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EXTENDED ABSTRACT

Numerical Analysis of Reinforced Exterior Concrete Beam-Column Joints Retrofitted Using FRP under Cyclic Loads

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1. Introduction

Recent earthquakes worldwide have illustrated the vulnerability of existing reinforced concrete (RC) beam-column joints to seismic loading. Inadequate shear reinforcement in the existing beam-column joints, especially exterior ones, is believed to be the prime cause of failure/collapse of many moment-resisting RC frame buildings. Hence, effective and economical strengthening techniques to upgrade joint shear resistance in existing structures are needed. Retrofitting using FRP composites has grown in popularity over the last two-decade advantages such as fast and easy installation, high strength/weight ratio, and resistance to corrosion. In this study have been conducted a numerical analysis of 11 RC beam-column joints without FRP and strengthened with FRP in a variety of configurations under cyclic loads. The analyses are performed by ABAQUS finite element program and are calibrated with the experiments. A range of issues in joints, including maximum load, initial stiffness, energy dissipation, load-displacement hysteresis loops, stiffness-displacement curves, and energy dissipation-displacement curves, are investigated. The numerical results were in good agreement with the corresponding experimental ones. The results obtained from the numerical analysis in this study, similar experimental results demonstrated that externally bonded FRP reinforcement is a viable solution towards enhancing the strength, energy dissipation, and stiffness characteristics of RC joints subjected to seismic loads.

2. Specifications of the connections

In this study, a series of exterior RC beam-column connections that have been experimentally tested by Antonopoulos and Thanasis (Antonopoulos and Thanasis, 2003) under cyclic loads were modeled using the finite element method in ABAQUS. Then, the hysteresis curves obtained from the numerical analysis and other results regarding the strength, energy dissipation, and stiffness of these connections were compared with the experimental data.

3. Finite element modeling

The materials to be included in the modeling were concrete, steel bars, and FRP. The software ABAQUS offers several constitutive models that can be used for FRP, concrete, and steel bars. Therefore, this section only briefly discusses these constitutive models and the specifications of the materials. But first, it is necessary to give a brief explanation of the modeling and behavior of concrete.

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3.1. Modeling of concrete

3.1.1. Concrete damaged plasticity model

The materials library of ABAQUS offers three different models for concrete analysis: smeared cracking, cracking, and damaged plasticity (Mostofinezhad, 2018). In this study, concrete behavior was simulated using the concrete damaged plasticity model, which is a powerful model for simulating the behavior of concrete under different loads. By describing the distinct behaviors of concrete under tension and compression, this model delivers a realistic representation of this material. In this model, the nonlinear behavior of concrete is expressed by the concepts of isotropic damaged elasticity and isotropic tensile and compressive plasticity. In this model, the damage states are expressed by two scalar parameters of compressive and tensile damage. The 3D concrete model was meshed with the element C3D8R, which is an eight-node element with three degrees of freedom per node (Abaqus, 2010).

3.2. Steel bars

In this study, longitudinal and transverse steel bars were modeled using an isotropic perfectly elastoplastic bilinear model. The plasticity of steel was introduced by kinematic hardening. The longitudinal and transverse reinforcements were modeled with the truss element T3D2, which is a linear three-dimensional element. This element can only bear axial forces and acts separately from concrete. Also, the bond-slip effects between concrete and reinforcement were ignored. The Poisson's ratio of the bars was considered to be 0.3 (Abaqus, 2010).

3.3. FRP

FRP composites were considered to be an orthotropic material with linear behavior before the ultimate strain. It was assumed that at the ultimate strain, FRP loses all of its tensile capacity at once. Considering the use of epoxy adhesive to attach fibers to concrete, before modeling, the thickness and modulus of elasticity of the fibers had to be adjusted accordingly. As mentioned, the FRP composite was modeled as an orthotropic layer. For FRP, meshing was performed with the element S4R, which is a shell element (Abaqus, 2010).

4. Results and discussion

The ultimate loads sustained during cyclic loading (ultimate strength) in the experimental and numerical analyses are compared in Table 1. This table shows a high level of agreement between the numerical results and the experimental data. According to this table, the maximum ultimate strength under cyclic loading that has been obtained from the numerical analysis is on average 9% higher than the corresponding value in the experimental data. As can be seen, all reinforcement designs have increased the lateral strength of the connections.

Table 1: Maximum ultimate strength of the specimens in the numerical analysis and experimental data

Specimen	Compressive strength of concrete (MPa)	Ultimate Load Obtained from experimental results (KN)		Ultimate Load Obtained from numerical results (KN)		Num/Exp	
		Left to right∗	Right to left∗	Left to right∗	Right to left∗	Left to right∗	Right to left∗
C1	19.5	31.32	27.13	32.54	32.73	1.04	1.20
C2	23.7	30.82	31.08	32.14	32.38	1.04	1.04
S33	26	34.66	35.28	38.41	38.31	1.11	1.08
S33L	26.3	44.63	40.40	43.26	43.24	0.97	1.07
F21	27	51.08	50.29	56.19	54.27	1.10	1.08
F12	29.5	44.45	44.40	47.25	47.23	1.06	1.06
F11	22.8	42.76	42.44	48.28	48.01	1.13	1.13
F22	27.2	50.04	49.14	56.52	56.20	1.13	1.14
F22A	27.8	57.38	52.56	61.97	58.34	1.08	1.11
F22W	29.2	55.84	54.89	60.63	59.38	1.08	1.08
GL	19.5	44.13	43.04	49.48	48.82	1.12	1.13

∗ Direction of applied load

5. Conclusions

This study investigated the effect of FRP sheets and strips on the strength of exterior RC connections under cyclic loads using the finite element software ABAQUS and compared the results with experimental data. From this investigation, the following results were concluded:

- The high level of agreement between numerical and experimental results before and after reinforcement with FRP shows that numerical modeling can serve as a practical and inexpensive tool for analyzing the cyclic behavior of RC beam-concrete connections both with and without FRP reinforcement.
- Like the experimental evidence, the numerical results suggest that the strengthening of RC connections that have a low shear strength with external FRP coatings is a good solution for enhancing their strength, energy dissipation and stiffness properties under seismic loads.

6. References

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