RESPONSE OF REINFORCED MASONRY SHEAR WALLS TO STATIC AND DYNAMIC CYCLIC LOADING

by

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SYNOPSIS

The post-elastic behaviours of four reinforced brickwork shear walls subjected to dynamic cyclic loading are compared with results from similar statically tested walls. Surprisingly, in contrast with the static tests, marked load deterioration and stiffness degradation occurred with dynamic cycling in those walls where flexural action predominated. In the walls failing in shear there was little difference between the dynamic and static test results.

INTRODUCTION

Because steel yield stresses and concrete ultimate compressive stresses are known to increase as the straining rate increases, it has been customary to assume that results from static tests of structural components using these materials will provide a conservative basis for use in the seismic situation. However, this assumption is questioned as the material strain-rate dependent properties are necessarily based on monotonic loading whereas cyclic loading prevails in the seismic situation. Also other factors are likely to affect the dynamic behaviour of a composite material such as reinforced masonry or reinforced concrete.

The prime objective of this test programme was to determine the effect of dynamic cyclic loading on the stiffness degradation and load deterioration properties of reinforced brick walls. Four walls were tested allowing a direct comparison with results from the similar statically tested walls which had indicated(1,2) that provided bearing loads and reinforcing ratios were low and aspect ratios were sufficiently high a ductile flexural behaviour could be obtained with little load deterioration and stiffness degradation. However even those walls where shear dominated gave load-deflection loops of large area indicating considerable energy absorption capacity.

EXPERIMENTAL DETAILS

Details of the 4" wide walls are shown in Figs. 1 and 2. Construction procedures and properties of the 8 5/8" x 4" x 2 5/8" reinforcible brick unit, the 2000 psi lime mortar and the 3000 psi fluid grout which was used to fill all cores are given in references 1 and 2 together with a description of the testing equipment and procedure.

Dynamic testing was undertaken using a MTS closed-loop electro-hydraulic structural loading system with such capacity that the maximum attainable frequencies for sinusoidal double amplitude displacement of 0.5" and 2" were approximately 1 hertz and 0.3 hertz respectively.

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Continuous plots of load-deflection at the wall top were obtained directly using an x-y plotter and are recorded in Figs. 1 and 2. As it was desired to cycle before major load deterioration occurred, several cycles were conducted at a relatively small displacement amplitude before progressing to large amplitudes.

DISCUSSION OF RESULTS

Generally those walls which showed a high degree of deterioration during static testing behaved in a similar manner under dynamic conditions. Consider Fig.1 showing walls B1 of aspect ratio two, supporting bearing loads of 250 psi. In both cases, for the first two loading sequences (A and B in the dynamic case, 1-3 and 4-7 in the static case) only mild deterioration of the load and minor stiffness degradation occurred. A further sequence C, of the dynamic test, caused large deterioration, the load capacity in one direction falling from a maximum of 12.5 to 4 kip.

The most surprising result was in the dynamic behaviour of wall B2, Fig.2a, which supported no bearing load. According to static test results, a most flexural situation was expected producing a satisfactory stable ductile behaviour, as shown for example by wall B3 Fig.2(b) which supported a bearing load of 125 psi. However, in the dynamic test severe stiffness degradation and load deterioration were evident. Sequences A, B and C at displacements of ±0.4 in., 0.70 in. and 0.9 in. respectively, showed progressively degrading stiffness effects due mainly to load deterioration.

Whereas a stable flexural action prevailed throughout the static test, for later cycles in the dynamic situation the wall deflected by sliding along the mortar bed above the second course. Due to the wall motion the products of material disintegration and crushing at the corner dislodged allowing buckling and bending of the compression steel to occur. Thus the contribution of the compression zone and dowel action of the shear resistance was negligible. As the wall must then rely on "aggregate interlock" for shear resistance, bearing load may have been beneficial so the comparison of these two walls may not be as favourable to the dynamic situation as at first thought.

It is suggested that effective confinement of the reaction corner material, possibly difficult to achieve, would prevent this undesirable behaviour. The confinement of the masonry would prevent early buckling of the steel and so retain the steel couple as an efficient seismic load resisting mechanism.

The tests were restricted to in-plane loading of the walls and it is conceivable that in the real seismic situation transverse and vertical ground accelerations could induce a more deleterious behaviour by facilitating further dislodgement of fragmented material. Again confinement of the reaction corner material could alleviate the problem.

Dynamic analyses were conducted(1) on structural models subjected on a computer to the excitation of the 1940 El Centro N-S component earthquake. Provided that the deflection ductilities were less than 6, similar ductilities were required of equivalent elastoplastic models and of Clough's(3) basic degrading stiffness models (idealized force-deflection diagrams which are reasonable, but slightly conservative, approximations to the test behaviour of "flexural" masonry walls such as in Fig.2(b)). But it was shown(1) that very much greater ductilities are required of models idealizing the severe stiffness degradation encountered in the dynamic test, Fig.2(a).

If a sufficiently ductile behaviour cannot be confidently predicted, which is certainly true of the low aspect ratio walls of the static tests (1,2), and may well be true of "unconfined" walls that otherwise behave flexurally, walls must be designed to withstand forces associated with the design earthquake which may be several times the code specified values which have proved satisfactory design loads for ductile framed structures. Lack of appreciation of this fact has lead to the mistaken belief that there is an inherent weakness in masonry under seismic conditions whereas in fact the earthquake forces which must be resisted by this type of structure have been underestimated. The same argument applies to reinforced concrete shear walls. Factors of safety in code specified allowable stresses have often compensated for underestimated loads but the merit of a more rational design approach cannot be over-emphasized.

CONCLUSIONS

Of the four walls tested, the three that showed a high degree of structural deterioration in the static tests behaved similarly under dynamic conditions. However, for the "flexural" brick walls, dynamic testing revealed that in contrast with the satisfactory ductile behaviour of the comparable wall tested statically, a severe but unexpected loss of structural capability occurred with load repetition. This leads to the belief that, contrary to normally accepted opinion, cyclic static test results may not give a conservative basis for seismic design.

Dynamic testing was restricted to brick masonry but it is obvious that similar doubts must exist about the dynamic behaviour of concrete masonry and, to a lesser extent, reinforced concrete, particularly in narrow shear walls, where confinement is difficult.

As many masonry shear walls have been shown in the static tests to have performances which are shear dominated and as structural deterioration occurs under dynamic loading of walls expected to behave flexurally, all walls should be designed to carry earthquake loads greater than code values pertaining to ductile frames. If and when effective methods of confining masonry at the reaction corners are found, it may then be possible to ensure sufficient ductility so that walls may be designed for lower earthquake loads.

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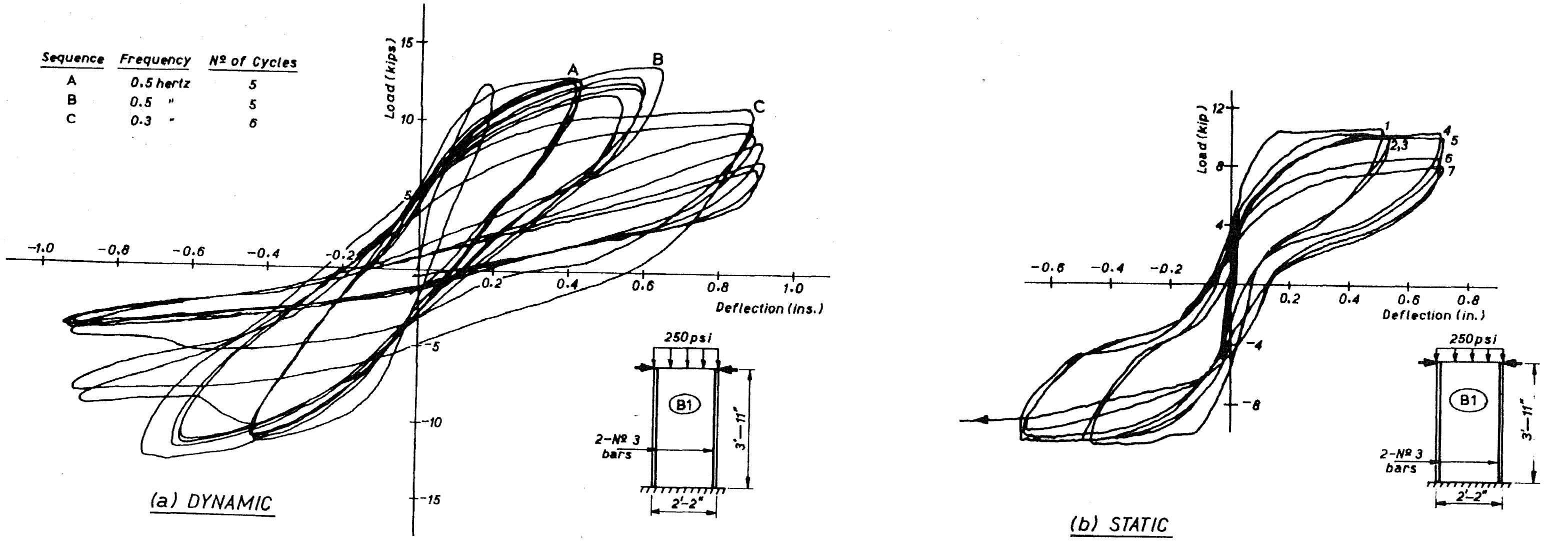
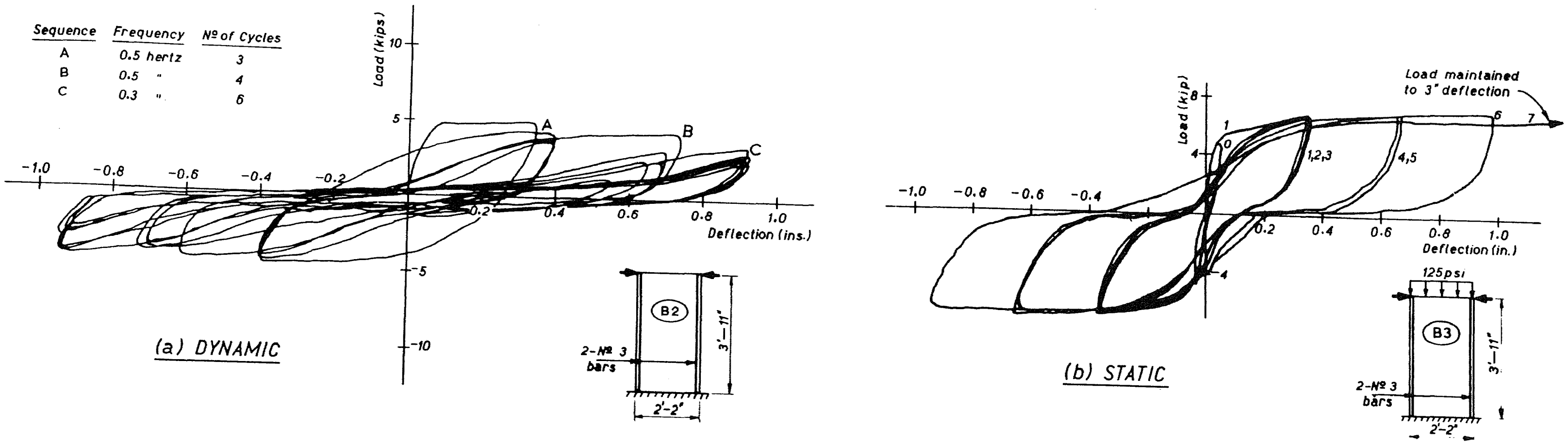


(a) DYNAMIC

(b) STATIC

Fig. 1—LOAD-DEFLECTION CYCLES OF WALLS WITH LOAD DETERIORATION DUE TO SHEAR



(a) DYNAMIC

(b) STATIC

Fig. 2—LOAD-DEFLECTION CYCLES OF WALLS WITH FLEXURAL ACTION