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Criteria for technical and environmental design of tunnel portals

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Abstract

The architectural and landscape aspects connected to tunnel portals have become very important since a new culture of environmental protection has emerged in recent years and has forced designers to better integrate infrastructure with the environment. The technical, architectural and landscape aspects of tunnel portal design are analyzed and discussed in this paper providing a systematic comparison of different architectural solutions. A design flow chart for a tunnel portal design is also presented.

Keywords: Infrastructure; Architectural; Tunnel portal design; Solutions; Culture

1. Introduction

The environmental integration of tunnel portals is an important issue in the design and construction of roads and railways today. Starting from a historical evaluation of tunnel portal design and considering the geotechnical constraints, it has proved possible to define a flow-chart that indicates the key points that must be taken into account by a tunnel designer (Maturana Plaza, 1996; Pelizza et al., 1997; Lacroix et al., 1991).

With the coming of the industrial age, road and railway networks became strategically important for national economies and for the circulation of people and goods. Tunnel construction, around the first half of the nineteenth century, was considered a great undertaking and all the portals of that period were monumental—since the general feeling was that the work of digging a mountain also was monumental. Therefore, the visual impact of the work did aim to provide environmental integration. A monumental portal was in reality just to confer honor to the technical triumph. Good examples of this type of portal are the portals of the 12 700 m long Fréjus railway tunnel (Italy, 1857–1870), and the portals of the 19 700 m long Sempione railway tunnel (Italy, 1895–1906). Every detail of the portals recall the Triumph Arches of classical Rome. Fig. 1 shows a comparison between the 'Titus Triumph Arch', (Rome, 5th century BC), and the 'Fréjus Railway Tunnel Monumental Portal'; a great similarity is evident (Langella, 1997).

After only fifty years (during the first half of the twentieth century), it can be seen that portals no longer had a monumental style, this is considered to be a reflection of the fact that the digging of a tunnel was no longer such a difficult event as before.

In the twentieth century, technology has had new targets: improving working conditions inside the tunnel, improving excavation machines and speeding up construction times, and the increasing use of new materials such as concrete. According to architectonic rationalism, the work of man must be evident in the natural landscape, this means that an infrastructure such as a tunnel must be seen to be a passage from one valley to another and that the portal should mark this passage within the landscape. Portals are considered to be only tunnel inlets and hence, in this style, follow an architectonic approach based on simplicity.

In Europe, during reconstruction after the 2nd World War II, the construction of buildings, roads, and infrastructure in general typically took place with minimal environmental constraints. The lack of adequate town-planning tools and environmental sensitivity had clear consequences for tunnel portal design. An example from this period is given by the Casarza tunnel (Fig. 2), near Florence, on the Milan–Rome motorway (1958).

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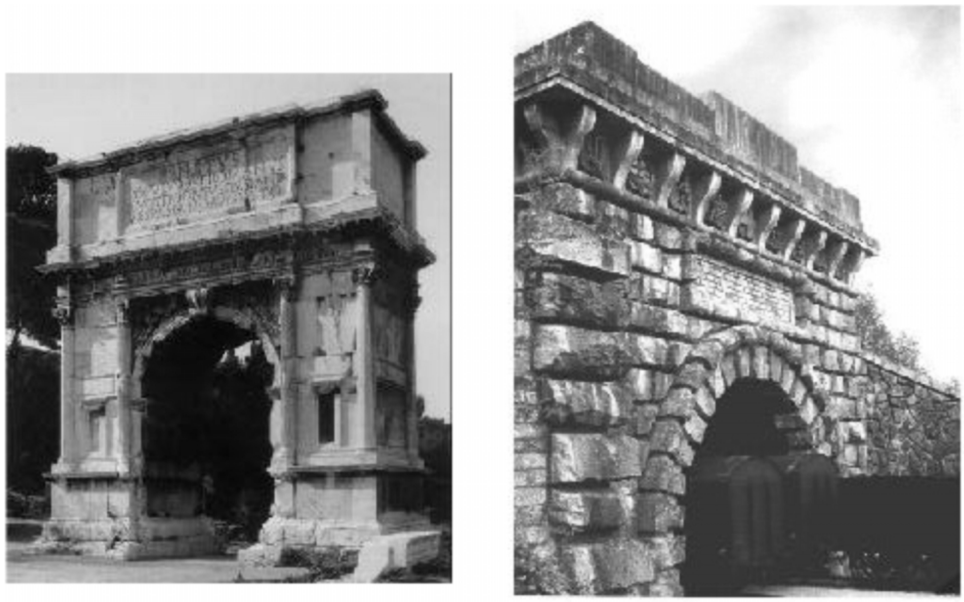

(a) (b)

Fig. 1. Comparison between the Titus Triumphal Arch (a) and the Fréjus Railway Tunnel Monumental Portal (b).

During the 1960s, many motorways were designed and constructed with the function and costs as the most important factors. This influenced the design such that, if a bulkhead had to be built, a slope supporting wall could be used, the ground could be stripped as much as necessary and concrete supporting walls could be left in sight.

Only during the early 1980s did the new environmental awareness lead to a change in the typology of tunnel portals. Remarkable and significant differences can be seen by comparing the recently constructed and older portals of the Turin–Savona motorway (Fig. 3 and Fig. 4). In the more recent years, portal architectonic design takes into account the features of the landscape within which the portal has to be integrated.

At present, the architectonic quality is of primary importance in portal design—obviously without undermining the function of the various elements of a portal. The aim is to take care of the formal aspects of portal design while not disfiguring the landscape. This is also aided by the evolution of construction techniques that can address slope stability problems.

This new environmental attention is clearly visible in the recently constructed Italian Aosta–Monte Bianco motorway. As an example, Fig. 5 shows the Villeneuve tunnel portal (Monte Bianco side), during construction

Fig. 2. Casarza tunnel, on the Milan–Rome motorway. The slope-supporting wall is a blot on the whole landscape and a remarkable amount of ground stripping is evident.

Fig. 3. The Uvi Tunnel portal (Torino side, Turin–Savona motorway). It is made of concrete and appears to be a solid structure with linear frontal and lateral walls, refined by functional wall brackets, which protrude above the inlet.

Fig. 4. The arched portal of the Maloni tunnel (Torino side, Turin–Savona motorway).

and in operation. It can be noted that filling above the artificial tunnel and the vegetation replacement allow the portal to integrate into the beautiful mountain landscape.

A modern portal architectonic design can also be developed based on the philosophy of moulding the portal into the landscape. This means that portals are designed to be beautiful while the technological elements of the tunnel (ventilation system, water inflow control, etc.) are integrated into the structure (Vibert, 1996; Vibert and Baron, 1997; Ranzo et al., 1990; Pelizza, 1991).

2. Influence of geotechnical characteristics on tunnel portal design

Generally speaking, the main factors that influence tunnel portal design and execution techniques are:

i. site morphology;
ii. geological and geotechnical conditions of the involved rock and soil masses;
iii. slope stability;
iv. surface water (rivers, irrigation canals, etc.) and groundwater;
v. surface constraints (i.e. buildings, infrastructures, etc.);
vi. direction of excavation;
vii. environmental constraints;
viii. safety aspects (for example risk of avalanches);
ix. area seismic condition.

Among these, environmental constraints and geotechnical aspects are the most important in the choice of the suitable technical solution also the time factor should not be forgotten—the portal must be developed quickly so that the tunnel construction can begin in the shortest possible time. In fact, the construction methods can be categorized by taking into account whether ground reinforcing techniques are necessary or not. When a rock mass is found (even if weak or with joints) generally speaking it is possible to open slopes with high dips and important reinforcing works are not necessary. In this case, it is usually possible to excavate a cut as far as the tunnel depth and then build the portal structures. If the slope is unstable or is destabilized by the excavation, it may be necessary to consider building a provisional structure from which the tunnel excavation will start. Many different techniques have been applied for these works—such as conventional retaining walls, sheet pile walls (cantilevered or anchored), walls made from jet-grouted columns, steel pipes, conventional large diameter piles, conventional grouted ground reinforcing, etc. Usually when these conditions are present, the tunnel also has to be constructed using ground reinforcing techniques (Peila and Pelizza, 1994)

2.1. Portals in rock masses

The construction of a tunnel portal in a rock mass generally requires an excavation whose shape and dimensions are strictly linked to the slope morphological conditions. The portal area is usually formed using explosives. In this case, many different solutions can be

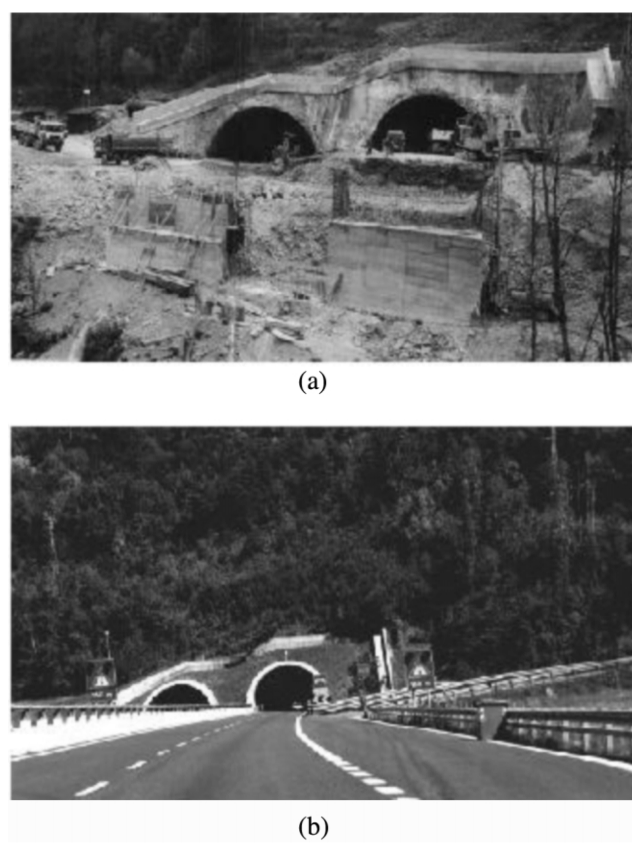

Fig. 5. Villeneuve tunnel portal (a) view during construction. The micropile diaphragm slope support can be noted. (b) View in operation.

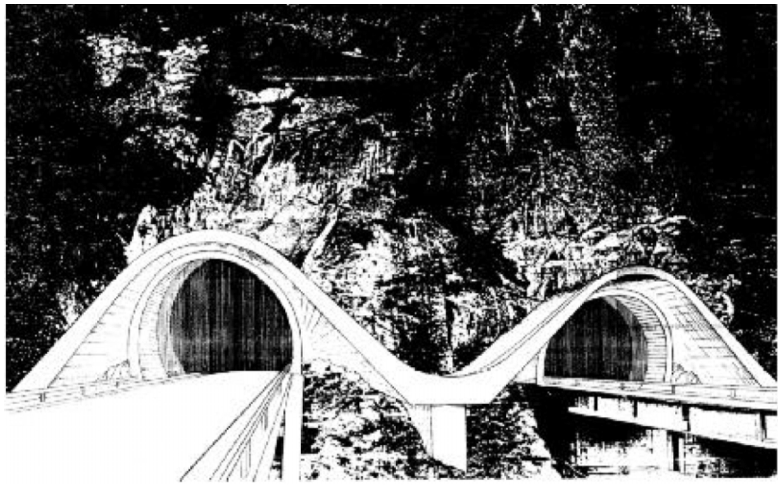

Fig. 6. Example of an artificial concrete tunnel to protect against rock-fall.

adopted for the final portal layout since stability problems are generally reduced and the most important aspect is linked to the architectural and environmental design.

The main geotechnical problems are usually those of rock mass movement. These problems can occur both during construction and during operation. In both cases, the problem requires the stabilizing of the rock slope using active techniques (bolts, tendons, etc.) thus preventing movement or intercepting the rock blocks before they can reach the road or railway using passive techniques (net fences, ditches, walls or an artificial tunnel). In this latter case it is necessary to develop a correct study of the possible trajectories and of the involved energies (Giani, 1992; Montani et al., 1996; Peila et al., 1996). Also, the seismic conditions are of great importance because, as well known, seismic events are one of the main causes of rock falls. The following figures show different choices of protection against rock-falls. Fig. 6 shows a solution with an artificial concrete tunnel which was adopted to reduce maintenance while Fig. 7 shows an example of tunnel protection using net fences. These two solutions give examples of different architectural approaches that can be used to solve the same geotechnical problem. In the first case, a landscape inscription or moulding is used while, in the second case, the concept of landscape integration has been applied.

2.2. Tunnel portals in soil

Tunnel portals in soil in the past presented many technical and execution problems that influenced the choice of tunnel location. Furthermore, it was usual practice, where possible, to remove the loose material or soil down to the rock mass which resulted in very large excavations and therefore obvious environmental problems.

Since the 1980s, the great diffusion of ground reinforcing techniques in Italy has offered the possibility of improving the stability conditions of excavations (Pelizza and Peila, 1993; Barisone et al., 1983; Francia et al., 1991; Carrieri et al., 1991a,b). It is possible to minimize the excavation dimensions thus reducing the environmental impact and allowing an easy re-modeling of the natural slope—usually over a relatively short length of an artificial tunnel.

The main geotechnical problems which can be encountered in this case are:

i. large and general instability of the slope,
ii. the need to stabilize the excavations in order to start the tunnel,
iii. instability in the first portion of the tunnel, just after the portal, with low height of cover above the tunnel,
iv. foundation problems below the artificial tunnel.

Fig. 7. Ramat tunnel portal with net fences.

When the problem is linked to large scale instability, the solutions are those that are usually adopted for slope stabilization and can be:

- drainage with various techniques
- interventions that are able to apply a force to the slope(tendons, diaphram walls, etc.)
- re-modeling of the slope with a geometry that is able to improve the stability.

These interventions can be combined to obtain a valuable solution from the technical and economical points of view. In this case, the environmental aspects are not strictly limited to the portal area but concern a general stability problem. Portal design must be developed taking the landslide stability conditions into account. In some cases, the portal structure can be used as a means to improve stability.

The need to stabilize the excavations is the most frequent aspect that has to be dealt with. The support structure can be designed taking two different architectonic concepts into account:

- the structure will be covered and therefore hidden after tunnel construction, even though, in the majority of cases, it maintains a structural function to guarantee the long term stability of the slope;
- the structure will remains visible since it is not possible to hide it (the structure must also guarantee long term stability in this case).

Obviously the two approaches have quite a different impact on the architectural design:

- in the first case the structure's main function is technical as good landscape conditions will be obtained due to the coverage of an artificial tunnel (which is always built) and the re-vegetation;
- in the second case, the chosen technique must also allow one to obtain a good architectural and environmental aspect.

2.3. Flow chart for tunnel portal design

In the following section, a general guideline for tunnel portal design is presented in accordance with the schemes proposed in the 'Guidelines for design, tendering and construction of underground works' developed in Italy by the National Project for Design and Construction Standards in Underground Works (1997).

The main steps are organized in key points, which must be taken into account in the design.

Flow chart for tunnel portal design

1. Landscape and environmental analysis (Pelizza et al., 1998)
   i. Evaluation of landscape situation, general architectural environment, local laws and special constraints, social aspects
   ii. Evaluation of the technological needs (ventilation etc.) (from the tunnel project)
   iii. Architectonic choice between:
      - portal inscription
      - portal integration
      - multicriteria analysis among the solutions
   iv. Evaluation of the environmental impact of the preliminary chosen solution
2. Site investigation
   i. Geological and geotechnical investigation with special attention to geotechnical properties that are important for:
      - land slide
      - ground water condition
      - rock-fall
   ii. Seismic condition of the area
3. Surface and underground constraints
   i. Influence of tunnel portal construction on the surface
      - definition of displacements that are acceptable for the structures
   ii. Influence of the portal on the hydrogeology and hydrology during construction (design of temporary solutions) and in operation (design of the final solution)
4. Prediction of ground mechanical behavior
   i. Large-scale landslides
      - evaluation of the critical parameters (water, etc.) and their influence
      - definition of the safety factors with and without the portal
   ii. Small landslides
      - evaluation of the critical parameters (water, etc.) and their influence
      - definition of risk condition
      - design of remedial techniques and evaluation of the obtained safety factor
   iii. Avalanche risks
      - definition of risk condition
      - design of protection techniques
   iv. Rock-falls
      - evaluation of possible detachment points, block size, trajectories and speed of the blocks
      - definition of risk conditions
      - choice and design of rock-fall protection works during construction and when the portal is in use
      - trajectories and impact energy evaluation
      - safety factor of unstable blocks
      - design of active or passive protection measures (if the artificial tunnel is chosen, the data

obtained at this step must be taken into account in point 6)

v. Preliminary portal design and evaluation of various possible construction methods.

5. Architectural and environmental design
   i. Final architectural and environmental design
      - architectural design of the final portal solution with design and location of technological buildings
      - design of final rehabilitation
      - choice and availability of construction materials
      - grassing techniques and choice of trees
      - evaluation of environmental and visual impact of rock-fall protection structures
   ii. Evaluation of ancillary works (access roads, working areas, etc...) and linked environmental problems
      - design of restoration works
6. Design choice and calculations
   i. Portal construction method design
      - design of reinforcement techniques
      - short term safety factor evaluation
      - long term safety factor
      - choice and design of the excavation techniques (blasting, mechanical, etc.)
      - choice and design of stabilization techniques for large landslides
      - safety factor evaluation taking tunnel portal into account
   ii. Structural design of the portal
      - foundation design
      - structural design taking the influence of the reinforcing techniques into account
      - structural safety factor evaluation during each phase of back filling.

3. Conclusions

Two different architectural approaches must be considered when designing a tunnel portal:

- insertion within the landscape—the portal must fit into an existing area, changing it as little as possible while being hidden as much as possible.
- integration with the landscape—the portal is inserted into the existing landscape as a work of sculpture—not only as a tunnel portal, but also as landscape architecture. The portal can be constructed in order to attract attention to it, if desired, i.e. it can be a symbol for a city entrance or a reference point for the area.

In both landscape approaches, the long term impact of infrastructure maintenance and social approval must be considered and the architectural design must allow all the geotechnical needs (the technical design basis) to be met.

In conclusion, environmental, architectural and engineering needs must all be considered in portal design since the final target is to guarantee a suitable environmental as well as technical solution for tunnel portals.

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