

# Structural behaviour of members and connections in large panel buildings

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Objektyp: **Article**

Zeitschrift: **IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen**

Band (Jahr): **4 (1969)**

PDF erstellt am: **22.05.2024**

Persistenter Link: <https://doi.org/10.5169/seals-5944>

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**Structural Behaviour of Members and Connections in Large Panel Buildings**

Comportement statique des éléments et des moyens de liaisons dans les constructions en panneaux assemblés de grand format

Statische Wirkung von Bauteilen und Verbindungen in Großtafelbauten

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(1) Specific Factors in Assessing the Safety of Structures of Panel Buildings

My contribution deals with some specific problems arising from the structural behaviour of members and connexions in panel apartment buildings. Structures of this kind have become very frequent lately. The methods of design in such panel structures have achieved a considerable degree of development, e.g. [ 5 ]. Still, many problems in this field remain unanswered. The resulting situation has been largely conditioned by the specific structural qualities of panel buildings, as follows :

(a) Load-bearing structures in panel buildings are spacial, and considerably rigid. Consequently, they are noticeably responsive to the effects of some subsidiary influences, such as various volumen changes of the concrete - either caused by long-term loading ( creep ), or by changes in humidity ( shrinkage ) and temperature.

(b) Load-bearing structures in panel buildings consist of floor slabs and wall panels. The behaviour of the structure depends on the bearing capacity and rigidity of the structural connections.

In addition to these, there are further problems common also to all cast-in-situ structures that are formed of the same kind of material, such as heavy concrete, light-weight

concrete, structural tiles, etc. In assessing the safety of any building structure ( including panel building structures ) one must start, then, from taking into consideration the variability of each specific factor that might influence the behaviour of the structure in question.

In the first place we are confronted with factors which, from a statistical point of view, are random. They are, e.g., the loads, the bearing capacity of the members and connections, as well as the quality of their making. The possibilities of considerable deviations or errors in workmanship cannot be statistically registered, but they must not be left out of our calculations.

Answering the needs of the building practice, some semi-probabilistic methods have been developed. These methods investigate only the variability of loading in structural members and their connections, as well as the variability of their bearing capacity. The variability of other phenomena is to be ascertained by systems of subsidiary coefficients. Ideally, the amount of such coefficients should be as high as possible, in order to assess the behaviour of the structure with a maximum of precision. For practical reasons, however, the amount of coefficients should be limited to a usable extent. In the present state of our information on structural behaviour, particularly in large panel buildings, many coefficients are often assessed, not on the basis of statistical investigations or other theoretical considerations, but rather on the basis of experiments - or even according to the individual opinion and empiric experience of the designer.

## (2) Loading of Structural Members and Connections in Panel Buildings

In panel buildings, various kinds of loads and other influences are acting on the structural members and connections. The effects of horizontal and vertical loads are assessed by well-established methods. The variability here does not substantially differ from the variability observed in other kinds of buildings. Frequent damages have recently

been found in the load-bearing structures of panel buildings, mostly cracks in the inter-panel connections. Owing to such occurrences, greater attention was called to the effects of the subsidiary influences ( see above ) exercised on panels and their connections.

The effects of shrinkage can appear in panels some time after their production. For that reason, the assembly of panels of insufficient age should be avoided. Especially noticeable are the effects of the shrinkage of concrete in panels and of infill-concrete in vertical connections ( joints ) between respective wall-panels. The values of shrinkage present an extensive scatter, as they are dependent on the quality and composition of the concrete, as well as the humidity and temperature of the surroundings, which may be vary considerably. The calculation cannot embrace the total amount of the scatter. Consequently, necessary precautions must be taken during the production, and particularly during the assembling.

The effects of the creep may appear favourable in the horizontal sections of panel walls, where they contribute to the redistribution of the compressive stresses. Unfavourable they may appear in the vertical connections between wall panels, where their long-term compressive strains are different.

The joints of the exterior structures register noticeable effects of the changes in the temperatures of the respective structures. Usually the exterior panel undergoes a change of temperature in the direction of its thickness. The changes of temperature cause the deformations of panels. If they are prevented, thermal stresses appear in the panels and their joints. The magnitude of such effects varies considerably, because — even with identical material in the panels — many different conditions are operating, such as the local meteorological influences, the orientation on the cardinal points of the horizon, the intensity of sunshine, the make and colour of exterior surface.

These observations have been confirmed by the results of measuring an actual eight-floor panel building, which was being undertaken in the course of three years [ 4 ] .

In view of the character of these effects, and in view of the amount of contemporary knowledge concerning those effects, the procedure in calculating the structures is, for the present, as follows : either empirical coefficients are being introduced, which reduce the bearing capacity of connections, or fictitious forces are being employed, which determine, e.g., the dimensions of transversal reinforcements.

### (3) Bearing Capacity of Members and Connections

We have pointed out that the actual bearing capacities of structure members and their connections practically show some deviations from the design bearing capacities. The causes of such deviations have their origins either in the character of the structure itself, or in the method of calculation. Let us mention the most important factors in this line :

a) The strength of the concrete in actual structures differs from the strength ascertained by means of test cubes. This happens most frequently with the light-weight concrete.

b) The strength of the concrete in actual structures is lower than is required, which may be caused by insufficient control during the production of the concrete, or by special conditions during the hardening of the concrete ( this applies mostly to the infill-concrete in the precast structures ). Also, local reduction in the strength of the concrete may occur, e.g. in wall panels. Such events are dangerous in plain concrete structures.

c) The dimensions of the sections differ from the design ones. This may have various causes ; in the first place causes due to production or assembling.

d) Quite often one finds deviations from the design eccentricity of loading. It is well known that in calculating the wall panels and their horizontal joints a certain assembling eccentricity is being introduced, the magnitude<sup>of</sup> which is reckoned mostly on the basis of various considerations. It is desirable to arrive at a greater accuracy of eccentricities, on the basis of measuring actual structures, which of course would be very laborious.

e) Another source of deviations may be found in the methods of calculation. Either the calculation itself is merely approximate, or our present data of information are insufficient. This applies particularly to the bearing capacities of the various joints of panels. Moreover, in calculating, one may consider a different, less complicated fixing of wall panels than is employed in actual structure.

f) In all types of pre-cast structures, and the more so in panel building structures, deviations may occur in the bearing capacities of panels and their joints, owing to differing methods of assembling and their differing precision.

#### (4) An Example of Assessing the Safety of Joints of Panels

Since 1964 we have been engaged in theoretical and experimental research in the bearing capacity of selected joints of panels. The results of these investigations are shown in design formulae of joints.

The investigation on the vertical joints between wall panels was more fully reported on in [ 2, 3 ]. The investigation on the horizontal joints of wall and floor panels was shortly reported in [ 1 ]. On the whole, one hundred and fifteen full-scale test specimens have been examined ; they present various modes of connection.

In each kind of joint, it was found impossible to subject to experimental examination a sufficient number of models, which would yield results for statistical estimation. Consequently, eventual deviations from the design formulae of the design bearing capacity must be assessed with the aid of wider considerations based on the detailed knowledge.

An instance may be adduced from the horizontal joints of wall and floor panels. Let us consider a symmetrical joint, as per Figure 1 . Both wall and floor panels are solid. The thickness of the upper and the lower wall panel is identical. Also the thickness of the left and the right floor panel is identical. The loads, acting on the connection (Figure 1 ) are symmetrical. Usually the most dangerous section is section 2 - 2 . To assess this section, we presume a simplification of the loading, as

per Figure 2 . The reasons for this procedure are more fully explained in [ 1 ] .

The actual course of the compressive stress in the section 2 - 2 is shown in Figure 3 . For the treatment of the bearing capacity of the section 2 - 2 , the course of the stress as in

Figure 4 is assumed. It was ascertained experimentally that the area of the statically effective section  $\bar{F}_2$  is larger than the area of the sections  $F_1$  and  $F_3$  respectively, and that the bearing capacity of the section 2 - 2 can be expressed by the formula

$$\bar{N}_2 = R_{c,fl} \cdot \bar{F}_{fl} + R_{c,i} \bar{F}_i , \quad (1)$$

where  $R_{c,fl}$  and  $R_{c,i}$  mean the strength of the concrete in the floor slabs, and the strength of the infill-concrete, respectively,  $\bar{F}_{fl}$  and  $\bar{F}_i$  mean the respective areas of the floor slab ends, and of the infill-concrete,

$$\bar{F}_{fl} + \bar{F}_i = \bar{F}_2 .$$

For practical use we propose the following formula

$$N_2 = ( k_1 R_{c,fl} F_{fl} + k_2 R_{c,i} F_i ) k_3 , \quad (2)$$

where  $F_{fl}$  and  $F_i$  mean the respective areas of the floor slab ends, and of the infill-concrete;

$$F_{fl} + F_i = F_2 ;$$

$k_1 = 0,9$  is the coefficient expressing the local deterioration of the concrete in the area  $F_1$  ,

$k_2 = 0,7$  - the coefficient expressing the greater deviation in the strength values of the infill-concrete compared to the floor-slab concrete,

$k_3$  - the coefficient expressing the effectiveness of the area  $F_2$  ,

$k_3 = 1,0$  , if the floor-slabs are solid,

$k_3 = 0,9$  , if the floor slabs are provided

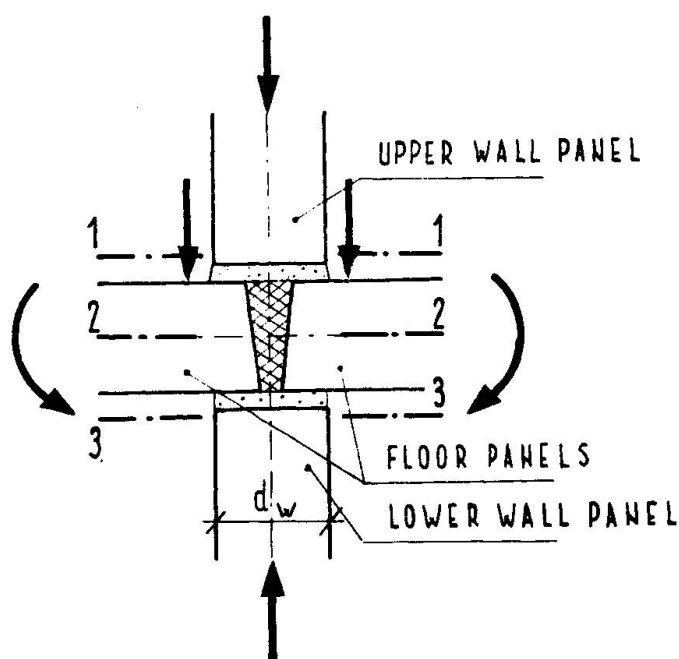


FIG. 1

SECTION 2-2

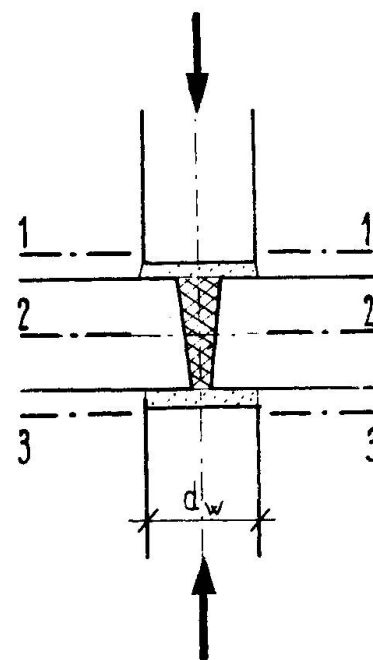


FIG. 2

SECTION 2-2

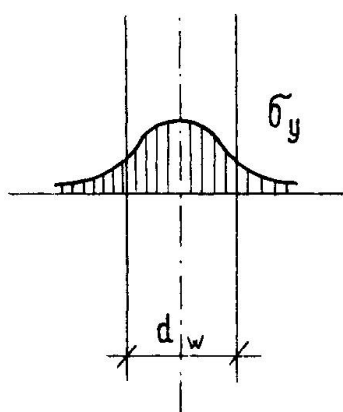


FIG. 3

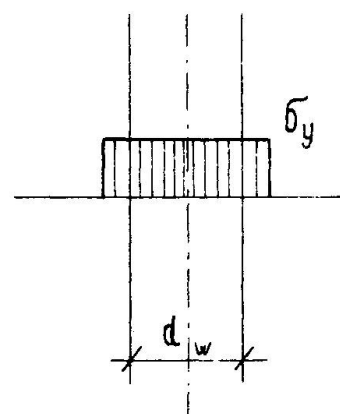


FIG. 4

with longitudinal holes.

The above formula (2) concerns a smaller area  $F_2$  than the area  $\bar{F}_2$  in the above formula (1), in order to express the unfavourable influence of some other factors acting on the joints.

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## SUMMARY

The safety of structures in large panel building must be treated taking into account special features of these structures. It concerns the loads and other subsidiary influences, as well as the bearing capacity of members (panels) and connections (joints). An example of assessing the safety of joints between wall panels and floor slabs, including the design formulae, is given.

## RESUME

La sécurité des constructions en panneaux assemblés de grand format doit être traitée avec les problèmes inhérents à ce genre de constructions.

Ceci est valable tant pour les charges et les autres influences, que pour la résistance propre à chaque élément ou liaison.

On donne un exemple pour le calcul de la sécurité des liaisons entre des éléments de parois et des dalles de planchers, à l'aide de la formule indiquée.

## ZUSAMMENFASSUNG

Die Sicherheit von tragenden Konstruktionen in Grosstafelbauten muss unter Berücksichtigung der speziellen Eigenschaften dieser Konstruktionen behandelt werden. Das gilt sowohl für Belastungen und andere Einflüsse als auch für die Tragfähigkeit einzelner Bauteile und Verbindungen (Knoten). Ein Beispiel zur Beurteilung der Sicherheit von Knotenpunkten aus Wand- und Deckenelementen mitsamt Berechnungsformel wird angeführt.