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CYCLIC TESTS OF EXISTING AND RETROFITTED SWAY FRAMES OF SFOBB

Final Report of the Project

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Whole Report plus other volumes probably @ ITS or Campus

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DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
COLLEGE OF ENGINEERING
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Report to the California Department of Transportation
May 27, 1998

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16. Abstract

This report summarizes a comprehensive experimental and analytical study of sway frames of the San Francisco-Oakland Bay Bridge. The study had five inter-related parts. Each part is described in one volume of the reports. This report is Volume 5 and "Final Summary Report" of the five-volume report consisting of: (1) Cyclic Tests of Rivets for SFOBB Sway Frame Specimens, (2) Cyclic Tests of Riveted and Bolted Angle Connections of SFOBB, (3) Cyclic and Monotonic Tests of Truss Verticals of SFOBB (4), Analyses of Cyclic Behavior of Existing and Retrofitted Sway Frames of SFOBB, and (5) Cyclic Tests of Existing and Retrofitted Sway Frames of SFOBB(This Report).

The main objective of the study was to conduct cyclic tests of riveted sway frames specimens. Half-scale sway frame specimens simulated the sway frames in the 288-ft spans trusses of the East Bay Crossing of the SFOBB. The specimens represented the existing and retrofitted conditions. A total of four tests were conducted on three sway frame specimens. Test specimens were subjected to inelastic cyclic displacement in transverse direction while the constant gravity loads of upper deck and lower deck were applied throughout the tests.

Tests 1 and 2 represented the existing conditions of the sway frames in SFOBB behaved in a ductile manner. There was no significant visible damage until ductility of 3 when local buckling started and at ductility of 5 when lateral torsional buckling was visible. Tests 3 and 4 represented the retrofitted condition. Seismic retrofit consisted of primarily bolting plates and angles to the existing truss vertical and converting the I-shaped cross section to a boxed shape. The retrofit proved to be extremely efficient. Specimen could easily reach cyclic ductilities of 8 and 9 without showing much visible damage.

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EXECUTIVE SUMMARY

Cyclic Tests of Existing and Retrofitted Sway Frames of SFOBB

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The main objective of this proof testing and research program was to provide the California Department of Transportation (Caltrans) with the information needed to finalize seismic retrofit design of the East Bay Crossing of the San Francisco-Oakland Bay Bridge (SFOBB). The main emphasis of the research was on conducting cyclic tests of 1/2-scale riveted specimens representing typical sway frames of the 288-ft span double deck trusses of the East Bay Crossing. The results of the tests and associated analyses were used to establish cyclic behavior of the sway frames in their existing conditions as well as to develop and proof test seismic retrofit strategies for the sway frames. In addition to cyclic tests of the sway frames, a number of rivet and riveted connection specimens were also tested and studied.

This study was part of a more comprehensive experimental and analytical study of sway frames of the San Francisco-Oakland Bay Bridge. The study had five inter-related

parts. Each part is described in one volume of the report. This report is Volume 5, and the Final Report, of the five-volume report series. Following is the list of reports for the entire project.

1. Cyclic Tests of Rivets for SFOBB Sway Frame Specimens
2. Cyclic Tests of Riveted and Bolted Angle Connections of SFOBB
3. Cyclic and Monotonic Tests of Truss Verticals of SFOBB
4. Analyses of Cyclic Behavior of Existing and Retrofitted Sway Frames of SFOBB
5. Cyclic Tests of Existing and Retrofitted Sway Frames of SFOBB(This Report).

The main objective of the study was to conduct cyclic tests of riveted sway frames specimens. Half-scale sway frame specimens simulated the sway frames in the 288-ft spans trusses of the East Bay Crossing of the San Francisco-Oakland Bay Bridge. The specimens represented the existing as well as retrofitted conditions of the sway frames. A total of four tests were conducted on three rivetted sway frame specimens. Test specimens were subjected to inelastic cyclic displacement in transverse direction while the constant gravity loads of upper deck and lower deck were also applied throughout the tests. One specimen represented the existing conditions while three other specimens represented the existing conditions with various level of retrofit added.

The specimen representing the existing conditions of the sway frames in SFOBB behaved in a ductile manner. It did not show much visible damage until ductility of 3, (coresponding to a lateral drift of 8 inches in the bridge) at which time local buckling of truss verticals started. Later, at ductility of about 5 (lateral drift of 14 inches), lateral torsional buckling also started and some rivets in the connection area sheared. At the end of the test the specimen still could carry its gravity load. However, damage was very visible. The second specimen was also similar to first with only some rivets replaced with bolts. Similar damage occurred which led to a decision to retrofit the truss verticals to prevent local and lateral torsional buckling

Specimen 3 represented the retrofitted condition. Seismic retrofit consisted of primarily bolting plates and angles to the existing truss vertical and converting the I-shaped cross section to a boxed shape. This retrofit called Box-Retrofit proved to be extremely efficient. Specimen could easily reach cyclic ductility of 8 (lateral drift displacements of 22 inches in the bridge) without showing much visible damage. The bulk of ductility and energy dissipation was the result of bolt slippage of added retrofit angles and plates.

Since Specimen 3 did not have significant damage, it was repaired and the bracket under the upper floor beam that has been heavily yielding was replaced with a new one and Test 4 was performed on this specimen. The performance of this specimen was also superior and at the end of the test, damage consisted of primarily failure of few bolts and yielding of bracket that easily could be repaired.

It was recommended that when ductility demand on truss verticals exceeds 3 (lateral displacement drift of 8 inches in the bridge), the truss verticals be retrofitted following the proposed Box-Retrofit strategy.

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The study reported here was sponsored by the California Department of Transportation (Caltrans) as "Ductility of Bay Bridge in Transverse Direction" project. The authors would like to express their appreciation for the support as well as technical advice and input received from Caltrans engineers. Particularly, the support and technical input from James Roberts, George Amaro, Tim Leahy, Li-Hong Sheng and Steve Altman of Caltrans were very useful and are sincerely appreciated. The authors would like to express their special thanks to Gerrard Hight and Ray Zelinski of Caltrans for their technical input and valuable review comments.

The tests reported here were conducted in the Department of Civil and Environmental Engineering of the University of California, Berkeley. The cyclic tests of the existing specimen were part of Sung-Wook Cho's doctoral work. The cyclic tests of partially or fully retrofitted sway frame specimens were conducted by Lev Stepanov, Abolhassan Astaneh-Asl and Marcial Blondet with assistance of Judy Liu, Charles Bowen, Lincoln Oro, Derek Westphal and Sanjay Ravat, Graduate Students Research Assistants. Hana Mori conducted the material tests for the project. The staff of Department of Civil and Environmental Engineering provided valuable assistance in conducting the tests and in collecting the data. The efforts of William Mac Cracken, Chris Moy, Todd Merport, Mark Troxler, Richard Parsons and Douglas Zulaica of the Department were essential and are appreciated.

Christie Fabricators of Richmond, California fabricated the riveted specimens. Special thanks are due to Alan Straub, Vice President of Christie Fabricators. The project was administered by the Institute of Transportation Studies (ITS) of the University of California at Berkeley. The dedicated efforts and support of Professor Adib Kanafani, Director of ITS, Stephen W. Owen and the staff of ITS were invaluable and are acknowledged. Lynn E. Deetz of Sponsored Projects Office was University Representative for the Project. Her assistance was also vary valuable and is sincereley appreciated. The report was printed at the Kinko's Corporate of Berkeley under Jerry Penniman's supervision.

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Chapter 1

INTRODUCTION

By

A. Astaneh-Asl

1.1 Introduction

Currently, the California Department of Transportation is in the process of design and development of seismic retrofit for the East Bay Crossing of the San Francisco-Oakland Bay Bridge (SFOBB) shown in Figure 1.1. Comprehensive studies of seismic behavior of the East Bay Crossing conducted at the University of California at Berkeley, (Astaneh-Asl, 1992) resulted in development of a number of feasible seismic retrofit strategies for the East Bay Crossing. One of the major seismic vulnerabilities of the East Bay Crossing was identified as being the transverse movement of the upper deck relative to the lower deck in 288-ft span double deck trusses as shown in Figure 1.2. The transverse movement is also expected to be one of the vulnerabilities of the Richmond-San Rafael bridge. The bridge is another Caltrans double-deck riveted span in the San Francisco Bay and its structure is similar to SFOBB but has half of the width of SFOBB.

To design efficient and economical seismic retrofit to control the lateral movements of the upper deck, some limited yielding can be permitted to occur during a maximum credible earthquake. To ensure that seismic yielding will occur at desirable locations and would not cause excessive damage to gravity load-carrying components of the bridge, realistic cyclic tests of specimens representing a transverse cross-section were needed and were conducted. This report summarized the studies and their results.

For the sway motions in the transverse direction, Figure 1.2, one of the most efficient seismic retrofit strategies appears to be utilizing ductility of steel superstructure to reduce seismic forces and to minimize the need for extensive and costly retrofit. Otherwise, considering the dynamic characteristics of the bridge in the transverse direction, to maintain near elastic behavior and minimize the damage during a maximum credible earthquake, it would be very expensive, if possible at all, to retrofit the sway frames in the transverse direction.

However, it appears that by utilizing ductility of the steel super-structure, an efficient, economical, practical, and safe seismic retrofit strategy could be developed. With this strategy, the seismic retrofit could be designed so that:

1. Under a maximum credible earthquake, which can occur once or twice during the remaining life of the bridge, the sway frame structure would experience some yielding at predetermined areas at top and bottom ends of the truss verticals, shown in Figure 1.3. With this strategy, the bridge generally would survive with minimum damage. It is also expected that the sway frames will function fully under the gravity live and dead load during and after a maximum credible earthquake.
2. Under service earthquakes, which can occur several times during the life of the bridge, the retrofit system, based on such strategy, should enable the structure to remain nearly elastic and survive these relatively frequent earthquakes without any noticeable structural or non-structural damage that would require repairs after such earthquakes.

1.2 Objectives

The main objectives of the research reported here were:

a) To conduct cyclic tests of existing sway frames of the SFOBB in order to establish cyclic behavior of the bridge in its as-is condition.

b) To conduct cyclic and monotonic tests of the critical components of the sway frames to establish their cyclic properties. The components included, rivets, bolts, riveted double angle connections and truss verticals.

c) To develop efficient and practical seismic retrofit strategies to limit the damage to the SFOBB East Bay Crossing to a minimum in an economical way.

d) Conduct cyclic tests of one or two promising retrofit strategies and refine them further to be applied to sway frame specimens

e) Apply the most promising retrofit strategy to sway frame specimens and conduct proof-testing of the retrofitted specimen.

f) Make recommendations to Caltrans on seismic retrofit of 288-ft trusses of the East Bay Crossing shown in Figure 1.1.

1.3 Research Program

The main part of the proposed research was to conduct realistic cyclic tests of 1/2-scale transverse sway frame specimens of the 288-foot span trusses. Important issues that were addressed by using data obtained from these tests were:

1. Cyclic and monotonic behavior of rivets under tension, shear and combination.
2. Cyclic behavior of double-angle connections of the floor beams to truss verticals.
3. Cyclic local buckling and low cycle fatigue fracture of locally buckled areas.
4. Deterioration of stiffness and strength of sway frames under cyclic loading.
5. The extent and nature of damage to the gravity load carrying components
6. Probability of instability due to P-Delta effect and collapse of upper deck.
7. Verifying how well the current analytical tools can predict the actual behavior.
8. Establishing hysteresis energy dissipation and hysteresis damping.
9. Establishing the level of damage in existing sway frames.
10. Studying how easily the damage can be repaired without closure of the lanes.

To address the above issues, the experimental and analytical studies of sway frames of the SFOBB conducted. The studies of sway frames of the San Francisco-Oakland Bay Bridge (SFOBB) and its components consisted of the following five inter-related experimental and analytical programs to develop seismic retrofit recommendations.

The five volumes of the reports on five parts of the project are:

1. Cyclic tests of rivets for SFOBB sway frame specimens (Oro, Mori and Astaneh-Asl, 1996)
2. Cyclic tests of riveted and bolted angle connections of SFOBB (Yin and Astaneh-Asl, 1995)
3. Cyclic and monotonic tests of truss verticals of SFOBB (Astaneh-Asl, Westphal, Stepanov and Cho, 1996).
4. Analyses of cyclic behavior of existing and retrofitted sway frames of SFOBB (Yan, Shen and Astaneh-Asl, 1997)
5. Cyclic tests of existing and retrofitted sway frames of SFOBB (Astaneh-Asl, Cho and Stepanov, 1998).

This report is Volume 5 of the above report series and the concluding volume of the project. In this report a summary of the results of the research presented in Volumes 1 through 4 is provided in Chapter 6 of this report. As a result, this report can be considered as the Final Summary Report of the Project.

The project was conducted at the Department of Civil and Environmental Engineering of the University of California Berkeley with A. Astaneh-Asl as Principal Investigator and at the Illinois Institute of Technology with J. H. Shen as Co-Principal Investigator and subcontractor. Figure 1.3 shows some of the project team members and Caltrans engineers involved in the project.

Box 2, Folder 5

Item 2

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