# INCREASING THE CAPACITY OF THE AP-6 MOTORWAY AND GUADARRAMA TUNNELS: OPERATION BY REVERSIBLE ROADWAY AND EVOLUTION IN THE SAFETY SYSTEMS

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## ABSTRACT

Several years ago, the toll motorway AP-6 had serious traffic jam problems during peak time both at departure and return of the weekends and holidays in the passageway of the Sierra de Guadarrama (about 60 km to the northwest of Madrid), with an ADT -average dayly traffic- over 85,000 vehicles per day during those periods. The circulation under the mountains was developed through two tunnels of 3,000 m long each. These tunnels were built at different time.

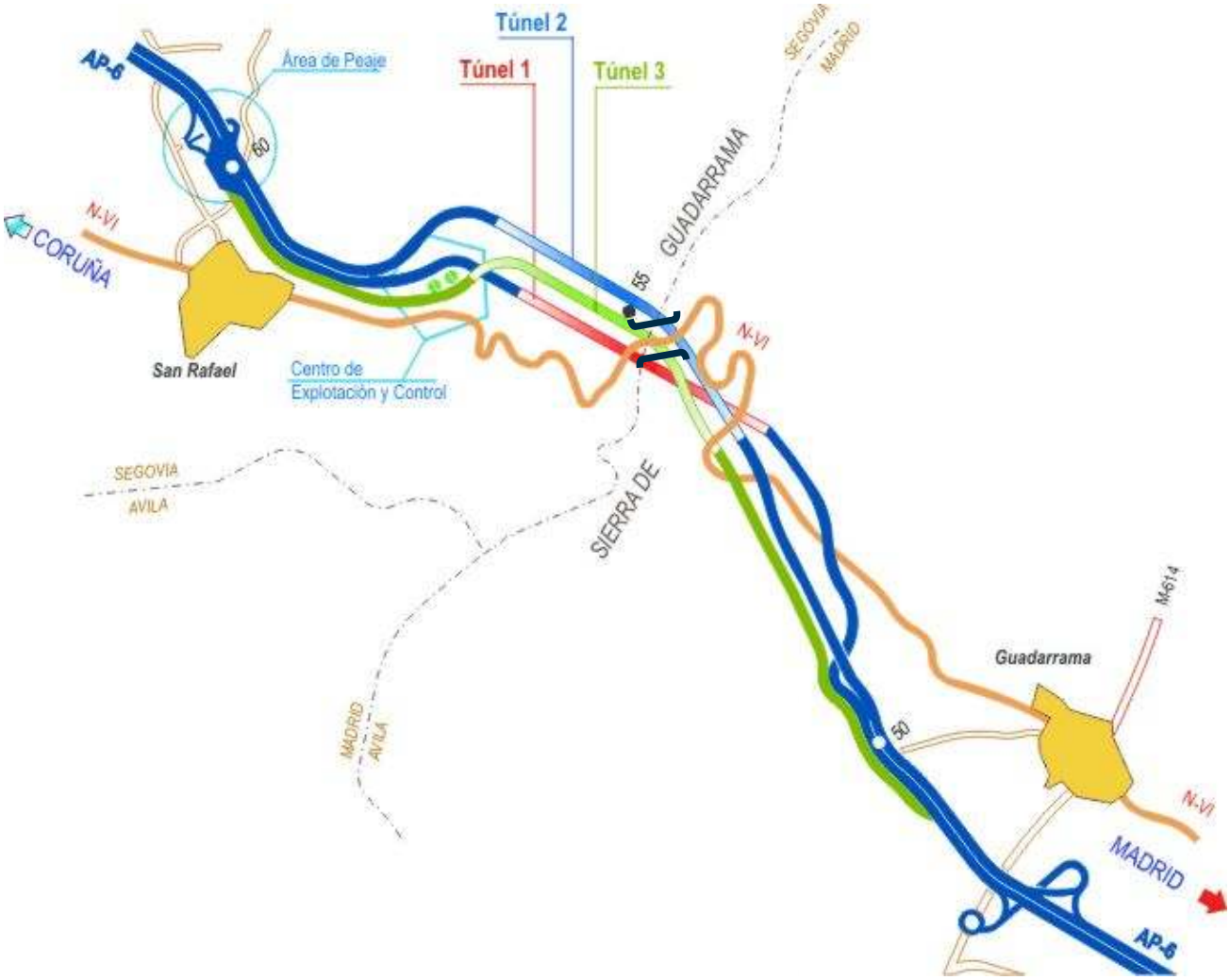
This communication examines both the design criteria used and the project carried out to increase the capacity and the modification of the existing circulation system, using the central carriageway of this section for reversible operation.

This paper examines aspects of project design and project of the accesses to the reversible carriageway and also the operation and system security, and will present the experiences registered in this regard from the start up.

At the same time, the already existing tunnels were updated regarding to safety requirements to follow the current safety standards for road tunnels (Directive 2004/54/EC) and its transposition into Spanish law.

## 1. INTRODUCTION AND GENERAL INFRASTRUCTURE SCHEME

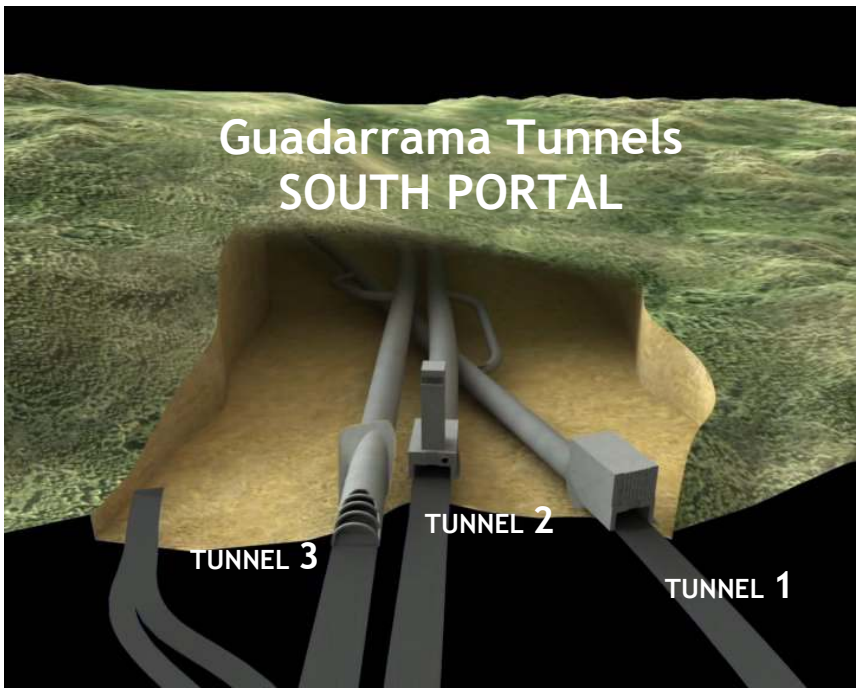
During the last years it has been done on the toll AP-6 motorway between Las Rozas and San Rafael (at about 60 km from Madrid) certain works which include the construction of a third tunnel under the Sierra de Guadarrama mountains, which meant that in a section of the motorway of about 13 km that had three roadways, one of them was adapted for reverse-flow traffic (fig.1).




"Figure 1 –Location of the tunnels"

The Guadarrama tunnel system is on the AP-6 roadway between P.K. 49, where the south traffic distributor is located, and P.K. 49, where the north traffic distributor is located before the San Rafael toll.

Construction of the third Guadarrama tunnel and of roadway serving the tunnel began in August of 2004 and the whole works ended in July 2008.



"Figure 2 – Guadarrama Tunnels. South Portal"

It just so happens that the third tunnel is one of the first in Spain to begin service under Spain's new security regulations. Thus, Royal Decree (RD) 635/2006 on minimum security requirements for road tunnels in Spain, enacted to implement the European Community Directive 54/2004 in accordance with Spanish legislative procedures, stands as the regulation to be followed both for new tunnels that will begin service and for tunnels already in operation. It should be said that the Spanish regulation is, on the whole, much stricter than the European one.

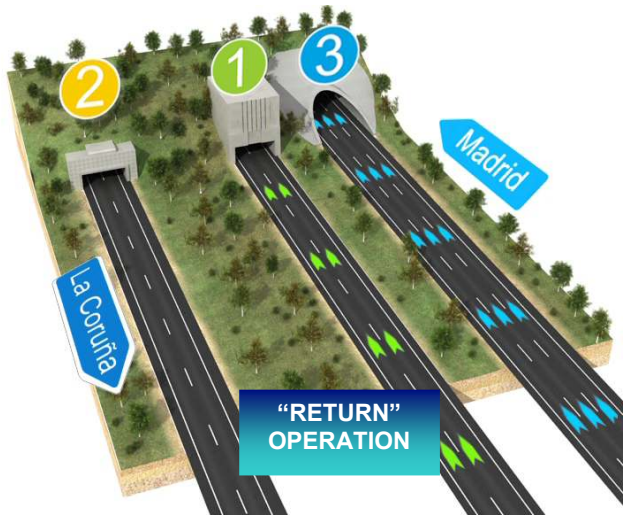
Once all of the planned works were completed, the motorway have three tunnels: tunnel 1 (2,870 metres), tunnel 2 (3,340 metres) and tunnel 3 (3,148 metres), listed in chronological order of construction and commencement of service. In addition, the motorway have two traffic distributors.

Tunnel 1, which until now has operated for the Madrid-bound roadway for all types of vehicles, become part from now on of a reverse-flow roadway which will operate for either Madrid-bound traffic or La Coruña-bound traffic according to demand and road conditions. In principle, this roadway is for light vehicles only, except for those occasional circumstances when it will become necessary to allow heavy vehicles to pass (for example, the closing of tunnel 2 or 3 in the event of a serious incident, or maintenance works).

Tunnel 2 is for A Coruña-bound traffic, both heavy and light vehicles.

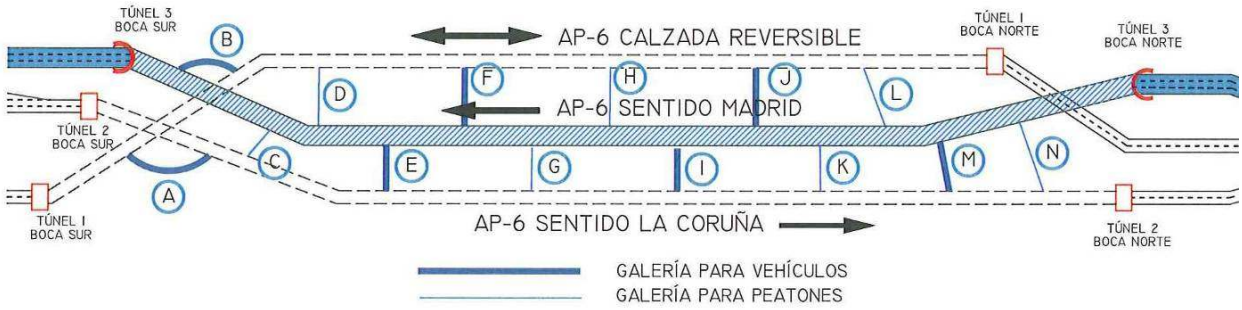

"Figure 3 – 'Go Out' Operation Configuration"

Tunnel 3 is for Madrid-bound traffic. Tunnel 3 accepts both light and heavy vehicles. Its alignment is approximately parallel to the alignment of tunnel 2, and both of these tunnels cross over tunnel 1 at about 250 metres from the South portal (fig. 2), after which the alignment of tunnel 3 is almost equidistant in height and length between the two other tunnels.




"Figure 4 – 'Return' Operation Configuration"

Yet without a doubt, the most important works as regarding tunnel operational safety was the construction of thirteen auxiliary safety tunnels that join the new tunnel 3 to tunnels 1 and 2 and an additional auxiliary safety tunnel joining tunnels 1 and 2 (fig. 5). Altogether, these auxiliary tunnels have a total length of 2,211 metres, with an average distance between emergency exits of less than 190 metres in the new tunnel, 360 metres tunnel 1 and 380 metres in tunnel 2. These average distances between emergency exits more than meet the requirements of Directive 2004/54/CE, which sets a minimum distance of 400 metres. For tunnels 1 and 2, vehicle and pedestrian safety tunnels alternate, beginning with a vehicle tunnel starting at the South portal. This means that for tunnel 3, the vehicle and pedestrian safety tunnels alternate in pairs. Therefore, seven of the tunnels have a section that allows access to emergency and fire extinguishing vehicles with 5 metres between faces and 3.5 metres of clearance. Since the auxiliary vehicle tunnels alternate with pedestrian-only tunnels, the requirements of both Spanish and European regulations for connections every 1,500 metres are also met. [3]




"Figure 5 – Tunnels & auxiliary passages scheme"

## 2. DESIGN OF THE TRAFFIC DISTRIBUTORS

### 2.1. Functional scheme

In the functional scheme proposed for the expansion, the carriageway that had been used to carry traffic heading in the direction of Madrid until the implementation of the new tunnel has been adapted as a reversible carriageway, in one direction or the other according to traffic conditions. The operation with three carriageways is currently only adopted in cases of need, and only for light vehicle traffic, which implies in itself an improvement in safety conditions for the users of tunnel 1 since this is the tunnel with the greatest limitations, in both its horizontal and vertical alignment. Therefore this tunnel will serve most of the time as an evacuation passage and access for emergency vehicles in the case of accident, as well as for routine maintenance operations, since it is connected to the new tunnel, and via this to tunnel 2, by a system of auxiliary passages. [3]

The reversible carriageway has been designed so that it may automatically be opened or closed in one or the other direction. At both ends of the stretch there are traffic distributors giving access to the reversible carriageway or allowing incorporation from the same. [2]

### 2.2. Layout design

From the point of view of layout design, important conditioning factors existed for the South Distributor (pict. 1) owing to the fact that it was necessary for it to be situated in a specific stretch that did not reach 2,000 m, between a slip road and viaduct. This stretch is situated on a wide curve to the left and with a slope of approximately 6%. In the ascending direction (entry) the treatment given was that of a fork, changing from one carriageway of 4 lanes to two carriageways of 2 + 3 lanes. It was therefore necessary to prepare the design with an ample length of transition from 4 to 5 lanes before the separation of the lanes, and then also proceed to make the transition from 4 to 3 lanes in the carriageway in the ascending direction (direction La Coruña). For the incorporation, the design was a confluence from two carriageways of 2+3 lanes to one of 4 lanes, with no greater complications, except the proximity of the deceleration lane for the immediately following slip road. [2]

“Picture 1 – South Distributor”

The North Distributor was situated benefiting from the exit of the San Rafael semi-trunk toll road, and was also conditioned by the viaduct of the same name, situated some 2,000 m from the toll. Here the entry difficulties are fewer, since it is possible to “dedicate” toll lanes to each carriageway.

## 2.3. Design of the mechanical and ITS installations

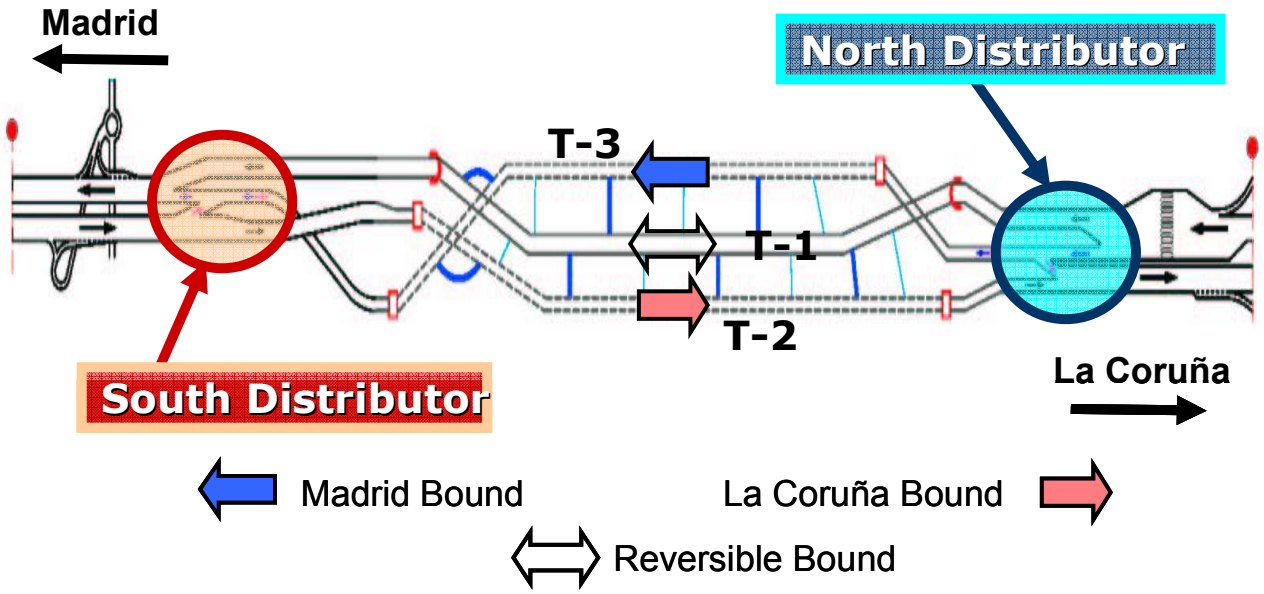

“Picture 2 – Variable Message Panel in South Distributor”

From the point of view of the ITS –Intelligent Transportation Systems- installations, these are absolutely necessary in order to be able to operate the opening and closing of the carriageway fluidly and safely in both directions. For this reason, and based on the design of the Bus-HOV –High Occupancy Vehicle- carriageway that has been operating successfully for more than a decade on the A-6 between Puerta de Hierro and Las Rozas, we designed a system of horizontal lifting barriers and lighted markers as horizontal signalling, reinforced by a complete system of variable signalling (panels and crosses/arrows). Added to this is closed circuit TV with total coverage in the stretch which

allows the monitoring and supervision of operations from the Control Centre. The system has been designed so that the opening and closing operations may be carried out totally automatically, although initially they were carried out with in-situ presence of operating personnel in order to validate the execution of the algorithms programmed into the system and in turn reinforce with their presence that which was indicated by the panels (pict. 2) and crosses/arrows at each moment. [4]

All the lighting of this reversible carriageway is controlled from seven control centres situated throughout the length of the roadway which automatically manage the activation and deactivation of the lighting, the status signals of the generator sets and the status signals of the medium voltage doors and cells. The management of the ITS equipment is carried out via signal concentrators, which hang from four new remote stations and the other existing ones along the carriageway.

## 3. TRAFFIC MANAGEMENT. OPENING OF THE REVERSIBLE CARRIAGEWAY




"Figure 6 – Carriageways' scheme"

For the operation of opening and closing of the reversible carriageway (fig. 6) a series of operation protocols was designed which also included the criteria for deciding whether or not to use the said carriageway. In this respect it was determined that the reversible carriageway should open (in one or the other direction) in the following cases: serious accident in one of the non-reversible tunnels which affects the carriageway for a long period of time; considerable traffic congestion in a non-reversible tunnel owing to holiday traffic; maintenance operations with an important effect on traffic; performance of a simulation. For non-programmed causes, accidents and congestion, prior notification must be given to the Duty Manager who will request authorisation from the Operations Unit Manager and the Operations Director. [2]

### 3.1. Prior inspection.

A highway administration vehicle from the Control Centre travels along the whole of the reversible carriageway, in the opposite direction to that of the proposed circulation, to verify that all the signalling elements and barriers are in the condition required by the direction of circulation. The condition of the carriageway is also checked, as is the absence

of fortuitous obstacles or those deriving from possible previous work. No service vehicle may remain on the carriageway. The highway administration coordinator who performs the inspection must carry a checklist which must be completed and signed.

### 3.2. Activation of the signalling plan. [2]

The signalling plan is programmed in the Integrated Equipment Management application, and it is executed by phases or plans, which in the case of opening of the carriageway will always be implemented in the opposite direction to that of the traffic, except the establishment of the direction of circulation in the tunnel which will be the first operation to be performed, while for the closing of the carriageway the plans will be implemented in the same direction as that of circulation.

- Opening and closing of the carriageway in the direction of Coruña (DC).
    a) Circulation tunnel in the direction of Coruña (action in all the systems)
    b) Launch plan Open North Distributor DC: action on VMPs, cross/arrow panels and moveable barriers and lighted markers (lit direction Coruña and lit direction Madrid, closing access)
    c) Launch plan Open Carriageway T1 DC (automatic ventilation)
    d) Open barriers South Distributor
    e) Signal South Distributor DC and open left lane South distributor
    f) Open right lane South distributor
    g) Close South distributor: Switch off installations of steps e) and f) and wait 10 min. to close the hinged barriers DC.
    h) Total closure of carriageway and tunnel: normalisation steps b), c) and d)


"Picture 3 – Variable Message Panel in North Distributor"

- Opening and closing of the carriageway in the direction of Madrid (DM).
    a) Circulation tunnel in the direction of Madrid (action in all the systems)

b) Launch plan Open South Distributor DM: action on VMPs, cross/arrow panels and moveable barriers and lighted markers (lit direction Madrid and lit direction Coruña, closing access)
c) Launch plan Open Carriageway T1 DM (automatic ventilation)
d) Cone exit from toll plaza in order to guide the traffic to one carriageway or the other
e) Open barriers and lanes North Distributor
f) Signal North Distributor DM
g) Close North Distributor (pict. 3): Switch off installations of step f) and wait 10 min. to close hinged barriers DM.
h) Total closure of carriageway and tunnel: normalization steps b), c) and d)

## 4. EMERGENCY MANAGEMENT. RECENT EXPERIENCES

The emergencies which have occurred since the connection passages between the tunnels became operational, in March 2007, have been limited to various incidents of level 0 and 1 (presence of adverse meteorological phenomena in the exit of a tunnel; a call from an SOS post; the transit of special vehicles with authorisation; a stationary vehicle on the carriageway without obstructing the traffic or with partial obstruction; the transit of special services; heavy traffic; a stationary vehicle in a lay-by; detection of a vehicle with excessive dimensions; etc…), which can be considered frequent or usual situations that form part of the ordinary management of tunnel operation. None of these emergencies, owing to their own nature and as defined in the corresponding action protocols, led to the need to activate the Evacuation Plan.

However, an emergency has taken place which has led to the activation of the Evacuation Plan [2]. This type of emergency is that caused by the breaking of the turbocharger of a heavy vehicle, normally with loads close to the maximum authorised, and which approaches Tunnel 2 with the engine labouring after the six kilometres of ascent at 5% prior to the tunnel entrance. The characteristics of this incident mean that it is initially detected via the DAI system associated with the closed circuit television, once the vehicle has stopped and has already begun to emit a large amount of smoke, which makes it difficult for the Control Centre operator to identify visually the cause of this smoke. Therefore, in the absence of more data and with the premise that the sooner action is taken the more effective the intervention will be, the emergency is catalogued as the most serious, since the origin of the smoke is unknown.

### 4.1. Real emergency

In one of the real situations that occurred, of which we will give details below, the intensity of the traffic was moderate-high (approximately 1,500 vehicles per hour) and the meteorological conditions in the exterior were good (clear). In this case, detection was made via the AID system –Automatic Incident Detection-, which notified the Control Centre of a stationary vehicle on the carriageway inside Tunnel 2 (direction La Coruña). As a consequence interlocking took place of the camera located at the site of the incident, it being partially possible to detect the origin of the incident upon observation of a large quantity of smoke, very concentrated, but without it being possible to determine the exact cause and the type of vehicle or vehicles involved in the incident (pict. 4 & 5). The continuous recording system with which the AID system is provided allows the conservation of the recording of all the cameras from 10 minutes before the alarm is raised until the end of the emergency. Thanks to this device, it was possible to reconstruct the management of the emergency in detail.

"Picture 4 – Beginning of the emergency"

Given the type of incident that occurred and the information available, the action protocol corresponding to the emergency catalogued as "fire in tunnel or explosions in vehicles or installations with risk of spreading" was immediately activated. The first measure which was immediately taken was the activation of emergency signalling in the tunnel (flashing amber lights at both ends), back up lighting in the whole tunnel and communication of the emergency to the Permanent Emergency Team (PET).

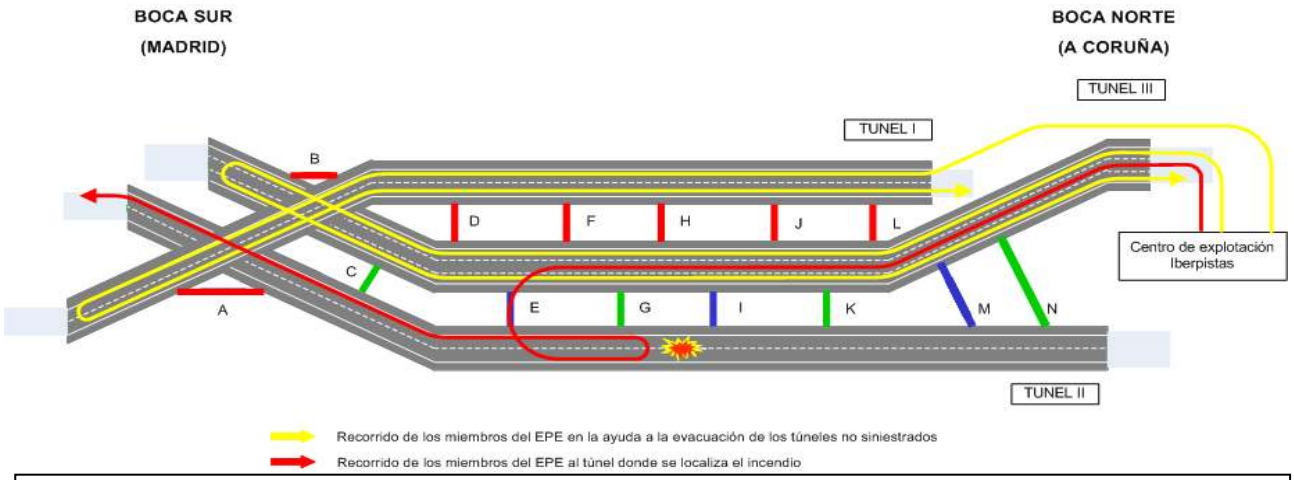
"Picture 5 – Smoke control through ventilation"

Immediately afterwards, the procedure for closing Tunnel 2 was implemented, in the first instance, and subsequently the closure of tunnel 3, in order to facilitate access by emergency vehicles from the operational base via the passages connecting both tunnels (fig. 7). The Tunnel Closure Plan was implemented automatically and without failures by means of the external signalling protocol via variable message panels, cross/arrow panels in the entrances and traffic lights and closure barriers. Also simultaneously, the Ventilation Protocol was activated, both in Tunnel 2 and in the evacuation passages to provide them immediately with excess pressure. With regard to the behaviour of the smoke, although the potential for generation could not have been high, it was ascertained that initially the

phenomenon of “backlayering” or backward flow of smoke due to buoyancy occurred, although only for a few metres, which allowed the zone upstream from the incident, occupied by the detained vehicles, to remain free from smoke at all times.

In the communication with the Control Centre the field agent stated that there were no casualties and that the vehicle ignition was switched off, with no more smoke being generated. The Duty Manager decided at this moment to inform the external agents: the Traffic division of the Civil Guard (which was already aware of the emergency since it shares a channel with the operational services of Iberpistas-abertis), the Fire Brigades of the Community of Madrid and the Council of Segovia, Health and Civil Protection Services, via 112 and direct numbers.

## 4.2. Activation of the Evacuation Plan




*Route of the members of the permanent emergency team (EPE)*

“Figure 7 –Permanent Emergency Team (PET) route”

Simultaneously the Evacuation Plan was activated. The Interior Emergency Plan specifically contemplates the transitory situation of the need to evacuate Tunnel 2 while Tunnel 1 is closed for restoration work. The users even began to evacuate their vehicles motu propio before being instructed via megaphone and the FM channels with signal inside the tunnel, via which, and interrupting the broadcast, specific notification messages were inserted in the action protocol: “Tunnel blocked by accident. Stop with your engine switched off and emergency lights on. Wait for instructions”. In the Control Centre various calls were received from users via the SOS posts requesting information and instructions. Entry to the passages began barely three minutes (3’00’’) after the beginning of the emergency. The effectiveness of the measure taken, even taking into account that many of the affected parties took action on their own initiative, and also the effectiveness of the ITS systems involved (megaphones and radiofrequency) were very positively assessed.

## 4.3. Positive and negative behaviour

As has been seen, not everybody followed the instructions given, so that some drivers carried out manoeuvres in order to leave their vehicles parked on the hard shoulder and even driving in reverse or turning around. These manoeuvres, which are made spontaneously in order to try to free the carriageway, cause a serious added risk as well as causing the opposite effect in the case of occupying the hard shoulder, since this is of sufficient width to allow emergency vehicles to approach the possible incident zone.

Furthermore, another negative aspect detected was that very few vehicles respected the minimum safety distance from the vehicle in front when joining the queue.

However, as a very positive aspect in the management of the emergency we must emphasise the fact that the presence in the tunnel of personnel of the concessionary, duly trained and identified and with clear and precise instructions, generated confidence and security and guaranteed the guidance and rapid evacuation of the people in the tunnel towards the emergency exits, as well as the return to the vehicles once the tunnel was free from danger. The evacuation was carried out in approximately seven and a half minutes (7'30'') from the activation of the Evacuation Plan. The return to the vehicles was also carried out rapidly (practically twenty five minutes (25'00'') from the detection of the emergency), and allowed the reopening of Tunnel 3 (in the direction of Madrid) sooner than expected.

### 4.4. Return to normality


"Picture 6 – Inside the emergency passage"

The recovery of operational conditions did not cause any further problems, and the re-opening of Tunnel 2 was only undertaken once all the vehicles stationed inside had been removed, including the vehicle that caused the emergency, which was removed with the aid of a breakdown truck, this having been checked by the Traffic division of the Civil Guard who covered the whole length of the tunnel in a vehicle and also checking via the Control Centre by means of the Closed Circuit Television, looking to see whether anybody remained inside the passages (pict. 6). In the specific case of this emergency, the whole duration of the same was 59 minutes (until the traffic was totally regularised), with the duration of closure of Tunnel 2 being 42 minutes, and that of Tunnel 3 being 31 minutes, times which can be considered reasonable and very close to the "theoretical" times obtained in the drill carried out by Iberpistas-abertis before the opening of Tunnel 3.

## 5. CONCLUSIONS

The experience relative to the operation of the reversible carriageway has to date been highly satisfactory. A relevant fact to be highlighted is that of the peculiarity and effectiveness presented by the opening in two phases of the South Distributor (first the left lane, of direct entry, and then the right in a second phase) assisted by the cross/arrow

panels and the double row of lighted markers set into the carriageway. Another point to emphasise is the fact that the South Distributor is situated on a significant slope and on a wide curve to the left, which facilitates the fact that the vehicles accede, generally, at moderate speeds (without the occurrence of sharp breaking which would lead to retentions and would even call into question the infrastructure created) and “naturally”. The maximum intensities recorded support this fact, with peaks of 2,300 vehicles on the reversible carriageway and 2,800 in the carriageway in the direction of La Coruña.

Regarding safety, the main conclusions relative to the ITS equipment and applications involved are as follows:

- The ITS detection systems worked perfectly. This demonstrated the great efficiency of the AID system, which in a high percentage of cases is that which first raises the alarm.
- The Tunnel Closure Plan and the Ventilation Protocol were activated automatically and without failures.
- It was confirmed that the management of the first intervention, which is that carried out using the means belonging to the tunnel operator, is absolutely decisive.
- The good design of the Evacuation Plan was confirmed.
- Generally positive behaviour by the users involved in the emergency, since many even abandoned their vehicles motu propio and began to make their way to the emergency exits, while others requested help via the SOS posts.
- High effectiveness of the ITS systems involved in the evacuation (megaphone and radiofrequency), as well as the messages broadcast.

“Picture 7 – Exit tunnel 3”

It is worthwhile highlighting that a study and analysis of situations such as these is always carried out by Iberpistas-abertis, preparing reports that help to improve management.

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