Retrofitting of Ayala Bridge, an Historic Steel bridge in Manilla (Philippines)

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ABSTRACT: Ayala Bridge, in the center of Manilla, is a steel arch bridge built in the 1950s. It is comprised of 2 simply supported steel bridges constructed with 3 trusses connected together. The bridge has to be retrofitted for conformity to new codes (traffic and seismic). The retrofitting solution designed by Freyssinet was chosen because of its economy when considering both deck and foundations: it consists of minimizing the current seismic loads on piers and abutments, to get them lower than actual loads seen in the past under historic seismic and typhoon. Longitudinally, the 2 decks are linked together and extended with beams and new piles: the overall structure is working as a frame. Transversally, some seismic devices are placed. The overall steel structure is then strengthened using additional steel profiling and prestressing. Major parts of the work has been done with no traffic interruption at all.

1 GENERAL INSTRUCTIONS

Ayala Bridge is one of the major bridges located in the center of Manilla (Philippines) over Pasig River. As a strategic axis (20 000 vehicles per day), its closure needed to be reduced to a minimum. It is comprised of 2 independent steel arch bridge of 61,6 meters (south span) and 73,8 meters (north span), constructed with 3 trusses connected together [figure 1]. Transversally, the deck is composed of a concrete slab supported by stringers beams. The deck of 25,9 meters width supports 4 traffic lanes each of 3,05 meters and 2 sidewalks.

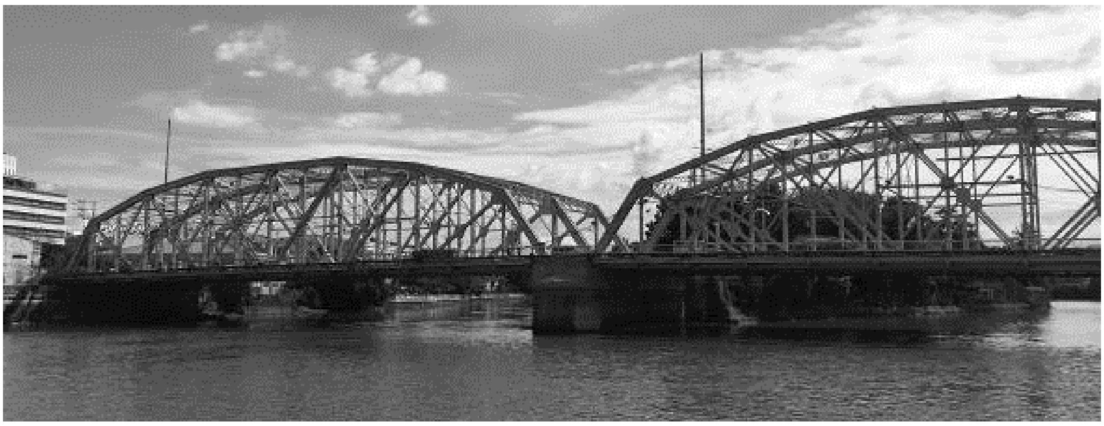

Figure 1. Global view of Ayala Bridge

Each bridge is fixed on piers and free on the abutments longitudinally, and fixed on piers and abutments transversally. The bearings are located under each arch.
The buried part of the concrete pier and abutment is about 2/3 of the total height. Piers and abutments are placed on driven timber piles.
In 2009, the bridge was declared as a historic legacy and landmark by the National Historical Institute, and consequently, should be preserved for posterity.
Rehabilitation and retrofitting of Ayala Bridge should be done in accordance with AASHTO 2002 regarding traffic loads including seismic action.

2 SURVEY AND INVESTIGATION

A full diagnosis of the present state of the bridge was done prior to any design work. The aim was to determine the current condition of the structure (steel trusses, bearings, deck, concrete structure), get essentials data to complete the design (confirmation of as built sections), and to check assumptions taken at tender stage regarding the soil capacity.
At this stage, a global geometry inspection of the steel structure are done with a 3D laser scanning technology in order to get the current configuration of trusses members and connecting nodes (with rivets and gusset plates).
For the assessment of inherent material properties and existing conditions, the steel materials are tested in order to define its grade, strength, weldability, corrosion state and residual thickness. Regarding the concrete, carbonation and chloride content are defined as well as the location of rebar and its diameter. Compressive strength with samples and concrete homogeneity with ultrasonic pulse velocity are also measured to evaluate the quality of the existing material.
Soil investigation consists of cone penetration tests to evaluate the soil bearing capacity. Friction sleeve and vane tests are used to determine soil cohesive strength. CTP piezocone test is added to measure the pore water pressures to aid checking the risk of liquefaction.
Various laboratory investigation with samplings have been done to determine density, sieve analysis, Attenberg’s limits and organic content.
The conclusion of tests done on the superstructure is that the steel structure and concrete deck are relatively well preserved, except in some areas located under the deck concrete structure that are extremely corroded. On the other hand, soil characteristics appeared to be poor compared to assumptions taken at tender stage. The retrofitting solution needed then to be adapted to real soil capacity.
If the investigation is correct regarding the substructure and superstructure, we identified a huge risk existing on the wooden pile capacity.

3 DESIGN OF THE RETROFITTING SOLUTION

3.1 Re-design of the actual bridge

In order to mitigate the lack of information regarding the wooden piles, the bridge was re-designed with the highest earthquake or typhoon felt since 1950.
The analysis of the bridge using FE model with software SAP 2000 allowed us to define the maximum reactions on piers and abutments. The stability of piers and abutment were then checked using Plaxis software taking into account soil and structure interaction [figure 2]. Wooden piles demand were also checked, with seismic action already felt since 1950 and compared to their capacity.

Due to a significant increase of the seismic action to conform to the AASHTO 2002 code [figure3], it was not possible to keep the bridge in its actual configuration (overloading of pier foundation and abutment would require significant strengthening).
A new solution had, therefore, to be developed by Freyssinet.

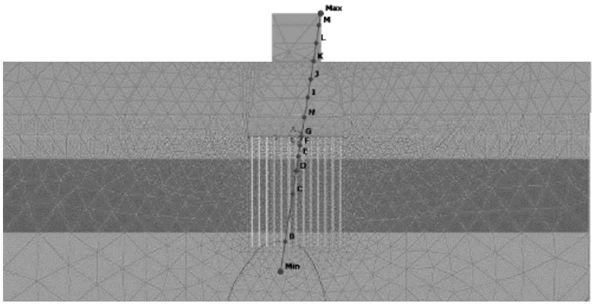

Figure 2. FE model of piers with soil-structure interaction

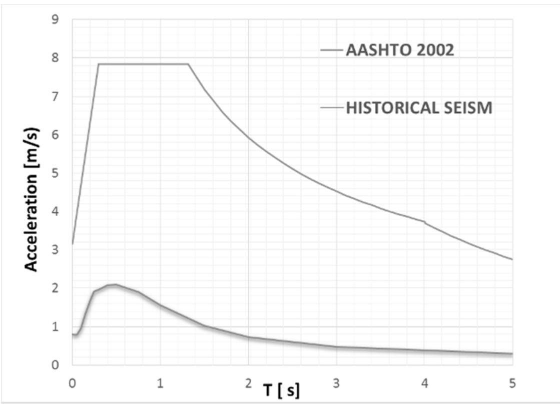

Figure 3. Comparison of AASHTO design spectrum and historic seism spectrum previously experienced by the bridge

3.2 Seismic retrofitting

3.2.1 General Concept

The global behaviour of the bridge is critical for the existing foundations. The chosen retrofitting solution aims at minimizing the loads on the piers and foundations, calculated with current seismic codes, to reduce them to lower than the actual loads seen in the past on the structure under historic seismic or typhoon conditions.

3.2.2 Longitudinally

Longitudinally, the two concrete decks are connected together with a continuity slab and extended using ground concrete beams, approach slabs and additional piles [figure 4].
Indeed, the major longitudinal seismic effect is an axial load. The existing pier and abutments are self-stable when they are surrounded by soil but become unstable under an additional horizontal longitudinal seismic effort. The approaches on ground beams (length 25 meters) and 2 meter

diameter pile (length 20m) will support the longitudinal seismic actions. Besides this, in order to minimize the effect on the pier and abutments, the bridge is placed on isolators.
The overall structure is then working as a frame, with small impact on the actual foundations.
Particular attention was paid to connection of the ground beam to the abutment and to the new piles.

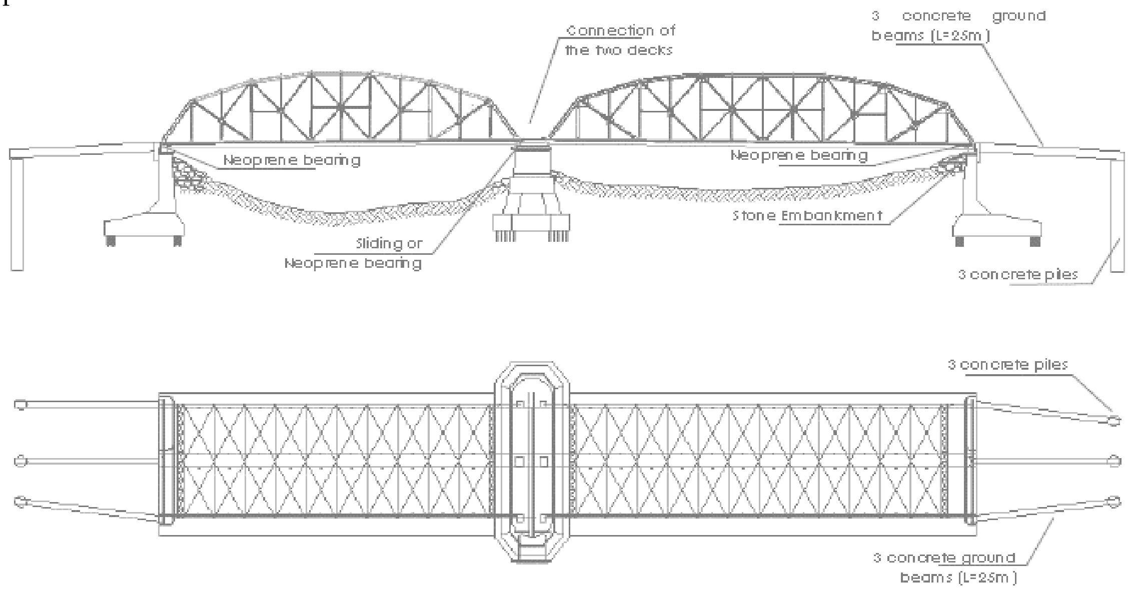

Figure 4. Global view of Ayala Bridge

3.2.3 Transversally

Transversally, Fluid Viscous Dampers (FVD) are used simultaneously with isolators or High Damper Rubber Bearings (HDRB) to dissipate energy. Lateral stability under service loads is insured thanks to stop fuses [figure 5].

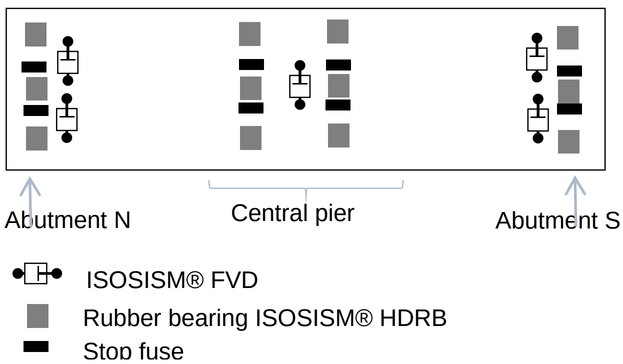

Figure 5. Layout of the bridge for transversal retrofitting

These seismic devices are used to increase the overall damping and to ensure integrity of the bridge during and after an earthquake. They have low resistance to slow displacement (thermal variation) and become active during seismic motion [figure 6].
In case of Ayala Bridge, FVD was chosen in order to comply with the past maximum loads seen by the pier [table1]. The overall seismic protection system was designed iteratively.

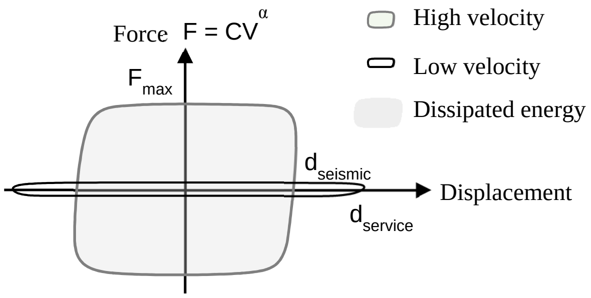

Figure 6. Fluid Viscous Dampers: Behaviour law and picture of FVD installed on pier

Table 1. Comparison of horizontal transversal effort on foundations

Fy	South abutment [kN]	Central pier [kN]	North abutment [kN]
Existing bridge	4063	13884	5125
Already seen typhoon/seism	3656	3656	3656
Retrofitted bridge	3200	2550	3150

3.2.4 Abutment and piers

Substructures are not completely embedded in the ground (around 2/3 of their height is embedded). Due to high seismic action at ground level and despite reduced longitudinal horizontal efforts, the abutments appear to be unstable whereas the pier remains stable.
Considering that buried Substructure are self-stable under earthquake, the retrofitting solution consists, for the north abutment, in placing additional stone revetments on the embankment in front of the abutment [figure 7].
This solution could not be applied to the south abutment, due to the depth of the river bed. Indeed, the stone embankment would have defined a slope that would have had an impact on the ship channel. To ensure stability of south abutment, 18 soil nails each of 25 meters long (capacity 800 kN) were required to be placed along the abutment [figure 8].

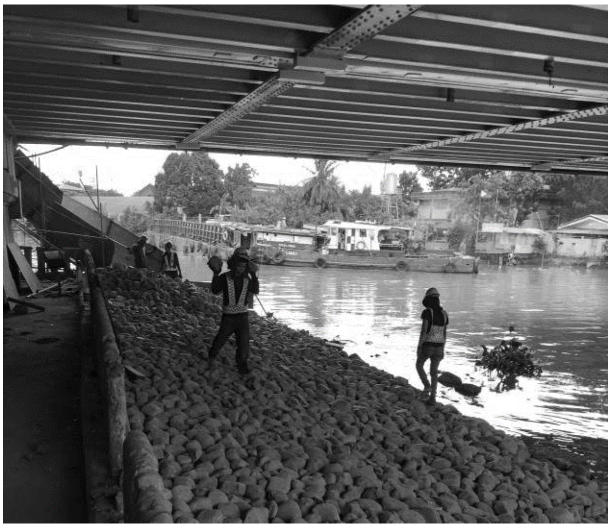

Figure 7. Embankment for north abutment

Figure 8. Soil nails dispatched along north abutment

3.3 *Concept of arch bridge strengthening*

The whole structure was checked using a 3D model on SAP 2000. All steel profiles were checked according to AASHTO 2002 code. This strengthening solution was chosen due to its economy in terms of work and materials.

The strengthening solution consists of adding a T profile welded on the top chord and on top of the transverse beam (to mitigate transversal effects) [figure 9 and 10].

Specific top nodes of the steel truss have been detailed to provide a proper connection between top chord and the top transverse strengthening members by taking into account the existing riveted gusset plates [figure 11].

The bottom chord was strengthened by adding a straight centrally mounted prestressing cable placed inside the profile of each truss in order to balance extra-tension.

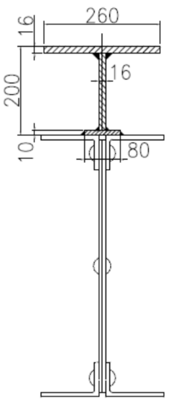

Figure 9. T profile welded on transverse beam

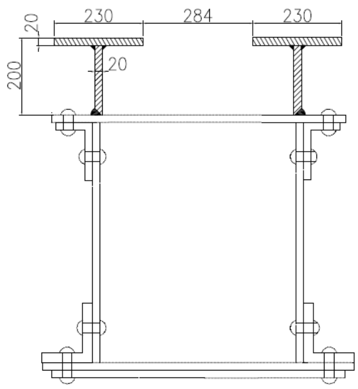

Figure 10. T profiles welded on top chord

Figure 11. Example of node strengthening

Figure 12. View of the top chord being protected

The longitudinal rebars placed in the existing concrete slab appeared to be discontinuous at each crossbeam. In order to ensure the global function of the concrete slab during transversal seismic event, it was necessary to recreate this continuity by pouring a new slab (connected to the old one) on the top of the existing one.
Finally, the full steel structure was sand-blasted, restored locally as required to protect using a long-term corrosion protection system [figure 12].

4 CONCLUSION

In this paper, we present an innovative solution designed and applied by Freyssinet on the Ayala Bridge in Manilla (Philippines). The technical solution consisted of reducing the load to the foundations using dampers and isolators (transversally) and an extended structure to support seismic loading (longitudinally).
One of the key elements for success in such project has been the need for the preliminary inspection to be as exhaustive as possible. Finally, this paper is presented to enable the reader to develop a full and comprehensive understanding of the different problems to be solved when considering any number of given/ chosen repair techniques.