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Strengthening of Existing Precast Waffle Slabs Using Unbonded Tendons

Renforcement des planchers en dalle nervurée précontraints par post-tension sans adhérence

Verstärkung der vorgespannten Kassettendecken mit nachträglicher Vorspannung

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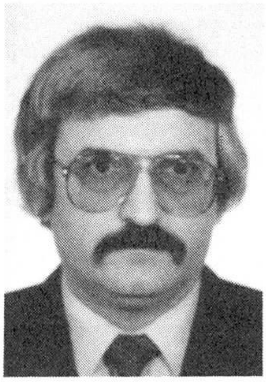

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SUMMARY

Inspecting a particular structural system tensioned together from precast reinforced concrete elements, considerable corrosion of the reinforcing tendons was found. The paper outlines some questions of dimensioning strengthening by supplementary post-tensioning.

RÉSUMÉ

L'expertise de bâtiments construits par éléments préfabriqués et solidarisés par post-tension a montré la corrosion considérable des câbles de précontrainte. L'article traite de certains problèmes du dimensionnement lié au renforcement des planchers endommagés en utilisant la précontrainte additionnelle.

ZUSAMMENFASSUNG

Es wurden bei den aus Fertigteilelementen, durch nachträgliche Vorspannung zusammengesetzten Gebäuden bei den Spannkabeln der Decken bedeutende Korrosionsschäden entdeckt. Der Artikel wirft einige Fragen zur Dimensionierung der Verstärkung durch zusätzliches Vorspannen auf.

1.INTRODUCTION

The IMS structural system tensioned together from precast reinforced concrete units is primarily fit for construction of dwellings and public buildings. The system was developed in Yugoslavia the late 1950s, however, it has been used in several countries. Since the middle of the 70s, about 400,000 m^2 floor has been built using this method. In the original version, in every field, one precast "waffle slab" unit is joined to the columns through the cut-outs at the edges by tensioning the columns together in both directions after filling the joint gaps with a material rapidly hardening (Fig. 1).

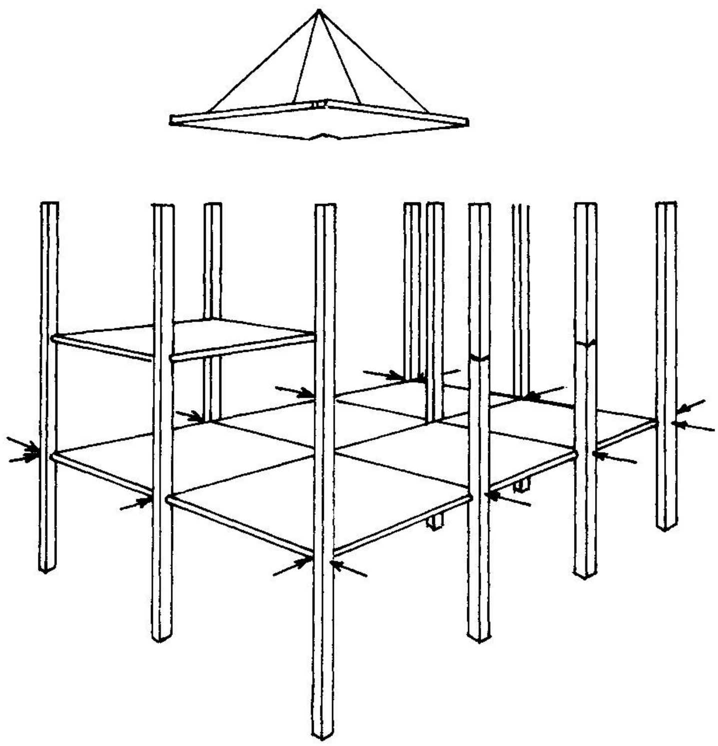


Fig.1 The IMS construction system

Later the system has been developed by tensioning the floor panels together from several (two or four) precast floor units. Thus, larger column distances became possible. Interaction of the multielement waffle slab structure is provided by primary tensioning in the column lines and by secondary tensioning applied in both directions in the span-thirds.

In the system, the horizontal and vertical connections of the structural units are created by post-tensioning, thus, in the multielement system, also the bending capacity is guaranteed by the tensioning alone.

Stresses of the waffle slab floor were computed by a lattice model, effects of the supplementary tensioning were considered as external forces concentrated in anchoring and inversion points of the tensioning tendons [2] (Fig. 2).

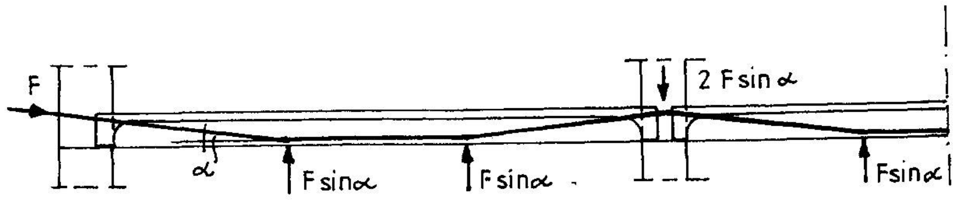


Fig.2 Concentrated external forces equal to tension force

The grid system will be statically solved by a spatial bar system program, thus, components of the stressing forces in the floor plane can be considered, consequently, also the normal forces can be computed in addition to bending moments and shear forces.

Efficiency of the strengthening by post-tensioning fundamentally depends on the distribution of the normal force originating from the stressing force applied concentratedly in the waffle slab ribs as well as on moments and reactions due to replacing forces arising in consequence of zig-zag cable arrangement and acting perpendicularly to the floor plane.

Parameter tests were carried out on a quarter of a fictitous building of 18,0*42,0m. Effect of the subsequent steps of the transverse post-tensioning, that of the column stiffness, role of the location of force application, effect of the possible different lattice models as well as the role of the 3,5 cm thick floor slab in stiffening have been investigated. Test results are summarized below.

4. COMPARISON OF THE POSSIBLE LATTICE MODELS

Distribution of post-tension forces introduced at the edges of the floor slab primarily affects the size of reaction force to be taken by friction in the floor-to-column joints. Determination of the normal force to be considered in the joint is a rather uncertain job, and it considerably depends on the computation model applied. Therefore, computations were carried out with different models for consideration of the effects of tensioning.

In the case of the spatial lattice model, degree of freedom in joints is 6, thus, for a large floor, accurate consideration of the floor structure may be difficult, and data preparation for a complicated model is rather time consuming.

The most simple model only consists of ribs (Model No.1), the next one - containing again only vertical bars - takes the influence of the slab between the ribs into account by computing the cover plate ribs (Model No.2). In-plane stiffening role of the 3.5 cm thick slab can be modelled by transverse grids either according to the Hungarian Standard with a width six times the slab thickness (6*v) (Model No.3-4.

2. LOAD BEARING CAPACITY LOSS

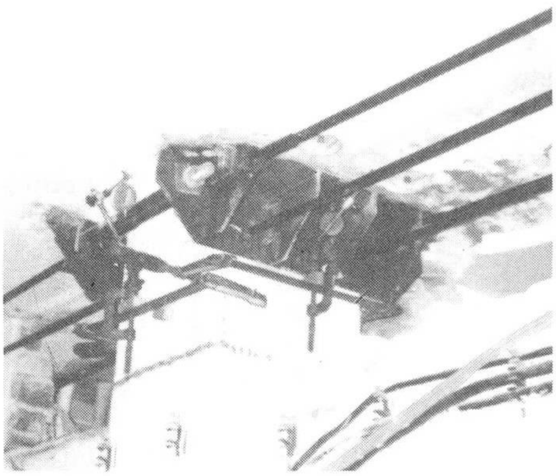
Since 1991, considerable corrosion of the reinforcing tendons in cable channels concreted subsequently has been found in IMS buildings in Hungary, mainly in floor-to-column joints.

Due to corrosion, efficiency of tensioning, thus, load bearing capacity of the floor decrease. Although probability of load bearing capacity loss in the most stressed cross-section increases considerably due to the gradual decrease of the tension force of about 30% according to computations [1], and surpasses the value of 10^{-4} allowed by the Hungarian Standard, this does not mean automatically the collapse of the floor.

However, the experience shows that corrosion failures do not occur gradually. In several cases, rupture of reinforcing tendons was found even in some cross-sections of only several year old buildings. Rearrangement of internal forces due to local rupture of the reinforcing tendons was investigated by the authors of the paper [1] by the spatial lattice model. It was stated that in the case of rupture of reinforcing tendons of one of the directions in the column-floor joint, the perpendicular moment of the same joint increased due to the rearrangement of the stresses so that probability of the progressive collapse of the floor considerably rises, i. e. strengthening of the structure becomes necessary.

3. FLOOR STRENGTHENING BY POST-TENSIONING

Load bearing capacity of the floor structures failed - especially in the case of multielement systems - can be most favourably guaranteed by supplementary post-tensioning. In order to avoid corrosion failures, tensioning strands in greased polyethilene tube should be used. Supplementary tensioning can be arranged - in function of the building's destination - either in the blocks of the waffle slab or under the floor plane usually by zig-zag strands (Photos 1 and 2).



Photos 1. and 2. Structural details

with/without eccentricity), or with the equivalent cross-section parameters suggested by Szilárd [3] (Model No.5-6. with/without eccentricity). Diagonal stiffening bars can be either hinged or clamped to ribs.

In any model, decrease of stresses computed from normal forces arising in ribs can be observed moving from the application spot of the tension force. Hinged or clamped joint of diagonal stiffening bars in model has no considerable influence, but eccentricity of the 3.5 cm floor slab cannot be neglected. At the column lying farther from the application of the tension force, the different models show an essential difference in the stresses that can be computed from the normal force. The most simple model fully neglecting the influence of the 3,5 cm slab is unfit for modelling, but even the model containing only cover plate ribs overestimates the stresses arising from normal forces (»35-40%) and bending moments that can be computed from tensioning (»15-20%) (Fig. 3).

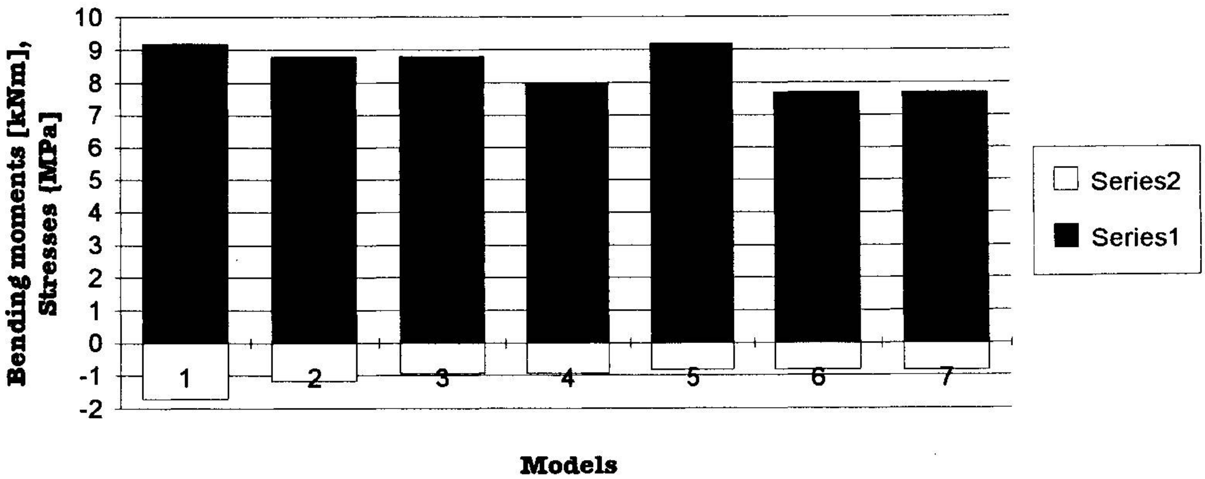


Fig.3 Effect of the different models. Series 1: Bending moment near the column, Series 2: Stresses computable from the normal force

Summarizing, we can state that distribution of the tension force and the effect of the 3.5 cm thick floor slab can be only considered by a sophisticated model. The proposed model is: perpendicular cover plate ribs according to the Hungarian Standard + hinged bars after Szilárd + eccentricity; but of course, it can be a mixed model, too, consisting of bars and flat shells.

5. SUPPORTING EFFECT OF COLUMNS

Colums can be regarded as clamped between floor planes. From their displacement stiffness, a horizontal spring constant can be determined, and this was added to the vertical point-like support as boundary condition. The examination aims at determination of the degree of decrease of the efficiency of tensioning by horizontal displacement stiffness of the columns coming away from the introduction spot of the tension force. Comparison of the stresses computed from normal forces of the ribs in cables' direction after the complete stressing of the building show that this is a ≈3% decrease so it is not essential.

6. SUBSEQUENT STEPS OF POST-TENSIONING

Distribution of the normal force due to the tension force was investigated with the assumption that tensioning occurs symmetrically right and left from the axis of symmetry of the building. Formation of stresses computable from normal forces arising in ribs in direction of the cables is shown in two different steps in Figs. 4. It reveals that the influence of the particular steps of tensioning is considerable only in a zone of about 2 m of the columns - because of the essential in-plane stiffness of the grid. Consequently, the sequence of the tensioning has no particular influence on the final stresses arising from tensioning - in the case of the specific tension force of 1-2 MPa sufficient in practice.

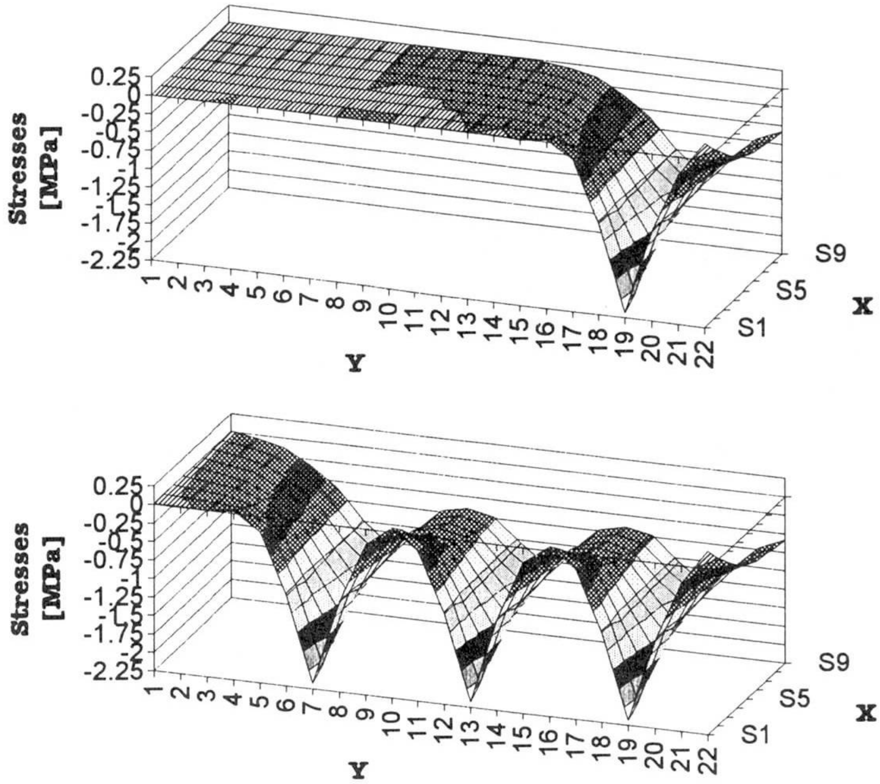


Fig.4 Distribution of stresses computed from normal forces arising in ribs in the cables' direction after the first and third steps of tensioning

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