ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-MOPORI11

SEISMIC ANALYSIS FOR SAFETY REQUIREMENTS OF SPIRAL2 ACCELERATOR

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Abstract

The SPIRAL2 Accelerator at GANIL is a superconducting ions continuous wave LINAC with two associated experimental areas. Mechanical engineers have been highly involved in the design of SPIRAL2 equipment since the beginning of the project in 2004. During the development phase, Computer Aided Design and calculation codes have been used throughout the complete process: from the ion sources, the LINAC, the beam transport lines and the experimental halls equipped with detectors. SPIRAL2 has to meet different safety requirements, among which seismic hazard. This involves justifying that the integrity of the radiologic containment barrier is always maintained in case of earthquake. This paper reports the improvement in design and calculation methods performed by GANIL engineers to meet the seismic safety requirements, specifically the non-missility feature of the equipment. The modal-spectral simulations, used to demonstrate the mechanical strength of equipment in case of earthquakes, was an important part of this design activity in the past 10 years. New methods have been used to calculate welds, fasteners and the ground anchor of the structural supports of the heaviest equipment.

INTRODUCTION

The non-missility criteria consists in preventing equipment weighing more than 500 kg at height 1.5 m to be projected on ground floor or walls of the building, which is used as containment barrier. The mechanical supports and frames have to withstand dynamic load corresponding to earthquake S.M.S (Security Maximum Seism) [1]. Also, fasteners and anchors to ground have to be analysed to prove that they withstand such loads. For example, LINAC supporting frame had to be reinforced for seismic load after first installation (Fig. 1).

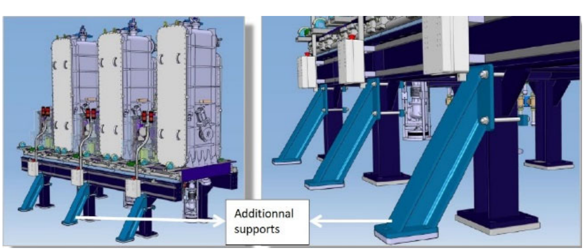

Figure 1: Additional supporting features LINAC A.

All calculation have been performed with the Finite Element Analysis Code ANSYS 2020 R1. The spectral load in three directions X, Y and Z is provided by Civil Engineering (Fig. 2) and implemented in the Finite Element Model and combined to gravity. First, a modal analysis is performed to identify the Eigen modes of the structure. Then two load cases will be compared to identify the most severe: gravity + seism or gravity - seism. The X, Y and Z direction loads are also combined to each others: either by quadratic combination, or by Newmark combination.

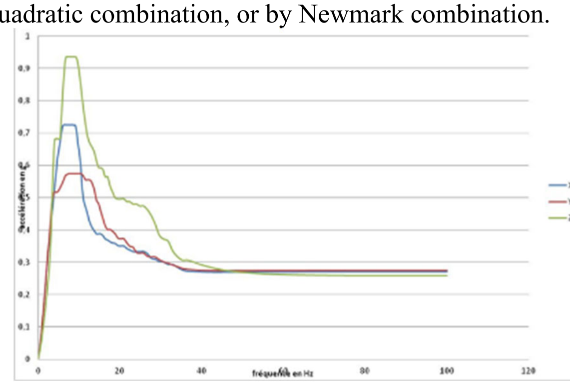

Figure 2: Spectral load based on S.M.S.in S3.

EXAMPLE 1 : NFS DETECTOR

NFS (Neutron for Science) is the first experimental area linked to SPIRAL2 accelerator. NFS is composed of a time-of-flight baseline and irradiation stations. A new detection system named FALSTAFF has been installed in the Time-of-flight NFS area as shown. This detector fully equipped weighs 592 kg, and hence is subject to non-missility requirements, has been clamped to ground as shown in Fig. 3.

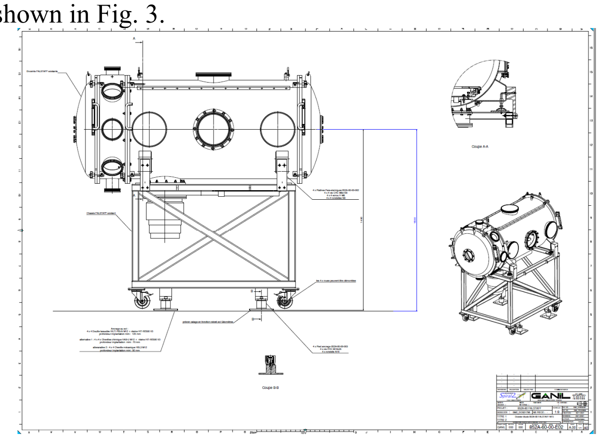

Figure 3: FALSTAFF detection assembly drawing.

In this example, only the structural frame and the feet of the vacuum chamber has to be calculated in order to prove that the FALSTAFF detector will not be projected under seismic load. We will focus on the fasteners and anchorage analysis even if welds and stresses are also post-treated.

Figure 3 shows how the equipment is clamped to the frame with metal plates and to the ground. The bonded anchors that have been calculated and selected according to the method described in [2].

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Fasteners Analysis

All the fasteners are represented in the F.E. model as beam elements (Fig.4).

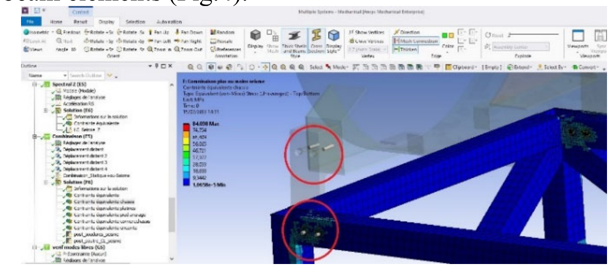

Figure 4: F.E. model frame and beam for fasteners.

A program -code lines- has been developed to extract shear and tension load on each fasteners. The analysis is then made using the combined load criteria described in Eurocode 3 [3] and in Eq. (1) below.

$$\dots\quad \frac{F_s}{F_{s,Rd}} + \frac{F_t}{(1{,}4\ F_{t,Rd})} < 1 \qquad (1)$$

In Eq. (1) Ft is tension load in bolt, Fs is shear load in bolt, Ft,Rd is tension strength of stainless steel bolt, Fv,Rd is shear strength of the bolts. The tension strength of the stainless steel fasteners are previously determined. The results show that the fasteners M8 in stainless steel A4-70 fulfils the combined load criteria.

Bonded Anchors

The force and moment are extracted from the model and the most loaded feet using an online code developed by anchors supplier HILTI (Fig. 5).

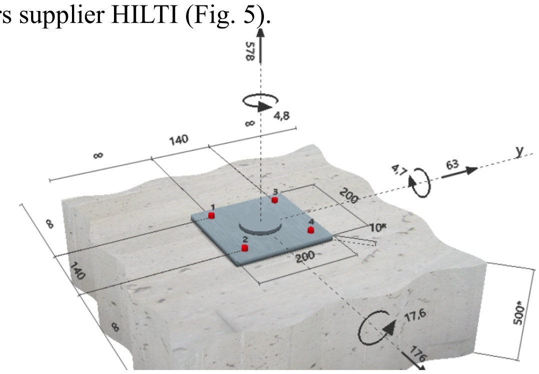

Figure 5: Forces and moment at most loaded feet.

The wedge anchor selected for this equipment is HILTI HL-M12 with an embedment in concrete of 80 mm. The FALSTAFF Detection holding structure fulfil seismic requirements as shown in [4].

EXAMPLE 2: WATER RETENTION S3

The cooling circuit of the beam-dump of the experimental area S3 is a closed circuit. The heat exchanger (Fig. 6) of the cooling circuit is located in the S3 experimental area, which is 9.5 meters underground in the SPIRAL2 accelerator building.

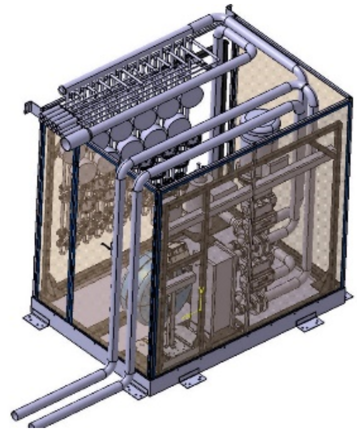

Figure 6: Exchanger structure and retention tray.

The water retention tray of the exchanger has to be waterproof and maintain its structural integrity in case of seismic event . The tray and the structure holding the exchanger components (valve, tubes, tanks..) are made of stainless steel 316L.The tray has to contain the entire volume of water of the closed circuit in case of leakage because the water is potentially contaminated. The aim of the calculation is to prove that no crack or damage will appear on the tray and that the structure will hold the different exchanger equipment under seismic load.

Mechanical Stresses

The results are post-treated in terms of Von Mises Stresses for all mechanical parts (Fig.7).

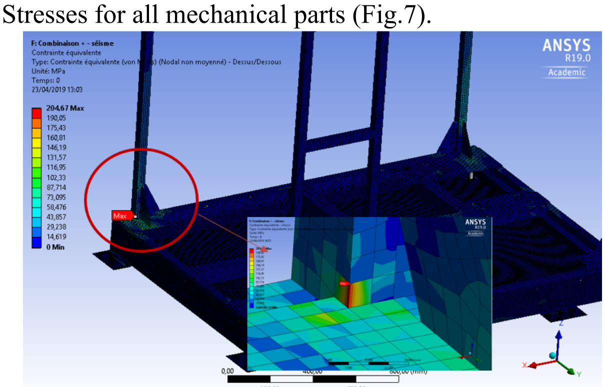

Figure 7: Max stress in the supporting beam.

Von Mises Stresses are compared to Yield Strength as shown in Eq. (2) of the stainless steel with a safety factor of λ=1,1.

$$\frac{Fy}{1.1x\sigma_{VonMises}} - 1 > 0 \qquad (2)$$

Welds Analysis

The strength of welding joint are calculated with the method described in Eurocode 3 – Part 1-8 [3]. The safety coefficient for stainless steel structure is Υ_{M2}=1.25 and applied in order to compensate the dispersion of the thresholds of materials. The mechanical strength criteria described in [3] are normally adapted to static load. The fact that a modal-spectral calculation is performed leads to a non-dynamic type of analysis and therefore allows to use static mechanical strength law. Figure 8 shows a sketch with stresses needed to calculated weld criteria

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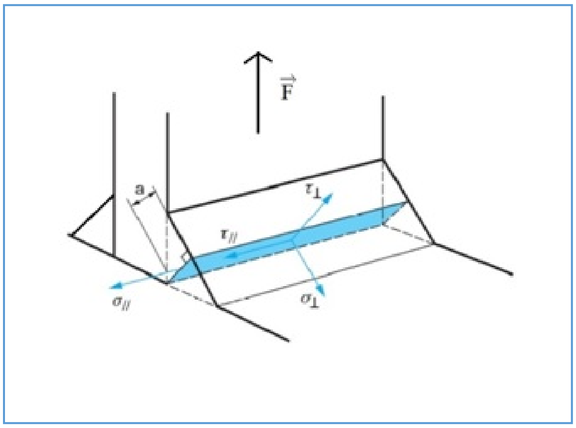

Figure 8: Sketch of normal and shear stress in a weld.

The main criteria to meet is based on equivalent stress as described in Eq. (3) and (4):

$$\sigma_{eq}=\left[\sigma_{normal}^2+3\left(\tau_{normal}^2+\tau_{parallel}^2\right]^{0.5}\right. \quad (3)$$

$$\sigma_{eq}\leq\frac{f_u}{(\gamma_{M2})} \quad (4)$$

The main difficulty was to find a way to extract the loads and shell stress at the junction element from Finite Element simulation. The transferred load will allow to calculate analytically the shear and tensile stress on the weld area (Fig. 9). To achieve this, a specific computer program has been developed by an external specialised company and code lines inserted in the Finite Element model.

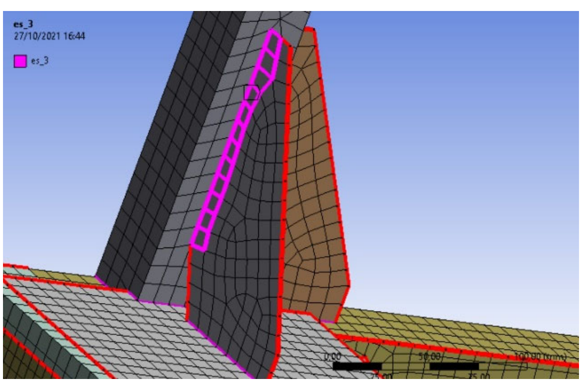

Figure 9: Elements corresponding to weld junction.

The code lines applied to the F. E. model generates automatically a table file with the transferred load at each node and elements of the identified junction. The calculation is then performed analytically in an Excel spreadsheet.

Table 1 : Calculated Load Stresses on Weld

	Load (N)	Unit
Fx from F.E. model	153	N
Fy from F.E. model	576	N
Fz from F.E. model	12	N
Weld length	125	mm
Weld size	2.5	mm
Shear stress τ //	49	MPa
σ equivalent	85	MPa
σ Criteria (st. steel)	385	MPa

The calculations show that all criteria are reached [5], and consequently there is no risk of damage or leakage on the tray and on the structure in case of earthquake.

CONCLUSION

The calculations and analysis described here shows the difficulty to match theoretical Eurocode 3 criteria with global F. E. Simulation. The code lines used to extract relevant values from model was one of the key to solve that problem. The computer program was sub-contracted to an external expert and is now adapted for each new calculation. Each SPIRAL2 heavy equipment is now in line with seismic requirements. A method has been summarized for all seismic calculation at GANIL-SPIRAL2 [6] and [7].

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