Structural stability of precast buildings

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Structural Stability of Precast Buildings

Stabilité structurale des bâtiments préfabriqués

Stabilität vorgefertigter Hochbauten

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INTRODUCTION

The great development in the industrialization of building and the vast proportion of constructions made of parts prepared in advance require both research and standardization for the various types of prefabricated building, and suitable constructive directives.

GENERAL STABILITY

The general stability of a system consisting of precast panels is determined in a decisive way by the vertical joints between the prefabricated elements and the horizontal belts between the components prepared in advance.

The function of the horizontal and vertical joints from the construction point of view is to secure:

a) the stability of the structure to horizontal forces, winds and earthquakes;

b) the stability of the construction as a means for the creation of an alternative system for the passage of forces in case of defect or failure in one of the elements or in the connections, in order to prevent a general destruction as a result from a "progressive-collapse";

c) the stability of the construction for the passage of the vertical loads.

HORIZONTAL FORCES

In spite of their great rigidity, the precast constructions are sensitive to horizontal forces, winds and earthquakes, as a result from the sensitivity of the connections between elements prepared in advance.

In comparison with conventional constructions which are relatively elastic and light, the horizontal forces operated on a precast panel construction in an earthquake are relatively great, as they are proportional to the rigidity of the structure and its weight.

Seismology enables today a precise registration of vibrations, and accelograms registered during an earthquake serve as data for the dynamic calculation of structure in earthquakes.

Most of the standards include a standard spectral line for the evaluation of the dynamic forces of a planned construction in an expected earthquake:

$$F_z = \alpha \cdot \beta \cdot \gamma_z \cdot \delta \cdot \theta \cdot \eta \cdot W_z \qquad (1)$$

F_z = equivalent horizontal force equals to earthquake.

As the dynamic coefficient β is function of the dynamic properties of the structure, it is important to determine the fundamental period of vibration "T". In the simplest way of a console with one mass "m":

$$T = 2\pi\sqrt{\frac{m}{K}} \qquad (2)$$

In a structure with a number of masses, the fundamental period of vibration T may be determined with the help of a computer, in a precise analytical way, or in an approximate way according to:

$$T = 2\cdot\pi\sqrt{\frac{\Sigma W_i A_i^2}{g\,\Sigma W_i A_i}} \qquad (3)$$

(See Figure No. 1).

In various standards, there are empirical formulas for determining the fundamental period; in the French "Règles Parasismiques 1969" [3] , there is, for example, a formula for the evaluation of a period suiting a structure with concrete walls, which, by its definition, is very close to the precast panel building:

$$T = 0.06\,\frac{H}{\sqrt{L}}\sqrt{\frac{H}{2L + H}} \qquad (4)$$

(See Figure No. 3).

On the other hand, in the American "Recommendation for Lateral Force" S.E.A.O.C. [2] , after the changing of the formula into metric units, and in the French standard P.S.69 [3] for reinforced concrete skeleton, the period T is evaluated according to:

$$T = 0.09\,\frac{H}{\sqrt{L}} \qquad (5)$$

(See Figure No. 3).

A comparison was prepared between period formulas (4) and (5) and is obtained in Figure (3) for constructions of a different width L_x, beside uniform load calculation Figure (2).

$$T = 2\pi\sqrt{\frac{\Sigma W_i A_i^2}{g \Sigma W_i A_i}}$$

$$T = 1.79 H^2\sqrt{\frac{W}{g E I}}$$

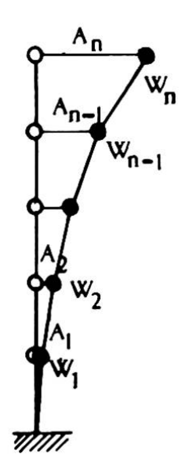

Figure (1)

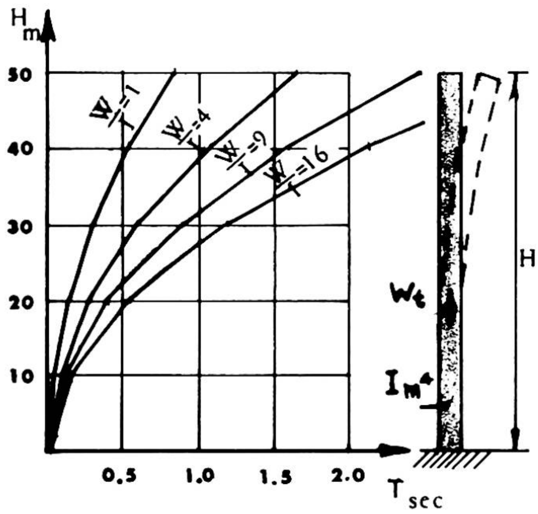

Figure (2)
Uniform load calculation

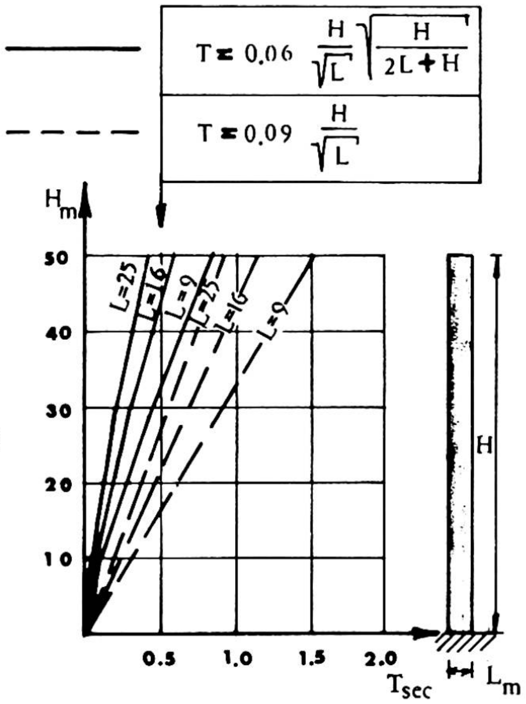

Figure (3)
Comparison between code formulas

Figure (3) shows that the evaluation according to formula (4) gives a lower period than formula (5), the lateral forces therefore being greater in precast panel constructions than in reinforced skeleton.

Partial results of computer calculation for a number of prefabricated buildings, show a higher period than formula (4).

UNEXPECTED FORCES

In the last years, we have witnessed a number of failures in precast buildings, resulting from forces unforeseen in advance, such as an explosion of gas container, of hot water boiler, etc...

In picture No. 4, are seen the results of a hot water boiler explosion, on the 4th floor of an 8 storey building in Jerusalem in July 1975. The building consists of precast facades and ceilings, and gables cast in situ.

The comparison of the results of the relatively great damage caused by the known explosion of a gas container on the 18th floor of a 22 storey precast building at Ronan Point, London, in May 1968, and the relatively small damage in the explosion on the ground floor of a precast building in Algiers, stresses the importance of the horizontal and vertical belts cast between the precast parts, for the stability of the construction in the case of such failures. "Ronan Point building was not properly braced as was the one in Algiers or as the CEB/CIB Recommendations require". (Reference [4]).

In order to prevent a progressive collapse in the case of failure in one of the construction components, there should be an alternative way for the passage of forces, as the precast parts are usually simply supported and the reserves in absence of fixing are small. There is a possibility of using a three dimensional system of belts cast around the precast parts, in order to ensure continuity, which may serve as substitute for the passage of forces, thus preventing a progressive collapse.

The efficiency of such a belt system depends to a great extent on the properties of the joints:

Figure (4)
Results of boiler explosion
in Jerusalem

a) Ability of the vertical joint between precast panels to transfer tangential forces on all the height of the wall, in a "joint organisé" with keys, etc., in order to secure a participation of nearby walls and to transfer them into one stiffening shear wall.

b) use of the intersection between the horizontal and vertical belts to transfer the shearing forces as a bolt ("verrou") 1 action.

c) possibility of the joints to transfer tensile forces by the reinforcement in the belts, by locking bars or by steel welding.

d) keeping infinite stiffness of the ceilings in their plane by belts between the ceilings and a suitable peripheral ring beam.

The reliability of the joints depends, inter alia, on their geometric shape and their execution. Fine sections, shrinking cracks and lack of precision in execution may cause failures which have not been taken into the account of stability.

VERTICAL LOADS

What characterizes precast constructions from the point of view of passage of vertical loads are the bearing walls with a big slenderness with a minimum reinforcement and sometimes with no reinforcement at all.

The load carrying capacity of such a bearing wall is influenced by the buckling following the big slenderness, by the eccentricity resulting from inaccuracies in execution and by eccentricity of the loads. In order to illustrate the buckling and eccentricity problems in precast constructions with their bearing walls, an example of curves was prepared [5] [6] on the basis of "CEB" recommendation [1] , as follows:

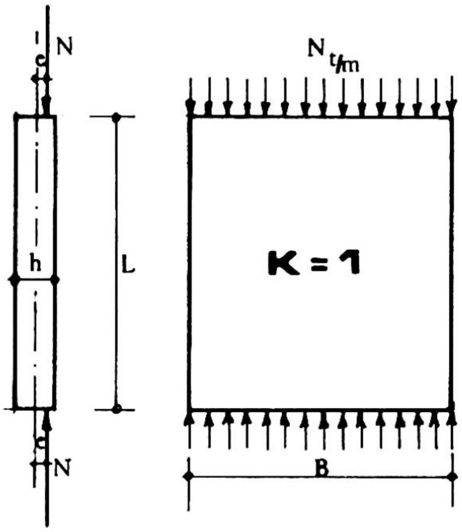

Figure (5)
Assumption is that the vertical ends are free

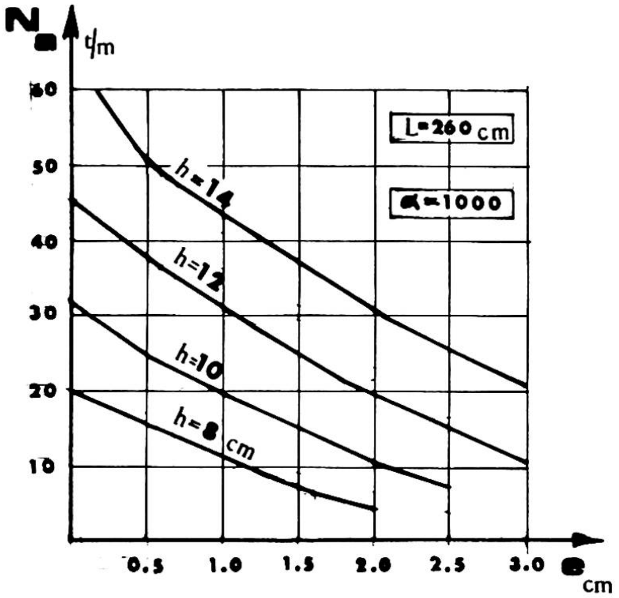

Figure (6)
Allowed load on walls as function of eccentricity for height of L = 260cm. and α = 1000

N_u - The load carrying capacity of the wall taking into consideration buckling.

$$N_u = \varphi N = \varphi\left(\frac{e^*}{h};\bar{\lambda}\right) \times \sigma_b \times A_b \tag{6}$$

$$\bar{\lambda} = \frac{L}{h\sqrt{\alpha}} \tag{7}$$

CONCLUSION

Precast buildings have specific stability problems both from the horizontal and vertical points of view. These subjects require the continuation of research and development.

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SUMMARY

In spite of their great rigidity, the precast buildings have specific stability problems, determined in a decisive way by the sensitivity of the connections between elements. The function of the joints is to secure the stability of the structure to horizontal and vertical forces, and to prevent a general destruction as a result from a "progressive collapse".

RESUME

En dépit de leur grande rigidité, les bâtiments préfabriqués ont des problèmes spécifiques de stabilité, déterminés par la sensibilité des joints entre les éléments. La fonction de ces joints est d'assurer la stabilité de la structure soumise à des forces horizontales et verticales, et d'empêcher une destruction générale découlant d'un effondrement de proche en proche.

ZUSAMMENFASSUNG

Vorgefertigte Hochbauten zwigen eine grosse Steifigkeit. Trotzdem existieren Stabilitätsprobleme, die vorwiegend auf die Verbindungen zwischen den einzelnen Elementen zurückzuführen sind. Die Verbindungen müssen die Stabilität der Tragwerke unter vertikalen und horizontalen Lasten sicherstellen und fortschreitendes Versagen verhindern.