REHABILITATION OF THE MONTEMOR TUNNEL

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1. INTRODUCTION

The aim of this paper is to present the main design and construction criteria adopted at the Montemor Tunnel Rehabilitation Project, in order to fulfil the minimum safety requirements, according to the Directive 2004/54/EC of the European Parliament, for tunnels in the Trans-European Road Network with more than 500m in length. The Montemor Tunnel, under operation since 1994, has two twin tubes, with an overall length of 740m each, and is located at the A9 motorway, at the Lisbon external ring road (Figure 1). Taking into account the Tunnel safety requirements, the following issues are pointed out: geological, hydro geological and structural conditions, fire resistance, including the upgrading of mechanical and electrical infrastructures.

Figure 1: Location of the Montemor Tunnel

2. MAIN CHARACTERISTICS OF THE MONTEMOR TUNNEL

The Montemor Tunnel was built in 1994 with two completely independent tubes, with about 130m^2 of cross section each, and near 740m of overall length. The tubes with concrete structure were built using NATM technology, except the zones contiguous to the portals, which were built using the cut and cover method. The vertical minimum gabarit is 4,7m. Each tube has three uni-directional traffic lanes with 3,75m width each, as well as a left berm with 1m and right berm with 4m width (slow traffic side). The transversal gradient is constant with a value of 2,5% and the average longitudinal gradient is about 5,3%, corresponding to near 38m of differential levels between opposite portals. The average daily traffic is about 13.550 vehicles, corresponding to approximately 3% to heavy goods over 3,5 t.

Taking into account the Tunnel main characteristics, the following issues were analysed at the Montemor Tunnel Rehabilitation Project (Figure 2):

- Hydrogeology and structural conditions: evaluation of the need for structural refurbishment, taking into account the effective structural resistance against water pressure and fire, including the risk for the surface structures and infrastructures.
- Safety and risk reduction measures with efficiency demonstrated through a comparative risk analysis, considering the fire as the most hazardous condition for both users and rescue personnel. Including also traffic main issues such as: overtaking of heavy goods vehicles and circulation of dangerous goods vehicles, emergency and evacuation signalization.
- Mechanical infrastructures: replacing and upgrading of both ventilation and smoke control systems, for fire and evacuation scenarios, on an automation base.
- Electrical infrastructures: analysis of the illumination systems (normal, safety, evacuation and automation), including upgrading and replacement of cables with fire protection. Adoption of a new system for automatic fire and accidents detection.
- Water and drainage: water system for fire combat as well as drainage of flammable and toxic liquids, allowing the circulation of dangerous goods vehicles. Additionally, the drainage system was designed and maintained in order to prevent fire and flammable and toxic liquids from spreading inside and between tubes.
- Road signing: upgrading of signs and panels, mainly: tunnel sign and classification, as for instance: emergency exits (nearest exits distances on the side walls), emergency stations (fire extinguishers, SOS) and panels with lane signals (including open and close lanes).

On the following chapters the hydrogeological, structural, safety and risk reduction measures, as well as some of the main mechanical infrastructures issues are presented.

Figure 2: View of the tunnel portals, as well as of both the existent ventilation and drainage systems

3. TUNNEL HYDROLOGICAL AND STRUCTURAL CONDITIONS

3.1 Hydrogeological conditions

The Montemor Tunnel was excavated mainly on rocky layers of a clayed and green marls complex (SW side), as well as on a complex of sandstones, including weathered sandstones, soft marls and clays (NE side), with an average inclination of about 15º to SE. The Tunnel is located at the base of some hills, close to two small water streams and has a maximum cover of about 30m. This hydrogeological scenario, where the permeability is dependent from the more weathered materials, lead to the existence of a ground water table located above the Tunnel base, especially after strong raining periods (Figures 3 and 4).

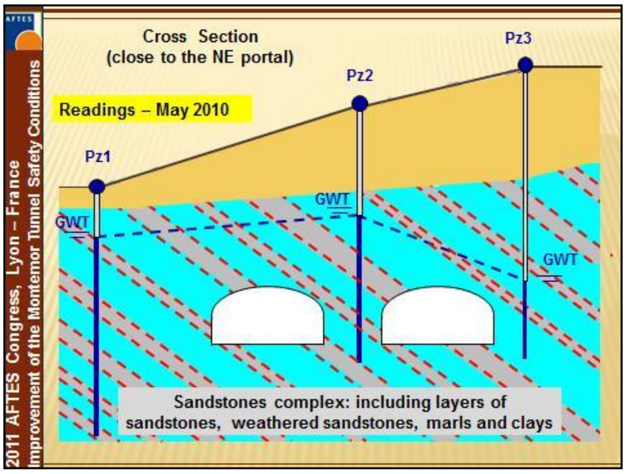

Figure 3: Hydrogeological cross section

In order to confirm all the main hydrogeological conditions, a very important input for the Montemor Tunnel Rehabilitation Project, nine piezometers were installed in three cross sections. The piezometer readings (Figure 3) allowed the confirmation of the main hydrogeological scenario. This situation led to the installation of new geodrains in order to assure the location of the ground water table below the Tunnel base, respecting the initial Project assumptions.

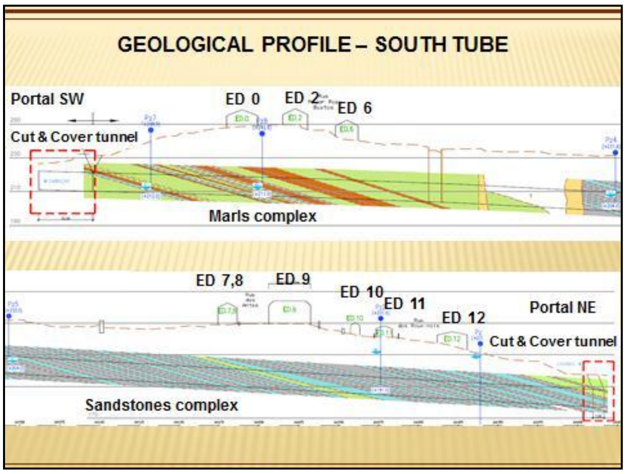

Figure 4: Geological longitudinal profile

3.2 Surface occupations

At the surface, over the Tunnel, are located several medium and small size buildings, including the EB1/J1 Montemor School. All the buildings were identified (ED1 to ED12) and strictly analyzed from both the structural and social point of views (Figures 5 and 6).

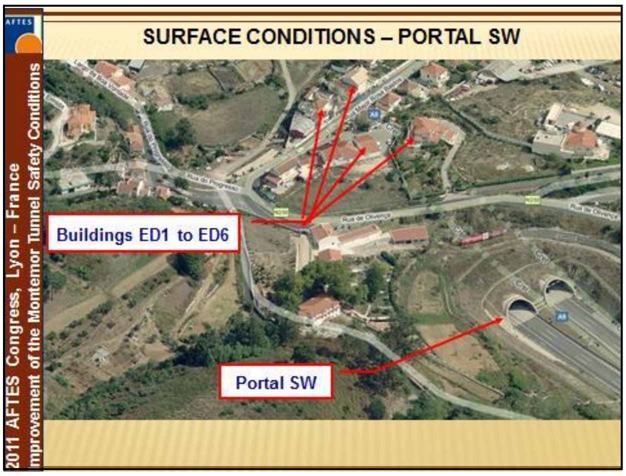

Figure 5: Surface conditions close to the Portal SW

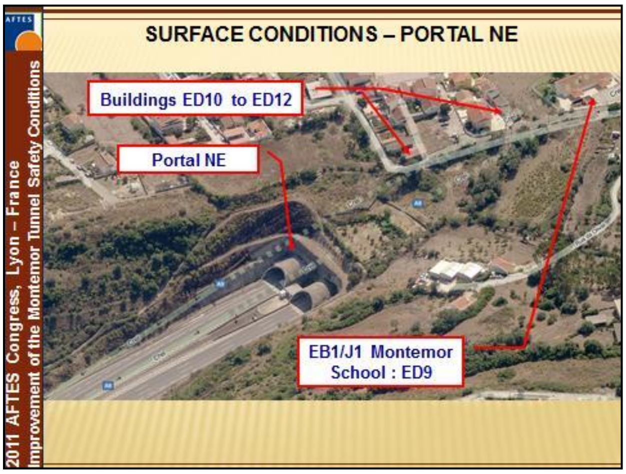

Figure 6: Surface conditions close to the Portal NE

3.3 Structural conditions

According to the original Project, which led to the Montemor Tunnel construction in 1994, the Tunnel has two main kinds of structures:

- Reinforced concrete cross section, built using the cut and cover method: 41m at the SW side and 5m at the NE side, including both portals.
- Plain concrete cross section, built using the NATM method with a minimum thickness of 0,30m, final lining, over initial lining. The initial lining, dependent from the geological conditions, comprised the following elements: shotcrete, steel ribs, radial and umbrella arch nailing.

In order to confirm this information, as well as to assess the effective structural resistance, several nondestructive or slightly destructive diagnostic tests were performed (Figures 7 and 8):

- Detection of the internal reinforcing steel cover (pacometer).
- Detection of the reinforcing steel corrosion.
- Detection of the concrete carbonation.
- Detection of the clorets percentage at various depths at the concrete.
- Concrete resistance and deformability (UCS).
- Detection of the steel reinforcing and profiles using georadar devices (800MHz and 1,6MHz).

Figure 7: Tunnel structural evaluation

Figure 8: Structural evaluation using georadar

The obtained results allowed, in general, the confirmation of the main information stated at the Tunnel original Project.

3.4 Ground water table

As already stated, in order to confirm all the main hydrogeological conditions, nine piezometers were installed, corresponding to the Tunnel 3 cross sections. The piezometer readings (Figures 3 and 9) allowed the confirmation of the main hydrogeological scenario, leading to the proposal for the installation of new geodrains, as well as to the implementation of a monitoring and survey plan, in order to assure the permanent location of the ground water table below the Tunnel base.

Figure 9: Piezometer installation

3.5 Fire resistance

According to the European Parliament order nº2004/54/CE, it is mandatory to assess the Tunnel fire resistance (Figure 10). In particular if the eventual local collapse could, as consequence, lead also to the collapse of social important structures and infrastructures located at the surface. In this scenario, it was important to check the Montemor Tunnel structural resistance against fire. For this purpose and according to the collected information, the Tunnel standard fire resistance was previously classified with the criterion R180 (the load bearing function is maintained during 180 minutes of fire exposure, according to the EN1992-1-2).

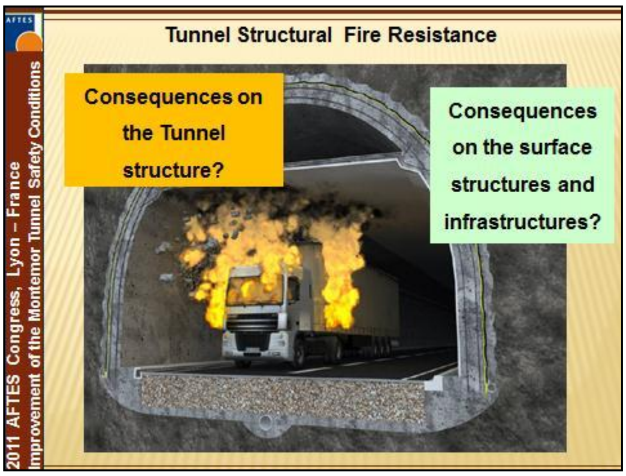

Figure 10: Tunnel structural fire resistance

The structural fire resistance was checked using the standard temperature – time curve, stated at the EN1991-1-2, as well as the relations between the evolution of the temperature with the concrete depth and the variation of resistance with the temperature for slabs, proposed at the EN1992-1-2 (figures 11 and 12).

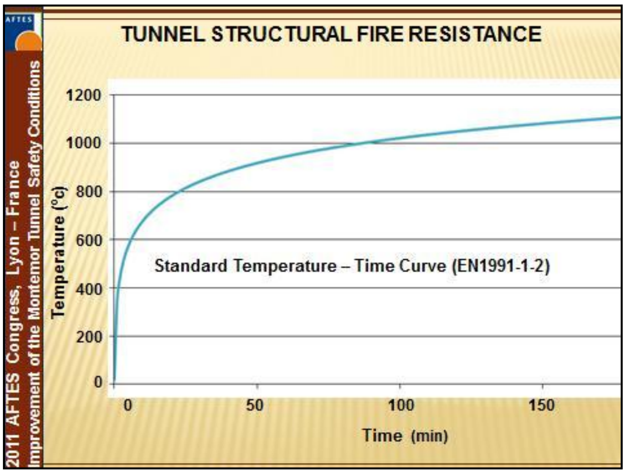

Figure 11: Standard temperature – time curve

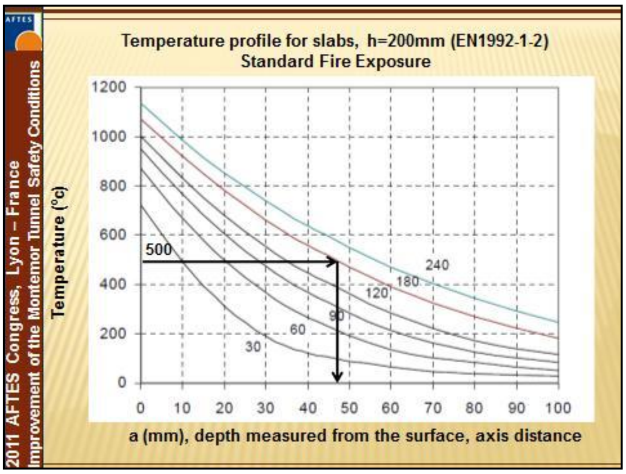

Figure 12: Temperature evolution with depth for concrete elements (500 ºC isotherm)

Taking into account the results of both calculations and diagnostic tests, at the cut and cover sections it was proposed the adoption of a layer of insulating material at the internal surfaces, acting as a passive thermal barrier. This fire protection layer, with a minimum thickness of 25mm, was formed by sprayed inorganic vermiculite cement, with the following advantages:

- Slowing down the increase of temperature at the Tunnel structure, compatible with the R180 classification, as well as indirectly with the safety of the surface structures and infrastructures;
- Vermiculite cements are inorganic materials which do not burn, produce smoke or release toxic gases under high temperature conditions;
- Compatible with the Tunnel minimum gabarit;
- Allows sprayed application and the coating final surface is suitable for painting and good finishing, as well as easy to repair.

In order to comply with the R180 classification it was also necessary to design dilatation joints, at each 25m at the concrete Tunnel final lining, with 50mm width of gap (Figure 13).

Finally, it should be stated that all the Tunnel equipment will be designed to have a minimum level of fire resistance, keeping the necessary safety functions during fire.

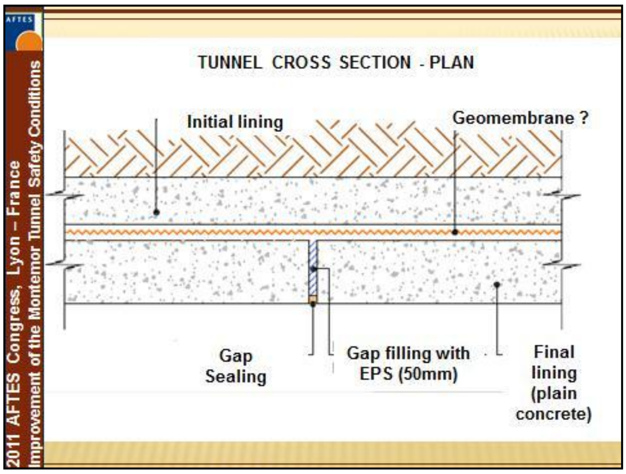

Figure 13: Detail of dilatation joint

4. SAFETY AND RISK REDUCTION MEASURES

4.1 Risk analysis

The adopted methodology for the risk analysis, taking into account all design factors and traffic conditions that could affect the Tunnel safety, mainly traffic characteristics and type, was constrained by the lack of experience and information regarding the Portuguese tunnels. In this scenario and as reference, the experience of other European countries on a multi criteria approach was considered (Figure 13), in order to assess whether additional safety measures and/or supplementary equipment would be necessary to compensate the no fulfillment of all the minimum requirements and, as consequence, to ensure a level of safety not lesser than the one existing at the same A9 motorway, but outside the Tunnel.

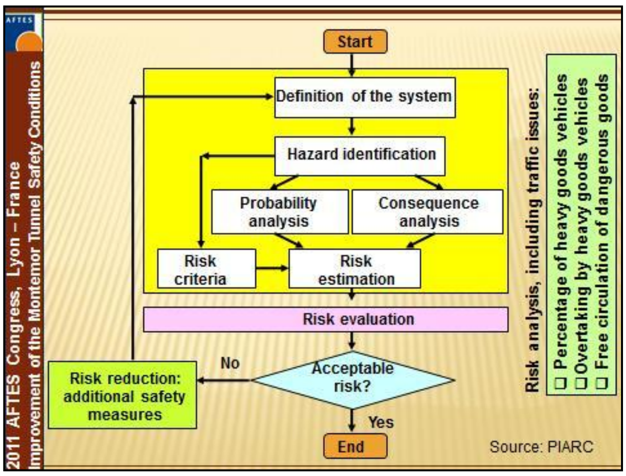

Figure 13: Risk assessment process

2011 AFTES Congress, Lyon – France
Improvement of the Montemor Tunnel Safety Conditions

Summary of Minimum Requirements according to Directive 2004/54/EC EP

● Mandatory for all tunnels
* Mandatory with exceptions
O Not mandatory

Vehicles/day (V/D) >2000
Tunnel length: 500 to 1000m

Existent tunnel

		Chapter		Factor	Comments
Structural measures	2 tubes or more	2.1	-	2,0	V/D half Directive
	Gradient < 5%	2.1	*	0,85	V/D half Directive
	Emerg. walkways	2.3.1	*	>1,0	Exceed Directive
	Emerg. exits at least every 500m	2.3.3-2.3.9	*	0,7	Could be 1, as it is an existent tunnel
	Cross connections at least each 1500m	2.4.1	O	1,0	Not applicable to a tunnel with 750m
	Lay-bys at least each 1000m	2.5	O	1,5	Continuous emergency lane
	Drainage of flammable and toxic liquids	2.6	*	1,0	Designed according to the Directive
	Fire resistance of structures	2.7	●	1,0	According to the Directive
Lighting	Normal lighting	2.8.1	●	1,0	According Dir.
	Safety lighting	2.8.1	●	1,0	According Dir.
	Evacuation light.	2.8.1	●	1,0	According Dir.
Ventilation	Mechanical vent.	2.9	O	>1,5	Both tubes
Emergency stations	At least every 150m	2.10	*	1,0	According to the Directive
Water supply	At least every 250m	2.11	●	1,0	According to the Directive
Road signs		2.12	●	1,0	According Dir.
Control centre		2.13	O	1,4	Exceed the Directive
Monitoring systems	Video	2.14	O	>2,0	Over the Directive
	Automatic incident / fire detection	2.14	●	>1,0	3 systems (CO, visibility and video)
Communication systems	Radio emergency	2.16.1	O	1,0	According Dir.
	Emergency Radio messages for users	2.16.2	●	1,0	According Dir.
	Loudspeakers	2.16.3	●	1,0	According Dir.
Emergency power supply		2.17	●	1,0	According Dir.
Fire resistance of equipment		2.18	●	1,0	According Dir.
Partial Multiplied Factor				7,5	Structures and equipment well above Directive requirements
Other traffic requirements					
Heavy goods percentage		1.3.2		5,0	3% against 15%
Heavy goods overtaken		3.8		<0,25 to>0,1	Statistical Risk
Dangerous goods circulation		3.7		1,0	Return period >1000 years
Final Multiplied Factor				>3,7	Overall conditions above Directive requirements

Figure 14: Risk analysis methodology

The risk analysis was carried out considering all the minimum requirements stated at the the Directive 2004/54/EC of the European Parliament, as well as the traffic characteristics of the Montemor Tunnel. A multiplicative factor was applied to all the considered minimum requirements, supposing they are independents and equivalents, according to the following methodology (Figure 14):

- Factor equal to 1,0, when the existent situation or the adoption of additional measures is according to the Directive minimum requirements.
- Factor lesser than 1,0, when the existent situation is not according to the Directive minimum requirements (ex: longitudinal gradient of 5,3%, comparing with the minimum requirement of 3,0 to 5,0%, lead to a factor of 0,85).
- Factor bigger than 1,0, when the existent situation or the adoption of additional measures exceeds the Directive minimum requirements (ex: 2 tubes and a number of vehicles / day lesser than 4.500 per lane without a duplication forecast in the next 15 years, comparing with the minimum requirement value of 10.000, lead to a factor of about 2,0).

The first partial multiplied factor results from the multiplication of all factors due to the structure and infrastructure factors, leading to a value much bigger than 1,0 (7,5). Furthermore, it was also possible to consider the extra risk due to the other traffic requirements, mainly the heavy goods vehicles overtaken. The multiplication of those factors with the previous partial value led to value of 3,7, bigger than 1,0, ensuring, as consequence, a safety level bigger than the one existing at the same A9 motorway, but outside the Tunnel.

Taking into account this analysis, the following hypothesis and measures were adopted and proposed:

- Maximum fire heat release rate of 30MW, correspondent to a heavy goods vehicle.
- Ventilation solution (sanitary and safety) based on a minimum consumption approach.
- In case of fire, an evacuation and smoke control solution allowing the smoke flow always upwards, on both tubes, and, in consequence, the evacuation of users always downwards.
- The free circulation of heavy and heavy dangerous goods vehicles, including the overtaking.

4.2 Signing: emergency and evacuation

Outside and inside the Tunnel overall length preventive safety signing was proposed to be upgraded, according to the Directive 2004/54/EC of the European Parliament. The signing upgrading will include the following main situations: tunnel sign and classification, as well as, for instance: emergency exits (nearest exits distances on the side walls), emergency stations (fire extinguishers, SOS) and panels with lane signals (including open and close lanes).

5. MECHANICAL INFRASTRUCTURES

5.1 Fire situation

The mechanical active safety systems were designed accordingly to the philosophy based on the guarantee of smoke control in order to prevent it from affecting large tunnel sections before extraction, improving the speed and effectiveness of fire – fighters activities, as well as the speed of users evacuation.

As already stated it will be proposed that in fire situation the smoke flow will be done always upwards, facilitating user's evacuation on the opposite downward direction. This option can be justified by the following issues:

- Tunnel tubes big cross section, about 130m^2.
- Tunnel small length, about 740m, equivalent to approximately 38 hydraulic diameters.
- Only about 3% of heavy goods traffic over 3,5 t.
- Existence of 3 traffic lanes, in each tube, with 3,75m wide and a continuous berm on the slow traffic side with 4m.
- In spite of the Tunnel overall length is lesser than 3.000m, the existence of a Control Centre allowing the Tunnel technical active management.
- Auto evacuation could be performed always downwards, decreasing, at least 3 times the evacuation time (for the same distances), comparing with the same operation upwards. This strategy is according with the common practice for upwards direction traffic. For the downwards direction, the increase of risk is compensated by the specific measures considered, as demonstrated through the risk analysis (Figure 15).

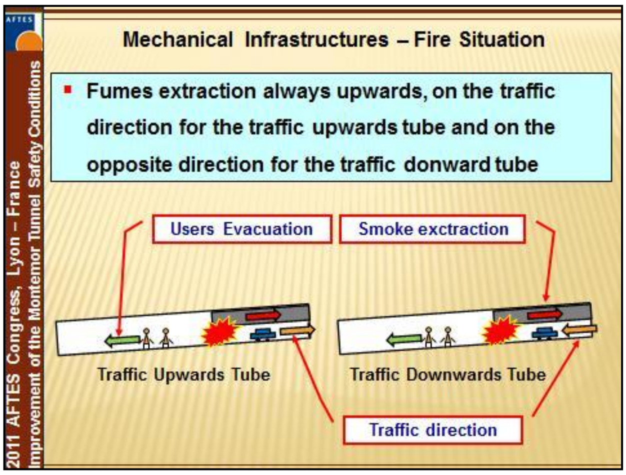

Figure 15: Mechanical infrastructures: fire situation

The demanded sanitary ventilation system has an extraction flow rate of about 1/3 of the value necessary to assure the overall smoke flow, allowing the satisfaction of the ventilation requirements, in each tube, with the partial operation of the smoke control system (with the double function of ventilation and smoke control). This solution allows the optimization of the energy costs. In order to control the ventilation and the containment of smoke in a well-defined tube, 2 pairs of reversible fans will be proposed to be installed, in each tube. In what concerns ventilation procedures, the velocity of the flow inside the contaminated tube will be measured by a laser-doppler system and the reversible fans will be operated to accelerate the flow in that direction. In what concerns smoke, all the jet fans of the tube will be operated, in a pair by pair basis, following a pre-defined sequence and the ventilation fans from the non-affected tube, will be operated in the upward direction in order to prevent a backward of the smoke flow. A time delay in the launching of the system was also assumed so that the initial stratification of the smoke remains undisturbed, then making it easier the auto-evacuation through the fire section, and allowing to bring the ventilation system to a stop if by the time the fire is detected it is running.

5.2 Ventilation and other equipment

In spite of the Tunnel overall length is lesser than 1.000m, the proposed mechanical ventilation system was designed taking into account the following issues: the control of pollutants emitted by road vehicles under normal and peak flow, as well as when traffic is stopped due to an incident or accident, and also the control of heat and smoke during fire. In order to achieve those purposes the ventilation system will comprise the installation of unidirectional ventilators, with the exception of 4 reversible ventilators, with 2 rotational speeds, located in the central zone of each tube, in order to manage both sanitary and smoke control situations. All fresh air ventilators (sanitary ventilation) will be equipped and monitored through automation in order to allow the optimization of both ventilation and air opacity conditions, leading to safer driving conditions under minimum energy consumption.

6. MAIN CONCLUSIONS

The Montemor Tunnel Rehabilitation Project, developed in order to fulfil the Directive 2004/54/EC, demanded the overtaking of some constraints, mainly:

- Due to the Tunnel age, some difficult at the confirmation of the Tunnel structural characteristics, mainly the ones related with the initial lining.
- Absence, up to now, of a well-defined methodology for risk analysis on the Portuguese tunnels.

Finally it should be pointed out the importance of a flexible and progressive timetable for the implementation of the Directive 2004/54/EC of the European Parliament, taking into account the particularities of each tunnel and each country.

7. ACKNOWLEDGEMENTS

The authors thank to the Owner of the Montemor Tunnel (BRISA) his permission for the presentation of this present paper.

8. REFERENCES

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