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EXTENDED ABSTRACT

Experimental and Numerical Study on the Effect of Logitudinal Reinforcment Debonding at Beam-Column Connections

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1. Introduction

In concrete beams, plastic hinges form at the beam-column connections, playing a crucial role in providing the required ductility. Due to the high stress and strain in this area, failure typically initiates as flexural and flexural-shear cracks. High-rise concrete beams are prone to single cracks in the critical region, reducing the plastic hinge length. Additionally, the longitudinal strains applied to the reinforcement in this area are high, leading to the buckling of the longitudinal reinforcement. This study aims to improve the behavior of high-rise reinforced concrete beams under cyclic loading by introducing a rubber sheath to separate the reinforcement and concrete at the plastic hinge. Full-scale specimens were tested under cyclic loading and numerically analyzed. The primary goal is to enhance the behavior of high-rise reinforced concrete beams under cyclic loading by using a rubber sheath to separate the reinforcement and concrete. The rubber sheath separation not only improved shear behavior but also reduced crack width. The number of cracks and the extent of damage at the end of the test were significantly reduced in the concrete specimen with the rubber sheath. This reduction in damage increases structural safety and reduces repair costs after events such as earthquakes. In the final part of this study, a finite element model was developed, and modeling parameters in the reinforcement-concrete interaction models were examined to achieve a numerical model with results close to the experimental tests conducted in the laboratory.

2. Methodology

2.1. Experimental study

To investigate the effect of the debonding of longitudinal reinforcements in the plastic hinge area on real-scale reinforced concrete beams, an experiment was conducted on real-scale concrete beam samples at the Crisis Management and Infrastructure Engineering Center of Urmia University. Two laboratory models in real dimensions were studied. Each sample, as part of a concrete bending frame, included two reinforced concrete beams and a square column for studying high-rise beams and minimum permissible reinforcement according to ACI regulations (Committee, 2008). The geometric specifications, longitudinal and transverse reinforcements, concrete, and laboratory conditions of both laboratory models are identical. These two laboratory models, named B1 and B2 in this study, where B1 is the base sample and B2 has debonding by a tubular rubber sheath in the longitudinal reinforcement with a length of 30 centimeters from the support edge.

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2.2. Numerical modeling

In the simulation of laboratory models, LS-Prepost software version 4/9 was used, and for analysis, solvers from LS-Dyna version R13 were utilized. In this research, since the loading was quasi-static, the analysis was also performed using the Implicit method. While the Implicit analysis enjoys high stability, achieving convergence in all analysis steps is one of the main challenges faced in this method (Erhart, 2016). Among the various types of software elements for meshing, for concrete elements, ELFORM equal to one of the SOLID type was used, and for steel elements (reinforcements), ELFORM equal to one of the BEAM type was used.

3. Results and discussion

In this study, the numerical results of the samples with two different concrete behavioral models, CDPM and Winfrith, have been compared with their cyclic test results. A general comparison has also been made between the numerical results of the two concrete behavioral models for the final fracture moment, crack patterns, and similar cases. By examining the axial strain diagram in an element of the longitudinal reinforcement according to the Winfrith behavioral model, it is observed that in the numerical sample with debonded bar from concrete, the strain throughout the analysis time is approximately less than the state without debonding, and the sample without rubber sheath, before reaching the end of the analysis time, experiences buckling (sudden increase in strain in the diagram) and the element fractures. In the axial strain diagram of the same element in the CDPM behavioral model, it is observed that contrary to the previous behavioral model, the axial strain of the steel element of the sample with rubber sheath is only less than the axial strain of the steel element without rubber sheath in the first half of the loading, and after that, it shows an upward trend.

4. Conclusions

Observations made on laboratory samples suggest that by using the debonding of longitudinal bar from concrete by a rubber sheath, the number of cracks created in the plastic hinge area can be significantly reduced. Also, the concentration of damages occurred more at the connection point and will not transfer to the rest of the concrete beam. Regarding the buckling of longitudinal reinforcements, it can be inferred that by using a rubber sheath and debonding bar in the plastic hinge area, the type or mode of buckling of longitudinal reinforcements can be changed from overall buckling (buckling between several transverse reinforcements) to local buckling (buckling between two stirrups).

In the studies conducted on numerical models, two concrete behavioral models were considered for the samples. These two behavioral models behaved exactly the same in the linear and elastic region and in the nonlinear region, in spite of being different from each other, they estimated the laboratory resistance very accurately to a great extent. Also, the examination of numerical samples showed that by debonding, the amount of damage in the plastic hinge area can be reduced and also concentrated in a smaller range. The examination of axial strains in numerical samples showed that by debonding, a uniform strain distribution can be achieved in the longitudinal reinforcements of the plastic hinge, which will reduce the concentration of stress and strain in the longitudinal bars of the plastic hinge.