Case study: The supporting steel structure of the ice rink – city of Tg. Mureş, Romania

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Case study: The supporting steel structure of the ice rink – city of Tg. Mureş, Romania

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ABSTRACT: The article describes the applied technological solutions to transform an existing ice rink into an indoor arena in the city of Târgu Mureş, Romania. The ice rink presently is managed by "Clubul Sportiv Mureşul" Association and the new indoor arena will have a capacity of 1800 fixed seats. Using a large free span (50 m) structure will overcome the in situ technological constraints due to the position of the existing building. There is limited access due to the fact that the ice rink is situated between two buildings and the river Mureş flows alongside the third side. Also, the existing refrigeration system makes access impossible within the ice pad structure area. Taking into account the above mentioned restrictions, the article describes the applied structural solutions which will make the structural steelwork erection possible. The structural solution using steel will ensure fast and easy erection of the structural steel framework without causing damage to any of the existing buildings and installations.

1 INTRODUCTION

1.1 *About the scope of works*

To find a technological solution to transform an existing ice rink into an indoor arena in the city of Târgu Mureş with a capacity of 1800 fixed seats imposed to use a large free span (50 meter) steel structure. With the condition of a clear height of 9,00 m over the ice pad area, the geometrical dimensions of the proposed building resulted 58,60x 67,00 x13.00 m (width x length x height) . The building on the ground floor consists of the ice pad area - 1800 m^2 (60 x 30 m) and the necessary annexes (public area, offices and dressing rooms etc.) of 2200 m^2. The scope of works included the following main requirements:

- To cover the existing ice rink in order to extend the usage lifetime;
- To have a capacity of 1800 fixed seats;
- To ensure 90 min fire rating of the steel structure;
- To ensure the specific internal micro climate.

1.2 *Constrains*

Due to the destination and the particular position of the building - limited access due to the fact that the ice rink is situated between two buildings and the river Mureş flows alongside the third side, there were the following constrains:

- Access for erection only from one side, without the access on ice pad structure due to the existing refrigeration system;
- To keep the existing buildings;
- To control the designed assemblies self weight, in order to facilitate the erection.

Also the pressure of a short deadline acted as constraint. The site conditions and the proposed architecture should be seen in figure 1.2.1.

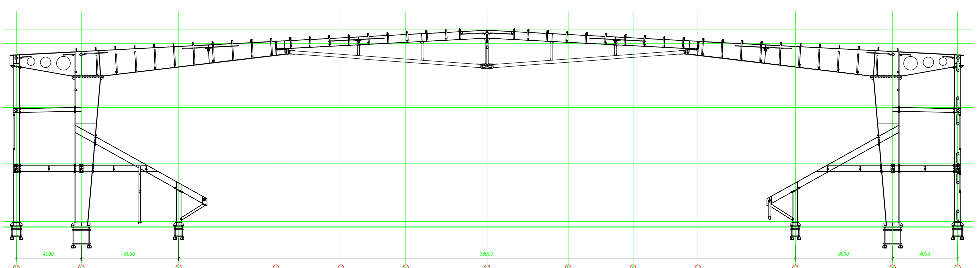
Figure 1.2.1. The site conditions and the architecture of the building (view from access side)

2 DETAILED DESCRIPTION OF THE DESIGNED BUILDING

2.1 *Structure*

The primary load-bearing structure of the building uses a simple portal frame shape (figure 2.1.1), combined with a king post truss rafter, steel frames based on a 6.0 m grid. The clear span of the frame is 50 m, with additional 4 m extension on both sides. The frames have fixed base connections, tapered columns, hunched and king-post truss rafters and a pitch roof angle of 3^0. The supporting structure of the tribune is fixed to the frame column in the transverse plane, increasing in that way the lateral stiffness of the whole transverse frame. Additional flange braces connect the frame rafter lower flange to the roof purlins, in order to prevent lateral-torsional buckling of the rafter. All the assemblies are made from welded steel sections. A structural steel with S355 steel grade (f_y=355 N/mm^2) have been used.
For the first and second floor slab in situ reinforced concrete solution was applied. For the composite action of steel and concrete, mechanically fixed shear studs have been used on floor beams. Precast concrete elements were designed for the tribune. A central skylight cut out of the roof to bring daylight down to the ice rink.
The 90 min fire resistance of the structural steel columns and 60 min for rafters and floor beams is assured by intumescent coating of the steelwork.

Figure 2.1.1. Characteristic section of the structure



2.2 *The building envelope*

The insulated building envelope makes it possible to control the indoor climate regardless of the outdoor climate. In the case of this type of buildings, air tightness is a more important feature of the building envelope than thermal insulation. Large glazing of the facade has been avoided due to energy costs by operating the facility. Windows are placed mainly on facility area, because the most optimized ice rink could be done by a fully closed casing.
The wall cladding is made of 120 mm thick horizontal sandwich panels. On the roof 200 mm thick rock wool insulation is laid down on the supporting trapezoidal steel profiles, waterproofing is assured by a protective membrane.
The supporting structure of the facade is a steel framework of rectangular hollow sections.

2.3 *Indoor climate*

Ice rink design and operation are totally unique and differ in many ways from standard buildings. Thermal conditions vary from -5 ºC on the ice surface to +10 ºC in the stand and +20 ºC in the public areas like dressing rooms and offices.

The main concern during the design process was to ensure optimal parameters of the interior climate. The optimal parameters of a well-working facility are defined mainly by:

- Adequate insulated walls and ceiling;
- Efficiency of the refrigeration plant;
- Adequate mechanical ventilation;
- Efficiency of the heating system;
- Adequate air dehumidification.

High humidity of indoor air should bring corroding problems with steel structures and indoor air quality problems like fungi and mould growth. Obviously it was necessary the use of Building Management System (BMS) to control the indoor climate and energy use of the whole ice-rink facility. This advanced technology can reduce energy consumption by even 50 % and thus decrease operating costs of the ice rink facility while improving the indoor climate.

2.4 *Sustainability and life cycle cost*

Sustainable construction is about achieving a viable balance between economic competitiveness, social benefit and environmental impact. Economic competitiveness is defined mainly by the selected materials and designed solutions. Cost estimation for the described ice rink solution is presented below (table 2.4.1). From the point of view of social benefit ice rinks are attractive sports and recreational facilities promoting health and social activity as a key element of "quality of life" (7). From the point of view of environmental impact - energy consumption is in the key role when speaking of the life cycle costs and above all the environmental load of the facility during its life cycle (8). The key to the effective utilization of the energy resources is in the consciousness of the energy-sinks and the various parameters affecting the energy consumption. The construction, plant system and operation define the energy consumption of an ice rink. The construction characteristics are the heat and moisture transfer properties of the roof and walls, as well as air infiltration through cracks and openings in the building envelope.

The structure of the floor is also important from the energy point of view (7). Plant characteristics include the refrigeration, ventilation, dehumidification, heating, lighting and ice maintenance systems. The operational characteristics are the length of the skating season, air temperature and humidity, ice temperature, supply air temperature and fresh air intake of the air-handling unit as well as the control- and adjustment parameters of the appliances. Figure 2.4.2.a. shows the estimated energy spectrums and figure 2.4.2.b. illustrates the estimated energy flows of a small sized ice rink. Based on these reference values, figure 2.4.3 illustrates the estimated expenses for the life cycle expenses evaluation.

Table 2.4.1. Cost estimate for the ice rink according to DIN 276 cost groups.

Cost group	Description	Total [Euro]	Percentage [%]
100	Site cost	0	0.00%
200	Utilities	0	0.00%
300	Construction costs	2.000.000	60.60%
400	Mechanical and electrical works	600.000	18.20%
500	Site finishing	300.000	9.10%
600	Equipment	300.000	9.10%
700	Design, project management	100.000	3.00%
	Cost group 100-700	**3.300.000**	**100.00%**
	General project development cost	330.000	
	Total project cost	**3.630.000**	

Notes: Estimated values based on Romanian price level in year 2007.

Figure 2.4.2. Spectrum of heating energy need (a) and electric consumption spectrum (b) of a prototype ice rink in Munich (source 7)

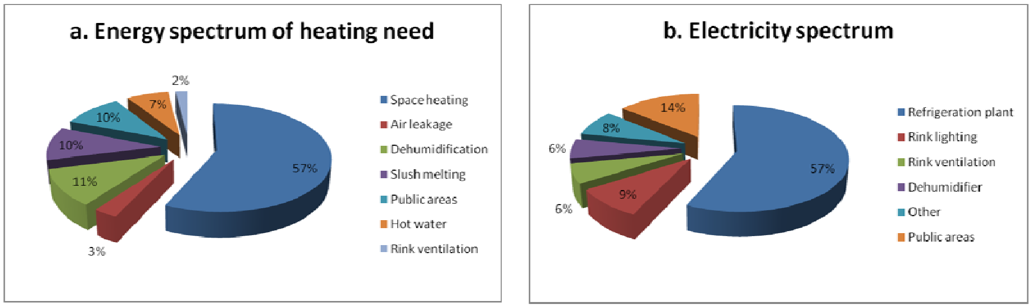


Table 2.4.3. Estimated expenses for the ice rink utilization phase (main utilization area HNF=5700 m^2).

Expenditures –utilization phase	Target value [Euro/m^2 x HNF x 1year]
Cleaning of the building	4.45
Water sewage	3.90
Heating	2.25
Cooling	8.55
Electricity	6.45
Service / maintenance /inspection	1.10
Miscellaneous	2.25
Building maintenance	4.45
Utilization subtotals	**33.40**

2.5 *Acoustics and noise control*

Minimum acoustical quality of an ice rink should enable clear and understandable speaking even amplified spoken words and music. Therefore environmental acoustics has been included in the design process. The importance of the acoustics is emphasized in multipurpose rinks. The most significant acoustic parameter is the reverberation time, which has been determined to be low enough (less than 3 sec). Too high background noise level caused by ventilation and compressors (inside) or traffic (outside) has also negative effects on the acoustic indoor environment. The noise caused by the ice rink facility to its surroundings (outdoor condenser fans or the sound of an ice hockey game may cause disturbing noise) can be neglected due to the given position of the facility.

3 STRUCTURAL DESIGN OF THE BUILDING

3.1 *Loading of the main structure*

In order to evaluate the structural response, in the design process have been considered the following loads (characteristic values):
- Live loads on floors u_k= 5 kN / m^2
- Snow loads on the roof according to CR 1-1-3-2005 (2), $s_{o,k}$=1.5 kN/m^2
- Wind loads on building envelope according to NP-082-04 (3), q_{ref}=0.4 kN/m^2
- Fire loads of 120 MJ/m^2
- Seismic action according to P100-2006 (4), with peak ground acceleration a_g=0.12g and control period of seismic motion T_c=0.7 sec
- Load combination for ultimate limit state (ULS) and serviceability limit state (SLS) according to CR-0-2005 (1).

3.2 *Design checks of the main structure*

The design of the steel structure has been performed following the Romanian code STAS 10108/0-78 (5). For strength, stability and stiffness requirements of the structural elements the prescription of SR-EN1993-1-1, SR-EN1993-1-8 and P100/2006 (4) were used also.

In the case of large spanned structures, the vertical deflection under gravitational loads represents one of the major constraints in the design process. In order to keep under control the deformations of the frames, fixed base connections, tapered columns and hunched king-post truss rafter solution were chosen. The rafters have been extended on both sides over the annexes, increasing that way the vertical and horizontal stiffness of the frame. A suitable horizontal and vertical bracing was provided in order to control structural flexibility, eigen values and deflections of the main structure. Fly braces were provided at the inner flange or the rafter in order to improve the flexural-torsional buckling resistance of these elements.

Having section class 3 of the structural elements, linear elastic structural analysis has been performed, using a behavior factor under seismic action q=1 according to P100-2006. Even q=1, the combinations of actions for seismic design situations were not the dominant load combinations. The design checks of the structural elements for ULS include persistent or transient design situations (fundamental combinations) where snow loads play the key role.

For SLS design checks of the structural elements fundamental and exceptional load combinations were used. Performing a dynamic 3D analysis of the structure, with the structural masses concentrated on joints, first longitudinal eigen period of T_{long}=0.588 sec and first eigen period of T_{transv}=0.448 sec were obtained.

The maximum transverse and longitudinal sway deformation for SLS check under seismic loads according to P100-2006 are:

$$d_{r,x}^{SLS} = 0.014 \le \frac{d_{r,a}^{SLS}}{\nu \cdot q} = \frac{0,005 \cdot h}{0.4 \cdot 1.0} = 0.1125\,m\,,\ d_{r,y}^{SLS} = 0.047 \le \frac{d_{r,a}^{SLS}}{\nu \cdot q} = \frac{0,005 \cdot h}{0.4 \cdot 1.0} = 0.1375\,m$$

The maximum vertical deformation of the rafter for SLS check under snow load is:

$$f = 161.4mm \le f_a = \frac{L}{300} = 166.7mm$$

In order to have a detailed overview about the behavior of the structure, a finite element linear elastic analysis (FEM) of the transverse frame has been performed with Ansys computer program. The elements of the frame were modeled using shell finite elements (Shell 43) (see Fig. 3.2.1). At the level of the roof the forces were applied as point loads, at the purlins location. The connections between structural elements rafter-to-column, beam-to-column, rafter-to-rafter, column base connections were considered fully rigid. The detailed FEM results confirmed the previously evaluated ULS and SLS results. The recorded vertical displacement in case of FEM linear elastic analysis was 152 mm. Figure 3.2.2 shows the stress distribution along the transverse frame, where we can observe the maximum stress concentration around of the joint of the king post rafter and the hunched frame rafter.

Figure 3.2.1. FEM model of the transverse frame

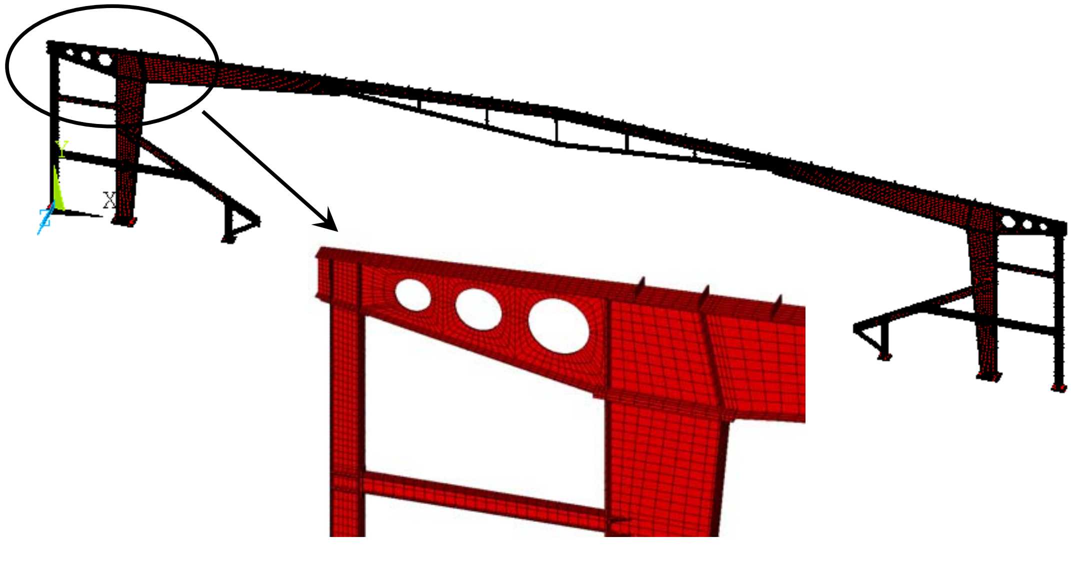
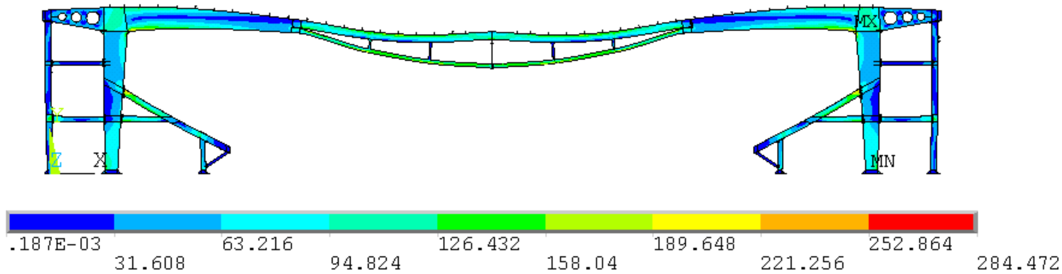
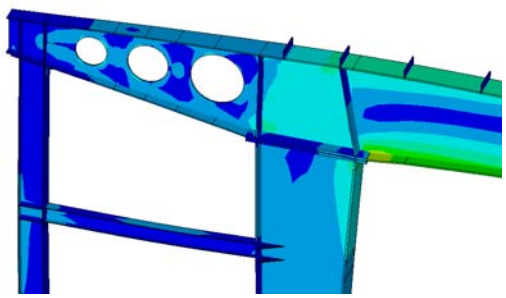
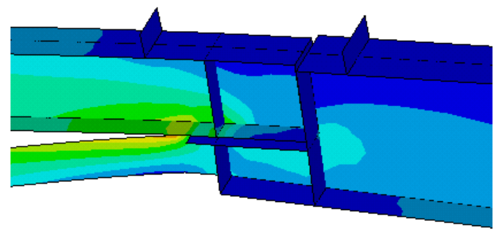


Figure 3.2.2. Stress distribution along the transverse frame in the fundamental design load situation



Resulted maximum stress not exceed 285 N/mm^2.





3.3 *Robustness of the structure*

According to Knoll and Vogel (9) robustness is the property of systems that enables them to survive unforeseen or unusual circumstances.

As a result of our risk analysis two aspects could represent a risk in case of unusual circumstances: floor vibration due to occupants (e.g. important event) and major rafter deflection in case of excessive snow loads. As a practical application, elements 13, 14 and 15 of robustness were chosen to control the identified risks. The different elements of robustness according to Knoll and Vogel (9) used in risk analysis are centralized in table 3.3.1.

Table 3.3.1. Covered elements of robustness ranged according to methods based on risk analysis

	Elements of robustness	**Event control**	**Direct approaches**		**Indirect approaches**	**Reduction of consequences**
			Specific load resistance method	**Alternate path method**		
1	Strength		x		x	
2	Structural integrity and solidarization				x	
3	Second line of defense				x	x
4	Multiple load path or redundancy				x	
5	Ductility versus brittle failure				x	
6	Progressive failure versus zipper stopper					x
7	Capacity design and fuse element					x
8	Sacrificial and protective devices					x
9	The knock-out scenario					x
10	Stiffness considerations			x	x	
11	The benefits of strain hardening		x	x		
12	Post buckling resistance			x	x	
13	**Warning, active intervention and rescue**	**x**				**x**
14	**Testing**		**x**	**x**		
15	**Monitoring, quality control correction and prevention**	**x**				**x**
16	Mechanical devices	x				

In order to control the *rafter vertical deflection* elements 13 and 15 of the robustness (table 3.3.1) were used. A deflection sensor has been proposed to monitor vertical deflections of the king post rafter. The registered deflection should be seen all the time through the internet, the monitoring software will be set up to generate automatically warning mail message in case of a given value of vertical deflection is exceeded.

In order to control the *floor vibration* element 14 of the robustness (table 3.3.1) was used. In situ measurements have been proposed before the opening of the ice rink in order to establish the real eigen period of the floor.

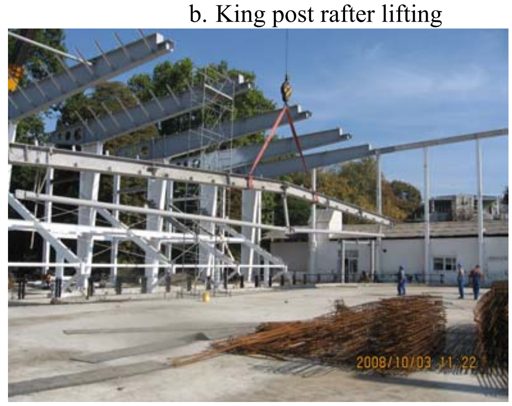
4 ERECTION OF THE STEEL STRUCTURE

The most challenging activity has proven to be the erection of the main structure. Due to the restricted access only from one side, it was necessary to keep permanently clean this area, or use it only for short time storage. That imposed a clear delivery order of the structural elements, according to their structural position. Otherwise it would have resulted in a supplementary moving of the assemblies on site until they arrive in the final position. The joints have been positioned in a way to facilitate a proper erection. The column and the hunched rafter part on the roof were erected first – the tribune structure served as a stabilizer for the partially erected frame. For this operation a common 10 tonne capacity crane was used. This was followed by the erection of the king post rafter assembly in the middle part of the roof (see figure 4.1). For this operation a special 110 tonne capacity crane was used, lifting with 35 meter radius the central king post rafter assembly into the final position. Only a week was necessary to perform the erection of all rafters, in this way the high renting costs for the special crane equipment were minimized.

Figure 4.1. Erection phase of the king post rafter

a. King post rafter positioning

b. King post rafter lifting

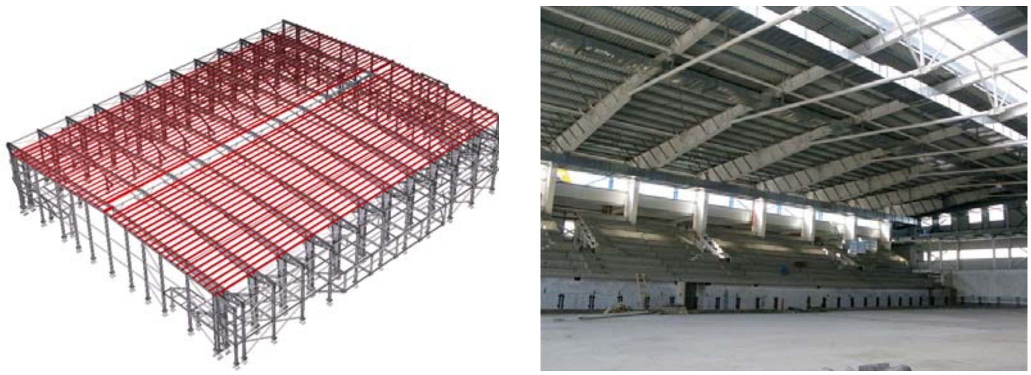


5 CONCLUDING REMARKS

The paper illustrates the successful application of the steel structure for a large span using a simple portal frame shape, combined with a king post truss rafter. A wide range of design parameters are briefly summarized. The paper emphasizes how the restricted access to the site dominates the whole design and execution process, and why the ice rink design and operation are totally unique and differ in many ways from standard buildings. The paper shows the importance of environmental acoustics in particular cases which should be included in the design process. From the structural point of view a good agreement between 3D structural analysis and FEM has been found. Also the application of different elements of structural robustness is shown in the paper.

This case study is a good example of the merging of architecture, structural engineering and other specialties; even if at the first look it would seem to be a simple application.

Figure 5.1. The whole structural model and the actual stage of the building



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