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COMBINED THERMAL AND ACOUSTIC DESIGN OF ENCLOSURES FOR OUTDOOR APPLICATIONS

Edoardo A. Piana[1*] **Jorge Joaquin Garcia**[1]
Diego Tonetti[1] **Roberto Spezie**[2]

[1] Applied Acoustic Laboratory, University of Brescia, Italy
[2] TERNA Rete Italia S.p.A., Rome, Italy

ABSTRACT

One of the most effective methods to control the noise spreading of sound sources is to put them inside sound-absorbing/insulating enclosures. When such sources also generate a certain amount of heat, the panels separating the source and the receiver must be provided with ventilation openings that can greatly reduce the effectiveness of the enclosure from an acoustic point of view. The issue gets significantly more difficult if the system must be installed outdoors and only natural convection is to be used, as this requires taking into account the effects of wind, air temperature, and solar radiation. All these factors usually require increasing the dimensions of the openings and then a lower sound attenuation. The framework used to conduct a combined thermodynamic and acoustic investigation on a high-voltage device that produces impulsive sound and is intended for placement in residential areas is described in this paper.

Keywords: *high voltage switchgear, dynamic thermal analysis, sound insulation, noise spreading.*

1. INTRODUCTION

The availability of electricity and the possibility of dispatching it in a safe and sensible way, depending on the customers' needs, is becoming fundamental. In the past years, TERNA Rete Italia S.p.A. developed a number of solutions to improve the lines capacity [1] and to maintain the network with real-time operations [2].

In this framework, the new Compact Pole System (CPS) project was recently presented. The idea is to be able to install the switchgear needed for the operations also in urban areas, close to the receivers. Being the switches high-voltage elements that need to be protected from undesired access and based on mechanical parts producing impulsive noise, it is important to place these elements inside an enclosure. On the other hand, the heat generated by the high-voltage elements needs to be dissipated outside the volume of the enclosure. A further difficulty is that the CPS could be placed in any type of environment. This means that it must withstand not only low temperatures, but mainly the components must be able to survive the typical summer temperatures and the heat caused by the radiation of the sun. In this framework, it is necessary to perform a thermal study that considers not only the environmental variables but also the thermal characteristics of the materials used to assemble the building. Moreover, some openings are necessary to guarantee the heat exchange, and such openings must be small enough to avoid noise spreading from the switchgear to the surrounding area.

The paper is organized as follows: Section 2 describes the building where the CPS is located, and the thermal/sound sources placed inside. Section 3 shows the thermal model implemented in Energy+. Section 4 illustrates the acoustic model for the noise spreading. Section 5 discusses the thermal and acoustic results. Finally, Section 5 concludes the work.

**Corresponding author*: edoardo.piana@unibs.it.

2. DESCRIPTION OF THE CSP BUILDING AND OF THE THERMAL/ACOUSTIC SOURCES

The system is made of:
- a main volume, containing the switchgear and the accessories, called the GIS room;
- some panels with aesthetic functions, placed at 40 cm from the GIS room walls;
- a steel framework;
- a shelter containing the accessory devices.

Figure 1 shows an outline of the system.

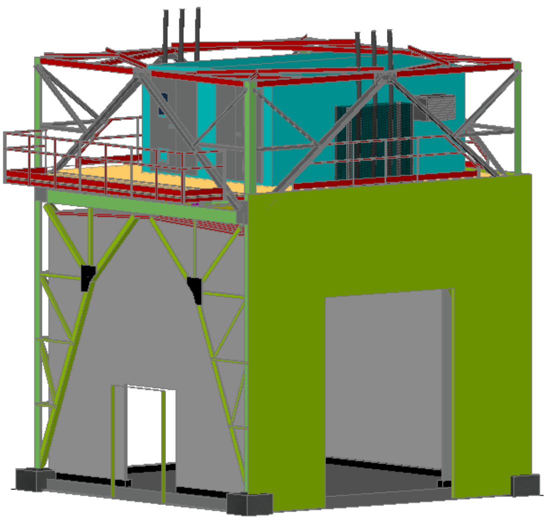

Figure 1. 3D outline of the system.

The green panels of Figure 1 are placed in the lower part of the trellis and have an aesthetic purpose. They are attached to the trellis beams and conceal a second set of inner panels, forming the vertical walls of the GIS room. The big hatch is normally closed and is used for the maintenance of the switchgear placed inside, while the small door is used for the access of the personnel. Above the GIS room is placed a small shelter, hosting the control and service devices.
The foot plant of the GIS room is 8 x 8 m^2, with a height of 6.5 m. To guarantee a sufficient number of air changes per hour due to natural convection, and thus the cooling of the high voltage devices, some openings are placed on two opposite sides of the room. These openings, represented in Figure 2, are:
- two inlets, placed in the lower part of the front side (dimensions 3.125 x 0.5 m^2);
- an outlet, in the higher part of the panel opposite the one where the inlets are located (dimensions 0.675 x 7.0 m^2).

The inlets are symmetrical to the vertical centreline of the panel. The openings will be protected by grilles, introducing a pressure drop of about 20 Pa. The position and dimensions of the openings have been decided after some fluid dynamic simulations carried out with COMSOL Multiphisics® in order to obtain a fair distribution of the air flows inside the GIS room.

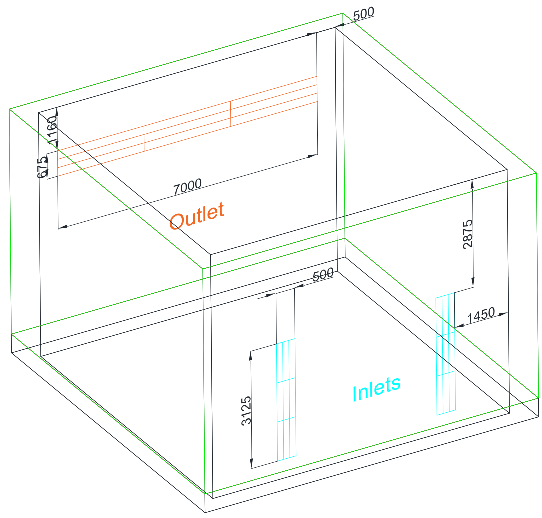

Figure 2. Positions of the inlets and the outlets.

3. THERMAL MODEL

The CPS will be subject to interactions with the environment: temperature changes, radiation of the sun, and wind. All these elements change with time and are a function of the location selected for the system. Using a finite element model such as COMSOL to predict the thermal behavior of the system is particularly challenging if the effect of non-stationary weather conditions must be captured. For this reason, after performing a validation of the COMSOL model [3], it was decided to switch to EnergyPlus. This software allows an estimation of the temperature inside the GIS room in non-stationary conditions. For this reason, EnergyPlus takes into account both the thermal conductivity and the thermal capacity of the walls. The assumptions adopted for the simulations are the following:
- Location: Catania. The weather data have been retrieved from those available from the local airport.
- To consider the increase of the temperature due to global warming, the weather data have been morphed to

simulate the conditions in 2050 (https://energy.soton.ac.uk/ccworldweathergen/)
- Time span for the calculation: solar year (01 January – 31 December)
- Time step: hour + day
- Aesthetic panels: trapezoidal steel sheet 1 mm; rockwool, density 70 kg/m^3, thickness 78 mm; perforated sheet steel, thickness 1 mm – overall thickness 80 mm.
- GIS room panels: trapezoidal steel sheet 1 mm; rockwool, density 70 kg/m^3, thickness 48 mm; perforated sheet steel, thickness 1 mm – overall thickness 50 mm.
- Distance between the aesthetic walls and the walls of the GIS room: 400 mm
- Height of the aesthetic panels from the floor: 500 mm
- Model used for the airflow in EnergyPlus: Airflow Network
- WindPressureCoefficientArray computed using fluid dynamic simulations (Figure 3) carried out on the system for 5 different angles of incidence of the wind on the structures (Table 1).

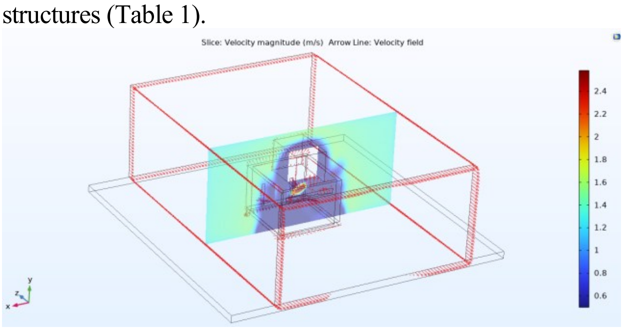

Figure 3. Example of fluid dynamic simulation for the computation of the wind pressure coefficients.

Table 1. Wind pressure coefficients.

	Wind pressure coefficients	
Angle of incidence	Inlet	Outlet
0	-1.99636	-1.09497
23	-1.08254	-0.14105
45	-5.79697	.1026984
68	0.38094	0.610374
90	0.14567	0.824607

- Thermal power to be dissipated in the GIS room: 5300 W
- The assumptions made allow us to consider also the effect of the wind
- The temperature computed by EnergyPlus must be intended as the average temperature inside the GIS room

4. ACOUSTIC MODEL

After defining the thermal characteristics of the CPS, it is possible to move on to the acoustic simulations. First, it is necessary to feed the simulation program with the acoustic emission characteristics of the source. For this purpose, the measurements conducted in the field for the switchgear of a specific supplier were used. On that occasion, the sound energy during the opening (O) and closing (C) events of the actuators was estimated. These characteristics were then composed to obtain the sound energy of an OCO+2CO event. Based on the hypotheses made with TERNA regarding the standard operations, this sequence occurs every 15 minutes.
As regards the sound power level to be associated with the sources was:

- Event power level OCO+2CO in 15 minutes = 93.2 dB(A)
- Event power level OCO+2CO diluted in 8 hours (night period) = 84.2 dB(A)

The spectrum associated with the events is reported in Figure 4, representing the average sound pressure level measured on the envelope surface during the tests.

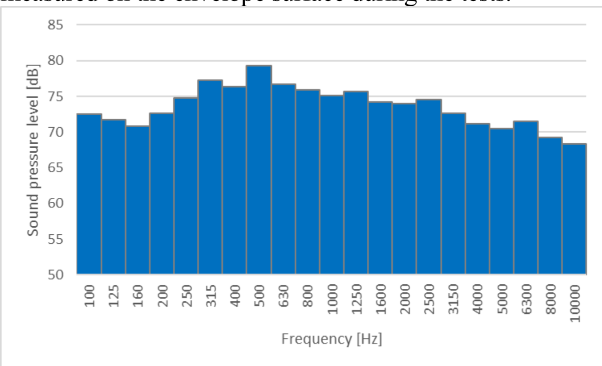

Figure 4. Spectrum used for the power levels.

The characteristics of the panels were derived, based on what was established for the thermal part, from the Metecno catalog for the "Wall Panel" type of products with the thicknesses indicated in the previous section. Figure 5 and Figure 6 show the graphs of the sound absorption and sound insulation offered by the Metecno panels respectively. These values were inserted into Ramsete to carry out simulations of the sound pressure level propagating outside the GIS room. The software can consider the diffraction effect and the transmission effect at the same time.

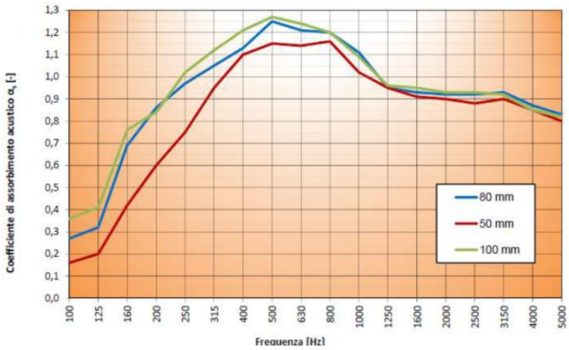

Figure 4. Sound absorption of the panels.

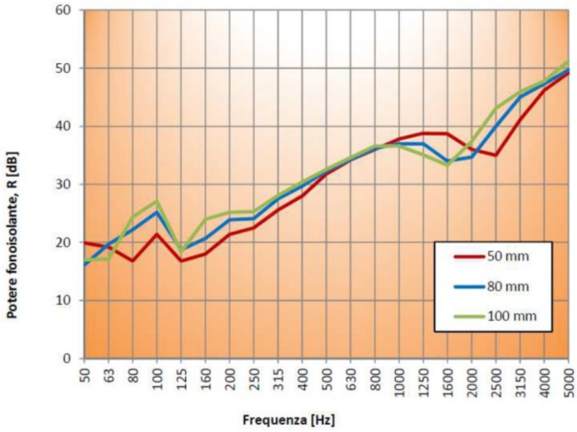

Figure 5. Sound insulation of the panels.

In Ramsete, the following assumptions were adopted:

- Insulation of the GIS room panels equal to that of the 50 mm Metecno panels
- Insulation of the openings equal to 0 dB
- Absorption of the GIS room panels and aesthetic panels equal to the absorption declared for the 50 and 80 mm panels
- Calculations at the receivers made at distances of 15 and 30 m and at heights of 2 m, 5 m, 8 m and 11 m.
- Distribution of sound pressure levels symmetrical to the axis that joins the two faces with the vents (only the series of receivers placed on the right side will be considered)

5. THERMAL AND ACOUSTIC RESULTS

Figure 6 shows the average temperature inside the GIS room on a 1-hour basis during the year. The limit temperature given by the company making the switchgear is 40 °C. It can be observed that this temperature is exceeded only in limited times:

o at 14.00 - 06 July (T_in=40.0 °C) with an outdoor temperature T_out=37.1 °C

o at 11.00 - 9 August (T_in=40.5 °C) with an outdoor temperature T_out=37.7 °C

o at 11.00 - 18 August (T_in=40.3 °C) with an outdoor temperature T_out=37.4 °C

Moreover:

- The thermal inertia of the panels leads to a phase shift in the thermal load due to solar radiation
- The maximum air speed in the inlet openings corresponds to 0.3 m/s for a volumetric flow rate of approximately 0.5 m^3/s

Since suppliers also ask not to exceed 35 °C of average temperature during the 24 hours, in Figure 7 the annual trend of the average daily temperatures is reported. The limit value of 35 °C is never exceeded.

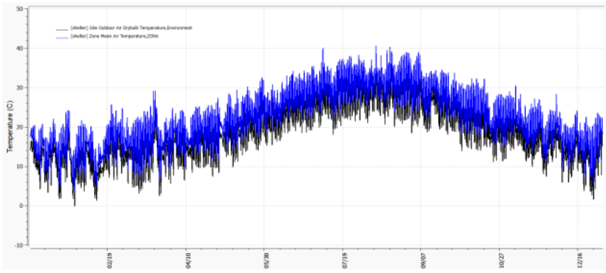

Figure 6. Indoor (blue line) and outdoor (black line) profiles with 1 hour time step.

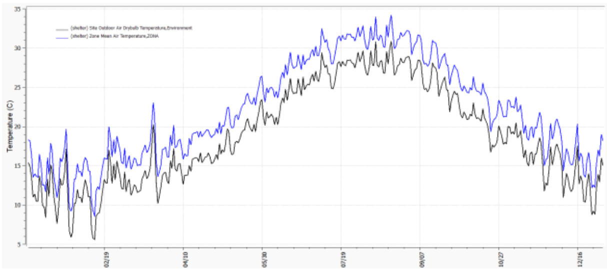

Figure 7. Indoor (blue line) and outdoor (black line) profiles with 1 day time step.

As concerns the acoustic results, Figure 8 shows the result of the simulation made with Ramsete. According to Italian legislation, the results of the simulations were compared to the emission, immission, and differential limits.

- Emission: is to be intended as the sound pressure level emitted only by the specific sound source to be investigated
- Immission: is the energetic sum of the sound pressure level emitted by the specific sound source that is intended to be investigated with the background sound pressure level

- Differential: difference between the immission levels and the background noise level (algebraic difference)

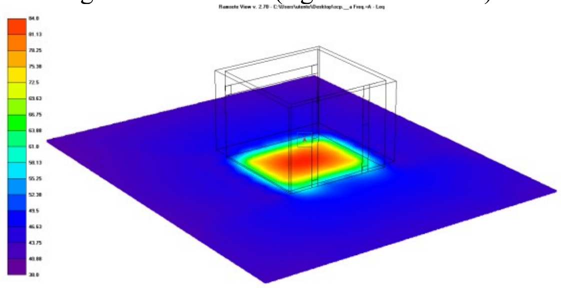

Figure 8. Sound pressure level computed by Ramsete.

The emission and immission limits are a function of the acoustic class being investigated and must be evaluated by diluting the source's contribution over the 16 hours for the daytime period (6-22) and 8 hours for the night-time period (22-6). The tables below provide the limit values and the predicted ones. The limits are based on the acoustic classes established by the Municipality where the installation will take place.

The differential must instead be evaluated in correspondence with the living environments and must not exceed 5 dB during the day and 3 dB during the night.

Table 2 shows, for the various measurement points considered, the values of the sound pressure levels estimated by the calculation code for the dilution of an event in 8 hours and for 15 minutes.

Table 2. Emission values and comparison with the legislation limits. A green cell indicates the limits are fulfilled.

Punto di stima	SPL(dB(A)) per 8 ore	SPL(dB(A))-15'	Classe I	Classe II	Classe III	Classe IV	Classe V	Classe VI
I15_2	19.9	29.3	35	40	45	50	55	65
I15_5	20.3	30.7	35	40	45	50	55	65
I15_8	21.4	32.8	35	40	45	50	55	65
I15_11	22.1	34	35	40	45	50	55	65
I30_2	14.6	24.6	35	40	45	50	55	65
I30_5	14.9	25.6	35	40	45	50	55	65
I30_8	16	26.4	35	40	45	50	55	65
I30_11	16.4	28.2	35	40	45	50	55	65
L15_2	18.7	28.8	35	40	45	50	55	65
L15_5	19.2	30.2	35	40	45	50	55	65
L15_8	21.2	32.4	35	40	45	50	55	65
L15_11	23.4	33.7	35	40	45	50	55	65
L30_2	13.7	24.6	35	40	45	50	55	65
L30_5	14	25.5	35	40	45	50	55	65
L30_8	15.8	26.3	35	40	45	50	55	65
L30_11	16.3	28.1	35	40	45	50	55	65
O15_2	20.2	32.6	35	40	45	50	55	65
O15_5	21	33.1	35	40	45	50	55	65
O15_8	22.2	34	35	40	45	50	55	65
O15_11	22.9	34.8	35	40	45	50	55	65
O30_2	15	27.1	35	40	45	50	55	65
O30_5	15.4	27.6	35	40	45	50	55	65
O30_8	16.5	28	35	40	45	50	55	65
O30_11	17	29.2	35	40	45	50	55	65

The estimation points are indicated with a code of the type XDIST_h where:

- X can assume the values: I (inlet face), L (lateral face), or O (outlet face)
- DIST indicates the distance from the side of the GIS room at which the estimate was performed (15 m or 30 m)
- h indicates the height from the ground at which the estimate was performed (2 m, 5 m, 8 m or 11 m).

It can be observed that the emission limits are always respected.

As regards the immission values, given by the energetic sum of emissions and background noise, some assumptions must be made on the value of the residual noise level, which depends on the position of the area considered, the quality of the acoustic classification, and the presence of sources in neighbouring areas. Since the most critical period is the night-time period, the assessment was made only in that period. In the calculations, the assumption was made that the residual noise is 5 dB lower than the night-time emission limit for the area considered.

Table 3 shows the immission values calculated for the various points and the class limits. In this case, the limit values are respected for all points. The values shown in grey are lower than the limit of applicability of the differential with open windows for the night-time period.

Table 3. Immission values and comparison with the legislation limits. A green cell indicates the limits are fulfilled.

Punto di stima	Classe I	Classe II	Classe III	Classe IV	Classe V	Classe VI	Classe I	Classe II	Classe III	Classe IV	Classe V	Classe VI
I15_2	32.7	36.0	40.4	45.1	50.0	60.0	40	45	50	55	60	70
I15_5	33.4	36.4	40.5	45.2	50.1	60.0	40	45	50	55	60	70
I15_8	34.6	37.0	40.8	45.3	50.1	60.0	40	45	50	55	60	70
I15_11	35.5	37.5	41.0	45.3	50.1	60.0	40	45	50	55	60	70
I30_2	31.1	35.4	40.1	45.0	50.0	60.0	40	45	50	55	60	70
I30_5	31.3	35.5	40.2	45.0	50.0	60.0	40	45	50	55	60	70
I30_8	31.6	35.6	40.2	45.1	50.0	60.0	40	45	50	55	60	70
I30_11	32.2	35.8	40.3	45.1	50.0	60.0	40	45	50	55	60	70
L15_2	32.5	35.9	40.3	45.1	50.0	60.0	40	45	50	55	60	70
L15_5	33.1	36.2	40.4	45.1	50.0	60.0	40	45	50	55	60	70
L15_8	34.4	36.9	40.7	45.2	50.1	60.0	40	45	50	55	60	70
L15_11	35.2	37.4	40.9	45.3	50.1	60.0	40	45	50	55	60	70
L30_2	31.1	35.4	40.1	45.0	50.0	60.0	40	45	50	55	60	70
L30_5	31.3	35.5	40.2	45.0	50.0	60.0	40	45	50	55	60	70
L30_8	31.5	35.5	40.2	45.1	50.0	60.0	40	45	50	55	60	70
L30_11	32.2	35.8	40.3	45.1	50.0	60.0	40	45	50	55	60	70
O15_2	34.5	37.0	40.7	45.2	50.1	60.0	40	45	50	55	60	70
O15_5	34.8	37.2	40.8	45.3	50.1	60.0	40	45	50	55	60	70
O15_8	35.5	37.5	41.0	45.3	50.1	60.0	40	45	50	55	60	70
O15_11	36.0	37.9	41.1	45.4	50.1	60.0	40	45	50	55	60	70
O30_2	31.8	35.7	40.2	45.1	50.0	60.0	40	45	50	55	60	70
O30_5	32.0	35.7	40.2	45.1	50.0	60.0	40	45	50	55	60	70
O30_8	32.1	35.8	40.3	45.1	50.0	60.0	40	45	50	55	60	70
O30_11	32.6	36.0	40.3	45.1	50.0	60.0	40	45	50	55	60	70

As regards the comparison with the differential limit, the same assumptions made for the calculation of the emissions regarding the residual noise level apply. Since the most critical period is the night-time, the evaluation was made only considering a maximum differential of 3 dB. Table 4 shows the result of this calculation. The cells for which the value is higher than the legal limit for Class I (3 dB) have been highlighted in red, while the numerical values shown in grey refer to those points where the differential cannot be

applied because the emissions are lower than 40 dB(A) with the windows open.
The result is that, only for Class I there are exceedances below 15 m of distance. For the higher classes (II - V) the differential is always respected.

Table 2. Differential and comparison with the legislation limits.

	Differenziale Classe I	Differenziale Classe II	Differenziale Classe III	Differenziale Classe IV	Differenziale Classe V
I15_2	2.7	1.0	0.4	0.1	0.0
I15_5	3.4	1.4	0.5	0.2	0.1
I15_8	4.6	2.0	0.8	0.3	0.1
I15_11	5.5	2.5	1.0	0.3	0.1
I30_2	1.1	0.4	0.1	0.0	0.0
I30_5	1.3	0.5	0.2	0.0	0.0
I30_8	1.6	0.6	0.2	0.1	0.0
I30_11	2.2	0.8	0.3	0.1	0.0
L15_2	2.5	0.9	0.3	0.1	0.0
L15_5	3.1	1.2	0.4	0.1	0.0
L15_8	4.4	1.9	0.7	0.2	0.1
L15_11	5.2	2.4	0.9	0.3	0.1
L30_2	1.1	0.4	0.1	0.0	0.0
L30_5	1.3	0.5	0.2	0.0	0.0
L30_8	1.5	0.5	0.2	0.1	0.0
L30_11	2.2	0.8	0.3	0.1	0.0
O15_2	4.5	2.0	0.7	0.2	0.1
O15_5	4.8	2.2	0.8	0.3	0.1
O15_8	5.5	2.5	1.0	0.3	0.1
O15_11	6.0	2.9	1.1	0.4	0.1
O30_2	1.8	0.7	0.2	0.1	0.0
O30_5	2.0	0.7	0.2	0.1	0.0
O30_8	2.1	0.8	0.3	0.1	0.0
O30_11	2.6	1.0	0.3	0.1	0.0

6. CONCLUSIONS

The non-stationary thermal simulations have provided comforting results, with occasional exceedances of the maximum temperature of 40 °C in the hypothesis of placing the SCP in Catania and projection of meteorological data to 2050. As regards the acoustic part, having maintained the size and position of the ventilation openings as studied with the thermal analyses, there would be exceedances of the legal limits only for the receptors positioned below 15 m. and belonging to Class I.

7. REFERENCES

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