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Effect of confining of boundary elements of slender RC shear wall by FRP composites and stirrups

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ABSTRACT

Existing concrete shear walls may be considered vulnerable for continuing service life due to changes in the seismic codes requirements, subjecting to intensive dynamic loads such as earthquake or explosion, and damages due to some local destructive loads. A review on the previous studies shows that despite the squat walls, very limited analytical and/or experimental studies have been already conducted on the FRP strengthening of slender RC shear walls under monotonic loading. In this paper the main focus is on the confinement of the boundary elements of shear walls with FRP composites and its effect on flexural behaviour of the wall. Nonlinear finite element analysis is performed on two shear wall specimens using damage plasticity model and considering tension stiffening effect. Results of the current study showed the superior effectiveness of strengthening FRP composite layers on ductile behaviour of concrete shear walls; i.e. the confinement of the boundary elements with FRP increased the ultimate displacement under almost constant load up to 50%. Furthermore, the results showed that it is sufficient to apply the FRP layers only on the boundary elements in the plastic hinge region of the wall.

1. Introduction

Shear walls are the major structural elements in reinforced concrete buildings to resist lateral loads. They must provide adequate strength and sufficient ductility to avoid brittle failure under strong lateral loads during an earthquake. Nevertheless, many of the previously constructed shear walls are now counted weak because of inadequate design or performance, and destructive effects of environmental surrounding condition. This is why many of existing shear walls need be strengthened.

Since the fibre reinforced polymer (FRP) materials offer several advantages in terms of material properties and performance over traditional building materials, the use of FRP in civil engineering applications has increasingly grew up in recent years. Some of these benefits are: low density, very high tensile strength to weight ratio, high tensile modulus to weight ratio, corrosion resistance and good fatigue characteristics [1–3]. Furthermore, FRP materials do not add significant weight to the structure and thus do not alter the magnitude and distribution of the seismic loads. Upgrading of structures by means of FRP compared to other existing techniques is not very labour-intensive and destructive to the operation of the facilities during the construction period; and hence it is not essential the complete shutdown of the facilities and relocation of the occupants [1].

Research on the behaviour of reinforced concrete (RC) members with externally bonded FRP jackets has been mainly concentrated on columns or piers, where its use is more common in practice. Attention to application of FRP sheets on RC walls, though not uncommon as a practical retrofit measure, has been less paid by researchers [4]. In this paper, the effect of FRP jackets on the boundary elements of slender shear walls is studied.

The study on concrete shear walls goes back to early 1970s. The Construction Technology Labs of Portland Cement Association conducted comprehensive and extensive studies on the shear walls from 1974 to 1983 [5], and their results in detail were reported in some references [6]. The primary purpose of PCA experiments was to determine the ductility, energy dissipation capacity and strength of structural walls to develop seismic design criteria for shear wall in earthquake resisting buildings [5]. To reach these objectives, 22 shear wall specimens with scale of 1–3 subjected to monotonic and reverse loading were experimented. Results of the tests showed that the inelastic deformation capacity of shear wall was limited by crushing of web concrete and combined crushing and shearing failure of compression zone concrete [5]. Furthermore, based on results of this experimental program, the importance of providing sufficient confining reinforcement in the boundary elements was emphasised [7]. Besides, based on the experimental work, some analytical models were developed to predict the inelastic strength of walls subjected to reverse cyclic loading and to

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calculate the natural frequencies of walls [8,9]. The study on the subject was continued by some other researches like Tasnimi [10], Su and Wong [11], Thomsen and Wallace [12] and Perry et al. [13].

Marini and Meda studied retrofitting of concrete shear walls by high performance jackets using steel meshes; and concluded that this method considerably increases the strength and displacement capacity of the wall [14]. Hatami et al. investigated the strengthening of steel shear walls by carbon fibre polymers. Their tests showed that applying of CFRP sheets on steel shear walls increases energy absorption of the wall as well as its stiffness and loading capacity [15].

Meftah et al. [16] employed a model based on mixed finite element (FE) method to calculate dynamic characteristics of RC shear walls strengthened with bonded composite plates. The results showed that material properties of the plates have a significant effect on the deflection of the strengthened shear walls, with small effect on their frequencies. Furthermore, Meftah et al. [17] studied the effect of composite plates on mitigation of the dynamic properties of shear walls using finite element techniques. The numerical investigation showed good efficiency of the plates on dynamic and lateral stiffness characteristics. Linde and Bachmann [18] presented a model for simulation of dynamic behaviour of concrete shear walls and by numerical modelling, proposed some design rules to improve the capacity of the walls.

Note that most of aforementioned studies from the literature are focused on the dynamic behaviour of slender walls strengthened with FRP layers; however, nonlinear static analysis is also very informative and provides more applicable data for design; though it has been less under investigation. The current study is mainly concentrated on the behaviour of RC shear walls strengthened with FRP composites under monotonic loading. Attempt is made to clarify if there is any major behavioural difference to attach the FRP sheets around the whole height of the slender shear walls or just around some limited parts in their boundary elements region; also to seek appropriate FRP strengthening configurations leading to higher loading capacity and ductility as well as less damage to the wall.

2. Behaviour of shear walls

Despite relative simplicity in design and construction of reinforced concrete shear walls, the actual behaviour of the walls is complex [19]. The aspect ratio of shear wall (height to length ratio) plays the major role on the overall behaviour of the wall. A wall with aspect ratio less than two or three is categorised as a squat or low rise wall. For this wall, the beam theory cannot be applied because of deep beam effects. On the other hand, a shear wall with height to length ratio greater than this dividing limit is commonly referred to as tall wall or slender wall and behaves essentially similar to a RC beam [20].

The overall response of slender (or tall) shear walls is influenced by a combination of flexural, shear and axial deformations [19]. Wall sections are subjected to axial compression due to gravity load from the tributary floor area in addition to its own self-weight. The compression forces in the wall are normally below the balanced point on the axial force-bending moment interaction curve; different from the forces in columns in high-rise buildings which are subjected to large axial compressive forces [20].

Fig. 1 shows a typical bending moment–curvature relationship for a high rise shear wall section subjected to monotonic loading.

As it is seen in the figure, the wall response is primarily linear elastic. In this phase, the wall section is un-cracked and thus the slope of the curve is calculated based on gross section properties of EI_g [21], where E and I_g are the modulus of elasticity of concrete and the moment of inertia of the wall section, respectively. When the applied bending moment increases beyond the elastic range, the first crack occurs and the nonlinearity in the wall behaviour starts. Initiation of additional cracks leads to decrease of the flexural stiffness and hence the slope of this phase of the wall response is approximately parallel to the flexural stiffness of the cracked transformed section, EI_{cr}, where I_{cr} is the moment of inertia of cracked transformed wall section. Further increasing of the applied moment leads to yielding of reinforcement and reaching the ultimate capacity of the under-reinforced concrete sections [21].

Since the analysis of reinforced concrete shear walls designed to resist earthquake loads involves consideration of nonlinear material behaviour, it requires a special treatment and scrutiny in modelling. The finite element technique approach has been employed in recent years to model the reinforced concrete shear walls by researches [22].

3. Finite elements simulation

In this paper, the FE model was built within the commercially available software package, ABAQUS 6.7. The plasticity model used in this study is damage plasticity. The concrete damage plasticity model in the software is capable for modelling all types of concrete elements including beam, shell and solid. The inclusion of damage is the major difference between a plastic damage model and a plasticity model [22]. It uses concepts of isotropic damage elasticity in combination with isotropic tensile and compressive plasticity to represent the inelastic behaviour of concrete. It also can be used with rebar to model concrete reinforcement. Using this model accompanied with a visco-plastic regularization of the constitutive equations in the software improves the convergence rate in the softening regime [23]. Note that in general, the commercially software packages are employed for general purposes and for this reason they may not necessarily have all the capabilities required to accurately model the application of interest [22]. Therefore, the professional users may have to pay a lot of efforts to calibrate the software for any special case. For introducing the damage plasticity model, introduction of material properties is particularly important.

3.1. Concrete properties

Complete stress–strain curves of concrete in compression and tension are used to predict structural behaviour up to failure and post failure. In compression, stress–strain relationship can be

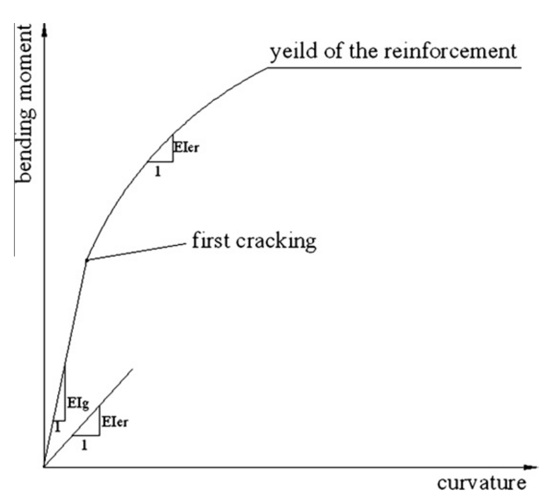

Fig. 1. A typical bending moment–curvature for a high rise concrete shear walls [21].