Influence of crack on the behavior of steel plate shear wall under lateral loading

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ABSTRACT

Experimental and numerical studies of Steel Plate Shear Wall (SPSW) and its successful performance under past earthquakes have introduced this system as a lateral bearing system. There are lots of unknown information about SPSW despite of reported numerous studies. The effect of crack on the SPSW behavior is one of the unknown aspects about SPSW. Although crack had affected of some experimental tests, its effect on the SPSW behavior have not been investigated comprehensively. Even in numerical studies, due to complicity of crack in modeling and analyzing especially in nonlinear studies, it has not been evaluated comprehensively. Because of thin steel plate and inherent of welding, emerging of crack in SPSW is deniable. Therefore, in this paper the effect of central and edge cracks on the behavior of SPSW were studied numerically and parametrically. Numerical results indicated that the central crack are more destructive than edge cracks in case of fracture, ultimate strength, and energy absorption. Although small cracks do not have considerable effect on the behavior of SPSW, the central crack with long length lead the SPSW to fracture in elastic zone. Moreover, although long edge crack reduce ultimate strength and energy absorption, it does not lead the SPSW to fracture. Due to difficulty of crack modeling and crack analysis in SPSW, the necessary relations were proposed to obtain pushover diagram without needing to FE modeling. The proposed relation estimate the pushover diagram of system in good agreement with FE results.

KEYWORDS

Steel shear wall; Crack; Seismic behavior; Stiffness; Strength.

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1. Introduction

Steel Plate Shear Walls (SPSWs) are capable system against lateral loading [1]. This system enjoy high stiffness and strength as well as considerable ductility [2]. This system had shown ductile behavior in past earthquakes [3]. These advantages pursued designers to use it in their projects. Also, some strategic building has been built using SPSW. Generally, in small scale and full scale laboratories studies, continues infill steel plate is used [2-6] that is dissimilar with real projects condition. Due to limitation of steel plates in case of practical dimensions and SPSWs technical construction, constructor utilize two plates for infill plates. The two plate are welded together at mid-height of infill plate that is susceptible to crack.

Since it is used thin plates for infill plates of SPSWs systems and due to nature of crack, existing of crack in infill plate is undeniable. Also, in some experimental studies [7,8], the emerging of crack reported although the main feature of those studies were not to study of crack in SPSW. Therefore, there is a gape knowledge in this field. In so doing, in this study the effect of crack on the SPSW is investigated numerically and parametrically.

2. Methodology

Numerically study are carried out using Finite Element (FE) method. In so doing, capacities of ANSYS and ABAQUS softwares are used. The crack initiation is obtained by ABAQUS and then the crack propagation is modeled by ANSYS. This technic is because of limitations the mentioned softwares and their capabilities in modeling and analyzing.

The geometrical properties and crack location at mid-height of infill plate in FE models are shown in Fig. 1. The infill plate equals 4mm were designed for all models. The boundary frame was design to resist the post bucking behavior of infill plate. For each model, a specific name were selected that contains two parts. First part, EF or CF represent edge or central crack, respectively. The second part shows the crack length in mm. Models with crack length of 4, 8, 16, 32, 64, 128, 256, 512, and 1024 mm were modeled.

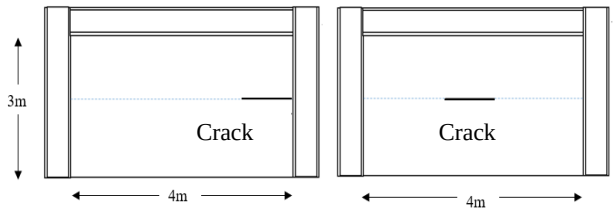

Figure 1. Cracked SPSW

3. Results and discussion

4. Load-displacement curve

The load-displacement curves of FE models are shown in Fig. 2. Based on the figure, edge crack lead the curve down but it is not cause to suddenly fracture of SPSW. Leading the curve down represent reducing in ultimate strength and energy absorption. But, walls with central crack length greater than 3.2% of infill plate are fractured suddenly. Moreover, central crack length greater than 12.8% of infill plate cause to fracture of wall in elastic zone. It is concluded that wall with central crack length great than 12.8% should not be used as seismic zones.

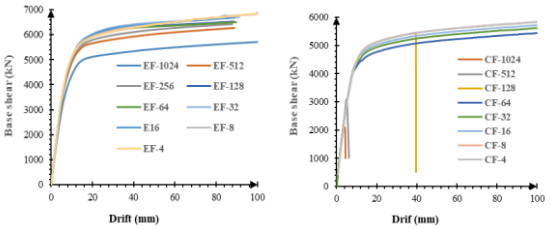

Figure 2: Load-displacement curve of FE models

4.1. Stress in SPSW

Fig. 3 shows the yielded state of SPSW for edge and central crack at ultimate drift. As shown in this figure, long crack length prevent forming of stress tension field action in infill plate. Also, crack with small length does considerable effect on the tension stress field action. Moreover, in wall with long central crack, yielding is concentrated at two ends of crack. In the other words, infill plate dosed participate in energy absorbing because of fracturing of infill plate in elastic zone. But, in wall with long central crack, considerable area of infill plate is yielded however the tension field action is not completed.

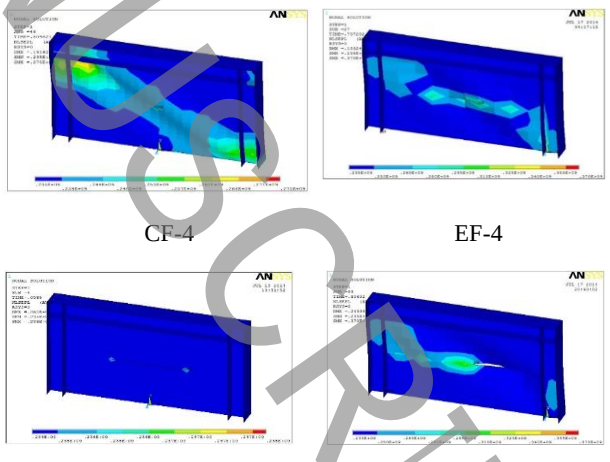

Figure 3. Yielding of SPSW for edge and central cracks

5. Parametric model

Modeling of SPSW is complicated even without accounting cracks. Considering the crack effect, the complexity of modeling is further enhanced. To overcome this problem a parametric model is proposed for cracked SPSW. For this meaning, displacement and strength of infill plate and main frame are calculated separately. To archive pushover curve of cracked SPSW, the obtained curves are combined together. Shear displacement of infill plate, Δ_{wp}, without taking into account of crack effect is obtained from Eq. (1).

$$\Delta_{wp}=\frac{0.65\,\sigma_t}{E}\,\frac{3+sin^2 2\alpha}{sin 2\alpha}\,d \qquad (1)$$

Where, E is the Yang modulus, σ_t is the tension yield strength, d is the frame height, and α is tension field action.

It is assumed that ultimate strength, F_f, and ultimate elastic displacement, Δ_f, of main frame are calculated when two hinges are formed at the two ends of columns.

$$\Delta_f=\frac{M_p\,d^2}{6E\,I_c} \qquad (2)$$

$$F_f=\frac{4M_p}{d} \qquad (3)$$

Where I_c, and M_p are the moment of inertia and plastic moment of column. The load-displacement of uncracked SPSW is drawn using the Eq. (1) to (3) in elastic zone. To tack into account of crack, the infill plate length, b, is modified. If it is assumed that b2 be cracked infill and cracked equal to, and crack propagated length be b1 therefore the modified infill plate length accounting cracking is equal to $b_2 = \mathrm{b} - b_1$.Therefore, shear strength of cracked infill plate is calculated by Eq. (4).

$$\mathrm{F_{w2}} = (\tau_{cr} + 0.5\,\sigma_t\ \sin 2\alpha)\ b_2.t \qquad (4)$$

5.1. Verification of parametric method

In Fig. 4 the FE results are compared with proposed method to evaluate the accuracy of results. As seen in the figure, the proposed method shows a good agreement with FE results. Its error in elastic zone is around 2% in calculating of stiffness. In addition, it calculate the ultimate strength 5% lower than FE results.

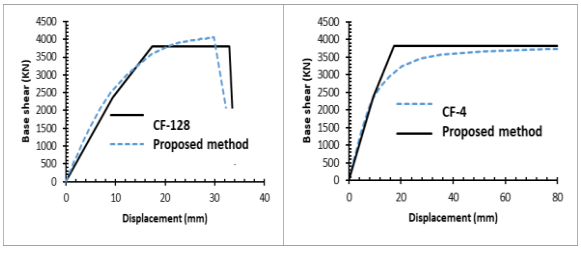

Figure 4. Comparing of proposed method with FE results

6. Conclusions

In this paper the effect of crack on the behavior of SPSW were studies numerically and parametrically. The results are summarized as follows:

- Crack with small length does not considerable effect on the behavior of SPSW.

- Both long edge and central cracks in infill plate reduces the ultimate strength and energy absorption of SPSW. But, central crakes are more critical than edge crakes.

- In central crake length greater than 3.2% of infill plate length, it cause to suddenly fracture of SPSW in inelastic zone. Moreover, wall with central crake length greater than 3.2% of infill plate length, fractured in elastic zone with significantly low energy absorption.

- Central long crack prevent forming the yielding of diagonal infill plate whereas edge crack does not considerable impact on it.

- The proposed parametric model are in good agreement with FE results in case of predicting pushover curve.

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