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Study on the Seismic Bearing Capacity and Reinforcement Size Effect of RC Columns Reinforced with Steel Strips

Jufeng GU [a,1] and Junhua LI [a,2]
[a] *School of Civil and Environmental Engineering, Ningbo University, Ningbo, China*

Abstract. The existing seismic test of the RC column reinforced with steel strips is used as the simulation object, and then its seismic performance is analyzed by ABAQUS. The establishment of the corresponding finite element model is completed by selecting the appropriate constitutive model and interface treatment criteria, and the error between the simulation results and the test results is small, so the modeling method is feasible. Subsequently, with the change of size, the influence of the seismic bearing capacity and reinforcement effect of the steel strip were researched. From the results, it can be seen that: When the size increases, under steel belt reinforcement the improvement of the seismic bearing capacity increases first and then decreases. And based on the finite element analysis, a method for calculating the bearing capacity of RC columns reinforced with steel strips, which takes into account the effect of size effects, is proposed. The average error between calculation and simulation is within 7%, so this method is feasible.

Keywords. Steel strip, bearing capacity, size effect, finite element

1. Introduction

Earthquakes do great damage to structures, so it is necessary to reinforce columns with poor seismic performance. As a new reinforcement method, the steel strips reinforcement method has attracted attention due to its rapid reinforcement and low cost. It is reinforced by tying steel straps directly on the concrete column by a pneumatic baler [1]. However, as a quasi-brittle material, concrete has size effects. In actual engineering, the size of concrete columns may be very large. This change will have an impact on the bearing capacity and the reliability of reinforcement. Therefore, it is necessary to reach the effect of size on the seismic bearing capacity of RC columns reinforced with steel strips and the reinforcement effect of steel strips.

At present, many scholars have conducted a large number of experimental studies on the seismic performance of reinforced specimens. Haidong Wang et al. tested the seismic performance of the RC column, which was reinforced using low-prestressed steel hoop, and the diameter he chose was just 240mm [2]. Yong Yang et al. carried out an experimental reach on the seismic performance of RC square columns, and the sizes

[1] Jufeng Gu, First author, School of Civil and Environmental Engineering, Ningbo University, Ningbo, China; E-mail: 1759420965@qq.com.
[2] Junhua Li, Corresponding author, School of Civil and Environmental Engineering, Ningbo University, Ningbo, China; E-mail: lijunhua@nbu.edu.cn.

are 250mm and 300mm [3-4]. Fei Zhao carried out low-cycle repeated loading tests on four square columns with high axial compression ratio, in order to study their seismic performance [5]. But the column size is only 250mm. Yansheng Guo used steel strips to reinforce the SRC column with a size of 300mm after the fire [6]. After that, an experimental study on its seismic performance was carried out.

Due to equipment constraints, it is not difficult to find that the current research is mostly based on small-sized components. However, in the study of confined concrete, significant size effects can be found in large-sized reinforced specimens [7-9]. Research conclusions based on small-sized specimens may not be directly applicable to large-sized specimens. In this paper, a finite element model is established by ABAQUS. By comparing the simulation data with the existing test data, the accuracy verification of the finite element simulation is completed. Then, by studying the relationship between the size and the seismic bearing capacity, a calculation method for the bearing capacity of RC columns reinforced with steel strips considering the effect of the size effect is established.

2. Finite Element Modeling and Verification

2.1. Constitutive Relations of Concrete

The constitutive relation of concrete of unreinforced specimens adopts the constitutive relation suggested in "*Code for Design of Concrete Structures GB50010-2010*" [10].

There are some errors in the deformation of concrete under restraint when ABAQUS is used to process steel strip reinforcement specimens. Under lateral restraint, the phenomenon of increasing peak strain and deformation capacity of concrete is not fully considered. Therefore, the constrained concrete constitutive model is used for simulation, but if the steel belt constraint is still established in the finite element model, the constraint effect will be repeatedly calculated, which will make the simulated bearing capacity too large. Therefore, this paper adopts the idea of correcting the peak strain of the constitutive model without correcting the peak stress [11]. The stress-strain model expression is as follows:

$$\sigma = \begin{cases} (1-d_c)E_c\varepsilon & (\varepsilon \le \varepsilon_{c,r}) \\ f_{c,r} & (\varepsilon_{c,r} \le \varepsilon \le \varepsilon_{cc}) \\ 0.1f_{c,r} + (f_{c,r} - 0.1f_{c,r})\exp\left[-\left(\dfrac{\varepsilon-\varepsilon_{cc}}{\alpha}\right)^{\beta}\right] & (\varepsilon_{cc} \le \varepsilon) \end{cases} \tag{1}$$

$$d_c = 1 - \frac{\rho_c n}{n-1+(\dfrac{\varepsilon}{\varepsilon_{c,r}})^n} \quad (\varepsilon \le \varepsilon_{c,r}) \tag{2}$$

$$\rho_c = \frac{f_{c,r}}{E_c\varepsilon_{c,r}} \tag{3}$$

$$n = \frac{E_c \varepsilon_{c,r}}{E_c \varepsilon_{c,r} - f_{c,r}} \tag{4}$$

$$\frac{\varepsilon_{cc}}{\varepsilon_{c,r}} = e^{(2.9224 - 0.00367 f_{c,r})(\frac{f_{el}}{f_{c,r}})} \tag{5}$$

$$f_{el} = \frac{2 t_g s_g}{b_c (s + s_g)} \cdot f_g \tag{6}$$

$$\alpha = 0.005 + 0.0075 \frac{4 t_g s_g f_g}{b_c (s + s_g) f_{c,r}}, \beta = 0.92 \tag{7}$$

In which $\varepsilon_{c,r}$ is the compressive strain of concrete, which corresponds to the characteristic value of compressive strength; ε_{cc} is the compressive strain of the concrete under the restraint of the steel strip, which corresponds to the peak stress; f_{el} is the steel strip's lateral stress ; f_g is the steel strip's yield strength; t_g is the total thickness of the steel strip; s_g is the width of a single strip; s is the clear distance between two adjacent strips; b_c is the side length of the RC column ; α and β is the shape parameter, α reflects the change of concrete ductility, and β is 0.92 for the square column.

2.2. Steel Constitutive Relations

The constitutive model of the steel bar and the steel strip adopts the double-line model. The rising section of this model is a diagonal line, and it is a horizontal line after the yield point.

$$\sigma = \begin{cases} E_s \varepsilon & (\varepsilon \le \varepsilon_y) \\ f_y & (\varepsilon_y < \varepsilon \le \varepsilon_s) \end{cases} \tag{8}$$

In which f_y is the yield strength of steel; ε_y is the strain corresponding to the yield strength; ε_s is the strain corresponding to the ultimate strength.

2.3. Interface Handling

Interface between rebar and concrete: The interface is simulated by means of built-in area. And in order to simulate the slip, the hysteresis model proposed by Clough is introduced.

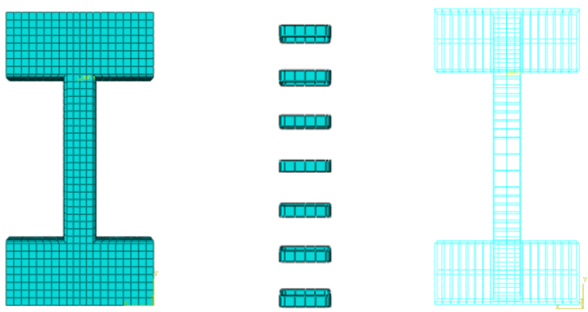
Interface between steel strip and concrete: From the experiments in Reference [4], it can be seen that the steel strip will stick to the surface of the RC column before the specimen is completely destroyed. Therefore, the assumptions of the simplification of the steel strip in Reference 10 are adopted: 1) The contact between the steel strip and the concrete is completely bonded; 2) In order to simplify the model, only in-plane strip stresses and strains need to be considered. Therefore, the binding command in ABAQUS was used to simulate the connection of the steel strip to the concrete.

2.4. Boundary Conditions and Loads

The steel strip prestress is applied by setting the temperature linear expansion coefficient for the steel strip unit. To ensure that the stress is along the length of the strip, the local coordinate system is set to the strip element coordinate system. The boundary conditions of the model are consistent with the actual loading conditions. Boundary conditions: 1) The bottom end is fixed; 2) The degrees of freedom of the top except in the UX and UZ directions are constrained; 3) The repeated loads in the UX direction and the axial pressure in the UZ direction are applied on the top.

2.5. Element Selection and Meshing

Considering the size of the specimen and the steel strip, the unit length is set to 30mm. The concrete is simulated by three-dimensional solid element C3D8R; the steel strip is simulated by three-dimensional surface element S4R; and the steel bar is simulated by three-dimensional truss element T3D1. Meshing is done by controlling the size of the elements. The models are shown in figure 1.

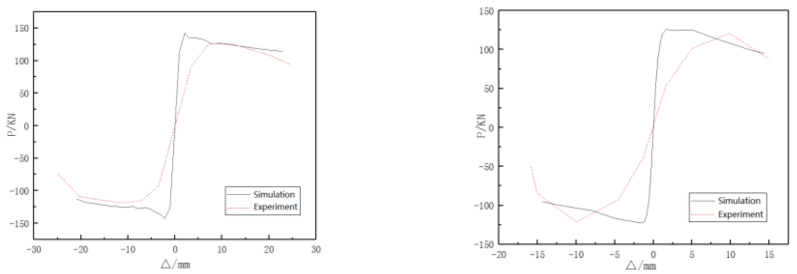


(1) Concrete (2) Steel strip (3) Rebar

Figure 1. Finite Element Model.

2.6. Comparison between Finite Element Simulation and Experiment

Through the above modeling method, the two specimens RC and JRC1 in Reference 3 are modeled and analyzed. The horizontal force P-horizontal displacement Δ relationship curve and skeleton curve of the top of the two specimens can be obtained by the ABAQUS post-processor. In figure 2, the comparison chart of the skeleton curve obtained from the simulation and the test is shown.



(1) Specimen JRC1 skeleton curve (2) Specimen RC skeleton curve

Figure 2. RC and JRC1 simulation and test comparison.

There is an error in the initial slope of the curve, which can be known from figure 2. But it is not difficult to find from table 1 that the peak load values obtained from the simulation and the test are relatively consistent. For the RC column reinforced with steel strips, this finite element modeling method can effectively analyze the seismic bearing capacity of the column. So this method is available.

Table 1. RC and JRC1 skeleton curve feature points.

Number		JRC1 (Simulation)	JRC1 (Experiment)	RC (Simulation)	RC (Experiment)
Yield point	P_y/kN	124.60	109.04	109.29	101.19
	Δ_y/mm	1.18	5.61	0.87	5.61
Peak load point	P_m/kN	134.13	122.73	124.29	120.92
	Δ_m/mm	4.15	9.58	1.68	9.91
Limit displacement point	P_u/kN	111.62	104.32	120.92	102.78
	Δ_u/mm	22.32	20.78	9.91	12.50

3. Finite Element Simulation

3.1. Parametric Design

In order to study the size effect of the seismic capacity of RC columns reinforced with steel strips, a controlled variable analysis is required. The RC column design is carried out with a similar relationship [12], and the ratio is 2:3:4:5:6. The cross-sectional dimensions of the RC column are 200mm×200mm, 300mm×300mm, 400mm×400mm, 500mm×500mm, and 600mm×600mm. Considering the existence of long and short columns in the actual project, the shear-span ratio is set to: 1.5, 2.0, 2.5, 3.0.

Table 2. The main parameters of the test piece.

Number (Reinforced)	Number (Unreinforced)	Size/mm	Shear-span ratio	Longitudinal reinforcement ratio	axial compression ratio	Strip spacing/mm	Stirrup reinforcement ratio
PSRC-A1-2	PSRC-A1-1	200×200	1.5	0.75% (4B10)	0.3	120	0.89%

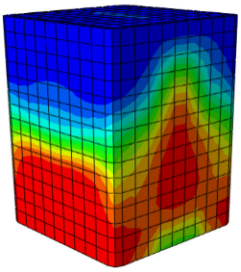
PSRC-A2-2	PSRC-A2-1		2.0				A8@100 (ends: 1.79% A8@50)
PSRC-A3-2	PSRC-A3-1		2.5				
PSRC-A4-2	PSRC-A4-1		3.0				
PSRC-B1-2	PSRC-B1-1	300×300	1.5	0.75% (6B12)	0.3	80	0.89% A10@140 (ends: 1.79% A10@70)
PSRC-B2-2	PSRC-B2-1		2.0				
PSRC-B3-2	PSRC-B3-1		2.5				
PSRC-B4-2	PSRC-B4-1		3.0				
PSRC-C1-2	PSRC-C1-1	400×400	1.5	0.75% (6B14)	0.3	60	0.89% A12@150 (ends: 1.79% A12@75)
PSRC-C2-2	PSRC-C2-1		2.0				
PSRC-C3-2	PSRC-C3-1		2.5				
PSRC-C4-2	PSRC-C4-1		3.0				
PSRC-D1-2	PSRC-D1-1	500×500	1.5	0.75% (4B20+4B14)	0.3	48	0.89% A14@156 (ends: 1.79% A14@78)
PSRC-D2-2	PSRC-D2-1		2.0				
PSRC-D3-2	PSRC-D3-1		2.5				
PSRC-D4-2	PSRC-D4-1		3.0				
PSRC-E1-2	PSRC-E1-1	600×600	1.5	0.75% (4B28+4B10)	0.3	40	0.89% A14@130 (ends: 1.79% A14@65)
PSRC-E2-2	PSRC-E2-1		2.0				
PSRC-E3-2	PSRC-E3-1		2.5				
PSRC-E4-2	PSRC-E4-1		3.0				

Note: X in PSRC-XY-Z is the size (ABCDE represents 200mm, 300mm, 400mm, 500mm, 600mm in turn), Y is the shear span ratio (1,2,3,4 represents 1.5, 2.0, 2.5, 3.0 in turn), Z represents whether it is reinforced (1 means not reinforced, 2 means reinforced)

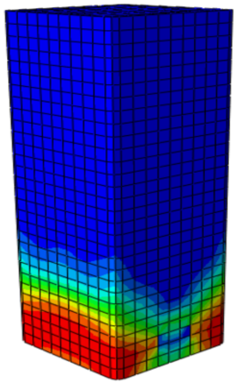
Due to the limitation of the size of the specimen and the diameter of the steel bar, the form of the reinforcement and the hoop cannot be completely consistent. Therefore, by keeping the longitudinal reinforcement ratio at 0.75%, keeping the stirrup reinforcement ratio in the non-encrypted area at 0.89%, keeping the stirrup reinforcement ratio in the encrypted area at 1.79%, the design of the specimens maintains a similar relationship. The axial compression ratio is 0.3. C30 concrete is used. The width of the steel strip is 30mm, the thickness is 1mm, and the yield strength is 600Mpa. For the reinforced specimen, the number of reinforcement layers is 1, and the volume distribution rate is kept at 0.5%. In table 2, the main parameters of the test pieces can be found.

3.2. Simulation Results and Analysis

Destruction of the specimen: Through the damage cloud map, the damage characteristics of the specimen can be directly observed. Take the damage cloud map of the 600mm specimen as an example, as shown in figure 3. It is not difficult to find that if its shear-span ratio is different, its failure form is also different, although they are the same size. Through the damage cloud map (its shear-span ratio is 1.5), the damage that develops upwards to the slope can be observed. So the specimen fails in shear-oblique compression. Through another damage cloud map (the shear-span ratio of the specimen is 3.0), damage can only be seen on both sides of the specimen. So bending failure occurs in the specimen.



(1) PSRC-E1-2(λ=1.5)



(2) PSRC-E4-2(λ=3.0)

Figure 3. Damage cloud map.

Seismic bearing capacity: By connecting the peak load points (loaded in the same direction) on the hysteresis curve one by one, we can obtain the skeleton curve. And the peak load point can be clearly obtained through the skeleton curve, then the seismic bearing capacity can be obtained. Taking the peak load points of specimens with sizes of 200mm, 400mm and 600mm as examples, the data are shown in table 3. It is not difficult to find that if the shear-span ratio increases, the seismic bearing capacity will decrease; and if the section size increases, the seismic bearing capacity will increase accordingly.

Table 3. Seismic bearing capacity.

Number (Reinforced)	Seismic bearing capacity/ kN	Number (Unreinforced)	Seismic bearing capacity/ kN
PSRC-A1-2	121.6	PSRC-A1-1	110.7
PSRC-A2-2	105.9	PSRC-A2-1	86.2
PSRC-A3-2	68.6	PSRC-A3-1	62.5
PSRC-A4-2	53.6	PSRC-A4-1	51.2
PSRC-C1-2	538.6	PSRC-C1-1	440.5
PSRC-C2-2	472.1	PSRC-C2-1	331.6
PSRC-C3-2	333.1	PSRC-C3-1	264.9
PSRC-C4-2	262.2	PSRC-C4-1	217.2
PSRC-E1-2	1178.8	PSRC-E1-1	995.9
PSRC-E2-2	1087.0	PSRC-E2-1	733.7
PSRC-E3-2	778.9	PSRC-E3-1	596.7
PSRC-E4-2	623.9	PSRC-E4-1	479.3

In order to more intuitively express the effect of steel strip reinforcement, it is set as the ratio of the increase in seismic capacity to the seismic capacity of the unreinforced specimen. Through figure 4 we can find that the reinforcement effect of the steel strip will change with the size of the section. Taking specimens with a shear-span ratio of 1.5 as an example, comparing the seismic bearing capacity of the reinforced and unreinforced specimens, we can find that when the section size increases gradually, the reinforcement effect of the steel strip increases first and then decreases. The seismic bearing capacity of the 200mm steel strip-reinforced specimen was increased by 9.84%; the 300mm specimen was 10.06%; the 400mm specimen was 22.26%; the 500mm specimen was 21.58%; and the 600mm specimen was 18.34%.

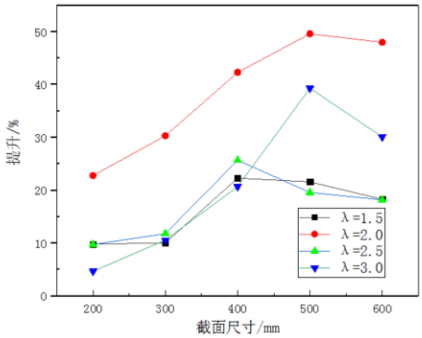


Figure 4. Influence of size on reinforcement effect of steel strip.

4. Bearing Capacity Calculation Method Considering Size Effect

4.1. Calculation Method of Bending Failure Bearing Capacity

Under the influence of pressure, bending moment and shear force, when the RC column reinforced with steel strips undergoes bending failure, its stress mechanism is similar to that of a biased column. So, the calculation method of the normal section bearing capacity of the biased column can be used for analysis.

The calculation method of this paper is based on the calculation model given in "*Code for Design of Concrete Structures GB50010-2010*" [10]. It divides the flexural bearing capacity into concrete and steel bars.

In reference [13], when analyzing the bearing capacity of normal section considering size effect, the idea of introducing the size effect factor to reduce the concrete strength is proposed. In the previous analysis, it can be seen that the reinforcement effect of the steel strip also has a size effect. Because the reinforcement mechanism of the steel belt is to provide the hoop stress to make the concrete in a state of three-way stress, so as to improve the strength. However, the stress in height direction of the column is not provided. Therefore, the following assumptions can be made. Steel strips can enhance the flexural performance of concrete columns by enhancing the strength.

In summary, the influence of size on the flexural capacity can be simulated by modifying the concrete strength. The following formulas can be obtained from the balance of forces and moments.

$$N_u = \alpha_1 f_c hx + f_y^{'} A_s^{'} - f_y^{'} A_s \tag{9}$$

$$M_u = \alpha_1 f_c hx(h_0 - \frac{x}{2}) + f_y^{'} A_s^{'} (h_0 - a^{'}) \tag{10}$$

In which N_u is the axial pressure value; M_u is the bending moment value; α_1 is the concrete strength reduction factor; f_c means the characteristic compressive strength of the constrained concrete, which takes into account size effects; h_0 means the effective height of section; $f_y^{'}$ means the design compressive strength of longitudinal steel; $A_s^{'}$ means the sum of cross-sectional areas of the longitudinal steels under compression; f_y means the design tensile strength of longitudinal steel; A_s means the sum of the cross-sectional areas of the longitudinal steels in tension; x means the height of equivalent compression area; $a^{'}$ means the thickness of protective layer of RC column.

The compressive strength of concrete reinforced with steel strips can be calculated using the formula suggested by Richard in Reference [14].

$$\frac{f_{cc}}{f_{co}} = 1 + \frac{k_1 f_1}{f_{co}} \tag{11}$$

In which f_{cc} means the ultimate compressive strength of constrained concrete; f_1 means the compressive stress caused by the steel strip on the side surface of the RC column; k_1 represents the coefficient of concrete strength enhancement; f_{co} represents the compressive strength of unconstrained concrete.

In reference [15], Yong Yang studied the change law of concrete strength when concrete is reinforced by steel belt, and then proposed the calculation formula. Studies have shown that the values of $\frac{f_1}{f_{co}}$ and $\frac{f_{cc}}{f_{co}}$ are linearly fitted to 15.6, and the strength boost is calculated as follows.

$$\frac{f_{cc}}{f_{co}} = 1 + 15.6 \frac{f_1}{f_{co}} \tag{12}$$

$$f_1 = \frac{2t_g b}{h(b + s_g)} f_g \tag{13}$$

$$f_g = \alpha_g f_{yg} \tag{14}$$

In which t_g is the thickness of the steel strip; f_{yg} is the design tensile strength of the steel strip; s_g is the spacing between the steel strips along the height direction of the column; b means the width of steel strip; h means the width of concrete specimen.

For steel strips, α_g means the ratio of average stress to yield stress when the specimen reaches its limit, as shown in table 4.

After averaging the reduction factor, the reduction factor for the strength of the steel strip is 0.35.

Table 4. Average stress of steel strip.

Number	Yield strength/MPa	Average stress/MPa	Reduction factor
PSRC-E1-2	600.0	189.1	0.315
PSRC-E2-2	600.0	208.4	0.348
PSRC-E3-2	600.0	216.4	0.361
PSRC-E4-2	600.0	250.1	0.416

Note: Take the size 600mm specimen as an example

The data was analyzed by the above formula, and the concrete strength improvement value was obtained, as shown in table 5.

Table 5. Concrete strength improvement.

Size/mm	200	300	400	500	600
Strength improvement/MPa	5.61	5.1	4.68	4.32	4.01

From table 5, we can find that when the section size gradually changed from 200 to 600, the strength improvement caused by the steel strip first increases and then decreases. Unreinforced concrete also has size effect, so the effect of size effect should be considered. Xie Yongping conducted an experimental study on the size effect of reinforced concrete, and then he proposed the corresponding formula for calculating the strength of concrete [16]. The formula is shown below.

$$f_{co}(h) = 1.201 f_{co} / \sqrt{1 + \frac{h}{247.6}} \tag{15}$$

Based on the above analysis, formulas (12), (13) and (14) show that the concrete strength calculation formula under steel strip restraint is as follows.

$$f_{cc} = f_{co} + 5.46 \frac{2t_g b}{h(b + s_g)} f_{yg} \tag{16}$$

Substituting formula (15) into formula (16), the concrete strength formula that considering the effect of size under the restraint of the steel belt can be obtained.

$$f_c = 5.46 \frac{2t_g b}{h(b + s_g)} f_{yg} + 1.201 f_{co} / \sqrt{1 + \frac{h}{247.6}} \tag{17}$$

Taking the strength obtained by formula (17) into formulas (9) and (10), the flexural bearing capacity will be calculated. Afterwards, these can be converted to shear force by formula (18). In this way, the horizontal bearing capacity of the specimen is obtained.

$$V_u = \frac{M_u}{H - \psi h} \tag{18}$$

In which ψ is the influence factor of the plastic hinge that takes into account the constraining influence of the base on the bottom of the column. The simulation results show that it can be approximately taken as 0.37.

The horizontal load data calculated by formula (18) are shown in table 6. By comparing the calculated and simulated results, we can conclude that the average error is 5.9%.

Table 6. Simulation results and calculation results.

Number	Simulation result /kN	Calculated result /kN	Ratio
PSRC-A3-2	68.6	72.4	0.948
PSRC-A4-2	53.9	59.0	0.914
PSRC-B3-2	166.3	156.3	1.064
PSRC-B4-2	136.5	127.3	1.072
PSRC-C3-2	335.0	306.5	1.093
PSRC-C4-2	265.7	249.8	1.064
PSRC-D3-2	494.4	467.4	1.057
PSRC-D4-2	439.5	413.8	1.062
PSRC-E3-2	788.1	759.1	1.038
PSRC-E4-2	631.8	618.5	1.021

4.2. Calculation Method of Shear Failure Bearing Capacity

Based on the calculation method in "*Code for Design of Concrete Structures GB50010-2010*" [10], a shear failure calculation method is proposed. In this method, the shear force on the specimen is considered in two parts. One is carried by concrete and another by stirrups. It can be seen from the analysis in 4.1 that the strength of the concrete is improved by the steel strip, and the improvement is affected by the size. In summary, the bearing capacity formula for shear failure of RC columns reinforced with steel strips is shown below.

$$V = V_c + V_s + V_g \tag{19}$$

In which V_c means the shear force of concrete; V_s means the shear force of stirrups; V_g means the shear force of steel belt.

For concrete, there is a conversion between the tensile strength and compressive strength [17]. Combined with the analysis of the influence of the steel strip in 4.1, the following assumptions are made in this paper. The shear force raised by the steel belt can be seen as an increase in the tensile strength of concrete.

Hong Zhou [18] studied the effect of size on concrete strength. And in experiments, it was found that increasing the size of concrete causes its tensile properties to decrease. Therefore, this effect cannot be ignored.

Therefore, equation (19) can be simplified to the following equation.

$$V = V_{c,g} + V_s \tag{20}$$

In which $V_{c,g}$ is the shear force borne by the concrete considering the effect of size and steel strip reinforcement.

The characteristic value f_{tk} of the concrete axial tensile strength can be calculated from the characteristic value $f_{cu,k}^{'}$ of the cubic compressive strength [17].

$$f_{tk} = 0.88 \times 0.395 f_{cu,k}^{0.55} (1 - 1.645\delta)^{0.45} \times \alpha_{c2} \tag{21}$$

In which δ is the coefficient of variation of the cubic compressive strength, which is taken as 0.14; α_{c2} is the reduction coefficient of concrete, which is taken as 1.00.

In summary, the increase value of concrete tensile strength can be obtained from table 5 and equation 21. As shown in table 7.

Table 7. Concrete strength improvement.

Size/mm	200	300	400	500	600
Strength improvement/MPa	0.79	0.75	0.72	0.69	0.66

Due to the influence of size, the characteristic value f_{tk} of concrete axial tensile strength needs to be reduced. After that, the strength increase values $f_t^{'}$ obtained in table 7 were added. We can obtain the tensile strength f_{t2} considering the effect of size and steel strip reinforcement. The formula is as follows.

$$f_{t2} = f_t^{'} + 1.201 f_{tk} / \sqrt{1 + \frac{h}{247.6}} \tag{22}$$

Substitute f_{t2} into the shear force calculation formula (23) that proposed in the "*Code for Design of Concrete Structures GB50010-2010*" [10], and the calculation formula (24) of $V_{c,g}$ can be obtained.

$$V_c = \alpha_{cv} h h_0 f_{tk} \tag{23}$$

$$V_{c,g} = \alpha_{cv} h h_0 (f_t^{'} + 1.201 f_{tk} / \sqrt{1 + \frac{h}{247.6}}) \tag{24}$$

In which α_{cv} means the coefficient of bearing capacity, α_{cv} is taken as $1.75/(\lambda+1)$, and λ means the shear-span ratio; h means the width of section; h_0 means the effective height of section.

The formula for calculating the shear force borne by the stirrups is as follows [10].

$$V_s = f_{yv} \frac{A_{sv}}{s} h_0 \tag{25}$$

In which f_{yv} represents the design tensile strength of stirrups; A_{sv} represents the sum of stirrups areas in the same cross section; s means the spacing of stirrups.

The total shear force can be obtained by adding the shear force obtained by formula (24) and formula (25) into formula (20).

The results are shown in table 8. By comparing the calculated and simulated results, we can conclude that the average error is 7.7%.

Table 8. Simulation results and calculation results.

Number	Simulation result /kN	Calculated result /kN	Ratio
PSRC-A1-2	121.6	132.7	0.916
PSRC-A2-2	105.9	122.2	0.867
PSRC-B1-2	274.6	289.7	0.948
PSRC-B2-2	244.6	268.7	0.910
PSRC-C1-2	538.6	497.2	1.083
PSRC-C2-2	472.1	463.2	1.019
PSRC-D1-2	844.4	773.6	1.091
PSRC-D2-2	772.9	772.9	1.066
PSRC-E1-2	1178.8	1083.2	1.088
PSRC-E2-2	1087.0	1017.7	1.068

5. Conclusion

1) There is only a small error between the bearing capacity obtained from the simulation and the test result. So this finite element modeling method can effectively analyze the RC columns reinforced with steel strips. 2) When the size increases gradually, the reinforcement effect of the steel strip tends to increase first and then decrease. There is a clear size effect. 3) On the basis of the existing calculation method, the size effect reduction factor is introduced and the influence of the steel strip is considered. Based on this, the calculation formulas of flexural and shear bearing capacity are established. Comparing the simulation and calculation results, it is found that the agreement is good.

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