Adjustment of Parameters in Stress-Strain Relationship of Strip Elements in Steel plate Shear Wall Model under Cyclic Loading

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ABSTRACT: Despite many advantages of steel plate shear wall (SPSW) system, such as lightness, high stiffness, ductility, and fast implementation, this system is not as pervasive as other lateral load resisting systems such as bracing or reinforced concrete shear walls. To solve this problem, numerical parametric studies of system with consideration of seismic uncertainties which needs accurate non-linear models including behavioral deterioration of system is necessary. So, in this paper, besides studying existing macroscopic modeling of steel plate shear walls, a new model is introduced which is modified version of Strip model's application with focusing on stress-strain curve proposed by one of researchers. After suggesting essential adjustments in this model and showing their necessities with emphasizing on experimental and finite element results, correctness of new model by doing several finite element analysis in different models with various plate thickness and length to height ratio is verified and proper values for parameters is proposed.

1- Introduction

One of the disadvantages of steel plate shear wall (SPSW) system is the common numerical model which is time-consuming and arduous. Currently, detailed numerical modeling and non-linear analysis by existing finite element software, requires special expertise and has its difficulties in analyses (difficult modeling, large number of needed elements, considerable time and cost consumption and convergence difficulties in analyses). Studying simple behavior models which predict the behavior of the system in different conditions and, at the same time, are easy to use by engineers, is a fertile ground for further researches. In this regard, macro modeling methods for thin SPSWs such as strip model and equivalent truss model have been presented. Choi and Park (2012) presented a hysteretic model for strip elements, by considering the plate's buckling effect and yield principles of the steel material of the plate, in order to assign an accurate behavior to strip elements in common strip modeling. They extracted a stress-strain curve for strip elements and developed it by OpenSees software (Mazzoni et al., 2006), using the cyclic analysis results of a simple finite element model of an SPSW (Figure 1). They examined it's validity by modeling some experimental samples in OpenSees software and it was revealed to be more accurate than previous models.
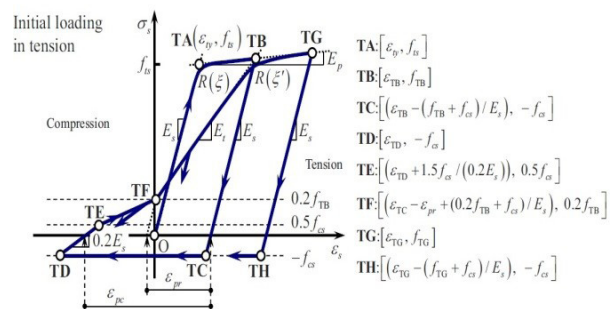

Figure 1. Choi and Park's proposed stress-strain curve for strip elements [1]

2- Methodology

In order to verify Choi and Park's proposed model, Sabouri-Ghomi and Sajadi's (2012) single story experimental sample (depicted in Figure 2) was modeled in OpenSees software by strip modeling. Then cyclic analysis was performed and it was compared with experimental results. According to the Figure 2, calculated maximum strength matches the experimental results, but the point at which hysteresis loop enters the opposite loading curve, has moved to both positive and negative directions, so it causes the central area of the hysteresis loop to decrease. One of the main reasons being, the simplifying assumption used by Choi and Park in their

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proposed model for compressive strength (f_{cs}) and tensile strength of plates (f_{ts}). Other reasons include some constants such as representative coefficients for vertical coordinates of points (TE) and (TF), and the constant in the equation ε_{pr} and reloading curve slope in tensile test ($0.2E_s$) in the suggested model (Figure 1).
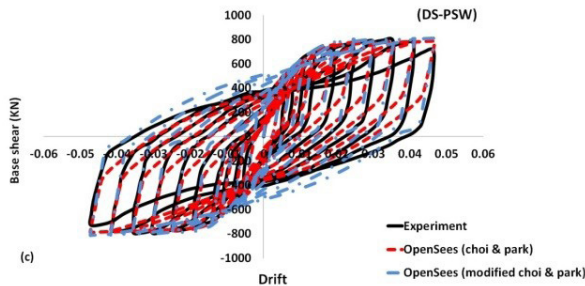
Figure 2. Comparison between the results of Choi and Park's original model, adjusted parameters model and experiment.

In order to examine the effect of model parameters on hysteresis loop, the fifth cycle of loading was performed on the experimental samples of Sabouri-Ghomi and Sajadi (2012) with different values for a parameter while others remained constants. Thus, these 6 parameters were chosen as model variables, and proper values of these parameters were calibrated for Sabouri-Ghomi and Sajadi's experimental samples as presented in Table 1. Which led to a better agreement between experimental and OpenSees modeling results, as demonstrated in Figure 2.

Table 1. Calibrated values for Sabouri's experimental sample

Material Parameters	Modified Chio & Park	Chio & Park
f_{ts}/F_y	0.87	0.97
f_{cs}/F_y	0.3	0.05
tensionReloadStiffness Ratio (β) / E_s	0.2	0.2
TFfactor / f_{TB}	0.52	0.2
TEfactor / f_{Cs}	0.3	0.5
ε_{pr}	0.6	0.5

3- Calibrating the parameters of Chio and Park's proposed for real models

In order to calibrate the parameters of Choi and Park's proposed model for real models, 8 types of single story SPSWs with different length to height ratios and plate thicknesses were designed with capacity-based design principles (AISC 820., 2007). The aforementioned SPSWs were modeled in ABAQUS and OpenSees softwares and were subjected to cyclic loading.

Constant thickness and different length to height ratio:

According to the results, increase in length to height ratio leads to increase in tensile strength of the strip elements, in a way that makes it closer to yield point of the plate (F_y). But has no effect on compressive strength of the strip elements. In other words, we can assume f_{cs} to be $0.1F_y$ for plate thickness of 3.18 mm and different values for L/h.

Increase in length to height ratio has led to decrease in ε_{pr} coefficient. In other words, reduction of ε_{pr} indicates that a lot of plastic strains occurred in the plate due to n th loading cycle, are recovered by reloading in n+1 th cycle and the plate have become closer to its initial condition at start of the diagonal tensile field. Changes in vertical coordinate coefficient of the point TE are not very regular. Generally, it is less than 0.5 in high and low length to height ratios (L/h= 0.85, 2.5) and above 0.5 in moderate length to height ratios (0.85 < L/h < 2.5). In fact, the value suggested by Choi and Park (0.5) is the mean calibrated value. Vertical coordinate coefficient of the point TF is much smaller for lower length to height ratios than moderate and high length to height ratios which is 0.32. Obtained results for the β coefficient indicate that it is directly proportional to length to height ratio, and equals to 0.5 for L/h higher than 2. And one of the factors influencing this coefficient is the stiffening of the system caused by frame and its interaction with the plate.

Different thickness and constant length to height ratio:

Calibration results for models with different thicknesses and constant length to height ratios indicate that increase in plate thickness leads to considerable increase in compressive strength, so that in thick plates (t=9.53 mm), it has become 0.4 times the yield strength of the plate, but the tensile strength has increased slightly. Also the value of the β coefficient is not dependent on the plate thickness and is always equal to the suggested value that is 0.2. Increased thickness has led to decrease in coordinate coefficients of the points TF and TE, so that obtained values are always less than the suggested values in the original model. Values for coefficient ε_{pr} equals to 0.4 in thin plates (3.18 and 3.42 mm), 0.6 in moderate plates (4.76 and 6.35 mm) and 0.8 in thick plates, which indicates that as the plate gets thicker, more plastic strain, caused by previous cycle, resides in it.

4- Conclusions

Investigation of proposed method by Thorburn and et.al for hysteresis modeling of infill plate using Strip elements regardless of compression strength of elements shows that, pinching in obtained hysteresis curves is so severe than experimental results and the absorbed energy obtained by this method is so conservative. Next, proposed method by Chio and Park for increasing the accuracy of Strip modeling studied. Obtained results in this paper showed that the considered values for parameters of the model that relying on theoretical principles suggested by Chio and Park, do not lead to same results in different models. In other words, coefficients are function of geometrical and strength parameters of the real model (aspect ratio and thickness of plate). In this regard, in this paper, modified Chio and Park's model introduced. The main difference between the amounts of parameters in modified model and original model are as follows:

- Increase in length to height ratio has no effect on compressive strength of the strip elements and we can

assume f_{cs} to be $0.1F_y$ for different values of L/h, but increase in plate thickness leads to considerable increase in compressive strength which is varied between 0.1 to $0.4F_y$.

- Tensile strength of the strip elements varies between 0.7 to $0.85F_y$ for different plate thickness and between $0.7F_y$ to $0.95F_y$ for different length to height ratio.

- Beta coefficient (β) is not dependent on the plate thickness and is always equal to the suggested value that is 0.2, but increase in length to height ratio leads to increase in Beta coefficient.

- Increase in length to height ratio has led to decrease in ε_{pr} coefficient and increase in plate thickness has led to increase in ε_{pr} coefficient.

- Increase in plate thickness has led to decrease in coordinate coefficients of the points TF and TE. Increase in length to height ratio has led to increase in coordinate coefficients of the points TE, but coefficient of the point TF varies irregular.

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