TEHRAN RESALAT TUNNEL INNOVATIONS

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ABSTRACT

Due to the increase in vehicle traffic and limited real estate, the construction and complexity of road tunnels are increasing substantially throughout the world. Also, tunnels safety is very important issue.

Nowadays, most of the modern tunnels are equipped with different systems, such as: lighting, fire alarm, fire fighting, closed circuit television (CCTV), emergency telephones, Intercom, barriers, automatic ventilation, traffic counting and lane control and traffic signs.

Tehran Resalat Tunnel has been equipped with the above systems which shall be explained briefly in this paper. In order to reduce the cost of project, some innovations have been considered during the performance.

Keywords: Resalat Tunnel, innovations, Fire protection, CCTV, Cable damage

1. INTRODUCTION

Tehran Resalat Tunnel with 1800m length and two separate tubes was constructed in Tehran in 2006. Tehran is one of the most crowded and polluted cities in the world with about 10 million population and Resalat Tunnel is located at the center of the city. Because of the importance of safe transportation through the tunnel, safety systems were considered for the tunnel.

Forty eight jet fans (30 KW, single speed) were provided for ventilation of the tunnel. One 20/0.4 kV substation which is located at mid distance on top of the tunnel, feeds all of the electrical equipment of the tunnel. We were encountered two issues during tunnel cabling:

- huge number of the cables
- cables damage by vermin

To overcome the first problem and in order to reduce the number of cables, among the different methods of jet fan motor starting (i.e., on line continuous, star-delta, soft-starters and drive system), soft-starters were selected.

To solve the second issue and in order to protect cables damage against vermin, we used perforated cover plates on the cable trays, instead of using armored cables or usage of anti-termite and anti-rodent cables.

2. LIGHTING SYSTEM

Unlike almost all other exterior lighting, tunnel lighting is on generally 24 hours a day; in fact on a sunny day more light is needed in the threshold of a tunnel to give the eye time to adapt from the very high daylight illumination level down to the comparative darkness of the tunnel interior.

Among different kinds of luminaries, high pressure sodium vapour lamp projectors including symmetrical axial reflector were installed in the Tehran Resalat Tunnel. High efficiency and long life are two major benefits of high pressure sodium vapour lamps. High efficiency of the lamps causes less use of lighting fixtures, accordingly energy saving and cost. Because of heavy traffic and high pollution of tunnel weather, the tunnel's luminaries were selected dust tight and jet proof to IP65. The body is made of aluminium, which is first heavily anodized and then powder coated to be anti-corroded in front of humidity and exhaust gas from vehicles.
Road tunnels lighting design is very important. At entry portals, drivers need to quickly adjust to the different intensities between outside and tunnel environments. Drivers must also be able to clearly distinguish other vehicles within the tunnel, which may be masked by the silhouette of larger vehicles towards the exit portal. So, according to the international standards of the CIE (Commission Internationale de Eclairage) (CIE 1984, 1990), we designed 5 lighting zones, the so-called threshold zone, in the transition zone (2 zones), in its interior and in the exit one, for drivers' eye easy adaption.

3. FIRE ALARM SYSTEM

Compared to tunnels for other modes of transport, fire safety problems in road tunnels are more challenging due to specific features of their infrastructure, nature of traffic using them and insufficient safety rules on vehicles. As there are no international valid standards or common views of how to build fire detection systems inside tunnels, the definition of state of the art is very often the subject of individual interpretation by tunnel designers. On the other hand, from a legal point of view, state of the art can be based on relevant publications and experiences which are publically known and accessible.

![Figure 1](image)

Fire detection systems are an essential element of fire protection systems of road tunnels (Figure 1). Fire detectors should provide early warnings of a fire incident at its initial stage and hence facilitate early activation of emergency systems. Their role is crucial in preventing smoke spread in the tunnel, to controlling/extinguishing fires, and to aid in directing evacuation and fire-fighting operations.

There are currently five fire detection technologies that have been used or tested for tunnel protection. They are: linear heat detection systems, flame detectors, CCTV fire detectors, smoke detection systems and spot detectors. The main features of these technologies and their applications in tunnels are listed in Table 1.

Linear heat detection systems are the primary detecting technology used in European tunnels, while flame detectors are mainly used in Japanese tunnels. Sprinklers, as a spot heat detector, are installed in some tunnels around the world. CCTV cameras are already widely applied in tunnels for incident prevention and management. There are significant interests in extending tunnel CCTV cameras into automated fire detection. Roadway smoke detection systems, such as smoke beam detectors and plenum and duct smoke detectors, have a fast response time to a fire incidence, however, false alarm problems associated with diesel engine and ill-maintained vehicle exhaust in tunnels seem to preclude any widespread use of these detection systems in tunnels.
In Tehran Resalat Tunnel, linear sensor heat detectors as well as CCTV detectors have been considered for fire alarm system. Also, manual call points were installed every 100 m through the tunnel, in order to inform the operator of the control room manually by drivers of any probable fire event in case the detection system is out of order.

Sensor cables are combined heat detectors where have been installed through the tunnel in order to measure temperature rate of rise as well as absolute temperature measurement. The sensor cable is capable of operating between -40 ºC to +85 ºC. Also, aggressive exhaust fumes, salts, humidity and fog, dust and dirt, as well as vibration do not influence the functionality of the fire detection system.

### Table 1[4]: Current available tunnel fire detection technologies

<table>
<thead>
<tr>
<th>Detecting principle</th>
<th>Linear heat detection system</th>
<th>Flame detector</th>
<th>CCTV detector</th>
<th>Smoke detection system</th>
<th>Spot detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detecting capability</td>
<td>Heat</td>
<td>Radiation</td>
<td>Image</td>
<td>Smoke</td>
<td>Heat, smoke, gas, etc.</td>
</tr>
<tr>
<td></td>
<td>Moderate response;</td>
<td>Fast response;</td>
<td>Fast response;</td>
<td>Fast response;</td>
<td>Moderate response;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Locating fires;</td>
<td>Locating &amp; monitoring fires;</td>
<td>Locating fires;</td>
<td>Locating fires;</td>
</tr>
<tr>
<td>Reliability</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Moderate to high</td>
</tr>
<tr>
<td>Availability</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate to high</td>
</tr>
</tbody>
</table>

### 4. CLOSED-CIRCUIT TELEVISION (CCTV)

The purpose of the CCTV system is to provide surveillance, security and incident control throughout the tunnel.

Full video surveillance within road tunnels longer with more than 500 m length is now mandatory in Iran. So, video surveillance system has been considered for Tehran Resalat Tunnel to ensure a highest level of safety and fast reaction to emergencies.

The surveillance system includes: fixed and motorized cameras, one switching Matrix, one operator terminal PC base, six CCTV monitors. Twenty one cameras have been installed along the northern and southern tube of the tunnel. Three of the cameras installed at the tunnel portals are mobile and the others are fixed. Each of the cameras is housed in robust, external grade housing and mounted on a locking pan tilt head.

The system is capable of automatically zooming and focusing on each of the internal emergency intercom point, when someone calls the control room. The CCTV cameras have been installed on the right wall of the tunnel at 5 m height; bellow the lights and cable trays.

All the video signals of each three or four cameras are transmitted to the local marshalling box by coaxial cables. In the marshalling box, there is an analogue/digital converter which converts analogue signals of the cameras to digital signals and transmit them to the control building through single mode fiber optic cable.

Video-image processing for fire alarm and incident applications is a major technical innovation. Resalat Tunnel CCTV system has this functionality. The smoke and fire detection with image processing technology was first put to use in 1994 by British companies. Other
systems, use infrared camera with special filters in Germany. The video signal is captured and
digitized with a grabber and, after this, is evaluated with algorithms for flame, smoke and
incident. The image processing result is made available as a pre-alarm or alarm to a fire alarm
or relevant systems and control signals are sent to CCTV system for automatic activation of
specific cameras on monitors.[1]

In order to use image-processing technology in tunnels, the tunnel lighting needs to be
adequate and cameras should be located no more than 100m apart.

5. COUNTING STATIONS

In order to gain information about the incident, number of vehicles, classification, speed,
headway and percentage of road occupancy on each lane, the counting station system has
been provided for Tehran Resalat Tunnel. The system consists of a set of magnetic loop
detectors and detector controller module. The system has been housed in a waterproof
enclosure and laid out in a manner that is ideal for gauging different traffic variables at a
number of counting sites along the road. The detector is able to store data for at least two days
long, which can be inputted into a portable computer when the communication system or
main power fails. The detector controller module is a cabinet forming the counting station.
This cabinet contains:

- A 19", 6U high rack, containing the different electronic cards (e.g. CPU card
  MER330/6, power supply card FAY-267/8, bus card BERD-457, four-channel
detector card TD624ES, communication card
- A mains power module including auxiliary connections, power outlet and main
  protection.
- Transformer and line filter.
- Knife disconnects terminal blocks for the detectors.

Loop detector cable is a copper conductor with ethylene propylene rubber insulation and 2.5
m m² cross section which has been laid in a groove made in the pavement and sealed with
epoxy resin bitumen.

The function of the system is so that detector controller module detects vehicle presence by
means of an inductance change caused by the vehicle passing over a loop buried in the road
surface.

The functional traffic parameters which are measured are as follows:

- Intensity (flow): number of vehicles on the road over a given period of time.
- Occupancy: percentage of time a vehicle remains within the metered area.
- Headway: distance between two consecutive vehicles
- Speed: average speed Kmh⁻¹

6. VENTILATION CONTROL SYSTEM

The ventilation system consists of 48 jet-fans distributed along the Resalat Tunnel which have
been installed in two tunnels of different traffic direction (30 jet-fans in the north tube and 18
jet-fans in the south tube). The air flow which has to be moved, is determined by "CO
emission", "opacity" and "fire".

The ventilation control system has been designed considering the following patterns:

- Keeping the tunnel environment within the traffic security criteria
- Making the power consumption and operational costs reasonably economical
- Convenient management.

The criteria of Resalat Tunnel ventilation control system design has been given in table 2.
Table 2: Criteria of ventilation control system design\textsuperscript{[6]}

<table>
<thead>
<tr>
<th>Traffic Situation</th>
<th>CO concentration (ppm) (PIARC 1995)</th>
<th>Extinction coefficient K (k m(^{-1})) (BD 78/99)</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid traffic above 50 k m(^{1})</td>
<td>100</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Seldom congested</td>
<td>150</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Tunnel enclosure necessary</td>
<td>250</td>
<td>12</td>
<td>Within 5 min.</td>
</tr>
</tbody>
</table>

Environmental components used for the Resalat Tunnel operational system are as follows\textsuperscript{[3]}:
- Co and Visibility (VI) Sensors
- Wind Sensors

The CO and VI sensor housing has been made of an anti-corrosive and durable material with a protection degree of IP65. Two sets of opto-electronic CO-VI detectors have been installed in each tunnel tube. Each measuring point comprises a pair of sensors mounted directly on the tunnel wall, separated by 10m. Five levels have been set to control "CO" and "Opacity" of tunnel air pollution by means of jet fans.

CO Levels:
- CO\(_{\text{low}}\) 0 PPM < CO < 25PPM
- CO\(_{\text{medium-low}}\) 25 PPM < CO < 50 PPM
- CO\(_{\text{medium}}\) 50 PPM < CO < 75 PPM
- CO\(_{\text{medium-high}}\) 75 PPM < CO < 100 PPM
- CO\(_{\text{high}}\) 100 PPM < CO < 150 PPM
- CO\(_{\text{very high}}\) 150 PPM < CO < 200 PPM
- CO\(_{\text{dangerous}}\) 200 PPM < CO < 250 PPM

Opacity Levels:
- OP\(_{\text{low}}\) 0 K m\(^{-1}\) < OP < 4 K m\(^{-1}\)
- OP\(_{\text{medium-low}}\) 4 K m\(^{-1}\) < OP < 5 K m\(^{-1}\)
- OP\(_{\text{medium}}\) 5 K m\(^{-1}\) < OP < 6 K m\(^{-1}\)
- OP\(_{\text{medium-high}}\) 6 K m\(^{-1}\) < OP < 7 K m\(^{-1}\)
- OP\(_{\text{high}}\) 7 K m\(^{-1}\) < OP < 9 K m\(^{-1}\)
- OP\(_{\text{very high}}\) 9 K m\(^{-1}\) < OP < 10.5 K m\(^{-1}\)
- OP\(_{\text{dangerous}}\) 10.5 K m\(^{-1}\) < OP < 12 K m\(^{-1}\)

In case of fire, air speed inside the tunnel should be kept between 3 m s\(^{-1}\) and 5 m s\(^{-1}\), in order to evacuate the gases from the tunnel perfectly. So, jet-fans are adjusted by control system. The air speed of tunnel is measured by wind sensor. The 4-blade poly propylene propeller wind sensor has been installed in the Resalat Tunnel to measure directional air currents in the tunnel.

7. POWER SYSTEM

One 20/0.4 KV substation which has been located at mid distance on top of the tunnel, feeds all of the electrical equipment of the tunnel. The power distribution network of the tunnel is divided into normal and emergency sections. In normal conditions, all of the equipments are being fed from two 1600 KVA, 20/0.4 KV, ONAN transformers. Transformers are being fed from a 20 KV ring distribution network of Tehran. In case of any failure in normal distribution network, one 1200 KW emergency diesel generator feeds all of the necessary equipments such as fire alarm and protection systems, half of the lighting system, control and
monitoring systems and a number of the jet-fans which are necessary at fire condition. Moreover, an uninterruptable power supply system (UPS) feeds some systems such as emergency telephone system, fire alarm system, CCTV, servers and part of the lighting system.

Cabling between 20/0.4 KV substation and two tubes of tunnel has been done through a cable shaft. We encountered two issues during cabling:

1. huge number of the cables
2. cables damage by vermin

7.1. Huge number of the cables

Most of the cables feed ventilation and lighting systems. In order to reduce the current consumption of the lamps, lighting fixtures have been equipped with correction factor capacitors. So, the size of cables reduced.

At starting condition, jet-fans take current 6 times more than normal operation. So, it leads to be increased the size of the cables. There are 4 methods for motor starting which are: on line continues (D.O.L), star-delta, drive system (frequency convertors) and soft starter.

**Direct-on-line start (D.O.L)**[8]

This is by far the most common starting method available on the market. The starting equipment consists of only a main contactor and thermal or electronic overload relay. The disadvantage with this method is that it gives the highest possible starting current. A normal value is between 6 to 7 times the rated motor current but values of up to 9 or 10 times the rated current exist. Besides the starting current there also exists a current peak that can rise up to 14 times the rated current since the motor is not energized from the first moment when starting (figure 2). High starting current leads to an increase the size of cables and switches.

![Figure 2: Current curve at D.O.L and Torque/speed curve at D.O.L start](image)

During a direct-on-line start, the starting torque is also very high, and is higher than necessary for most applications. The torque is the same as the force, and an unnecessary high force gives unnecessary high stresses on couplings and the driven application.

**Star-delta start[8]**

This is a starting method that reduces the starting current and starting torque. The device normally consists of three contactors, an overload relay and a timer for setting the time in the star-position (starting position). The motors must be delta connected during a normal run, in order to be able to use this starting method. The received starting current is about 30 % of the starting current during direct on line start and the starting torque is reduced to about 25 % of the torque available at a D.O.L start (figure 3). This starting method only works when the application is light loaded during the start. If the motor is too heavily loaded, there will not be enough torque to accelerate the motor up to speed before switching over to the delta position.
To reach the rated speed, a switch over from star to delta position is necessary, and this will very often result in high transmission and current peaks. In some cases the current peak can reach a value that is even bigger than for a D.O.L start. Also, in star-delta starting, two series of cables, three cables for star-position and three cables for delta-position to be laid between electrical panel and motor. So, it leads to huge number of cables.

Figure 3:

a. Torque/speed curve at Star-Delta start  b. Current curve at Star-Delta start

**Frequency converter**[8]

The frequency converter is sometimes also called VSD (Variable Speed Drive), VFD (Variable Frequency Drive) or simply Drives, which is probably the most common name. The drive consists primarily of two parts, one which converts AC (50 or 60 Hz) to DC and the second part which converts the DC back to AC (0-250 HZ). As the speed of the motor depends on the frequency, this makes it possible to control the speed of the motor by changing the output frequency from the drive and this is a big advantage if there is a need for speed regulation during a continuous run. By controlling the frequency, the rated motor torque is available at a low speed and the starting current is low, between 0.5 and 1.0 times the rated motor current, maximum 1.5 x In. Disadvantage of drive starters is that the method is very expensive and there is no need for speed regulation during a normal run.

**Softstarter[8]**

A softstarter has thyristors in the main circuit, and the motor voltage is regulated with a printed circuit board. The softstarter makes use of the fact that when the motor voltage is low during start, the starting current and starting torque is also low. During the first part of the start the voltage to the motor is so low that it is only able to adjust the play between the gear wheels. In other words, eliminating unnecessary jerks during the start. Gradually, the voltage and the torque increase so that the machinery starts to accelerate (figure 4). One of the benefits of this starting method is the possibility to adjust the torque to the exact need. This method reduces maintenance costs. So, we used this method for jetfans starting for our project to balance the costs and reduce the number of cables.

Figure 4:

a. Torque/speed curve - Softstarter  b. Current curve - Softstarter
7.2. Cable damage by vermin

The common method to repel rodents and termites from cables is use of metallic armour or glass roving cables. Disadvantage of this method is that armoured cables are expensive and for the projects such as tunnels, length of the cables is very high and it leads to an increase in the cost of the project. Also, cabling and bending of armoured cable is very difficult.

The second method is use of anti-termite and anti-rodent cables. This method is a good solution to protect cables from hostile animals. Some chemical, non-hazardous, non-toxic additives are used within the jacket polymer. Usually, for an effective anti-rodent and anti-termite, a layer of corrugated steel tape is formed between two polyethylene jackets. So, this method problem is similar to the first method.

In Tehran Resalat Tunnel project, we used un-armoured fire resistance, low smoke, halogen free cables on the cable trays. In order to protect cables against rodents, we used cover plates on the cable trays. Meanwhile, perforated cover and cable trays have been used in our project, in order to circulate the air within cover and cable tray. Use of the cover plates and un-armoured cables instead of armoured cables, decreased the cost of the project. Easier cabling was another benefit of this method.

8. OTHER SYSTEMS

Moreover, fire fighting, traffic signs, emergency telephones, intercom, barriers, over height detectors, lane control signs, speed control signs and variable control signs have been considered for the Tehran Resalat Tunnel.

9. CONCLUSIONS

In this paper, a brief explanation about the systems of Tehran Resalat Tunnel was presented. It was quoted that soft starters are the best method for jet-fan starting. Also cabling with un-armoured cables through bottom ventilated cable trays with perforated cover plates is the best solution to protect cables against rodents.

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