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POST-TENSIONED STEEL FRAME

The effective covering and the method of its erection are developed for unique large-span buildings.

Розроблено ефективне покриття для унікальних великопрогонових споруд і спосіб його зведення.

compass curve, guide way, hinge joint, lifting jack, post-tensioned frame, tubular section

Introduction

The Department of computer technologies of construction of the Airport faculty of the Institute of Municipal Economy has carried out the patent analysis of new structural decisions for buildings frames and technologies of their erection in seven leading countries over the last twenty years under the supervision of the head of the department, professor Yu.V. Veryuzhsky and professor V. N. Pershakov.

A post-tensioned frame [1] is one of the most effective and interesting decisions both in a structural plan and by the method of its erection.

The frame design consists of rigid-frame sections, pivotally connected in one chain: two end sections and an intermediate one. There can be a variant with a few intermediate sections. The intermediate section of the steel frame construction leans on the end sections and consists of:

- an upper compressed chord, which, in the inactive state, is a chain of straight or partially bent elements;
- a lower chord, consisting of metal, preferably steel tubular sections, that are guide ways for a strained cable;
- posts and diagonals between the upper and lower chords.

Frame elements action under tension

The pre-stressing technology is used to erect the steel construction. With tension acting at lower chord, forces affect the upper chord too. Curvature of the lower chord changes as the upper chord bends with constant distance between the upper and lower chords, that is constant lengths of posts and diagonals between these chords.

Curvatures of the upper and lower chords depend on the design length of every tubular segment of the lower chord. Gradual design reduction of the lower chord segments lengths will lead only to the relatively small bending of the upper chord. Every tubular section of the lower chord is connected by means of posts and diagonals with the upper chord.

Therefore further tension of the lower chord only causes compression of its tubular sections, and the whole construction resists further change of curvature of the upper chord. The upper chord bending can reach a critical value. Therefore to prove further even bending of the upper chord, its sections are provided with hinge joints. With the help of such joints it is possible to bend the upper chord to form a compass curve with a relatively small radius, and to create structural systems like arches and portal frames. The degree of curving of the frame construction depends on its length and height.

If after reaching of the construction design curvature, the lower chord cable is further strained, tension in the compressed tubular sections of the lower chord grows together with tension in the posts and diagonals connecting the two chords. This phenomenon is required to increase structural durability and rigidity of the steel frame construction and to ensure its counteraction to an earthquake, wind and temporal loads.

Pre-stressing forces, required to resist above-listed loads are 0,1–100 times more than the forces required to give necessary curvature to the frame construction.

While tensioning the cable, a gap between the strained cable and internal surfaces of the tubular elements influences deformations between the lower chord segments. This gap is from 3 to 100 mm and more. Its size depends both on ratio of the tubular section diameter to distance between posts, and on the required bending degree of every element of the chord.

To couple the cable with the tube a cavity between the cable and internal wall of the tubular section is filled with jointing material. It is, as a rule, a mixture of Portland cement, water and chemical additions.

Every pair of adjacent tubular sections is connected with a sliding joint like a fitting pipe. There is a corrugated chasing on both ends of the fitting pipe.

The width of the chasing area corresponds to the depth to which the fitting pipe enters the tubular section.

Places, where the fitting pipe overlaps the tubular section, are filled with liquid binding material. Because of the overlapping places all the tubular sections of the lower chord have appropriate tensile strength.

When an external load acts on the steel frame construction, the lower chord is subjected to compression, which exceeds the compression, caused by the cable tension. The tubular sections of the lower chord can be compressed to the critical value which depends on tensile strength of the material the tubular sections and abutment joints are made of.

Steel frame erection technology

The technology of assembly and erection of the post-tensioned steel frame construction is shown in fig. 1–13.

Fig. 1, 2 and 3 show the post-tensioned steel frame on different stages of tension.

1. The intermediate section is assembled on the ground. The section consists of upper chord 4 and lower chord 7. Lower chord 7 is composed of tubular steel elements. Both chords are connected with diagonals 5 and posts 6. The strained cable passes along the tubular guide ways of lower chord 7.

2. End sections 1 and 10, that in working position will act as supports of the strained steel frame construction, are connected to each end of the intermediate section by means of hinge joints 2 and 9. Fig. 1 shows the whole assembled frame construction lying on the ground in a stress-free state.

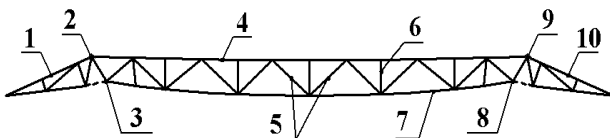


Fig. 1. Assembled steel frame before tension:

- 1 – left end section;
- 2 – left hinge joint;
- 3 – left point of strained cable fixing;
- 4 – upper chord of intermediate section;
- 5 – diagonal of intermediate section;
- 6 – post of intermediate section;
- 7 – lower chord of intermediate section;
- 8 – right point of strained cable fixing;
- 9 – right hinge joint;
- 10 – right end section

3. The cable, passing along the tubular guide ways of lower chord 7, is strained, and the cable ends are fixed in points 3 and 8. The cable tension brings the intermediate section to the required curvature, shown in fig. 2.

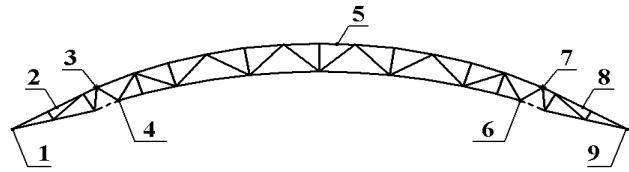


Fig. 2. Cable tension of the intermediate section:

- 1 – left point of cable fixing on end section;
- 2 – left end section;
- 3 – left hinge joint;
- 4 – left point of cable fixing on intermediate section;
- 5 – intermediate section;
- 6 – right point of cable fixing on intermediate section;
- 7 – right hinge joint;
- 8 – right end section;
- 9 – right point of cable fixing on end section

4. Cables, passing along the tubular guide ways of end sections 2 and 8, are fixed on the intermediate section 5 at points 4 and 6.

5. The cables of end sections 2 and 8 are strained simultaneously or alternately, and fixed in the strained state at points 1 and 9. As a result, end sections 2 and 8 turn in the hinged joints 3 and 7 relative to intermediate section 5 and close up with it by means of locking knots.

U-shaped state of the steel frame construction is shown in fig. 3.

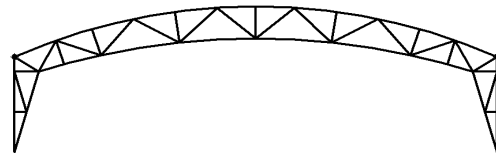


Fig. 3. Tense state of the steel frame

6. The whole pre-tensioned steel frame construction is lifted by a crane and set in the vertical design position.

Fig. 4 illustrates the pre-tensioned steel frame in the design position.

7. The free tails of the strained cables of the end sections serve as anchors to fix steel frame construction 2 in foundations 1 and 3 of the buildings covered.

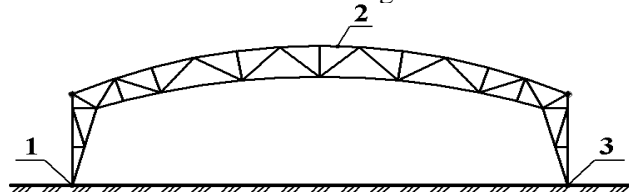


Fig. 4. Design position of the steel frame:

- 1 – left foundation;
- 2 – steel frame construction;
- 3 – right foundation

There is a possibility to erect the construction without using cranes.

In order to arrange a covering, some above mentioned constructions are set parallel to each other. Connections between them can be pre-tensioned constructions too. The assembled multi-frame construction is covered with roofing material. Metal sheet, plywood or asbestos-cement sheets can serve as roofing material. Use of the above-mentioned frames in multispan buildings is shown in fig. 5.

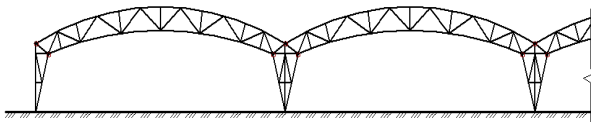


Fig. 5. Steel frame constructions in multispan building

Variants of post-tensioned steel frames

Fig. 6, 7 and 8 represent a variant of steel frame construction in which an intermediate section 3 and end sections 2 and 4 are trusses with parallel chords. Such construction in non-operating position is shown in fig. 6.

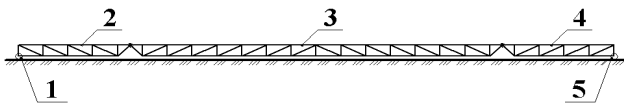


Fig. 6. Steel construction consisting of frames with parallel chords before tension:

- 1 – left traveling roller;
- 2 – left end section;
- 3 – intermediate section;
- 4 – right end section;
- 5 – right traveling roller

Erection technology of is similar to the above described one. Erection can be performed with the help of traveling rollers 1 and 5 located in the lower parts of end sections 2 and 4 that roll along the appropriate guide ways located on the assembly area surface. Fig. 7 and 8 show the steel frame construction in the strained and design positions, respectively.

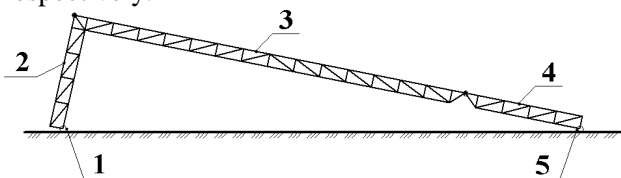


Fig. 7. Tension of the steel frame (variant with parallel chords):

- 1 – left traveling roller;
- 2 – left end section;
- 3 – intermediate section;
- 4 – right end section;
- 5 – right traveling roller

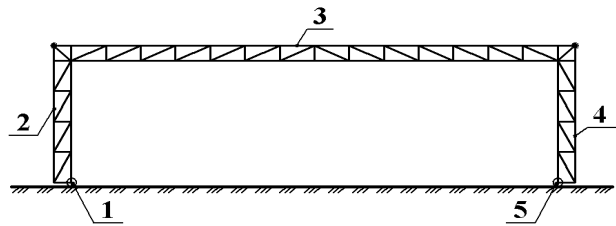


Fig. 8. Design position of the steel frame (variant with parallel chords):

- 1 – left traveling roller;
- 2 – left end section;
- 3 – intermediate section;
- 4 – right end section;
- 5 – right traveling roller

Use of steel frame constructions for buildings with a round outline plan view is shown in fig. 9.

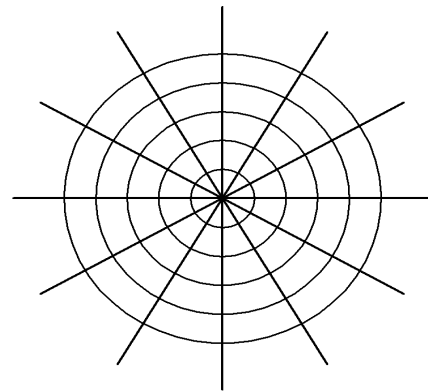


Fig. 9. Steel frames in buildings with a round outline plan view

The constructions are radii of a round contour.

Fig. 10 shows how the above-mentioned frames can be used at their mutual intersection at right-angles.

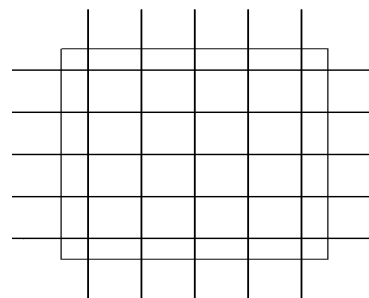


Fig. 10. Right-angle intersection of the steel frames

Fig. 11, 12 and 13 illustrate the use of the steel frame construction in large-span buildings.

Fig. 11 shows how this construction is assembled using temporary supports 3, 5, 8 and 11.

In this case an intermediate section is a composite construction, consisting of three separate trusses: one central truss 6 and two edge ones 4 and 9. To free ends of trusses 4 and 9 supporting trusses 1 and 12 are joined by means of hinged joints 2 and 10.

One strained cable 7 passes along tubular guide ways of three trusses 4, 6 and 9.

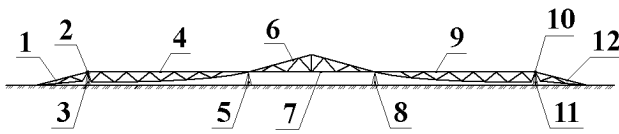


Fig. 11. Steel large-span frame assembly:

- 1 – left supporting truss;
- 2 – left hinge joint;
- 3 – temporary support;
- 4 – left edge truss of intermediate section;
- 5 – temporary support;
- 6 – central truss of intermediate section;
- 7 – strained cable of intermediate section;
- 8 – temporary support;
- 9 – right edge truss of intermediate section;
- 10 – right hinge joint;
- 11 – temporary support;
- 12 – right supporting truss

Fig. 12 represents the state of the construction after the strained cable of the intermediate section has already been stretched, and hydraulic lifting jack 5 with a lifting rope, fastened on it, set on the axis of central truss 4.

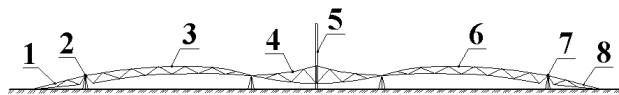


Fig. 12. Tension of steel large-span frame:

- 1 – left supporting truss;
- 2 – left hinge joint;
- 3 – left edge truss of intermediate section;
- 4 – central truss of inter-mediate section;
- 5 – hydraulic lifting jack;
- 6 – right edge truss of intermediate section;
- 7 – right hinge joint;
- 8 – right supporting truss

Cables passing along tubular guide ways of supporting trusses 1 and 8 are fastened on two edge trusses 3 and 6.

Cables passing along tubular guide ways of supporting trusses 1 and 8, are fastened on two edge trusses 3 and 6. The cables of supporting trusses 1 and 8 are simultaneously stretched and fixed in their strained state. This causes supporting trusses 1 and 8 rotation in hinged joints 2 and 7 relative to the intermediate section.

Locking knots of adjacent sections close up, and the whole steel frame takes its vertical position. Central truss 4 of the intermediate section is lifted with the help of hydraulic jack 5.

When the frame construction reaches the position shown in fig. 13, column 3 is set on the axis of the covered span, and the temporary supports are removed.

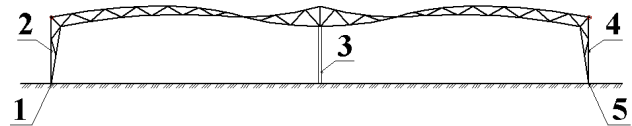


Fig. 13. Steel large-span frame in design position:

- 1 – left foundation;
- 2 – left supporting truss;
- 3 – central column;
- 4 – right supporting truss;
- 5 – right foundation

Free ends of the strained cables of supporting trusses 2 and 4 serve as anchors to fix the whole steel frame construction in foundations 1 and 5 of the building covered.

Distances between the edge supporting trusses 2 and 4 and the central column 3 can be up to 100 metres.

First of all, buildings of aviation hangars must resist wind loads. Experimental investigations have shown that buildings with post-tensioned steel frame constructions, with their low materials consumptions and minimum costs on their assembly, can resist the force of typhoon.

Conclusion

This technology of post-tensioned steel frame constructions erection is used for covering unique large-span buildings (agrarian farms, factory buildings, aviation hangars), where a large area needs effective peripherally supported coverage.

Creating analogous frame constructions for small span buildings it is possible to use different combinations of materials. The lower chord can consist of steel tubular sections, and elements of the upper chord, posts and diagonals between two chords can be wooden.

References

1. Patent 4,676,045 United States; E04B1/24 - E04C3/38, E04B1/35E, E04C3/40; Post-tensioned steel structure / Ellen Peter (HK); № US4676045; 1987-06-30.