EXPERIMENTAL ANALYSIS OF THE DEFORMABILITY OF PARTITION WALLS

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1. Introduction

In recent years, examination of structural deformations and of consequences of excessive deformations has become prominent. One of the most frequent harmful consequences is failure of non-load-bearing structures joining the load-bearing members. To prevent similar deficiencies, one possibility is to delimit structural deformations so as to safeguard structural soundness through testing deformability of non-load-bearing members, determining the stress pattern due to deformation constraint. Beyond the analysis of actual building damages, also laboratory tests are needed, because here both the initial data and circumstances of the test are exactly known, permitting separate investigation of each deformation effect. In this study, investigation of partition walls — as the most frequently damaged structure group — will be presented, with results and conclusions.

2. The test program

In Hungary, common partition wall types belong to five groups with respect to structure and static behaviour:

1. partition wall systems of room-size units (precast r.c. partition walls);
2. partition walls composed of units (special bricks, gypsum perlite, etc.) both horizontally and vertically smaller than room-size, built in-situ with mortar joints;
3. partition walls built of vertically narrow boards, with mortar joints;
4. partition walls of thin, 10 to 15 mm sheets (plasterboard, chipboard, chaff panes, etc.) either nailed or screwed to the frame members;
5. partition walls of similar units as in group 4, only that sheets are not fixed to, but freely sliding in the grooves of the frame units.

Among the five groups the last one has not been examined because deformabilities of such partition walls are simple to deduce from geometrical data (slab size, groove size). Inherent deformation of a sheet in itself is negligible, but after being constrained in the frame, excessive slenderness may result in inadmissible buckling.

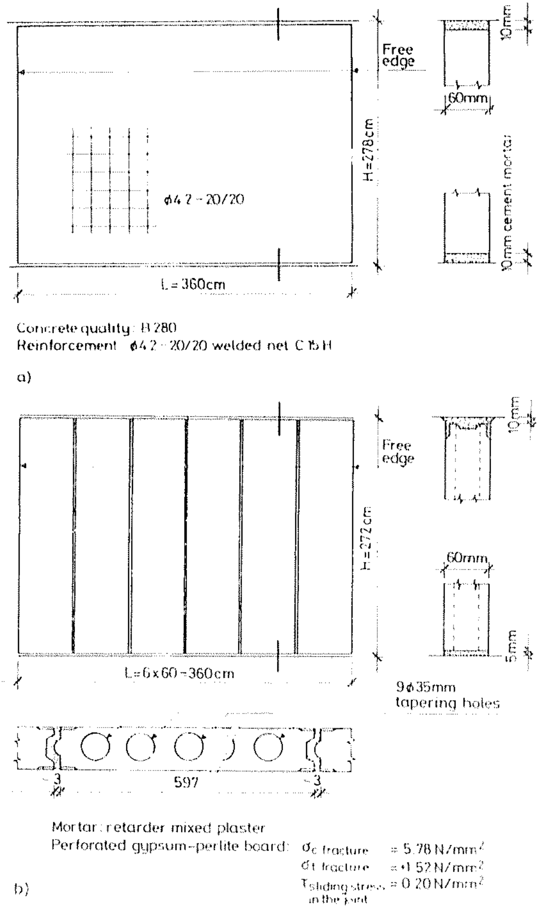


Fig. 1a, b

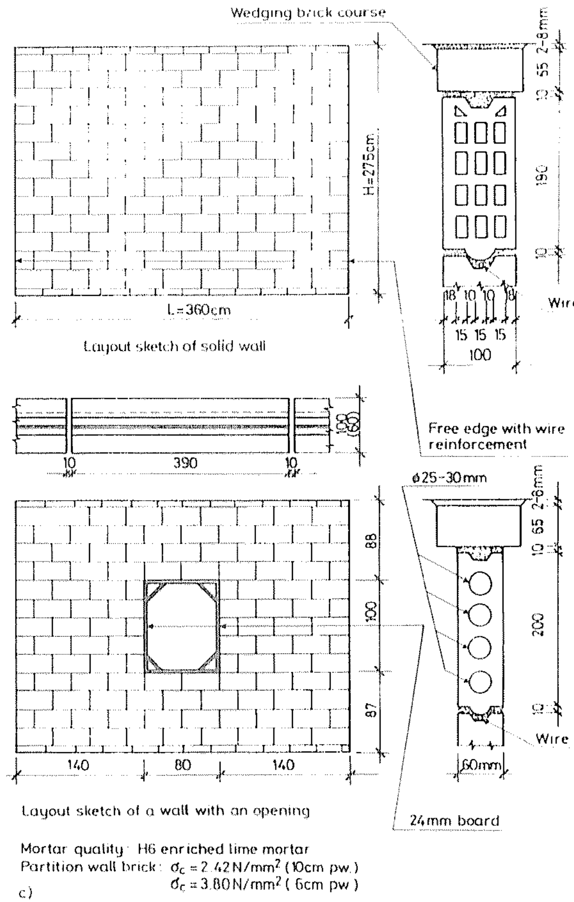


Fig. 1c

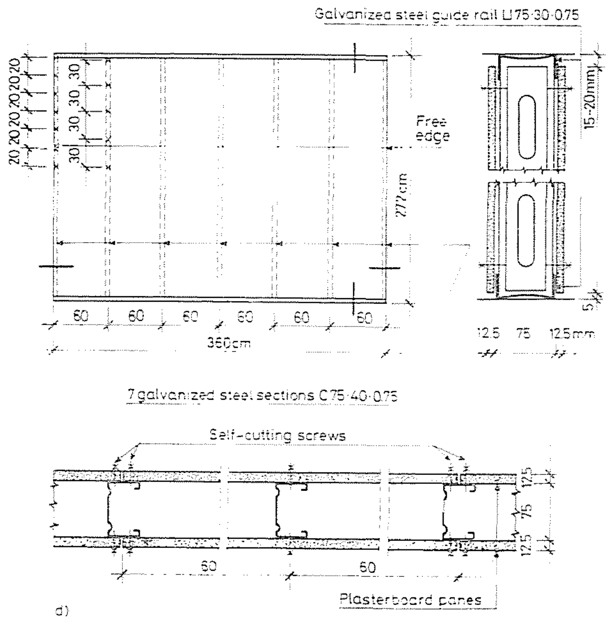


Fig. 1d

Fig. 1. Built-up of tested partition walls
Data of a) precast r.c. partition wall: b) perforated gypsum-perlite partition wall: c) brick partition wall: d) partition wall type KÖZFAL

For test purposes one type was chosen from each of the other groups, that one mostly used in Hungary. Dimensions and structures of the tested partition walls are shown in Fig. 1.

The indicated strength characteristics have been previously determined in small-scale experiments.

Based on the analysis of geometrical constraints acting on the partition walls, three fundamental cases of deformation have been examined:

a) vertical in-plane compression of wall panels:

b) vertical in-plane bending of wall panels:

c) in-plane distorsion of wall panels.

The layout of the test equipment for these deformation cases is shown in Fig. 2.

For each fundamental deformation case, generally two wall panels each of the different partition wall types have been tested. The actual number of tests was modified in due course compared to the planned one, upon confronting the obtained and the expected measurement results. Features and number of the accomplished tests have been compiled in Table 1.

The tests were carried out in the Laboratory of the Department of Strength of Materials and Structures, Technical University, Budapest.

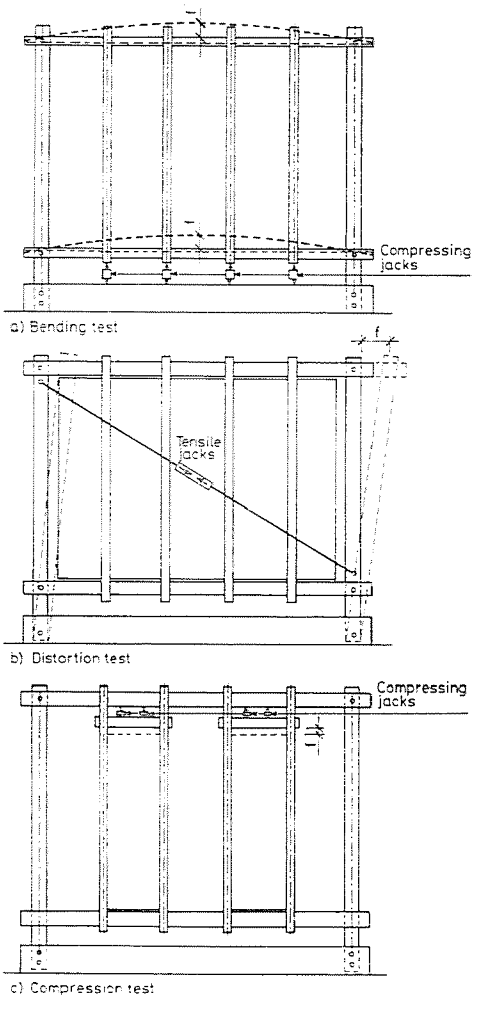


Fig. 2. Layout of the testing equipment

3. Experimental results

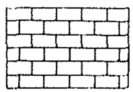
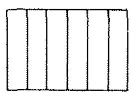
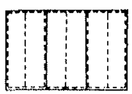
3.1. Behaviour of compressed wall strips

The tested wall strips subject to vertical compression behaved perfectly elastically under load, and after a significant lateral buckling, they essentially failed by instability (Fig. 3).

Test results have been compiled in Table 2.

Table I

Table I. The overall experimental program

Group of partition walls	Type	Compressed wall strip 	Wall pane in bending 			Wall pane in distorsion 	
			full 1:1.3 side ratio	with opening	full 1:2 side ratio	full	with opening
1. 	precast r.c. 6 cm thick	*	1 spec.	*	*	1 spec.	*
2. 	special brick walls 6 and 10 cm thick	1 spec. 10 cm; 1 spec. 6 cm; (1 m wide strips)	2 spec.	1 spec.	1 spec. 1 spec.	2 spec.	1 spec.
3. 	Perforated gypsum-perlite partition 6 cm thick	Gypsum-perlite board 60 cm wide 3 spec.	2 spec.	**	2 spec.	3 spec.	**
4. 	KÖZFAL 2×1 sheets of plaster-board mounted on steel frame	stress in-admissible	2 spec.	**	*	2 spec.	**

* calculable from other measurement data ** unused, openings discontinue the wall

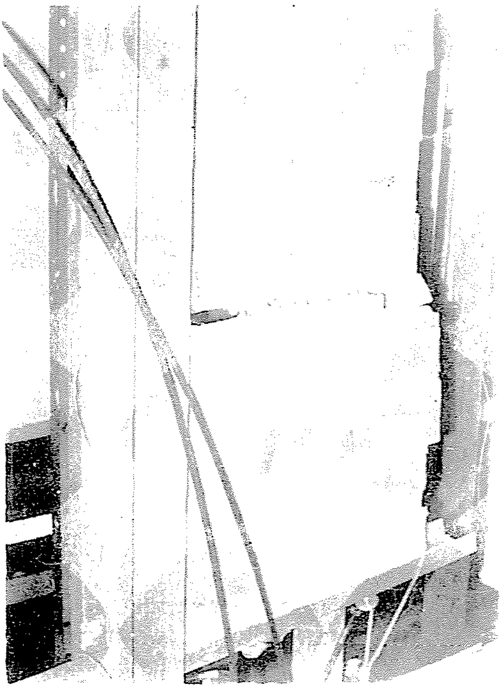


Fig. 3. Failure pattern of a brick partition wall in compression

Table 2

Results of compression tests on partition wall strips

	Special brick partition wall 6 cm thick	Special brick partition wall 10 cm thick	Hollow gypsum-perlite partition wall 6 cm thick*
N_f kN/m	135.7	112.1	96.6
σ_f N/mm²	2.26	1.21	1.61
ε_{max}	$0.66 \cdot 10^{-3}$	$0.42 \cdot 10^{-3}$	$0.44 \cdot 10^{-3}$
f_f mm	7.6	6.0	**
E N/mm²	2890	2240	3490

Legend:

N_f — force due to fracture referred to a wall strip 1 m wide;
σ_f — mean value of stress across the wall cross section (ignoring the hollows opening);
ε_{max} — maximum specific compression in the walls referred to the median plane;
f_f — relative deformation of the edge beams (max. value);
E — modulus of elasticity of walls in vertical direction;
* — mean of three specimens of gypsum-perlite partition walls;
** — no evaluable data.

3.2. *Behaviour of wall panels in bending*

Wall panels under deformation constraint due to edge beams exhibited behaviour in either of two typical groups:

— The failure of partition walls in groups 1, 2 and 3 of Chapter 2 was very similar; they strongly resisted deformation constraint and the first cracks appeared at a low deformation value of the edge beams (Fig. 4); with further increase of deformation and load the surroundings of the compressed wall corners shattered, the load decreased.

These partition walls can be considered as solid, "brittle", by reason of their behaviour.

— The KÖZFAL-type partition walls in group 4 almost did not resist deformation constraint till the edge joints closed. Thereafter, with wedging of the panel, the resistance increased but then shattering near the joints has already begun. Total failure was marked by tearing off of plasterboards.

The failure pattern of the solid partition walls was of a type dependent on the side proportions.

Wall panels with side ratios of 1:1.3 are seen to exhibit skew shear cracks first, vertical cracks due to bending are not characteristic (Figs 5, 6). The first vertical cracks in 1:2 walls appeared at a very low (2 to 4 mm) deformation stage in the symmetry axis, and actually divided the wall panel into two members of separate stress patterns (Fig. 7). Further on, these members failed as distorted wall panels. The cause of this phenomenon will be treated in Chapter 4.

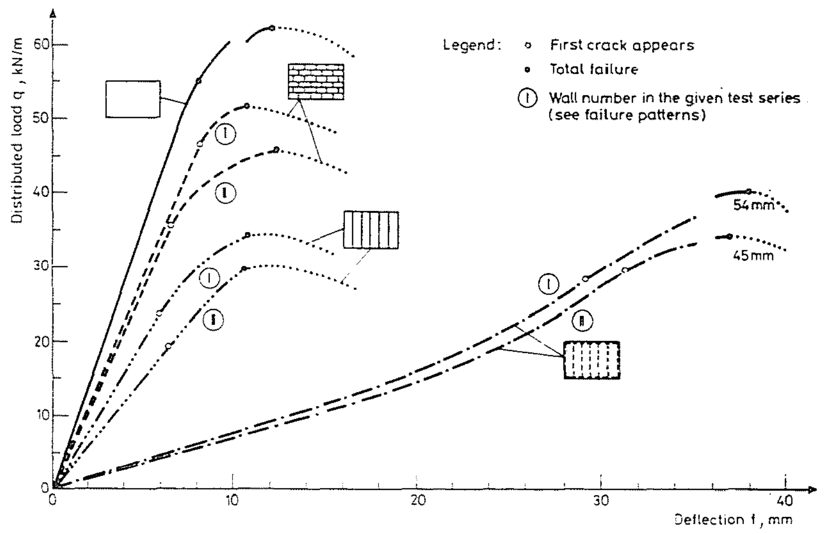


Fig. 4. Force-deflection diagram of partition walls 1 : 1.3 in bending

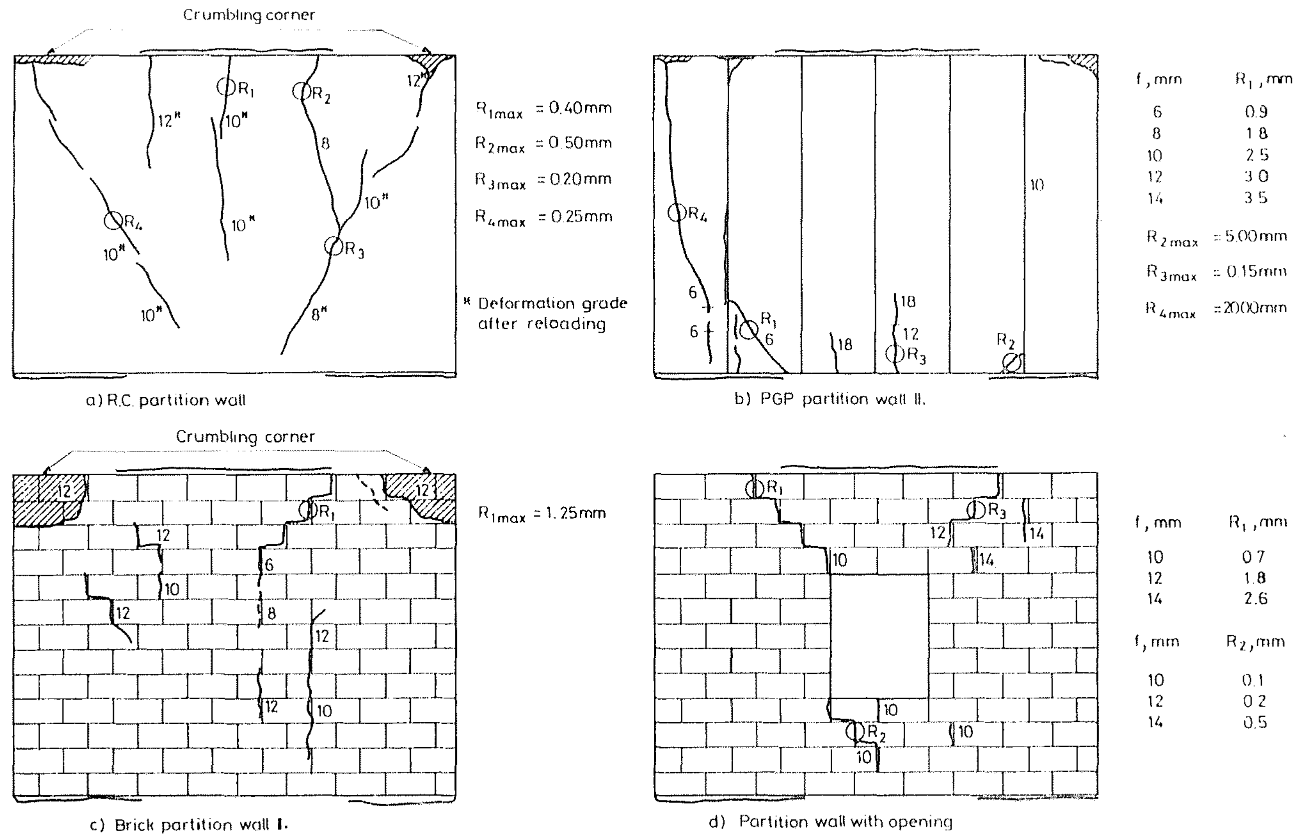


Fig. 5. Failure pattern of partition walls 1 : 1.3 in bending (load and support as in Fig. 2a)

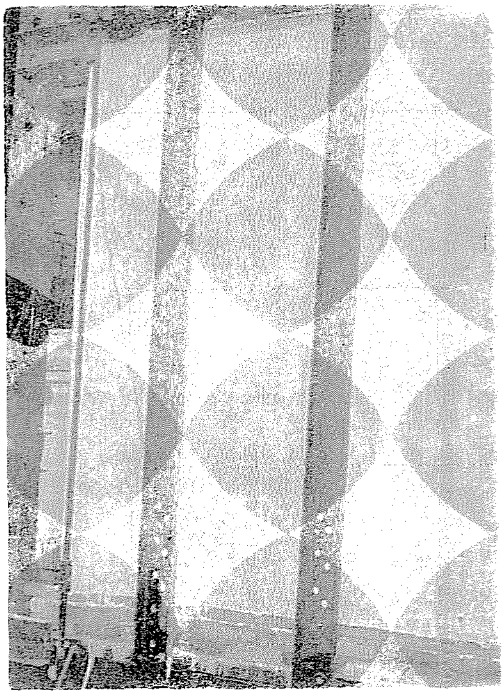
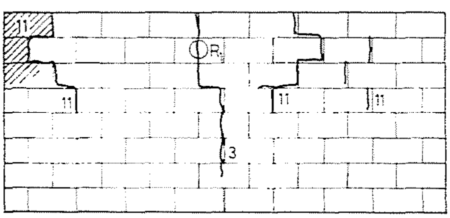
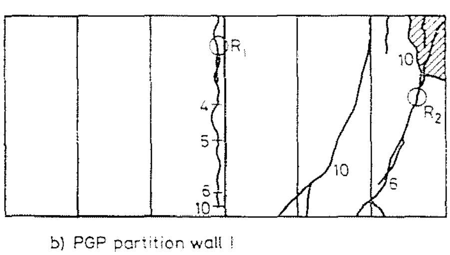


Fig. 6. Failure pattern of PGP partition wall in bending



a) Brick partition wall 10cm thick I

f, mm	R_1, mm
3	0.40
5	0.90
11	2.50



b) PGP partition wall I

f, mm	R_1, mm
4	0.30
6	1.50

f, mm	R_2, mm
6	6.00
10	14.00

***Fig. 7.* Failure pattern of partition walls 1 : 2 in bending (load and support as in Fig. 2a)**

3.3. *Behaviour of distorted wall panels*

The stress-strain diagram for distorted wall panels shows a different behaviour between solid and assembled partition walls, similarly as for walls in bending (Fig. 8).

In analysing failure patterns, it is interesting to observe that also the failure of perforated gypsum-perlite partition walls consisting of vertical boards started with two skew cracks crossing all the panel, to be followed by slip along the joints (Fig. 9).

The effect of joints was manifest first by making the oblique cracks "stepped".

3.4. *Behaviour of walls with openings*

The test series on solid walls, measurement results and analysis of the stress pattern (see Chapter 4) showed solid partition walls to have a low deformability arising mostly from the plastic deformation of edge joints. Openings were expected to reduce the load capacity, and to increase deformability of partition walls, hence to improve their behaviour under deformation constraint.

This proved to be correct for walls both in bending and in distorsion. Among solid walls with and without openings, in both cases the wall with openings has the flatter stress-strain diagram (Figs 10a and b), i.e., the wall is less resistant to the deformation constraint. Thus, solid partition walls with openings practically restrict less the deformations of adjacent structural mem-

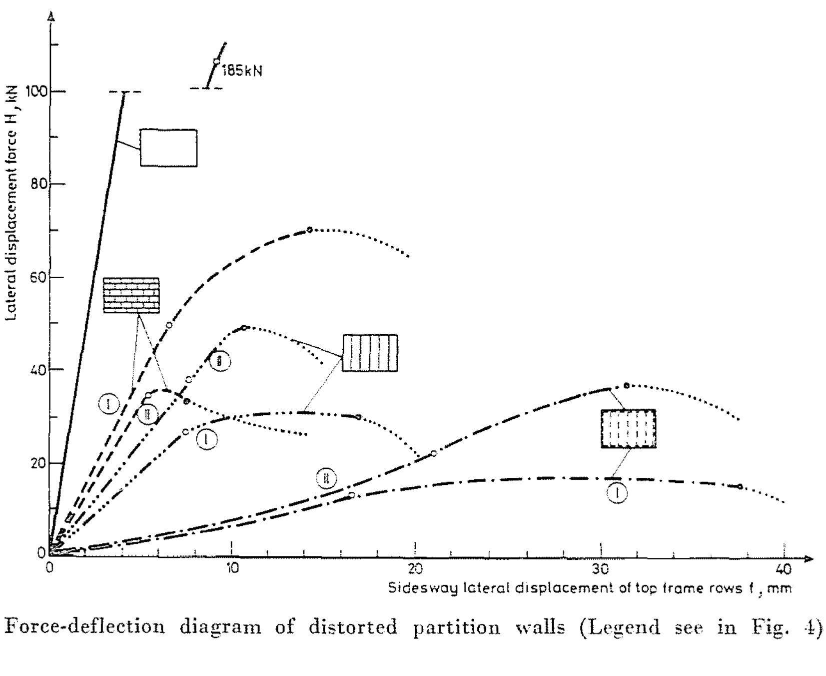


Fig. 8. Force-deflection diagram of distorted partition walls (Legend see in Fig. 4)

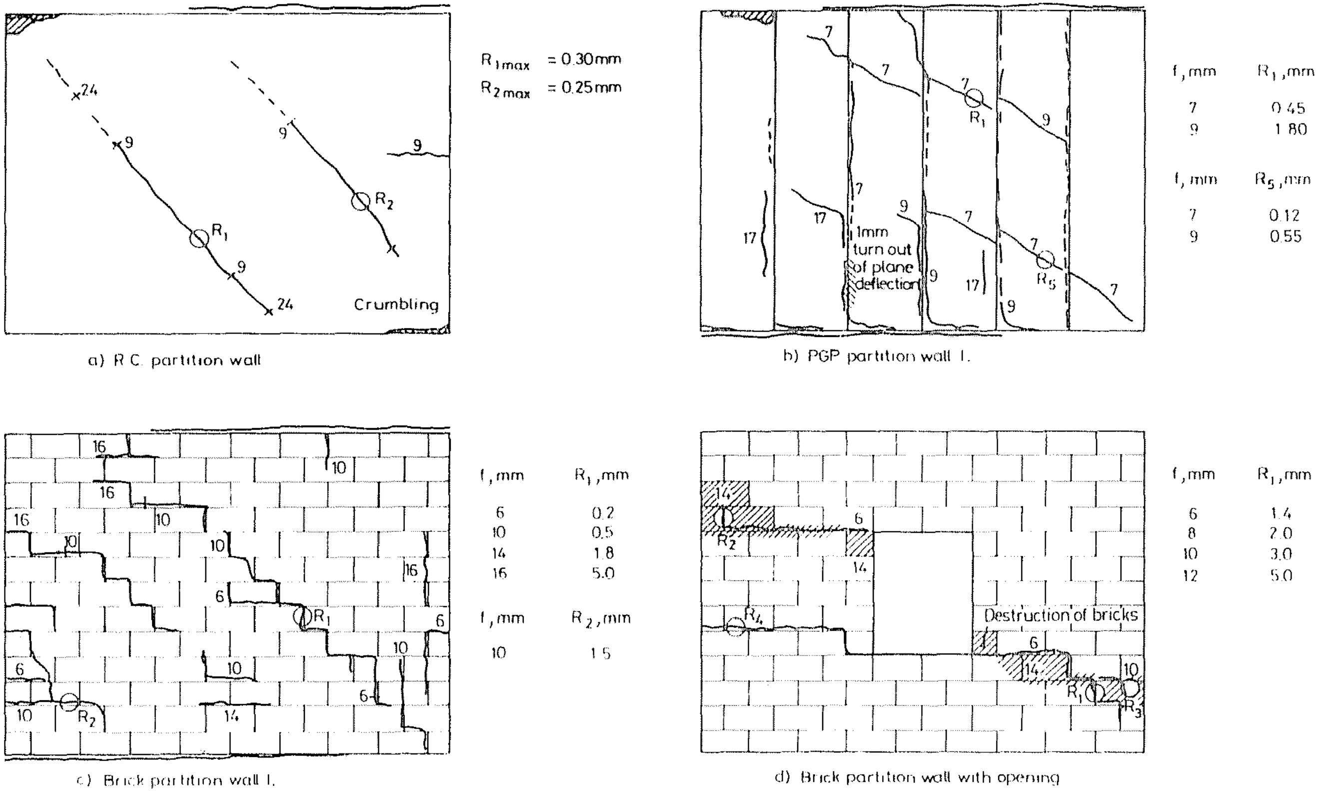


Fig. 9. **Failure pattern of distorted partition walls (load and support as in Fig. 2b)**

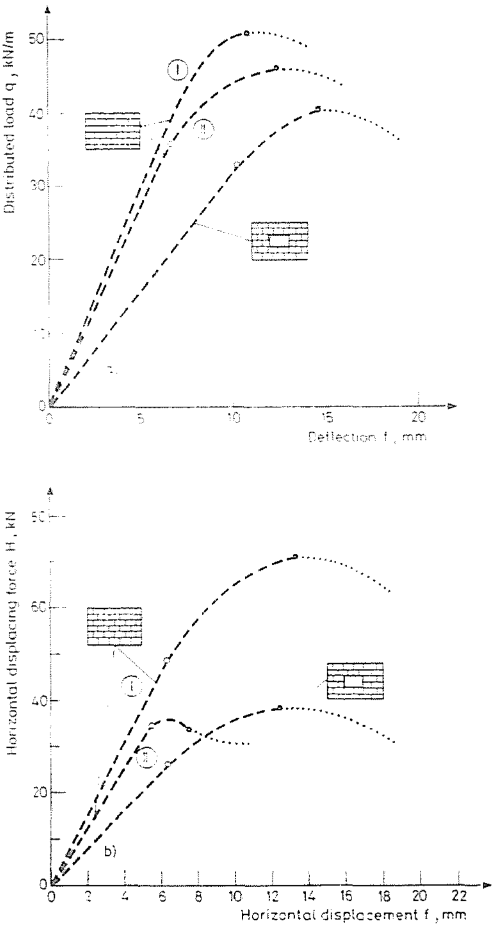


Fig. 10. Comparison of brick partition walls with and without opening
a) partition walls in bending; b) distorted partition walls

bers, and actually, deformations in their neighbourhood are greater than for a full partition wall in the same position. This is why actually, the former types are the first to crack.

For the sake of simplicity, the tested partition walls were supplied with window-like rather than door-like openings. Knowing the stress pattern of the full wall, this was of no importance.

4. Stress pattern of partition walls; approximation of deformability

The tested partition walls are, according to their static behaviour, inhomogeneous and anisotropic diaphragms, with significant compressive but low tensile strength. Beside strength characteristics of their components, their behaviour is determined primarily by their connections (mortar joints, ties). The stress pattern of such diaphragms is well approximated by a finite element model where the unit and the joint strip are separate elements, permitting to reckon with different properties for each. For practical calculations, however, this method is inadequate; simpler, easier relationships are needed.

The suggested approximate calculation relies on the test observation of curvature differences between the enclosing structure and the partition wall

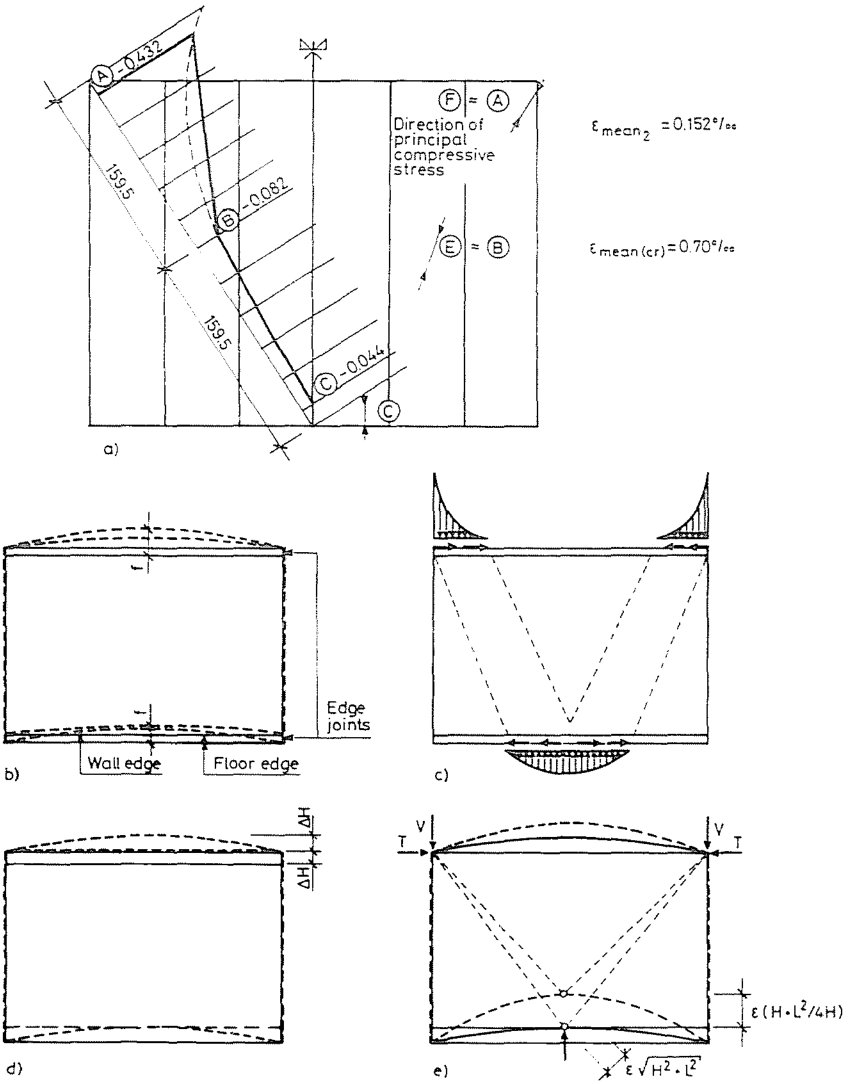


Fig. 11. Stress pattern of a wall panel in bending. a) Variation of ε along the compressed diameter; b) scheme of deformations of edge beams and wall; c) nature of boundary forces; d) and e) two components of wall panel deformation in bending

imposed by the deformation constraint. (Figure 11 shows this train of thought for a wall in bending, but the solution is similar for distorted walls.)

Constraints were transmitted to the wall near the corners and on the opposite side in the middle, resulting in stress peaks (Figs 11b and c). Stress peaks were the most important in edge joints causing plastic deformations in mortar joints.

Away from the corners, stresses rapidly decreased (Fig. 11a). The other important fact is that, according to measurements, the median axes of the walls were practically free of stresses, the arch effect occurred in the edge beam rather than in the wall itself. This stress state in the wall may arise from a boundary force system involving — beside the vertical force system — also an inter-balancing horizontal force system at opposite connections of wall and beam (Fig. 11c) transmitted from the beams to the wall through adhesion and friction. The outlined boundary forces are balanced by two skew wall strips within the wall itself. Accordingly, the total deformation of the wall panel consists of two parts: plastic compression of edge joints (Fig. 11d) and vertical component of the compression of the skew wall strip (Fig. 11e).

Thus:

$$f_{\max} = \Delta H + \varepsilon_f \left(H + \frac{L^2}{4H} \right) \tag{1}$$

where:

$f_{\max}$ maximum permissible edge beam deformation;
ΔH plastic compression of the edge joints;
ε_f average strain of the compressed wall strip;
H height of the wall panel;
L length of the wall panel.

Computing the admissible deformation of the edge structure may reckon to a certain degree with the effect of partition walls to limit the deformation by applying an increasing factor k. Accordingly, using experimental data, the relationship for full partition walls of $L/H = 1.5$ simplifies to:

$$f_{\max} = 5 + \frac{L}{2000} \, [\mathrm{mm}]. \tag{2}$$

For $L = 4.5$ m, the permissible maximum deformation of the edge structure is 7.25 mm.

This relationship holds as long as the horizontal forces can balance the adhesion and the friction on the wall edge. This is seen from tests and calculations not to hold for partition walls of $L/H = 2$, where the wall corners slip at essentially smaller deformations than the computed limit, so the wall panel cracks in the middle. Thus, for longer partition walls a mobile joint is desirable.

For assembled partition walls, $k = 1.0$ in Eq. (1), and the inherent deformation of the wall panel is zero, therefore the deformation maximum is simply the size of the covered joint.

With the above train of thought, for every type of deformation, simple relationships similar to (1) and (2) can be written. Selecting for the given structural system a partition wall system with a calculated deformability not exceeding deformation of the load-bearing structure, soundness of the partition wall system is ensured. In case of solid partition walls, even calculated greater deformations of the load bearing structure do not damage them because these possess a significant load capacity (see in Figs 4 and 8), thus limiting deformations of the surrounding structures to a greater extent than involved in factor k. In such cases, however, the partition walls essentially and undesirably rearrange the stress pattern of the structure causing reconstruction difficulties and a risk of hazard in new buildings; e.g. overload of compressed partition walls may involve casualties.

Summary

The deformability of partition walls has to be known to establish deformation limits of structures, and in design, for coordinating the applied structures and the partition wall system. Stress pattern of partition walls of units is, however, rather complicated, preventing purely theoretical calculation of the deformation. To define the deformability, a test series was imposed for investigating fundamental deformation cases (compression, bending, distorsion) on room-size partition walls of different structures to scale 1:1. Test results helped to deduce simple relationships for the design practice, indicating the permissible maximum of the deformation value of the edge structures for the chosen partition wall.

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