Abstract

The city of Genoa suffers of severe space limitations due to the presence of steep hills surrounding the basin of the old port and in the vicinity of the coastline. To resolve traffic congestion in the East-West direction, a flyover road has been constructed in the 60’s along the border between the old port area and the historical centre. Traffic growth, safety concerns and large-scale urban renovation programs that have transformed the old port and the historical waterfront into a highly attractive entertainment and commercial area have however demanded the construction of a new road link allowing removal of the flyover. Several studies have been therefore conducted in the recent years for the definition of the characteristics of the new link; feasibility studies ended up in 2000 by indicating that a submarine tunnel crossing the central harbour basin was the most preferred solution. A contract for the development of a preliminary design of the infrastructure has then been awarded in 2003 to a joint venture formed by High-Point Rendel Ltd, D’Appolonia S.p.A., Tunnel Engineering Consultants B.V., and Technital S.p.A.. The paper describes the design alternatives considered during the preliminary design and the main features of the selected solution. Basically, two main alternatives have been studied to a significant detail: an immersed tube and a bored tunnel. Consideration of the impact on port activities has led to the choice of the bored tunnel solution.

Keywords: submarine tunnelling, immersed tunnels, bored tunnels, impact studies

1. Introduction

The historical city of Genoa lies at the base of steep hills and completely surrounds the basin of the old port. The urban developments occurred from mid XIX to the XX century have expanded the city limits eastward, to include mainly residential settlements, and westward, to include mixed heavy industrial and residential areas and new port facilities. Expansions have been mainly concentrated along the coast and along two narrow valleys, located at the each side of the historical settlement (Figure 1). At the mid of last century the city of Genoa counted more than 800 thousand inhabitants; in order to solve the increasing traffic problems a flyover road has been constructed at the south margin of the historical city, along the border of the old commercial port. However, due to severe space limitations, the road has narrow sections, limited radii of curvature and its supporting structures have been designed for light traffic loads only, in order to reduce their size.

The crisis of the heavy industrial sector and the evolution of maritime transportation systems have induced, in the last decades of the past century, a large decrease in the population, down to roughly 600 thousand inhabitants, and a substantial misuse of large areas that have been therefore subjected
to a wide urban transformation program, still in process. As a result of these transformations, large commercial and office spaces have been realized at the west side of the city, while the old port has been transformed into a highly attractive commercial and recreational area directly facing the historical waterfront, recently classified by UNESCO among the world’s most important architectural heritages.

Because of the new situation, and also because of the increasing inefficiency of the existing flyover road, the local administrations have started to plan a new east-west road link allowing the substitution of the existing flyover, at least in the section lying at the border of the historical centre.

Since early planning, dating back to mid 80’s, it was envisaged to construct a submarine tunnel crossing the entrance to the basin of the old port (Figure 1). However, the proposal has led to long discussions because of several reasons, mainly related to opponents fearing significant disruptions to port activity during construction of the tunnel and limitations to future port expansions, and to citizens concerned about the loss of the beautiful scenery that is presently offered to the people driving on the flyover.

In 2000, the City Administration has launched a feasibility study conducted by international advisors that, after examination of all the possible alternatives including bridges and inland tunnels, concluded that the most preferred solution was represented by a submarine tunnel crossing the harbour with the shown alignment. The results of the study have been formally adopted by the Administration and in 2003 a contract for the development of a preliminary design of the infrastructure has been awarded to a joint venture composed by High-Point Rendel Ltd., UK, D’Appolonia Spa, Italy, Tunnel Engineering Consultants BV, The Netherlands, and Technital Spa, Italy. The project has been recently approved by the Italian Ministry of Infrastructure and it is pending for decisions concerning financing of further advancements.

In this paper, a review of the most important conceptual aspects and the logical phasing of the design decisions adopted in the preliminary design will be presented.

2. Selection of the basic layout
Several alternative layouts and construction techniques have been reconsidered in the first phase of the preliminary design.

The feasibility study confirmed, based on estimates of the traffic flows, the need of establishing junctions to the west with the highway gate “Genova Ovest”, giving access to the A-12, A-10 and A-7 highways, and with the existing and already planned city roads and, to the east, with the existing city roads at the root of the old port area and with a new road leading to the Fiera Internazionale and to existing city roads to the east of the old city.

Starting from these results and taking into consideration the possibility of using different construction techniques: cut-and-cover, conventional and machine boring and immersed tube, the alternative corridors depicted in Figure 2 have been identified and compared with respect to the following criteria:

- cost/efficiency ratio, both in terms of traffic reduction on the city roads and, consequently, capability for substitution of the existing flyover, and in terms of time gain for the east-west trips;
- severity of impacts on city traffic and port activities both during construction and operation;
- risk level, both related to construction and operation phases, compared with the existing situation;
- interference with archaeological or architectural features.
To select among the alternatives, different types of analyses, from traffic simulations to qualitative and quantitative risk analyses and impact screening, have been performed in the first phase of the preliminary design. Nearly all the criteria have indicated that the most preferred alignment was lying in the central corridor (C-layouts), while the North (N-layouts) and the South (S-layouts) corridors were leading to obtain bad scores in some of the criteria considered.

Figure 2 – Different alignments considered in the preliminary design

In particular, within the central corridor, the alignments C3A/C3B have been considered as the most preferred because of their minimal impact on port activities. Along this alignment both an immersed tube (C3A) and a machine bored (C3B) solutions have been considered possible, based on the results of the geological/geotechnical studies (Figure 3). These two solutions have been therefore developed to a significant detail during the second phase of the preliminary design.

Figure 3 – Geological section along alignment C3

At the end of the second phase, a more complete re-evaluation of the environmental impacts especially concerning the interaction with present and future port activities has led to the final choice in favour of the C3B alternative. The most relevant engineering details, E&M, ventilation and safety equipments as well as refined traffic analyses, junction design and detailed cost/benefit analyses have finally been produced in the third and last phase of the project for the preferred solution.

Before illustrating the main features and the structural concepts of the two alternatives, the situation of the activities going on in the central harbour needs further clarifications. With reference to Figure 1, the south most area close to the breakwater hosts a large container terminal. Proceeding north and eastward along the circle of the inner basin, the first half of the port is used for ferries and cruise ships; the rest of the inner basin (the old port) has been transformed into marinas for leisure boats and yachts. Berths for small luxury cruise ships are also provided. In the east basin, protected by the breakwater, several industrial activities related to ship building and repair have been located, including five dry docks. Then marinas and other industrial activities follow to the east, up to the area of the Fiera Internazionale and related marinas.

The above described situation indicates that a very intense traffic, comprising very large cruise and container vessels, is directed into the inner basin also necessitating of difficult manoeuvres for berthing. The construction of an immersed tube tunnel has been considered a risk for the continuity and safety of
the traffic inside the inner basin. In addition, the Port Authority has required keeping the maximum opportunity for future dredging on the access channel to the north berths of the container terminal.

3. Main infrastructure features
Road design has been performed in accordance to Italian and European standards. The design speed has been set to 80km/h. The crossing may be subdivided into three sections: the west approach, the main submarine crossing and the east approach.

The west approach comprises a system of ramps, totally developed underground, linking to a fairly complicated junction, partly underground, connecting the highway gate to the service roads internal to the port areas, to the city roads on the west and on the east, and to the tunnel. This junction, named San Benigno, has been defined by a design performed independently and therefore has been taken as an input for the design of the crossing. The main complexities of the design of the west approach were related to severe geometrical requirements imposed on the horizontal and vertical alignments by the presence of existing railway lines and of the ancient city walls, once delimiting the west promontory of the harbour, on top of which the medieval light-house (Lanterna) is located. The extension and characteristics of the west approach are of course different for the two alternatives. Construction methods are mixed cut-and-cover and traditionally excavated tunnelling. The west approach also contains access to a ventilation and control building and safety exits.

The main submarine crossing presents different characteristics for the two alternative solutions but has the same capabilities in terms of traffic volumes and security. Based on traffic studies that have indicated a design flow of 4500 cars per hour, the road section has been selected with three lanes per carriageway. Figure 4 shows the two typical cross-sections of the crossing. Different solutions have been adopted for the emergency escape routes. The immersed tube section is roughly 32 m wide and 9 m high and contains the two carriageways plus the escape and service corridor in between them. The bored tunnel solution is a twin-tube 15 m diameter approximately. Emergency escape routes are through transverse corridors connecting the two tubes.

Figure 4 – Typical Cross-Sections for the alternative solutions

Consideration of construction methods has been one of the most important criteria in the definition
of the two solutions for the main submarine crossing and for its connections to the approaches.

A large underground parking facility has been designed at the east end of the infrastructure. Direct access to and from the east approach of the tunnel, as well as from surface roads, has been designed in order to minimize the traffic overload on the city roads. The parking size has been defined to host 3000 cars and 60 buses and will serve the old port area and the historical city. A subway station is also located in the vicinity. The presence of the parking and the vicinity to historical and archaeological areas have represented one of the basic criteria for the design of the east approach.

The east approach comprises a second ventilation building and emergency escape corridors. To the east, the approach gives access to a junction that interconnects several traffic directions: to and from the city roads, to the existing flyover that is maintained in its last section to host the through traffic (light), and to a new surface road that serves other intermediate junctions with existing city roads, service roads internal to the industrial port area and with the area of the Fiera. Heavy vehicles to and from all destinations will be routed on this surface road. This solution has been adopted to cope with space limitations and with the need of not interrupting the traffic on the existing flyover.

4. The immersed tube solution
The horizontal and vertical alignments of the immersed tube solution are presented in Figure 5 and 6, respectively.

![Figure 5 - Horizontal alignment](image)

![Figure 6 - Vertical alignment](image)

The main submarine crossing is accomplished by connecting five precast elements each one 130 m in length. The first 4 have the standard cross-section described in Figure 4, while the fifth element is larger because it includes the initial part of the ramps. The east and west approaches are built with the cut-and-cover method. Their extremes have been especially designed in order to connect with the immersed elements. To perform the connection, the preparation of trenches in the existing quays, that therefore require strengthening with pile curtains, is needed. The realisation of the cut-and-cover approach also requires the construction of deep diaphragm-walls down to impervious formations (the flysch or the overconsolidated clay). Figures 7 to 9 illustrate some details of the structural solutions adopted.

The preliminary design of the immersed tube alternative has been completed with a detailed study
of the construction phases, including prefabrication of the elements, dredging of the trench, sinking and protecting the tunnel.

Figure 7 – Plan view of the tunnel elements

Figure 8 – Cross-sections of the west approach

Figure 9 – Cross-section of the submerged tunnel

Figure 10 – Cross-sections of the east approach
5. The bored tunnel solution
As already mentioned, a bored tunnel solution has been developed in design phase two, in parallel with the immersed tube alternative. Figures 11 and 12 show the corresponding horizontal and vertical alignments.

Figure 11 – Bored tunnel – horizontal alignment with the San Benigno junction

Figure 12 – Bored tunnel – Vertical alignment

The criteria for the design of the bored tunnel solution have been defined starting from the submarine crossing. Based on subsoil characteristics, a slurry shield mixed face TBM or an EPBM have been identified as the boring tool. Cover above the tunnel and distance between the tubes have been the parameters that dictated the horizontal and vertical alignments of the crossing between the two shafts needed for launching and extraction of the TBM. A careful study of the organization of the construction phases has been performed in order to optimize surface land occupancy and TBM operation. It has been found that the best alternative is to place the TBM base camp at the west side of the crossing and that the TBM will proceed from west to east in the right tube and then east to west in the left tube, going back to the main shaft. At the end, the two shafts will be used to host ventilation equipments, safety equipments and control rooms, lay-bys and emergency bypasses between the two carriageways. Three transverse connections emergency corridors, to be excavated by soil freezing techniques, have been designed over the total length of the crossing (720 m).

In order to reduce the depth of the tunnels, local consolidation of the quay walls and substitution of the seabed in the vicinity of the walls with high density materials have been designed. The depth of the submarine part of the infrastructure is of course greater that the depth of the immersed tube solution. The approaches have been therefore designed to cope with the increased depth. For the west approach the use of traditional tunnelling techniques has been envisaged, while for the east approach
a partly open air excavation has been considered, in order to combine the construction of the approach with the realization of the underground parking. The need of keeping the maximum slopes within the limits imposed by regulations and traffic safety analyses has led to longer approaches than in the immersed tunnel solutions. Figures 13 illustrates the detail of the west TBM shaft.

The east shaft will only be used for the reception of the TBM and transfer to the other tube; therefore it will be much shorter (20 m) than the launching TBM shaft. The ramps connecting the tunnel with the underground parking are steeper than for the immersed tube tunnel.

6. The preferred solution
The comparison between the immersed tube and the bored tunnel solutions has been mainly performed in terms of impacts over port operations. It should be pointed out that the two solutions did not present significant differences in the construction cost.

As already mentioned, the main concerns regarding the immersed tube solution have been: a) temporary land occupancy on the west side for the construction of the approach using cut-and-cover techniques; b) temporary unavailability of the quays at the west side; c) interaction of the dredging and filling of the submarine trench and of the element sinking operations with the navigation into the inner basin of the port; d) risks associated with navigation and possible berthing over the tunnel. The bored tunnel solution overcame nearly all the above disadvantages. The two solutions did not present substantial differences as concerning operations at the east side.

At the end of design phase two, the bored tunnel solution has been therefore preferred for the realisation of the crossing.

During design phase three, designs of E&M, ventilation and security equipments as well as detailed studies of the junctions have also been performed. Final traffic simulations, environmental impact studies especially directed to evaluate the advantages in terms of pollution reduction with respect to the actual situation, cost estimates and financial planning have completed the preliminary design. Figure 14 illustrates a pictorial representation of the new infrastructure, including the San Benigno junction (small frame).