Proceedings of the 7th International Conference on Civil Structural and Transportation Engineering (ICCSTE'22)
Niagara Falls, Canada – June 05-07, 2022
Paper No. 228
DOI: 10.11159/iccste22.228

Long Span Steel Structures: Structural Typology Optimization and Enhancement- The Conceptual Design of an Aircraft Hangar

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Abstract – Long-span structures are generally defined as those with a span of tens of meters. They are commonly constructed as steel structures and used for a wide range of building types such as industrial buildings, warehouses, hangars, public halls, agricultural buildings, and arenas. However, the proper design of such structures improves the structural performance along the building time life. Moreover, the structural system has a significant impact on the entire project cost in terms of mass distribution efficiency. Furthermore, the failure consequences of these structures, as large-scale structures, are significant and it often causes huge economical loses at best, when there are no casualties. Consequently, it is highly important to choose the structural solution which provides less overall cost and safe operation of the intended building. This can be achieved by optimizing the structural typology of the building and choose the proper design solutions. For this purpose, this paper deals with the conceptual design of an aircraft hangar as a typical example of long-span steel structures playing a fundamental role in the airports around the world. Nowadays, and along the last decades, the leading manufacturers in the globe at the field of aviation have the passion to produce new generations of aeroplanes in their quest to ensure a better future for this service in the line with the incredible development in this industry and in the air-traffic growth. The new produced models of aircraft are wider, higher, and longer. Thus, that requires new airports facilities which are huge enough to accommodate the new large aircraft models. Heading the same way, this paper elaborated a comparative study of three suggested solutions which are possible structural systems of an aircraft hangar intended to accommodate Airbus A350 and Boeing 777 alternately.
The purpose of this study is the comparison of different topologies developed to design the structural system of the building in terms of structural behaviour, the load path, and the cost. The base geometry of the building is a rectangular shape with minimum unobstructed dimensions of 80×87m and total approximated free-space plan area of 7000 m^2. These base dimensions are required to accommodate the above-mentioned models of aircraft.
The models of the suggested solutions were built and analysed using the FE software AxisVM. Subsequently, the different solutions were designed, and the structural members were optimized to get higher utilization of the used mass. The study revealed that the second option produced the lighter needed structural steel material with highest mass efficiency. Nevertheless, it exhibited the highest deflection but within the limit. On the other hand, the first solution provides a very good option in the sense of global stability, with a reasonable mass efficiency and relatively large value of the used steel weight and highest lateral stiffness. About the third option, it showed an average steel weight with very accepted displacements values in the three directions, but with small mass efficiency ratio.
However, choosing between the options is highly depended on the structural behaviour, the cost and the feasibility of construction and design. It turns out that the first solution is an efficient option in sense of providing a stiff and rigid behaviour. From a cost perspective, the second option least cost option. However, from a practical point of view, the third solution as a spatial truss generated relatively small values of internal forces and reasonable distribution of the stress over the building, and that means easy and more feasibility to design and construct.

***Keywords*:** Long-Span steel structures, Truss system, Aircraft hangar, Industrial buildings, Structural typology optimization, Space truss, Exoskeletal truss.

1. Introduction

Long-span steel structures represent an effective solution for designers when it is needed to come up with unobstructed, column-free-space buildings with a span of tens of meters. Nevertheless, reinforced concrete and prestressed structural members [1] also present effective solutions for large scale buildings. Generally, this kind of structures are built to perform multi-functions in several sectors such as the industrial, agriculture sectors and warehouses [2]. Moreover, these buildings include activities where large movable objects are housed (e.g., aircraft hangars [3]), and where visibility is important for large audiences (e.g., auditoriums and covered stadiums). Such large-scale buildings need a special robust structural system with effective cost. Practically, a wide variety of the structural configurations and typologies could be adopted for long-span steel structures and large roofed enclosure, such as plate girder, truss structures, Space frame structures [4], or arches.

Trusses are open web girder, consisting of one-dimensional straight members assembled to give triangles. The individual elements are connected at nodes which are nominally pinned. The loads are applied to nodes in these structures. In case all the members and external applied loads are in the same plane, the system is considered a planer or 2D truss. This kind of the structures is subjected mainly to axial internal forces, in addition to a possible secondary bending moment at nodes when the nodes are stiff [5]. Truss configuration could be classified as Pratt truss [6], Warren truss [7], or X-truss [8].

Space frame is a structural system, assembled of linear elements so that the loads are transferred in a three-dimensional manner. In some cases, the constituent elements may be two-dimensional. Particularly, space frame often takes the form of a flat or curved surface [9]. This type of structures is preferred to many systems since it gives lightweight structures with low weight to capacity ratio. So, it is efficiently useable for large column-free spaces, such as sports facilities and aircraft hangars [10-11]. However, this paper deals with a typical example of long-span steel structures intended to be used as an aircraft hangar to accommodate Airbus A350 and Boeing 777 alternately. In the following, three different structural solutions are suggested, designed, and optimized. Finally, a comparison between the different solutions is presented based on the structural behaviour, mass efficiency and cost.

In contrary to the failure accidents of ordinary buildings [12], the collapse of special civil engineering facilities leads to significant losses in terms of economical loses and human casualties especially in the industrial locations [13]. Thus, as large-scale facilities, it has a significant importance to increase the knowledge about long-span structures in terms of structural behaviour, design, and assessment [14] under different conditions. This work deals with the structural typology enhancement of long-span steel structures. For this purpose, a typical aircraft hangar is designed and optimized using different structural configurations. The building is intended to accommodate Airbus A350 and Boeing 777 alternately. The different solutions (options) were designed, and the structural members were optimized to get higher utilization of the used mass of steel. Finally, the relevant solutions were compared on the basis of structural behaviour, load path, mass efficiency, and the cost.

2. Hypothesis and initial assumptions

2.1. Space Requirements and building dimensions

To determine the most efficient use of hangar space, we could combine templates (as shown in the Fig. 1) representing the considered aircrafts which is supposed to be accommodated (Airbus A350 and Boeing 777). As the building geometry is governed by the dimensions of the relevant aircrafts. In addition, the door size of the hangar is determined by the tail height and the wingspan of the relative aircrafts.

Certain assumptions are considered to define the global geometry of the hangar. Practically, the gate span is the equal to the maximum wingspan +5m, the available unobstructed building span is equal to the gate span +10m, the unobstructed building length is the maximum aircraft body length +10m, the unobstructed building height is equal to the maximum tail hight +2m.

After exploring the possible aircraft models of Boeing777 and Airbus A350 which are required to be accommodated. It was found that Boeing 777X-9 is the largest size model (with length of 76.7m, max wingspan of 71.8m and tail height of 19.7m) [15,16], thus it governs the size of the building. Consequently, the initial unobstructed dimensions of the building are outlined as follow,

The gate span	B_d=	64.8	+ 5	= 69.8 ≈ 70	m
The unobstructed span	B =	70	+ 10	= 80	m
The unobstructed length	L =	76.6	+ 10	=86.7 ≈ 87	m
The unobstructed height	H =	19.7	+ 2	= 21.7	m

2.2. Design Load considerations

For the purpose of conceptual design, the following actions were taken into consideration,

- Dead loads such as self-weight, roof cladding, wall cladding, lighting, building equipment’s and other loads.
- Snow loads, considering ground height of the building location of 151m above the sea level.
- Wind loads, considering the internal and external wind action pressure and suction. It is worth to mention that, due to the large openings in the building (the large open of the gate), the internal wind loads have a huge impact on the structural members due to the large values of the internal pressure coefficient. Consequently, large values of the wind actions.
- Imposed loads, Designers should expect certain load distribution to represent the loads generated through maintenance operation and the execution stage. Since the roof is not accessible except for normal maintenance and repair, the roof is considered of H-category (in accordance with European standards EN 1991-4[17]).
- Seismic loads were accounted considering the regulations of the European standards EN 1998-1[18]. The seismic magnitude is calculated considering ground type B, and peak ground accelerations of $ag_R = 0.14g$, importance factor $\gamma_I = 1$, behaviour factor $q = 4$, displacement behaviour factor $q_d = 4$, and lower bound factor $\beta = 0.2$ (as recommended by EN 1998-1[18]). To generate the seismic loads, the modal response spectrum analysis has been performed using the FE software.
- Thermal loads are considered to account for the actions that arise due to the change in temperature, thermal loads were defined considering T_{max}=10℃ and T_{min}=-10℃.

  Imperfection effect, the local imperfection was verified by implementing a buckling analysis and controlling the value of load factor above 2.5. The global imperfection was considered in the four directions using the global buckling modes after performing eigen value analysis.

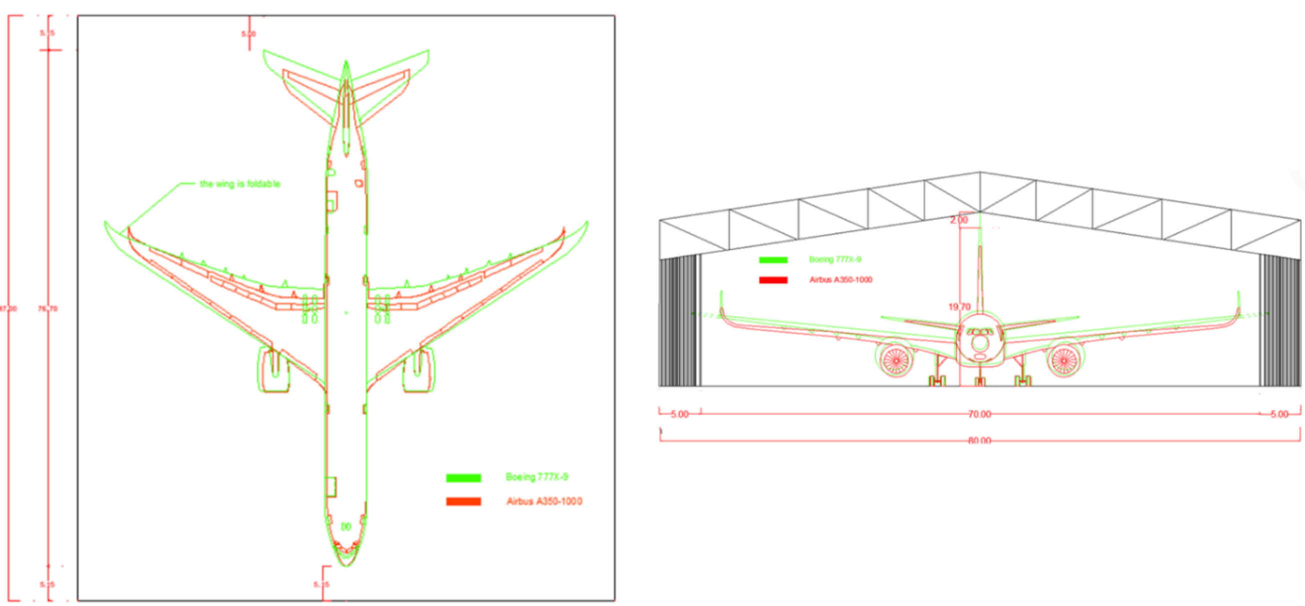

Fig. 1: The initial outline of the hangar- top view and front view.

3. suggested solutions (Typology description, analysis, and results)

The building is supposed to accommodate airplanes with body length and a wingspan of tens of meters. For such large span structures with a rectangular base, it is worth to rely on truss systems in general as truss systems offer large depth of the roof structure. In the following the three suggested structural options are explored as adopted structural solutions for such long-span structure.

3.1. The first solution

The first option consists mainly of 3-chord frame trusses parallel to each other as shown in Fig. 2, where the roof sandwich panels rest directly on the upper chords of the truss without considering transversal purlins or massive secondary steelwork between the main frames. The side walls consist of simple horizontal single section beams span between the chords of columns. For the back wall, vertical trusses are adopted in addition to simple horizontal beams run between them. The back-wall system is free-standing and resting in the lateral direction on the main 3-chord truss. The purpose of the using the vertical trusses in the back-wall system is to increase the back-wall frequency, thus it resists the dynamic effect of the wind. Fig. 2 below describes the initial layout of this option.

In order to ensure correct load path, the connection between the wall column and the roof system must be adjusted. Thus, it is assumed to have Node-to-Node link element, which is stiff enough in the two horizontal direction but not in the vertical direction, in this way it is guaranteed that the roof loads are transferred to the main 3-chord column but not to the wall system. Practically, the roof cladding KINGSPAN X-dekTM [19]is selected as skin element of the building. The upper layer (0.7mm) and bottom layer (1.1mm) and core thickness is 100mm thickness. The roof panels spanning 5.5m. For wall cladding, the wall panel Kingspan KS1150 TL [19] is selected, with thickness is 170 mm, and it is installed as double span. The wall panels spanning 4.25m. Eventually, upon on the capacity of the roof cladding which is 5.5m, the parallel 3-chord frames are spaced with 10.25m spacing (centre to centre), out of which, 5 m is the breadth of the single frame and 5.25 is the gap between subsequent frames. Based on the preliminary analysis of the main structural unit (3-cord frame), it was noticed that the compressed bracing and the compressed upper diagonals in such massive structure are too long. That is why, Pratt truss configuration was adopted to provide shorter diagonals and shorter buckling length of the upper compressed chords.

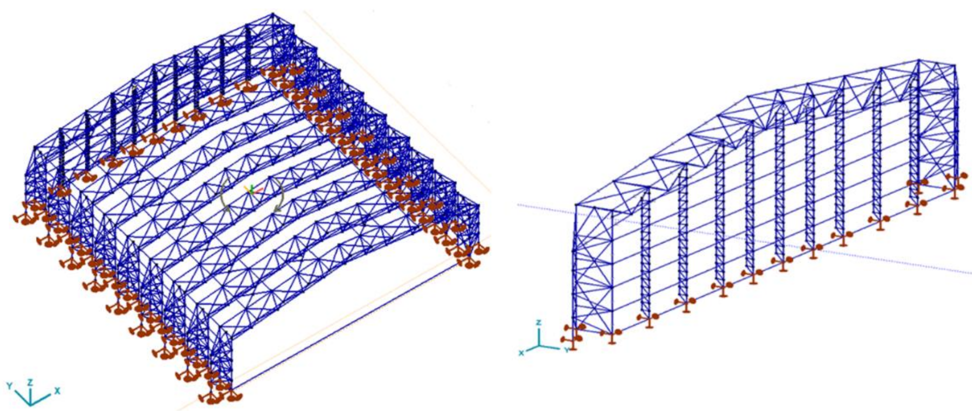

Fig. 2: The structural typology of the hangar (1st option), 3-D view of the global model and the 3-cord main frame with back-wall.

As shown in Fig. 2 the global model of the structure was built using the FE software. It consists of the main 3-chord frames in addition to side wall beams and roof bracings. The roof bracings have a great contribution to enhance the global behaviour of the structure and its global stability. The back wall system is included and verified in the global model. The structure was analysed, designed, and optimized in terms of optimization ratio (demand/capacity) of the structural members, as shown in Fig. 3. However, optimization process has been done on the basis of strength and stability of the members. Buckling analysis also conducted to evaluate the effect of geometrical nonlinearity of the structure in the deformed shape.

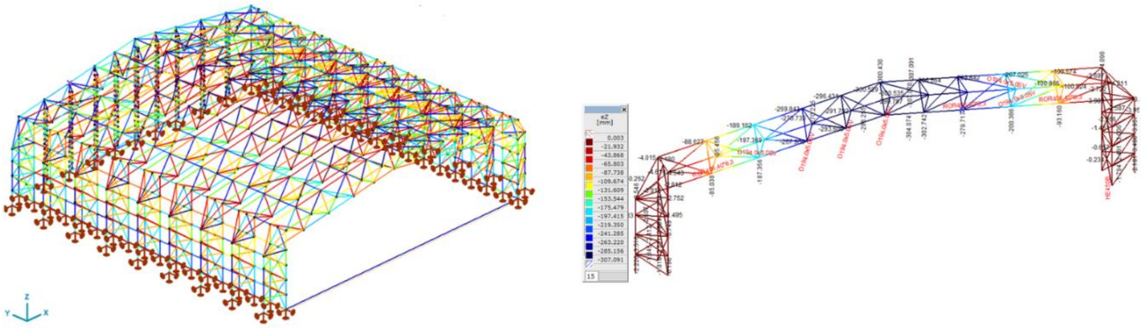

Fig. 3: the optimized global model of the first option.

A family of open and closed cross sections (total of 10 groups of cross-sections) were adopted for the different linear members. Table 1 shows a description of the cross sections used for the first option. Knowing that the cross-section shapes were chosen based on the preliminary analysis and design of the main structural unit of the building (3-chord frame). The size and the cross-section of the different members were confirmed by 3-D analysis of the global model. However, some change in the cross-section size was used to obtain optimum utilization ratios of the linear members.

Table 1: Cross-sections groups used based on the optimization process for the structure (1^{st} option).

Group	Structural member type	Cross-section type	Cross-section dimensions (mm)
1	upper chords	Rectangular Hollow Section	500×300×12.5-10 (b×h×t)
2	lower chords	Rectangular Hollow Section	500×300×16-10 (b×h×t)
3	Beam diagonals in tension	Circular Hollow Section	318.0× 7.0 (R×t) 194.0× 4.5 (R×t)
4	Beam diagonals in compression	Circular Hollow Section	318.0× 7.0 (R×t) 194.0× 4.5 (R×t)
5	beam bracing	Circular Hollow Section	194.0× 4.0 (R×t)
6	column chord	H-Shap profile	HE 400A , HE200B (European profile family)
7	column diagonals in tension	Circular Hollow Section	219.0×5.0 (R×t)
8	column diagonals in compression	Circular Hollow Section	273.0× 6.0 (R×t)
9	column bracing	Circular Hollow Section	133.0× 4.5 (R×t)
10	external diagonals of B-C connection	Circular Hollow Section	368.0× 7.0 (R×t)

For the purpose of comparison between the different solutions, the structural behaviour of the first solution was also characterized by the maximum displacement in the different directions, as shown in table 2, in addition to the economic efficiency which is quantified by the weight of the structure as a realistic indication of the building cost.

Table 2: The maximum displacements in the structure according to the 1^{st} solution.

The structural steel weight (Ton)	Max e_z (mm)	Max e_x (mm)	Max e_y (mm)
730.45	-247.972	-47.196	-44.967
	5.106	43.702	57.456

3.2. The second solution

In this solution, a superstructure carried mainly by three massive exoskeletal trusses and columns in the back wall was suggested, as shown in the Fig. 4. In addition to that, 2D planar parabolic trusses are spanning between the main trusses with a spacing of 10m between the 2D trusses, where they rest simply on the lower chords of the exoskeletal trusses. Over the planar trusses, IPE beams are used spanning between the planar trusses which support the sandwich panels of the roof. I.e., the structure consists mainly of 3 main structural units represented by huge exoskeletal frames, in addition to the planner parabolic truss and IPE beams. For the sidewall system, it is suggested to consider vertical planar trusses and simple horizontal beams in between, where the wall panels rest on the horizontal beams. Same wall system is adopted for back-wall used in the first solution (first option). About the wall-roof connection, similar to the relevant connections in the first option, it is assumed to have Node-to-Node link element with free vertical translation, to connect the sidewall column to the roof system. Consequently, the proper load path is guaranteed as the loads are transferred to the foundation through the exoskeleton column only. As a result, side wall and back wall are considered as free-standing structures rest laterally on the roof structural system. Same type of roof and wall sandwich panel designed in the 1st option are adopted for the second option. Practically, the roof panels span is 5.5m, and the wall panels span is 4.25m.

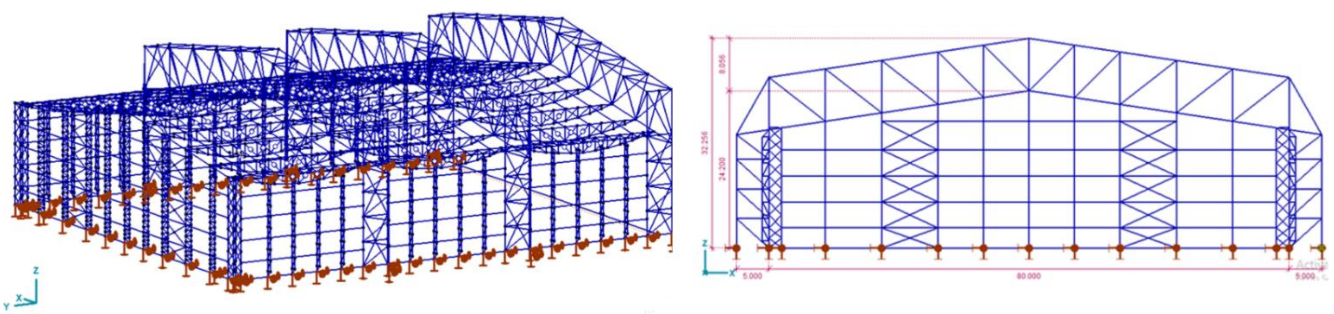

Fig. 4: The structural typology of the hangar (2nd option), 3-D view and the front view of the building showing the back-wall and the exoskeletal main truss

Preliminary analysis and design were performed, using separated models, for the exoskeletal main truss and the planar truss. Then, the global model of the building was built using the FE software, and the structural members were checked and optimized based on the optimization ratio (Fig. 5). It was noted that, by increasing the depth of the exoskeletal truss from 5m to 8m, a substantial drop of 40% in the normal forces were recorded comparing to the case corresponding to 5m height. Moreover, the deflection is dramatically reduced by 54% and the lateral displacement is reduced by 50%. According to that, an exoskeletal truss of 8m depth and 5 breadth is adopted.

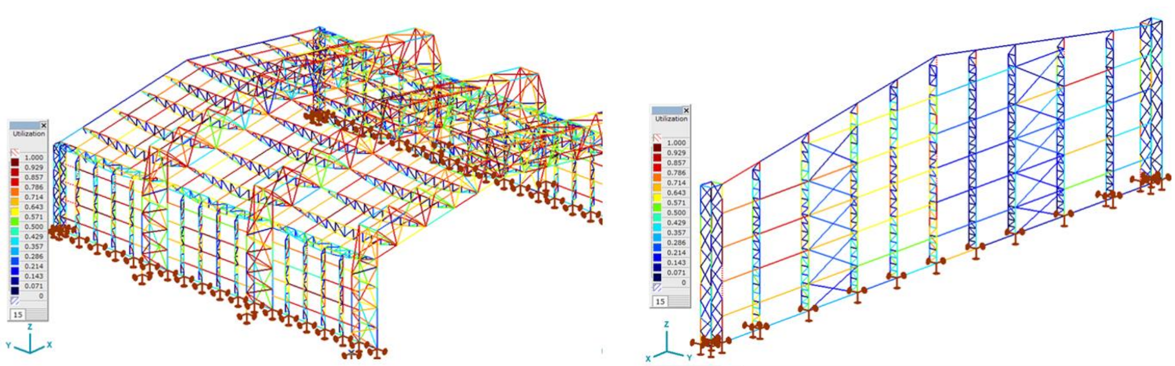

Fig. 5: the optimized global model of the second option.

A family of open and closed cross sections (total of 14 groups of cross-sections) were adopted for the different linear members used for the exoskeletal main truss and the planar transversal truss. Table 3 shows a description of the cross-sections adopted for the second option after the optimization process. The members that make up the structure are optimized and designed mainly using hollow cross section except for the column chords where HE-profiles (European family) are used. Tubes are used for all diagonals and bracings in the entire project and for main chords of exoskeletal trusses with thickness less than 25mm in order to reduce the complexity of the installation in the construction site and make it more feasible. Moreover, rectangular hollow sections are used for chords of the vertical trusses (sidewalls) and for the horizontal single-cross section beam in the side wall structural system.

Table 3: Cross-sections groups used based on the optimization process for the main structural units (2nd option).

The structural unit	Group	Structural member type	Cross-section type	Cross-section dimensions (mm)
The exoskeletal truss	1	upper chords	Circular Hollow Section	273,00×10,0 (R×t)
	2	lower chords	Circular Hollow Section	273,00×16,0 (R×t)
	3	Beam diagonals in tension	Circular Hollow Section	273,00×10,0 (R×t) 273,00×5,0 (R×t) 139.70×7,1 (R×t)
	4	Beam diagonals in compression	Circular Hollow Section	244,50×10,0 (R×t) 273,00×5,0 (R×t) 139.70×7,1 (R×t)
	5	beam bracing	Circular Hollow Section	114,30×7,1 (R×t)
	6	column chord	H-Shap profile	HE 400A - HE300M
	7	column diagonals in tension	Circular Hollow Section	273,00×5,0 (R×t)
	8	column diagonals in compression	Circular Hollow Section	273,00×5,0 (R×t)
	9	column bracing	Circular Hollow Section	108,00×7,1(R×t)
	10	external diagonals of B-C connection	Circular Hollow Section	273,00× 10.0 (R×t)
Planner truss	11	upper chords	Circular Hollow Section	244,5*10.0 (R×t)
	12	lower chords	Circular Hollow Section	323.90*7.1(R×t)
	13	Beam diagonals in tension	Circular Hollow Section	63.50*7.1 (R×t) 108.00*3.6 (R×t)
	14	Beam diagonals in compression	Circular Hollow Section	108.00*3.6 (R×t)

Similar to the first option, the displacement in the different directions was recorded and total weight of the structural steel was calculated (table 4).

Table 4: The maximum displacements in the structure according to the 2nd solution

The structural steel weight (Ton)	Max e_z (mm)	Max e_x (mm)	Max e_y (mm)
589.1	-318.137	-78.176	-82.555
	17.369	73.840	121.077

3.3. The third solution

The third suggested option is a spatial truss, consists of two layers, considering an upper and lower layer and diagonal bracing members between them. The general shape of the structure is parabolic spatial truss resting on columns on both sides. For the side columns, planner trusses are considered with 5 to 6m spacing. In simple words, the roof system is composed of member elements arranged in two parabolic shaped layers, bracing elements are used between them to connect the two layers and to form a curved spatial truss. Fig. 6 shows the arrangement of the spatial truss and the supports. In addition to that, 3-chord columns are used on each side in order to provide global stability in the longitudinal and lateral direction. Between columns, horizontal beams of single section are used to carry the wall sandwich panels and provide lateral supports for columns. The backwall system is a free-standing structure resting in the lateral direction on the roof system, it consists of vertical trusses supporting a horizontal beam which carry the wall sandwich panels.

Practically, same type of roof and wall sandwich panel designed in the first option were adopted for the third solution. The height of the space grid is 6.142m, the grid of the top chord is 6.83×6.00m and the grid of the bottom chord is 6.67×6.00m. Circular hollow sections are used for upper and lower layer members and for diagonals as well. About the structural system of the back wall, a free-standing wall with a similar configuration of that used in the first option was employed. In addition to that 4-chord columns among the wall were considered in order to support the roof as a main task and to increase the global stability of the wall as the secondary task. Using 4-chord columns in the back wall led to a significant reduce in the deflection of the roof in the middle and in the back of the roof.

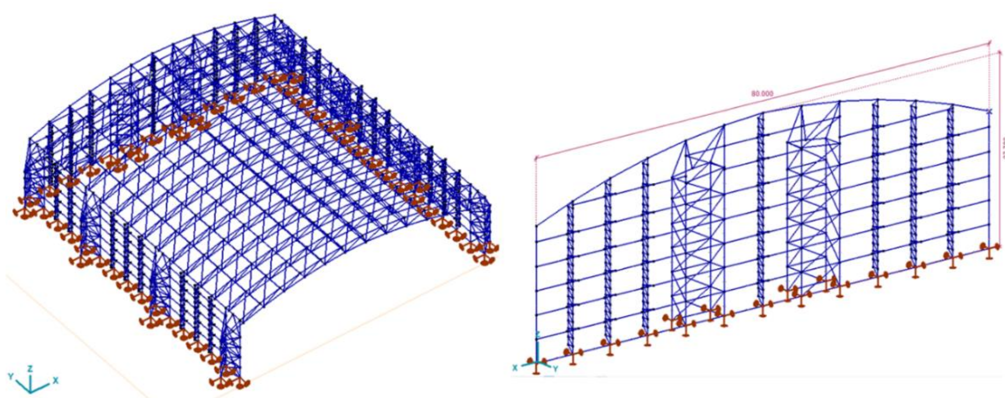

Fig. 6: The structural typology of the hangar (3st option), 3-D view of the global model and the back-wall structural system.

To achieve the preliminary model, the structural members were given an initial cross-sections comparable to those adopted in the first and second options. After an iteration process, the most favourable profiles were selected and optimized based on the utilization ratio Fig. 7. Table 5 shows a description of the cross sections adopted for the third option after the optimization process.

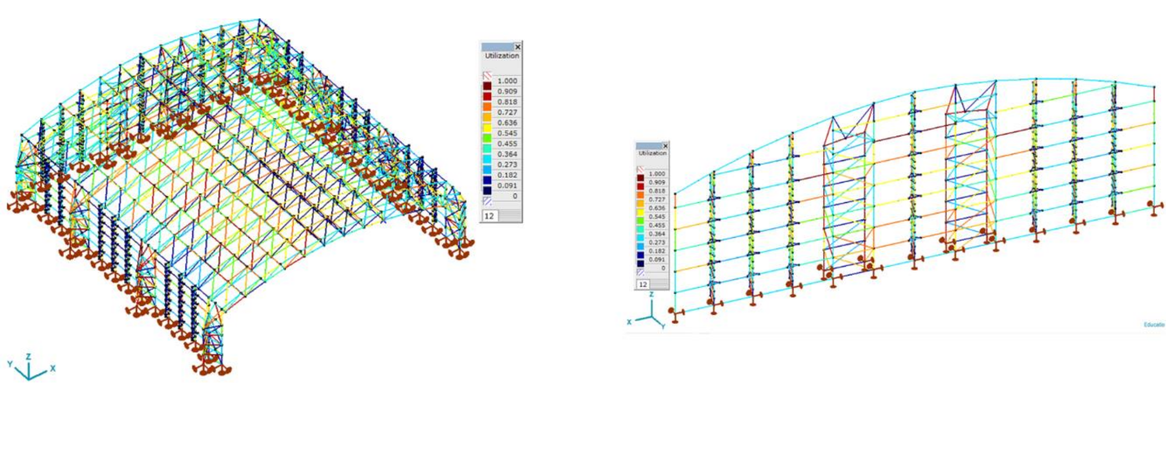

Fig. 7: the optimized global model of the third option.

Table 5: Cross-sections groups used based on the optimization process for the main structural units (3^{rd} option).

Group	Structural member type	Cross-section type	Cross-section dimensions (mm)
1	upper chords	Circular Hollow Section	273,00×25-10
2	lower chords	Circular Hollow Section	152.40×16-7,1(R×t) 121,00×4,0(R×t)
3	column chord	H-Shap profile	.HE 360B and HE320A
4	column diagonals	Circular Hollow Section	219,00 (R) with different thicknesses
5	horizontal single cross section beams in the sidewall	Rectangular Hollow Section	150×100×5 (b×h×t) 100×50×4 (b×h×t)

Similarly, the displacement in the different directions was recorded and total weight of the structural steel was calculated (table 6).

Table 6: The maximum displacements in the structure according to the 3^{rd} solution

The structural steel weight (Ton)	Max e_z (mm)	Max e_x (mm)	Max e_y (mm)
672.6	-260.076	-86.882	-50.499
	3.829	91.996	34.256

4. Comparison

In the following, charts are presented to compare between the studied solutions in terms of the extreme displacements, weight of the structural steel needed to make up the structure, the mass efficiency, and the maximum internal forces (Table 7) generated in the main structural members (cords of the main trusses and structural units).

Fig. 8 shows a comparison between the studied solutions in terms of extreme displacements. It is observed that the second solution shows the least stiffness in the vertical and longitudinal direction, while the first and third solutions show a relative high stiffness in the same direction. However, the first option provides the highest rigidity in the lateral direction. Fig. 9 shows a comparison between the studied solutions in terms of cost of construction quantified by the weight of the structural steel needed for the to construct the building.

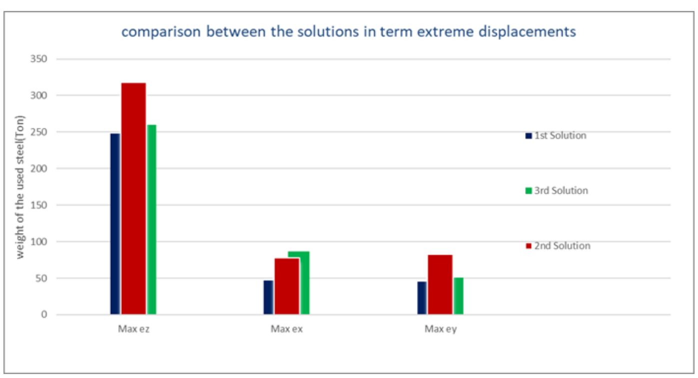

Fig. 8: The comparison between solutions in terms of extreme displacements. ex is the lateral displacement; ey is the longitudinal displacement; ez is the vertical displacement.

Fig. 10 shows a comparison between the studied solutions in terms mass efficiency. Knowing that, the mass efficiency is a parameter used to evaluate the contribution of the mass of the consumed material (steel) to the resistance of the structure. It is calculate using the following formula,

$$Mass\ efficiency \quad \mu = \frac{\sum M_i.\xi_i}{M} \tag{1}$$

Where: M_i: The mass of the structural member

ξ_i: The utilization of the structural member

M: The total mass of the structure

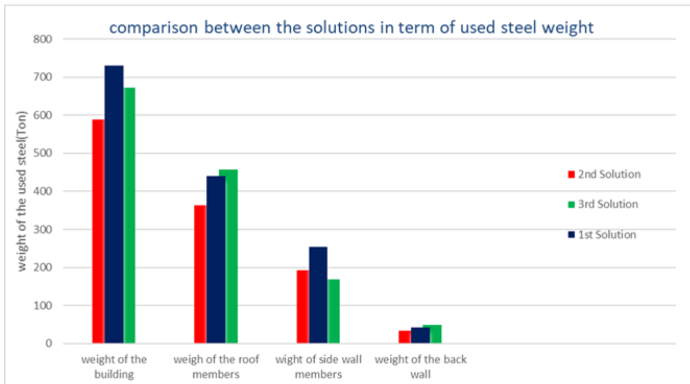

Fig. 9: the comparison between solutions in terms of the used steel weight

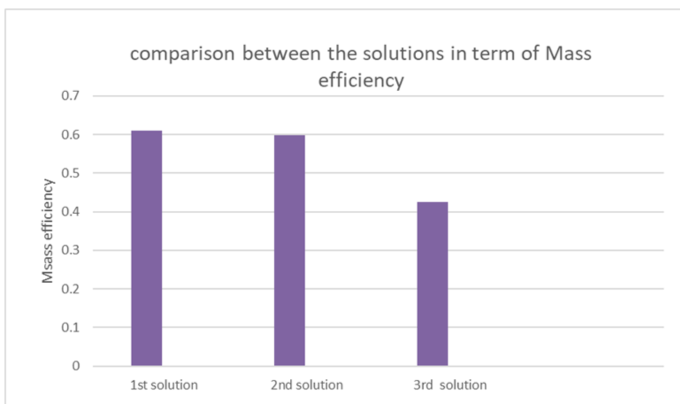

Fig. 10: the comparison between solutions in terms Mass efficiency

Table 7: Maximum internal axial forces generated in the main structural members

First solution	Main truss chords(kN)	Column chords(kN)	Truss diagonals(kN)	Column diagonals(kN)
	-4557.878	-2715.116	-1222.134	-853.063
	4302.911	1919.512	2400.5	1050.448
Second solution	Main truss chords	Column chords	Truss diagonals	Column diagonals
	-5488.331	-4958.122	-2030.223	-1170.783
	7913.151	2936.542	3598.828	1535.636
Third solution	Main chords of the upper layer	Longitudinal members of the upper layer	Main chords of the lower layer	Longitudinal members of the lower layer
	-3175.688	-1000.469	-1525.831	-409.86
	617.434	918.014	2472.768	691.955

6. Conclusion

Three different solutions were suggested as possible structural system of long-span steel structure serves as an aircraft hangar which is intended to accommodate Airbus A350 and Boeing 777 alternately.

The first suggested solution is composed of 3-cord frames parallel to each other with no secondary steelwork in the roof, except for the bracing system. The main structural unit of the system according to this option is a frame composed of 3-chord truss supported by 3-chord columns. In the second suggested solution, 3-chord exoskeletal massive truss frames are mainly employed to carry the roof system of the structure in contribution with planar trusses span between the main exoskeletal trusses. In the third solution, it is suggested to use a spatial parabolic truss rests on edge beams and on columns at three sides. The spatial truss is composed of two layers with diagonals between.

From the comparison above, we note that the second solution proved to be very efficient as it produced lighter structural steel weight with a high Mass efficiency ratio. Even though it results in the highest deflection, but it is still limited to L/250. More than that, the second solution provides the smaller size of the building, which means less cost in the sense of material consuming and building equipment. In fact, it was difficult to manage the high compressive forces in the chords of the exoskeletal truss and that represents the challenge in the second option. In contrary, in the third solution we had relatively small axial forces which could be handled easily. From global stability perspective, the first solution proved to have significant stability in the lateral and longitudinal directions, and that is attributed to the extensive horizontal members in the roof and the 3-chord columns distributed on the building sides. Moreover, the first solution shows a high value of the Mass efficiency ratio and a small deflection. On the other hand, it resulted in the largest steel weight among the evaluated options. The third option provided a reasonable steel weight and with very accepted displacements in the three directions. But with small mass efficiency ratio. Anyway, it is feasible option to design and construct since it produces a relatively small internal forces, which leads to near to uniform distribution of the stress over the building.

However, in this study, we design the building to accommodate a specific model of an aircraft which govern the base geometry of the building and we adopted specific structural topologies. To verify further the obtained results, we can consider base geometry with different models and different structural topologies. Moreover, it is worth to mention that the present work does not consider a crane or any special suspended equipment to the roof which have a significant impact on the design in case it is existed.

Acknowledgements

I would like to express the deepest appreciation to Dr. Kovács Nauzika and Dr. Dániel Balázs Merczel for their guidance and help. I am grateful for the valuable information and experience they shared with me to achieve this study.

References

[01] M.Abed, Z.Alkurdi, A.Kheshfeh, T.Kovács, and S.Nehme. "Numerical Evaluation of Bond Behavior of Ribbed Steel Bars or Seven-wire Strands Embedded in Lightweight Concrete." Periodica Polytechnica Civil Engineering 65, no. 2 (2021): 385-396..

[02] M.Kawaguchi, "Design problems of long span spatial structures," *Engineering Structures*, 13(2), 144-163, 1991.

[03] S. J. Luke, and W. P. Howson. "Modern aircraft hangars: a review of the design trends." *Structural Engineer* 80, no. 15 (2002).

[04] L. Tian, J. Hao, J. Wei, and J. Zheng. "Integral lifting simulation of long-span spatial steel structures during construction." Automation in Construction 70: 156-166, 2006.

[05] C. Mathieson, G. C. Clifton, and J. BP. Lim. "Novel pin-jointed connection for cold-formed steel trusses." Journal of Constructional Steel Research 116: 173-182, 2016.

[06] M. Laurendeau, P. J. Barr, A. Higgs, M. W. Halling, M. Maguire, and R. W. Fausett. "Live-load response of a 65-year-old Pratt Truss Bridge." Journal of Performance of Constructed Facilities 29, no. 6: 04014168, 2015.

[07] J. Becque, and T. Wilkinson. "Experimental investigation of the static capacity of grade C450 RHS T and X truss joints." In Proceedings of the 14th International Symposium on Tubular Structures. London, pp. 177-184. 2012.
[08] W. Yang, J. Lin, N. Gao, and R. Yan. "Experimental study on the static behavior of reinforced warren circular hollow section (CHS) tubular trusses." Applied Sciences 8, no. 11: 2237, 2018.
[09] Lan, Tien T. "Space frame structures." Structural engineering handbook 13, no. 4 (1999).
[10] REIDSteel publication, http://www.aircraft-hangars.com/hangar-door-types.
[11] S. Liu. "Design and construction of 306m span hangar roof at Capital Airport." International Journal of Space Structures 14, no. 3: 185-189, 1999.
[12] S.Ruggieri, C.Tosto, G.Rosati, G.Uva, and Giuseppe Andrea Ferro. "Seismic vulnerability analysis of Masonry Churches in Piemonte after 2003 Valle Scrivia earthquake: Post-event screening and situation 17 years later." *International Journal of Architectural Heritage* : 1-29, 2020.
[13] M.Khalil, S.Ruggieri, and G.Uva, "Assessment of Structural Behavior, Vulnerability, and Risk of Industrial Silos: State-of-the-Art and Recent Research Trends," *Applied Sciences*, 12(6), 3006, 2022.
[14] G.Uva, P.L.Ciampoli, V.Leggieri, A.Nettis, and S.Ruggieri, "A mechanical approach for estimating regional fragility curves of existing RC buildings stock in Puglia". In Proceedings of the COMPDYN 2019 7th ECCOMAS Thematic" Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, Crete, Greece' 06, 2019 (pp. 24-26).
[15] https://www.boeing.com/ - Boeimg777 specifications
[16] AIRBUS A350. Aircraft characteristics airport and maintenance planning. AIRBUS S.A.S 2005. France.
[17] EN 1991-4, Eurocode 1 - Actions on structures, European Committee for Standardization, Brussels, May 2006.
[18] EN 1998-4, Eurocode 8 - Design of structures for earthquake resistance, European Committee for Standardization, Brussels, July 2006.
[19] https://www.kingspan.com/hu/hu-hu