THE INFLUENCE OF HORIZONTALLY-PLACED REINFORCEMENT ON THE SHEAR STRENGTH AND DUCTILITY OF MASONRY WALLS

by

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SYNOPSIS

The hypothesis, that the shear strength and ductility of masonry walls can be increased by the placing of reinforcement in the horizontal mortar-joints, was confirmed by the carrying-out of dynamic cyclic - loading tests on wall elements, H-δ diagrams and hysteresis loops being obtained. It was found that shear strength increased with an increasing percentage of reinforcement, but if the whole shear-load carrying-capacity of the reinforcement is to be made full use of, then, in addition to the provision of suitable anchorage, the unreinforced wall must have sufficient ductility.

1. INTRODUCTION

The failure of masonry walls during earthquakes is usually attributed to the exhaustion of their shear resistance. This has been confirmed by the examination of masonry buildings damaged in, for instance, the Skopje (1963) and Banja Luka (1970) earthquakes in Yugoslavia. Less frequently failure occurs at the corners of wall piers as a result of high compression stresses which reach the strength of the material involved.

At the Institute for Research and Testing in Materials and Structures, Ljubljana, a hypothesis was proposed, that the shear strength and ductility of masonry walls could be increased by the placing of reinforcement in the horizontal mortar joints. Its validity was investigated by the carrying out of dynamic cyclic-loading tests on a series of reinforced and unreinforced wall elements, 1.0 m wide, 1.5 m high and 0.2 m thick.

To construct the wall elements hollow building-blocks of expanded-clay aggregate and lime-cement mortar were used. The walls were reinforced horizontally so that the percentage of reinforcement μ, calculated with respect to the vertical cross-section of the wall, varied from zero to 0.20%. A study was made of the effects of two different kinds of reinforcement: 1) sheets of expanded metal and 2) reinforcing bars of 6 mm dia mild steel. The reinforcement was placed either in every horizontal mortar joint or in every other joint.

2. DESCRIPTION OF THE TESTS AND ANALYSIS OF RESULTS

In the tests programmed sinusoidal horizontal displacements in the form of block-diagrams were applied to the wall elements. The loading frequency for the displacements was chosen as 1 c/s on the basis of the results given in a separate paper (see "The Influence of Frequency

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on the Shear Strength and Ductility of Masonry Walls in Dynamic Loading Tests" by the same authors). The wall elements were held under constant vertical load between two horizontal surfaceswhich were kept permanently parallel, thus permitting only horizontal and vertical movement of the upper surface with respect to the lower one. A diagram of the equipment used is given in the abovementioned paper. The horizontal reaction force induced in the wall (H) was measured by means of dynamometers and the relative displacement between the top and the bottom of the wall (δ) by means of inductive measuring devices. Hysteresis loops were drawn directly during the test (see Fig.1) and from these shear-force/displacement H-δ diagrams were prepared for each wall. These diagrams formed the basis for comparisons between the performances of individual wall elements.

The tests showed that the extent to which a wall's shear strength can be increased by the placing of horizontal reinforcement depends not only on the quantity and quality of the reinforcement used, but also to a great extent on the ductility of the unreinforced wall itself. Of course, in order for the reinforcement to have any effect at all, a certain minimum percentage must be used and suitable anchorage must be provided. It was found that if a certain percentage of reinforcement is placed in a wall with good ductility, then the shear-strength of the wall increases considerably. An example of the characteristic H-δ diagrams obtained in this case for the unreinforced and the reinforced wall is shown in Fig.2. In this diagram H_z represents the shear-load carrying-capacity of the unreinforced wall, and H_a the shear-load carrying-capacity contributed by the reinforcement. In this case the total shear strength of the reinforced wall is given by the expression:

$$H_{tot} = H_z + H_a$$

When, however, the same percentage of reinforcement in placed in a wall of lesser ductility, there is a smaller increase in the shear-strength of the wall. An example of the characteristic H-δ diagrams obtained in this case for the unreinforced and the reinforced wall is given in Fig.3. From the diagram it can be seen that the shear-load carrying-capacity of the unreinforced wall falls rapidly after its shear strength has been reached, so that although the contribution made by the reinforcement is approximately the same as before, the shearstrength of the wall as a whole is not increased to such an extent as in the case of the more ductile wall.

It is, of course, important that the reinforcement is ductile, too. During the tests it was found that the 6 mm mild steel bars showed more ductile behaviour then the sheets of expanded-metal, although the former kind of reinforcement was harder to anchor satisfactorily.

In Fig 4 the idealized way in which the shear load is distributed between an unreinforced but ductile wall and its reinforcement is shown schematically. The distributed loads are plotted against the total load applied to the wall for two different percentages of reinforcement, a larger percentage μ_1 and a smaller percentage μ_2. The same load-distribution scheme is used as a model for the calculation of shear stirrups for reinforced-concrete beams by the ultimate load theory in the ACI Shear Design Provisions for Reinforced and Prestressed Concrete Beams [1]. In this model an equation equivalent to the one given above is used to define the distribution of shear at ultimate load.

The following can be concluded from Figs.2 and 4:

- in the early stages of loading only insignificant loads are transferred to the reinforcement,
- when the shear-load carrying-capacity of the unreinforced wall is reached, all further loads are transferred to the reinforcement,
- when ultimate load is reached, the reinforcement is at its yield point,
- with further increases in shear displacement the load-carrying capacity of the reinforcement remains constant; the total load carried by the wall falls by the same amount as in the case of the unreinforced wall.

In general it was found that the shear strength of walls increases in proportion to the percentage of reinforcement used. The rate at which it increases depends on the yield-point stress of the reinforcement and on the shear-strength characteristics of the unreinforced wall. The latter depends on the referential shear strength of the wall τ_k, which is defined by the expression:

$$\tau_k = \frac{1}{1.5} \left\{ \sqrt{(1.5\,\tau_o)^2 + \left(\frac{\sigma_o}{2}\right)^2} - \frac{\sigma_o}{2} \right\},$$

where τ_o is the average shear stress in the wall at failure and σ_o is the corresponding compressive stress due to vertical load[2]. The shear-load carrying-capacity of an unreinforced wall of known referential shear strength is given by the expression:

$$H_z = F \cdot \tau_k \sqrt{1 + \frac{\sigma_o'}{1.5\tau_k}}$$

where F is the cross-sectional area of the wall and σ_o' is the actually-occurring compressive stress in the wall.

It was also found that the ductility of the walls rose with the amount of reinforcement used. Considerable increases in ductility were obtained in the case of reinforcement percentages equal to or greater than 0.15%.

CONCLUSION

It is concluded that the extent to which a wall's shear strength can be increased by reinforcing it horizontally depends not only on the quantity and quality of the reinforcement used and on the fundamental shear strength characteristics of the unreinforced wall, but also to a great extent on the ductility of the unreinforced wall.

BIBLIOGRAPHY

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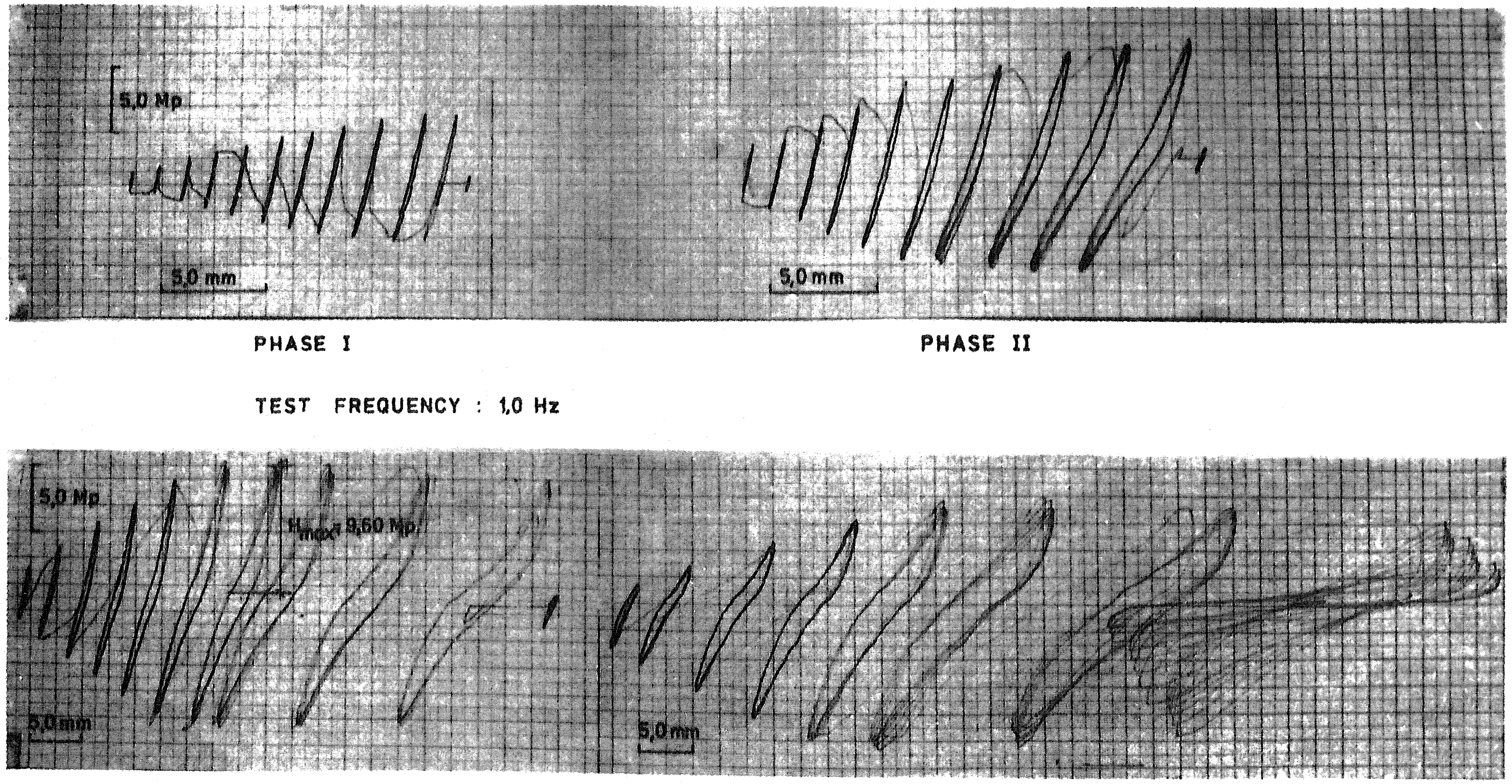

PHASE I

PHASE II

TEST FREQUENCY : 1,0 Hz

PHASE III

PHASE IV

EXPERIMENTALLY OBTAINED HYSTERESIS LOOPS H - δ
FOR
REINFORCED WALL ELEMENT

FIG. 1

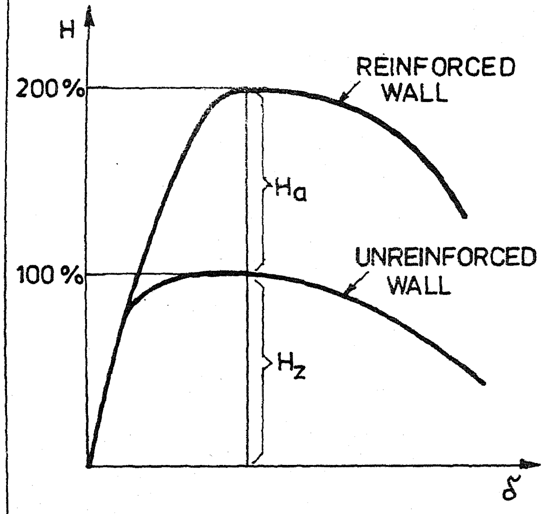

FIG. 2: H - δ DIAGRAMS FOR WALL WITH GOOD DUCTILITY

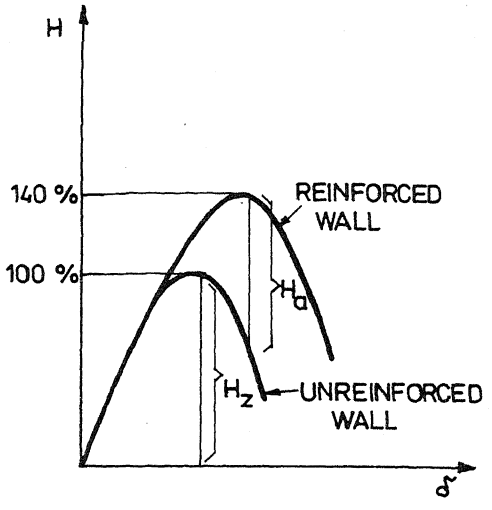

FIG. 3: H - δ DIAGRAMS FOR LESS DUCTILE WALL

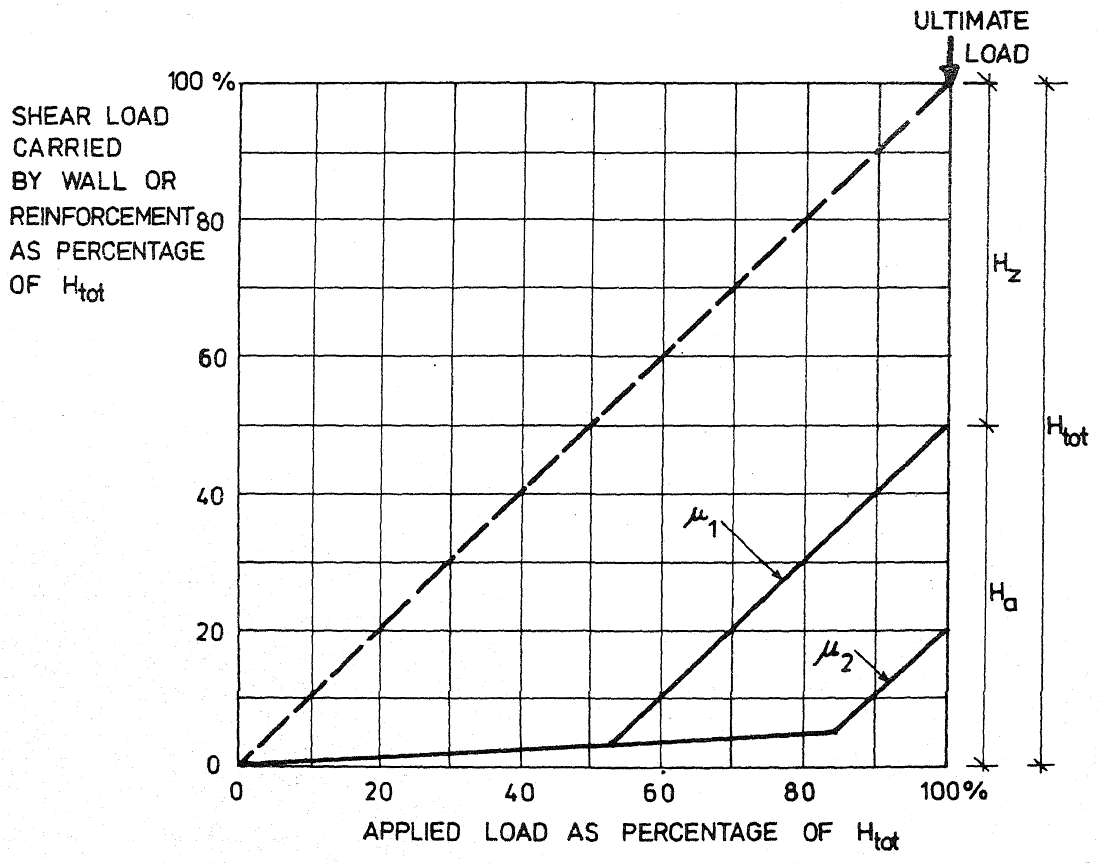

FIG. 4 : IDEALIZED SHEAR DISTRIBUTION BETWEEN WALL AND REINFORCEMENT

DISCUSSION

T. Paulay (New Zealand)

The use of horizontal reinforcement in masonry panels was reported in the paper and its beneficial influence was shown.. Would the authors consider that actual structures, particularly one and two storey masonry buildings, would perform satisfactorily without any vertical reinforcement ?

Author's Closure

With regard to the question of Mr. Paulay, we wish to state that the each type of wall should be tested in the laboratory to determine its shear-strength and bending-strength when subjected to a horizontal force acting in the plane of the wall with simultaneous constant vertical load.

It has been shown that the shear-strength of walls can be increased by the use of horizontal reinforcement, whereas the amount of vertical reinforcement needed depends on the size of the bending-moments induced by an earthquake, which are to a considerable extent dependent on the position of the point of contraflexure.

If no special calculations are made as to the effect of bending moments then vertical reinforcement may be placed at each end of the wall to provide additional safety. It was found by model tests (scale 1:2) carried out at our Institute that the shear-strength of a two-storey masonry building was not much increased by the construction of vertical reinforced-concrete tie-beams at its corners.

If, on the other hand, calculations show that the walls of a low-rise masonry building will fail because of exhaustion of shear-strength and not as a result of the influence of bending-moments, then there is no need for vertical reinforcement to be placed.