History, diagnosis and repair of the Corniche Kennedy in Marseilles

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Abstract. The Corniche Kennedy is an emblematic road of the city of Marseilles in France. Located on the seafront, it was built in the 19th century and widened in the 1960s to create a corbelled pedestrian promenade. Its widening structure, made of slabs resting on corbels anchored in a retaining wall or on crossing structures, has been subjected for more than 60 years to a very aggressive marine environment and presents many damages. After having carried out the diagnosis of the structure, the Infrastructure Department of the Metropole of Aix-Marseille-Provence selected the engineers of the Setec Group to carry out the complete project management for the rehabilitation of the Corniche Kennedy. Between 2018 and 2022, the Corniche Kennedy underwent major rehabilitation work, using modern techniques to prevent and treat the main pathology of the structure, the corrosion. This article presents all the steps of the rehabilitation of the Corniche Kennedy from diagnosis to maintenance of the structure after renovation.

1 Presentation of the structure

The Corniche Kennedy in Marseilles is a coastal road that runs along the Mediterranean Sea, from the Catalan beach to the Prado beaches. It was renamed in 1963 as a tribute to the American president assassinated the same year.

Fig. 1. The Corniche Kennedy in Marseilles

This major road in the city of Marseilles allows vehicles to connect the southern districts to the city center, and consequently makes the corniche a particularly busy road. Its bicycle path and pedestrian layout on the seafront make it a must for residents and tourists. The coastal road, built between 1848 and 1863, was widened between 1954 and 1968 to create a pedestrian promenade overlooking the sea.

Fig. 2. The Corniche Kennedy before the widening work

Fig. 3. Widening of the Corniche between 1954 and 1968

This widening structure is made up of corbels on which slabs rest. These corbels are distributed every 4 linear meters and are anchored on a continuous retaining wall or on bridges supporting the roads locally. The superstructure is made up of two sloping sidewalks
separated by a bench, known to be the longest in the world, and a parapet at the end of the structure.

![Diagram](image1)

**Fig. 4.** The structure of the Corniche Kennedy

As the work was carried out in three successive phases, different construction methods were used. To the north of the corniche, the corbels are made of reinforced concrete, the slabs are also monolithic, poured in place, and working on 4 sides, the parapet playing the role of a rolled-up beam.

![Diagram](image2)

**Fig. 5.** Reinforcement scheme of the first work stage of the widening works

On the south side, the corbels are made up of a prefabricated U-shaped mould in pre-stressed concrete, connected to a counterweight at the back of the retaining wall, and filled with reinforced concrete poured in place, the slabs are made up of 4 elements of 1 meter in pre-stressed concrete with adherent wires, and the parapet, which does not have a structural role, is hollowed out.

![Diagram](image3)

**Fig. 6.** Formwork/reinforcement plan for the third work stage of the widening work

For more than fifty years, the Corniche’s reinforced and pre-stressed concrete structures that constitute have been subjected to a particularly aggressive marine environment. Indeed, the structure is in permanent contact with sea spray and, as the waves hitting the rocks below, they splash the underside of the corniche.

![Image](image4)

**Fig. 7.** Waves hitting the underside of the Corniche

As a consequence, the corniche presents many apparent disorders: rust traces, cracks with traces of calcite, spalls and even detachment of the concrete by plate with apparent reinforcement.

![Image](image5)

**Fig. 8.** Spall with exposed reinforcement

Reinforcement work using additional prestressing was carried out on the crossing structures between 2003 and 2010. The corbelled construction located in the immediate vicinity of the bridges was also reinforced by additional reinforcement and concrete spraying on the underside of the slabs and on the corbels, and/or reinforcement of the corbels by moulding. However, as this work was only carried out over 500 meters of the 1.7 km of the Corniche, the structure has, as a result, significant damage requiring extensive regeneration work.

![Image](image6)

**Fig. 9.** View of the underside of the structure before the rehabilitation work
2 Diagnosis and repair project

The preliminary diagnosis, carried out in 2014 at the request of the project owner, and necessary for the study of the repair project, showed that the main structural disorders resulted from the rebars corrosion, mostly due to the chlorides penetration.

Indeed, potential measurements were carried out to determine the corrosive activity of the reinforcement. The potential cartographies showed potential values below -200 /-250 mV, which translates into a probability of active corrosion above 90% according to ASTM C876 standards.

Chemical analyses were also carried out on the concrete of the corniche, including on parts that had already been reinforced. The results of the tests showed that the chloride ion content, in relation to the mass of cement, is higher than 0.4%, the maximum rate authorized by the NF EN 206/CN standard in force for new concrete, over a depth of up to 6 cm. Cover concrete measurements have shown that the reinforcement has an average coating of less than 6 cm, so it has been contaminated by chlorides.

In this context, the Infrastructure Department of Aix-Marseille-Provence Métropole has undertaken a vast project of rehabilitation of this urban infrastructure and chose, in 2016, to award the complete project management to the group Setec engineers.

The repair project concerns the entire corniche structures from the “Maregraphe” (Marseille’s Tide Gauge Institute) to the Nhow Hotel over a length of 1.7 km, with the exception of the retaining walls and bridges which have already been repaired in 2010. Depending on their condition, the structural elements are either repaired or replaced with new ones.

As per the project owner’s wishes, the corniche being located near the “Maregraphe”, a site classified as an historical monument, the project was designed to preserve the architectural aspect of the original structures, while using modern civil engineering techniques to give them greater durability.

2.1 Corbels

Depending on the state of the damages and exposure, the corbels are either repaired or strengthened by encapsulating them with surrounding additional concrete. Existing corbels have been equipped with a cathodic protection system by impressed current, whereas a cathodic prevention system has been fitted on new corbels. This system makes it possible to cathodically polarize the structure to be protected by circulating a continuous electric current between the structure and an auxiliary anode.

Before deploying this protection to the entire linear, a pilot test was conducted in 2015 on 5 slabs and corbels of the corniche. It demonstrated its efficiency by achieving at least one of the three criteria of standard NF EN ISO 12696:

- Instantaneous off-current potential < -720 mV compared to a 0.5M Ag/AgCl/KCl electrode
- A depolarization of at least 100 mV from the time the system is switched off and for less than 24 hours.
- A depolarization of at least 150 mV from the time the system is switched off, for a period of more than 24 hours.

Between 0.2 and 2 mA/m² the structure is cathodically protected by preventing the appearance of new corrosion sites. Between 2 and 20 mA/m², the structure is cathodically protected by stopping active corrosion.

Additional investigations related to cathodic protection were also carried out during the project. Measurements of the resistivity of the concretes allowed to refine the sizing of the system and to define the output voltage of the rectifiers. Investigations also highlighted continuity defects between the rebars of the same corbel. The corbels must be subject to a systematic electrical continuity of the rebars, which is essential for current diffusion.

2.2 Slabs

Damaged slabs have been removed and replaced by new prefabricated elements. The formulation of the concrete used to prefabricate those new slabs, has been selected following a performance approach, aimed at respecting thresholds on durability indicators regarding rebars corrosion: water absorption capacity by immersion under
vacuum (Peau), gas permeability (Kgaz), apparent chloride diffusion coefficient and electrical resistivity (Dapp). A waterproofing membrane has also been applied on all slabs (new and existing ones).

Fig. 12. Installation of the new slabs

2.3 Benches and parapet

The benches and parapet have been removed along the entire corniche length and replaced with new prefabricated UHPFRC (Ultra-High-Performance Fibre-Reinforced Concrete) elements. Fibres are synthetic organic fibres to ensure a better durability against corrosion.

The new benches are designed with the same profile as the existing benches. The parapet has been redesigned to comply with the height standards for the safety of users.

Fig. 13. New parapet and benches in 2021

3 Completion of work

The work phasing has been studied in such a way to have the least possible impact on residents. The entire linear section is divided into four work stages, varying in length from 300 to 600 meters. The first stage started during Fall 2018, it was carried out by the Bouygues TPRF/Corexco consortium. Work stage 2 to 4 were awarded to the Eiffage Génie Civil/ GTM Sud/ Colas/ Freyssinet consortium. After 4 years of work, the final work stage will be completed in spring 2022.

The realization of the works required first of all the development of the road space in order to create a right-of-way for the construction machines and storage areas. A traffic lane and a bicycle path were temporarily removed during the work. Heavy traffic signals were put in place and a shared footpath for cyclists and pedestrians has been arranged.

The working site means of access have been chosen depending on the local constraints of the areas treated. In this context, during the 4 years of work, several access means had to be implemented to repair the infrastructures, located in cantilever above the rocks or the sea: scaffolding anchored in the rocks or the retaining wall, negative rolling tools and a bucket truck.

Fig. 14. Storm that caused damage to scaffold in 2019

The scaffolding, which was used extensively during the four phases and allowed access to the structure at all times, was also a source of hazards during the work. Indeed, during strong storms, the waves crashing on the rocks supporting the anchorages and rising to the underside of the decking caused numerous damages and necessitated the repair of the scaffolding and the recovery of the metal elements in the sea.

The work consisted of carrying out different workshops one after the other. First, the sidewalks were demolished using a milling machine and the existing benches were removed to an approved landfill. The parapet and slabs that were to be replaced, were sawn up and removed, while ensuring that the sawing water was collected by vacuuming. Waterproof tarpaulins were used for this purpose on the underlying means of access.

Fig. 15. Removal of existing slabs

Then, the corbels were treated according to their state of deterioration:
- Simple repair: identification of the areas to be treated, delimitation and purging until healthy concrete is found, trimming of the steel, and brushing, patching with a repair mortar compatible with the existing concrete. Several corbels that were simply repaired were also equipped with a cathodic protection system.

- Moulding: identification and purging of degraded areas of the existing bracket. Creation of several chases for the continuity by welding of all the reinforcement of the existing corbel. Carrotting and sealing of the anchor bars in the retaining wall on either side of the existing corbel. Installation of reinforcement cages equipped with anodic tapes on the external lateral faces of the mouldings (cathodic prevention) as well as at the interface between the existing corbels and the moulding corbels and on the underside (cathodic protection of the existing corbel). Installation of the U-shaped formwork and concreting.

**Fig. 16. Corbels reinforced by moulding**

New slabs, prefabricated in factory, were placed on the reinforced corbels, and the new parapet, consisting of 1-meter elements, prefabricated in UHPC, was sealed at the end of the latter. The new or existing slabs were waterproofed over the entire surface of the overhang, after having prepared the support by microblasting. The new benches, whose individual lengths vary between 1 and 2 meters, to follow the curvature of the Corniche, were then installed in accordance with the existing. The access stairs to the low sidewalk covered with limestone, as well as the access ramps for people with reduced mobility, were rebuilt before the pouring of the pink sidewalk concrete on both sides of the bench. Finally, the bicycle path was reinstalled, and the rights of way were cleared and reopened to the public.

**Fig. 17. The corniche Kennedy after its reopening**

Many controls were carried out by all the parties involved at each stage of the work. The cathodic protection was the subject of several stop points, which required a formal agreement from the supervisor before the work could continue:

- Verification the continuity of the existing corbel rebars. To do this, the electrical resistance between two armatures must be less than 1 ohm.
- Verification of the absence of short circuit between the anode tapes and the cathodically protected rebars.
- Verification the negative connections on the rebars (return of electric current to the rectifier).

**Fig. 18. Verification of the electrical continuity of the rebars on an existing corbel**

The concretes used in the new elements were also subject to many controls, particularly the concrete used for the prefabrication of the new slabs and developed with a performance approach. Before the start of prefabrication, suitability tests were carried out on the water absorption and on the electrical resistivity. The results of these tests were to be compared with the values of the study test of the concrete formula proposed by the company and validated by the project manager. Control tests were carried out during the construction to validate the prefabricated slabs.

The table below lists all controls carried out on durability indicators.
### Table 1. Verification of the electrical continuity of the rebars on an existing corbel

<table>
<thead>
<tr>
<th>Nature of the indicators</th>
<th>Timeframe for testing</th>
<th>Minimum frequency of controls</th>
<th>Expected results</th>
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<td>Tests of suitability</td>
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<tr>
<td>$\rho$</td>
<td>28 days</td>
<td>1</td>
<td>$\geq 0.8 \rho$ (study) 28d</td>
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<tr>
<td>water absorption</td>
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<td>$\rho$</td>
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<tr>
<td>water absorption</td>
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### 4 Supervision and maintenance of structures

French legislation provides various monitoring actions for engineering structures.

The project owner must carry out a periodic inspection once a year, to check the evolution of previously observed disorders, to note the presence of serious disorders presenting a risk, to list any routine maintenance work and the specialized maintenance work to be carried out. It must also have a periodic detailed inspection carried out by a company specialized in the diagnosis and maintenance of engineering structures. The purpose of this inspection is to check the condition of the structure, the acceptability of the condition of the devices ensuring the safety of users and the absence of apparent disorders presenting a risk. This surveillance action requires qualified personnel and means of access adapted to the environmental and traffic constraints of the structures.

For the Corniche Kennedy, the works contract also provides for monitoring of the installation by the constructor for a period of one year. This monitoring is carried out by certified personnel and includes monthly (during the first 3 months) and then quarterly (from 6 to 9 months) analysis of the operating and performance data of the installation, collected by the remote monitoring system. It also provides for the adjustment of operating parameters and a visit to the installation at 12 months. After the first year, the monitoring of the installation and the performance of the system is carried out by a specialized company on behalf of the project owner. The NF EN ISO 12696 standard specifies that the monitoring consists of carrying out the following tasks at least once a year:

- Update on all data records and previous inspections,
- Checking performance and adjusting the system in function,
- Visual examination of the installation,
- Provision of a monitoring report including the interpretation of the data collected and the recommendations/adjustments made on the cathodic protection installation.

![Fig. 19. Corniche Kennedy reopened to the public](image_url)

After four years of work, 219 slabs replaced, 7300 square meters of waterproofing, 219 corbels reinforced, 2600 square meters of surfaces protected by a system of cathodic protection by impressed current, 1700 square meters of surfaces repaired, 1100 linear meters of benches replaced, 1700 linear meters of parapet replaced, and 6700 square meters (670 m$^3$) of pink concrete poured, for an investment of 19 million euros of work, the corniche will return to its former splendor in Spring 2022, to the delight of tourists and Marseilles residents.

### References

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