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# Repair of El Zacatal bridge with ultra high performance concretre.

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## Background

Built in 1994, El Zacatal bridge is considered the longest bridge in México (it´s length is 3861 m and it is 9 m wide). It connects the Atasta Peninsula with Carmen island in the southwest of Ciudad del Carmen Campeche, México[1].

The structure consists of prefab elements, 121 tube headers, 496 AASTHO type IV modified beams and by 8 drawer locks, as well as 124 post - tensioned concrete slabs[2].

Fig 1. aerial photo, El Zacatal bridge

## Corrosion damage of concrete structures in marine environment

It is widely known that corrosion due to chloride ions is one of the main causes of damage in reinforced concrete structures in coastal and marine area[3].

Steel reinforcement in concrete is protected by high alkalinity of the pore products formed in the cement hydration process (ph >13). This high pore alkalinity keeps reinforcement bars inactive and regulates the speed of corrosion, thanks to the formation of a ferrous oxide layer over the bars[4]. However, when the chloride ions penetrate through concrete and reach a citric concentration, this protective layer is destroyed. In the presence of oxygen and moisture the corrosion process gets started[5].

Factors, such as permeability, the quality and width of the concrete slab are the elements that determine the speed of this process. The repair and restoring of concrete structures affected by chloride corrosion seem unavoidable[6]. The selected repair method must be reliable, durable, economic and cause the least possible impact. And, it must be structurally effective and easy to implement[7]. Due to this reason, the idea of repairing and reinforcing concrete structures with ultra high performance concrete (UHPC), with or without reinforcement, to protect, repair and restore specific parts of the structure in severe environmental conditions or under mechanical loads.

# Ultra High Performance Concrete (UHPC)

The use of UHPC as a repair material is more and more common[8].
The low permeability, created by a discontinuos pore structure and a dense microestructure, make that destructive substances, such as water, chloride ions, oxygen, etc., hardly will enter the structure and as a consequence, the causes of potential damage are limited[9].
Hence the use of UHPC as repair material can lengthen the useful life of concrete structures, and for this specific case of bridges.
The concrete structure is exposed to an aggressive environment, from a durability point of view, reason for which it has been necessary to make repair in it to increase its useful life.

| Element5 | No. of pieces indicated in the proyect |
|---|---|
| Shoe jacketing | 9 |
| Columns with dice (jacketed) | 16 |
| Columns without dice | 6 |
| Columns with crossbar (jacketed) | 32 |
| Type 1 header (jacketed) | 6 |
| Type 2 header (jacketed) | 10 |
| Type 3 header(jacketed) | 2 |
| Type 4 header (jacketed) | 1 |
| Type 33, 34 y 36 header (jacketed) | 3 |
| Type 35 header (jacketed) | 1 |
| **Total number of pieces to pour shown in the project:** | **86** |
| **Elements considered for verification:** | **50** |

*Table 1. Elements for repair in the first stage.*

Repair consists in the pour of UHPC in a form work mold referred to as jacketed, around elements to be repaired, see fig 2. Wich has a thickness of 15 cm for headers and columns.

## Proyect

The El Zacatal bridge rehab Will be done in two stages, the proyect is under the consortium of construction Companys: Grupo Industrial Rubio SA de CV y Grupo Empresarial de Puentes y Estructuras SA de CV with the technical advice of General Management of high way conservation (DGCC) of the infraestruture ministry, Communication and Transportation (SICT) and the company SATELSA SA de CV.
In this first stage 86 pieces will be repaired, as shown in table 1.

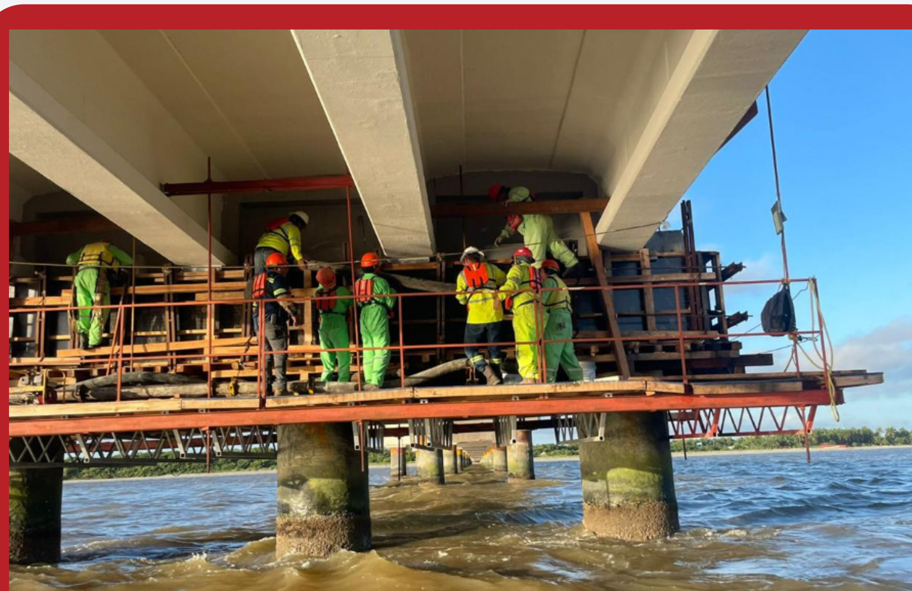


Fig 2. Element formwork, jacketed casing.

## UHPC specifications for repair

Durability specifications that are defined in mexican specifications NTC-CDMX-202310 and NMX-C-530-ONNCCE-2018,11 wich were used by the company that designed the proyect and following, in table 2, the most important are mention for concrete compliance:

| Concrete specifications | |
|---|---|
| 1) 24 [kgf/cm$^2$] hours Compressive strength | 500 |
| 2) Water to bindig material ratio | 0.4 |
| 3) Electric resistivity saturated at 3 days min. [kΩ-cm][12] | 50 |
| 4) Rapid chloride permeability at 3 days [Coulombs][13] | <1000 |
| 5) Maximum concrete temperature during mixing and placing [°C] | <32 |
| 6) Extensibility [cm][14] | 74 ± 4 |
| 7) Fresh state volumetric mass [kg/m$^3$][15] | 2,300 - 2,400 |
| 8) Maximum air content [%][16] | 2.20 |

*Table 2. Concrete specifications.*

Given that the performance values for durability such as saturated electric resistivity and rapid chloride permeability must be performed when the concrete has reached 90 days and 56 days, respectively according to the Mexican standard NMX-C-530-ONNCCE-2018,[11] SATELSA SA de CV requested that these specifications be modified so that ages coincide with the specification.

The mix design and technical support were suggested and have been performed by: Element5 Química Aplicada, MOVINCO CHEMICAL and INOVATIE, using as a reference the criteria established in the Mexican specification NMX-C-530-ONNCCE-2018.[11]

The materials used have been provided by the companies above mentioned and are described in Table 3:

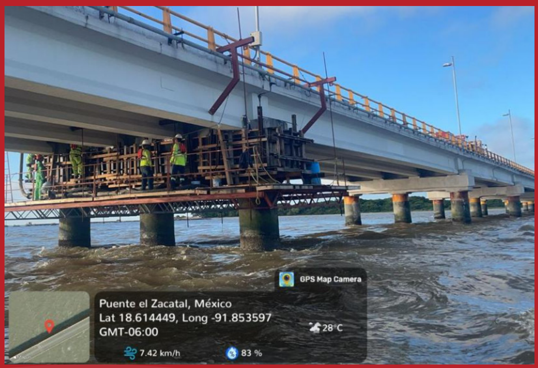
| Name | Description |
|---|---|
| e$^5$ PCE SUPER A-Clays SR | Most recent generation of hyperfluidifying admixture clay resistant and high consistency retention. |
| e$^e$ Control AIR | Air detrainer (excluder). |
| INO-FUME-950D | Silica fume 93% minimum purity. |

*Tabla 3. Materials used*

Due to the location of the plant responsible for the production of UHPC, freight times, temperatures and placement conditions, the operation requires that the concrete have a consistency retention longer than 2 hours without setting delays. The results obtained as far as the UHPC specs are shown in Table 4, comparing the specified in column 2 and the values obtained in column 3.

| Concrete specifications | | Obtained values |
|---|---|---|
| 24 hours [kgf/cm$^2$] compressive strength | 500 | 590* |
| Maximum air content [%] | 2.20 | 0.95 |
| Saturated electric resistivity at 90 days minimum [kΩ/cm] | 50 | 60 |
| Rapid chloride permeability at 56 days [Coulombs] | <1000 | 390 |
| Maximum temperature of concrete during production and placing [°C] | <32 | 32.1* |
| Extensibility [cm] | 74 ± 4 | 75* |
| Volumetric mass in the fresh state [kg/m$^3$] | 2,300 - 2,400 | 2401* |
| Water to binding material ratio | 0.4 | 0.27* |

Table 4. Results obtained from pours. *Average obtained from 10 consecutive pours..




Quality control for each component has been exercised, such as stone aggregates of Escarcega and Tabasco, as well as the CPC 40 Holcim cement.
A low clay inert aggregate (RIC) was requested from the cement company, addition that affects concrete durability and hence its content was requested below 10%.17-19 To verify this cement characteristic, the specification was requested that the ignition loss (%PPI) must be < 5%, as controlling this spec in the CPC dust, controls the cement´s RIC with this ratio: RIC(%) = 2 (PPI%).

## Curing and Protection of UHPC

To achieve an optimum development of concrete properties, the demolding of the structure time must be observed, these must not exceed 24 hours after the pour, contrary to this, significant cracks can occur.

After these, curing must start. When the surface begins to lose its brightness, a curing membrane must be applied. Then the structure must be covered with polyethylene film to protect its moisture. This Will avoid that the chlorides from seawater splashes on the element recently placed, penetrate concrete at early ages. See fig. 3. This polyethylene film protection must be kept in place during at least 56 days, so that the contaminating agents will not enter the material that still has the microsilica reaction addition taking place to reduce concrete porosity.

Figura 3. Curing and UHPC protection.

## Conclusions

The UHPC designed and implemented complies with the placing, workability, pumpability and consistency retention, as well as the specified technical requirements .
The design, preparation and implementation of this type of concrete requires a constant and detailed monitoring of the material´s quality, including the type of cement (restricting the inert clay fill in it), rigorous concrete plant manufacturing controls, as well as adequate articulation and coordination of all the involved parts, in a way that it will be possible to guarantee the successful project execution. This way, the final product will complie with the requirements to extend the useful life of the structure.

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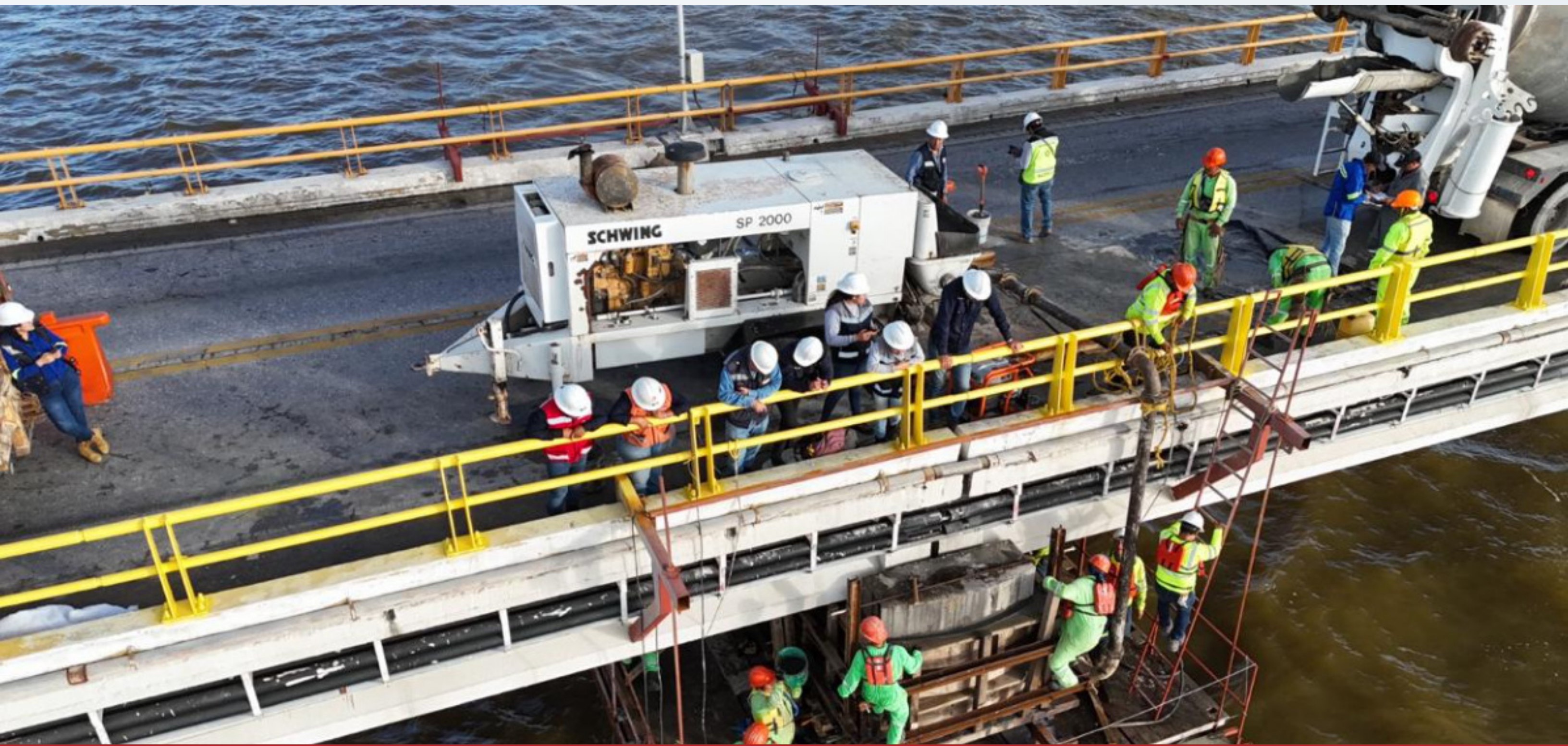


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