IABSE SYMPOSIUM

NANTES, 2018

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REPORT

International Association for Bridge and Structural Engineering IABSE

Design and Construction of the New "La Unidad" Bridge, Mexico

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Abstract

La Unidad Bridge is located in the south of the Gulf of Mexico, in the state of Campeche, Mexico. The new La Unidad Bridge will replace the existing bridge which was built in the 1980´s and presents several pathologies. The bridge is placed in a very important road parallel to the coast, in the heart of the Mexico´s oil industry, and allows the connection between the "El Carmen" Island and the continent. The new "La Unidad" bridge has a total length of 3285 m, and crosses over the sea with water heights comprised between 4 and 15 m. The bridge has 73 spans of 45 m; the deck is formed by 6 "I" beams of prestressed concrete, with concrete slab. The piers are composed by battered piles formed by steel pipes filled with reinforced concrete. The pile cap is placed directly over the piles. The design and construction of the bridge presented several challenges: the area where the bridge is located is prone to hurricanes and earthquakes, and the soil of the bridge site is relatively soft (formed by sands and clays) and an amplification of the seismic response occurs due to site effects. This paper presents the main aspects of the design and the construction of the New "La Unidad" Bridge. The bridge is now under construction and will be finished at the end of 2018.

Keywords: Bridge, concrete, prestressed concrete; battered piles, earthquake, offshore.

1 Introduction

The New "La Unidad" Bridge is located at the entry of the Terminos Lagoon, in the south of the Gulf of Mexico, in the state of Campeche (Figure 1). The bridge will replace an existing bridge, constructed in the 1980´s. This bridge presents several pathologies related with corrosion of its piers (Figure 2). During the lifetime of this bridge several unsuccessful attempts were made to repair it. Finally, in 2012 it was decided to replace it with a new bridge. This bridge is placed in a very important road parallel to the coast, and allows the junction between "El Carmen" Island and the continent. The "El Carmen" Island is in the heart of the Mexico´s oil industry (Figures 1 and 3).

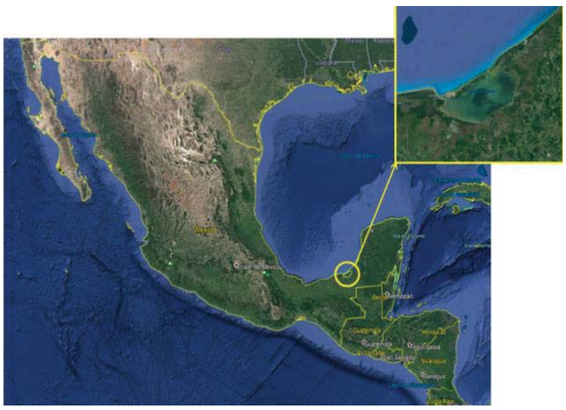


Figure 1. Location of the bridge site

Figure 2. Typical pathologies of the existing bridge

2 Description of the bridge

The New "La Unidad" bridge will be parallel to the existing one and it will be located at 15,5 m. It will have total length of 3285 m, and crosses over the sea with water heights comprised between 4 and 15 m.

Figure 3. Bridge site

The new bridge has 73 spans of 45 m each one. The deck is formed 6 "I" shaped prestressed concrete beams 2,2 m height, with a 22 cm thick concrete slab.

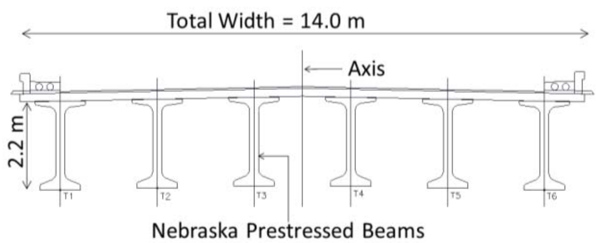


Figure 4. Deck section

The substructure has 74 piers, and is formed by 3 different types of them, whose shape depends on their location along the crossing (Figure 5).

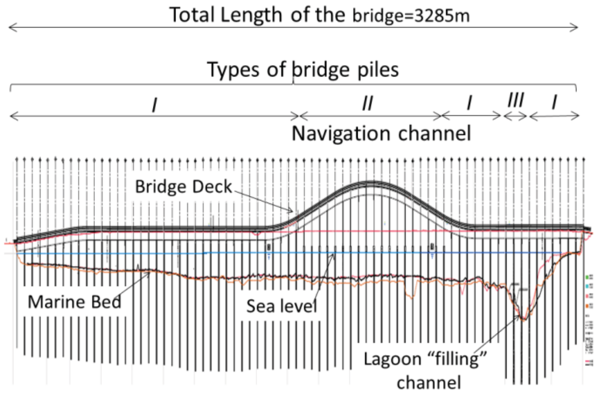
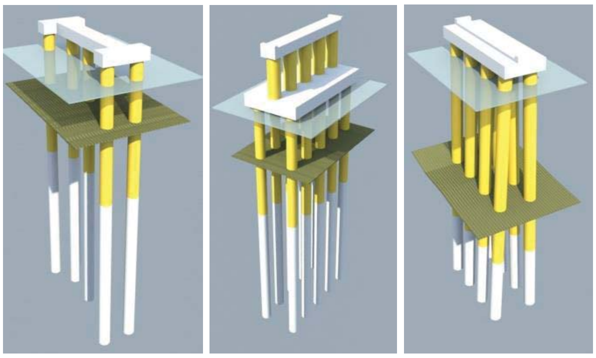


Figure 5. General bridge profile

Type I piers are the most common (50 elements), and consist of 7 tubular steel piles 1,2 m diameter, driven by blow, with reinforced concrete inside in the superior part. A reinforced concrete pile cap is supported on these piles.

Type II piers correspond to the area of the navigation channel under the bridge (19 piles) and are formed by 10 tubular steel pipes of 1,2 m diameter driven by blow, with reinforced concrete inside on the top part. A reinforced concrete footing rests on the piles, and reinforced concrete columns and a cap are placed over the footing.



(a) (b) (c)

Figures 6. Shape of piers: (a) type I, (b) type II, and (c) type III

The type III piers are the highest (3 elements), and correspond to the area of the "filling" channel of the "Términos" lagoon. This area has a high velocity in the seawater flow, and is particularly sensitive to scour. These piers are formed by 8 tubular steel piles of 1,5 m diameter. They are "A" shaped, and are inclined in longitudinal direction. These piles are also driven by blow, and filled with reinforced concrete. The pile cap is placed directly over the piles.

The 2 extreme abutments are also formed my 4 battered steel pipes partially filled with reinforced concrete with a RC pile cap on the top of them.

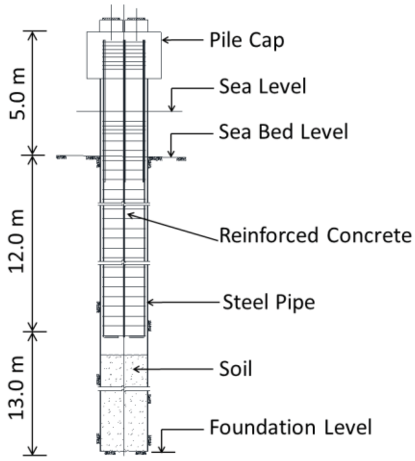


Figure 7. General configuration of piles

3 Characteristics of the bridge site

3.1 Geology and soil characteristics

The stratigraphy of the soil is very variable along the bridge. In general terms, it can be said that the soil is mainly made up of different strata of sands, clays with sand and clays, with consistencies from medium to firm.

The geotechnical exploration of the site consisted in 17 soil borings, with extraction of unaltered samples of different soil strata.

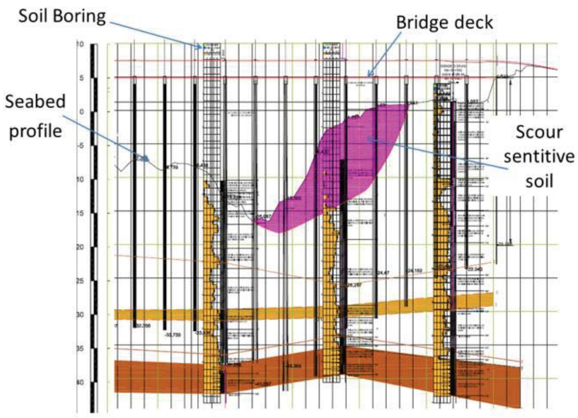


Figure 8. Example of stratigraphy and geotechnical exploration on "filling" channel of the lagoon

A particular feature of the bridge site is the presence of strong tides, which generate important water currents in several areas of the bridge. At the southern end of the bridge there is a natural channel through which the seawater flows, filling and emptying the lagoon twice a day. This zone presents an important risk of scour.

3.2 Seismicity

The bride site is located in a zone of relatively high seismicity, with seismic coefficients up to 0,3g. A particular seismic risk study was made for the bridge site considering the propagation velocities of waves in the ground from a study of refraction geophysics. This study allowed the definition of two different design spectra: one for the central part of the bridge (were the soil is "soft"), and other for the margins (were the soil is "stiff").

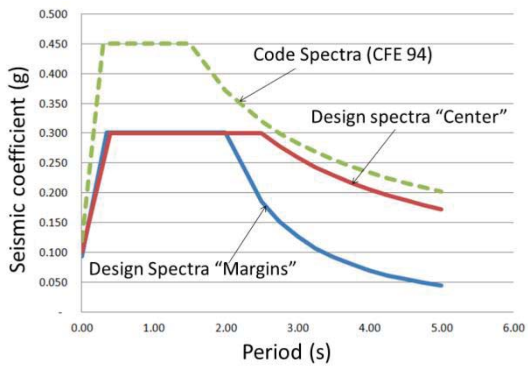


Figure 9. General configuration of piles

The particular seismic risk study also allowed a reduction of maximum seismic coefficient of the design spectra if compared with the "general" seismic provisions of Mexican design codes.

4 Bridge design

4.1 Superstructure

The deck of the bridge is relatively conventional and no special calculations were made to design it. The main "I" section beams are 2,2 m high Nebraska type, and are pretensioned with 56 single strand tendons 15 mm diameter. Nevertheless, given the high transverse flexibility of the 45 m span Nebraska type beams, special provisions were taken to assure their transport and installation.

4.2 Substructure

The main actions in the substructure design are seismic forces. Special calculations were made in order to optimise de seismic design of the bridge.

Detailed FEM models of different zones of the bridge were made. The definition of the different models was made based on the different piers types, and the different soil conditions along the bridge. The soil-structure interaction was taken into account by means of springs representing the different soil layers traversed by the foundation piles.

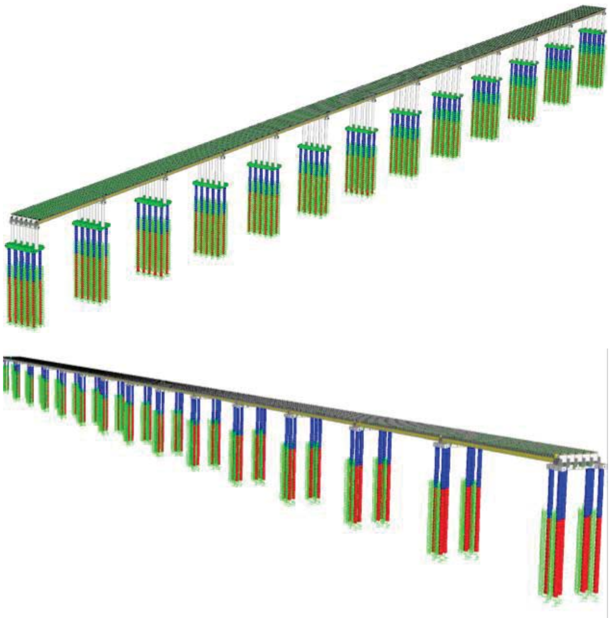


Figure 10. Examples of FEM of different bridge zones

The preliminary designs of bridges were made using the classical modal spectral method, but the results were very conservative.

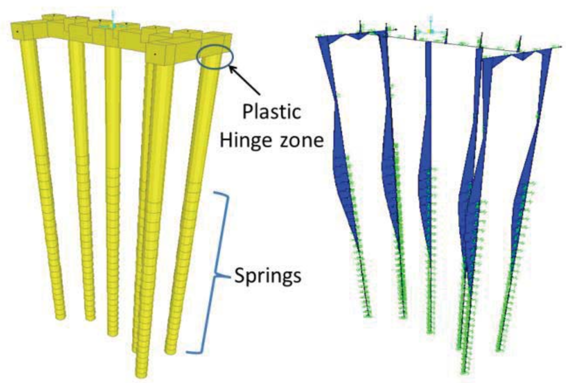


Figure 11. Detail of FEM of a type I pier, and typical obtained results (flexural moments)

In order to optimize de foundations and piers design, a time-history non-linear method was used to evaluate the seismic forces on those elements.

For that reason a set of (5) "synthetic" accelerograms were generated from the design spectra [1]. Figure 10 shows an example of the accelerograms obtained. A response spectra was calculated from the synthetic accelerograms in order to verify their agreement with the target spectra.

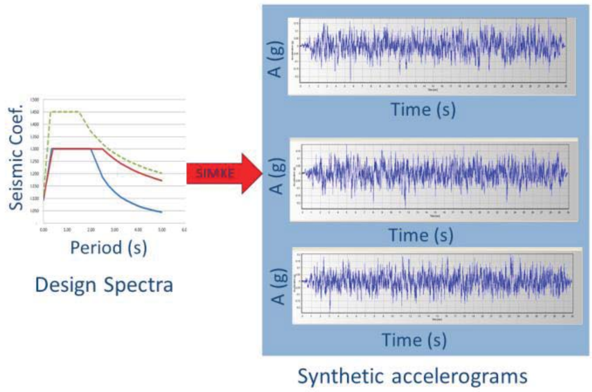


Figure 12. Example of generated accelerograms

The design method for the foundations and piers was the following:

I. Elaboration of FEM models of different section of the bridge.
II. Modal spectral calculation of the seismic response to evaluate de zones were the plastic hinges on piers will develop.
III. Calculation of Moment-Curvature diagrams of the piers sections were the plastic hinges will appear [2].
IV. Introduction of the plastic hinges in the FEM of the bridge.
V. Time-history non-linear seismic analysis of the response of the bridge for the set of 5 different simulated earthquakes (synthetic accelerograms).
VI. Verification of the resistance of the reinforce concrete sections of the piers,
VII. Verification of the load capacity of foundations (piles vertical load).

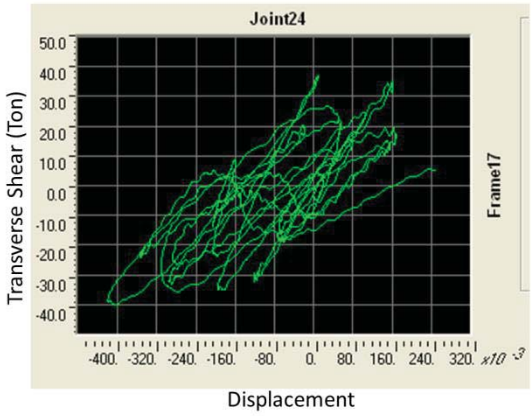


Figure 13. Typical hysteretic cycle in plastic hinge

With the non-linear calculations made the resulting maximum forces (flexural moments and shears) in the piers were 50 % less than those obtained for classical Modal-Spectral linear analysis. This was also verified for the maximum axial vertical load in the piers. Figure 13 shows the hysteretic cycle in a plastic hinge of the bridge that allows important energy dissipation.

A special care was made in the reinforcement detailing of the zones were the plastic hinge will form (in the connection between pile-caps and piles). The amount and separation of the transverse reinforcement was designed according to seismic design rules [3] (see figure 7).

5 Construction of the bridge

5.1 Substructure

The constructions stages for the piers are the following:

I. Topographical placement of the steel piles.
II. Installation of piles by driving.
III. Partial removal of soil from the interior of piles.
IV. Installation or armatures inside the piles and concrete casting,
V. Construction of reinforced concrete pile cap.

Figures 14 to 18 shows the different construction stages of a typical type I pier.

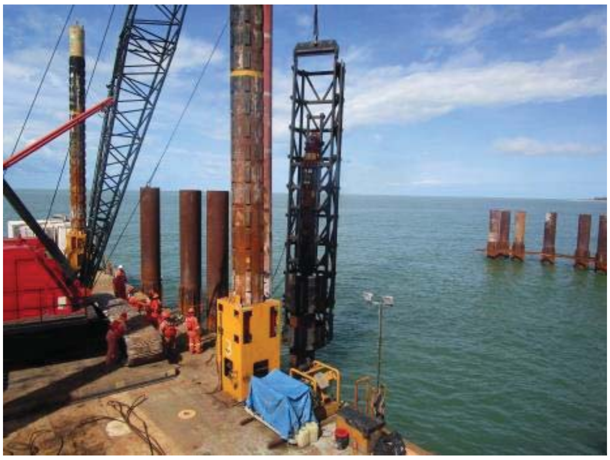


Figure 14. Driving of steel piles

Figure 15. Installation of steel armature of piles

Figure 16. Cast of concrete in piles

Figure 17. Cast of pile cap

Figure 18. Finished pier

5.2 Deck

The pretensioned beams of the deck are made in two different facilities installed on each side of the bridge. The installation of the precast beams is made by two launching gantries (one in each side of the bridge). Once the installation of beams is completed for each span, transverse diaphragms are constructed and postension transverse cables are installed. Finally the slab is cast.
The construction works above described are illustrated on Figures 19 to 24.

On September 7th a major earthquake (magnitude 8,2) affected the south of Mexico, important seismic accelerations were perceived on the bridge site. A detailed inspection of the new bridge was made after this event, and fortunately no damage was observed.

Figure 19. Precast beams manufacturing plant

Figure 20. Circulation of a precast beam on the bridge

Figure 21. Aerial view of the launching gantry on the north side of the bridge

Figure 22. Installation of precast beam

Figure 23. Launching gantry on the south side of the bridge

Figure 24. Aerial view of the construction works

6 Load capacity tests

In order to verify the main assumption of the design of the foundations, it was foreseen to carry out load test of the capacity of the piles in 9 different locations along the bridge. The load tests are made in the finished piles before the installation of the pile cap.

Figure 25 shows an example of a pile test. Figure 26 illustrates some of the obtained results.

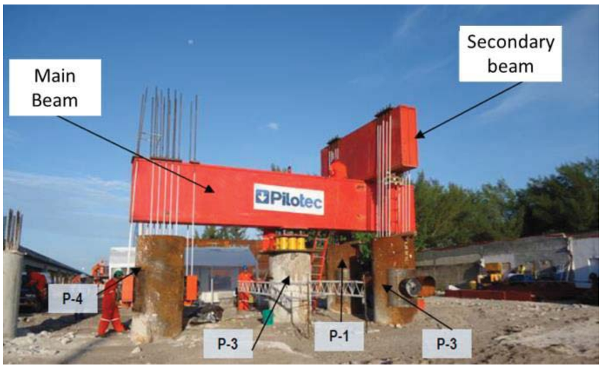


Figure 25. Pile test on pier 73.

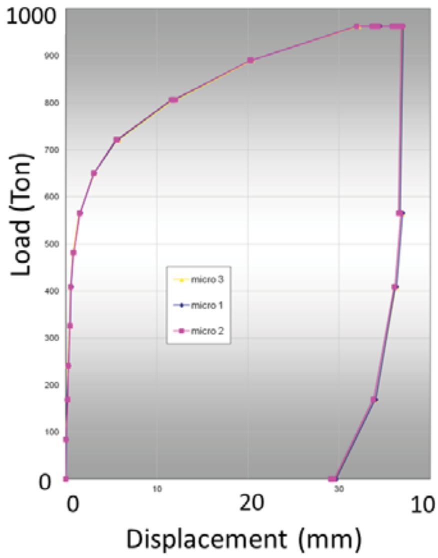


Figure 26. Test results.

The results found were good, the ultimate load capacity of a pile of 1.2 m diameter was 963 Ton. This value was compared with theoretical ultimate load capacity obtained from calculations using the results of the geotechnical exploration (903 Ton). The maximum design forces on this pile are:

- $P_{\text{Dead Load}}$=240 Ton
- $P_{\text{Dead Load+Live Load}}$=320 Ton
- $P_{\text{Dead Load+Eartquake}}$=481 Ton

The service and accidental design forces are lower than the measured on the load test.

This campaign of continue during the construction of the bridge, and the location of load test sites is defined according to the different geotechnical zones in which the bridge site was divided.

7 Conclusions

The new La Unidad bridge is a very long bridge, characterized by its construction in a marine site, with geotechnical complexity, and located in a seismic region. Special seismic risk studies were carried out. Non-linear time history calculations of the seismic response of the bridge were made. These calculations showed the capacity of the bridge to dissipate energy during strong seismic motions, and allowed an optimisation of the piers design. The results of the geotechnical calculations were compared with those obtained in load tests.

The main stages of the construction of the bridge were presented. The bridge is still under construction and will be finished at the end of 2018.

8 References

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[3] Priestley, Seible and Calvi, *Seismic design and retrofit of bridges*. John Wiley Editor, USA., 1996.