

PRESTRESSED TRUSS GIRDER AFTER 60 YEARS

Petr Moštěk^{1*}, Ladislav Klusáček¹

*petr.mostek@vutbr.cz

¹Brno University of Technology, Faculty of Civil Engineering, Veverí 331, Brno, 60200, 602 00, Czech Republic

Abstract

Many concrete roof structures built in the past century are dealing with corrosion of the prestressing reinforcement. This has been the cause of several failures of prestressed roof girders in the Czech Republic and Slovakia. This article focuses on prestressed truss roof girders. We will discuss various types that were constructed in former Czechoslovakia and abroad during the past century.

Keywords

Truss girder, prestressed concrete, industrial building, roof, prestressing reinforcement

1 INTRODUCTION

In recent years, there have been failures of prestressed concrete structures. Public awareness primarily associates these failures with bridge structures, but other types of structures, such as industrial halls, can also be affected.

The main cause of failures in prestressed concrete structures is typically the corrosion of the prestressing reinforcement due to inadequate or missing grout in cable ducts, combined with water infiltration. As indicated in [1], [2], [3], this problem is at a global scale, as the grouting of ducts was not performed perfect in the 1950s, 1960s, and 1970s (see Fig. 1). One of the issues at that time was an unsuitable grout mix, which caused water separation. The imperfection of the mixing equipment also played a role. Another contributing factor was the inadequacy of devices used for injecting the grout into the ducts, which could allow air to enter. Furthermore, poor workmanship on construction sites or in precast production plants may have also been a reason [1], [2]. According to [2], surface corrosion of wires in ungrounded cables was observed after just eight years.

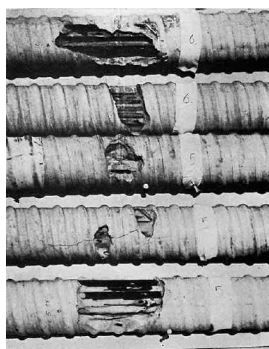


Fig.1 Samples of injected ducts in research conducted by FIB in the 1970s [3].



Fig. 2 Truss girder collapse in the Czech Republic from 2023 [4].



Fig. 3 Truss girder collapse in the Czechoslovakia from 1960s [5].

In 2010, 2018, 2023 (see Fig. 2), and 2024, five collapses of prestressed truss girders happened in the Czech Republic and Slovakia [4]. From the time of former Czechoslovakia, at least one case of collapse of this type of structure is known (see Fig. 3) [5]. The primary cause of these collapses was the corrosion of the prestressing reinforcement. Following discussions between ČKAIT (Czech Chamber of Chartered Engineers and Technicians) and the Ministry for Regional Development, a regulation was issued requiring owners of buildings with these structures to have them professionally inspected [6]. According to [4], an estimated 10,000 of these truss girders are located in the Czech Republic.

This article will describe the various types of prestressed truss roof structures used at that time, including examples of completed buildings from Czechoslovakia and abroad.

2 DISCUSSION

Types of truss structures

This type of structure was used for large-span roofs without internal supports, such as industrial halls, warehouses, and sports halls. In the 1950s, 1960s, and 1970s, steel structures were commonly designed. However, due to the need to reduce steel consumption, the gradual industrialization of concrete construction, and the development of prestressed concrete, concrete structures began to appear more frequently. Among the advantages of concrete structures are their fire resistance, low cost and low maintenance costs. However, a major disadvantage is their large weight, which can be reduced by designing truss structures. Compared to solid structures, trusses make better use of structural elements and require less material. On the other hand, their construction process is more labor-intensive. For this reason, truss structures are most efficiently produced as precast elements and in large series. Additional disadvantages include greater structural height, lower resistance to aggressive environments, and lower fire resistance in comparison to solid concrete girders [7], [8], [9], [10].

Roof structures for halls were either manufactured on-site or in production plants. On-site production was mainly used for large and heavy elements. The primary advantage of this method is that it eliminates the need for transporting the elements [11], [12].

Production in a permanent plant can be divided into two approaches: manufacturing complete elements that are transported to the construction site as a whole or producing smaller segments that are assembled on-site into a single structure. The advantage of the first method is the reduction of on-site work, higher quality of the produced elements, independence from weather conditions, and faster construction. However, its drawbacks include the transportation of large elements to the site and the need for heavy mechanization. The second method benefits from lower transportation requirements and reduced demands on the production plant. However, it requires a more labor-intensive assembly and the presence of skilled workers on-site [11], [12].

Frame

Frames are large reinforced concrete structures that can take the shape of a T (see Fig. 4), L, or a complete frame (see Fig. 5). Due to their size, they were manufactured on-site. They were assembled either as a single unit (see Fig. 5) or composed of smaller segments (see Fig. 6). These structures were primarily designed in the 1950s and, due to their labor-intensive construction, were mainly used in Eastern Europe [13].

Columns can be designed as either fixed into the foundation (see Fig. 4 and 5) or joint-supported. The upper structure can span the entire width (see Fig. 5) or be supported by cantilevers over part of the span, on which the skylight structure is placed (see Fig. 4), or it can be connected with joint. In the longitudinal direction, individual frames are connected by reinforced concrete beams, which, in combination with the roof covering, ensure the overall stiffness of the structure [7].

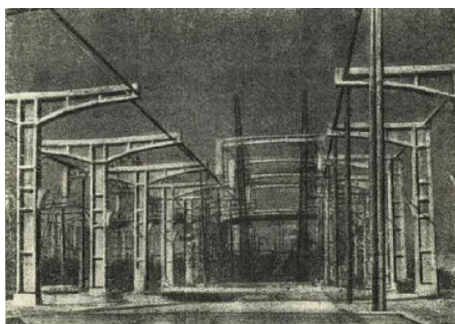


Fig. 4 T-shaped frame [16].

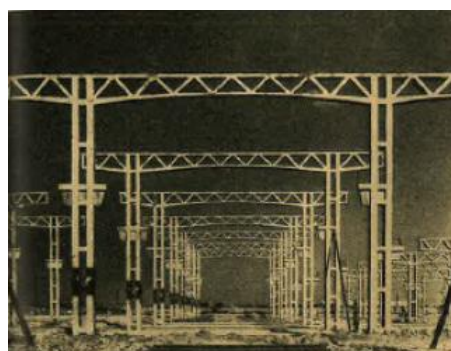


Fig. 5 Complete frame [16].

Girder

The first concrete truss girders began to appear at the beginning of the 20th century (Fig. 6). These were girders for railway bridges, which were also used for roofs and floors of buildings [14]. The first use of prestressed truss girders dates to the 1930s in Germany fig. 7 [15].

At that time, it was practical to use truss girders for a minimum span of 12 or 15 meters [7], [9], [16], but they were commonly used for spans of 18–30 meters and more [8], [17], [18]. The largest truss was designed in Germany, with a span of 70 meters (see Fig. 7) [15].



Fig. 6 First concrete truss girders at the beginning of the 20th century [14].

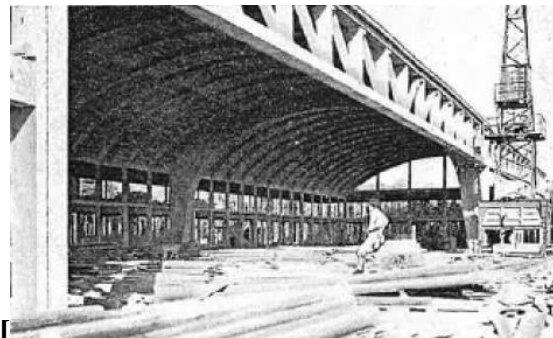


Fig. 7 Prestressed truss girder of a hangar in Berlin [15].

Initially, trusses were manufactured on-site, but with the development of prefabrication, production shifted to factories. Truss girders were produced either as a single piece (Fig. 8) or divided into segments (Fig. 10), which were then joined on-site. The elements were connected either using steel joints or prestressing. According to [17], [18], it was efficient to manufacture trusses as a whole for spans of 18 or 24 meters, and for larger spans, it was advantageous to design trusses consisting of two or more pieces (Fig. 10) [11], [12], [19].

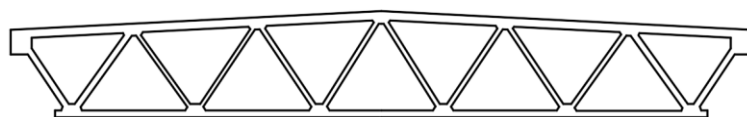


Fig. 8 Truss girder in one piece from Czechoslovakia.



Fig. 10 Divided truss girder from USSR [17].

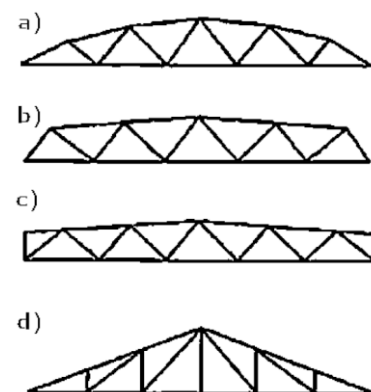


Fig. 9 Truss Girder shapes [7].

Trusses are divided into arched/parabolic (see Fig. 9a), polygonal (see Fig. 9b), parallel (see Fig. 9c), and saddle (see Fig. 9d) types. From a structural standpoint, arched trusses are the most advantageous, but they are more demanding in terms of production and roof covering installation. The polygonal shape is simpler to manufacture, and to install the roof covering, and is also suitable from a structural standpoint. Parallel trusses have a flat top chord or can have a slight incline. For steeper roofs, saddle trusses are used [7], [17], [18].

Arch

Arched structures are very economical in terms of material usage. If their shape is appropriately designed, only compressive stresses occur within them. The disadvantage is their labor-intensive production and assembly. Due

to their curved shape, horizontal forces develop at the supports, which must be absorbed. This can be achieved using a tie, a rigid support frame, or a rigid foundation [13].

Arches with a tie can be designed as either two-jointed or three-jointed (see Fig. 11). The tie can be made of steel or prestressed concrete. Ties can be designed as prestressed or non-prestressed. Arches with a tie can also be designed as spatial structures, where the arch includes purlins and transverse reinforcements, or they can be composed of individual segments that, when connected, form diamond-shaped arches [13].

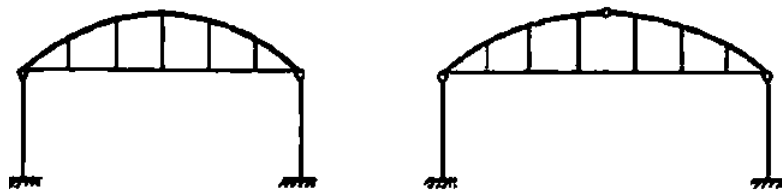


Fig. 11 Arch with tie [13].

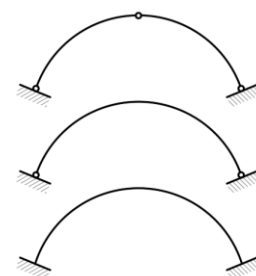


Fig. 12 Arch with a rigid foundation.

If there is a need to avoid a design with a tie, an arch can be designed with a rigid frame or foundation. Frames can be designed as fixed or joint-supported. An arch supported directly on the foundations can be designed as fixed, two-jointed and three-jointed (see Fig. 12) [13].

Western world

In the Western world, standard designs were developed for various types of skeletal buildings [19], [20]. Roof structures for hall buildings were more commonly designed as solid girders because they show lower labour intensity compared to truss girders [11].

Great Britain

An interesting roof structure was built in Gatwick, south of London. It is a roof for an aircraft hangar (see Fig. 13) with a length of 86 meters, a width of 36 meters, and a total height of 12.5 meters. The hall is surrounded by an extension on three sides. The supporting structure of roof is designed as a spatial truss frame made of prestressed concrete. The individual trusses, placed every 6 meters, are 2.6 meters high and have a span of 32 meters. The truss consists of an upper chord, which has 6 bars, each 1 meter long, and a lower chord made of 1 bar (see Fig. 14). Every second and fifth bar of the upper chord is connected to the lower chord by a diagonal brace. In the plane of the upper chord, the bars are indirectly connected by diagonal braces, which ensure rigidity in the transverse direction. The assembly of the trusses was performed on the ground beneath their final placement location. The individual elements were connected using prestressing and then lifted into their final position on temporary scaffolding. Once all the trusses were in place, the structure was prestressed in the transverse direction (concrete and Constructional Engineering no. 8/1958. Civil Engineering and Public Work's Review July/1958) [21].

Another component of this structure is the truss girder in the front wall of the hangar. It is a continuous beam with two spans, measuring 42.7 meters in length and 3 meters in height (see Fig. 15). This truss is made up of the outer upper chord of a spatial frame, which is complemented by the necessary elements. A notable feature of this structure is that, due to high shear forces at the support, two parabolic prestressing cables were designed and routed outside the structure. Their path was chosen to minimize the shear stresses at the supports (concrete and Constructional Engineering no. 8/1958. Civil Engineering and Public Work's Review July/1958) [21].



Fig. 13 View of the roof structure under construction at the Gatwick hangar [21].

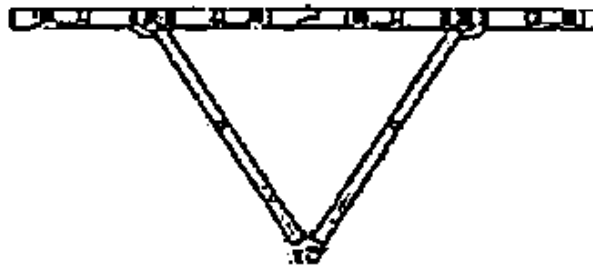


Fig. 14 Cross-section of the roof structure of the hangar at Gatwick [21].



Fig. 15 View of the truss in the front wall of the hangar at Gatwick [21].

In England, triangular trusses with a span of around 18 meters have been designed, consisting of 3 segments (see Fig. 16). The truss spacing is 4 meters. To achieve the effect of a frame, the trusses were additionally connected to the columns using a corner bar. The roof cladding is made of asbestos-cement panels, and the central part of the roof is designed to accommodate glazing [13].

In Bristol, England, a workshop building was constructed for the company Wilhelm. The roof consisted of two triangular prefabricated trusses and two prefabricated rods (see Fig. 17). These elements were then assembled on-site. The trusses are designed for a span of 18 meters and a center-to-center distance of 6 meters. The purlins are designed in an L-shape, and the roofing is made of asbestos-cement corrugated sheets [13].

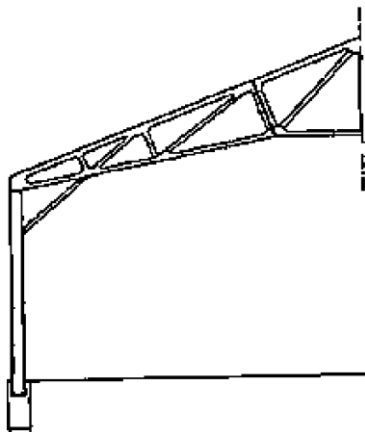


Fig. 16 Truss girder composed of 3 segments in England [13].



Fig. 17 View of the under-construction roof of the Bristol Workshop Building [13].

Spain

An interesting solution for truss girders appeared in Spain, where the tensioned elements were designed as exposed reinforcement. Triangular trusses with exposed lower reinforcement, for spans of 20 to 30 meters (see Fig. 18), were developed by Prof. Dr. C. Fernandez Casado. This method was used for the Endasa company hall in Avilés, with a span of 30.7 meters (see Fig. 19). The roof covering is made of corrugated asbestos-cement sheets [13].

Another example is the beams supported by cables (see Fig. 20), which were used in the Ensidese building in Avilés. Their span is around 14 meters, with a center-to-center distance of 3 meters. The lower chord is made of standard steel and is anchored at the ends using anchor heads [13].

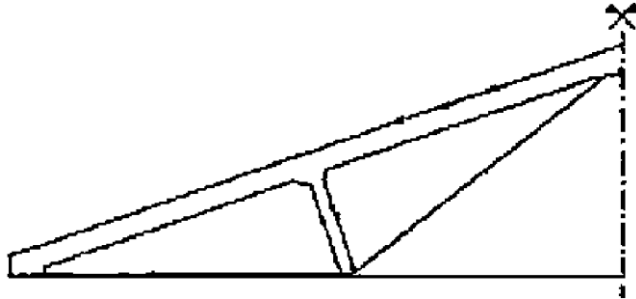


Fig. 18 Triangular truss girder with exposed bottom reinforcement from Spain [13].



Fig. 19 View of the expanded roof of the Hall in Avilés [13].



Fig. 20 Truss girder with exposed bottom reinforcement in the Ensidese building in Avilés [13].

In Torreon, Spain, at the I.N.T.A. (Instituto Nacional de Técnica Aeroespacial) airport, an assembly hall was built with window trusses designed in the Vierendeel shape, for a span of 15 meters and a center-to-center distance of 7 meters (see Fig. 21). The roof covering is made of reinforced concrete panels, which rest on the lower chord for the first truss and on the upper chord for the second truss (see Fig. 22) [13].

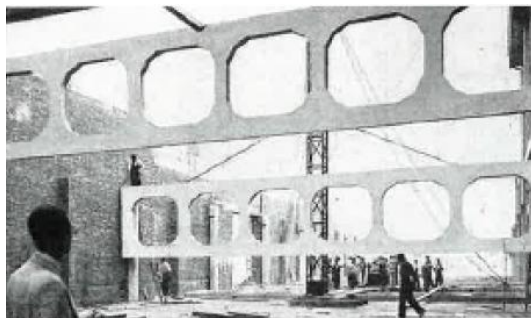


Fig. 21 View of the Vierendeel-shaped roof trusses for the assembly hall at the I. N. T. A airport [13].

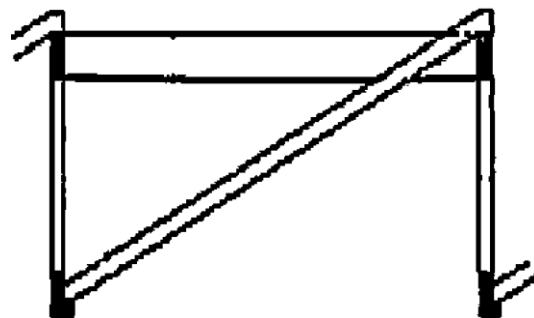


Fig. 22 Cross section of the roof structure of the assembly hall at the I. N. T. A. airport [13].

For the rolling mill in Avilés, Spain, heavy prestressed truss beams were designed. The crane track was placed on the robust lower chord, while the roof structure rested on the upper chord (see Fig. 23 and Fig. 24) [22].

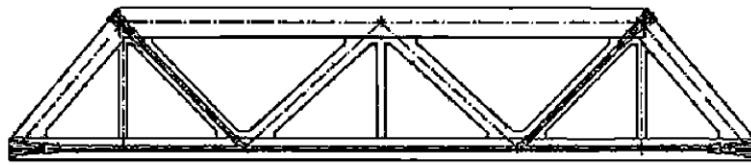


Fig. 23 Longitudinal section of a prestressed truss with a crane track on the bottom chord [22].

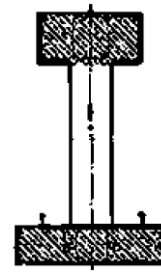


Fig. 24 Cross section of a prestressed truss with a crane track on the bottom chord [22].

Eastern world

The Eastern European countries aimed for maximum industrialization in construction and the cheapest and fastest assembly of precast structures. For this reason, each country developed standardized universal single-story halls that met the requirements for a large portion of industrial factories. The goal of the design was to minimize the number of different structural elements and ensure their interchangeability. For atypical operations, an individual design had to be made [11], [20].

Poland

In the Polish city of Łódź, a thermal power plant was built. The original design considered a monolithic structure with steel roof trusses. However, this design was changed, and in the areas of the boiler room and machine room, standardized prefabricated prestressed truss beams were designed (see Fig. 25). The roof truss girders in the machine room were designed for a span of 27 meters, and in the boiler room for 23 meters. The truss girders were designed as split, and on-site, and they were connected using prestressing [23].

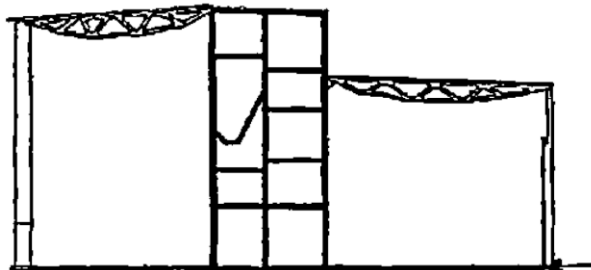


Fig. 25 Scheme of the production unit of the Łódź power plant [23].

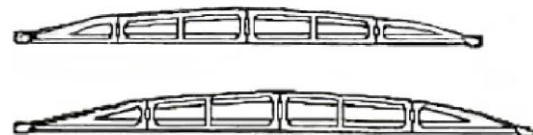


Fig. 26 Standardized truss roof trusses from Poland [24].

The standardization of structures in Poland began in 1951. The basic floor plan module was chosen to be 300 cm, and the height module 30 cm, which every structural element of the project had to meet. Although standardized elements could be somewhat influenced by local conditions, they still had to comply with the modular dimensions. For special structures, individual designs were created. By the end of 1959, the following dimensions were established in Poland:

- Span from 900 to 6000 cm.
- Column spacing from 600 to 3000 cm.
- Height of the aisles from 300 to 1200 cm.

In Fig. 27, an axonometric view of a standardized hall with a span of 36 meters and column spacing of 6 meters can be seen. In Fig. 26, examples of standardized Polish truss girders for spans of 21, and 24 meters are shown.

Trusses for spans of up to 18 meters were produced as a whole, and for spans greater than 18 meters, they were made in segments [24].

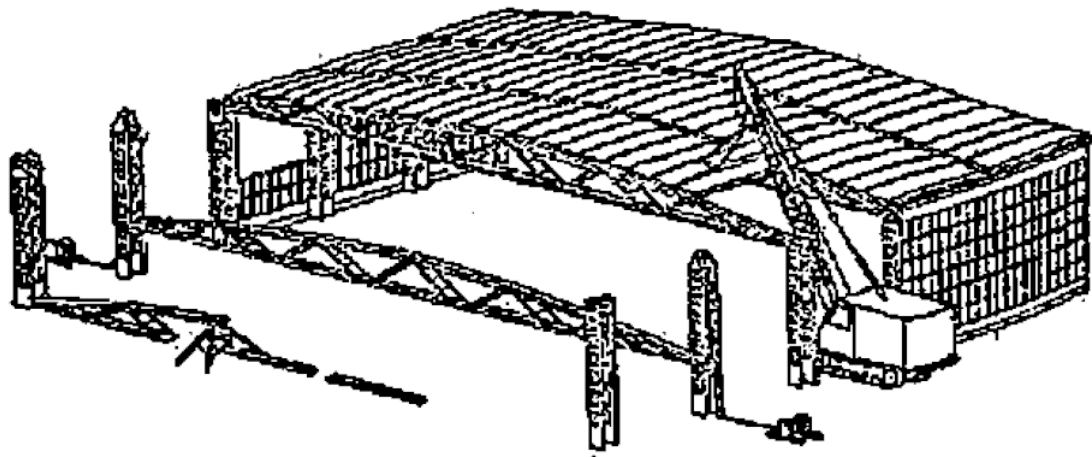


Fig. 27 Axonometric view of a standardized hall in modular coordination 3600x600 cm in the People's Republic of Poland [24].

USSR

The building of the blacksmith shop at the Obuda shipyard was designed in 1953. It is a two-aisled hall with a transverse layout, as seen in Fig. 28. The roof truss girder is designed as a continuous beam with two spans. During the assembly of the truss girders, it was possible to adjust the height of the inner support using steel plates. An interesting feature is that the use of hydraulic jacks was considered during the construction of this building, which would have allowed for the regulation of moments above the inner support [16].

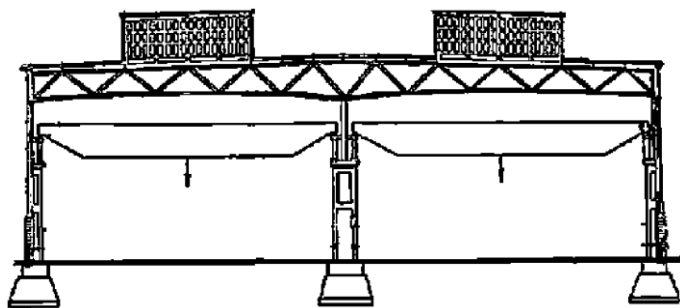


Fig. 28 Cross section of the forge building at the Obuda shipyard [16].

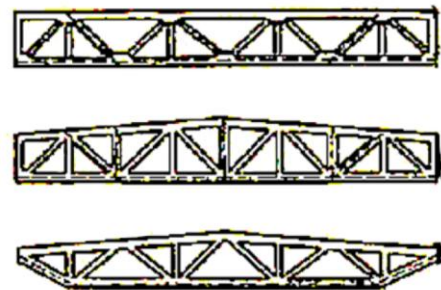


Fig. 29 Examples of standardized trusses from the USSR [18].

According to [19], the expansion of the use and development of prefabricated structures in the USSR was driven by a resolution of the Central Committee of the Communist Party of the Soviet Union (CC CPSU) from 1954. In 1960, the Soviet State Committee for Construction issued guidelines describing the principles of volumetric, spatial, and structural arrangement for industrial buildings. The basic floor plan module was chosen to be 300 cm, which every structural element of the project had to meet. The following dimensions were established:

- Span from 1200 to 3600 cm
- Column spacing of 600 and 1200 cm

On Fig. 30, an axonometric view of a unified hall with a span of 18 m and column spacing of 6 and 12 m can be seen. Examples of specific types of trusses for spans of 18, 24, and 30 m are shown in Fig. 29.

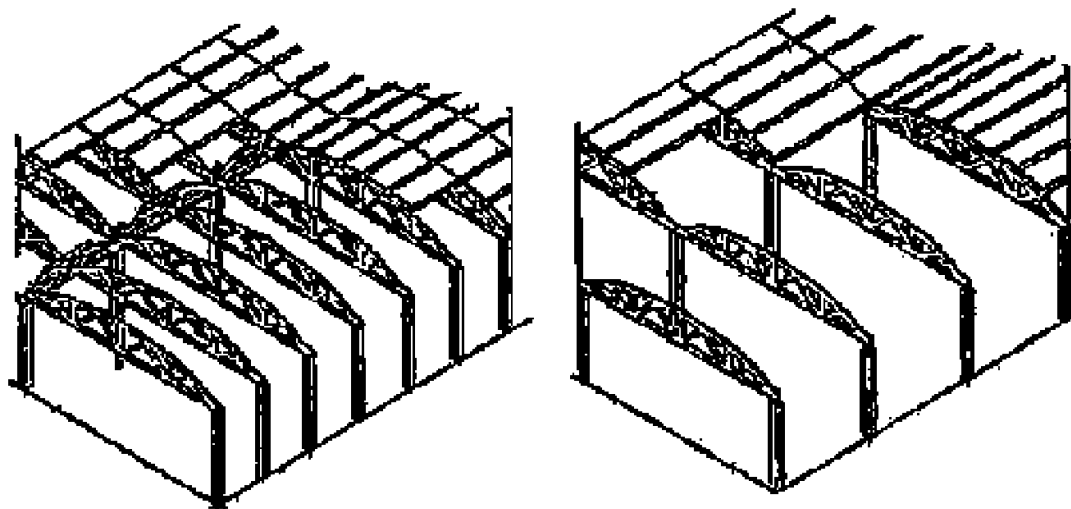


Figure 30 Axonometric view of standardized halls in modular coordination 1800x600 and 1800x1200 cm USSR [18].

Czechoslovakia

Research on truss girders in Czechoslovakia began in 1950. The first standardized design guidelines started appearing in 1952 [25]. The basic floor plan module was chosen to be 300 cm, and the height module 30 cm, which every structural element of the project had to meet. The following dimensions were selected for standardized halls [26]:

- Span from 1200 to 3600 cm
- Column spacing of 600, 1200 and 1800 cm

An axonometric view of the standard hall with SPP 10 18/6 trusses is shown in Fig. 33 [27].



Fig. 31 Truss girders SPP 1 – 18/6 [28].

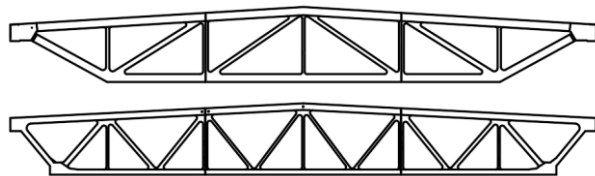


Fig. 32 On down girder SPP 6 – 18/6. On top truss girder VS 18.

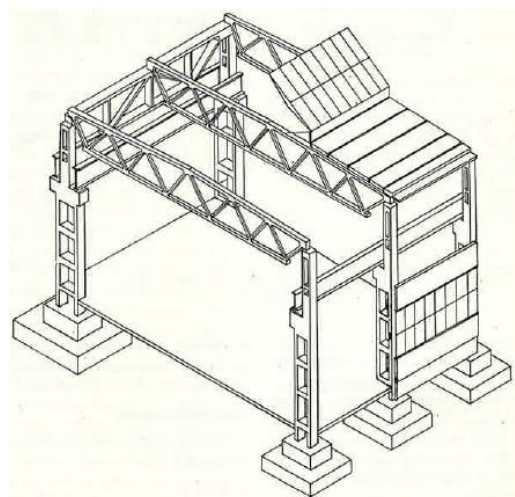


Fig. 33 Axonometric view of standardized halls with truss girders SPP 10 – 18/6 [27].

The first types of the now most well-known SPP trusses began to appear at the end of the 1950s, see Fig. 31 [28].

Another type of truss was developed by the n. p. (state enterprise) Priemstav Bratislava, which was later renamed to ZIPP Bratislava. This is the V-type, which is now referred to as VS. This type is similar to the SPP trusses but differs in the dimensions of the elements, the orientation of the diagonals, and the prestressed reinforcement, see Fig. 32 [29].

Another type of truss was designed by the state n. p. (state enterprise) Gotwaldov, see Fig. 34. An example of the use of these trusses is the ČSAO (Czechoslovak car repair shop) Holešov hall see Fig. 35. An interesting feature of this construction is that the trusses are designed as main beams, on which the purlins are placed on the lower chord, and the skylight structure is placed on the upper chord [30], [31].

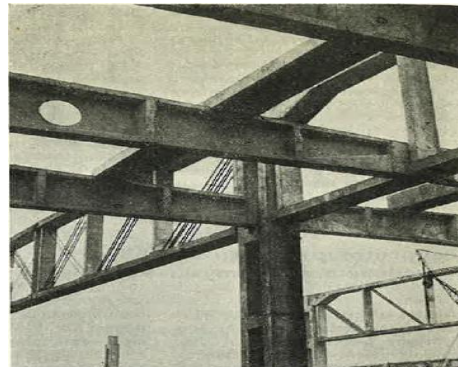
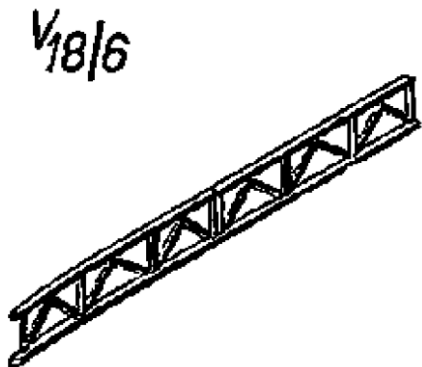


Fig. 34 Truss girder developed n. p. Gottwaldov [31]. Fig. 35 Czechoslovakia car repair shop Holešov [30].

5 CONCLUSION

For all types of post-tensioned concrete structures built in the 1950s, 1960s, and 1970s, there is a significant risk of corrosion of the tendons, which has led to the failure of several roof structures of industrial halls. The riskiest are the segmented trusses, which are then joined together at the construction site using post-tensioning or other metal connections. For this reason, it is essential not to underestimate this threat and have these structures inspected.

In this article, we have shown that during the 1950s, 1960s, and 1970s, various types of roof structures were designed. These included truss frames, truss girders, and arches. Each type of construction has been described individually.

At that time, the world was divided into the western world and the eastern socialist world, with each side following a different philosophy when it came to building design. As a result, the specific realized halls were divided into western and eastern worlds. The main difference was that in the eastern countries, there was an effort to build as cheaply and quickly as possible, which led to the design of standardized universal halls that had to meet the needs of the greatest possible number of industrial sectors. Halls from Great Britain, Spain, Poland, the Soviet Union, and Czechoslovakia were presented.

This article will be followed by another one that will address the structural analysis of the Czechoslovak truss type SPP or VS. The methods used in that period will be presented and compared with today's simplified and more detailed models.

The need for new recalculations arises both due to the higher snow loads required by current standards and the additional load from PV power plants, which represent a significant use of industrial hall roofs. Another reason may be a change in the purpose of the hall or the installation of new technological equipment for production needs. The mere fact that these structures are at the end of their service life should be a sufficient reason to verify their safety.

Acknowledgements

This work was supported by the research program of the Faculty of Civil Engineering, Brno University of Technology No FAST-S-25-8769.

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