Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 73/1/73/2 (1995)

Artikel: Experience with seismic retrofit of major bridges

Autor: Matson, Darryl D. / Taylor, Peter R.

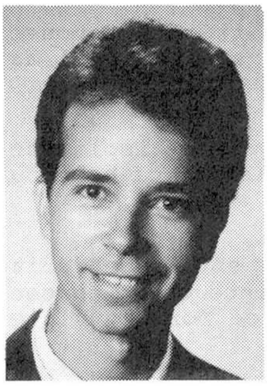
DOI: https://doi.org/10.5169/seals-55241

Experience with Seismic Retrofit of Major Bridges

Expérience acquise dans la consolidation parasismique de grands ponts

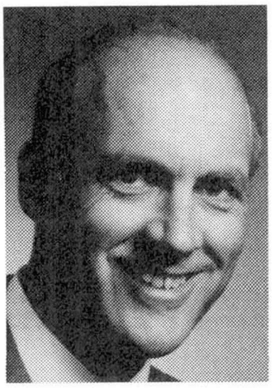
Erfahrungen bei der Verstärkung von grösseren Brücken gegen Erdbebeneinwirkung

Darryl D. MATSON
Civil Engineer
Buckland & Taylor Ltd
Vancouver, BC, Canada



Darryl Matson, born in 1964, received his M.A.Sc. in civil engineering in 1989 from the University of British Columbia. He has specialized in the design and retrofit of bridges, with an emphasis on seismic engineering.

Peter R. TAYLOR
Civil Engineer
Buckland & Taylor Ltd
Vancouver, BC, Canada



Peter Taylor, born in 1939, received his Ph.D. in civil engineering in 1965 from the University of Bristol. Since 1970 he has specialized almost exclusively in bridge engineering, and in the past ten years he has developed specific expertise in the seismic retrofitting of bridges.

SUMMARY

This paper describes aspects of seismic assessment and retrofit of four major bridges, one in California and three in Vancouver. Each bridge posed a different set of seismic problems and required a different set of retrofit solutions. Items of interest are the use of innovative analyses and their benefits, the implementation of innovative retrofit designs and their benefits, the prioritization of individual retrofit items, and the benefit of retrofitting over several years.

RÉSUMÉ

Cet article présente différents aspects de l'évaluation et de la consolidation parasismique de quatre grands ponts situés en Californie et à Vancouver. Lors de l'évaluation, chacun de ces ponts présenta des problèmes aséismiques différents et, conséquemment, requit des solutions différentes. Les principaux éléments d'intérêt présentés sont l'utilisation de méthodes d'analyse nouvelles ainsi que leurs avantages, l'emploi de concepts innovateurs pour la consolidation ainsi que leurs avantages, le traitement des éléments selon leur ordre d'importance ainsi que les avantages associés à la répartition dans le temps des travaux de réfection.

ZUSAMMENFASSUNG

Der Beitrag beschreibt einige Gesichtspunkte der Widerstandsbestimmung gegen Erdbebeneinwirkungen von vier größeren Brücken und die vorgeschlagene Verstärkung derselben. Eine der vier Brücken befindet sich in Kalifornien und drei sind in Vancouver, Kanada. Jede der vier Brücken stellte besondere seismische Probleme und benötigte eine spezifische Lösung für die Verstärkung. Speziell erwähnt werden neuartige Berechnungsmethoden für die Analyse und deren Nützlichkeit, die Ausführung von neuartigen Verstärkungsdetails und deren Vorteile, die Prioritätssetzung für verschiedene individuelle Verstärkungsdetails, und die Vorteile der Verstärkungsausführung über mehrere Jahre.

1. INTRODUCTION

This paper describes aspects of seismic assessment and retrofit of four major bridges, one in California and three in Vancouver Canada. They are:

Golden Gate Bridge South Approach, San Francisco, and
Burrard Street Bridge,
Granville Street Bridge, and
Second Narrows Bridge, Vancouver Canada.

Each bridge posed a different set of seismic problems and required a different set of retrofit solutions. Items of interest are the use of innovative analyses and their benefits, the implementation of innovative retrofit designs and their benefits, the prioritization of individual retrofit items, and the benefit of retrofitting over several years.

Analysis techniques used for the different structures included linear response spectrum analyses, both linear and non-linear time history analyses, as well as non-linear push over analyses.

Retrofits included member strengthening, installation of dynamic isolation bearings, the use of base isolation with friction dampers, installation of bearing restrainers and keepers, placement of bumpers, and bearing seat extensions.

Retrofit prioritization ranged from design and construction of the entire retrofit in one package for Golden Gate, to breaking the retrofit package into three phases and spreading the design and construction over a seven year period for Granville and Burrard.

The Golden Gate Bridge, located in San Francisco CA, is a 6-lane steel suspension bridge. The south approaches consist of a 215m long elevated steel viaduct, two 60m high concrete pylons, and a 100m long arch. The bridge is owned by the Golden Gate Bridge, Highway & Transportation District and was constructed in the mid 1930's. Figure 1 shows an elevation of the bridge.

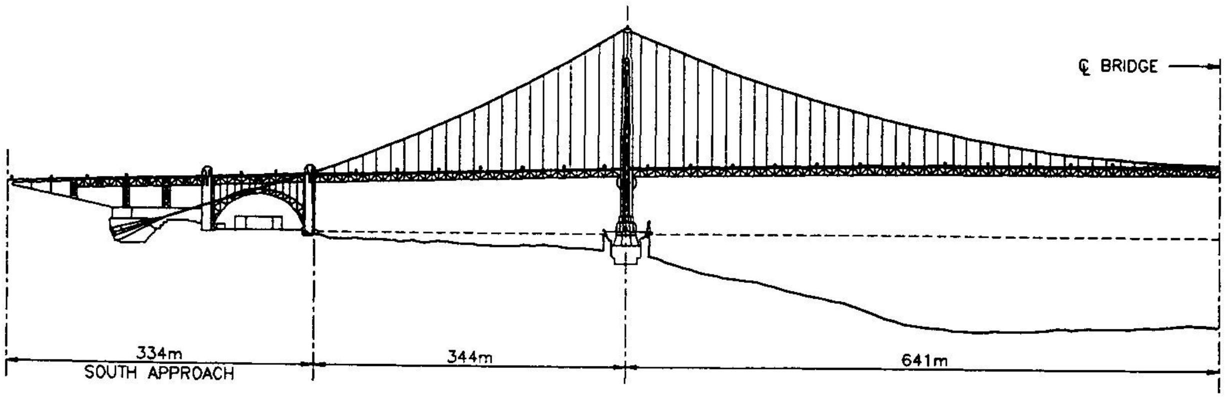


Fig.1 Golden Gate Bridge

The Burrard Street Bridge, located in Vancouver BC, is a 6-lane steel truss bridge with a main channel span of 90m. The bridge consists of 330m of steel spans and 510m of concrete approaches. The structure is owned by the City of Vancouver and was constructed in 1930. Figure 2 shows an elevation of the bridge.

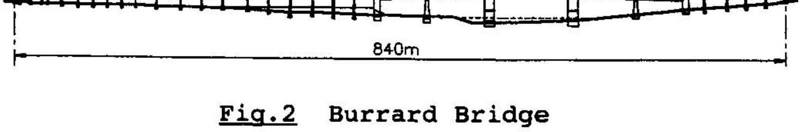


Fig.2 Burrard Bridge

The Granville Street Bridge, located in Vancouver BC, is an 8-lane steel truss bridge. The main channel span is 120m, and the bridge comprises 540m of steel spans and 630m of concrete approach spans. The structure is owned by the City of Vancouver and was constructed in 1950. Figure 3 shows an elevation of the bridge.

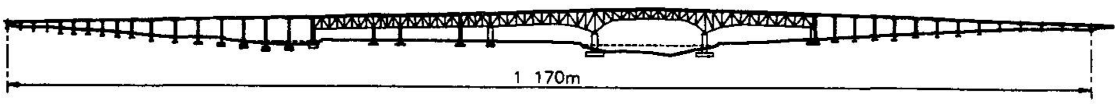


Fig.3 Granville Bridge

The Second Narrows Bridge, located in Vancouver BC, is a 6-lane steel truss bridge. The main channel span is 335m, and there is a total of 965m of steel spans and 330m of concrete stringer approaches. The structure is owned by the Province of Britísh Columbia and was constructed in 1958. Figure 4 shows an elevation of the bridge.

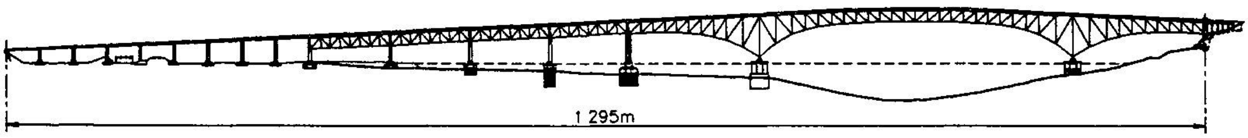


Fig.4 Second Narrows Bridge

2. SEISMIC CRITERIA

Seismic retrofit criteria varies with regional geology and with bridge authorities. Regional geology affects the size of the design earthquake, which is impacted by both the proximity to and the type of major faults in the region. Bridge authorities determine the level they wish to upgrade their structures to. A decision has to be made between retrofitting to a safety level or a functional level. A safety retrofit is meant to be the minimum upgrade required to avoid collapse of the bridge during a major earthquake, with significant repairs or possibly even replacement needed after the earthquake. A functional retrofit is a more significant upgrade that allows the bridge to remain operational after the design quake, with only minor repairs needed. Other factors affecting retrofit decisions are the importance of the bridge, the availability of alternate routes, and the amount of budget available.

The Golden Gate Bridge is a major structure in the San Francisco area, it is close to both the San Andreas and Hayward faults, and it is a major element in the regional transportation infrastructure. As such, the District required a functional retrofit to a level that would require only minor repairs following a Richter Magnitude 8.3 earthquake on the San Andreas fault, only 10km from the bridge site.

The City of Vancouver, however, decided that the Burrard and Granville Bridges would be upgraded to the safety retrofit level in stages. The stages were chosen based on priorities, and once complete, the bridges are to be re-evaluated for a functional level retrofit.

3. SEISMIC ASSESSMENT

3.3 Golden Gate Bridge

The south viaduct of the bridge was analyzed using linear response spectrum, linear time history, and fully non-linear time history analyses. Virtually all of the bracing in the steel superstructure was found to be deficient, as were many of the riveted connections. The steel supporting towers were also found to be lacking adequate strength and ductility. The existing bearings and their seat lengths were grossly deficient and were of major concern.

3.2 Burrard Street Bridge

The similar soil conditions along the length of the Burrard Bridge made the use of a linear response spectrum analysis appropriate. The lateral and longitudinal shear demands in the main piers were found to be a major problem. The lateral tension only bracing in the steel trusses was also deficient. The approach piers had a more moderate shear problem. Their lack of lateral bending capacity and ductility due to inadequate splices of undeformed reinforcing bars and inadequate transverse reinforcement was a concern. Bearing seat lengths in the approaches was also a problem.

3.3 Granville Street Bridge

As was the case with Burrard, the soil conditions made the use of a linear response spectrum analysis appropriate for the assessment of the bridge. The major deficiencies in the bridge were the short bearing seat lengths throughout the structure and the inadequate shear capacity of many of the concrete bent caps. The lateral bracing and the approach bents were a lesser problem, though still inadequate. The clearances between adjacent truss spans was inadequate, and pounding of the trusses was identified as a problem.

3.4 Second Narrows Bridge

Linear response spectrum analysis was initially used to assess the maximum member forces in the Second Narrows Bridge. However, the south end of the bridge is founded on rock while the north is on deep gravel deposits. The linear response spectrum analysis was too conservative since the spectrum, used for the entire structure, was amplified to account for the soil effects of the north end of the bridge. As a result, a linear time history analysis was used with soil amplification at the north side piers only. In addition, softening stiffness was used for overloaded bracing members from the instant of overload, allowing dynamic redistribution of the bracing load. The problems identified were steel bracing overload, inadequate bearing travel lengths, excessive shear in the bents of the approaches, and liquefaction in the deep gravels. In this case, the more sophisticated analysis was justified, and resulted in a better understanding of the bridges dynamic behaviour. The result was a retrofit whose cost was approximately 20% less than the cost of a retrofit based on a linear spectral analysis.

4. SEISMIC RETROFITS

4.2 Golden Gate Bridge

In the south viaduct, the bearings between the superstructure and the support towers are to be replaced with dynamic isolation bearings. In order to provide some redundancy and also to minimize the number of expensive deck expansion joints, all six of the viaduct spans are to be linked together axially. In addition, two of the main support towers are to be completely replaced.

By linking the spans together and installing isolation bearings, the seismic demands in the steel superstructure were reduced to low enough values that very minor additional retrofit is required.

4.2 Burrard Street Bridge

All of the truss span bearings were replaced with lead core dynamic isolation bearings to reduce the shear demands in the massive concrete piers. New lateral diaphragms were added to the approaches to provide a reliable load path for the seismic forces from the deck to the piers. The approach piers were allowed to rock at the soil level in the longitudinal direction. This resulted in large relative displacements at the level of the bearings so bearing restrainers were added throughout the approaches. In the transverse direction, a limited number of piers were strengthened to carry all of the seismic load.

Through the use of dynamic isolation bearings and pier rocking, the seismic input into the bridge was reduced to acceptable levels. In addition, these two strategies resulted in a more robust retrofit, elevating the retrofit to that of a functional retrofit for a very minor cost increase.

The retrofit chosen required only a linear response spectrum analysis, using secant stiffnesses to model the bearings and a reduced spectrum to capture the effect of the added damping.

4.3 Granville Street Bridge

In the truss spans of the bridge, the lateral bracing was strengthened and cable restrainers were added at the bearings. Large bumpers were added between adjacent trusses to reduce the impact loads associated with the trusses pounding into each other. The cap beams of the bents that support the truss spans were encased with new post-tensioned concrete.

The retrofit chosen for the Granville approaches was to isolate the approach superstructure from the supporting piers. Isolation bearings, similar to those used on Burrard and Golden Gate, could not be used here due to lack of clearance height between the substructure and the superstructure. Instead, sliding bearings free in the horizontal plane were used to replace the existing bearings and friction dampers were installed between the sub and superstructures. This, however, necessitated the use of a non-linear time history analysis for the final assessment of the approaches. The bearings and friction dampers were modelled as friction-spring-damping elements in this analysis.

The use of isolation and damping dramatically reduced the demands in the substructure, allowing for a modest retrofit in the piers. This consisted of wrapping the columns with fibreglass to increase confinement and ductility, and post-tensioning some of the bent caps.

4.4 Second Narrows Bridge

The bearings in the approach trusses are to be replaced with dynamic isolation bearings, and the main span bearings are to be constrained laterally. The bent caps of the approach piers are to be retrofit using post-tensioning for the caps and concrete encasement at the base of the columns. In addition, the bents will be allowed to rock. The bearings in the concrete girder approaches will also be retrofit to increase their performance during an earthquake.

Isolation of the main truss span was investigated, however a strength retrofit was chosen for several reasons. The large scale of the bearings did not encourage replacement. In addition, a replacement isolation system would have had to be relatively stiff to carry non-seismic loads elastically, thereby providing little benefit to the superstructure or the short supporting piers. Therefore, replacement of the bearings was not considered cost effective. However, since the main bearings were not expected to perform well in a seismic event, constraints will be added to maintain the bearings integrity. For the truss approach spans, the isolation system not only reduced the demands in the superstructure, but also in the much taller supporting piers, so it was cost effective and therefore will be installed.

Soil densification of the north piers was investigated, however the cost of densification around all of the piers was very high. A compromise was reached that accepted the risk of liquefaction around the approach piers supporting the concrete spans, but not around the main piers or the approach piers supporting the steel truss spans. The existence of very long seat lengths for the concrete approach span bearings made it unlikely that a span would be lost in the event of liquefaction, which ensured structural integrity.

5. PRIORITIZATION OF RETROFITS BASED ON RISK AND COST

During the seismic assessment stage for the Burrard, Granville and Second Narrows bridges, a semi statistical cost-risk-benefit analysis was performed on all of the retrofit items. This process resulted in each retrofit item receiving a high, medium, or low priority. As an example, a low cost item that resulted in a high benefit was given a high priority. The high priority items were packaged into phase one of the design, the medium priority items into phase two, and the low priority items into phase three.

In addition to spreading the cost of retrofitting these bridges over several years, the added time allowed the design engineers to benefit from "current thinking". Since the field of earthquake engineering is developing rapidly, the methods of assessing bridges for seismic deficiencies are continually evolving. When first assessed with linear techniques, the approach piers of Granville and Burrard bridges were highly over stressed in both bending and shear. Due to the large cost of retrofitting all of these piers, their upgrade was delayed until the final phase of the retrofit. When the final design of phase three was undertaken, the profession's understanding of pier behaviour had developed significantly. The re-evaluation of the piers used non-linear push over analyses and this indicated much less of a problem than was originally identified. In addition, recent testing of pier jacketing has shown that wrapping deficient columns is an effective and inexpensive retrofit measure, which through its use, further reduced the retrofit cost below that originally anticipated.

6. CONCLUSIONS

The engineering profession's understanding of how bridges behave in earthquakes is increasing every year. The analysis methods being used to assess existing structures are becoming more sophisticated, and the tools and remedies available to the retrofit designer are more and more detailed. With careful consideration of what is important, and a good understanding of how structures behave dynamically, designers can develop innovative retrofit methods with the use of sophisticated analysis techniques. However, as was the case with the Burrard Bridge, the use of these sophisticated analysis tools is not always warranted.

In addition, prioritization of retrofit items allows owners to spread the cost of retrofitting major bridges over several years. This also gives the designers an opportunity to gain valuable experience and avail themselves of current research and testing results for the more difficult and expensive portions of the retrofit.