APPENDIX 2.23 – SPAIN – Madrid – Cuatro Torres Tunnel

1. SUMMARY

The Cuatro Torres Tunnel is an urban tunnel that facilitates the access to four High Rise Buildings constructed on the grounds of the old Sports City of the Real Madrid.

The tunnel consists of one distributor ring with unidirectional traffic in a clockwise direction with three lanes. The tunnel also has in its central part a transversal connection, with bi-directional traffic and two lanes in each direction.

The purpose of the tunnel is to allow the towers' users access to the car parks located in their basements and to facilitate the incorporation of the buildings into the main exit routes of the towers' surroundings, both for public and private circulation.

In the northern part of the ring, close to Tower 4, the tunnel has three entrances. From their confluence, the traffic goes parallel to the Paseo de la Castellana after a turn to the right. At the end of the straight, there is an exit to the Paseo de la Castellana, one of the main avenues of the city, and another to the existing Pio XII tunnel.

At another right turn, there are the accesses at the southern part, near Tower 1, from three other Madrid streets. At the next right turn, circulation is again parallel to the Paseo de la Castellana. At the end of the straight, there are two other exits into other main streets of the city.

Figure 1 shows the location of the tunnel. Figure 2 shows a schematic layout with the arrangement of tunnel entrances and exits.

Figure 1 -Cuatro Torres Tunnel location

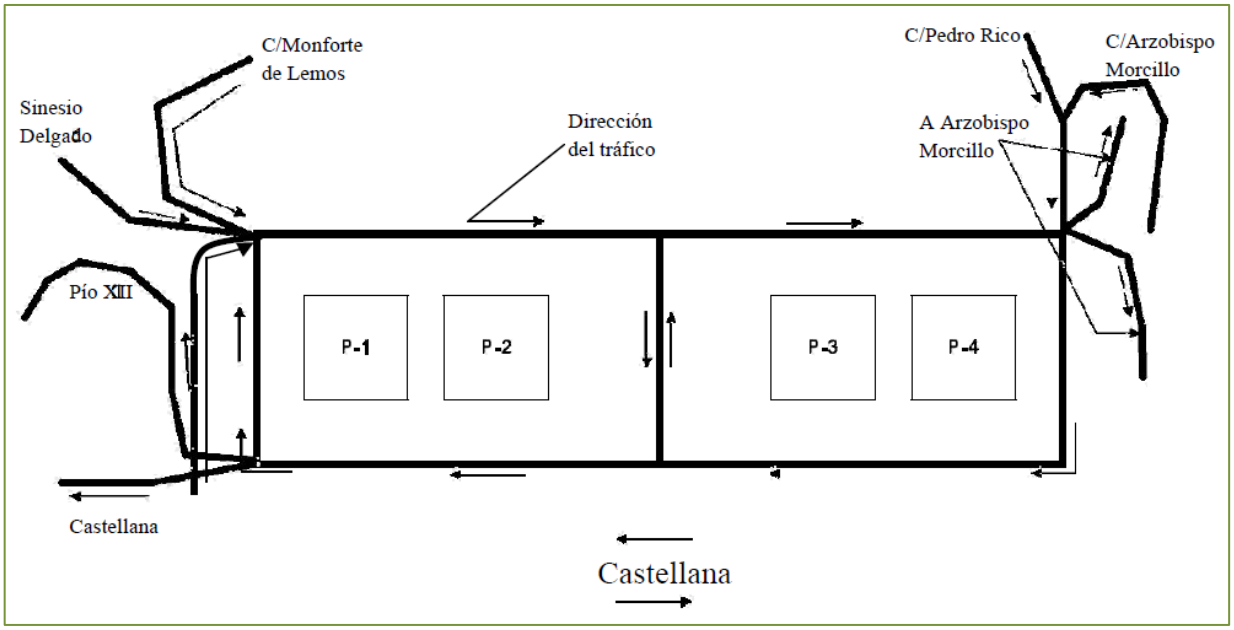

Figure 2 - Cuatro Torres Tunnel entrances and exits ramps layout.

Figures 3 and 4 show some accesses to the tunnel:

Figure 4 - access South Monforte de Lemos str.

Figure 4 - access North Arzobispo Morcillo str.

2. MAIN CHARACTERISTICS

2.1 GEOMETRY

- Total length: 2,746 m (including ramps).
- Ring Length: 1,125 m.

2.2 CROSS SECTION

2.2.1 Tunnel

- Lane widths: 3.50 m each.
- Variable number of lanes: 1 to 4.
- Sidewalks: variable width, 0.6 - 0.9m, in the ring area.
- Hard shoulders: 0.5 m, not possible in the accesses.
- Vertical clearance: 4.00 m.
- Total height: 5.00 m.

2.2.2 Lay-bys

Except at the entrance and exit ramps, the Cuatro Torres Tunnel has lay-bys in all areas of the ring. (Figures 5 and 6). These lay-bys accommodate vehicles stopping inside the tunnel in cases of emergency without affecting traffic circulation.

Figure 5 - lay-bys

Figure 6 - lay-bys

2.2.3 Emergency Exits

The Cuatro Torres Tunnel has eight emergency exits with fire-resistant, double wing doors with panic bars, (Figure 7), giving access to escape routes by ascending metallic pedestrian staircases (Figure 9) up to the street level (Figure 8). The portals of the tunnel are also considered as emergency exits, meaning that there is an additional nine evacuation exit.

All emergency exits have pressurisation systems.

Exits are indicated by light signals in the form of flags in the upper part of the doors and with photoluminescent signals for their correct location.

Figure 7 - emergency exit door

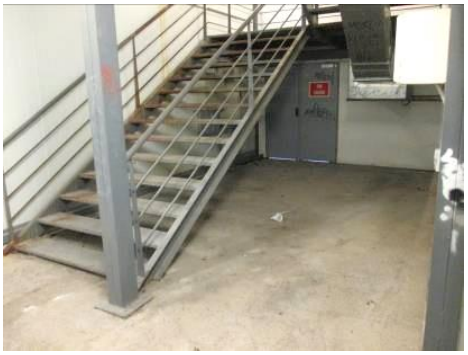

Figure 9 - ascending escape staircase

Figure 8 - exit on street level

2.3 TRAFFIC CONDITIONS

Traffic in the tunnel varies, with an estimated Daily Average Intensity of 14,000 vehicles. High traffic density is expected during peak hours due to motorists entering or exiting the car parks.

The total number of parking spaces, including those in the four towers, is around 1,200. Each tower has 5 or 6 parking levels below ground.

2.4 VENTILATION

2.4.1 Ventilation system

For the Cuatro Torres Tunnel, a mixed ventilation system has been adopted, combining longitudinal ventilation (Figure 11) with transversal ventilation with supply and extraction by means of axial fans (Figure 10). The ventilation shafts are located in technical rooms next to the emergency exits. The extraction air outlets are by means of a steel grate located on the surface. (Figure 12).

Figure 11 - jet fans in the ceiling

Figure 10 - axial fan

Figure 12 - steel gratings

2.4.2 Ventilation control

Ventilation is controlled by direct measurement of smoke, contaminant levels, opacity, and air velocity within the tunnel.

The measuring equipment is located at the points of greatest theoretical concentration. This guarantees the measurement of the entire profile of the particles and pollutants concentration.

The fans´ control contactors are managed according to the information obtained. The sensors are standard 4-20 mA output and are connected to analogy inputs of the remote station of the tunnel (ERU)

The control logic is programmed locally using algorithms at the remote stations.

Ventilation control has the following detection equipment:

- 16 NO_2 detectors,
- 16 CO detectors,
- 17 opacimeters,
- 3 anemometers and an outdoor wind detector,
- 4 indoor anemometers,
- 2 control centres.

The allowed levels of pollutants are:

- CO limit: 70/150 ppm,
- visibility (maximum K): 0.005 / 0.0075.

2.5 OPERATION AND SAFETY EQUIPMENT

The Cuatro Torres Tunnel has different fixed security facilities designed to ensure the correct operation of the systems, which contributes to an increase in safety of the tunnel users, as well as its infrastructure and equipment.

The fixed facilities of the tunnel are described in the following sections:

2.5.1 Power supply

The tunnel has two power supply connections. In case of failure of one of the electrical network lines, there is an electrical connection that can be operated at the output of the transformers to switch to the working network line. This ensures a continuous supply of power to the tunnel´s critical services.

To ensure uninterrupted power supply throughout the tunnel in case of an unexpected outage, such as a power failure at both supply companies, the critical security systems of the tunnel are fitted with three Uninterruptible Power Systems (15 kVA, 30 kVA and 40 kVA respectively), which allows 10 minutes of autonomy, at full load, to keep all the following systems operational:

- Equipment for the communications and fire detection technical room.
- Linear fire detection in the tunnel.
- Variable Message Signs, Cross-Arrows and Speed Signals.
- SOS system.
- CCTV.
- Tunnel contamination detection (CO / NO_2, opacity, anemometers).
- Lighting of the permanent circuit of the tunnel and the emergency / guided circuit.
- Public address system (PA).
- AID and CCTV processor.
- Radiocommunication system.
- Standard Remote Station and communications equipment with the Tunnel Control Centre of the City of Madrid.

2.5.2 Lighting.

❑ **Normal Lighting**

The tunnel lighting is provided by 250 W High-Pressure Sodium Vapour luminaries on the first level and 65 W fluorescent luminaries on the second level. There is no reinforcement lighting for the entrances and exits of the tunnel.

The tunnel´s lighting is provided by High-Pressure Sodium Vapour luminaries, located on both sides, at a height of 4.50 m above the road.

The lighting system has 4 levels of lighting (night, twilight, cloudy and sunny). With the input from 3 lux meters, the most appropriate lighting is selected depending on outside brightness, to minimise the contrast between the interior and exterior light.

Inside the tunnel there are several lighting areas. More intense lighting at the entrances and exits of the tunnel and less intense lighting along the tunnel. This is done so a gradual adaptation of vision is achieved.

For lighting control, the system is divided into two zones (one per ring): Ring 1 and Ring 2. Ring 1 comprises Tower 1 and Tower 2 zone and Ring 2 Towers 3 and Tower 4 zone. Each zone is controlled independently, regulating the circuits according to the information provided by the external luminosity sensors.

❑ **Emergency Lighting.**

The emergency lighting consists of 209 autonomous lights of 18 W, with an operating autonomy of 60 minutes. These lights are installed in the walls of the tunnel, every 20 metres at a height of 1.05 metres above road level.

❑ **Security Lighting**

The tunnel's security lighting consists of one third of the total luminaries of the tunnel's permanent lighting, located at the top of the tunnel´s walls. It is connected to the UPS.

2.5.3 Fire detection and extinguishing systems.

The fire detection system consists of a linear system for the central ring and the entry and exit ramps, and individual sensors in the technical rooms and transformation centres.

The fire extinguishing system consists of the following elements:

- Wet column for Fire Hoses and hydrants.
- Dry column for Fire Fighting Connections installed in the left wall, depending on the direction of traffic.
- Fire extinguishers.
- Two fire pressure pumps with three tanks of 10 m^3 each.

2.5.4 Traffic control systems.

❑ **Signalling system.**

The Variable Message System provides graphic and / or alphanumeric information for drivers in real time about incidents, traffic conditions, etc.

These types of signals, electronically illuminated, are strategically located in order to anticipate events in which drivers may encounter traffic congestion or other type of incidents.

Entrance signalling to the tunnel are variable external message panels with alphanumeric characters and two full-colour graphics at each access. Inside the tunnel there are four interior panels with alphanumeric characters and full-colour graphics, ten cross-arrow signs for lane marking and speed limits, three tricolour warning lights and tunnel closing, and thirty amber warning lights.

❑ **Traffic measurement system.**

Inside the tunnel there are eighteen double loop traffic detection points, which obtain reliable information on traffic conditions.

❑ **Vertical Clearance system**

The variable signalling panels installed at the access points indicate the permitted clearance (Figure 13).

In addition, there is an automatic gauge system, which detects if a vehicle's height is higher than the permitted height and manages its access. For this purpose, two sensors perform the detection, the first one detects a metal mass by means of an electromagnetic loop in the road and the second one detects the height by means of an infrared barrier (Figure 14).

When a vehicle with insufficient clearance is detected, the driver is informed and ordered to stop and not continue (hidden stop signal), or to leave the road at the next exit (hidden deviation signals). When an insufficient clearance is detected, the system sends an alarm to the Control Centre in order to warn operators.

Figure 13 - variable signalling panel (VMS)

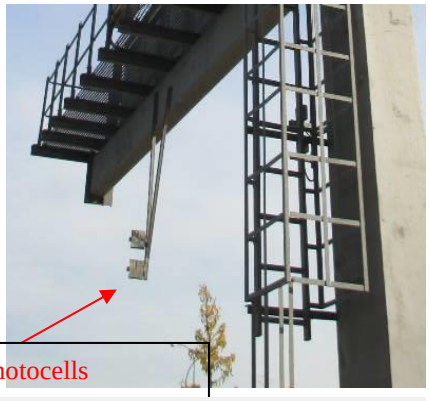

Figure 14 - automatic gauge detection

- **Closed-circuit television (CCTV) and automatic incident detection (AID)**

  At the tunnel´s entrances, there are movable CCTV cameras installed on 15 m high columns. Inside the tunnel there are fixed CCTV cameras spaced between 60 and 80 m. The CCTV system is integrated with the automatic incident detection system (AID), which allows the control centre operators to be informed of any incident on the road (stopped vehicles, traffic jams, pedestrians on the roadway, etc.)

2.5.5 SOS System.

The SOS System consists of 15 posts with IP technology, located every 66 metres on the right side of each direction of traffic and near the amber-amber traffic lights.

2.5.6 Public Access System.

The public-address system has loud speakers of 30 W with a coverage angle of 50° and its amplifiers are located in the technical rooms. There is coverage throughout the inner sections of the tunnel.

2.5.7 Radio Communication

The tunnel's radio communication system provides a service to the radio terminals with the same features as those available outside the tunnel, by extending the radio coverage existing outside the tunnel to the interior thereof. This facilitates communications of the vehicles inside the tunnel, and increases the security inside, as well as enabling communications between the emergency services when an incident occurs inside the tunnel.