INVESTIGATIONS ON THE BEARING CAPACITY OF CURTAIN WALLS

UNTERSUCHUNG DES TRAGVERHALTENS VORGEHÄNGTER FASSADEN-KONSTRUKTIONEN

INVESTIGATIONS SUR LA CAPACITE DE PORTANCE DE FACADES RIDEAUX

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SUMMARY

The construction and function of curtain wall structures were explained and problems were indicated which have to be regarded in determining the carrying capacity of these structures.

Explanations are given to cover experimentally the bearing behaviour. Special emphasis is laid on the necessity of theoretical calculations during test preparation, for the choice of the variables of the tests and especially for the interpretation of the test results.

ZUSAMMENFASSUNG

Aufbau und Wirkungsweise vorgehängter Fassadenkonstruktionen werden kurz erläutert, und es werden die Probleme aufgezeigt, die bei einer Beurteilung deren Tragfähigkeit zu beachten sind.

Verfahren zur versuchsmäßigen Erfassung des Tragverhaltens werden beschrieben und es wird auf die Notwendigkeit einer "theoretischen Begleitung" bei der Versuchsvorbereitung, bei der Auswahl der zu prüfenden Varianten und insbesondere bei der Beurteilung von Versuchsergebnissen hingewiesen.

Résumé

La construction et la fonction de facades rideaux sont représentées en bref et les problèmes devant etre prises en considération lors de la détermination de la capacité de portance sont indiqués

Les procédés pour déterminer la capacité de portance par des expériments sont décrits. On a souligné la nécessité de faire des calculs théoriques concernant la préparation de l'essai, le choix des variables d'essai et en particulier l'interprétation des résultats d'essai.

Key-words: curtain wall, bearing behaviour, extruded aluminium profile, testwall loading test, cover plates, load redistribution, air bag.

1 FORM AND FUNCTION OF CURTAIN WALLS

The curtain wall forms the skin of a building and is located in a defined distance in front of the bearing wall. Behind the facade plates is a continuous air space followed immediately by the thermal insulation layer. The curtain wall protects the insulation layer against humidity from outside, within the air space an air stream is circulating which transports both the water vapor defunding from inside of the building through the wall and the penetrated humidity from outside. Thus, a penetration of humidity is avoided and the long-lasting effectiveness of thermal insulation is guaranteed.

This facade system offers good physical behaviour and a wide variety of architectural possibilities; in practice it is therefore used very often.

2 SCHEME OF CONSTRUCTION

Normally the supporting system of curtain walls is composed of extruded aluminium profiles which, in order to avoid thermal bridges, were connected to the building as few as possible.

The profile may run in vertical or horizontal or even in both directions. The proper curtain skin composed of large-area and thin plates is fastened upon this substructure. Weather-resisting materials such as ceramic- or glass plates, high-pressure laminated sheet plates, cement or plastic-bound fiber plates, panels out of sheets, aluminium or plastics which normally are connected point-wise with the substructure are used. Normally these are brittle materials unable to compensate local overloads within the area of connection points by a yielding of the material.
For purposes of costs big fastening distances were chosen. Rivets, screws or metal clips were used as fastening devices.

In order to have space for movements due to temperature changes or to avoid stresses the diameter of the boring hole in the slab has to be bigger than the shaft diameter of the connection elements.

3 BEARING CAPACITY

The local bearing capacity of the slab within the connection area depends upon the diameter of the bore hole and the geometry of the connection element as well as the behaviour of the plate material within the bore hole area and is moreover influenced by the superposed bending stress of the plate. This stress, however, depends upon the distance of the fastening points and upon its distribution upon the substructure profiles, because, on behalf of the bending of the profiles at the different fastening points, "different settlements of columns" due to load shiftings appear. As all parameters influence eachother reciprocally there is a complex bearing system which, only in exceptional cases, may be computed as the mechanisms of possible stress shiftings were not known. Thus, the bearing capacity may only be determined by tests the real boundary conditions of which were stated as realistically as possible. Accompanying computations with varying parameters and punctual tests help, for complex systems with a great number of variations, to reduce the test volume and facilitate the assessment and evaluation of test results.

It goes without saying that the testing device has to be sufficiently resistant to deflection, as for statically indeterment systems the results may be influenced by possible deformations of the test wall. Furthermore it is absolutely necessary for the evaluation to register in relation to load, the deformations of the structure at the required places.

By using unsymmetric bearing profiles important additional stresses may be applied upon the connection elements of the facade cover as such profiles tend to twist. Furthermore it is possible that by an unpropriate choice of position and number of connection points the bearing capacity may be influenced unfavorably if no attention is paid to the interaction between substructure and cover plate. The following simple example shows that by placing additional connection points the bearing capacity is even reduced, whereas it should be noticed that either the plate or the connection element may fail.

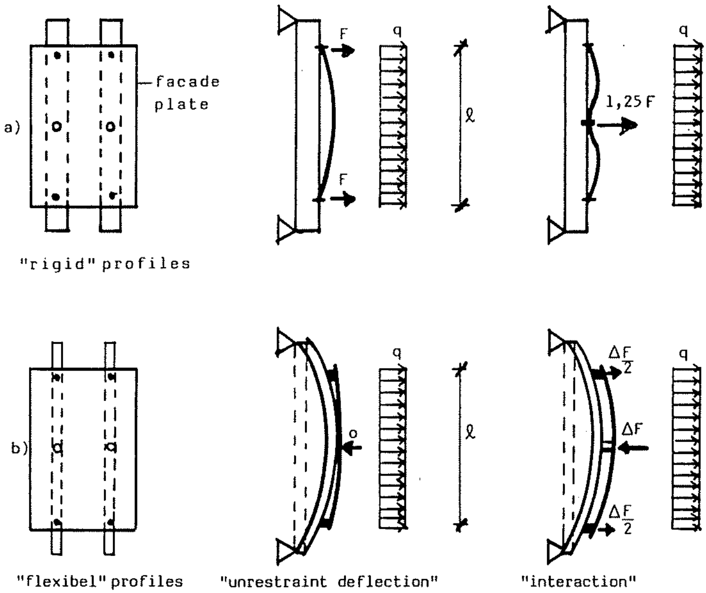

Fig. 1 Interaction between substructure and facade plates

According to fig. 1 a slab with 6 points positioned upon 2 "rigid" profiles is by 25% more stressed at the central fastening point than at the corner fastening for only 4 available fastening points. Thus, the central connection element, inspite of the in total bigger number of fastening points, will fail earlier than with only 4 fastening points.

4 DETERMINATION OF THE BEARING CAPACITY

In order to be able to estimate appropriately a facade system it is necessary to know the ultimate loads to be attained at different failure possibilities as well as the influence of a change of the distance of the connection points. These questions may be answered by so-called detail tests upon small sections of the facade in the statistically required number.
The connection element, for instance a rivet, may after the application of a centric tensile load, break within the shaft area or the sethead is drawn through the bore hole of the cover plate or the closing head is drawn through the substructure profile. The bearing capacity for the last quoted possibility depends upon the quality of the material and the wall thickness of the bearing profiles.

By stresses in the slap plane (absorption of the proper weight) either the fixing elements or the slab is submitted to shearing and breaks in direction to the free border.

The single tests upon the connection elements were carried through in an usual tensile testing machine using an appropriate facade element support.

In order to determine the influence of an additional bending stress, sections of the cover plates were supported in an annular way by supporting rings with different diameters so that the connecting element is situated in the central axis of the supporting ring, in this line of action they were stressed rectangularly to the slab plane. It is possible to simulate an internal connection (Fig. 2a) as well as a connection at the slab border.
The radius of the supporting rings corresponds approximately 0,2 times the distance of the connection elements.

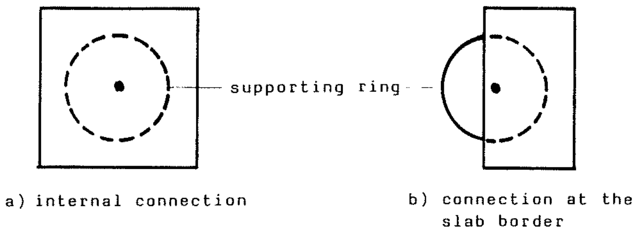

Fig. 2 Tests using supporting rings

For brittle materials the cover of which is composed of less extensive single elements (for instance ceramic - or natural stone plates) fundamental investigations for the estimation of their deformability and the influence of mounting precision are necessary, for instance single plates with 4 connecting points are rigidly supported at 3 points and at the forth "free" point a single load as tensile or compressive load is applied until failure of the plate. The deformations were measured and recorded. Furthermore rigidly supported plates were loaded at all 4 points with an equal load and, before that, deflected at one point back and forth to the building in order to determine the difference of the bearing capacity in comparison to the undeflected plate.

Furthermore the released bending stress of the plate which develops as moment peak in the area of bore holes of the plate, causes a failure of the plate even under lower loads.

If, on the contrary, the substructure profile is to flexible it may deflect more than the plate itself. Therefore under a suction effect in direction of the exterior load it is pressed against the plate in the mid-span; each of the two exterior fastening points have to absorb half of the resulting reaction forces. In this case an additional connection element in the centre wouldn't offer any advantage, as it is not loaded.

If the plate is fixed in a determined distance from the profile, for instance by placing a spacer at the connection point, an additional connection point in the center has even an unfavorable effect as the possible flexion without restraints of the profile doesn't happen and even under small load values restraints were produced.

The volume of the changes of tensile forces to be expected for usual placing of connection elements due to the above quoted effects may be drawn from the literature /1/ to /3/. The cover plate itself contains additional stresses. Especially for brittle materials this may cause a premature failure of the plate.

Calculations with finite elements show that even small torsions in the supporting area may change essentially the flux of forces. For a glass plate supported point for point around the bore hole area the result was that the border area besides the bore hole no longer participated in the transmission of the bending stresses, but the total bending within the area of the interior hole border has been transmitted with the consequence of increased bending stresses.

Finally it has to be mentioned that for "thin" plate materials and wider spans the contractions at the support increase so much for high deflections that an existing

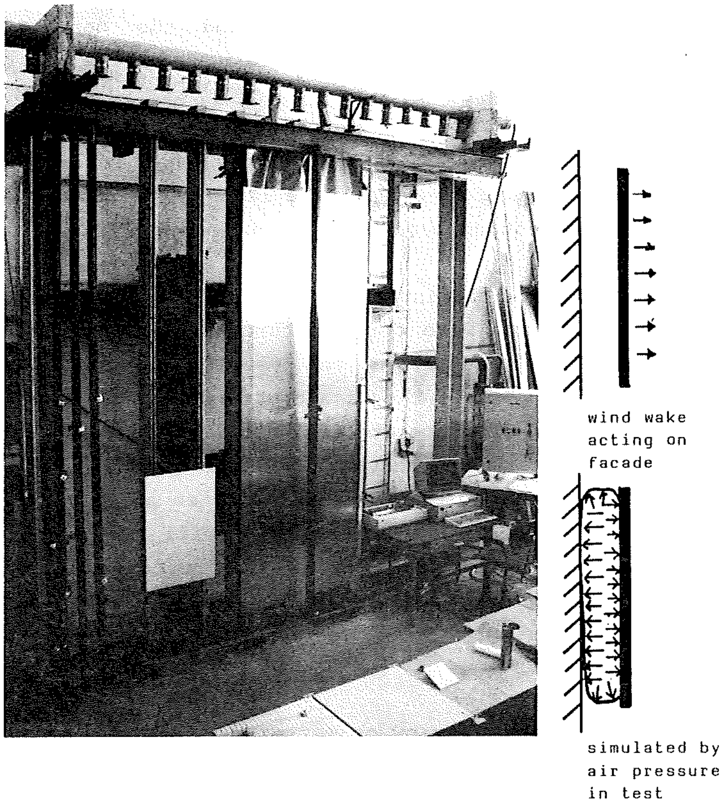

Fig. 3a Facade testing wall

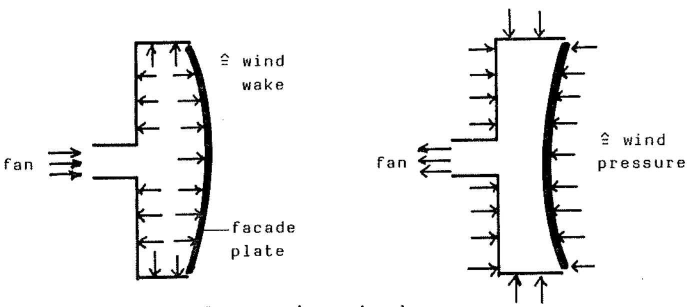

Fig. 3b Facade testing chamber

tolerance of the hole is consumed and the connection elements were moreover submitted to shearing stress.

The required tests were carried through either upon the facade testing wall, which is described hereafter, or in a testing room. At the facade wall the load is applied by air bags and in the testing room by a blast engine (Fig. 3).

In order to estimate the interaction of all single parts so-called element tests were carried through upon the facade testing wall which determine the bearing capacity of a representative section of the facade structure. For big-size story-high curtain elements at least two elements have to be loaded simultanously so that the center profile of the substructure gets the full load and a torsion of the profile due to the symmetric load introduction will not occur. A possible unfavorable influence of a profile torsion may be stated at the two existing and unilaterally loaded border profiles

5 TEST SETUP AND REALIZATION OF THE TEST

The above quoted facade testing wall is composed of a steel frame with vertical rigid girders. Guiding rails were welded to the front side of the girders upon which the wall supports of the bearing profiles were fastened by hammer head screws. The girders can be moved laterally and adjusted to the fastening axes. In the front area the space between the girders is bridged with timber plates. The air bags placed behind the facade slabs may completely support against these timber plates which, while blowing up, exert from the back side an equal surface load upon the facade plates. If for constructional reasons a loading of the whole surface is not possible, the air pressure applied in the tests is reduced mathematically in the proportion of the loaded to the really available total surface so that the loading indications relate to the total surface.

Normally loading is done in steps according the 40 mm of water. Every loading step is kept constant for about 1 minute. The air bags are blown up with a pneumatic equipment which, in the area of low pressure, owing to the existing electronic control, allows to apply any loads.

In front of the testing wall measuring rails are placed which may be moved rectangularly to the measuring plane. The deformations of the facades under different loads were measured with mounted dial gauges and recorded over an electronic data processing equipment and, for further processing, stored upon discettes.

A further possibility to test elements consists of mounting them as front face of a hermetic chamber and to apply the load by a blast equipment. This type of testing has the advantage that while simulating the wind suction stress by producing an underpressure in the chamber, the substructure at the facade back side becomes visible, the failure mechanism may be better determined and the different displacing components may be recorded separately.

The air pressure is measured by mercury-filled U-manometer with digital indication. The required pneumatic scattering is controlled over a pressure pick-off with a precision of 2 mm column of water.

6 THEORETICAL CALCULATIONS DURING THE TEST AND EVALUATION OF THE TEST RESULTS

It is obviously necessary before carrying through tests to get clear about the bearing mechanisms to expect because only in this case it is possible to consider the most essential points of the test run which may be important for a later evaluation.

It is particularly warned against deducing allowable loads only from ultimate loads of tests by dividing through a safety coefficient. It goes without saying that in the test, compared to a later application, existing higher material strength values submitted to reducing coefficients have to be taken into consideration. Furthermore particular features due to the system as well as influences which cannot be included into the test (for instance due to temperature changes) have to be taken into consideration.

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