SEVERE INTERACTION EFFECTS BETWEEN PLAIN AND IRREGULAR SHEAR WALLS

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ABSTRACT

When some of the shear walls in a high-rise building are interrupted at the base by large openings or setbacks, heavy horizontal interactions occur between the standard walls and the irregular walls. These interactions cause the distribution of loading in the base region of the individual walls to be significantly different from the external loading distribution.

Two types of structures are studied, the first including shear walls with base-story openings of different widths, and the second with base-story setbacks of different widths. The results of computer analyses indicate the severity of the interaction that can arise. They indicate a shear fixing effect by the standard walls on the bases of the opened walls, and a moment fixing effect on the bases of the setback walls. The results also illustrate the hazard of analyzing such discontinuous shear wall structures by approximate intuitive methods such as sharing the loading between the walls in proportion to their horizontal stiffnesses.

INTRODUCTION

The structural analysis of medium high-rise shear wall buildings is often made by an approximate hand analysis based on an intuitive assessment of the structure's behaviour. The fact that previously constructed buildings designed on the basis of similar analyses have remained standing has usually served to reinforce the designer's confidence in the adequacy of his calculations and in the validity of the assumptions on which they were based. In discontinuous shear wall structures an intuitive approach to the analysis may lead to grossly erroneous results, and the so far satisfactory performance of the building may merely reflect the large margin of safety in the design or that the critical test has yet to come.

The authors are concerned that this situation may apply to a significant proportion of medium high-rise apartment blocks that depend for their horizontal resistance on combinations of plain and discontinuous shear walls; in particular, the types of buildings in which some of the shear walls have openings or setbacks at the base, as shown in Figs. 1a and 1b. It is tempting to the designer to assume that the irregularities have little influence on the structure's behaviour and that the external loading may be shared between the walls in proportion to their flexural stiffnesses.

The purpose of this paper is to warn designers about the potential errors in such arbitrary methods of analysis by presenting the results of more accurate computer analyses for a range of structures of the types shown in Figs. 1a and 1b. The unexpected nature and magnitude of some of the results should help in this purpose.

ANALYSES

The structures analyzed were of the types shown in Figs. 1a and 1b. They were assumed to be symmetrical in plan and loaded symmetrically so that twist did not occur. Also, the floor slabs were assumed rigid in plane so that the deflection profiles of the walls were the same. For simplicity, the walls were taken to be identical in size, except for the openings or setbacks. The plan symmetry of the structures allowed them to be represented for analysis by planar models, each consisting of one standard wall and one discontinuous wall as shown in Figs. 2a and 2b. Hinged end, axially rigid, connecting links were used to simulate the diaphragm action of the slabs.

Ten cases were considered. Case 1 consisted of a pair of identical standard shear walls whose results were used for comparison throughout. Cases 2 to 6 each comprised a standard shear wall and a wall with a base-story opening. In these, so called Type I structures, the openings were increased progressively from case to case. Each of Cases 6 to 10, designated Type II structures, consisted of a standard shear wall and a wall with base-story setbacks. The width of setback was increased from case to case, while its sectional area was maintained constant at 0.9 m^2, so that only the inertia of the pedestal was varied. The dimensions of Types I and II structures are given in Fig. 2.

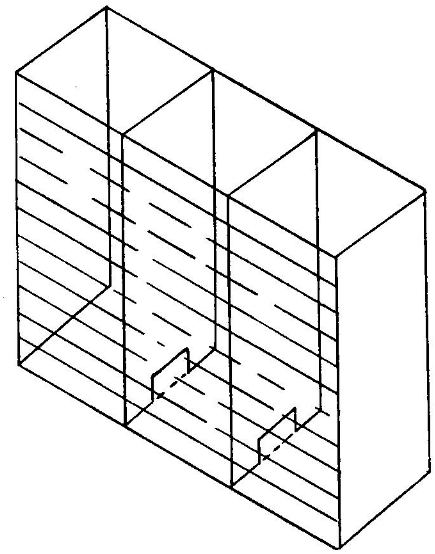

FIG. 1a. TYPE I STRUCTURE - STANDARD SHEAR WALLS AND WALLS OPENED AT THE BASE

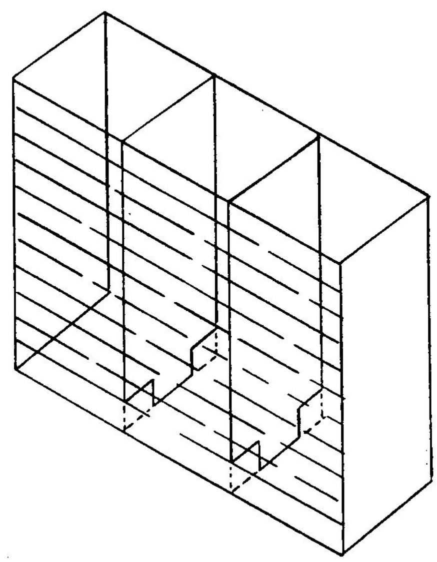

FIG. 1b. TYPE II STRUCTURE - STANDARD SHEAR WALLS AND WALLS WITH BASE SETBACKS

WALL	b(m)	h(m)	c(m)
W1	0.15	0	0
W2	0.15	2.50	1.00
W3	0.15	2.00	2.00
W4	0.15	1.50	3.00
W5	0.15	1.00	4.00
W6	0.40	0.60	4.80

WALL	b(m)	h(m)
W7	0.30	3.00
W8	0.45	2.00
W9	0.75	1.20
W10	1.00	0.90

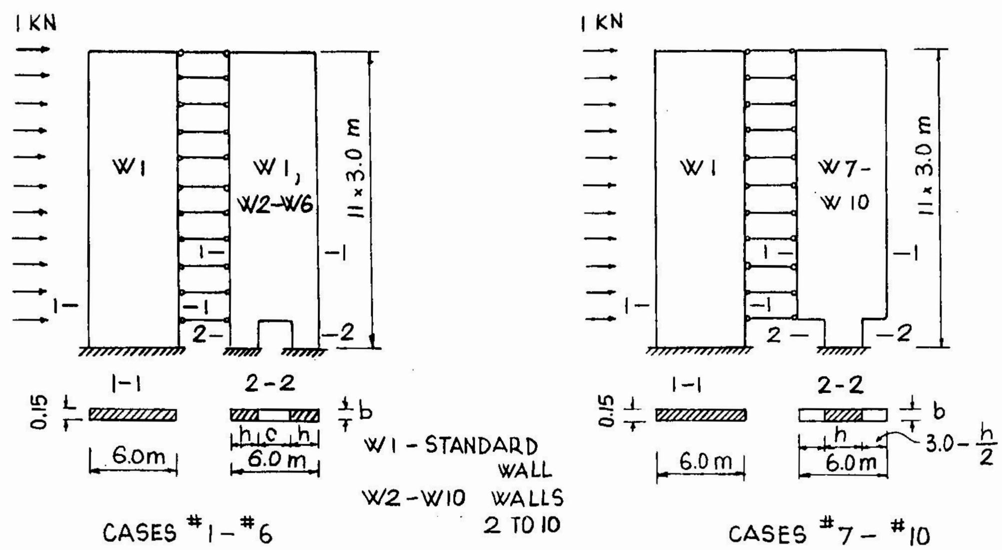

FIG. 2. DETAILS OF STRUCTURES ANALYSED

In the models for the computer stiffness matrix analysis of both Types I and II, the standard wall, and the discontinuous wall from the top to the 1st floor level, was represented by a vertical line of column elements with their moment of inertia and sectional area the same as the wall. In Type I structures, the base story columns beside the opening were represented by a single column element, continuous with the elements above. The element was assigned a moment of inertia equal to the net moment of inertia of the two walls about the centre-line, and a sectional area equivalent in shear stiffness to the racking resistance of the pedestals in combined shear and reverse bending. In Type II structures, the setback wall in the base story was represented by a column element with a moment of inertia and area equal to those of the setback walls.

RESULTS AND DISCUSSION

Figures 3a, 3b and 3c show the resulting loading, shear and bending moment, respectively, on the walls of the Type I structures. The results are significantly different in the base region from those that would be obtained on a load sharing basis.

Although in the upper six stories the external forces are shared equally between the standard wall and the opened wall, the discontinuity in the base story causes a severe disturbance of the wall forces in the first three stories. Generally, the force on the standard wall at the 1st floor is larger than the external loading at that level, while the load on the opened wall is reversed. In the case of the largest opening, the force on the standard wall at the 1st floor is seven times the externally applied load at that level while, at the 2nd floor it is reversed.

The shear force diagrams for the walls, Fig. 3b, are affected significantly in the base region by the interaction. The proportion of the total shear force carried at the base of the standard wall increases with each increase in the width of the opening in the discontinuous wall until, in the case of the maximum opening, the standard wall carries practically the whole of the external shear.

Because the disturbance in the wall loading occurs near the base, the effect on the bending moment diagrams is relatively small, with the standard and opened walls carrying approximately the same bending distribution, Fig. 3c.

The effect of an opening in one of the walls is summarized in Fig. 5a. It illustrates that because the base of the opened wall is reduced substantially in shear stiffness, but relatively little in bending stiffness, a shear fixing effect is applied to the opened wall by the standard wall. Consequently, the resulting shear in the standard wall may significantly exceed the shear estimated by an intuitive load sharing approach.

In the upper part of the Type I structures the effect of the disturbance at the base disappears in accordance with the St. Venant principle, and the loading, the shear and the bending moment are shared equally between the walls.

Figures 4a, 4b and 4c show the resulting horizontal force, shear force, and bending moment, respectively, on the walls of the Type II structures. These results are not only significantly different from any estimates based on a load sharing approach, but different also from the results for Type I structures. In Type II structures the force acting on the 1st floor of the standard shear wall is reverse in direction to the external loading, Fig. 4a, with a magnitude in the worst case of eight times the external loading. The force at the 2nd floor acts in the same direction as the external loading but with a magnitude of ten times the external loading. The loads at successive floors above diminish rapidly so that, by the 6th floor and above, the effects of the disturbance at the base have disappeared, and the loads are shared equally between the two walls.

The shear force diagram, Fig. 4b, shows results that would have been very difficult to anticipate from an intuitive approach. At the 1st floor the shear force in the standard wall in all cases exceeds the total external shear at that level. In Cases 9 and 10, with the two largest setbacks, the shear at the 1st floor of the standard walls is approximately twice the external shear. Simultaneously, the shear in the setback walls acts in the reverse direction to the external shear and is approximately equal to it in magnitude. At the base of the standard wall the shear is approximately equal to the total external shear while, at levels above the 2nd floor, the disturbance diminishes until, by Floor 6, it has disappeared.

The moment diagram for the standard wall, Fig. 4c, shows that, at the base, the wall carries more of the total external moment with each increase in the width of the setback until, for the two largest setbacks, the standard wall carries practically the whole external moment. Above the base the effect diminishes until, by the 6th floor, it has disappeared.

Figure 5b summarizes the effects of interaction between the walls in Type II structures. The external moment, which is shared between walls in the upper stories, is transferred almost entirely to the standard wall in the lowest stories where the setback wall is reduced in bending stiffness. The transfer of the moment from the setback wall to the plain wall causes the intense reversal of loading in the first two levels. This interactive behaviour may be described as a moment fixing effect on the setback wall by the standard wall.

CONCLUSIONS

In structures with discontinuous and plain shear walls, severe interactions arise in the region of the discontinuity, which make it difficult to estimate the resulting wall forces by an approximate method based on an intuitive approach. It is recommended that these types of structures should be analyzed by a more rigorous computer analysis.

Computer stiffness matrix analysis of structures comprising plain shear walls and walls with a central opening at the base, have shown that interaction between the walls transfers the majority of the base shear to the plain wall. In effect, the plain walls impose a shear fixing effect on the bases of the walls with openings. In the upper parts of the structure, however, this effect disappears and the walls share the external shear and bending moment as though both walls were continuous throughout.

When horizontal loading acts on structures combining plain walls and walls with base-story setbacks, the resulting interaction causes a transfer of moment from the discontinuous wall to the plain wall. Consequently, the plain wall carries at its base almost all the external moment. In effect, the plain walls exert a moment fixing effect on the setback walls. An additional, potentially serious, consequence is that the plain wall can be subjected at the 1st floor level to as much as twice the total external shear at that level. In the upper half of the structure, the effects of this disturbance disappear and the walls share the external shear and bending moment as though both walls were continuous throughout.

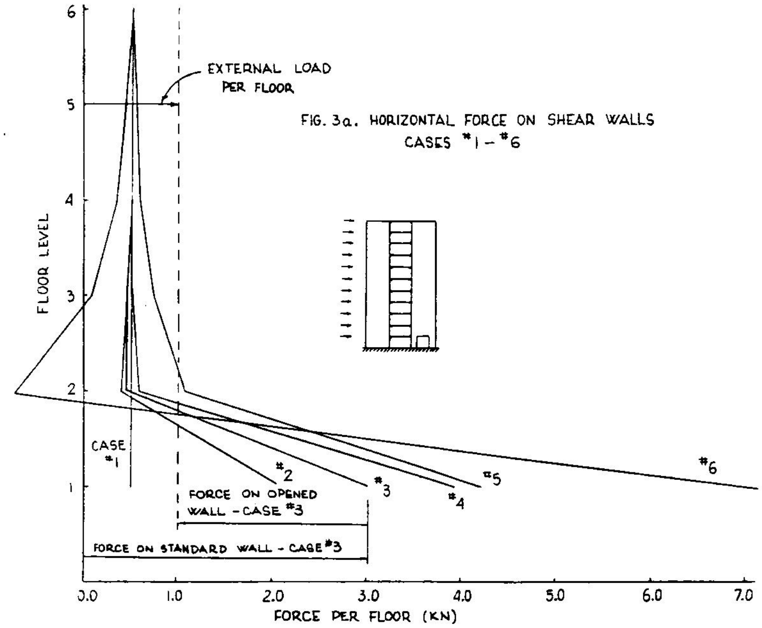

FIG. 3a. HORIZONTAL FORCE ON SHEAR WALLS CASES #1 - #6

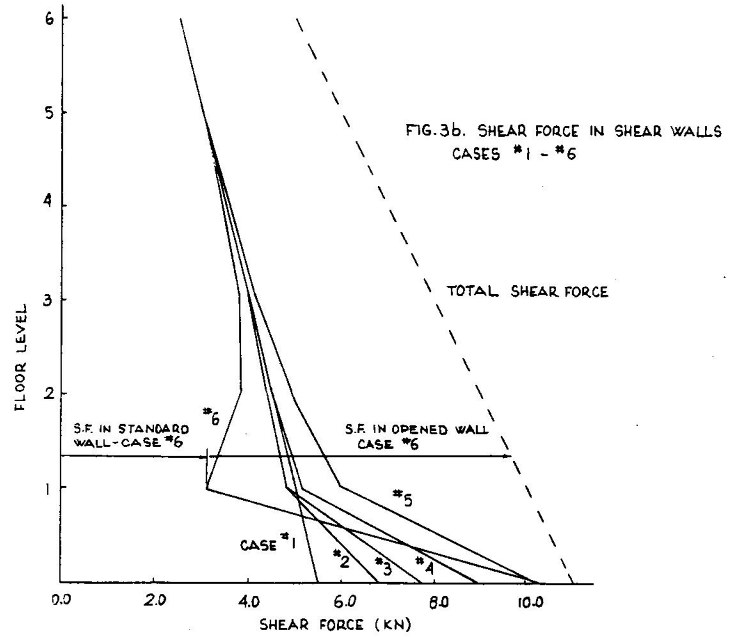

FIG. 3b. SHEAR FORCE IN SHEAR WALLS CASES #1 - #6

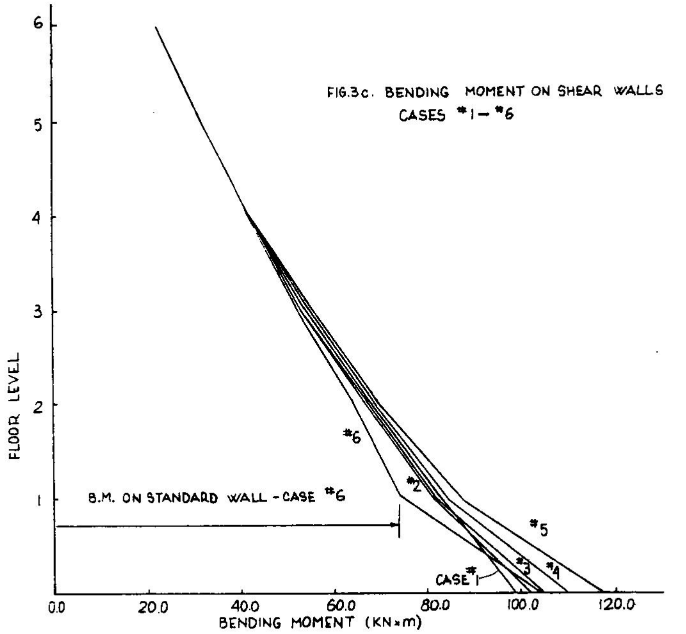
FIG.3c. BENDING MOMENT ON SHEAR WALLS
CASES #1 – #6
FLOOR LEVEL
B.M. ON STANDARD WALL - CASE #6
#6
#2
#5
#3
#4
CASE #1
0.0
20.0
40.0
60.0
80.0
100.0
120.0
BENDING MOMENT (KN×m)

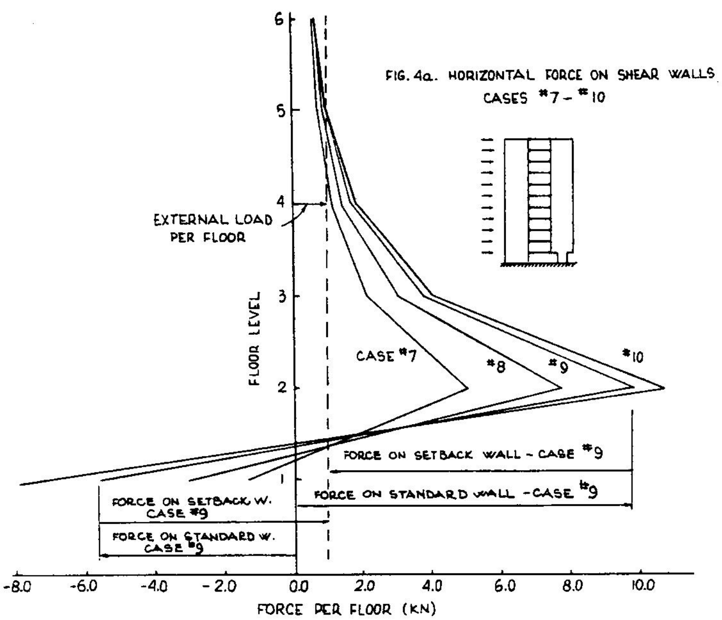
FIG. 4a. HORIZONTAL FORCE ON SHEAR WALLS
CASES #7 – #10
EXTERNAL LOAD PER FLOOR
FLOOR LEVEL
CASE #7
#8
#9
#10
FORCE ON SETBACK WALL - CASE #9
FORCE ON STANDARD WALL - CASE #9
FORCE ON SETBACK W. CASE #9
FORCE ON STANDARD W. CASE #9
-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
8.0
10.0
FORCE PER FLOOR (KN)

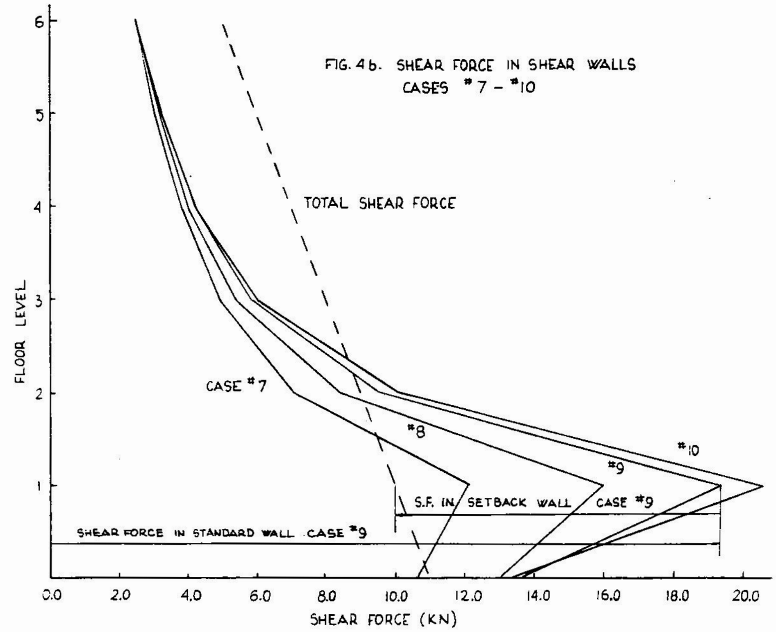
FIG. 4b. SHEAR FORCE IN SHEAR WALLS
CASES #7 - #10
TOTAL SHEAR FORCE
CASE #7
#8
#9
#10
S.F. IN SETBACK WALL CASE #9
SHEAR FORCE IN STANDARD WALL CASE #9
FLOOR LEVEL
SHEAR FORCE (KN)

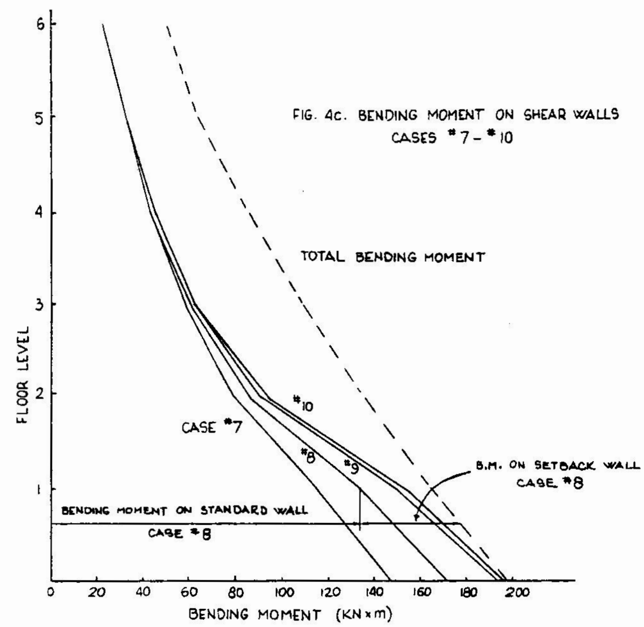
FIG. 4c. BENDING MOMENT ON SHEAR WALLS
CASES #7 - #10
TOTAL BENDING MOMENT
CASE #7
#8
#9
#10
B.M. ON SETBACK WALL
CASE #8
BENDING MOMENT ON STANDARD WALL
CASE #8
FLOOR LEVEL
BENDING MOMENT (KN×m)

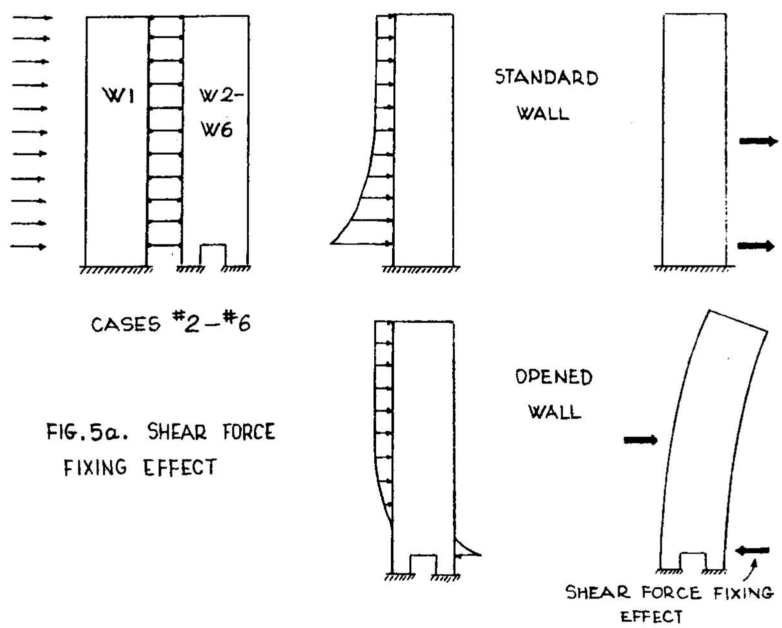

FIG. 5a. SHEAR FORCE FIXING EFFECT

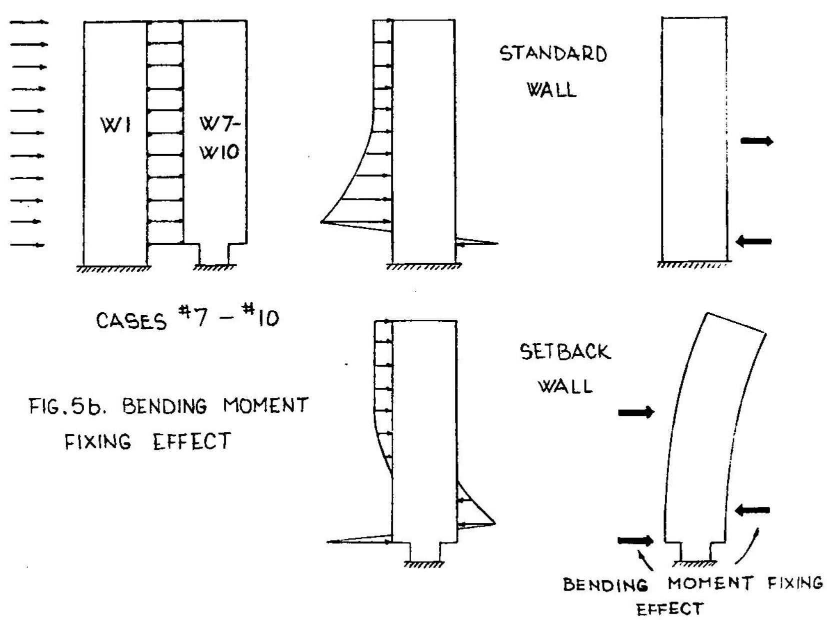

FIG. 5b. BENDING MOMENT FIXING EFFECT