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SEISMIC RETROFIT ANALYSIS AND DESIGN OF THE CNR OVERHEAD

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ABSTRACT

The CNR (Canadian National Railway) Overhead is a five-span 91 m long concrete bridge structure built in 1958 over railway tracks in Richmond, BC. The site conditions include fine grained soil, compact to dense sand, and silt and clay, with liquefaction potential. The design seismic event is 1:475 year with a 0.265g Peak Ground Acceleration. The superstructure consists of cast-in-place concrete deck on pre-cast I-girders. The girders are simply supported by four tapered wall piers and the abutments on high embankment fills. All piers have been placed on jacks, which is a challenge in finite element modelling as it causes instability in response spectrum analysis. The lateral load path during seismic events has to be re-established in the analysis and the retrofit design. The shear strength of the tapered wall piers and the girder seat length were both insufficient and were addressed in the retrofit design. The design also took into account the proximity to the railway tracks and solutions minimizing impact to the operation of the railway were provided. The retrofit addressed the limited redundancy in original design by adding positive connections along the lateral load path.

Introduction

The CNR (Canadian National Railway) Overhead is a significant five-span bridge structure over railway tracks in Richmond, BC. As part of a new 3 km long bus lane project along north bound of Highway 99 from Highway 91 east bound off-ramp to the intersection at Bridgeport Road, this bridge is being widened so that the deck can accommodate three lanes of traffic instead of the current two lanes. Highway 99 is a vital link between Peace Arch at US/Canada border to the City of Vancouver.

SNC Lavalin Inc. was retained by the BC Ministry of Transportation and Infrastructure (BCMoT) to evaluate the bridge strength both for additional live load and for seismic loading conforming to current bridge code, and to provide upgrade design as required.

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Description of the Bridge

The CNR Overhead on Highway 99 is a five-span 91m long structure built in 1958 with cast-in-place concrete deck on pre-cast I-girders (Fig. 1). The girders are simply supported by four tapered wall piers and the abutments. All piers have been placed on jacks, which in turn are seated on independent pile-caps and Franki piles. The abutments are supported on footing located near the top of the embankment fill.

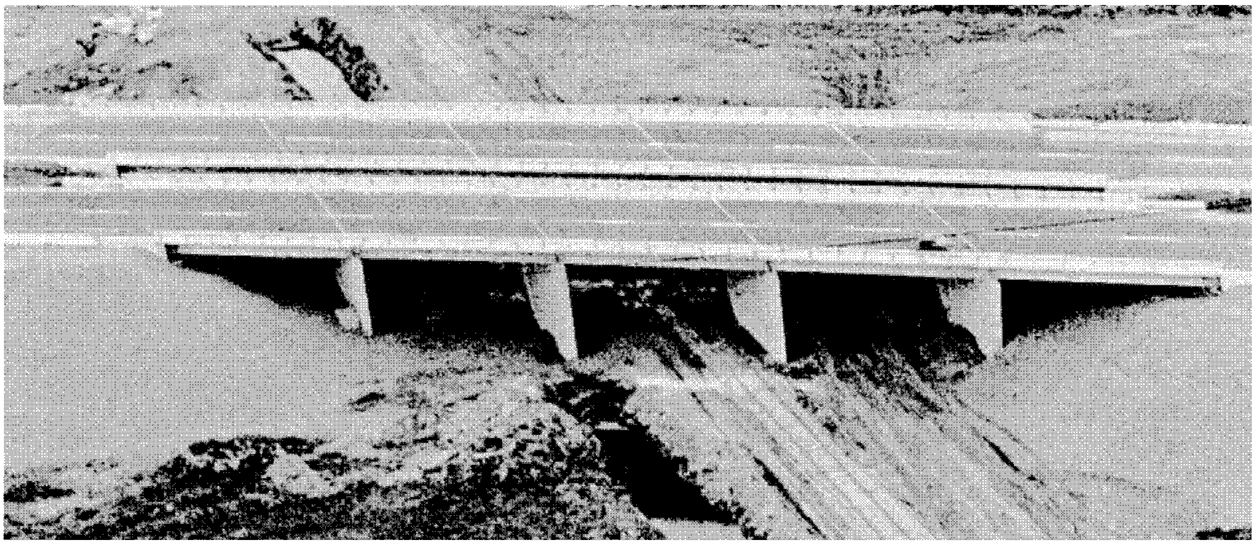

Figure 1. Historical Photo of the CNR Overhead

Geotechnical borehole data indicate that the fill consisted of medium to coarse sand with some silt, which is known locally as 'River Sand'. The fill was compact to very dense, based on CPT and SPT information. Sand at the railway track location (adjacent to piers) extends to about 4 m to 25 m below grade and varies from silty to gravelly with occasional thin clay layers.

The unique feature of the bridge structure is the usage of hydraulic jacks between piers and pile-caps. Although the jacks were intended for settlement compensation in the original design, there is no record showing the jacks have been used at any time. At Pier 1, the access chambers originally provided for the jack access have been backfilled with gravel material during installation of a buried pipe in 1980.

Settlement records from construction completion in 1959 through to 1962 and in 1985 show that the settlement at monitoring points varied from an average of 186 mm at Pier 2 to an average of 524 mm at the East Abutment. This settlement pattern is consistent with 'deep seated' settlement of the lower silt and clay at greater than 25 m below grade.

Design Criteria and Structural Analysis

The governing design code for the project is the Canadian Highway Bridge Design Code 2006 (CHBDC S6-06). A bridge designed according to S6-06 must withstand a 1-in-475 year design earthquake (10% probability of exceedance in 50 years). The values of spectral acceleration for a period of T seconds, Sa(T), obtained from the Earthquakes Canada website is summarized in Table 1.

Table 1. Ground parameters at the bridge location.

PGA*	Sa (0.2)	Sa (0.5)	Sa (1.0)	Sa (2.0)
0.265g	0.524g	0.348g	0.178g	0.089g

*Peak Ground Acceleration

The classification of the CNR Overhead Bridge is Economic Sustainability Route Bridge. Bridges in this class are considered essential to maintaining minimum effective transportation levels for economic purposes following a major earthquake.

The seismic retrofit levels are defined as follows:

- Seismic retrofit level: Safety 1 (S1). This level of retrofit is a collapse prevention upgrade comprising a superstructure retrofit and prevention of serious structural deficiencies in substructures.
- Service level: Significantly Limited. It is expected that limited access to emergency traffic is possible within days following the earthquake. Public access is not expected until repairs are completed.
- Damage level: Significant (no collapse). Damage does not cause collapse of any span or part of the structure, nor lead to the loss of the ability of primary support members to sustain gravity loads. Permanent offsets may occur and damage consisting of cracking, yielding, and major spalling of concrete may require closure.

The seismic safety retrofit of the CNR Overhead will achieve the required performance by assessing:

- Strength based capacities for all main structural members including girders, piers, pile-caps, abutments, etc;
- Displacement based capacities of bearing seat length;
- Post-earthquake stability safety factors.

A three-dimensional finite element model (Fig. 2) was built using computer program SAP 2000. The 5 span simply supported bridge structure was modeled with hinge joints for all beam elements. The effective stiffness per S6-06 was considered for all structural members.

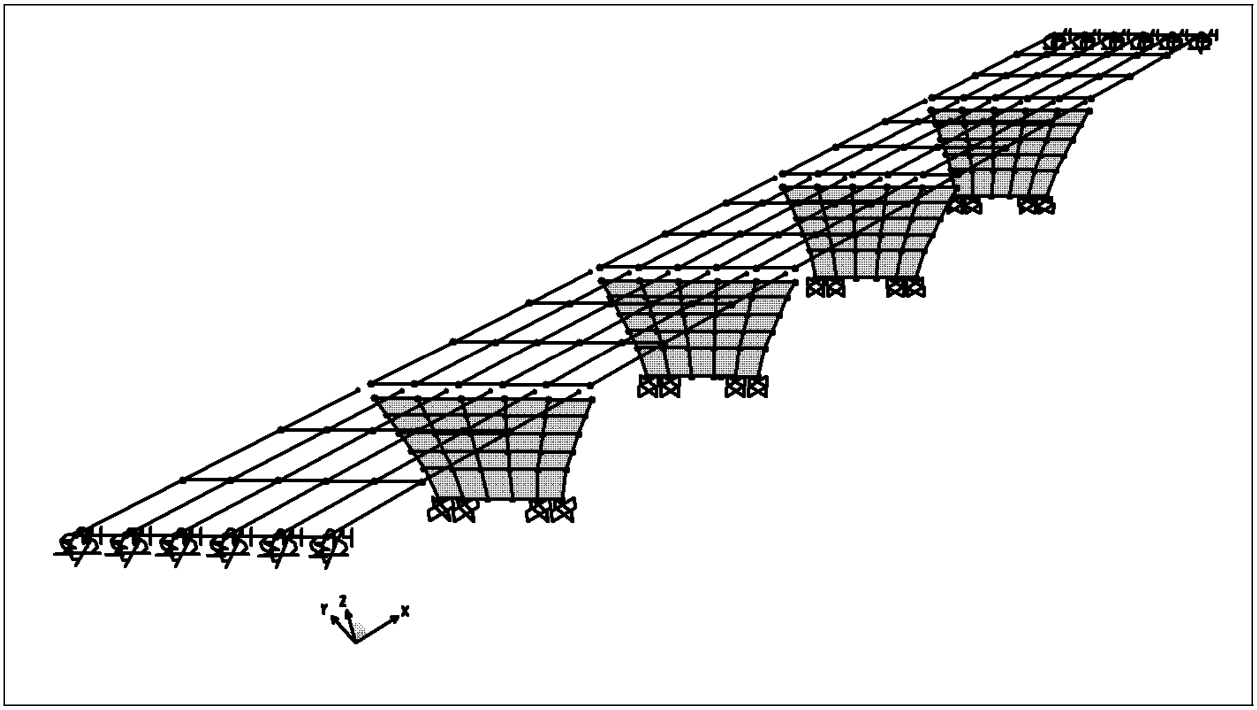

Figure 2. Finite Element Model of the Bridge

For seismic evaluation the piers are considered hinged at the jack location (Fig. 3). A debonding layer was provided between the top and bottom portion of the pilecap around the jacks which effectively disconnect the top and bottom portion of shear and moment transfer.

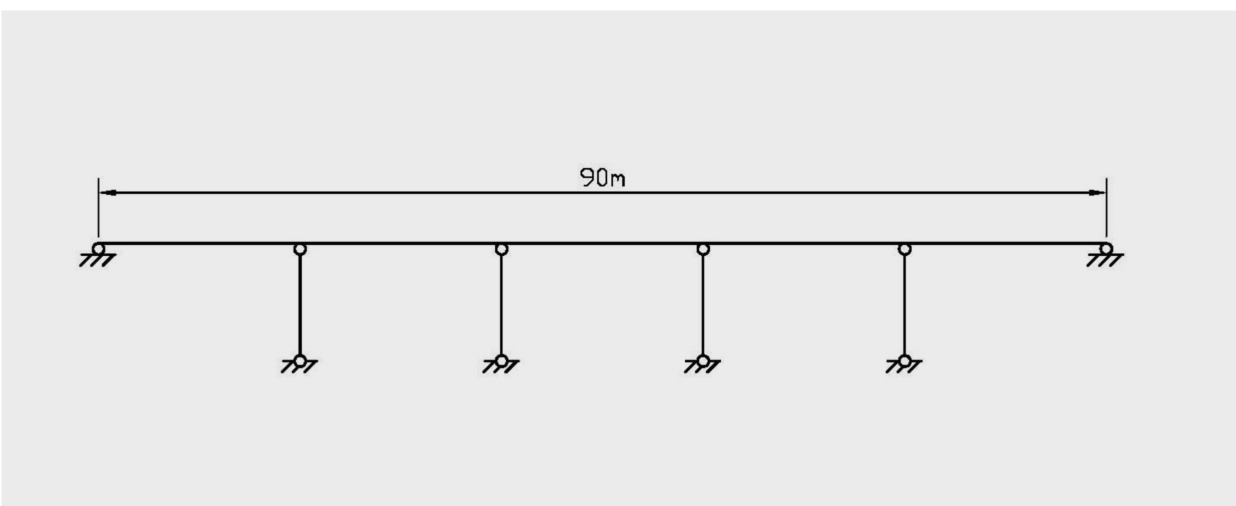

Figure 3. Simplified Model of the Bridge

A response spectrum analysis is considered appropriate per S6-06. The site specific spectra used in the analysis are developed by the geotechnical engineer (EBA Engineering Consultants Ltd.)

using six synthesized, spectrum-matched earthquake records compatible with the Uniform Hazard Response Spectra for the 1:475 events obtained from the Earthquakes Canada website. Ground springs at the abutments and under piers are defined with parameters recommended by the geotechnical engineer.

Seismic Deficiencies

The CNR Overhead in its current state does not have proper load path for seismic loadings from the deck level to the piles. The condition of precast girders sitting on piers without shear keys is common for bridges built in the 1950s, when seismic requirements were not as stringent.

The unique feature, and a challenge for seismic evaluation, of the bridge is the hydraulic jacks under the piers. The current state of the structure would be similar to hinge connections both at the top and at the bottom of the piers. When such boundary conditions were defined in the computer model, an un-stable condition occurred and the response spectrum analysis could not be run.

The fundamental deficiency, i.e., the lack of seismic load path, must be addressed in retrofit design, such as by establishing positive connections both at the top and at the bottom of the piers. In the computer analysis, the joint conditions at the bottom of the piers were changed to fixed so that a response spectrum analysis could be run properly.

Another key deficiency is the lack of seat length on top of piers for precast girders. No cap beam was provided in the original design. Over the years, some girders shifted possibly due to thermal expansions and/or vehicle induced forces on the skew deck (Fig. 4).

Large settlements have been measured in the past for the bridge. However, the trend of settlement versus time from existing settlement data indicates that future settlement will be minimal. Since settlement is expected to be minimal, the removal or grouting in of the jacks under bridge piers is acceptable.

Figure 4. Girder/Pier Detail

Retrofit Design

In discussions with the owner BCMoT, SNC's design team identified a number of preferred retrofit options, including adding link slab, strengthening wall piers, grouting jacks underneath piers, dowelling the pile-caps, adding new micro-piles, installing shear keys between girders and the piers, adding link slab between the North Bound abutment and the South Bound abutment wing walls and installing abutment tieback anchor (Fig. 5). A cost-effective design is important.

To perform a proper response spectrum analysis, the connections between the bottom of the pier and the pile-caps are assumed to be rigid after retrofit on the jacks. The resulting fundamental period of the bridge structure is 0.96 second.

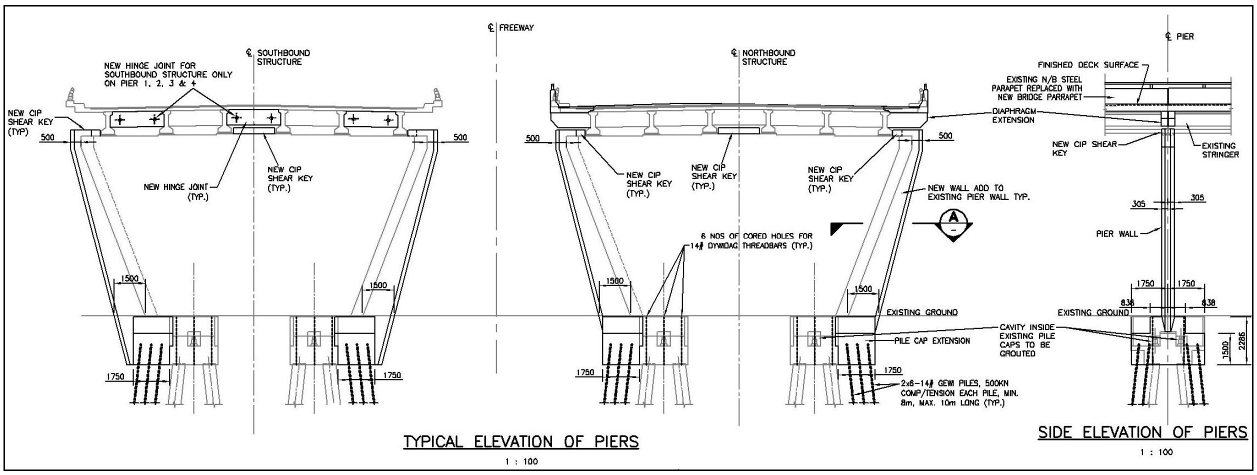

Figure 5. Typical Pier Retrofit

Adding link slab to superstructure

Adding link slabs by removing deck joints can provide an effective longitudinal axial load path at the deck level. The existing deck was separated by expansion joints; the I-girders were simply supported on wall piers without longitudinal restrainers. By integrating the whole deck slab as one single rigid diaphragm, the seismic behavior would be greatly improved resulting in substantial savings in retrofit construction cost.

The added advantage of adding a link slab is the improvement of driving condition for highway traffic due to the removal of deck joints.

Strengthening wall piers

The existing wall piers are lightly reinforced. The shear capacity of the pier is below the seismic demand since there is no shear ties provided, in particular at the pier/pile-cap interface. The bending capacity also need to be increased because the pier is under-reinforced and provides minimum ductility.

The wall extension consists of a conventional column rebar cage with spirals to increase shear and bending capacity, and to add nominal ductility.

Grouting jacks underneath piers

As discussed earlier the piers are hinged at the bottom due to the existence of the jacks. The small void area around the jack is grouted to ensure continuous lateral load path.

Dowelling the pile-caps

The typical existing pile-cap has two components – top portion and bottom portion - with debonding roofing paper in between. This system can provide only small overturning resistance induced by the structure self-weight and soil passive pressure. Such a resistance will not be sufficient for even moderate seismic demands. The dowelling can connect the top portion and the bottom portion to make the pile-cap integral for moment continuity.

Increasing uplift capacity of the foundation by adding new micro-piles

The existing Franki piles have limited uplift capacity, partly due to the tight lay-out of piles. New GEWI micro-piles are added around the existing pile-caps to provide the required uplift capacity. Micro-piles are selected for constructability advantage due to the limited space available under bridge deck.

Installing shear keys between girders and the piers

New shear keys will be installed to restrain the superstructure onto the piers, preventing excessive transverse movement.

Adding abutment wing-wall link slab

The existing wing walls cannot provide sufficient resistance for longitudinal seismic demands. To fully mobilize passive soil pressure at the embankment, new abutment wing-wall link slab can be installed.

Installing abutment tieback anchor

The installation of the abutment tieback anchors is to counter structural twisting induced by the 45 degree skew of the superstructure. It will also help to provide additional resistance to the inertial force in the longitudinal direction. After installing the tieback anchors, the longitudinal seismic effect is resisted by both the compression from passive soil pressure and the tension developed in the tieback anchors.

Conclusions

The seismic retrofit analysis and design of the five-span 91 m long CNR Overhead was summarized in this paper. Based on a response spectrum analysis and thorough investigation of potential retrofit options, we conclude the following:

1. The existing CNR Overhead structures do not have proper lateral load path for seismic resistance. A valid load path must be established during seismic retrofit.
2. The most beneficial and cost-effective seismic upgrade of the CNR Overhead is to provide a deck link slab, which makes the whole deck act as a rigid diaphragm to provide continuity across piers, to transfer longitudinal seismic loadings to the abutments, and to provide a better driving surface.
3. The transverse load path can be further improved by installing shear keys above piers, strengthening the wall piers, grouting jacks in the pile-caps, and dowelling the pile-caps.
4. The longitudinal load path can be supplemented by adding new micro-piles at all piers and installing tieback anchors at the abutments.

At the time of this paper, the deck widening construction including installation of deck link slab has been completed. Other seismic retrofit measures are pending additional construction funding.

Acknowledgments

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