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Summary

Before delving into the depths of this thesis and study, start with this concise summary which compiles the description, results, discussion, and conclusion. It offers a clear understanding of what the research has to offer, serving as a guide before exploring further.

The thesis investigates the structural behavior of a multi-story building utilizing the Finite Element Method (FEM), with analysis conducted through ANSYS Workbench, ANSYS Mechanical, and ANSYS Design Modeler software. During the research process, several noteworthy results emerged, particularly concerning snow, imposed, and wind loads, which introduced new complexities to the project necessitating their careful consideration. Following calculations, the snow, imposed, and wind loads were determined. The snow load, being relatively low due to the typical climate conditions in Norway, was found to be $S_l = 1200Pa$. Wind loads were analyzed separately for the front and back $W_{lfb} = 30.29Pa$ and the sides $W_s = 30Pa, 50Pa$ of the building, reflecting variations in the exposed area. By using the standard NS-EN 1991-1-1:2002+NA:2008 the imposed load value is given, due to the building being a residential building, this was the load value used: $I_l = 2000Pa$.

The analysis results suggest that the structure is experiencing both vertical and horizontal stress. Given the material selection of industrialized steel, the structure exhibits a high degree of resilience to the applied stresses, thereby avoiding potential failure. Specifically, the analysis reveals an axial maximal force of 1.99e5 N, a maximal bending moment of 49682 N, maximal horizontal deformation of 8.5 centimeters, and maximal vertical deformation of 2.5 centimeters. Furthermore, the results indicate a maximal reaction force in the y-direction of 1.9017e6 N and a total resultant force of 1.9018e6 N, encompassing all directions. Additionally, the analysis shows a maximal shear force of 19406 N, maximal torsional moment of 142.69 N, and maximal equivalent stress of 1.4908e8 Pa. These findings underscore the structural integrity and robustness of the system under consideration.

The geometric configuration of the structure exhibits a simplicity and minimalism in its design. However, there exists an opportunity for improvement by integrating additional beams into both vertical and diagonal-horizontal orientations. This augmentation would serve to enhance the structural integrity, providing an increased resilience against extreme failures. It is worth noting that current analysis does not suggest any imminent risk of such scenarios occurring, yet the incorporation of these additional beams would serve as a proactive measure to further reinforce the structure's stability and safety.

The conclusive segment of the thesis analysis underscores that the results obtained from the structural evaluation, as delineated in the preceding chapter, do not reveal any significant vulnerabilities such as buckling or cracking within the examined structure. These findings provides trust to the assertion that the structure exhibits a notable degree of structural integrity and resilience, thereby providing a high level of safety assurance. Consequently, it can be inferred with confidence that the structure is well-suited for residential purposes and can endure various loads and environmental conditions without compromising its stability or safety.

Pre Face

A little help goes a long way, and appreciation is always given.

I would like to express my sincere gratitude to Professor Dimitrios Pavlou for his instruction in the subject of Finite Element Method (FEM) and for his guidance during the course of my thesis. The knowledge acquired through this course has proven to be invaluable, and Professor Pavlou's mentorship has played a significant role in shaping my abilities as an engineer capable of addressing practical challenges.

Chapter 1

Introduction

The introduction serves as the focal point of the thesis, presenting its main focus and providing a concise overview of the study's purpose and rationale.

1.1 Background

The focal point of this study entails the analysis of a selected steel structure using the finite element method. The analysis aims to determine various structural parameters including the deformed shape, bending moment distribution, shear force distribution, axial force distribution, support reactions, and the Von-Mises stress map. The subject structure under examination is a five-story industrial building. The analytical process will be conducted utilizing the software tools ANSYS Mechanical, ANSYS Workbench, and ANSYS Design Modeler. These software tools facilitate the analysis process significantly. The structural analysis holds paramount importance as it ensures the accuracy of calculations, thereby ensuring the structural integrity of the building during its construction and operational phases.

There is always a reason for studying, and in this context, no exception exists. Understanding the principles behind why a building stands, particularly in the context of Norway's climate, is paramount to ensuring the safety of its occupants. Analyzing structural integrity while considering factors such as snow loads, wind forces, and the building's own weight is essential for identifying vulnerabilities. This process of identifying weaknesses is crucial for enhancing safety measures during construction.
Moreover, this academic pursuit serves to equip me, as an engineering student, with the necessary skills to tackle the complex structural challenges that I will encounter in my professional career. The ability to analyze structures is indispensable, as it provides engineers with the knowledge needed to effectively address real-world structural issues. This skill set will play an integral role in my future career. [1]

1.2 Concrete versus Steel

The use of steel as the primary construction material is widespread, along with concrete. Hence, the choice of steel over concrete requires scrutiny.
The economic benefits of using steel in construction are considerable. Steel requires less labor due to its ease of handling and is generally cheaper than concrete. Approximately 90 percentile of steel in today's market is recycled, retaining its strength, which is paramount. While reinforced concrete is renowned for its strength and widespread application, steel boasts the highest weight-to-strength ratio among construction materials, being up to eight times stronger than reinforced concrete in shear and tension stress.
Concrete's versatility lies in its ability to be molded into desired shapes. However, its capability to span considerable heights and lengths without additional supports is limited.

Both steel structures and reinforced concrete are deemed safe for use in construction. Safety holds paramount importance in any construction project, thereby making the selection of the appropriate material crucial. Although both materials are considered safe, the choice between steel and concrete should take into account their respective characteristics. Steel exhibits greater resilience to earthquakes and does not undergo the same degree of crumbling as concrete. This difference can be attributed to the molecular composition of the materials and their behavior under cyclic loading conditions, although a detailed exploration of these factors will not be explained any further.
[2]

Chapter 2

Architecture

Architecture may not seem directly relevant to mechanical engineering, but presenting the building in all its glory provides a vivid visualization of the potential outcomes of analyzing and creating a frame structure. This chapter will further elaborate on the use of fixed supports.

The architectural design was generated using Rhino, a software program commonly employed in architectural practice. Utilizing such a program enables visualization of the building's potential appearance within a realistic context.

The decision to encase the building entirely in glass was motivated by personal preference rather than the specific parameters of the project.'

The structure consists of beams and elements and incorporates a total of ten fixed supports to ensure stability and prevent movement in any direction. Fixed supports are chosen for their ability to restrict movement in the Y-direction (upwards), X-direction (depth), and Z-direction (sideways), as well as to limit moments in all directions. This makes them highly recommended for structures of this nature.

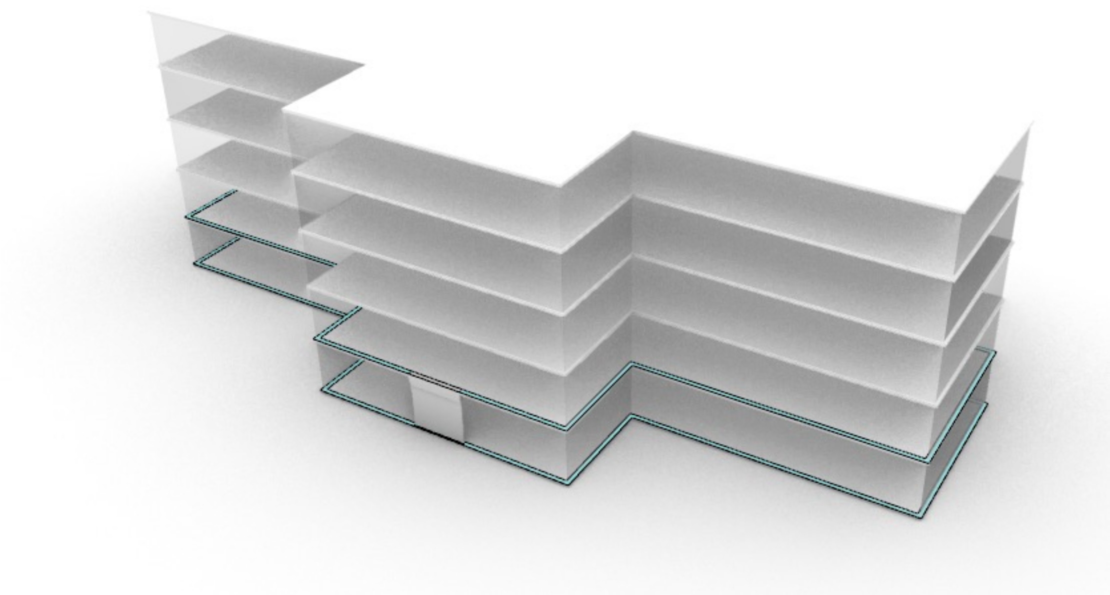

Figure 2.1: The interior of the building, showcasing possible internal design.

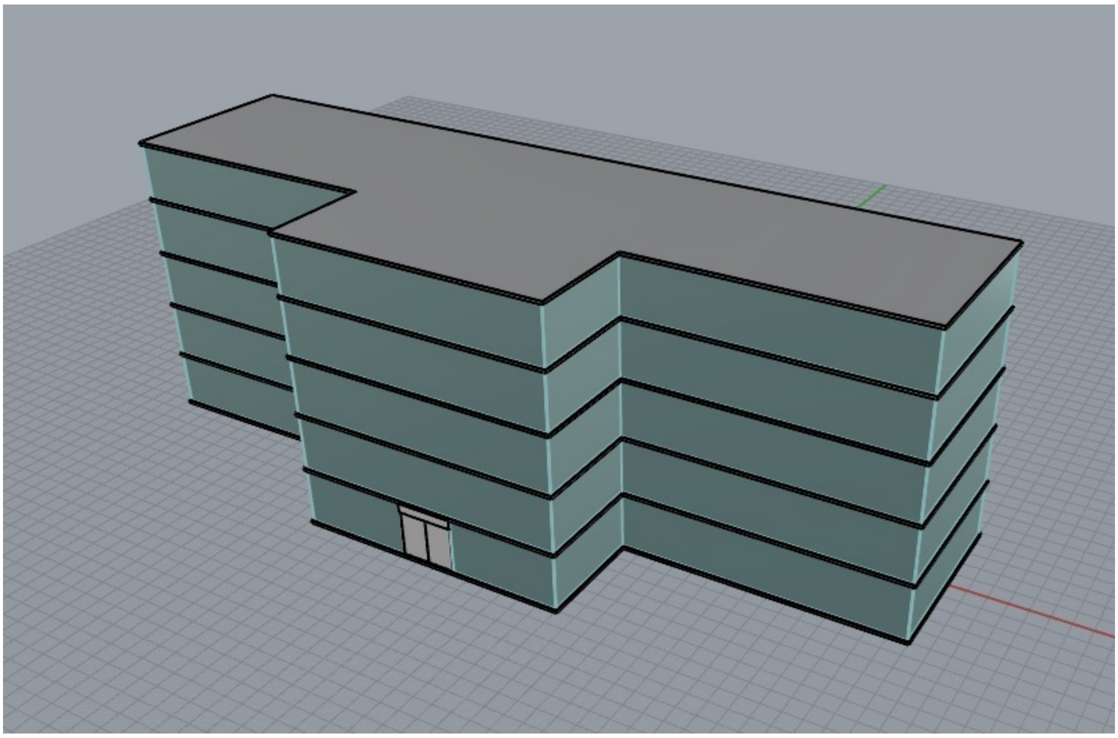

Figure 2.2: The exterior of the building, showcasing possible exterior design.

Chapter 3

Basic Theory

Theory is the foundation upon which everything is made possible. Before constructing a building or running a simulation, one must first uncover the underlying theory. It provides the explanation of what occurs and why, guiding the operation of simulations or constructions as expected. Formulas and notations are integral parts of this theoretical framework.

3.1 Finite Element Method

The differential equations used to describe the displacement field of a structure are difficult to solve by analytical methods. The problem can therefore be divided into sub-parts called finite elements (FE). The displacement field of each element is approximated by polynomials, which are then interpolated with respect to prescribed points located on the boundary of the element. [3]

Prior to delving into the theoretical aspects used to address the frame problem, it is necessary to clarify the fundamental concept of what the Finite Element Method is. The Finite Element Method is a method on how to calculate and approximate solutions to complex mathematical problems. In FEM the use of large matrices combined of smaller ones to get to the answer of complex mathematical problems is common. FEM is commonly used by engineers and other mathematicians when they need to design or construct a structure for practical applications. [1]

There is advantages and disadvantages to using the finite element method for analysis of a structural problem. The advantages being the possibility to analyze problems with complex geometry, analyze problems with complex loading and analyze a wide variety of engineering problems. [3]

The main and most important disadvantage of using the finite element method is that the results of the analysis are approximate. The results are not 100 percentile correct and the accuracy depends on the number of elements, the type of the element and also the adopted assumptions. [3]

3.2 Mathematical Background & Coordinate Systems

The mathematical background for the finite element method is rather complex. There is a need to understand both calculus and linear algebra to understand the mathematical background. The mathematical background includes vectors, such as scalar product, vector product, greens theorem and gradients. The use of coordinate systems are also highly regarded. The most commonly used coordinate system is the Cartesian coordinate system, however, the finite element method also uses coordinate systems such as; Cylindrical and spherical coordinate systems. [3]

3.3 Material & Cross Sectional Area

As said in the introduction to the thesis, there was a written section on steel versus reinforced concrete. From the Introduction there was clear the chosen material will be industrialized steel. The steel will be used for the frames and beams, and therefore for the structure of the whole building. There will not be any in-depth study into the materials used for the facade for the building since that is not relevant to the study. To use industrialized steel for construction there are guidelines to follow from the European committee for standardization.

One of the guidelines is the dimensions of the cross sectional area of the beams and members. Those dimensions are found in the Norwegian Standard for "Hot rolled steel channels, I and H sections - dimensions and masses". The chose fell on the taper flange IPE300 I-section beam from the Norwegian standard. The dimensions for the taper flange IPE300 I-section will be listed below. [4]

Table 3.1: Taper flange I sections IPN

Beam Type	G [kg/km]	h [mm]	b [mm]	s [mm]	t [mm]	A [cm^2]
IPN300	54.2	300.0	125.0	10.8	16.2	69.0

There are differences between I-beams and H-beams and they are important to discuss to find the reason for using I-beams instead of H-beams. I-beams are often used as the main framework in a steel construction due to its strength. The immense power of the I-beams reduces the need to use supports and other constructions to hold the beams. This saves money and time, most notably on extra material. The reduction of the need to use supports for the beams also increases the stability of the building, making I-beams the suitable choice for every builder. [5]

3.4 Snow, Wind and Imposed loads

For a building to be properly constructed in a safe way, there is a need to know the different loads the environment contributes with. Those loads are Snow loads and Wind loads, as-well as the dead/imposed load of the building itself. The snow loads tells you how much the weight of the snow contributes to the buildings loads. Snow is in most region‘s in Norway not a constant load factor, however, it is a seasonal phenomena and should be considered important. The building in question is the building that has been constructed during this thesis, and that building will be standing in the southern part of Norway, where there are less snow than in the northern parts, that is also important to consider.

$$S = \mu_i C_e C_t S_k \tag{3.1}$$

The thermal and exposure coefficients (C_e, C_t) are determined to be at value 1.0 in the southern parts of Norway. The characteristic value of the snow load S_k is determined to be at value $1.5Kn/m^2$ in Stavanger (from section 5.2(3)P in NS-EN 1991-1-3:2003+NA:2009). therefore, the snow load value is:

$$S = 1.5KN/m^2 * 1.0 * 1.0 * 0.8 = 1.2KN/m^2 \rightarrow 1.2KN/m^2 * 540m^2 = 648KN \tag{3.2}$$

The wind load varies on different characteristics, such as where in the landscape the building is located, and of course where in the country the building resides. It also depends on how close to the coast the building will be. In Norway, it is usual that cities and populated areas are close to the coastline. From Section NA.4.2 in NS-EN 1991-1-4 2005+NA:2009 we can find the reference wind velocity for Stavanger, which is 26m/s. From the wind velocity, there can be found a basic wind velocity, which in this case is the same as the reference wind velocity due to the building being a permanent installation located below the the minimum elevation for southern parts of Norway, being 900 metres. Basic wind velocity:

$$V_b = C_{dir} C_{season} C_{altitude} C_{probability} V_{b,0} \tag{3.3}$$

where:

$$C_{dir} = 1.0 \tag{3.4}$$

$$C_{season} = 1.0 \tag{3.5}$$

$$V_{b,0} = 26m/s \tag{3.6}$$

$$C_{alt} = 1.0 \tag{3.7}$$

$$C_{prob} = 1.0 \tag{3.8}$$

[6]

From here, there is a need to find the pressure the wind is exerting on the structure. First step is to find the mean wind velocity:

$$V_m(z) = C_r(z)C_0(z)V_b \tag{3.9}$$

where: $C_r(z)$= Roughness factor $C_0(z)$= Orography factor, set equal to 1.0 due to terrain [6]

The roughness factor can be found by the use of this formula:

$$C_r(z) = k_r ln(\frac{Z}{Z_0}) \tag{3.10}$$

where:

$$Z_0 = 1.0m \tag{3.11}$$

$$Z = 15m \tag{3.12}$$

$$k_r = 0.24 \tag{3.13}$$

[6]

This leads to a calculation where the mean wind velocity is found, the value found is 16.9m/s. In the next step, it is convenient to transform a wind speed into pressure, and from there into a force.

Finding the peak velocity pressure is an essential step to convert wind speed into a force, peak velocity pressure is found with this formula:

$$q_p(z) = (1 + 2k_p I_v(z))(\frac{1}{2}\rho V_m(z)) \tag{3.14}$$

where: $k_p = 3.5$, $\rho = 1.25kg/m^3$ (density of air). The values are found from Section NA.4.4 and NA.4.5 in NS-EN 1991-1-4 2005+NA:2009 The calculation yields an answer value of 37.87.

Now that the peak velocity pressure is known, the last step is to convert the pressure into a wind force. This step ensures smooth application of forces into ANSYS during the modeling part of the project. To find the wind force, the area of the wall surface and the external and the subsequent internal pressures needs to be found. The area is already known, so the final values to find are those of the external and internal pressure, those can be found by multiplying the peak velocity pressure value to some coefficients. The coefficients are those of internal and external pressure and can be found in Section 5.3 from NS-EN 1991-1-4 2005+NA:2009:

$$C_{pi} = +0.2 Internal \tag{3.15}$$

$$C_{pe} = -0.8 External \tag{3.16}$$

[6]

From there, this formula is used to find the equivalent forces:

$$F_{int} = c_s c_d q_p(z) c_{pi} A_{ref} \tag{3.17}$$

$$F_{ext} = c_s c_d q_p(z) c_{pe} A_{ref} \tag{3.18}$$

where the values for c_s and c_d is set equal to 1.0. The external wind forces obtained is as follows:

20.45kN for the front and back of the building and 4.5kN for the side of the building. The internal wind forces obtained is as follows:

5.1kN for the front and back of the building and 1.1kN for the sides of the building.

The last forces to be applied to the building during the modeling part is the imposed loads. Imposed loads are the weight the building puts on itself due to the material. From Section NA 6.2 in NS-EN 1991-1-1:2002+NA:2008 the values for the imposed loads are given.

The values depend on the category of the building, the category this building is in, is category A. That is because the building will serve as a residential building, similar to a hotel. The values that are given is $2.0kN/m$ for the floor beams. [7]

3.5 Beams

There is a difference between beams and bars even though they have similar geometric morphology. In addition to axial forces, beams carry bending moments and shear forces. Beams are usually used in construction such as building, bridges, foundations, structures and more. Where there is bending moment and shear forces, there is also rotation and deflection in the material normal to the beam‘s axis. [3]

Lets look at two-dimensional beam elements and find the stiffness matrix for that. For starters, a two-dimensional beam element has four degrees of freedom. By using a suitable polynomial $u(x)$ for displacements distributions along the beam‘s axis, the polynomial should contain four unknown constants. The function should and will have the following form:

$$u(x) = a_3x^3 + a_2x^2 + a_1x + a_0 \tag{3.19}$$

Using Equation (3.19), the following conditions

$$u(0) = u_1 \tag{3.20}$$

$$\frac{du(x)}{dx} = \vartheta_1, x = 0 \tag{3.21}$$

$$u(L) = u_2 \tag{3.22}$$

$$\frac{du(x)}{dx} = \vartheta_2, x = L \tag{3.23}$$

yield the following equations:

$$a_0 = u_1 \tag{3.24}$$

$$a_1 = \theta_1 \tag{3.25}$$

$$a_3L^3 + a_2L^2 + a_1L + a_0 = u_2 \tag{3.26}$$

$$3a_3L^2 + 2a_2L + a_1 = \theta_2 \tag{3.27}$$

The above equations can be written in the following matrix format:

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & L & L^2 & L^3 \\ 0 & 1 & 2L & 3L^2 \end{bmatrix} \begin{Bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{Bmatrix} = \begin{Bmatrix} u_1 \\ \theta_1 \\ u_2 \\ \theta_2 \end{Bmatrix} \tag{3.28}$$

The solution of the above matrix equation yields

$$\begin{Bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -\frac{3}{L^2} & -\frac{2}{L} & \frac{3}{L^2} & -\frac{1}{L} \\ \frac{2}{L^2} & \frac{1}{L^2} & -\frac{2}{L^3} & \frac{1}{L^2} \end{bmatrix} \begin{Bmatrix} u_1 \\ \theta_1 \\ u_2 \\ \theta_2 \end{Bmatrix} \tag{3.29}$$

Equation (3.29) can be rewritten in the following form, since the a-terms are all known

$$u(x) = x^3 \begin{bmatrix} \frac{2}{L^3} \\ \frac{1}{l^2} \\ -\frac{2}{L^3} \\ \frac{1}{L^2} \end{bmatrix}^T \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} + x^2 \begin{bmatrix} -\frac{3}{L^2} \\ -\frac{2}{L} \\ \frac{3}{L^2} \\ -\frac{1}{L} \end{bmatrix}^T \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} + x \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}^T \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} + \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}^T \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.30}$$

or the more common notation

$$u(x) = \begin{bmatrix} N_1 & N_2 & N_3 & N_4 \end{bmatrix} \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.31}$$

Where all the different N-notations are functions given by

$$N_1 = \frac{1}{L^3} \left(2x^3 - 3x^2 L + L^3\right) \tag{3.32}$$

$$N_2 = \frac{1}{L^3} \left(x^3 L - 2x^2 L^2 + x L^3\right) \tag{3.33}$$

$$N_3 = \frac{1}{L^3} \left(-2x^3 + 3x^2 L\right) \tag{3.34}$$

$$N_4 = \frac{1}{L^3} \left(x^3 L - x^2 L^2\right) \tag{3.35}$$

[3]

As it is known from the mechanics of solids, the internal forces, that is, bending moments $m(x)$ and shear forces $f(x)$ can be correlated to the displacement distribution $u(x)$ [3]:

$$f(x) = EI \frac{d^3 u(x)}{dx^3} \tag{3.36}$$

$$m(x) = EI \frac{d^2 u(x)}{dx^2} \tag{3.37}$$

Taking into account Equation (3.31), the above expressions yield:

$$f(x) = EI \frac{d^3}{dx^3} \begin{bmatrix} N_1 & N_2 & N_3 & N_4 \end{bmatrix} \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.38}$$

$$m(x) = EI \frac{d^2}{dx^2} \begin{bmatrix} N_1 & N_2 & N_3 & N_4 \end{bmatrix} \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.39}$$

or

$$f(x) = \frac{EI}{L^3} \begin{bmatrix} 12 & 6L & -12 & 6L \end{bmatrix} \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.40}$$

$$m(x) = \frac{EI}{L^3} \begin{bmatrix} 12x - 6L & 6Lx - 4L^2 & -12x + 6L & 6Lx - 2L^2 \end{bmatrix} \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.41}$$

The sign convention used in solids are not the same as used in Finite Elements, in Finite elements the sign convention is always the same way, no matter the node. Therefore the boundary conditions can be formulated:

$$f(0) = f_1 \tag{3.42}$$

$$m(0) = -m_1 \tag{3.43}$$

$$f(L) = -f_2 \tag{3.44}$$

$$m(L) = m_2 \tag{3.45}$$

Combining Equations (3.42)-(3.45) with Equations (3.38) and (3.39), the following formula can be obtained:

$$f_1 = \frac{EI}{L^3} \begin{bmatrix} 12 & 6L & -12 & 6L \end{bmatrix} \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.46}$$

$$-m_1 = \frac{EI}{L^3} \begin{bmatrix} -6L & -4L^2 & 6L & -2L^2 \end{bmatrix} \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.47}$$

$$-f_2 = \frac{EI}{L^3} \begin{bmatrix} 12 & 6L & -12 & 6L \end{bmatrix} \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.48}$$

$$m_2 = \frac{EI}{L^3} \begin{bmatrix} 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.49}$$

Equations (3.46)-(3.49) can be written in a matrix form providing the following element equation for a beam element:

$$\begin{Bmatrix} f_1 \\ m_1 \\ f_2 \\ m_2 \end{Bmatrix} = \frac{EI}{L^3} \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \begin{Bmatrix} u_1 \\ \vartheta_1 \\ u_2 \\ \vartheta_2 \end{Bmatrix} \tag{3.50}$$

[3]

To end the theory part on beams, I find it necessary to show the element equation of a beam under a 3D loading system, since the whole project is done in a 3D manner.[3]

$$\begin{Bmatrix} f_{1z} \\ m_{1y} \\ f_{2z} \\ m_{2y} \end{Bmatrix} = \begin{bmatrix} \frac{12EI_y}{L^3} & \frac{6EI_Y}{L^2} & \frac{-12EI_y}{L^3} & \frac{6EI_y}{L^2} \\ \frac{6EI_y}{L^2} & \frac{4EI_y}{L} & \frac{-6EI_y}{L^2} & \frac{2EI_y}{L} \\ \frac{-12EI_y}{L^3} & \frac{-6EI_y}{L^2} & \frac{12EI_y}{L^3} & \frac{-6EI_y}{L^2} \\ \frac{6EI_y}{L^2} & \frac{2EI_y}{L} & \frac{-6EI_y}{L^2} & \frac{4EI_y}{L} \end{bmatrix} \begin{Bmatrix} u_{1z} \\ \theta_{1y} \\ u_{2z} \\ \theta_{2y} \end{Bmatrix} \tag{3.51}$$

yielding

$$\begin{Bmatrix} f_{1x} \\ f_{1y} \\ f_{1z} \\ m_{1x} \\ m_{1y} \\ m_{1z} \\ f_{2x} \\ f_{2y} \\ f_{2z} \\ m_{2x} \\ m_{2y} \\ m_{2z} \end{Bmatrix} = \begin{bmatrix} [K_{fu}^{11}] & [K_{f\theta}^{11}] & [K_{fu}^{12}] & [K_{f\theta}^{12}] \\ [K_{mu}^{11}] & [K_{m\theta}^{11}] & [K_{mu}^{12}] & [K_{m\theta}^{12}] \\ [K_{fu}^{21}] & [K_{f\theta}^{21}] & [K_{fu}^{22}] & [K_{f\theta}^{22}] \\ [K_{mu}^{21}] & [K_{m\theta}^{21}] & [K_{mu}^{22}] & [K_{m\theta}^{22}] \end{bmatrix} \begin{Bmatrix} u_{1x} \\ u_{1y} \\ u_{1z} \\ \vartheta_{1x} \\ \theta_{1y} \\ \theta_{1z} \\ u_{2x} \\ u_{2y} \\ u_{2z} \\ \theta_{2x} \\ \theta_{2y} \\ \theta_{2z} \end{Bmatrix} \tag{3.52}$$

Where

$$[K_{fu}^{11}] = \begin{bmatrix} \frac{EA}{L} & 0 & 0 \\ 0 & \frac{12EI_z}{L^3} & 0 \\ 0 & 0 & \frac{12EI_y}{L^3} \end{bmatrix} \tag{3.53}$$

$$[K_{mu}^{11}] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \frac{6EI_y}{L^2} \\ 0 & \frac{6EI_z}{L^2} & 0 \end{bmatrix} \tag{3.54}$$

$$[K_{fu}^{21}] = \begin{bmatrix} \frac{-EA}{L} & 0 & 0 \\ 0 & \frac{-12EI_z}{L^3} & 0 \\ 0 & 0 & \frac{-12EI_y}{L^3} \end{bmatrix} \tag{3.55}$$

$$[K_{mu}^{21}] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \frac{6EI_y}{L^2} \\ 0 & \frac{6EI_z}{L^2} & 0 \end{bmatrix} \tag{3.56}$$

$$[K_{f\theta}^{11}] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \frac{6EI_z}{L^2} \\ 0 & \frac{6EI_y}{L^2} & 0 \end{bmatrix} \tag{3.57}$$

$$[K_{m\theta}^{11}] = \begin{bmatrix} \frac{GJ}{L} & 0 & 0 \\ 0 & \frac{4EI_y}{L} & 0 \\ 0 & 0 & \frac{4EI_z}{L} \end{bmatrix} \tag{3.58}$$

$$[K_{f\theta}^{21}] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \frac{-6EI_z}{L^2} \\ 0 & \frac{-6EI_y}{L^2} & 0 \end{bmatrix} \tag{3.59}$$

$$[K_{m\theta}^{21}] = \begin{bmatrix} \frac{-GJ}{L} & 0 & 0 \\ 0 & \frac{2EI_y}{L} & 0 \\ 0 & 0 & \frac{2EI_z}{L} \end{bmatrix} \tag{3.60}$$

$$[K_{fu}^{12}] = \begin{bmatrix} \frac{-EA}{L} & 0 & 0 \\ 0 & \frac{-12EI_z}{L^3} & 0 \\ 0 & 0 & \frac{-12EI_y}{L^3} \end{bmatrix} \tag{3.61}$$

$$[K_{mu}^{12}] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \frac{-6EI_y}{L^2} \\ 0 & \frac{-6EI_z}{L^2} & 0 \end{bmatrix} \tag{3.62}$$

$$[K_{fu}^{22}] = \begin{bmatrix} \frac{EA}{L} & 0 & 0 \\ 0 & \frac{12EI_z}{L^3} & 0 \\ 0 & 0 & \frac{12EI_y}{L^3} \end{bmatrix} \tag{3.63}$$

$$[K_{mu}^{22}] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \frac{-6EI_y}{L^2} \\ 0 & \frac{-6EI_z}{L^2} & 0 \end{bmatrix} \tag{3.64}$$

$$[K_{f\theta}^{12}] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \frac{6EI_z}{L^2} \\ 0 & \frac{6EI_y}{L^2} & 0 \end{bmatrix} \tag{3.65}$$

$$[K_{m\theta}^{12}] = \begin{bmatrix} \frac{-GJ}{L} & 0 & 0 \\ 0 & \frac{2EI_y}{L} & 0 \\ 0 & 0 & \frac{2EI_z}{L} \end{bmatrix} \tag{3.66}$$

$$[K_{f\theta}^{22}] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \frac{-6EI_z}{L^2} \\ 0 & \frac{-6EI_y}{L^2} & 0 \end{bmatrix} \tag{3.67}$$

$$[K_{m\theta}^{22}] = \begin{bmatrix} \frac{GJ}{L} & 0 & 0 \\ 0 & \frac{4EI_y}{L} & 0 \\ 0 & 0 & \frac{4EI_z}{L} \end{bmatrix} \tag{3.68}$$

[3]

3.7 Frames

Frames are structures consisting of beams. It is important to also show the mathematical background for frames since the structure being analyzed in the project consists of frame structures. The beams composing a frame generally have arbitrary directions. Therefore, all nodal parameters should be expressed with respect to a common system of coordinates, the global coordinate system. [3]

Firstly lets see the mathematical background for a frame element equation subjected to nodal forces.

The vertical deflection d_{1y} and a horizontal deflection d_{1x} with respect to the global coordinate system $x-y$. Can be correlated to the local coordinate system $\overline{x}-\overline{y}$ from this:

$$d_{1\overline{x}} = d_{1x}cos\vartheta + d_{1y}sin\vartheta \tag{3.69}$$

$$d_{1\overline{y}} = -d_{1x}sin\vartheta + d_{1y}cos\vartheta \tag{3.70}$$

In contrast, any slope ϕ_1 on node 1 of the beam element with respect to the global system $x-y$ is equal to the slope $\overline{\phi_1}$ with respect to the local system $\overline{x}-\overline{y}$:

$$\overline{\phi_1} = \phi_1 \tag{3.71}$$

Equation (3.81)-(3.83) can be written in the following matrix form:

$$\begin{Bmatrix} d_{1\overline{x}} \\ d_{1\overline{y}} \\ \overline{\phi_1} \end{Bmatrix} = \begin{bmatrix} C & S & 0 \\ -S & C & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} d_{1x} \\ d_{1y} \\ \phi_1 \end{Bmatrix} \tag{3.72}$$

Where $C = cos\vartheta$ and $S = sin\vartheta$ [3]

Similarly, any set of nodal forces $f_{1\overline{x}}$,$f_{1\overline{y}}$,$\overline{m}_1$ with respect to the local coordinate system $\overline{x}-\overline{y}$ can be correlated to the nodal forces f_{1x},f_{1y},m_1 with respect to the global system $x-y$:

$$\begin{Bmatrix} f_{1\overline{x}} \\ f_{1\overline{y}} \\ \overline{m}_1 \end{Bmatrix} = \begin{bmatrix} C & S & 0 \\ -S & C & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} f_{1x} \\ f_{1y} \\ m_1 \end{Bmatrix} \tag{3.73}$$

Let us now consider a frame member 1-2. For the displacements of node 2 we can formulate similar equations, that is,

$$\begin{Bmatrix} d_{2\overline{x}} \\ d_{2\overline{y}} \\ \overline{\phi}_2 \end{Bmatrix} = \begin{bmatrix} C & S & 0 \\ -S & C & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} d_{2x} \\ d_{2y} \\ \phi_2 \end{Bmatrix} \tag{3.74}$$

$$\begin{Bmatrix} f_{2\overline{x}} \\ f_{2\overline{y}} \\ \overline{m}_2 \end{Bmatrix} = \begin{bmatrix} C & S & 0 \\ -S & C & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} f_{2x} \\ f_{2y} \\ m_2 \end{Bmatrix} \tag{3.75}$$

Combination of Equations (3.72) and (3.74) yields

$$\begin{Bmatrix} d_{1\overline{x}} \\ d_{1\overline{y}} \\ \overline{\phi}_1 \\ d_{2\overline{x}} \\ d_{2\overline{y}} \\ \overline{\phi}_2 \end{Bmatrix} = \begin{bmatrix} C & S & 0 & 0 & 0 & 0 \\ -S & C & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & C & S & 0 \\ 0 & 0 & 0 & -S & C & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} d_{1x} \\ d_{1y} \\ \phi_1 \\ d_{2x} \\ d_{2y} \\ \phi_2 \end{Bmatrix} \tag{3.76}$$

In the same way, combining Equations (3.73) and (3.75), the following matrix equation can be obtained:

$$\begin{Bmatrix} f_{1\overline{x}} \\ f_{1\overline{y}} \\ \overline{m}_1 \\ f_{2\overline{x}} \\ f_{2\overline{y}} \\ \overline{m}_2 \end{Bmatrix} = \begin{bmatrix} C & S & 0 & 0 & 0 & 0 \\ -S & C & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & C & S & 0 \\ 0 & 0 & 0 & -S & C & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} f_{1x} \\ f_{1y} \\ m_1 \\ f_{2x} \\ f_{2y} \\ m_2 \end{Bmatrix} \tag{3.77}$$

We recall now the beam element equation for a beam 1-2 aligned to the local axis $\overline{x}$. Therefore, its nodal forces $f_{1\overline{y}}$,$f_{2\overline{y}}$ and moments $\overline{m}_1$,$\overline{m}_2$ are correlated to the corresponding vertical deflections $d_{1\overline{y}}$,$d_{2\overline{y}}$ and rotations $\overline{\phi}_1$,$\overline{\phi}_2$ by the following already known equations:

$$\begin{Bmatrix} f_{1\overline{y}} \\ \overline{m}_1 \\ f_{2\overline{y}} \\ \overline{m}_2 \end{Bmatrix} = \begin{bmatrix} 12EI/L^3 & 6EI/L^2 & -12EI/L^3 & 6EI/L^2 \\ 6EI/L^2 & 4EI/L & -6EI/L^2 & 2EI/L \\ -12EI/L^3 & -6EI/L^2 & 12EI/L^3 & -6EI/L^2 \\ 6EI/L^2 & 2EI/L & -6EI/L^2 & 4EI/L \end{bmatrix} \begin{Bmatrix} d_{1\overline{y}} \\ \overline{\phi}_1 \\ d_{2\overline{y}} \\ \overline{\phi}_2 \end{Bmatrix} \tag{3.78}$$

[3]

However, as has been mentioned, in frame members it should be taken into account the axial deflections and of course the corresponding nodal forces. To this scope, there is a bar element equation:

$$\begin{Bmatrix} f_{1\overline{x}} \\ f_{2\overline{x}} \end{Bmatrix} = \begin{Bmatrix} EA/L & -EA/L \\ -EA/L & EA/L \end{Bmatrix} \begin{Bmatrix} d_{1\overline{x}} \\ d_{2\overline{x}} \end{Bmatrix} \tag{3.79}$$

From there, the symmetric matrix equation for a frame structure can be obtained, this equation is used to analyze the frame structure:

$$[k] = \frac{E}{L} \begin{bmatrix} AC^2 + \frac{12I}{L^2}S^2 & (A - \frac{12I}{L^2})CS & \frac{-6I}{L}S & -(AC^2 + \frac{12I}{L^2}S^2 & -(A - \frac{12I}{L^2})CS & -\frac{6I}{L}C \\ sym & AS^2 + \frac{12I}{L^2}C^2 & \frac{6I}{L}C & -(A - \frac{12I}{L^2})CS & -(AS^2 + \frac{12I}{L^2}C^2) & \frac{6I}{L}C \\ sym & sym & 4I & \frac{6I}{L}S & -\frac{6I}{L}C & 2I \\ sym & sym & sym & AC^2 + \frac{12I}{L^2}S^2 & (A - \frac{12I}{L^2})CS & \frac{6I}{L}S \\ sym & sym & sym & sym & AS^2 + \frac{12I}{L^2}C^2 & -\frac{6I}{L}C \\ sym & sym & sym & sym & sym & 4I \end{bmatrix} \tag{3.80}$$

[3]

3.8 Safety Factor

The factor of safety is defined as the ratio of ultimate stress of the material relative to the working stress. It is important for engineering and building purposes for safety reasons and also building reasons. What the safety factor really does, is that it denotes the additional strength of the component material than the strength to carry that load. It tells the engineers how much stronger a system like a building needs to be for the intended load and also safety. The safety varies and as an engineer you would want it to be as low as possible without interfering with the safety measures.The lower the safety factor is, the lower the cost of material will be. [8] The formula used for the factor of safety is:

$$F.O.S = \frac{E}{\sigma_{max}} \tag{3.81}$$

To find the safety factor of the building, this formula will be used. However, the safety factor is a measure that ANSYS will calculate by itself.

Chapter 4

Numerical Modeling

Modeling in ANSYS is the phase where the steel structure is created. This step is crucial as it demonstrates how the structure is modeled, providing readers with a better understanding of the resulting outcome.

For the modelling part, there is need for coordinates. I have chosen to have 10 coordinates for every floor and every roof, however, the roof and floor coordinates will be the same. Under is a list of all the coordinates;

Table 4.1: The coordinates for the 5.story building

1st. story	2nd. story	3rd. story	4th. story	5th. story	5th. story(roof)
(0,0,0)	(0,0,3)	(0,0,6)	(0,0,9)	(0,0,12)	(0,0,15)
(0,15,0)	(0,15,3)	(0,15,6)	(0,15,9)	(0,15,12)	(0,15,15)
(6,15,0)	(6,15,3)	(6,15,6)	(6,15,9)	(6,15,12)	(6,15,15)
(6,30,0)	(6,30,3)	(6,30,6)	(6,30,9)	(6,30,12)	(6,30,15)
(0,30,0)	(0,30,3)	(0,30,6)	(0,30,9)	(0,30,12)	(0,30,15)
(0,45,0)	(0,45,3)	(0,45,6)	(0,45,9)	(0,45,12)	(0,45,15)
(-10,0,0)	(-10,0,3)	(-10,0,6)	(-10,0,9)	(-10,0,12)	(-10,0,15)
(-10,15,0)	(-10,15,3)	(-10,15,6)	(-10,15,9)	(-10,15,12)	(-10,15,15)
(-10,30,0)	(-10,30,3)	(-10,30,6)	(-10,30,9)	(-10,30,12)	(-10,30,15)
(-10,45,0)	(-10,45,3)	(-10,45,6)	(-10,45,9)	(-10,45,12)	(-10,45,15)

Following there will be a step by step procedure on how to model the structure, with short explanations.

- Workbench -> Engineering data. Check that the material is indeed structural steel and check the matrial properties. Also, check that the units are in metric.
- Geometry -> Edit Geometry in design modeler.
- Sketching -> line in zx-plane. Create the first base of the structure by drawing it, keep in mind the dimensions of the structure.
- Press generate and make sure the joint body appears.
- Create -> Body transformation -> translate. This is to translate the base joint body in positive Y-direction to make the separate stories. The increment will be 3 metres in the positive Y-direction. Keep repeating this step until you have 5 stories.
- Concept -> Lines from points. Connect all the vertical vertexes to create the vertical beams connecting the different floors. The generate. There should now be a joint body which is the whole structure.
- Concept -> Cross section -> I-section. To be able to get the right dimensions and results for the building the cross-section has to be defined. This is the step where that happens. Type in all the dimensions for the I-section from table 3.1, and generate.
- File -> close design modeler.
- Model -> edit in Mechanical. Mechanical is the software where forces and pressures will be applied. ALso, where the solutions will be derived from.
- Mesh -> generate mesh. Meshing is where the program represent the structure designed as a set of finite elements.
- Static structural -> Insert -> Line pressure. Add all the pressures needed for the structure, and be aware of the coordinate direction. Coordinate direction has to be the right one for the software to direct the force/pressure correct.
- Static structural -> Insert -> Fixed support. Select the ten vertexes holding the building upright, the base nodes.
- Static structural -> Insert -> Inertial -> Standard earth gravity. Its obvious why adding earth gravity will ensure that the results show a better representation in a real life situation.
- Solution -> Insert. Choose the solutions needed for the thesis. Choose Total deformation, Axial force, Total bending moment, Torsional moment, Total shear force, Equivalent stress (Von-mises) and Force reaction.

1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
6	Isotropic Elasticity		
12	Strain-Life Parameters		
20	S-N Curve	Tabular	
24	Tensile Yield Strength	2,5E+08	Pa
25	Compressive Yield Strength	2,5E+08	Pa
26	Tensile Ultimate Strength	4,6E+08	Pa
27	Compressive Ultimate Strength	0	Pa

Figure 4.1: Table over material properties

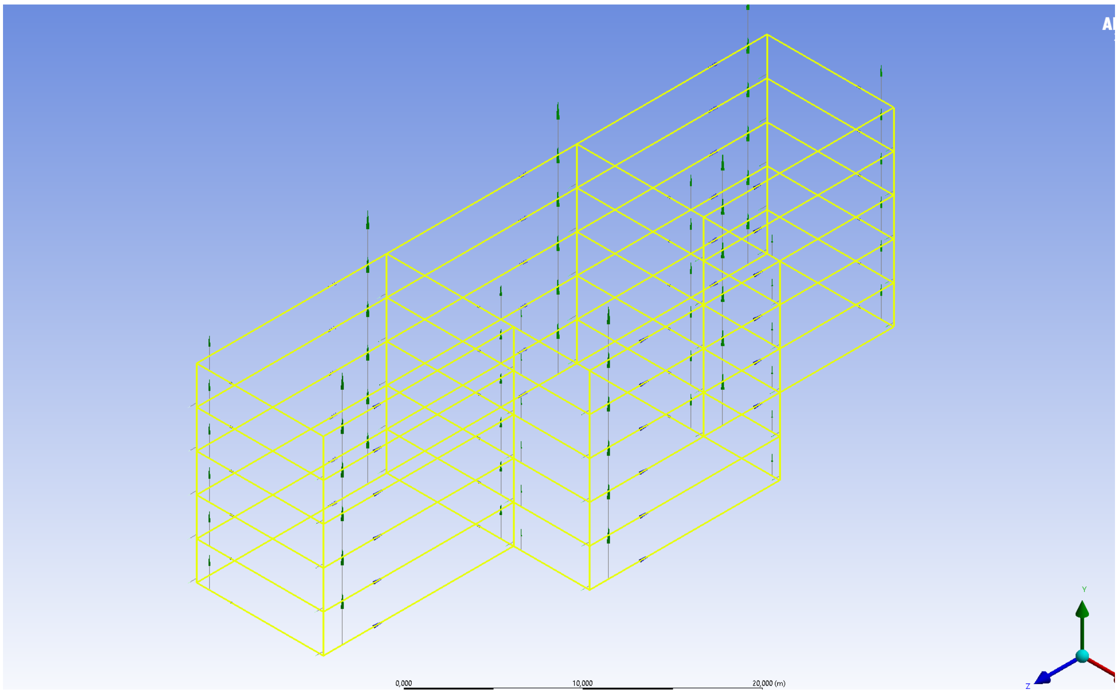

Figure 4.2: Showing the final line body structure after translating

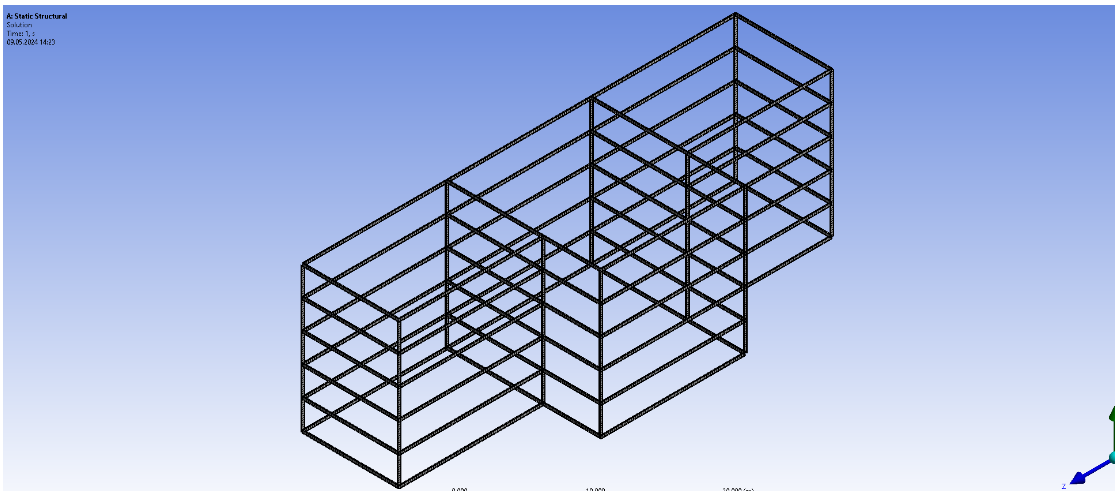

Figure 4.3: The frame structure after being meshed

Chapter 5

Results

The results show the structural changes that occur during the simulation when loads are applied. It's crucial to explain why these results occurred.

5.1 Axial force distribution

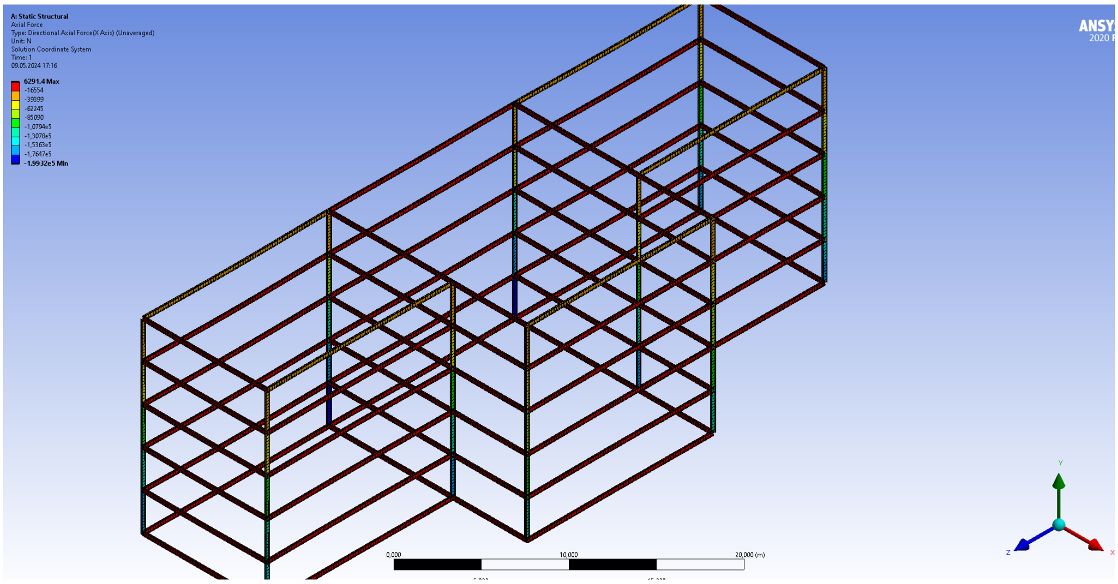

Figure 5.1: Axial force ditributions shown in real scale

The axial force distribution is essential for assessing whether the beams within a building are under compression or tension. Figure 5.1 illustrates the axial force distribution across the entire structure. ANSYS software indicates a maximum axial force of 6291.4N; however, this value is erroneous. ANSYS identifies the maximum axial force as the minimum value due to the negative sign convention, which designates maximal force occurring in a beam element under compression. The figure clearly indicates that the maximum axial force is exerted on the lower vertical beams at the rear of the structure.

The results reveal that the majority of the vertical beams are under compressive stress, while most of the horizontal beams are under tensile stress. This phenomenon can be attributed to horizontal forces in the x-direction and z-direction, which exert outward pressure on the beams, inducing tension.

5.2 Bending moment distribution

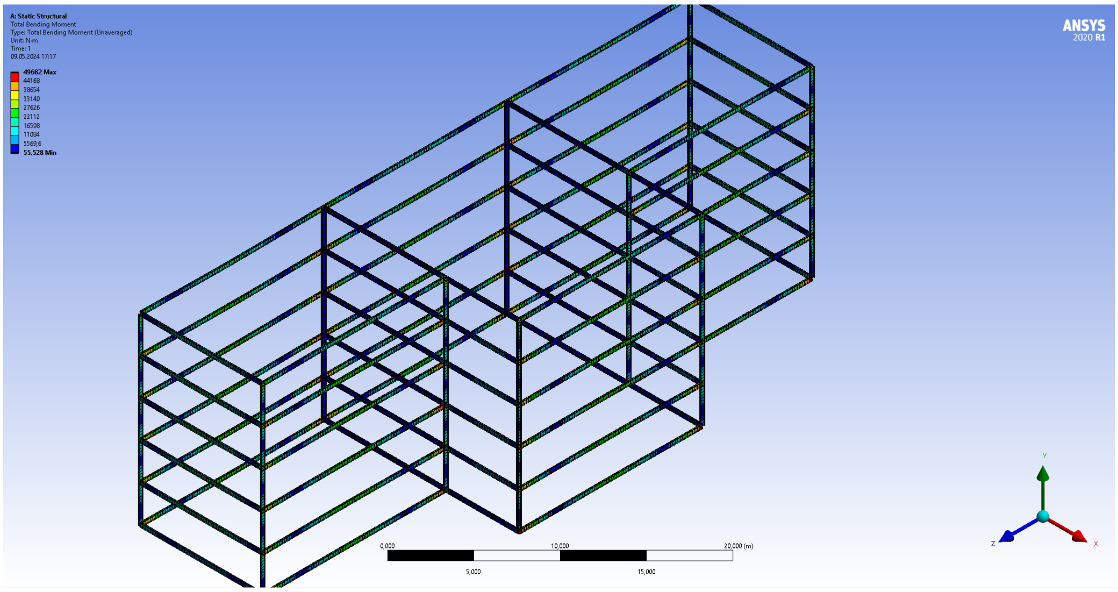

Figure 5.2: Bending moment distribution shown in real scale

The bending moment diagram provides insight into the beam's capacity to withstand external forces causing bending. As depicted in Figure 5.2, the connection point of the beam elements corresponds to the location where maximum bending occurs. This phenomenon arises due to the combined effect of vertical and horizontal loads acting on the beams, inducing significant stress in the connection, prompting the beam to bend. Fortunately, the bending moment is relatively moderate at 49,682 Nm, indicating that the structure is not at risk of failure. The figure also illustrates the minimum bending moment, which is surprisingly low at 55,528 Nm. This minimal bending occurs predominantly along both the horizontal and vertical beams, either at the midpoint or slightly off-center.

5.3 Deformed shape

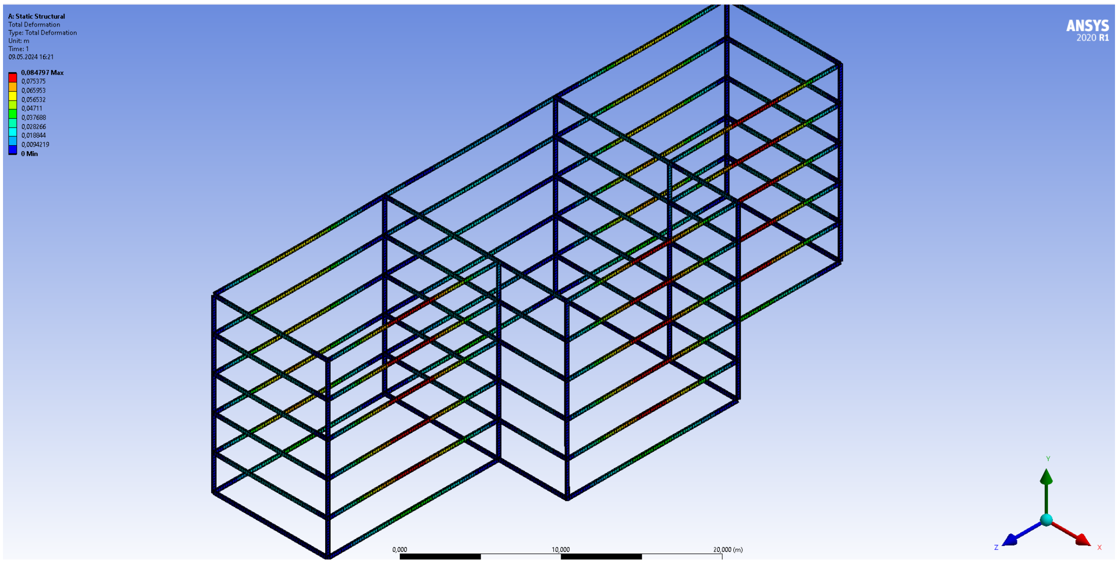

Figure 5.3: Deformation shown in real scale

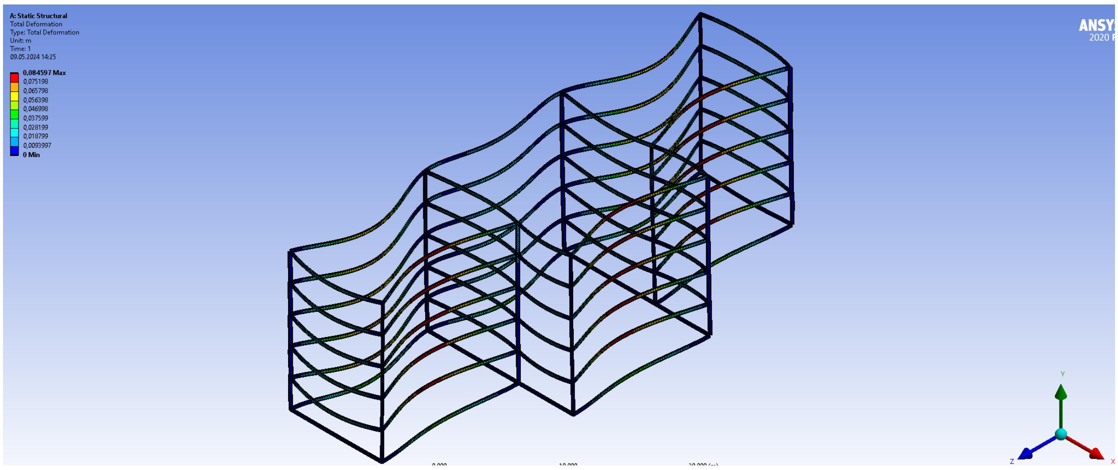

Figure 5.4: Exaggerated deformation

Details of "Directional Deformation"	
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Directional Deformation
Orientation	Y Axis
By	Time
Display Time	Last
Coordinate System	Global Coordinate System
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
Minimum	-2,0602e-002 m
Maximum	5,0222e-005 m
Average	-6,6449e-003 m
Minimum Occurs On	Line Body
Maximum Occurs On	Line Body
Information	

Figure 5.5: Showing the values of the deformation in the Y-axis(Vertically)

The deformed shape illustrates the extent of deflection or displacement experienced by the building under loading conditions. Given that all supports are fixed, minimal to no deformation occurs near these supports or at the ground level. As depicted in Figure 5.3, horizontal beams exhibit the greatest deflection horizontally, a phenomenon to be further discussed in the subsequent chapter. The maximum deflection observed is 0.084797 meters, approximately 8.5 centimeters.

Figure 5.5 presents the vertical deformation (Y-axis) resulting from the applied vertical loads, with a maximum deformation of 2.06e-002 meters or approximately 2.06 centimeters. Negative signs denote that the maximum vertical deflection occurs in the negative Y-direction, which is expected. Conversely, the minimal vertical deflection occurs in the positive Y-direction at a value of 5.02e-005 meters.

5.4 Support reactions

Definition	
Type	Force Reaction
Location Method	Boundary Condition
Boundary Condition	Fixed Support
Orientation	Global Coordinate System
Suppressed	No
Options	
Result Selection	All
Display Time	End Time
Results	
Maximum Value Over Time	
X Axis	9201, N
Y Axis	1,9017e+006 N
Z Axis	-1,1401e-006 N
Total	1,9018e+006 N
Minimum Value Over Time	
X Axis	9201, N
Y Axis	1,9017e+006 N
Z Axis	-1,1401e-006 N
Total	1,9018e+006 N
Information	

Figure 5.6: Fixed support reaction value

The reactions on the supports represent the response of the building to the applied loads and its own weight. These support reactions are inherently equal and opposite to the loads exerted by the building, as dictated by the principle of equilibrium in static structures. As illustrated in Figure 5.6, which depicts the support reactions extrapolated using ANSYS, the maximum and minimum values over time are equal, indicating a consistent force distribution on the building.

It is expected that all vertical support reactions are directed upwards, given that the applied forces, including gravity, act downwards. Additionally, the figure reveals reaction forces in both the z and x-directions due to horizontal loads on the structure. However, the z-direction reaction force appears relatively small. The negative sign associated with certain reaction forces signifies that they oppose the direction anticipated by the ANSYS projections.

5.5 shear force distribution

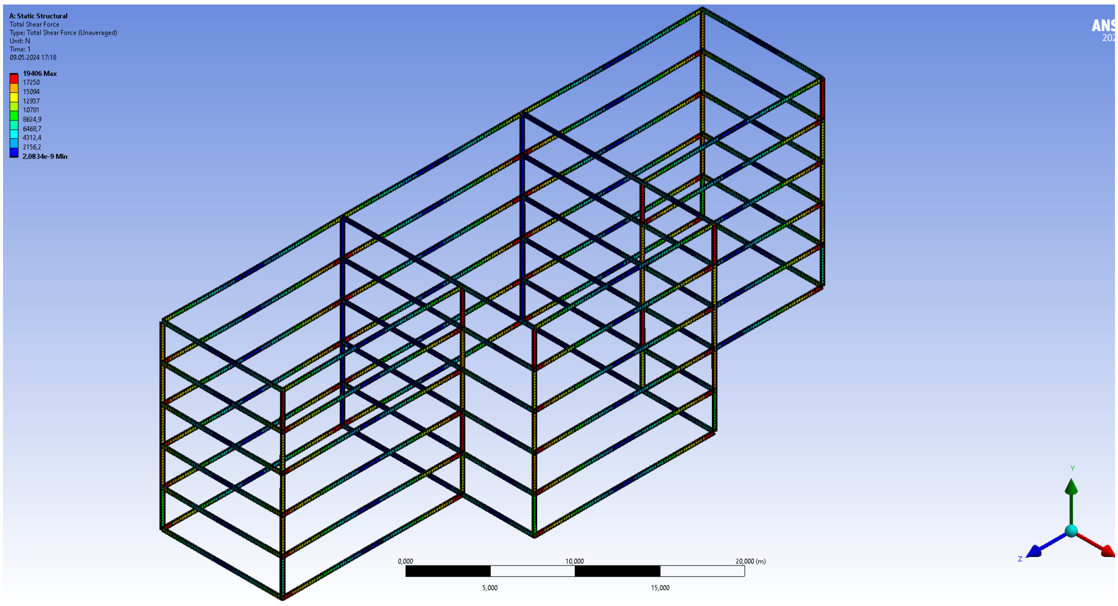

Figure 5.7: Shear force distribution shown in real scale

The shear force diagram illustrates the distribution of shearing forces acting on the entirety of the building structure. Shearing induces deformation in structural elements as the forces act in opposite directions on the beams. The highest shear forces typically occur in the vertical elements due to the combined effect of external and internal pressures exerting force in both directions, indicative of a tendency to "tear". Nevertheless, the beams possess sufficient strength to withstand these shearing forces.

The maximum shear force observed is 19406N, while the minimum is 2.08e-9N, occurring at the midpoint of the horizontal beams. This discrepancy arises because the vertical forces acting on the horizontal beams are unbalanced, with only one force exerting downward pressure and no opposing upward force. This situation is compounded by an internal force acting in one direction and an external force acting in the opposite direction. However, the area subjected to these opposing forces is limited to the height of the beam, which is 300mm.

Conversely, the maximum shear force is observed in the vertical elements, which have a height of 3 meters.

5.6 Torsional moment distribution

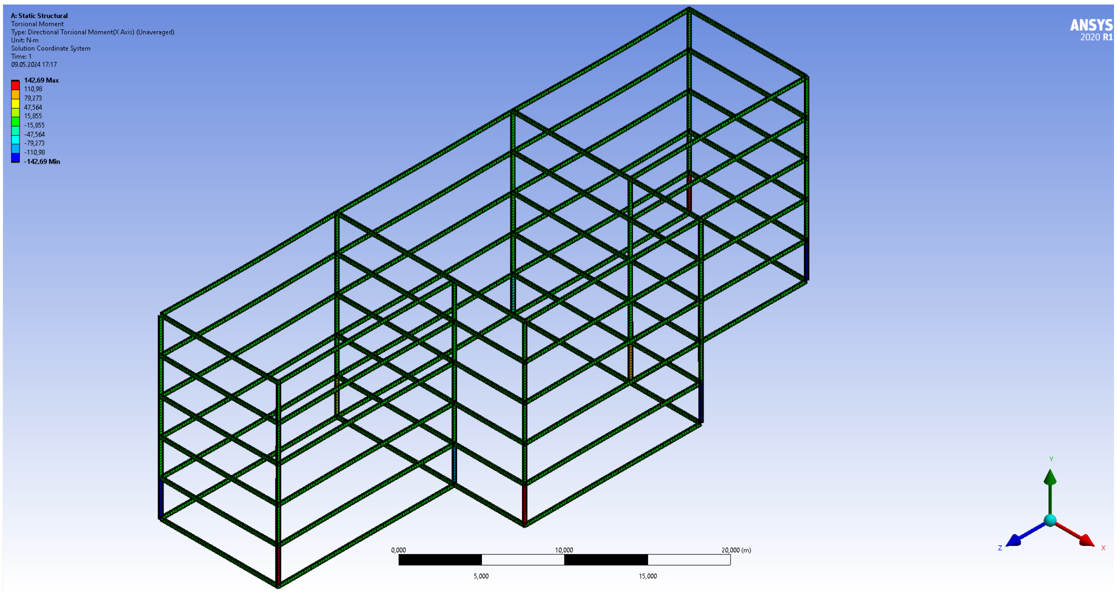

Figure 5.8: Torsional moment distribution shown in real scale

The torsional moment diagram depicts the distribution of torsional moments across the entire building structure. These moments induce a twisting effect on the beams due to forces acting along the transverse axis. This torsional effect can lead to the weakening and potential failure of the beams. Figure 5.8 illustrates that the highest torsional moments occur in the beams from the ground level up to the top of the first floor, where fixed supports are situated. This is attributed to the immobility of the fixed supports, which resist any movement despite the horizontal forces acting on the beams.

Consequently, the beams experience torsion as a result. The maximum torsional moment is measured at 142.69 N, while the minimum value appears to be 15.855 N. It should be noted that ANSYS displays the minimum value as negative, which is not accurate. The negative sign indicates that the force acts in the opposite direction to the positive orientation of the coordinate system.

5.7 Von Mises stress map

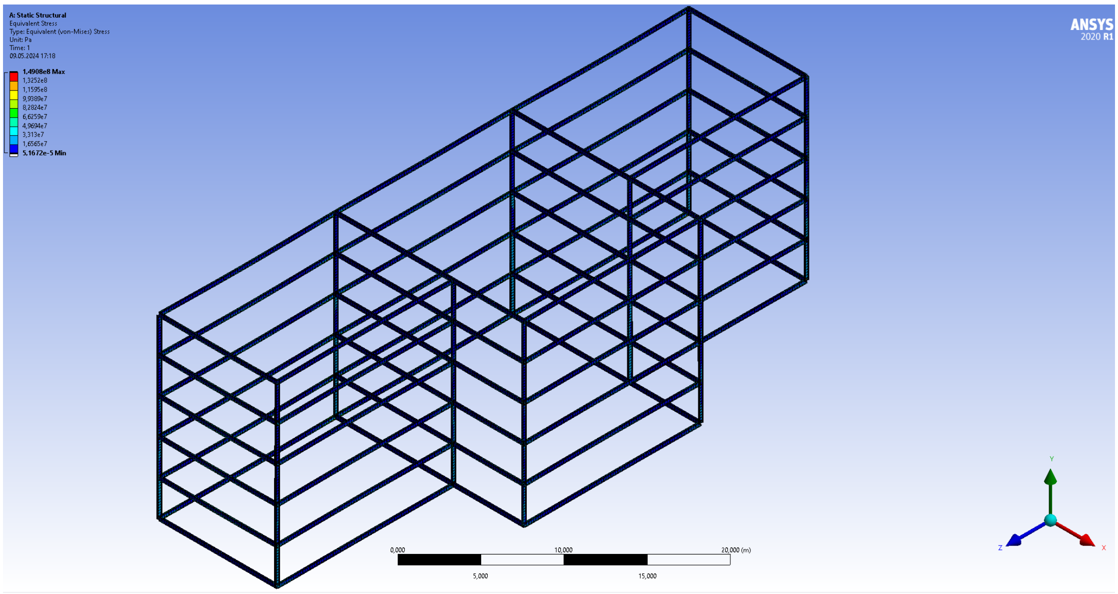

Figure 5.9: Von mises stress map shown in real scale

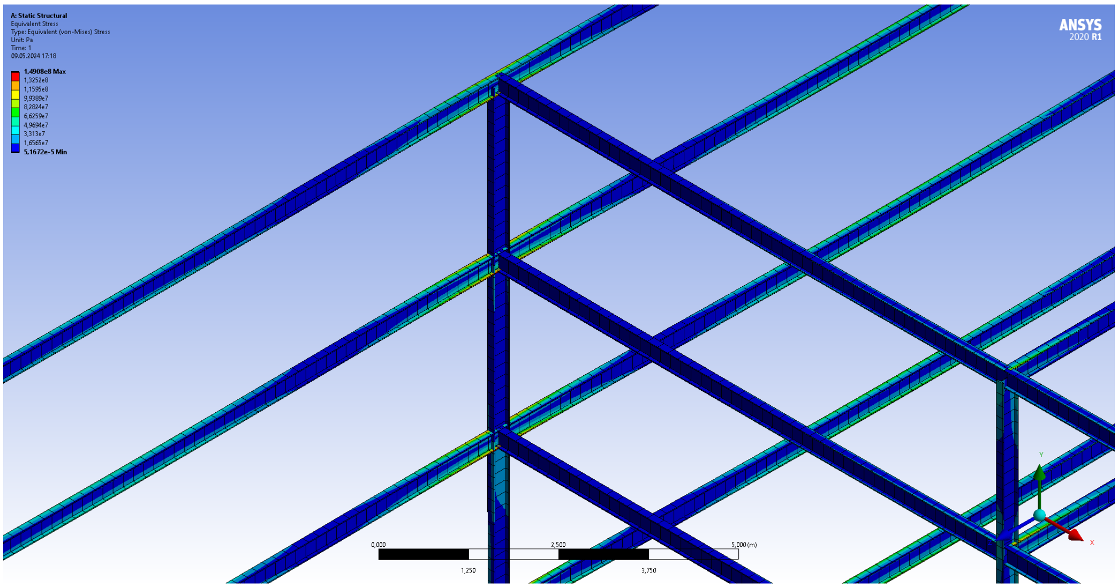

Figure 5.10: Von mises stress zoomed in on the connecting beams

The Von-Mises stress diagram serves as a comprehensive depiction of the equivalent stress experienced by a building, resulting from various stresses acting upon it. Von-Mises stress analysis provides a method for consolidating the diverse stresses present, facilitating the identification of critical areas within the structure that are susceptible to potential failure.

From the visualization presented in Figure 5.9, the Von-Mises stress is illustrated across the entirety of the structure, revealing that the majority of the building is subject to relatively low stress levels. The predominant stress values throughout the structure hover around 5.1672e-5 pascals, representing minimal stress. However, upon closer examination, certain sections of the beams exhibit significantly higher stress levels, reaching up to 3.313e7 pascals.

The most noteworthy observation emerges from the examination of beam connections, as depicted in Figure 5.10. These junctions experience the highest stress concentration within the structure, with a maximum stress value of 1.4908e8 pascals. This critical stress concentration underscores the importance of meticulous attention to the design and reinforcement of these connections to ensure structural integrity and safety.

5.8 Factor of safety

The factor of safety denotes the level of safety margin against buckling, breaking, and other structural failures. For structural steel materials and steel structures, a factor of safety of approximately 1.15 is typically desired. In the case of the structure investigated in the thesis, it exhibited a factor of safety of approximately 1342.28, significantly surpassing the recommended value. This indicates that the building in question possesses the capacity to endure substantially greater forces than those applied to it.

$$F.O.S = \frac{E}{\sigma_{max}} = \frac{2e + 11Pa}{1.49e + 8Pa} = 1342,28 \tag{5.1}$$

Where E is the young's modulus and the σ_{max} is the maximal equivalent stress.

Chapter 6

Discussion

To ensure a study holds value, it's crucial to thoroughly discuss the results to improve its quality. What alternative approaches could have been taken for a more favorable outcome? And what factors contributed to the results as they appeared?

The reasoning for conducting the analysis within Workbench rather than ANSYS APDL is attributed to the challenges encountered while attempting meshing in ANSYS APDL. Despite multiple attempts, the meshing process in ANSYS APDL did not showcase the intended results. Consequently, upon recommendation, Workbench was employed, where the analysis was executed successfully, with satisfactory results in terms of both functionality and visual representation.

Firstly, the results regarding the deformation in the horizontal plane are discussed. The findings reveal a substantial horizontal deformation of approximately 8.5 cm, which exceeds expectations given the applied force in the horizontal direction. This considerable deformation can be attributed to the rotation of the I-section beams in the vertical direction. When these beams are rotated vertically, they exhibit greater resistance to vertical forces compared to horizontal ones. Addressing this issue by rotating the beams horizontally could enhance sustainability in the horizontal plane; however, it would concurrently compromise sustainability in the vertical plane. Therefore, a viable solution entails the integration of additional beams into the structure. Diagonal beams spanning the surfaces and increased vertical beam implementation are recommended to mitigate deformation and enhance structural stability.

Secondly, enhancing the model geometry by incorporating more beam elements, as previously suggested, could provide improved representation of the structure's behavior. Additional surfaces could be included to better simulate the loads and stresses experienced by the building. However, attempts to add surfaces to the geometry proved unsuccessful in meshing. Consequently, the decision was made to convert snow and wind loads from pressures to distributed loads. Despite the preference for incorporating surfaces, weeks of effort in modeling did not yield satisfactory results, with ill-conditioned matrices persisting in the mesh. Hence, the chosen approach ensured that the beam elements remained subjected to wind and snow loads, as calculated in the basic theory chapter. Although the absence of surfaces presents limitations, this methodology still offers a realistic interpretation of the effects of snow, wind, gravity, and other applied loads on the building structure.

The factor of safety is a crucial metric in structural engineering, representing the ratio of the maximum stress a structure experiences to the allowable stress of the material before failure. Essentially, it serves as a safety measurement ensuring structural integrity. Standards dictate different factors of safety to ensure compliance with safety regulations. For instance, steel structures typically have a recommended factor of safety around 1.15.

In the context of this thesis, the analyzed building exhibits an exceptionally high factor of safety of 1342.28. This implies that the structure can withstand significantly more stress before failure. The elevated factor of safety is primarily attributed to the absence of heavy forces acting on the building, such as interior commodities like stairs or elevators.

It is important to note that if interior designs and commodities were included, the building would endure higher stresses, potentially altering the factor of safety. Nevertheless, the current high factor of safety indicates that the building is far from failing under its current conditions.

The Von-mises stress map, also known as equivalent stress, exhibits stress-like dimensions but is essentially a scalar quantity. Although it is termed as stress, it lacks the attribute of being localized on a specific plane or direction within the material. Equivalent stress is derived from the shear strain energy per unit volume across various points within the stressed material. This scalar quantity serves as an indicator of the likelihood of material failure according to the Von-mises failure criteria. [9]

The analysis shows that there are high levels of stress concentrated in the structural connections, making them vulnerable to failure. These connections are crucial points where different horizontal and vertical beams come together, carrying the weight of the structure. Because of their complexity and the convergence of multiple forces, they are prone to experiencing increased stress levels. Therefore, it's important to carefully design and reinforce these connections to maintain the stability and durability of the structure.

Additionally, connections play a vital role in spreading out the various loads on the structure, acting as channels to transfer forces to key points. If connections fail, it can have a domino effect on the overall integrity of the structure. That's why engineers often use a mix of bolting and welding techniques to strengthen these critical points against potential failure. This approach not only boosts the load-bearing capacity of connections but also ensures that the structure can withstand different operating conditions and external pressures.

The geometric configuration of the steel structure is characterized by minimalism, with fewer beams employed to distribute the structural load. To further enhance the building's strength, the addition of diagonal beams on each floor horizontally is proposed. The rationale behind the absence of vertical diagonal or supplementary beams is rooted in the building's intended aesthetic of having glass facades encompassing its entirety.

The incorporation of additional horizontal beams would strengthen the building's load-bearing capacity, delaying the onset of structural failure. However, the decision not to introduce more beams vertically is primarily driven by the desire to maintain the building's visually appealing exterior.

While the inclusion of more beams would undoubtedly fortify the structure, it comes with increased costs and labor requirements, aligning with the overarching principle of maintaining a minimalist design geometry. Achieving a structurally sound and failure-resistant building without incurring additional expenses for unnecessary materials represents an optimal outcome.

The consideration of fixed supports are of paramount importance, as they play a vital role in determining the structural response to external loads. Unlike roller or pin supports, fixed supports impose constraints on all degrees of freedom, including translations and rotations, thereby significantly influencing the deformation characteristics. Pin supports, in contrast, primarily restrict translational movement in the coordinate directions, while roller supports limit vertical movement while allowing horizontal displacement. Pin supports are generally reserved for smaller structures due to their limited capacity.

Upon thorough analysis of the results, it becomes apparent that both the maximum and minimum values of deformation remain constant over time, indicating a consistent distribution of forces acting on the building. The dominant reaction force resides in the positive Y-direction, signifying an upward force, as expected, given that all vertical loads on the structure act downwards due to gravity. Given the scale and complexity of the structure, fixed supports are strongly recommended for ensuring stability and mitigating structural deformations.

Furthermore, the results unquestionably affirm the appropriateness of selecting fixed supports, as they effectively mitigate deformations and ensure structural integrity under the applied loads. The accurate consideration of fixed supports underscores their crucial role in supporting the structure and maintaining its stability over time.

Chapter 7

Conclusion

The conclusion is the closing statement for the study.

At the conclusion of the study, several points warrant discussion. The overall structural integrity of the building is deemed sufficient for its intended use as a residential building. However, as discussed in the preceding chapter, enhancing the structural robustness by incorporating additional beams in both vertical and horizontal orientations would further increase the factor of safety beyond that extrapolated from the current results. It is important to note that the structure is currently not at risk of failure under the prevailing forces, including snow, wind, imposed loads, and gravitational forces.

Moreover, as emphasized in the discussion chapter, the inclusion of surfaces in the simulation would offer a more comprehensive understanding of the structural behavior with floors and roofs. Nevertheless, it is worth mentioning that there are no significant challenges in predicting the behavior of the structure solely based on beams and elements. Although ANSYS provides an approximation, the analysis reflects a realistic outcome.

The structure is deemed entirely safe and possesses the potential to serve as a fully functional residential building, whether as a hotel or an office space. Significantly larger forces would be required for the building to exhibit any signs of weakening or failure.

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