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## IOP Conf. Series: Earth and Environmental Science 643 (2021) 012067

# Axial compressive behaviour of double steel-concrete shear wall constrained with ribs and bars

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Abstract. The double steel-concrete shear wall combines the advantages of steel and concrete effectively, with high bearing capacity, good plasticity, superior seismic and fire resistance performance, saving materials and simple construction, and has obvious advantages in the application of high-rise buildings, especially super high-rise buildings. Research on axial compressive behavior of double steel-concrete shear wall constrained with ribs and bars is less. In this paper, the constitutive relation of double steel-concrete column with ribs and bars is used to change the relevant parameters and program to analyze the influence of ribs and bars on the axial compression performance of double steel-concrete shear wall.

#### **1. Introduction**

The application of double steel-concrete shear wall in high-rise buildings has obvious advantages <sup>[1-2]</sup>. Nie Jianguo et al.<sup>[3-4]</sup> conducted tests and theoretical studies on the double steel steel-concrete combined with welded bolts and reinforcement, indicating that the combined shear wall has a high shear bearing capacity and good seismic performance. JI et al.<sup>[5]</sup> proposed the combined shear wall form of double steel-concrete shear wall with circular steel tube concrete column as the edge constraint member, and the concrete-filled steel tube column as the edge constraint member can enhance the seismic performance of shear wall. Clubley et al. [6-7] conducted tests and numerical simulation studies on the double steel-concrete shear wall with internal welded shear connectors, indicating that the internal welded shear connectors have strong shear resistance. Hossain et al.<sup>[8]</sup> studied the shear performance of the double-sided compacted steel plate filled with concrete composite shear wall set with bolts and showed that the shear wall had good shear performance. Ma Kaize et al.<sup>[9]</sup> pointed out that combined shear walls with stiffeners have better seismic performance through comparative tests.

The above researches mainly focus on the influence of the setting of bars and stiffeners on the seismic performance of such combined shear walls, but the influence of the setting of bars and ribs on the axial

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compression performance of such combined shear walls is less. In this paper, the double steel-concrete shear wall combined with bars and ribs is studied in the form of a combination of bars and ribs. The influence of bars and ribs on the axial compression performance of the combined shear wall is studied through the axial compression simulation analysis of the double steel-concrete shear wall combined with bars and ribs.

#### 2. Design of double steel-concrete shear wall constrained with ribs and bars

The design of double steel plate concrete shear wall with bars is shown in **Fig.1**, including bars, double steel plate and concrete. The concrete is in the interlayer between the two layers of steel plates, and the constrained bars are arranged in parallel along the vertical direction of the wall.

The double-layer steel-concrete shear wall with bars overcomes the shortcomings of the general steel plate shear wall, such as its easy buckling, poor hysteresis performance and large bearing capacity reduction.

On the one hand, the bar pass through the double steel plate and fastens the concrete inside the sandwich of the double steel, so as to increase the effective restraint area of the steel to the concrete and prevent the concrete from peeling off after compression damage. The restraint on concrete increases at the position of the bar, the bar constraint the central outside convex deformation of steel wall and provide transverse elastic supporting function for the steel plate, improve its flexural rigidity, the bending deformation is reduced. So the change of radial stress levels off. The set of the steel plate can provide larger average lateral restriction for the concrete, make the compressive strength of concrete wall is able to improve significantly.



Fig.1 Plans, elevations, sections of double steel-concrete shear wall with bars(1-bar)

At the same time, the half wavelength of steel plate buckling decreases, and the critical buckling bearing capacity increases. The phenomenon of local premature buckling in the general steel plate combined with concrete shear wall is inhibited and delayed. On the other hand, the inner-filled concrete can effectively prevent the steel plate from buckling inward, while the coupling action of the bar provides transverse elastic constraint support for the steel plate, which can effectively delay the outward drum buckling of the steel plate and restrain the concrete in the wall, and postpone the local buckling of the steel plate commonly existed in the steel plate concrete shear wall. Simultaneously, the steel plate and bars coordinate deformation, work together, both on the concrete lateral restraint, restraint effect significantly increased, thus to achieve the steel plate and concrete stress together. The ultimate bearing

capacity, plastic deformation capacity and toughness of shear wall structure are increased, lateral stiffness and hysteretic performance is greatly improved and enhanced.

By adding ribs to the inner walls of the steel plates, the double concrete shear walls with ribs and bars can overcome the deficiency of the double steel-concrete shear walls with bars and provide a way to significantly improve the restraint capacity of the steel plates and to break the buckling and spreading of the area between the bar.

#### 3. Constitutive relation of constrained concrete



Fig 2 lateral force diagram of double steel reinforced concrete shear wall with bars and ribs

Two Side pressure of double steel concrete shear wall is not the same when axial compression core concrete hit vertical peak pressure  $f_{cc}$  due to the presence of long, short edge, namely in three triaxial compressive state. The following ranks of expressions are given by application of William-Warnke 5 parameter failure criterion of concrete compressive strength for the core.

$$\tau_0 = 6.9638 \left( \frac{0.09 - \sigma_0}{c - \sigma_0} \right)^{0.9297} \tag{1}$$

$$c = 12.2445 (\cos 1.5\alpha)^{1.5} + 7.3319 (\sin 1.5\alpha)^2$$
<sup>(2)</sup>

$$\sigma_0 = \sigma_{\rm oct} / f_{\rm co} \tag{3}$$

$$\tau_0 = \tau_{\rm oct} / f_{\rm co} \tag{4}$$

$$\sigma_{\rm oct} = \frac{f_{11}^{'} + f_{12}^{'} + f_{\rm cc}}{3};$$
 (5)

$$\tau_{\rm oct} = \frac{\sqrt{\left(f_{_{l1}}^{'} - f_{_{l2}}\right)^2 + \left(f_{_{l2}}^{'} - f_{_{\rm cc}}\right)^2 + \left(f_{_{\rm cc}} - f_{_{l1}}^{'}\right)^2}}{3} \tag{6}$$

$$\cos \alpha = \frac{2f'_{l1} - f'_{l2} - f_{cc}}{3\sqrt{2}\tau_{oct}}$$
(7)

In the equation,  $\sigma_{oct}$ ,  $\tau_{oct}$  are respectively eight octahedral normal stress, eight octahedral shear stress;  $\sigma_0 \, \cdot \, \tau_0$  are respectively relative value of eight octahedral normal stress, relative value of eight octahedral shear stress;  $\alpha$  is partial plane angle. IOP Conf. Series: Earth and Environmental Science 643 (2021) 012067 doi:10



Fig 3 stress-strain curve of confined concrete and unconstrained concrete

The plate not only bears longitudinal compression, but also from the concrete lateral extrusion, in the three dimensional stress state for longitudinal and radial compression ring tension under the action of the axial pressure. Radial compressive stress is much smaller to the longitudinal compressive stress and circumferential tensile stress relatively. So it can be neglected. If the steel plate is under plane stress state, the yielding of steel plate Obeys Von Mises yield criterion. Plate long side, short edge to core concrete confinement effect is different, so the circumferential stress development of the long, the short side is not the same. The general long side bends before the short side, so  $f_{sr1}, f_{sr2}$  is not the same. According to Von Mises yield criterion, there is:

$$f_{a_1}^2 - f_{a1}f_{sr1} + f_{sr1}^2 = f_{ay}^2$$
(8)

$$f_{a2}^2 - f_{a2}f_{sr2} + f_{sr2}^2 = f_{ay}^2$$
(9)

In the equation,  $f_{a1}$ ,  $f_{a2}$  are respectively the longitudinal stress of long side, the short side of steel plate.

Width to thickness ratio of the steel plate is the main factor that affects the failure mode of double steel reinforced concrete shear wall with bars and ribs

To R > 0.85, the sample will occur buckling failure; To  $R \le 0.85$ , test piece need not consider local buckling.

$$R_{\rm l} = \frac{D}{t} \sqrt{\frac{12(1-\nu^2)}{4\pi^2}} \sqrt{\frac{f_{\rm ay}}{E_{\rm a}}}$$
(10)

$$R_{2} = \frac{B}{t} \sqrt{\frac{12(1-v^{2})}{4\pi^{2}}} \sqrt{\frac{f_{ay}}{E_{a}}}$$
(11)

In the equation,  $f_{ay}$ ,  $E_{a}$  are respectively the yield strength and modulus of elasticity.

To R > 0.85, The long edge of steel will occur plate buckling failure,  $f_{a1} = f_b$ ;  $f_{a1}$  is the steel plate local buckling strength.

$$\frac{f_{\rm b}}{f_{\rm ay}} = \frac{1.2}{R_{\rm l}} - \frac{0.3}{R_{\rm l}^2} \le 1.0 \tag{12}$$

To  $R \leq 0.85$ ,

$$f_{\rm a1} = 0.89 f_{\rm ay}$$
 (13)

Similarly, To R > 0.85, the short side of steel plate will occur destruction of local buckling,  $f_{a2} = f_b$ ,  $f_{a2}$  is local buckling strength of steel plate.

$$\frac{f_{\rm b}}{f_{\rm ay}} = \frac{1.2}{R_2} - \frac{0.3}{R_2^2} \le 1.0 \tag{14}$$

(15)

To  $R_2 \le 0.85$  $f_{a2} = 0.89 f_{ay}$ 

#### 4. FEM simulation analysis

The research model W-1 is established for the axial compression performance of the double steelconcrete shear wall with bars. The length of the double steel-concrete shear wall D=1000mm and the short side length B=200mm. According to the constitutive relation of confined concrete with double steel plate shear wall with bars, enter the calculation program, and the calculated W-1 confined concrete constitutive is shown in **Fig.4**.



Fig.4 The constitutive relation of double steel-concrete shear wall with bars

The calculated characteristic value of confined concrete with double steel plate shear wall with bars is shown in **Table 1**:

Table 1	Characteristic	values of	double	steel-concrete	shear wall	with bars
	Model	fcc(Mpa)	ecc	r	N(MN)	_
	W-1	48.4055	0.002	9 2.0746	11.213	-

Change the width of the rib, by using the constitutive relationship of CFST column with of bars, considering the constraints of the stiffener, modifying the parameters, analyzing the influence of constraints of bars on the axial compression performance of the double steel-concrete shear wall, the characteristic values of the axial compression bearing capacity of the double steel-concrete shear wall are shown in **Table 2**.

Table 2 Characteristic values of the axial	compression l	bearing capac	city of the	double steel	-concrete		
shear wall							

Model	bjv(mm)	<i>t</i> <sub>jv</sub> (mm)	ŋ	$f_{cc}(Mpa)$	ecc	r	N(MN)
WNZ-1	10	12.00	2.4570	48.5449	0.0029	2.0692	11.5870
WNZ-2	14	8.57	4.1600	48.6207	0.0029	2.0663	11.6020
WNZ-3	18	6.67	6.3194	48.6924	0.0029	2.0636	11.6150
WNZ-4	22	5.45	8.9345	48.7428	0.0029	2.0617	11.6250

Confined concrete constitutions of WNZ-1, WNZ-3, WNZ-4 are shown in Fig. 5:



Fig.5 Constitutive comparison of double steel-concrete shear wall constrained with ribs and bars

To obtain the critical value of the rib-plate stiffness ratio, we expand the research parameters and continue to increase the rib-plate stiffness ratio. See Fig.6 for the obtained curve.



Fig.6 Critical value of the rib-plate stiffness ratio of double steel-concrete shear wall constrained with ribs and bars

As can be seen from Fig.6, before the rib-plate stiffness ratio of double steel-concrete shear wall constrained with ribs and bars is 9.659468, the concrete strength shows an increasing trend; however, after it exceeds 9.659468, the concrete strength remains stable. Therefore, for double steel-concrete shear wall constrained with ribs and bars, the maximum rib-plate stiffness ratio should not exceed 9.659468 to save steel.

#### 5. Conclusion

1) By adding stiffeners to form double steel-concrete shear wall constrained with ribs and bars, the entire steel plate concrete shear wall plate is strengthened to effectively reduce the elastic-plastic buckling between bars, improve the overall constraint, and improve the axial compression performance of the double steel-concrete shear wall.

2) The stiffening research results of the rectangular CFST column can be extended to the double steel-concrete shear wall, which is similar to the rectangular CFST column with larger length and width.

The research method of the rectangular CFST column with larger length and width is used to analyze the double steel-concrete shear wall.

3) When the bar is set alone, the double steel-concrete shear wall has insufficient binding effect on the core concrete. When the rib and the bar are set at the same time, the binding effect on the steel wall and the core concrete can be given full play, so that the capacity and strength of the confined concrete can be significantly improved. The reason is that the binding action of the bar increases the flexural rigidity of the rib and reduces the out-of-plane deformation of the stiffening zone, thus delaying the deformation, buckling and failure of the steel plate.

4) The increase of the stiffener generous help to the constraints of the core concrete, increase the compressive strength of concrete. The constraints of the steel wall to the core concrete are obviously slow after a critical value. Increasing the ratio of floor stiffness cannot effectively improve the strength of concrete, but will cause waste. In the design and construction practice, the ratio should not exceed the critical value.

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