REDUCTION OF STRENGTH AND STIFFNESS AND HYSTERETIC CHARACTERISTICS OF PERFORATED THIN STEEL PLATE SHEAR WALLS

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SUMMARY

The strength and stiffness of unstiffened perforated steel plate shear panels decrease with increasing size of opening. This reduction is approximately linear with increasing area of opening. This mather was verified with conducting a series of quasi - static cyclic loading tests on unstiffened steel plate shear panels, with centrally placed circular and square openings. All the panels tested exhibited adequate ductility and stable S- shaped hysteresis loops, with the energy absorbed per cycle increasing with the maximum amplitude of the shear displacement. Experimental results are copmared with a previously developed theoretical model for predicting the hysteretic characteristics of unstiffened plate shear panels, which incorporates the influences of shear buckling and plastic yielding of the plate, and an assumed linear reduction in stiffness and strength to allow for openings.

INTRODUCTION

The structural elements commonly used in tall buildings, to resist lateral forces induced by wind and earthquakes, are moment resisting frames, braced frames and shear walls. Shear wall systems, which have been built almost exclusively of reinforced concrete, usually consist of a series of plane walls, often surrounding an interior service area to form a central core. They are always heavily reinforced, particularly when used in seismic regions.
In recent years, steel plate shear walls have been incorporated in a number of tall buildings, mainly in Japan and North America [1-3]. They consist of thin steel plates, framed by columns and beams, as shown in Figure 1. The beneficial properties of steel plate shear walls are enhanced stiffness, strength and ductility, stable hysteretic characteristics and a large capacity for plastic energy absorption.
The majority of the steel plate shear walls constructed to date, have incorporated plates that are stiffened to prevent shear buckling. However, Kulak and co-workers[4-7] have reported on a comprehensive, large scale, experimental and theoretical investigation of the static and quasi-static cyclic loading behaviour of unstiffened, thin steel plate shear walls. The results of this investigation highlighted the beneficial postbuckled reserve of stiffness and strength and stable hysteretic characteristics of unstiffened, thin steel plates. The theoretical analysis, which was based on neglecting the critical shear stress and replacing the web plate

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by a series of inclined tensile strips, showed satisfactory correlation with test results.

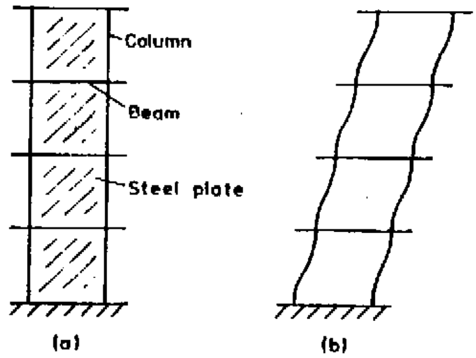

Fig . 1. Steel plate shear wall. (a) Construction details.(b) Shear displacements.

Recently, Roberts and Sabouri-Ghomi [8-11] carried out an experimental and theoretical investigation of the hysteretic characteristics of unstiffened plate shear panels. The theoretical model developed, incorporates the influences of shear buckling and plastic yielding of the web plate, and was validated by comparison with test data. The theoretical model was also incorporated in non-linear dynamic analyses of steel plate shear walls.
In practice, it may often be necessary to introduce openings in steel plate shear walls, for access and services. Herein, an experimental and theoretical investigation of the hysteretic characteristics of unstiffened steel plate shear panels, with centrally placed circular openings, is described and the theoretical model which was presented before by Roberts and Sabouri-Ghomi was modified.

2 EXPERIMENTAL INVESTIGATION

2.1 Details of test specimens

Quasi-static cyclic loading tests were performed on unstiffened steel plate shear panels, detailed in Fig. 2 and Table 1. The panels had aspect ratios, b/d, equal to 300/300 and 450/300 and plate thicknesses, h. equal to 0.83 and 1.23 mm. The diameter of the central circular openings, D, varied from 0 to 150 mm.
The edges of the plates were clamped between pairs of rigid, pinjointed frame members, by two rows of 8 mm diameter, high-tensile bolts. The corners of the plates were cut away in a circular arc to clear the pins, resulting in effective plate dimensions 30 mm greater than the internal dimensions of the frame. Two diagonally opposite pinned corners of the panel were connected to the hydraulic grips of the testing machine and load reversals applied along the panel diagonal.
Tensile tests were performed on speciments of the two plate thicknesses used to manufacture the test panels and their average properties, young's modulus, E, and yield stress δo, (0.2 % proof stress) are given in Table 1.

2.2 Test procedure

All panels were tested by applying equal and opposite loads along one panel diagonal. An x-y plotter connected to the testing machine, enabled the diagonal load, *P*, versus the corresponding displacement, q, curves to be plotted automatically during the tests.

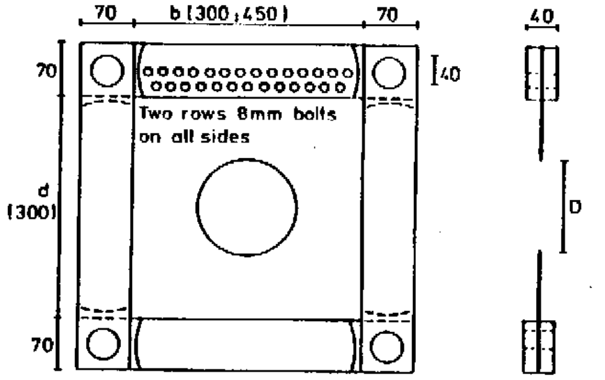

Fig. 2. Test details of perforated shear panel

For each test. tensile forces were applied along one panel diagonal until the corresponding displacement reached a prescribed value, generally 1.6 mm, which was well into the elasto-plastic range of the panels. The panel was then unloaded and compressive forces were applied along the same panel diagonal until the displacement in the opposite direction reached a prescribed value, generally 1.6 mm.This process was repeated to obtain at least four complete cycles of load, with the diagonal displacement being increased by a prescribed amount, generally

TABLE 1
Details of Test Panels

Test	b (mm)	d (mm)	h (mm)	D (mm)	E (kN/mm^2)	δ_o (N/mm^2)
2	300	300	0.83	0	202	219
5	300	300	0.83	60	202	219
8	300	300	0.83	105	202	219
11	300	300	0.83	150	202	219
3	300	300	1.23	0	203	152
6	300	300	1.23	60	203	152
9	300	300	1.23	105	203	152
12	300	300	1.23	150	203	152
14	450	300	0.83	0	202	219
17	450	300	0.83	60	202	219
20	450	300	0.83	105	202	219
23	450	300	0.83	150	202	219
15	450	300	1.23	0	203	152
18	450	300	1.23	60	203	152
21	450	300	1.23	105	203	152
24	450	300	1.23	150	203	152

0.4 mm, in each direction during successive cycles. For all tests, the displacement along the panel diagonal was controlled at a constant rate of 0.01 mm/s.

3 RESULTS

The hysteresis loops for all tests are shown in Figs 3-6. All the panels tested exhibited stable S-shaped hysteresis loops, with the energy absorbed per cycle (area enclosed by hysteresis loop) increasing with the maximum amplitude of the shear displacement. All panels exhibited adequate ductility, being able to sustain at least four complete cycles of loading, involving large plastic strain reversals, without any apparent reduction in load-carrying capacity.

The ultimate strength and stiffness of panels decreased with increasing size of opening, as shown in Fig. 7. P_u/P_{uo} is the ratio of the strenght of a perforated panel to that of a similar, unperforated panel. S/So is the ratio of the slope of the skeleton curve of a perforated panel to that of a similar, unperforated panel, the skeleton curve being the load-deflection curve obtained by increasing the load monotonically from zero. From these results, it is apparent that the strength and

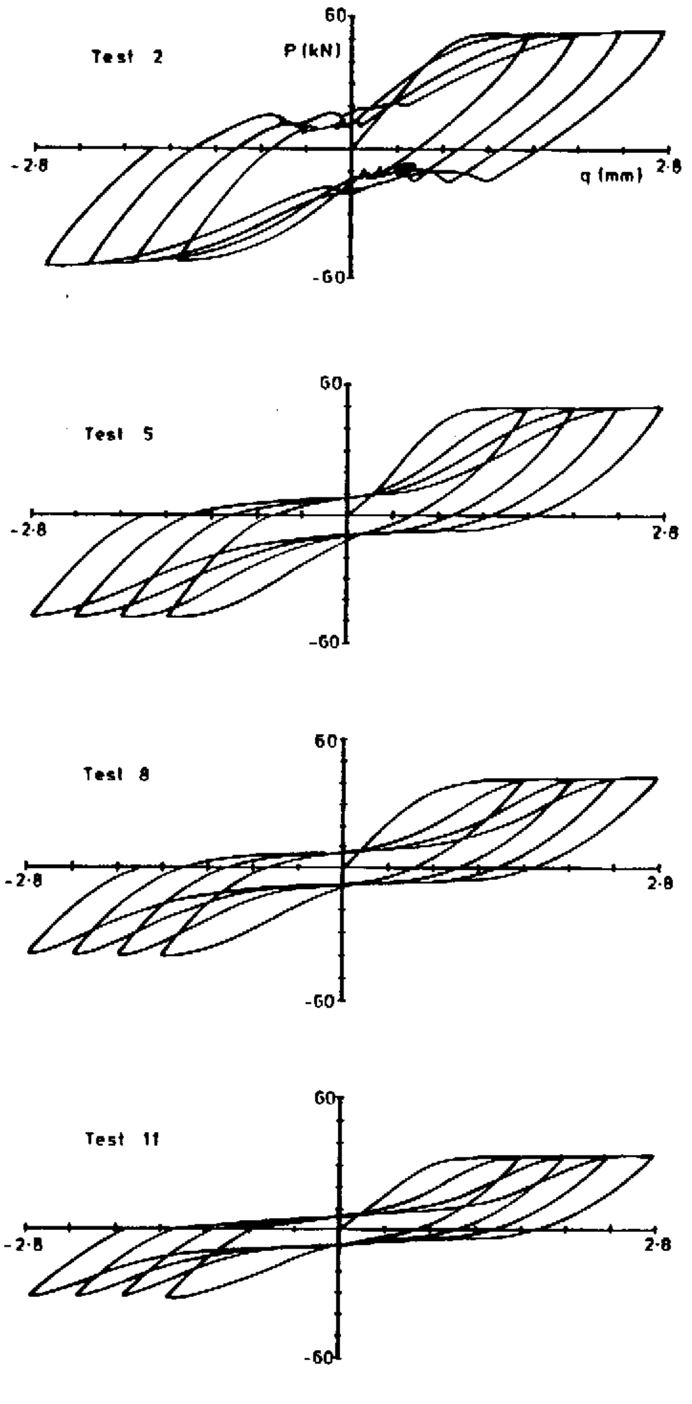

Fig. 3. Hysteresis loops for panels having $b/d = 1$ and $d/h = 360$.

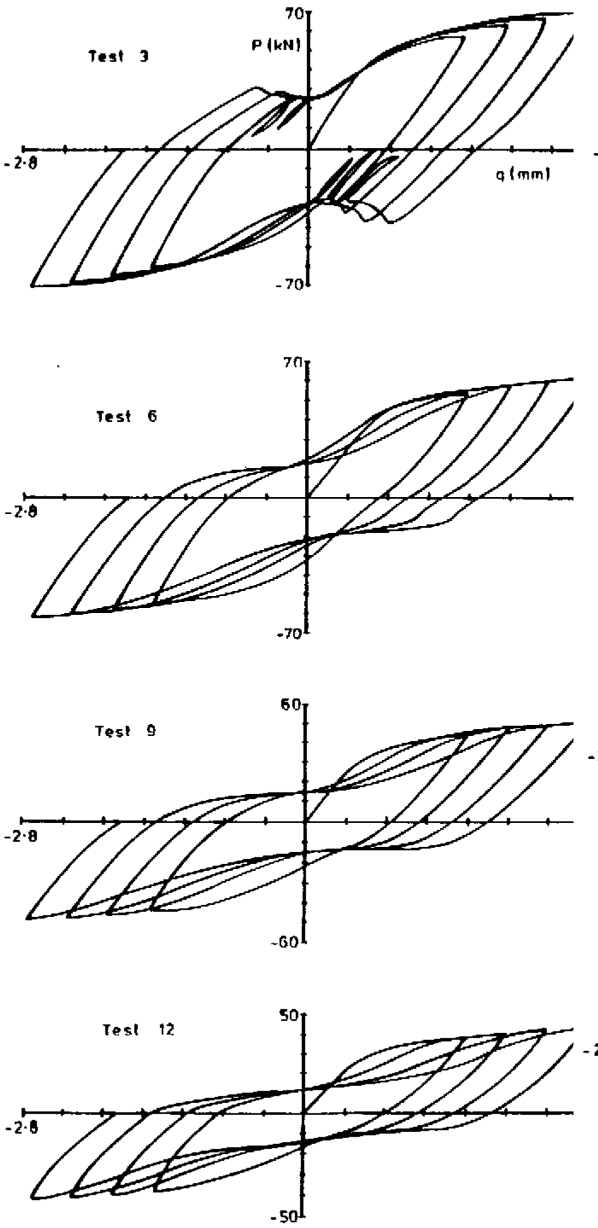

Fig. 4. Hysteresis loops for panels having $b/d = 1$ and $d/h = 245$.

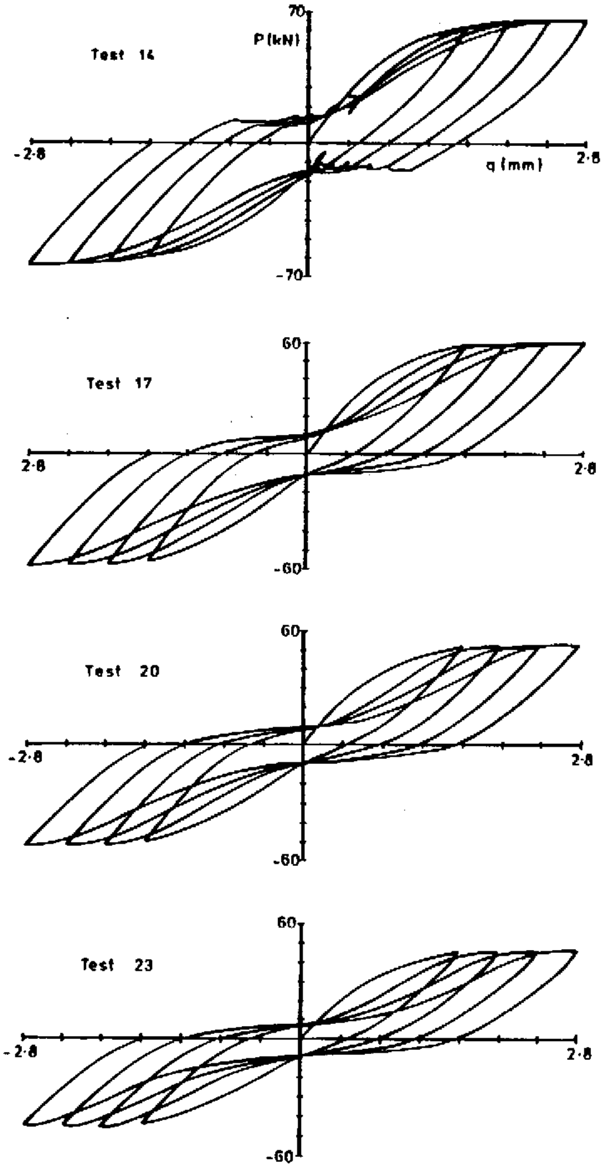

Fig. 5. Hysteresis loops for panels having $b/d = 1.5$ and $d/h = 360$.

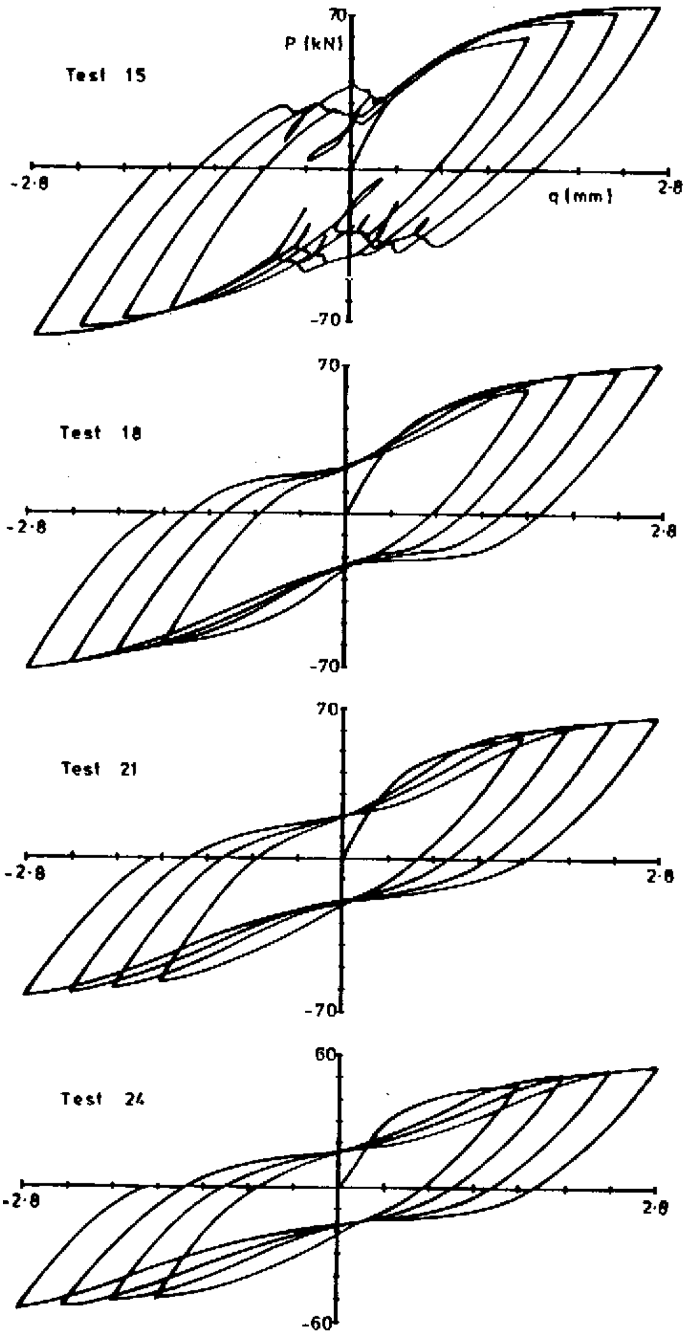

Fig. 6. Hysteresis loops for panels having $b/d = 1.5$ and $d/h = 245$.

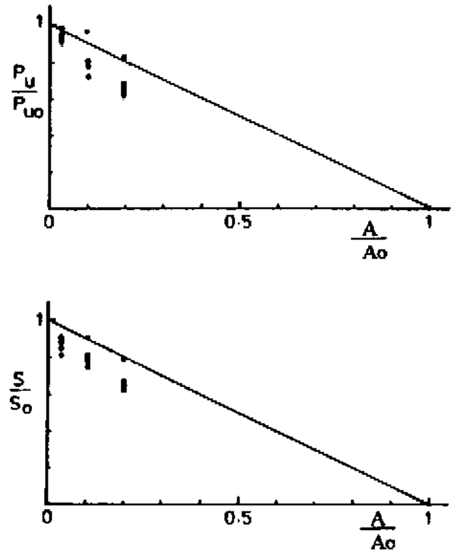

Fig.7. Variation of strength and stiffness of shear panels with size of opening.

stiffness of a perforated panel, can be approximated by applying a reduction factor (1 - A/Ao) to the strength and stiffness of a similar unperforated panel in which Ao is the area of the panel and A is the area of the opening.
This modified method is more realistic compare with previous method which was suggested by Sabouri and Roberts. Also with this modified method the strength and stiffness of shear panels with other logical openings such as square can be obtain.

4 COMPARISON OF EXPERIMENTAL AND THEORETICAL RESULTS

A theoretical model for predicting the hysteretic characteristics of unstiffened steel plate shear panels, has been developed recently by Roberts and Sabouri-Ghomi[8]. The theoretical model incorporates the influences of shear buckling and plastic straining of the web plate and can readily be incorporated in non-linear dynamic analyses of steel plate shear walls.[9.10] Theoretical results for perforated plates were obtained in accordance with this model, but including the modified reduction factor (1 - A/Ao) applied to both stiffness and strength, to allow for the perforations.
Typical comparisons of experimental and theoretical results are shown in Fig 8. In general, this modified method has more reasonable agreement, with the theoretical results being conservative for the following reasons.

(i) The boundaries of the plate were assumed to be simply supported which results in an underestimation of the critical load.
(ii) Strain hardening was neglected.
(iii)The reduction factor (1 - A/Ao) applied to both stiffness and strength is conservative.
(iv) Elongated plastic buckles in the plate resist load reversals more efficiently than the assumed plastically strained flat plate, since they act as inclined struts.

3. Baldelli, J. A., Steel shear walls for existing buildings. Engng J., AISC, 20(2) (1983) 70-7.
4. Thorburn, L. J., Kulak, G. L,& Montgomery, C. J., Analysis and design of steel shear wall systems. Structural Engineering Report 107, Department of Civil Engineering, University of Alberta, Canada, 1983.
5. Timler, P. A.& Kulak, G. L., Experimental study of steel plate shear walls. Structural Engineering Report 114, Department of Civil Engineering, University of Alberta, Canada, 1983.
6. Tromposch, E. W.& Kulak, G. L., Cyclic and static behaviour of thin panel steel plate shear walls. Structural Engineering Report 145. Department of Civil Engineering, University of Alberta, Canada, 1987.
7. Kulak, G. L., Unstiffened steel plate shear walls: static and seismic behaviour. In *Steel structures: Recent Research Advances and their Applications*, ed M. N. Pavlovic. Elsevier applied Science Publishers, 1986, pp. 561-80.
8. Roberts, T. M.& sabouri-Ghomi, S., Hysteretic characteristics of unstiffened plate shear panels. *Thin-Walled Struct.* (in press).
9. Sabouri-Gomi. S.& Roberts, T. M., Nonlinear dynamic analysis of thin steel plate shear walls. *Computers Struct.*, 39 (1/2) (1991) 121-7.
10. Sabouri-Ghomi, S.& Roberts, T. M., Nonlinear dynamic analysis of steel plate shear walls including shear and bending deformations. *Engng Struct.*, (in press).
11. Roberts, T. M.& Sabouri-Ghomi, S., Hysteretic characteristics of Unstiffened perforated steel plate shear panels. *Thin-Walled Structures.* 14 (1992) 139-151.