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Bond-Slip Behavior Analysis of Recycled Concrete-Filled Double Steel Plate Composite Shear Walls Using ABAQUS

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This paper was funded by Science Research Project of Hebei Education Department (ZC2023044) and Doctoral Innovation Fund Project of Tangshan College (141905).

Abstract: A detailed numerical simulation of recycled concrete composite shear walls was conducted using ABAQUS finite element software. By establishing a composite wall model and constitutive model, the bonding slip performance of the composite wall was analyzed. For double-steel plate recycled concrete composite shear walls, the results show that the stress under bonding slip conditions is 15.1% higher on average compared to that without considering bonding slip. It is suggested that the bonding force between steel plates and concrete can bear part of the internal forces in recycled concrete composite walls, which should not be ignored.

Keywords: Bonding-Slip; Recycled Concrete; Composite Shear Wall; ABAQUS

1. Introduction

With the development of high-rise buildings and immersed tube tunnels, double steel plate-concrete composite shear walls have become key load-bearing components due to their high strength, stiffness, and ductility. Additionally, driven by the industry's demand for sustainable development, recycled concrete, as a green building material and renewable resource, has opened new avenues for low-carbon construction through its application in composite shear walls. Chen Daoshen et al. [1] conducted a finite element analysis of the seismic performance of double steel plate-recycled concrete composite shear walls, Song Wenqing et al. [2] conducted a finite element analysis of the seismic performance of steel plate-concrete composite shear walls, and Du Jiahao et al. [3] studied the seismic performance of steel-reinforced concrete composite walls considering bond slip. However, these studies have not specifically addressed the bond slip performance of recycled concrete in double steel plate-concrete composite shear walls. This paper, in the context of the national dual-carbon goals, applies recycled concrete to composite shear walls and uses ABAQUS finite element software to investigate the bond slip performance between recycled concrete and steel plates.

2. Composite Shear Wall Model

2.1 The Established Wall Model

The combined shear wall specimen model adopted is a double steel plate concrete combined shear wall, with the size of 1260mm×412mm×2006mm, concrete strength grade of C30, steel plate of

Q235 grade steel, the external steel plate thickness of 8mm, and three vertical partitions with the same height and thickness of 6mm as the external steel plate, as shown in Figure 1.

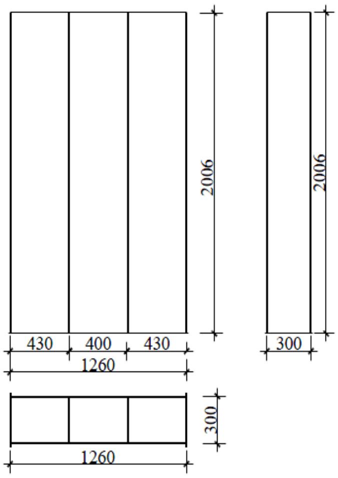
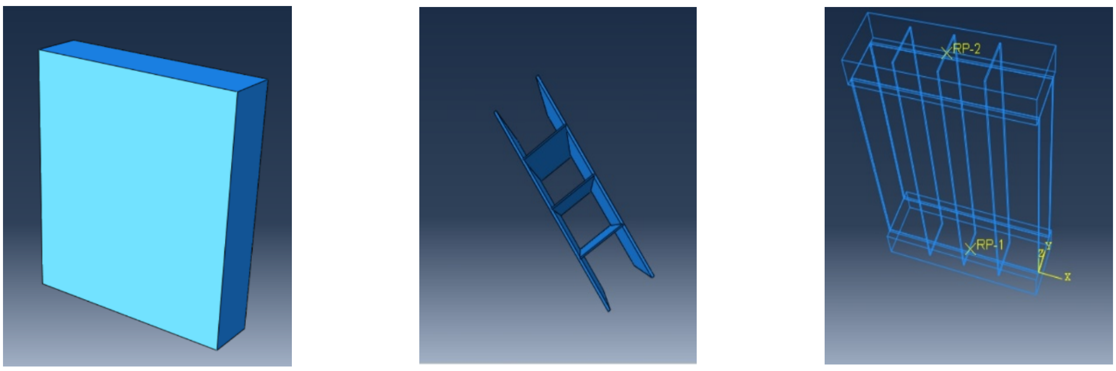


Figure 1: Wall Model.

The components are established as shown in Figure 2. To prevent stress concentration, a point RP-1 is set on the top surface of the specimen and coupled with the top surface of the loading beam. A concentrated force in the Z direction is applied at point RP-1 using a displacement loading method. A fully fixed load is applied at point RP-2, as detailed in Figure 2(c).

The concrete, steel plates, and rib plates in the walls are modeled using three-dimensional solid models. These models can deform and stretch, and all use the linear shrinkage integration element C3D8R. The shear wall model is discretized and regularized through meshing to ensure accuracy, efficiency, and model convergence. The mesh size for concrete is 30mm, and for steel plates, it is 50mm. The global seed size for concrete is set at 30, while for steel plates and rib plates, it is 50, making the mesh finer compared to that of concrete.



A) Overall Model View

B) Steel Plate and Partition Combination Diagram

C) Concrete Components

Figure 2: Wall Component Model.

2.2 The Selected Constitutive Model

2.2.1 Selection of Constitutive Model of Recycled Aggregate Concrete

$$Y=\begin{cases} ax+(3-2a)x^2+(a-2)x^3, 0\le x<1 \\ \dfrac{x}{b(x-1)^2+x}, x\ge 1 \end{cases}$$

In the formula, $x = {}^{\varepsilon}/_{\varepsilon}$, $y = {}^{\delta}/_{f}$.a is the parameter value of the rising section of the curve, $a = {}^{dy}/_{dx}\,|x = 0$. b is the parameter value of the descending section of the curve. a=1.17 and b=4.58 are obtained by fitting the boundary conditions and experimental data, as shown in Figure 3

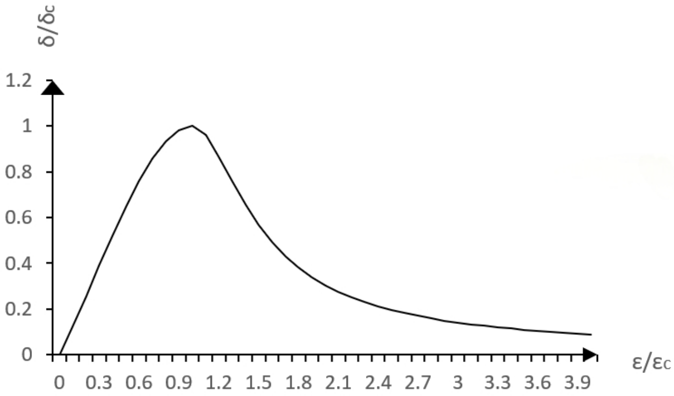


Figure 3: Damage Constitutive Behavior of Recycled Concrete.

The constitutive damage of recycled concrete is selected as shown in Figure 3[4], and the simplified elastoplastic damage constitutive equation of recycled concrete is as follows.

$$y = (1 - D)[-a + (1 - b)x]$$

Based on the fitting of experimental data, the parameters of stress-strain constitutive equation for recycled gravel concrete are a=-0.07, b=0.85, α=0.44 and m=-0.17. The damage threshold is shown in table 1, and the damage parameters can be obtained in table 2.

Table 1: Compressive Damage Stress Strain of Concrete.

Plastic Strain	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006
Yield Stress (Unit Mpa)	0.12277	0.25512	0.38799	0.52048	0.64625	0.76032

Table 2: Concrete Tensile Damage Parameters and Non-Elastic Strain.

Damage Parameters	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
Non-Elastic Strain (Unit Mpa)	0.08	0.009	0.1	0.1	0.2	0.	0.4	0.5	0.6

2.2.2 Selection of Constitutive Model for Ordinary Concrete.

The KINH model is selected for the general concrete constitutive model, and the stress-strain curve is shown in Figure 4.

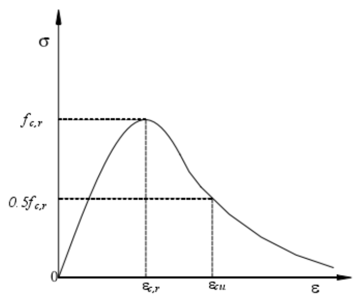


Figure 4: Uniaxial Compressive Stress-Strain Relationship of Concrete.

The parameters are determined according to the following formula:

$$d_c = \begin{cases} 1 - \dfrac{p_c n}{n - 1 + x^n}, x \le 1 \\ 1 - \dfrac{p_c}{\alpha_c (x-1)^2 + x}, x > 1 \end{cases}$$

The concrete compression damage model is calculated by the above formula, and the data are shown in Table 3 and Table 4.

Table 3 Compressive Damage Stress Strain of Concrete.

Plastic Strain	0.00000	0.00008	0.00009	0.00012	0.00019	0.00048
Yield Stress	14.85734	18.54005	19.34651	20.58667	22.68105	26.21344

Table 4: Concrete Tensile Damage Parameters and Non-Elastic Strain.

Damage Parameters	0.00000	0.04212	0.04736	0.05670	0.07745	0.15283
Inelastic Strain	0	0.00008	0.00009	0.00012	0.00019	0.00048

2.2.3 Selection of Steel Constitutive Model

The steel is used to achieve its yield strength as the basis for judging the material yield. The constitutive model of steel plate adopts the elastic-plastic strengthening constitutive model. Considering the influence of initial defects and initial stress of steel, the elastic modulus and yield strength of steel plate are reduced by 20%. The elastic strengthening constitutive model of the two-fold line.

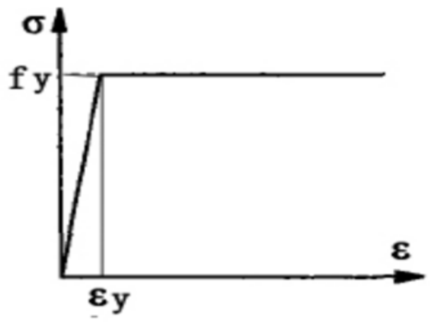
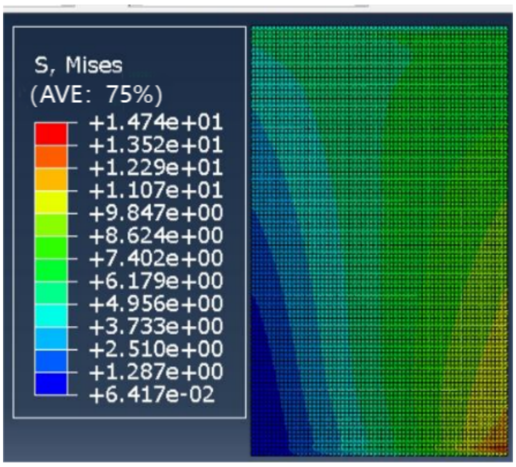


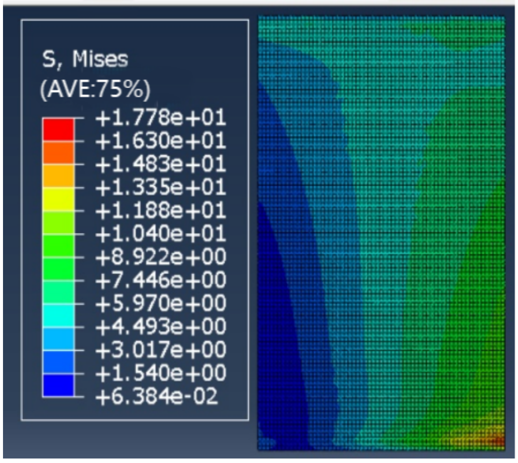
Figure 5: Steel Plate Constitutive Model.

3. Analysis on the Influence of Bonding-Slip

3.1 Stress Analysis of Steel Plate

For composite shear walls, recycled concrete with coarse aggregate replacement rate of 30% and axial compression ratio of 0.3 were used to analyze the stress conditions of specimens by changing the horizontal load size.





(a) No Bond Slip (b) Bond Slip

Figure 6: Stress Cloud of Steel Plate Under Horizontal Load 3×105N.

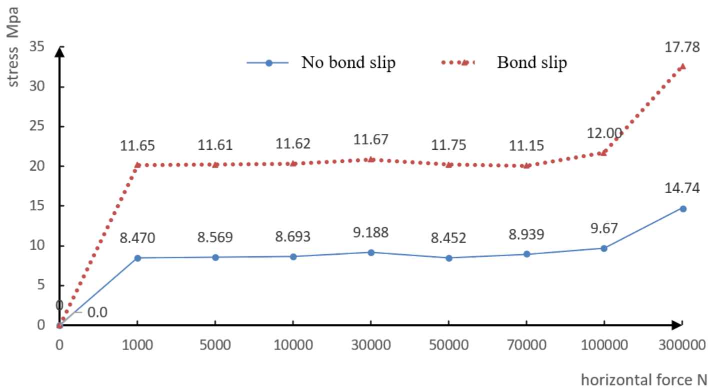


Figure 7: Load-Stress Diagram of Steel Plate.

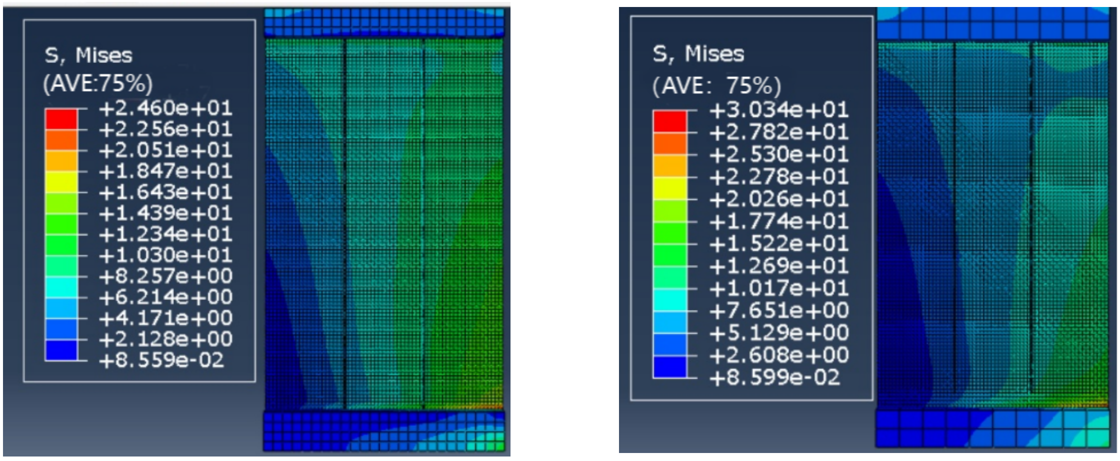
Through comparative analysis, it is found that, with the vertical load of the specimen kept constant, the stress in the steel plate increases as the horizontal load increases, regardless of whether bond slip is considered. When the vertical load and horizontal load remain constant, the stress on the steel plate considering bond slip is about 3 MPa higher than that without bond slip. When the horizontal load does not exceed 1×105N, the stress on the steel plate increases gradually. Without bond slip, the rate of increase in stress is between 1% and 8%, while it is between 0.3% and 8%with bond slip. When the horizontal load exceeds 1×105 N, the stress on the steel plate increases sharply. Without bond slip, the increase is approximately 52.43%, while it is approximately 48.17% with bond slip. Overall, the stress on the steel plate with bond slip is 29.34% higher than that without bond slip. The comparison results are shown in Figure 7. The specific data on the load and stress of steel plate are presented in Table 5.

Table 5: Load and Stress Data of Steel Plate.

Steel Plate	Without Considering Bond Slip (MPa)	Change Rate	Consider bonding Slip (MPa)	Change Rate
0	0	_	0	_
1.00E+03(N)	8.47	_	11.65	_
5.00E+03(N)	8.569	1.17%	11.61	0.34%
1.00E+04(N)	8.693	1.45%	11.62	0.08%
3.00E+04(N)	9.188	2.61%	11.67	0.43%
5.00E+04(N)	8.452	8.01%	11.75	0.69%
7.00E+04(N)	8.939	5.67%	11.15	5.11%
1.00E+05(N)	9.67	8.18%	12	7.62%
3.00E+05(N)	14.74	52.43%	17.78	48.17%

3.2 Stress Analysis of Recycled Concrete

For the recycled concrete wall with externally attached double steel plates, the stress nephograms with a vertical load of 3×105 N are shown in Figure 8, including considering the bond-slip and no-bond-slip between the steel plates and concrete.



(a) No bond slip (b)Bond slip

Figure 8: Stress cloud of recycled concrete under horizontal load of 3×105N.

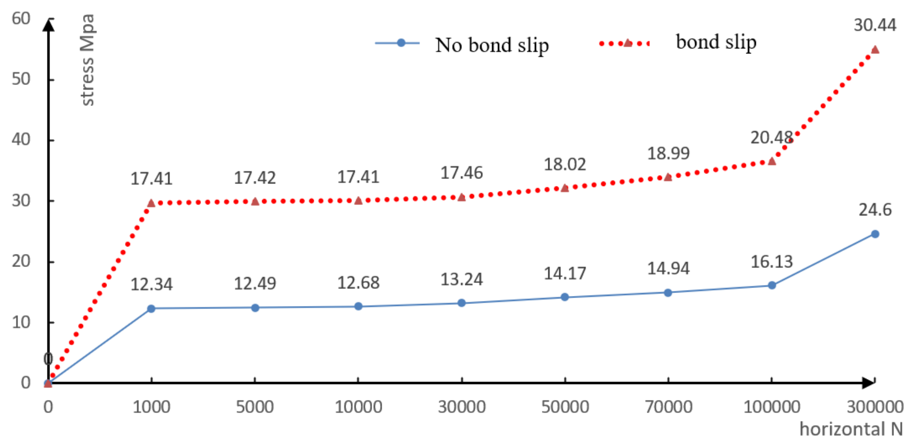


Figure 9: Load-stress Diagram of Recycled Concrete.

Through comparative analysis, it was determined that, irrespective of bond slip consideration, the stress in the recycled concrete wall increases with the increment of horizontal load when the vertical load applied to the specimen is maintained constant. When the vertical load and horizontal load remain constant，the stress under the condition of considering bond slip is about 5.5MPa higher than that without considering bond slip. When the horizontal load does not exceed 1×105N, the stress in the recycled concrete wall increases gradually. Without considering bond slip, the stress rate increases between 1% and 8%, while the stress rate increases between 0.6% and 8%with bond slip. When the horizontal load exceeds 1×105 N, the stress increases sharply. Without considering bond slip, the increase is approximately 52.51%, while it is approximately 48.63%with bond slip. Overall, the stress in the recycled concrete wall with bond slip is 30.72% higher than that without bond slip. The comparison results are shown in Figure 9. The specific data on the load and stress of recycled concrete are presented in Table 6.

Table 6: Load and Stress Data of Recycled Concrete.

Recycled Concrete	Wall	Without Considering Bond Slip (MPa)	Change Rate	Consider Bonding Slip (MPa)
Change Rate 0(N)	0(N)	0	_	0
_1.00E+03(N)	1.00E+03 (N)	12.34	_	17.41
_5.00E+03(N)	5.00E+03(N)	1.22%	17.42	0.06%
1.00E+04(N)	12.68	1.52%	17.41	0.06%
3.00E+04(N)	13.24	4.42%	17.46	0.29%
5.00E+04(N)	14.17	7.02%	18.02	2.63%
7.00E+04(N)	14.94	5.34%	18.99	5.38%
1.00E+05(N)	16.13	7.97%	20.48	7.85%
3.00E+05(N)	24.6	52.51%	30.44	48.63%

4. Conclusion

The foregoing analysis demonstrates that, for recycled concrete-filled double steel plate composite shear walls, the stress under bond-slip conditions exhibits an average 15.1% increase compared to the scenario without bond-slip consideration. This finding highlight that the interfacial bond force in recycled concrete composite walls contributes to the bearing of internal forces. Consequently, in practical force analysis of recycled concrete composite walls, the bond-slip behavior between steel plates and recycled concrete must be incorporated into the design considerations.

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