Study on axial compression ratio limits of large size S-CLIP reinforced columns

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Abstract. Based on the constraint mechanism of concrete, an improved method of S-Clip reinforcement was proposed. Experimental study and numerical simulation were carried out on the large size normal reinforcement column and S-Clip reinforcement column, and the numerical calculation analysis was carried out on the improved S-Clip reinforcement column. On the premise of ensuring the bending failure form, the reasonable axial compression ratio limit of S-Clip reinforcement column was studied to provide a reference for the application of S-Clip reinforcement method. The results showed that the deformation capacity of both S-Clip reinforced column and the improved S-Clip reinforced column decreased with the increase of the axial compression ratio limit. The numerical simulation results were close to the test results, and the stiffness reduction rules and other rules had good approximation, and the failure modes were consistent. For the improved S-CLIP reinforcement column, the test axial compression ratio should not exceed 0.3. The influence of size effect was not considered in this study.

Keywords. improved S-Clip reinforcement, low axial pressure ratio limit, failure mode, numerical simulation.

1. Introduction

The section size of reinforced concrete bridge columns is large and the axial compression ratio is low. When S-CLIP reinforcement is selected to replace the traditional composite stirrup, the shear bearing capacity provided by the stirrup is reduced to some extent. In order to meet the basic requirements of bending failure, it is very important to control the limit value of axial compression ratio. Many scholars have put forward many improved methods for the brittle failure of concrete short columns. Liu Tao and Wang Qingxiang [1] proposed a new reinforcement method for concrete bridge columns, and proved through the test results that the ductility and peak load of the concrete columns with this new reinforcement method are improved to a certain extent compared with the concrete columns with stirrup reinforcement. Gandan[2] found that the constraint effect of the outsourced steel tube on the core concrete significantly improved the bearing capacity and ductility of the short column. However, the cost of the outsourced steel tube was relatively high, and the outsourced steel tube was prone to corrosion of the components. Chen Chenyuan[3] established the failure test model of reinforced concrete short columns and concluded that the effect of stirrup type on ductility was greater than that on strength.

G.P Romis [4] also explored the influence of CFRP on the mechanics and energy dissipation of reinforced concrete short columns through experiments. A.B.M.A. Kaish[5] proposed three kinds of square sheathing for short concrete columns to ensure the improvement of mechanical and ductility properties of short concrete columns, and carried out experimental research on short concrete columns with square sheathing under axial and eccentric loading modes. L. A. E. M. Shehata[6] proposed that carbon fiber reinforced plastic sheet was used to strengthen the concrete short column to ensure good fatigue performance according to the characteristics that the concrete short column is easy to be damaged. S. L. Billington and J. K. Yoon[7] proposed a precast segmental concrete bridge pier and
conducted seismic test research on it, indicating that the precast segmental concrete bridge pier has better integrity and energy dissipation capacity.

He Shiqin[8] carried out finite element analysis on short reinforced concrete columns with S-Clip stirrup, providing a reference for the industrial promotion of s-CLIP reinforcement method.

Research has shown that for large size bridge column, according to the traditional form of reinforcement, although there is a breakthrough of composite transverse stirrups, but cause cross section is very big, transverse shear bearing capacity of composite stirrups provide is very limited, not enough to affect the damage form of pillars, so in order to improve the construction speed, the external S-CLIP reinforced, checked by actual measured nearly three times more can improve the construction speed. The original S-CLIP reinforcement only paid attention to the fixation of vertical reinforcement and the reinforcement of anchorage, but ignored the effective constraint of concrete on the concrete section. The improved S-CLIP reinforcement changed the layout direction of the ring, utilized the strength of the constrained concrete, and further ensured the resistance of the bridge column. As bridge columns with low axial compression ratio have special structural mechanical properties and the shear bearing capacity of the section is weakened by the replacement of the hoop, the applicable axial compression ratio limit value must be studied on the premise of ensuring ductility design.

2. Brief description of the experimental study

The section size and reinforcement of the test specimen are shown in Figure 1. The axial compression ratio of C30 concrete is 0.071.

![Figure 1. Section size and reinforcement of test material](image)

A total of 4 specimens were made, each weighing 16 tons and 2 tons of reinforcement, belonging to larger size specimens. The reasonableness and feasibility of the S-clip reinforcement method were sought through the comparison between specimen A and As, specimen B and specimen Bs. It was noted that the semi-circle part of s-clip reinforcement in the designed specimen was perpendicular to the column section. 70 tons of axial pressure was applied in the test, and the yield and ultimate bearing capacity, yield displacement and ultimate displacement measured by low-cycle repeated tests were listed in Table 1. The Numbers in brackets were theoretical calculation results. According to the specification, the shear bearing capacity of S-CLIP bars is not taken into account since they can not span the whole section, so the specific method of substitution is not discussed here.
Table 1. Test loading and displacement data

|          |  A   |   As  |  B    |   Bs  |
|----------|------|-------|-------|-------|
| $P_v$ kN | 423  | 448   | 545   | 583   |
|          | (392)| (392) | (515) | (519) |
| $P_u$ kN | 525  | 519   | 691   | 696   |
|          | (438)| (483) | (651) | (656) |
| $\delta_v$ mm | (13.8)| (13.8) | (13.8) | (13.8) |
| $\delta_u$ mm | (150.5)| (150.2) | 189.7 | 191.2 |
| $\delta_u / \delta_v$ | (6.0) | (6.0) | (7.0) | (7.1) |
|          | (10.1)| (10.0) | (10.2) | (10.5) |
| $P_v$ kN | -506 | -402  | -524  | -533  |
|          | (392)| (392) | (515) | (519) |
| $P_u$ kN | -506 | -526  | -681  | -688  |
|          | (483)| (483) | (651) | (656) |
| $\delta_v$ mm | (-126.4)| (-148.3) | (-146.9) | (-148.4) |
| $\delta_u$ mm | (-139) | (-139.0) | (-141.7) | (-140.8) |
| $\delta_u / \delta_v$ | 6.0 | 7.1 | 7.0 | 7.1 |
|          | (10.1)| (10.0) | (10.2) | (10.5) |

Figure 2. Load displacement relation and skeleton curve measured by low cycle repeated loading test
Test results show that the test under the condition of axial compression ratio 0.071, all specimens are buckling destruction, from the failure pattern, low cyclic test roots are in the direction of the positive and negative two column reinforced the yield for damage marks, is evident in bending form (as shown in figure 2, figure 3, figure 4), while removing the composite stirrups, the shear bearing capacity of the lower no influence to the damage form of pillar. On the contrary, we observed that the skeleton curve of the column with S-CLIP bar was not lower than that of the composite stirrup column, and had a slightly better performance (as shown in Figure 2). And eight root of concrete fracture suggests, equipped with S-CLIP column stirrup reinforcement fracture number than ordinary composite stirrups column, apparently because of the location of the transverse level stirrup SCLIP maximum uniformity to decorate, make between stirrups longitudinal reinforcement buckling length relative to the minimum, reinforced stress caused by a more even.

3. Improved S-CLIP reinforcement and its numerical simulation analysis

The simulation results of A, As, B and Bs. are very similar to the test results, and the failure
morphism is completely consistent. The comparison results was shown in Figure 5 and Figure 6.

3.1.\textit{Simulate hysteresis curve}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{hysteresis_curve.png}
\caption{Hysteresis curve set of A, As and As'.}
\end{figure}

Through the previous analysis, it can be seen that the simulated curve of the tested specimen is in good agreement with the experimental curve, with a high degree of fitting, which indicates that the concrete constitutive model adopted by the finite element model and the corresponding parameter setting are reasonable, thus verifying the feasibility and rationality of the finite element analysis. In the
test, it is impossible for us to test all the specimens. According to the finite element simulation results in this paper, the transverse S-clip reinforcement in the test is more conducive to improving the seismic performance of reinforced concrete columns to a certain extent under low axial compression ratio.

Comparing the hysteresis curve of specimens B, BS and BS' with that of specimens A, AS and AS', the ultimate displacement and ultimate load are relatively large. It shows that the higher the reinforcement ratio, the greater the bearing capacity and the greater the stiffness of the specimen.

By comparing the hysteresis curve test results with the finite element simulation results, it was found that the simulation curves of A, As, B and Bs were in good agreement with the test curves, and the error was within 15%. The peak load value and maximum deformation of finite element calculation are close to the test value, and there are some deviations. The main reasons are as follows: the bond slip between reinforcement and concrete is not considered in the computer simulation, as well as the initial defects of materials, transportation and installation errors, test loading conditions, etc. In general, ABAQUS finite element software can be used for further analysis of specimens.

3.2. Skeleton curve

(a) Comparison between test skeleton curve and simulation skeleton curve of A

![Skeleton curve comparison A](image)

(b) Comparison between test skeleton curve and simulation skeleton curve of AS

![Skeleton curve comparison AS](image)
According to the skeleton curve, yield displacement and limit displacement were extracted, and the ductility coefficient $\mu_\Delta$ was calculated as shown in Table 2. Compared with the measured data in Table 3, it had a good approximation, which indirectly verified the reliability of the improved S-CLIP clamp scheme.

### Table 2. Calculation of displacement ductility coefficient $\mu_\Delta$

| Model | $u_y/\text{mm}$ | $u_m/\text{mm}$ | $\mu_\Delta$ | average |
|-------|-----------------|-----------------|---------------|---------|
|       | P               | R               | P             | R       |       |
| A     | 24.56           | 20.4            | 130           | 115     | 5.29   | 5.64   | 5.47   |
| As    | 24.6            | 20.5            | 150           | 130     | 6.10   | 6.34   | 6.01   |
| As'   | 25.2            | 21.1            | 155           | 135     | 6.15   | 6.40   | 3.20   |
| B     | 26.7            | 20.8            | 140           | 120     | 5.24   | 5.77   | 3.19   |
| Bs    | 26.5            | 20.7            | 155           | 130     | 5.85   | 6.28   | 3.18   |
| Bs'   | 27.1            | 21.3            | 160           | 130     | 5.90   | 6.10   | 3.23   |

Note: P stands for forward and R stands for reverse, same as below

### Table 3. Calculation of displacement ductility coefficient $\mu_\Delta$

| Model | $u_y/\text{mm}$ | $u_m/\text{mm}$ | $\mu_\Delta$ | average |
|-------|-----------------|-----------------|---------------|---------|
|       | P               | R               | P             | R       |       |
| A     | 24.56           | 20.4            | 75.39         | 64.27   | 3.07   | 3.15   | 3.11   |
| As    | 24.6            | 20.5            | 73.06         | 62.32   | 2.97   | 3.04   | 3.01   |
| As'   | 25.2            | 21.1            | 79.63         | 68.36   | 3.16   | 3.24   | 3.2    |
| B     | 26.7            | 20.8            | 85.71         | 65.94   | 3.21   | 3.17   | 3.19   |
| Bs    | 26.5            | 20.7            | 84.8          | 65.41   | 3.2    | 3.16   | 3.18   |
| Bs'   | 27.1            | 21.3            | 88.35         | 68.16   | 3.26   | 3.2    | 3.23   |

### 4. Analysis of axial compression ratio

Axial compression ratio increases, ductility deteriorates. The axial pressure used in the specimen was relatively small (the test axial pressure ratio was 0.0432 and the corresponding design axial pressure ratio was 0.058). In this paper, the specimen As' was selected as the research object (As, As' could be seen from Section 10 that the hoop fitting method of As' was most beneficial to improving the ductility performance of the column under low axial pressure ratio). Under 0.1, 0.15, 0.2, 0.25, 0.3 and 0.35 six different axial pressure ratios (test axial pressure ratio), the specimen A was used as a reference.
to analyze the hysteretic seismic performance of the specimen. Make hysteresis curves of A and As’ under different coaxial pressure ratios. In addition, the skeleton curves of A and As are also presented in this paper under different coaxial pressure ratios.

For column A and As’ column, at the initial stage of loading under six axial pressure ratios, the hysteresis loop curve was expanded in a linear form. With the increase of load, the slope of curve decreases, and stiffness degradation occurs to different degrees in column A and column As’ of six kinds of axial pressure ratio. The greater the axial compression ratio is, the more obvious the degradation is. Among them, for A and As’ columns, when the axial pressure ratio (test axial pressure ratio) is 0.3, the hysteresis curve area is the largest and the energy dissipation capacity is the strongest. When the axial compression ratio (test axial compression ratio) is 0.35, the stiffness and bearing capacity of Column A and column As’ drop at the fastest speed, which indicates that the overall deformation capacity of column A and Column As’ is the worst.

For Column A and As’ column, under the six axial pressure ratios, at the initial stage of loading, skeleton curves basically overlap, indicating that the change of axial pressure ratio at the initial stage of loading has little influence on column A and As’ column. Subsequently, both Column A and As’ column entered the plastic stage, and the greater the axial pressure ratio was, the greater the peak bearing capacity was. In the failure stage, with the increase of loading displacement, the greater the axial compression ratio is, the faster the bearing capacity and stiffness decline speed will be. When the axial compression ratio (test axial compression ratio) is 0.35, the decline speed will be the fastest. This shows that for column A and As’ column, the greater the axial pressure ratio is, the worse the ductility is.

Under the action of different coaxial pressure ratios, the calculated values of the displacement ductility coefficient of specimen A and specimen As’ are shown in Table 4 and Table 5.

| Table 4. Displacement ductility coefficients of A with different axial compression ratios |
|---|---|---|---|---|
| ratios | $u_y/\text{mm}$ | $u_m/\text{mm}$ | $\mu_d$ | average |
| | P | R | P | P | P | R |
| 0.1 | 24.5 | 20.1 | 74.72 | 63.31 | 3.05 | 3.15 | 3.10 |
| 0.15 | 24.3 | 19.8 | 73.63 | 61.97 | 3.03 | 3.13 | 3.08 |
| 0.2 | 24.1 | 19.3 | 72.78 | 60.22 | 3.02 | 3.12 | 3.07 |
| 0.25 | 23.8 | 19.1 | 71.64 | 59.02 | 3.01 | 3.09 | 3.05 |
| 0.3 | 23.5 | 18.8 | 70.26 | 58.09 | 2.99 | 3.09 | 3.04 |
| 0.35 | 23.2 | 18.4 | 67.51 | 55.38 | 2.91 | 3.01 | 2.96 |

| Table 5. Displacement ductility coefficients of As’ with different axial compression ratios |
|---|---|---|---|---|
| ratios | $u_y/\text{mm}$ | $u_m/\text{mm}$ | $\mu_d$ | average |
| | P | R | P | P | P | R |
| 0.1 | 24.9 | 20.8 | 78.19 | 66.98 | 3.14 | 3.22 | 3.18 |
| 0.15 | 24.7 | 20.5 | 76.07 | 65.19 | 3.08 | 3.18 | 3.13 |
| 0.2 | 24.3 | 20.2 | 74.11 | 64.03 | 3.05 | 3.17 | 3.11 |
| 0.25 | 23.9 | 19.8 | 72.17 | 62.17 | 3.02 | 3.14 | 3.08 |
| 0.3 | 23.6 | 19.5 | 69.62 | 60.25 | 2.95 | 3.09 | 3.02 |
| 0.35 | 23.4 | 19.1 | 65.81 | 55.96 | 2.77 | 2.93 | 2.85 |
AS can be seen from Table 5 and 6, with the increase of axial pressure ratio, the displacement ductility coefficients of A and As` both decrease. It is generally believed that the ductility coefficient required for reinforced concrete seismic structures is 3 ~ 4. However, for As`, only when the axial pressure ratio ≤0.3, the displacement ductility coefficient > 3. Therefore, the maximum axial pressure ratio (test axial pressure ratio) of As` specimen is 0.3.

In order to ensure the deformation capacity of the column, the setting of axial pressure ratio should be strictly controlled. The maximum axial pressure ratio (test axial pressure ratio) of As` column in this paper was 0.3, and the corresponding design axial pressure ratio was 0.489. In practical application, the ductility performance of As` column is guaranteed by reasonably limiting the axial compression ratio.

5. Conclusion
(1) The numerical simulation results of S-CLIP reinforced concrete bridge columns with Abaqus finite element method were close to the original test results, indicating the number. The value analysis method has the engineering guiding significance in the research of this problem.
(2) This paper further studies the mechanical properties of reinforced concrete columns after the reinforcement scheme is improved, and it is concluded with the numerical analysis of the original test model.
(3) In view of the small number of original test specimens and the limitations of the research work under specific axial compression ratio, in order to extend the engineering applicability of the improved reinforcement scheme, the scope of application of the axial compression ratio was studied. In accordance with the ductility requirements of seismic structures, the limit value of the axial compression ratio of the improved reinforcement scheme was suggested to be 0.3.

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7. References
[1] Niu JG, Feng XL and Chen X 2012 Experimental study on the axial compression ratio of short columns of plastic steel fiber lightweight aggregate Concrete Chinese Journal of Silicate 37(12) pp 3866-3871
[2] Gan D, Zhou XH, Liu JP and Li J 2015 Composite Effect of circular steel Tube restrained Reinforced concrete short column under reciprocating Load Journal of Building Structures 36 pp 222-229
[3] Chen CY, Liu KC, Liu YW and Huang WJ 2010 A case study of reinforced concrete short column under earthquake using experimental and theoretical investigations Structural engineering and mechanics 36(2) pp 197-206
[4] Promis G, Ferrier E and Hamelin P 2009 Effect of external FRP retrofitting on reinforced concrete short columns for seismic strengthening Composite structures 88 pp 367-379
[5] Kaisha A, Alam MR, Jamil M, Zain FMF and Wahed MA 2012 Improved ferrocement jacketing for restrengthening of square RC short column Construction and building materials 36 pp 228-237
[6] Shehata L, Carneiro L and Shehata LCD 2002 Strength of short concrete columns confined with CFRP sheets Materials and structures 35 pp 50-58
[7] Billington SL and Yoon JK 2004 Cyclic response of unbonded posttensioned precast columns with ductile fiber-reinforced concrete Journal of bridge engineering 9 pp 353-363
[8] He SQ, Li H, LI PF and An XH 2014 Three-dimensional finite element Analysis of short columns under axial compression of Concrete with S-CLIP Stirrups Journal of north China university of technology 26(3) pp 73-77