Chapter 6: Conclusion and Recommendation for Further Study

6.1 Conclusion

The result of the study on seismic strengthening of substandard reinforced concrete columns with lap splice confined by Fiber Reinforced Polymer is presented in this thesis. In which, a new model of tri-uniform bond stress distribution along lap splice was proposed in order to assess lap splice strength in either pre-yielding range or post-yielding range. The thesis is divided into four parts. The first part gives an overview of deficiencies characteristic of sub-standard reinforced concrete column in seismic-proof consideration, and a development of retrofitting methods to strengthen this structure. The second part is a study on proposing a new bond stress distribution along lap splice bar in sub-standard reinforced column confined by either stirrup or Fiber Reinforced Polymer; the proposed model focuses on bond stress distribution in case of lap splice bar working in post-yielding range (plastic), but it is also however applicable in pre-yielding range (elastic). The third part is an experimental work on strengthening sub-standard reinforced concrete column by fiber reinforced polymer. The last part is a development of a nonlinear analysis model to simulate a sub-standard reinforced concrete column confined by fiber reinforced polymer. The objectives of this study are to study bond stress characteristics on a starter bar of a laps splice in reinforced concrete column, investigate the factors affect lap splice strength, and conduct an experiment and an analysis to assess effectiveness of fiber reinforced polymer wrapping on lap splice strength. According to the experimental results and analytical investigation, the following conclusions can be drawn.

1. Fiber reinforced polymer is an effective wrapping material to retrofit sub-standard reinforced concrete columns. A short lap splice length in a sub-standard reinforced concrete column causes a brittle failure, non-ductile seismic behavior. In contrast, FRP wrapping around lap splice zone effectively increases bond stress between lap splice bar and around concrete by providing additional lateral confinement; as a result, brittle failure could be avoided and even lap splice can be strengthened to reach post-yield range.

2. A nonlinear analysis model of a reinforced concrete column has been developed to take into account the effectiveness of fiber reinforced polymer confinement on lap splice strength. The input parameters including column section design, steel and concrete strength, lap splice length, amount of transverse steel, a concrete cover reinforcing bar, a given layers of FRP, properties of FRP, a method of wrapping around a RC column, and an exciting load applied to basement of column. The output would be a seismic response of the column, the column strength and lap splice strength.

3. A proposed tri-uniform bond stress distribution model is applicable to calculate a lap splice strength unconfined or confined by fiber reinforced polymer in either pre-yielding or post-yielding range.

4. A Proposed tri-uniform bond stress distribution model also provides an approach to estimate a required number of fiber reinforced polymer sheets in order to get desired lap splice strength. A simple computational procedure have been build, it can play as a practical designing tool.

5. An experimental results again prove that fiber reinforced polymer confinement effectively increase lap splice strength, and column ductility. FRP wrapping around lap splice zone provides additional lateral strength, prevent splitting cracks, protect lap splice from early failure in pre-yielding range.

6. A parametric investigation figure out the factors affect lap splice strength, that including: lap splice length, concrete cover depth, stirrup confinement and number of fiber reinforce concrete layers.

7. An analytical modeling result strongly verifies a proposed tri-uniform bond stress distribution along lap splice. The existing experiments of reinforced concrete column confined by FRP were simulated by developed non-linear model, its lap splice strength calculated based on proposed bond stress model. The analytical results close to the experimental ones in a range of about 10%.

8. A proposed model have been verified by the experimental study, in which, fourteen columns tested in beam testing configurations were built, its lap splice strength was estimate by proposed bond stress distribution model. The predicted failure modes were identical to experimental ones. The predicted slip and strain distribution in some cases agree well to experiment.

6.2 Recommendation for Further Study

The research works conducted in this thesis is not perfect. There are still a lot of works that need to be done towards the completeness of issue of seismic strengthening of sub-standard reinforced concrete column. The followings are given as recommendations for future work.

1. A model of tri-uniform stress distribution was built based on existing bond slip relationship. Bond stress acting along lap splice bar is generally assumed to be uniform in three zones. Even though the model was verified by analytical and experimental approaches it is possible to simulate more accurately by dividing a lap splice into finite discretions, bond stress on each can be obtained by an existing local bond-slip relationship.

2. A research focused on strengthening lap splice zone by fiber reinforced polymer. To extend to another retrofitting material, a research methodology represented in this thesis could be applied to figure out bond characteristics along lap splice since it was retrofitted by some materials such as: ferro-cement, steel plate…etc.

3. A nonlinear analysis model was developed to simulated a reinforced concrete column with short lap splice strengthened by FRP, a good verification was found in comparison its result with some existing experiments. However, there are some improvement can be done. First, a steel spring (section 5.1.4) consists of three nonlinear sub-springs: bond slip spring, lap splice spring, and reinforcing bar spring. It is appropriate to exclude bond slip sub-spring from a steel spring since it is presented for an embedded bar in basement or under slap or column-beam joint. It is not an element of a upper column, therefore, its slip should not participate to fiber section (see section 5.1), and it should stand alone as an independent part as a elastic part or fiber section (Fig 5.2). Second, some built-in hysteresis rules embedded in Ruaumoko2D have a great capacity to simulate non-linear behavior; however, an accuracy of analyzing result can be enhanced if these hysteresis rules

can be customized. Finally, a finite element method can be applied here to model a reinforced concrete column, in which steel, concrete are discrete and simulated by finite 3-dimensions solid element.

4. An experiments conducted in this research were applied by a static load. In order to get a high accuracy of structural member behavior subjected to Earthquake, an excitation load should be used. Since a tested member subjected to reversed load, FRP on all sides are equally extended, this therefore will give more accurate member strength.

5. More experimental results could be gathered to verify and improve an accuracy of proposed bond stress model and developed analysis model.

6. An experiment should extend to some available retrofitting materials such as: ferro-cement, steel plates jacketing which also strengthen lap splice strength.

7. A friendly user-interface computing application could be built based on this research. It could provide as a practical designing tool for retrofiting engineering.

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