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Seismic Retrofit of the Lake Washington Ship Canal Bridge

Consolidation parasismique du pont-canal du Lac Washington

Seismische Verstärkung der Schiffskanalbrücke des Lake Washington

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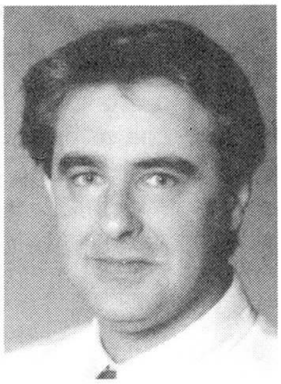

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SUMMARY

This paper describes the seismic vulnerability assessment and retrofit design of the Lake Washington Ship Canal Bridge in Seattle, one of the most important bridges in the State of Washington. A short description of the structural configuration of the bridge, as well as information on the site seismicity and local geological hazards are included in the paper. The assessment methodology and the technical criteria used for evaluating the seismic capacity of the bridge are briefly explained. Finally, the structure's seismically deficient elements are listed and the retrofit schemes that have been selected for the immediate seismic rehabilitation of the bridge's most vulnerable steel truss units are described.

RÉSUMÉ

Cet article décrit l'évaluation de la vulnérabilité vis-à-vis de séismes et le projet de consolidation du pont-canal du Lac de Washington à Seattle, un des plus importants de l'État de Washington. Une description de la structure du pont, ainsi qu'une information sur la séismicité du site et des dangers géologiques locaux sont également inclus. La méthodologie d'évaluation et les critères techniques utilisés pour estimer la capacité sismique du pont sont expliqués. Les éléments déficients de la structure sont énumérés et les projets retenus pour la réhabilitation d'un point de vue sismique des éléments de treillis métallique les plus faibles sont décrits.

ZUSAMMENFASSUNG

Dieses Referat beschreibt die Einschätzung der seismischen Verwundbarkeit und den verstärkten Entwurf der Lake-Washington-Schiffskanalbrücke in Seattle, eine der wichtigsten Brücken im Staat Washington. Eine kurze Beschreibung der Konstruktion der Brükke wie auch Informationen über das seismographische Gebiet und der lokalen geologischen Risiken sind in diesem Referat aufgenommen. Die Methodik der Einschätzung und die technischen Kriterien, die für die Evaluation der seismischen Kapazität benutzt worden sind, sind in Kürze erklärt. Die seismisch ungenügenden Bauteile sind aufgelotet. Schliesslich wird die seismische Verstärkung beschrieben.

1. INTRODUCTION

The SR5 Lake Washington Ship Canal Bridge was constructed between 1959 and 1961 on the principal north-south route of Interstate 5 in Seattle, Washington (Fig. 1). The bridge is a complex, multi-level structure, consisting of 17 individual structural units that are separated by expansion joints. It carries twelve lanes of highway traffic with an annual average traffic in excess of 200,000 vehicles per day. It is documented to be one of the most important highway bridges in the State of Washington and as such its seismic resistance upgrading was sought by the Washington State Department of Transportation. Phase I of the structure's seismic rehabilitation was initiated in 1993 and it included an extensive vulnerability assessment of the bridge. Since then, the second phase (Phase II) of the bridge's rehabilitation program has been also initiated. Phase II included the design of the required retrofit schemes to protect the most vulnerable structural units: the steel trusses crossing the Ship Canal waterway. Results from Phase I were extensively used for the design of the most effective and cost competitive retrofit schemes for the steel truss units. Construction of the Phase II retrofit items is expected to be complete during the second semester of 1995. A final retrofit phase (Phase III) is scheduled and it will cover the seismic upgrade of the bridge's north and south concrete approaches.

A brief description of the bridge configuration along with the methodology used for its seismic vulnerability assessment and major results of the Phase I study are discussed in the paper. The main seismic retrofit schemes that have been designed for the seismic protection of the structure's truss units are also described.

2. STRUCTURE AND SITE DESCRIPTION

The total bridge length of 1,350 m is divided into the south approach, the steel trusses and the north approach with lengths of 352 m, 699 m and 299 m, respectively. The south and north approaches consist of multi-span reinforced concrete frame structures. At the concrete approaches, expansion joints consist of split columns between frames. The six spans of the steel trusses are supported by rocker and pinned bearings (Fig. 2). Reinforced concrete portal bents support the truss bearings. The foundations are spread footings, except for a few pile foundations located at the south approach.

The site soils are generally good, comprised of glacially consolidated till.

3. SITE SEISMICITY AND GEOLOGICAL HAZARDS

A site specific seismicity study confirmed that the response spectrum specified by AASHTO [1] with $a_{max} = 0.29g$, soil profile II and 5% damping is appropriate for the bridge site. Three regional zones responsible for earthquake generation were considered: a shallow crustal zone, a deep subcrustal zone and the Cascadia Subduction Zone. It is considered that the above spectrum represents motions resulting from a deep focus, near source earthquake of magnitude 7.5 with a 10% probability of being exceeded during a 50-year interval.

The geotechnical study concluded that liquefaction and instability of the foundation soils are not likely and that there is a low potential for ground surface rupture as related to faulting in the bedrock underlying the bridge alignment.

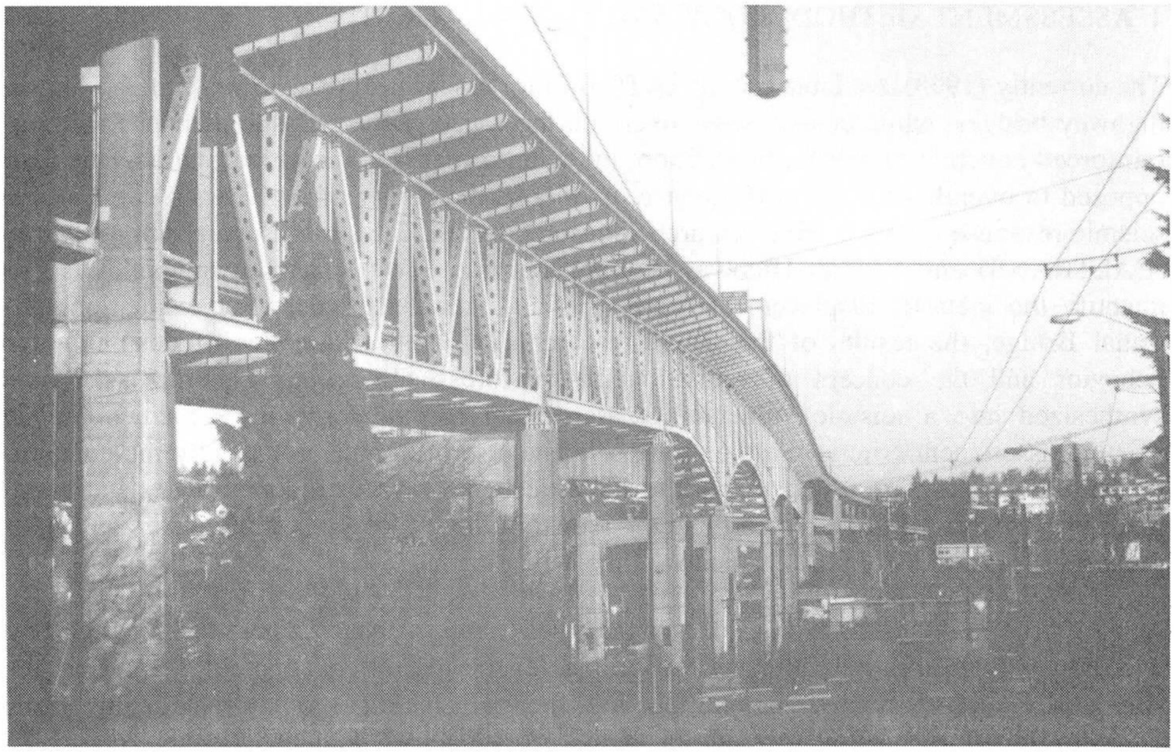

Fig. 1 The Lake Washington Ship Canal Bridge along Interstate 5. Steel truss units across the Ship Canal Waterway.

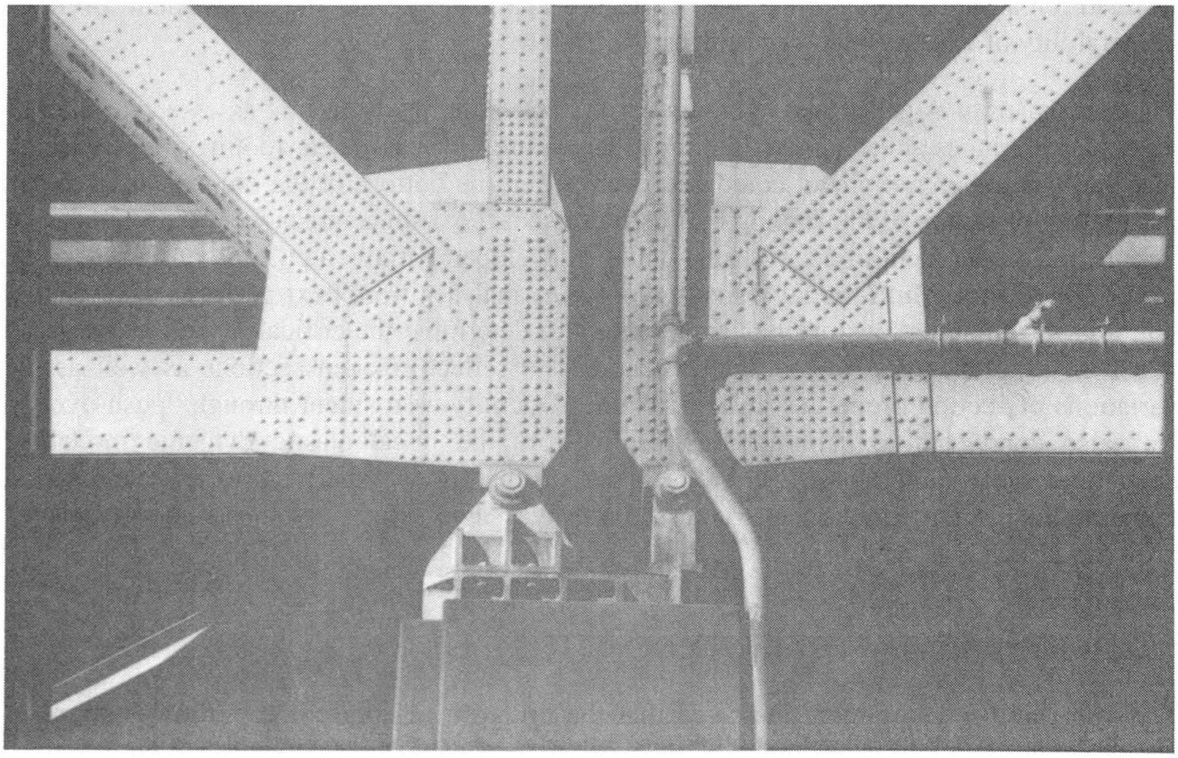

Fig. 2 A typical rocker bearing subject to loss of vertical support due to earthquake motions. Bearing collars, longitudinal restrainers and compression bumpers are used to mitigate the catastrophic consequences of support loss and toppling of the bridge's superstructure.

4. ASSESSMENT METHODOLOGY AND TECHNICAL CRITERIA

The currently (1993) available criteria (ATC 6-2) for assessment of seismic vulnerability of existing highway bridges, while conservative, overlook the capacity for inelastic displacements in existing reinforced concrete members. In addition, the criteria focus on individual member performance as opposed to overall structure performance, overlooks the ability of a given structure to redistribute seismic response forces. Recent research sponsored by the California Department of Transportation (CALTRANS) and Federal Highway Administration (FHWA) has shown that it is possible to quantify the inelastic displacement capacity of individual members. For evaluation of the Ship Canal Bridge, the results of the above research [2, 3], the principles of designing for ductile behavior and the concept of redistribution of forces throughout a complex structure were synthesized into a seismic vulnerability assessment methodology that remedied the defects in existing assessment criteria. Furthermore, selective use of nonlinear statically incremental analysis ("push-over" analysis) which tracks the inelastic behavior of structures under increasing lateral loads was performed to help determine the redistribution of lateral seismic forces as the structure's properties transition from the elastic to the inelastic range.

A set of criteria was developed as part of the assessment procedure. These technical criteria cover a wide range of factors pertaining to the bridge seismic performance such as appropriate material strengths, guidelines for foundation modeling, flexural, shear and joint strength, and seismic input. The developed techniques provide a more efficient tool than previously available for the vulnerability assessment of existing highway bridges to seismically induced damage. The analysis tool was the outcome of an extensive literature survey that resulted in an effective synthesis of existing research into a lucid, conservative methodology. The continuous input from bridge engineering experts and researchers specializing in seismic evaluation and retrofit of bridges resulted in a methodology that has universal applicability for the assessment of the seismic vulnerability of existing highway bridges.

The assessment was performed in a number of steps: columns were first assessed for their ability to form plastic hinges at each end without a prior failure in shear. Then, footings were checked to see that the plastic hinge moment could be developed at the bottom of the column prior to rocking of the footing or failure of the footing by flexure or shear. All splice areas were then checked to verify that the plastic moment in the column could be developed without a pull-out or an otherwise failure of the splice bars. Multi-modal response spectrum analyses were next performed for each separate unit and for combinations of units as necessary to determine the critical responses. Great care was taken in the preparation of the analysis models to reflect cracked sections as well as the actual variations of section properties in the structure. Ductility assessment through "push-over" analysis was also conducted to calibrate the results from the lineal elastic dynamic models. Finally, demand/capacity ratios based on the forces of the modal analyses were calculated and the vulnerability of the individual structural units was assessed by synthesizing the results of the previous phases.

5. STRUCTURAL VULNERABILITY RESULTS

The vulnerability assessment indicated that the bridge in its present condition contains elements which would compromise its survival under the design level seismic event. Noting that the adopted assessment criteria and design seismic event represent conservative estimates of the expected conditions, the vulnerability assessment shows that certain structural elements have a high probability of failure during the design event. These failures indicate that most of the structure will

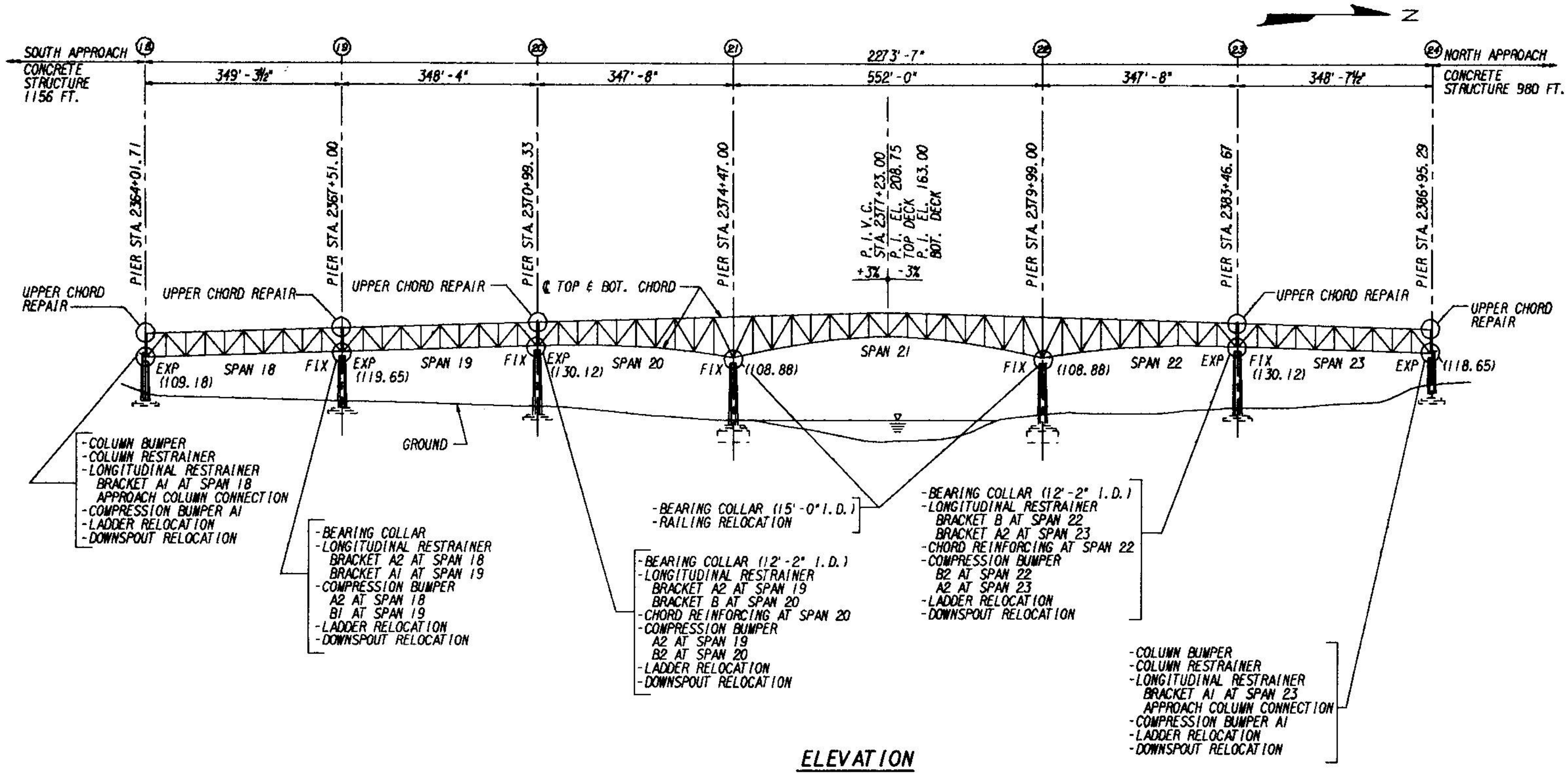

Fig.3 SR5 Lake Washington Ship Canal Bridge
General Layout of Seismic Retrofit items.

experience severe damage, with several portions of the structure likely to collapse. Specifically, the most vulnerable elements are (Fig. 3):

- Truss bearings.
- Truss lateral bracing members.
- Double-deck box girder crossbeams.
- Columns.

6. RETROFIT SCHEMES

A set of retrofit measures was designed during Phase II for the seismic strengthening of the steel truss units. The proposed retrofit measures include (Fig. 3):

- Concrete-filled steel collars at truss bearing bolsters (at Bents 19 through 23).
- Compression "bumpers" between the concrete approach structures and the truss chords, and between truss chords at the expansion joints (at Bents 18, 19, 20, 23 and 24).
- Longitudinal restrainers at the bottom chords of the trusses (at Bents 18, 19, 20, 23 and 24).

After the completion of the retrofit design, a new series of analyses was performed to ensure that the retrofit schemes will behave as intended, i.e., by markedly improving the structural seismic response. Both multi-modal response spectrum analyses and nonlinear time history analysis with structural models incorporating gap elements and nonlinear springs were performed. The results indicated that these retrofit schemes will greatly improve the bridge seismic behavior providing at least the level of seismic performance specified in the vulnerability criteria. The total estimated construction cost of the items cited is $5,700,000 in present day US dollars.

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