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Reliability-based dynamical design of a singular structure for high energy physics experiments

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ABSTRACT

The present work presents a comprehensive design and dynamic calculation of singular metallic structures, part of the Neutrino Experiment NEXT. The experiment uses an electroluminescent TPC chamber, a high-pressure 136Xe gas vessel enclosing the detector. A lead-block "castle" or containing box shields this vessel against external γ-rays from all directions; in spite of its heavy weight, the castle must be regularly open for the detector maintenance. Since the structures will be constructed at a middle-level seismic localization (*Laboratorio Subterráneo Canfranc*, Spain), the earthquake hazard must be taken into account. Vessel and castle are supported by a rigid frame, which must satisfy two requirements: (i) the Spanish seismic standard, (ii) for equipment protection, the detector maximum horizontal acceleration must be <1 [m/s^2]. This frame rests on special base isolators to decrease horizontal accelerations in case of an earthquake. Three dynamical calculations are conducted: (i) a response spectrum analysis to comply with the standard, (ii) five time-history analyses to calculate tolerances and, (iii) a reliability-based approach using 1000 time-history responses to ensure satisfaction of the operating requirements. The final outcome is the design of a singular structure optimized for the NEXT experiment with a probability of failure against any standard earthquake of only 0.125%.

1. Introduction

The Neutrino Experiment NEXT, is a high energy physics undertaking that searches the neutrinoless double beta decay detected by a TPC (Time Projection Chamber): a high-pressure 136Xe xenon gas vessel. The experiment is located at a middle-level seismic zone: the *Laboratorio Subterráneo* at *Canfranc* (LSC) in the Pyrenees mountains, close to the border between Spain and France. The vessel is shielded against external radiation inside a heavy structure (called "lead castle", see Fig. 1); for more details refer to [1] and Section 3.

A metallic structure with seismic isolators to support the vessel and the lead castle is designed and calculated. This structure is composed of a very rigid rectangular frame with a vertical extension called "pedestal" to elevate the vessel, see

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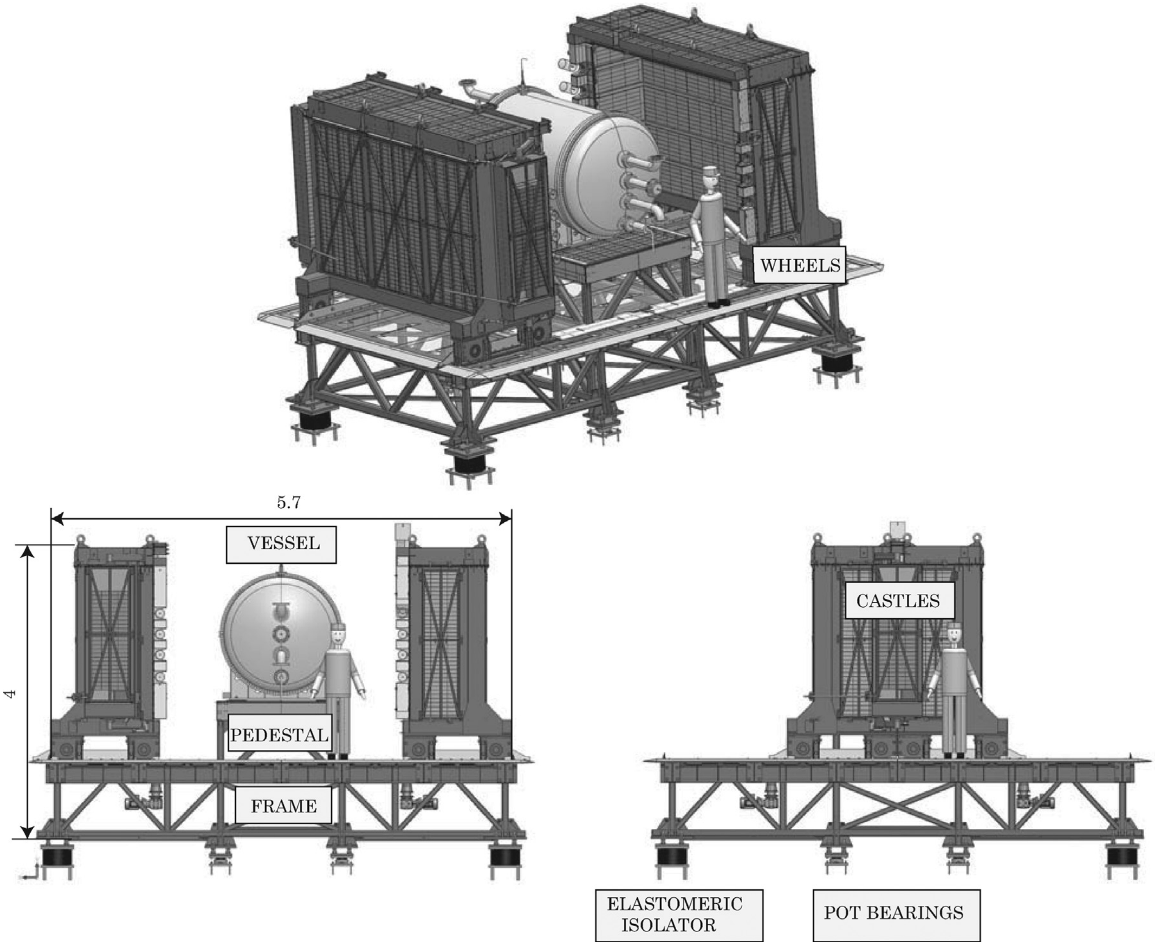

Fig. 1 – Three-dimensional view of the singular NEXT structure (top). Front views of open (bottom-left, for maintenance) and closed (bottom-right, for operation) configurations. Structure composed of frame, pedestal, lead castle, vessel and seismic isolators. Dimensions in [m].

Fig. 1. The objective of the complete structure is to ensure the safety of the vessel, operating systems and personnel, and to guarantee the integrity of the experiment even in the case of an earthquake. The total cost, including all its elements, is a comparably moderate 145,000 euros.

But the cost of the vessel is high—more than two million euros—mostly due to the 100 [kg] of xenon isotope 136Xe that amounts to 1.5 million euros; consequently, any damage in the vessel could provoke a gas escape and great economic loss. Since the structure is assembled at LSC, it must satisfy the Spanish seismic standard [2] as part of the project risk analysis. Due to operating requirements of the electronics, gas system, electric installation and other equipment (see Fig. 1 top), this structure has to guarantee that the detector maximum horizontal acceleration a_{Hmx} at the vessel intakes is lower than 1 [m/s^2].

The structural set is considered singular for several reasons: first, its elements combine beams with steel tubular close and open sections, and several steel and stainless steel large sheets. Second, the most important loads are gravitational from the castle, constructed in two symmetric parts that periodically must be opened for vessel maintenance; consequently, several different load distributions on the frame have to be considered. Third, the whole structure is of high stiffness to prevent detrimental displacements in the vessel and to guarantee the watertight closure of the castle. Finally and due to the seismic nature of the design, the frame is supported by two types of base isolators, see again the Fig. 1, increasing the difficulty of the calculations.

The base isolation technology, [3], is in construction one of the most advanced protections against earthquakes that contain critical devices such as computer servers [4], electronic equipments [5,6], precision machinery [7], etc. According to [8], the two main challenges in the design of structures with seismic isolation are the consideration of the variability of ground motions, see [9], and the non-linear response of the isolators. For these reasons, reliability-based designs have gained interest in the structural engineering community, for example see [8,10].

The main objective of the present work is the design and calculation of the singular structures, considering the seismic activity at the LSC. From the calculation point of view, the finite element (FE) method is used to model the full structure with a modal and two dynamic approaches.