Numerical evaluation of yielding shear panel device: a sustainable technique to minimise structural damages due to earthquakes

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Abstract

Earthquake is one of the most catastrophic natural events that affect human civilization causing loss of human lives and destruction of cities; recent earthquakes in the Asia-Pacific region highlight the importance of further research to develop sustainable techniques to limit structural damages due to this catastrophe. As the occurrence and severity of an earthquake are beyond our control, it is the after effects that we have to focus on to minimise the loss of human lives. Structures must be designed to absorb the enormous amount of energy exerted by earthquakes to sustain this sudden natural impact. The current research investigates the performance of a recently developed Yielding Shear Panel Device (YSPD), which will be designed to absorb earthquake energy by exploiting the significantly high ductility of stainless steel. YSPD is a small, inexpensive and easy to install device. The basic notion is to concentrate the inevitable structural damages to YSPDs and hence keeping the main structural components intact. The simplicity of YSPD would allow the damaged devices to be replaced by the new ones without any major structural reconstruction.

Earthquake damage control and YSPD

Recent catastrophic earthquakes clearly show the severity of this natural phenomenon on human civilization leaving us ponder to find ways to minimise the resulting loss of lives and structures. One of the major criteria towards building a sustainable city should be providing safe living place, which will be less vulnerable to natural disasters. Earthquakes can cause significant damages to structures and the rehabilitation of these damaged components is a complex and expensive process. A number of active, semi-active and passive control mechanisms have been developed during the last few decades to limit structural damages. Active control devices depend on data collected through real-time recording instrumentation and dissipate energy by real time controlling the actuators placed within a structure, whilst passive control devices have no active feedback collection mechanism but are uniquely designed and positioned to absorb the horizontal thrust. One of the major drawbacks of active control mechanism is its reliance on external power supply, which is most likely to disrupted during an earthquake. Passive energy dissipation techniques, on the hand, do not require any power source and are easy to rehabilitate, incur less cost and are relatively simple to design. Use of metal yielding devices is popular amongst available passive control techniques due to their simplicity in both design and implementation. Metallic structural components are installed at predetermined, appropriate locations to become active during an earthquake excitation and dissipate significant portion of the exerted energy through material yielding.

Yielding Shear Panel Device (YSPD) was first proposed by Schmidt et al. (2004) to exploit the energy dissipative capability of in-plane shear deformation in steel plates. This device can be placed below a structural beam using a V-brace as shown in Figure 1. Due to earthquake excitation, the plate inside the hollow shell will deform and dissipate energy and thus will save the structure from excessive deformation. Chan (2008) conducted a series of monotonic and cyclic tests using various plate thicknesses and device configurations. These results showed stable energy dissipating capacity of YSPD and thus confirms the suitability of YSPD as a passive control device (Chan et. al. 2009).
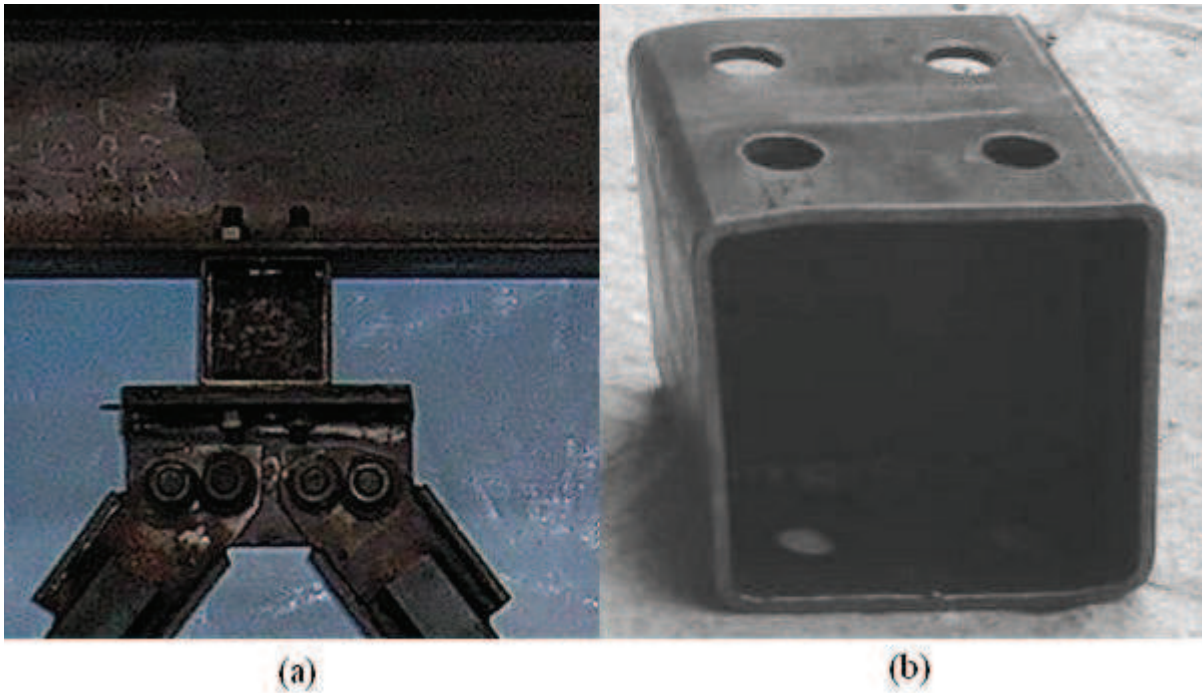
Figure 1. (a) Typical YSPD-brace assembly (b) Yielding shear panel device (YSPD) (Chan 2008)

The current research aims to simulate the test results numerically using Finite Element models developed using ANSYS, which should pave the way for thorough investigation of its performance and the effects of various parameters on its seismic response and to enhance its performance by exploiting the pronounced ductility of stainless steel.

Numerical Modelling of YSPD

Developed numerical model of YSPD includes the effects of material and geometric nonlinearity as well as initial imperfections, which are essential to simulate its response in practical applications. Definition of support conditions to model the connection between the YSPD and the beam was the most challenging aspect; use of spring elements enabled to achieve appropriate stiffness to replicate experimental behaviour. Appropriate material modelling is essential for an accurate numerical model; an advanced nonlinear material model, Chaboche model, is adopted which uses decomposed kinematic hardening rule to simulate nonlinear material behaviour. A 4-node shell element is used which has six degrees of freedom at each node. Full integration with in compatible modes option is used for greater accuracy. Furthermore, geometric nonlinearity option is incorporated which results from the out of plane large displacement of diaphragm plate due to buckling. Thus, the used model is capable to analyse post buckling behaviour of YSPD.

Initial geometric imperfections are an inseparable property of real structures. But there is no general procedure to incorporate initial imperfection in finite element modelling. The most commonly adopted technique to define the distribution of initial imperfections is to perform an elastic buckling analysis prior to the non linear analysis and to use one of the eigenmode buckled shapes as the initial imperfect shape (Ashraf et. al. 2006). As the first buckling mode required the least force, the first buckling mode deformation is scaled as a function of plate thickness and this deformation is applied as initial geometric imperfection with an amplitude of 0.2t, where t is the thickness of the diaphragm plate.

As the YSPD will be connected to a steel base plate through bolts, the edge of the hollow shell should be allowed to move freely in one direction and obstructed by the base plate in the other direction. To model this connection appropriately contact element is used which has been connected to each node of the edge of hollow shell on the side of base plates. The contact element is modelled in such way that it has a compression stiffness equivalent to steel base plate and a negligible tensile stiffness. Also the bolted connections are modelled using contact elements.

The deformation based solution of YSPD subjected to monotonic or cyclic loading results a highly nonlinear problem due to the material nonlinearity as well as geometric nonlinearity, which is solved using an advanced iterative solver available in ANSYS. Figure 2 compares the deformed shape of one of the YSPDs analysed as part of the current research, whilst Figure 3 shows the load deformation behaviour. The comparisons clearly show the accuracy of the developed model, which will be used to generate additional results to investigate the effects of various parameters on the its energy absorption performance.
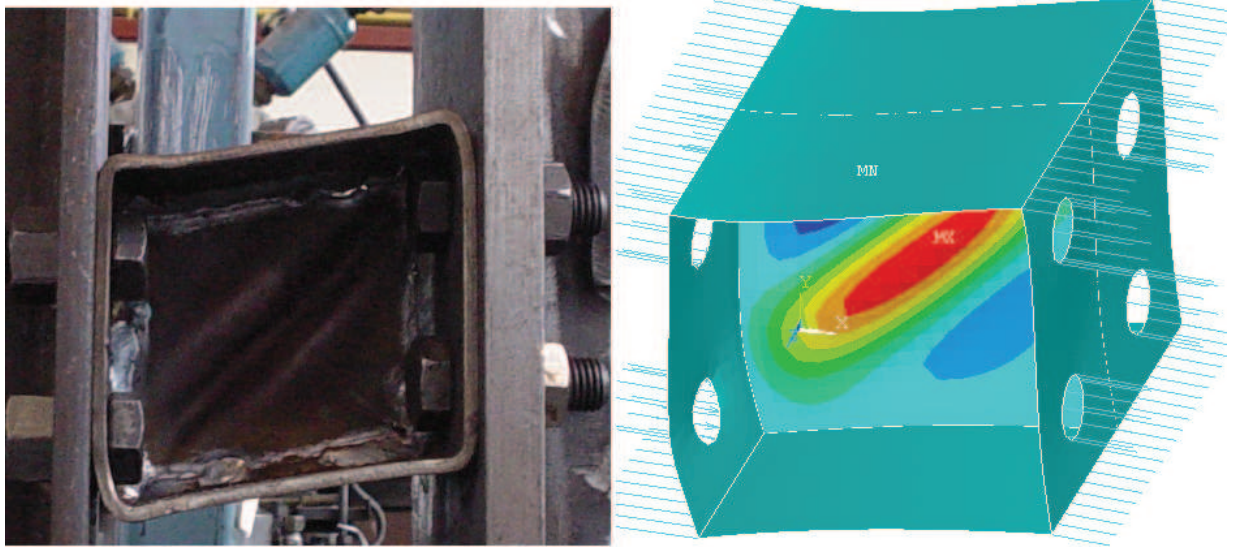

Figure 2. Experimental and Finite Element deformed shape of YSPD
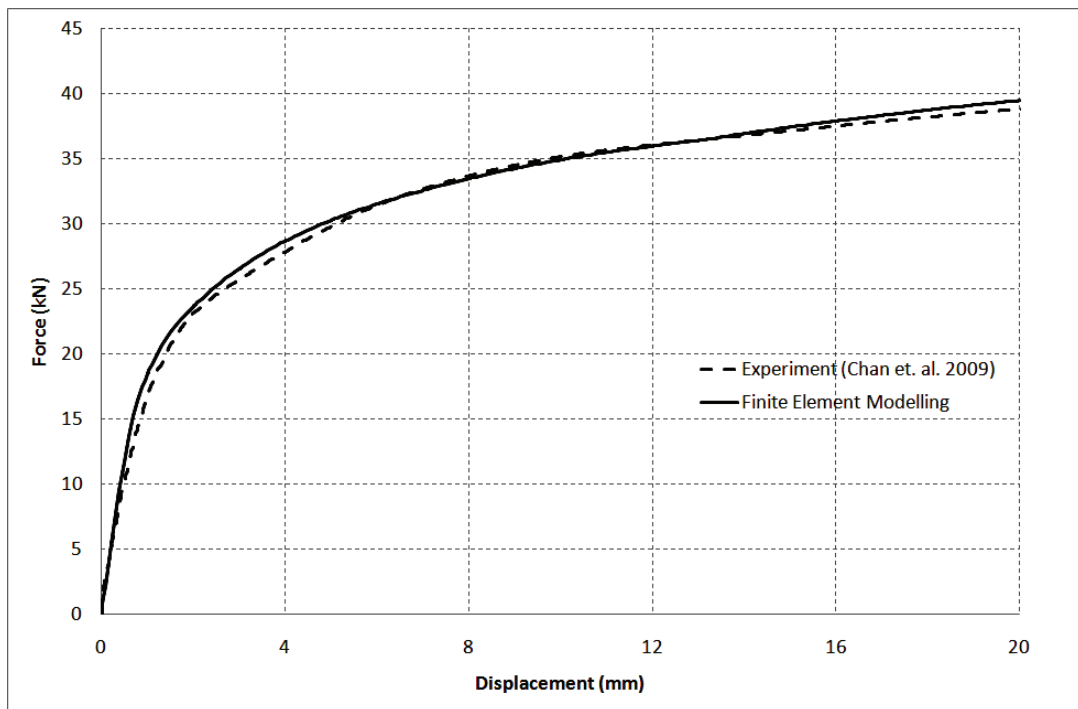

Figure 3. Force-displacement behaviour of YSPD

Conclusion

The basic aspects of the numerical modelling technique adopted for YSPD are explained herein giving appropriate reference to material modelling, initial geometric imperfections and support conditions. Preliminary results show good agreement with test results; further models are currently being developed to generate useful results. These should facilitate to understand the mechanics of YSPD under cyclic loading, which should eventually lead to the development of practical design rules. Currently available test results were performed on carbon steel YSPDs; the current research project aims to explore the use of stainless steel to take advantage of its significantly higher ductility. Stainless steel YSPDs could emerge as a cost-effective sustainable alternative to available energy dissipation devices.

References

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