AN ANALYTICAL MODEL FOR STEEL SHEAR WALL STRENGTHENED WITH CFRP USING COMPOSITE THEORY

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These shear walls were initially utilized as a retrofit system, however, after their good performance was approved, they were applied as a structure system. Some advantages of this system are high ductility, energy absorption, stiffness and strength, on contrary the disadvantage of this system is low elastic strength of steel walls. To improve shear performance of steel shear walls, adding vertical and horizontal stiffeners (Kharrazi, 2005), low yield point plate materials (Vian and Bruneau, 2004), strengthening with concrete (Rahai and Hatami, 2009; Arabzadeh et al., 2011), perforated web plate (Thorburn, 1983) and covering steel plate with FRP materials (Hatami et al., 2012; Nategh Alahi and Khazaei poul, 2012; Rahai and Alipour, 2011) have been studied. Due to light weight, high elasticity module and high tension strength, FRP materials have a wide application in civil engineering. Covering plate with FRP increases the shear strength, energy absorption, excessive post buckling field distribution and stiffness of shear wall. So far, configuration of fiber orientation, behavior and seismically parameters of composite steel shear wall have been evaluated by numerical and empirical methods (Nategh Alahi and Khzaei poul, 2012) and yet no explicit analytical method has been presented, but experimental and numerical studies absolutely depend on dimension and mechanical properties of steel and FRP. Plate-frame interaction in most cases yields the precise values (Roberts and Sabouri, 1991). Rahai and Hatami, some specimen strengthened with CFRP layers have been studied and in these experimental tests, fiber orientation, thickness of CFRP and shear wall dimension under cyclic loading was evaluated. Finally, some equations were proposed for nonlinear behavior of CSSW using elastic analysis. Rahai and Alipour evaluated the ductility, stiffness, yield shear force factors under push over analysis as well as thickness of FRP layers and conclude that in diagonal tension field, overall strength and stiffness of shear wall have been increased. In addition, Nateghi Alahi and Khazaei poul conducted five experimental tests on composite steel shear wall under cyclic loading, different fiber angle and thickness. They concluded that fiber inclination is the most important variable on behavior of composite shear wall; moreover, they concluded that initial and secant stiffness of CSSW would increase if principal orientation of fiber material is in tension filed angle. In this article, over-strength and seismic parameter of composite steel plate shear wall, strengthened with FRP materials using analytical and almost simple methods, have been studied. Furthermore, stress and strain in FRP material in different fiber angles, extra strength due to FRP, stiffness of shear wall after adding FRP and Elastic shear displacement in FRP were achieved using these equations.

SPSW-FRP Composite Model: a). *FRP Elastic Shear Strength:* The over shear strength in CSPSW, due to FRP, was achieved by Eq. (1).

$$F_{SFRP} = \iint_{A_{frp}} \tau_{xy} dA = b_{frp} t_{frp} \left[\frac{8C^2S^2}{S_{Lt}^2} + \frac{4C^2S^2}{S_{Tt}^2} + \frac{\left(C^2 - S^2\right)^2}{S_s^2}\right]^{-1/2} \tag{1}$$

b). *FRP Elastic Shear Displacement:* To evaluate FRP in CSPSW, Elastic displacement must be determined. For this reason, the internal strain energy in material and the work done by external shear force must be equal, yields the Elastic shear displacement, Eq. (2).

$$\Delta_{SFRP} = d_{frp}\sigma_{11}^2\left(\frac{C^4}{E_{xx}} + \frac{S^4}{E_{yy}} + \frac{C^2S^2}{G_{xy}}\right)\times\left(\frac{8C^2S^2}{S_{Lt}^2} + \frac{4C^2S^2}{S_{Tt}^2} + \frac{\left(C^2 - S^2\right)^2}{S_s^2}\right)^{\frac{1}{2}} \quad (2)$$

Using PFI method and equation (1) and (2), parametric push curve for steel plate without FRP, strengthened with FRP, is achieved and has been compared to FEM curves. In PFI method, tension field angle is optimum fiber angle of FRP material. In Figure 1, the Elastic strength, elastic displacement of plate, CFRP, frame and are shown, and then by superposition, pushover curve for composite steel plate shear wall is achieved.

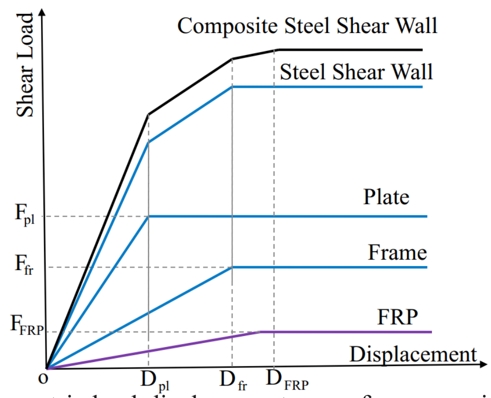

Figure 1. Parametric load-displacement curve for composite shear wall

The counclusions are as follows:

1- Using composite structural analysis, some equations are obtained for elastic shear strength and shear displacement for composite steel shear walls.
2- Optimum fiber direction is on tension diagonal tension field in plate.
3- After FRP orientation in CSSW, the module of elasticity in main direction and tensile strength in fiber material are the most important variables to achieve desirable stiffness and shear strength.
4- In failure criteria in composite materials, Azai-Tsai-Hill yields the most reliable estimate for shear strength and maximum stress Criterion yields the most reliable estimate for Elastic shear displacement.
5- Using stress – strain equation given in this article, stress and strain can be obtained in arbitrary direction in FRP material.

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