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Rectangular staircases without beams

Balkenlose Treppen mit rechtwinkligen Grundriss

Escaliers rectangulaires sans poutres

Escadas rectangulares sem vigas

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1. *Introduction*

The most varied calculation methods have been adopted for the design of staircases consisting of rectangular flights and landings not supported by beams (1).

Besides the difficulties inherent in the calculations of plates, there is the further difficulty of defining the degree of support imparted to the flight and landing slabs by their intersection. The displacements of the intersection lines depend on the behaviour of the structure as prismatic.

Some results are presented of tests carried out on a plastic model and a reinforced concrete prototype. The main objective of the tests was to obtain information about the behaviour of this type of structures and so to be able to judge the calculation methods adopted.

The present case is considered to be another of the many examples demonstrating the advantages derivable from experimental studies, on both models and prototypes. In fact, the experimental methods not only supply information relative to the particular case studied, but, when suitably interpreted, furnish the necessary elements for judging the existing theories and the basis for establishing new calculation methods. This is of the greatest interest, in view of the limitations of the general theories which usually only give the solution of pratical problems when supple-

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(1) Zuchsteiner, W. — «Treppen» — Beton Kalendar, Zweiter Teil, Wilhelm Ernst und Sohn, Berlin, 1953. Krysztal, A. — «The Design of Staircases» — Concrete and Constructional Engineering, Vol. XLIX, N.º 7, London, July 1954.

mented by further hypotheses. Experiment suggests these hypotheses and allows their evaluation.

It is often verified that forecasts made before tests, even when made by experienced engineers, are as a rule invalidated by the experimental results.

These remarks apply, above all, to constructions that differ from the conventional ones because, for the latter, the experience accumulated often allows perfectly satisfactory forecasts to be made. This is only natural as for these constructions the stage for comparing the calculation methods with the actual behaviour of the structure has been passed.

2. *Experimental studies*

The experimental studies undertaken were made on a model and a prototype.

The model of methyl metacrilate (perspex), fig. 1, represented a staircase of the type shown schematically in fig. 2, to a scale of 1/20.

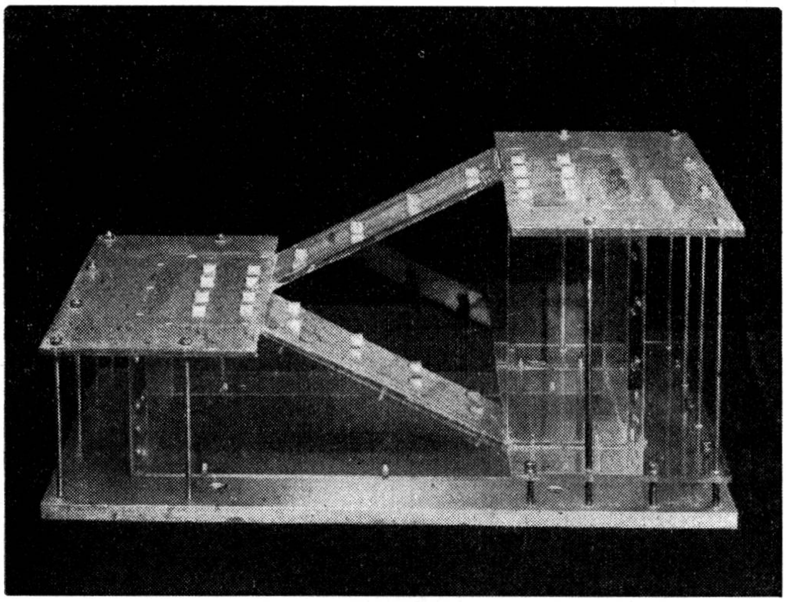

FIG. 1. Model to a scale 1/20

The numbers shown in fig. 2 indicate the dimensions of the model in centimeters. The model test consisted in the application of vertical forces and the measurements of displacements and strains at different points.

Table I gives some results obtained when applying concentrated vertical forces. Note that in spite of having sought to give a considerable horizontal rigidity to the model, this, when subject to vertical loads, underwent horizontal displacements which cannot be considered negligible.

Fig. 3 shows two of the influence surfaces of the bending moments. These surfaces were determined for 18 sections, by applying concentrated forces at different points and measuring the strains at the sections under study. Another test was carried out (fig. 4) in which a uniform load was applied. The deformation obtained is shown in fig. 5.

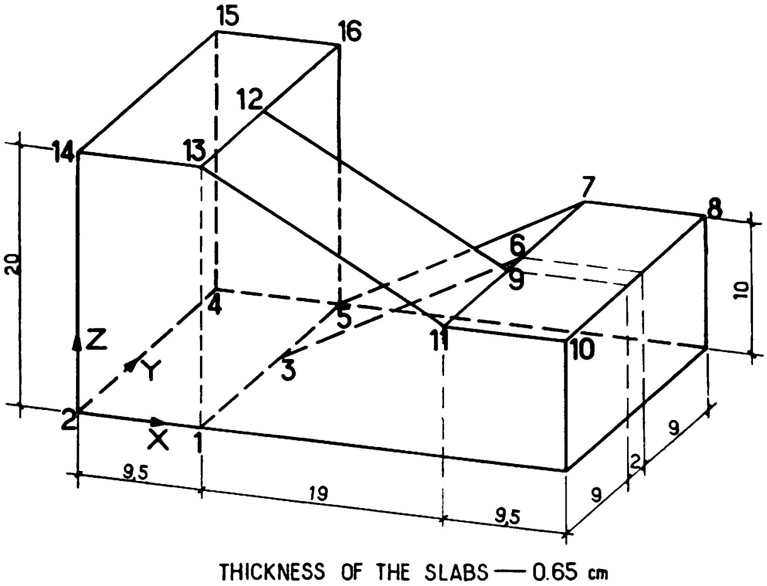

FIG. 2. Staircase studied on model

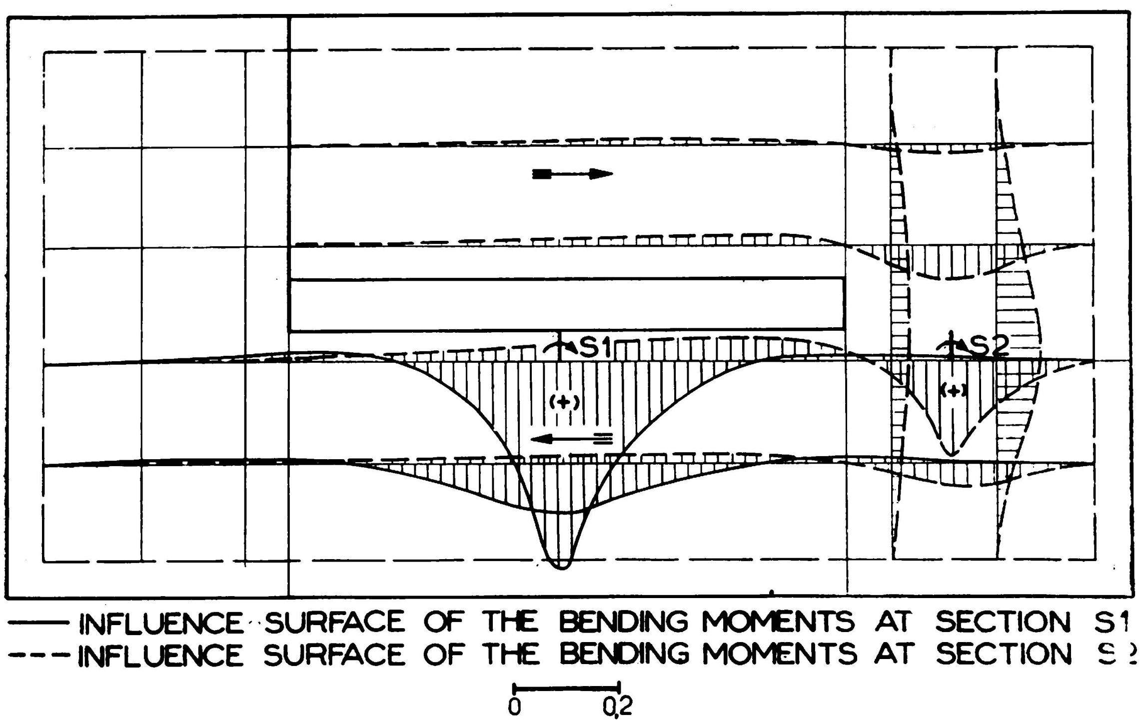

FIG. 3. Influence surfaces of the bending moments at two sections

The reinforced concrete staircase tested was of the type shown schematically in fig. 6. The landings were 20 cm thick, the flights 25 cm approximately and the rest of the dimensions are given in meters in fig. 6. As there was a guard which imparted considerable rigidity

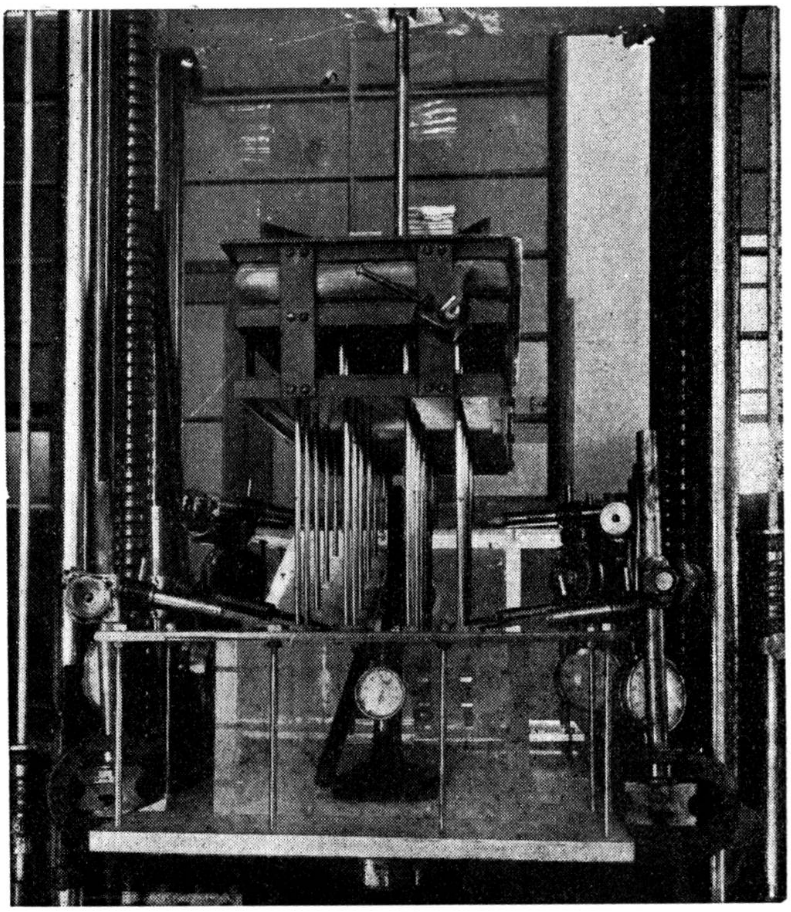

Fig. 4. Model test with uniform load

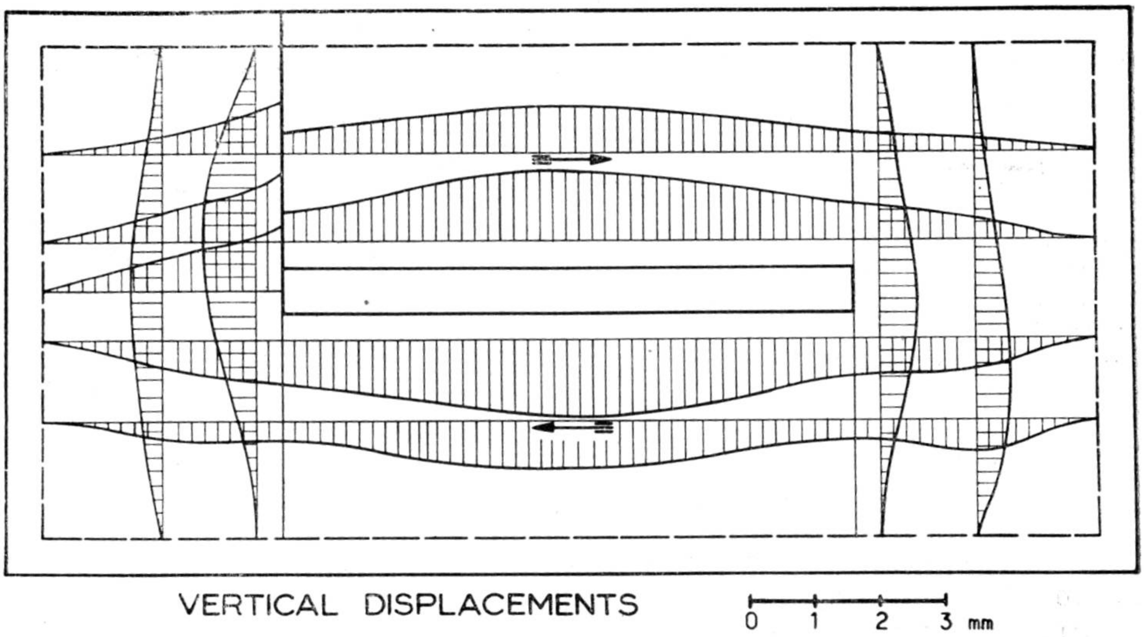

Fig. 5. Displacements due to uniform load

to the stair it was decided to make concentrated load tests before and after removal of the guard along line 17, 21 in the intermediate flight.

Fig. 7 shows the deformations obtained after removal of the guard for concentrated loads and uniform loads applied on zone (18, 19, 23, 24)

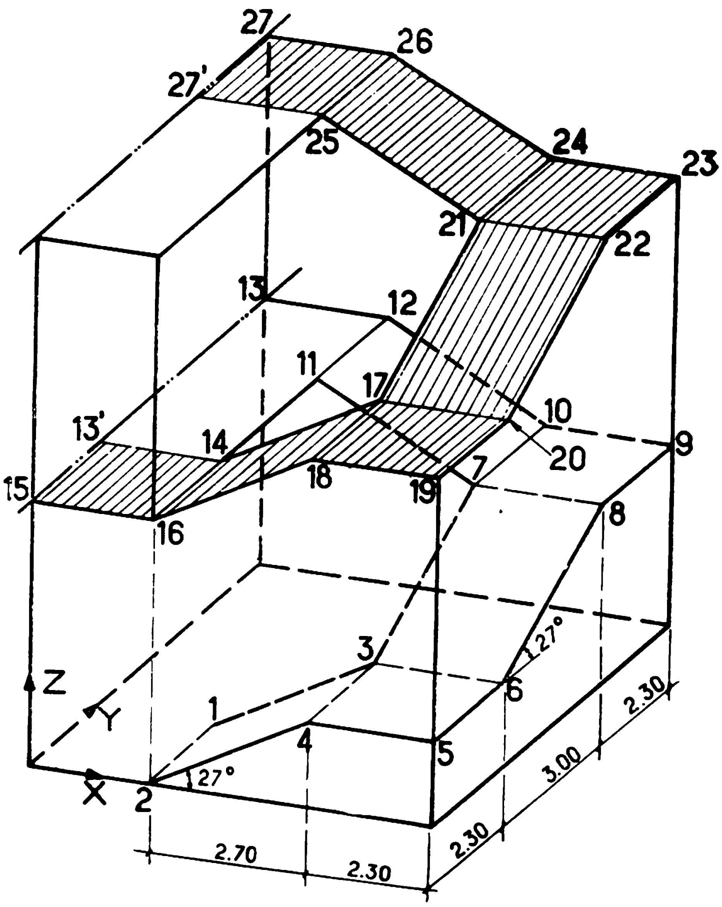

FIG. 6. Reinforced concrete staircase studied on prototype

and on the shaded zone (fig. 6). Attention is called to the considerable asymmetry of the deformations in relation to landings (17, 18, 19, 20) and (21, 22, 23, 24) which will be explained further on.

Fig. 8 gives a view of the application of the uniform load.

3. *Calculation methods*

The general theories of elastic calculation which are available cannot be applied directly to the structures concerned. The theory of plates makes it possible to study the separate behaviour of the flights or landings, but in order to be used it is necessary to know the boundary conditions which are not known, principally along the intersection lines. In fact the vertical displacements of these lines are partly impeded by the behaviour of the structure as prismatic (forces in the plane of the plates), but, the behaviour in this way imparts considerable horizontal forces which at times cannot be absorbed.

In this case, the vertical displacement of the intersection lines can increase in relation to what they would be when calculated on the basis of the structure being prismatic and assuming that supporting points in the wall cannot move horizontally.

Considering a vertical force applied to the intersection line (fig. 9), this force will resolve itself in accordance with the planes of the plates

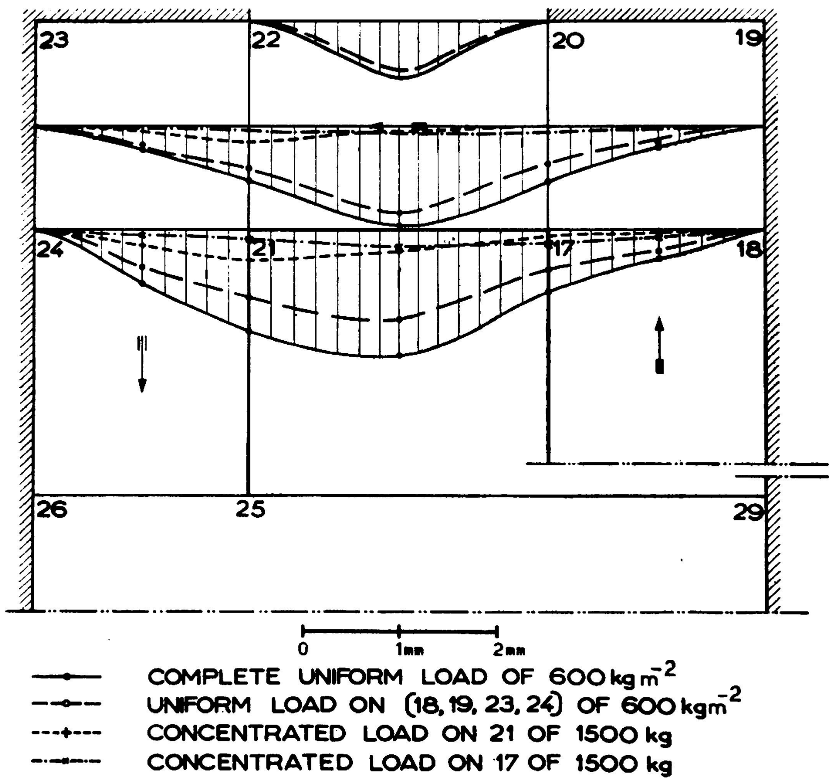

FIG. 7. Displacements measured during the test of the reinforced concrete staircase

and assuming that the points of the plates at the supports cannot undergo horizontal displacements, the vertical displacements of the intersection line can be calculated approximately from some simple hypotheses. It is considered that intersection lines remain straight and that the maximum stresses are constant along lines connecting the intersections to the supports.

Calculating, for the model of fig. 1, the displacements due to the application of a concentrated load of 10 kg at the intersection, in accordance with the above scheme, a displacement of 0.12 mm is obtained whilst the measured displacement was 0.20 mm. It is of interest to note that in the calculation the points of the other landings are assumed not to undergo deflection, which however is not borne out experimentally, as can be seen from Table I.

For the concrete staircase, the application of a concentrated load at the intersection (point 21, fig. 6), when considering the structure as prismatic, results in a calculated vertical displacement of point 21 of 0.03 mm.

The hypothesis of the structure behaving prismatically implies considerable horizontal forces, and whenever the structure cannot absorb these forces, horizontal displacements take place, which result in considerable vertical displacements of the intersection lines. Thus for example in the case of the landing (21, 22, 23, 24) of the staircase of fig. 6 when applying a vertical force in 21, forces are developed having horizontal components which tend to impose horizontal displacements of the supports corresponding to a clockwise rotation of the landing slab. These horizontal displacements result in vertical displacements of the intersections. In order to calculate these last displacements the scheme given in fig. 10 can be taken and torsional rigidity and bending moments due to the connection to the wall can be ignored, only taking into consideration the bending in a vertical plane.

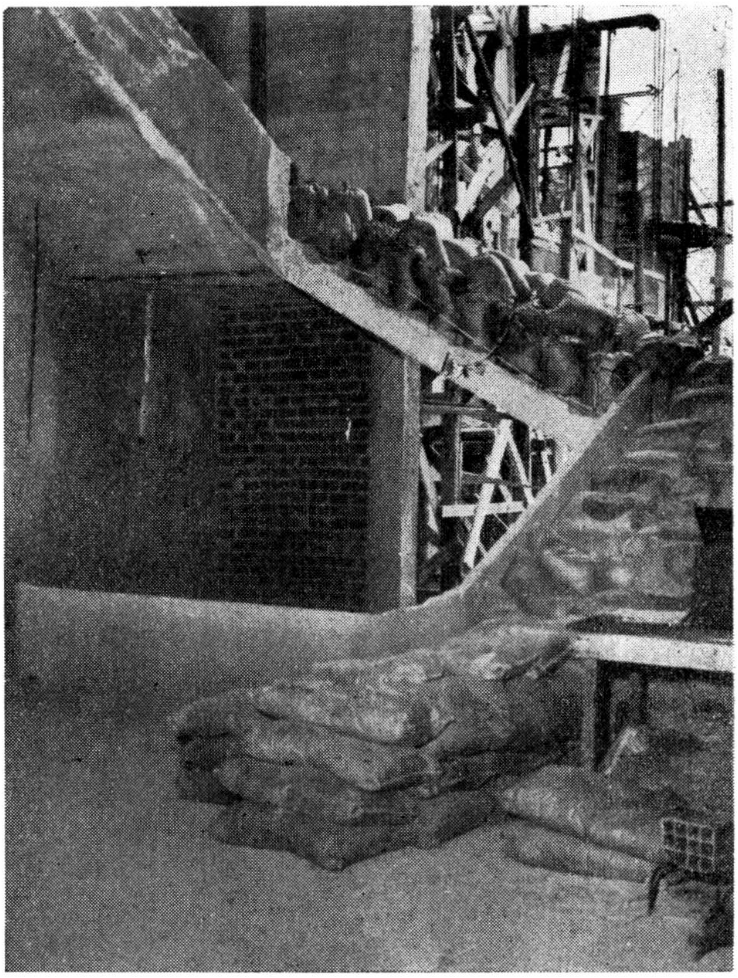

FIG. 8. Application of the uniform load

When the calculation is made in this way for a concentrated load of 1500 kg a vertical displacement of 0.40 mm was obtained, which is near the measured displacement of 0.31 mm, and much greater than the displacements computed when the structure is considered prismatic and joined to fixed points (0.03 mm).

The fact of the displacements of landing (17, 18, 19, 20) being much less than those of landing (21, 22, 23, 24) is explained by its rigid connection to the body of the building.

The above results show that it is very diffficult to obtain a horizontal rigidity which would give vertical displacements of the intersections equal to those calculated when taking the structure as prismatic.

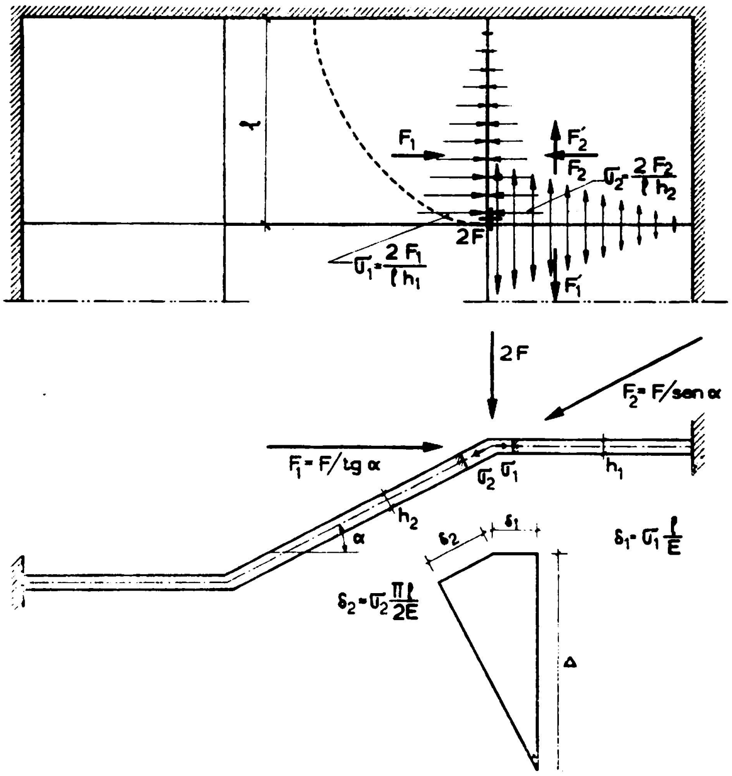

FIG. 9. Displacements of the prismatic structure

Even so, when the deformability of the staircase is small for the horizontal forces, the vertical displacements of the intersection lines between flights and landings are also small, and it would be justifiable to assume that these intersection lines function as indeformable supports in relation to the deformability of the slabs under bending. Such a hypothesis favours safety for negative bending moments at the intersections but is unfavourable for safety for positive bending moments in the middle of the flights.

When the deformability of the intersection lines is large, due to possible horizontal displacements, it becomes necessary to estimate this deformability and take it into consideration when designing the slabs. Note, for example, that in the case of the staircase of fig. 6, in spite of the important deformability of the intersections, they contribute considerably towards reducing the positive bending moments in the flights.

4. *Conclusions*

The above considerations show that the difficulty of designing staircases without beams derives from the interaction of three types

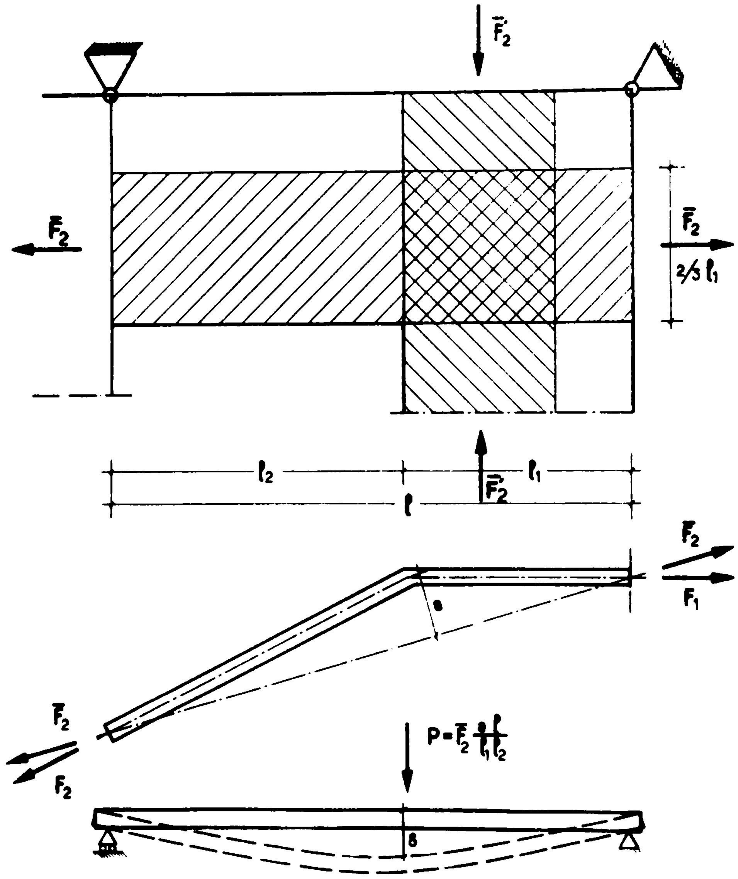

Fig. 10. Influence of horizontal displacements

of behaviour; as a plate, as a prismatic structure and in bending under the action of horizontal impulses acting on the flight and landing slabs.

In order to solve the problem it is of interest, above all, to determine the vertical deformability of the intersections, as once this is known, the problem can be solved with satisfactory approximation. This deformability depends not only on the geometry of the structure itself but also on the rigidity of the structure to which it is connected.

The considerations given are based on the criteria of elastic calculation. It is considered to be of interest also for this type of structure to develop methods of limit design.

In the case of the deformability of the intersection being small in relation to the deformability of the slabs, it should be possible to adopt a limit design for the latter assuming that the intersections behave as fixed supports. However, the value of such a method can only be proved by experiments planned for this purpose but which it has not been possible to carry out.

The author wishes to acknowledge the colaboration given by Mr. Arga e Lima in the studies related to this paper and by Mrs. Maria Emília Campos e Matos and Mr. João Madeira Costa who carried out the model and prototype tests respectively.

TABLE I

Forces		Displacements		
Point of application	Value kg	Point	Direction	Value mm
12	10	12	z z	— 0.20
		13	x x	+ 0.01
		16	x x	— 0.03
		9	z z	— 0.07
6 and 9	10	6 and 9	z z	— 0.21
		13	x x	+ 0.03
		16	x x	— 0.02
		12	z z	— 0.09
		3	z z	— 0.05
3	10	3	z z	— 0.10
		6	z z	— 0.03

SUMMARY

The results of model and prototype tests on rectangular staircases composed of slabs without beams are presented.

Design methods of this type of stairs are discussed. Such discussion is based on the interpretation of the experimental results. It is shown that to solve the problem it is especially important to determine the vertical deformability of the intersection line of the flight and landing slabs.

ZUSAMMENFASSUNG

Die vorliegende Arbeit enthält die Ergebnisse der Modell- und Prototypversuche an Treppen rechtwinkligen Grundrisses, bestehend aus nicht von Balken getragenen Platten. Auf Grund dieser Daten werden Verfahren besprochen welche zur Bemessung von Bauwerken dieser Bauart angewendet werden.

Dabei zeigt es sich, dass es besonders darauf ankommt, die lotrechte Verformung der Schnittlinien der Treppenläufe und -podeste festzustellen.

RESUMO

Apresentam-se os resultados de ensaios sobre modelo e sobre protótipo de escadas de planta rectangular constituídas por lages não apoiadas em vigas.

Discutem-se, a partir da interpretação dos resultados experimentais, os métodos de cálculo de estruturas deste tipo. Mostra-se que para resolver o problema interessa sobretudo determinar a deformabilidade vertical das linhas de intersecção entre as lages dos patins e dos lances.

RÉSUMÉ

On présente les résultats d'essais sur modèle et sur prototype d'escaliers, rectangulaires en plan, constitués par des dalles non appuyées sur des poutres.

Les méthodes de calcul de ce type d'escalier sont discutées en se fondant sur l'interprétation des résultats expérimentaux. On montre que, pour résoudre le problème, il importe surtout de déterminer la déformabilité verticale des lignes d'intersection des dalles des paliers avec celles des volées.

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