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Lateral stiffness and vibration characteristics of damaged RC coupled shear walls strengthened with thin composite plates

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Abstract

This paper deals with the bending and vibration analysis of moderately damaged coupled shear wall structures with externally bonded carbon fiber-reinforced polymer (CFRP) sheets. In the analytical formulation, the adherent and the adhesive layers are all modelled as shear walls, using the mixed finite-element method (FEM). The anisotropic damage model is adopted to describe the damage extent of the RC coupled shear walls. A free vibration analysis is carried out to determine the frequencies of multi-storey strengthened shear wall structures with openings. Test problems are conducted to demonstrate the accuracy and effectiveness of the proposed method. Numerical results are presented to show the performance of reinforced concrete coupled shear wall structures bonded with composite plates in which a damaged RC shear wall with openings strengthened by a thin steel sheets is treated as a comparator. The effects of damage extent and of the bonded sheets on the bending and vibration characteristics of damaged RC coupled shear wall structures are also studied.

Keywords: Free vibration; Damaged reinforced concrete structures; Coupled shear walls; Strengthened shear walls; Composite plates; Finite-element method

1. Introduction

Coupled shear walls are very frequently incorporated into high rise buildings as an efficient means of providing resistance to lateral forces arising from winds and strong ground motions. Recently, in north Algeria, similar buildings are constructed. However, the recent earthquakes, have repeatedly demonstrated the vulnerabilities of the aged or deteriorated structures to seismic demands.

Many experimental studies have shown that the carbon fiber-reinforced plastic (CFRP) sheets are mechanically effective for upgrading damaged RC structures. To predict the overall response of reinforced concrete shear walls with or without openings bonded with thin composite sheets, the strengthened shear wall can be idealized as moderately thick stepped shear walls composed of dissimilar, orthotropic shear walls of different heights and widths, with thin adhesive layers between them. Moreover the shear wall systems are susceptible to structural damage over their lives due to many factors, such as, impact, operating loads, fatigue and corrosion. Therefore, the capability to predict the static and/or dynamic responses of such structures is of prime importance in the field of strengthening buildings in some earthquake-prone countries such as Algeria.

Visual inspection has been still is the most common method used in detection of damage on a structure. The increased size and complexity of today's structures can reduce the efficiency of the visual inspections. Conventional visual inspection can be costly and time consuming, especially when disassembly is necessary to provide access to the area being inspected. In addition, these visual inspection techniques are often inadequate for identifying the status of a structure where the damage is invisible to the human eyes. Nondestructive damage detection (NDD) technique such as ultrasonic and eddy current scanning, acoustic emission, X-ray inspection, etc., provide options to detect the occurrence of damage.

The earlier investigations on the analysis of coupled shear wall structures are focused on the effect of flexible foundations [1–4] and local deformation at beam–wall joints on the internal forces and deflection of stiffened

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coupled shear walls [2–7], carried out using a discrete-continuous approach and the finite element method (FEM), whereas the bending and vibration characteristics of damaged RC coupled shear walls strengthened by externally bonded FRP sheets has not been studied. Therefore, few researches on efficient analyses and experimental studies of strengthened shear wall have been undertaken [8,9]. Extensive testing such as [10–12] has shown that externally bonded CFRP laminates are particularly suited for improving the short- term behavior of deficient reinforced concrete beams and slabs.

The context of this work is within the rehabilitation of civil engineering infrastructures. In the present study, the bonding of smaller thin composite plates to the original wall using adhesive layers leads to the composite shear wall element. In general the elastic properties of the original shear wall differ from those of the bonded plates, while those of the adhesive layers are also different. In the analytical formulation, the adherent and the adhesive layers are all modeled as shear walls using a mixed FEM [13] to derive the stiffness matrix of equivalent composite shear wall element.

The anisotropic damage model is adopted to describe the damage extent. The FEM is employed to determine the deflection and dynamic characteristics in free vibration analysis problem. Numerical results are presented to show the performance of reinforced concrete coupled shear wall structures strengthened with composite sheets.

2. Finite element for analysis of shear walls

Application of the FEM to shear walls analysis can be dated back to 1960s. Theoretically, the FEM, being the most powerful tool of analysis available, can be applied to any type of building structures. However, due to relatively low efficiency and high computing cost, full finite element analysis of shear wall have never been popular. The principal causes for low efficiency of the method is the presence of parasitic shear in many of the lower order element such as Q4 element which has two translations degree of freedom (DOF) per node as shown in Fig. 1. Because displacement shape functions of this element are expressed in linear functions, deformation of element edges can be expressed by straight lines and the shear stresses in an element are constant and cannot represent the actual stress distribution accurately if the finite element mesh is not fine. However, it is felt that the best method of dealing with parasitic shear is to avoid them by using elements that can exactly represent the strain state of pure bending.

To improve the computational efficiency of the FEM, finite strip element [14], and higher order element [15,16] were developed to modelize the shear wall with the rotational DOF for representing the strain state of pure bending so to avoid parasitic shear problem.

Therefore, the 12 DOF plane stress element as Cheung element [17] and Lee element [13] with drilling DOF (Fig. 2), was used in many research works as [18].

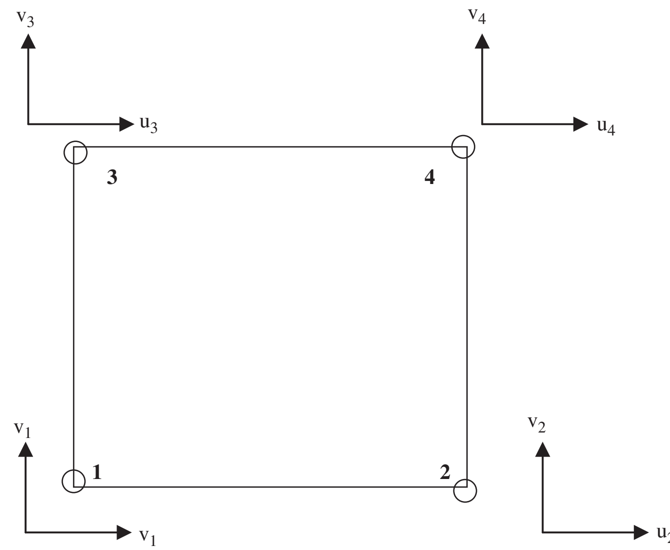

Fig. 1. Q4 element.

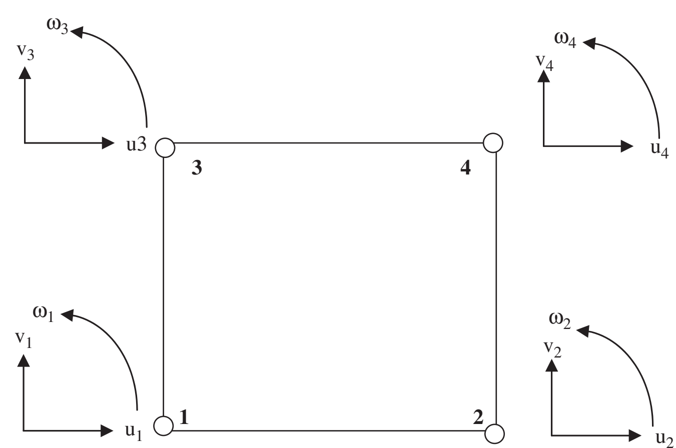

Fig. 2. Cheng's Beam type element.

As suggested by Kwan [13,19], by neglecting the lateral strains in the wall, which are generally of little significance, the DOF can be reduced from 12 to 8 as shown in Fig. 3. Use of this simplified Cheung's element, which is computationally more efficient, is recommended rather the original Cheung's element.

Using the mixed FEM, Kwan [13] developed a wall element with 8 DOF. This element included two existing elements, namely the simplified Cheung's element [15] and Kwan's strain-based element [19].

3. Theoretical analysis and solution procedure

3.1. Material properties of damaged shear walls

Voyiadjis and Kattan [20] proposed an anisotropic damage model, where the elastic energy configuration of deformed and damaged state is equivalent to the elastic energy configuration of deformed but undamaged state. Based on this assumption, the relations of elastic constants