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Concrete Structures with Steel Elements Outside the Concrete Section

Structures en béton avec des éléments en acier hors de la section du béton

Betonkonstruktionen mit äusserer Bewehrung

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SUMMARY
This article deals with structural concepts, design procedures and expériences gained in the development and application of a very light and slender structural system in reinforced or prestressed concrete made of ordinary aggregates. Tensile members in such systems are either ordinary reinforcement or prestressing tendons. They are outside the concrete cross-section, free in space but protected against corrosion. The system is very suitable for precast concrete elements, both linear and plane.

RESUME
L'article expose la conception structurale, les méthodes d'analyses et les expériences acquises dans le développement et les applications d'un système de structures très légères et élancées, en béton armé ou précontraint, de granulats normaux. Les éléments tendus de ces systèmes sont soit l'acier pour béton armé soit l'acier de précontrainte. Ils sont hors de la section du béton, libres mais protégés contre la corrosion. Le système est très favorable pour les éléments en béton préfabriqués, autant linéaires que plans.

ZUSAMMENFASSUNG
In diesem Beitrag sind das Konstruktionsprinzip, der Entwurfsprozess und die Erfahrungen beschrieben, die bei der Entwicklung und Anwendung eines sehr leichten und schlanken Konstruktionssystems aus Stahl- oder Spannbeton mit normalen Betonzuschlägen gewonnen wurden. Die Zugglieder in diesen Systemen sind äussere Bewehrungs- und Vorspannstähle, die gegen Korrosion geschützt sind. Das System ist für vorfabrizierte Stab- und Flächenelemente geeignet.

1. INTRODUCTION

The possibility of efficient corrosion protection of steel elements free in space, and the philosophy of design of reinforced and prestressed concrete structures according to the limit states, enable today the design of such structural systems in which reinforced concrete parts of the system are subjected to relatively high compressive forces and small bending moments, while tensile steel parts of the system are designed outside the reinforced concrete cross-section. The steel elements are free in space but suitably protected against corrosion. The tension part of the system may be designed either of the ordinary steel for reinforced concrete or of prestressing tendons.

The considered structural system, especially for large spans, may be understood as a two-chord catenary system, in which upper chord ① has the axial and the flexural rigidity, while the lower, tension chord ②, has only the axial rigidity. The mutual connection of these two chords is achieved by means of compressed bars ③ at a suitable distance λ_i. But, at the same time, this structural system may be simply understood as a girder ①, elastically supported by discrete bracings ③, whose stiffness depends on axial rigidity and the configuration of tensile element ②, Fig. 1.

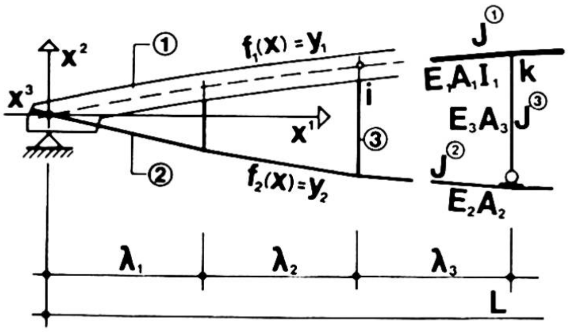

Fig. 1

In some cases it is convenient to prestress the system to the necessary degree. However, due to deformations under dead and live load, a certain degree of self-prestressing is inherent to the system and is, in many cases, quite sufficient.

The structural system can be designed as linear or plane. All system elements, in fact, are essentially in an axial or predominantly membrane stress state.

Owing to the considerable reduction of concrete cross-section, achieved in such structural systems, they are considerably lighter than classical ones. They are also more deformable so that, as a rule, the limit state of deformations is governing the design.

Special attention has to be paid to the fact that creep and shrinkage develop in the reinforced concrete elements of the system, while such deformations does not arise in the tensile steel member.

2. BASIC ASSUMPTIONS, DESIGN PROCEDURE AND AN EXAMPLE OF SYSTEM BEHAVIOUR

Generally, the structural system, Fig. 1, is considered as a set of bars as finite elements of corresponding geometrical and rheological characteristics. In the design it is assumed that the steel elements of the system, in the serviceability domain, behave elastically, while the linear creep theory is valid for the elements possessing time-dependent properties. With respect to the relatively high deformability of the whole system, a geometrical non-linearity of the problem is assumed and the Second Order Theory has to be applied.

The relation between stresses and strains in concrete elements of the system is taken in the usual form [1]

$$\varepsilon_c(t,t_0) = \frac{\sigma_c(t_0)}{E_c(t_0)}\left[1 + \phi(t,t_0)\right] + \frac{\sigma_c(t) - \sigma_c(t_0)}{E_c(t_0)}\left[1 + \chi(t,t_0)\phi(t,t_0)\right] + \varepsilon_{sh}(t,t_0) \qquad (1)$$

where the meanings of symbols are in accordance with the notations adopted by the CEB [2].

In the algorithm for the calculation of states of stress and deformation of the considered system, the displacements and the rotations of nodes of the system have been taken as unknown values. The external loads acting on system members are reduced to the selected nodal points of the system, so that the generalized elastical potential for all elements of the system can be formulated as follows

$$P = \sum_J P_J^{(r)}, \qquad ((r) = 1, 2, 3) \tag{2}$$

where $P_J^{(r)}$ is the generalized elastical potential for the element J belonging to the part (r) of the system.

In the global coordinate system (x^1, x^2, x^3), the set of changes of nodes position vectors and bars rotation vectors can be formally presented as

$$\bar{e}_i = (dx_i^1, dx_i^2, dx_i^3, \theta_i^1, \theta_i^2, \theta_i^3), \qquad (i = 1, 2, \ldots m) \tag{3}$$

where m is the total number of nodes of the system.

Using the equality of the work of external actions on generalized displacements of nodes and the work of internal forces, the conditional equations for unknown values can be expressed in the form

$$\{Q_i\} = \frac{\partial P}{\partial \bar{e}_i} \tag{4}$$

where Q_i is the set of external actions in the node i.

The equations (4), in fact, represent a system of equilibrium conditions for each node of the system. Most generally, the number of equations is $6m$. The system consists of non-linear algebraic equations and is, in this case, solved by the Newton-Raphson method. Applying the set of vectors

$$\bar{g}_i = \{Q_i\} - \frac{\partial P}{\partial \bar{e}_i} \tag{5}$$

which represent "unbalanced" actions in the system nodes, the problem is reduced to the solution of the system of linear algebraic equations [3]. The calculation has to be iterated until the desired accuracy in the relation (4) is reached.

The computer programme for the solution of this general formulation of the problem is made at the Faculty of Civil Engineering of the University of Belgrade [4]. The iterative procedure is very fast and gives completely satisfactory results. The programme provides solutions for both linear and plane systems. The first step in the iteration represents, in fact, the solution of the problem according to the First Order Theory.

As an example, Fig. 2a) shows such a linear system, of the type which has been already many times applied in practice as a roof girder in various industrial buildings. The connection between compressed reinforced concrete part of the system ① and ordinary reinforcing tensile steel element ② of the system is provided by bracing elements ③, only at two points in the span. The geometrical characteristics of the system and the rheological data for materials used are presented in Fig. 2a).

Fig. 2b) shows the diagrams of bending moments M and deflections w of the reinforced concrete girder ① of the system in time $t=0$ and $t \to \infty$, calculated by the First Order Theory, when the system, in fact, behaves as a braced beam. On the basis of analysis of the behaviour of such linear type systems and the presented results, it can be concluded that:

- a considerable reduction of bending moments is achieved in relation to bending moments obtained in classical girder of the same span and of the approximately equal internal forces lever arm;

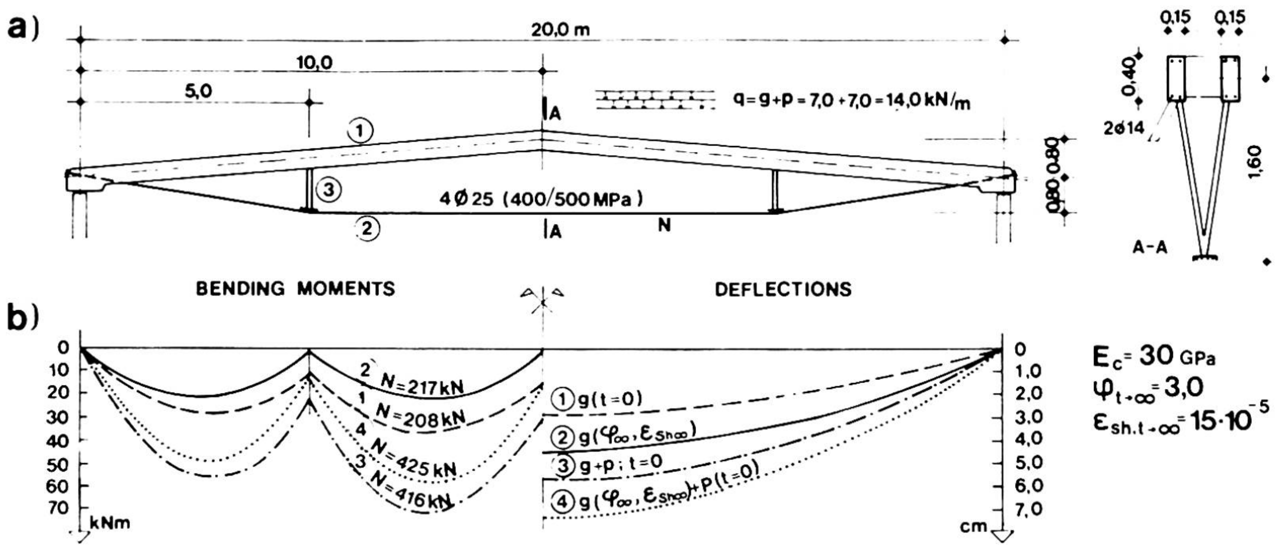

Fig.2

- total deformation due to the action of dead and live loads is within the limits of the allowed deflections even for classical reinforced concrete girders ($l/400$). Therefore, it would be possible even to reduce the cross-section of the reinforced concrete element, if permitted by the function of the roof because of the increase of deflection;
- time-dependent deformation at $t\rightarrow\infty$, is, in this case, only 1,5 times the elastic deformation at t=0. This relatively small increase of deformation with time is the consequence of a relatively small change of the curvature of the element ① with time;
- due to concrete creep in this type of the system the force in tensile element does not decrease with time but even increases a little, while relatively little loss of the tensile force results from concrete shrinkage. As high compressive stresses act in reinforced concrete element, it can be understood why the tensile force, due to both creep and shrinkage, does not decrease at all but is practically independent of time;
- for spans not exceeding about l=30 m, stresses and deformations calculated under assumptions of either the Second or the First Order Theory are not essentially different. Only after a considerable reduction of the stiffness of the reinforced concrete element, and possible use of prestressing steel for the tensile element, these differences become noticeable, so that the Second Order Theory must be applied.

Experimental investigations of the behaviour of such linear systems, with spans of l=12,5 m and l=20 m, showed a good agreement with the theoretically obtained results at all stages of loading, including the ultimate load.

These structural systems are designed so that the ultimate limit state, as a rule, is attained when the ultimate tensile force of the tension element is exhausted, thus providing a ductile fracture. To achieve this, the bracings are designed with increased safety.

3. APPLICATION OF THE CONSIDERED STRUCTURAL SYSTEM

Prefabricated light-weight systems, of the type shown in Fig. 2, have already been applied in Yugoslavia and have prooved to be a very economical solution. For spans up to about l=30 m, an ordinary concrete steel is most frequently used for the tensile element while for larger spans prestressing steel has to be used.

However, in both cases, it is possible to realize a desired degree of prestressing.

The form of the cross-section of compressed element may be arbitrary. In order to secure lateral stability of such linear type systems during mounting and construction, two parallel elements are frequently used, mutually discontinually connected by diaphragms. In order to meet transport requirements, for larger spans such linear girders may be constructed of two or more precast elements, most frequently jointed by high-strength bolts. As the element forms are very simple, such precast elements can be very economically industrialy produced in large series. The required on-site work at the mounting of such structures is very low. Also, demountable precast concrete structures may be easily realized in this system.

Fig. 3 shows the application of the proposed system as a grid structure which is elastically supported at four points in the span, and Fig. 4 shows a relatively flexible precast mushroom slab of reinforced concrete, also elastically supported by the lower tensile elements designed in two orthogonal directions.

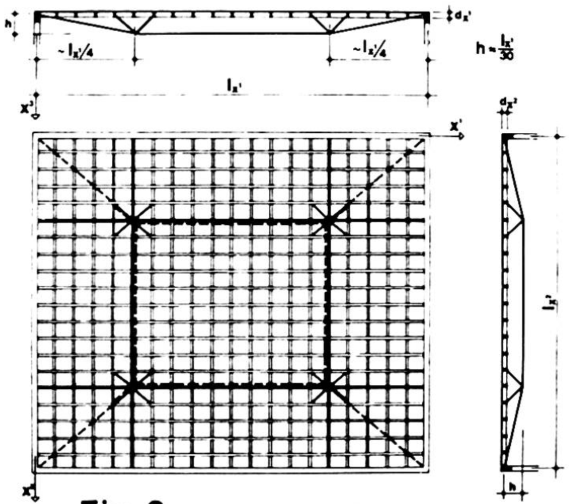

Fig. 3

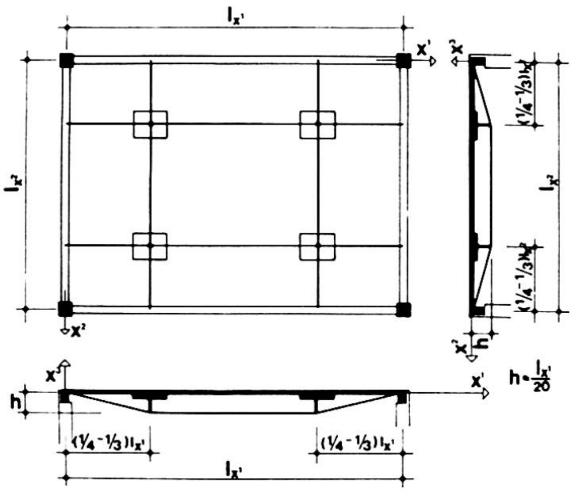

Fig. 4

Fig. 5 shows the design of a new hangar for simultaneous maintenance of two B-747 airplanes at the Belgrade International Airport. The span of the three main girders, (Pos GN), designed in the proposed structural system, is 135 m. The distance between girders is 25 m.

This design for the hangar structure has been selected in severe competition with other invited Yugoslav companies that offered steel hangar structures, because of its technical and economical advantages. Following the requirements of the minimum warming volume of the hangar, the whole roof structure is hanged on three main girders. The roof structure is also designed of secondary linear precast girders of the same type already presented in Fig. 2. At the moment of the preparation of this article, the hangar construction has already begun.

4. CONCLUSIONS

The presented structural systems are very light and are very appropriate especially for roof systems in industrial and other buildings. The elements of the systems are usually precast. Because of their light-weight they are very suitable for structures in earthquake zones.

Very important characteristic of those systems is that, depending on the necessary degree of prestressing, either ordinary reinforcement or tendons may be prestressed in order to influence the stress of deformation states during con-

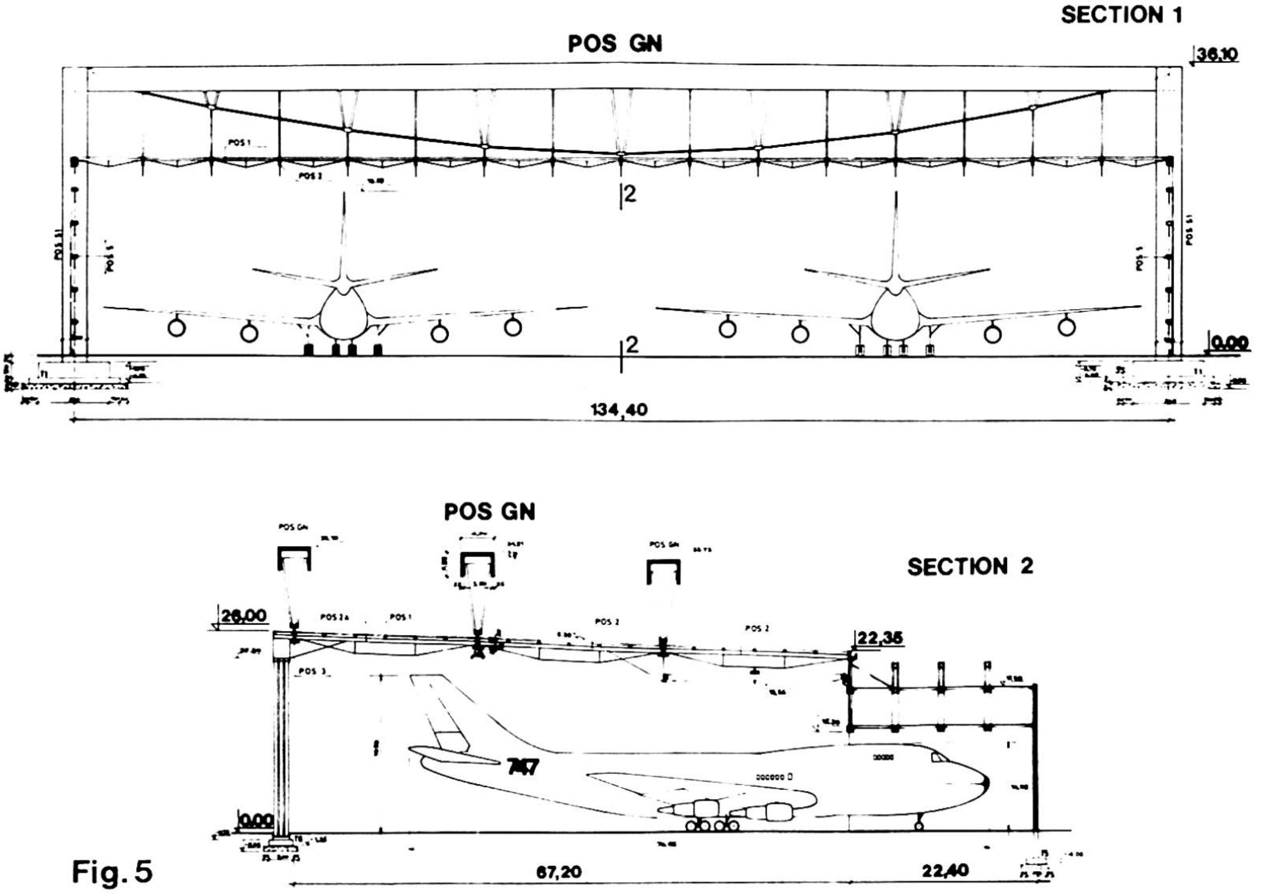

Fig.5

struction or for service loads.

The analysis of behaviour of such structures for creep and shrinkage effects shows that the time-dependent deformations of concrete have no essential influence upon the change of forces with time in the system. That insensibility to the loss of prestress force explains the possibility to prestress the system, to a necessary degree, in some cases even with the ordinary reinforcement.

Owing to relatively small self-weight, simple precasting, small quantities of required materials, easy transportation, short mounting time and the possibility of demounting, the presented structural system is very efficient and shows considerable technical and economical priorities over currently applied classical systems.

REFERENCES

[1] NEVILLE A.M., DILGER W.H., BROOKS J.J., Creep of plain and structural concrete. Construction Press, 1983.

[2] CEB-FIP Model Code for concrete structures. Bulletin d'information CEB No. 124-125/1978.

[3] MØLLMANN H., Analysis of hanging roofs by means of the displacement method. Polyteknisk Forlag, Lyngby 1974.

[4] IVKOVIĆ M., PRAŠČEVIĆ Ž., KLEM N., Contribution fo the computer analysis of hanging roofs, (in Serbo-Croatian). 14 Congress of the Yugoslav Association for Theoretical and Applied Mechanics, 1976.