POLITECNICO DI TORINO

Department of Structural, Building and Geotechnical Engineering

Master Course in Civil Engineering

Master's Course Thesis

Numerical modeling strategies for the structural assessment of reinforced concrete monumental buildings

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Abstract

Preserving historical cultural property, transferring historical buildings to future generations, and preserving architectural features that have been abandoned for centuries due to natural disasters, fires, wars, and apathy toward adverse environmental conditions are all important values that are currently the subject of many science and art branches.

There is a dearth of an effective and long-term knowledge of how to conserve historical structures. The fact that structural evaluation and conservation procedures are a complicated topic with numerous challenges and ambiguities is one of the most fundamental reasons for this. This necessitates a collaborative approach to work. A full static and dynamic examination of these structures in conformity with contemporary standards is necessary in order to reuse them and make them endure longer.

The C Hall of the Turin Exhibition Center, a prominent 20th-century structure, was meticulously inspected and the structural evaluation done in this research, with the goal of identifying problems, proposing solution suggestions, and emphasizing a sustainable and effective conservation method.

Pier Luigi Nervi, one of the most recognized architects and engineers of the period, constructed the Turin exposition hall, which became an iconic edifice in the years following World War II. Hall B was constructed initially, followed by Hall C two years later. This construction, made of reinforced concrete and prefabricated parts, is credited as being the first to test Nervi's innovation, ferrocement.

In this study, critical elements were determined by seismic evaluation of the structure using a low-fidelity beam model, after which historical information about the building was discussed, Nervi's Construction methods were emphasized, and finally, critical elements were determined by seismic evaluation of the structure using a low-fidelity beam model. Then 11 critical elements have been chosen from the structure. These elements have all been verified using a combination of static and dynamic loading. These combinations have been examined by a shear assessment and a normal-moment interaction diagram. As a result, it was attempted to validate these aspects using existing standards. As a consequence, solution approaches based on the structure's response to a seismic influence on the structure were attempted to be offered.

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Chapter 1

1. Introduction

Due to the numerous uncertainties, determining and analyzing the behavior of a historical and monumental structure is a very difficult task. Therefore, such investigations are so significant from a technical and scientific standpoint, as they strive to conserve the building's architecture and track it over time.

When it comes to Italy's historical structures, we can state that its historical and cultural heritage is vast, and this topic is always current. When we consider the last few years, the importance of such reinforced concrete structures has gradually increased due to changing and increasing technology and research, necessitating the need to update prior norms. Today, it is possible to say that relatively little effort has been done to restore reinforced concrete structures, the most widely used building material on the all over world.

As a result, proposals for various experiments and redesigns for the preservation of such structures began to be developed. It is the goal of this project to determine the important components of such structures as well as the factors that affect them by partnering with significant institutions throughout the world.

The goal of this thesis is to do a seismic assessment of Pier Luigi Nervi's exhibition hall in Turin, Italy. To do so, you'll need to know the building's materials, geometric structure, the environment it's in, the standards in place at the time it was created, and the current construction structure and earthquake requirements.

Considering the movements generated by the earthquake is one of the most significant aspects of the architecture to consider. In cities with a high seismic risk, such as Turin, it's critical to take into account the earthquake effect. The goal of this research is to calculate and verify the critical modes of crucial elements and to evaluate the seismic motions to be made by examining the response spectra.

The most essential elements and the most stressed elements were analyzed in the findings obtained by applying the earthquake in the x-y-z direction. A low fidelity model was used in the analytical process. The behavior of only one-dimensional (BEAM188) elements is used to create this phrase.

As stated at the outset, the examination and correct analysis of the reinforced concrete and prefabricated reinforced concrete elements, which have a very complex and important future for this structure, will aid in the development of an appropriate response method and plan for the protection of architectural works with insufficient references and guidelines.

Chapter 2

2. Case of Study: Turin Exhibition Center

Some politicians and businesspeople in Turin want to build a contemporary exhibition hall to help the city fast recover from the devastation caused by WWII. Thus, in 1948, the Turin exposition hall was constructed on the site of the auto show in the Valentino Park, which had been largely wrecked by the war. [1]

Figure 2.1 Exterior of the complex of Torino Esposizioni in 1960 (Archivio Storico Fiat, Torino), [17]

An innovative structure, designed by Nervi and Bartolli and made of reinforced concrete and prefabricated parts, has emerged as the world's first structure to utilize Nervi's innovation, ferrocement. [1] Pier Luigi Nervi, an engineer and architect, created a precast construction for the enormous center hall. The hall has a roughly square plan with two side galleries, labelled B and C, and a semicircular apse, covering an area of approximately 200 square meters. Heavy structures are located beneath it in a semicircular hall. He used a reinforced concrete he devised called ferrocement on the sloping roof of the Turin exhibition hall he constructed (iron cement). Spraying cement mortar over a mesh of tiny steel wires to build layers of desired shape and thickness resulted in light and durable shell pieces. The great hall's ferrocement roof spans 96m x 75m and is connected to each other. The length and thickness of these wavy roof components are 4.40m and 4cm, respectively. On average, the vault is less than 8 cm thick. The ability to close large-width spans with little material is crucial for this structure, and the lightweight material decreases construction time.

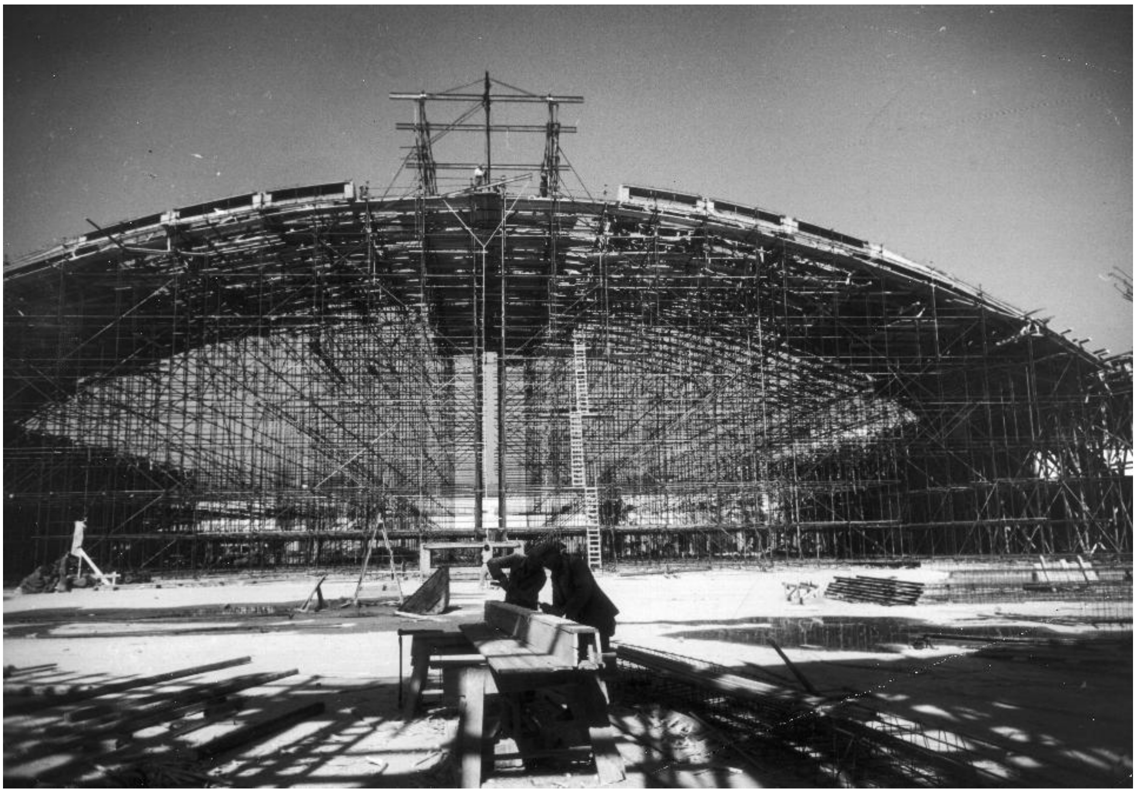


Figure 2.2 Scaffolding for the construction with prefabricated elements [2]

Price, time, and the atmosphere produced by war were some of the most difficult difficulties for P.L. Nervi to design. Nervi has chosen a prefabricated element technique as the best answer to these issues. The construction of the building began in 1948 with the most important hall, Hall B or Hall Agnelli.

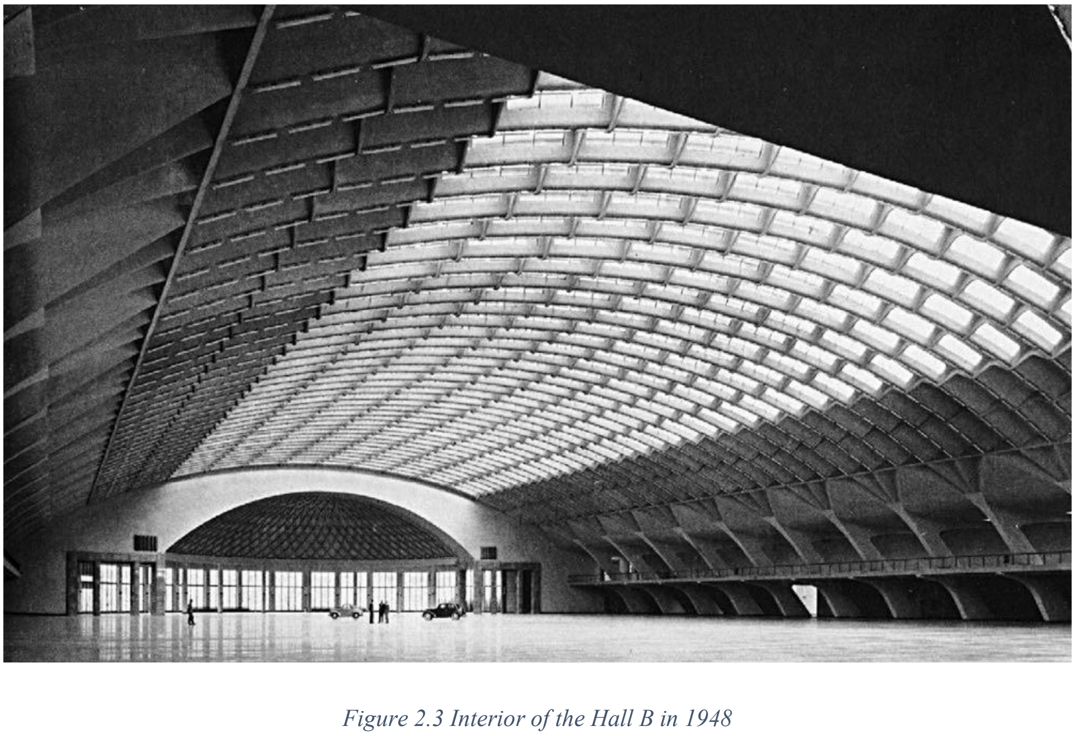


Figure 2.3 Interior of the Hall B in 1948

Nervi has employed structurally efficient and cost-effective approaches, such as thin, light shells that maintain the architectural rhythm. Nervi used prefabrication and ferrocement materials defined by the client to overcome the time, cost, and other challenges indicated in the contract in order to obtain the required outcome. Rather than being original, Nervi's techniques arose from a desire to find answers to the aforementioned challenges. [3]

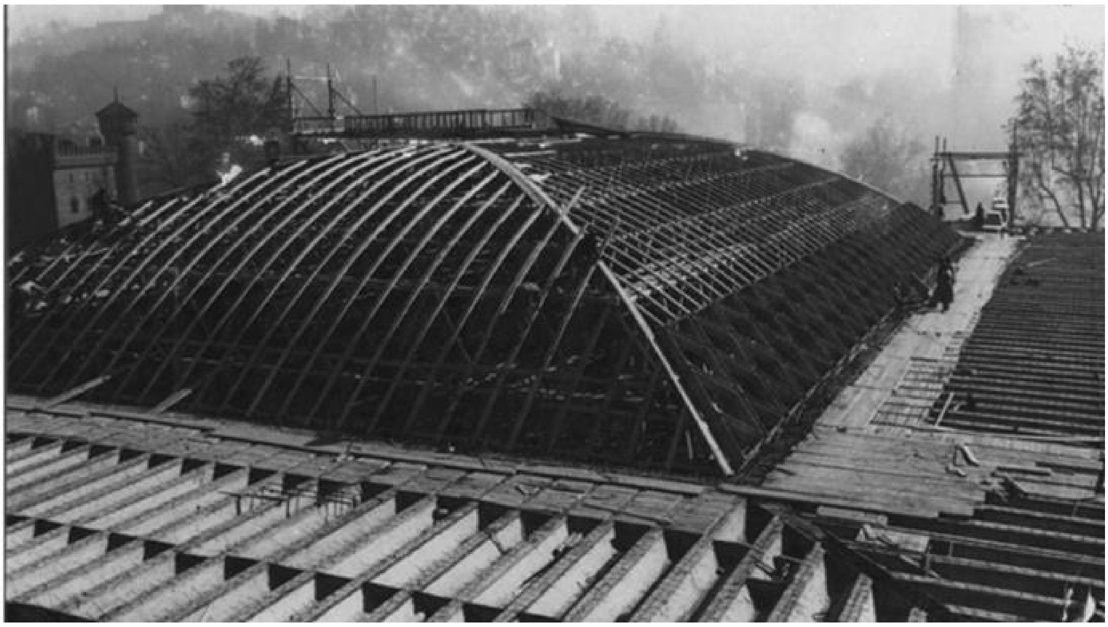


Figure 2.4 the Hall C during its construction site in images of the time in 1950, the assembly of the diamond elements in ferrocement on the vault centering. (Archivio MAXXI Roma, Fondo Nervi.)

A contemporaneous hall, Hall C, was erected two years after Hall B, or Salone Agnelli, was completed. The size of Hall C is less than that of Hall B. The prefabricated materials and design ideas employed in the building of Hall B were also utilized in the construction of Hall C, resulting in a perfect blend of components. He set out to solve the most challenging structural challenge by determining the best technique and building system for passing large spans in a cold environment in a short amount of time. For one and two curvature roofs, he used ferrocement as prefabricated pieces and material. As a result, it was able to cross huge spans without the use of particularly demanding parts or materials due to the so-called resistance to form. [3]

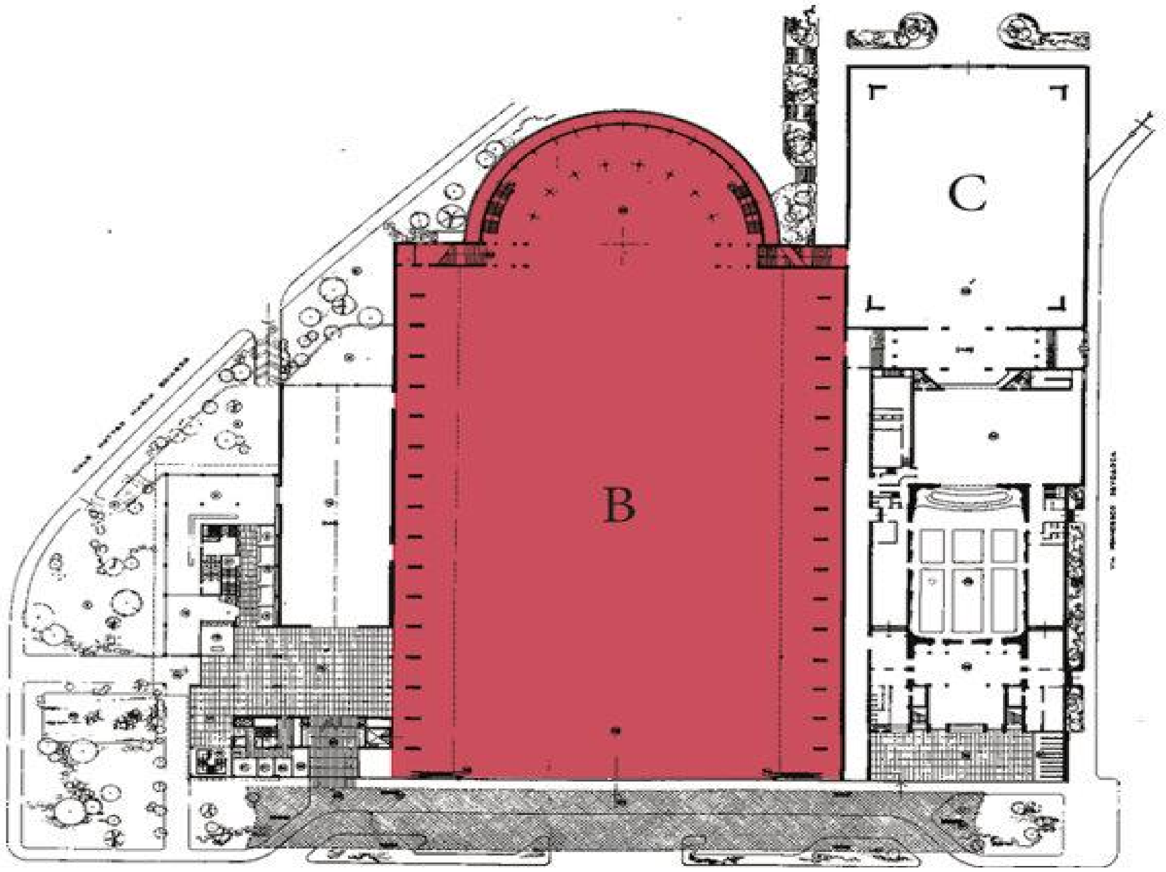


Figure 2.5 Plan of Torino exhibition center

This structure, with its effective architectural and unique material, may be merged with the benefits of the construction process. One of the most crucial transition pieces is the one that connects the corrugated roof to the structural piers. A prefabricated framework of rhombic components linked by reinforced concrete ribs was used to construct the Rotunda's 40-meter-diameter semi-dome. The structure is completed with a ferrocement plate for top-wheeled vehicles. The ribs have a 7-millimeter depth of detail.

The inside ribs serve as a functional and beautiful architectural feature. The lower-level ceiling slabs and side galleries of the hall have been replaced with 7.50 m long precast beams with a double curve and support, which are linked and structurally supported by a thin floor slab.

2.1 Salone Agnelli Or Hall B

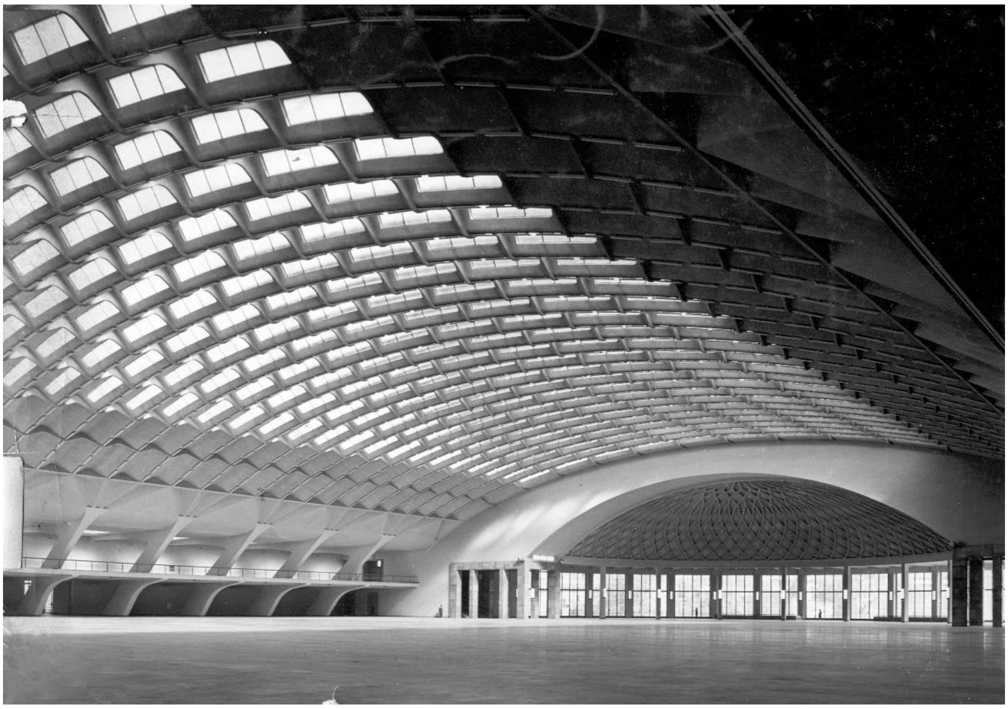


Figure 2.6 Interior of Hall B

It gradually diminishes towards the supports until the structural hypothesis of a two-hinged arch is satisfied, which is congruent with the calculation approach utilized, and the undulations are largest at the ridge level. As a result, just two-thirds of the vault's arch is divided into spans. In Hall B, you can examine the architectural and structural design that he used in his prior works. The slanting form of the columns supports the gallery by providing perfect shelving on the long side of the space and a horizontal ceiling facing the horizontal loft on the first level.

The most statically interesting part of pavilion B is the apsidal section, which summarizes Pier Luigi Nervi's undeniable talent; it provides a highly harmonious, aesthetically valid, and well-lit structure in which the semi-dome discharges its horizontal response into a hardened annular floor that functions like an arch placed on a horizontal plane.

The structure's primary elements are depicted in the diagram below.

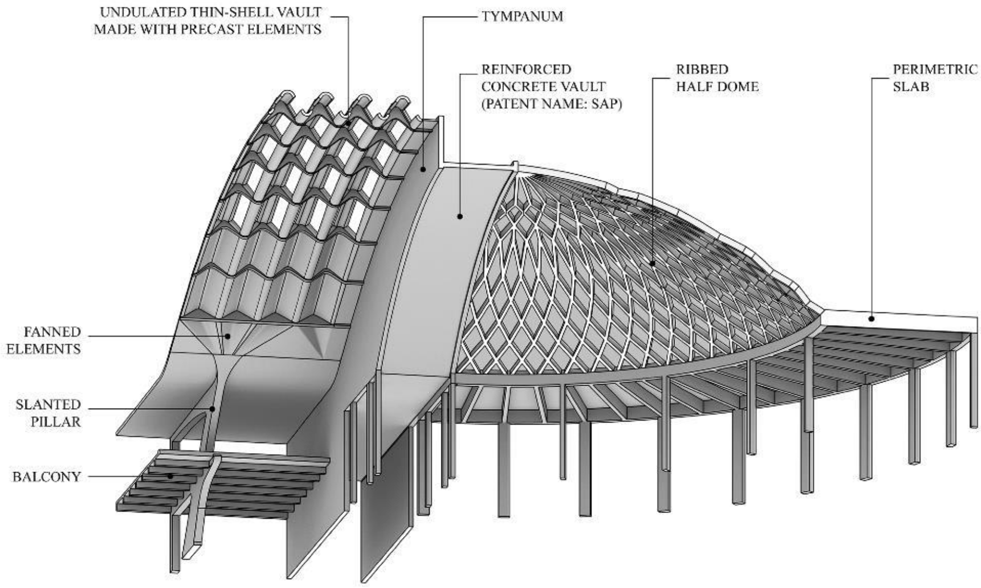


Figure 2.7 structural concept of Hall B

When we consider the facts already provided, we can see that Hall B is a complicated structure. The structure is made up of a variety of various parts. It's made up of 390 prefabricated parts in seven depths, as well as slanted columns and fan elements created by Nervi for low loads.

2.2 Hall C

The decision to expand the Turin Exhibition Hall was made in 1949, and hall C was constructed. Nervi was in charge of the design. Nervi is having difficulty dealing with a few issues. After a few attempts, he was able to solve them. First and foremost, there was a deadline for the hall, which would be 65x50 meters in size. He erected a vaulted ceiling with a 10m long perimetric plate after numerous attempts. As a result, materials including prefabricated parts and ferrocement, which were employed for Hall B's half dome, began to be utilised.

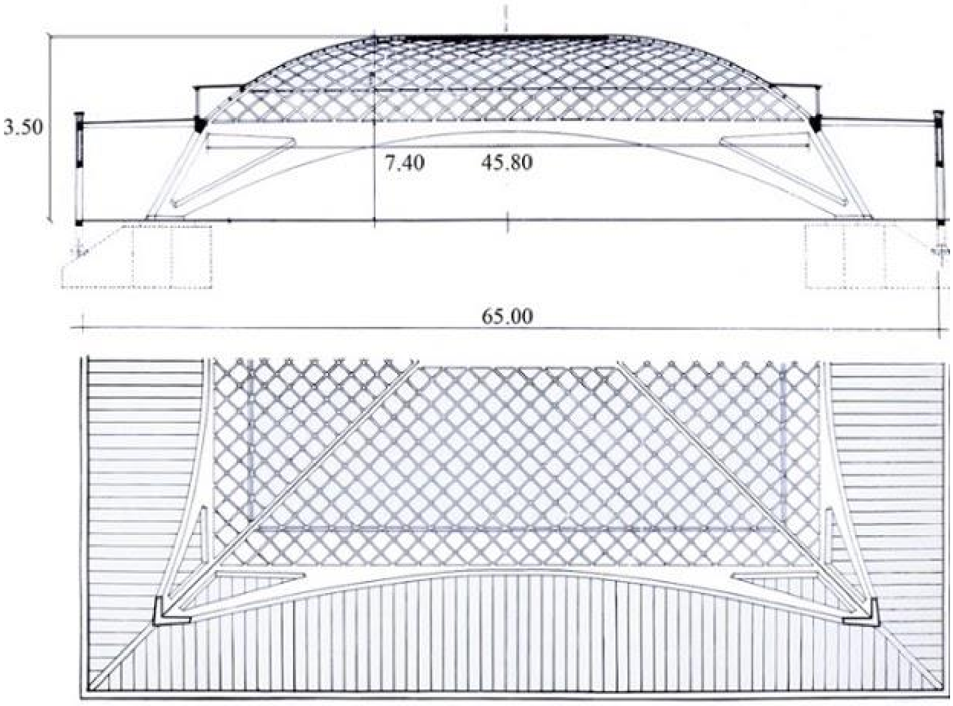


Figure 2.8 Hall C plan and section (from the Rassegna tecnica della Società degli ingegneri e architetti in Torino)

He employed an undulating reinforced concrete beam structure, something Nervi had considered but never tried before. As a result, the environmental problem has been solved. Nervi got the patent for this system (patent number 465636) on May 19, 1950, in Rome, once it was completed. [4]

It developed its patent number 445781, which was registered on August 26, 1948, after the building of the Turin exposition hall was finished. These patents became a distinguishing aspect of Nervi's style, and it was widely adopted in the years that followed. [5] [4]

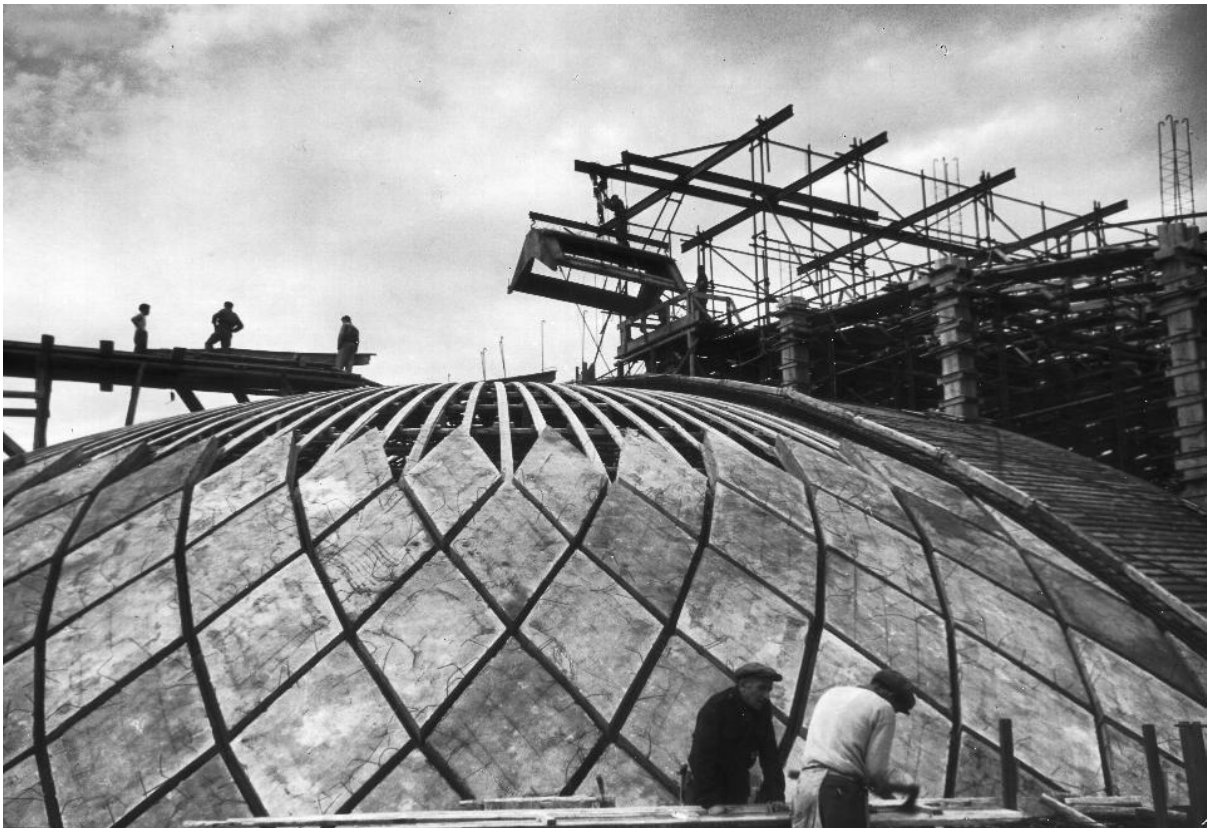


Figure 2.9 construction of the roof

On four arches, he built the magnificent vault of the hall. These arches were angled in accordance with the vault's thrust and the weight of the surrounding roof fog. The reinforced roof system's horizontal stiffness was meant to disperse and balance the vault's thrust. "The vault is computed as a thin membrane vault as well as a vault made up of elemental arches, each of which is resistive on its own," Nervi says.

Figure 2.10 Interior of Hall C today

Chapter 3

3. Modelling

Important qualitative and quantitative information gathered via a very rigorous and in-depth review of calculation reports and execution project tables is utilized to recreate the Turin Exhibition Hall as accurately as possible. The geometry of the building must be created before mechanical modeling can begin. Thus, by making modeling decisions, we will be able to achieve our desired aim to a large extent. In this situation, a low-quality model was constructed that was appropriate for our global analysis and will be calibrated for future uses.

3.1 Finite Element Method

The finite element method (FEM), also known as finite element analysis (FEA), is a computer methodology used in engineering to generate approximate solutions to boundary value issues. The Finite Element Method is an analytical method in structural engineering that allows for 3-dimensional static and dynamic analysis of structures, linear and non-linear solutions, and results that may be shown numerically or visually. [6]

The finite element method is a popular approach for estimating the behavior of structures under static and dynamic loads, as well as determining structural element stress. This strategy, which is preferable in terms of speed and cost, allows you to combine numerous construction element models (rod, shell, plate, prism (solid)). [7]

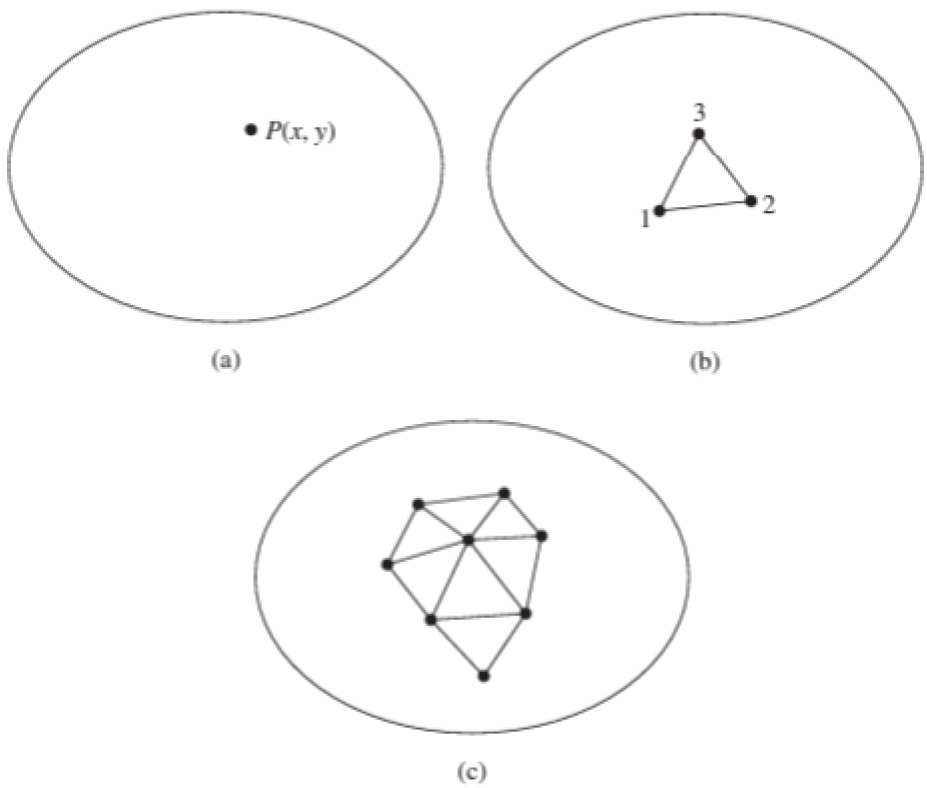


Figure 3.1 FEM - Basic Concepts: a) A General Variable P(x,y) b) Triangular Finite Element c) Triangular [6]

With reference to Figure 4.1, the general concepts and terminology of finite element analysis will be explained. The illustration represents a volume of a substance or materials with known physical qualities. The domain of a boundary value issue to be addressed is represented by the volume. For the sake of simplicity, we will consider a two-dimensional situation with a single field variable (x, y) to be determined at each position P (x, y) so that a known governing equation (or equations) is fulfilled exactly at each such location. [6]

A mathematical solution, that is, a closed-form algebraic expression of the independent variables, is achieved. In practice, the domain, as well as the governing equation, may be geometrically complicated, and the possibility of achieving an accurate closed-form solution is quite low. As a result, in engineering assessments of complicated issues, approximate solutions based on numerical approaches and digital computing are most frequently achieved. Finite element analysis is an effective tool for getting accurate approximation solutions. [6]

The information collected from the experimental data was utilized to model the elements in order to get their mechanical behavior. All structural aspects of the geometric model were employed exclusively in ANSYS for this by using Beam 188 element types.

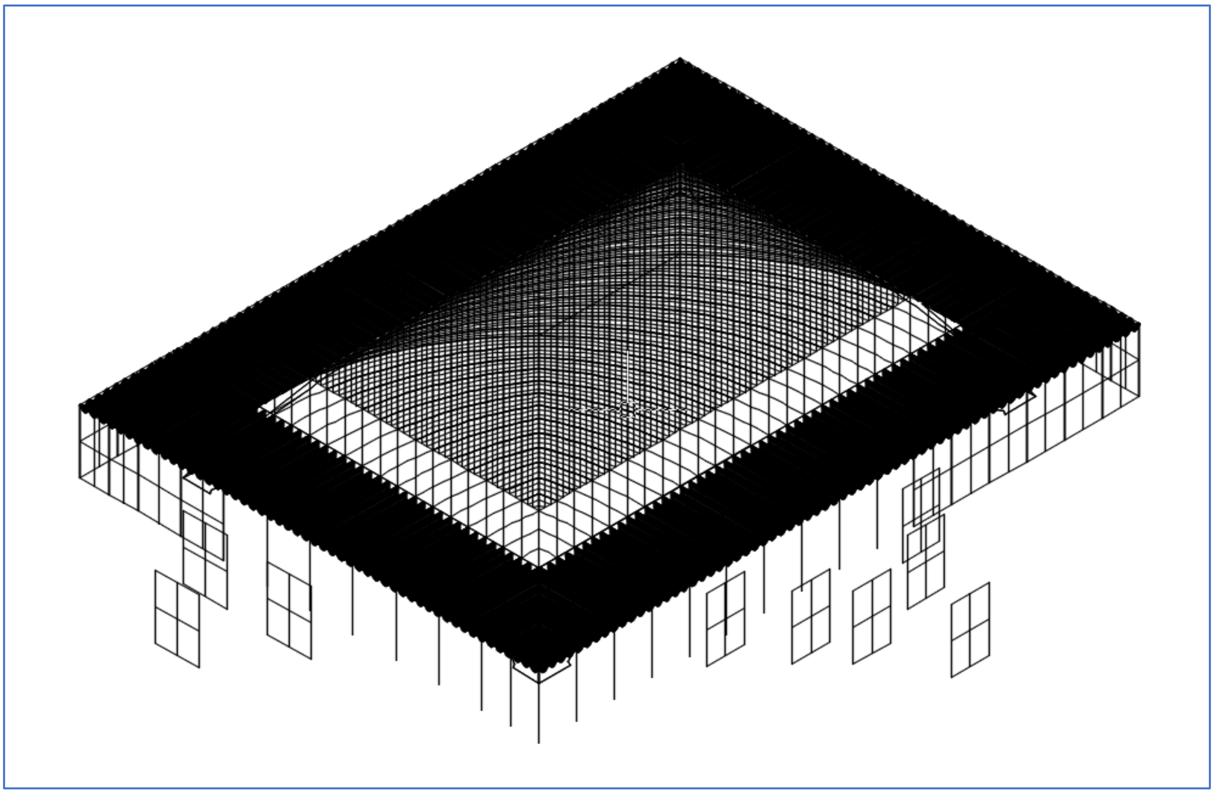


Figure 3.2 AutoCAD 3D model perspective view

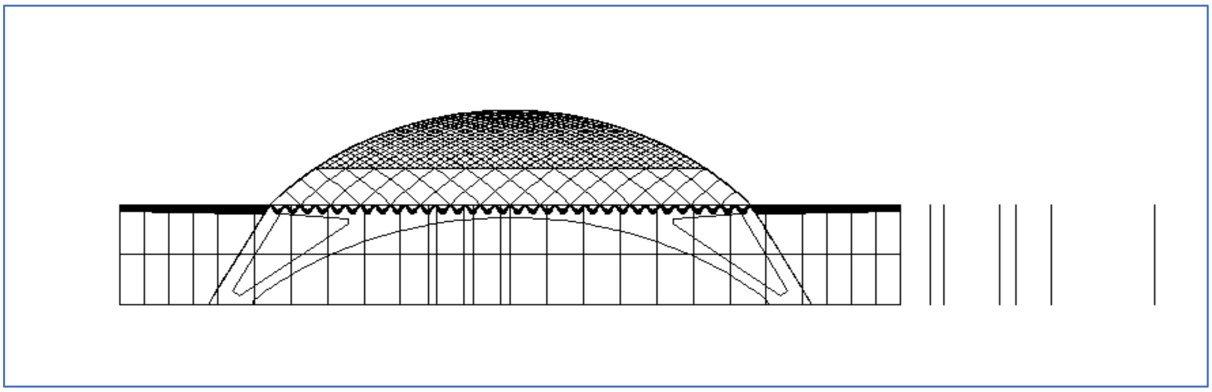


Figure 3.3 AutoCAD 3D model right side view

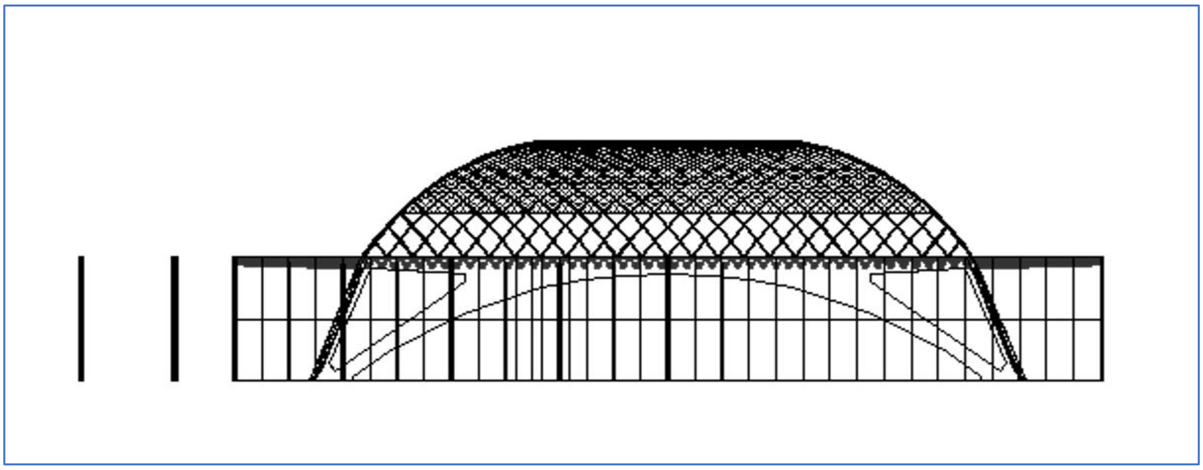


Figure 3.4 AutoCAD 3D model front view

Mechanical parametric design software

APDL is a programming language in its purest form. Because the commands in the ANSYS application may be defined in a parametric language, users can conduct repeated processes automatically. To put it another way, setting values to variables ensures that these values may be used throughout the study. The results of calculations on parameters set using various expressions and functions may be shown to the user. The user can be notified at intermediate stages and requested feedback by using loops and logic inquiries. Additionally, by constructing macros from scripts, a whole analysis may be performed automatically.

ANSYS software was used to construct a mechanical model. The core geometric model, which was originally produced in AUTOCAD 3D, was imported to ANSYS MECHANICAL APDL. After that, the element type in the imported geometric model was determined. (See BEAM 188 for further information.) The building's material kinds were then defined. The building's materials were created using characteristics including elastic modulus, Poisson's ratio, and density. Because these qualities in the construction materials have an impact on the mass and stiffness of the structure, they should be carefully analyzed as a key parameter. The beam components' cross-sections were specified as rectangular, and then the structure's materials, element type, and cross-sections were assigned to the necessary elements. The entire structure was then meshed. The building's boundary conditions were then determined. As a result, the model was developed in order to do the analysis we desired.

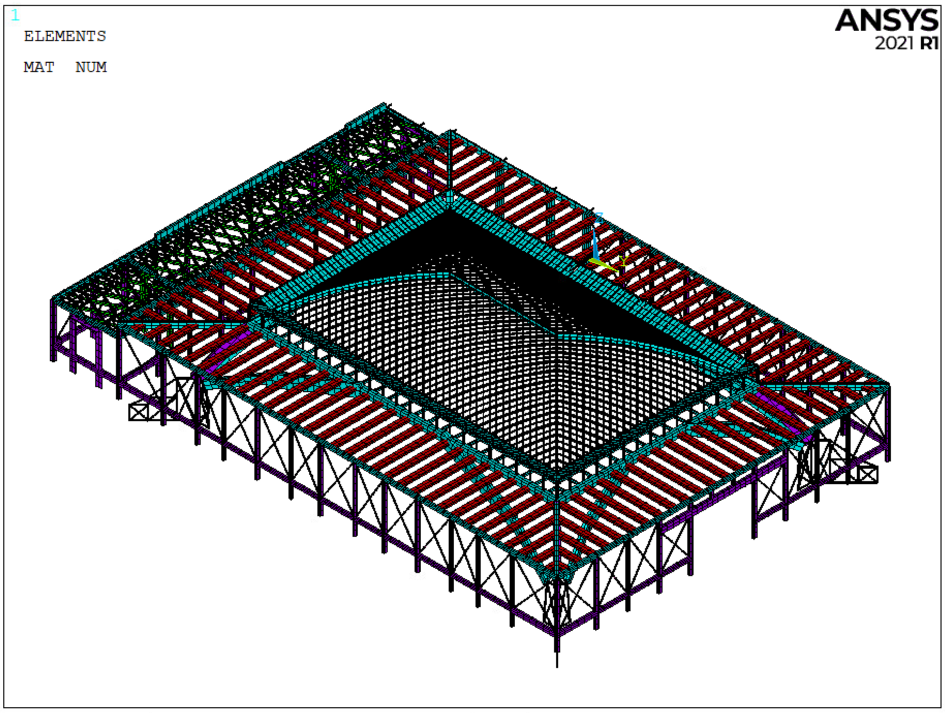
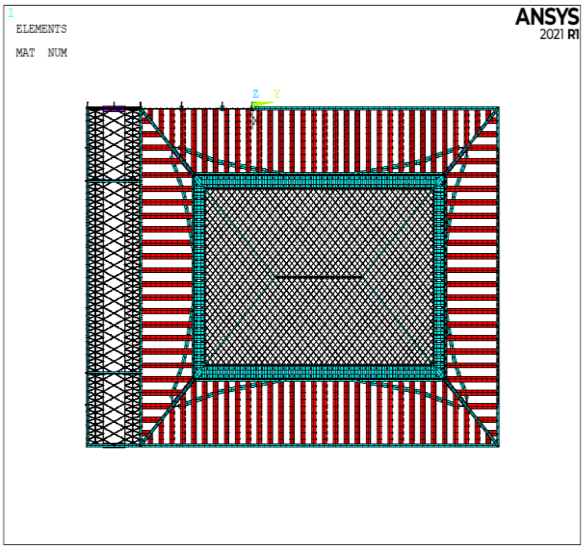


Figure 3.5 Ansys exporting model from AutoCAD 3D



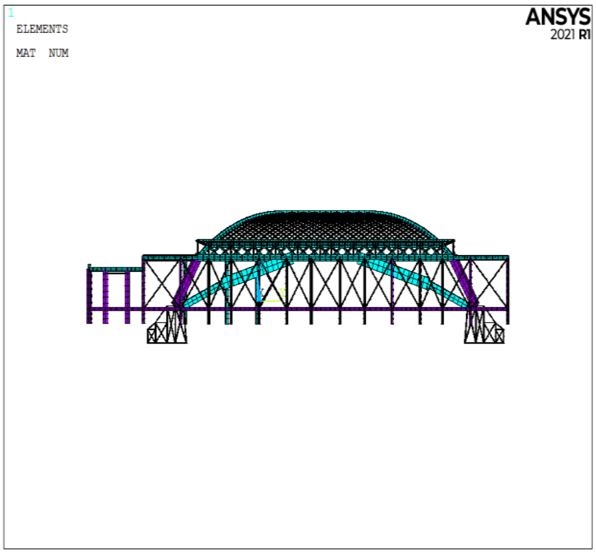


Figure 3.6 ANSYS model top view

Figure 3.7 ANSYS model front view

As previously stated, the structure was constructed entirely of beam type pieces, resulting in a model that was both versatile and adaptable. However, defining some elements that were not accurately represented by beam elements proved problematic. In these circumstances, truss structures with beam components are built using an imagined material specified as having the same stiffness and mass as the real structure.

Beam 188 Element type

We must assign and specify degrees of freedom to the nodes in order to construct a mechanical model. To assign this parameter in the Ansys Mechanical APDL Software, you must first describe the kind of element to be utilized. Only BEAM188 components were utilised in this example. The attributes of the Beam188 element type, as described in the program, can be found below.

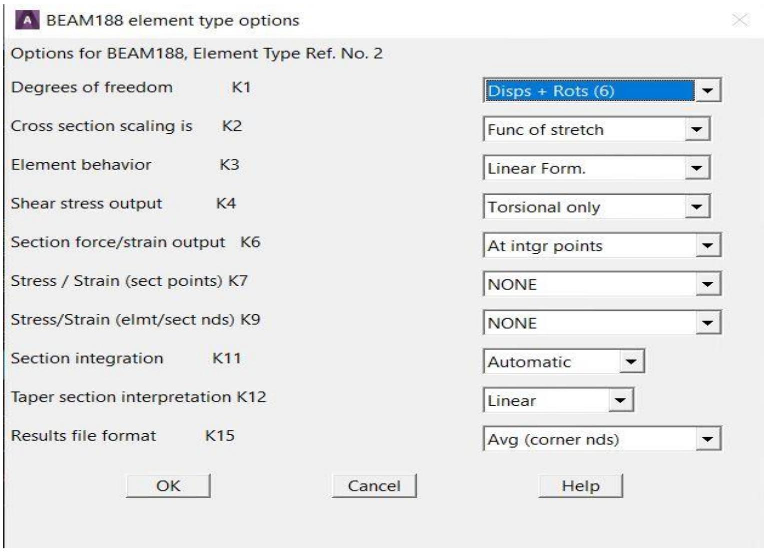
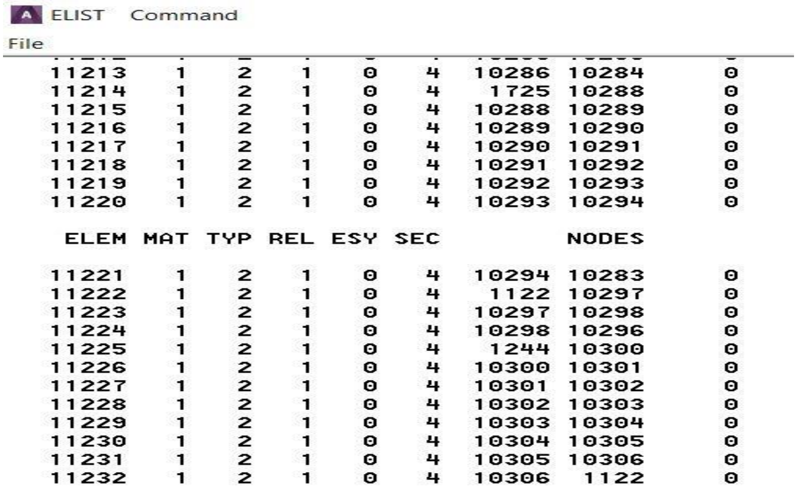


Figure 3.8 Beam188 element type properties

A basic step in the finite element analysis approach is to discretize the geometric elements by creating a mesh. This approach is not especially onerous in the example in question, with just one-dimensional parts and a need to study the general behavior of the structure. In reality, the finite element's unit length is specified.

This element, which pertains to the Timoshenko beam theory, is often employed for slender or somewhat thick beams. The continuous shear strain throughout the cross section is then taken into account. The application cannot be extended to components that are too stocky for the first order theory utilized to evaluate shear deformability. In reality, using Timoshenko's theory results in the conservation of plane sections after deformation, which could not possibly be the ideal representation for an element that differs too much from a beam. The ratio of shear stiffness to bending stiffness (GAL2 / EI) may be used to determine the element's applicability, and a value of more than 30 is preferred.

To make model in Ansys Mechanical APDL, it has been used 11232 elements, 7141 line has been created and 27 different material model has been defined.



ELIST Command

File

ELEM	MAT	TYP	REL	ESY	SEC	NODES		
11213	1	2	1	0	4	10286	10284	0
11214	1	2	1	0	4	1725	10288	0
11215	1	2	1	0	4	10288	10289	0
11216	1	2	1	0	4	10289	10290	0
11217	1	2	1	0	4	10290	10291	0
11218	1	2	1	0	4	10291	10292	0
11219	1	2	1	0	4	10292	10293	0
11220	1	2	1	0	4	10293	10294	0
11221	1	2	1	0	4	10294	10283	0
11222	1	2	1	0	4	1122	10297	0
11223	1	2	1	0	4	10297	10298	0
11224	1	2	1	0	4	10298	10296	0
11225	1	2	1	0	4	1244	10300	0
11226	1	2	1	0	4	10300	10301	0
11227	1	2	1	0	4	10301	10302	0
11228	1	2	1	0	4	10302	10303	0
11229	1	2	1	0	4	10303	10304	0
11230	1	2	1	0	4	10304	10305	0
11231	1	2	1	0	4	10305	10306	0
11232	1	2	1	0	4	10306	1122	0

Figure 3.9 element numbers

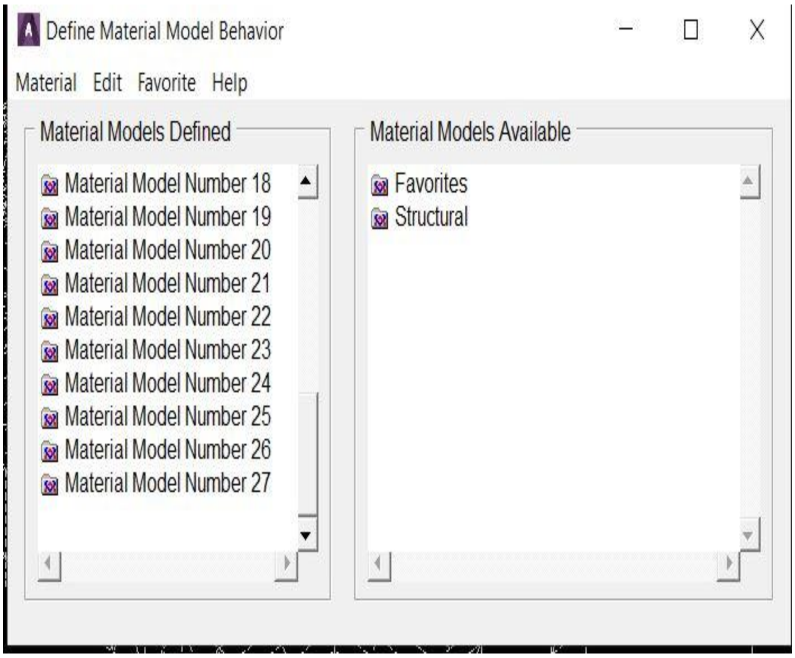
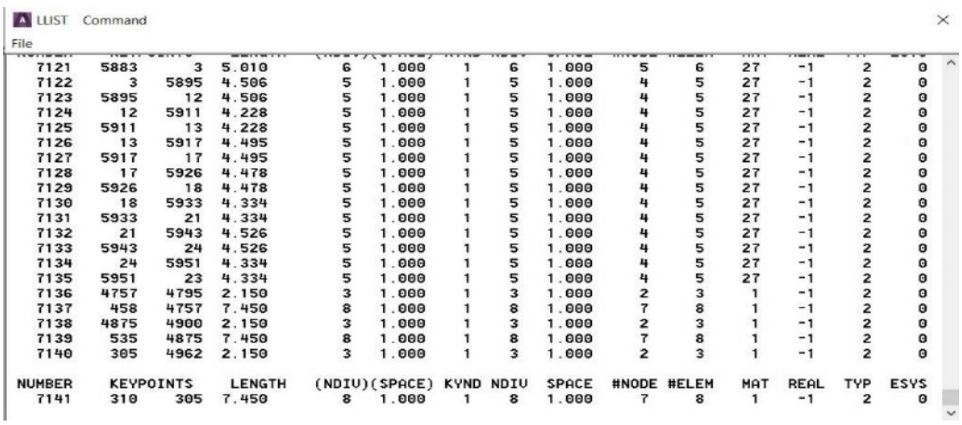


Figure 3.10 material model numbers



LLIST Command

File

NUMBER	KEYPOINTS		LENGTH	(NDIV)	(SPACE)	KYND	NDIV	SPACE	#NODE	#ELEM	MAT	REAL	TYP	ESYS
7121	5883	3	5.010	6	1.000	1	6	1.000	5	6	27	-1	2	0
7122	3	5895	4.506	5	1.000	1	5	1.000	4	5	27	-1	2	0
7123	5895	12	4.506	5	1.000	1	5	1.000	4	5	27	-1	2	0
7124	12	5911	4.228	5	1.000	1	5	1.000	4	5	27	-1	2	0
7125	5911	13	4.228	5	1.000	1	5	1.000	4	5	27	-1	2	0
7126	13	5917	4.495	5	1.000	1	5	1.000	4	5	27	-1	2	0
7127	5917	17	4.495	5	1.000	1	5	1.000	4	5	27	-1	2	0
7128	17	5926	4.478	5	1.000	1	5	1.000	4	5	27	-1	2	0
7129	5926	18	4.478	5	1.000	1	5	1.000	4	5	27	-1	2	0
7130	18	5933	4.334	5	1.000	1	5	1.000	4	5	27	-1	2	0
7131	5933	21	4.334	5	1.000	1	5	1.000	4	5	27	-1	2	0
7132	21	5943	4.526	5	1.000	1	5	1.000	4	5	27	-1	2	0
7133	5943	24	4.526	5	1.000	1	5	1.000	4	5	27	-1	2	0
7134	24	5951	4.334	5	1.000	1	5	1.000	4	5	27	-1	2	0
7135	5951	23	4.334	5	1.000	1	5	1.000	4	5	27	-1	2	0
7136	4757	4795	2.150	3	1.000	1	3	1.000	2	3	1	-1	2	0
7137	458	4757	7.450	8	1.000	1	8	1.000	7	8	1	-1	2	0
7138	4875	4900	2.150	3	1.000	1	3	1.000	2	3	1	-1	2	0
7139	535	4875	7.450	8	1.000	1	8	1.000	7	8	1	-1	2	0
7140	305	4962	2.150	3	1.000	1	3	1.000	2	3	1	-1	2	0
7141	310	305	7.450	8	1.000	1	8	1.000	7	8	1	-1	2	0

Figure 3.11 line numbers

Chapter 4

4. Eigen-Value Analysis

Eigen-value analysis is a technique for determining the structure's free vibration periods and mode forms. The mass and stiffness matrices of the structural system may be used to derive free vibration periods and modes.

The account comes with 100 modifications. In general, even though these modes appear to be in big numbers, mass participation rates reveal that much more may be acquired. The mass participation ratio expresses how much of the overall mass of the structure may be activated and involved in the oscillating motion by a mode vibration corresponding to a free vibration period.

There are two methods for doing modal analysis of structures: theoretical and experimental. The mass, damping, and stiffness attributes of the structure are used to create a physical description in theoretical modal analysis. The analytical model of the structure is created using these physical features. The standard modal analysis approach using the analytical model is used to get the structure's natural frequencies, mode shapes, and modal damping ratios. The modal model of the structure is generated using these data. The values obtained are known as natural values since no external load is applied to the structure during the modal analysis. Finally, the modal model is used to determine the structure's response under the provided boundary conditions and loadings. These reactions, known as frequency and push behavior, are used to develop the structure's behavior model.

The force (i.e., effect) applied to the structure and the acceleration (i.e., reaction) produced from the structure are measured and analyzed in experimental modal analysis of structures. The frequency response function, which will be used to determine the dynamic properties of the structure, is produced from the ratio of the response to the effect after the effect and response values have been measured.

In order to define dynamic analysis of structures, modal analysis is used. To acquire a sufficient number of vibration modes, it used Eurocode 8: Design of buildings for earthquake resistance. According to Eurocode 8, the total effective mass participation factor for vibration modes operating on a structure must be larger than 90% in each direction. As a result, the vibration modes with the highest effective participation factor are considered, and they must be used until 90 percent of the total is reached. The vibration modes having a participating mass larger than or equal to 5% of the total mass under investigation were chosen using the reference criteria in paragraph 7.3.3.1 of NTC 2018.

4.1 Mass Participation Factor

MODE	FREQUENCY (Hz)	PERIOD (s)	MASS X (%)	MASS Y (%)	MASS Z (%)
1	2.45618	0,40714	18.26	15.83	0
2	2.53911	0,39384	0	0	5.62
3	3.36930	0,29680	0	37.12	0
7	4.00873	0.24946	7.46	0	0
8	4.42008	0.22624	11.33	0	0
9	4.70036	0.21275	9.37	0	0
21	6.98866	0,14309	0	0	13.21

Table 4.1 Mass participation factors

Out of the 100 modes that were analyzed in Ansys software for the eigen-value analysis, the seven modes mentioned above in Table 5.1 were chosen. Since the participating masses did not achieve the 5 percent threshold specified by NTC18 and also because the majority of the modes are local and not global enough to be of interest to us, these seven modes were chosen from a range of 1 to 21 characteristic modes of vibration. The seven modes have been summarized with the mode shapes.

4.2 Mode Shapes with Respect to Frequency

In the below it has been reported the mode shapes of each one of the seven modes.

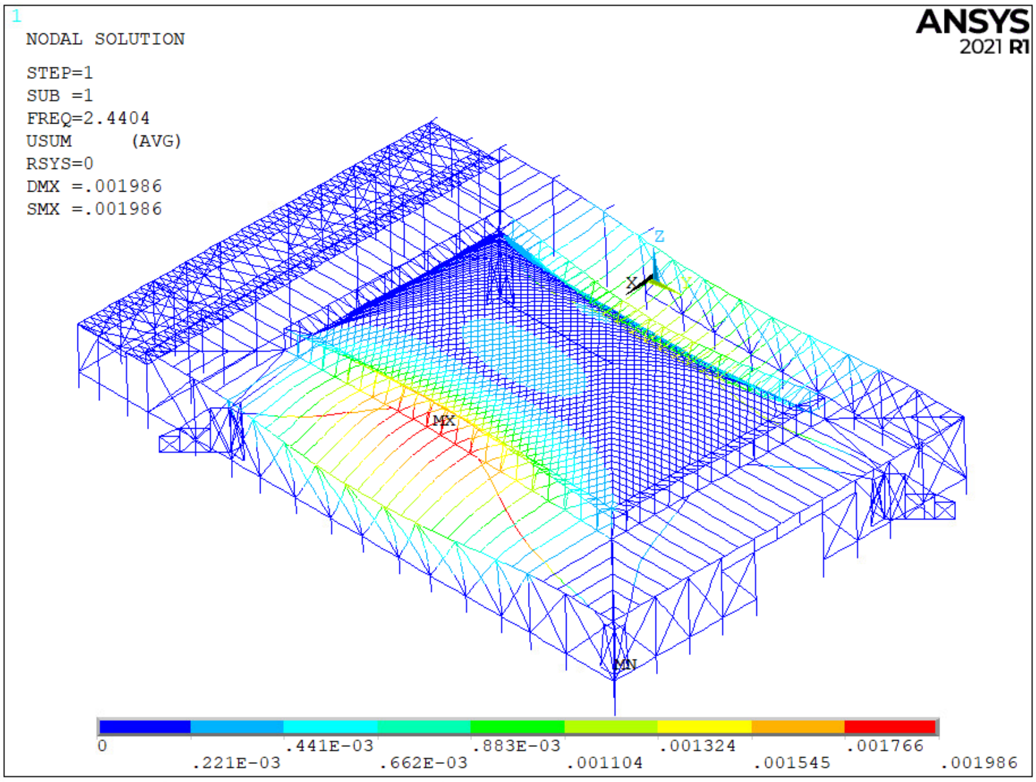


Figure 4.1 Mode 1 Freq=2.44

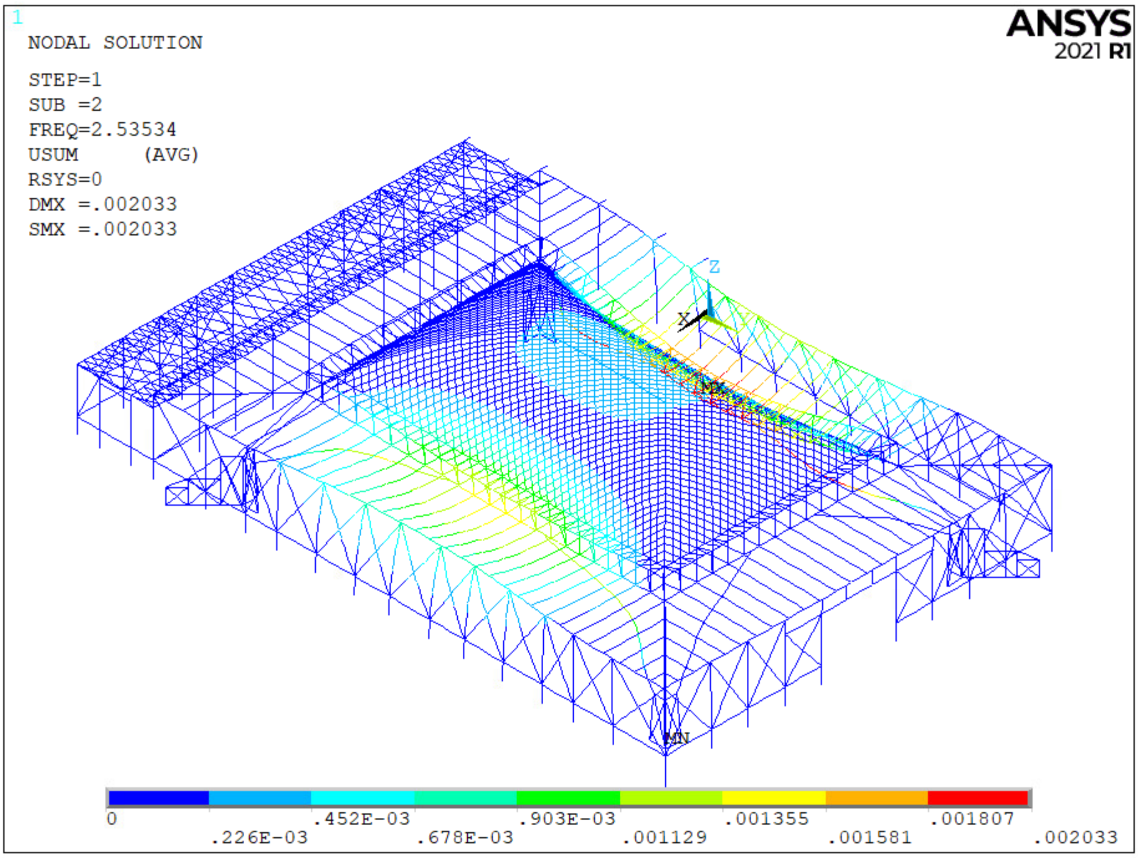


Figure 4.2 Mode 2 Freq=2.53

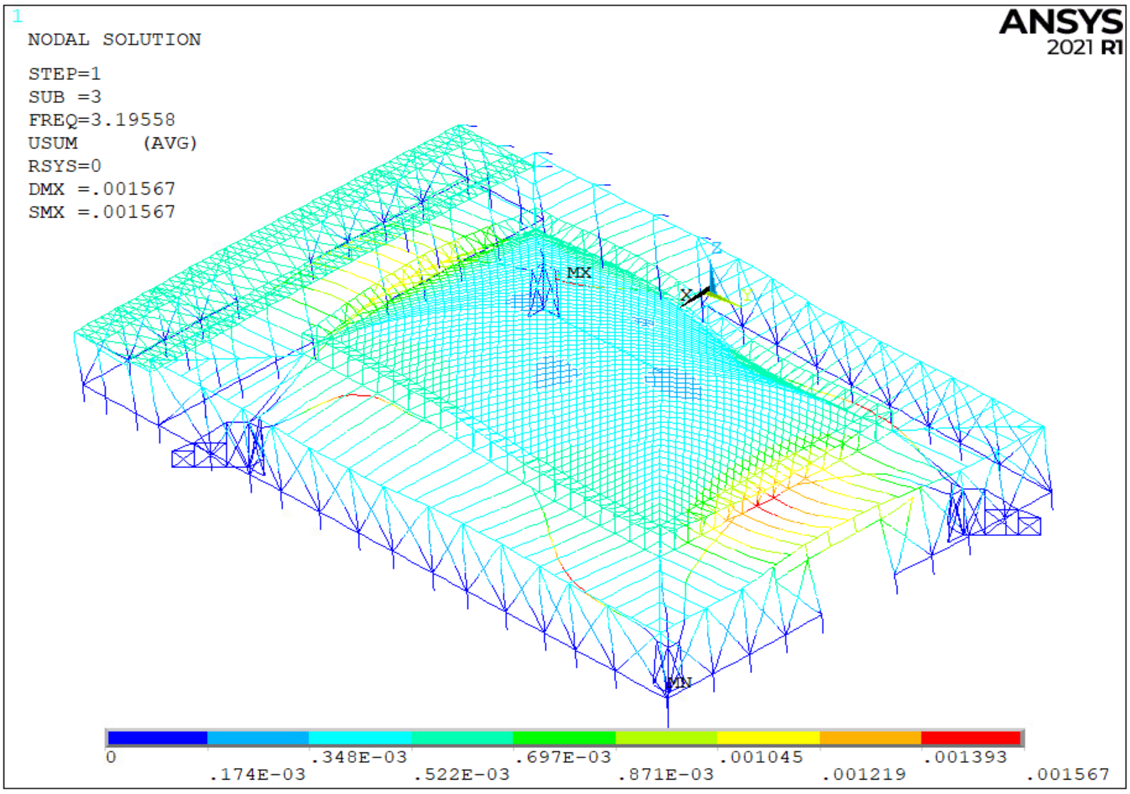


Figure 4.3 Mode 3 Freq=3.20

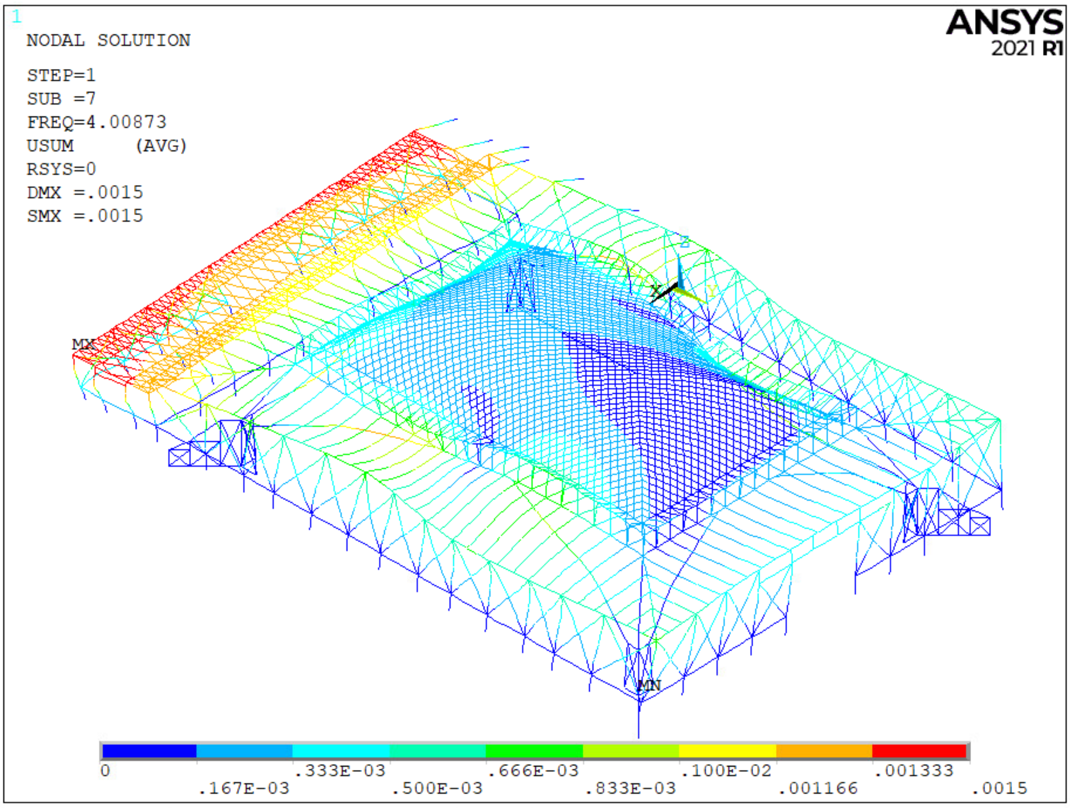


Figure 4.4 Mode 7 Freq= 4.00

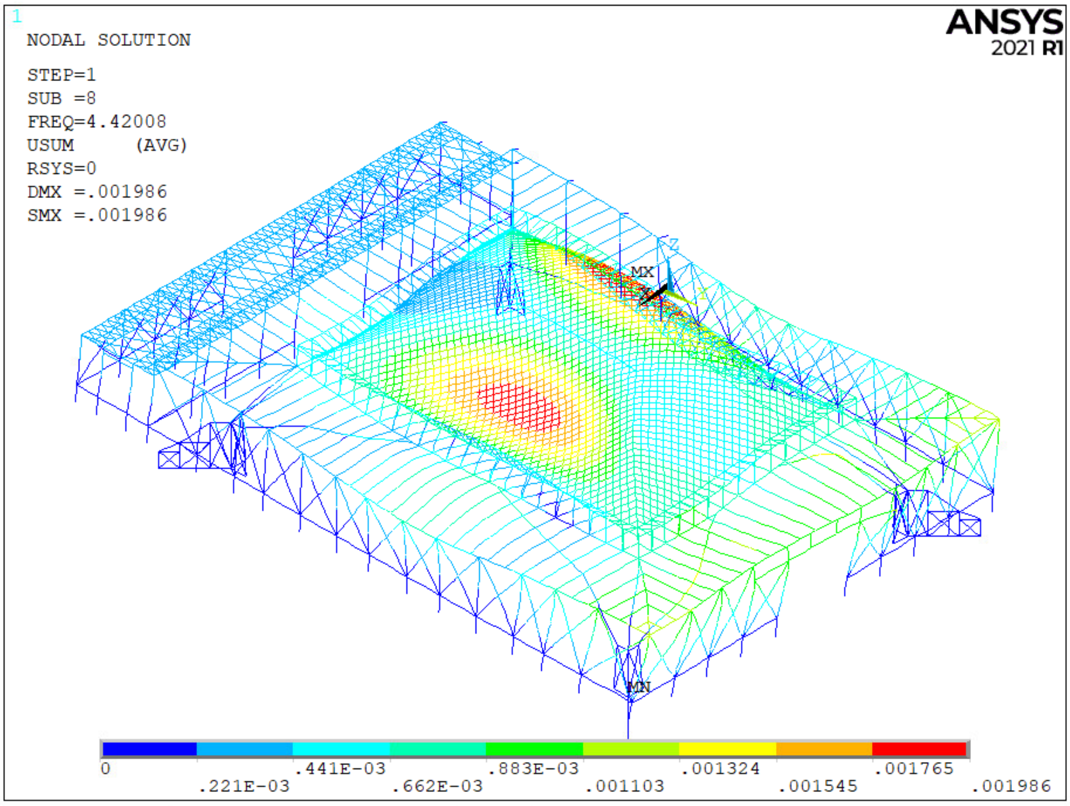


Figure 4.5 Mode 8 Freq=4.42

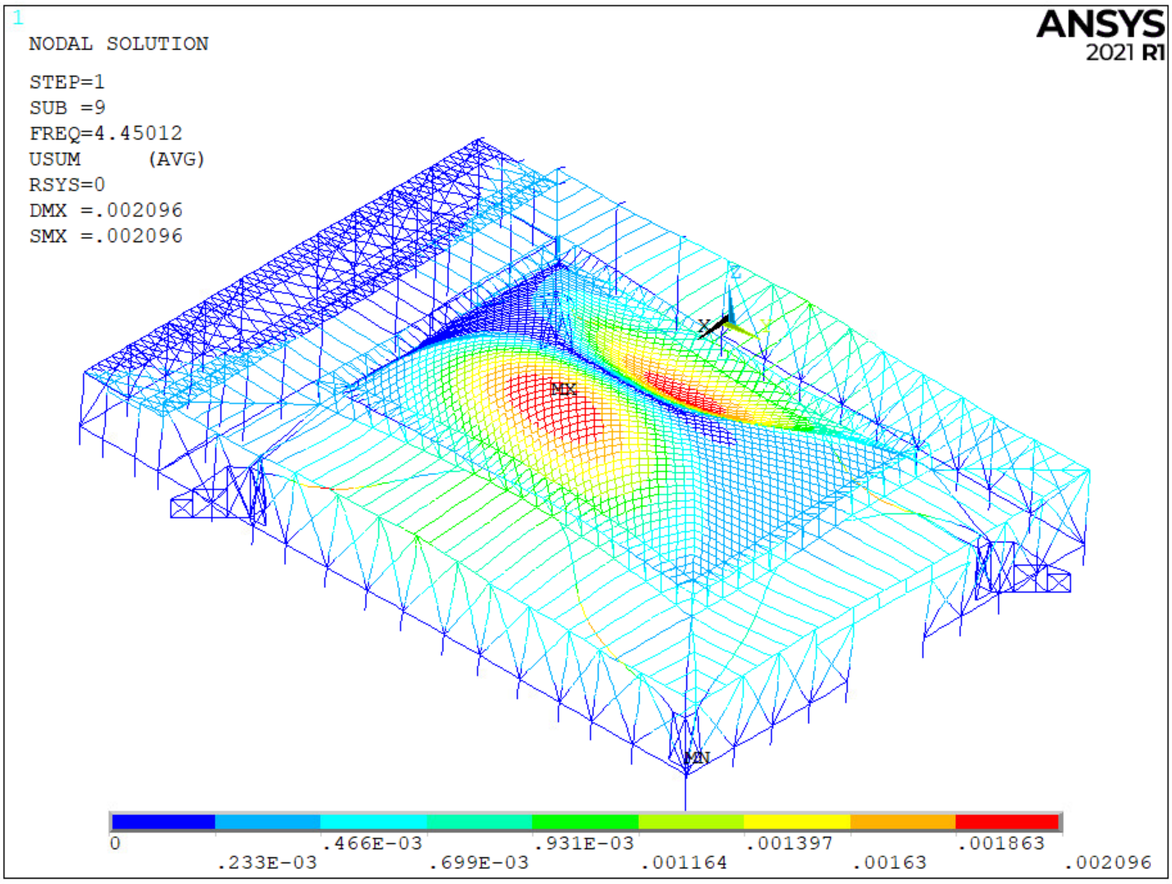


Figure 4.6 Mode 9 Freq= 4.45

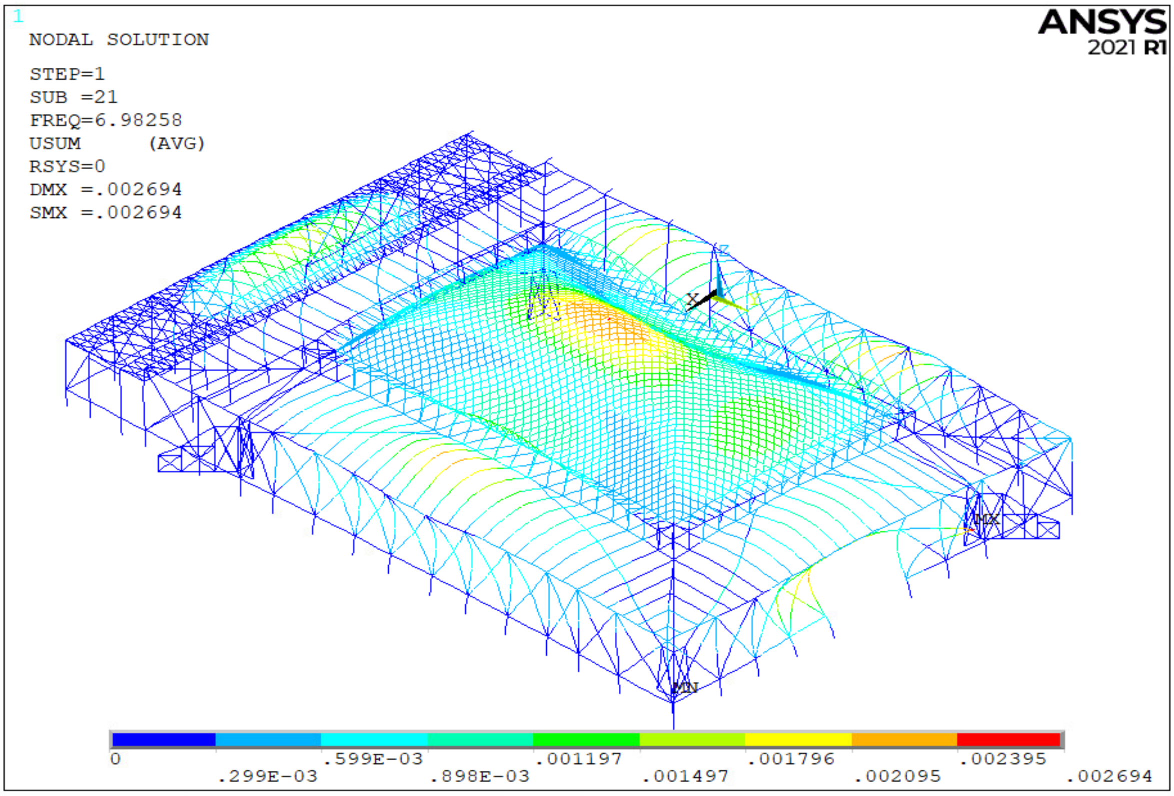


Figure 4.7 Mode 21 Freq=6.98

The main direction of the modes is shown in below Table 3.2.

MODE	FREQUENCY (Hz)	PERIOD (s)	DIRECTION
1	2.45618	0,40714	1° mode in X direction
2	2.53911	0,39384	1° mode in Z direction
3	3.36930	0,29680	1° mode in Y direction
7	4.00873	0.24946	**2° mode in X direction**
8	4.42008	0.22624	3° mode in X direction
9	4.70036	0.21275	4° mode in X direction
21	6.98866	0,14309	**2° mode in Z direction**

Table 4.2 Direction of modes

The structure's mass participants in each direction were considered while choosing the vibration modes, and each of the 100 modes was assessed separately in order to extrapolate only those modes that involved global modes of vibration. Some modes may have significant levels of mass participations, but these numbers may have an impact on some local structural components. A few modes were consequently ignored because of that reason. Modal being applied has low fidelity and that the modal type also influences the values. The modes that we are primarily interested in for computation and structural reaction are those that have an impact on the global rather than the local.

Chapter 5

5. Response Spectrum Analysis

Response spectrum analysis, a multimodal analysis, is used to assess the seismic performance of an existing structure. It is feasible to convert a highly complicated dynamic problem to a smaller and easier static problem using this strategy, which is still utilized and encouraged in many laws today. We may conceive of them as extremely basic independent oscillators when undertaking this type of study. It is feasible to define the acceleration using the response spectrum's proper period and to know the mass in the mode under discussion. As a result, calculating the static force in the modal form under consideration is simple.

We will assume that the structure has larger resistance in the elastic range and no ductile qualities based on the response spectrum analysis' evaluation with behavior factor q=1, which means that the elastic spectrum coincides with the design spectrum. This is an unfavorable scenario because, while taking into consideration the structure's potential for plastic resistance, the acting accelerations will therefore be maximized rather than minimized.

Because not all these modes are active at the same time, the various forces caused by these individually available mods are not simply put together. A mathematical method is required since spectral curves are only designed to offer the highest value and are insufficient to determine the contributions of the various modes at a particular time. By assuming that the highest contributions from all modes occur at the same time, an upper bound is determined. The sum of absolute values can be used to combine contributions from all modalities. However, because it achieves an inflated value, it is not commonly utilized in sizing. [8]

Instead, it has been demonstrated that the value obtained in systems with discrete free vibration frequencies using the SRSS (square root of the sum of squares) method produces values that are extremely near to the time history domain solutions. With the Complete Quadratic Combination (CQC) method, the constraints of this rule may be removed, and this rule could also be utilized for systems with near free vibration frequencies. If the interplay of the modes is ignored, the CQC and SRSS rules provide the same outcome. There is no requirement for a dynamic computation in the time history domain with these combinations. However, when spectrum curves representing the dynamic features of the earthquake are employed, this approach is truly a dynamic method. In addition, as compared to time domain analysis, behavior spectrum analysis is far more convenient. [8] As a result, two effect approaches known as and CQC are used to combine them (perfect square combination).

Seismic stresses for each constituent in the structure may be computed using this approach. For various earthquake combinations, static stresses are also applied. When we look at it, we can see that the drag vector is defined, which is a vector that moves in three spherical directions with various densities at the same time.

The structure's key elements are then identified and bending, and shear force restrictions are implemented in the most vulnerable areas. Response spectrum has been obtained by using the software is called “SIMQKE_GR”. Below parameters have been entered into the software.

Zone 4 calculated based on the site's geographic location.

Nominal life : 50 years

Class of use : 4 (It is dependent on the degree of suffocation. Even in the case of a calamity, a public facility with significant strategic activities is classified as Class 4. The fact that Torino Esposizioni is a pavilion capable of holding large-scale events justifies this option, and the prospect of employing this structure for civil protection reasons is not to be ruled out.)

Coefficient used (cu) : 2 [Directly related to the usage class. This option doubles the project's seismic action's return duration.]

Subsoil category : C [Medium-thickened coarse-grained soil layers having mechanical qualities that gradually increase with depth. There are no geological studies of any type accessible, however this category was chosen since a "gravel bank" is referenced in the calculation report while doing foundation inspections.]

Topographic category : T1 [For level terrain or slopes with less than a 15% average inclination.]

SLV is taken into account as a limit state. The ultimate limit state for the preservation of life, according to the studies, is regarded human.

Damping ratio: %5 (0.05)

We assume a seismic project activity with a return time of 949 years and a construction reference period of 100 years, based on the given criteria. This means that the event's probability of occurrence for the life limit state is always 10%, but it's prolonged for a reference period that's double what's regarded for a class 2 structure in this situation. As a result, the return period is defined as the inverse of the likelihood of the event occurring in a single year, whereas the probability (10%) is relative to the reference period in question.

Longitude	7.6761
Latitude	45.0781
Nominal life	50
Class of use	IV
c_u	2
V_R	100
Subsoil Class	C
Topografic Class	T1
PV_R	0.1
T_R	949
ξ	5

Table 5.1 Parameters for SIMQKE_GR software

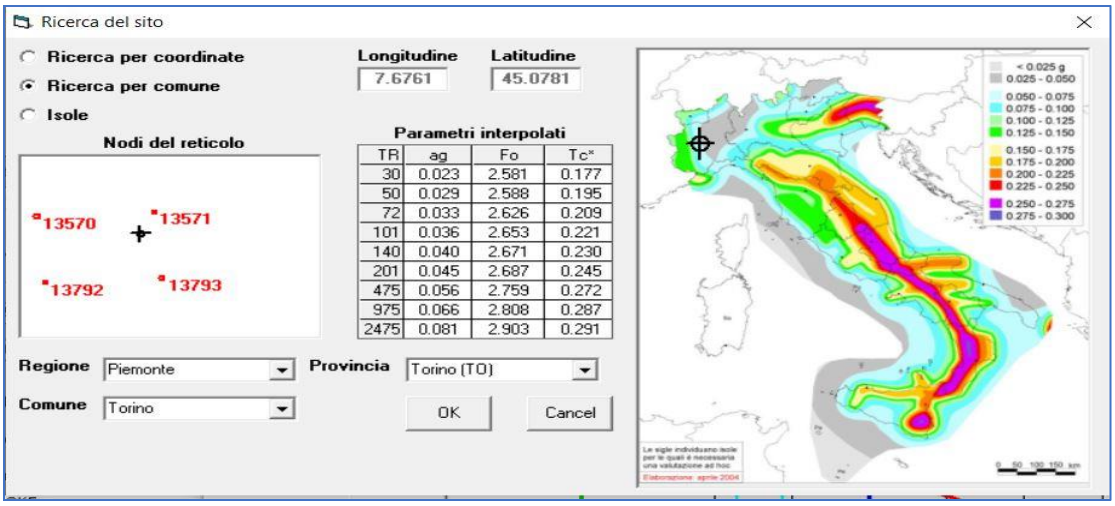


Figure 5.1 Location that used for response spectrum

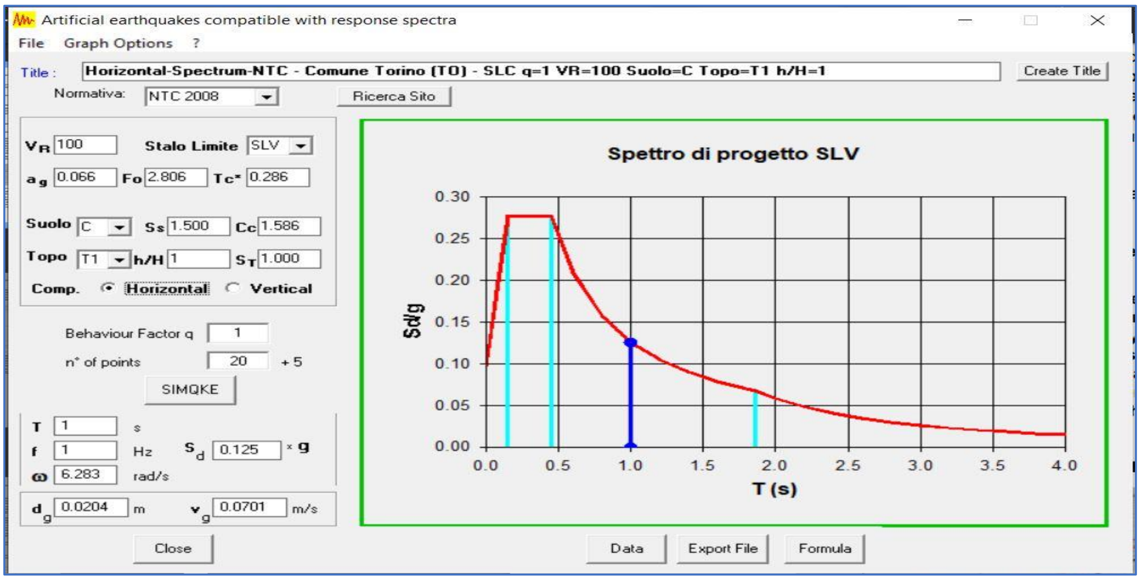


Figure 5.2 Parameters for SLV horizontal spectrum

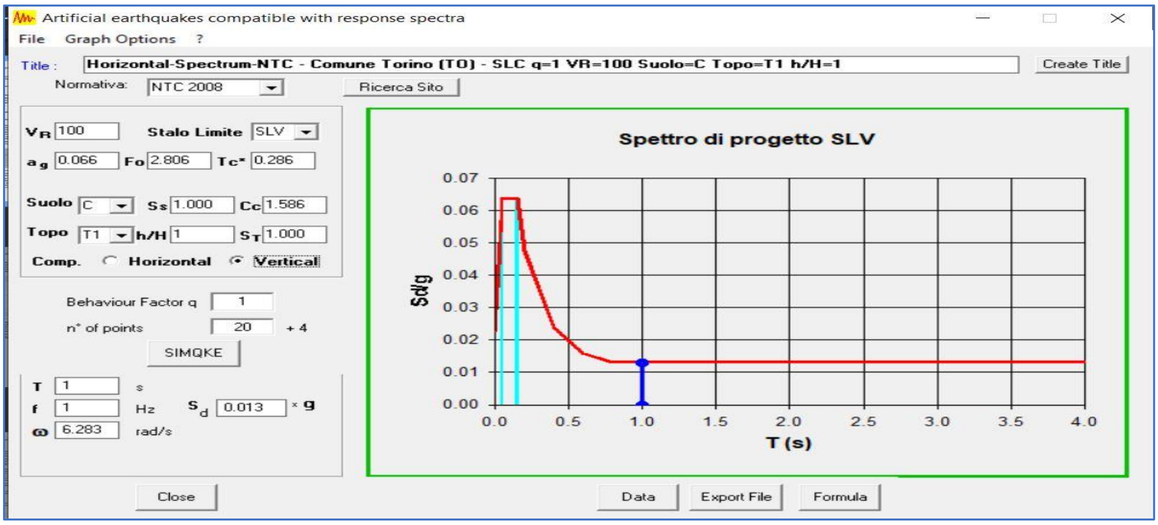


Figure 5.3 parameters for SLV vertical

5.1 Selection of Critical Zones

All the structural elements are not taken into account for the previously mentioned combinations because Ansys Mechanical does not support automatic checks. We want to define a few particularly interesting parts of the structure in this paragraph. The analysis that has been done before allows for the identification of key locations among Pavilion C's primary structural elements. The most stressed macro-elements of Hall C are listed below, based on a precise study of each macro-element:

• The diagonal beam, the main rib of the vault, and the two horizontal braces of the arches all meet at the top of the inclined strut, which is a key location suffering external strain and internal compression, displaying significant stress levels.

• **Long side arch:** the most stressed area is at the strut's base, where the element is subjected to both external tension and internal compression. This structural element's midspan portion is the one that has the most displacement.

• **Short side arch:** The short side arch functions similarly to the long side arch, but with lower stress levels.

• **Pavilion vault**: stresses are concentrated in the lower half, near the skylight, where the void section of the diamond shape decreases collaboration between neighboring ribs, resulting in greater tension and compression values in the central zone immediately after the midspan on both sides. In compression, the four major ribs that correspond to the skylight and connect to the inclined strut are the most strained.

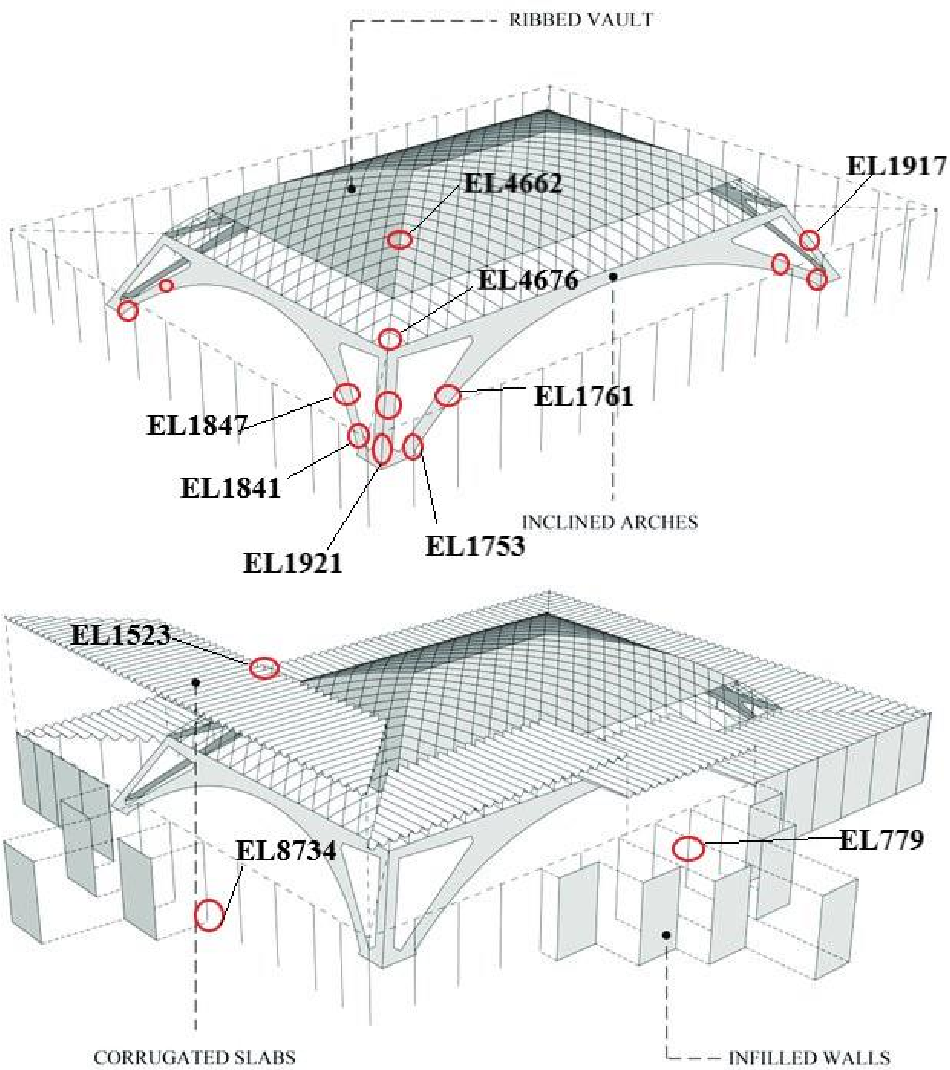


Figure 5.4 Critical sections

The results that have been taken from dynamic analysis comparing with the static anlaysis which has been done before, 11 elements and different parts of structure have been chosen. The elements that have been chosen are shown in Figure 6.4. The name of the elements which are defined by Ansys software.

EL_4676 is at the base of major ribs. It has been selected because of the normal stress at base and **EL_4662** is the midpoint elements of major ribs. It has been selected due to bending moment and shear force which effect so much strain on major ribs

EL_1523 is the undulated slab of the internal frame. It has been chosen because of effectiveness of normal and bending moment on the long side of the beam.

EL_1753 is the base of the long side of arches and **EL_1761** is the middle point of the long side arches. These are the most critical part of the structure that can have strains more than other part of structure.

EL_1841 is the base of the short side of the arches while **EL_1847** is the midpoint of the short side arches.

EL_1921 is the base of the pier while **EL_1917** is the middle point of the pier. The corner of the inclined pier is the critical point as well.

EL_8734 is the pillar close to the gallery side which **EL_779** is the pillar at the side which is other side of gallery.

The critical elements which have been selected on software are reported by its properties in the below Table 6..1.

ELEMENT NUMBER	MATERIAL TYPE	SECTION NUMBER
779	13	71
1523	12	84
1753	12	82
1761	12	82
1841	12	79
1847	12	79
1921	13	81
1927	13	81
4662	12	93
4676	12	93
8734	13	95

Table 5.2 Critical elements properties

MATERIAL NUMBER	12
E_x [Pa]	3.00E+10
DENSITY	2500
POISSON RATIO	0.2
CONCRETE TYPE	TIP 680
f_{ck} [MPa]	46
f_{yk} [MPa]	260

Table 5.3 Material 12 properties

MATERIAL NUMBER	**13**
E_x **[Pa]**	3.00E+10
DENSITY	2500
POISSON RATIO	0.2
CONCRETE TYPE	500
f_{ck} **[MPa]**	25.2
f_{yk} **[MPa]**	260

Table 5.4 Material 13 properties

SECTION NUMBER	**L1**	**L2**
	[cm]	[cm]
71	30	40
79	60	105
81	70	138
82	60	115
84	70	90
93	25	75
95	30	30

Table 5.5 Section sizes

After that, dynamic measures were taken into consideration for the most pressured locations. The dynamic evaluations performed were solely for the purpose of determining structural criticalities and high-risk zones.

Ansys software was used to do three assessments with a response spectrum with q=1 shifting the direction of the seismic action. The primary stress zones were explored, and a comparison was conducted to see if they related to the static analysis's highlighted zones, and which, if any, would be the most vulnerable to damage.

Normal stress which is defined Fx in software, shear stress in the y and z directions which are defined SFy and SFz in software and bending moments in the y and z directions which are define My and Mz were the stress outputs for the three separate directions.

It may be recognized which structural elements are most impacted by the seismic activity by looking at the related deformed structure with total displacements in each direction

5.1.1 Displacement in X Direction

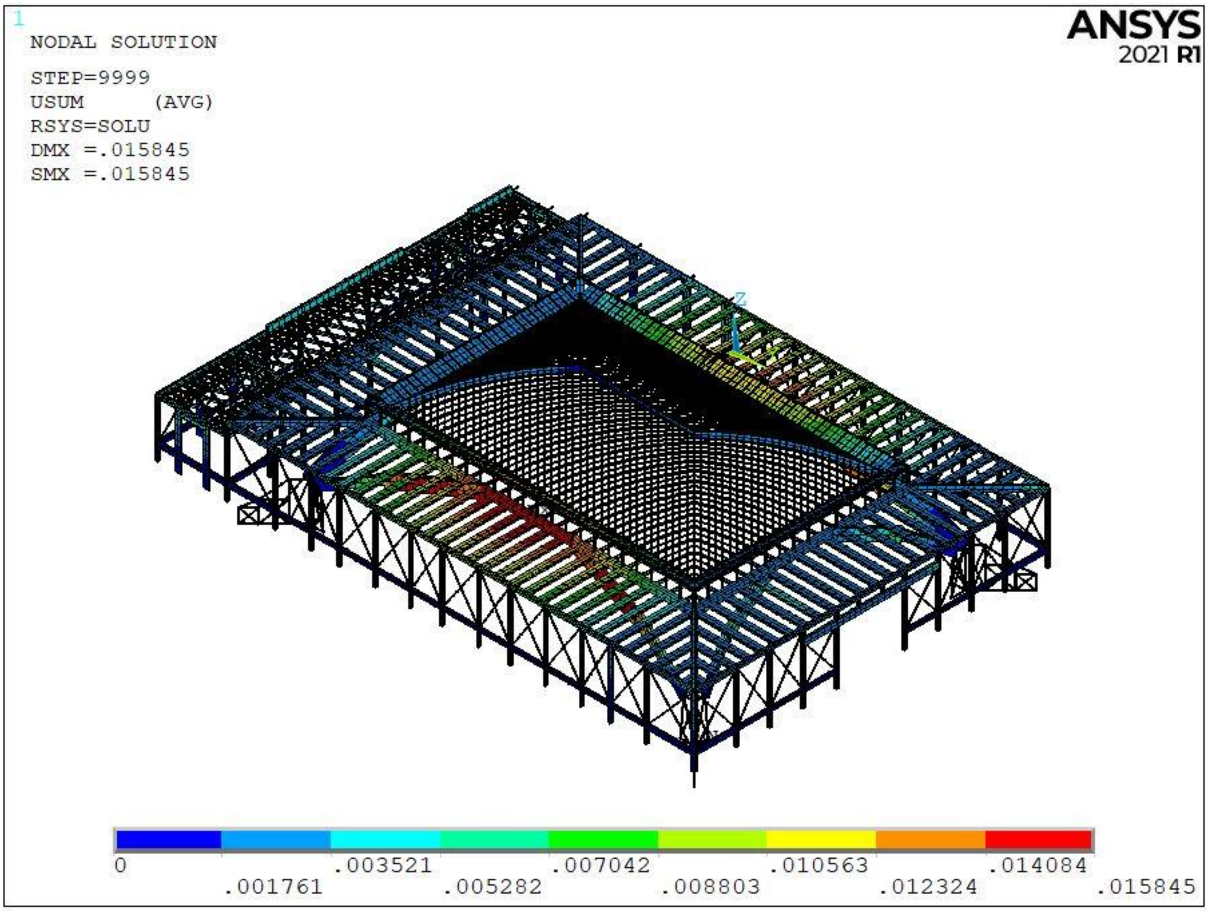


Figure 5.5 Total displacement in X direction

X_ Displacement	[mm]
Ux	13.65
Uy	3.99
Uz	12.34
Usum	15.85

Table 5.6 x direction displacement summary

We began by calculating the overall displacement in the x-direction, as shown in the diagram, and the most impacted region appears to be in the middle area of the corrugated floor (along the long length of the hall) near the vault, as well as the central area under the inclined arches. Both of these zones were previously identified as being at risk. In the locations recently examined, the overall displacement (USUM) combined with this direction is a significant entity, measuring roughly 16mm (1.59cm).

5.1.2 Displacement in Y Direction

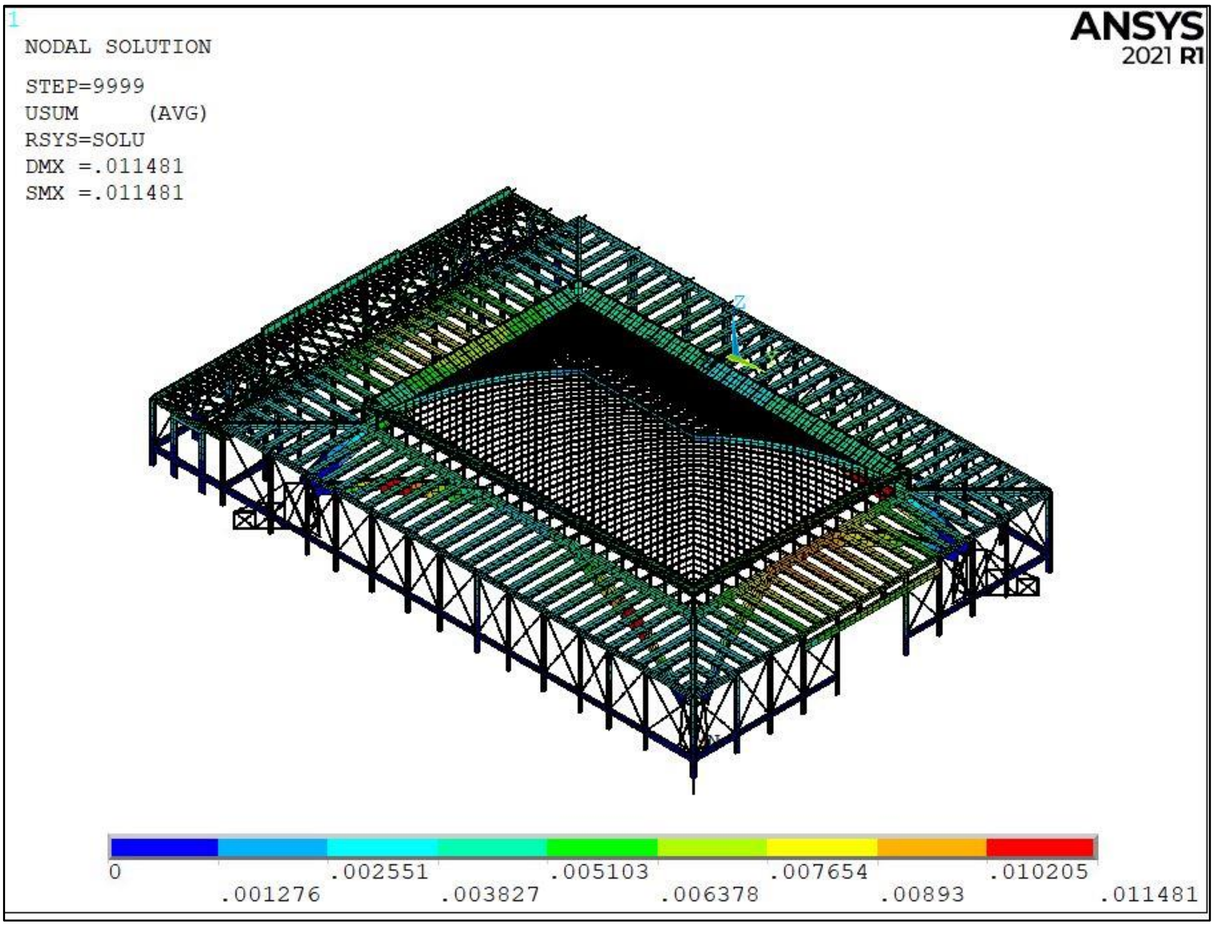


Figure 5.6 Usum dispalcement in Y direction

Y_ Displacement	[mm]
Ux	9.68
Uy	8.42
Uz	6.92
Usum	11.32

Table 5.7 y direction displcement summary

The corrugated floor on the short side of the hall looks to be more significantly impacted in the y-direction. In this situation, the inclined arches are still engaged in considerable displacements, but there is less influence in the area of the long arch's midsection, but mostly in the area specified as 14 of the arch, compared to the prior direction. In this direction, the overall displacement is around 11.32mm (1.13 cm).

5.1.3 Displacement in Z Direction

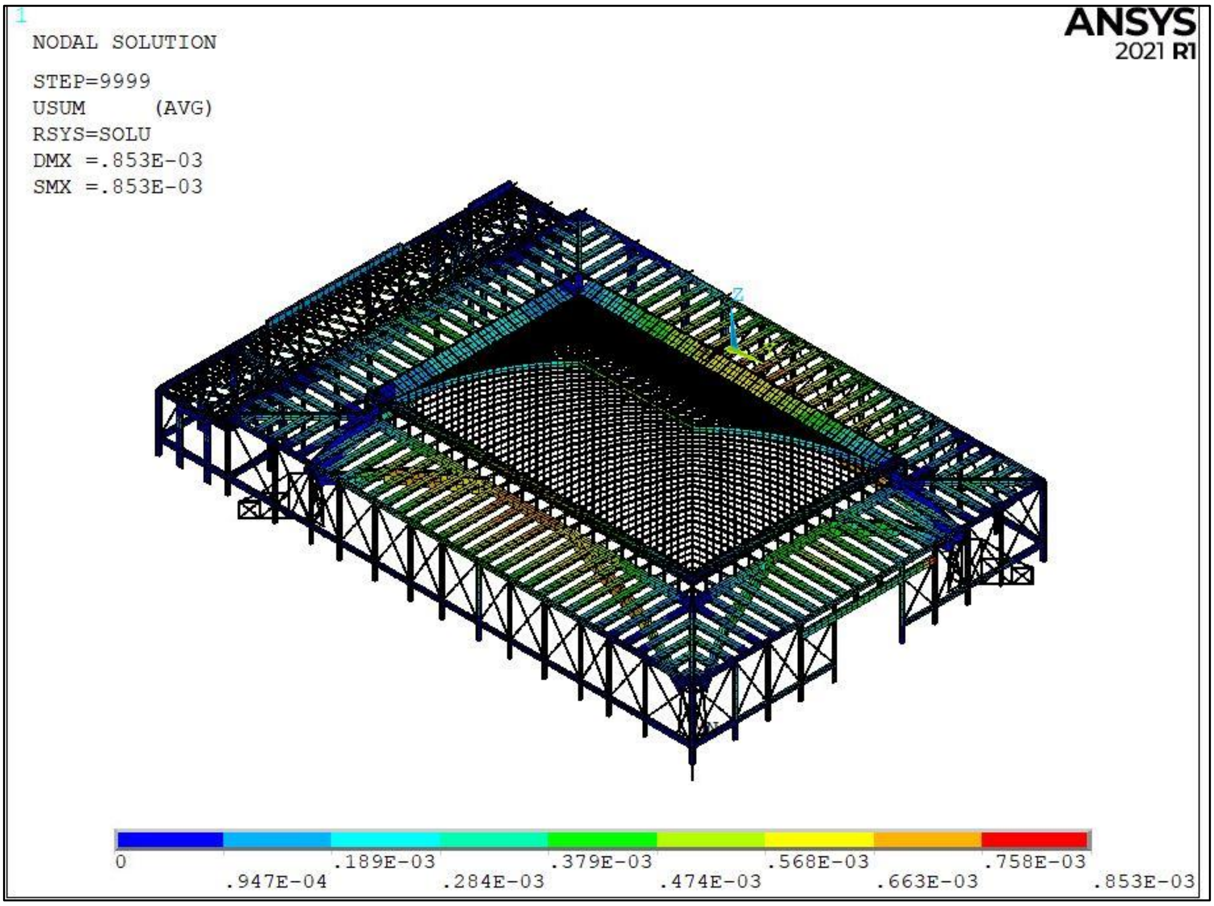


Figure 5.7 Total displacement in Z direction

Z_ Displacement	[mm]
Ux	0.694
Uy	0.845
Uz	0.599
Usum	0.845

Table 5.8 z direction displacement summary

The quantities fall dramatically in the z direction, barely surpassing one millimeter. Because z is not the major direction of seismic motion, it operates with lower order displacements than x and y. The four center sides of the corrugated floor, the pavilion vault at the central rib, and a portion of the roof of the side gallery are the parts most exposed in this example. In this direction, the greatest displacement is roughly 0.85 mm.

5.2 Seismic Stresses Calculation

The ANSYS mechanical 17.2 program is used to compute the seismic stresses completely automatically for each structural member. Considered is the soliciting seismic activity, which acts independently in all three directions. Three sets of stresses are determined in this manner, each one corresponding to a different direction.

The stresses in each structural component for each direction taken into consideration are output using a script made especially for this purpose. The values of the spectrum in terms of frequency and accelerations, the kind of combination to be utilized, and the number of modes to compute must all be specified in this set of commands.

The moment, shear, and normal values associated with each mode of vibration have been integrated using a statistical criterion: the NTC 2008 outlines two approaches for combining the effects of the various modes.
The first method, known as SRSS, calculates the combined effect by taking the square root of the total of the squares of the effects of the various modes:

$$E_d = \sqrt{E_1^2 + E_2^2 + E_3^2 \dots E_N^2}$$

where N is the number of ways to vibrate.

The CQC (complete quadratic combination) is used when the modal periods differ by less than 10% and contains a correlation coefficient between the distinct modes.

$$E_d = \sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N} \rho_{ij} \cdot E_i \cdot E_j}$$

$$\rho_{ij} = \frac{8\zeta^2 \beta_{ij}^{3/2}}{(1-\beta_{ij})\left[(1-\beta_{ij})^2 + 4\zeta^2\beta_{ij}\right]}$$

where βij is the ratio between the inverse of the periods of each pair of modes i-j ($\beta ij = T_j/T_i$) and ζ is the viscous damping. Since there are modes that are extremely near to one another in the frequency domain, as was clearly evident during the modal analysis, the CQC combination approach is employed in the scenario at hand.

The data are collected and combined automatically using ANSYS mechanical APDL. The stated results were obtained straight from software.

Normal stress, bending stress in y and z directions, and shear stresses in y and z directions are characterized sequentially as Fx, My, Mz, SFy, SFz. All of the findings from each direction have been provided in the following chapters for the most critical components that have been taken into account and described before chapter in 6.2.

5.2.1 Seismic Action In X-Direction

The most significant stresses in the elements at risk are produced by the seismic activities occurring in the x-direction, which appear to have the greatest influence on the structure. In this instance, both the normal stress and the shear stress in the z and y directions appear to be particularly prevalent at the base of the inclined arches on the long side. On the other hand, it appears that the section at the base of the corner pier experiences more bending moment in the y direction than it does in the z direction at the base of the short arch.

ELEM	FX	MY	SFZ	MZ	SFY
	[N]	[Nm]	[N]	[Nm]	[N]
1753	619320	195890	40990	417690	99697
1761	618690	216570	34328	252240	81718
1841	567830	328580	97168	244860	82501
1847	567390	219940	92280	209820	72777
1523	363650	104530	12747	33955	34061
4662	12854	2288.6	4760.7	1648	9729.1
4676	121030	46914	18874	1720	2137.6
779	6733.1	689.61	5083.6	2016.2	556.37
8734	4044.5	727	1013.8	3040.9	2222.2
1921	85141	411640	70408	123190	32801
1927	93555	202560	68544	27825	29301

Table 5.9 Seismic stresses on critical elements in x direction

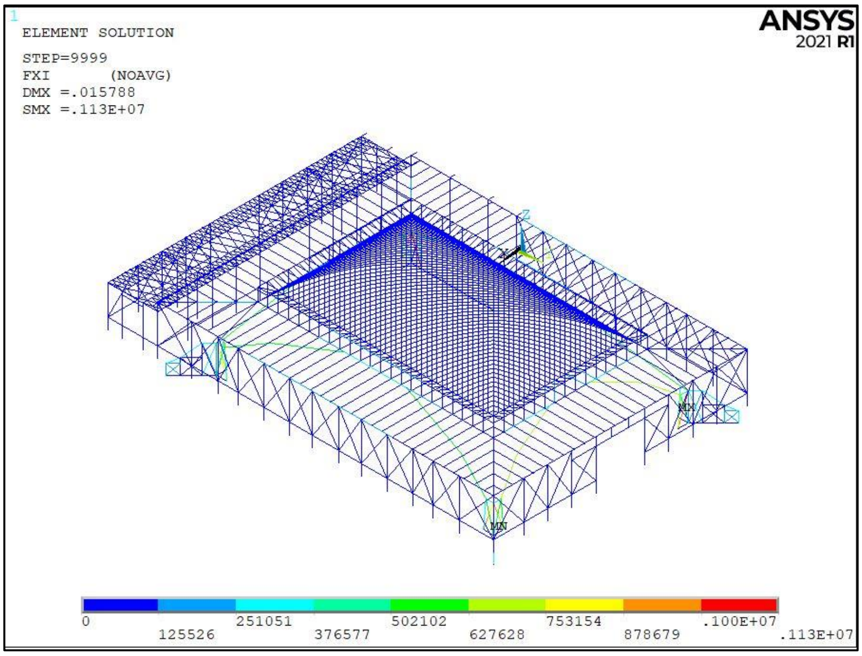


Figure 5.8 Normal stresses on axial direction

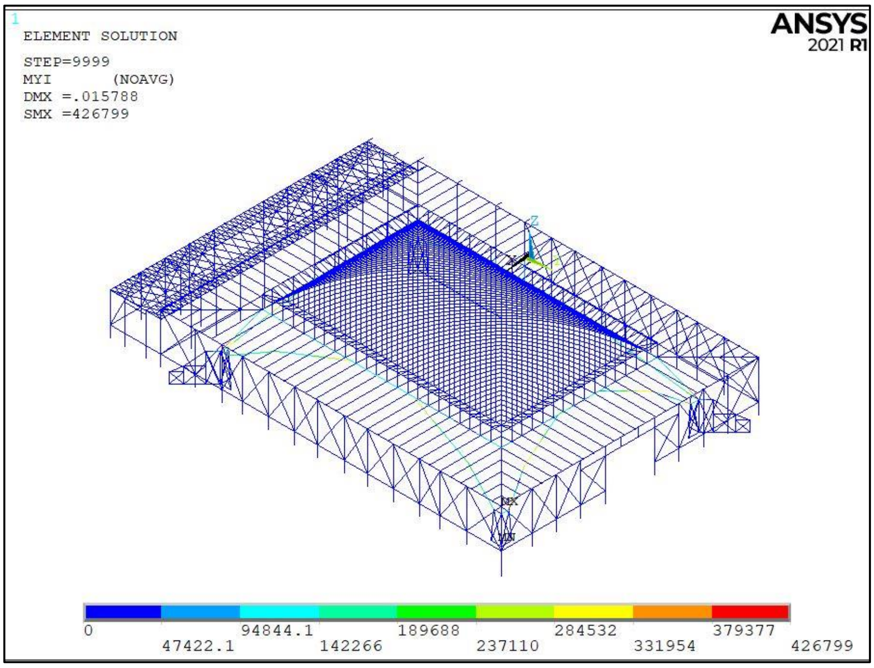


Figure 5.9 Bending stresses (My)

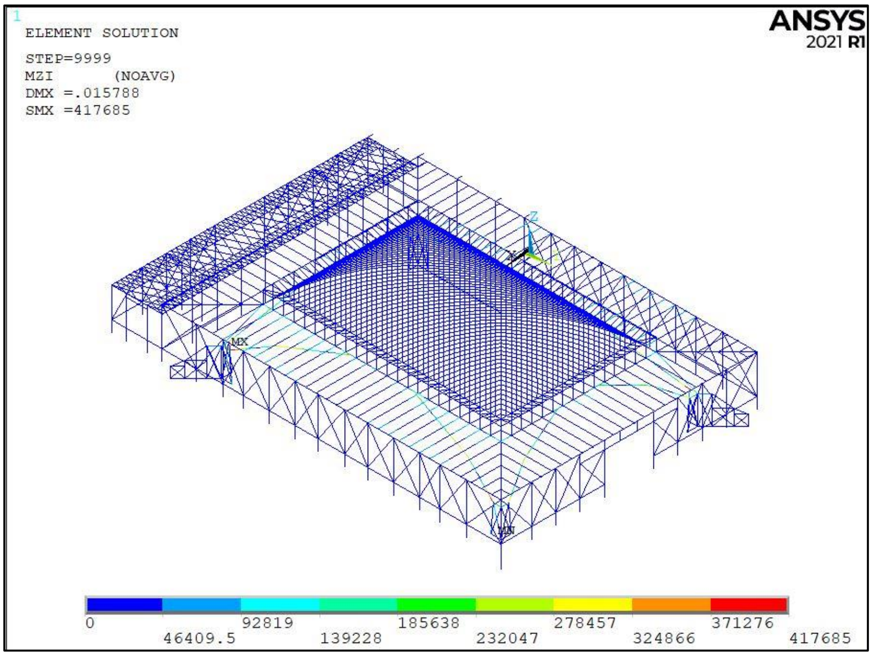


Figure 5.10 Bending stresses (Mz)

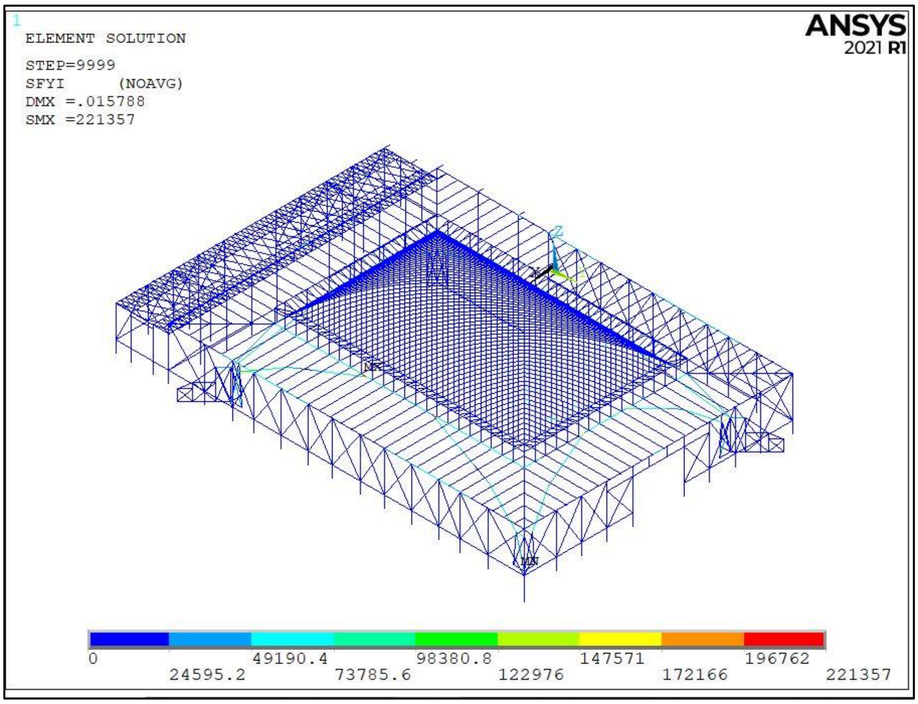


Figure 5.11 Shear stresses (Ty)

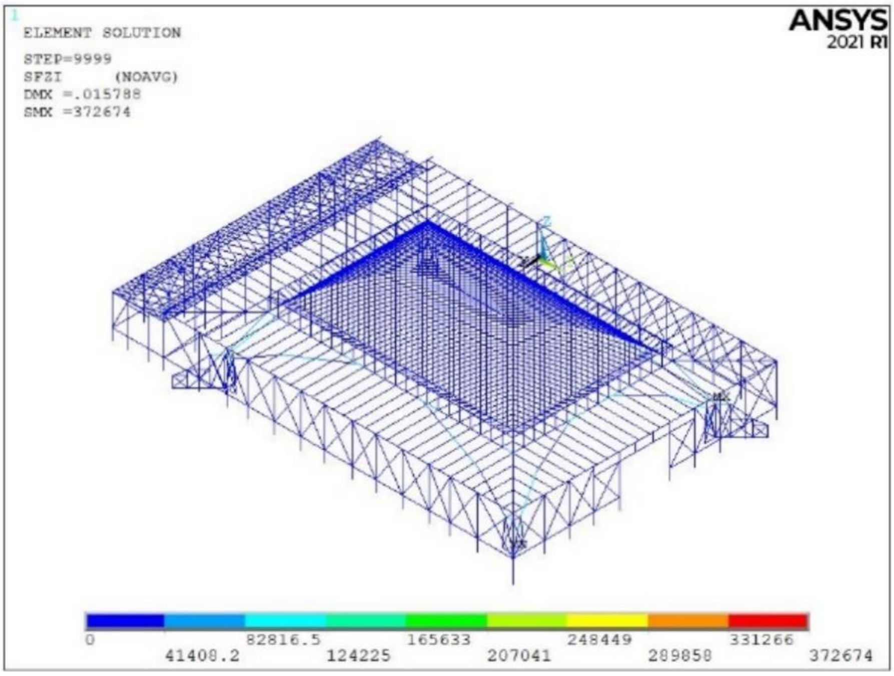


Figure 5.12 Shear stresses (Tz)

5.2.2 Seismic Action In Y-Direction

The stresses in the y direction are calculated by considering just the spectral accelerations in the y direction. The arches at the base and the midpoints of the structure are the most affected. The normal and shear stresses are larger in these portions compared to the other parts because of the seismic applied in the y direction. Table 6.9 shows the results obtained by the program after CQC combination for the most critical parts. Following that, the results were plotted and reports were written.

ELEM	FX	MY	SFZ	MZ	SFY
	[N]	[Nm]	[N]	[Nm]	[N]
1753	663040	397870	96610	402210	106550
1761	662210	272820	88536	309350	85415
1841	291170	136220	9999.1	206650	57028
1847	290970	125320	7162.2	106170	49221
1523	145550	70901	32111	58562	56893
4662	8022.5	3592.7	585.71	2333.6	14077
4676	132330	62859	24023	1826.3	556.27
779	24344	390.87	675.46	3306.6	3694.9
8734	4862.3	50.229	199.27	12318	8422.9
1921	75246	549530	87136	155900	38464
1927	72719	287850	84881	43907	39578

Table 5.10 Seismic stresses on critical elements in y direction

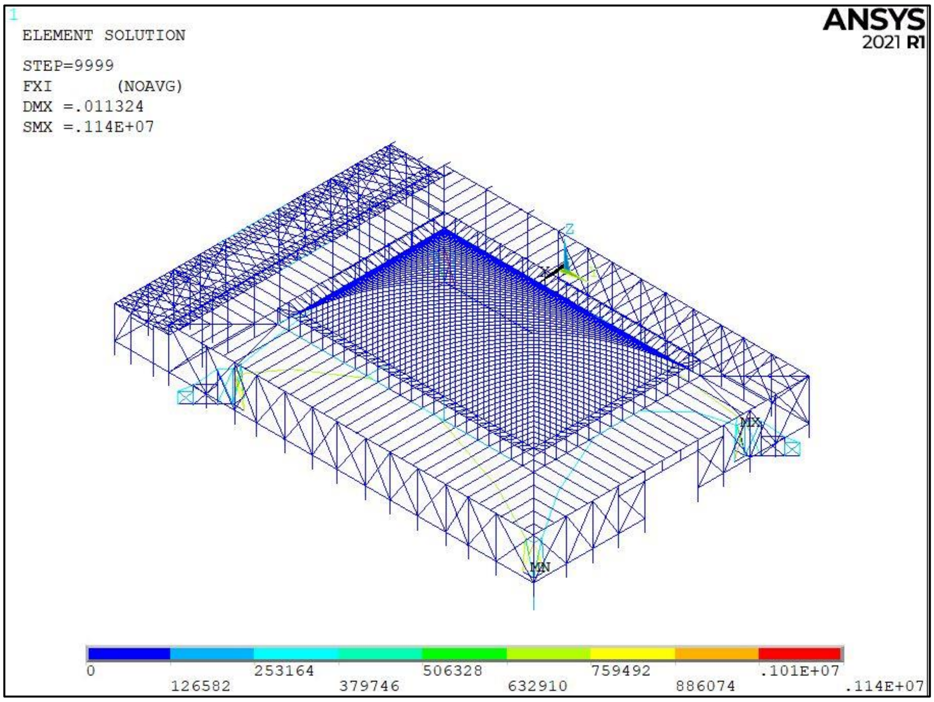


Figure 5.13 Normal stresses (Fx)

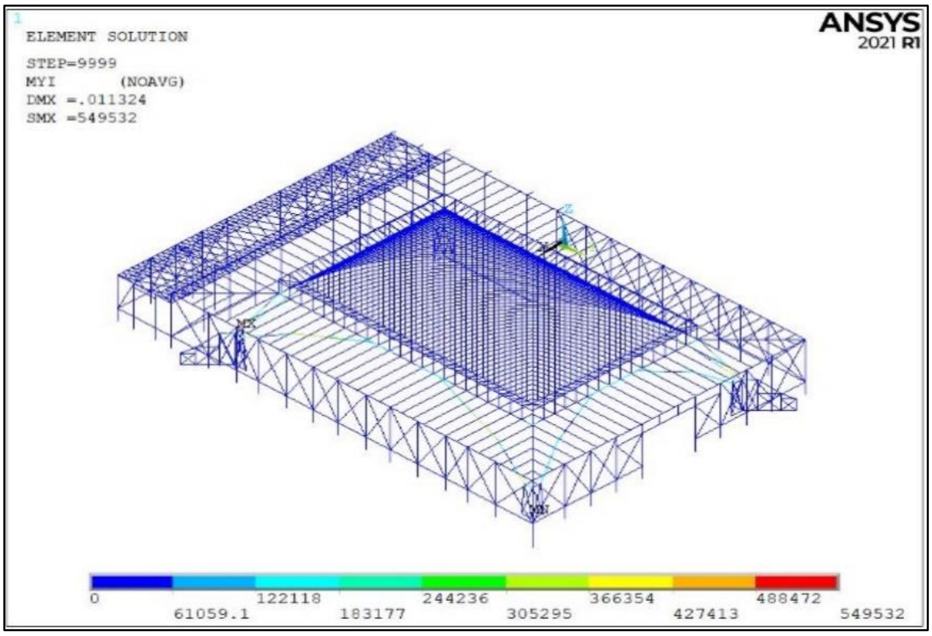


Figure 5.14 bending stresses(My)

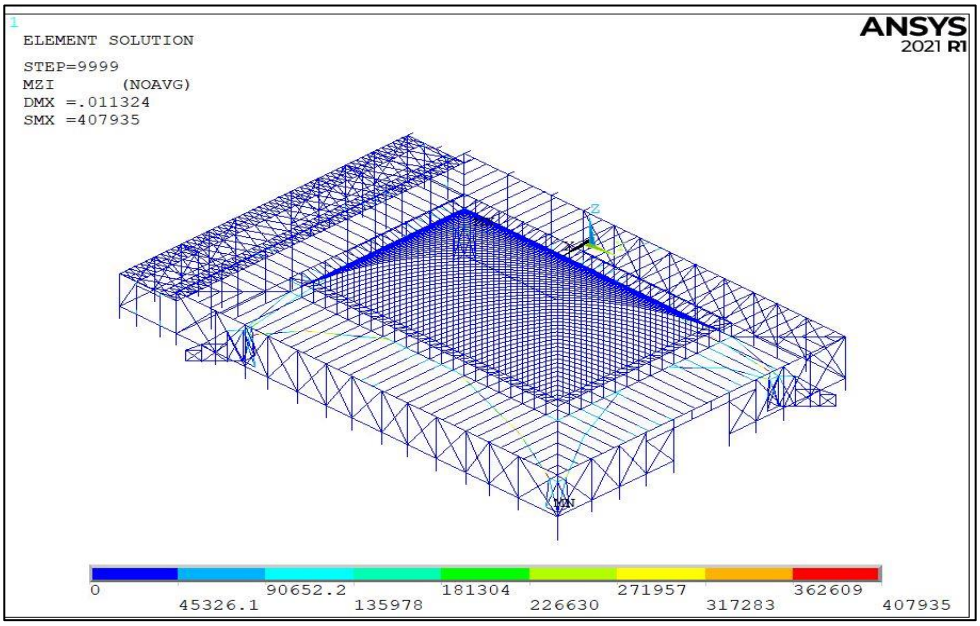


Figure 5.15 Bending stresses (Mz)

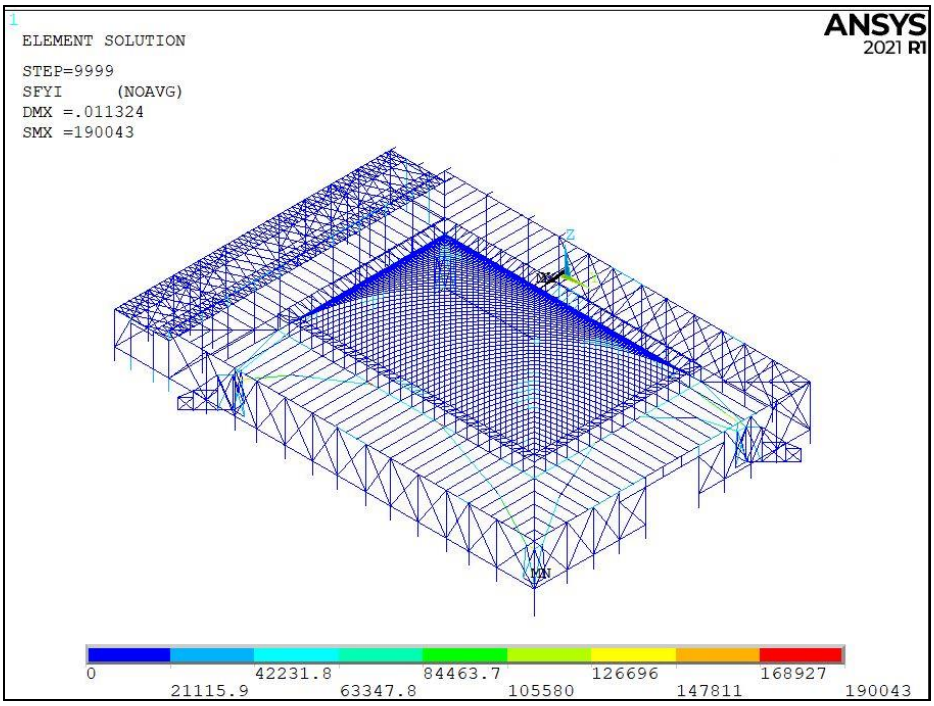


Figure 5.16 Shear stresses (Ty)

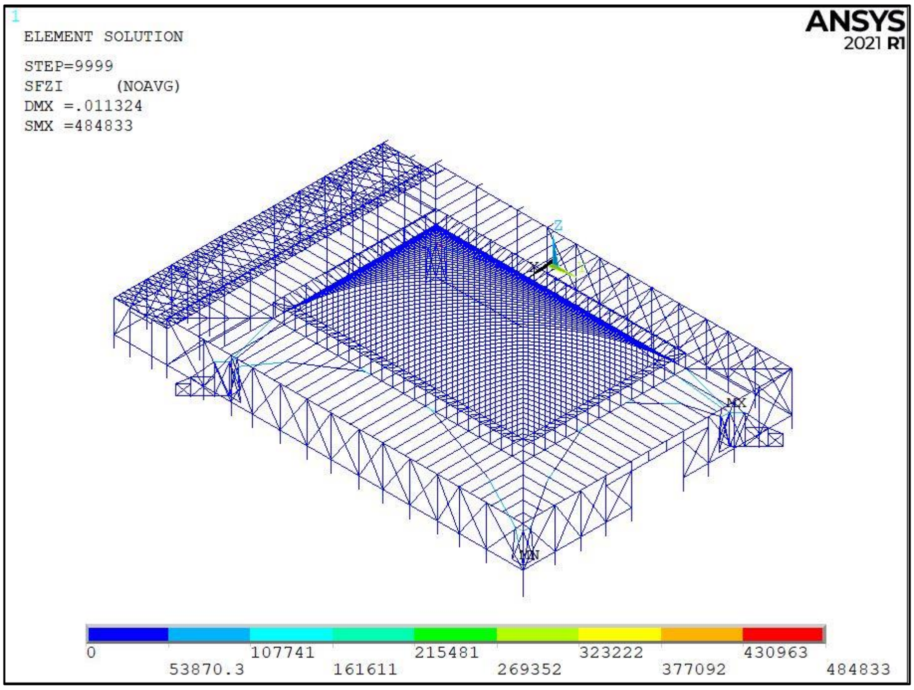


Figure 5.17 Shear stresses (Tz)

5.2.3 Seismic Action In Z-Direction

The stresses in the z direction are determined by taking just the spectral accelerations in the z direction into account. Because z direction isn't our major direction while seismic applied on structure ,it has not been reported significant effects on the structure. Table 6.10 shows the results obtained by the program after CQC combination for the most critical parts. Following that, the results were plotted, and reports were written.

ELEM	FX	MY	SFZ	MZ	SFY
	[N]	[Nm]	[N]	[Nm]	[N]
1753	58946	20399	5811.8	21752	5478.4
1761	58711	19058	3827.5	14893	4290.5
1841	25281	6026.8	2107.4	16333	5502.7
1847	25223	8896.3	1827.7	12258	3933.3
1523	37492	5434	731.47	1690.7	1189.6
4662	4384.4	751.82	357.72	217.87	1317.8
4676	48291	3106.8	1825.4	90.054	147.24
779	3145	64.589	59.316	881.22	385.16
8734	2039.9	7.344	51.372	455.33	383.24
1921	66481	14147	5050.3	4551.5	1659.7
1927	66574	3657.1	5319.1	634.23	1416

Table 5.11 Seismic stresses on critical elements in z direction

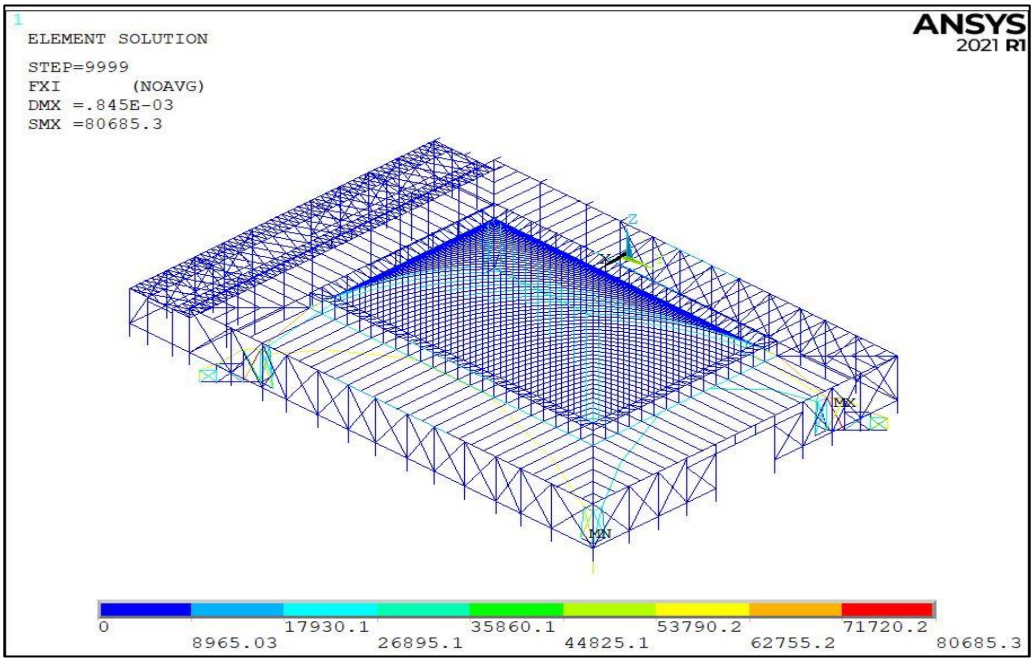


Table 5.12 Normal stresses(Fx)

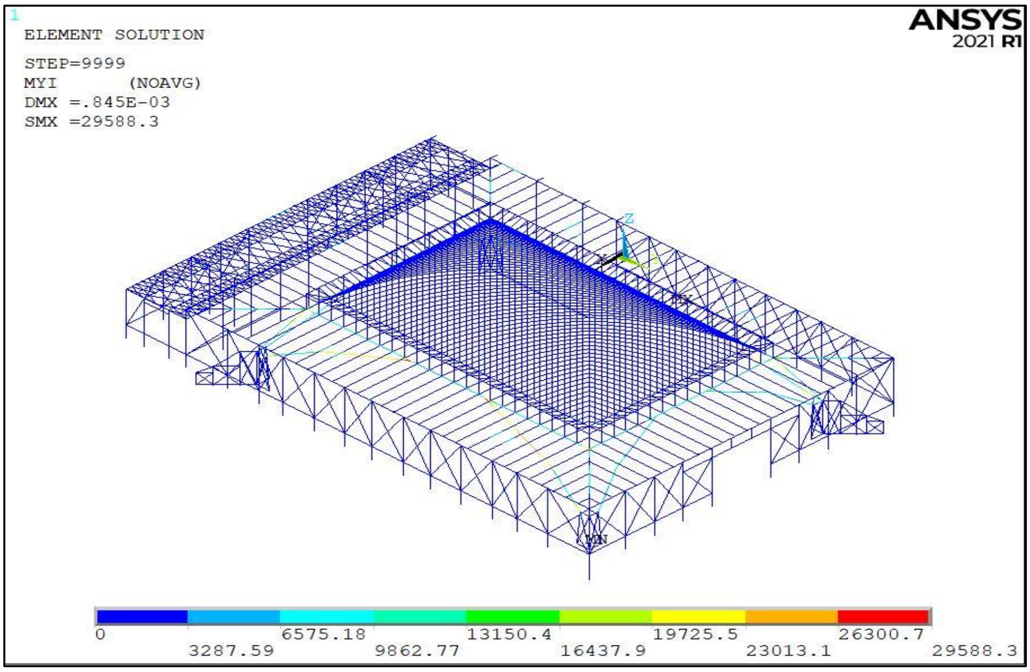


Figure 5.18 Bending stresses (My)

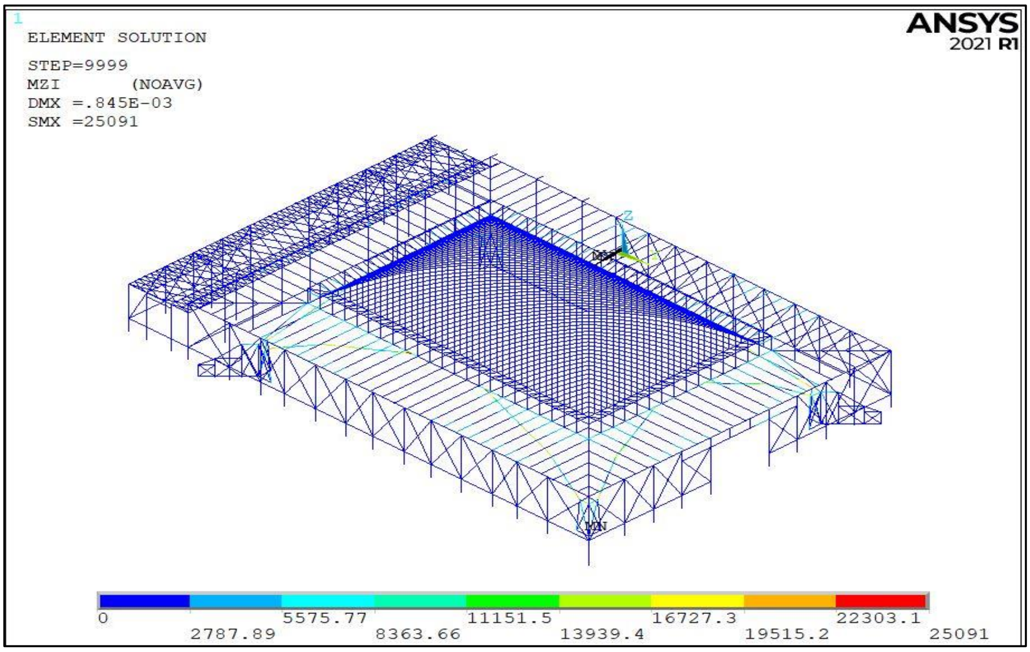


Figure 5.19 Bending stresses (Mz)

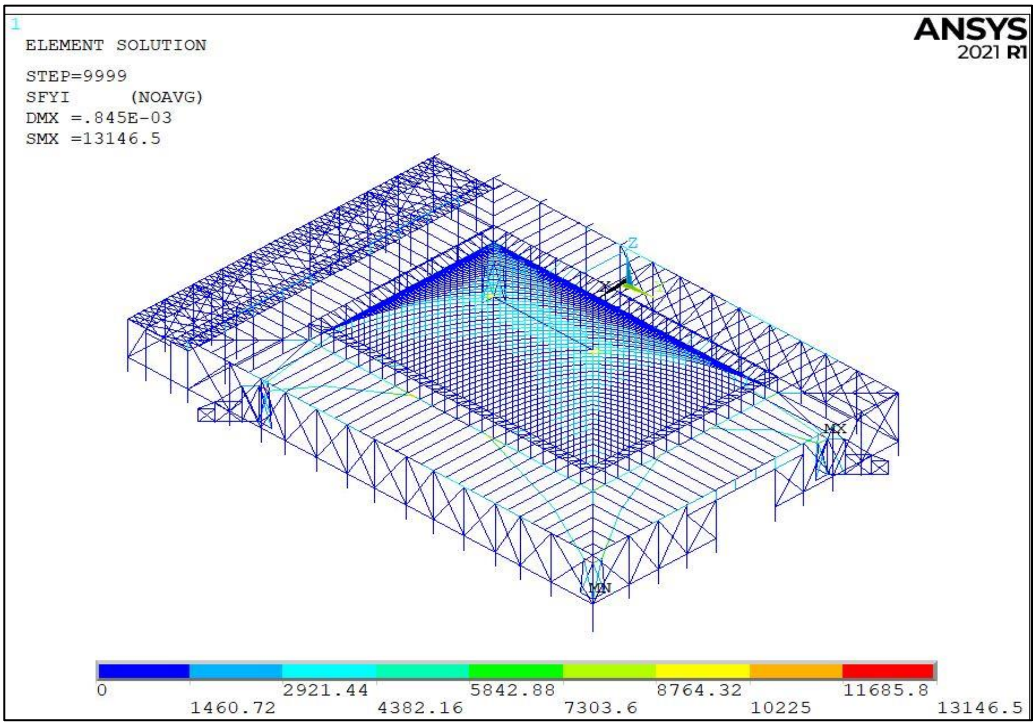


Figure 5.20 Shear stresses (Ty)

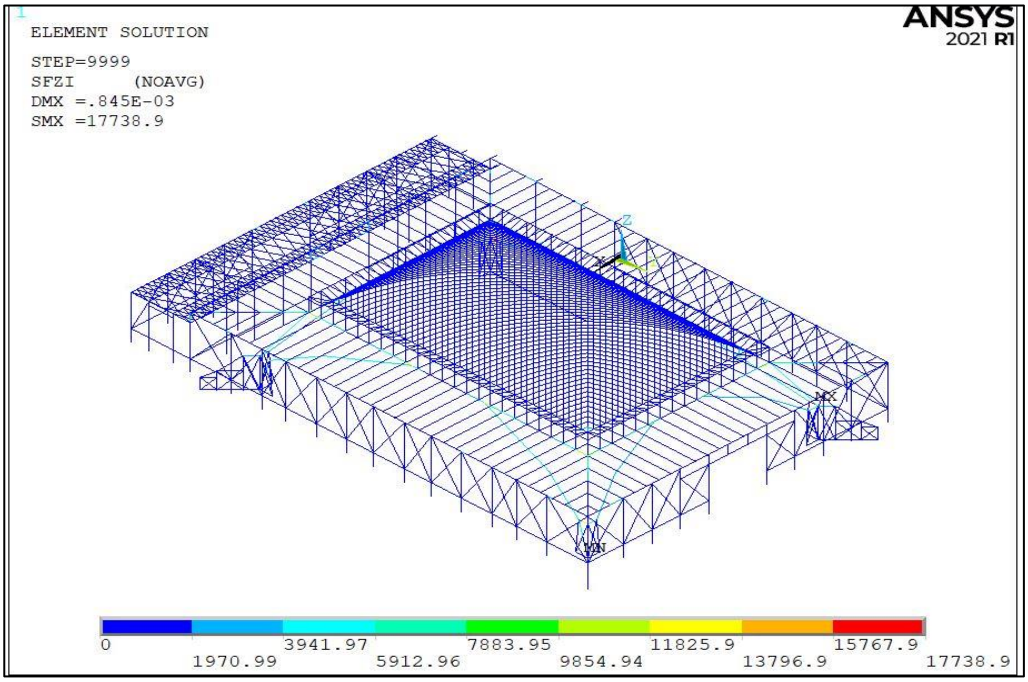


Figure 5.21 Shear stresses (Tz)

Chapter 6

6. Seismic Assessment

Prior to determining the seismic behavior of existing structures, it is important to identify the structural system aspects of the existing structures. Additionally, examining the building's construction history and learning about any prior damage, repairs, or modifications allows for the collection of crucial information. The project plan can be used to determine the existing structure; if not, survey studies can be used. The project plan can also be used to evaluate the strength of the structural materials used to build the structure, as well as the results of material tests and ground surveys. [9] The structural characteristics of existing engineering constructions should be accurately assessed. to ascertain the structural system qualities of the structures, which are unknown given the circumstances under which they were constructed in the past, and how much damage they sustained as a result of the events that transpired while they were in use (earthquakes, meteorological effects, fatigue, creep, etc.) [9] [10]

The critical sections which have been defined and mentioned before have been taken into account in order to analyze the seismic behavior of the structures. The cross sections of elements and material has been used for that element has taken from “Investigations on the structural criticalities of Pier Luigi Nervi's Hall C in the Turin Exhibition Center” academic master thesis which has been written by Virginia Sparascio. The reinforcement of the sections have taken from “Report 3: Torino Esposizioni, Salone C. Experimental investigations on structures”.

6.1 Combinations of Actions

The seismic combinations are made by defining three drag vectors in the three stress groups that correspond to the three orientations. In the table below it is reported the case study as an combination of stresses that obtained. totally for each element there are 48 combinations of dynamic plus static analysis results and one has been considered only for the case of static analysis. Hence, 49 options have been considered for each element and each direction.

Table 7.1 indicates the combinations of seismic actions which has been taken into account while verifying the elements and it has been defined by case number as it shows in table from 1 to 24 cases for one direction since y and z directions have been considered the total permutations are 48 and one is evaluated by using only static analysis results or considering vertical actions on structure.

The seismic combinations are formed by creating three drag vectors based on the three stress groups associated with the three orientations. For instance, the most common earthquake combination X will be:

[Case 1] 1 Ex+0.3Ey+0.3Ez

where Ei are the program's output stress groups. In order to enhance the impact, static stresses with their own sign are added to seismic stresses. The combination indicates that seismic action have a 100 percent effect in the X direction, a 30 percent effect in the Y direction, and a 30 percent effect in the Z direction. Then a summary of these 3 direction results has been written and named case 1. The other combinations have been considered for each and every permutation obtained like case 1. The results of all permutations considered for verification of pressoniflation and shear stresses for each and every critical element.

CASE 1	1Ex+0.3Ey+0.3Ez
CASE 2	1Ex+0.3Ey-0.3Ez
CASE 3	1Ex-0.3Ey-0.3Ez
CASE 4	1Ex-0.3Ey+0.3Ez
CASE 5	-1Ex+0.3Ey+0.3Ez
CASE 6	-1Ex+0.3Ey-0.3Ez
CASE 7	-1Ex-0.3Ey-0.3Ez
CASE 8	-1Ex-0.3Ey+0.3Ez
CASE 9	0.3Ex+1Ey+0.3Ez
CASE 10	0.3Ex+1Ey-0.3Ez
CASE 11	-0.3Ex+1Ey-0.3Ez
CASE 12	-0.3Ex+1Ey+0.3Ez
CASE 13	0.3Ex-1Ey+0.3Ez
CASE 14	0.3Ex-1Ey-0.3Ez
CASE 15	-0.3Ex-1Ey-0.3Ez
CASE 16	-0.3Ex-1Ey+0.3Ez
CASE 17	0.3Ex+0.3Ey+1Ez
CASE 18	0.3Ex-0.3Ey+1Ez
CASE 19	-0.3Ex-0.3Ey+1Ez
CASE 20	-0.3Ex+0.3Ey+1Ez
CASE 21	0.3Ex+0.3Ey-1Ez
CASE 22	0.3Ex-0.3Ey-1Ez
CASE 23	-0.3Ex-0.3Ey-1Ez
CASE 24	-0.3Ex+0.3Ey-1Ez
Static anlaysis	$E_{d,static}$

Table 6.1 seismic combinations

6.2 Verification

The bending and shear check is performed for each part in the selected critical elements which is shown in figure 6.4 chapter 6. It has been used the combinations of stresses indicated in Table 7.1. The mechanical properties of concrete and cross sections of elements which are defined in previous chapter have been taken from previous works which has been done on Turin exhibition center C Hall [11]. The steel mechanical properties are established based on information gathered through archives and publications on the materials used at the time [12] [13] , and the legislation in effect at the time of construction is utilized to categorize them [14]. The reinforcement quantities information are taken from report which is performed some destructive and non-destructive tests. [15]

Due to lack of information about the structure present regulations suggest that about resistances of material to be decrease by confidence factor which is defined 1.35.

The studied analyses are utilized to determine where the structure has weaknesses in terms of static and dynamic capability in order to rationally lead and arrange the experimental testing. This allows us to zero in on certain regions of the structure and study them quantitatively using more precise models.

It is reported below for the analysis has been done step by step;

1. Stress calculations with respect to the combinations of static and dynamic actions which has been defined before

2. Sectional properties of the elements which has been reported before

3. Verification with bending-compression (presso flessione)

4. Shear verification using MATLAB code as well as Excel file

5. Bending Moment-Normal Forces interaction diagram [M-N]

Excel file was utilized for the calculation, combination, and verification results. To utilize the final values for verifications, the solicitations collected in the preceding stage are merged as follows:

$$E_d = (M_i \;\; V_i \;\; N_i \;) \pm (M_i \;\; V_i \;\; N_i \;)_{CQC}$$

$$E_{d,i+} = E_{STA,i} \pm \left|E_{CQC,i}\right|$$

6.2.1 Assessment with Interaction Domain

The values which have been taken from combination of action have been used in order to check in interaction domain. It has been used the excel file which is provided by Prof. Alessandro Fantilli to check M-N interaction diagram.

For the assessment of the existing structure, we have to consider the biaxial bending and we can use a simplified way, by conducting the verification separately in each direction, with the uniaxial moment of resistance reduced by 30%. It is shown below the critical section comparing with the interaction diagram. Then, it must be checked that The ratio between normal stressing and resistant stress of the concrete alone must be less than 0.65.

$$\frac{N_{Ed}}{f_{cd}A_c} \leq 0.65$$

The all-critical elements have been checked and verified all of with respect to the empirical formula.

6.2.1.1 EL 1753 (Long Archway At The Base)

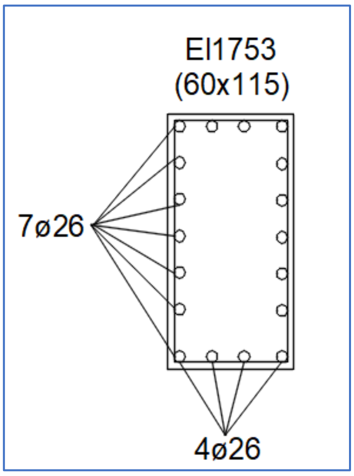


Figure 6.1 El1753 cross section

In the Figure 7.1 indicates the cross-section of element (El1753) which is represent C hall's long archway at the base point. It has been defined by 60 cm width and 115 cm in depth. The reinforcement quantities are 4Φ26 at the bottom and top ,7Φ26 at the side of the cross-sections. The concrete which has been used for the element is TIP680 which has 46 MPa characteristic strength and it has assumed that steel characteristic strength is 260 MPa from the report that has been written in 1950-1980. [13]

The below Table 7.2 and table 7.3 have been reported the static analysis and combination of actions with respect to the dynamic analysis results. The static analysis results have been taken from previous work which has been done before [11]. The combinations of actions have been done by using excel file.

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-2590000	435762	223663	-65398	899837

Table 6.2 static analysis results (EL1753)

In the Table 7.2 can be seen that the normal force on the long archway at the base point is 2590 kN. The bending moment in y axis is 435 kN in z axis is about 900 kN which is double of the y axis. The shear forces are 223 kN and 65 kN in y and z axis respectively.

EL1753	Estatic+ Ed					Estatic- Ed				
	N	My	Ty	Tz	Mz	N	My	Ty	Tz	Mz
	[N]	[Nm]	[N]	[N]	[Nm]	[N]	[Nm]	[N]	[N]	[Nm]
1Ex+0.3Ey+0.3Ez	-1754084	757132.7	356968.5	6318.54	1444716	-3425916	114391.3	90357.48	-137115	354958.4
1Ex+0.3Ey-0.3Ez	-1789452	744893.3	353681.5	2831.46	1431664	-3390548	126630.7	93644.52	-133627	368009.6
1Ex-0.3Ey-0.3Ez	-2187276	506171.3	289751.5	-55134.5	1190338	-2992724	365352.7	157574.5	-75661.5	609335.6
1Ex-0.3Ey+0.3Ez	-2151908	518410.7	293038.5	-51647.5	1203390	-3028092	353113.3	154287.5	-79148.5	596284.4
-1Ex+0.3Ey+0.3Ez	-2115066	643270.5	298136.4	-17229.3	1198017	-3064934	228253.5	149189.6	-113567	601657
-1Ex+0.3Ey-0.3Ez	-1873431	685516.1	337789.5	-11071.3	1372318	-3306569	186007.9	109536.5	-119725	427356.2
-1Ex-0.3Ey-0.3Ez	-1393102	870994.9	415800.6	29866.42	1691414	-3786898	529.12	31525.39	-160662	108259.8
-1Ex-0.3Ey+0.3Ez	-1634737	828749.3	376147.5	23708.34	1517113	-3545263	42774.7	71178.48	-154504	282560.6
0.3Ex+1Ey+0.3Ez	-1723480	898518.7	361765.6	45252.54	1433880	-3456520	-26994.7	85560.38	-176049	365794.4
0.3Ex+1Ey-0.3Ez	-1758848	886279.3	358478.6	41765.46	1420828	-3421152	-14755.3	88847.42	-172561	378845.6
-0.3Ex+1Ey-0.3Ez	-2130440	768745.3	298660.4	17171.46	1170214	-3049560	102778.7	148665.6	-147967	629459.6
-0.3Ex+1Ey+0.3Ez	-2095072	780984.7	301947.4	20658.54	1183266	-3084928	90539.3	145378.6	-151455	616408.4
0.3Ex-1Ey+0.3Ez	-2130440	768745.3	298660.4	17171.46	1170214	-3049560	102778.7	148665.6	-147967	629459.6
0.3Ex-1Ey-0.3Ez	-2095072	780984.7	301947.4	20658.54	1183266	-3084928	90539.3	145378.6	-151455	616408.4
-0.3Ex-1Ey-0.3Ez	-1723480	898518.7	361765.6	45252.54	1433880	-3456520	-26994.7	85560.38	-176049	365794.4
-0.3Ex-1Ey+0.3Ez	-1758848	886279.3	358478.6	41765.46	1420828	-3421152	-14755.3	88847.42	-172561	378845.6
0.3Ex+0.3Ey+1Ez	-2146346	634289	291015.5	-18306.2	1167559	-3033654	237235	156310.5	-112490	632115
0.3Ex-0.3Ey+1Ez	-2544170	475957	227085.5	-54523.8	926233	-2635830	395567	220240.5	-76272.2	873441
-0.3Ex-0.3Ey+1Ez	-2264238	593491	280058.7	-29929.8	1124055	-2915762	278033	167267.3	-100866	675619
-0.3Ex+0.3Ey+1Ez	-2517938	516755	231197.3	-42900.2	916945	-2662062	354769	216128.7	-87895.8	882729
0.3Ex+0.3Ey-1Ez	-2264238	593491	280058.7	-29929.8	1124055	-2915762	278033	167267.3	-100866	675619
0.3Ex-0.3Ey-1Ez	-2517938	516755	231197.3	-42900.2	916945	-2662062	354769	216128.7	-87895.8	882729
-0.3Ex-0.3Ey-1Ez	-2146346	634289	291015.5	-18306.2	1167559	-3033654	237235	156310.5	-112490	632115
-0.3Ex+0.3Ey-1Ez	-2544170	475957	227085.5	-54523.8	926233	-2635830	395567	220240.5	-76272.2	873441

Table 6.3 EL1753 combinations results

Table 7.3 shows the results which has been obtained from the combination with respect to the static actions and dynamic actions.

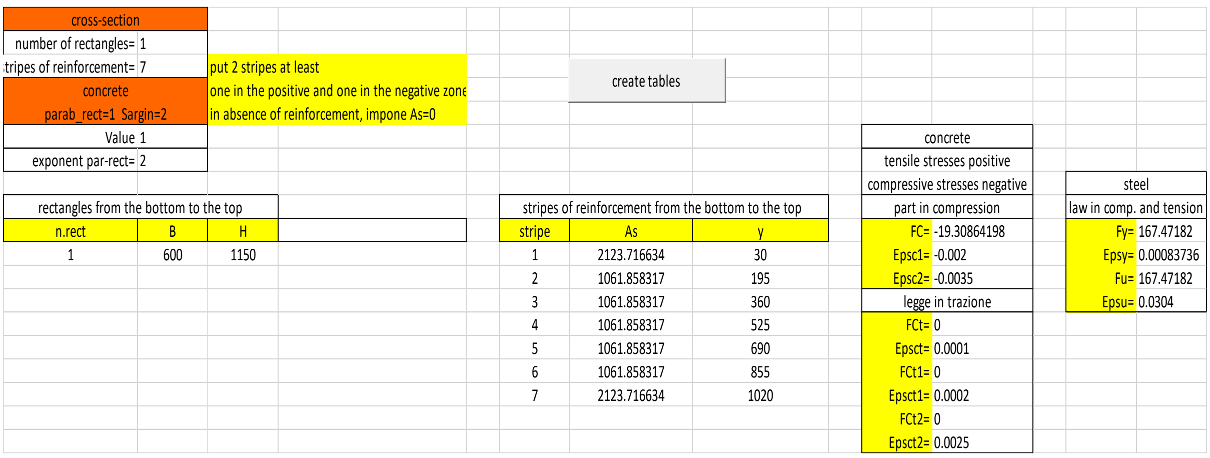


Figure 6.2 Excel file input parameter

The values are in millimeter (mm) and in the software it must been defined material properties which are f_{cd} and f_{yd} for concrete and steel, cross-section, stripes of reinforcement, reinforcement area and their location. After defining values, it has to run the macro excel file it will give general N-M interaction diagram.

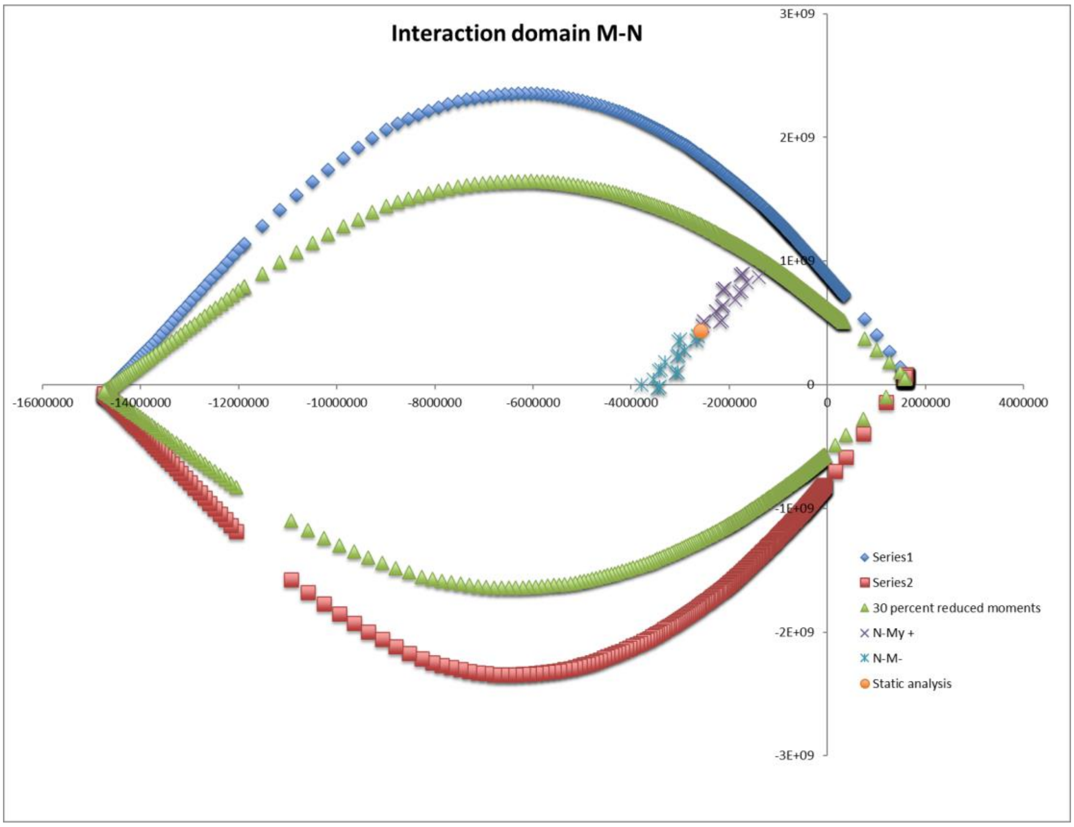


Figure 6.3 N -My interaction domain diagram (EL1753)

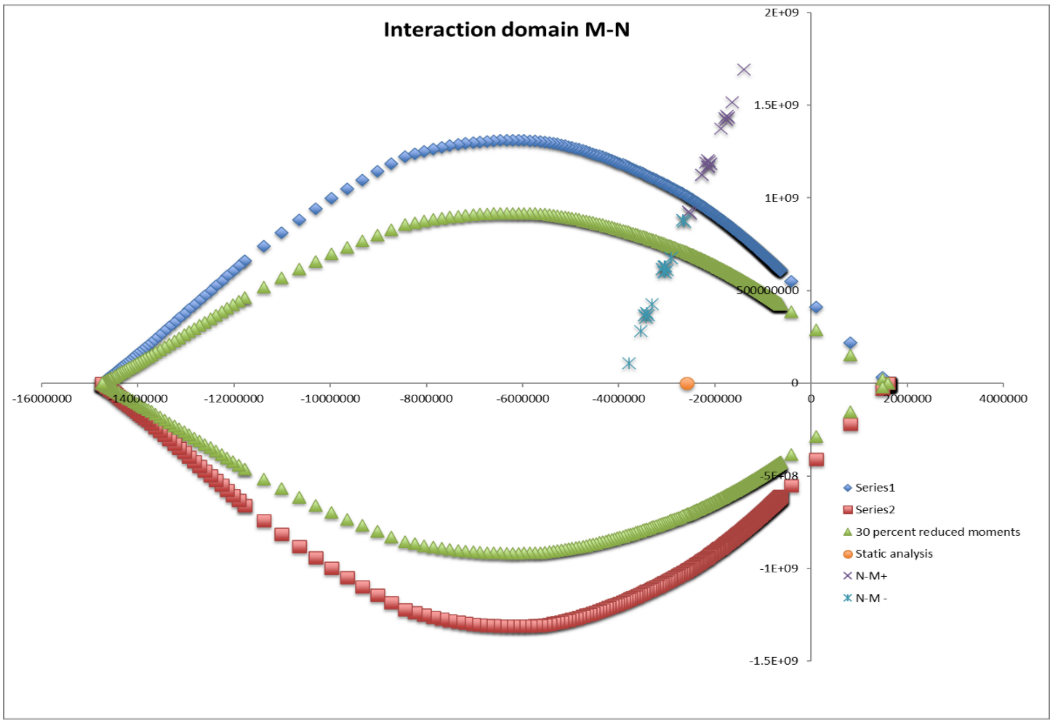


Figure 6.4 N -Mz interaction domain diagram (EL1753)

In the Figure 7.3 and Figure 7.4 were shown the graphicaly results Normal Force-Bending moment interaction diagram with respect to the in y and z axis. In the graph demonstrate blue and red line which are obtained by the excel macro code and the green is shown the 70 % of the general moment which is obtained by code. Because We must include biaxial bending while assessing the current structure, and we may simplify the process by doing the verification individually in each direction, with the uniaxial moment of resistance lowered by 30% as it mentioned before. The points which are purple, and blue represents the results of bending moment combinations with dynamic and static analysis which are totally 48 points. The orange point is represented the static analysis bending moment results.

In Figure 7.3, the bending moments derived from combination actions are expressed between the N-M interaction diagram, indicating that it is verified with regard to the y axis bending moment resistance. However, the result for z axis bending moments reported in Figure 7.4 are not totally verified since certain locations are outside of the defined graph. The pressure in z axis is high for the base of the long archway and pressoniflation isn't verified for the element in z axis.

Ned [N]	Fcd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c} \le 0.65$	Check
-1754084	19.31	690000	0.13	ok
-1789452	19.31	690000	0.13	ok
-2187276	19.31	690000	0.16	ok
-2151908	19.31	690000	0.16	ok
-2115066	19.31	690000	0.16	ok
-1873431	19.31	690000	0.14	ok
-1393102	19.31	690000	0.10	ok
-1634737	19.31	690000	0.12	ok
-1723480	19.31	690000	0.13	ok
-1758848	19.31	690000	0.13	ok
-2130440	19.31	690000	0.16	ok
-2095072	19.31	690000	0.16	ok
-2130440	19.31	690000	0.16	ok
-2095072	19.31	690000	0.16	ok
-1723480	19.31	690000	0.13	ok
-1758848	19.31	690000	0.13	ok
-2146346	19.31	690000	0.16	ok
-2544170	19.31	690000	0.19	ok
-2264238	19.31	690000	0.17	ok
-2517938	19.31	690000	0.19	ok
-2264238	19.31	690000	0.17	ok
-2517938	19.31	690000	0.19	ok
-2146346	19.31	690000	0.16	ok
-2544170	19.31	690000	0.19	ok
-3425916	19.31	690000	0.26	ok
-3390548	19.31	690000	0.25	ok
-2992724	19.31	690000	0.22	ok
-3028092	19.31	690000	0.23	ok
-3064934	19.31	690000	0.23	ok
-3306569	19.31	690000	0.25	ok
-3786898	19.31	690000	0.28	ok
-3545263	19.31	690000	0.27	ok
-3456520	19.31	690000	0.26	ok
-3421152	19.31	690000	0.26	ok
-3049560	19.31	690000	0.23	ok
-3084928	19.31	690000	0.23	ok
-3049560	19.31	690000	0.23	ok
-3084928	19.31	690000	0.23	ok
-3456520	19.31	690000	0.26	ok
-3421152	19.31	690000	0.26	ok
-3033654	19.31	690000	0.23	ok
-2635830	19.31	690000	0.20	ok
-2915762	19.31	690000	0.22	ok
-2662062	19.31	690000	0.20	ok
-2915762	19.31	690000	0.22	ok
-2662062	19.31	690000	0.20	ok
-3033654	19.31	690000	0.23	ok
-2635830	19.31	690000	0.20	ok
-2590000	19.31	690000	0.19	ok

Table 6.4 checking N_Ed/(f_cd A_c)

6.2.1.2 EL 1761 (Long Archway At The Middle Point)

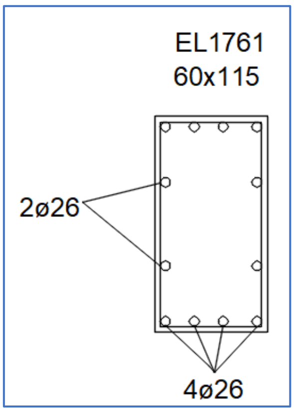


Figure 6.5 Cross-section (EL1761)

EL1761 is defined code name to represent long archway at the middle point in the software. It has the same cross section with the long archway at the base point but with different reinforcement quantities. It has 60cm width and 115cm depth. It has 4Φ26 at the bottom and top as well at the side of the rectangular cross-section. It has 2Φ26 in each side of the cross section of element. The results which has been taking from static analysis has been reported in Table 7.5.

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-2550000	435762	223663	67044	-890378

Table 6.5 Static analysis results (EL1761)

The values for normal, shear and bending moments are more or less the same as long archway at the base point which is EL1753 as defined.

EL1761	Estatic+ Ed					Estatic- Ed				
	N	My	Ty	Tz	Mz	N	My	Ty	Tz	Mz
	[N]	[Nm]	[N]	[N]	[Nm]	[N]	[Nm]	[N]	[N]	[Nm]
1Ex+0.3Ey+0.3Ez	-1715034	739895.4	332292.7	129081.1	-540865	-3384966	131628.6	115033.4	5006.95	-1239891
1Ex+0.3Ey-0.3Ez	-1750260	728460.6	329718.4	126784.6	-549801	-3349740	143063.4	117607.7	7303.45	-1230955
1Ex-0.3Ey-0.3Ez	-2147586	564768.6	278469.4	73662.95	-735411	-2952414	306755.4	168856.7	60425.05	-1045345
1Ex-0.3Ey+0.3Ez	-2112360	576203.4	281043.7	75959.45	-726475	-2987640	295320.6	166282.4	58128.55	-1054281
-1Ex+0.3Ey+0.3Ez	-2075680	613383.8	284034.1	109173.2	-689528	-3024320	258140.2	163291.9	24914.8	-1091228
-1Ex+0.3Ey-0.3Ez	-1834232	690787.8	316918	113144.6	-596548	-3265769	180736.2	130408.1	20943.43	-1184208
-1Ex-0.3Ey-0.3Ez	-1354388	866407	380551.2	148988.9	-392202	-3745612	5117.04	66774.84	-14900.9	-1388554
-1Ex-0.3Ey+0.3Ez	-1595836	789003	347667.4	145017.5	-485182	-3504164	82521	99658.65	-10929.5	-1295574
0.3Ex+1Ey+0.3Ez	-1684570	779270.4	334880.6	167026.7	-500888	-3415430	92253.6	112445.5	-32938.7	-1279868
0.3Ex+1Ey-0.3Ez	-1719796	767835.6	332306.3	164730.2	-509824	-3380204	103688.4	115019.8	-30642.2	-1270932
-0.3Ex+1Ey-0.3Ez	-2091010	637893.6	283275.5	144133.4	-661168	-3008990	233630.4	164050.6	-10045.4	-1119588
-0.3Ex+1Ey+0.3Ez	-2055784	649328.4	285849.8	146429.9	-652232	-3044216	222195.6	161476.3	-12341.9	-1128524
0.3Ex-1Ey+0.3Ez	-2091010	637893.6	283275.5	144133.4	-661168	-3008990	233630.4	164050.6	-10045.4	-1119588
0.3Ex-1Ey-0.3Ez	-2055784	649328.4	285849.8	146429.9	-652232	-3044216	222195.6	161476.3	-12341.9	-1128524
-0.3Ex-1Ey-0.3Ez	-1684570	779270.4	334880.6	167026.7	-500888	-3415430	92253.6	112445.5	-32938.7	-1279868
-0.3Ex-1Ey+0.3Ez	-1719796	767835.6	332306.3	164730.2	-509824	-3380204	103688.4	115019.8	-30642.2	-1270932
0.3Ex+0.3Ey+1Ez	-2107019	601637	278093.4	107730.7	-707008	-2992981	269887	169232.6	26357.3	-1073748
0.3Ex-0.3Ey+1Ez	-2504345	437945	226844.4	79478.9	-888138	-2595655	433579	220481.6	54609.1	-892618
-0.3Ex-0.3Ey+1Ez	-2224441	563521	269512.4	100075.7	-736794	-2875559	308003	177813.6	34012.3	-1043962
-0.3Ex+0.3Ey+1Ez	-2478233	471695	229062.6	87133.9	-858352	-2621767	399829	218263.4	46954.1	-922404
0.3Ex+0.3Ey-1Ez	-2224441	563521	269512.4	100075.7	-736794	-2875559	308003	177813.6	34012.3	-1043962
0.3Ex-0.3Ey-1Ez	-2478233	471695	229062.6	87133.9	-858352	-2621767	399829	218263.4	46954.1	-922404
-0.3Ex-0.3Ey-1Ez	-2107019	601637	278093.4	107730.7	-707008	-2992981	269887	169232.6	26357.3	-1073748
-0.3Ex+0.3Ey-1Ez	-2504345	437945	226844.4	79478.9	-888138	-2595655	433579	220481.6	54609.1	-892618

Table 6.6 Combination of actions results (EL1761)

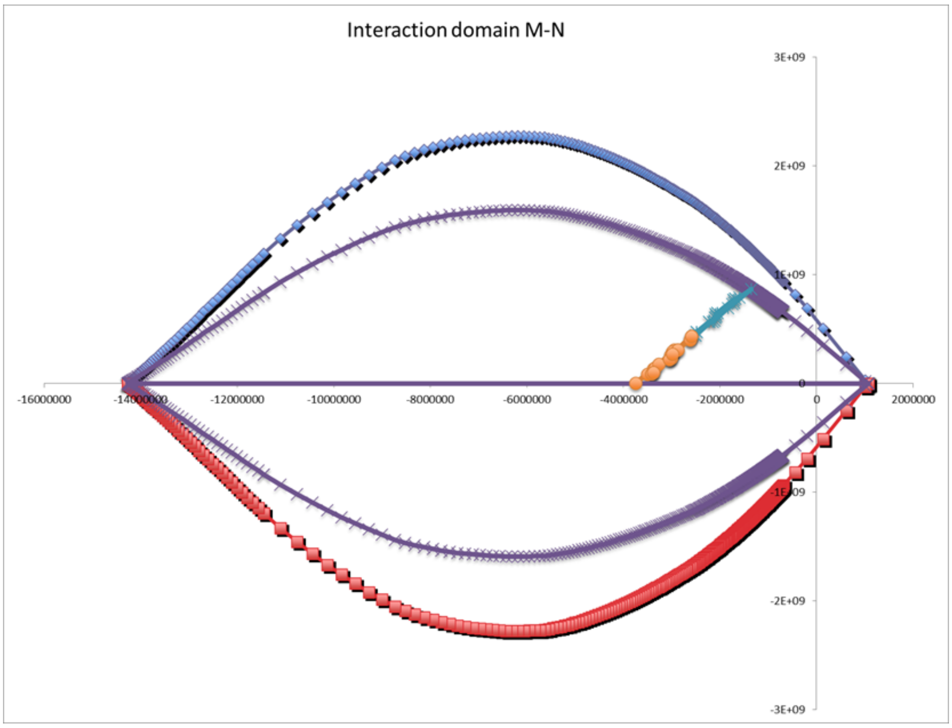


Figure 6.6 N-My interaction domain (EL1761)

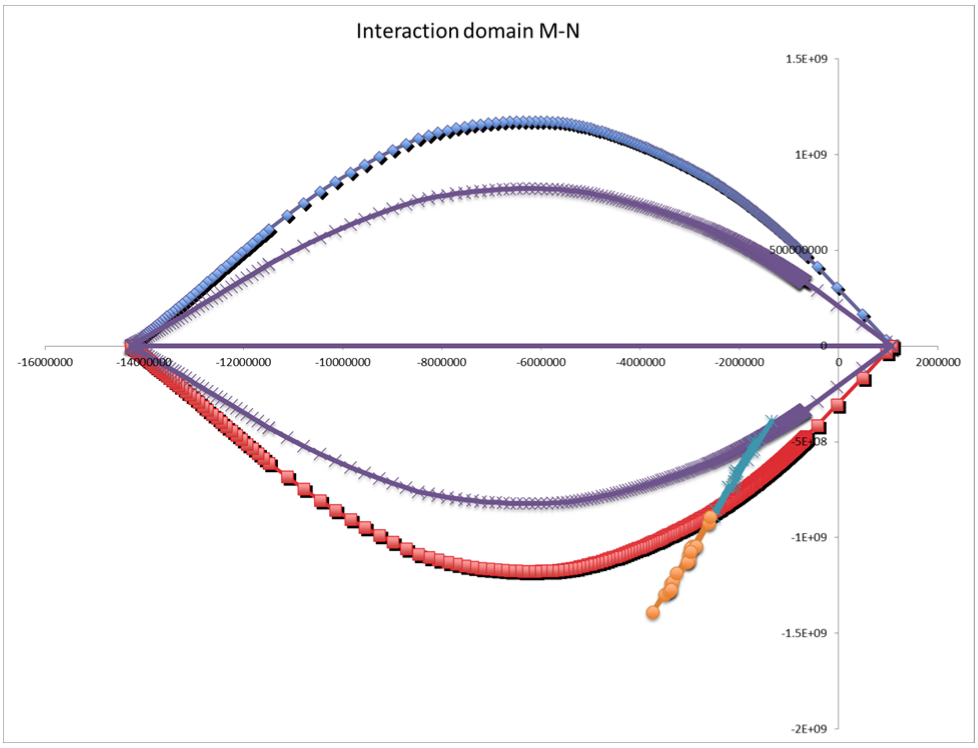


Figure 6.7 N-Mz interaction domain (EL1761)

In the Figure 7.6 is results which obtained from excel macro code by putting normal forces and bending moment which have been defined combination of actions. All points are between the graph which is defined 30 % reduced bending moment resistance. Therefore, it has enough resistance in the y axis with respect to bending moment combinations.

The Figure 7.7 is the results for the z axis normal forces- bending moment interaction diagram. The points are out of the graph which means that it’s not verified with respect to pressoniflation. The results are expected the same as the EL1753 because the stress is on the long archway in base and in the mid-point are more or less same.

Ned [N]	Fcd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c}$	Check
-1715034	19.31	690000	0.13	ok
-1750260	19.31	690000	0.13	ok
-2147586	19.31	690000	0.16	ok
-2112360	19.31	690000	0.16	ok
-2075680	19.31	690000	0.16	ok
-1834232	19.31	690000	0.14	ok
-1354388	19.31	690000	0.10	ok
-1595836	19.31	690000	0.12	ok
-1684570	19.31	690000	0.13	ok
-1719796	19.31	690000	0.13	ok
-2091010	19.31	690000	0.16	ok
-2055784	19.31	690000	0.15	ok
-2091010	19.31	690000	0.16	ok
-2055784	19.31	690000	0.15	ok
-1684570	19.31	690000	0.13	ok
-1719796	19.31	690000	0.13	ok
-2107019	19.31	690000	0.16	ok
-2504345	19.31	690000	0.19	ok
-2224441	19.31	690000	0.17	ok
-2478233	19.31	690000	0.19	ok
-2224441	19.31	690000	0.17	ok
-2478233	19.31	690000	0.19	ok
-2107019	19.31	690000	0.16	ok
-2504345	19.31	690000	0.19	ok
-3384966	19.31	690000	0.25	ok
-3349740	19.31	690000	0.25	ok
-2952414	19.31	690000	0.22	ok
-2987640	19.31	690000	0.22	ok
-3024320	19.31	690000	0.23	ok
-3265769	19.31	690000	0.25	ok
-3745612	19.31	690000	0.28	ok
-3504164	19.31	690000	0.26	ok
-3415430	19.31	690000	0.26	ok
-3380204	19.31	690000	0.25	ok
-3008990	19.31	690000	0.23	ok
-3044216	19.31	690000	0.23	ok
-3008990	19.31	690000	0.23	ok
-3044216	19.31	690000	0.23	ok
-3415430	19.31	690000	0.26	ok
-3380204	19.31	690000	0.25	ok
-2992981	19.31	690000	0.22	ok
-2595655	19.31	690000	0.19	ok
-2875559	19.31	690000	0.22	ok
-2621767	19.31	690000	0.20	ok
-2875559	19.31	690000	0.22	ok
-2621767	19.31	690000	0.20	ok
-2992981	19.31	690000	0.22	ok
-2595655	19.31	690000	0.19	ok
-2550000	19.31	690000	0.19	ok

Table 6.7 checking N_Ed/(f_cd A_c)

6.2.1.3 EL1841 (Short archway at the base)

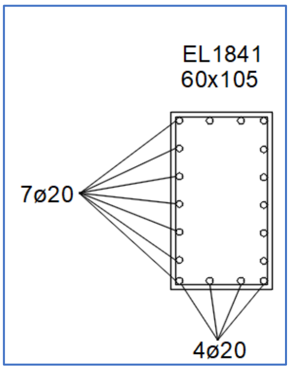


Figure 6.8 cross-section (EL1841)

EL1841 is defined in the code to represent the short archway at the base point. It has defined as beam188 element like others, and it is rectangular cross section which is 60 cm by 105 cm. it has 4Φ20 at the top and bottom. It has been placed 7Φ20 in each side of the element. The concrete cover is 3 cm. The concrete strength is 46 MPa and 260 MPa is the steel yielded strength.

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-1290000	-241427	135171	-64435.8	425833

Table 6.8 static analysis results (EL1841)

The Table 7.8 is shown the static analysis results. It has almost half stress values on the base of the short archway with respect to the long archway base point. The normal force is 1290 kN and shear forces are 135 kN 64 kN in y and z respectively. The bending moments are 241 kNm around y axis and 425 kNm around z axis which almost double in z axis.

EL1841	Estatic+ Ed					Estatic- Ed				
	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
1Ex+0.3Ey+0.3Ez	-627235	129827	236431.2	36364.15	737587.9	-1952765	-612681	33910.79	-165236	114078.1
1Ex+0.3Ey-0.3Ez	-642403	126211	233129.6	35099.71	727788.1	-1937597	-609065	37212.41	-163971	123877.9
1Ex-0.3Ey-0.3Ez	-817105	44478.96	198912.8	29100.25	603798.1	-1762895	-527333	71429.21	-157972	247867.9
1Ex-0.3Ey+0.3Ez	-801937	48095.04	202214.4	30364.69	613597.9	-1778063	-530949	68127.59	-159236	238068.1
-1Ex+0.3Ey+0.3Ez	-963382	-66236.1	187921.1	-21557.3	593611.8	-1616618	-416618	82420.9	-107314	258054.2
-1Ex+0.3Ey-0.3Ez	-679645	105307.4	226166.2	34564.31	700390.9	-1900355	-588161	44175.83	-163436	151275.1
-1Ex-0.3Ey-0.3Ez	-291087	325890.2	284941.3	94285.62	881564	-2288913	-808744	-14599.3	-223157	-29898
-1Ex-0.3Ey+0.3Ez	-574824	154346.6	246696.3	38163.99	774784.9	-2005176	-637201	23645.75	-167036	76881.1
0.3Ex+1Ey+0.3Ez	-820897	-4824.96	218600.1	-24654.1	710840.9	-1759103	-478029	51741.89	-104218	140825.1
0.3Ex+1Ey-0.3Ez	-836065	-8441.04	215298.5	-25918.5	701041.1	-1743935	-474413	55043.51	-102953	150624.9
-0.3Ex+1Ey-0.3Ez	-1176763	-205589	165797.9	-44652.3	554125.1	-1403237	-277265	104544.1	-84219.3	297540.9
-0.3Ex+1Ey+0.3Ez	-1161595	-201973	169099.5	-45916.7	563924.9	-1418405	-280881	101242.5	-82954.9	287741.1
0.3Ex-1Ey+0.3Ez	-1176763	-205589	165797.9	-44652.3	554125.1	-1403237	-277265	104544.1	-84219.3	297540.9
0.3Ex-1Ey-0.3Ez	-1161595	-201973	169099.5	-45916.7	563924.9	-1418405	-280881	101242.5	-82954.9	287741.1
-0.3Ex-1Ey-0.3Ez	-820897	-4824.96	218600.1	-24654.1	710840.9	-1759103	-478029	51741.89	-104218	140825.1
-0.3Ex-1Ey+0.3Ez	-836065	-8441.04	215298.5	-25918.5	701041.1	-1743935	-474413	55043.51	-102953	150624.9
0.3Ex+0.3Ey+1Ez	-1007019	-95960.2	182532.4	-30178.3	577619	-1572981	-386894	87809.6	-98693.3	274047
0.3Ex-0.3Ey+1Ez	-1181721	-177692	148315.6	-36177.7	453629	-1398279	-305162	122026.4	-92693.9	398037
-0.3Ex-0.3Ey+1Ez	-1057581	-108014	171527	-34393.1	544953	-1522419	-374840	98815	-94478.5	306713
-0.3Ex+0.3Ey+1Ez	-1232283	-189746	137310.2	-40392.5	430703	-1347717	-293108	133031.8	-88479.1	420963
0.3Ex+0.3Ey-1Ez	-1057581	-108014	171527	-34393.1	544953	-1522419	-374840	98815	-94478.5	306713
0.3Ex-0.3Ey-1Ez	-1232283	-189746	137310.2	-40392.5	430703	-1347717	-293108	133031.8	-88479.1	420963
-0.3Ex-0.3Ey-1Ez	-1007019	-95960.2	182532.4	-30178.3	577619	-1572981	-386894	87809.6	-98693.3	274047
-0.3Ex+0.3Ey-1Ez	-1181721	-177692	148315.6	-36177.7	453629	-1398279	-305162	122026.4	-92693.9	398037

Table 6.9 Combination of actions results (EL1841)

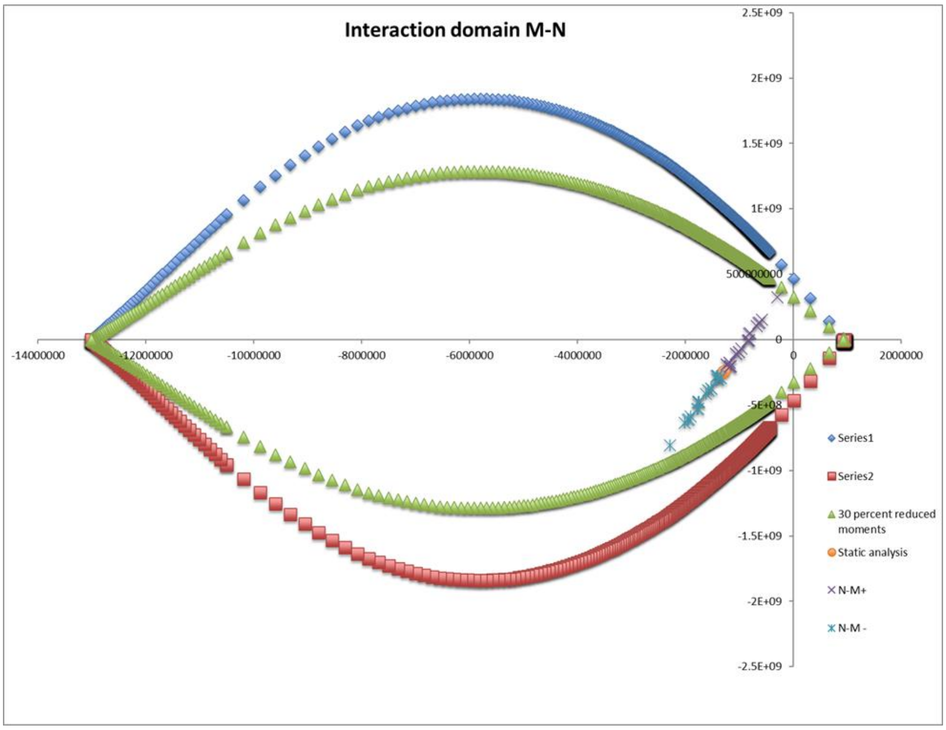


Figure 6.9 N-My interaction domain (EL1841)

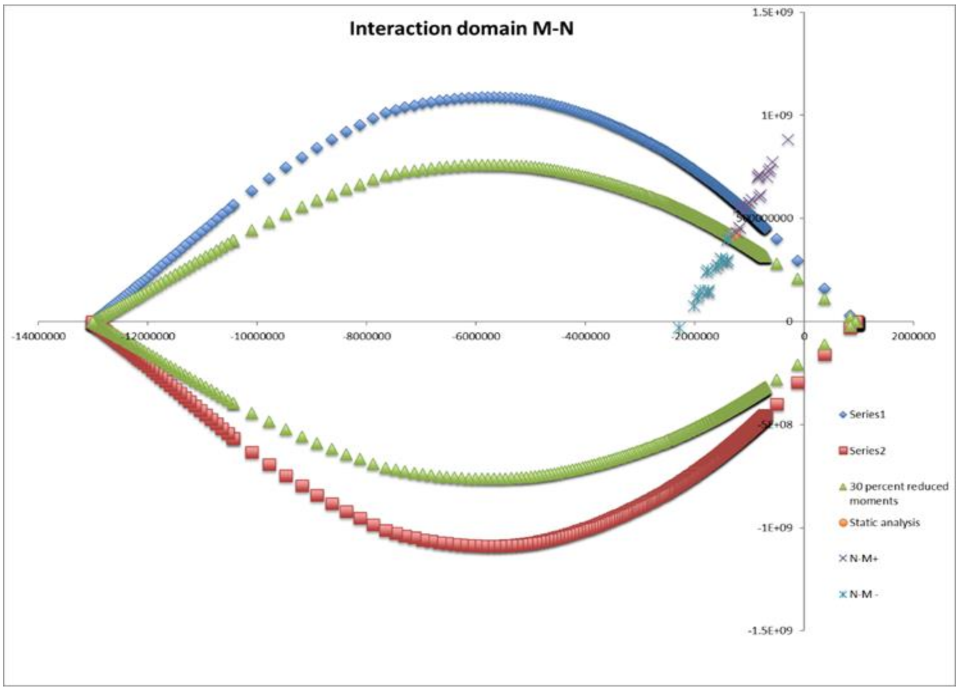


Figure 6.10 N-Mz interaction domain (EL1841)

In Figure 7.9 and Figure 7.10 are the graphs of N-M interaction diagram for y and z axis. The combinations of Normal forces and bending moments are stated between the 30% reduced bending moment graph in the y direction. On the other hand, some points are out of the graph in z direction graph which is shown in Figure 7.10. The element has no enough resistance for the z direction action of normal stresses-bending moment.

Ned [N]	$f$cd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c} \leq 0.65$	Check
-627234.7	19.31	630000	0.05	ok
-642403.3	19.31	630000	0.05	ok
-817105.3	19.31	630000	0.07	ok
-801936.7	19.31	630000	0.07	ok
-963382.12	19.31	630000	0.08	ok
-679645.3	19.31	630000	0.06	ok
-291087.28	19.31	630000	0.02	ok
-574824.1	19.31	630000	0.05	ok
-820896.7	19.31	630000	0.07	ok
-836065.3	19.31	630000	0.07	ok
-1176763.3	19.31	630000	0.10	ok
-1161594.7	19.31	630000	0.10	ok
-1176763.3	19.31	630000	0.10	ok
-1161594.7	19.31	630000	0.10	ok
-820896.7	19.31	630000	0.07	ok
-836065.3	19.31	630000	0.07	ok
-1007019	19.31	630000	0.08	ok
-1181721	19.31	630000	0.10	ok
-1057581	19.31	630000	0.09	ok
-1232283	19.31	630000	0.10	ok
-1057581	19.31	630000	0.09	ok
-1232283	19.31	630000	0.10	ok
-1007019	19.31	630000	0.08	ok
-1181721	19.31	630000	0.10	ok
-1952765.3	19.31	630000	0.16	ok
-1937596.7	19.31	630000	0.16	ok
-1762894.7	19.31	630000	0.14	ok
-1778063.3	19.31	630000	0.15	ok
-1616617.9	19.31	630000	0.13	ok
-1900354.7	19.31	630000	0.16	ok
-2288912.7	19.31	630000	0.19	ok
-2005175.9	19.31	630000	0.16	ok
-1759103.3	19.31	630000	0.14	ok
-1743934.7	19.31	630000	0.14	ok
-1403236.7	19.31	630000	0.12	ok
-1418405.3	19.31	630000	0.12	ok
-1403236.7	19.31	630000	0.12	ok
-1418405.3	19.31	630000	0.12	ok
-1759103.3	19.31	630000	0.14	ok
-1743934.7	19.31	630000	0.14	ok
-1572981	19.31	630000	0.13	ok
-1398279	19.31	630000	0.11	ok
-1522419	19.31	630000	0.13	ok
-1347717	19.31	630000	0.11	ok
-1522419	19.31	630000	0.13	ok
-1347717	19.31	630000	0.11	ok
-1572981	19.31	630000	0.13	ok
-1398279	19.31	630000	0.11	ok
-2580000	19.31	630000	0.21	ok

*Table 6.10 checking Ned/(fcd*Ac)*

6.2.1.4 EL1847 (Short Archway in the middle point)

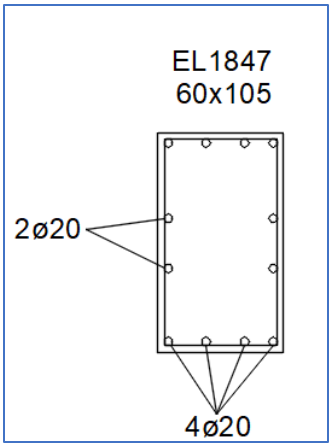


Figure 6.11 cross-section (EL1847)

EL1847 is defined for short archway in the middle point in the software code. It has the same cross-section, material properties and concrete cover like the base of the short archway element. The only difference with respect to the EL1841 is the reinforcement quantities. It has $4\Phi20$ in all side of the element. Table 7.11 which is below shows the static analysis values for the EL1847. The values are the more or less same as the base point of the arch.

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-1230000	-241427	-75081	29100	429419

Table 6.11 static analysis results (EL1847)

EL1847	**EStatic+ Ed**					**EStatic- Ed**				
	N	**My**	**Ty**	**Tz**	**Mz**	**N**	**My**	**Ty**	**Tz**	**Mz**
	[N]	**[Nm]**	**[N]**	**[N]**	**[Nm]**	**[N]**	**[Nm]**	**[N]**	**[N]**	**[Nm]**
1Ex+0.3Ey+0.3Ez	-567752	18777.89	13642.29	124077	674767.4	-1892248	-501632	-163804	-65877	184070.6
1Ex+0.3Ey-0.3Ez	-582886	13440.11	11282.31	122980.4	667412.6	-1877114	-496294	-161444	-64780.4	191425.4
1Ex-0.3Ey-0.3Ez	-757468	-61751.9	-18250.3	118683	603710.6	-1702532	-421102	-131912	-60483	255127.4
1Ex-0.3Ey+0.3Ez	-742334	-56414.1	-15890.3	119779.7	611065.4	-1717666	-426440	-134272	-61579.7	247772.6
-1Ex+0.3Ey+0.3Ez	-903646	-111585	-29315.9	69037.96	551081.8	-1556354	-371269	-120846	-10838	307756.2
-1Ex+0.3Ey-0.3Ez	-620127	-3779.71	4782.51	122787.8	655656.8	-1839873	-479074	-154945	-64587.8	203181.2
-1Ex-0.3Ey-0.3Ez	-231858	149140.6	56600.5	179116	798453	-2228142	-631995	-206762	-120916	60385.04
-1Ex-0.3Ey+0.3Ez	-515378	41335.49	22502.07	125366.2	693878	-1944623	-524189	-172664	-67166.2	164960
0.3Ex+1Ey+0.3Ez	-761246	-47456.1	-2846.91	64494.51	602212.4	-1698754	-435398	-147315	-6294.51	256625.6
0.3Ex+1Ey-0.3Ez	-776380	-52793.9	-5206.89	63397.89	594857.6	-1683620	-430060	-144955	-5197.89	263980.4
-0.3Ex+1Ey-0.3Ez	-1116814	-184758	-48873.1	50170.11	468965.6	-1343186	-298096	-101289	8029.89	389872.4
-0.3Ex+1Ey+0.3Ez	-1101680	-179420	-46513.1	49073.49	476320.4	-1358320	-303434	-103649	9126.51	382517.6
0.3Ex-1Ey+0.3Ez	-1116814	-184758	-48873.1	50170.11	468965.6	-1343186	-298096	-101289	8029.89	389872.4
0.3Ex-1Ey-0.3Ez	-1101680	-179420	-46513.1	49073.49	476320.4	-1358320	-303434	-103649	9126.51	382517.6
-0.3Ex-1Ey-0.3Ez	-761246	-47456.1	-2846.91	64494.51	602212.4	-1698754	-435398	-147315	-6294.51	256625.6
-0.3Ex-1Ey+0.3Ez	-776380	-52793.9	-5206.89	63397.89	594857.6	-1683620	-430060	-144955	-5197.89	263980.4
0.3Ex+0.3Ey+1Ez	-947269	-128953	-34548.3	60760.36	536474	-1512731	-353901	-115614	-2560.36	322364
0.3Ex-0.3Ey+1Ez	-1121851	-204145	-64080.9	56463.04	472772	-1338149	-278709	-86081.1	1736.96	386066
-0.3Ex-0.3Ey+1Ez	-997715	-146745	-42414.9	57104.96	511958	-1462285	-336109	-107747	1095.04	346880
-0.3Ex+0.3Ey+1Ez	-1172297	-221937	-71947.5	52807.64	448256	-1287703	-260917	-78214.5	5392.36	410582
0.3Ex+0.3Ey-1Ez	-997715	-146745	-42414.9	57104.96	511958	-1462285	-336109	-107747	1095.04	346880
0.3Ex-0.3Ey-1Ez	-1172297	-221937	-71947.5	52807.64	448256	-1287703	-260917	-78214.5	5392.36	410582
-0.3Ex-0.3Ey-1Ez	-947269	-128953	-34548.3	60760.36	536474	-1512731	-353901	-115614	-2560.36	322364
-0.3Ex+0.3Ey-1Ez	-1121851	-204145	-64080.9	56463.04	472772	-1338149	-278709	-86081.1	1736.96	386066

Table 6.12 combination of actions results (EL1847)

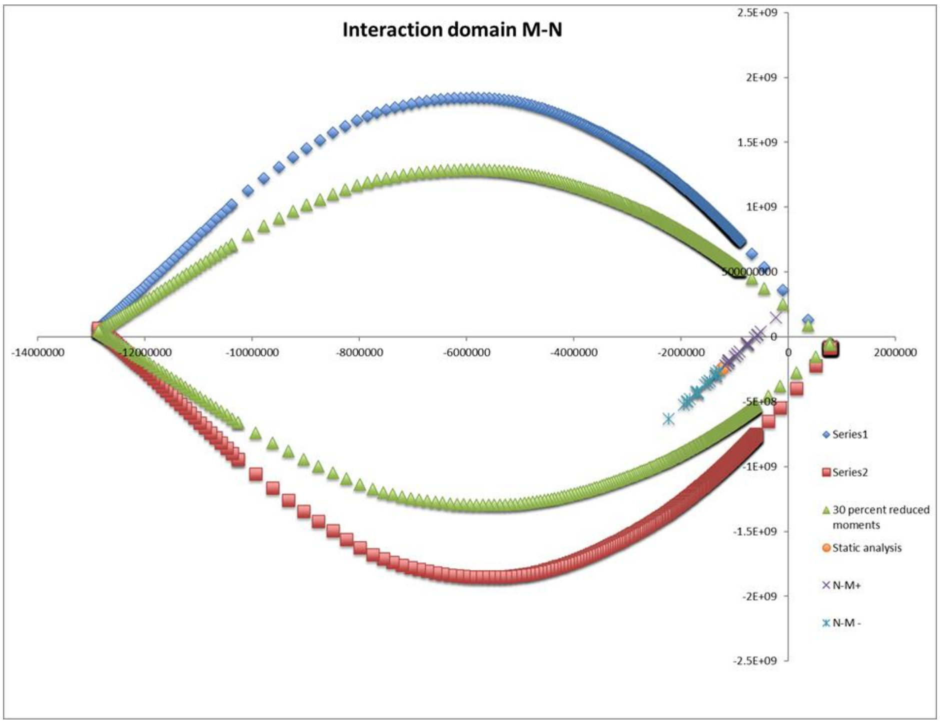


Figure 6.12 N-My interaction domain (EL1847)

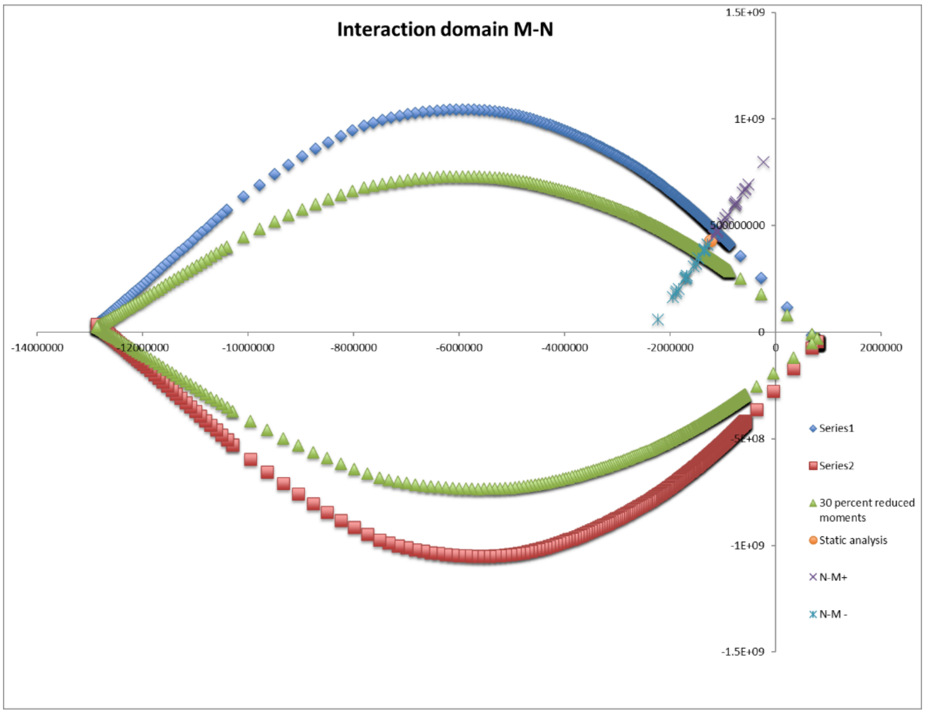


Figure 6.13 N-Mz interaction domain (EL1847)

Figure 7.12 and Figure 7.13 are the output of excel macro code and files which are the results for N-M interaction diagram. The cross-section, material properties are the same as the base point of the arch as well as the stresses act on the midpoint is the same as base point. Therefore, the results can be expected the same which is verified in y direction and hasn't enough resistance in z direction.

Ned [N]	$f$cd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c} \leq 0.65$	Check
-567752	19.31	630000	0.05	ok
-582886	19.31	630000	0.05	ok
-757468	19.31	630000	0.06	ok
-742334	19.31	630000	0.06	ok
-903646	19.31	630000	0.07	ok
-620127	19.31	630000	0.05	ok
-231858	19.31	630000	0.02	ok
-515378	19.31	630000	0.04	ok
-761246	19.31	630000	0.06	ok
-776380	19.31	630000	0.06	ok
-1116814	19.31	630000	0.09	ok
-1101680	19.31	630000	0.09	ok
-1116814	19.31	630000	0.09	ok
-1101680	19.31	630000	0.09	ok
-761246	19.31	630000	0.06	ok
-776380	19.31	630000	0.06	ok
-947269	19.31	630000	0.08	ok
-1121851	19.31	630000	0.09	ok
-997715	19.31	630000	0.08	ok
-1172297	19.31	630000	0.10	ok
-997715	19.31	630000	0.08	ok
-1172297	19.31	630000	0.10	ok
-947269	19.31	630000	0.08	ok
-1121851	19.31	630000	0.09	ok
-1892248	19.31	630000	0.16	ok
-1877114	19.31	630000	0.15	ok
-1702532	19.31	630000	0.14	ok
-1717666	19.31	630000	0.14	ok
-1556354	19.31	630000	0.13	ok
-1839873	19.31	630000	0.15	ok
-2228142	19.31	630000	0.18	ok
-1944623	19.31	630000	0.16	ok
-1698754	19.31	630000	0.14	ok
-1683620	19.31	630000	0.14	ok
-1343186	19.31	630000	0.11	ok
-1358320	19.31	630000	0.11	ok
-1343186	19.31	630000	0.11	ok
-1358320	19.31	630000	0.11	ok
-1698754	19.31	630000	0.14	ok
-1683620	19.31	630000	0.14	ok
-1512731	19.31	630000	0.12	ok
-1338149	19.31	630000	0.11	ok
-1462285	19.31	630000	0.12	ok
-1287703	19.31	630000	0.11	ok
-1462285	19.31	630000	0.12	ok
-1287703	19.31	630000	0.11	ok
-1512731	19.31	630000	0.12	ok
-1338149	19.31	630000	0.11	ok
-1230000	19.31	630000	0.10	ok

*Table 6.13 checking Ned/(fcd*Ac)*

6.2.1.5 EL1523 (Internal frame undulated slab)

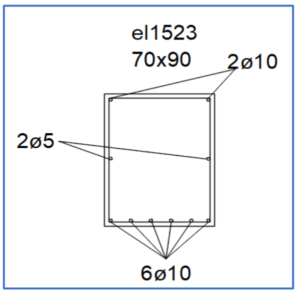


Figure 6.14 cross-section (EL1523)

EL1523 is defined for the undulated slab internal frame in ANSYS software code. In reality it has wavy shape but in software it has been defined as rectangular cross-section with 70 cm by 90 cm. The reinforcements are assumed to be placed 6Φ10 at the bottom, 2Φ10 in the top and 1Φ5 at each side. The concrete and steel strength parameters are the same as arches. The concrete cover is assumed 3.5 cm. Table 7.14 is shown static analysis results for the undulated slab. It has been acted 1580 kN normal forces, 0.3 kN and 47 kN shear forces in y and z direction respectively. The bending moment in y direction is 224 kNm and 93 kNm in z direction.

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-1580000	-224731	-306.9	-46789	-93544

Table 6.14 static analysis results (EL1523)

EL1523	Estatic+ Ed					Estatic- Ed				
	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
1Ex+0.3Ey+0.3Ez	-1161437	-97300.5	51178.88	-24189.3	-41513.2	-1998563	-352162	-51792.7	-69388.7	-145575
1Ex+0.3Ey-0.3Ez	-1183933	-100561	50465.12	-24628.1	-42527.6	-1976067	-348901	-51078.9	-68949.9	-144560
1Ex-0.3Ey-0.3Ez	-1271263	-143102	16329.32	-43894.7	-77664.8	-1888737	-306361	-16943.1	-49683.3	-109423
1Ex-0.3Ey+0.3Ez	-1248767	-139841	17043.08	-43455.9	-76650.4	-1911233	-309621	-17656.9	-50122.1	-110438
-1Ex+0.3Ey+0.3Ez	-1372879	-159040	30956.41	-31705.8	-61581.9	-1787121	-290422	-31570.2	-61872.2	-125506
-1Ex+0.3Ey-0.3Ez	-1187636	-110063	40938.14	-29969.2	-52054.4	-1972364	-339399	-41551.9	-63608.8	-135034
-1Ex-0.3Ey-0.3Ez	-949996	-35560.6	71401.35	-16672.7	-21444.5	-2210004	-413901	-72015.2	-76905.3	-165643
-1Ex-0.3Ey+0.3Ez	-1135238	-84538.3	61419.62	-18409.3	-30972	-2024762	-364924	-62033.4	-75168.7	-156116
0.3Ex+1Ey+0.3Ez	-1314107	-120841	67161.28	-10634.5	-24288.3	-1845893	-328621	-67775.1	-82943.5	-162800
0.3Ex+1Ey-0.3Ez	-1336603	-124101	66447.52	-11073.3	-25302.7	-1823397	-325361	-67061.3	-82504.7	-161785
-0.3Ex+1Ey-0.3Ez	-1554793	-186819	46010.92	-18721.5	-45675.7	-1605207	-262643	-46624.7	-74856.5	-141412
-0.3Ex+1Ey+0.3Ez	-1532297	-183559	46724.68	-18282.7	-44661.3	-1627703	-265903	-47338.5	-75295.3	-142427
0.3Ex-1Ey+0.3Ez	-1554793	-186819	46010.92	-18721.5	-45675.7	-1605207	-262643	-46624.7	-74856.5	-141412
0.3Ex-1Ey-0.3Ez	-1532297	-183559	46724.68	-18282.7	-44661.3	-1627703	-265903	-47338.5	-75295.3	-142427
-0.3Ex-1Ey-0.3Ez	-1314107	-120841	67161.28	-10634.5	-24288.3	-1845893	-328621	-67775.1	-82943.5	-162800
-0.3Ex-1Ey+0.3Ez	-1336603	-124101	66447.52	-11073.3	-25302.7	-1823397	-325361	-67061.3	-82504.7	-161785
0.3Ex+0.3Ey+1Ez	-1389748	-166668	28168.9	-32600.1	-64098.2	-1770252	-282794	-28782.7	-60977.9	-122990
0.3Ex-0.3Ey+1Ez	-1477078	-209208	5353.1	-41711.3	-87852.6	-1682922	-240254	-5966.9	-51866.7	-99235.4
-0.3Ex-0.3Ey+1Ez	-1464732	-177536	25789.7	-34063.1	-67479.6	-1695268	-271926	-26403.5	-59514.9	-119608
-0.3Ex+0.3Ey+1Ez	-1552062	-220076	7732.3	-40248.3	-84471.2	-1607938	-229386	-8346.1	-53329.7	-102617
0.3Ex+0.3Ey-1Ez	-1464732	-177536	25789.7	-34063.1	-67479.6	-1695268	-271926	-26403.5	-59514.9	-119608
0.3Ex-0.3Ey-1Ez	-1552062	-220076	7732.3	-40248.3	-84471.2	-1607938	-229386	-8346.1	-53329.7	-102617
-0.3Ex-0.3Ey-1Ez	-1389748	-166668	28168.9	-32600.1	-64098.2	-1770252	-282794	-28782.7	-60977.9	-122990
-0.3Ex+0.3Ey-1Ez	-1477078	-209208	5353.1	-41711.3	-87852.6	-1682922	-240254	-5966.9	-51866.7	-99235.4

Table 6.15 Combinations of actions results (EL1523)

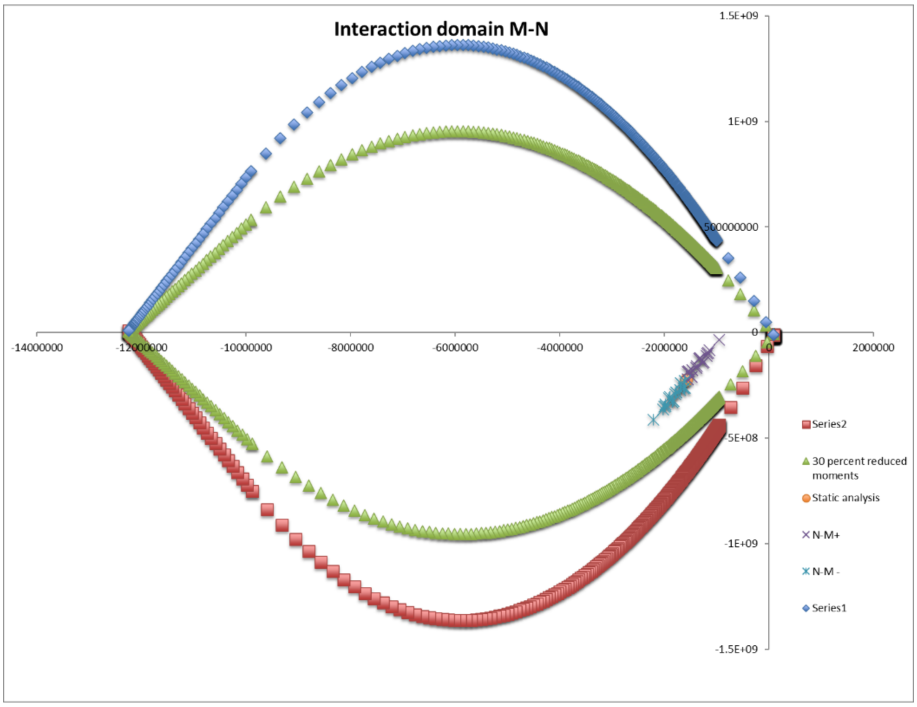


Figure 6.15 N-My interaction domain (EL1523)

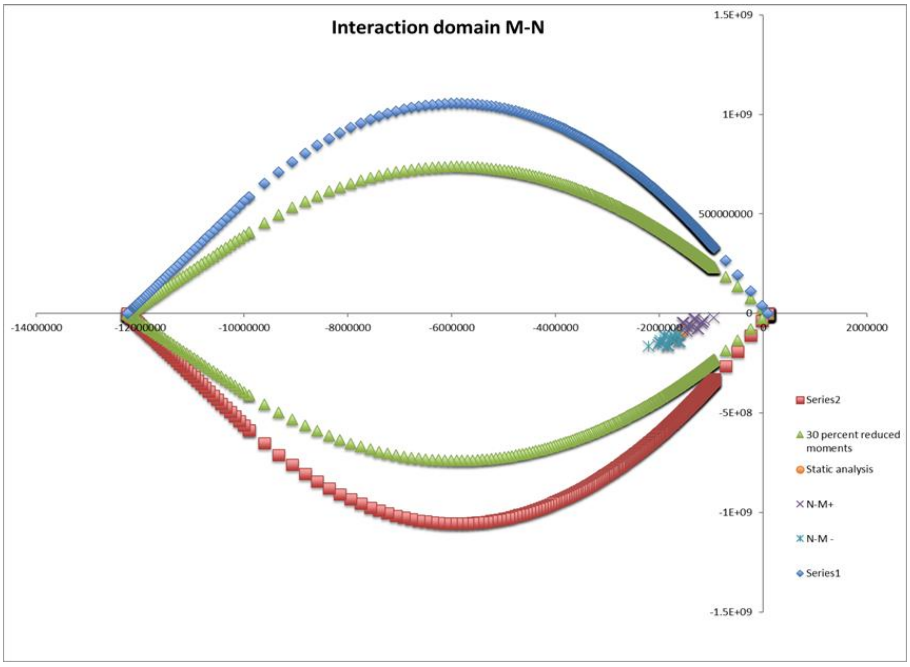


Figure 6.16 N-Mz interaction domain (EL1523)

Figure 7.15 and Figure 7.16 are the graph of interaction diagram with action of combinations in y and z direction. All the values are between the N-M reduced 30% bending moment resistance graph .Hence the element has passed the pressoniflation which has enough resistance for the acting normal stress and bending moment.

Ned [N]	$f$cd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c} \leq 0.65$	Check
-1161437.4	19.31	630000	0.10	ok
-1183932.6	19.31	630000	0.10	ok
-1271262.6	19.31	630000	0.10	ok
-1248767.4	19.31	630000	0.10	ok
-1372878.8	19.31	630000	0.11	ok
-1187636.4	19.31	630000	0.10	ok
-949995.96	19.31	630000	0.08	ok
-1135238.4	19.31	630000	0.09	ok
-1314107.4	19.31	630000	0.11	ok
-1336602.6	19.31	630000	0.11	ok
-1554792.6	19.31	630000	0.13	ok
-1532297.4	19.31	630000	0.13	ok
-1554792.6	19.31	630000	0.13	ok
-1532297.4	19.31	630000	0.13	ok
-1314107.4	19.31	630000	0.11	ok
-1336602.6	19.31	630000	0.11	ok
-1389748	19.31	630000	0.11	ok
-1477078	19.31	630000	0.12	ok
-1464732	19.31	630000	0.12	ok
-1552062	19.31	630000	0.13	ok
-1464732	19.31	630000	0.12	ok
-1552062	19.31	630000	0.13	ok
-1389748	19.31	630000	0.11	ok
-1477078	19.31	630000	0.12	ok
-1998562.6	19.31	630000	0.16	ok
-1976067.4	19.31	630000	0.16	ok
-1888737.4	19.31	630000	0.16	ok
-1911232.6	19.31	630000	0.16	ok
-1787121.2	19.31	630000	0.15	ok
-1972363.6	19.31	630000	0.16	ok
-2210004	19.31	630000	0.18	ok
-2024761.6	19.31	630000	0.17	ok
-1845892.6	19.31	630000	0.15	ok
-1823397.4	19.31	630000	0.15	ok
-1605207.4	19.31	630000	0.13	ok
-1627702.6	19.31	630000	0.13	ok
-1605207.4	19.31	630000	0.13	ok
-1627702.6	19.31	630000	0.13	ok
-1845892.6	19.31	630000	0.15	ok
-1823397.4	19.31	630000	0.15	ok
-1770252	19.31	630000	0.15	ok
-1682922	19.31	630000	0.14	ok
-1695268	19.31	630000	0.14	ok
-1607938	19.31	630000	0.13	ok
-1695268	19.31	630000	0.14	ok
-1607938	19.31	630000	0.13	ok
-1770252	19.31	630000	0.15	ok
-1682922	19.31	630000	0.14	ok
-1580000	19.31	630000	0.13	ok

*Table 6.16 check Ned/(fcd*Ac)*

6.2.1.6 EL4676 (Lateral rib_ at the base)

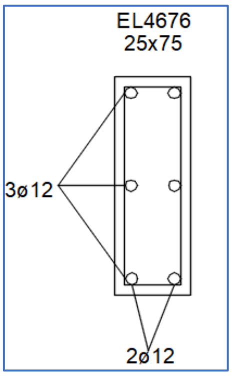


Figure 6.17 cross-section (4676)

EL4676 is the definition of code for the lateral rib of the C hall at the base point. It has defined 25 cm by 75 cm rectangular shape cross-section. The steel and concrete strength parameters are like the other elements as mentioned before. It has 2Φ12 at the bottom and top , 3Φ12 in each side. The concrete cover is 3.5 cm.

Table 7.17 is demonstrated the static analysis results which has been taken from previous works. Normal force is 1100 kN and shear forces are 4 kN, 44 kN in y and z direction respectively. The bending moment in y direction is 75 kNm and 3 kN in z direction.

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-1100000	74663.4	-4218.45	44332.8	2884.2

Table 6.17 static analysis results (EL4676)

EL4676	Estatic+ Ed					Estatic- Ed				
	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
1Ex+0.3Ey+0.3Ez	-924784	141367.1	-1869.8	70961.32	5179.106	-1275216	7959.66	-6567.1	17704.28	589.2938
1Ex+0.3Ey-0.3Ez	-953758	139503.1	-1958.14	69866.08	5125.074	-1246242	9823.74	-6478.76	18799.52	643.3262
1Ex-0.3Ey-0.3Ez	-1033156	101787.7	-2291.9	55452.28	4029.294	-1166844	47539.14	-6145	33213.32	1739.106
1Ex-0.3Ey+0.3Ez	-1004182	103651.7	-2203.56	56547.52	4083.326	-1195818	45675.06	-6233.34	32118.08	1685.074
-1Ex+0.3Ey+0.3Ez	-988709	113778	-3125.85	59965.49	4163.316	-1211291	35548.84	-5311.05	28700.11	1605.084
-1Ex+0.3Ey-0.3Ez	-948603	130052.5	-1969.93	66637.18	4850.372	-1251397	19274.28	-6466.97	22028.42	918.0278
-1Ex-0.3Ey-0.3Ez	-860858	168956.3	-613.74	81957.15	6194.896	-1339142	-19629.5	-7823.16	6708.452	-426.496
-1Ex-0.3Ey+0.3Ez	-900964	152681.8	-1769.67	75285.46	5507.84	-1299036	-3354.96	-6667.23	13380.14	260.5598
0.3Ex+1Ey+0.3Ez	-916874	152528.6	-2976.73	74565.62	5253.516	-1283126	-3201.84	-5460.17	14099.98	514.8838
0.3Ex+1Ey-0.3Ez	-945848	150664.6	-3065.07	73470.38	5199.484	-1254152	-1337.76	-5371.83	15195.22	568.9162
-0.3Ex+1Ey-0.3Ez	-1018466	122516.2	-4089.27	62145.98	4167.484	-1181534	26810.64	-4347.63	26519.62	1600.916
-0.3Ex+1Ey+0.3Ez	-989492	124380.2	-4177.61	63241.22	4221.516	-1210508	24946.56	-4259.29	25424.38	1546.884
0.3Ex-1Ey+0.3Ez	-1018466	122516.2	-4089.27	62145.98	4167.484	-1181534	26810.64	-4347.63	26519.62	1600.916
0.3Ex-1Ey-0.3Ez	-989492	124380.2	-4177.61	63241.22	4221.516	-1210508	24946.56	-4259.29	25424.38	1546.884
-0.3Ex-1Ey-0.3Ez	-916874	152528.6	-2976.73	74565.62	5253.516	-1283126	-3201.84	-5460.17	14099.98	514.8838
-0.3Ex-1Ey+0.3Ez	-945848	150664.6	-3065.07	73470.38	5199.484	-1254152	-1337.76	-5371.83	15195.22	568.9162
0.3Ex+0.3Ey+1Ez	-975701	110702.1	-3263.05	59027.3	4038.144	-1224299	38624.7	-5173.85	29638.3	1730.256
0.3Ex-0.3Ey+1Ez	-1055099	76340.1	-3596.81	44613.5	2942.364	-1144901	72986.7	-4840.09	44052.1	2826.036
-0.3Ex-0.3Ey+1Ez	-1072283	104488.5	-3557.53	55376.5	3858.036	-1127717	44838.3	-4879.37	33289.1	1910.364
-0.3Ex+0.3Ey+1Ez	-1048319	82553.7	-3891.29	47702.9	3006.144	-1151681	66773.1	-4545.61	40962.7	2762.256
0.3Ex+0.3Ey-1Ez	-1072283	104488.5	-3557.53	55376.5	3858.036	-1127717	44838.3	-4879.37	33289.1	1910.364
0.3Ex-0.3Ey-1Ez	-1048319	82553.7	-3891.29	47702.9	3006.144	-1151681	66773.1	-4545.61	40962.7	2762.256
-0.3Ex-0.3Ey-1Ez	-975701	110702.1	-3263.05	59027.3	4038.144	-1224299	38624.7	-5173.85	29638.3	1730.256
-0.3Ex+0.3Ey-1Ez	-1055099	76340.1	-3596.81	44613.5	2942.364	-1144901	72986.7	-4840.09	44052.1	2826.036

Table 6.18 combinations of actions result (EL4676)

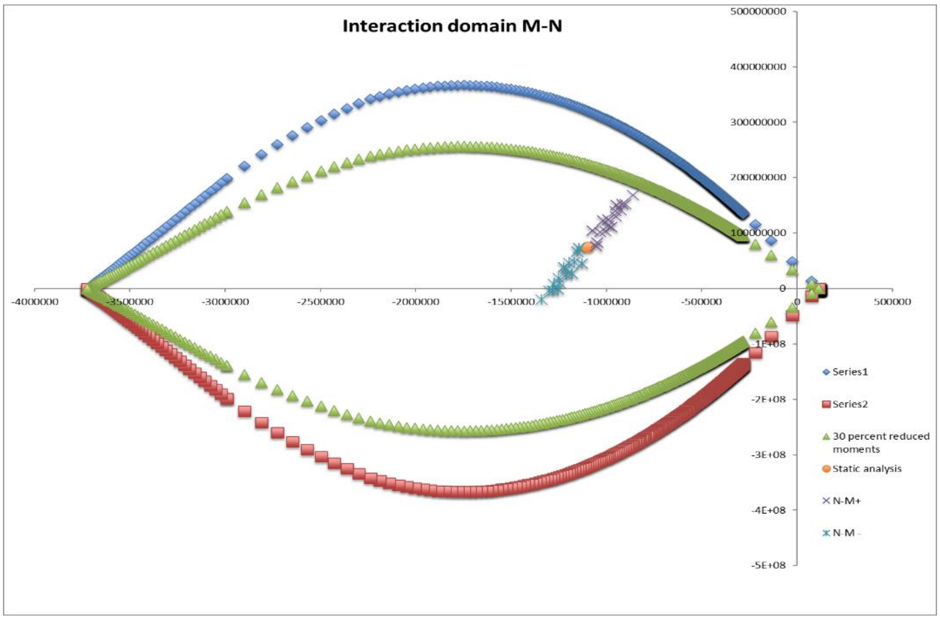


Figure 6.18 N-My interaction domain (EL4676)

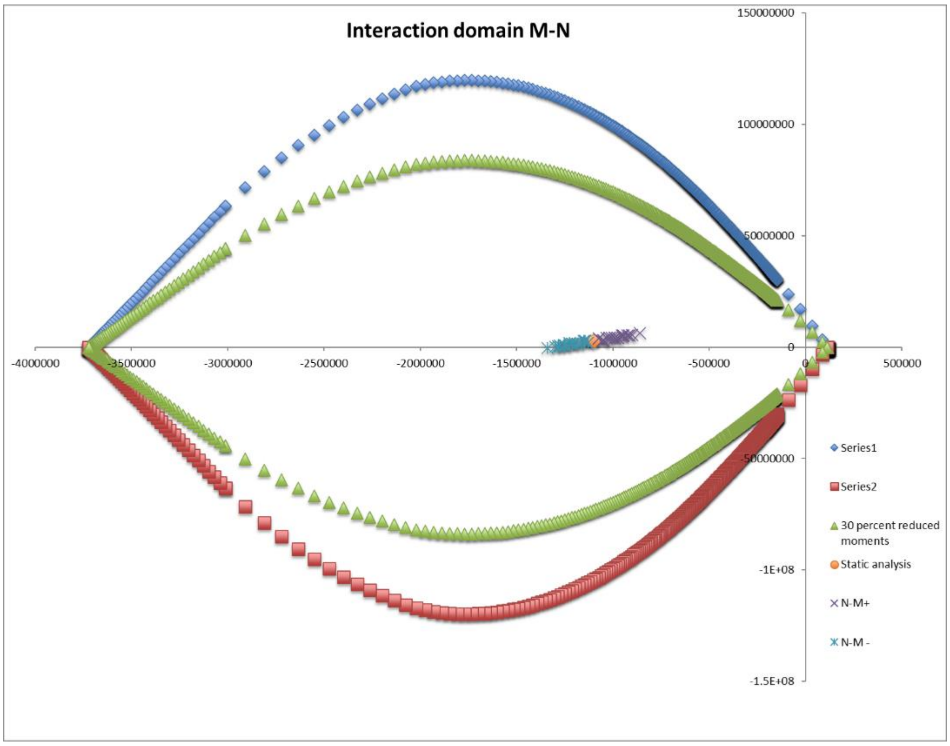


Figure 6.19 N-Mz interaction domain (EL4676)

Figure 7.18 and Figure 7.19 are the output of macro excel file results with the combination of actions results. It is shown the N-M interaction diagrams which obtained in general values as well as reduced 30% bending moment resistance. All the 49 points which is defined for each direction with static analysis result and actions combinations are stated between the graph in y and z direction. Therefore, the lateral rib has enough resistance for the acting forces on the element with bending moment.

Ned [N]	ƒcd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c} \leq 0.65$	Check
-924783.7	19.31	187500	0.26	ok
-953758.3	19.31	187500	0.26	ok
-1033156.3	19.31	187500	0.29	ok
-1004181.7	19.31	187500	0.28	ok
-988709.32	19.31	187500	0.27	ok
-948603.1	19.31	187500	0.26	ok
-860858.08	19.31	187500	0.24	ok
-900964.3	19.31	187500	0.25	ok
-916873.7	19.31	187500	0.25	ok
-945848.3	19.31	187500	0.26	ok
-1018466.3	19.31	187500	0.28	ok
-989491.7	19.31	187500	0.27	ok
-1018466.3	19.31	187500	0.28	ok
-989491.7	19.31	187500	0.27	ok
-916873.7	19.31	187500	0.25	ok
-945848.3	19.31	187500	0.26	ok
-975701	19.31	187500	0.27	ok
-1055099	19.31	187500	0.29	ok
-1072283	19.31	187500	0.30	ok
-1048319	19.31	187500	0.29	ok
-1072283	19.31	187500	0.30	ok
-1048319	19.31	187500	0.29	ok
-975701	19.31	187500	0.27	ok
-1055099	19.31	187500	0.29	ok
-1275216.3	19.31	187500	0.35	ok
-1246241.7	19.31	187500	0.34	ok
-1166843.7	19.31	187500	0.32	ok
-1195818.3	19.31	187500	0.33	ok
-1211290.7	19.31	187500	0.33	ok
-1251396.9	19.31	187500	0.35	ok
-1339141.9	19.31	187500	0.37	ok
-1299035.7	19.31	187500	0.36	ok
-1283126.3	19.31	187500	0.35	ok
-1254151.7	19.31	187500	0.35	ok
-1181533.7	19.31	187500	0.33	ok
-1210508.3	19.31	187500	0.33	ok
-1181533.7	19.31	187500	0.33	ok
-1210508.3	19.31	187500	0.33	ok
-1283126.3	19.31	187500	0.35	ok
-1254151.7	19.31	187500	0.35	ok
-1224299	19.31	187500	0.34	ok
-1144901	19.31	187500	0.32	ok
-1127717	19.31	187500	0.31	ok
-1151681	19.31	187500	0.32	ok
-1127717	19.31	187500	0.31	ok
-1151681	19.31	187500	0.32	ok
-1224299	19.31	187500	0.34	ok
-1144901	19.31	187500	0.32	ok
-1100000	19.31	187500	0.30	ok

*Figure 6.20 check Ned/(fcd*Ac)*

6.2.1.7 EL4662 (Lateral rib in the midpoint)

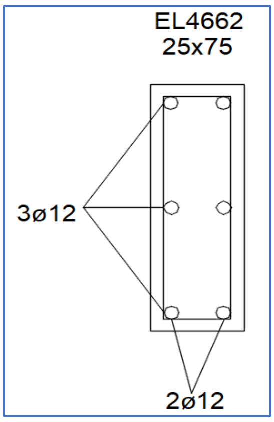


Figure 6.21 cross-section (EL4662)

EL4662 is defined for the lateral rib in the midpoint in the software code. It has the same cross-section , material properties , concrete cover with respect to the lateral rib at the base point.

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-222156	-35048.8	22854.6	-9187.9	4641

Table 6.19 static analysis results (EL4662)

EL4662	EStatic+ Ed					EStatic- Ed				
	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
1Ex+0.3Ey+0.3Ez	-205580	-31456.8	37202.14	-4144.17	7054.441	-238732	-38640.8	8507.06	-14231.6	2227.559
1Ex+0.3Ey-0.3Ez	-208211	-31907.9	36411.46	-4358.8	6923.719	-236101	-38189.7	9297.74	-14017	2358.281
1Ex-0.3Ey-0.3Ez	-213024	-34063.6	27965.26	-4710.23	5523.559	-231288	-36034	17743.94	-13665.6	3758.441
1Ex-0.3Ey+0.3Ez	-210393	-33612.5	28755.94	-4495.6	5654.281	-233919	-36485.1	16953.26	-13880.2	3627.719
-1Ex+0.3Ey+0.3Ez	-212503	-32694.7	31601.88	-6936.2	6104.858	-231809	-37402.9	14107.32	-11439.6	3177.142
-1Ex+0.3Ey-0.3Ez	-207024	-32103.5	34668.28	-4249.6	6634.393	-237288	-37994.1	11040.92	-14126.2	2647.607
-1Ex-0.3Ey-0.3Ez	-198657	-30219	42802.4	-1352.14	8004.024	-245655	-39878.6	2906.804	-17023.7	1277.976
-1Ex-0.3Ey+0.3Ez	-204136	-30810.2	39736	-4038.74	7474.489	-240176	-39287.4	5973.2	-14337.1	1807.511
0.3Ex+1Ey+0.3Ez	-208962	-30544	40245.67	-7066.66	7534.361	-235350	-39553.6	5463.53	-11309.1	1747.639
0.3Ex+1Ey-0.3Ez	-211593	-30995.1	39454.99	-7281.3	7403.639	-232719	-39102.5	6254.21	-11094.5	1878.361
-0.3Ex+1Ey-0.3Ez	-219305	-32368.2	33617.53	-8238.08	6414.839	-225007	-37729.4	12091.67	-10137.7	2867.161
-0.3Ex+1Ey+0.3Ez	-216674	-31917.1	34408.21	-8452.72	6545.561	-227638	-38180.5	11300.99	-9923.08	2736.439
0.3Ex-1Ey+0.3Ez	-219305	-32368.2	33617.53	-8238.08	6414.839	-225007	-37729.4	12091.67	-10137.7	2867.161
0.3Ex-1Ey-0.3Ez	-216674	-31917.1	34408.21	-8452.72	6545.561	-227638	-38180.5	11300.99	-9923.08	2736.439
-0.3Ex-1Ey-0.3Ez	-208962	-30544	40245.67	-7066.66	7534.361	-235350	-39553.6	5463.53	-11309.1	1747.639
-0.3Ex-1Ey+0.3Ez	-211593	-30995.1	39454.99	-7281.3	7403.639	-232719	-39102.5	6254.21	-11094.5	1878.361
0.3Ex+0.3Ey+1Ez	-211509	-32532.6	31314.23	-7226.26	6053.35	-232803	-37565	14394.97	-11149.5	3228.65
0.3Ex-0.3Ey+1Ez	-216322	-34688.2	22868.03	-7577.68	4653.19	-227990	-35409.4	22841.17	-10798.1	4628.81
-0.3Ex-0.3Ey+1Ez	-220277	-34036.2	28678.63	-7941.7	5617.61	-224035	-36061.4	17030.57	-10434.1	3664.39
-0.3Ex+0.3Ey+1Ez	-219221	-33905.8	25476.77	-8293.12	5064.55	-225091	-36191.9	20232.43	-10082.7	4217.45
0.3Ex+0.3Ey-1Ez	-220277	-34036.2	28678.63	-7941.7	5617.61	-224035	-36061.4	17030.57	-10434.1	3664.39
0.3Ex-0.3Ey-1Ez	-219221	-33905.8	25476.77	-8293.12	5064.55	-225091	-36191.9	20232.43	-10082.7	4217.45
-0.3Ex-0.3Ey-1Ez	-211509	-32532.6	31314.23	-7226.26	6053.35	-232803	-37565	14394.97	-11149.5	3228.65
-0.3Ex+0.3Ey-1Ez	-216322	-34688.2	22868.03	-7577.68	4653.19	-227990	-35409.4	22841.17	-10798.1	4628.81

Table 6.20 combinations of actions result (EL4662)

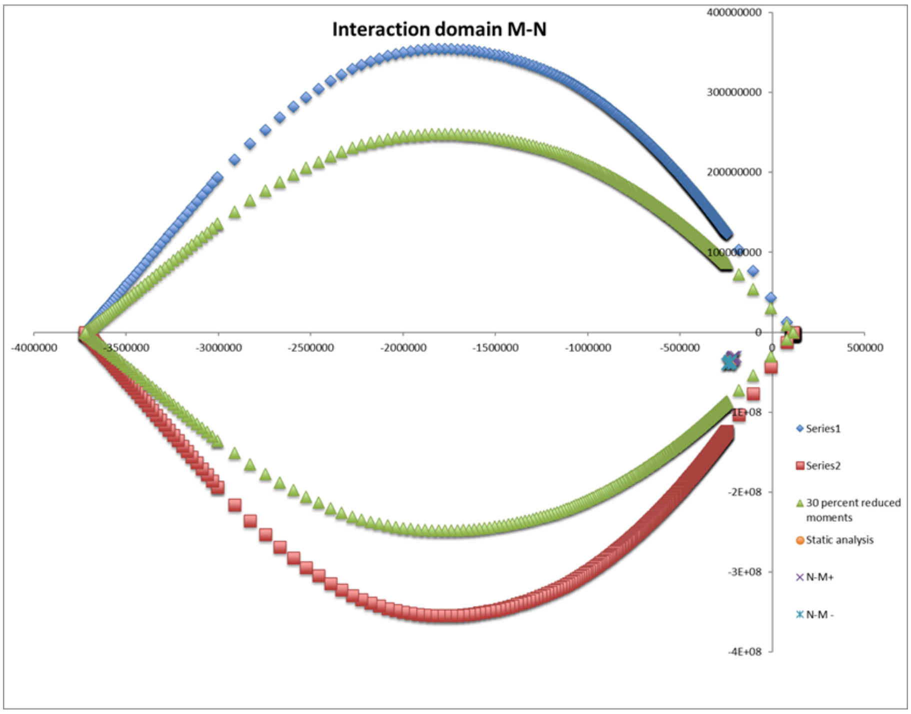


Figure 6.22 N-My interaction domain (EL4662)

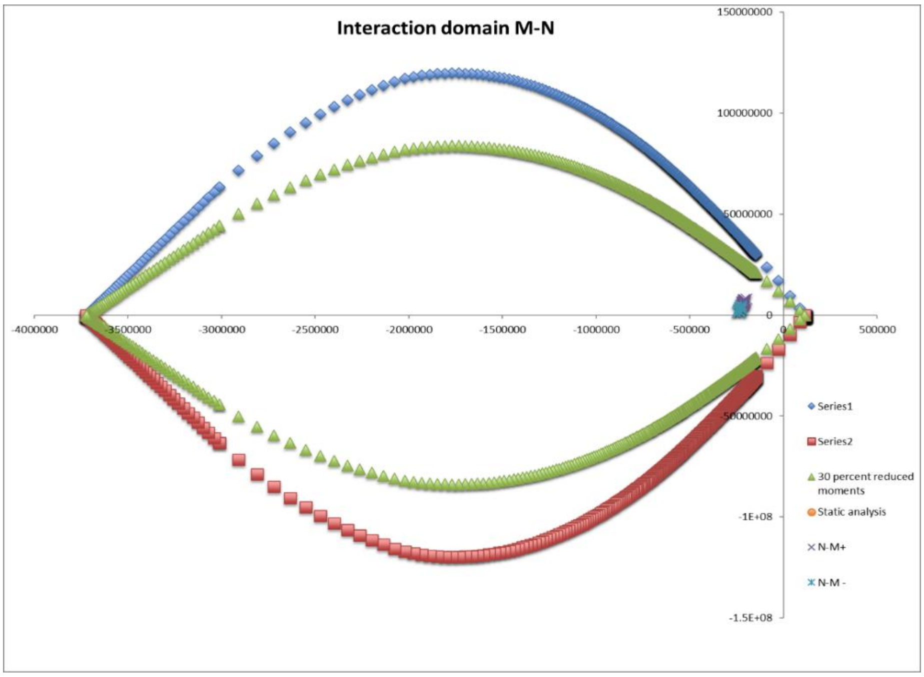


Figure 6.23 N-Mz interaction domain (EL4662)

As it is shown in Figure 7.22 and Figure 7.23 all the values of Normal forces- Bending moments combinations are placed between the reduced bending moment resistance with respect to normal forces. Hence , The lateral rib in the midpoint has enough resistance for the acting axial forces and bending moment.

Ned [N]	$f$cd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c} \leq 0.65$	Check
-205580	19.31	187500	0.06	ok
-208211	19.31	187500	0.06	ok
-213024	19.31	187500	0.06	ok
-210393	19.31	187500	0.06	ok
-212503	19.31	187500	0.06	ok
-207024	19.31	187500	0.06	ok
-198657	19.31	187500	0.05	ok
-204136	19.31	187500	0.06	ok
-208962	19.31	187500	0.06	ok
-211593	19.31	187500	0.06	ok
-219305	19.31	187500	0.06	ok
-216674	19.31	187500	0.06	ok
-219305	19.31	187500	0.06	ok
-216674	19.31	187500	0.06	ok
-208962	19.31	187500	0.06	ok
-211593	19.31	187500	0.06	ok
-211509	19.31	187500	0.06	ok
-216322	19.31	187500	0.06	ok
-220277	19.31	187500	0.06	ok
-219221	19.31	187500	0.06	ok
-220277	19.31	187500	0.06	ok
-219221	19.31	187500	0.06	ok
-211509	19.31	187500	0.06	ok
-216322	19.31	187500	0.06	ok
-238732	19.31	187500	0.07	ok
-236101	19.31	187500	0.07	ok
-231288	19.31	187500	0.06	ok
-233919	19.31	187500	0.06	ok
-231809	19.31	187500	0.06	ok
-237288	19.31	187500	0.07	ok
-245655	19.31	187500	0.07	ok
-240176	19.31	187500	0.07	ok
-235350	19.31	187500	0.07	ok
-232719	19.31	187500	0.06	ok
-225007	19.31	187500	0.06	ok
-227638	19.31	187500	0.06	ok
-225007	19.31	187500	0.06	ok
-227638	19.31	187500	0.06	ok
-235350	19.31	187500	0.07	ok
-232719	19.31	187500	0.06	ok
-232803	19.31	187500	0.06	ok
-227990	19.31	187500	0.06	ok
-224035	19.31	187500	0.06	ok
-225091	19.31	187500	0.06	ok
-224035	19.31	187500	0.06	ok
-225091	19.31	187500	0.06	ok
-232803	19.31	187500	0.06	ok
-227990	19.31	187500	0.06	ok
-222156	19.31	187500	0.06	ok

*Table 6.21 check Ned/(fcd*Ac)*

6.2.1.8 EL779 (External pillar at the base)

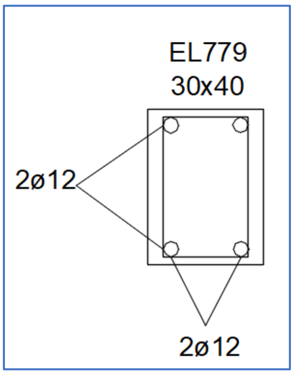


Figure 6.24 cross-section (EL779)

EL779 is represent the external pillar at the base point in the software code. It is defined cross-section beam which is 30cm by 40cm. The concrete parameters are different from the elements which is defined before. It has been defined for TIP500 concrete which has 26 MPa compressive strength. The steel strength parameters are the same as other elements which is 260 MPa. The concrete cover is 4cm at side and 2cm in the top and bottom. It has 2Φ12 in the top and bottom. Table 7.25 is shown the static analysis results,

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-221980	-1450.6	-2394.3	1297.5	-6105.5

Figure 6.25 static analysis results (EL779)

The axial force is 222 kN and shear forces are 2.4 kN 1.3 kN in y and z direction respectively. The bending moment in y direction is 1.45 kNm and 6.1 kNm in z direction.

EL779	Estatic+ Ed					Estatic- Ed				
	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
1Ex+0.3Ey+0.3Ez	-207000	-624.352	-613.912	6601.533	-2832.95	-236960	-2276.85	-4174.69	-4006.53	-9378.05
1Ex+0.3Ey-0.3Ez	-208887	-663.106	-845.008	6565.943	-3361.69	-235073	-2238.09	-3943.59	-3970.94	-8849.31
1Ex-0.3Ey-0.3Ez	-220466	-897.628	-1726.65	6160.667	-5345.65	-223494	-2003.57	-3061.95	-3565.67	-6865.35
1Ex-0.3Ey+0.3Ez	-221607	-858.874	-1957.75	6196.257	-4816.91	-222353	-2042.33	-2830.85	-3601.26	-7394.09
-1Ex+0.3Ey+0.3Ez	-210474	-1026.49	-878.405	3562.05	-3884.05	-233486	-1874.71	-3910.19	-967.05	-8326.95
-1Ex+0.3Ey-0.3Ez	-211382	-694.709	-1278.99	6479.95	-3428.14	-232578	-2206.49	-3509.61	-3884.95	-8782.86
-1Ex-0.3Ey-0.3Ez	-203526	-222.212	-349.419	9641.016	-1781.85	-240434	-2678.99	-4439.18	-7046.02	-10429.1
-1Ex-0.3Ey+0.3Ez	-202618	-553.996	51.17	6723.116	-2237.77	-241342	-2347.2	-4839.77	-4128.12	-9973.23
0.3Ex+1Ey+0.3Ez	-194673	-833.47	1583.059	3515.835	-1929.67	-249287	-2067.73	-6371.66	-920.835	-10281.3
0.3Ex+1Ey-0.3Ez	-196560	-872.224	1351.963	3480.245	-2458.41	-247400	-2028.98	-6140.56	-885.245	-9752.59
-0.3Ex+1Ey-0.3Ez	-200599	-1285.99	1018.141	2164.915	-3668.13	-243361	-1615.21	-5806.74	430.0852	-8542.87
-0.3Ex+1Ey+0.3Ez	-198712	-1247.24	1249.237	2129.325	-3139.39	-245248	-1653.96	-6037.84	465.6748	-9071.61
0.3Ex-1Ey+0.3Ez	-200599	-1285.99	1018.141	2164.915	-3668.13	-243361	-1615.21	-5806.74	430.0852	-8542.87
0.3Ex-1Ey-0.3Ez	-198712	-1247.24	1249.237	2129.325	-3139.39	-245248	-1653.96	-6037.84	465.6748	-9071.61
-0.3Ex-1Ey-0.3Ez	-194673	-833.47	1583.059	3515.835	-1929.67	-249287	-2067.73	-6371.66	-920.835	-10281.3
-0.3Ex-1Ey+0.3Ez	-196560	-872.224	1351.963	3480.245	-2458.41	-247400	-2028.98	-6140.56	-885.245	-9752.59
0.3Ex+0.3Ey+1Ez	-209512	-1061.87	-733.759	3084.534	-3627.44	-234448	-1839.33	-4054.84	-489.534	-8583.56
0.3Ex-0.3Ey+1Ez	-219842	-1296.39	-1837.9	2679.258	-5611.4	-224118	-1604.81	-2950.7	-84.258	-6599.6
-0.3Ex-0.3Ey+1Ez	-215802	-1191.05	-1504.08	2965.902	-5389.88	-228158	-1710.16	-3284.52	-370.902	-6821.12
-0.3Ex+0.3Ey+1Ez	-213552	-1425.57	-1067.58	2560.626	-4837.16	-230408	-1475.63	-3721.02	34.374	-7373.84
0.3Ex+0.3Ey-1Ez	-215802	-1191.05	-1504.08	2965.902	-5389.88	-228158	-1710.16	-3284.52	-370.902	-6821.12
0.3Ex-0.3Ey-1Ez	-213552	-1425.57	-1067.58	2560.626	-4837.16	-230408	-1475.63	-3721.02	34.374	-7373.84
-0.3Ex-0.3Ey-1Ez	-209512	-1061.87	-733.759	3084.534	-3627.44	-234448	-1839.33	-4054.84	-489.534	-8583.56
-0.3Ex+0.3Ey-1Ez	-219842	-1296.39	-1837.9	2679.258	-5611.4	-224118	-1604.81	-2950.7	-84.258	-6599.6

Table 6.22 combinations of actions result (EL779)

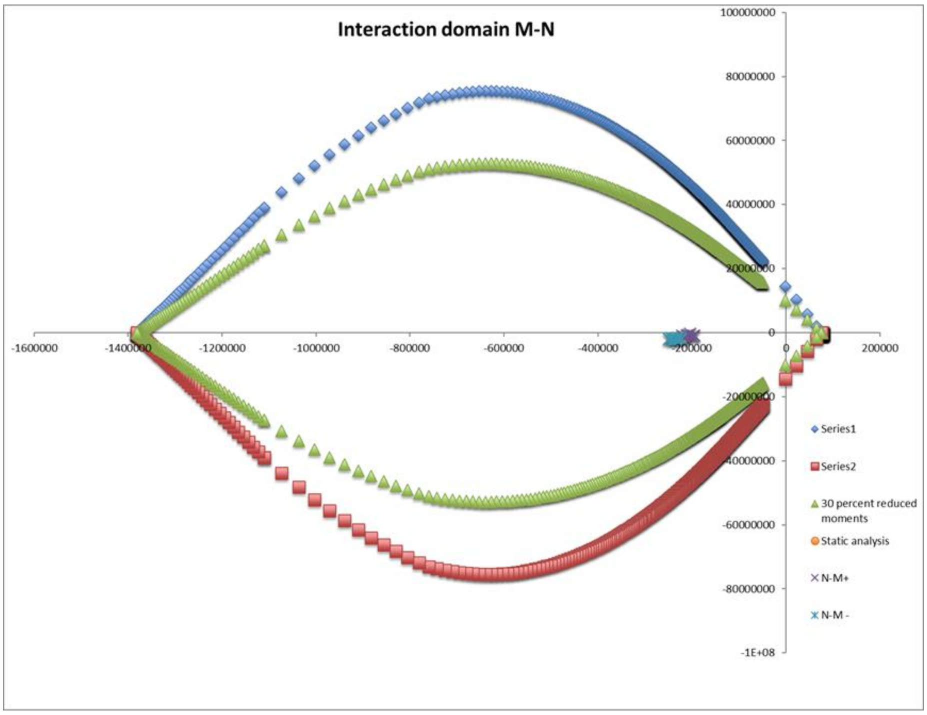


Figure 6.26 N-My interaction domain (EL779)

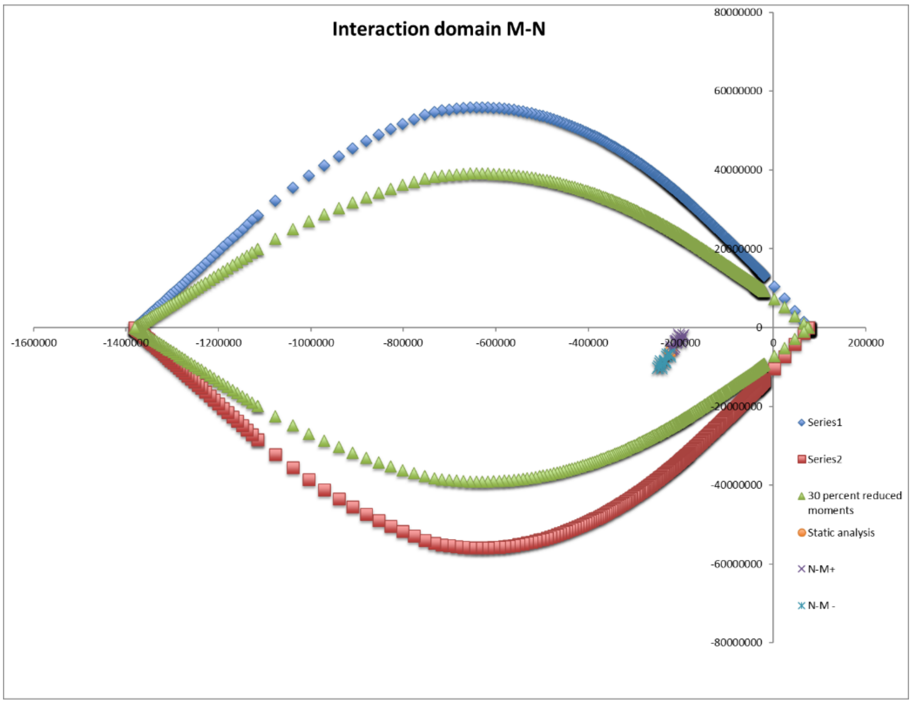


Figure 6.27N-Mz interaction domain (EL779)

Figure 7.26 and Figure 7.27 are the N-M interaction diagrams for the external pillar at the base point with the combinations of normal forces and bending moments. In both direction the all-combinations values are between the reduced bending moment resistance -normal forces diagram. The external pillar has enough strength to resist against axial forces and bending moments.

Ned [N]	$f$cd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c} \leq 0.65$	Check
-207000	10.91	120000	0.16	ok
-208887	10.91	120000	0.16	ok
-220466	10.91	120000	0.17	ok
-221607	10.91	120000	0.17	ok
-210474	10.91	120000	0.16	ok
-211382	10.91	120000	0.16	ok
-203526	10.91	120000	0.16	ok
-202618	10.91	120000	0.15	ok
-194673	10.91	120000	0.15	ok
-196560	10.91	120000	0.15	ok
-200599	10.91	120000	0.15	ok
-198712	10.91	120000	0.15	ok
-200599	10.91	120000	0.15	ok
-198712	10.91	120000	0.15	ok
-194673	10.91	120000	0.15	ok
-196560	10.91	120000	0.15	ok
-209512	10.91	120000	0.16	ok
-219842	10.91	120000	0.17	ok
-215802	10.91	120000	0.16	ok
-213552	10.91	120000	0.16	ok
-215802	10.91	120000	0.16	ok
-213552	10.91	120000	0.16	ok
-209512	10.91	120000	0.16	ok
-219842	10.91	120000	0.17	ok
-236960	10.91	120000	0.18	ok
-235073	10.91	120000	0.18	ok
-223494	10.91	120000	0.17	ok
-222353	10.91	120000	0.17	ok
-233486	10.91	120000	0.18	ok
-232578	10.91	120000	0.18	ok
-240434	10.91	120000	0.18	ok
-241342	10.91	120000	0.18	ok
-249287	10.91	120000	0.19	ok
-247400	10.91	120000	0.19	ok
-243361	10.91	120000	0.19	ok
-245248	10.91	120000	0.19	ok
-243361	10.91	120000	0.19	ok
-245248	10.91	120000	0.19	ok
-249287	10.91	120000	0.19	ok
-247400	10.91	120000	0.19	ok
-234448	10.91	120000	0.18	ok
-224118	10.91	120000	0.17	ok
-228158	10.91	120000	0.17	ok
-230408	10.91	120000	0.18	ok
-228158	10.91	120000	0.17	ok
-230408	10.91	120000	0.18	ok
-234448	10.91	120000	0.18	ok
-224118	10.91	120000	0.17	ok
-221980	10.91	120000	0.17	ok

*Table 6.23 check Ned/(fcd*Ac)*

6.2.1.9 EL8734 (External pillar in the gallery side)

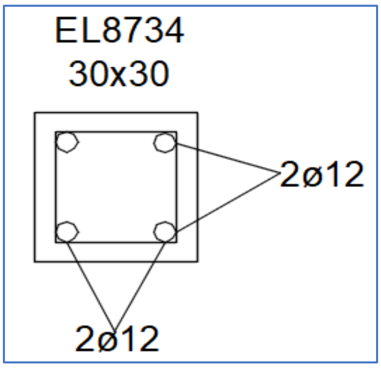


Figure 6.28 cross-section (EL8734)

EL8734 is the name in code to represent the external pillar at the midpoint in the C hall gallery side. It has the same material properties and reinforcement bars like external pillar (EL779). It is 30 cm by 30 cm square cross-section. The concrete cover is defined 2cm.

Table 7.24 is for the results of static analysis which is 109 kN axial force and 5.8 kN shear force in y direction ,0.11 kN in z direction. The bending moments are 0.13 kNm, 7.23 kNm in y and z axis respectively.

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-109130	134.19	5776.1	105.97	7233.2

Table 6.24 static analysis results (EL8734)

EL8734	Estatic+ Ed					Estatic- Ed				
	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
1Ex+0.3Ey+0.3Ez	-103015	878.4619	10640.14	1194.963	14106.1	-115245	-610.082	912.058	-983.023	360.301
1Ex+0.3Ey-0.3Ez	-104239	874.0555	10410.2	1164.139	13832.9	-114021	-605.676	1142.002	-952.199	633.499
1Ex-0.3Ey-0.3Ez	-107156	843.9181	6195.742	1044.577	8024.299	-111104	-575.538	5356.458	-832.637	6442.101
1Ex-0.3Ey+0.3Ez	-105932	848.3245	5965.798	1075.401	7751.101	-112328	-579.945	5586.402	-863.461	6715.299
-1Ex+0.3Ey+0.3Ez	-105074	443.5838	9375.805	595.9296	12363.52	-113186	-175.204	2176.395	-383.99	2102.882
-1Ex+0.3Ey-0.3Ez	-103890	869.4207	9124.02	1159.094	11888.86	-114370	-601.041	2428.18	-947.154	2577.541
-1Ex-0.3Ey-0.3Ez	-100955	1313.34	11904.48	1793.996	15848.68	-117305	-1044.96	-352.279	-1582.06	-1382.28
-1Ex-0.3Ey+0.3Ez	-102140	887.5031	12156.26	1230.831	16323.34	-116120	-619.123	-604.064	-1018.89	-1856.94
0.3Ex+1Ey+0.3Ez	-102442	404.7222	14980.63	624.7916	20600.07	-115818	-136.342	-3428.43	-412.852	-6133.67
0.3Ex+1Ey-0.3Ez	-103666	400.3158	14750.69	593.9684	20326.87	-114594	-131.936	-3198.49	-382.028	-5860.47
-0.3Ex+1Ey-0.3Ez	-106093	304.2642	13417.37	226.2516	18502.33	-112167	-35.8842	-1865.17	-14.3116	-4035.93
-0.3Ex+1Ey+0.3Ez	-104869	299.8578	13647.31	195.4284	18775.53	-113391	-31.4778	-2095.11	16.5116	-4309.13
0.3Ex-1Ey+0.3Ez	-106093	304.2642	13417.37	226.2516	18502.33	-112167	-35.8842	-1865.17	-14.3116	-4035.93
0.3Ex-1Ey-0.3Ez	-104869	299.8578	13647.31	195.4284	18775.53	-113391	-31.4778	-2095.11	16.5116	-4309.13
-0.3Ex-1Ey-0.3Ez	-102442	404.7222	14980.63	624.7916	20600.07	-115818	-136.342	-3428.43	-412.852	-6133.67
-0.3Ex-1Ey+0.3Ez	-103666	400.3158	14750.69	593.9684	20326.87	-114594	-131.936	-3198.49	-382.028	-5860.47
0.3Ex+0.3Ey+1Ez	-104418	374.7027	9352.87	521.263	12296.2	-113842	-106.323	2199.33	-309.323	2170.2
0.3Ex-0.3Ey+1Ez	-107335	344.5653	7253.07	401.701	9561	-110925	-76.1853	4299.13	-189.761	4905.4
-0.3Ex-0.3Ey+1Ez	-108498	360.0147	8586.39	418.519	11385.54	-109762	-91.6347	2965.81	-206.579	3080.86
-0.3Ex+0.3Ey+1Ez	-106845	329.8773	8019.55	298.957	10471.66	-111415	-61.4973	3532.65	-87.017	3994.74
0.3Ex+0.3Ey-1Ez	-108498	360.0147	8586.39	418.519	11385.54	-109762	-91.6347	2965.81	-206.579	3080.86
0.3Ex-0.3Ey-1Ez	-106845	329.8773	8019.55	298.957	10471.66	-111415	-61.4973	3532.65	-87.017	3994.74
-0.3Ex-0.3Ey-1Ez	-104418	374.7027	9352.87	521.263	12296.2	-113842	-106.323	2199.33	-309.323	2170.2
-0.3Ex+0.3Ey-1Ez	-107335	344.5653	7253.07	401.701	9561	-110925	-76.1853	4299.13	-189.761	4905.4

Table 6.25 combination of actions results (EL87354)

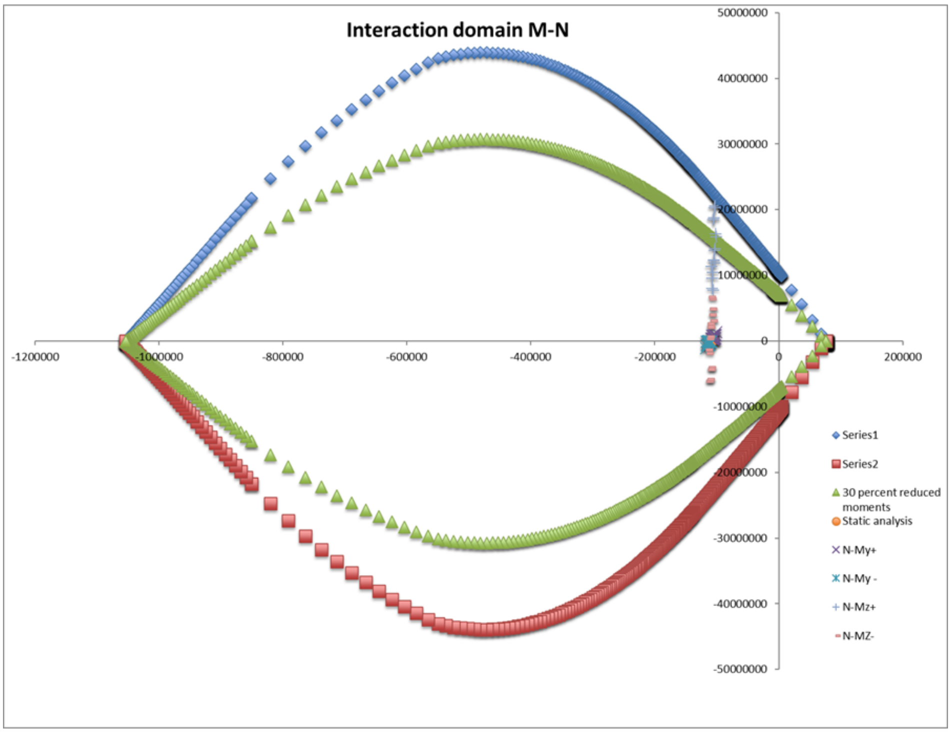


Figure 6.29 N-M interaction diagram (EL8734)

Figure 7.29 is the graph which is represent N-M interaction diagram for the y and z directions. The cross-section of the pillar is defined square therefore it can be using the same interaction diagram for both directions. In the graph can be seen some points are outside of the reduced bending moment, normal forces interaction diagram. Therefore, the pillar hasn't enough resistance for the acting normal forces and bending moments.

Ned [N]	$f$cd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c} \leq 0.65$	Check
-103015	10.91	90000	0.10	ok
-104239	10.91	90000	0.11	ok
-107156	10.91	90000	0.11	ok
-105932	10.91	90000	0.11	ok
-105074	10.91	90000	0.11	ok
-103890	10.91	90000	0.11	ok
-100955	10.91	90000	0.10	ok
-102140	10.91	90000	0.10	ok
-102442	10.91	90000	0.10	ok
-103666	10.91	90000	0.11	ok
-106093	10.91	90000	0.11	ok
-104869	10.91	90000	0.11	ok
-106093	10.91	90000	0.11	ok
-104869	10.91	90000	0.11	ok
-102442	10.91	90000	0.10	ok
-103666	10.91	90000	0.11	ok
-104418	10.91	90000	0.11	ok
-107335	10.91	90000	0.11	ok
-108498	10.91	90000	0.11	ok
-106845	10.91	90000	0.11	ok
-108498	10.91	90000	0.11	ok
-106845	10.91	90000	0.11	ok
-104418	10.91	90000	0.11	ok
-107335	10.91	90000	0.11	ok
-115245	10.91	90000	0.12	ok
-114021	10.91	90000	0.12	ok
-111104	10.91	90000	0.11	ok
-112328	10.91	90000	0.11	ok
-113186	10.91	90000	0.12	ok
-114370	10.91	90000	0.12	ok
-117305	10.91	90000	0.12	ok
-116120	10.91	90000	0.12	ok
-115818	10.91	90000	0.12	ok
-114594	10.91	90000	0.12	ok
-112167	10.91	90000	0.11	ok
-113391	10.91	90000	0.12	ok
-112167	10.91	90000	0.11	ok
-113391	10.91	90000	0.12	ok
-115818	10.91	90000	0.12	ok
-114594	10.91	90000	0.12	ok
-113842	10.91	90000	0.12	ok
-110925	10.91	90000	0.11	ok
-109762	10.91	90000	0.11	ok
-111415	10.91	90000	0.11	ok
-109762	10.91	90000	0.11	ok
-111415	10.91	90000	0.11	ok
-113842	10.91	90000	0.12	ok
-110925	10.91	90000	0.11	ok
-109130	10.91	90000	0.11	ok

*Figure 6.30 check Ned/(fcd*Ac)*

6.2.1.10 EL1921 (Central Arches_at the base)

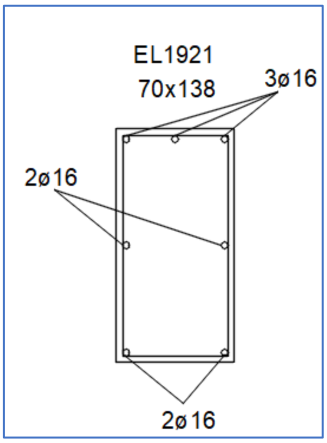


Figure 6.31 cross-section (EL1921)

EL1921 is the name in software code for the central arches foot at the base point. It has been defined 70 cm by 138 cm rectangular cross-section shape. It has 2Φ16 reinforcement bar at the bottom and 3Φ16 on the top. 1Φ16 at each side in the middle. The concrete cover is 4cm.

Table 7.26 is shown the static analysis results for the EL1921. Normal force is 218 kN and 25.7 kN shear force in y direction 15.5 kN shear force in z direction. The bending moments are 25 kNm and 68.4 kNm in y and z direction respectively.

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-2178100	25027	25703	-15508	-68400

Table 6.26 static analysis results (EL1921)

EL1921	Estatic+ Ed					Estatic- Ed				
	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
1Ex+0.3Ey+0.3Ez	-2050441	605770.1	70541.11	82555.89	102925.5	-2305759	-555716	-19135.1	-113572	-239725
1Ex+0.3Ey-0.3Ez	-2090330	597281.9	69545.29	79525.71	100194.6	-2265871	-547228	-18139.3	-110542	-236995
1Ex-0.3Ey-0.3Ez	-2135477	267563.9	46466.89	27244.11	6654.55	-2220723	-217510	4939.11	-58260.1	-143455
1Ex-0.3Ey+0.3Ez	-2095589	276052.1	47462.71	30274.29	9385.45	-2260612	-225998	3943.29	-61290.3	-146185
-1Ex+0.3Ey+0.3Ez	-2089559	361332.6	51159.26	41220.14	29830.72	-2266641	-311279	246.744	-72236.1	-166631
-1Ex+0.3Ey-0.3Ez	-2063985	506854.7	63617.59	66871.41	74863.45	-2292215	-456801	-12211.6	-97887.4	-211663
-1Ex-0.3Ey-0.3Ez	-2011323	850207.6	89922.96	123891.6	176020.2	-2344877	-800154	-38517	-154908	-312820
-1Ex-0.3Ey+0.3Ez	-2036897	704685.5	77464.63	98240.37	130987.5	-2319303	-654632	-26058.6	-129256	-267787
0.3Ex+1Ey+0.3Ez	-2057367	702293.1	74505.21	94265.49	125822.5	-2298833	-652239	-23099.2	-125281	-262622
0.3Ex+1Ey-0.3Ez	-2097256	693804.9	73509.39	91235.31	123091.6	-2258944	-643751	-22103.4	-122251	-259892
-0.3Ex+1Ey-0.3Ez	-2148341	446820.9	53828.79	48990.51	49177.55	-2207859	-396767	-2422.79	-80006.5	-185978
-0.3Ex+1Ey+0.3Ez	-2108452	455309.1	54824.61	52020.69	51908.45	-2247748	-405255	-3418.61	-83036.7	-188708
0.3Ex-1Ey+0.3Ez	-2148341	446820.9	53828.79	48990.51	49177.55	-2207859	-396767	-2422.79	-80006.5	-185978
0.3Ex-1Ey-0.3Ez	-2108452	455309.1	54824.61	52020.69	51908.45	-2247748	-405255	-3418.61	-83036.7	-188708
-0.3Ex-1Ey-0.3Ez	-2057367	702293.1	74505.21	94265.49	125822.5	-2298833	-652239	-23099.2	-125281	-262622
-0.3Ex-1Ey+0.3Ez	-2097256	693804.9	73509.39	91235.31	123091.6	-2258944	-643751	-22103.4	-122251	-259892
0.3Ex+0.3Ey+1Ez	-2063503	327525	48742.2	36805.5	19878.5	-2292697	-277471	2663.8	-67821.5	-156679
0.3Ex-0.3Ey+1Ez	-2108651	52247	25742.2	-15476.1	-63138.5	-2247550	-2193	25663.8	-15539.9	-73661.5
-0.3Ex-0.3Ey+1Ez	-2159735	299231	45422.8	26704.9	10775.5	-2196465	-249177	5983.2	-57720.9	-147576
-0.3Ex+0.3Ey+1Ez	-2114588	80541	29061.6	-5439.3	-54035.5	-2241613	-30487	22344.4	-25576.7	-82764.5
0.3Ex+0.3Ey-1Ez	-2159735	299231	45422.8	26704.9	10775.5	-2196465	-249177	5983.2	-57720.9	-147576
0.3Ex-0.3Ey-1Ez	-2114588	80541	29061.6	-5439.3	-54035.5	-2241613	-30487	22344.4	-25576.7	-82764.5
-0.3Ex-0.3Ey-1Ez	-2063503	327525	48742.2	36805.5	19878.5	-2292697	-277471	2663.8	-67821.5	-156679
-0.3Ex+0.3Ey-1Ez	-2108651	52247	25742.2	-15476.1	-63138.5	-2247550	-2193	25663.8	-15539.9	-73661.5

Table 6.27 combination of actions results (EL1921)

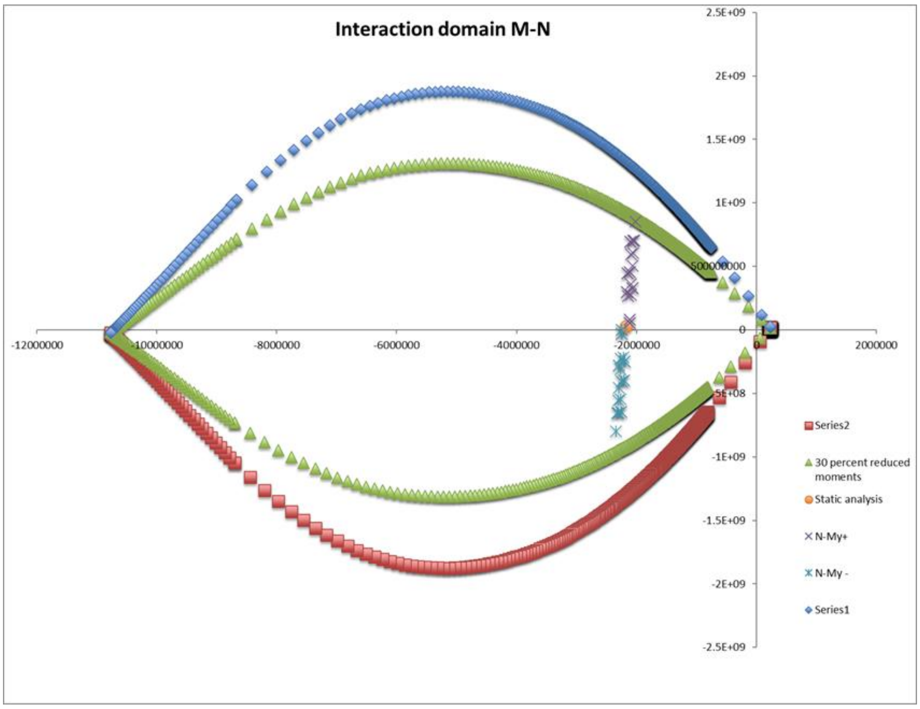


Figure 6.32 N-My interaction domain (EL1921)

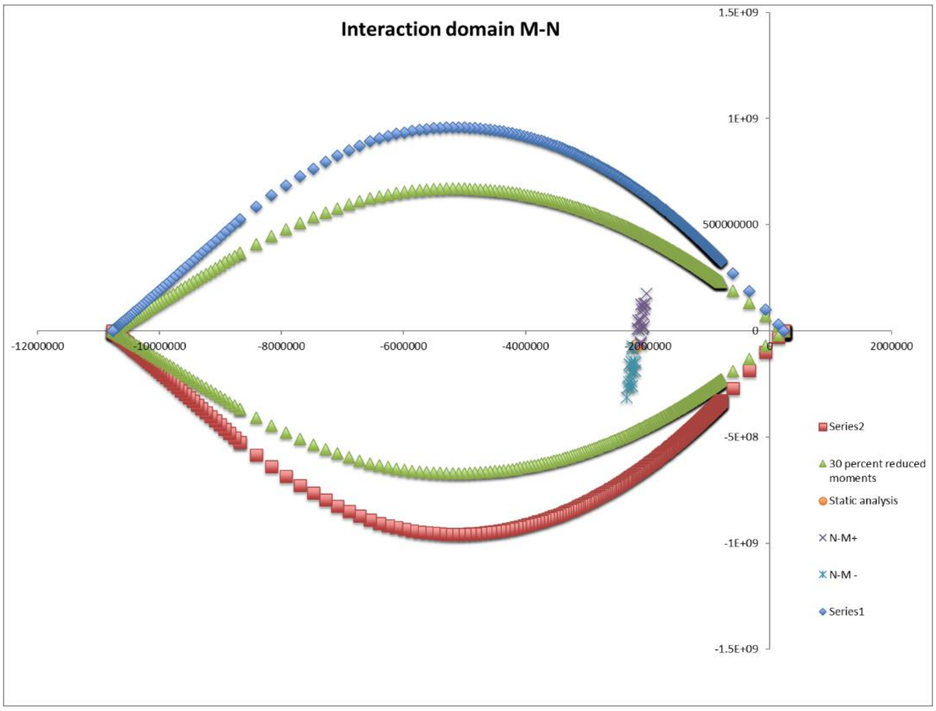


Figure 6.33 N-Mz interaction domain (EL1921)

Figure 7.32 and Figure 7.33 are the output for macro code to make N-M interaction diagrams with the results of actions of combinations. The values of normal forces and bending moments that obtained by combination of static analysis and dynamic analysis are placed between reduced bending moment- normal forces interaction diagram. Therefore Central arches at the base point has enough resistance for the acting forces.

Ned [N]	$f$cd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c} \leq 0.65$	Check
-2050440.9	10.91	966000	0.19	ok
-2090329.5	10.91	966000	0.20	ok
-2135477.1	10.91	966000	0.20	ok
-2095588.5	10.91	966000	0.20	ok
-2089558.9	10.91	966000	0.20	ok
-2063985.2	10.91	966000	0.20	ok
-2011322.9	10.91	966000	0.19	ok
-2036896.6	10.91	966000	0.19	ok
-2057367.4	10.91	966000	0.20	ok
-2097256	10.91	966000	0.20	ok
-2148340.6	10.91	966000	0.20	ok
-2108452	10.91	966000	0.20	ok
-2148340.6	10.91	966000	0.20	ok
-2108452	10.91	966000	0.20	ok
-2057367.4	10.91	966000	0.20	ok
-2097256	10.91	966000	0.20	ok
-2063502.9	10.91	966000	0.20	ok
-2108650.5	10.91	966000	0.20	ok
-2159735.1	10.91	966000	0.20	ok
-2114587.5	10.91	966000	0.20	ok
-2159735.1	10.91	966000	0.20	ok
-2114587.5	10.91	966000	0.20	ok
-2063502.9	10.91	966000	0.20	ok
-2108650.5	10.91	966000	0.20	ok
-2305759.1	10.91	966000	0.22	ok
-2265870.5	10.91	966000	0.21	ok
-2220722.9	10.91	966000	0.21	ok
-2260611.5	10.91	966000	0.21	ok
-2266641.1	10.91	966000	0.22	ok
-2292214.8	10.91	966000	0.22	ok
-2344877.1	10.91	966000	0.22	ok
-2319303.4	10.91	966000	0.22	ok
-2298832.6	10.91	966000	0.22	ok
-2258944	10.91	966000	0.21	ok
-2207859.4	10.91	966000	0.21	ok
-2247748	10.91	966000	0.21	ok
-2207859.4	10.91	966000	0.21	ok
-2247748	10.91	966000	0.21	ok
-2298832.6	10.91	966000	0.22	ok
-2258944	10.91	966000	0.21	ok
-2292697.1	10.91	966000	0.22	ok
-2247549.5	10.91	966000	0.21	ok
-2196464.9	10.91	966000	0.21	ok
-2241612.5	10.91	966000	0.21	ok
-2196464.9	10.91	966000	0.21	ok
-2241612.5	10.91	966000	0.21	ok
-2292697.1	10.91	966000	0.22	ok
-2247549.5	10.91	966000	0.21	ok
-2178100	10.91	966000	0.21	ok

*Table 6.28 check Ned/(fcd*Ac)*

1.1.1.1 EL1917 (Central Arches_in the middle point)

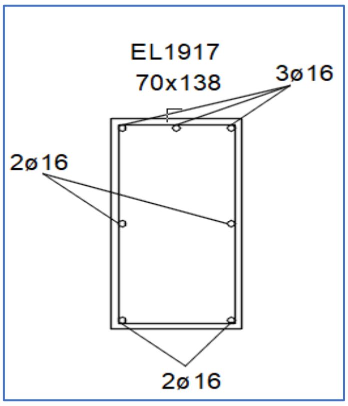


Figure 6.34 cross-section (EL1917)

EL1917 is the code name for the central arches in the middle point which has the same cross-section with EL1921. It has also same material properties and reinforcements bars. Table 7.29 is shown the static analysis results for the EL1921. Normal force is 210 kN and 25.7 kN shear force in y direction 75.34 kN shear force in z direction. The bending moments are 206.7 kNm and 34.413 kNm in y and z direction respectively.

	N [N]	My [Nm]	Ty [N]	Tz [N]	Mz [Nm]
Static analysis	-2104600	206730	25703	-75343	34413

Table 6.29 static analysis results (EL1917)

EL1917	Estatic+ Ed					Estatic- Ed				
	N	My	Ty	Tz	Mz	N	My	Ty	Tz	Mz
	[N]	[Nm]	[N]	[N]	[Nm]	[N]	[Nm]	[N]	[N]	[Nm]
1Ex+0.3Ey+0.3Ez	-1977118	422776.1	68437.52	20028.55	51942.46	-2232082	-9316.14	-17031.5	-170715	16883.54
1Ex+0.3Ey-0.3Ez	-2016939	418585.9	67548.08	17127.85	50801.56	-2192261	-5125.86	-16142.1	-167814	18024.44
1Ex-0.3Ey-0.3Ez	-2062026	294523.9	45620.48	-34012.6	46321.54	-2147174	118936.1	5785.52	-116673	22504.46
1Ex-0.3Ey+0.3Ez	-2022205	298714.1	46509.92	-31111.9	47462.44	-2186995	114745.9	4896.08	-119574	21363.56
-1Ex+0.3Ey+0.3Ez	-2016189	332881.2	49908.75	-20111.8	43453.33	-2193011	80578.78	1497.248	-130574	25372.67
-1Ex+0.3Ey-0.3Ez	-1990644	385557.5	61859.24	4686.43	50598.45	-2218556	27902.46	-10453.2	-155372	18227.55
-1Ex-0.3Ey-0.3Ez	-1938048	512671.1	86966.29	60168.94	60431.59	-2271152	-99211.1	-35560.3	-210855	8394.41
-1Ex-0.3Ey+0.3Ez	-1963592	459994.7	75015.8	35370.67	53286.47	-2245608	-46534.7	-23609.8	-186057	15539.53
0.3Ex+1Ey+0.3Ez	-1984037	461171.1	72091.52	31846.65	46865.85	-2225163	-47711.1	-20685.5	-182533	21960.15
0.3Ex+1Ey-0.3Ez	-2023858	456980.9	71202.08	28945.95	45724.95	-2185342	-43520.9	-19796.1	-179632	23101.05
-0.3Ex+1Ey-0.3Ez	-2074875	365828.9	52406.48	-12064.7	36893.55	-2134325	47631.14	-1000.48	-138621	31932.45
-0.3Ex+1Ey+0.3Ez	-2035054	370019.1	53295.92	-9163.95	38034.45	-2174146	43440.86	-1889.92	-141522	30791.55
0.3Ex-1Ey+0.3Ez	-2074875	365828.9	52406.48	-12064.7	36893.55	-2134325	47631.14	-1000.48	-138621	31932.45
0.3Ex-1Ey-0.3Ez	-2035054	370019.1	53295.92	-9163.95	38034.45	-2174146	43440.86	-1889.92	-141522	30791.55
-0.3Ex-1Ey-0.3Ez	-1984037	461171.1	72091.52	31846.65	46865.85	-2225163	-47711.1	-20685.5	-182533	21960.15
-0.3Ex-1Ey+0.3Ez	-2023858	456980.9	71202.08	28945.95	45724.95	-2185342	-43520.9	-19796.1	-179632	23101.05
0.3Ex+0.3Ey+1Ez	-1990180	321320.8	47547	-24433	42970.21	-2219020	92139.2	3859	-126253	25855.79
0.3Ex-0.3Ey+1Ez	-2035267	216201.2	25786.6	-75112.6	38490.19	-2173933	197258.8	25619.4	-75573.4	30335.81
-0.3Ex-0.3Ey+1Ez	-2086284	307353.2	44582.2	-34102	39167.21	-2122916	106106.8	6823.8	-116584	29658.79
-0.3Ex+0.3Ey+1Ez	-2041197	230168.8	28751.4	-65443.6	34687.19	-2168003	183291.2	22654.6	-85242.4	34138.81
0.3Ex+0.3Ey-1Ez	-2086284	307353.2	44582.2	-34102	39167.21	-2122916	106106.8	6823.8	-116584	29658.79
0.3Ex-0.3Ey-1Ez	-2041197	230168.8	28751.4	-65443.6	34687.19	-2168003	183291.2	22654.6	-85242.4	34138.81
-0.3Ex-0.3Ey-1Ez	-1990180	321320.8	47547	-24433	42970.21	-2219020	92139.2	3859	-126253	25855.79
-0.3Ex+0.3Ey-1Ez	-2035267	216201.2	25786.6	-75112.6	38490.19	-2173933	197258.8	25619.4	-75573.4	30335.81

Table 6.30 combination of actions results (EL1917)

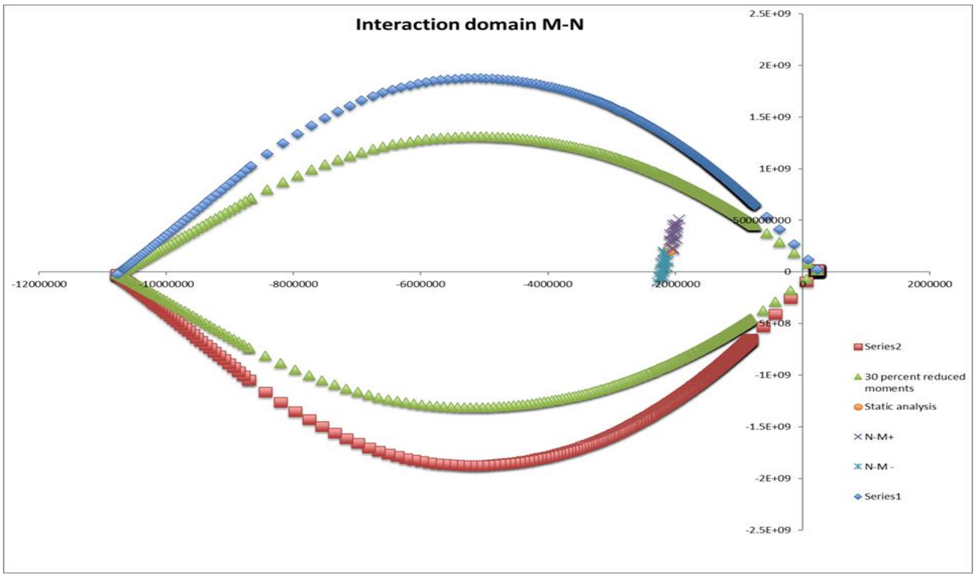


Figure 6.35 N-My interaction domain (EL1917)

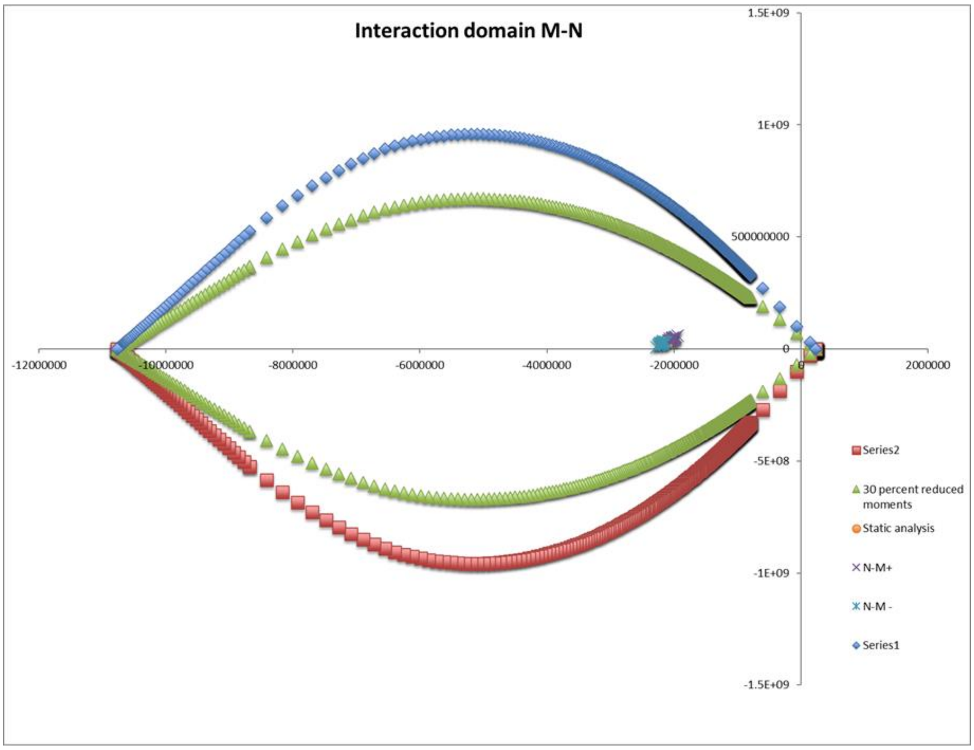


Figure 6.36 N-Mz interaction domain (EL1917)

Figures 7.35 and 7.36 show the output of macro code for creating N-M interaction diagrams with the consequences of combinations' actions. The values of normal forces and bending moments obtained from a combination of static and dynamic analysis are shown on a reduced bending moment-normal forces interaction diagram. As a result, the central arches in the middle point provide enough resistance to the active forces.

Ned [N]	$f$cd [MPa]	Ac [mm^2]	$\frac{N_{Ed}}{f_{cd}A_c} \leq 0.65$	Check
-1977118.4	10.91	966000	0.19	ok
-2016939.2	10.91	966000	0.19	ok
-2062025.6	10.91	966000	0.20	ok
-2022204.8	10.91	966000	0.19	ok
-2016189	10.91	966000	0.19	ok
-1990644.3	10.91	966000	0.19	ok
-1938047.8	10.91	966000	0.18	ok
-1963592.5	10.91	966000	0.19	ok
-1984037.2	10.91	966000	0.19	ok
-2023858	10.91	966000	0.19	ok
-2074874.8	10.91	966000	0.20	ok
-2035054	10.91	966000	0.19	ok
-2074874.8	10.91	966000	0.20	ok
-2035054	10.91	966000	0.19	ok
-1984037.2	10.91	966000	0.19	ok
-2023858	10.91	966000	0.19	ok
-1990180.4	10.91	966000	0.19	ok
-2035266.8	10.91	966000	0.19	ok
-2086283.6	10.91	966000	0.20	ok
-2041197.2	10.91	966000	0.19	ok
-2086283.6	10.91	966000	0.20	ok
-2041197.2	10.91	966000	0.19	ok
-1990180.4	10.91	966000	0.19	ok
-2035266.8	10.91	966000	0.19	ok
-2232081.6	10.91	966000	0.21	ok
-2192260.8	10.91	966000	0.21	ok
-2147174.4	10.91	966000	0.20	ok
-2186995.2	10.91	966000	0.21	ok
-2193011	10.91	966000	0.21	ok
-2218555.7	10.91	966000	0.21	ok
-2271152.2	10.91	966000	0.22	ok
-2245607.5	10.91	966000	0.21	ok
-2225162.8	10.91	966000	0.21	ok
-2185342	10.91	966000	0.21	ok
-2134325.2	10.91	966000	0.20	ok
-2174146	10.91	966000	0.21	ok
-2134325.2	10.91	966000	0.20	ok
-2174146	10.91	966000	0.21	ok
-2225162.8	10.91	966000	0.21	ok
-2185342	10.91	966000	0.21	ok
-2219019.6	10.91	966000	0.21	ok
-2173933.2	10.91	966000	0.21	ok
-2122916.4	10.91	966000	0.20	ok
-2168002.8	10.91	966000	0.21	ok
-2122916.4	10.91	966000	0.20	ok
-2168002.8	10.91	966000	0.21	ok
-2219019.6	10.91	966000	0.21	ok
-2173933.2	10.91	966000	0.21	ok
-2104600	10.91	966000	0.20	ok

*Table 6.31 check Ned/(fcd*Ac)*

6.2.2 Shear Assessment

Structures were frequently examined in the early stages of structural assessment practice based on the design need. Generally, design codes were employed, and if a given construction complied with the code, it was considered as safe. It was later shown that such a simple technique might result in a conservative evaluation result in many cases, particularly when it came to shear capability. This occurs because the ancient structures were created in accordance with the old design codes, whilst the evaluation is carried out in accordance with the current rules. In terms of shear, the present regulations are more stringent than the earlier ones in various ways. [16]

It's inaccurate assumption of linear longitudinal stress state in fractured concrete This is due to the fact that shear behavior cannot be generalized under all situations. It is extremely sensitive to changes in factors such as beam section, shear span ratio, and steel reinforcement. It is even possible for seemingly similar beams to behave differently. This is because shear behavior and strength are impacted by multiple parameters, and there are likely parameters or correlations between these parameters that have yet to be discovered. [17]

The design shear resistance V_{Rd} of structural members with shear reinforcement must be assessed using an appropriate lattice structure. The ideal lattice's resistant elements are the transverse reinforcement, longitudinal reinforcement, compressed concrete stream, and inclined core struts. Brittle failure, the most hazardous outcome of shear motion, can occur.

The shear assessment updated code is shown below which provided by Italian code; [18]

Tension-shear: assess the shear reinforcement

$$V_{Rs} = 0.9\, d\, \frac{A_{sw}}{s} f_{yd} \left(cotg(\alpha) + cotg(\theta)\right) \sin(\alpha)$$

Compression-shear: assess the concrete

$$V_{Rc} = 0.9\, d\, b_w\, \alpha_c\, \nu\, f_{cd}\, \frac{cotg(\alpha) + cotg(\theta)}{1 + cotg^2(\theta)}$$

Resistance shear of a section

$$V_{Rd} = \min(V_{Rs}, V_{Rc})$$

Where

$$\alpha = 90° \; and \; \theta = 45°$$

$$\alpha_c \begin{cases} = 1 & if \quad N_{ed} \geq 0 \; (tension) \\ = 1 + \frac{\sigma_{cp}}{f_{cd}} & if \quad 0 \leq \sigma_{cp} \leq 0.25 f_{cd} \\ = 1.25 & if \quad 0.25 f_{cd} \leq \sigma_{cp} \leq 0.5 f_{cd} \\ = 2.5 \left(1 - \frac{\sigma_{cp}}{f_{cd}}\right) & if \quad 0.5 f_{cd} \leq \sigma_{cp} \leq f_{cd} \end{cases}$$

$$\sigma_{cp} = \frac{|N_{ed}|}{A_c}$$

$$\nu = 0.5$$

$A_{sw} = 2\frac{\varphi_{sw}^2}{4}$: shear reinforcement area

α: angle of inclination of the transverse reinforcement with respect to the axis of the beam

b_w: minimum section width (in mm)

θ: inclination of concrete struts with respect to the beam axis

Shear force calculations were performed using MATLAB code and the current Italian code. The design shear force and resistance shear force were compared using an excel spreadsheet. Each critical element's results have been provided. The action of combinations results and static analysis results (totally 49 values for each direction) are taken into account while doing verification of shear assessment .The outcomes are addressed in following.

EL1753 (Long archway at the base)

For the long archway at the base, it has been used Φ8 transverse rebar with 20cm space. The results which are provided by MATLAB code and excel file is shown in Table 7.32.

Ty [N]	Tz [N]	VRc [N]	VRS [N]	VRd [N]	CHECK Ty	CHECK Tz
356968.5	6318.54	3304045	8.49E+04	8.49E+04	NOT VERIFIED	OK
353681.5	2831.46	3311795	8.49E+04	8.49E+04	NOT VERIFIED	OK
289751.5	-55134.5	3398971	8.49E+04	8.49E+04	NOT VERIFIED	OK
293038.5	-51647.5	3391221	8.49E+04	8.49E+04	NOT VERIFIED	OK
298136.4	-17229.3	3383147	8.49E+04	8.49E+04	NOT VERIFIED	OK
337789.5	-11071.3	3330198	8.49E+04	8.49E+04	NOT VERIFIED	OK
415800.6	29866.42	3224943	8.49E+04	8.49E+04	NOT VERIFIED	OK
376147.5	23708.34	3277893	8.49E+04	8.49E+04	NOT VERIFIED	OK
361765.6	45252.54	3297339	8.49E+04	8.49E+04	NOT VERIFIED	OK
358478.6	41765.46	3305089	8.49E+04	8.49E+04	NOT VERIFIED	OK
298660.4	17171.46	3386516	8.49E+04	8.49E+04	NOT VERIFIED	OK
301947.4	20658.54	3378766	8.49E+04	8.49E+04	NOT VERIFIED	OK
298660.4	17171.46	3386516	8.49E+04	8.49E+04	NOT VERIFIED	OK
301947.4	20658.54	3378766	8.49E+04	8.49E+04	NOT VERIFIED	OK
361765.6	45252.54	3297339	8.49E+04	8.49E+04	NOT VERIFIED	OK
358478.6	41765.46	3305089	8.49E+04	8.49E+04	NOT VERIFIED	OK
291015.5	-18306.2	3390002	8.49E+04	8.49E+04	NOT VERIFIED	OK
227085.5	-54523.8	3477177	8.49E+04	8.49E+04	NOT VERIFIED	OK
280058.7	-29929.8	3415835	8.49E+04	8.49E+04	NOT VERIFIED	OK
231197.3	-42900.2	3471429	8.49E+04	8.49E+04	NOT VERIFIED	OK
280058.7	-29929.8	3415835	8.49E+04	8.49E+04	NOT VERIFIED	OK
231197.3	-42900.2	3471429	8.49E+04	8.49E+04	NOT VERIFIED	OK
291015.5	-18306.2	3390002	8.49E+04	8.49E+04	NOT VERIFIED	OK
227085.5	-54523.8	3477177	8.49E+04	8.49E+04	NOT VERIFIED	OK
90357.48	-137115	3649590	8.49E+04	8.49E+04	NOT VERIFIED	OK
93644.52	-133627	3649590	8.49E+04	8.49E+04	NOT VERIFIED	OK
157574.5	-75661.5	3575469	8.49E+04	8.49E+04	NOT VERIFIED	OK
154287.5	-79148.5	3583219	8.49E+04	8.49E+04	NOT VERIFIED	OK
149189.6	-113567	3591292	8.49E+04	8.49E+04	NOT VERIFIED	OK
109536.5	-119725	3644242	8.49E+04	8.49E+04	NOT VERIFIED	OK
31525.39	-160662	3649590	8.49E+04	8.49E+04	OK	OK
71178.48	-154504	3649590	8.49E+04	8.49E+04	OK	OK
85560.38	-176049	3649590	8.49E+04	8.49E+04	NOT VERIFIED	OK
88847.42	-172561	3649590	8.49E+04	8.49E+04	NOT VERIFIED	OK
148665.6	-147967	3587923	8.49E+04	8.49E+04	NOT VERIFIED	OK
145378.6	-151455	3595674	8.49E+04	8.49E+04	NOT VERIFIED	OK
148665.6	-147967	3587923	8.49E+04	8.49E+04	NOT VERIFIED	OK
145378.6	-151455	3595674	8.49E+04	8.49E+04	NOT VERIFIED	OK
85560.38	-176049	3649590	8.49E+04	8.49E+04	NOT VERIFIED	OK
88847.42	-172561	3649590	8.49E+04	8.49E+04	NOT VERIFIED	OK
156310.5	-112490	3584438	8.49E+04	8.49E+04	NOT VERIFIED	OK
220240.5	-76272.2	3497263	8.49E+04	8.49E+04	NOT VERIFIED	OK
167267.3	-100866	3558604	8.49E+04	8.49E+04	NOT VERIFIED	OK
216128.7	-87895.8	3503011	8.49E+04	8.49E+04	NOT VERIFIED	OK
167267.3	-100866	3558604	8.49E+04	8.49E+04	NOT VERIFIED	OK
216128.7	-87895.8	3503011	8.49E+04	8.49E+04	NOT VERIFIED	OK
156310.5	-112490	3584438	8.49E+04	8.49E+04	NOT VERIFIED	OK
220240.5	-76272.2	3497263	8.49E+04	8.49E+04	NOT VERIFIED	OK
223663	-65398	3487220	8.49E+04	8.49E+04	NOT VERIFIED	OK

Table 6.32 shear assessment verification results (EL1753)

The resistance shear force is the minimum value for the shear resistance in concrete and steel. The shear resistance is provided by steel resistance shear force which is about 85 kN. Most of the shear values in y direction aren't verified. Because the shear stress which is applied is lower than the resistance shear stress which elements can carry. On the other hand, shear stress in z direction have been verified for all action of combinations values as well as static result value.

EL1761 (Long archway in the middle point)

It has been used the same transversal reinforcement like long archway at the base (EL1753).

Ty [N]	Tz [N]	VRc [N]	VRS [N]	VRd [N]	CHECK Ty	CHECK Tz
332292.7	129081.1	3295488	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
329718.4	126784.6	3303207	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
278469.4	73662.95	3390274	84853.04	84853.04	NOT VERIFIED	OK
281043.7	75959.45	3382554	84853.04	84853.04	NOT VERIFIED	OK
284034.1	109173.2	3374517	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
316918	113144.6	3321608	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
380551.2	148988.9	3216460	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
347667.4	145017.5	3269368	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
334880.6	167026.7	3288812	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
332306.3	164730.2	3296532	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
283275.5	144133.4	3377876	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
285849.8	146429.9	3370157	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
283275.5	144133.4	3377876	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
285849.8	146429.9	3370157	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
334880.6	167026.7	3288812	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
332306.3	164730.2	3296532	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
278093.4	107730.7	3381384	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
226844.4	79478.9	3468450	84853.04	84853.04	NOT VERIFIED	OK
269512.4	100075.7	3407115	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
229062.6	87133.9	3462728	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
269512.4	100075.7	3407115	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
229062.6	87133.9	3462728	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
278093.4	107730.7	3381384	84853.04	84853.04	NOT VERIFIED	NOT VERIFIED
226844.4	79478.9	3468450	84853.04	84853.04	NOT VERIFIED	OK
115033.4	5006.95	3649590	84853.04	84853.04	NOT VERIFIED	OK
117607.7	7303.45	3649590	84853.04	84853.04	NOT VERIFIED	OK
168856.7	60425.05	3566636	84853.04	84853.04	NOT VERIFIED	OK
166282.4	58128.55	3574355	84853.04	84853.04	NOT VERIFIED	OK
163291.9	24914.8	3582393	84853.04	84853.04	NOT VERIFIED	OK
130408.1	20943.43	3635301	84853.04	84853.04	NOT VERIFIED	OK
66774.84	-14900.9	3649590	84853.04	84853.04	OK	OK
99658.65	-10929.5	3649590	84853.04	84853.04	NOT VERIFIED	OK
112445.5	-32938.7	3649590	84853.04	84853.04	NOT VERIFIED	OK
115019.8	-30642.2	3649590	84853.04	84853.04	NOT VERIFIED	OK
164050.6	-10045.4	3579033	84853.04	84853.04	NOT VERIFIED	OK
161476.3	-12341.9	3586752	84853.04	84853.04	NOT VERIFIED	OK
164050.6	-10045.4	3579033	84853.04	84853.04	NOT VERIFIED	OK
161476.3	-12341.9	3586752	84853.04	84853.04	NOT VERIFIED	OK
112445.5	-32938.7	3649590	84853.04	84853.04	NOT VERIFIED	OK
115019.8	-30642.2	3649590	84853.04	84853.04	NOT VERIFIED	OK
169232.6	26357.3	3575525	84853.04	84853.04	NOT VERIFIED	OK
220481.6	54609.1	3488459	84853.04	84853.04	NOT VERIFIED	OK
177813.6	34012.3	3549794	84853.04	84853.04	NOT VERIFIED	OK
218263.4	46954.1	3494181	84853.04	84853.04	NOT VERIFIED	OK
177813.6	34012.3	3549794	84853.04	84853.04	NOT VERIFIED	OK
218263.4	46954.1	3494181	84853.04	84853.04	NOT VERIFIED	OK
169232.6	26357.3	3575525	84853.04	84853.04	NOT VERIFIED	OK
220481.6	54609.1	3488459	84853.04	84853.04	NOT VERIFIED	OK
223663	67044	3478455	84853.04	84853.04	NOT VERIFIED	OK

Table 6.33 shear assessment verification results (EL1761)

Table 7.33 is shown results for shear forces which is provided by excel file and MATLAB code. The shear resistance is minimum for the steel shear resistance which is the same as EL1753 (V_{Rd} = 85kN). It has almost the same effect as the long archway at the base in y direction. The element doesn't have enough resistance for some values in z direction as well.

EL1841 (Short archway at the base)

The transversal reinforcements which are used for the short archway at base is the same as long arches with the same space.

Ty [N]	Tz [N]	VRc [N]	VRS [N]	VRd [N]	CHECK Ty	CHECK Tz
236431.2	36364.15	2796083	7.73E+04	77276.88	NOT VERIFIED	OK
233129.6	35099.71	2799398	7.73E+04	77276.88	NOT VERIFIED	OK
198912.8	29100.25	2837583	7.73E+04	77276.88	NOT VERIFIED	OK
202214.4	30364.69	2834267	7.73E+04	77276.88	NOT VERIFIED	OK
187921.1	-21557.3	2869555	7.73E+04	77276.88	NOT VERIFIED	OK
226166.2	34564.31	2807538	7.73E+04	77276.88	NOT VERIFIED	OK
284941.3	94285.62	2722610	7.73E+04	77276.88	NOT VERIFIED	NOT VERIFIED
246696.3	38163.99	2784627	7.73E+04	77276.88	NOT VERIFIED	OK
218600.1	-24654.1	2838412	7.73E+04	77276.88	NOT VERIFIED	OK
215298.5	-25918.5	2841727	7.73E+04	77276.88	NOT VERIFIED	OK
165797.9	-44652.3	2916194	7.73E+04	77276.88	NOT VERIFIED	OK
169099.5	-45916.7	2912878	7.73E+04	77276.88	NOT VERIFIED	OK
165797.9	-44652.3	2916194	7.73E+04	77276.88	NOT VERIFIED	OK
169099.5	-45916.7	2912878	7.73E+04	77276.88	NOT VERIFIED	OK
218600.1	-24654.1	2838412	7.73E+04	77276.88	NOT VERIFIED	OK
215298.5	-25918.5	2841727	7.73E+04	77276.88	NOT VERIFIED	OK
182532.4	-30178.3	2879093	7.73E+04	77276.88	NOT VERIFIED	OK
148315.6	-36177.7	2917277	7.73E+04	77276.88	NOT VERIFIED	OK
171527	-34393.1	2890144	7.73E+04	77276.88	NOT VERIFIED	OK
137310.2	-40392.5	2928329	7.73E+04	77276.88	NOT VERIFIED	OK
171527	-34393.1	2890144	7.73E+04	77276.88	NOT VERIFIED	OK
137310.2	-40392.5	2928329	7.73E+04	77276.88	NOT VERIFIED	OK
182532.4	-30178.3	2879093	7.73E+04	77276.88	NOT VERIFIED	OK
148315.6	-36177.7	2917277	7.73E+04	77276.88	NOT VERIFIED	OK
33910.79	-165236	3085806	7.73E+04	77276.88	OK	OK
37212.41	-163971	3082490	7.73E+04	77276.88	OK	OK
71429.21	-157972	3044305	7.73E+04	77276.88	OK	OK
68127.59	-159236	3047621	7.73E+04	77276.88	OK	OK
82420.9	-107314	3012333	7.73E+04	77276.88	NOT VERIFIED	OK
44175.83	-163436	3074350	7.73E+04	77276.88	OK	OK
-14599.3	-223157	3159278	7.73E+04	77276.88	OK	OK
23645.75	-167036	3097261	7.73E+04	77276.88	OK	OK
51741.89	-104218	3043477	7.73E+04	77276.88	OK	OK
55043.51	-102953	3040161	7.73E+04	77276.88	OK	OK
104544.1	-84219.3	2965694	7.73E+04	77276.88	NOT VERIFIED	OK
101242.5	-82954.9	2969010	7.73E+04	77276.88	NOT VERIFIED	OK
104544.1	-84219.3	2965694	7.73E+04	77276.88	NOT VERIFIED	OK
101242.5	-82954.9	2969010	7.73E+04	77276.88	NOT VERIFIED	OK
51741.89	-104218	3043477	7.73E+04	77276.88	OK	OK
55043.51	-102953	3040161	7.73E+04	77276.88	OK	OK
87809.6	-98693.3	3002796	7.73E+04	77276.88	NOT VERIFIED	OK
122026.4	-92693.9	2964611	7.73E+04	77276.88	NOT VERIFIED	OK
98815	-94478.5	2991744	7.73E+04	77276.88	NOT VERIFIED	OK
133031.8	-88479.1	2953559	7.73E+04	77276.88	NOT VERIFIED	OK
98815	-94478.5	2991744	7.73E+04	77276.88	NOT VERIFIED	OK
133031.8	-88479.1	2953559	7.73E+04	77276.88	NOT VERIFIED	OK
87809.6	-98693.3	3002796	7.73E+04	77276.88	NOT VERIFIED	OK
122026.4	-92693.9	2964611	7.73E+04	77276.88	NOT VERIFIED	OK
135171	-64435.8	3222901	7.73E+04	77276.88	NOT VERIFIED	OK

Table 6.34 shear assessment verification results (EL1841)

Table 7.34 is reported values for the shear forces resistance and action of combinations results. The shear resistance is minimum for the steel shear resistance which is V_{Rd} = 77.3kN. The element isn't verified in y direction with comparing most of the values. But there is only one value isn't verified about shear resistance in z direction.

EL1847 (Short archway in the middle point)

It has been used the same transversal reinforcements and spacing like long arches.

Ty [N]	Tz [N]	VRc [N]	VRS [N]	VRd [N]	CHECK Ty	CHECK Tz
13642.29	124077	2783081	7.73E+04	77276.88	OK	NOT VERIFIED
11282.31	122980.4	2786389	7.73E+04	77276.88	OK	NOT VERIFIED
-18250.3	118683	2824548	7.73E+04	77276.88	OK	NOT VERIFIED
-15890.3	119779.7	2821240	7.73E+04	77276.88	OK	NOT VERIFIED
-29315.9	69037.96	2856498	7.73E+04	77276.88	OK	OK
4782.51	122787.8	2794529	7.73E+04	77276.88	OK	NOT VERIFIED
56600.5	179116	2709665	7.73E+04	77276.88	OK	NOT VERIFIED
22502.07	125366.2	2771634	7.73E+04	77276.88	OK	NOT VERIFIED
-2846.91	64494.51	2825374	7.73E+04	77276.88	OK	OK
-5206.89	63397.89	2828681	7.73E+04	77276.88	OK	OK
-48873.1	50170.11	2903091	7.73E+04	77276.88	OK	OK
-46513.1	49073.49	2899783	7.73E+04	77276.88	OK	OK
-48873.1	50170.11	2903091	7.73E+04	77276.88	OK	OK
-46513.1	49073.49	2899783	7.73E+04	77276.88	OK	OK
-2846.91	64494.51	2825374	7.73E+04	77276.88	OK	OK
-5206.89	63397.89	2828681	7.73E+04	77276.88	OK	OK
-34548.3	60760.36	2866033	7.73E+04	77276.88	OK	OK
-64080.9	56463.04	2904192	7.73E+04	77276.88	OK	OK
-42414.9	57104.96	2877059	7.73E+04	77276.88	OK	OK
-71947.5	52807.64	2915218	7.73E+04	77276.88	OK	OK
-42414.9	57104.96	2877059	7.73E+04	77276.88	OK	OK
-71947.5	52807.64	2915218	7.73E+04	77276.88	OK	OK
-34548.3	60760.36	2866033	7.73E+04	77276.88	OK	OK
-64080.9	56463.04	2904192	7.73E+04	77276.88	OK	OK
-163804	-65877	3072578	7.73E+04	77276.88	OK	OK
-161444	-64780.4	3069271	7.73E+04	77276.88	OK	OK
-131912	-60483	3031112	7.73E+04	77276.88	OK	OK
-134272	-61579.7	3034420	7.73E+04	77276.88	OK	OK
-120846	-10838	2999162	7.73E+04	77276.88	OK	OK
-154945	-64587.8	3061131	7.73E+04	77276.88	OK	OK
-206762	-120916	3145995	7.73E+04	77276.88	OK	OK
-172664	-67166.2	3084026	7.73E+04	77276.88	OK	OK
-147315	-6294.51	3030286	7.73E+04	77276.88	OK	OK
-144955	-5197.89	3026978	7.73E+04	77276.88	OK	OK
-101289	8029.89	2952569	7.73E+04	77276.88	OK	OK
-103649	9126.51	2955877	7.73E+04	77276.88	OK	OK
-101289	8029.89	2952569	7.73E+04	77276.88	OK	OK
-103649	9126.51	2955877	7.73E+04	77276.88	OK	OK
-147315	-6294.51	3030286	7.73E+04	77276.88	OK	OK
-144955	-5197.89	3026978	7.73E+04	77276.88	OK	OK
-115614	-2560.36	2989627	7.73E+04	77276.88	OK	OK
-86081.1	1736.96	2951468	7.73E+04	77276.88	OK	OK
-107747	1095.04	2978601	7.73E+04	77276.88	OK	OK
-78214.5	5392.36	2940442	7.73E+04	77276.88	OK	OK
-107747	1095.04	2978601	7.73E+04	77276.88	OK	OK
-78214.5	5392.36	2940442	7.73E+04	77276.88	OK	OK
-115614	-2560.36	2989627	7.73E+04	77276.88	OK	OK
-86081.1	1736.96	2951468	7.73E+04	77276.88	OK	OK
-75081	29100	2927830	7.73E+04	77276.88	OK	OK

Table 6.35 shear assessment verification results (EL1847)

The values for shear force resistance and action of combinations are provided in Table 7.35. The shear resistance is minimum for the steel shear resistance which is the same as EL1841 (V_{Rd} = 77.3kN). The element is validated in the y direction by comparing all of its values. On the other hand, 7 values for shear resistance in the z direction have not been validated.

EL1523 (internal frame undulated slab)

It is made assumption Φ5 transversal reinforcement with 20 cm has been used for undulated slab due to its wavy cross section shape.

Ty [N]	Tz [N]	VRc [N]	VRS [N]	VRd [N]	CHECK Ty	CHECK Tz
51178.88	-24189.3	2.90E+06	2.57E+04	25747.12	NOT VERIFIED	OK
50465.12	-24628.1	2.90E+06	2.57E+04	25747.12	NOT VERIFIED	OK
16329.32	-43894.7	2.92E+06	2.57E+04	25747.12	OK	OK
17043.08	-43455.9	2.92E+06	2.57E+04	25747.12	OK	OK
30956.41	-31705.8	2.94E+06	2.57E+04	25747.12	NOT VERIFIED	OK
40938.14	-29969.2	2.90E+06	2.57E+04	25747.12	NOT VERIFIED	OK
71401.35	-16672.7	2.85E+06	2.57E+04	25747.12	NOT VERIFIED	OK
61419.62	-18409.3	2.89E+06	2.57E+04	25747.12	NOT VERIFIED	OK
67161.28	-10634.5	2.93E+06	2.57E+04	25747.12	NOT VERIFIED	OK
66447.52	-11073.3	2.94E+06	2.57E+04	25747.12	NOT VERIFIED	OK
46010.92	-18721.5	2.98E+06	2.57E+04	25747.12	NOT VERIFIED	OK
46724.68	-18282.7	2.98E+06	2.57E+04	25747.12	NOT VERIFIED	OK
46010.92	-18721.5	2.98E+06	2.57E+04	25747.12	NOT VERIFIED	OK
46724.68	-18282.7	2.98E+06	2.57E+04	25747.12	NOT VERIFIED	OK
67161.28	-10634.5	2.93E+06	2.57E+04	25747.12	NOT VERIFIED	OK
66447.52	-11073.3	2.94E+06	2.57E+04	25747.12	NOT VERIFIED	OK
28168.9	-32600.1	2.95E+06	2.57E+04	25747.12	NOT VERIFIED	OK
5353.1	-41711.3	2.97E+06	2.57E+04	25747.12	OK	OK
25789.7	-34063.1	2.96E+06	2.57E+04	25747.12	NOT VERIFIED	OK
7732.3	-40248.3	2.98E+06	2.57E+04	25747.12	OK	OK
25789.7	-34063.1	2.96E+06	2.57E+04	25747.12	NOT VERIFIED	OK
7732.3	-40248.3	2.98E+06	2.57E+04	25747.12	OK	OK
28168.9	-32600.1	2.95E+06	2.57E+04	25747.12	NOT VERIFIED	OK
5353.1	-41711.3	2.97E+06	2.57E+04	25747.12	OK	OK
-51792.7	-69388.7	3.08E+06	2.57E+04	25747.12	OK	OK
-51078.9	-68949.9	3.08E+06	2.57E+04	25747.12	OK	OK
-16943.1	-49683.3	3.06E+06	2.57E+04	25747.12	OK	OK
-17656.9	-50122.1	3.06E+06	2.57E+04	25747.12	OK	OK
-31570.2	-61872.2	3.03E+06	2.57E+04	25747.12	OK	OK
-41551.9	-63608.8	3.07E+06	2.57E+04	25747.12	OK	OK
-72015.2	-76905.3	3.13E+06	2.57E+04	25747.12	OK	OK
-62033.4	-75168.7	3.09E+06	2.57E+04	25747.12	OK	OK
-67775.1	-82943.5	3.05E+06	2.57E+04	25747.12	OK	OK
-67061.3	-82504.7	3.04E+06	2.57E+04	25747.12	OK	OK
-46624.7	-74856.5	3.00E+06	2.57E+04	25747.12	OK	OK
-47338.5	-75295.3	3.00E+06	2.57E+04	25747.12	OK	OK
-46624.7	-74856.5	3.00E+06	2.57E+04	25747.12	OK	OK
-47338.5	-75295.3	3.00E+06	2.57E+04	25747.12	OK	OK
-67775.1	-82943.5	3.05E+06	2.57E+04	25747.12	OK	OK
-67061.3	-82504.7	3.04E+06	2.57E+04	25747.12	OK	OK
-28782.7	-60977.9	3.03E+06	2.57E+04	25747.12	OK	OK
-5966.9	-51866.7	3.01E+06	2.57E+04	25747.12	OK	OK
-26403.5	-59514.9	3.01E+06	2.57E+04	25747.12	OK	OK
-8346.1	-53329.7	3.00E+06	2.57E+04	25747.12	OK	OK
-26403.5	-59514.9	3.01E+06	2.57E+04	25747.12	OK	OK
-8346.1	-53329.7	3.00E+06	2.57E+04	25747.12	OK	OK
-28782.7	-60977.9	3.03E+06	2.57E+04	25747.12	OK	OK
-5966.9	-51866.7	3.01E+06	2.57E+04	25747.12	OK	OK
-306.9	-46789	2.99E+06	2.57E+04	25747.12	OK	OK

Table 6.36 shear assessment verification results (EL1523)

The values for shear force resistance and action of combinations are provided in Table 7.36 for the undulated slab. The shear resistance is minimum for the steel shear resistance which is V_{Rd} = 25.7 kN. The element isn't verified in the y direction by comparing most of values. On the other hand, all the values for shear resistance in the z direction have been validated.

EL4676 (Lateral rib at the base)

It is used Φ6 transversal reinforcement with 20 cm has been used for lateral rib at the base.

Ty [N]	Tz [N]	VRc [N]	VRS [N]	VRd [N]	CHECK Ty	CHECK Tz
-1869.8	70961.32	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-1958.14	69866.08	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-2291.9	55452.28	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-2203.56	56547.52	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-3125.85	59965.49	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-1969.93	66637.18	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-613.74	81957.15	9.61E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-1769.67	75285.46	9.70E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-2976.73	74565.62	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-3065.07	73470.38	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-4089.27	62145.98	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-4177.61	63241.22	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-4089.27	62145.98	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-4177.61	63241.22	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-2976.73	74565.62	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-3065.07	73470.38	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-3263.05	59027.3	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-3596.81	44613.5	9.71E+05	5.42E+04	54169.57	OK	OK
-3557.53	55376.5	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-3891.29	47702.9	9.71E+05	5.42E+04	54169.57	OK	OK
-3557.53	55376.5	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-3891.29	47702.9	9.71E+05	5.42E+04	54169.57	OK	OK
-3263.05	59027.3	9.71E+05	5.42E+04	54169.57	OK	NOT VERIFIED
-3596.81	44613.5	9.71E+05	5.42E+04	54169.57	OK	OK
-6567.1	17704.28	9.71E+05	5.42E+04	54169.57	OK	OK
-6478.76	18799.52	9.71E+05	5.42E+04	54169.57	OK	OK
-6145	33213.32	9.71E+05	5.42E+04	54169.57	OK	OK
-6233.34	32118.08	9.71E+05	5.42E+04	54169.57	OK	OK
-5311.05	28700.11	9.71E+05	5.42E+04	54169.57	OK	OK
-6466.97	22028.42	9.71E+05	5.42E+04	54169.57	OK	OK
-7823.16	6708.452	9.71E+05	5.42E+04	54169.57	OK	OK
-6667.23	13380.14	9.71E+05	5.42E+04	54169.57	OK	OK
-5460.17	14099.98	9.71E+05	5.42E+04	54169.57	OK	OK
-5371.83	15195.22	9.71E+05	5.42E+04	54169.57	OK	OK
-4347.63	26519.62	9.71E+05	5.42E+04	54169.57	OK	OK
-4259.29	25424.38	9.71E+05	5.42E+04	54169.57	OK	OK
-4347.63	26519.62	9.71E+05	5.42E+04	54169.57	OK	OK
-4259.29	25424.38	9.71E+05	5.42E+04	54169.57	OK	OK
-5460.17	14099.98	9.71E+05	5.42E+04	54169.57	OK	OK
-5371.83	15195.22	9.71E+05	5.42E+04	54169.57	OK	OK
-5173.85	29638.3	9.71E+05	5.42E+04	54169.57	OK	OK
-4840.09	44052.1	9.71E+05	5.42E+04	54169.57	OK	OK
-4879.37	33289.1	9.71E+05	5.42E+04	54169.57	OK	OK
-4545.61	40962.7	9.71E+05	5.42E+04	54169.57	OK	OK
-4879.37	33289.1	9.71E+05	5.42E+04	54169.57	OK	OK
-4545.61	40962.7	9.71E+05	5.42E+04	54169.57	OK	OK
-5173.85	29638.3	9.71E+05	5.42E+04	54169.57	OK	OK
-4840.09	44052.1	9.71E+05	5.42E+04	54169.57	OK	OK
-4218.45	44332.8	9.71E+05	5.42E+04	54169.57	OK	OK

Table 6.37 shear assessment verification results (EL4676)

The values for shear force resistance and action of combinations are provided in Table 7.37 for the lateral rib at the base. The shear resistance is minimum for the steel shear resistance which is V_{Rd} = 54.2 kN. The element is verified in the y direction by comparing most of values. On the other hand, some actions combinations shear forces which are provided while in x and y direction 100% effected loads with respect to static analysis results aren't verified in z direction.

EL4662 (Lateral rib in the midpoint)

It has been used same cross-section and transversal reinforcement as rib at the base.

Ty [N]	Tz [N]	VRc [N]	VRS [N]	VRd [N]	CHECK Ty	CHECK Tz
37202.14	-4144.17	8.21E+05	5.42E+04	54169.57	OK	OK
36411.46	-4358.8	8.21E+05	5.42E+04	54169.57	OK	OK
27965.26	-4710.23	8.22E+05	5.42E+04	54169.57	OK	OK
28755.94	-4495.6	8.22E+05	5.42E+04	54169.57	OK	OK
31601.88	-6936.2	8.22E+05	5.42E+04	54169.57	OK	OK
34668.28	-4249.6	8.21E+05	5.42E+04	54169.57	OK	OK
42802.4	-1352.14	8.19E+05	5.42E+04	54169.57	OK	OK
39736	-4038.74	8.20E+05	5.42E+04	54169.57	OK	OK
40245.67	-7066.66	8.21E+05	5.42E+04	54169.57	OK	OK
39454.99	-7281.3	8.22E+05	5.42E+04	54169.57	OK	OK
33617.53	-8238.08	8.24E+05	5.42E+04	54169.57	OK	OK
34408.21	-8452.72	8.23E+05	5.42E+04	54169.57	OK	OK
33617.53	-8238.08	8.24E+05	5.42E+04	54169.57	OK	OK
34408.21	-8452.72	8.23E+05	5.42E+04	54169.57	OK	OK
40245.67	-7066.66	8.21E+05	5.42E+04	54169.57	OK	OK
39454.99	-7281.3	8.22E+05	5.42E+04	54169.57	OK	OK
31314.23	-7226.26	8.22E+05	5.42E+04	54169.57	OK	OK
22868.03	-7577.68	8.23E+05	5.42E+04	54169.57	OK	OK
28678.63	-7941.7	8.24E+05	5.42E+04	54169.57	OK	OK
25476.77	-8293.12	8.24E+05	5.42E+04	54169.57	OK	OK
28678.63	-7941.7	8.24E+05	5.42E+04	54169.57	OK	OK
25476.77	-8293.12	8.24E+05	5.42E+04	54169.57	OK	OK
31314.23	-7226.26	8.22E+05	5.42E+04	54169.57	OK	OK
22868.03	-7577.68	8.23E+05	5.42E+04	54169.57	OK	OK
8507.06	-14231.6	8.28E+05	5.42E+04	54169.57	OK	OK
9297.74	-14017	8.27E+05	5.42E+04	54169.57	OK	OK
17743.94	-13665.6	8.26E+05	5.42E+04	54169.57	OK	OK
16953.26	-13880.2	8.27E+05	5.42E+04	54169.57	OK	OK
14107.32	-11439.6	8.26E+05	5.42E+04	54169.57	OK	OK
11040.92	-14126.2	8.28E+05	5.42E+04	54169.57	OK	OK
2906.804	-17023.7	8.29E+05	5.42E+04	54169.57	OK	OK
5973.2	-14337.1	8.28E+05	5.42E+04	54169.57	OK	OK
5463.53	-11309.1	8.27E+05	5.42E+04	54169.57	OK	OK
6254.21	-11094.5	8.27E+05	5.42E+04	54169.57	OK	OK
12091.67	-10137.7	8.25E+05	5.42E+04	54169.57	OK	OK
11300.99	-9923.08	8.25E+05	5.42E+04	54169.57	OK	OK
12091.67	-10137.7	8.25E+05	5.42E+04	54169.57	OK	OK
11300.99	-9923.08	8.25E+05	5.42E+04	54169.57	OK	OK
5463.53	-11309.1	8.27E+05	5.42E+04	54169.57	OK	OK
6254.21	-11094.5	8.27E+05	5.42E+04	54169.57	OK	OK
14394.97	-11149.5	8.27E+05	5.42E+04	54169.57	OK	OK
22841.17	-10798.1	8.26E+05	5.42E+04	54169.57	OK	OK
17030.57	-10434.1	8.25E+05	5.42E+04	54169.57	OK	OK
20232.43	-10082.7	8.25E+05	5.42E+04	54169.57	OK	OK
17030.57	-10434.1	8.25E+05	5.42E+04	54169.57	OK	OK
20232.43	-10082.7	8.25E+05	5.42E+04	54169.57	OK	OK
14394.97	-11149.5	8.27E+05	5.42E+04	54169.57	OK	OK
22841.17	-10798.1	8.26E+05	5.42E+04	54169.57	OK	OK
22854.6	-9187.9	8.24E+05	5.42E+04	54169.57	OK	OK

Table 6.38 shear assessment verification results (EL4662)

The values for shear force resistance and action of combinations are provided in Table 7.38 for the lateral rib in the midpoint. The shear resistance is minimum for the steel shear resistance which is V_{Rd} = 54.2 kN. (it's the as the base point). The element is verified in the y and z direction by comparing most of values.

EL779 (External pillar at the base)

It is assumed that for the external pillar transversal reinforcement is Φ6 with 20cm space as lateral rib.

Ty	Tz	VRc	VRS	VRd	CHECK Ty	CHECK Tz
[N]	[N]	[N]	[N]	[N]		
-613.912	6601.533	307030.5	1.53E+04	15341.73	OK	OK
-845.008	6565.943	307412.7	1.53E+04	15341.73	OK	OK
-1726.65	6160.667	309757.4	1.53E+04	15341.73	OK	OK
-1957.75	6196.257	309988.3	1.53E+04	15341.73	OK	OK
-878.405	3562.05	307734	1.53E+04	15341.73	OK	OK
-1278.99	6479.95	307917.9	1.53E+04	15341.73	OK	OK
-349.419	9641.016	306327.1	1.53E+04	15341.73	OK	OK
51.17	6723.116	306143.2	1.53E+04	15341.73	OK	OK
1583.059	3515.835	304534.2	1.53E+04	15341.73	OK	OK
1351.963	3480.245	304916.3	1.53E+04	15341.73	OK	OK
1018.141	2164.915	305734.4	1.53E+04	15341.73	OK	OK
1249.237	2129.325	305352.3	1.53E+04	15341.73	OK	OK
1018.141	2164.915	305734.4	1.53E+04	15341.73	OK	OK
1249.237	2129.325	305352.3	1.53E+04	15341.73	OK	OK
1583.059	3515.835	304534.2	1.53E+04	15341.73	OK	OK
1351.963	3480.245	304916.3	1.53E+04	15341.73	OK	OK
-733.759	3084.534	307539.2	1.53E+04	15341.73	OK	OK
-1837.9	2679.258	309631	1.53E+04	15341.73	OK	OK
-1504.08	2965.902	308812.9	1.53E+04	15341.73	OK	OK
-1067.58	2560.626	308357.2	1.53E+04	15341.73	OK	OK
-1504.08	2965.902	308812.9	1.53E+04	15341.73	OK	OK
-1067.58	2560.626	308357.2	1.53E+04	15341.73	OK	OK
-733.759	3084.534	307539.2	1.53E+04	15341.73	OK	OK
-1837.9	2679.258	309631	1.53E+04	15341.73	OK	OK
-4174.69	-4006.53	313097.4	1.53E+04	15341.73	OK	OK
-3943.59	-3970.94	312715.2	1.53E+04	15341.73	OK	OK
-3061.95	-3565.67	310370.5	1.53E+04	15341.73	OK	OK
-2830.85	-3601.26	310139.6	1.53E+04	15341.73	OK	OK
-3910.19	-967.05	312393.9	1.53E+04	15341.73	OK	OK
-3509.61	-3884.95	312210	1.53E+04	15341.73	OK	OK
-4439.18	-7046.02	313800.8	1.53E+04	15341.73	OK	OK
-4839.77	-4128.12	313984.7	1.53E+04	15341.73	OK	OK
-6371.66	-920.835	315593.7	1.53E+04	15341.73	OK	OK
-6140.56	-885.245	315211.6	1.53E+04	15341.73	OK	OK
-5806.74	430.0852	314393.5	1.53E+04	15341.73	OK	OK
-6037.84	465.6748	314775.6	1.53E+04	15341.73	OK	OK
-5806.74	430.0852	314393.5	1.53E+04	15341.73	OK	OK
-6037.84	465.6748	314775.6	1.53E+04	15341.73	OK	OK
-6371.66	-920.835	315593.7	1.53E+04	15341.73	OK	OK
-6140.56	-885.245	315211.6	1.53E+04	15341.73	OK	OK
-4054.84	-489.534	312588.7	1.53E+04	15341.73	OK	OK
-2950.7	-84.258	310496.9	1.53E+04	15341.73	OK	OK
-3284.52	-370.902	311315	1.53E+04	15341.73	OK	OK
-3721.02	34.374	311770.7	1.53E+04	15341.73	OK	OK
-3284.52	-370.902	311315	1.53E+04	15341.73	OK	OK
-3721.02	34.374	311770.7	1.53E+04	15341.73	OK	OK
-4054.84	-489.534	312588.7	1.53E+04	15341.73	OK	OK
-2950.7	-84.258	310496.9	1.53E+04	15341.73	OK	OK
-2394.3	1297.5	310064	1.53E+04	15341.73	OK	OK

Table 6.39 shear assessment verification results (EL779)

Table 7.39 shows the values for shear force resistance and action of combinations for the lateral rib in the midway. The steel shear resistance is minimal, with VRd = 15.3 kN. By comparing all values, the element is validated in the y and z directions.

EL8734 (External pillar in the gallery side)

It is assumed that for the external pillar transversal reinforcement is Φ6 with 20cm space as external pillar EL779.

Ty [N]	Tz [N]	VRc [N]	VRS [N]	VRd [N]	CHECK Ty	CHECK Tz
10640.14	1194.963	2.12E+05	2.12E+04	21213.26	OK	OK
10410.2	1164.139	2.12E+05	2.12E+04	21213.26	OK	OK
6195.742	1044.577	2.12E+05	2.12E+04	21213.26	OK	OK
5965.798	1075.401	2.12E+05	2.12E+04	21213.26	OK	OK
9375.805	595.9296	2.12E+05	2.12E+04	21213.26	OK	OK
9124.02	1159.094	2.12E+05	2.12E+04	21213.26	OK	OK
11904.48	1793.996	2.11E+05	2.12E+04	21213.26	OK	OK
12156.26	1230.831	2.11E+05	2.12E+04	21213.26	OK	OK
14980.63	624.7916	2.11E+05	2.12E+04	21213.26	OK	OK
14750.69	593.9684	2.12E+05	2.12E+04	21213.26	OK	OK
13417.37	226.2516	2.12E+05	2.12E+04	21213.26	OK	OK
13647.31	195.4284	2.12E+05	2.12E+04	21213.26	OK	OK
13417.37	226.2516	2.12E+05	2.12E+04	21213.26	OK	OK
13647.31	195.4284	2.12E+05	2.12E+04	21213.26	OK	OK
14980.63	624.7916	2.11E+05	2.12E+04	21213.26	OK	OK
14750.69	593.9684	2.12E+05	2.12E+04	21213.26	OK	OK
9352.87	521.263	2.12E+05	2.12E+04	21213.26	OK	OK
7253.07	401.701	2.12E+05	2.12E+04	21213.26	OK	OK
8586.39	418.519	2.13E+05	2.12E+04	21213.26	OK	OK
8019.55	298.957	2.12E+05	2.12E+04	21213.26	OK	OK
8586.39	418.519	2.13E+05	2.12E+04	21213.26	OK	OK
8019.55	298.957	2.12E+05	2.12E+04	21213.26	OK	OK
9352.87	521.263	2.12E+05	2.12E+04	21213.26	OK	OK
7253.07	401.701	2.12E+05	2.12E+04	21213.26	OK	OK
912.058	-983.023	2.14E+05	2.12E+04	21213.26	OK	OK
1142.002	-952.199	2.14E+05	2.12E+04	21213.26	OK	OK
5356.458	-832.637	2.13E+05	2.12E+04	21213.26	OK	OK
5586.402	-863.461	2.13E+05	2.12E+04	21213.26	OK	OK
2176.395	-383.99	2.14E+05	2.12E+04	21213.26	OK	OK
2428.18	-947.154	2.14E+05	2.12E+04	21213.26	OK	OK
-352.279	-1582.06	2.14E+05	2.12E+04	21213.26	OK	OK
-604.064	-1018.89	2.14E+05	2.12E+04	21213.26	OK	OK
-3428.43	-412.852	2.14E+05	2.12E+04	21213.26	OK	OK
-3198.49	-382.028	2.14E+05	2.12E+04	21213.26	OK	OK
-1865.17	-14.3116	2.13E+05	2.12E+04	21213.26	OK	OK
-2095.11	16.5116	2.14E+05	2.12E+04	21213.26	OK	OK
-1865.17	-14.3116	2.13E+05	2.12E+04	21213.26	OK	OK
-2095.11	16.5116	2.14E+05	2.12E+04	21213.26	OK	OK
-3428.43	-412.852	2.14E+05	2.12E+04	21213.26	OK	OK
-3198.49	-382.028	2.14E+05	2.12E+04	21213.26	OK	OK
2199.33	-309.323	2.14E+05	2.12E+04	21213.26	OK	OK
4299.13	-189.761	2.13E+05	2.12E+04	21213.26	OK	OK
2965.81	-206.579	2.13E+05	2.12E+04	21213.26	OK	OK
3532.65	-87.017	2.13E+05	2.12E+04	21213.26	OK	OK
2965.81	-206.579	2.13E+05	2.12E+04	21213.26	OK	OK
3532.65	-87.017	2.13E+05	2.12E+04	21213.26	OK	OK
2199.33	-309.323	2.14E+05	2.12E+04	21213.26	OK	OK
4299.13	-189.761	2.13E+05	2.12E+04	21213.26	OK	OK
5776.1	105.97	2.13E+05	2.12E+04	21213.26	OK	OK

Table 6.40 shear assessment verification results (EL8734)

Table 7.40 shows the values for shear force resistance and action of combinations for the lateral rib in the midway. The steel shear resistance is minimal, with VRd = 21.2 kN. By comparing all values, the element is validated in the y and z directions.

EL1921 (Central Arches at the base)

It is taken transversal reinforcement is Φ6 from report which has been done before with 20cm space is assumed.

Ty [N]	Tz [N]	VRc [N]	VRS [N]	VRd [N]	CHECK Ty	CHECK Tz
70541.11	82555.89	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
69545.29	79525.71	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
46466.89	27244.11	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
47462.71	30274.29	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
51159.26	41220.14	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
63617.59	66871.41	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
89922.96	123891.6	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
77464.63	98240.37	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
74505.21	94265.49	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
73509.39	91235.31	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
53828.79	48990.51	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
54824.61	52020.69	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
53828.79	48990.51	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
54824.61	52020.69	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
74505.21	94265.49	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
73509.39	91235.31	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
48742.2	36805.5	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
25742.2	-15476.1	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK
45422.8	26704.9	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
29061.6	-5439.3	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK
45422.8	26704.9	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
29061.6	-5439.3	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK
48742.2	36805.5	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
25742.2	-15476.1	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK
-19135.1	-113572	2.05E+05	4.18E+03	4176.361	OK	OK
-18139.3	-110542	2.05E+05	4.18E+03	4176.361	OK	OK
4939.11	-58260.1	2.04E+05	4.18E+03	4176.361	NOT VERIFIED	OK
3943.29	-61290.3	2.05E+05	4.18E+03	4176.361	OK	OK
246.744	-72236.1	2.05E+05	4.18E+03	4176.361	OK	OK
-12211.6	-97887.4	2.05E+05	4.18E+03	4176.361	OK	OK
-38517	-154908	2.06E+05	4.18E+03	4176.361	OK	OK
-26058.6	-129256	2.05E+05	4.18E+03	4176.361	OK	OK
-23099.2	-125281	2.05E+05	4.18E+03	4176.361	OK	OK
-22103.4	-122251	2.04E+05	4.18E+03	4176.361	OK	OK
-2422.79	-80006.5	2.04E+05	4.18E+03	4176.361	OK	OK
-3418.61	-83036.7	2.04E+05	4.18E+03	4176.361	OK	OK
-2422.79	-80006.5	2.04E+05	4.18E+03	4176.361	OK	OK
-3418.61	-83036.7	2.04E+05	4.18E+03	4176.361	OK	OK
-23099.2	-125281	2.05E+05	4.18E+03	4176.361	OK	OK
-22103.4	-122251	2.04E+05	4.18E+03	4176.361	OK	OK
2663.8	-67821.5	2.05E+05	4.18E+03	4176.361	OK	OK
25663.8	-15539.9	2.04E+05	4.18E+03	4176.361	NOT VERIFIED	OK
5983.2	-57720.9	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	OK
22344.4	-25576.7	2.04E+05	4.18E+03	4176.361	NOT VERIFIED	OK
5983.2	-57720.9	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	OK
22344.4	-25576.7	2.04E+05	4.18E+03	4176.361	NOT VERIFIED	OK
2663.8	-67821.5	2.05E+05	4.18E+03	4176.361	OK	OK
25663.8	-15539.9	2.04E+05	4.18E+03	4176.361	NOT VERIFIED	OK
25703	-15508	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	OK

Table 6.41 shear assessment verification results (EL1921)

Table 7.41 shows the values for shear force resistance and action of combinations for the lateral rib in the midway. The steel shear resistance is minimal, with VRd = 4.2 kN. Most of the values aren't verified in y and z direction.

EL1917 (Central Arches in the middle point)

It is taken transversal reinforcement is Φ6 from report which has been done before with 20cm space is assumed as EL1921.

Ty [N]	Tz [N]	VRc [N]	VRS [N]	VRd [N]	CHECK Ty	CHECK Tz
68437.52	20028.55	2.00E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
67548.08	17127.85	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
45620.48	-34012.6	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	OK
46509.92	-31111.9	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	OK
49908.75	-20111.8	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	OK
61859.24	4686.43	2.00E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
86966.29	60168.94	1.99E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
75015.8	35370.67	2.00E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
72091.52	31846.65	2.00E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
71202.08	28945.95	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
52406.48	-12064.7	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK
53295.92	-9163.95	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	OK
52406.48	-12064.7	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK
53295.92	-9163.95	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	OK
72091.52	31846.65	2.00E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
71202.08	28945.95	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	NOT VERIFIED
47547	-24433	2.00E+05	4.18E+03	4176.361	NOT VERIFIED	OK
25786.6	-75112.6	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	OK
44582.2	-34102	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK
28751.4	-65443.6	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	OK
44582.2	-34102	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK
28751.4	-65443.6	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	OK
47547	-24433	2.00E+05	4.18E+03	4176.361	NOT VERIFIED	OK
25786.6	-75112.6	2.01E+05	4.18E+03	4176.361	NOT VERIFIED	OK
-17031.5	-170715	2.04E+05	4.18E+03	4176.361	OK	OK
-16142.1	-167814	2.03E+05	4.18E+03	4176.361	OK	OK
5785.52	-116673	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	OK
4896.08	-119574	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	OK
1497.248	-130574	2.03E+05	4.18E+03	4176.361	OK	OK
-10453.2	-155372	2.04E+05	4.18E+03	4176.361	OK	OK
-35560.3	-210855	2.05E+05	4.18E+03	4176.361	OK	OK
-23609.8	-186057	2.04E+05	4.18E+03	4176.361	OK	OK
-20685.5	-182533	2.04E+05	4.18E+03	4176.361	OK	OK
-19796.1	-179632	2.03E+05	4.18E+03	4176.361	OK	OK
-1000.48	-138621	2.02E+05	4.18E+03	4176.361	OK	OK
-1889.92	-141522	2.03E+05	4.18E+03	4176.361	OK	OK
-1000.48	-138621	2.02E+05	4.18E+03	4176.361	OK	OK
-1889.92	-141522	2.03E+05	4.18E+03	4176.361	OK	OK
-20685.5	-182533	2.04E+05	4.18E+03	4176.361	OK	OK
-19796.1	-179632	2.03E+05	4.18E+03	4176.361	OK	OK
3859	-126253	2.04E+05	4.18E+03	4176.361	OK	OK
25619.4	-75573.4	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	OK
6823.8	-116584	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK
22654.6	-85242.4	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	OK
6823.8	-116584	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK
22654.6	-85242.4	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	OK
3859	-126253	2.04E+05	4.18E+03	4176.361	OK	OK
25619.4	-75573.4	2.03E+05	4.18E+03	4176.361	NOT VERIFIED	OK
25703	-75343	2.02E+05	4.18E+03	4176.361	NOT VERIFIED	OK

Table 6.42 shear assessment verification results (EL1917)

Table 7.42 shows the values for shear force resistance and action of combinations for the lateral rib in the midway. The steel shear resistance is minimal, with VRd = 4.2 kN. Most of the values aren't verified in y and z direction.

Chapter 7

7. Discussion of the Results

Seismic assessment of Turin exhibition center C Hall has been done with respect to axial forces, shear forces and bending moments in the most 11 critical elements of structure. These critical sections are arches which in both side, pillar in both side, lateral rib, and internal undulated slab. Each of these sections have different seismic response. In below it's been discussed the response of these elements separately. In Figure 7.1 and Figure 7.2 are shown the elements which not verified in terms of N-M interaction diagram and shear assessment, respectively. The long and short arches are the most stressed part which haven't pass the verification with respect to the N-M interaction diagram. On the other hand, most of the elements don't pass the shear verification. Because it has been used the different steel type for stirrups which aren't allowed to use in current code and the space between stirrups are 20cm which is in all part of columns. The other problem is that we make some simplification and have the low fidelity model which isn't given accurate results. The shape of the elements are different in reality and we make simplified it whole structure is beam elements.

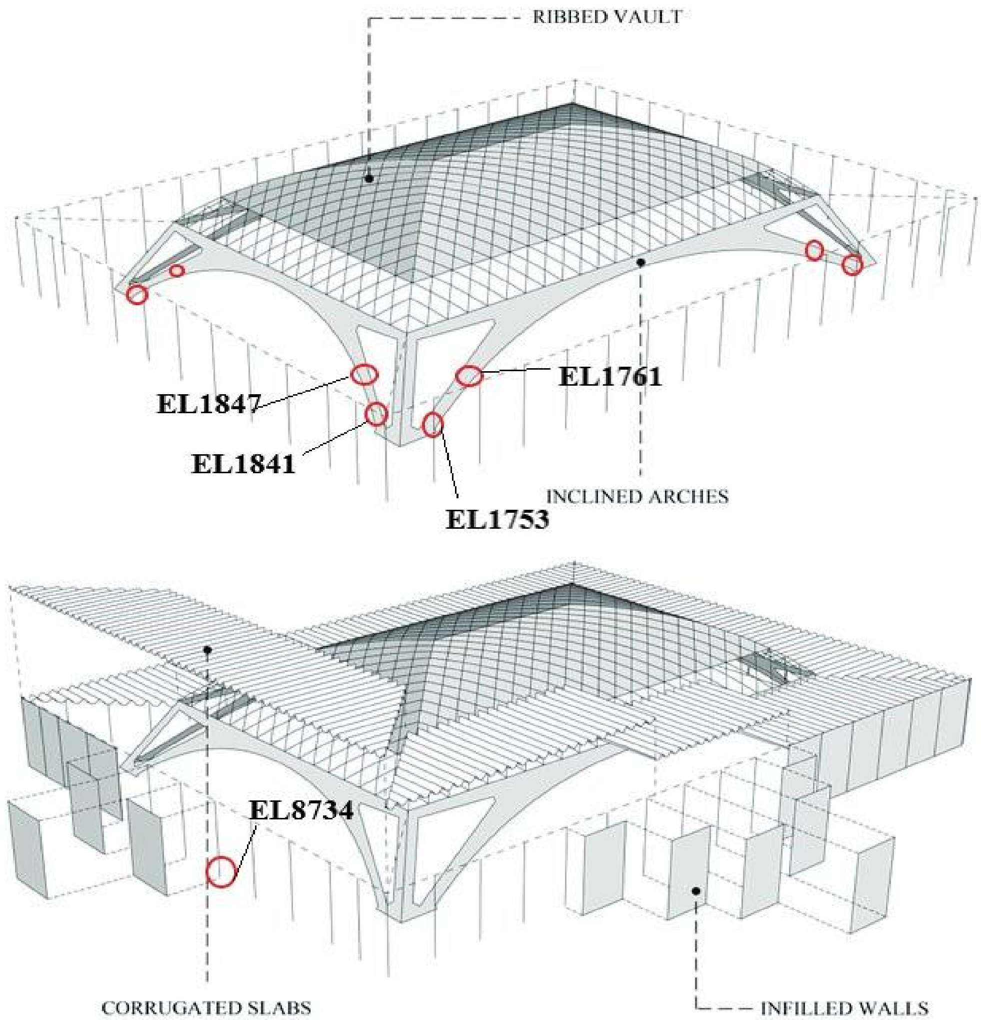


Figure 7.1 Non verified section with respect to N-M interaction diagram

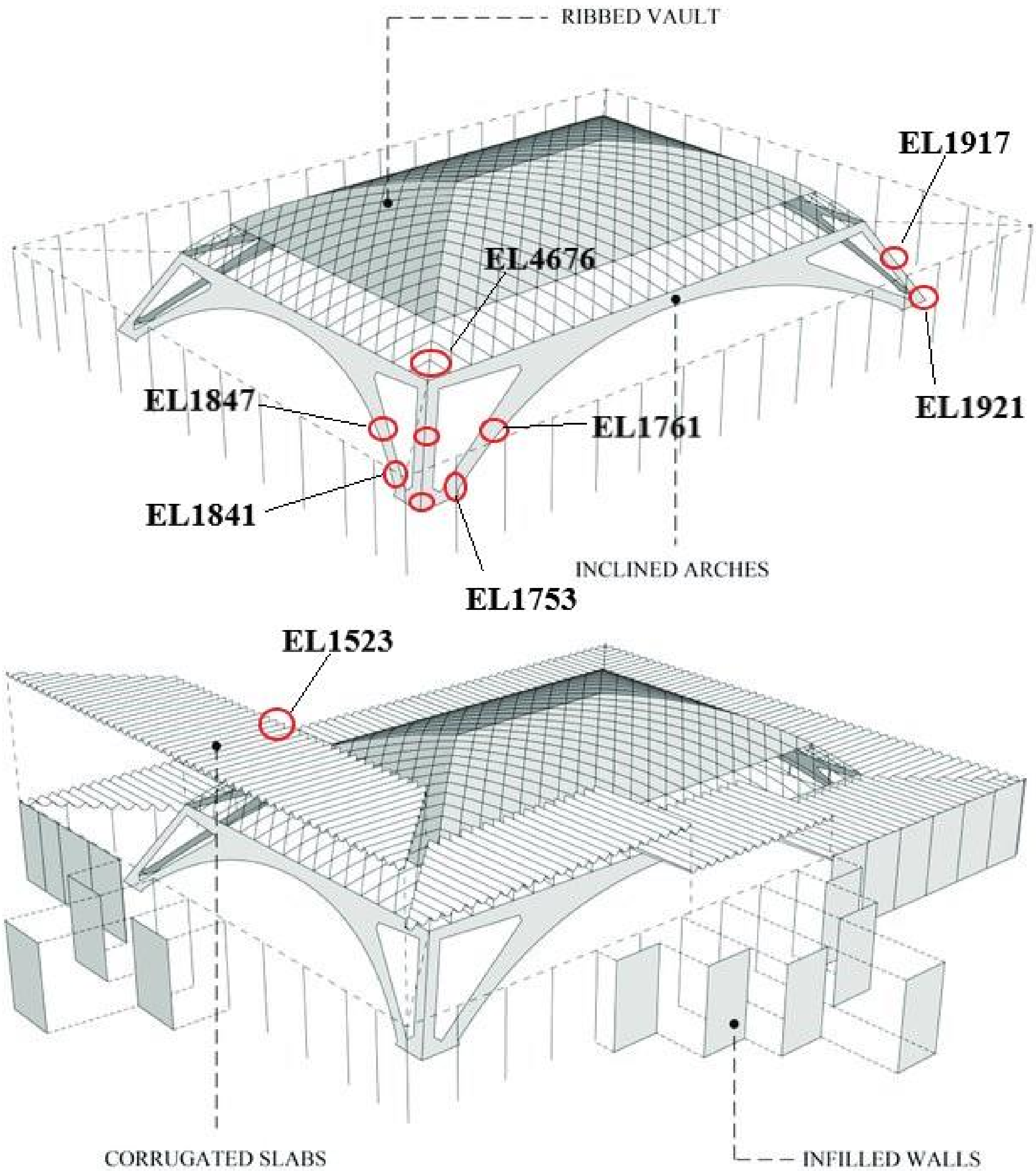


Figure 7.2 Non verified sections with respect to shear assessment

7.1 Long side Arches

In terms of seismic actions, the arches of C Hall are the most essential structural element. Because the most stressed location is at the strut's base, where the element is subjected to external tension and internal compression. In prior work, the arches were statically examined, and the base and midway of the arches were taken into consideration. When compared to the other elements, the base of the arches has the most shear stress. This is defined as EL1753 in code. The transversal reinforcement in the y direction is not validated due to shear stress, and the normal force-bending moments interaction diagram in the z direction is not verified as intended. Φ8/20 has been utilized for transversal reinforcement to withstand severe shear stress. In terms of shear evaluation, however, the midpoint of the arches is not verified in both directions. It is possible to shorten the space between transversal reinforcement to enhance shear resistance, or it is possible to use better steel with higher strength values. The bending moment can be reduced by changing the cross-section size or increasing the concrete strength by utilizing a different concrete type. The acquired results are not high fidelity, hence further analysis and experimental data should be collected to better understand the situation.

7.2 Short side Arches

Short side of arches has been acted like long side of arches. The results are showing with less stress on the short side, but it is also not verified like long side of arches. It has been defined less cross-section and decrease the steel strength parameter. In the long side it has been used 4Φ26 in top and bottom and 7Φ26 in side of elements while in short side it has been used Φ20 instead of Φ26. The transversal reinforcements are the same as long side of arches.

7.3 Internal frame undulated slab

The interior frame of the undulating floor, formed by the perimeter beams, is subjected to normal stress and bending moment at the centre of the long side. In real cross-section of the undulated slab It has wavy shape of beam and longitudinal reinforcements are 3Φ10 and 2Φ12 in the bottom, 2Φ5 in the side of cross-section and 6Φ5 at the top. It has been used also wire mesh with the concrete which is called ferrocement. In the report it has been simplified by 70/90 rectangular cross-section by putting 6Φ10 at the bottom, 2Φ5 in the side of cross-section 2Φ10 in the top. The transversal reinforcement has been defined Φ5 as its written on report.

7.4 Lateral rib

Normal stress near the base and bending moment and shear around the midway heavily loaded the primary ribs. It has been selected as critical section the base and midpoint of the rib. Main ribs in midpoint has been verified in point of view interaction diagram as well as shear assessment. On the other hand, the base of the rib isn’t verified in the z direction shear stress. For the element which is defined EL4662 and EL4676 has been assumed Φ6/20 tranversal reinforcement as the pillar.

7.5 Pillars

Because of the highest normal stresses indicated by static analysis, the pillar closest to the gallery side (EL8734) and the pillar closest to the structural middle (EL779) have been classified as critical elements. The pillars' evaluation has been confirmed using the interaction diagram and shear assessment. The pillars are strong enough to support the weight that they should.

Chapter 8

8. Conclusion

The purpose of this thesis was to comprehend the structural behavior of Hall C at the Torino Exhibition Center which is designed and constructed between 1948 and 1950 by engineer Pier Luigi Nervi, it is one of the greatest landmarks of twentieth-century cultural heritage, containing a significant number of revolutionary building techniques and materials such as ferrocement, which Nervi invented. The suggested low-fidelity model has enabled extrapolation and analysis of data inherent in the static and, more importantly, dynamic behavior of the structure in issue.

The determination of the seismic performance of the Turin exhibition center is examined in this research. The eigen-value and response spectrum analysis of the structure was performed by transferring the structure's three-dimensional model from AutoCAD 3D to ANSYS Mechanical APDL.

In the plugging, the model was assumed without mass, and 100 vibration modes were retrieved in this manner. The modal analysis indicated the modes of vibration with the greatest effect on the structure, and 7 modes were chosen from 21 characteristic modes since current code states that the minimum participation factor must be larger than 5%. It was discovered that the first and third modes had the most participants.

A simplified analysis with response spectrum and behavior coefficient q=1 was performed to define and perform dynamic analysis. The stresses and displacements were obtained from software and integrated using the CQC combination method. Instead of inspecting every section of the structure, 11 critical elements were chosen to characterize all the structure's behavior in terms of dynamic and static analysis. The selection of most critical elements are the base and middle of the arches on both long and short side, the base and middle of the inclined corner pillars, the middle of the internal undulated slab, and the lateral ribs at the base of the vault, as well as the lateral ribs on the gallery side.

Following that, the response spectrum data, which include axial stresses, shear stresses, and bending moments for each critical element, were integrated with static analysis results from a previous thesis. The cross-section and material parameters were obtained from prior study, and the reinforcement information was derived from a previous experimental report. Using the excel file, N-M interaction domain diagrams were evaluated, and 30 percent lower bending moment owing to existing structure is suggested in present code with 48 values of combination actions and 1 value with only static analysis. As a consequence, 49 points in the interaction diagram were examined in each direction for each critical element. The shear assessment for each critical element and each combination action was checked using excel and MATLAB code.

Complex structures, such as the Turin exhibition center, need an in-depth seismic assessment since, even if they are located in areas with low seismic risk, this variable might lead to significant issues created by the work's original idea. In terms of preserving historical structures, transmitting all work done to the other generations and developing a dialogue space would surely advance the history. Because each structure has its own unique aspects, it exhibits a variety of architectural and engineering characteristics. As a result, every structure investigated, and every type of structural challenge faced will throw a bit lighter on the engineers who is working on this topic.

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ANNEX 1

MATLAB CODE

```
% Shears calculated in tip680 for EL1523

b = 700;

h = 900;

d_1 = 30;

d_2 = h-d_1;

fcd=19.31

fyd=167.47

% stirrups phi5 and 20cm space

Asw = 2*pi*((5^2)/4); %mm^2

s = 200; %mm

alpha =pi/2;

theta = pi/4;

VRs = 0.9*d_2*(Asw/s)*fyd*(cot(alpha)+cot(theta))*sin(alpha);

ni = 0.5;

bw = b;     %min((b+h),2*b);

VRc = 0.9*d_2*bw*ni*fcd*((cot(alpha)+cot(theta))/(1+(cot(theta))^2));

VRd = min(VRs,VRc);
```

ANNEX 2

ANSYS CODE

```
%EIGEN-VALUE ANALYSIS

% In X direction

/SOLU

ANTYPE,2

MODOPT,LANB,100

EQSLV,SPAR

MXPAND,100,,,0

LUMPM,0

PSTRES,0

MODOPT,LANB,100,0,0,,OFF

SOLVE

FINISH

/SOLU

ANTYPE,SPECTR

DMPRAT,0.05

SPOPT,SPRS,100,YES

SCAFAC=1

B=1

SED,1*B,0*B,0*B,    % The seismic is apply in x direction, if


SVTYP,2,1,

PGA=0.097*9.81*SCAFAC

FREQ,0.250,0.538,2.198,6.578
```

```
SV,0,0.014*9.81*SCAFAC,0.066*9.81*SCAFAC,0.271*9.81*SCAFAC,0.271*9.81*SCAFAC
SOLVE
FINISH
% in Y direction
/SOLU
ANTYPE,SPECTR
DMPRAT,0.05
SPOPT,SPRS,100,YES
scafac=1
B=1
SED,0*B,1*B,0*B,
SVTYP,2,1,
PGA=0.097*9.81*scafac
FREQ,0.250,0.538,2.198,6.580
SV,0,0.014*9.81*scafac,0.066*9.81*scafac,0.271*9.81*1,0.271*9.81*scafac
SOLVE
FINISH
% in Z direction
/SOLU
ANTYPE,SPECTR
DMPRAT,0.05
SPOPT,SPRS,100,YES
scafac=1
B=1
```

```
SED,0*B,0*B,1*B,

SVTYP,2,1,

PGA= 0.022*9.81*scafac

FREQ,0.250,1.000,6.667,20.000

SV,0,0.001*9.81*scafac,0.009*9.81*scafac,0.062*9.81*1,0.062*9.81*scafac

SOLVE


FINISH

/SOLU

SIGNIF=0

ANTYPE,MODAL              ! Mode-frequency analysis

EXPASS,ON

MXPAND,100,,,YES,SIGNIF          ! Expand 100 mode shapes (to be choosen based on the
fem of the building), calculate element stresses

SOLVE

FINISH

/SOLU

ANTYPE,SPECTR

CQC,SIGNIF,DISP, ,STATIC          ! Cqc mode combination, with signif=vedi sopra and
displacement solution requested

! SRSS,SIGNIF,DISP                    ! Square root of sum of squares mode combination, with
signif=vedi sopra and displacement solution requested

SOLVE

FINISH

/POST1

/INP,,MCOM
```

%Element table

```
ETABLE,FxI,SMISC,1     ! axial forces Fx
ETABLE,FxJ,SMISC,14
ETABLE,MZI,SMISC,3     ! bending moment Mz
ETABLE,MZJ,SMISC,16
ETABLE,MyI,SMISC,2     ! bending moment My
ETABLE,MyJ,SMISC,15
ETABLE,SFyI,SMISC,6     ! shear forces SFy
ETABLE,SFyJ,SMISC,19
ETABLE,SFzI,SMISC,5      ! shear froces Sfz
ETABLE,SFzJ,SMISC,18
PRETAB,FXI,FXJ      ! list element table results
PLLS,FXI,FXJ,1,0,0  !plot Fx diagram
PRETAB,FXI,FXJ,MZI,MZJ,MyI,MyJ,SFyI,SFyJ,SFzI,SFzJ       %plot element table
```