The Oudayas tunnel (Morocco)
A challenging passage under historical buildings

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ABSTRACT: The Oudayas Tunnel is part of the Bouregreg Valley development project in Rabat, Morocco’s capital, being the solution of the heavily trafficked road dividing the two historic and crowded town sectors: the "Kasbah des Oudayas", the ancient fortress on the rock facing the Ocean and closing the river outlet, and the Medina, the tight and pulsing town’s heart.

The twin tunnel connects the river shore and the ocean coast passing underneath the Kasbah. The design considers the low overburden as well as the sea level, minimising the effects of the hydrostatic pressure. The densely constructed surface and the narrow available corridors at the portals require two extremely close tunnels.

Major project aspect are the ancient walls overhanging the riverside portal. These walls are temporarily stabilised through a steel scaffolding; they are then cut at the base, inserting a confining concrete beam resting on micropiles. The ancient structures are subsequently disconnected from their foundation for the excavation and the realisation of the culvert upper slab. Finally the culvert is completed. At the end, the ancient walls will rest on the culvert, dismantling the temporary stabilising structures.

1 INTRODUCTION

The traffic conditions in Rabat, the capital city of Morocco are heavy. An urban development plan of the city was set up by the King of Morocco in order to improve the exploitation conditions of many interesting areas along the river next to the town centre, to ease the congestion of many crucial avenues, bridges and crossings as well as to make attractive the investment in real estates in this area. This project is known as the "Aménagement de la Vallée du Bouregreg", by the name of the river dividing the two neighbouring cities of Rabat and Salé. It develops in two subsequent main phases, starting from the zone nearer to the Ocean.

A dedicated agency was created with the aim to follow up the concept formulation, the design, the realisation and the management during exploitation: the "Agence pour l’Aménagement de la Vallée du Bouregreg" (AAVB or the Agency).

The "Tunnel des Oudayas" is one of the main works concerning the first phase.

The coastal road is presently crossing a sensitive environment between the Kasbah and the Medina (Figure 1).

The tunnel will eliminate the continuous interference, restoring worthy conditions to the location.

During the design development, several alternatives were studied and the best solution identified not uniquely on technical bases (feasibility, costs, etc.) but also considering urbanistic problems, respecting all the safety requirements even if demanding quite complex technical solutions.
The geomechanical conditions along the tunnel are not extreme and neither is its length: approximately 500 m (280 m in underground excavation and 220 m in cut & cover techniques). The overburden is nevertheless a fundamental aspect, with a maximum of 20 m at the tunnel axis. A major sector crosses, with only 3-4 m overburden, the garden of the Kasbah.

Main aspect remains undoubtedly the proximity of pre-existing buildings and especially the ancient walls and towers of the Kasbah des Oudayas, all set along the tunnel at variable overburden. The walls western towers and buildings at the Esplanade portal, are situated immediately above the tunnel. A special construction method needed to be engineered in order to allow the excavation of the tunnel's culvert exactly underneath the Kasbah's wall. The works for stabilising the foundations of these buildings, towers and walls are actually ongoing and recent results of the monitoring system are presented in this article.

2 SITUATION

The traffic density along the mentioned axis is very high: approx. 30'000 vehicles per day in average, of which 3'500 HLV's (heavy load vehicles). The alignment is quite complex and includes uneasy conditions such as sharp curves and high slopes. The minimum radius $R_{\text{min}}$ 50 m is no longer respecting any standard and is furthermore followed by an opposite curve with $R \approx 100$ m, which in general leans invasion of the opposite traffic lane.

Steep sections, up to 6%, locally higher, cause the risk of high speed downwards as well as dense exhaust fumes by older trucks driving uphill.

The service level of the road (particularly for the heavy trucks) is therefore not satisfying, generating a significant slow-down of the traffic.

The disturbances created by the heavy traffic to this very sensitive environment (important historical and touristic site) is becoming progressively intolerable, including the serious risk of accident with heavy consequences.

Considering the whole reconditioning plan of the "Vallée du Bouregreg", the present environment quality is highly insufficient regarding the aspects related to the urban planning.

3 REQUIREMENTS AND KEY ASPECTS

Along with the initial study of the situation, several key aspects and related requirements became determinant factors for the design development, before the geomechanical and geotechnical aspects.

Elimination of the high slopes and the sharp curves
- Horizontal radius $> 150$ m
- Vertical radius $> 2'000$ m
- Elimination of the separation between the Medina and the "Kasbah des Oudayas"
- Traffic deviation in a tunnel
- Remake of the "Croisette" (the new road following the existing axis, dedicated to local and service traffic)

The project ending points are defined
- From the crossing Bab Al Bahr to the Surf Club
- The corridor is therefore defined (see figure 1)
- Ocean side: between the cemeteries Chouhada and Al Jabouri, excluding any underground invasion
- Esplanade side: releasing sufficient surface for its redevlopment.

The safety becomes a fundamental factor of the project, implemented in several aspects (general layout, ventilation, etc.). The present security standards for urban tunnels are applied. Therefore, the two traffic directions are separated in two mono-directional tubes.

Two escape shaft are located at the centre of the tunnel.

4 STUDY OF ALTERNATIVES AND FINAL TRACING

Key aspects for the project, in order to qualify different alignment alternatives were identified as:
- Alignment characteristics (i.e. slopes and curves)
- Risks (i.e. effect on the population or workers, influence of karsts, proximity of historic buildings, phases, influence on the existing traffic conditions)
- Economical aspects (i.e. underground and/or cut & cover length, total length)
- Urban planning (e.g. freed surface, connection capacity to other parts of the reconditioning plan)

Geomechanics and all the related particular features of this work (e.g. low overburden and low cohesion) was not considered a key aspect, but rather a given condition of tunnel projects.

The actual alignment (Figure 2) represents the best possible solution minimising the risks, maximising the urbanistic aspects, provided the safety aspects are respected. A full cut & cover solution was excluded because of the difficult surface conditions and high urbanisation, including the ancient walls and structures of the Kasbah, a national heritage.

5 PARTICULAR CONDITIONS

The project is affected by two features defining its particularity, beyond being a tunnel in urban environment with shallow overburden.
existing tunnel containing a wastewater pipe directly interfering with the project alignment
− historic buildings (the ancient walls and structures) lying directly above the project section.

In the past, during the construction of the dam at the river estuary, a tunnel was excavated under the Kasbah for the material transport. Inside this tunnel a wastewater pipe (diameter approx. 160 cm, in precast concrete) has been lodged during the 70's.

This existing tunnel (see Figure 3) directly interferes with the project, crossing it along approximately 150 m on the ocean side (50% of the underground section).

The wastewater pipe cannot be removed diverting the wastewater into other connections because actually it serves the surrounding portion of the Medina and the Kasbah des Oudayas.

The only possible solution, was relocating the pipe out of the project alignment, keeping the connections to the inflowing collectors and the delivery point. Its crossing of the new road is planned at the ocean portal location, where the new tunnel lies higher than the wastewater pipe.

The existing tunnel has been clogged along the interfering section before the excavation of the new tunnel, once the new wastewater collector was in service. The collector service was interrupted for less than half a day in order to provide the diversion into the new section and the clogging of the older portion.

The portal location at the Esplanade side directly interferes with ancient walls and historic buildings (see Figures 4).
During execution, the principal task is the stabilisation of the ancient walls, in order to exclude the widening of the already existing fissures and, eventually, a collapse due to a strength lack at their base. The construction of the cut & cover section in fact calls for a separation of the foundation of these structures, allowing the excavation and the construction of the box structure of the culvert. In service state, the loads of the historic buildings need to be transferred to the box structure of the cut & cover section.

Prior to these aspects, it has to be noted that the road cannot be chosen freely.

- Above the tunnel, the surface and the urbanisation require a minimum cover. The only possible surface solution would be the existing road, which is the reason itself of this project
- Below the tunnel, the sea level causes further difficulties, requiring an excavation partly under the water table in possibly salty environment. Furthermore, an excessively low deep point of the alignment would require too steep ramps for the connection to the existing roads.

6 THE CROSSING OF THE ANCIENT WALLS AND THE HISTORIC BUILDINGS

The requirement was (and still is) essentially the following: keeping the existing ancient structures stable, safe and intact during the whole sequence of the works, from the excavation through the entire tunnel's lifecycle. This signifies limiting any settlement to the possible minimum and assuring the cohesion of the walls.

The design solution is on one hand conceptually simple, while on the other hand it implies a complex execution sequence and the application of several unusual techniques in tunnelling.

The concept foresees:
- The creation of a rigid frame around the foundation of the historic buildings and the walls, stabilising the upper parts for limiting any risk for cracks opening and collapse
- The disconnection of the foundation from the bedrock
- The excavation for the culvert
- The realisation of the culvert
- The transfer of the loads of the ancient buildings to the culvert.

The actual sequence for assuring a stable situation during the works considers the following phases before the excavation and the construction of the box structure of the cut & cover section, as a result of a complex and multiphase design process, started approx. 4 years ago with the first concepts, consolidated with a final design, and presently realised through the implementation design and the works execution.

- A steel scaffolding confines the walls, in order to lock up the walls themselves during the succeeding works at the foundations (risk for differential settlement and following disconnection of walls portions) (see Figure 5a and b).
Consolidation of the walls through grouting of the major fissures, in order to assure a kind of monolithic behaviour of the structures

Excavation at the wall's foundation level, in order to free the walls on both sides for construction of the frame around the walls (see Figure 6)

Construction of this frame at a higher level than the one of the culvert (through U shaped beams) and load transfer to a level below the foundation of the tunnel, through micropiles Tubfix (see Figure 7).

The works are now in the phase of the preparation of the support system of the walls: the U-beams.

Initially, the design foresaw the possibility to clamp the base of the walls within two parallel longitudinal beams, connected by steel bars, laying on piles transferring the loads below tunnel level. In fact, detailed investigations of the nature of these ancient walls disclosed the presence of a soft core (ancient construction system consisting in a double block skin wall) and partially of bedrock at the U-beams elevation. The implementation design actually includes the insertion of several concrete elements going across the walls, realised by cutting the walls with diamond saw and pouring reinforced concrete beams protruding from the walls (see Figure 8). These will then be linked by longitudinal beams as foreseen in the final design, supported by micropiles.
The excavation up to the final elevation is carried out in further three phases, in order to grant the maximum stability and rigidity to the ancient structures:

- The piles for the excavation's lateral support are realised from the surface, drilled, inserted and grouted.
- The upper slab of the box structure is realised, proceeding to a 1.6 m deep excavation under the U-beams. This slab is supported with similar micropiles as the U-beams and extends under the entire complex of the ancient structures in order to assure their monolithic behaviour and reduce any discontinuous settlements: a major fissure could actually be of prejudice to the stability of the entire structure.
- The main excavation is realised under the slab, stabilising the lateral support walls through active ground anchors (see Figure 9). During this phase, the micropiles supporting the U-beams, therefore the whole ancient structures, need to be removed in order to provide the required space for working and finally realising the box structure of the cut & cover section. At this moment, before the excavation, the loads of the historic buildings will be transferred to the upper slab.

This load transfer will be a delicate phase of the project. The detailed sequence is still under preparation and the whole details are not yet defined. Two different possibilities remain still open for further decision:

- A preliminary phase with expansion grouting between the U-beams and the upper slab, in order to anticipate and control this transfer or
- A gradual cut of the micropiles allowing micro-settlements of the U-beams on the slab. This will depend (among others) on the behaviour of the structures during the present initial construction phase.

A complete and continuously active monitoring system allows a real-time control of the situation. A back-analysis will provide the best possible answer for selecting the most fitting sequence.

Once the final excavation level is reached, the concrete box structure will be completed.

7 CONCLUSIONS

The Tunnel des Oudayas is a kind of a precious jewel amongst the tunnelling projects around the world, small and technically extreme complex. This is surely exciting and rewarding as major and worldwide better known tunnels.

We are looking forward to accomplishing this tunnel with the cooperation of everybody involved without major technical difficulties, as the works presently in progress demonstrate.

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