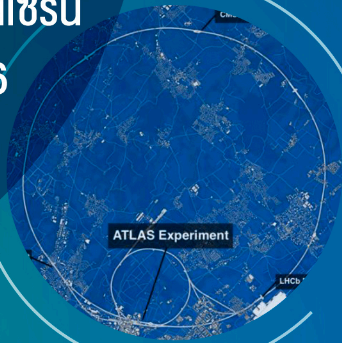
CERN SUMMER STUDENT PROGRAMME 2023

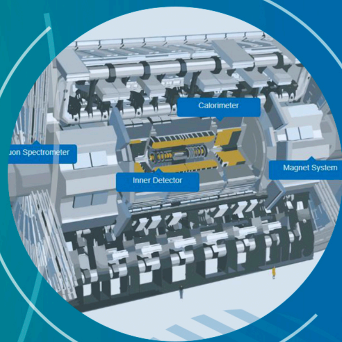
CERN

รายงานการเข้าร่วมโครงการนักศึกษาภาคฤดูร้อนเซิร์น

ระหว่างวันที่ 3 มิถุนายน - 27 สิงหาคม 2566

ณ เซิร์น กรุงเจนีวา สมาพันธรัฐสวิส





นายภูริณัฐ เลิศนิมิตธรรม

คณะวิศวกรรมศาสตร์ ภาควิชาวิศวกรรมเครื่องกล

จุฬาลงกรณ์มหาวิทยาลัย

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Acknowledgments

I would like to express my gratitude towards Her Royal Highness Princess Maha Chakri Sirindhorn for selecting me to participate in the prestigious 2023 CERN Summer Student program.

I would like to take this opportunity to express my special thanks to Dr. Norraphat Srimanobhas for organizing and assisting with a project collaboration with CERN. Also, Dr. Chayanit Asawatangtrakuldee for encouraging me to apply to the program and for all their valuable suggestions. The wonderful journey at CERN could neither have begun nor been completed without them.

I would also like to express my appreciation to Audrey Piccini, Carlotta Accettura, Federico Carra, and Benoit Riffaud for their valuable guidance that not only enhanced my understanding of the engineering subjects but also sharpened my working skills in many aspects. Furthermore, I extend my thanks to Alessandro Bertarelli and the Mechanical & Materials Engineering department for their consistent support and for creating a wonderful working environment that motivates me to wake up and work every day.

I also would like to thank CERN and the Synchrotron Light Research Institute for organizing the privilege program that not only provides opportunities to study engineering and science but also the experience of working with a world-class research laboratory. It has been exactly what CERN said: “Opportunities in a place like nowhere else on Earth”.

Lastly, I wanted to thank my family and friends who have been supporting me in education and life.

Contents

Chapter 1

CERN, the European Organization for Nuclear Research

In 1949, the Second World War ended. A European laboratory had been proposed to make Europe science reach world-class again and also aim to reunite people from various countries after the war. Two years later, a UNESCO meeting in Paris was organized on the subject of the decision to build the *European Council for Nuclear Research* or in French *Conseil Européen pour la Recherche Nucléaire* (CERN).

The largest Nuclear Research was decided to be built in Geneva, Switzerland. Later, the first experiment of CERN was started in 1957, and 8 years after that CERN scientists were able to observe antinuclei. CERN has continued to build a higher-energy particle accelerator to push the science frontier forward. In 1983, They discovered W and Z particles which are the particles that involve weak force one of the 5 forces in the standard model. In 1995, they were able to produce the first antimatter. Moreover, they have been developing technologies to produce and keep antimatter to study and try to solve the mystery of mater-antimatter asymmetry in the universe. [1]

In 2008, CERN succeeded in starting up the Large Hardon Collider (LHC), the largest and the most powerful particle accelerator in the world with a 27 km [1] circumference sitting under the ground in Switzerland and France, 13 Tev [1] Nominal energy for proton collisions. Following this, on 4 July 2012 in the main auditorium (where the summer student lectures took place (see figure 1: 04 July 2012 CERN main auditorium)), CERN announced the discovery of the Higgs boson particle or God particle, The particles associated with the Higgs field which is the field giving mass to elementary particles.

figure 1: 04 July 2012 CERN main auditorium

The most recent news CERN also found pentaquarks in 2015. Outer than success in science CERN has encountered many difficulties. To overcome those, CERN invented technologies such as touch screens, the world wide web, the highest performance cryogenic cooling, and ultrahigh vacuum. (See more information at https://home.cern/, CERN Esplanade des Particules 1 P.O. Box 1211 Geneva 23 Switzerland)

CERN Member state

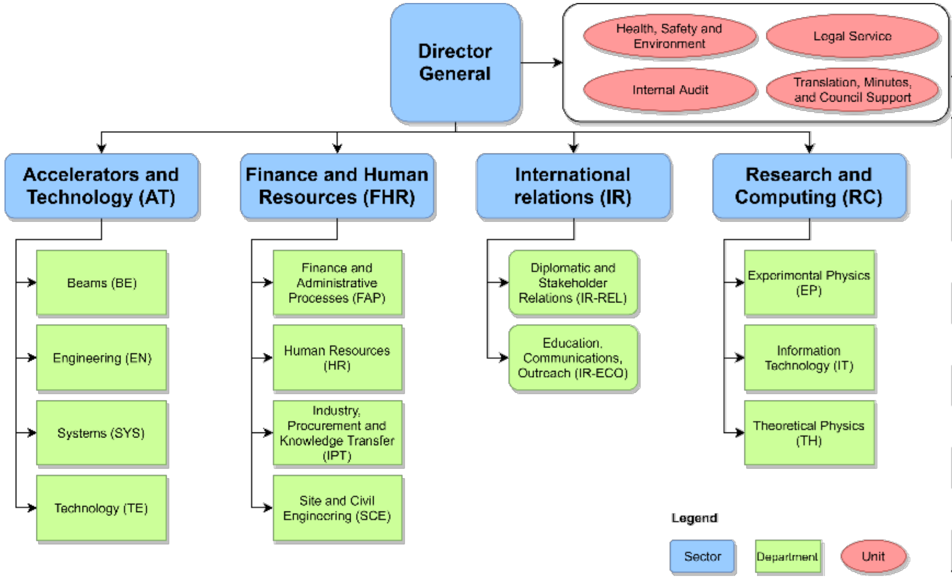
There are 23 member states [1] that fund the operating cost. They have the privilege to make important decisions and to do the full collaboration. There are also other types of associations such as Observer and Non-member states, which include Thailand.

CERN Mission

CERN has been built to fulfill 4 main goals. According to the website, the mission includes "...perform world-class research in fundamental physics, provide a unique range of particle accelerator facilities that enable research at the forefront of human knowledge, in an environmentally responsible and sustainable way, unite people from all over the world to push the frontiers of science and technology, for the benefit of all, train new generations of physicists, engineers and technicians, and engage all citizens in research and in the values of science..." [1]

CERN employees

There are more than 17,500 employees (according to data in 2017 [1]) which are divided into 4 sections (shown in figure 2: CERN organization chart 1) including Accelerators and Technology where the engineering department is. The Engineering Department consists of 9 groups (see figure 3: CERN organization chart 2) working collaboratively.



Heads of departments	
Accelerator Systems	Brennan Goddard
Beams	Rhodri Jones
Engineering	Katy Foraz
Experimental Physics	Manfred Krammer
Finance and Administrative Processes	Florian Sonnemann
Human Resources	James Purvis
Industry, Procurement and Knowledge Transfer	Christopher Hartley
Information Technology	Enrica Porcari
Site and Civil Engineering	Mar Capeans Garrido
Technology	José Miguel Jiménez
Theoretical Physics	Gian Francesco Giudice

figure 2: CERN organization chart 1 [2]

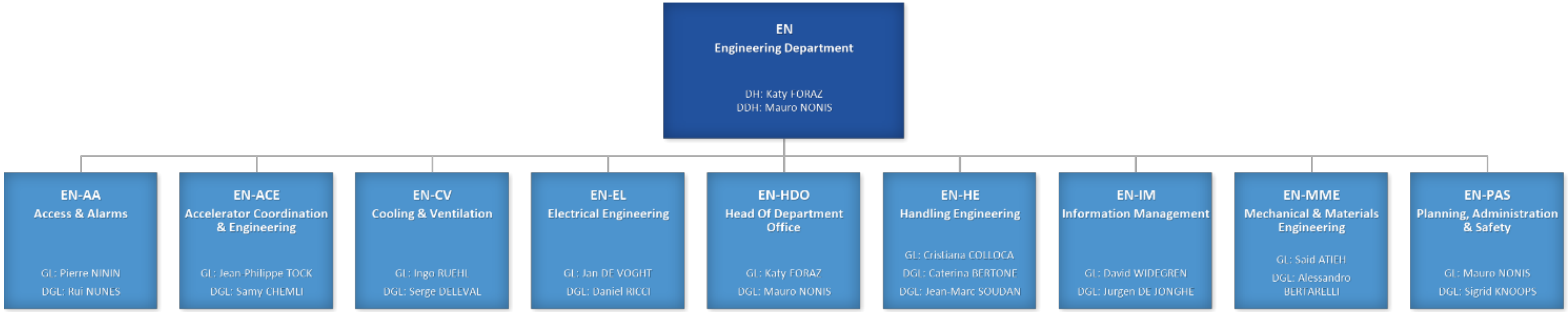


figure 3: CERN organization chart 2 [1]

CERN Mechanical and Material Engineering (MME)

Apart from the fact that CERN is the largest nuclear research which is working with experimental and theoretical physics to solve the mysteries of the universe, behind the phenomenal experiment, CERN requires an amount of engineering innovation to meet experimental requirements as the experiment has to inevitably deal with extreme conditions such as cryogenic, extremely high temperatures, high radiation, intense magnetic fields, vacuum, and many other engineering constraints. CERN MME is an important group of engineers (figure 4: CERN Member state 3) that are established to encounter these challenges. The group dedicates themselves to 3 responsibilities.

First, Design, Simulations, and Measurements. As MME face extreme conditions, they use computer-aided design (CAD) software to provide calculations and simulations to help develop and optimize designs. Moreover, the Mechanic Measurements Laboratory is a part of MME, they efficiently perform measurements in mechanical stress and strain, displacement, pressure, and vibration.

Second, fabrication. After design and simulation, MME fulfills extensive requirements by providing third-party contributions and internal facilities. CERN workshop facilities are capable of delivering conventional and high-precision manufacturing works produced by a wide range of manufacturing processes. For instance, additive and subtractive Digital Fabrication manufacturing, sheet-metal forming, wide methods of welding, laser cutting, and micrometric 3D metrology manufacturing.

Last, Material science and Non-Destructive Testing. Materials and Non-Destructive Testing (NDT) expertise and facilities are also included in the group as they are able to develop, select, characterize, and control quality. In addition, dynamic and static measurements at room and cryogenic temperatures, material testing, metallurgical characterization and analysis including optical, electron microscopy and focus ion beam electron microscopy, image analysis, mechanical testing, X-ray computed tomography, and failure analysis are provided by MME.

In brief, due to the 3 main competencies of the group, they are able to support the entire engineering process for the largest nuclear research facility in the world.

figure 4: CERN Member state 3 [1]

Internship activities

I applied for the internship via "The Thai-CERN Collaboration Program under the initiative of H.R.H Princess Maha Chakri Sirindhorn" which has been supporting 4 Thai students to work at CERN as summer students every year. This program allows students to participate in CERN experiments and research. This section will provide the activities of the CERN summer student program from my perspective.

Summer Student Lectures

Apart from working with the CERN research team, I had an opportunity to attend daily lectures which equipped me with knowledge and skills in different areas including theoretical and experimental physics, statistics, computers, and technologies.

figure 5:Summer student lectures session [3]

ATLAS visiting

ATLAS detector is one of seven experiments at the Large Hardon Collider (LHC) (figure 6: CERN Detector). It is used to analyse the particles produced by collisions. Moreover, it is also the largest particle detector that has ever been built 46m long, 25m in diameter, and 100m below ground [1] (figure 7: ATLAS detector). Additionally, this detector was taking an important part of the Higgs boson discovery in 2012.

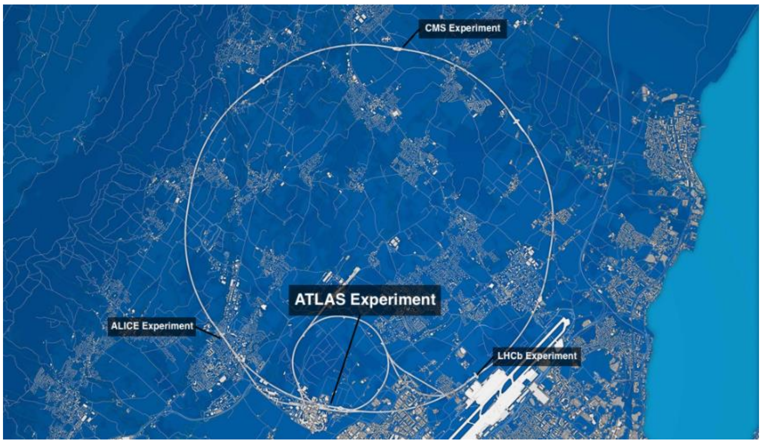


figure 6: CERN Detector [1]

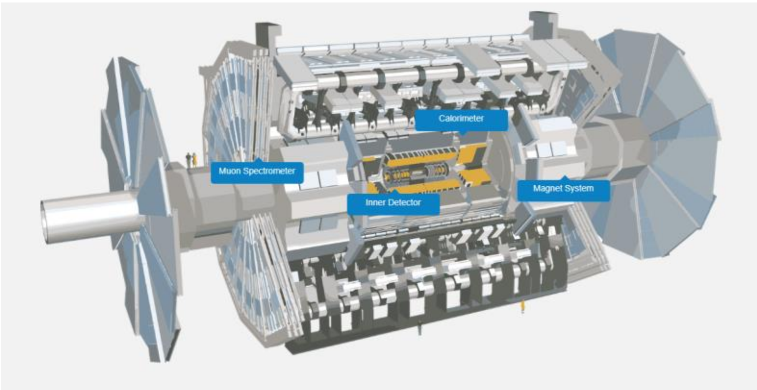


figure 7: ATLAS detector [1]

Antiproton Decelerator (AD) and ELENA visiting

AD is the machine used to lower the energy level of antiprotons which are produced by fixed target collision. AD is capable of decreasing the antiproton to around a tenth of the speed of light [1] which is too high to keep the antiproton to study. However, AD can work co-ordinately with ELENA, which is the reducing energy synchrotron, to trap the antiproton for study.

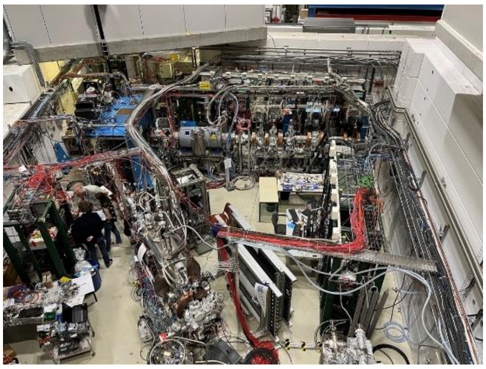


figure 8: AD and ElENA visit

Data Centre visiting

Data Center (figure 9: Data Centre) is a crucial part of the experiment since the detectors generate massive amounts of data which require a large number of processors and a great deal amount of storage which leads to high electricity consumption. Surprisingly, to avoid exorbitant electricity costs, CERN uses magnetic tapes to store large amounts of data for long-term storage.

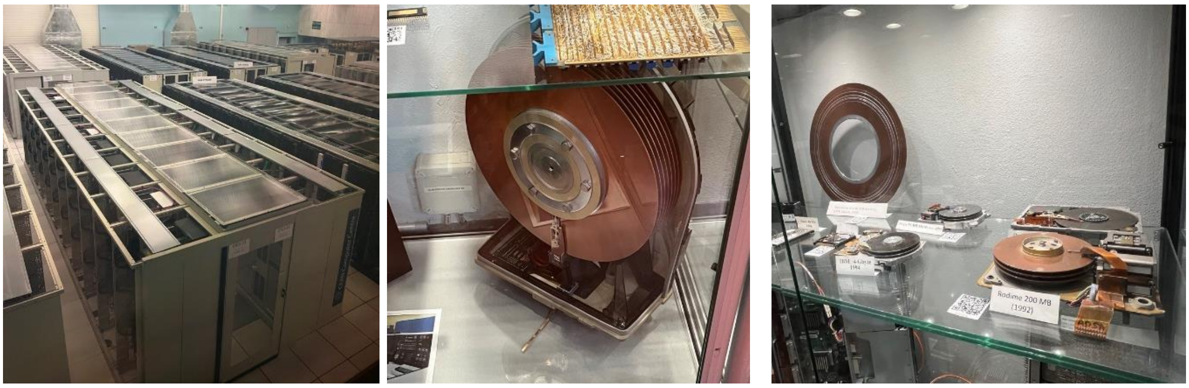


figure 9: Data Centre

CERN Workshop visiting

I had an opportunity to visit the lab where I saw the process of how CERN manufacturing tools for used in experiments. The CERN workshop has responsibility for all fabrication processes. The fabrication process for CERN is a big challenge because of the design requirements, to illustrate, high tolerance, materials that are hard to manufacture such as copper, titanium, and niobium, and highly complex shapes.

- Digital fabrication
  - Laser cutting: the tool used to cut the metal sheet. Laser cutting works by using the heat of a laser beam to melt the metal to a specified 2D pattern.
  - Wire Electrical Discharge Machining: the subtractive manufacturing machine. It cut the block of metal by eroding the metal with an electric discharge between the wire and the metal. The charges are conducted through running wire that passes to the metal as can be seen from figure 10 EDM wire cutting . This results in high accuracy and precision dimensions.

EDM Wire cutting

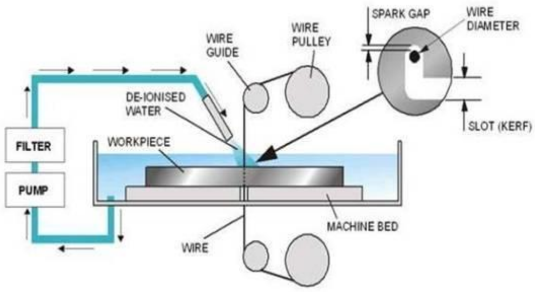


figure 10 EDM wire cutting [4]

- CNC: CERN has a bedroom scale of CNC to fabricate high-precision large structures. The high precision of the large structure is challenging because a large structure can deform due to its massive weight.
- Additive manufacturing: Selective Laser Melting (SLM) is the additive manufacturing method that forms a workpiece from powder material and uses a laser to fuse each layer. CERN uses additive manufacturing to produce complex shape designs. For instance, the Fork of a *wire scanner* has a complex shape in order to reduce weight. Nevertheless, this is impossible to manufacture with other methods.

- High-quality Welds
  - Metal cold-forming method: Fabricating tee joint pipe can be done in 2 ways. The first way is using two straight pipes joining by connecting them with the weld directly shown in figure 11: Tee joint cold forming (a) straight pipe joining (b) cold forming.(a). Although this method is the simplest way to implement, this gives a bad-quality weld and obviously cannot be used for vacuum at CERN. The other way is to make an oval-shaped hole in the pipe which can be seen in figure 11: Tee joint cold forming (a) straight pipe joining (b) cold forming.(b) on the left side. Then, high-surface hardness spherical metal is passed through the hole to create a tee shape which can be seen from (b) on the right side followed by welding the straight pipe to the tee joint. Because the straight weld can control better quality, this method to fabricate tee joints is used at CERN.

(a) [5] (b)

figure 11: Tee joint cold forming (a) straight pipe joining (b) cold forming.

- Electron-beam weld (EB weld): the method of welding by high-speed electrons emitted into a joint. It can be seen from figure 12: Electron-beam welding method that an electron-beam weld penetrates deeply into the joint which can be beneficial for many applications. EB weld is used to weld many crucial apparatuses such as Quadrupole resonator pole shoes and CRAB cavities.

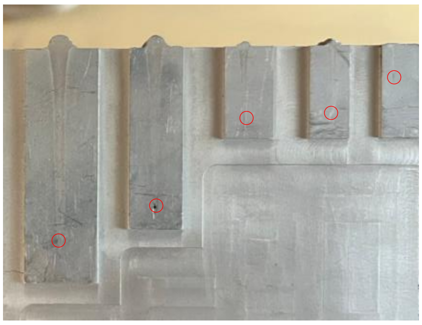


figure 12: Electron-beam welding method

- Hydro forming: the manufacturing process that forms a shape to mould by the pressure of water pushing from inside. CERN uses a hydro-forming process to fabricate Radiofrequency cavities, pipe flexible joints for LHC, etc.

LHC flexible joint (see figure 13: LHC flexible joint manufactured by hydroforming) is essential for LHC since LHC encounters large thermal contraction expansion due to a supper conductors cryogenic cooling system. If LHC didn't have flexible joints, it would suffer from thermal stress which causes metal fractures.

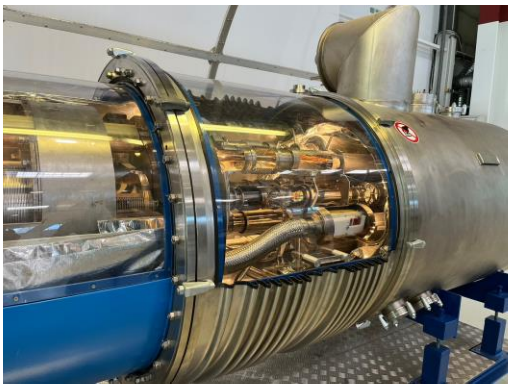


figure 13: LHC flexible joint manufactured by hydroforming

Measurement laboratory

- 3D Scanning Vibrometer System: equipment used to measure vibration frequency with the Doppler effect. It is capable of measuring the mode shapes.

Chapter 2: Project

During the internship, I worked on structural analysis of the 4 designs of CO2 transfer line supports which were planned to be installed for cooling the sub-detector of the ATLAS detector (figure 14: Main transfer line and ATLAS experiment). These supports are subjected to many loads caused by weight loads and thermal expansion/contraction of the pipes (figure 15: Transfer lines support structural shows one of the designs of supports). The analysis is a process not only required using the software ANSYS to calculate the result with the finite element method but also calculated analytically. In addition, the assessment of the welds and the bolts was carried out. Moreover, the seismic assessment of the support was computed (figure 16: Transfer lines support seismic analysis). These assessments have been done following EN 1993 Eurocode 3: Design of steel structures and EN 1998 Eurocode 8: Design of structures for earthquake resistance. These Eurocodes provide guidelines for calculation and failure criteria. It is really important to follow these principles to make a good validation.

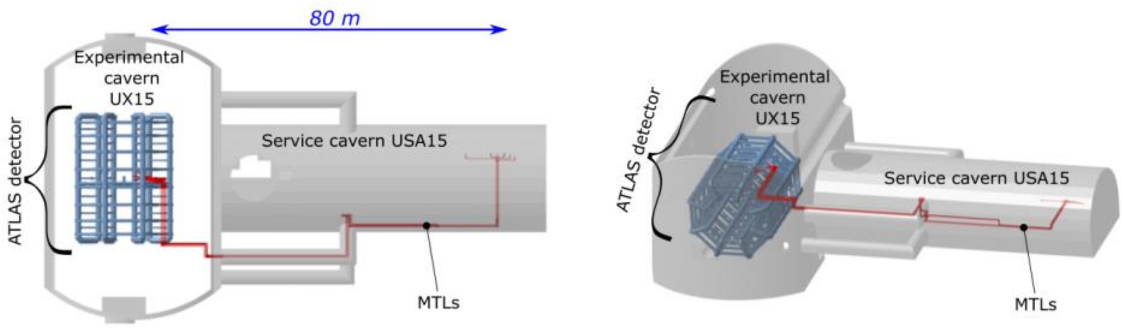


figure 14: Main transfer line and ATLAS experiment [6]

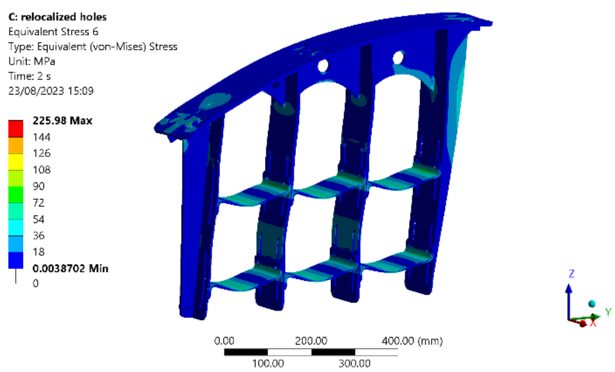


figure 15: Transfer lines support structural analysis.

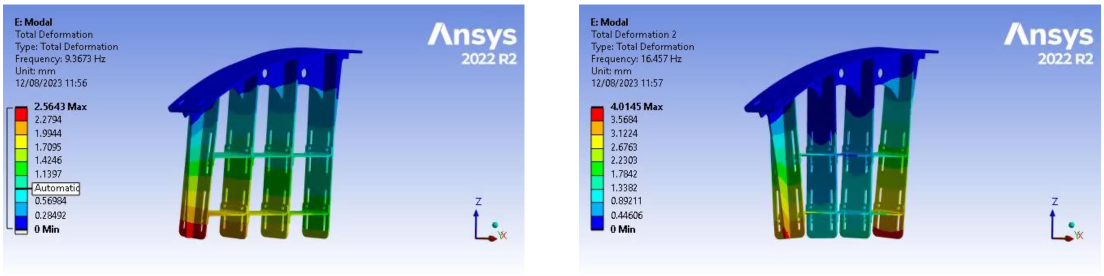


figure 16: Transfer lines support seismic analysis

Apart from the calculations that I had to do; these calculations were part of the iterative design. Thus, what I had to do after the calculations was to communicate with the design team on how the design could be improved. Then the design team will try to improve by looking at catalogs, checking with standards, and considering the fabric processes. Next, they will provide the CAD model back to the calculation office to validate again.

Also, in finite element analysis, the components such as bolts, and weld often have to be simplified. Then these bolts and welds can be assessed later by analytical calculation. Since I worked on the welds assessment, I found some pain points about how the weld is assessed. I started to invent new ways to evaluate the strength of the weld which helped to determine the local stress of the weld instead of the average along the weld. Due to the fact that this method can calculate the local utilization factor of the weld, it is the most suitable for circular weld joints since a sum of force in circular weld often cancels out (see figure 17: Average forces and local forces), the average of the force can be far lower than reality. With the same logic, this method is also suitable for long welding joints since the average force can underestimate the force (see figure 17: Average forces and local forces). This method also helps to calculate the maximum weld resulting in a more conservative evaluation and this also helps to locate where the weld is critical.

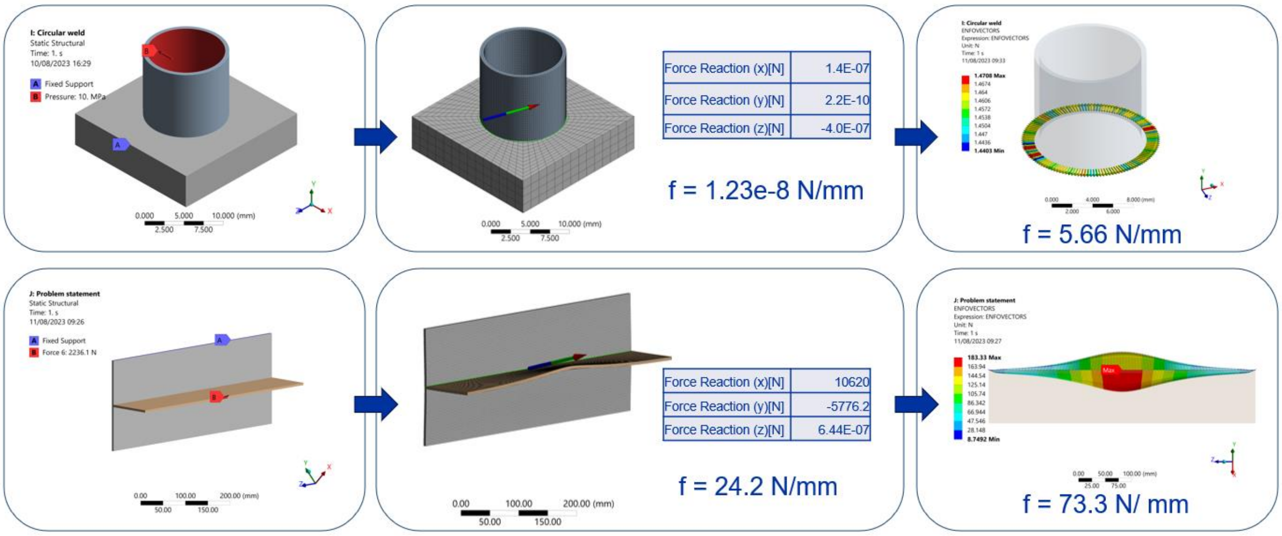


figure 17: Average forces and local forces

This assessment method can be used by exporting the location and internal force of the nodes (figure 18: Force exported from ANSYS) and taking it as input for the MATLAB code that I have done. The code gives a local utilization factor for each node (figure 19: Force Calculated by MATLAB).

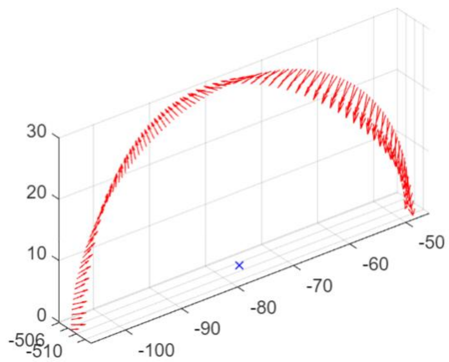


figure 18: Force exported from ANSYS

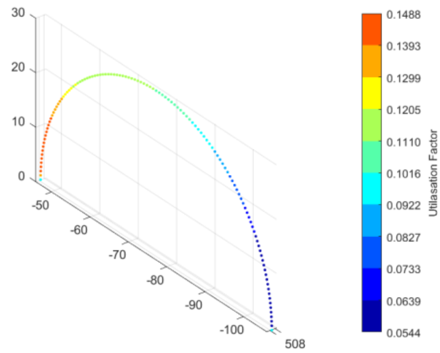


figure 19: Force Calculated by MATLAB

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Report

2-Phase CO_2 Transfer Lines for the ATLAS Experiment: Detailed analysis of Supports

Abstract:

This document describes the calculations and dimensioning of the supports of the cooling pipes of the 2-Phase CO_2 transfer lines for the ATLAS experiment.

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HISTORY OF CHANGES

REV. NO.	DATE	PAGES	DESCRIPTIONS OF THE CHANGES
01	11/09/23	41	

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1. Scope of Analysis

2-phase CO_2 transfer pipes were planned to install for cooling the sub-detector of the Atlas detector [1]. There are six independent pipes which are supported by various designs of supports including support ZC1, ZC2, ZB1, and ZB2. They have been designed differently due to space constraints.

This report provides information about the 4 design of pipes supports finite element analysis outcomes. These supports have been subjected to the worst cases which may be caused by weight loads and thermal expansion/contraction of the pipes. The assessment of the welds and the bolts was carried out according to the Eurocode 3 NF EN 1993-1-8 [2]. Finally, the seismic assessment of the support was computed following the Eurocode 8 NF EN 1998-1:2004 [3].

2. Component Description

2.1 Geometry

As can be seen from Figures 2-1 and 2-2, terminologies of the components of supports are defined. The top plate, Left plate, Middle-left plate, Middle-right plate, Right plate, and Core plate are connected by welding. Then, this assembly is installed into the cavern by wrenching the top plate into the concrete (for ZC1 and ZC2) or other structures (for ZB1 and ZB2). Once the assembly is in place, each pipe is lifted, and the bottom plate is inserted under the pipe which then fastens the bottom plate to other plates with bolts.

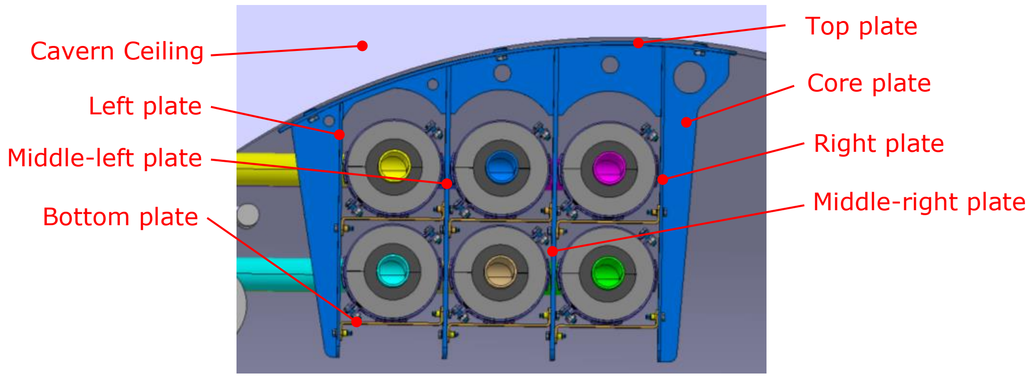
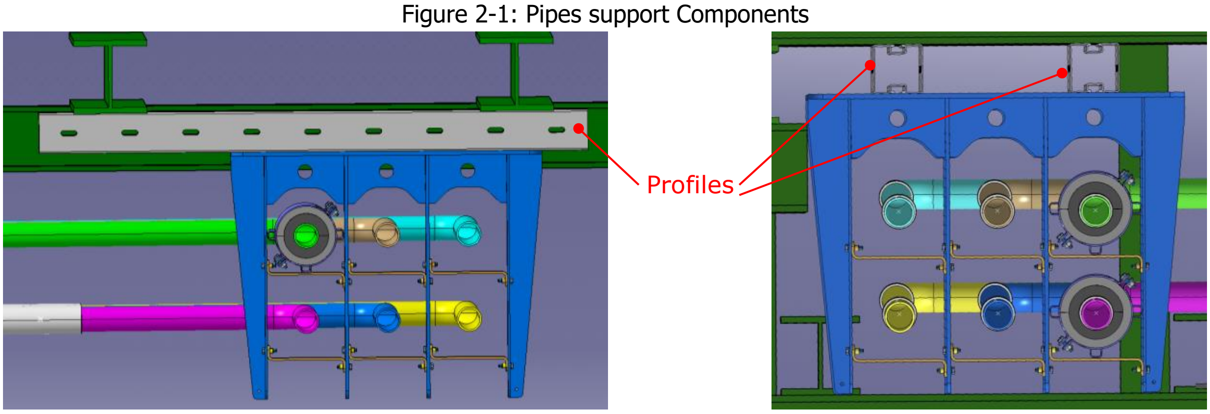
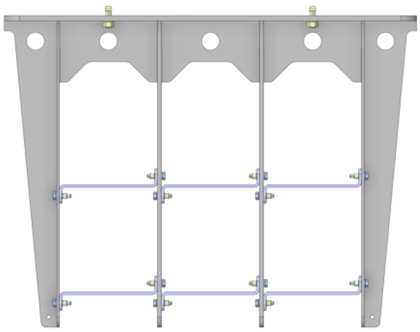


Figure 2-1: Pipes support Components

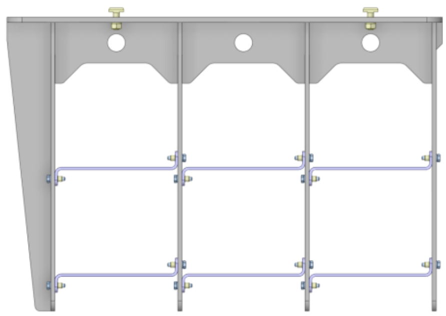


(a) (b)

Figure 2-2: Pipes support Components (a) the profiles slotted holes oriented along the support (b) the profiles slotted hole oriented perpendicular to the support



a)



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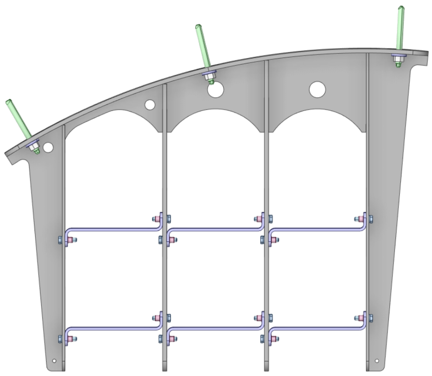
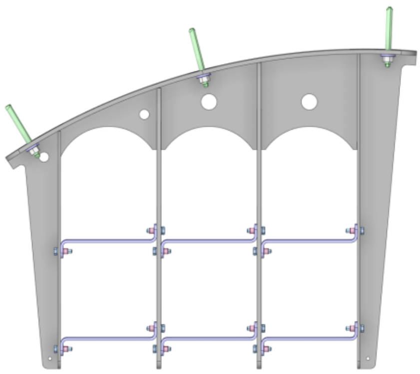


c)



d)

Figure 2-3: Pipes support various designs a) ZB1 b) ZB2 c) ZC1 d) ZC2.

Figure 2-3 shows the 4 different designs of the pipes supports. ZB1 and ZB2 have a flat shape top plate which is attached to other structures by 4 bolts. ZB2 is wider than the other supports. It is designed to allow pipes to move both transversely and longitudinally. Whereas the other supports allow the pipes to move only in the longitudinal direction. ZC1 and ZC2 have a curved plate that conforms to the cavern ceiling.

2.2 Material

2 materials are used to fabricate the supports consisting of SS304L and Carbon steel in category 8.8. Table 2-1 shows materials selected for the calculations of each component and Table 2-2 gives information for SS304L properties.

Material	Components
SS304L	All plates and welds
Carbon steel in category 8.8	Bolts, nuts, and washers

Table 2-1: The Materials selected for the components.

Material	Density [kg/m^3]	Poisson's ratio [-]	Elastic modulus [GPa]	Tensile yield stress [MPa]	Tensile ultimate strength [MPa]
SS304L	7900	0.27	196	200	500

Table 2-2: Material properties [4]

2.3 Static load cases

2.3.1 Pipes Supports ZB1, load case.

As can be seen in Figure 2-4, 12 uniform line distributed loads are acting on the structure which include 6 vertical loads acting 90 mm above from bottom plate and 6 horizontal loads acting 90 mm distance from the left side of the plates. While the loads in the vertical direction resulted from pipes and fluid weight, the loads in the horizontal direction are caused by thermal expansion/contraction which led to pipes deflection and contact with the side plates. According to EDMS-2939582 [5], the value of each vertical load is approximately 1250 N, and the horizontal load is about 150 N for each.

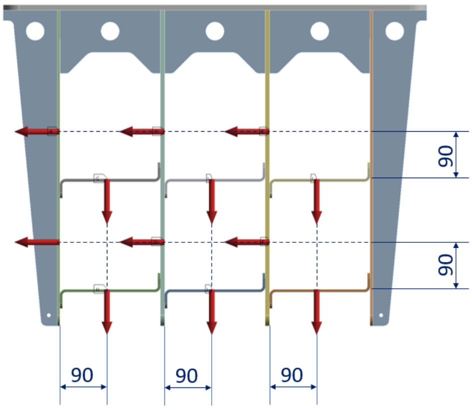


Figure 2-4: ZB1 load case

2.3.2 Pipes Supports ZB2, load case.

From Figure 2-5, forces in only the vertical direction can be seen. As mentioned in section 2.1 the support ZB2 allows the pipes to move not only in the longitudinal direction but also transverse direction. Thus, there has no force acting in the horizontal direction. The forces in the vertical direction are assumed to act on the centre of the bottom plate which has a value of 1250 N for each.

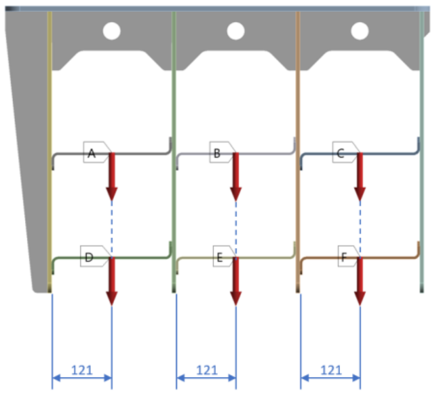


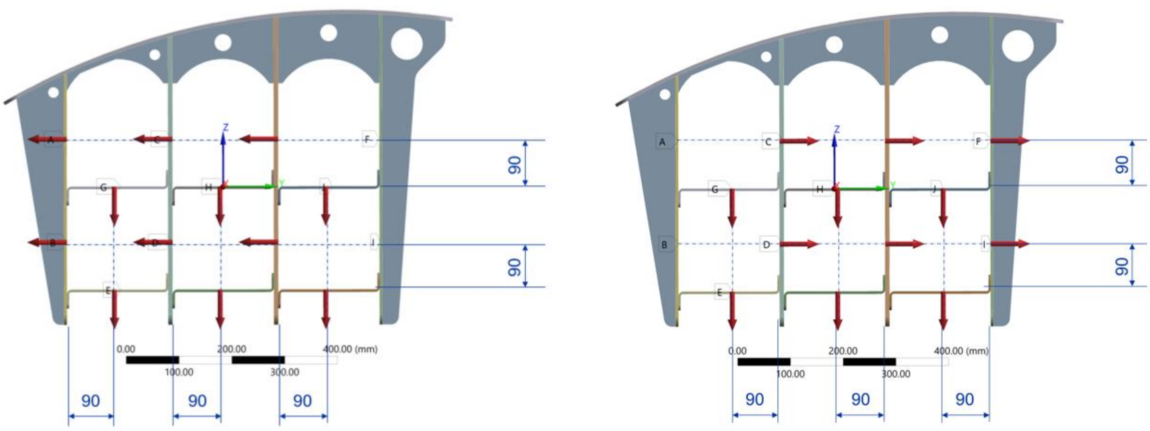
Figure 2-5: ZB2 load case

2.3.3 Pipes Supports ZC1 and ZC2, load case 1.

As same as the support ZB1, the supports ZC1 and ZC2 have forces in both horizontal and vertical directions. The locations of the forces are indicated in Figure 2-6 (a). One thing that ZC1 and ZC2 distinguish from ZB2 is the magnitude of the force acting in the horizontal direction. Regarding EDMS-2939582 [5] each horizontal force has a value of maximum 900 N which is 6 times higher than the horizontal load in the case of ZB1.

2.3.4 Pipes Supports ZC1 and ZC2, load case 2.

Another thing that ZC1 and ZC2 are different from ZB1 is the fact that ZC1 and ZC2 geometry are not symmetrical. For this reason, to find the worst case, the horizontal forces have been assumed to act in the right direction with the same magnitude of the horizontal forces in load case 1, and vertical forces acting distanced from the right side of the plates 90 mm as shown in Figure 2-6 (b).



(a) (b)

Figure 2-6: (a) ZC1 & ZC2 load case 1 (b) ZC1 & ZC2 load case 2

2.4 Failure Criteria

2.4.1 Bolts assessment

The structures are fastened with the bolts as illustrated in Figure 2-7 and Figure 2-8. For designs ZB1 and ZB2, there are 4 M12 bolts that connect between other structures and the support. For the 12 faces that connect the bottom plates to the assembly of support, each face has 2 M8 bolts which are connected with long slotted holes. For designs ZC1 and ZC2, there are 6 M12 injection anchors which are fixed to the slotted holes of the top plate to the cavern ceiling and 12 faces as same as designs ZB1 and ZB2. These bolts have been verified following Eurocode 3 EN1993-1-8:2005 [2]. Section 3.6 of EN1993-1-8 provide information about design resistances which are criteria to prevent several modes of failure.

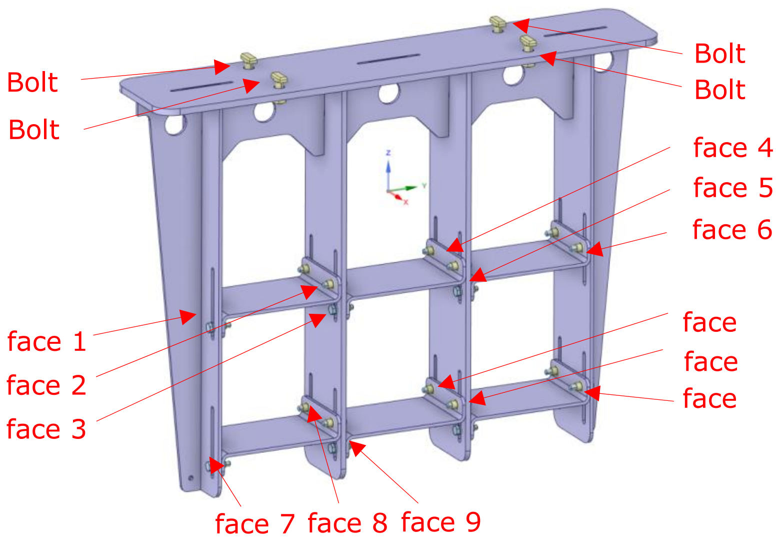


Figure 2-7: Bolts and Contacts denomination for ZB1 and ZB2

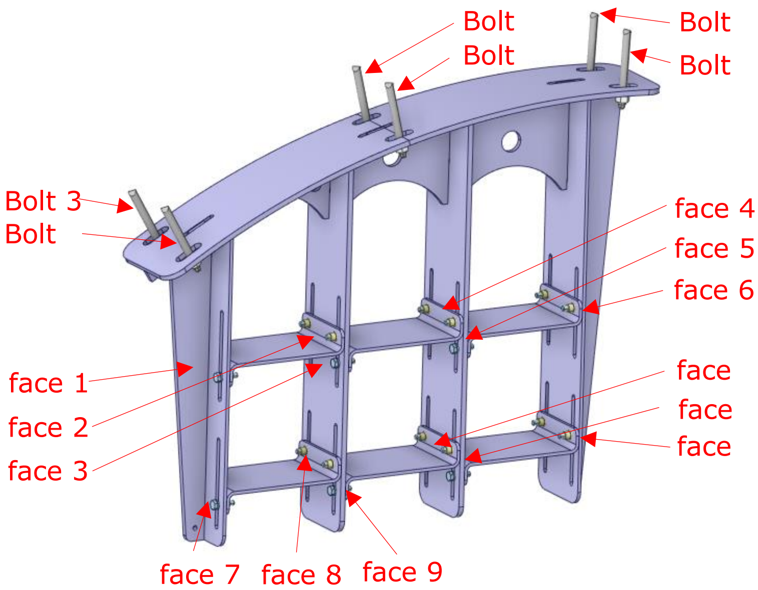


Figure 2-8: Bolts and Contacts denomination for ZC1 and ZC2

All the bolts are assumed to be class 8.8 which has a yield strength of 640 MPa and Ultimate tensile strength of 800 MPa according to Eurocode 3 EN 1993-1-8:2005 [2].

Design Preload

Design Preload is the preload used in design calculation which can be calculated by following the equation in 3.1 in section 3.6.1 Eurocode 3 EN1993-1-8:2005 [2].

Design Slip resistance

To verify that bolts will not slide along a hole, criterion specified in Eurocode 3 EN1993-1-8:2005 section 3.9 [2] is used to calculate the maximum force that can tolerate slipping. All slotted holes in pipe support have been checked by this failure criteria. In the calculation, all slotted holes are assumed to be long slotted holes with the axis of the slot parallel to the direction of load transfer (ks=0.63) and have a slip factor of μ=0.15 (steel-to-steel conservative value). The design slip resistance can be calculated by

$$F_{s,Rd} = \frac{k_s n \mu}{\gamma_{M3}}(F_{p,C} - 0.8F_{t,Ed}) \qquad (2\text{-}1)$$

The designs ZC1 and ZC2 use injection M12 bolts to hold the support to the cavern ceiling. These bolts are injected with the resin HIT-RE 500 v4 [6]. The resin enhances the total resistance force which can be calculated by the following equation (see Eurocode 3 EN 1993-1-8 : 2005 section 3.9.2 and section 3.6.2.2(4) [2])

$$F_{s,Rd} + F_{b,Rd,resin} = \frac{k_s n \mu}{\gamma_{M3}}(F_{p,C} - 0.8F_{t,Ed}) + \frac{k_t k_{s'} d t_{b,resin} \beta f_b}{\gamma_{M4}} \quad (2\text{-}2)\ ;$$

where

k_s *is the slotted hole factor given in Eurocode* 3 *EN*1993 − 1 − 8 : 2005(*E*) *section* 3.9 *table* 3.6

n *is the number of the friction surface*

μ *is the slip factor*

$F_{p,C}$ *is the design preload*

$F_{t,Ed}$ *is the design tensile force per bolt for the ultimate limit state*

β *is the coefficient depending of the thickness ratio of the coneected plates*

$f_{b,resin}$ *is the bearing strength of the resin*

$t_{b,resin}$ *is the effective bearing thickness of the resin*

k_t *is* 1.0 *for seviceability limit state, and* 1,2 *for ultimate limit state*

$k_{s'}$ *is the hole clearance factor*

m *is the differece* (*in mm*) *between the normal and oversized hole dimensions*.

Other criteria

In this scope of analysis shear resistance per shear plane, bearing resistance, tension resistance, and punching shear resistance have also been verified by principals following Eurocode 3 EN 1993-1-8 : 2005 section 3.6 table 3.4 [2].

2.4.2 Weld assessment

As this structure consists of a large amount of welds with the majority not heavily stressed, only a set of critical and representative welds (section4.1.2.6) has been analysed for this study according to the European standard code NF-EN-1993 Design of steel structure Part 1-8 [2]. In the standard, the directional method applied for throat section of fillet welds assumes that the forces transmitted by a unit length of weld are resolved into components parallel and transverse to the longitudinal axis of the weld and normal and transverse to the plane of its throat. A uniform distribution of the stress is assumed on the throat section of the weld, leading to the normal stresses and shear stresses shown in Figure 2-9:

- $\sigma_\perp$ is the normal stress perpendicular to the throat.
- $\sigma_\parallel$ is the normal stress parallel to the axis of the weld.
- $\tau_\perp$ is the shear stress (in the plane of the throat) perpendicular to the axis of the weld.
- $\tau_\parallel$ is the shear stress (in the plane of the throat) parallel to the axis of the weld.

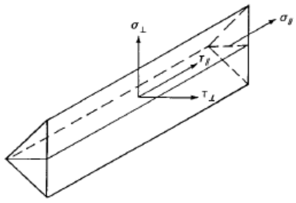


Figure 2-9. Stress on the throat section of a fillet weld

The normal stress $\sigma_\parallel$ parallel to the axis is not considered when verifying the design resistance of the weld. The design resistance of the fillet weld will be sufficient if the following are both satisfied:

$$\sigma_{Eqv} = \sqrt{\sigma_\perp{}^2 + 3(\tau_\perp{}^2 + \tau_\parallel{}^2)} \leq \frac{f_u}{\beta_w \cdot \gamma_{M2}} = f_{uEqv} \quad \text{and} \quad \sigma_\perp \leq 0.9\frac{f_u}{\gamma_{M2}} = f_{u\perp} \qquad (2\text{-}3)$$

Where:
f_u is the nominal ultimate tensile strength of the weaker part joined (360MPa)
γ_{M2} is the partial safety factor for joints (1.25)
β_w is the appropriate correlation factor taken from tables (0.8)

The support will be fastened with weld that have the same material with the plates, however for conservative calculation the weld material has been assumed to be S235.

<u>Intermittent weld</u>
For long total weld length, continuous welding can cause distortion. One of the solutions is applying the intermittent welding method. Although, intermittent welding method can reduce distortion, the strength of the joint decrease relative to continuous welding. The strength of intermittent welding also depends on the number of welds applied *n* and the space between welds *e*. As Eurocode 3 1993-1-8:2005 section 4.9 (7) [2] states that "(7) If the design resistance of an intermittent weld is determined by using the total length ℓ_{tot}, the weld shear force per unit length $F_{w,Ed}$ should be multiplied by the factor (e+ℓ)/ℓ, see Figure 4.7" (Figure 2-10). Hence, in this analysis, the intermittent weld factor has been used to estimate and optimize intermittent welds.

Utilisation factor

$$\text{utilisation factor} = \max\left(\frac{\sigma_{Eqv}}{f_{uEqv}}\frac{(e+l)}{l}, \frac{\sigma_\perp}{f_{u\perp}}\frac{(e+l)}{l}\right) \qquad (2\text{-}4)$$

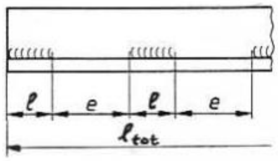


Figure 4.7: Calculation of weld forces for intermittent welds

Figure 2-10: figure 4.7 in Eurocode 3 1993-1-8 : 2005 section 4.9 [2]

2.4.3 Seismic analysis

The CO2 pipes supports need to withstand earthquake-induced loads. Consequently, a seismic load has been taken into consideration for the analysis which can be determined by the equations according to Eurocode 8 (EN 1998-1:2004, clause 3.2.2.5 'Design Spectrum for elastic analysis'). There are two types of seismic response spectrum which are conventional spectrum for elastic and design spectrum for elastic analysis. The type of analysis that has been applied is the design spectrum for elastic analysis because of the fact that the CO2 pipe system and support have ductile properties. This led to energy dissipation and reduced seismic force. This phenomenon relates to behaviour factor q which is an approximation ratio between the conventional elastic analysis model and the completely elastic with 5% viscous.

The seismic action characteristic depends on many geological factors and directions. In the analysis, seismic action has 3 orthogonal directions which are assumed to be independent. The 2 orthogonal horizontal directions share the same spectrum, while the one vertical direction has different ground acceleration compared to the horizontal directions, resulting in a different spectrum curve for this component.

For this analysis, the parameters are provided by Technical Specification Design, Supply, and Installation of 2-Phase CO2 Transfer Lines for the ATLAS Experiment; Earthquakes resistances, table 7 [1] and are shown again in this document in the table below. The calculation results are available in Figure 2-11 or Table 7-1 in Appendix.

Parameter	Value	Reference
Peak ground acceleration a_{gR}	1.1 m s-2	EDMS 1158454
Importance factor γ	1.4 (category IV)	arrêté bâtiment, article III, highest importance (EDMS 1158454)
Design ground acceleration $ag = \gamma\, a_{gR}$	1.54	
Spectrum type	1	
Ground type	B	EDMS 1142510
Behaviour factor q	3	EN 1998-4, section 5.5 (3) welded steel pipelines

Table 2-3 Earthquake resistance design values [1]

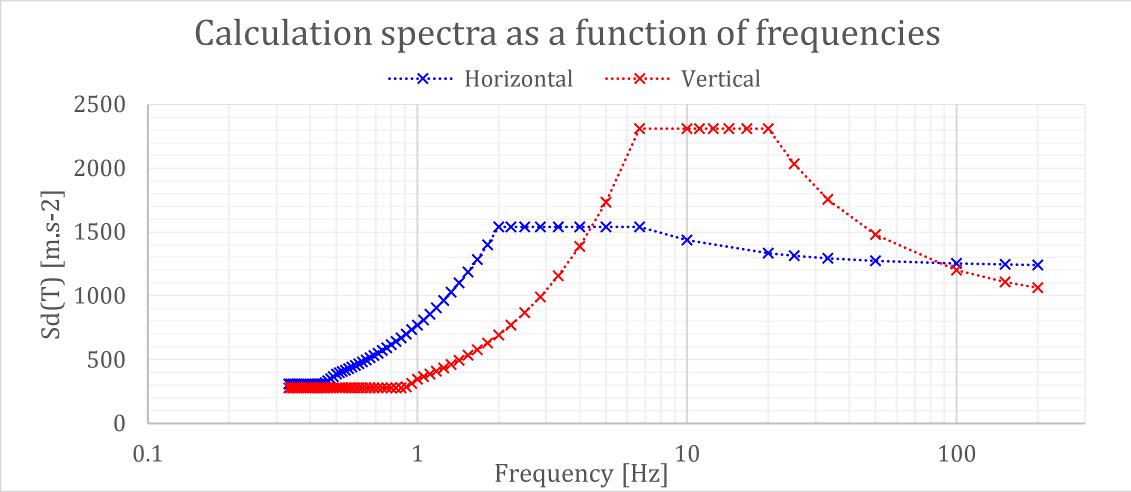


Figure 2-11: seismic actions

The seismic actions can be taken into account by combining the seismic effects with the effects due to other actions by

$$G_{k,j} + \Sigma \psi_{E,i} \cdot Q_{k,i} \qquad (2\text{-}5)$$

where
$G_{k,j}$ is the characteristic value of permanent action j
$\psi_{E,i}$ is the combination coefficient for variable action i
$Q_{k,j}$ is the characteristic value of the accompanying variable action i

(See clause 3.2.4 'Combinations of the seismic action with other actions' Eurocode 8 EN 1998-1:2004 [3]). For seismic loads, the combination coefficient is equal to 1 (see Eurocode 8 EN 1998-1:2004 [3]).

The analysis can be performed using various methods, namely, the **Lateral force method**, **the Modal response spectrum**, and the **Non-linear method**. Those are different procedures to analyse for different purposes. The one that is selected for analysing CO2 pipes support is the Modal response spectrum method as it is suggested by criteria following Eurocode 8 EN 1998-1:2004 section 4.3.3.1 [3].

<u>Modal response spectrum method</u>

Modal analysis is the analysis used to provide natural frequency ω_i, mode shape of the responses ϕ_i, and participant factor γ_i. The participation factor is the factor that represents how much the mode contributes to the action effects for each mode in a particular direction. It is used to calculate the response by following the equation.

$$Mode\ coefficient\ A_i = S_i\ ;\ where\ S_i\ is\ the\ elastic\ response\ spectrum\ of\ mode\ i \qquad (2\text{-}6)$$

- Response

$$Acceleration\ response: R_i = \omega_i^2 A_i \phi_i \qquad (2\text{-}7)$$
$$Velocity\ response: R_i = \omega_i A_i \phi_i \qquad (2\text{-}8)$$
$$Displacement\ response: R_i = A_i \phi_i \qquad (2\text{-}9)$$

The equations (2-7), (2-8), and (2-9) are responses corresponding to frequency ω_i. However, earthquakes excite the system with random frequencies. This excitation is characterized by spectrums. Hence, the system does not respond to only one mode shape but exhibits as combination mode shapes. To represent this combination the total response has been defined.

The total response can be estimated by mode combination, which can be done by combining the response from each mode.

However, not all the mode shapes have to be taken into consideration since the calculation can be approximated by using sufficient mode shapes that would contribute significantly to the responses. The parameter related to this approximation is the effective mass $M_{eff,i}$. Effective mass is the parameter measuring modes-actions contribution in each direction for each mode as same as the participation factor. However, the effective mass is equal to the participation factor square $M_{eff,i} = \gamma_i^2$ and it can be proven that the sum of the effective mass of all modes is equal to the total mass. These properties proved to be beneficial to the analysis. Therefore, the effective mass has been used in the analysis.

The Eurocode 8 EN 1998-1:2004 section 4.3.3.3.1 [3] indicates the following criterion: "…the sum of the effective modal masses for the modes taken into account amounts to at least 90% of the total mass of the structure…" or "…all modes with effective modal masses greater than 5% of the total mass are taken into account…"

Mode combination methods

Each method has a different way of calculating the combining response and is only suitable for some conditions that match the method assumptions.

- Square Root of Sum of Squares (SRSS)
  The modes of vibration are assumed to have negligible interaction with each other and negligible effect of closely spaced modes. The criteria used regarding Eurocode 8 EN 1998-1:2004 section 4.3.3.3.2(1) [3] is "…The response in two vibration modes i and j (including both translational and torsional modes) may be taken as independent of each other, if their periods Ti and Tj satisfy (with $T_j \leq T_i$) the following condition: $T_j \leq 0.9 \cdot T_i$…". This indicates that to use this method, two vibration modes have to separate apart more than 10% from each other ($\frac{Ti-Tj}{Ti} \geq 0.1$).
- Complete Quadratic Combinations (CQC)
  In case of modes are *closely space modes* and the Eurocode 8 EN 1998-1:2004 section 4.3.3.3.2(1) [3] is not met, CQC shall be applied since the CQC method takes modes coupling effects and damped effects into account.

Combination of the effects of the seismic action component

Seismic actions in each direction are defined independently and are evaluated separately. These components of seismic action effects then have to be combined according to Eurocode 8 EN 1998-1:2004 clause 4.3.3.5 [3]. There are two ways to combine the effects. First, the effects may be combined by the square root of the sum of the squared values which will give a conservative approximation. The other way is the way to calculate total effects with more accuracy which can be computed by following equations.

$$E_{tot} = \max\begin{pmatrix} E_{Edx} + 0.30E_{Edy} + 0.3E_{Edz}, \\ 0.30E_{Edx} + E_{Edy} + 0.3E_{Edz}, \\ 0.3E_{Edx} + 0.30E_{Edy} + E_{Edz} \end{pmatrix} \qquad (2\text{-}10)$$

Where

E_{Edx} is the action effects due to solicitation x seismic action

E_{Edy} is the action effects due to solicitation y seismic action

E_{Edz} is the action effects due to solicitation z seismic action

Note that action effects can be deflection, stress, force, etc.

Flow chart

Seismic analysis procedures are summarized in figure 1-13

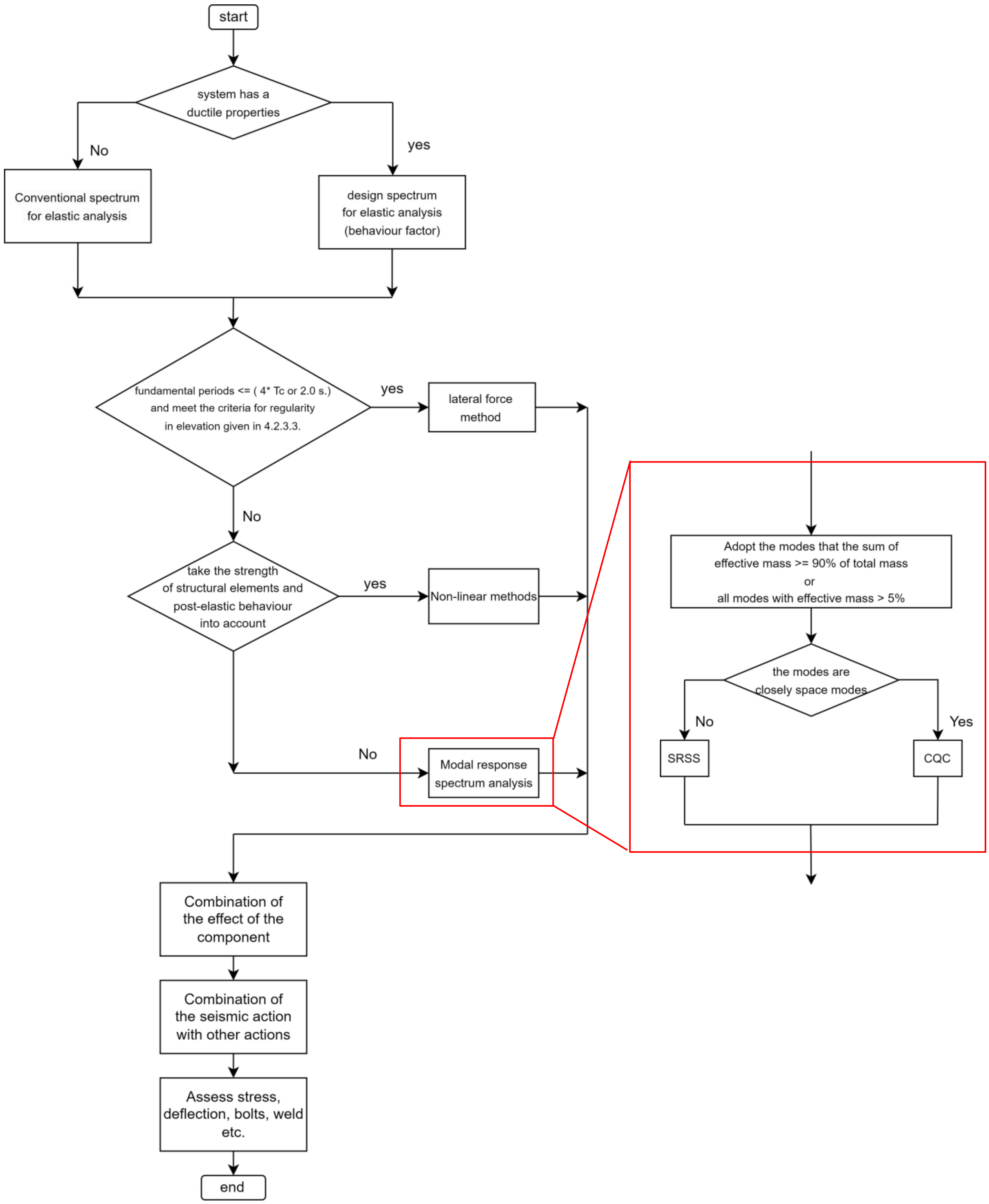


Figure 2-13: Seismic Analysis Flowchart

2.4.3.1 Seismic analysis load condition for ZB1 and ZC1

Seismic analysis has been only performed for the pipes support ZB1 and ZC1. The combined effects of ZB1 have been assumed to imply the effects on ZB2. Likewise, the effects of actions for ZC1 have been used to imply to the effects of ZC2. These assumptions are based on the fact that geometries and boundary conditions between ZB1 and ZB2 are approximately the same, and it can be clearly seen that ZB2 is less critical as it has no horizontal force. As well as ZC2, it can be seen that ZC2 capable to carry more loads than ZC1 as it has bulky material more and has less stress concentration points than ZC1. This will be further discussed in section 4.1.

Instead of the forces acting horizontally and vertically, the pipes support has been assumed to carry a distributed mass with the weight of 80 kg, as a representation a section of the pipes and the fluid inside (which is equivalent to about 9 m of line). These masses have been placed in the centre of each bottom plate as can show in Figure 2-12.

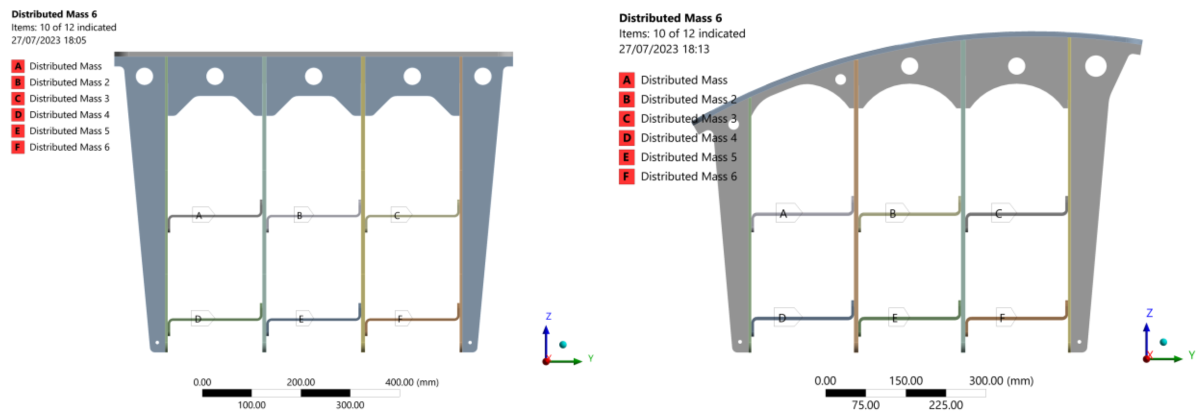


Figure 2-12: (a) distributed mass on ZB1 (b) distributed mass on ZC1

3. Numerical Model Details

3.1 Software

Operating System: Microsoft Windows 10 Professional x64 Edition, ANSYS - Ansys 2022 R2
The units used in the analysis are SI (mm, kg, N, s, mV, mA).

3.2 Mesh

The mesh of the supports is shown in Figure 3-1 and mesh information can be found in Table 3-1.

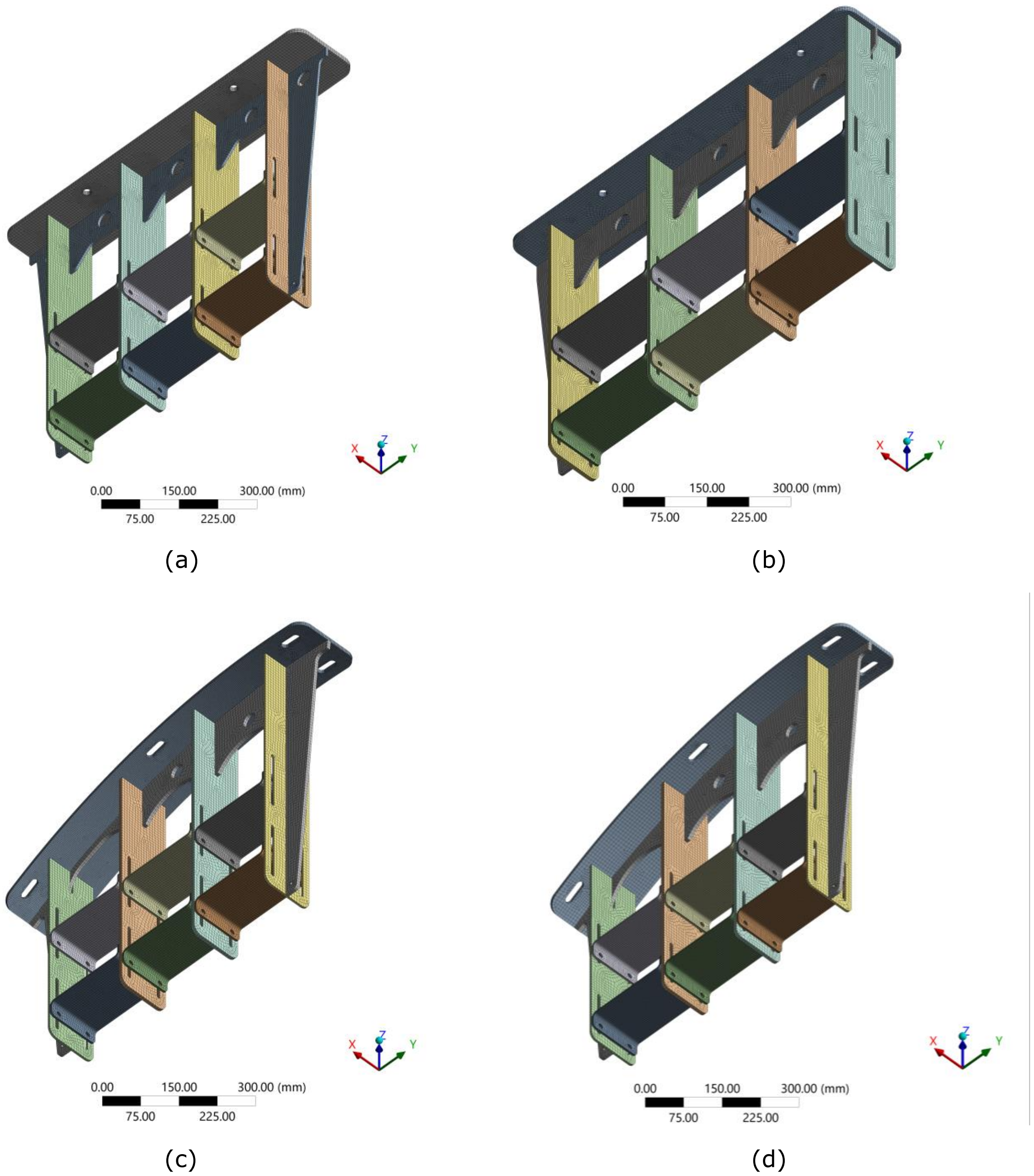


Figure 3-1: mesh (a) ZB1 mesh (b) ZB2 mesh (c) ZC1 mesh (d) ZC2 mesh

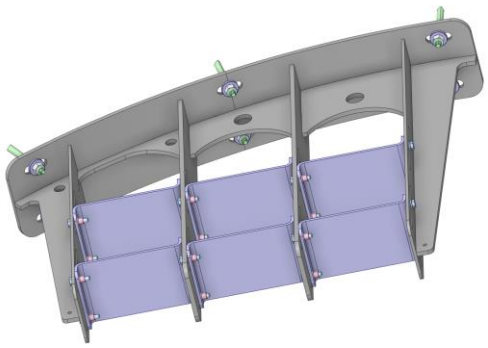
Pipes support	Number of Nodes	Element Name	Number of Elements
ZB1	324995	SOLID 186	57232
ZB2	522310	SOLID 186	99552
ZC1	710897	SOLID 186	27560
		SOLID 187	349814
ZC2	246836	SOLID 186	41529

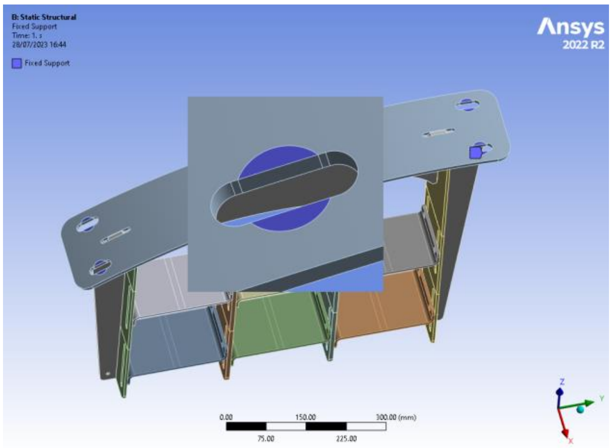
Table 3-1: Nodes & Elements data

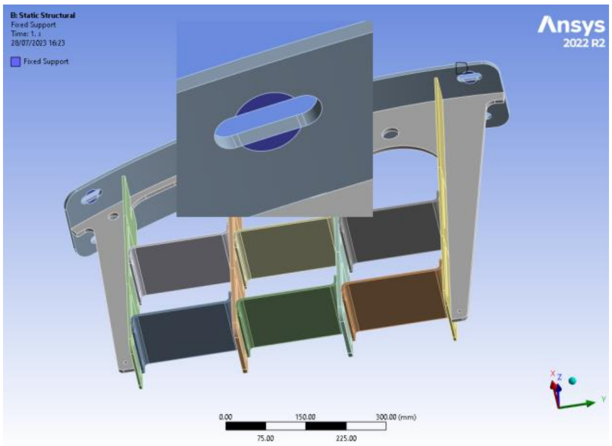
3.3 Boundaries and Load Conditions

The M12 bolts and washers that fix pipes supports to the ceiling have been removed. The washer faces had been projected to plate on both sides then the fixed support was applied, as shown in Figure 3-2 (b).

All the bolts fastened to the bottom plates also have been removed and replaced with face-to-face bonded contacts. All the weld joints have been assumed to be face-to-face bonded contacts for statics and seismic analysis and edges-to-face bonded contacts for weld assessment.







(a) (b)

Figure 3-2: (a) SpaceClaim model (b) Simplified model.

4. Results

4.1 Statics structural

This section reports the results of pipe supports subjected only to statics load. It will provide information about Total deformation and Von Mises stress. Overall, it can be observed that the total deformation of all supports is under 0.65 mm. Besides artificially high stress from boundary condition or assumption, the stress on the structure is under the material yield strength.

4.1.1 Deflection

4.1.1.1 ZB1

Figure 4-1 shows that the maximum deformation is located at the bottom plates which are deformed around 0.27 mm in the z-direction. It also deflects slightly to the left by less than 0.24 mm.

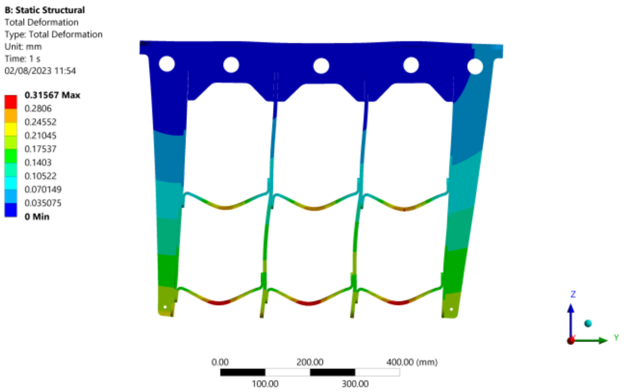


Figure 4-1: Total deformation result of ZB1

4.1.1.2 ZB2

Since the bottom plate of the ZB2 design is wider than ZB1, it shows a larger deformation. Moreover, the left plate shows a relatively large bend due to the moment from the weight of the pipe which can be seen in Figure 4-2.

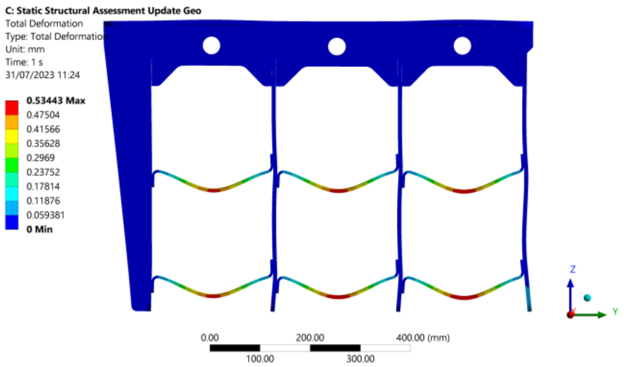
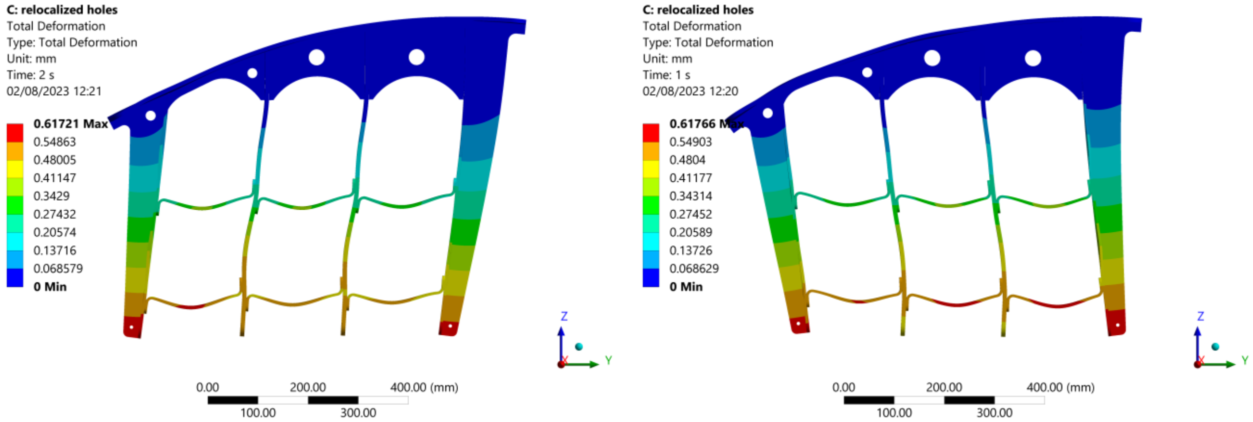


Figure 4-2: Total deformation result of ZB2

4.1.1.3 ZC1

Two load cases have been applied to the structure resulting in deformation as shown in Figure 4-3. Both load cases are shown an amount of total deformation around the same value. The tips of the core plate appear to have large deformation in the y-direction for over 0.6 mm for both load cases.



(a) (b)

Figure 4-3: Total deformation result of ZC1 (a) deformation of load case 1 (b) deformation of load case 2

4.1.1.4 ZC2

Although the deformation shape of ZC2 is similar to ZC1, the ZC2 design has a marginally lower deformation than ZC1 by about 0.05 mm as can be seen in the pictures below.

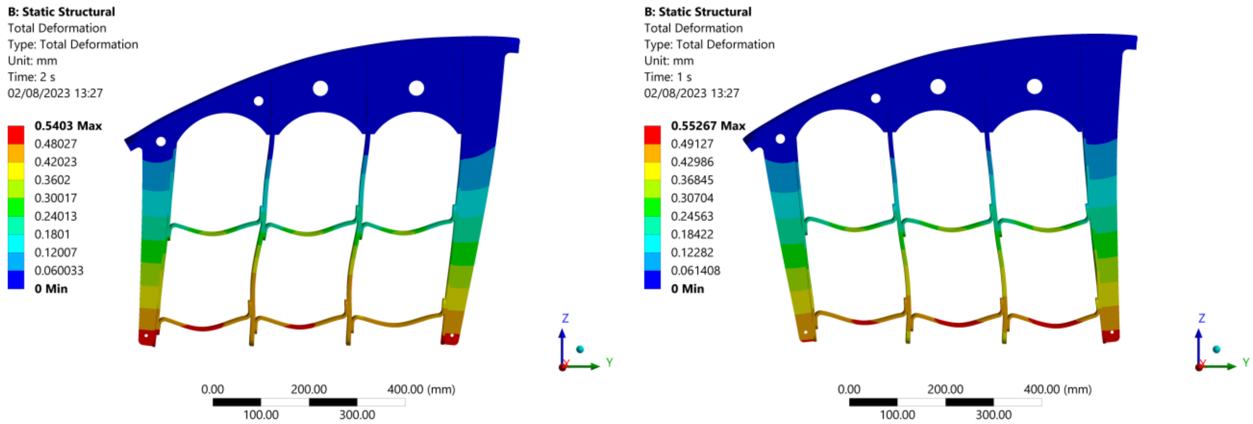


Figure 4-4: Total deformation result of ZC2 (a) deformation of load case 1 (b) deformation of load case 2

4.1.2 Stress

4.1.2.1 ZB1

The result of the statics structural analysis is given in Figure 4-5. It can be seen that the value of maximum stress is 71.7 MPa which is not above the yield strength.

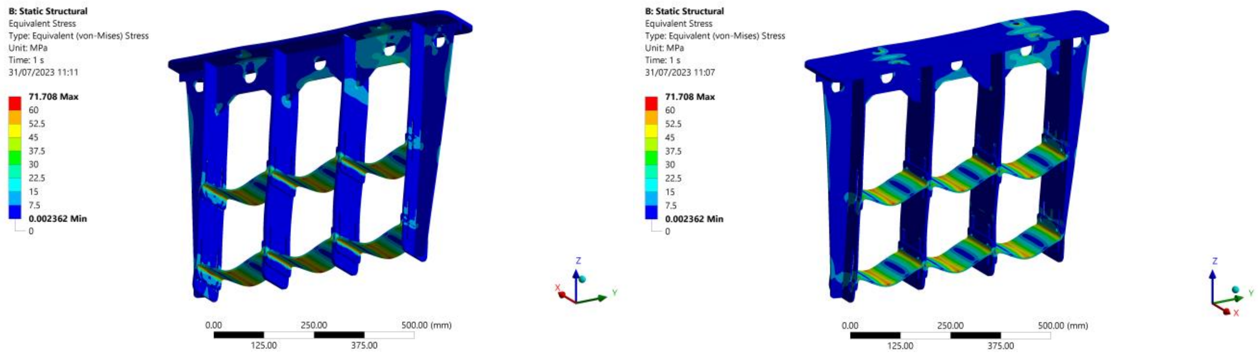


Figure 4-5: ZB1 equivalent stress

4.1.2.2 ZB2

Similar to ZB1, ZB2 shows no critical sign as maximum values of stress stand at 105 MPa. The details are displayed in Figure 4-6.

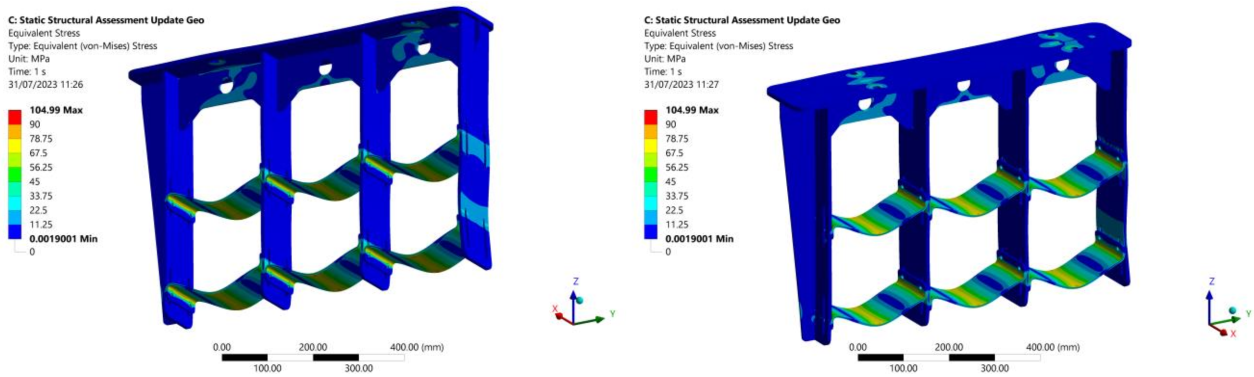


Figure 4-6: ZB2 equivalent stress

4.1.2.3 ZC1

Figure 4-7 and Figure 4-8 show the maximum stress is above the yield strength of the material. The points, where the stress is above yield strength, are located at fixed supports and sharp edges which are often singularities caused by the numerical model. This can be assessed by bolts and weld assessment. Apart from the inaccurately high stress due to numerical process, the rest area on the structure, stress is lower than 100 MPa.

Load case 1

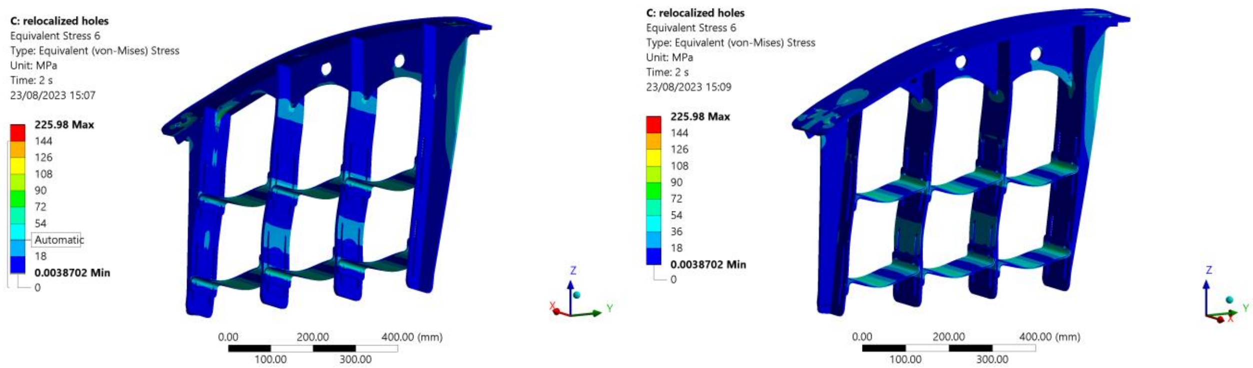


Figure 4-7: ZC1 load case 1 equivalent stress

Load case 2

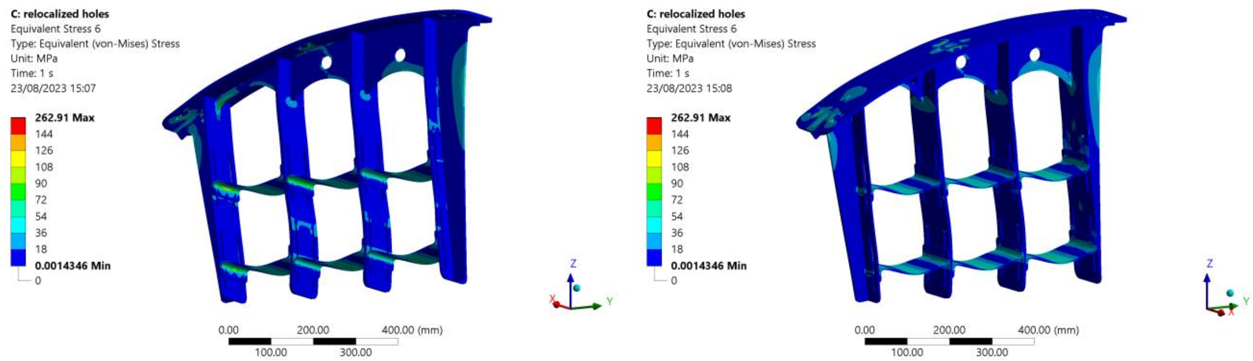


Figure 4-8: ZC1 load case 2 equivalent stress

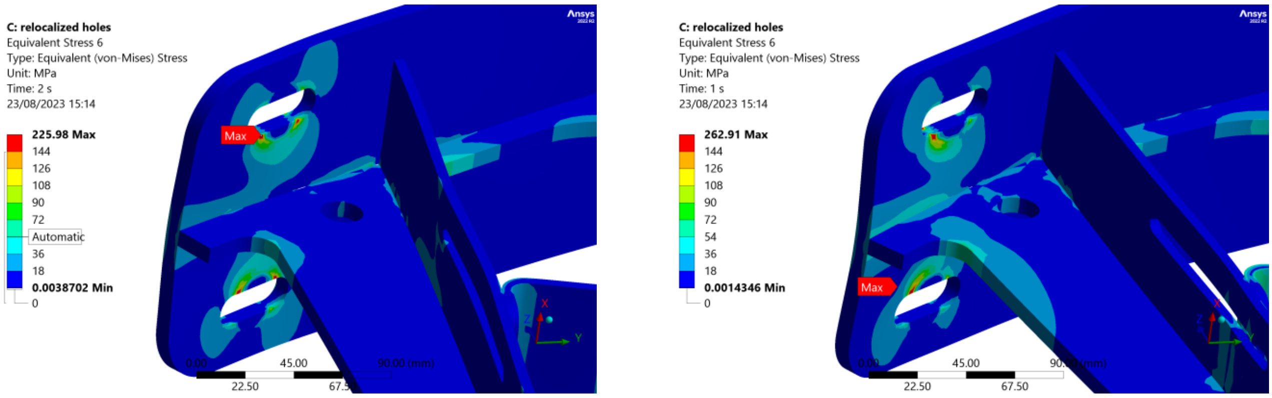


Figure 4-9: ZC1 Numerical peak stress

4.1.2.4 ZC2

Maximum stress of ZC2, which occurs in the load case 2, is 169 MPa or 94% of the yield strength. However, by a closely observe (Figure 4-9 and Figure 4-10) the high stress only can be seen in the fixed supports and sharp edges points. For the same reason as mentioned in section 4.1.2.3 this high stress cannot represent the physical model. The other area than fixed support and sharp edges, stress is less than 120 MPa which the highest stress located at bent region of the bottom plate.

Load case 1

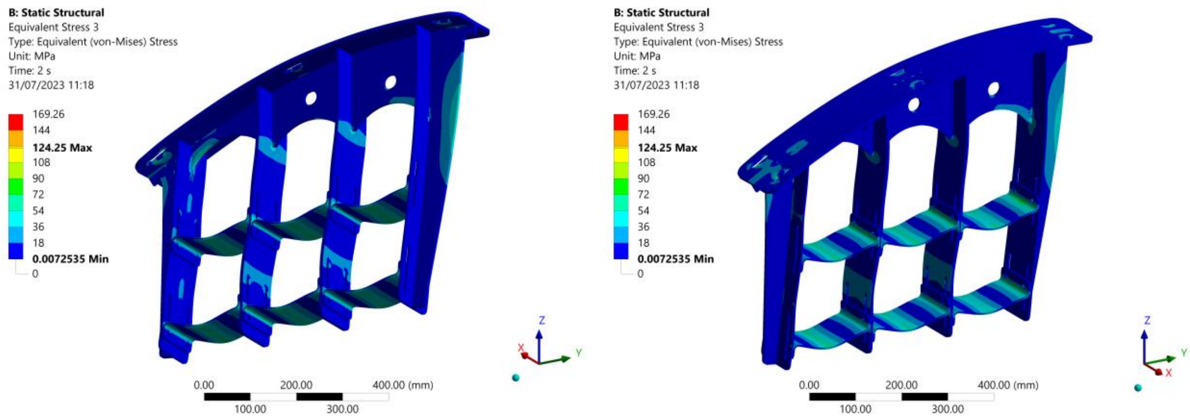


Figure 4-10: ZC2 load case 1 equivalent stress

Load case 2

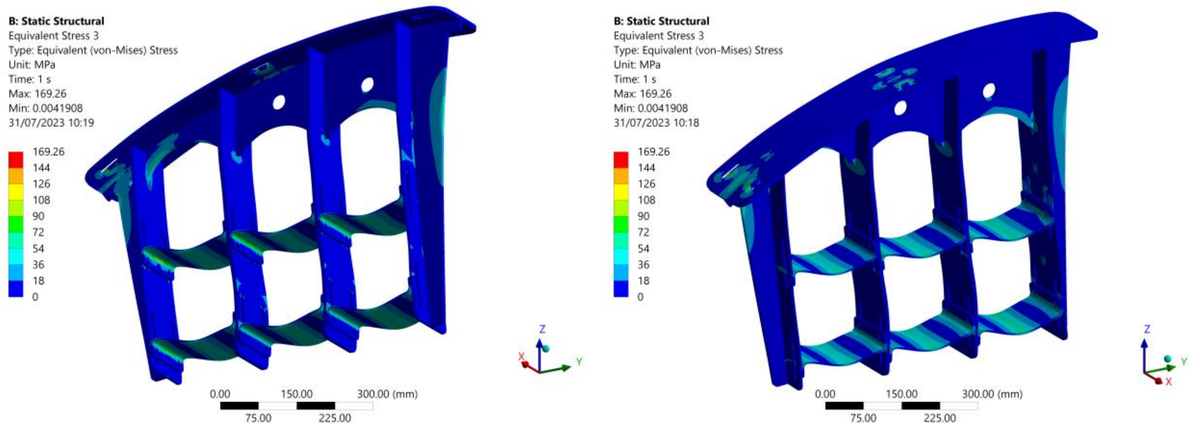


Figure 4-11: ZC2 load case 2 equivalent stress

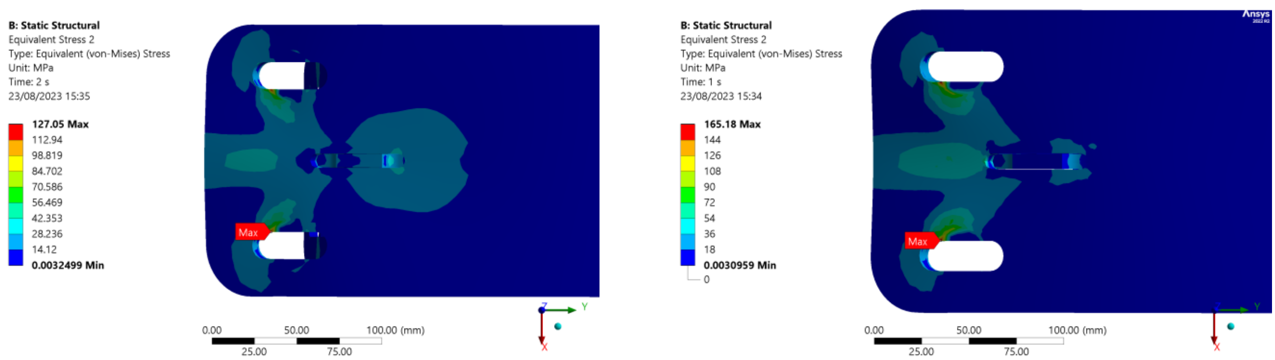


Figure 4-12: ZC2 Numerical peak stress

4.1.2.5 Statics effects on bolts

All the tables in Appendix section 7.1.2 illustrate the force acting on the fixed bolts and bottom plate bolts. Those tables show that for fixed bolts of the ZB1 is more critical than ZB2. ZC1 is more critical than ZC2. By comparison among the bottom bolts of each support, the force of the ZC1 and ZC2 are about the same which are far higher than the force of ZB1 and ZB2. Consequently, to simplify the problem and reduce the process of analysis, only ZB1 and ZC1 have been selected to perform the seismic analysis. In addition, the bolt assessments for fixed bolts of ZB1 and ZC1 have been used to represent the bolts of ZB2 and ZC2, respectively. Moreover, the bottom plate bolts assessment is done by using the results from only ZC1 to represent every pipes supports.

The bolt utilisation factors have been calculated in this case to preliminarily check the designs.
<u>ZB1</u>

Comment: the following paragraph in italics is under discussion and will be updated.

The values of slip resistance and tension resistance have been taken according to MUPRO data sheet, as a substitute of calculation analytically based on Eurocode 3 EN 1993-1-8:2005 [2]*. The Eurocode 3 guidelines* [2] *have been used to evaluate other failure modes, including shear resistance, punching resistance, and bearing resistance. Among these, the mode of failure yielding the highest utilisation factor is a slip resistance mode. The utilisation factors of the fixed bolts are presented on the Table 4-1.*

As illustrated in Figure 2-2 (a) and (b), ZB1s are fixed with the MUPRO MPT-support profiles Q100. While some of ZB1 are fixed with the profile slot oriented in the x-direction, some are fixed with the slot aligned in the y-direction. As a consequence, force in both x and z directions must be lower than the slip resistance force and the force in y direction must less than the tensile resistance force. Additionally, utilisation factor for slip is the force in x-direction or z-direction divided by slip resistance force and utilisation factor of tensile is y-direction force divided by tensile resistance force.

From MUPRO datasheet (page 8/24) [7] *for profile Q100-2.5 M12 the maximum tensile load is equal to 8 kN and the maximum transverse load is equal to 9.5 kN.*

Utilisation Factor	bolt1	bolt2	bolt3	bolt4
Punching shear	1.08%	1.48%	1.08%	1.49%
Bearing	0.38%	1.48%	0.38%	1.48%
Combined Shear and tension	2.89%	5.73%	2.89%	5.73%
Slip	4.55%	17.82%	4.54%	17.83%
Overall	4.55%	17.82%	4.54%	17.83%

Table 4-1: utilisation of each ZB1 fixed bolt

ZC1

Table 4-2 and Table 4-3 show the results of utilisation of the fixed bolts and the bottom plate bolts, respectively. The results show the same trend as the highest utilisation factor belong to the slip failure.

Utilisation Factor	bolt1	bolt2	bolt3	bolt4	bolt5	bolt6
Punching shear	3.64%	3.61%	3.61%	3.64%	5.15%	5.16%
Bearing	1.58%	1.55%	1.20%	1.20%	2.89%	2.89%
Combined Shear and tension	17.81%	17.50%	50.23%	50.08%	9.10%	8.99%
Slip	17.81%	17.50%	50.23%	50.08%	9.10%	8.99%
Slip resistance of Utilisation Factor for the bolt without resin	17.81%	17.50%	50.23%	50.08%	9.10%	8.99%

Table 4-2: utilisation of each ZC1 fixed bolt

Utilisation factor	Bearing	combined Shear and tension	Slip	overall
face1	2.05%	4.54%	21.23%	21.23%
face2	2.15%	4.46%	21.70%	21.70%
face3	2.16%	3.26%	21.88%	21.88%
face4	2.27%	3.81%	23.19%	23.19%
face5	2.23%	4.71%	22.50%	22.50%
face6	2.38%	5.52%	24.80%	24.80%
face7	2.01%	3.39%	20.50%	20.50%
face8	2.09%	3.41%	21.21%	21.21%
face9	2.06%	3.38%	21.05%	21.05%
face10	2.21%	3.28%	22.42%	22.42%
face11	1.94%	3.65%	19.58%	19.58%
face12	2.14%	3.91%	21.91%	21.91%

Table 4-3: utilisation in a particular load case factor of each bolt in a specified face (1 bolt) when only static loads are applied.

4.1.2.6 Statics effects on weld

By looking to reaction force of the weld joints of all support, only 4 weld joints are plausible to cause failure. First one is joining between top plate and core plate, the second weld joint is connecting between the left side of the right plate to the core plate, the third weld joint is fixing between right side of the right plate to the core plate, and the last one is fastening left side of left plate to core plate. All weld denominations are indicated in figure 4-13.

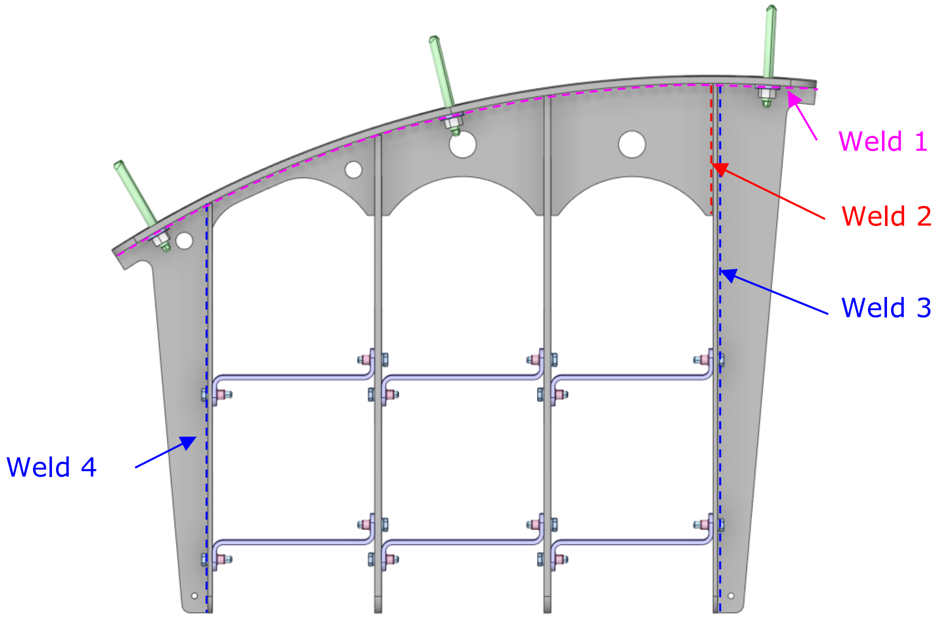


figure 4-13: weld denomination

The maximum forces of each weld joint of each support have been inspected and are listed in Table 7-9. The table shows that ZC1 and ZC2 have a little difference in maximum force per length and the values are far higher than ZB1 and ZB2. Therefore, only the ZC1 has been performed weld assessment. The other supports welding technique is applied as same as ZC1.

ZC1 weld assessment

Results of the weld assessment of ZC1 subjected to the statics load are provided in Table 7-10. Since both weld 3 and weld 4 are subjected to the same welding technique and weld 4 is more critical, weld 3 calculation has been omitted.

Utilisation factors have been calculated by using equation (2-4). The results of the calculations are shown in Table 4-4 which shows that no weld has a utilisation factor higher than 20%.

Weld denomination	utilisation factor
Weld 1	12.06%
Weld 2	14.29%
Weld 4	10.18%

Table 4-4: utilisation factor of continuous weld subjected to static loads.

Due to weld 1 and weld 3 having long weld lengths, the intermittent weld method may apply to the support to avoid thermal bending in the welding process. The strength of intermittent weld has been calculated by applying intermittent factor $(e+\ell)/\ell$. Also, the number of welds has been minimised to find the lowest number of welds required. The results are provided in Table 4-5.

Weld denomination	number of welds	weld length [mm]	%Coverage	utilisation factor
Weld 1	4	30	13.84%	87.30%
Weld 4	3	30	18.57%	77.11%

Table 4-5: utilisation factor of optimized intermittent weld subjected to static loads.

4.2 Seismic Actions Effects

4.2.1 ZB1 Seismic analysis

The distributed masses and gravity have been inserted. These masses are pulling the structure down causing stress which is computed by statics structural analysis. The stress due to the loads has been inputted into the modal analysis. The output of the modal analysis can be seen in Table 7-12. It shows that natural frequencies of **at least 16 modes** should be taken in the calculation of the response spectrum.

From Table 7-13, the table shows that some natural vibration periods are spaced with each other less than 10% which means some modes are *closely spaced modes*. Therefore, SRSS cannot be applied and inevitably **CQC has been used** in the response spectrum analysis.

4.2.2 ZC1 Seismic analysis

With the same analysis procedure, the results of the modal analysis of design ZC1 show the same trend with design ZB1 as can be seen from table 7-14 and table 7-15. The tables indicate that more than or equal to 16 modes should be included in the calculation and natural vibration periods are closely spaced. Thus, the CQC method has been applied as well with the ZB1 Spectrum response analysis.

The Reaction forces due to seismic actions are detailed 7.3

4.3 Combined effects

The static effects and seismic action effects have been combined on the most unfavourable side to determine the conservative utilisation factors of both bolts and weld.

4.3.1 Bolts assessment

To combine the load on the most unfavourable side, all the static loads have been converted to positive values, and compressed loads are assumed to be transferred to plates. The outcomes of the combined load are presented in Table 7-20 for the support ZB1, Table 7-21 and Table 7-22 for the supports ZC1.

4.3.1.1 ZB1

Fixed Bolts

Comment: the following paragraph in italics is under discussion and will be updated.

It is important to note that although utilisation factors of slip in Table 4-6 are in the applicable level. The slip forces are exceeding the slip resistance according to Eurocode 3 EN 1993-1-8:2005 [2] *during seismic event occur. Nevertheless, the bolts slip forces are under the limit when the support subject only static loads.*

Utilisation Factor	bolt1	bolt2	bolt3	bolt4
punching shear	2.48%	2.86%	2.48%	2.86%
Bearing	5.62%	6.60%	5.66%	6.56%
combined Shear and tension	19.13%	20.48%	24.51%	26.59%
Slip	60.38%	63.56%	60.42%	63.46%
Overall	60.38%	63.56%	60.42%	63.46%

Table 4-6: utilisation of each ZB1 fixed bolt

4.3.1.2 ZC1

The results in Table 7-21 have been evaluated by the criteria in Eurocode 3 EN 1993-1-8:2005 [2] consisting with tension resistance, shear resistance, combined tension, and shear resistance, bearing resistance, punching resistance, and slip resistance. The outcomes are provided in Table 4-7. The maximum utilisation percentages are yielded the slip resistance mode. Moreover, the table 4-7 also provides information of the comparison between the bolt without resin utilisation factor (Slip resistance can be calculated by equation 2-1) and injection bolt utilisation factor (Slip resistance can be calculated by equation 2-2).

Utilisation Factor	bolt1	bolt2	bolt3	bolt4	bolt5	bolt6
punching shear	7.59%	7.58%	5.01%	5.04%	6.92%	6.95%
Bearing	11.15%	11.12%	10.92%	8.40%	10.79%	10.80%
combined Shear and tension	20.40%	20.32%	18.74%	18.71%	17.48%	17.55%
Slip resistance of Utilisation Factor for the bolt without resin	43.39%	42.95%	71.04%	71.00%	27.98%	27.80%
Slip resistance of Utilisation Factor for injection bolt	36.27%	31.98%	53.67%	53.64%	21.06%	20.92%

Table 4-7: utilisation of each ZC1 fixed bolt

As can be seen from Table 4-8, the utilisation of some bolts exceeds 100% which is the result of slip failure which occurs only when seismic actions are applied. Therefore, the bottom plate bolts are suggested to use a high frictional washer (friction coefficient between the washer and the plate should be higher than 0.25) or weld the bottom plate to prevent slipping. (The reaction force can are shown in table 7-22)

Utilisation factor	Bearing	combined Shear and tension	Slip	overall
face1	11.76%	21.46%	128.50%	128.50%
face2	11.45%	21.78%	125.36%	125.36%
face3	15.08%	24.58%	164.23%	164.23%
face4	9.78%	17.32%	105.40%	105.40%
face5	11.12%	19.31%	117.56%	117.56%
face6	7.57%	13.32%	80.37%	80.37%
face7	9.19%	14.97%	97.09%	97.09%
face8	7.34%	12.04%	76.49%	76.49%
face9	8.55%	13.77%	90.44%	90.44%
face10	7.88%	12.51%	82.51%	82.51%
face11	8.95%	14.91%	95.14%	95.14%
face12	8.05%	13.34%	84.78%	84.78%

Table 4-8: utilisation in a particular load case factor of each bolt in a specified face (1 bolt) static and seismic loads are applied.

4.3.2 Weld assessment

Same as bolt assessment process the static forces have been converted to positive values and added to seismic reaction loads (Table7-23).

By evaluating the values in Table 7-23 according to Eurocode 3 EN 1993-1-8:2005 [2], the weld joints which are considered as the continuous weld yield a utilisation factor as indicated in Table 4-9 which shows a slight increase of utilisation factor compared to values in table 4-9.

Weld denomination	utilisation factor
Weld 1	17.00%
Weld 2	16.00%
Weld 4	13.23%

Table 4-9: utilisation factor of continuous weld

Table 4-10 shows the minimum number of welds which are subjected to the combination of load. The number of welds required for this case is higher by 1 compared to the case where the support is subjected to only static loads.

Weld denomination	number of welds	weld length [mm]	%Coverage	utilisation factor
Weld 1	4	30	13.84%	93.60%
Weld 4	3	30	18.57%	96.78%

Table 4-10: utilisation factor of optimised intermittent weld

5. Conclusions and Recommendations

The 4 designs of the support have been evaluated, according to the Eurocode 3 EN 1993-1-8:2005 [2] and Eurocode 8 EN 1998-1:2004 [3], under subjection not only static loads due to thermal expansion/contraction but also seismic action causing by earthquakes. This has been done by numerical methods using ANSYS and by analytical calculations. The support subjected to statics load exhibit significant effect on stress especially ZC1 and ZC2 which are subjected to the large magnitude of forces acting in the horizontal direction; however, the stress is not over the yield strength. The loads also have a crucial effect on bolts and weld joints. Thus, all the reaction forces acting on bolts and welds have been calculated.

Due to similarity between supports (geometries, size & class of bolts, and welding techniques), the calculation can be simplified by using the results of one support and assume to imply to others with conservative side. By comparing the effects of static load, it shows that the reaction force of fixed bolts of ZB1 is more critical than ZB2. Likewise, the reaction forces of ZC1 fixed bolts are more critical than ZC2. Moreover, the reaction forces of the bottom plate bolts and stress of the weld joints are most critical on ZC1. As a result, the seismic reaction of ZB1 and ZC1 have been calculated. The seismic calculation of ZB2 and ZC2 have been omitted.

While Fixed bolts of ZB1 (and ZB2) have utilisation factor of slip resistance lower than 65%, fixed bolts of ZC1 (and ZC1) have utilisation factor almost 75% without resin applied and lower than 55% with resin applied.

The bottom plate bolts have utilisation factor exceed 100% due to possibility of these bolts slipping along a slot. This situation only occurs when seismic action take place. To prevent slipping in any case, the bottom plate should be weld to the assembly or using high frictional washer.

For the weld, weld 2 and other weld joints should apply continuous weld. As a result, these weld joints will have utilisation factor below 16%. For weld 1, the weld joints should be applied intermittent welding method with number of welds more than 6 weld length 30 mm. As well as weld 4, intermittent welding techniques with weld length 30 mm should be applied, but the number of welds should be at least 6. The number of welds is calculated analytically with many assumptions. Hence, welder should apply much higher number of weld than optimised number of welds.

6. References

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[2] AFNOR, "Eurocode 3: Design of steel structures Part 1-8: Design of joints," European Committee for Standardization, Brussels, 1993.

[3] AFNOR, "Eurocode 8 - Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for building," European Committee for Standardization, Brussels, 2004.

[4] AFNOR, "NF EN 10088-2 - Stainless steels - Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes," 2005.

[5] A. Piccini, "FLEXIBILITY ANALYSIS: 2-Phase CO2 Transfer Lines for the ATLAS Experiment," 2023.

[6] HITLI, "HIT-RE 500 V4 injection mortar Anchor design (EN 1992-4) / Rods&Sleeves / Concrete," HITLI, 2020.

[7] MÜPRO, "Support technology and vibration control system," MÜPRO, Frankfurt, 2019.

7. Appendices

7.1 Statics load effects

7.1.1 Force coordinate and sign convention

For y-direction, when reaction force is a tensile force the value are assume to be positive For x and z direction all of forces of the fixed bolts are according to the directions as illustrated in Figure 7-1 for ZB1 and ZB2 Figure 7-2 for ZC1 and ZC2. Forces of the bottom plate bolt in x and y direction are regarding to coordinate as indicated in Figure 7-3.

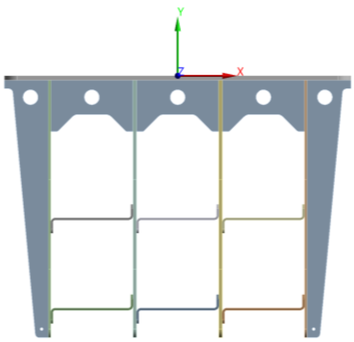

Figure 7-1: ZB1 and ZB2 fixed bolts coordinate

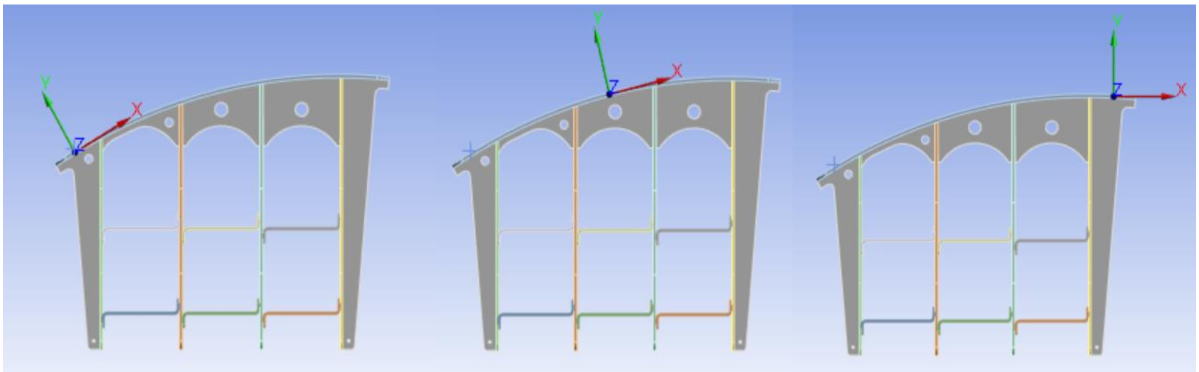

Figure 7-2: ZB1 and ZB2 fixed bolts coordinate

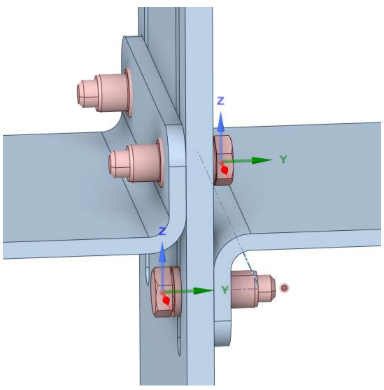

Figure 7-3: Bottom plate bolts coordinate

7.1.2 Static loads effects on bolts

ZB1

The force of the fixed bolts of ZB1 have been extracted and are listed in table 7-1 with the coordinate according to Figure 7-1.

Bolt Denomination	Fx [N]	Fy [N]	Fz [N]
Bolt 1	-97.06	1576.30	-157.82
Bolt 2	546.54	2172.10	-612.47
Bolt 3	-93.92	1577.00	157.68
Bolt 4	544.44	2174.60	612.61

Table 7-1: ZB1 static loads reaction forces on each bolt

Reminding that the bottom plate bolts in the model had been removed and then replaced with face-to-face bonded contact. The reaction forces of the contact are defined as the faces force. To estimate the forces acting on each bolt, the bolts on each face are assumed to carry the loads equally. Thus, the force on the table below divided by two is approximately equal to the force on each bolt on the specified face.

Each face-to-face contact reaction force has been extracted and listed in Table 7-2. It is appearance that the maximum force placed at face 9.

Contact	Fx [N]	Fy [N]	Fz [N]
face1	2.512	-197.4	662.4
face2	-2.512	-197.4	587.6
face3	-0.043	-98.7	642.2
face4	0.043	-98.7	607.8
face5	-2.540	-33.3	644.1
face6	2.540	-33.3	605.9
face7	-1.497	203.8	651.0
face8	1.497	203.8	599.0
face9	-0.054	281.1	651.4
face10	0.054	281.1	598.6
face11	1.506	360.6	643.3
face12	-1.506	360.6	606.7

Table 7-2: ZB1 static loads reaction forces on each face (2 bolts)

ZB2

The reaction forces of the fixed bolts of ZB2 are demonstrated in Table 7-3. It can be seen that all the bolts have about the same magnitude which is significantly lower than the maximum force of the ZB1 fixed bolt.

Bolt Denomination	Fx [N]	Fy [N]	Fz [N]
Bolt 1	-327.95	1965.0	-538.53
Bolt 2	327.95	1976.7	-643.89
Bolt 3	-331.20	1967.1	538.55
Bolt 4	331.21	1975.8	643.88

Table 7-3: ZB2 static loads reaction forces on each bolt

The data on the forces of specific bolts are provided in Table 7-4. It is evident that face 12 has the highest magnitude.

Contact	Fx [N]	Fy [N]	Fz [N]
face1	-1.248	11.66	641.3
face2	1.248	11.66	622.3
face3	-0.2251	-50.11	629.6
face4	0.2252	-50.11	634.0
face5	0.8354	-174.5	637.2
face6	-0.8353	-174.5	626.3
face7	0.5463	209.4	629.2
face8	-0.5463	209.4	634.3
face9	0.1635	237.1	617.6
face10	-0.1635	237.1	645.9
face11	-0.3051	276.8	630.6
face12	0.3051	276.8	632.9

Table 7-4: ZB1 static loads reaction forces on each face (2 bolts)

ZC1

Table 7-5 show the reaction forces of fixed bolts subjected to two different load cases. These bolts are widely different from fixed bolt of ZB1 and ZB2. For this reason, the force from the table below cannot be compared to the fixed bolt reaction force of ZB1 and ZB2. By observation, load case 1 resulting in highest shear load at the bolt 3 which the total load stand at and load case 2 causing the highest tensile load on bolt 6 which have the total force equal to 2.9 kN.

load case 1			
Bolt Denomination	**Fx [N]**	**Fy [N]**	**Fz [N]**
Bolt 1	-1229.3	1926.8	-99.567
Bolt 2	-1208.2	1913.8	93.411
Bolt 3	3583.8	-728.01	367.39
Bolt 4	3573.5	-746.68	-359.06
Bolt 5	641.15	726.84	-251.69
Bolt 6	633.68	719.18	250.06

load case 2			
Bolt Denomination	**Fx [N]**	**Fy [N]**	**Fz [N]**
Bolt 1	-840.62	-177.88	25.069
Bolt 2	-886.91	-148.75	-25.012
Bolt 3	-615.65	1913.5	-396.99
Bolt 4	-609.49	1930.4	398.14
Bolt 5	287.71	2728.1	-955.59
Bolt 6	317.07	2737.0	958.71

Table 7-5: ZC1 static loads reaction forces on each bolt in a particular load case

On the contrary, the bottom plate bolts of the support are quite similar as the bolts used are the same class & size and the geometry are about the same. Table 7-6 illustrates the maximum reaction force occurs in the load case 1 and it is positioned at the face 6. The value of the force is far higher than the force in ZB1 and ZB2.

load case 1				load case 2			
Contact	**Fx [N]**	**Fy [N]**	**Fz [N]**	**Contact**	**Fx [N]**	**Fy [N]**	**Fz [N]**
face1	1.0906	-141.9	-589.0	face1	1.8269	1332.1	-641.1
face2	-1.0959	-141.6	-672.7	face2	-1.8191	1330.0	-620.1
face3	-0.0261	763.6	-552.8	face3	0.3379	262.5	-674.6
face4	0.0232	763.3	-708.2	face4	-0.3418	261.4	-586.7
face5	2.1912	1696.7	-517.6	face5	-0.3722	-795.7	-697.5
face6	-2.1926	1696.9	-743.3	face6	0.3642	-793.7	-563.9
face7	0.1484	350.0	-607.9	face7	0.2579	685.7	-626.9
face8	-0.1515	349.5	-652.9	face8	-0.2542	681.5	-634.6
face9	1.5494	640.1	-644.3	face9	0.8801	416.8	-571.9
face10	-1.5498	640.2	-616.9	face10	-0.8822	417.5	-689.3
face11	0.9248	906.0	-594.4	face11	0.6854	152.7	-605.1
face12	-0.9276	906.4	-667.0	face12	-0.6848	154.3	-656.1

Table 7-6: ZC1 statics load reaction forces on each face (2 bolts) in a particular load case

ZC2

The forces on the fixed bolts of ZC2 are listed in Table 7-7. With the same trend as ZC1 the highest shear load is positioned at bolt 3 under load case 1 and the highest tensile load is located at bolt 6 under load case 2.

load case 1				**load case 2**			
Bolt Denomination	**Fx [N]**	**Fy [N]**	**Fz [N]**	**Bolt Denomination**	**Fx [N]**	**Fy [N]**	**Fz [N]**
Bolt 1	-1590.8	1757.4	-98.699	*Bolt 1*	-432.42	-83.79	-7.4306
Bolt 2	-1594.3	1773.5	89.772	*Bolt 2*	-507.82	-48.47	11.05
Bolt 3	2862.5	-973.86	561.22	*Bolt 3*	173.61	2151.40	-640.62
Bolt 4	2858.2	-970.74	-553.01	*Bolt 4*	196.05	2147.50	646.91
Bolt 5	1680.2	1138.6	-542.38	*Bolt 5*	-740.83	2301.00	-781.59
Bolt 6	1678.6	1133.4	548.34	*Bolt 6*	-705.38	2322.80	782.2

Table 7-7: ZC2 static loads reaction forces on each bolt in a particular load case

Force of the bottom plate bolts of the support ZC2 are minimally different from the reaction force of ZC1 as can be seen that some figures are higher than forces on the face of ZC1 by not over 80 N in y-direction and not over 20 N in x and z direction. As illustrated in Table 7-8.

load case 1				load case 2			
Contact	**Fx [N]**	**Fy [N]**	**Fz [N]**	**Contact**	**Fx [N]**	**Fy [N]**	**Fz [N]**
face1	-1.0087	-27.1	600.6	face1	-0.7130	1251.0	628.1
face2	1.0092	-27.2	660.6	face2	0.7086	1250.1	633.5
face3	-1.2393	839.4	556.9	face3	-1.0210	208.9	666.5
face4	1.2393	839.3	704.2	face4	1.0226	208.8	594.8
face5	-1.5336	1732.3	521.4	face5	0.1596	-833.5	694.9
face6	1.5335	1732.4	739.8	face6	-0.1582	-830.6	565.8
face7	0.5405	236.7	623.8	face7	-1.3385	761.9	609.1
face8	-0.5402	236.7	637.3	face8	1.3398	761.3	652.4
face9	-0.6417	548.6	650.9	face9	-0.8046	477.9	564.5
face10	0.6417	548.6	610.3	face10	0.8071	477.7	696.8
face11	-1.6638	829.6	600.3	face11	-0.7428	205.0	600.8
face12	1.6641	829.6	660.9	face12	0.7428	206.4	660.3

Table 7-8: ZC2 statics load reaction forces on each face (2 bolts) in a particular load case

7.1.3 Static loads effects on Weld

Maximum force per length [N/mm]				
Support	**Weld 1**	**Weld 2**	**Weld 3**	**Weld 4**
ZC1	90.12	126.82	65.91	100.72
ZC2	102.22	127.56	67.80	88.62
ZB1	44.20	36.87	34.78	34.78
ZB2	52.50	8.80	24.95	7.77

Table 7-9: Maximum force per length of the supports

	Forces				**Stresses**			**Criteria**	
Weld denomination	fx [N/mm]	fy [N/mm]	fz [N/mm]	total force per unit length [N/mm]	τ⊥ [MPa]	σ⊥ [MPa]	τII [MPa]	σEqv [MPa]	|σ⊥|[MPa]
Weld 1	-64.664	-24.541	-58.936	90.87	-18.290	-6.941	-16.670	43.421	6.941
Weld 2	-45.901	-104.472	72.651	135.28	-12.983	-29.549	20.549	51.436	29.549
Weld 4	39.289	93.249	6.270	101.38	11.113	26.375	1.774	32.796	26.375

Table 7-10: Statics load reaction on weld

7.2 Seismic actions calculation results

Horizontal	
F [Hz]	Acc. [mm/s2]
0.333333	308
0.338983	308
0.344828	308
0.350877	308
0.357143	308
0.363636	308
0.37037	308
0.377358	308
0.384615	308
0.392157	308
0.4	308
0.408163	308
0.416667	308
0.425532	308
0.434783	308
0.444444	308
0.454545	318.1818
0.465116	333.1531
0.47619	349.2063
0.487805	366.4485
0.5	385
0.512821	394.8718
0.526316	405.2632
0.540541	416.2162
0.555556	427.7778
0.571429	440
0.588235	452.9412
0.606061	466.6667
0.625	481.25
0.645161	496.7742
0.666667	513.3333
0.689655	531.0345
0.714286	550
0.740741	570.3704
0.769231	592.3077
0.8	616
0.833333	641.6667
0.869565	669.5652
0.909091	700
0.952381	733.3333
1	770
1.052632	810.5263
1.111111	855.5556
1.176471	905.8824
1.25	962.5
1.333333	1026.667
1.428571	1100
1.538462	1184.615
1.666667	1283.333
1.818182	1400
2	1540
2.222222	1540
2.5	1540
2.857143	1540
3.333333	1540
4	1540
5	1540
6.666667	1540
10	1437.333
20	1334.667
25	1314.133
33.33333	1293.6
50	1273.067
100	1252.533
151.5152	1245.552
200	1242.267

(a)

Vertical	
F [Hz]	Acc. [mm/s2]
0.333333	277.2
0.338983	277.2
0.344828	277.2
0.350877	277.2
0.357143	277.2
0.363636	277.2
0.37037	277.2
0.377358	277.2
0.384615	277.2
0.392157	277.2
0.4	277.2
0.408163	277.2
0.416667	277.2
0.425532	277.2
0.434783	277.2
0.444444	277.2
0.454545	277.2
0.465116	277.2
0.47619	277.2
0.487805	277.2
0.5	277.2
0.512821	277.2
0.526316	277.2
0.540541	277.2
0.555556	277.2
0.571429	277.2
0.588235	277.2
0.606061	277.2
0.625	277.2
0.645161	277.2
0.666667	277.2
0.689655	277.2
0.714286	277.2
0.740741	277.2
0.769231	277.2
0.8	277.2
0.833333	277.2
0.869565	277.2
0.909091	286.3636
0.952381	314.2857
1	346.5
1.052632	364.7368
1.111111	385
1.176471	407.6471
1.25	433.125
1.333333	462
1.428571	495
1.538462	533.0769
1.666667	577.5
1.818182	630
2	693
2.222222	770
2.5	866.25
2.857143	990
3.333333	1155
4	1386
5	1732.5
6.666667	2310
10	2310
11.11111	2310
12.5	2310
14.28571	2310
16.66667	2310
20	2310
25	2032.8
33.33333	1755.6
50	1478.4
100	1201.2
151.5152	1106.952
200	1062.6

(b)

Table 7-11: Seismic actions calculation results (a) Horizontal direction (b) Vertical direction

MODE	FREQ.	x-dir.		y-dir.		z-dir.	
		Eff. Mass Ratio	Cumulative Eff. Mass Ratio	Eff. Mass Ratio	Cumulative Eff. Mass Ratio	Eff. Mass Ratio	Cumulative Eff. Mass Ratio
1	9.585	0.90494	90.494%	2.52E-09	0.000%	1.25E-11	0.000%
2	14.571	1.96E-04	90.514%	2.64E-10	0.000%	7.56E-10	0.000%
3	15.411	2.62E-09	90.514%	0.85752	85.752%	1.27E-05	0.001%
4	37.078	1.01E-11	90.514%	4.02E-05	85.756%	4.56E-04	0.047%
5	40.277	3.46E-10	90.514%	1.86E-04	85.775%	4.19E-03	0.466%
6	40.94	3.93E-14	90.514%	3.78E-05	85.778%	0.86804	87.270%
7	41.125	1.52E-11	90.514%	1.26E-04	85.791%	5.43E-02	92.698%
8	41.863	3.02E-09	90.514%	4.56E-04	85.837%	1.55E-02	94.250%
9	43.239	7.61E-13	90.514%	1.11E-03	85.947%	3.15E-03	94.565%
10	64.144	1.71E-03	90.684%	2.57E-08	85.947%	3.90E-08	94.565%
11	64.369	2.64E-03	90.948%	1.41E-08	85.947%	1.68E-09	94.565%
12	64.615	1.43E-03	91.091%	1.08E-09	85.947%	4.39E-09	94.565%
13	64.659	6.39E-04	91.155%	7.48E-09	85.947%	3.41E-08	94.565%
14	65.118	1.39E-03	91.294%	1.83E-09	85.947%	1.86E-08	94.565%
15	65.514	1.08E-03	91.402%	9.73E-09	85.947%	3.20E-08	94.565%
16	76.542	2.96E-09	91.402%	0.10706	96.653%	1.35E-03	94.700%
17	130.95	9.08E-06	91.403%	1.16E-08	96.653%	1.94E-08	94.700%
18	149.93	5.71E-02	97.111%	2.82E-11	96.653%	3.58E-10	94.700%
19	156.44	2.53E-09	97.111%	4.91E-09	96.653%	6.54E-04	94.765%
20	156.53	6.89E-11	97.111%	2.25E-06	96.654%	4.04E-05	94.769%
21	156.54	5.24E-09	97.111%	7.45E-06	96.654%	2.32E-05	94.772%
22	156.59	3.26E-11	97.111%	1.23E-06	96.655%	5.09E-06	94.772%
23	156.73	1.21E-11	97.111%	1.37E-10	96.655%	4.14E-06	94.773%
24	156.76	1.16E-09	97.111%	5.34E-07	96.655%	1.83E-06	94.773%
25	170.57	7.30E-07	97.111%	1.22E-10	96.655%	5.23E-12	94.773%
26	238.81	7.16E-04	97.183%	1.77E-10	96.655%	1.63E-08	94.773%
27	259.3	6.31E-10	97.183%	2.00E-06	96.655%	5.46E-05	94.778%
28	272.74	1.10E-08	97.183%	2.68E-05	96.657%	1.62E-05	94.780%
29	306.34	7.76E-08	97.183%	5.76E-12	96.657%	5.97E-13	94.780%
30	306.43	3.33E-09	97.183%	2.98E-13	96.657%	2.26E-13	94.780%

Table 7-12: Effective mass from modal analysis for design ZB1

MODE	FREQ.	Ti	Tj	$\frac{(Ti-Tj)}{Ti}*100\%$
1	9.59	0.1043	0.0686	34.22%
2	14.57	0.0686	0.0649	5.45%
3	15.41	0.0649	0.0270	58.44%
4	37.08	0.0270	0.0248	7.94%
5	40.28	0.0248	0.0244	1.62%
6	40.94	0.0244	0.0243	0.45%
7	41.13	0.0243	0.0239	1.76%
8	41.86	0.0239	0.0231	3.18%
9	43.24	0.0231	0.0156	32.59%
10	64.14	0.0156	0.0155	0.35%
11	64.37	0.0155	0.0155	0.38%
12	64.62	0.0155	0.0155	0.07%
13	64.66	0.0155	0.0154	0.70%
14	65.12	0.0154	0.0153	0.60%
15	65.51	0.0153	0.0131	14.41%
16	76.54	0.0131	0.0076	41.55%
17	130.95	0.0076	0.0067	12.66%
18	149.93	0.0067	0.0064	4.16%
19	156.44	0.0064	0.0064	0.06%
20	156.53	0.0064	0.0064	0.01%
21	156.54	0.0064	0.0064	0.03%
22	156.59	0.0064	0.0064	0.09%
23	156.73	0.0064	0.0064	0.02%
24	156.76	0.0064	0.0059	8.10%
25	170.57	0.0059	0.0042	28.58%
26	238.81	0.0042	0.0039	7.90%
27	259.30	0.0039	0.0037	4.93%
28	272.74	0.0037	0.0033	10.97%
29	306.34	0.0033	0.0033	0.03%
30	306.43	0.0033		

Table 7-13: Closely-space modes analysis for design ZB1

MODE	FREQ.	x-dir.		y-dir.		z-dir.	
		Eff. Mass Ratio	Cumulative Eff. Mass Ratio	Eff. Mass Ratio	Cumulative Eff. Mass Ratio	Eff. Mass Ratio	Cumulative Eff. Mass Ratio
1	9.3673	0.88703	88.703%	2.17E-06	0.000%	4.02E-07	0.000%
2	16.457	1.55E-02	90.248%	2.56E-07	0.000%	2.59E-09	0.000%
3	20.896	2.08E-06	90.249%	0.81859	81.859%	4.23E-04	0.042%
4	35.992	1.12E-09	90.249%	9.86E-07	81.859%	2.05E-03	0.247%
5	39.103	4.00E-10	90.249%	3.21E-03	82.180%	2.37E-02	2.621%
6	39.537	3.59E-07	90.249%	1.26E-03	82.306%	7.53E-01	77.902%
7	40.362	2.29E-08	90.249%	1.84E-03	82.490%	1.59E-01	93.783%
8	40.728	6.12E-09	90.249%	8.94E-04	82.579%	2.90E-04	93.812%
9	41.192	4.00E-10	90.249%	1.42E-03	82.721%	4.83E-03	94.295%
10	62.895	9.27E-05	90.258%	2.83E-08	82.721%	4.63E-08	94.295%
11	63.216	6.25E-03	90.883%	1.75E-09	82.721%	5.12E-08	94.295%
12	63.646	1.30E-03	91.013%	1.10E-08	82.721%	3.72E-08	94.295%
13	63.904	1.51E-03	91.164%	3.69E-09	82.721%	7.32E-08	94.295%
14	64.126	5.21E-04	91.216%	2.05E-09	82.721%	2.87E-08	94.295%
15	64.698	2.28E-04	91.239%	3.54E-09	82.721%	6.55E-09	94.295%
16	92.937	4.16E-06	91.239%	0.12877	95.598%	1.79E-03	94.474%
17	93.049	2.75E-05	91.242%	9.64E-03	96.562%	1.36E-04	94.487%
18	154.6	5.26E-02	96.503%	1.13E-07	96.563%	1.78E-08	94.487%
19	156.58	8.55E-11	96.503%	1.75E-06	96.563%	6.64E-04	94.554%
20	156.65	3.60E-10	96.503%	2.17E-06	96.563%	4.35E-06	94.554%

Table 7-14: Effective mass from modal analysis for design ZC1

MODE	FREQ.	Ti	Tj	$\frac{(Ti - Tj)}{Ti} * 100\%$
1	9.3673	0.1068	0.0608	43.08%
2	16.457	0.0608	0.0479	21.24%
3	20.896	0.0479	0.0278	41.94%
4	35.992	0.0278	0.0256	7.96%
5	39.103	0.0256	0.0253	1.10%
6	39.537	0.0253	0.0248	2.04%
7	40.362	0.0248	0.0246	0.90%
8	40.728	0.0246	0.0243	1.13%
9	41.192	0.0243	0.0159	34.51%
10	62.895	0.0159	0.0158	0.51%
11	63.216	0.0158	0.0157	0.68%
12	63.646	0.0157	0.0156	0.40%
13	63.904	0.0156	0.0156	0.35%
14	64.126	0.0156	0.0155	0.88%
15	64.698	0.0155	0.0108	30.39%
16	92.937	0.0108	0.0107	0.12%
17	93.049	0.0107	0.0065	39.81%
18	154.6	0.0065	0.0064	1.26%
19	156.58	0.0064	0.0064	0.04%
20	156.65	0.0064		

Table 7-15: Closely-space modes analysis for design ZC1

7.3 Seismic Actions Effects

7.3.1 Seismic actions effects on bolts

ZB1

- Fixed Bolts

  Seismic action effects of the force on each bolt are listed in Table 7-16. The results show that seismic action has large effects on bolts as the loads due to seismic action is higher than 75% of the total load.

Bolt Denomination	Fx [kN]	Fy [kN]	Fz [kN]
Bolt 1	5.639	2.051	2.167
Bolt 2	5.492	2.017	2.121
Bolt 3	5.646	2.060	2.185
Bolt 4	5.484	2.008	2.104

Table 7-16: ZB1 seismic actions reaction forces on each fixed bolt in a particular load case

ZC1

- Fixed Bolts

  Seismic action for ZC1 has a significant effect as can be seen from table 7-17. The force due to seismic action is higher than 50% of the total force.

Bolt Denomination	Fx [kN]	Fy [kN]	Fz [kN]
Bolt 1	1.655	2.095	3.592
Bolt 2	1.647	2.104	3.591
Bolt 3	1.421	0.740	2.385
Bolt 4	1.429	0.738	2.380
Bolt 5	1.299	0.938	2.619
Bolt 6	1.294	0.947	2.619

Table 7-17: ZC1 seismic actions reaction forces on each fixed bolt in a particular load case

- Bottom plate bolts

  Forces on each face due to seismic action has been calculated and are detailed on the table 7-18. Notably, the reaction force caused by seismic action surpasses 55% of the total load.

Contact	Fx [N]	Fy [N]	Fz [N]
face1	1880.9	2670.3	3031.1
face2	1518.7	3476.7	2901.2
face3	1530.5	3598.5	4032.5
face4	1171.2	2595.2	2344.8
face5	1068.0	2436.3	2773.4
face6	775.1	945.2	1619.5
face7	1094.2	1701.1	2242.5
face8	819.5	1354.5	1639.1
face9	503.4	1783.5	2026.3
face10	644.0	1551.3	1770.2
face11	513.0	1948.1	2190.3
face12	943.2	1331.2	1846.2

Table 7-18: Seismic actions reaction forces on each face (2 bolts) in a particular load case

7.3.2 Seismic actions effects on weld

Maximum force per length due to the seismic action are shown in Table 7-19. The table shown that seismic effects on weld joints are less than 30% of the total forces.

Weld denomination	fx [N/mm]	fy [N/mm]	fz [N/mm]
weld 1	22.156	13.239	28.183
weld 2	12.791	4.306	7.530
weld 3	15.218	28.010	12.601

Table 7-19: seismic action reaction forces on the weld joints

7.4 Combined effects

7.4.1 Combined effects on bolts

ZB1

Fixed Bolts

Bolt Denomination	Fx [kN]	Fy [kN]	Fz [kN]
Bolt 1	5.736	3.627	2.325
Bolt 2	6.038	4.189	2.733
Bolt 3	5.740	3.637	2.343
Bolt 4	6.029	4.182	2.716

Table 7-20: ZB1 combined reaction forces on each fixed bolt

ZC1

Fixed Bolts

load case 1			
Bolt Denomination	**Fx [kN]**	**Fy [kN]**	**Fz [kN]**
Bolt 1	2.885	4.022	3.691
Bolt 2	2.856	4.017	3.684
Bolt 3	5.005	0.740	2.753
Bolt 4	5.003	0.738	2.739
Bolt 5	1.940	1.665	2.871
Bolt 6	1.927	1.666	2.869

load case 2			
Bolt Denomination	**Fx [kN]**	**Fy [kN]**	**Fz [kN]**
Bolt 1	2.496	2.095	3.617
Bolt 2	2.534	2.104	3.616
Bolt 3	2.037	2.654	2.782
Bolt 4	2.039	2.668	2.778
Bolt 5	1.587	3.666	3.575
Bolt 6	1.611	3.684	3.578

Table 7-21: ZC1 combined reaction forces on each fixed bolt in a particular load case

Bottom plate bolts

load case 1			
Contact	**Fx [kN]**	**Fy [kN]**	**Fz [kN]**
face1	1.882	2.670	3.620
face2	1.520	3.477	3.574
face3	1.531	4.362	4.585
face4	1.171	3.359	3.053
face5	1.070	4.133	3.291
face6	0.777	2.642	2.363
face7	1.094	2.051	2.850
face8	0.820	1.704	2.292
face9	0.505	2.424	2.671
face10	0.646	2.192	2.387
face11	0.514	2.854	2.785
face12	0.944	2.238	2.513

load case 2			
Contact	**Fx [kN]**	**Fy [kN]**	**Fz [kN]**
face1	1.883	4.002	3.672
face2	1.521	4.807	3.521
face3	1.531	3.861	4.707
face4	1.172	2.857	2.932
face5	1.068	2.436	3.471
face6	0.775	0.945	2.183
face7	1.094	2.387	2.869
face8	0.820	2.036	2.274
face9	0.504	2.200	2.598
face10	0.645	1.969	2.459
face11	0.514	2.101	2.795
face12	0.944	1.485	2.502

Table 7-22: ZC1 combined reaction forces on each bolt in a particular load case

7.4.2 Combined effects on weld

Weld

	Forces				Stresses			Criteria	
Weld denomination	fx [N/mm]	fy [N/mm]	fz [N/mm]	total force per unit length [N/mm]	τ⊥ [MPa]	σ⊥ [MPa]	τII [MPa]	σEqv [MPa]	|σ⊥|[MPa]
Weld 1	86.821	37.780	87.118	128.665	24.557	10.686	24.641	341.387	59.613
Weld 2	58.692	108.778	80.181	147.331	16.601	30.767	22.679	57.588	30.767
Weld 4	54.507	121.259	18.871	134.279	15.417	34.297	5.338	224.517	173.278

Table 7-23: Combined load reaction on weld

Chapter 3: Diary

3 June 2023

After the long flight, I arrived in Geneva. In the city, people usually travel by bus or tram, which costs around 3 to 5 CHF. A bus ticket can be selected from a machine at a station and can be paid for conveniently by card or cash. Moreover, tram and bus schedules and the network map are organized in the phone application, TPG. I take tram number 18 to get to CERN then transfer to bus number 68 to Saint-Genis-Shuman. Not only does the room of the Shuman hostel have all the necessary furniture including a refrigerator, but it also has a great view of Cret de la Neige mountain. After I had unpacked my bag, I walked to the grocery store near the hostel, Carrefour Market, to buy food and appliances. The store has ingredients for food which are low prices relative to stores in Switzerland. It also has a shelf of ingredients for Thai and Asia dishes.

4 June 2023

Geneva is the second-biggest city in Switzerland, the top ten most expensive city in the world, the nearest city to the CERN site, and the city that I chose to begin the journey. I dropped off at Bel-air Trams station which stands directly in front of Geneva Lake. I walked along the side of the river to park Jardin Anglais where the Jet d'Eau fountain is closely seen. This imposing fountain shoots water up to the sky over 100 meters high and can be seen from anywhere in the town. After that, I went to the Musee d'ethnographine. It has fine art and sculpture from various eras to be observed. I spent almost 3 hours appreciating piece by piece of artwork and still, I was unable to manage to look at all the artwork in the gallery. Surprisingly, At the art gallery, people are allowed to borrow folding chairs to bring and sit in front of the piece that they like and begin to sketch. As far as I'm concerned, this is a good idea as this helps to support people who like art and somehow helps to conserve historic art.

5 June 2023

The day I consider it to be a leap step in my career path as it was my first day as a summer student at CERN. I started the day by meeting with colleagues from different countries, it has been nice to have got to know someone from different countries. Then, I met my supervisor from France, Audrey Piccini, and got to know with MME team.

6 June 2023

I started my work with basic courses about CERN's policy including Computer Security, Emergency Evacuation, Safety at CERN, Data Privacy Basics, Radiation Protection, and Bike Riding. Even though those are basic things to learn, and nothing seems so interesting, CERN creates courses to be a scenario game. In order to pass each level, players have to read the information they gave. I enjoyed playing the games they made, and I got to learn new things. After I had finished all the courses, I started to read documents about the project that I had contributed to. As an engineer, those documents are inspiring as when I saw how many constraints of the CO_2 pipeline design are, I felt challenged to work with this project.

At noon, I had lunch with the MME team in the cafeteria near the office. In CERN, the cafeterias are different from restaurants as they have a bakery and frozen food while the restaurants have many fresh foods to select from at the same price. For this reason, people in the office cook lunch from their homes. Since then, I have brought lunch to the office every day.

7 June 2023

I have learned about the finite element software, ANSYS which is a strong tool for helping engineering calculation and simulation. To illustrate, it can be used to calculate stress in a structure, can be adapted to calculate the resonance frequency of vibration, and can do many other things. Nevertheless, the software used without accurate engineering judgment is likely to result in the wrong estimation. Although I have some background in using this program, I don't feel confident using it. Hence, I had been taking a lot of time to comprehend it. What's more, I visited the design office of the MME department and got to know the designer who was working with pipe support to understand more about the project. Also, I had a chance to visit the CERN fabrication facility where staff use large CNC and weld a pipe. After the visit, I began to understand more about the project constraints. For instance, the length of CO_2 pipes which are limited because pipes have to be loaded down into the cavern, the limited space in the cavern affects the fabrication method used, and thermal contraction/expansion of the pipe causes a massive force to act on the supports.

8 June 2023

I had been spending the whole morning studying ANSYS software before visiting the Data Center. It is an important part of the experiment since the detectors generate massive amounts of data which require a large number of processors and a great deal amount of storage which leads to high electricity consumption. Surprisingly, to avoid exorbitant electricity costs, CERN uses magnetic tapes to store large amounts of data for long-term storage.

9 June 2023

In the morning, I attended the department's weekly meeting for the first time. I introduced myself in front of others nervously. In the meeting, people update their own projects and share the problems they are facing. After this, I went back to finish reading the ANSYS lecture. For a whole week, I spent time to settle down trying to understand the project as much as possible, learning the tool that I used on this project, and blending with the team. Finally, I received CAD models of the various designs of pipe supports. Following this, I began to prepare the model for the Finite Element process.

10 June 2023

I woke up early and traveled to Gare Cornavin to buy a train ticket to Lyon, France with my friends. After arriving at Lyon, we began the trip by wandering around and enjoying the Renaissance architecture at Vieux Lyon, Lyon's old town. Later, we had Quenelle, Tablier de sapeur, and Rosette de Lyon, which are the local dishes of Lyon. I really enjoyed the food. Originally, we planned to visit Lyon Housemuseum and Housemuseum Galleries but we did not have much time left so we just strolled around the town.

11 June 2023

Sunday is considered to be the day for rest in Europe as many stores are closed. As well as I'm, I let myself relax by sketching pictures that I took from Lyon and Musee d'ethnographine in Geneva. Then, I went to the Geneva Botanical Garden and Greenhouse which has plenty of different kinds of plants. It keeps tropical plants in an environment-controlled glass house which most of them you can see in Thailand. The park is not as big as Garden by the Bay in Singapore. However, seeing greenery would help you to release all the stress from a long week. I walked to Parc de La Perle du Lac which is the park nearby. It has a lake shore where people go for BBQ parties. I went there to sketch a picture of the shore during sunset.

12 June 2023

When we face a complicated Engineering problem, we simplify the problem with accurate assumptions. As same as Finite Element Analysis (FEA), we allow the removal of fasteners like bolts and weld fillets from the model. This simplification helps to reduce the time used for calculating as we can analyze the problem efficiently. By doing this we have to assess the bolts and weld joints later. I spent time studying how to assess the bolts according to EN1993-1-8: 2005 while I waited for the computer to calculate.

13 June 2023

I continued to work on the project trying to find the worst-case scenario with the different load cases acting on the structure. Then, validated the structure and bolts subject to those load cases.

Gabriele Ceruti, an Italian engineer in the office, suggested I go to a supermarket far from Schuman hostel around 10 minutes by bike, Intermarche supermarket. It is a larger supermarket, with cheaper food, and higher quality goods than any other groceries store nearby.

14 June 2023

I attended a meeting that discussed digital twins. This topic has recently generated significant interest in the field of mechanical engineering because it enables predictions of real-world situations through Machine Learning (ML). These ML models are trained using simulation results. This process is used to establish a seamless connection between the physical reality and simulations. I was interested in this presentation a lot even downloaded some articles to read about it more. I was highly interested in this presentation and even downloaded some articles to read more about it.

In the afternoon, I gathered with my friends. We talked about our own projects. Then, we visited the Atlas Detector control room. It seems like a rocket control room that we can see in movies. Next, we went to synchrocyclotron the first particle accelerator in CERN which started up in 1957.

15 June 2023

After many different simulations with various designs and force configurations were run, the design has been validated, with no issue with the structure and bolts. I began to assess the welds. When structures are fabricated by the welding process, heat from the process becomes a problem. Due to the high temperatures of the welding, the structure can deform during the process. To avoid this the intermittent welding method is applied. This method is the series of welds in which each weld is separated with unwelded spaces. However, this method has less strength than continuous welding. Therefore, I have to find the optimal point with a trade-off between the strength and deflection of the structure.

16 June 2023

I continue my work with weld assessment and weld optimization. People in the office invited me to the Friday evening party at Restaurant 1 in CERN. It is a great party where I can get to know new people in the MME department. I met other summer students at the restaurant and joined them after. We talked and walked around CERN.

17 June 2023

I went hiking with other summer students at Mont Salève where the mountain has a natural trail that has a view of the whole city of Geneva. We started in a bakery store in the local area and bought Baguette for lunch. Then, we hike for 3 hours with one stopping at Filenvol Park to buy drinks before going to the Plage des Eaux-Vives beach to feel the cold water of Geneva Lake and the warm summer breeze.

18 June 2023

Sunday is always a day for rest, I woke up late and cooked a lunch meal, Japanese beef, and rice which is too hard to cook during weekdays as it requires many ingredients. Followed by writing the report and doing laundry. I was getting everything ready for work on Monday.

19 June 2023

I worked with the MME design teams to iterate the design of pipe support. I calculated the analysis result and reported it back to the design team. Then they changed the design to improve it and then they sent the CAD model back to me to start to calculate all over again. This time I have to report the result of stress on the weld and the method to optimize. Hence, I began to work on presentation slides.

20 June 2023

I continued to assess the weld joint of the support. Other than that, every time after lunch the people in the MME office like to drink a coffee and talk for half an hour before beginning to start working again, but today's special because a nice colleague brought Éclairs. It is the best Éclair I have ever had. The sweetness of it helps me pass a rough sleepy afternoon.

21 June 2023

CADFEM firm recently invented a weld and bolt assessment tool which is directly related to my work. Luckily, CADFEM introduced this tool to MME department members, and I had a chance to attend. This tool helps engineers to assess bolts and welds more efficiently and accurately. It is different a method than the method that I used. I tried to comprehend this tool as much as possible as it will help to validate the calculations further.

22 June 2023

I presented the welding assessment to Benoit Riffaud who is an engineer in the design team. Benoit wants to know about the safety margin of the current design and how he will adjust it to minimize the weld. Then, he assigned me a job to calculate the minimum number of welds for each intermittent welding joint. I calculated the number of welds that are needed to withstand the worst situation that can happen. In the evening, there was heavy rain, and I had an appointment with a friend and Prof. Chayanit Asawatangtrakuldee. I was late for half an hour. We went to Geneva to a Chinese restaurant. Prof. Chayanit just went to China before coming to Switzerland and her Chinese friends suggested this restaurant. I was impressed by the tasty food. More than that we had no problem at all when we wanted to order because Prof. Chayanit can speak Mandarin very well. We also had an ice cream after dinner.

23 June 2023

Today, the MME department had a BBQ party from noon until evening. MME colleagues bought their dessert from home and shared it at the party. I tasted many desserts such as Flan Pâtissier, Flan aux fraises, and Napoleon Dessert. I like Flan Pâtissier the most because of the perfect combination of creamy custard and crunchy pie on the bottom.

In the evening, I took a tram and headed to the Geneva Music Festival which took place around Cathédrale Saint-Pierre Genève. The festival consisted of more than 30 stages with a wide range of music genres. For instance, Jazz, Classical, Pop, Electro, Drone, etc.

I walk around the festival to find the stage just to enjoy it. After a while, I went straight to stage 17 which took place in the Court of the Reading Society. The place is an open space surrounded by European-style buildings. Immediately after I walked in, remarkable Portuguese pianist, Leonor Mendes, started to perform classical music composed by Debussy and Prokofiev. With just only a single piano on the stage, she can perform as rich of dynamic as a collective of instruments.

I decided to stay at stage 17 until late-night to listen to Quatuor féminin Arès which is a band consisting of 4 instruments, 2 violins, a viola, and a cello. I was impressed by this band the most at the festival as they revealed strong rhythmic integrity and consistency. I was overwhelmed by these memorable melodies.

24 June 2023

Today I woke up early to take a train to Annecy, a city in France which is known to be "the Venice of the Alps" because of its canals. We strolled around the old town in the late morning then we had lunch at a restaurant. One of the dishes we tried was Raclette, which is a melted cheese served with steamed potatoes. After lunch, we went to the most famous tourist attraction of Annecy, the Annecy Lake. The scenic view of the turquoise lake surrounded by mountains really impressed me.

25 June 2023

Jazz music is my favorite genre since it is designed for musicians to fully express their own feelings through improvisation. It also allows musicians to perform both as a solo and as a band. I went back to the Geneva Music Festival to enjoy jazz music performed by the Chtabam Kalam band and the Cendric Schaerer trio. Chtabam Kalam is a band that plays jazz while blending multi-origins of music especially Cuban rhythms and Arab-Andalusian melodies. The sound they play is extraordinary as I heard the strong appearance of Cuban rhythm from Congas and percussion.

Cedric Schaerer Trio is a jazz band combining jazz, hip-hop, and African grooves. They play music with a fast tempo and high complexity. I was impressed by the drum solo. It is very fun to listen to. The drummer plays part of the solo from the song “Caravan” which is the same solo in the movie name “Whiplash”.

26 June 2023

After a nice weekend, I went back to work in the early morning. I started to learn how to use the weld tool kit which can help a lot with my project. Although it is a very useful tool to analyze a structure with welding, it is a developing tool, and I found many technical problems with this tool. I tried hard to find a way to fix the problem with the tool but still got into many problems. I had a nice meal with my colleagues before leaving for a meeting with the Thai ambassador in Geneva. It was a nervous situation in the first place, but they gave us a warm welcome. We talked about many things such as CERN, the UN, Switzerland’s dishes, and Switzerland’s culture.

27 June 2023

I woke up early because it was the first day of the summer student lectures and I wanted to drop by my office to spend an hour with my work and to discuss with my supervisor before going to the lectures.

The lecture started with an introduction then the Particle world lecture started. It is a lecture about the basics of the standard model. Followed by the Detectors lecture, lecture was about detectors since cloud chambers developed until ATLAS.

I was back in the office to continue learning to use the weld tool kit. The tool had too many technical problems, so I had to simplify the problem and try to use a weld tool kit to verify my weld assessment method. Then I came to the conclusion that my weld assessment method is more conservative than the weld tool kit.

28 June 2023

I dropped by the office and worked for an hour before commuting from Building 112 for 2.5 km to Building 500 for the lectures. I have had no problem traveling this far because CERN has electric bikes for employees to borrow. I had lectures on particle world and detectors continued from the day before as well as the lecture on From Raw Data to Physics Results. I came back to the office to continue my work with the support. Also, I learned how to do seismic analysis.

29 June 2023

As usual, I dropped by the office and then went for lectures continued from the previous day. I came back to the office and then I received an email of 4 support files with different designs from the design engineer. I have to run the stress analysis for all of them to ensure that they are safe. I work until late to finish all the stress analysis because I want to continue learning about seismic analysis. I let the simulation run and then went back to the hostel.

30 June 2023

I opened the computer to see the results of the simulations that I let them run the day before. I saw unusually high stress from one of the supports. My job is to develop a suggestion for a redesign.

1 July 2023

I needed to meet my friends at the bus station for our trip to Mont Blanc, but I overslept. Fortunately, I still managed to catch the bus at the last minute. It took approximately only 2 hours to arrive at Chamonix. We needed to hurry to catch the train, so we had only pizza for lunch. Then, we took the Montenver Railway to the Mer de Glace Glacier. During the ride, we enjoyed the beautiful scenery of the Mont Blanc range and the forests. We stopped by and entered the manmade ice cave where we were literally surrounded by ice. We also get a chance to see the glacier's changing level each year, which has made me become more aware of the severe impacts of climate change. After getting back to the city, we had fondue with cold cuts for dinner.

2 July 2023

I woke up later but not too late to get some things from Carrefour which will close at noon. I bought food for next week. I brought up a notebook and began to sketch a picture of the sculpture I liked and the scenery of Mont Blanc.

3 July 2023

I prepared a PowerPoint to present the results of structure analysis that I found unusually high stress. Then I discussed this with the design team providing them with information that I tried to redesign and letting them consider if that design is feasible or not. After that for a few hours, they sent new designs for me to work on.

4 July 2023

Today, I felt a little unlucky on the way to work. I got a flat tire. When I was bringing my bike to get it fixed, it was quite a distance from my office to the bike workshop, and it was a sunny day. I changed my eyeglasses to sunglasses and placed my eyeglasses in my shirt pocket. Then, I decided to ride the bike with a flat tire to the workshop. Suddenly, the bike hit a bump, and my eyeglasses popped out of my pocket. I walked back to find them, but they were already as flat as the tire. Someone might have driven over them. I had to work without the glasses all day.

5 July 2023

I studied seismic analysis from Eurocode 8 [7]. Then I left the office on time today because I had a plan to get a haircut. I rode a bike for about 10 mins to Val Thoiry. I tried to communicate with a barber in English, but I failed to communicate with her, so I went to buy some snacks instead.

6 July 2023

I left the office on time because I found a new barber shop near the hostel. This time, I got a haircut, but one problem was that they only accepted cash in euros, which I didn't have, so I had to go back to the hostel and exchange money with my friends.

7 July 2023

I attended the summer student lectures in the morning and had lunch with friends they invited me to a summer student party in the evening. I went back to work to analyse the bolts on the supports. After work, I went to the grocery store to buy snacks for a party. I got to know a lot of people from many different countries at the party, but I arrived home a little late.

8 July 2023

Unfortunately, today I planned to go to Aletsch Glacier with friends, but I overslept and missed a train. So, I made up for myself by planning a Sunday trip. First, I wanted to go to Aletsch Glacier as my friends did. Later, I was working on this report. I looked into last year's reports, and I found out that they had a great time at Oeschinensee Lake. Consequently, I changed my plan to go to the Lake instead.

9 July 2023

Today was the first time that I would travel by myself. I began the day with a scenic train ride to Kendersteg. Once I arrived, I took a gondola to get to Oeschinensee Lake. I was impressed by the stunning view of the crystal-clear water and alpine peaks around the lake. I spent only about 1 hour around the lake then I took a train to Interlaken which is a town located between Lake Thun and Lake Brienz. After having lunch at Interlaken, I traveled to my last destination of today, Iseltwald. This is a which has become more popular after its appearance in the Korean series, Crash Landing on You. I strolled along Brienz lakeside and the village where I could see the traditional Swiss houses. I also visited the pier at Iseltwald boat station which is the filming location of Crash Landing on You. The pier is so popular that you need to pay for the entrance fee.

10 July 2023

Today was a productive day. I attended the summer student lectures, gaining some insights. Spent the afternoon preparing the weld and bolts assessment under combined actions, a challenging task. As a break, I enjoyed a delicious bowl of ramen for lunch that I had cooked in the evening of the previous day.

11 July 2023

I learned a new tool for assessing anchor bolts and concrete. It helps verify that injection bolts won't fail due to any failure modes. Additionally, it evaluates whether the concrete won't crack due to the force transferred by the anchor bolts.

12 July 2023

I continued working on the simulation and studied more about seismic assessment. To be frank, I was confused a lot by this Eurocode, but I tried hard on it. I made several trials and errors, and I gained understanding slowly. I left the office around 19:00. It was getting late, and I was tired, so I chose to cook something easy like instant noodles from Thailand that my friend gave me.

13 July 2023

In the morning I went to the lectures class as usual but in the afternoon, I didn't go to the office because today I attended the Machine Learning lecture which is an additional lecture for summer students who are interested. I am interested in this subject because when I was in the digital twin presentation, I learned how powerful machine learning is as it can be adapted to numerical simulation to predict situations happening in reality. This is really useful for mechanical engineering applications. Therefore, I want to learn the basics of it, and I intend to study it further by enrolling in a course at the university. In the night I went to the Saint-Genis-Pouilly celebration event for French National Day to see wonderful fireworks (figure 20: French national day firework).

figure 20: French national day firework

14 July 2023

I skipped the lecture session today to visit CERN workshops (see section 'CERN Workshop visiting'. I and colleagues in the department had a nice tour visiting machines that are used to fabricate apparatus for the experiments at CERN. I was impressed with the EB weld machine the most because of the fact that EB is a particle accelerator that helps to build bigger particle accelerators like LHC.

15 July 2023

My friend and I took the train to Milan. It took around 4 hours to arrive at Milano Centrale station. Upon arriving, we were starving so we had brunch at Debbie's, a famous restaurant with good ratings. We ordered coffee, Parma Ham, and Pistachio croissant. Later on, we went to Sforzesco Castle which houses different museums (figure 21: Sforzesco Castle museum). After a visit to Pinacoteca di Brera, one of the museums at Sforzesco, we strolled around the city while waiting for our friends, who took the bus, to arrive. Once all of them arrived, we headed to the Duomo Cathedral, which is the fifth-largest cathedral in the world. It took more than 500 years to build this subtle piece of art. For dinner, we had a fresh homemade pasta which was very delicious.

figure 21: Sforzesco Castle museum

16 July 2023

On the second day in Milan, we revisited the Duomo Cathedral once more because we were all amazed by its impressive architecture. Then, we went to The Last Supper Museum but unfortunately, we were told that all tickets were sold out and we needed to book at least 2 months in advance. So, we got to Navigil where there are the two remaining canals that had previously encircled Milan, Naviglio Pavese, and Naviglio Grande. After that, it was almost midday so we had an authentic Italian pizza for lunch. The pizza was so good as the crust was thin and crispy, combined with fresh mozzarella cheese, tomato sauce, and aromatic basil. For a perfect ending to this meal, I had a scoop of salted caramel and a scoop of pistachio gelato which are extremely rich in flavor and texture. After boosting our energy with a fancy meal, we went to Galleria Vittorio Emanuele II, one of Italy's most iconic shopping arcades. It is famous for its stunning architecture and high-end shops and cafes.

17 July 2023

After the long weekend, I was back to study in the summer student class. The class this day was intense. I learned about Radio Frequency, Experimental Physics at Hadron Colliders, and Flavour Physics. Then, I went back to the office to continue with the weld assessment.

18 July 2023

I attended the class in the morning. The class I liked the most today was Radio Frequency. A lecturer taught about radio frequency mechanical design, fabrication, and optimization. In the afternoon, I wrote the pipe support analysis report. It was progressing slowly. After work, I rode a bike to Val Thoiry to look for ice cream and fruit.

19 July 2023

In the morning, I attended a class in which they were giving a lecture about particle accelerator's medical applications, especially Radiotherapy which helps fight against one of the worst enemies of humans, cancer. It is interesting for me as an engineering student to see those advanced technologies that help people.

I visited the measurement lab in the afternoon where the lab is right down from my office. Although a finite element is one of the strongest tools for an engineer, it won't be very useful if we don't have information about material properties. CERN is the frontier of technologies and new technologies are mostly related to new materials. The measurement laboratory has been built to support the MME. They help MME to test material properties and validate the result of FEA simulation. It had been inspiring just to see how they use the laboratory equipment (see section 'Measurement laboratory'). Moreover, I had a chance to visit the warehouse where LHC was born. Not only have I learned the LHC fabrication process but also, have seen how they manufacture High luminosity LHC.

20 July 2023

Before I came to this place, I had been asking myself what I wanted to do after the summer student program ended and how I could strengthen the relationship between Thailand and CERN. Finally, I got the idea that I wanted to collaborate on a final-year university project with CERN to maintain close contact with them and introduce my university. I have been working for them for almost 2 months, and they are already familiar with my working style and capabilities. Therefore, I thought it was a good time to propose the project. I asked them this and they said it is highly possible to do this collaboration since it is a win-win situation but there was some concern about employment for non-member states. Nevertheless, I had a solution to this problem by advising Prof. Norraphat.

21 July 2023

I left the office at 5:00 and back to the hostel. I packed a bag to have a weekend in Paris. I fully charged my phone and camera batteries. Then, I traveled to the train station. The train was delayed for half an hour and when it arrived, I could find my bogie. I was running around and finally found it exhaustively. While I was on the train, I was checking my report. I arrived in Paris around midnight.

22 July 2023

My first impression of the city was not different from what I expected it would be. I went to the hotel generator which is the shared room hotel. I shared this with other CERN summer students. Everyone went to sleep immediately after we arrived.

In the morning, I was heading to the Louvre Museum (figure 22: Louvre Museum). It is a very large and crowded museum. The museum is full of famous oil paintings, sculptures, decorative arts, etc. Despite the fact that I had been enjoying with arts for more than 4 hours, I saw only about 60% of the museum. I walked out from the Louvre to visit Notre Dame cathedral which suffered from fire in 2019 and still renovating to this day. I walked along the Seine River just enjoying the city and stopped near the Eiffel Tower at a restaurant named "Le Recrutement". I spent a nice evening at the Eiffel Tower.

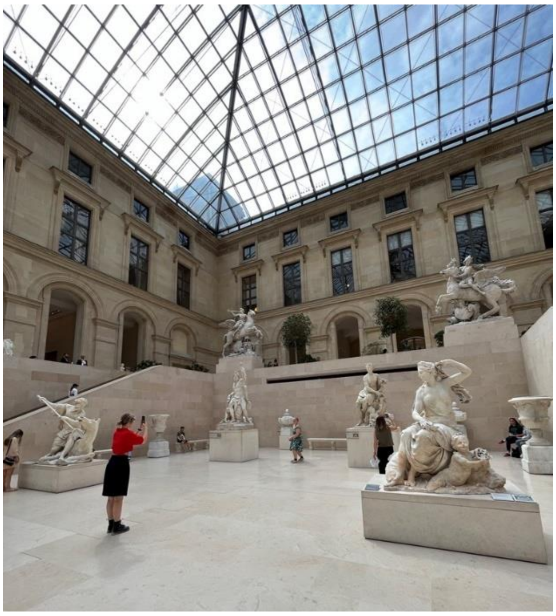

figure 22: Louvre Museum

23 July 2023

The day started at the Generator hostel, then Montmartre the church on the top of the hill where I can see a panoramic view of the city. This place also has a charming district. After this, I went to Arc de Triomphe and when I got there, the rain started to fall. It was beginning to be heavy. Inevitably, I had to go to a fast-food restaurant which I regretted doing. If I could change one thing it would be the weather as it led me to that restaurant instead of a local food restaurant. Following this, I went to Pantheon which is free for someone under 25 and work in France. At that moment, I noticed that I shouldn't have paid for any of the museums in Paris. The trip ended with Museum d'Orsay where many masterpieces of arts stay there including many Van Gogh works. Along the way to get there, I had a chance to see the Tour de France parade.

I decided to take a plane back from Paris to Geneva to avoid exhausting feelings on Monday. Nevertheless, the plane I took had a technical issue which caused a delay of two hours. Consequently, I was back home late and felt tired.

25 July 2023

Prof. Norraphat returned to CERN. I went straight to his office to consult about employment opportunities for non-member states for the final-year project. Apparently, Chulalongkorn University has a good relationship with the CMS experiment. Therefore, it is possible for me to register as a CMS user to maintain my computing account. The next step is to await approval of the project from the Deputy Group Leader.

28 July 2023

This day was the last day of the summer student lectures. Thanks to all the lecturers and CERN, I have learned many new things which helped to urge my curiosity. I went back to the office and got the big news that I would be assigned to another project. I was happy and worried at the same time. On the one hand, it was good news as I will have the opportunity to get more experience. On the other hand, my recent project is still ongoing. I was afraid that I wouldn't be able to manage that work. Still, I have no hesitation in accepting work gladly.

29 July 2023

Today my father's friend who was traveling from Zurich to France and not forget to pass by to visit me. I had been having a good time talking to him and his family. After that, I took time all day to focus on my project report and dairy.

30 July 2023

Grindelwald is the little village in Vale that is the distance from Interlake city by around 30 minutes. This village is the starting point of many hiking trails. I picked one of those. The trial I picked takes 4 and a half hours to walk. It starts from Grindelwald first passing to the lake, Bachsee, and heading to the top of Faulhorn before descending to Bussalp. I took a cable car to Grindelwald First and walked around cliff walk. The was quite misty and windy in the morning, so I couldn't see the view well. I took off from the trail starting point to Bachsee Lake. When I arrived, I took a nap and then had lunch. After that, the sky was beginning to clear. Fortunately, I could see the view of Jungfraujoch snow mountain and other mountains. I walked along the trail and got back to Bussalp on time before the bus took off.

31 July 2023

I worked on the report of the pipe support all day. I felt tired but suddenly I got good news today. I finally had approval from the deputy group leader to do the collaboration project.

1 Aug 2023

It was a Switzerland national day. After work, all Thai summer students and Prof. Norraphat went to Geneva. It has been a while since I had Thai food, I missed Thai food especially Mu kratha or Thai BBQ. I told prof. Norraphat this. So, he brought us for a Korean BBQ. It is a pretty crowded restaurant because the food is really good. We enjoy the city a little bit. When we went back the tram was cancelled. We had to walk from Meyrin, Jardin-Alpin-Vivarium to CERN. Unexpectedly, we had a chance to see massive fireworks shot from Alpine Botanical Garden.

2 Aug 2023

I began to work on the new project which is about assessing the deflection and the weld of the jack support that supports the Hilumi-LHC. The challenge of the task is the massive weight of the magnet resulting in the deflection which is unfavorable for high-precision tools such as the Hilumi-LHC magnet. Therefore, I need to design the support that meets the deflection criteria.

3 Aug 2023

I continued to redesign the jack support trying to minimize the deflection with various designs. Still, the designs that I did did not meet the criteria.

4 Aug 2023

I studied more about the deflection of beams to find the stiffest beam that is available in the CERN warehouse. I tried to use the beam in many configurations of the beam and the deflection seemed to decrease significantly; however, it was not met the criteria.

5 Aug 2023

I woke up early as I had a trip to Zermatt today. It took me about 3 hours to get there by train. Before the trip, I had selected the Matterhorn Glacier Trail as most people suggest that it is one of the most scenic hikes to do in Zermatt, and the level of difficulty is not too high. During the hike, I saw a glimpse of snow and glacier. I also had a chat with an aunty whose son also works at CERN. When I hiked for around 2 hours, I felt a little bit exhausted, so I had a sandwich that I had prepared last night. I continued the hike and saw Matterhorn from different angles. Matterhorn is an iconic mountain that is featured on Toblerone chocolate packaging and inspired the shape of the chocolate. After 4 hours of hiking, I finished the trail and I felt so sad to leave because I still wanted to enjoy this majestic view.

6 Aug 2023

Nothing special for today, I sat in my hostel room remoted to a computer at the office, and let simulations run while I let myself rest by having a nice cup of coffee and croissant for breakfast. I cooked delicious dishes for lunch, dinner, and tomorrow's lunch.

7 Aug 2023

I came to work a little late today, so I had to do everything fast. I opened a computer and started to work on the jack support project. I let the simulation run and continued working with the report. At the end of this day, I finally found the design that met the deflection criteria.

8 Aug 2023

From the previous day, I found the design that met the deflection criteria; however, it was not the end of the story because I had to assess the weld of the jack support. The design team specifies where to put the weld and provides the information about size of the weld. I took it to evaluate the strength and summary in an Excel file.

9 Aug 2023

I let my supervisor check the weld assessment of the jack support. She suggested that the weld size should be increased, and the intermittent weld should be applied for the weld located near the magnet. The benefit of intermittent weld in it can decrease weld distortion due to heat from the welding process. I tried to optimize the intermittent weld and summery the result in the Excel file.

11 Aug 2023

It was a lonely day; almost everyone had gone on holiday. When I went to the cafeteria for lunch, there were only Gabriele, me, and the shopkeeper. Furthermore, it was the day I had to say goodbye to Gabriele as he was going on holiday and wouldn't return to work until August 28, 2023, while I had already returned to Thailand.

12 Aug 2023.

This weekend, I decided not to go anywhere far because I felt tired from work and I was excited for a final presentation on 17 August 2023. So, I planned to spend time this weekend working. I worked in the morning trying to finish the new project and also writing an internship report for my university. In the afternoon, I went to Geneva to buy souvenirs for my family. For my father, I bought coffee beans originating from Italy and Switzerland. For my mother, since she likes to cook bread a lot, I bought bread knives, while for my sister I definitely have no idea what I should give things to represent Switzerland to her. So, I ended up buying products from London for her.

13 Aug 2023

I woke up late letting myself rest to have a fresh start tomorrow. The first thing I did was check the simulation that I had done last night but it turned out to fail. I had to prolong working on this project instead of preparing the presentation. Eventually, after many hours, I could get the simulation to run without errors and without any idea how I did that. Then, I did the summary report for the simulation result.

14 Aug 2023

I went back to work after the refreshing holiday. At first, I thought it wasn't going to be a rough week because only one work left was preparing the presentation, but I found out later that it had been the hardest week ever in CERN.

15 Aug 2023

The hardest part was to fit all the work that I had been doing for two months to 10 minutes. Then, I made a mistake by adding too much technical information but too less of work I have done.

16 Aug 2023

I continued to stack my mistakes up until I ended up with 50 pages of slides which were full of technical staff. Then I realized that no way I can't present this in time to someone who doesn't know much detail about this technical. I began to cut the subject out page by page, topic by topic and to organize my thoughts on what I was going to say.

17 Aug 2023

Today was a big day for me as I had to present the final presentation. I still checked the presentation slide until the last minute to make sure that no additional refinement was needed. When it was time, I was super nervous. After the presentation they bombarded me with questions luckily, due to preparing almost 50 slides, I had all the answers in them. When I finished the presentation, I went straight back to the hostel fell asleep around 18:00, and woke up in the morning of the next day.

18 Aug 2023

I worked on jack support analysis by summarizing the results of the analysis in the Excel file. When it was done, I submitted it to Carlotta. She checked my work, and she spotted some flaws in the weld assessment method that I invented. I tried to find a way to fix these flaws. So, I began to start coding MATLAB.

19 Aug 2023

I went to Gare Cornavin to catch a train to Lucerne. From there, I transited to Engelberg village, which is not far from the city of Lucerne. I took a cable car up to the top of Mount Titlis. The cable car I boarded could rotate around, allowing me to have a 360-degree view, which was a great experience for me. The scenery at the top of the mountain was wonderful. Additionally, I visited an ice cave, which was quite slippery and nearly caused me to fall. I also had the chance to play in the snow. Then, I went back to Lucerne to visit Chapel Bride, the oldest wooden bridge in Europe. It has several historic paintings along the way. I walked from the bridge to see the Lion Monument. It is a large dying lion sculpture on a rock cliff. It was built for the Swiss soldiers who died during the French Revolution. Then I go to Zurich to sleep over at the house of my father's friend's in Dietlikon.

20 Aug 2023

My father's friend offered to be a guide today. We began the day by visiting ETH, one of my dream universities. Then, we had lunch at Le Cedre – Bellevue Restaurant where we enjoyed Mediterranean food before visiting Zurich Zoo. There is a wide variety of animals at the Zoo from lions, and elephants, to penguins. After that, I said goodbye to my father's friend and his family and took a train to Bern. When I arrived, I walked around Bern's Old Town and visited the Einstein Museum which was established in dedication to Albert Einstein, who lived in Bern. I also went to the Bear Pit to observe bears, the symbol of Bern, but I was not lucky enough to see them.

21 Aug 2023

I still worked on MATLAB code and then I finally came up with a perfect idea to assess a straight weld joint. However, I thought it was not enough because the method that I invented can be really useful in the case of circular weld joints. Still, it is hard to implement a code for assessing a circular weld joint. I used the entire evening to figure it out.

22 Aug 2023

I spent time working on the circular weld assessment code. I discussed the result of the weld assessment and the collaboration project. I also registered as a CMS user.

23 Aug 2023

About a few days from this day, I had to go home, I still had a lot of work to do. I discussed the pipe support analysis with Audrey and edited the report by adding more information. I also had to write a report for my university. Everything seems a little overwhelming to me.

24 Aug 2023

deI continued working on the reports. Additionally, I transferred and organized all the files into a shared folder. It was a hot day as a heat wave swept across Europe. The temperature in my office reached almost 40 degrees Celsius. However, the weather felt different from Thailand because it was less humid. The office has no air conditioner. It has only a few little fans. Although I had a lot of work, I felt unproductive. Later we all moved to another building which has an air conditioner. So we could continue to work efficiently.

25 Aug 2023

My contract was sadly ending on this day. I attended my last weekly meeting with MME where I met every colleague. Then, back to the office to finish the internship report for my university. At 15:00, I participated in a presentation by my officemate and my dear friend, Khawla Ajidad. It was her final presentation about the thermal analysis of the main transfer lines which is very complex work and I was really impressed with her work. In the evening I walk all over the office to say goodbye and thank everyone I know. Next Audrey picked me up to go to CERN shop and restaurant 1 where colleagues had chips and snacks. We talked and had fun together. It was a nice moment, but I was feeling so sad that soon I had to leave.

26 Aug 2023

I packed my bag and tried to figure out how to transfer money to my bank account. I was 80% ready to leave this place at noon. Therefore, I let myself relax a little by going to Geneva shopping street to buy a bit more for myself, my family, and my friends. I went to Geneva Lake to appreciate how beautiful the city is, and I put my legs into the water because I wanted to remember this place as much as possible. There were more people I wanted to say goodbye to. I texted my summer student friends inviting them for dinner at Luigia. It is a nice pizzeria near CERN where people can get there on a short walk.

27 Aug 2023

I finished packing my bag around 8:00. So, so I had plenty of time left to do some things. I decided to go to Carrefour spending all the coins I had to buy snacks for a long flight. Then, I took a bus going straight to Geneva airport and left Switzerland.

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Education:

- B.Eng. in Mechanical Engineering Chulalongkorn University (Third year) (GPA 3.90)
- Science & Math program, Roong Aroon school

Key Competencies

Languages

- Thai (native)
- English (bilingual)
  - TOEIC score 795 (Listening 460, Reading 335)

Related coursework

- Vibration
- Computer-Aided Mechanical Design
- Design of Mechanical Elements and Mechanics of material
- Automatic Control
- Physics

Mechanical engineering computer literacy

- Fusion 360
- ANSYS Workbench (Statics structural, Modal, Spectrum Response, and Harmonic response)
- ANSYS APDL
- ANSYS Space Claim
- MATLAB
- Microsoft Excel, Word, and PowerPoint
- Python

Work Experience

- Mechanical and Material Engineering Summer student at CERN, Geneva, Switzerland (2023, 5 June – 25 August)
    - Contributed to ATLAS upgrading project by providing numerical and analytical calculations for the Main Transfer Lines supports.
- Internship at Seagate Technology Thailand, Nakhon Ratchasima, Thailand (2022, 30 May - 5 August)
    - Supported root cause analysis in the production process through finite element analysis, which enhanced my computer and analytical skills.

Certificate

- Solving Ordinary Differential Equations with MATLAB (2022, October 19)
- Introduction to Statistical Methods with MATLAB (2022, September 23)
- Solving Nonlinear Equations with MATLAB (2022, August 20)
- MATLAB Fundamentals (2022, January 23)
- Promotion of Academic Olympiads and Development of Science Education Foundation (POSN), Physics camp 2, Triam Udom Suksa School (2019, March 29)
- POSN, Physics camp 1, Debsirin School (2018, October 19)

Projects

- Main transfer lines supports structural and seismic analysis (2023, 5 June- 25 August)
- Crack failure analysis of a component of *Head Gimbal Assembly* (HGA) in the production line (2022, 30 May - 5 August)
- *Head stack Assembly (HSA)* & Resonance tester finite element simulation (2022, 30 May - 5 August)
- Study the effect of Component Material properties of HGA on resonance failure (2022, 30 May - 5 August)
- HSA Resonance Curve failure detector by Hypotheses testing (2022, 30 May - 5 August)

Extracurricular activities

- Participant in Mechanical engineering’s volunteer camp at Lamphun, Ban ko (2022, January 4-9)
- Engineering Innovation Club, Nitad Engineer Bootcamp workshop, staff, and mechanical design team
- Member of Mechanical Engineering Academic

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