

STRUCTURAL DESIGN OF THE MULTIFUNCTIONAL SPORTS HALL IN THE CITY OF BLAJ, ROMANIA

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ABSTRACT:

The multifunctional sports hall presented in the paper is of a dual-mixed type, combining spatial frames with reinforced concrete diaphragms and a steel roof frame. The spans of the roof girder are very large, 53.80 m. They were designed as spatial structures made of two lattice beams, braced between the upper and the lower chords, plus a set of counterbraces in the transvers vertical plane. As the sports hall was built in a seismic area of the country, a system of seismic protection needed to be adopted. The paper presents the architectural, technical and functional solution of the Sports Hall, explaining in detail the solution adopted for the seismic isolation of the building.

1. INTRODUCTION

1.1 Importance of the structure in the national context

The city of Blaj played an important historical role in the development of the country of Romania as it is today through the great event of the National Assembly in Blaj. The National Assembly in Blaj took place on May 15, 1848, during the Romanian Revolution. Around 3000 to 4000 people were part of the event. During the assembly, the Romanians from Transylvania, that were under occupation at that time, exposed their national, political, religious, and social claims, so that they would benefit the same rights as other nations living in the province (Bolovan, 2021). Today, the city where a great number of Romanian personalities did their studies, is undergoing a series of transformations through The Sustainable Urban Mobility Plan and The Integrated Urban Development Strategy; both plans are important stages in the long-term development of all basic sectors of the community.

Part of The Integrated Urban Development Strategy was the construction of a modern sports hall, where sports and other social activities could be carried out. The multifunctional Sports Hall, built to the current standards, is a construction built to last 100 years. It was designed for a capacity of over 2000 seats and will be used for sport competitions such as volleyball, basketball, handball, boxing and exhibitions, concerts, shows, fairs. The investment was financed from the local budget of the city of Blaj and from the County of Alba budget, through a partnership between the two public entities. The construction works at the Polyvalent Hall started in 2021, after the City Hall handed over the site to the company that won the tender, and the investment

was completed in 2022. The design of the structure was carried out by SC Asiza Architecture Office SRL as the general design company, with the specialized designers: Vlad Sebastian Rusu Individual Architecture Office and SC Struktoplan SRL. The general contractor was SC ACI SA from Cluj-Napoca.

1.2 General description of the construction

The Sports Hall is a construction built to last 100 years. It was designed for a capacity of 2000 sits and will be used for different type of sports such as basketball, volleyball, handball, and other events such as fairs or concerts. The building was equipped according to the requirements for gym homologation (CEV, 2016, FIFA, 2022, EHF, 206, ITF Tennis).

The multipurpose sports hall has 3 levels, underground, ground floor and first floor. The structural system is composed of spatial frames combined with reinforced concrete diaphragms and the roof framing is made of steel. The size of the structure is 57.8 x 83 m, with a ridge elevation of 13.35 m.

The roof was designed in the form of a steel spatial structure made of lattice beams, with a 53.8 m span, across the area of the playing field and the gradens; across the area corresponding to the reception hallway and the awning over the entrance, the solution chosen consists of IPE laminated plate beams. The cross-section (from the architectural plane), through the central area of the gym, is shown in Figure 1.

In the corners of the playing surface, four towers with the size in plane 3.75 x 3.75 m and the height 8 m were chosen as the design solution. The towers have a dual scope: support for the 53.8 m

longitudinal girders and they also hold the elevators. The towers are made of diaphragms with reinforced concrete walls.

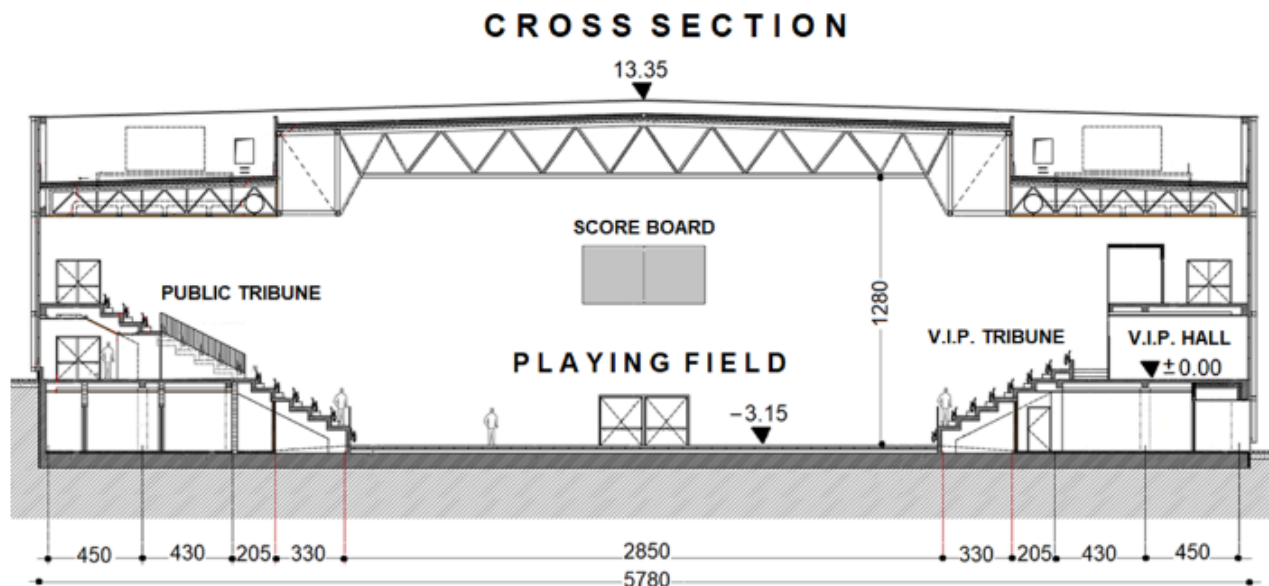


Figure 1. Cross-section of the central area of the Sports Hall

1.3 Seismic protection

In general, when seismic protection is needed, it relies on three key operational principles: energy dissipation, isolation and structural connection (Rachisor, 2020). A solution of seismic isolation of another Sports Hall in Romania was presented by (Mojolic, 2022), where three passive systems were proposed: friction pendulum systems, high damping rubber bearings and lead rubber bearings. The solution adopted implies the placing of the isolation system immediately under the roof, solution similar to other long span structures such as Kyoto Aquarena (Katsunori, 2008) and Ataturk International Airport (Constantinou, 2001). Another study (Gu, 2023) investigated the isolation effect of different type of bearing systems, Thick Rubber Bearing – Disk Sprin Bearing, Laminated Rubber Bearings, Natural Rubber Bearings, under different seismic excitations. (Babaei, 2024) shows the advantage of diving a building into two sub-systems, a soft and a stiff one. (Kherad, 2020) showed that for regular steel buildings the use of a specific type of yielding plate dampers at the bottom of the columns of the lowest storey of the building has a significant impact in creating repairable buildings even for major earthquakes.

1.3.1 Dissipation devices: A portion of the energy produced by an earthquake can be absorbed through the use of dampers, reducing the seismic impact on the structure (Titirla, 2023). Dampers provide minimal resistance to slow movements but are highly effective in responding to rapid displacements (as is the case of earthquakes). Dampers can be integrated with isolation systems, particularly high-damping elastomeric bearings (Sraavan Ashwin, 2022), to reduce structural displacement while controlling stresses within the structure. Dampers can be installed to greatly lower the cost of structural repairs after an earthquake. Additionally, they allow critical facilities like hospitals to remain operational. Moreover, they offer effective protection for older buildings that were not originally designed to endure seismic forces.

1.3.2 Isolation devices: The structure is decoupled from ground motion through flexible connections, primarily using reinforced elastomeric bearings or sliding systems (Warn, 2012), which increase the structure's fundamental vibration period and reduce seismic acceleration response (Clemente, 2019). The effectiveness of the isolator is directly linked to its horizontal stiffness, leading to significant displacements during a seismic event. Structural isolation results in a clear low-frequency response, reduced accelerations, and increased relative displacement (Clemente, 2019).

1.3.3 Connection devices: An approach that adds value to the overall behaviour is to limit the seismic displacements so that the connection devices to the neighbouring systems are simplified. In such cases, the designers can use two types of devices: Passive protection – mechanical bearings that transfer both service loads and seismic forces from the foundation to the structure (Kelly, 1990, Skinner, 1993).

Seismic connectors – their key characteristic is that they offer minimal resistance to displacements caused by temperature changes, shrinkage, and creep. Their primary function is to ensure a strong connection between the superstructure and its supports during rapid displacements caused by seismic events. Additionally, connectors help distribute significant horizontal seismic forces across all supporting structures (piers) to which they are attached. The seismic connectors are known by various names, shock transmission units (STUs), lock-up devices (LUD), rigid connection devices (RCD) or displacement-control devices (DCD) (Patel, 2015). In (Castellano, 2004) a series of buildings fitted or retrofitted with STU are presented: the Marin County Civic Centre Hall of Justice in California, USA retrofitted with 29 STUs, The Emilia-Romagna Tower in Bologna, Italy, under construction at the time, fitted with 12 STUs, the Santa Maria della Misericordia Hospital in Udine, Italy, fitted with 39 STUs.

2. STRUCTURAL CONFIGURATION OF THE STEEL ROOF AND SEISMIC PROTECTION

2.1 Roof configuration

The roof's longitudinal girders are designed as spatial structures consisting of two lattice beams, each 3.8 meters in height, positioned 2.8 meters apart between their centrelines. The two lattice beams are braced between the upper and the lower chords, along with a set of counterbraces in the transverse vertical plane, adjacent to the secondary beams. The chords of the beams were made using semi-box sections (with two vertical walls), made of IPE-U rolled profiles solidarized with plates, Figure 2; such a section has the advantage of easy performance of maintenance works. The spatial girders are supported simply by four towers, with each beam resting on independent supports composed of elastomeric bearings.

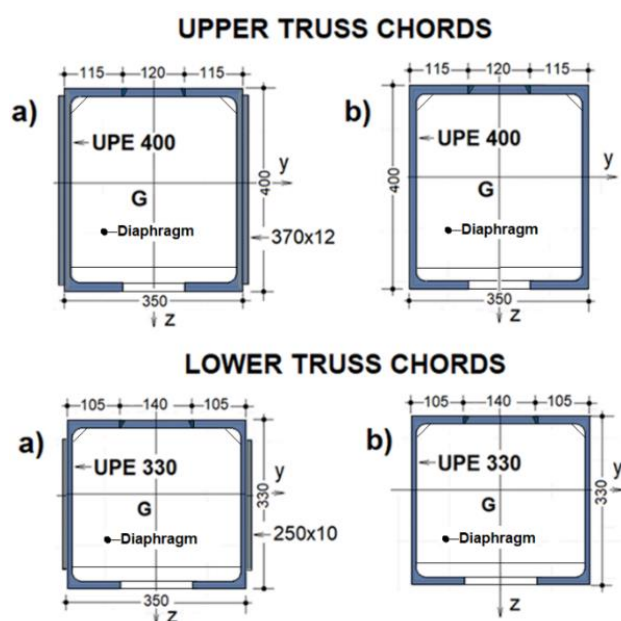


Figure 2. Cross-sections main lattice girders a) central area of the girder; b) marginal side of the girder

Above the playing surface, in the transverse direction, secondary lattice beams are positioned with a span on 29.0 m. The bars are rectangular pipes; on the other side, above the gradens, secondary beams with a span of 10.65 m were needed, with the chords made of rolled H profiles, that rest at one end on the main girders, and at the other end on the marginal columns' mare of reinforced concrete.

Space lattice beams have been designed between the towers and at the ends of the main girders in the transverse direction. These beams provide stability to the main girders and contribute to the spatial configuration of the roof framing by creating a rigid perimeter. Between the space beams at the end and the first transverse beam in the central area, 3 connecting pendulums were arranged. The pendulums complete the horizontal plate structure of the upper chords. The upper chords are provided with a system of bracings in the horizontal plane and three planes of longitudinal vertical bracings.

2.2 Seismic protection system used at the Sports Hall in Blaj

The seismic protection system has the following constitutive elements: elastomeric supports between the girders and the concrete towers, that allow for a free movement along the predefined horizontal direction; hydraulic dampers and the wind-bracing system in the plane of the roof.

2.2.1 Elastomeric supports: The main girders are simply supported on the four towers, each girder having independent supports under the form of elastomeric devices. Such a solution was chosen to ensure the horizontal deformations from external actions and temperature variations, up to 50 mm. Using this solution the structure of the roof can be deformed freely, Figure 3.

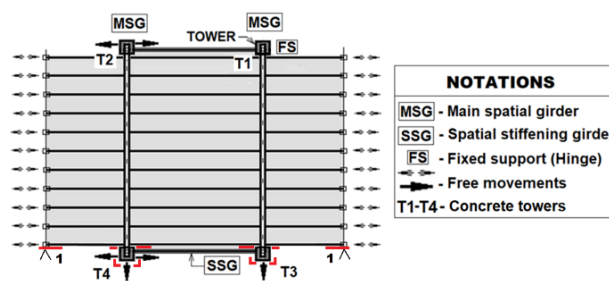


Figure 3. Free movements of the roof structure

Integral or partial limitation of displacements is solved through a central steel pivot, Figure 4, fixed to the upper plate of each concrete tower. Through U profiles, the accepted displacement direction can be controlled.

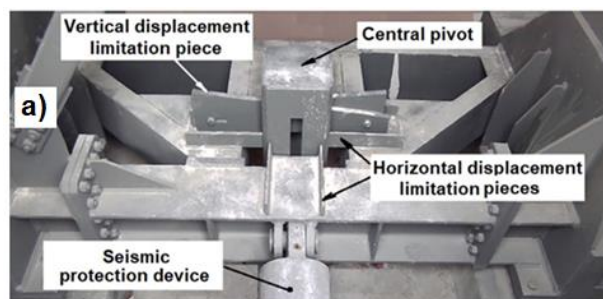


Figure 4. Central pivot used to limit or block the displacements

2.2.1. Hydraulic dampers: For the case studied, along the direction of the free displacements, hydraulic dampers were mounted, that are blocking the free displacements when a certain value of the horizontal force in the device was reached. When the free displacements are blocked, the four towers are mobilized to take the seismic force. Such devices are shock transmission units (Patel, 2015); these devices have as components a piston, a piston rod and a cylinder pipe. They serve as temporary connectors, allowing unrestricted movement during normal conditions, but locking in place during an earthquake. In such events, forces are transmitted to the connected elements. Shock transmission units, or lock-up devices, function by utilizing the principle that the rapid movement of a viscous fluid through a narrow gap, orifice, or port creates high resistance, while slow movement at low velocity generates minimal resistance. As a result, these devices lock during rapid motions but produce only minor reaction forces due to friction during slow movements, such as those caused by thermal expansion or contraction. Although shock transmission units do not dissipate energy and therefore do not reduce load

impacts, they temporarily alter the static system of a structure in extraordinary circumstances, such as converting from simply supported to hinged-supported elements. Their primary purpose is to control load distribution and share forces among multiple structural components, in this case, the building's four towers. In addition, devices avoid large movements of the structural elements.

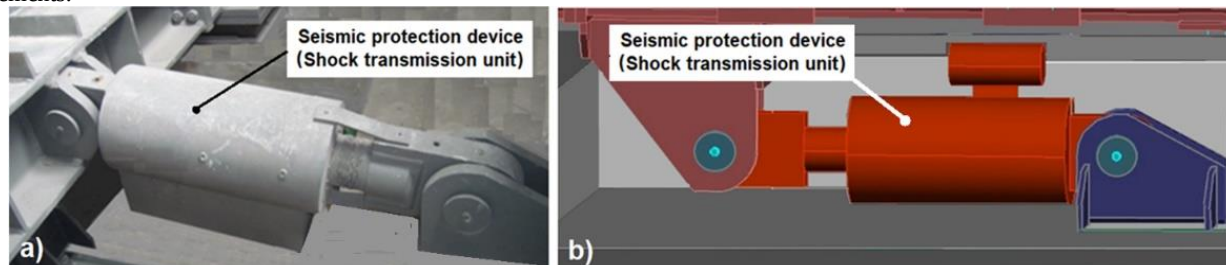


Figure 5. Seismic protection devices: shock transmission units: a) unit positioned longitudinally; b) unit positioned transversally

Shock transmission units of STU 1000-100 type used at Sport Hall have the following characteristics (ISOSIM, 2016): $F_d=1000\text{kN}$; $d_0=\pm 50\text{mm}$, where F_d is the force given by the manufacturer. According to EN15129 § 5.3.3, the devices shall be designed to withstand a maximum force $F_{\max}$ equal to:

$$F_{\max} = F_d \cdot \gamma_x = 1500 \text{ kN} \quad (1)$$

Where: $\gamma_x = 1.5$ is a reliability factor.

By using the presented supports solutions and hydraulic displacement blocking devices for major values of seismic forces, two static transverse schemes of the steel framing structure are obtained, as shown in Figure 6: one for the normal loading case and a different static scheme in case of a seismic event.

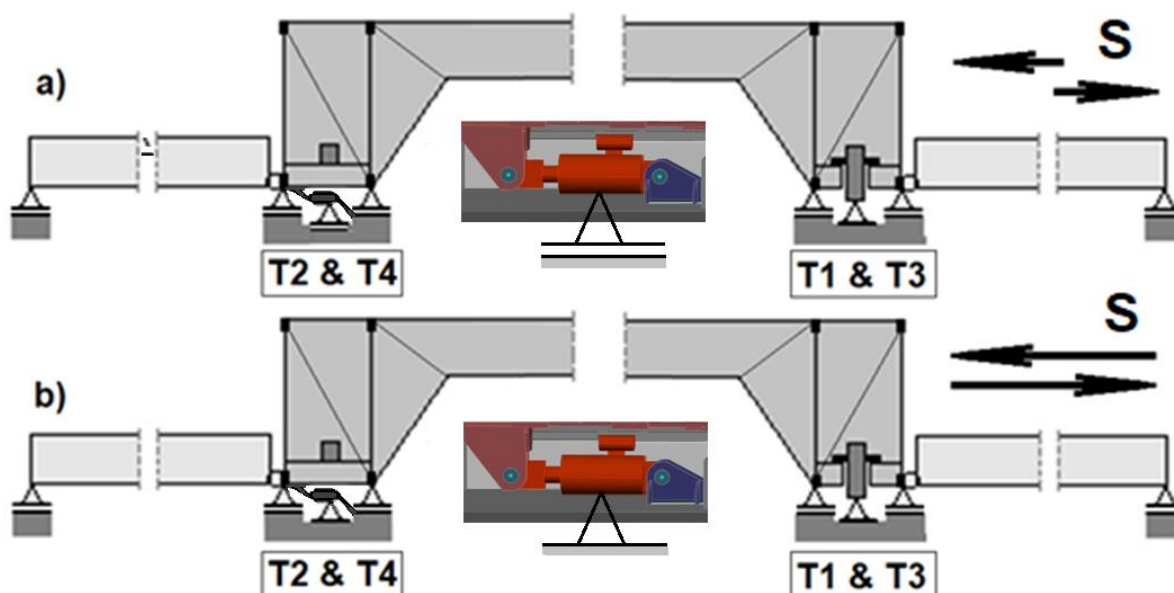


Figure 6. Static transverse schemes of the steel frame structure: a) Normal loading cases; b) Major seismic events

2.2.2. Roof wind-bracing: The wind bracing of the roof was designed to work efficiently under two loading hypotheses, Figure 7:

- In the fundamental group loading hypotheses (self-weight, variable actions, snow and wind action) the wind bracing has the purpose of ensuring the spatial structure of the roof; a limited deformation along the direction of the free movement permitted by the support devices was taken into account.

- In the seismic loading hypothesis, the shock absorbers become active, and the bracing system has an active role to the horizontal diaphragm effect in the plane of the roof.

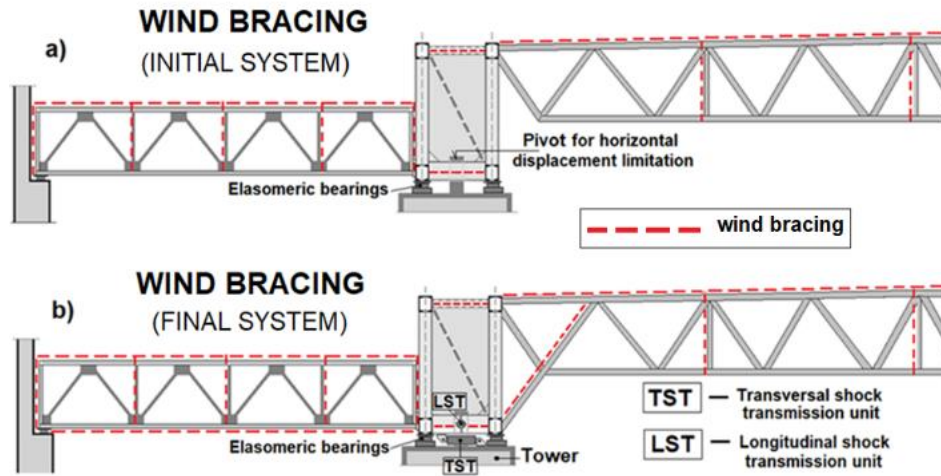


Figure 7. Wind-bracing configuration: a) initial configuration of the roof girders; b) final configuration

3. CONCEPTUAL DESIGN OF THE STRUCTURE

3.1 Actions on the structure

The location of the structure in Blaj, Alba County, is from the point of view of climate and seismicity in a zone with the following loads characteristic values and design parameters:

- According to CR 1-1-3-1012, the site is in the snow zone characterized by a normal value of the load on the ground $S_{0,k}=1.5 \text{ kN/m}^2$; the snow loading is denoted with Z.
- According to CR 1-1-4-2012, the location is in a zone characterized by a reference value of the dynamic wind pressure of 0.6 kPa (IMR=50 years); the wind loading noted as W.
- According to Seismic Design code P100-2013, the site is in the area with peak ground acceleration $a_g=0.15 \cdot g$ and a control period of the seismic motion $T_c=0.7 \text{ s}$; the seismic action is S. For the determination of the global seismic force (Fb) it was considered the self-weight of the structure (denoted as GP) and the load for the long-term value of the snow (GP+0.40Z).
- The construction falls within the Importance Class II, cr-0-2012, which corresponds to the factor $\gamma_I=1.2$ - (e) for Conference halls, shows or exhibitions, with a capacity of over 200 people in the total exposed area, tribunes of stadiums or gyms.

3.2 Load combinations

Load combination for ultimate limit state (ULS) and serviceability limit state (SLS) according to CR 0-2005, are as follows:

- At ULS, in the Fundamental group, 3 combinations were considered: $1.35 \text{ GP} + 1.50 \text{ Z} + 1.05 \text{ W}$, $1.35 \text{ GP} + 1.50 \text{ V} + 1.05 \text{ Z}$ and $0.90 \text{ GP} + 1.50 \text{ W}$; the special group takes into account the seismic action $1.00 \text{ GP} + 0.40 \text{ Z} + 1.00 \text{ S}$.
- At SLS 2 combinations were taken into account in the Fundamental group: $1.00 \text{ GP} + 1.00 \text{ Z} + 0.70 \text{ W}$ and $1.00 \text{ GP} + 1.00 \text{ V} + 0.70 \text{ Z}$.

The AxisVM X6 computing program have been used to analyse the building resistance structure and the main results obtained for the central zone of the roof structure are synthetized Figure 8, 9, 10 (XC Project, 2020).

The maximum vertical deformation, f , at SLS, of the main girders, is:

$$f = 165 \text{ mm} < \frac{L}{300} = 179 \text{ mm} \quad (2)$$

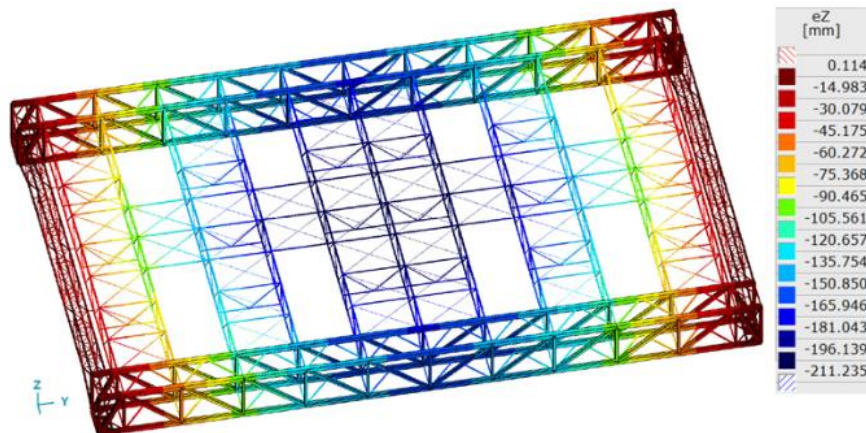


Figure 8. Vertical deformations at SLS

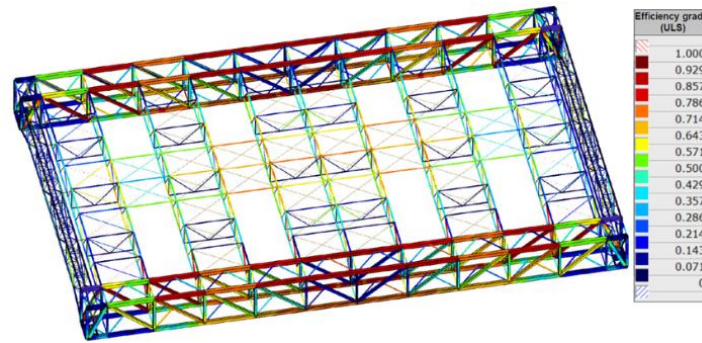


Figure 9. Utilization level of structural elements at ULS

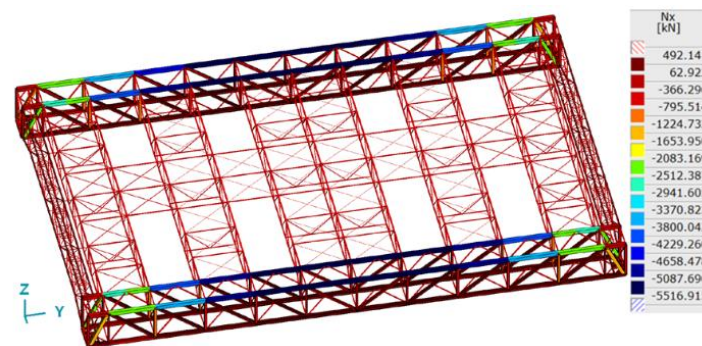


Figure 10. Axial compression forces at ULS in the main girders

The most loaded bars, of about 93%, are members of the top chord situated in the middle zone of the main truss girders. For resistance design, connection design and global stability checks of the steel roof structure, the Eurocode (SR EN1993-1-1), and the handbook *Constructions and Steel Bridges* (Moga, 2023) were used. For individual member checks, both method A and B of Eurocode (SR EN1993-1-1) was performed.

For the most stressed bars of the main girders the simplified analytical method presented in Eurocode (SR EN 1993-2), has been also used, presented below. As per SR EN 1993-2, § 6.3.3, a simplified equation can be applied to verify a member subjected to both bending and compression:

$$\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}} + C_{mi,0} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{M_{y,Rk}/\gamma_{M1}} \leq 0.9 \quad (3)$$

Where:

N_{Ed} – the compression force design value,

$M_{y,Ed}$ – the design value of the maximum bending moment about the y-y axis of the member, determined from the first order analysis without accounting for imperfections,

4. CONCLUSIONS

The Multipurpose Sport Hall in city of Blaj - Alba County, is an important civil construction, being appreciated by the inhabitants of the city and of the neighbouring area, with positive implications on the possibilities of carrying out large-scale sports and cultural activities.

The most modern solutions are used to ensure the indoor climate - temperature, and the purity of the air, as well as artificial

$C_{mi,0}$ – the equivalent moment factor, as specified in Annex A (SR EN 1993-1-1),

χ_y – the equivalent moment factor, as specified in Annex A.

For members with uniform sections classified as cross-section classes 1, 2 and 3, subjected to axial compression and either monoaxial or biaxial bending, the verification equation (3) can be expressed in the following simplified forms (4) for monoaxial bending and (5) for biaxial bending.

$$\frac{N_{Ed}}{\chi_{min} N_{Rk}/\gamma_{M1}} + C_{my,0} \frac{M_{y,Ed}}{M_{y,Rk}/\gamma_{M1}} \leq 0.9 \quad (4)$$

$$\frac{N_{Ed}}{\chi_{min} N_{Rk}/\gamma_{M1}} + C_{my,0} \frac{M_{y,Ed}}{M_{y,Rk}/\gamma_{M1}} + C_{mz,0} \frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 0.9 \quad (5)$$

lighting, by using efficient and low-energy solutions. Also, the fire resistance of the construction is ensured.

The construction improves the cultural, social, sports and leisure infrastructure of the town and meets the needs of the community, the capacity of the hall representing about 10% of the population of the locality, which in turn represents about 0.10% of the country's population.

The architectural, technical, and functional solutions implemented align with current standards in this field and reflect significant efforts from all parties involved—administration,

beneficiaries, architects, engineers, and construction specialists - who have demonstrated a high level of technical expertise and rigor.

The building is a durable civil construction, designed for a period of use of 100 years, using high-performance materials, having high mechanical strengths, and are adopted modern technically solutions to take over exceptional loading from the earthquake. As a seismic protection for the Sports Hall, the solution chosen was a STU in combination with seismic isolators-elastomeric bearings. In case of a seismic event, the shock absorbers become active, and the bracing system takes an active role. The solution presented can be used in other steel structures with large span roofs.

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