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Czechoslovak Research in the Area of Prestressed Metallic Structures

Recherches tchécoslovaques dans le domaine des constructions métalliques précontraintes

Tschechoslowakische Forschung auf dem Gebiete der vorgespannten Metallkonstruktionen

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1. COORDINATED SCIENTIFIC AND RESEARCH ACTIVITIES

In the Czechoslovak Socialist Republic it is predominantly the Building Research Institute of the Czech Technical University in Prague (formerly a part of the Institute of Theoretical and Applied Mechanics of the Czechoslovak Academy of Sciences) and the Chair of Metal and Timber Structures of the Slovak Technical University in Bratislava that have been systematically engaged in the research of prestressed metallic structures (PMS). Since 1960 the state scientific and research programs for prestressed steel structures (PSS) have been regularly elaborated, each for the period of five years. The mentioned two institutions have mutually coordinated the scientific and research activities in the area of PSS in the state-wide scale.

The purpose of the first research period (1961-1965) especially was to prepare, in the cooperation with other working units, the Czechoslovak specification for the designs of PSS /7/. Hence, most activities were aimed towards that goal. Theoretical and experimental investigations pertained to the problems of designing, proportioning, constructing, economy, execution and verification of the actual behavior of the basic, most common types of web-plate structures and trusses /2,4,12,20,31,33-35,40,45-47,51,55,58/.

Rather rich outcomes of the first research period enabled Czechoslovakia not only to partake significantly in the success of the 1st International Conference on PSS, Dresden (German Democratic Republic) 1963 /12/, but even to organize the 2nd International Conference, Tale (Czechoslovakia) 1966 /13/, and to demonstrate there the Czechoslovakian achievements in the area of PMS until that time. Also the first Czechoslovakian monograph on PMS /4/ appeared, making the engineering public acquainted with the then state of knowledge in the area and providing a deeper exposition of the contents of the specification /7/.

The specification /7/ for designing PSS is one of the first codes in the world. It concerns mainly the structures prestressed by high-strength tendons and is based on the Limit States (Load

Factor) Concept /79,81/. The appropriate constructional materials are therein recommended, the principal organization -, transport -, and technological hints and data are provided. The attention is paid specifically to the construction and economical design of prestressed web-plate girders, queen post trusses and open-web trusses.

During the second research period (1966-1970), reflected mainly by the publications /63,65,66,68,70,72,74,75,82,84-86,89, 91,94/, more involved problems were studied. They pertained, for instance, to the perfected economical proportioning of prestressed plate girders, and that also in the elasto-plastic state, composite girders, trussed beams, spatial roof-trusses, etc. Experimental investigations were performed to confirm theoretical results from the both periods. Some Czechoslovak achievements from the second research period were given publicity also at the 3rd International Conference on PMS, Leningrad (USSR) 1971 /15/. The second research period was concluded by the monograph /11/.

The objective of the third scientific and research period (1971-1975) is to deepen further the theory of PMS and, in addition to that, to solve also a number of technological problems. Consideration should be given, inter alia, to more complex systems prestressed by tendons; systems prestressed by other means; reconstructions and strengthening of structures through prestressing; dynamics and fatigue of PMS; modern design methods, especially those using the mathematical programming; special problems.

The specification /7/ for designing the basic types of PMS will be revised. Numerous remarkable findings have been acquired during the past research periods also in other fields than in that of web-plate structures and trusses - e.g., in the areas of prestressed suspended roofs /1,3,4,11-15,27,29,36,38,41,42,48,49,52, 54,64,69,77,78,90/; suspended bridges /4,11-13,15,23,39,88/; guyed masts /4,5,11,30,44,73/; pressure vessels /4,19,24,37/; exploitation or removing of residual stresses /4,11,18,32,56,61/, etc. Nonetheless, no regulations for these disciplines will be incorporated in the revised specification /7/ as it is felt that these disciplines merit their own codes. They would certainly deserve a broader treatment in this paper, too. However, the shortage of space hinders that.

At present, a new specification is being prepared for the executions of PSS. A part of the scientific and research groundworks has been already accomplished /9,11/. During the first and second research periods, also many experimental investigations of the technological nature were performed, especially on the high--strength rods, strands and ropes, and on their anchorages /6,10, 12-15,21,22,25,26,28,43,50,67,71,76,80,87,92,93/, with the aim to exploit the results for the specification. Among other things, the elasticity moduli both of virgin and prestretched elements, their actual bearing strength, as well as the state of strain of the zinc-poured sockets were observed.

At least a selection of some Czechoslovak findings is briefly dealt with in the sequel.

2. TRUSSES

Trusses prestressed by high-strength tendons are statically indeterminate systems even when supported in a statically determinate manner. If their geometry is given or preselected, these structures can be economically designed by an inverse method /4,11,34,40,59, 63,70/:

The optimal total tendon forces are found, e.g., by the use of a linear programming technique, with the theoretical weight of the truss employed as the decision function. For these forces and the considered external loads, the truss members can be easily proportioned. After the sections have been picked up, the redundant forces in tendons are calculated, e.g. by the force method. The necessary prestressing forces are specified by the differences between the optimal total forces and the statically indeterminate forces in tendons. - In the reality, the design appears to be a little more involved, because of several intervening load combinations, differentiated prestress accuracy factors and some other coefficients not known in advance.

Much simpler is the design of those trusses, where the distinct tension members are prestressed independently, by the coaxial tendons. Each tendon influences only one member. The design of prestressed tension members is treated in /4,7,11,55/. The non-prestressed truss members are designed as in a structure without tendons.

The most complicated optimization problems are those where the system geometry is to be varied. In /60,68/, the variable parameters were: the amount of panels, the depth and the distance of plane roof trusses with parallel chords, the distance and the type of purlins, the type and the size of the used profiles, the configuration of the prestressing tendons and the magnitude of prestressing. The involved analytical expressions were solved numerically for the selected characteristic cases. In Fig.1, the theoretical steel consumption over the ground plan of 24m x 48m is correlated with the distance of the roof trusses which have the depth of 2,9m.

The results of the theoretical investigations were utilized in a typification study of the roof trusses /4,31/. A roofing using tubular ∇ - trusses, Fig.2a,b, proved to be very economical. Prestressing of trusses with the chords of constant cross-sections and the spans of 24; 30; 36m by two polygonal wire-ropes economizes 20 through 22% or 14 through 16% of steel, at the heavy cladding (240 kg/m^2) or at the light cladding (60 kg/m^2), respectively. The top truss web consist of purlins only, being connected for torsion with the concrete cladding slabs; during the erection, the crossed prestressed strands are employed as the temporary diagonals.

Prestressed open-web structures of a special character are the transmission and television masts /4,5,11,30,44,73/.

3. WEB-PLATE STRUCTURES

A good deal of attention has been paid to the economical design of a plate girder prestressed by a straight high-strength tendon near the tension flange /4,7,8,11,33,46,47,51,62,65,66,72, 75,82,89,91,94/. The highest economy can be achieved in a girder with the optimal asymmetry when the both girder flanges in the critical sections and the tendon along the entire length are fully stressed. Problems of the optimum design were solved for the case of a tendon of the optimum length as well as of the length equaling the girder span; for various positions of the tendon with respect to the tension flange; for equal or differentiated design stresses of the flanges; for flanges with limited or unlimited cross-section areas. Four distinct decision functions were considered, the simplest being that of preselected tension flange parameter φ_2, Fig.3, or that of maximum bearing capacity at the constant volume. In a research program, conducted by one of the authors during his stay abroad, also the optimum design of a prestressed composite (steel - concrete) girder was studied, besides other topics /82/. In the case of the prestressed steel resp. composite girder, numerous intervening expressions and variables were replaced, through the analytical manipulations, by one resp. two equations only, for two resp. three unknowns, governed by one decision function. Because of their complexity, the expressions were solved numerically (by the use of a computer) for a representative selection of situations. The appropriate aids, as that one in Fig.3, can be worked out to facilitate the practical design.

The economical proportioning of prestressed steel plate girders was investigated both in elastic and elasto-plastic ranges, Fig.4 /65,75/. However, the buckling problems entangle the exploitation of the plastic reserve so far that not too much additional economy can be gained from the plastic design.

Another research topic was the prestressed deep trussed beam, i.e. a beam supported by posts and a polygonal tendon, Fig.5 /7,11, 74/. When the structure geometry is known, the design can be realized also by an inverse method similar to that for trusses. The optimum tendon force follows from the requirement that the critical sections of the beam should be fully stressed. The redundant tendon force can be readily calculated with the aid of the chart in Fig.5.

An inverse design technique combined with the linear programming was elaborated also for continuous beams prestressed by the enforced deformations of redundant constraints, e.g., by the intentional displacements of redundant supports /70,86/.

4. CLOSURE

The endavour of designers to economize maximally steel, without reducing the safety of structures, attracts the interest always more to PMS - as testified, e.g., by the themes of the contemporaneous international congresses (Leningrad 1971, Amsterdam 1972, Dresden 1974). The state of stress can be modified efficiently through prestressing structures in such a way that the internal effects are redistributed to the less utilized sections or section fibres, and the structural elements can be better and more evenly exploited.

It is our pleasure to conclude that Czechoslovakia belongs among the countries having recognized early the hopefulness and importance of PMS, so that the Czechoslovakian specialists have been able to contribute significantly to the scientific and engineering progress in this field.

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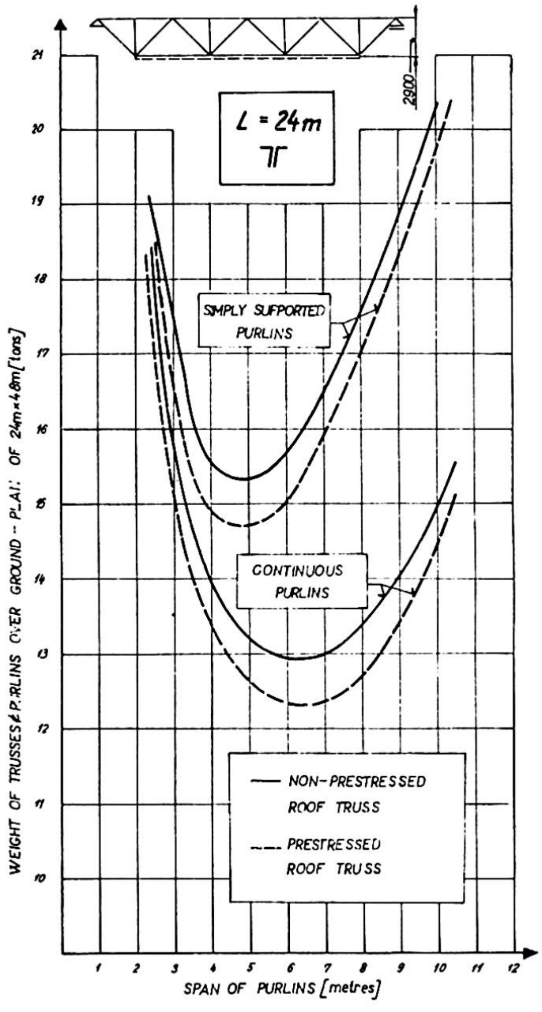
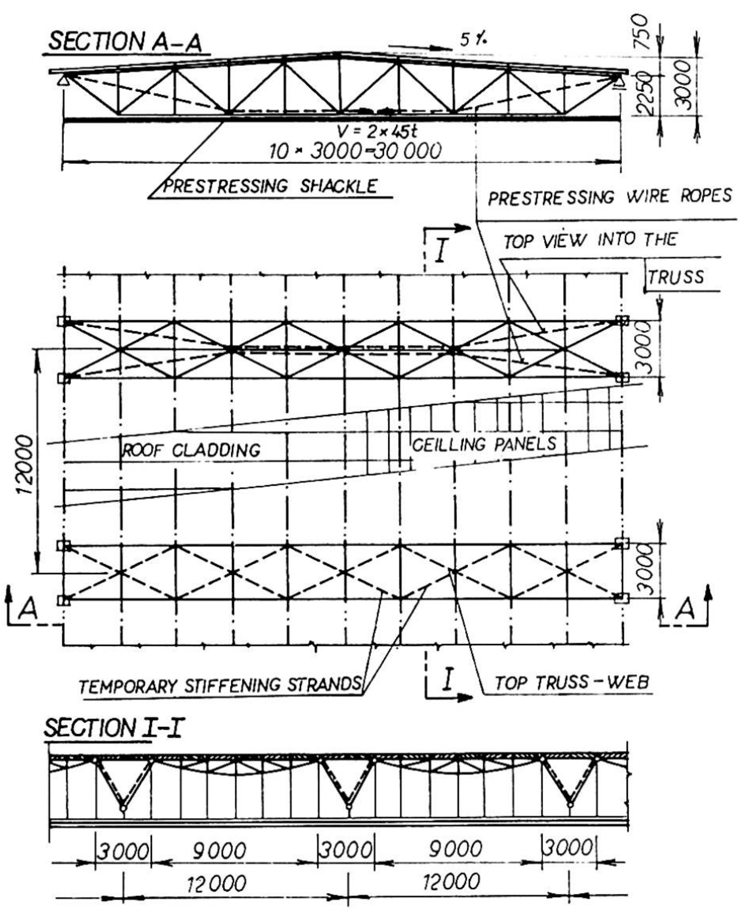
6. SUMMARY

Since 1960, the Czechoslovakian research in the area of prestressed metallic structures has been organized and planned for five-year periods. Achievements from the two periods are described, when mainly the basic structural types have been investigated. The specification for the designs of prestressed steel structures has been published and the specification for the executions of prestressed steel structures is in preparation. To illustrate some results of the accomplished scientific and research activities, problems of the economical design of prestressed steel trusses and web-plate structures are briefly treated.

7. ILLUSTRATIONS

Fig. 1
Weight of a steel roof as affected by truss distance





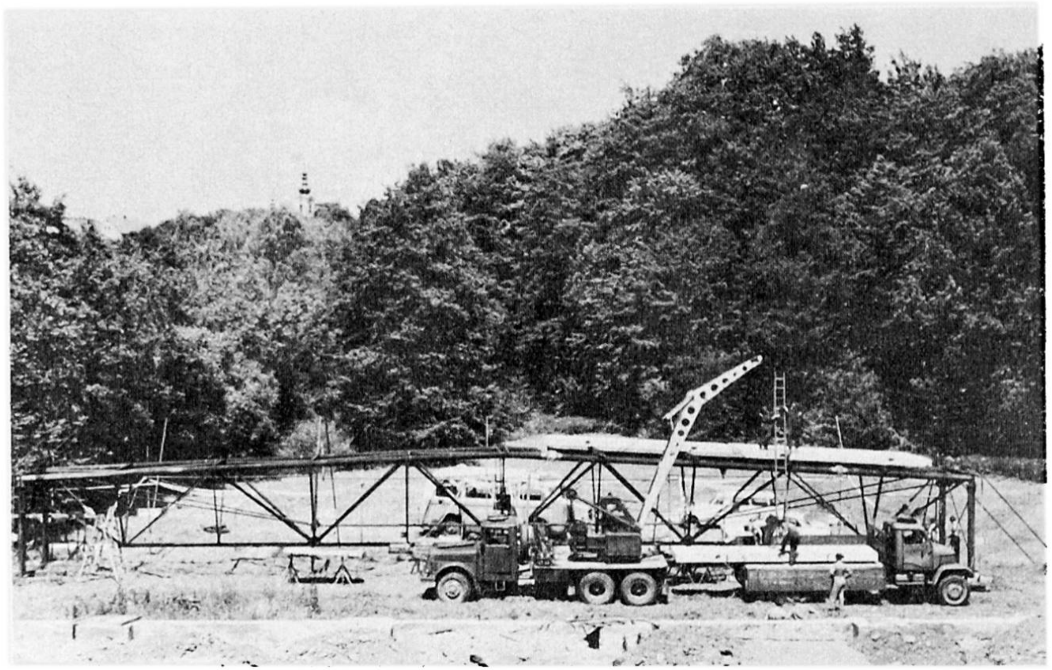


Fig. 2 Tubular roof truss prestressed by two polygonal tendons

(a) General layout

(b) Experimental investigations

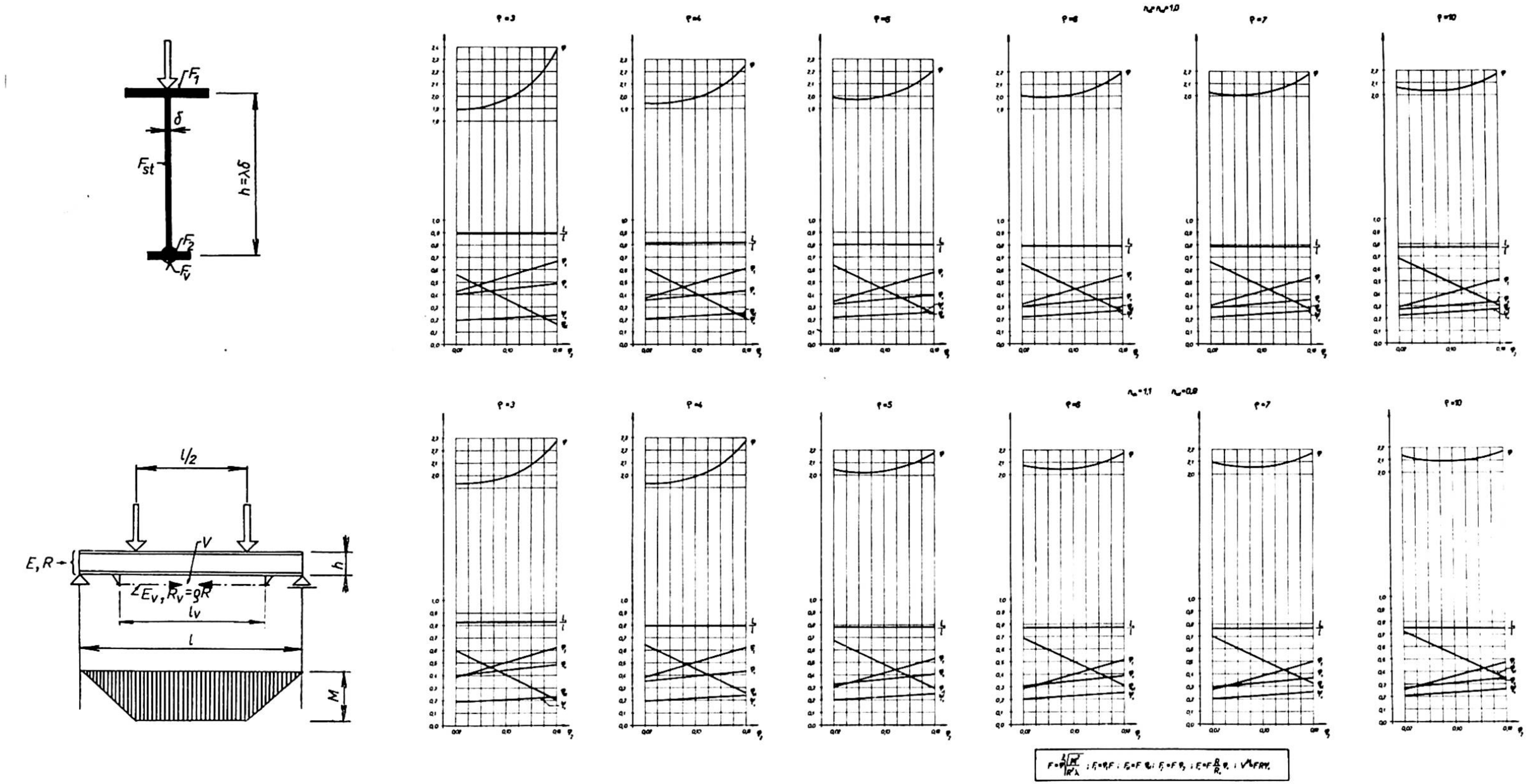


Fig. 3 Formulas and coefficients for a straightforward proportioning of a prestressed plate girder

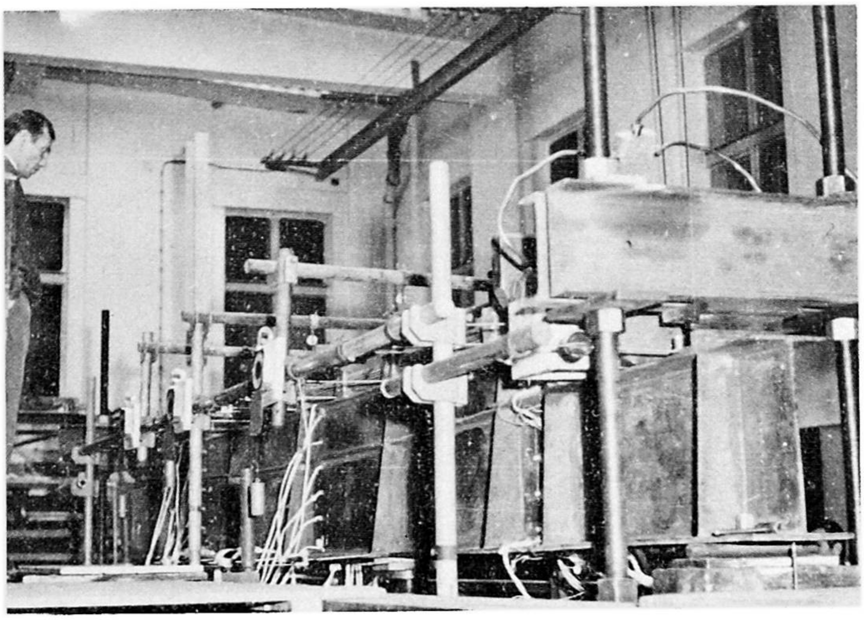
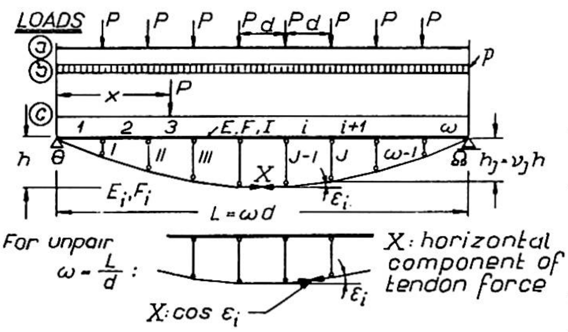


Fig. 4 Tests of plate girders in which prestressing exerted the elasto-plastic state



$$\boxed{X = \frac{\max M_0}{K_Z K_T h}}$$

$\max M_0$ - max bending moment of simply supported beam

K_Z - from table below, for respective load

$$K_T = 1 + \frac{I}{h^2 \lambda^3}\left(\frac{\alpha}{F}\lambda^3 + \frac{\beta}{F_S} + \frac{E}{E_t}\,\frac{\gamma}{F_t}\right)$$

$\lambda = \frac{L}{h}$; coefficient α, β, γ from table below

For posts with unequal areas : $\frac{1}{F_S} = \sum_{J=1}^{\Omega-1} \frac{\nu_J}{F_{sJ}}$

NO OF PANELS ω	LOAD a: BENDING MOMENTS max M_0/PL	LOAD b: M_0/pL^2	LOAD c: $M_0/P(L-x)$	LOAD a: LOAD COEFFICIENTS K_Z	LOAD b: K_Z	LOAD c: K_Z	COEFFICIENTS FOR CALCULATING SHAPE FACTOR K_T: α	β	γ	δ	RELATIVE LENGTHS OF POSTS ν_J: I $\Omega - I$	II $\Omega - II$	III $\Omega - III$
2	0,25				0,8		3	48	$3(\lambda^2+4)^{1,5}$	0,25	1		
3	0,333				1,023		1,8	32,4	$1,2[(\lambda^2+9)^{1,5}+0,5\lambda^3]$	0,19	1		
4	0,5				0,9485		2,087	20,87	$1,043[(\lambda^2+9)^{1,5}+(\lambda^2+1)^{1,5}]$	0,21	0,75	1	
5	0,6				1,007		1,849	17,12	$0,7397[(\lambda^2+11,11)^{1,5}+(\lambda^2+2,777)^{1,5}+0,5\lambda^3]$	0,19	0,66̇	1	
6	0,75	0,125	1	1	0,977		1,965	13,58	$0,6550[(\lambda^2+11,11)^{1,5}+(\lambda^2+4)^{1,5}+(\lambda^2+0,444)^{1,5}]$	0,20	0,55̇	0,88̇	1
7	0,8571				1,004		1,862	11,83	$0,5320[(\lambda^2+12,25)^{1,5}+(\lambda^2+5,444)^{1,5}+(\lambda^2+1,361)^{1,5}+0,5\lambda^3]$	0,19	0,5	0,83̇	1
8	1				0,987	$\frac{x(L-x)}{\delta L^2 \sin\frac{\pi x}{L}}$	1,925	10,11	$0,4812[(\lambda^2+12,25)^{1,5}+(\lambda^2+6,25)^{1,5}+(\lambda^2+2,25)^{1,5}+(\lambda^2+0,25)^{1,5}]$	0,20	0,437	0,75	0,937
9	1,111				1,002		1,867	9,075	$0,4140[(\lambda^2+12,96)^{1,5}+(\lambda^2+7,29)^{1,5}+(\lambda^2+3,24)^{1,5}+(\lambda^2+0,81)^{1,5}+0,5\lambda^3]$	0,20	0,4	0,7	0,9
10 & more	$0,125\frac{\omega^{3}-1}{\omega}$				1	≈	1,875	$120\left(\frac{\omega}{\omega^3-1}\right)^2\sum\nu$	$1,875(\lambda^3+8\lambda+19,2\lambda^{-1})$	0,20	μ_J		

General formulas for coefficients

$\omega = \frac{L}{d}$ No. of panels

Superscripts a, b, ... - kind of loads

$$\alpha = \frac{6\omega}{\sum_{J=1}^{\Omega-1} \nu_J(\nu_{J-1} + 4\nu_J + \nu_{J+1})} ; \qquad \nu_J = \frac{h_J}{h} ;$$

$$\beta = \alpha\left(\frac{PL}{\max M_0^a}\right)^2 \sum_{J=1}^{\Omega-1} \nu_J ; \qquad K_z^b = \frac{6\omega}{\alpha \sum_{J=1}^{\Omega-1} \nu_J\left[\mu_{J-1} + 4\left(\mu_J + \frac{1}{\omega^2}\right) + \mu_{J+1}\right]} ;$$

$$\gamma = \frac{\alpha}{\omega} \sum_{J=1}^{\Omega-1} \sec^3 \varepsilon_i ; \qquad \mu_J = \frac{M_{0J}^a}{\max M_0^a}$$

Fig. 5 Formulas for the redundant force X in the tendon of a trussed beam