THE DAMAGE OF THE TALL BUILDING AT PÉCS

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Abstract

In the structure of the 24 storey tall building at Pécs constructed by IMS prestressed concrete skeleton system in 1975-78 significant corrosion damages occurred at the prestressing tendons of the column floor-slab joints because of the high chloride content of the joining mortar. After only 10 years of service 70 per cent of the prestressing tendons were severely corroded and almost 30 per cent of them failed. Because of loss of the prestressing force the interaction between the floors and columns of the floor-slab system and the stiffening system of the building was weakened. Especially the cantilever type facade structures have got in a disadvantageous state while at the crossings of the prestressing wires and the columns and at the anchorages of the cantilever beams there are ungrouted sections. Because of the decrease of the safety of the structure the building containing 250 flats was evacuated for the period of the strengthening works. The detailed examinations of the experts proved the necessity of the given measures and simultaneously worked out the basic theoretical ideas of the strengthening of the structure.

The column – floor junction (the local reinforcement) has to assure

the support of the floor-slabs at the columns;

the interaction and mutual work of the floor system;

the safe fastening of the cantilevers.

From the different variants the method which applies for the support of floor-slabs reinforced concrete drops at the edge columns and steel collars at the internal ones seems to be the most advantageous.

For the repair of the stiffening system (the global strengthening) it is necessary to hold together the floor-slab system. Advantageous is the method which does not require the alteration of the foundation structure. The detailed inspection showed that by the strengthening of the top bracing of the existing shear walls the rigidity of the building might be guaranteed.

According to the examination carried out it can be stated that the strengthening is technically possible.

The supervision of the more than 300 000 square meter buildings constructed in Hungary by the IMS technology, the development of the methodology of corrosion exploration at damages and the improvement of the strengthening method were initiated with the inspection of the tall building at Pécs. The recognition of the corrosion at damages allowed to start the well organized strengthening works.

Keywords: IMS prestressed concrete skeleton, tall building, prestressed concrete floor-slab, prefabricated skeleton, chloride corrosion, corrosion of prestressing tendons, strengthening of floor-slab, strengthening of stiffening system.

1. Introduction

The design of the 24 storey high tall building at Pécs was started in 1973 and the construction work was started in year 1975. (*Fig. 1*). The building was constructed by the Yugoslavian so-called IMS prestressed concrete skeleton system and it was the first significant application of the aforementioned building system. The main features of the IMS system are the following: the one-part precast floor-slab was applied to the provisional cantilevers fixed to the multistorey prefabricated columns which in this state works as a beam lattice supported on its four corners. The 2–3 cm wide gap between the columns and the floor-slabs is filled with a special quickly hardening mortar (UP paste). Into the 15–20 cm wide gaps between the floor-slabs the prestressing wire bundles crossing the columns which then prestress them; in the ribs of the floor-slabs between the columns are placed compressing forces occur. At the meeting points of the columns and the floor slabs filled by UP paste compression forces exist and the so developed frictional force assures the vertical reaction forces of the floor-slabs. Thus, the application of supporting cantilevers in the final state is not necessary.

After filling the gaps between the prefabricated floor-slabs, the column-floor-slab joint is capable to endure significant amount of bending moment and this produces a skeleton structure containing the columns and prestressed beams in the line of the columns and the floor-slabs are working as beam lattices supporting to the prestressed girders. From the aforementioned is clear that the statical model of the structure during the construction process significantly alters.

The advantage of the IMS skeleton system consist in its capability for elastic displacements which is very profitable in earthquake sensitive areas and the material saving floor element. In order to gain experience on the application of the IMS skeleton system, the construction of the tall building at Pécs was permitted.

2. The Main Conclusions of the Inspection of the Building

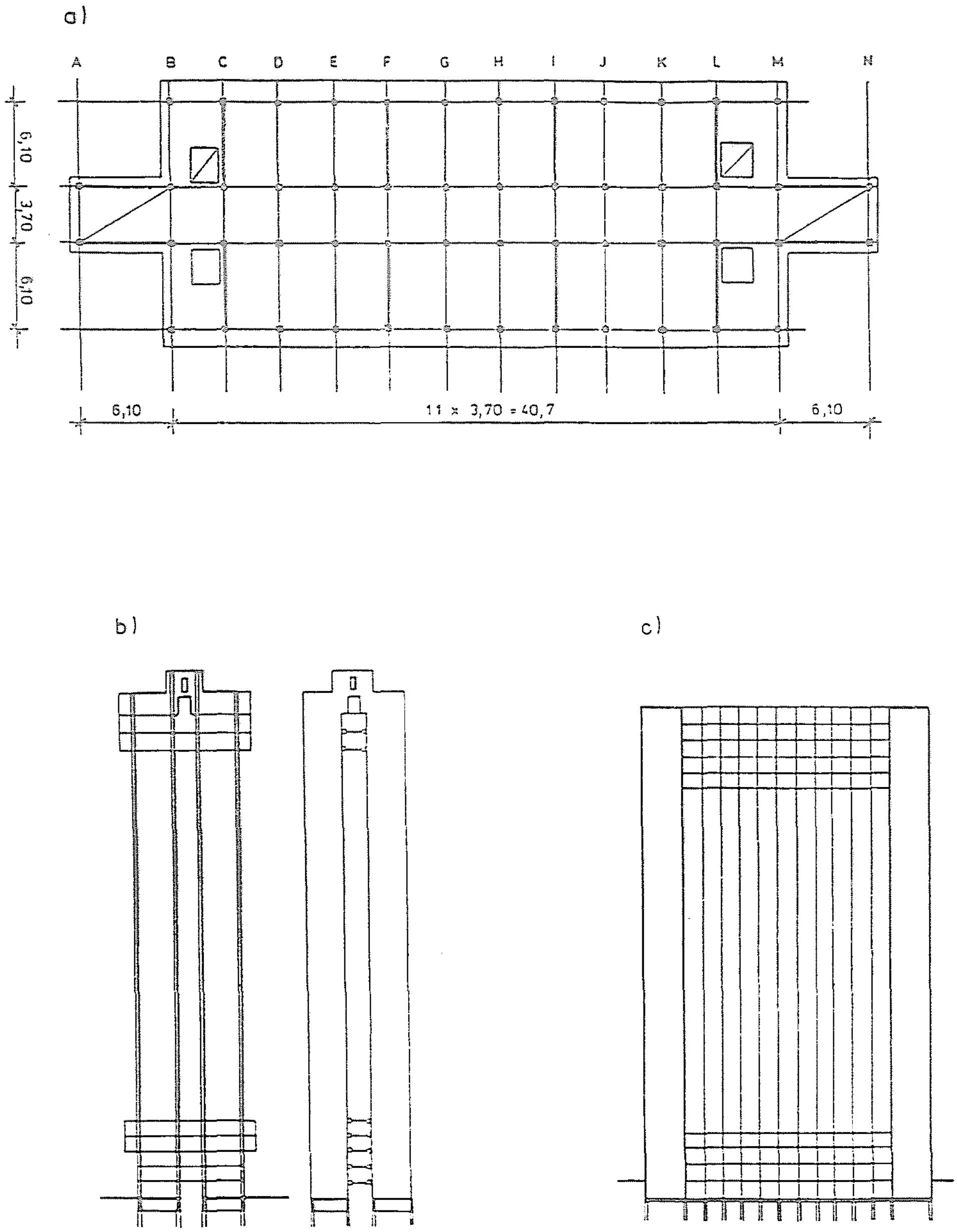
The Report summarizing the experience of the experimental construction today is not available yet.

The first inspection of the building was made in the year of 1983 [1]. At the top storey prestressing tendons were exposed the on 6 places and in every place initial corrosion was found. The proposals were:

to follow the exposures;

to check the grouted places;

to continue the exposures on the lower levels.


a)
A
B
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6,10
3,70
6,10
6,10
11 × 3,70 = 40,7
6,10
b)
c)

The second inspection for preparing the reconstruction works was made in 1989 [2] when at the upper stories already strong corrosion damages were found. Then the operator of the building ordered the detailed inspection of the corrosion problem [2] and the results of this inspection are contained in the 1989 year Report. The main statements of this Report are the following:

- from the 80 places investigated
  at 70 % strong corrosion,
  at 30 % failure of the prestressing tendons were found;
- the corrosion was caused by the high chloride content of the filling mortar – the UP paste – applied at the column floor-slab joints, the chloride corrosion always occurs in the neighborhood of the UP paste;
- the corrosion is an increasingly accelerating process which can cause a dangerous situation in a few years;
- at the crossing of the columns and at the cantilevers the prestressing wires are not properly grouted (*Fig. 2)*; they are in a critical state especially at the cantilevers subjected to weather effects and the facade elements supported by them.

According to the request of the operator (Pécsi Ingatlankezelő Vállalat) in November, 1991, the experts of the Department of Reinforced Concrete Structures TUB based on the results of the recent examinations of the site supervisions and the approximate calculations the following preliminary statements announced:

- because of the failure or strong corrosion in almost one third of the prestressing tendons the prestressing force significantly decreased;
- therefore the connection between the columns and the floor-slabs greatly weakened;
- the decrease of the frictional forces assured by the prestressing and the moment bearing capacity of the connection unfavorably influenced either the load-bearing capacity of the floors or the efficiency of the stiffening system of the structure.

The control analyses showed the design assumption of the interaction of the stiffening shear-wall system and the elastic skeleton. Because of the decrease of the moment bearing capacity of the skeleton, the stiffening wall system does not have the necessary safety because

- the safety of the floor-slab and the stiffening system decreased;
- the state of the cantilever facade may become critical and the danger of the progressive collapse cannot be excluded.

Meanwhile the analysis pointed out that due to the not calculated load bearing reserves of the structure there was no direct life danger yet. Such reserves are the interaction of the facade wall panels (different to the plans),

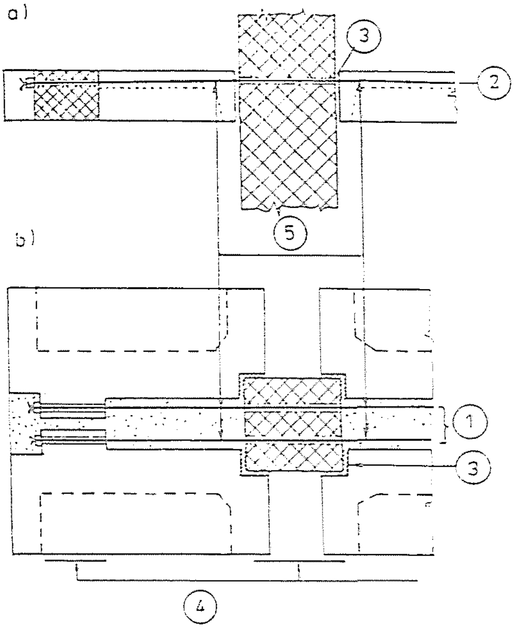

Fig. 2. The places of the wire corrosion and the ungrouted sections
a.) section, b.) ground plan,
1. cast in situ concrete, 2. prestressed wire,
3. joining mortar (PU), 4. ungrouted sections,
5. corroded tendons

the minimal probability of the simultaneous corrosion at failure among the near joints, the advantageous differences of the standard loads and the effective loads, etc.

Finally, regarding the suggestions of the representatives of the Department of Reinforced Concrete Structure the following decisions were made:

- the building must be strengthened;
- because of the decreased safety, for the period of the strengthening works the building must be systematically evacuated, for this a three months period is available;
- the strengthening is carried out in two steps:
  - provisional strengthening within a short period;
  - final strengthening in a one year period.

The evacuation of the building according to our suggestions was carried out by the end of March, 1990. In January, 1990 the Department of Reinforced Concrete Structures started the detailed expert analysis, the

Földmérő és Talajvizsgáló Intézet has continued the exploration of joints and the MODULTERV started the design of the strengthening.

The following detailed analyses essentially supported or evaluated the preliminary standpoint of the Department. Alteration only occurred in the estimation of the separation or the unification of the provisional and final strengthening. The detailed exposures showed that the state of the cantilevers suffering the weather circumstances were not worse than that of the internal joints therefore the provisional strengthening might be missed and the strengthening might be carried out in one step.

2.1 Other Characteristic Damages

In the following the main ideas and method of the strengthening of the building will be reviewed proposed by the Department in its Preliminary Report (June, 1990) and Final Report (November, 1991). The suggestions rose after the Final Report and the causes of the chloride corrosion are not dealt with.

The detailed expert supervision explored not only the chloride corrosion but several other characteristic deficiencies. Considering the load bearing capacity the most important problems are the following:

- The crossing of the columns and the prestressing wires are nowhere grouted properly, at several places the tendons are failed, in general strong corrosion is found.
- There are ungrouted sections at the end of the cantilever elements too (*Fig. 3*). This means plus danger even if there is no chloride contained mortar nearby.
- At the joint of the columns at some places the grouting was not carried out or in several places instead of cement mortar plastic mortar was applied which according to the exposure in some places is still in plastic state. This is dangerous because at the joints the force transfer is made by 100 x 100 mm large steel sheet and at the ends of the columns against bursting the amount of stirrups is not satisfactory.
- The wall panels of the facade which according to the design are supported on every storey by the end of the cantilever elements, because of the filling of the separating gaps along the total height (more than 50 meters) work as one unit of dilatation which makes the support on the cantilevers and the force equilibrating system uncertain.

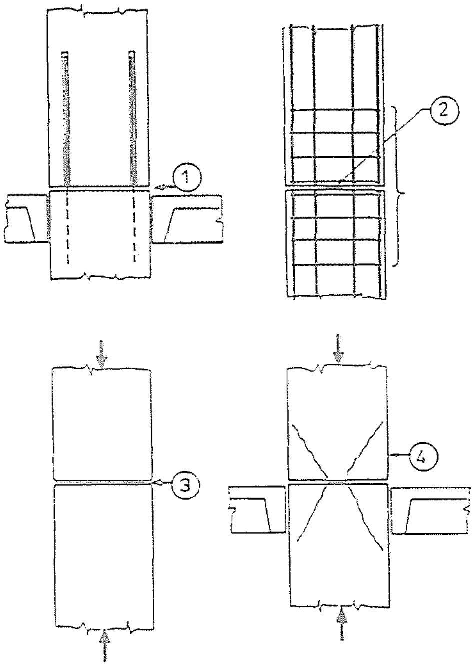

Fig. 3. The places of the column joint deficiencies
1. ungrouted joint,
2. steel plate,
3. effectively grouted joint,
4. cracks, splitting

3. Suggestions for Strengthening the Tall Building

In the case of the tall building the failures of the prestressing tendons because of the corrosion significantly decreased the safety of

the floor-slab system and
the stiffening system.

3.1 The Simultaneous Strengthening of the Floor-Slabs and the Stiffening System

In the process of choosing the strengthening method it would be advantageous to find the simultaneous way of strengthening the floor-slab system (local strengthening) and the stiffening system (global strengthening). For this purpose compensation of the loss of prestressing forces by subsequently applied cables seemed to be suitable and this way to restore the frictional forces and the moment bearing capacity at the column-floor-slab joints in order to combine the local and the global strengthening. This way unfortunately cannot be realized because at the floor-column joints:

- there is a need of compensation of the prestressing force (*Fig. 4*);
- the prestressing force is anchoraged beside the column in a 1–1.5 meter length by bond, in the length between the columns the prestressing force is acting (remaining prestressing) and so the prestressing is unnecessary;
- the subsequent prestressing in the middle section therefore can be disadvantageous;
- the subsequent prestressing is acting on the whole floor system. At the columns only a smaller part of the prestressing is effective and so the increase of the frictional force is hardly attainable. In the internal sections of a long building the effectiveness of the subsequent prestressing computationally cannot be followed.

From the statical point of view the curve shaped unbonded outer cables would be a possible solution but the realization of this solution is dubious.

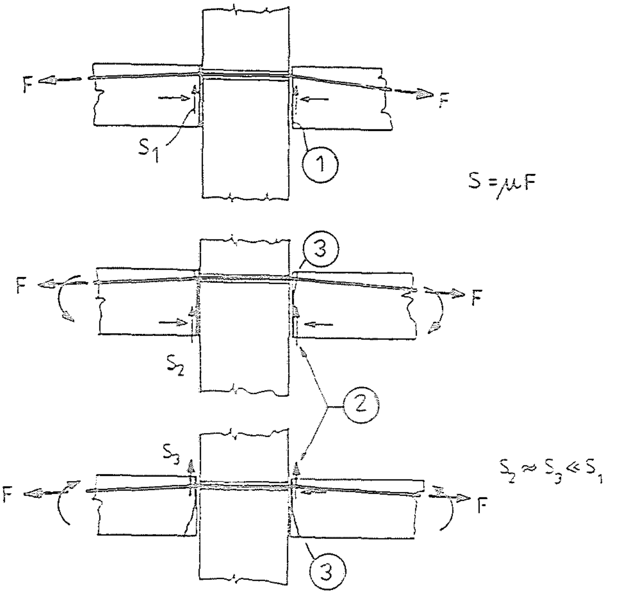

Fig. 4. The statical state of the column-floor-slab interaction
$S = \mu F$ force of friction,
1. The full cross-sectional area is under compression,
2. the area under compression,
3. cracks

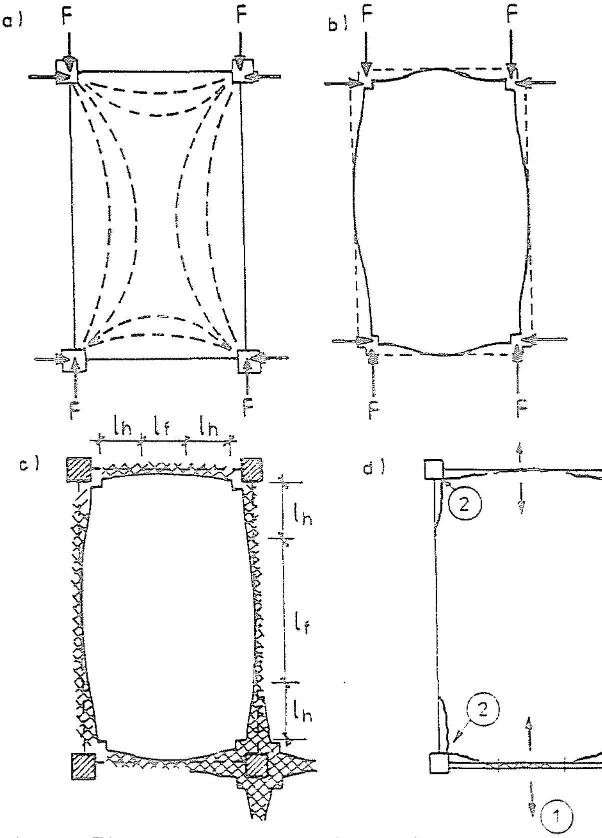

Fig. 5. The effects of prestressing in the floor-slabs
a. The distribution of the prestressing force. (Initial state),
b. The deformations after the prestressing.
c. State after the corrosion:
l_h - the length of anchorage
l_f - active prestressing length
d. Tension (1) and compression (2) in the floor-slabs

3.2 The Method of Local Strengthening

The checking of the precast floor elements showed that the middle part of the lattice could bear the actual loading merely by normal reinforcement. In spite of this that strengthening method is effective which is suitable to restore the initial force equilibrium state (*Fig. 5*). It is not easy to find such a method therefore it is necessary to satisfy the following requirements:

– the floor elements have to be supported at the columns;

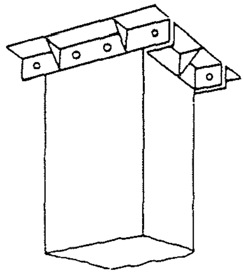

Fig. 6. Steel collar

- it is expedient to restore the bending moment bearing capacity, therefore
- the top bracing near the columns or a stocks like connection is advantageous to achieve the load bearing capacity and the connection of the precast floor system, the anchorage of the cantilever elements;
- the unity of the precast floor system at least in the surface of the outer columns of the building should be assured;
- at the joints of the columns protection against bursting is necessary ;
- the structure has to function in the case of extreme loads (e.g. earthquake).

3.21 The possibilities to strengthen the floor-slab system

From the numerous solutions the followings are used most generally:

1. Steel 'collar' (*Fig. 6*)
   - at the columns,
   - steel collar and beam support at the lines of the columns.
2. Steel structure twin girder support (*Fig. 7*)
   - simple twin girders on the columns,
   - twin girders with tensile struts.
3. Point supported plates (*Fig. 8*)
   - reinforced concrete drops,
   - steel grid work.

The different floor-slab strengthening methods can be applied independently or combined.

The solution of principle of the steel collar strengthening method is shown in the *Fig. 9* with the suspension of the cantilever (*Fig 9.a*) and with hanging (*Fig 9.b*). In each case there is the need of the circumference fastening of the structure (i.e. tie).

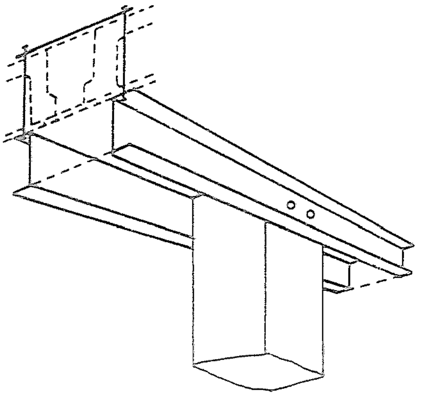

Fig. 7. Strengthening with twin girders

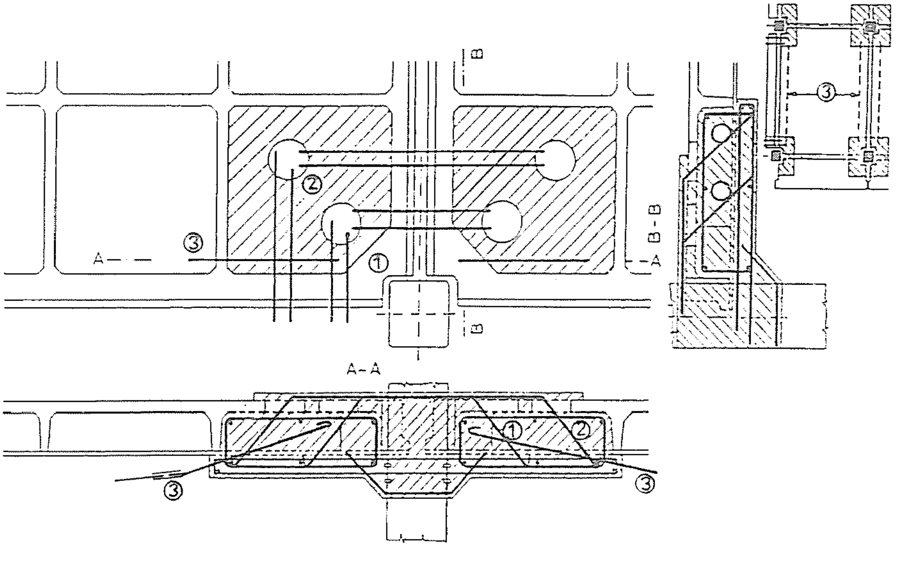

Fig. 8. Reinforced concrete drop
(1) and (2) shear reinforcement,
(3) bottom bracing

The reinforced concrete drop and the steel collar can be applied mixed (*Fig. 10.a*). At edge columns the reinforced concrete drop, at internal columns the steel collar is the most advantageous because

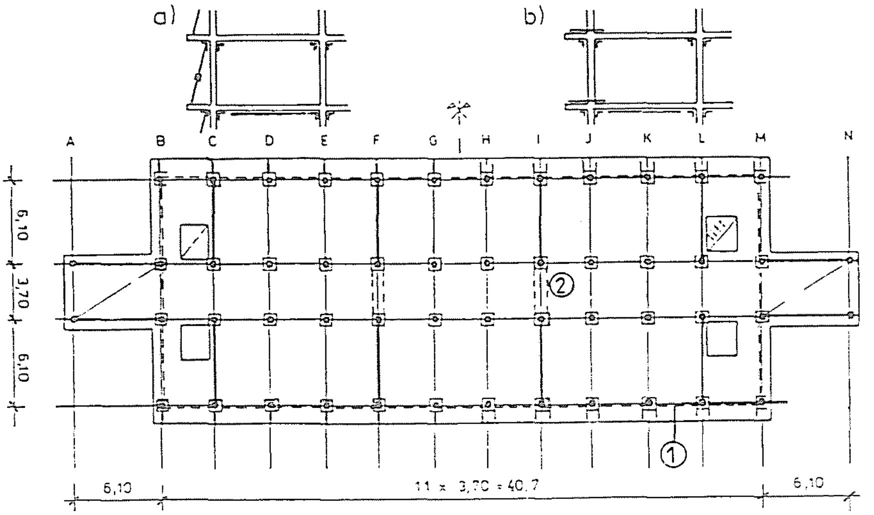

Fig. 9. The strengthening with steel collar
a. suspension of the cantilever,
b. bracing of the cantilever.
1. tie.
2. internal braces of the shear wall

- the reinforced concrete drop assures the collaboration of the elements therefore there is no need of ties;
- application of the steel collar at internal columns is simple and sufficient.

The further advantages of the reinforced concrete drops are the following:
- recovery of the bending moment load-bearing capacity of the column floor-slab joint;
- therefore at the stiffening system the frame effect works;
- in case of earthquake the structure has an advantageous significant plastic displacement ability.

When analyzing the failure mechanism of the in two directions prestressed floor-slab system in this tall building the following can be stated:
- at the internal columns in one joint even the simultaneous loss of the bisectional prestressing forces does not cause splitting of the floor-slab because the prestressing holds the structure together and so the floor element for geometrical reasons stretches;
- the internal joints get into critical state when the loss of prestressing force in both directions simultaneously happens at two or three neighboring joints;

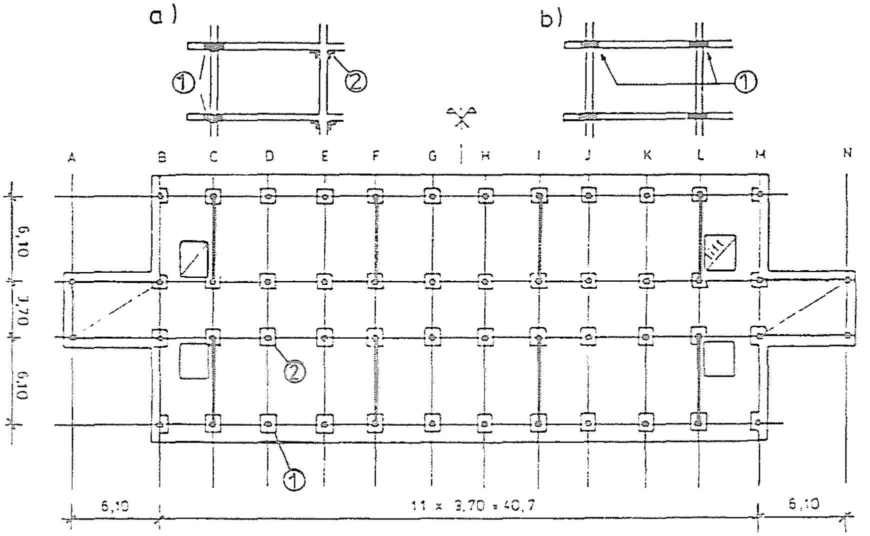

Fig. 10. Reinforced concrete drop and mixed strengthening
a. concrete drop (1) and steel collar (2),
b. concrete drop

- if the building in circumference sense is satisfactorily joined up then at the internal joints the simple vertical support is satisfactory even in the cases of extreme loads such as earthquake;
- at the corner or edge columns – especially at the cantilever cases – the failure of a single joint can cause a critical situation.

It is mentioned that in any case of the so-called multielement floor system, the analysis of the failure mechanism leads to significantly less advantageous result. Because of the frequent use of the single and multielement system, the analysis has to be made for each building.

3.3 The Global Strengthening

During the development of the stiffening system of the tall building, the interaction between the shear walls and the frame skeleton was assumed. Because of the decrease of the prestressing force the moment bearing capacity of the floor-slab-column joints is also reduced and the alternating bending moment from the wind load can lead to initiation of cracks on the upper and bottom part of the floor. Simultaneously with the compressed zone the frictional forces decreases too and the support of the floor unfavorably changes (*Fig. 4*). Because of the weakening or loss of the frame effect which was taken into consideration in design of the stiffening system the strengthening seems to be reasonable.

The main ideas of the global strengthening may be formulated as follows:

- it is necessary to assure the collaboration, the mutual in plane work of the precast floor elements;
- the overload of the shear walls has to be stopped;
- that mode of strengthening has to be chosen which is soluble with the existing foundation system and does not require the strengthening or alteration of the foundation; or
- the strengthening works are concentrated to one or a few places;
- the structural solution of the strengthening can endure the extreme earthquake-loads as well.

3.31 The possibilities of the strengthening of the stiffening system

The strengthening of the stiffening system of the building in the lateral and the longitudinal direction can be made by similar but slightly different methodology.

3.311 The strengthening of the stiffening system in lateral direction

The lateral stiffening system in its actual state is shown in *Fig. 11a*. According to the control calculations the actual top braces are overloaded. The possible variants of the strengthening are:

- to build in new shear walls;
- to alter the statical system of the existing walls, i.e.
- the strengthening of the internal braces
    - on every storey (*Fig. 11b*) or
    - in some places (*Fig. 11c*).

The most advantageous solution from the point of view of the structural forming as well as the constructing is the strengthening of the top braces. This has the advantage that the constructing works are concentrated in one place and there is no need to reconstruct the frame effect during the floor-slab strengthening, so it affords a solution to realize such strengthening which does not increase significantly the moment bearing capacity of the joints.

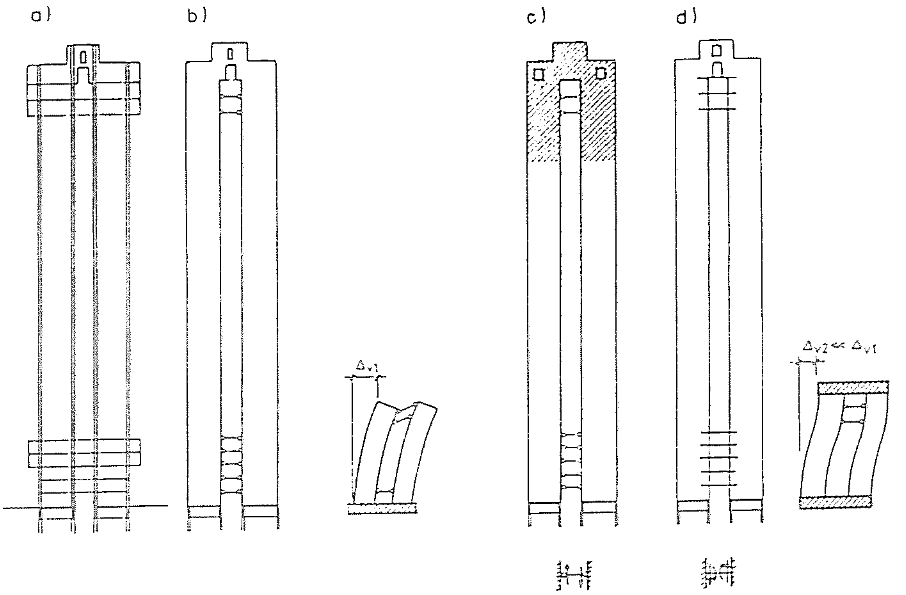

Fig. 11. The strengthening of the stiffening system in lateral direction

a. cross section,
b. the shear walls,
c. top bracing,
d. internal bracing

3.312 The strengthening of the stiffening system in longitudinal direction

The structural shape of the stiffening system is shown in *Fig. 12*. The stiffening system is hardly sufficient almost in the case of properly operating frame effect. The possible methods of strengthening are:

- to build in new shear wall(s);
- to reconstruct the frame effect;
- to alter the statical system of the existing walls by
  - partial or
  - total top bracing.

Among these variants we suggest again the strengthening with top bracing, namely the structural forming of the top stories of the building have to be altered in any case.

According to the control analyses the stiffening system of the tall building can be repaired most simply and effectively in both longitudinal

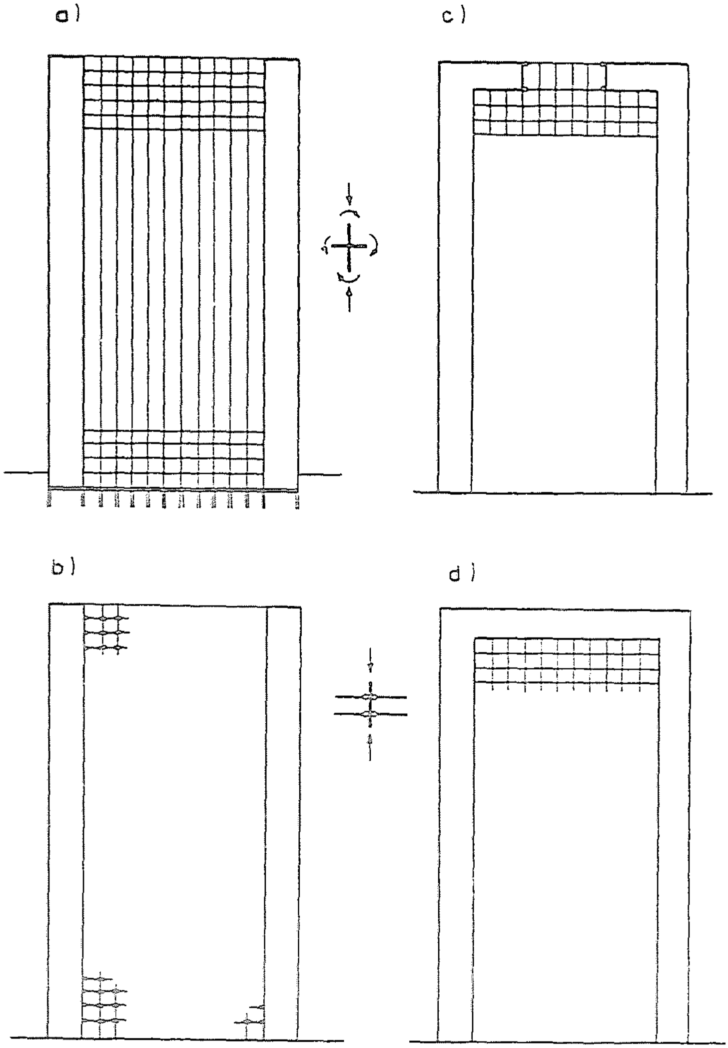

Fig. 12. The strengthening of the stiffening system in longitudinal direction,
a. the stiffening system,
b. the shear walls with frame,
c. partial top bracing,
d. total top bracing

and lateral direction by the strengthening of the top bracing of the existing stiffening shear walls.

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