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CYCLIC PERFORMANCE OF LOW YIELD STRENGTH STEEL PANEL SHEAR WALLS

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Abstract

An experimental program of steel panel shear walls is outlined and some results are presented. The specimens tested utilized low yield strength (LYS) steel for the infill panel and reduced beam sections (RBS) at the ends of the beams. Two specimens in the program make allowances for the penetration of the wall panel by utilities, which would exist in an actual retrofit situation. The first, consisting of multiple holes, or perforations, in the steel panel, also has the characteristic of reducing the panel's strength further than the LYS property alone, from that of the solid panel. The second such specimen utilizes quarter-circle cutouts in the top corners of the frame, which are reinforced to transfer all of the panel's forces to the adjacent framing.

Introduction

The selection of Steel Plate Shear Walls (SPSWs) as the primary lateral force resisting system in buildings has increased in recent years as design engineers discover the benefits of this option. Its use has matured since initial designs did not allow for utilization of the post-buckling strength of the plate (only elastic and shear yield behavior was allowed) resulting in very thick plate sizes, and, as a result, very stiff structures and therefore large accelerations during a seismic event. In addition, surrounding frame members required additional strengthening to prevent mechanism formation as a result of the forces exerted by the panel at ultimate displacements.

Research in Canada (Thorburn et al. 1983) led to a new SPSW design philosophy that reduced plate thickness by allowing the occurrence of shear buckling. After buckling, lateral load is carried in the panel via the subsequently developed tension field. Smaller panel thicknesses also reduce forces on adjacent members, resulting in more efficient framing designs. However, some obstacles still exist that impede further general acceptance of this system. For example, the panel thickness, using a typical material yield stress, required by a given design situation is often much thinner than plate actually available from steel mills. Attempts at alleviating this problem were recently addressed by the use of light-gauge, cold-formed steel panels, in a new application (Berman and Bruneau 2003). Other means of reducing demand on framing adjacent to an SPSW put forth by other researchers include the connection of the infill panel to only the beams in a moment frame (Xue and Lu 1994). However, more work is required to ensure the viability of the SPSW system in a wide range of situations.

The University at Buffalo (UB) and the Multidisciplinary Center for Earthquake Engineering Research (MCEER) initiated a co-operative experimental program with National Taiwan University (NTU) and National Center for Research on Earthquake Engineering (NCREE) in order to further address the above issues with regards to SPSW performance. Four specimens were designed and fabricated for pseudo-static cyclic testing at NCREE. Low yield strength (LYS) steel panels, of 2.6mm thickness made by China Steel, were used as the infill material. The thickness and reduced yield strength of 165 MPa are two properties that will help alleviate over-strength concerns mentioned above. Two additional features in the specimens were designed to help reduce demand on the adjacent framing. Reduced Beam Sections (RBS), or “dogbones,” were added to the beam ends in order to force all inelastic action in the beams to those locations. The authors feel this detail will result in increasingly efficient designs of the “anchor beams,” defined as the top and bottom beams in a multistory frame, which “anchor” the tension field forces of the SPSW infill panel.

Experimental Program

A total of four LYS SPSW specimens were designed by the researchers at UB, fabricated in Taiwan, and tested at the NCREE laboratory at NTU. The frames, consisting of 345MPa steel members, were 4000mm wide and 2000mm high, measured between member centerlines. The infill panels are 2.6mm thick, LYS, with an initial yield of 165MPa. All specimens have a beam-to-column connection detail which includes reduced beam sections (RBS) at each end. This detail will aid in the efficient anchoring of tension field forces from the infill panel, as is required at the extremes (top and bottom beams) of a SPSW-retrofitted/designed steel frame. A solid panel specimen is shown schematically in Fig. 1.

Two specimens have solid panels while the remaining two provide utility access through the panels by means of cutouts. One specimen consists of a panel with a total of twenty holes, or perforations, each with a diameter of 200mm, as pictured in Fig. 2. Previous research has investigated the effect of a single perforation in an unstiffened shear panel (Roberts and Sabouri-Ghomi 1992). That work led to some conservative reduction factors that could be applied to the properties of a solid panel, reducing the stiffness and strength to account for the presence of the perforation. The multiple perforations of the specimen in the current project represent a slightly different application, with the common goal of utility access, making the SPSW system more acceptable.

The other specimen is a solid panel, with the top corners of the panel cutout and reinforced to transmit panel forces to the surrounding framing. The intention of the final two specimens is the accommodation of penetrations by utilities necessary for building operation.

All specimens were tested using a cyclic, pseudo-static loading protocol similar to ATC-24. Loading history was displacement-controlled, and applied horizontally to the center of the top beam using four actuators.

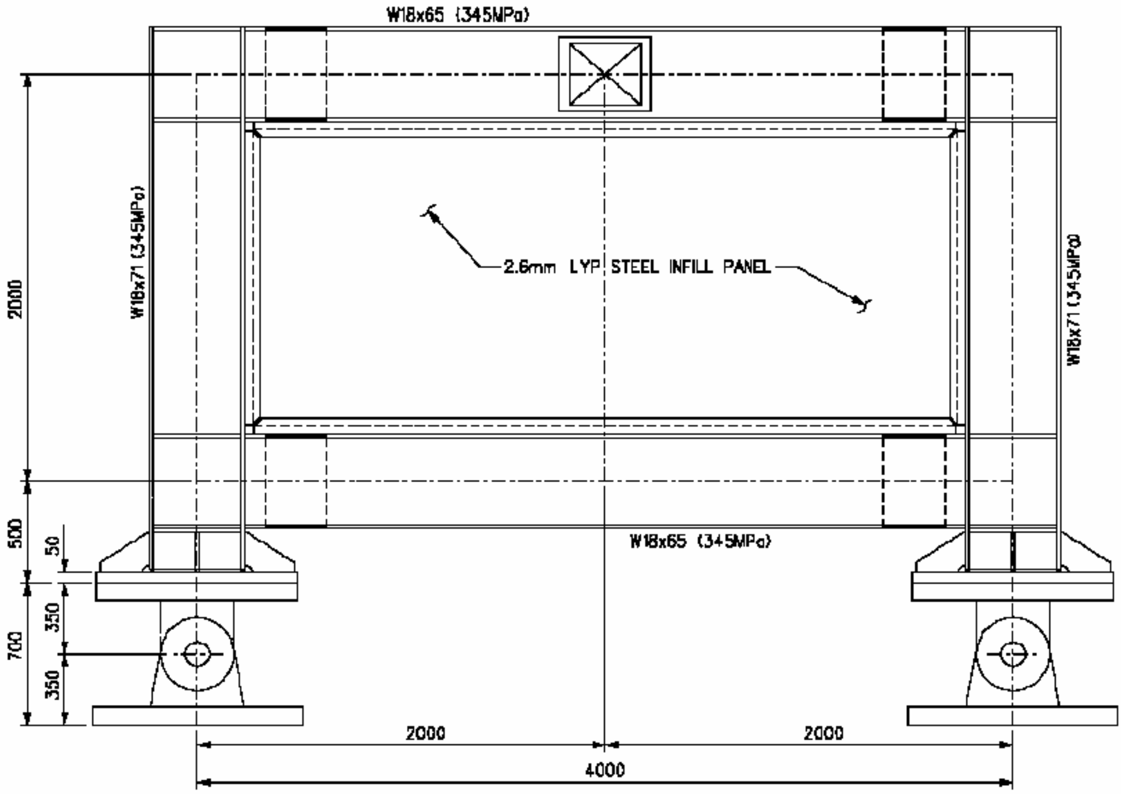

Fig. 1 - Schematic of Test Specimen

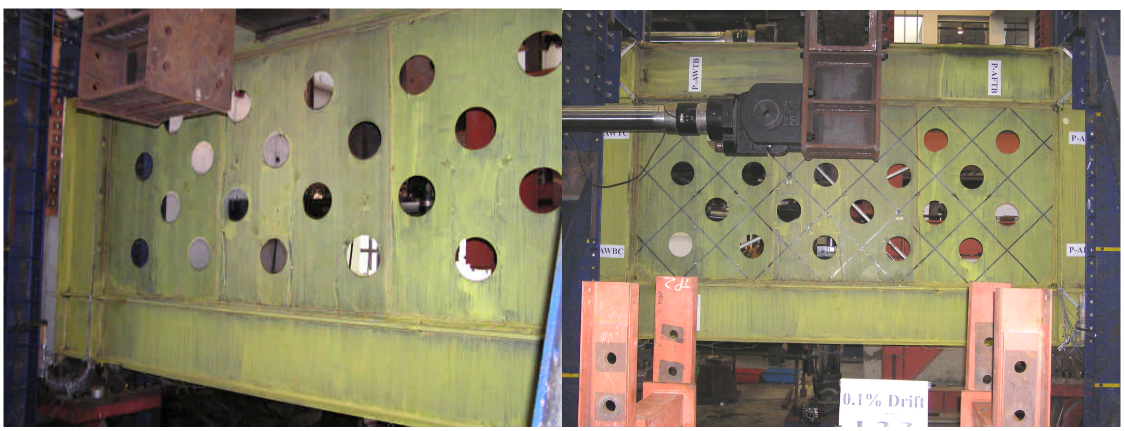

Fig. 2 - Specimen P before testing

Experimental Results

The first specimen, S1, a solid panel specimen, was tested in August of 2003. The hysteresis of the specimen is shown in Fig. 3 with pushover plots from SAP2000. The panel fractured during the test, at various locations adjacent to the weld splicing together the full panel at the third points. The RBS connections localized all beam yielding to those regions, as designed. However, a poorly executed weld at the bottom beam-to-column connection failed, ending the test at a drift of approximately 3%.

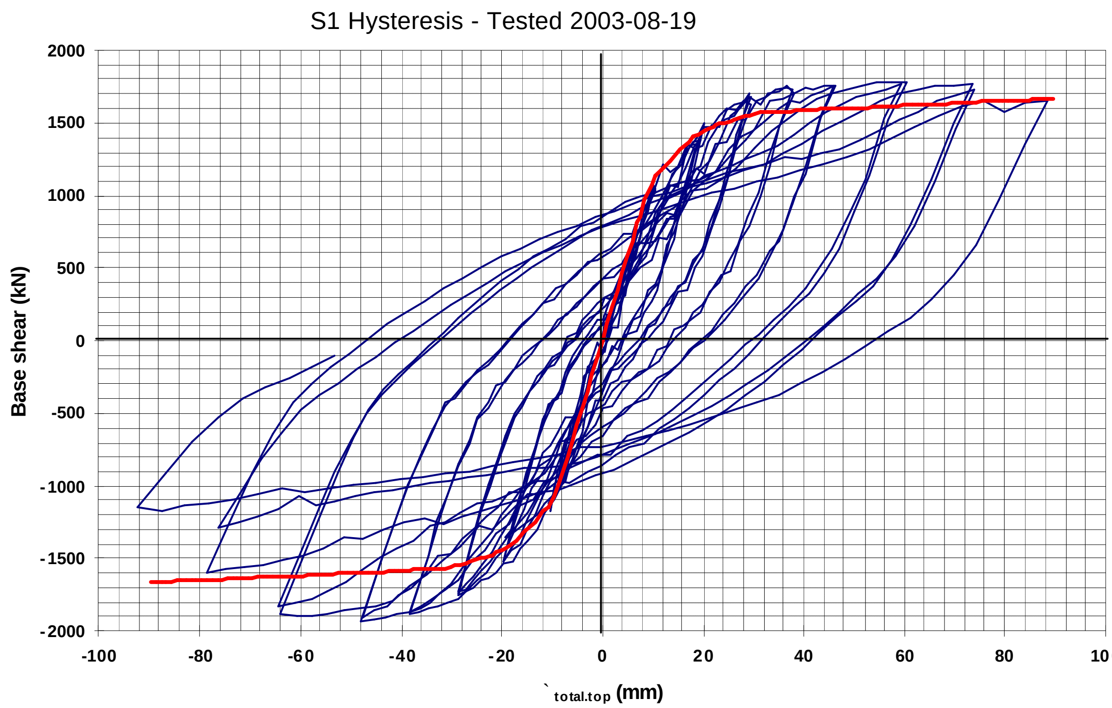

Fig. 3 Hysteresis plot for Solid Panel Specimen S1

The second specimen tested, P, was the perforated panel specimen, tested in November of 2003. Photos of the buckled panel and a yielded RBS connection following the test are shown in Figs. 4 and 5. The hysteresis of the specimen is shown in Fig. 6. Small fractures were found at panel corners at the conclusion of the test. Panel welds splicing together the three pieces remained intact for the entire test. An instability with the loading scheme led to an application of torsion by the loading detail at the center of the top beam. Two attempts were made to correct the problem, but damage to the specimen incurred in the initial incident of out-of-plane movement caused by the torsion was too much for the specimen to handle at larger displacements. Columns continued to rotate about the longitudinal axis, and the test was concluded after reaching a drift of 3%, when a weld failed in the continuity plate at the top of a column.

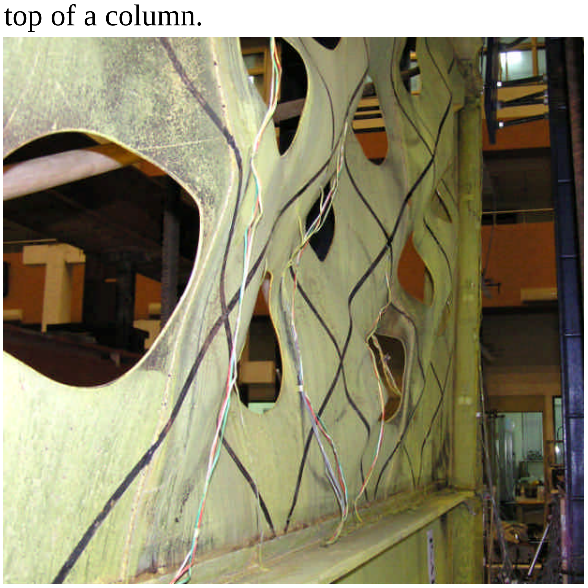

Fig. 4 Buckled panel following test of Specimen P

Fig. 5 RBS yielding and buckles at corner of panel following test of Specimen P

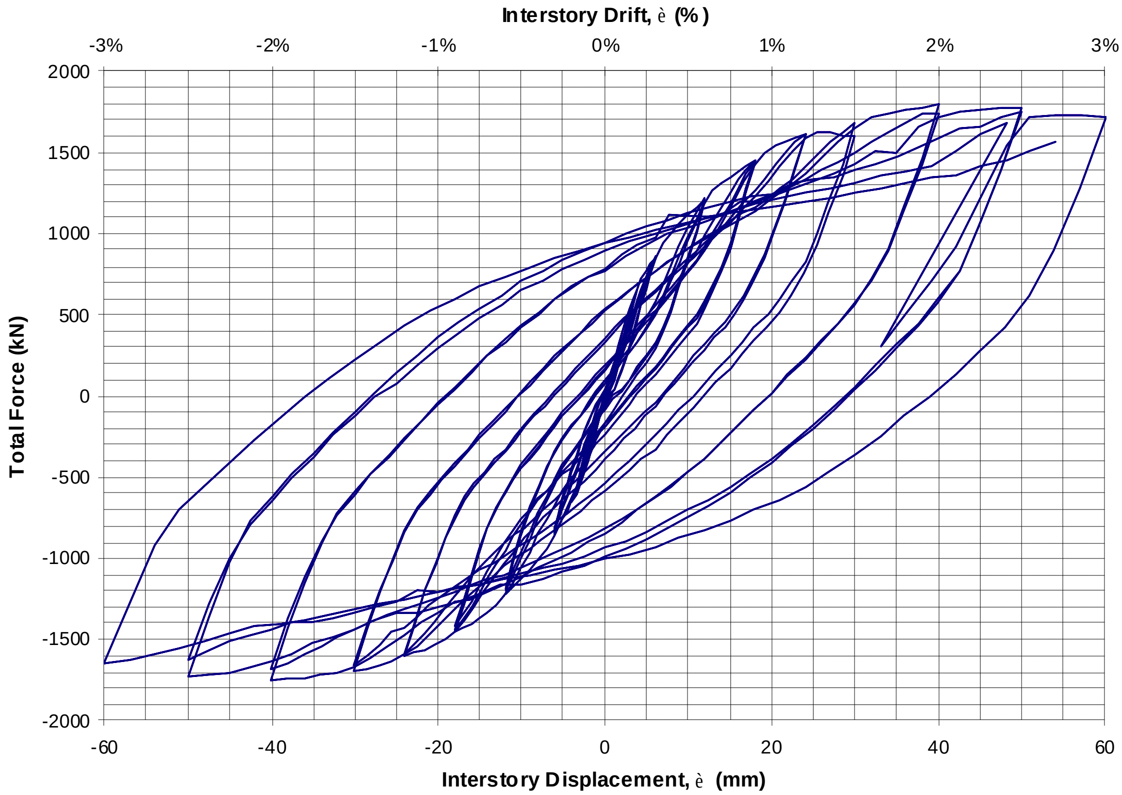

Fig. 6 Hysteresis plot for Perforated Panel Specimen P

Discussion of Test Results

The first specimen tested, S1, performed well. The test was cut short by an error in fabrication, fracturing a weld at the bottom beam connection to the column. Fig. 3 compares the top displacement versus base shear hysteresis of the test, with a SAP2000 pushover analysis. The model uses a strip model to represent the tension field action of the infill panel, and provides a good prediction of the initial stiffness and inelastic backbone curve for the specimen. Although some tearing of the infill panel occurred during the test, this did not result in noticeable degradation of the specimen's energy dissipation behavior, as stresses were redistributed within the panel around the tears. The drop off at the end of the test was due to the beam connection failure.

The second specimen tested, P, performed well at the beginning of the test, behaving elastically at small displacements and exhibiting stable hysteretic behavior in the inelastic range. The stiffness and strength were both reduced, as anticipated, from the first specimen tested, which had a solid panel. Yielding in the panel spread between the perforations, remaining mainly in the narrow region between the holes. From a qualitative standpoint, the perforations reduced the audible sound of the panel buckling as the specimen was cyclically loaded. This would be beneficial in a building application, towards the negative perceptions of building occupants.

Unfortunately this test had some problems during execution. The "H" shaped loading detail, as seen in Fig. 2, rotated about the top beam axis, imparting torsion on that beam, causing damage to the beam-to-column connections and the RBS details. Even after attempts to stabilize the specimen, the damage imparted on the specimen could not be overcome. The test was concluded at a drift of 3%, when a weld fractured, as mentioned above. Even though specimen P did not reach a larger drift as hoped, even in its damaged state it reached a drift identical to that of the first solid panel specimen tested. Test results from the remaining two specimens will be presented at the KKCNN meeting.

Conclusions

Steel Plate Shear Walls of Low Yield Steel appear to be a viable option for use in resistance of lateral loads imparted during seismic excitation. The lower yield strength and thickness of the tested plates result in a reduced stiffness and earlier onset of energy dissipation by the panel as compared to currently available hot-rolled plate.

The perforated panel specimen shows promise towards alleviating stiffness and over-strength concerns using conventional hot-rolled plates. This option also provides access for utilities to penetrate the system, important in a retrofit situation, in which building use is pre-determined prior to SPSW implementation.

The reduced beam section details in the beams performed as designed. Use of this detail may result in more economical designs for beams "anchoring" an SPSW system at the top and bottom of a multi-story frame.

Acknowledgements

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