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RECOMMENDATIONS TOWARDS THE STANDARDIZATION OF THE VENTILATION EQUIPMENT IN ROAD TUNNELS

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ABSTRACT

The road tunnel safety regulations specify the requirements of the ventilation system to achieve an acceptable level of risk in the tunnel, but they do not provide specific guidelines about the standardization of the equipment to be installed. This is an important point that must be taken into account to reduce the life cycle cost of the ventilation equipment throughout its lifetime, improving its maintainability, compatibility and integration with other systems. The present paper summarizes the outcome document, recently released by the Spanish National Committee of PIARC, assessing minimum requirements and recommendations towards the standardization of the ventilation equipment in road tunnels and the advantages linked to this standardization.

Keywords: Standardization, Ventilation Equipment, Maintenance, Integration, Life Cycle Cost.

1. INTRODUCTION

The safety requirements in road tunnels have been significantly increased in the latest years. The directives, laws and regulations that rule safety in tunnels have been focused in specifying the safety levels that must be guaranteed, as well as the systems that are needed to be installed to achieve these levels. However, they do not embrace other important matters related to the standardization of the equipment, its maintainability, compatibility and integration with other systems. These issues must also be considered to ensure a reliable performance of the equipment along its operational life, paying especial attention to the aggressive environment existing in most of the road tunnels.

Taking into account the above considerations, the Spanish Tunnel Committee of PIARC decided to set up several “standardization” Working Groups, each one focused on a different tunnel system. The objective of these WGs is to develop documents with baseline recommendations about the functional characteristics and the requested values that should be specified for each electro-mechanical equipment to be installed in the tunnel.

Among all different electro-mechanical systems in road tunnels, the ventilation is probably the most critical one to guarantee the safety and comfort of the users. In addition, the ventilation system takes up a substantial part of the total investment in tunnel installations, it has a significant energy consumption during normal tunnel operations and it also takes most of the budget and resources assigned for equipment maintenance.

2. DOCUMENT ON STANDARDIZATION OF VENTILATION EQUIPMENT

2.1. Considerations for standardization assessment

Under the coverage of the ATC (Spanish Tunnel Committee of PIARC), a Working Group for standardization of ventilation equipment in road tunnels was established in October 2018. The WG included 26 professionals from 17 different companies and organizations involved in the tunnel industry. The objective of the Working Group was to develop a useful and practical guideline document with recommendations towards the standardization of the ventilation equipment [1].

To facilitate the standardization assessment, the ventilation machinery was classified in four main categories according to its functionality, with different types of equipment in each category, as shown in figure 1.

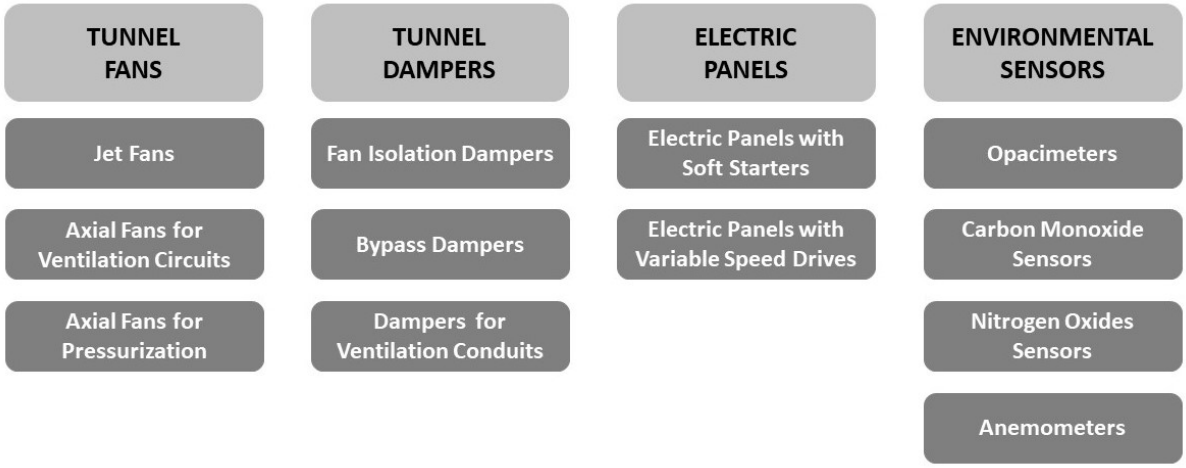

Figure 1: Ventilation equipment classification

Following this classification, the most important technical characteristics of each type of equipment were analysed and recommended values were defined to guarantee its functionality and its durability in the tunnel environment. Some technical characteristics were equally relevant to all the types of equipment on the same category, while others were applicable only to one type of equipment. As an example, the corrosion resistance has been assessed for all the equipment to class C5 according to ISO 12944 [2], as this is the most predictable environment inside the tunnels.

Tunnel fans were the machinery with more possibilities for being standardized. Over sixty technical characteristics were identified and assessed for their standardization, providing suitable values and recommendations. These characteristics were gathered in the following areas (between brackets the number of characteristics subjected to standardization in each area):

1. Electric motor parameters (12)
2. Devices for control and monitoring (6)
3. Junction boxes for power supply and signals (7)
4. Power supply cables (3)
5. Aerodynamic performance (5)
6. Impeller balancing (3)
7. Sound level (2)
8. High temperature resistance (2)
9. Corrosion protection (1)
10. Quality of materials (3)
11. Fan types (12)
12. Installation in tunnel (9)

Regarding tunnel dampers were identified the following areas where several characteristics were assessed for standardization:

1. Installation in tunnel (3)
2. Typology, size, and modules (6)
3. Aerodynamic performance (4)
4. Actuators and operating system (17)

5. High temperature resistance (4)
6. Corrosion protection and quality of materials (9)

With respect to electrical panels the use of variable speed drives (VSD) was recommended to start-up and control the tunnel fans. VSDs provide a smooth start-up of the motor and reduce the power consumption by adjusting the rotational speed of the fan to the requested ventilation performance at each moment, as a result, significant savings in electric power consumption are achieved. VSDs can also control the electrical parameters and the signals from the fan. Soft starters were proposed as a lower cost alternative to VSDs. The use of direct on line starting for the fans was rejected.

Regarding environmental sensors, different technologies were assessed and minimum technical requirements were defined.

2.2. Engagement of the stakeholders

The standardization of the ventilation equipment is a joint task that should involve all stakeholders of the tunnel project. These are some recommendations to be followed for achieving a certain level of standardization on the equipment.

- Consultants and designers: During the design stage of the ventilation system, standardization criteria should be used to specify the equipment, for example minimizing the number of different models for the same type of equipment, especially in the case of fans.
- Contractors: During project execution the standardization criteria used at the design stage must be maintained, avoiding changes based exclusively in economic considerations. Standardization principles shall also be followed for any project requirement that has not been clearly defined in the design, such as possible additional accessories on the main equipment.
- Equipment manufacturers: All units of equipment of the same type must be manufactured with consistency in their uniformity. Manufacturers must facilitate the interchangeability of spare parts for similar types of equipment. In addition, the availability of spare parts must be ensured throughout the lifetime of the equipment. It is advisable that equipment manufacturers take an active role with proposals that could improve the standardization.
- Maintenance Teams: The maintenance of the equipment must be carried out by qualified personnel, using recommended original spare parts. The level of standardization of the installed equipment must be kept along all its lifetime, avoiding replacement of parts or components that can generate exceptions or singularities.
- Tunnel owners: They are the ones who should promote and demand standardized ventilation equipment, taking advantage of all the related benefits, optimizing the tunnel management and reducing costs.

3. ADVANTAGES OF THE VENTILATION EQUIPMENT STANDARDIZATION

3.1. Maintenance optimization

Maintenance of the tunnel installations ensures the durability and good performance of the equipment over the years. There are two types of maintenance to be considered:

- Preventive (planned) maintenance. It is related to routine activities carried out on the equipment to guarantee the reliability during all its lifetime.

- Corrective maintenance. It includes all those activities that are carried out to set back in operation any equipment that has been damaged. This type of maintenance is carried out as a matter of urgency because the detection of any anomaly or dysfunction in the equipment or installation may affect to the tunnel safety.

The standardization of the ventilation equipment optimizes both types of maintenance activities. The standardization must be oriented to increase the quality of the equipment to be standardized. Following this principle, the installation of standardized equipment with higher quality will result in less maintenance requirements and the implementation of more effective maintenance procedures. Furthermore, a standardized ventilation equipment reduces the quantity and variety of spare parts that must be kept in stock to face any replacement during maintenance. Corrective maintenance activities are also reduced as the installation of higher quality equipment leads to lower rate of failures.

On the other hand, equipment standardization also leads to a "Maintenance Standardization". A reliable maintenance programme can be scheduled based on standardized equipment parameters that have been previously assessed. The periodicity of preventive maintenance can be adjusted to the real equipment conditions, avoiding unnecessary stoppages on the tunnel.

Ventilation equipment with highly standardized characteristics will simplify the maintenance training. Equipment from different manufacturers will be subjected to uniform maintenance training courses as their characteristics will be the same.

3.2. Streamlined technical specifications

Each tunnel project requires a bespoke design of its ventilation system, and the ventilation equipment specifications are based on that design. Most of the times, the ventilation equipment is selected according to one of these practices:

- Brief and general specifications. They are outlined by the designer of the tunnel ventilation system, leaving technical details of the equipment to relevant regulations (PIARC guidelines, handbooks, …) and ultimately to the Contractor. Any lack of definition is usually solved based on economic criteria. In the absence of a design obligation, the cheapest option is usually chosen.
- Very detailed specifications. They are included as part of the ventilation design. This generates an additional workload in the design phase. The result is often a very rigid specifications that complicates their practical implementation in the tunnel. Once the design has been approved, it is very difficult to implements any modification, if it would be needed. The equipment specifications must satisfy the design criteria and be suitable for the tunnel conditions but taking especial care that the technical requirements of the equipment are not oversized.

A reference document providing recommended standardized values for the main equipment characteristics could be a useful tool to assist the ventilation designers in the task of issuing consistent equipment specifications. It would also avoid equipment selection based on lowest price criteria and barely compliance options, due to unspecified ventilation equipment characteristics.

3.3. Constructability and durability

Standardized ventilation equipment allows simple installation procedures and methods of statement, saving time for installation and on-site testing and reducing their related costs.

The equipment standardization shall facilitate the onsite constructability of the ventilation system under severe space restrictions. It should also be considered to keep enough space around the equipment for installation and maintenance activities, as well as possible replacements of the equipment or some parts during its operational life.

The parameters related to durability of the ventilation equipment has been standardized to withstand the harsh tunnel conditions.

3.4. Compatibility and integration with other systems

The ventilation is one of the most critical systems in the tunnels, therefore it must be compatible and perfectly integrated with other systems.

The interface between the ventilation equipment and the ventilation control system must be fail-safe to guarantee the reliability of the whole system and the tunnel safety.

The signals to be provided by the ventilation equipment to the control system must be standardized, as well as the protocols of communication between the local control panels and the control system. Clear mapping of the signals to be managed must be defined on the ventilation design.

The ventilation control system must collect and record updated data coming from the ventilation equipment (tunnel fans, dampers, electric panels and sensors) being some of these data the input signals for the ventilation algorithms. Data collection should be made according to pre-defined sampling times. It is recommended a statistic analysis of these data, as they can provide valuable information about equipment performance, optimising its maintenance and extending its operative lifetime.

3.5. Improvements in Life Cycle Cost Analysis

The directives of the European Union and the Administrations of many countries have been paying attention, since years ago, to the economic cost of infrastructures construction, maintenance and operation throughout their lifetime. In this sense, the European Union Directive 2014/24/EU on public procurement [3] and other national regulations stimulate or directly dictate to consider the Life Cycle Cost as a key factor for awarding public contracts.

Life Cycle Cost (LCC) is defined as the total cost of ownership related to acquisition, operation and maintenance over the life of the infrastructure system and is the actual cost that the buying organization will have to bear during the years that the system will be in operation. For most electro-mechanical systems maintenance costs increase over time, while the residual value of installed equipment decreases. Infrastructure owners must ensure that their total cost of ownership is as low as possible.

The figure 2 shows a typical example of how is divided the total life cycle cost of a ventilation system considering a lifetime of 25 years. The operational cost, mainly the electricity consumption, is the highest one, followed by the acquisition and maintenance costs, being marginal the resell value.

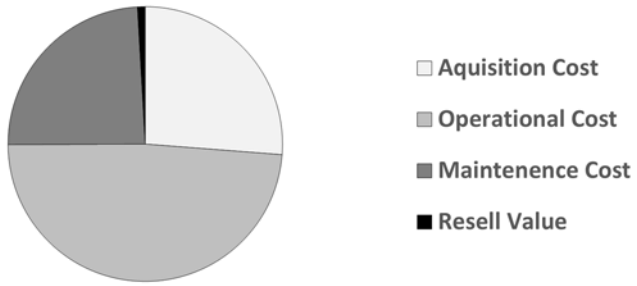

Figure 2: Typical LCC share for a Tunnel Ventilation Project

The acquisition costs are easy to calculate as they are directly related to the purchasing price of the ventilation equipment. In most of the cases the standardization upgrades the technical characteristics of the ventilation equipment increasing its acquisition cost, in any case, this negative consequence is compensated by the reduction of the other costs. One example could be the recommendation for using variable speed drives to operate the fans: the purchase of these devices increases the acquisition cost but the savings in power consumption reduces significantly the operational cost and therefore, the life cycle cost of the ventilation system is significantly lower.

The operational cost involves all the expenses needed for the operation of the ventilation system. Among all these expenses the electricity consumption is by far the highest one. The standardization must be oriented towards the use of higher efficiency equipment, setting a minimum rate of output performance per kilowatt.

The maintenance costs are the ones more directly related to the equipment standardization. An important drawback to get a reliable LCC analysis is how to estimate realistic costs of preventive and corrective maintenance. These costs are the most uncertain ones, as the preventive maintenance depends on manufacturer's recommendations and the corrective maintenance on the MTBF (Mean Time Between Failures) of the equipment, also to be provided by the manufacturer.

Although the equipment has to comply with mandatory technical specifications, there are many parameters that are subjected to the manufacturer criteria, therefore the maintenance requirements cannot be fairly assessed and subsequently the level of uncertainty on its associated costs is very high. Similar situation occurs on the MTBF, which also rely on manufacturer's information. On the contrary, when the main parameters of the ventilation equipment have been standardized, the maintenance requirements can be established according to uniform criteria for all the manufacturers.

To illustrate the positive impact of the equipment standardization and the use of VSDs on the LCC a case study of a motorway tunnel with longitudinal ventilation system has been assessed. The LCC analysis was made for 32 jet fans during 25 years of operational life and considering two different scenarios:

- with standardization and using VSD.
- without standardization and direct on line starting.

The inputs for the calculations were based on rough estimates and cost assumptions. The results are shown in figure 3.

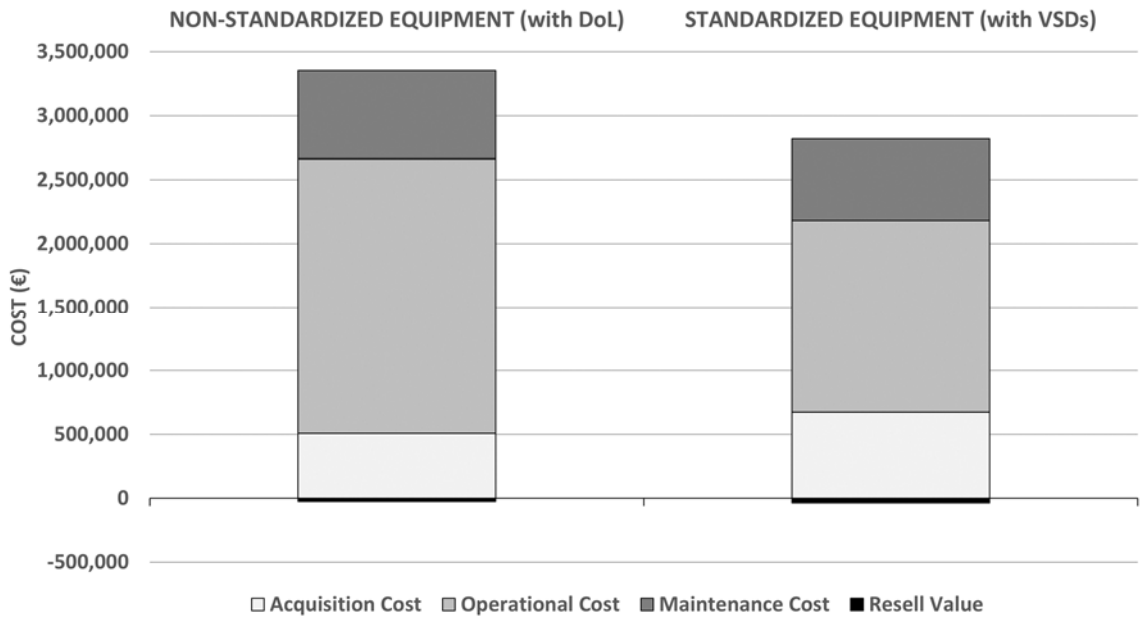

Figure 3: Example LCC of Tunnel Ventilation Equipment (25 years)

4. SUMMARY AND CONCLUSIONS

It has been noted the necessity of improving the standardization of the electro-mechanical equipment installed in road tunnels, being the ventilation one of the systems with more possibilities to be standardized. In this regard, a guideline document with recommendations towards the standardization of the ventilation equipment has been prepared by a Working Group under the Spanish Tunnel Committee of PIARC. The equipment standardization is a joint task that must involve all the stakeholders in a road tunnel project. The common goal must be to achieve a maximum level of standardization not only in a single tunnel, but also among all the tunnels in a road network.

The standardization of the ventilation equipment improves the constructability, durability of the whole ventilation system and its integration with other systems. It improves and facilitates the development of technical specifications for ventilation systems at the design stage of a road tunnel project. Furthermore, if the main technical characteristics of the ventilation equipment are standardized, the task and periodicity of the maintenance activities can be adjusted to the real needs of the equipment. This leads to a cost-cutting on the budget assigned to maintenance and a significant reduction on the life cycle cost of the equipment.

5. REFERENCES

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[3] Directive 2014/24/EU of the European Parliament and of the Council of February 26, 2014.