether. The comparison indicated similar costs with each alternative. Therefore, it was found more beneficial economically and structurally to replace both towers 2 and 3. Tower 1 is in better condition with little or no corrosion. Because of this, it was recommended and approved to keep the existing tower 1 structure. The north approach viaduct retrofit involved a similar scheme with replacement of all the steel towers as well.

Throughout the course of the project, the understanding that the original bridge appearance must not be altered was maintained. With Sverdrup Civil, Inc as the prime consultant on this project, we hired the services of a historical preservationist to oversee, review, and suggest ways in which structural retrofit details could be incorporated into the structure without altering the bridge's original historic appearance. Items such as the use of perforated plates to simulate the original member lacing were scrutinized and reviewed as the issue of whether strength or historical preservation was most important.

3. CONCLUSION

The seismic retrofit of the Golden Gate Bridge offered engineers a chance to use their creativity in analyzing, designing, and detailing ways to aid the structure in surviving the next large earthquake. The key retrofit item was the installation of isolation bearings at all support points. This single item dramatically reduced the forces in the entire structure thus requiring less retrofit throughout the structure. Large isolation joints at the boundaries were one downfall to the isolation bearings but were well worth it in exchange for reduced seismic forces. The replacement of the supporting steel towers demonstrates the true concept of value engineering. Life cycle cost comparisons, as shown here, illustrate the importance of careful investigation of retrofit alternatives in order to save money and provide the required structural aspects. Severe corrosion of the existing towers was a major contributor to the decision to replace them. Linking of adjacent simply supported spans was also a major refinement in that it lessened the possibility of a drop span condition and improved the overall structure behavior for out of phase movements.

The south viaduct is as important a structure as any other portion of the bridge. Without the survival of any one portion of the bridge, the bridge would have to be closed. Therefore, the south viaduct is a critical transportation link to the main suspension span and is equally important. We believe we have investigated and devised a scheme that will improve the viaduct's overall behavior, prevent collapse, and maintain serviceability.

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