Experimental Study on Shear Performance and Bearing Capacity Calculation of Regionally Confined Concrete Beams

Jianying Zhou*, Lidan Li

School of Architecture and Engineering, Kaili University, Kaili, Guizhou, 556011, China

*Corresponding author's e-mail: 1614937379@qq. com

Abstract. As a relatively novel structural form, regionally confined concrete (RCC) has seen limited research and application in beams. This paper investigates the shear performance of RCC beams through experimental studies and a synthesis of existing literature. The shear bearing capacity was calculated using the*Technical Specification for Regionally Confined Concrete Structures* (hereinafter referred to as the*Specification*), and the results were compared with experimental data. The findings indicate that RCC enhances shear bearing capacity and improves ductility during shear failure. However, the extent of ductility improvement requires further experimental quantification. Recommendations for future research on RCC beam shear performance are also proposed.

Keywords: Regionally confined concrete beams; Shear performance; Shear capacity; Experiment

1 Introduction

Building upon confined concrete research, Cao Xinming[1] introduced the concept of regionally confined concrete (RCC). RCC involves applying confinement only to critical regions of a structural member. As illustrated in Figure 1, the cross-section is divided into multiple zones, each confined by transverse stirrups and longitudinal reinforcement to restrict lateral deformation of concrete. This unique confinement mechanism alters the mechanical behavior and failure modes of structural members.

Over the past two decades, significant theoretical advancements in RCC have been achieved, primarily focusing on columns, including studies on bearing capacity, axial compression ratio, ductility, energy dissipation, and stress-strain relationships in highly confined zones[2]–[11]. The release of the*Specification*in Guizhou Province (2017)[12] marked a milestone, providing guidelines for engineering applications. Despite progress, research on RCC beams remains scarce. This paper addresses this gap by experimentally analyzing the shear performance of RCC beams, collating published data, and validating the*Specification*through comparative calculations.

Despite two decades of development, RCC remains understudied, with limited adoption in engineering practice predominantly restricted to column applications. Research

G. Zhao et al. (eds.), *Proceedings of the 2025 8th International Conference on Traffic Transportation and Civil Architecture (ICTTCA 2025)*, Atlantis Highlights in Engineering 39,
https://doi.org/10.2991/978-94-6463-793-9_33

on RCC beams, particularly their shear behavior, remains scarce. To address this gap, this study systematically investigates the shear performance of RCC beams through experimental testing and synthesis of published data. The Specification is utilized to calculate shear bearing capacity, and computational results are rigorously compared with experimental outcomes. Through this comparative analysis, the strengths and limitations of the current methodology are elucidated, and actionable recommendations for future research are proposed.

2 Regionally Confined Concrete Beams

RCC beams differ from traditional RC, steel-concrete composite, and other confined concrete beams in their stirrup configuration. In simply supported beams under service loads, the neutral axis divides the cross-section into compression and tension zones. Confining the compression zone enhances concrete strength and ultimate compressive strain, thereby improving bearing capacity and ductility.

To date, research on regionally confined concrete (RCC) beams remains limited. Ding Jiajun [13] and Jiang Jitong [14] conducted experimental and analytical studies on the flexural performance of steel-reinforced RCC beams. In [14], the flexural capacity formula from the Specification was applied to fiber-reinforced polymer (FRP)-confined RCC beams, with critical recommendations for refining the code's implementation in such hybrid systems. Zhou Jianying [15] further investigated the flexural stiffness of RCC beams, analyzing stiffness degradation under varying load conditions. However, studies focusing on shear performance are exceedingly scarce, with only fragmented literature addressing this critical aspect of RCC behavior.

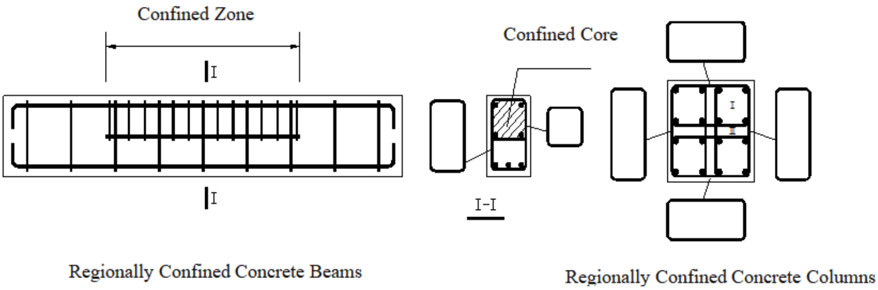


Fig. 1. Typical Reinforcement of Restrained Concrete Beams and Columns in Area Constraints

In 2005, Bai Jie [16] conducted experimental research on the shear performance of regionally confined concrete (RCC) beams, performing a comparative analysis between RCC beams and conventional reinforced concrete (RC) beams. A shear capacity formula for RCC beams was derived, and key mechanical behaviors—including sectional strain distribution, moment-curvature relationships, load-deflection curves, stress-strain responses, and failure modes—were systematically investigated under shear loading. However, insufficient longitudinal tensile reinforcement in the test specimens resulted in premature tensile failure dominating the ultimate failure mode. Consequently, the study failed to isolate and effectively characterize the intrinsic shear behavior of RCC beams, as the observed failure mechanism was governed by tensile rather than shear effects.

In 2008, Ma Jing [17] conducted experimental tests on the shear behavior of regionally confined concrete (RCC) beams. The results demonstrated that RCC significantly enhances shear capacity compared to conventional reinforced concrete (RC) beams, with marked superiority in resisting shear deformation. A key mechanism identified was the independent load-bearing role of the upper confinement, which effectively delayed diagonal crack propagation during later loading stages, providing observable pre-failure warnings. Comparative analyses between experimental results and theoretical predictions were documented in the literature. However, the shear capacity calculation method employed in the study deviated from the Specification, and certain data assumptionswere suboptimal due to technological constraints of the time. To address these limitations, this study recalculates the shear capacity using the Specification-prescribed methodology and recalibrates the original dataset for improved accuracy.

In 2017, Guo Guyue [18] conducted a comprehensive investigation into the shear performance of regionally confined concrete (RCC) beams, combining experimental tests and finite element analysis (FEA) to evaluate factors influencing shear behavior. The study validated the shear calculation model proposed in the Technical Code for Regionally Confined Concrete Structures against experimental data, demonstrating that confined stirrups significantly enhance shear resistance by mobilizing the confinement assembly as an integrated shear-resisting component. Key findings confirmed that the hypothesis of treating the confinement system as a unified shear-bearing entity aligns with design requirements for load-bearing capacity calculations. However, discrepancies arose from suboptimal parameter assumptions in the model,

3 Experimental Analysis

3.1 Test Setup

Five beams were tested: four RCC beams (R1-1 to R1-4) and one conventional RC beam (N1-1). All beams had cross-sectional dimensions of 150 mm × 300 mm, with stirrup spacing of 50 mm. The reinforcement configurations are detailed in Figure 2 and Table 1. Concrete strength was 39.5 MPa, and steel properties are listed in Table 1.

Table 1. Reinforcement Parameters

Steel Reinforcement	HRB400				
Diameter(mm)	25	22	20	10	8
Yield Strength(MPa)	442.5	464.5	457	529.5	491

A two-point symmetric loading system was employed under displacement control. Displacement gauges were installed at mid-span, loading points, and supports (Figure

2). The distance between loading points and supports is provided in Table 2. The loading conditions of each beam on site are shown in Figure 4.

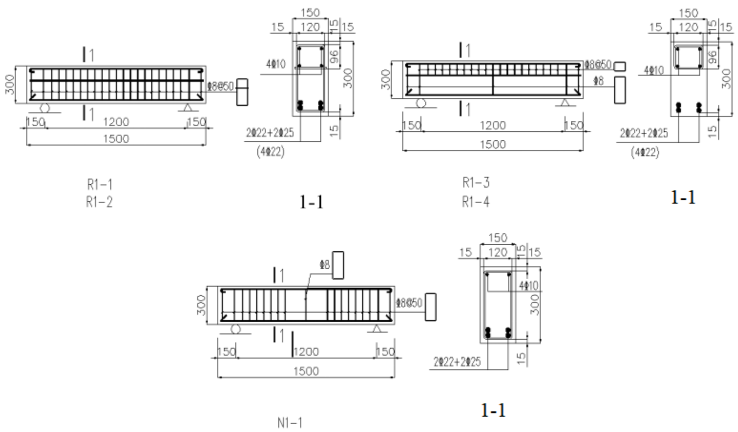


Fig. 2. Sectional reinforcement

Table 2. Distance from the loading point to the center of the support (mm)

Specimen	R1-1	R1-2	R1-3	R1-4	N1-1
Distance	300	350	300	300	300

FigThis study tested five beams, including four regionally confined concrete (RCC) beams and one conventional reinforced concrete (RC) beam (N1-1). All beams shared identical cross-sectional dimensions of 150 mm × 300 mm, with a uniform stirrup spacing of 50 mm. The reinforcement configurations were as follows:

R1-1 and R1-2: RCC beams equipped with ordinary stirrups throughout the cross-section.

R1-3 and R1-4: RCC beams featuring confined stirrups positioned exclusively in the compression zone.

N1-1: Conventional RC beam without regional confinement.

The tested compressive strength of the concrete was 39.5 MPa, while the measured yield strengths of the steel reinforcement are listed in Table 1.

The test utilized a mid-span two-point symmetric loading system conducted on a static reaction frame, employing load-controlled protocols until structural failure. To measure displacement, displacement transducers were installed at the mid-span, loading points, and supports. Stirrup configurations and the distance between loading points and support centers for each beam are detailed in Table 2. Post-assembly reinforcement cages are illustrated in Figure 3.

During the experimental process, various factors may introduce errors to the experimental results. To address this, we have implemented a series of measures to prevent experimental errors throughout the process. The experimental setup may introduce uncertainties from the following aspects:

①Material heterogeneity: Differences in concrete curing and fluctuations in the mechanical properties of reinforcement may affect the load-displacement response. To minimize the impact, all concrete used is commercial concrete, and all components and standard test blocks are cured under the same conditions. The reinforcement is sampled for yield strength testing.

②Loading System Alignment: Asymmetric loading may lead to unintended torsion. A laser level was used to ensure symmetric alignment of the two-point loading system.

③Displacement Measurement Accuracy: Slippage of displacement transducers was minimized by fixing them with magnetic bases and verifying initial zero-point readings.

④Welding Defects: Premature stirrup fractures in R1-1 (Figure 8a) highlighted stress concentrations at welded joints. Future tests should employ continuous stirrups or improved welding techniques.

3.2 Experimental Observations

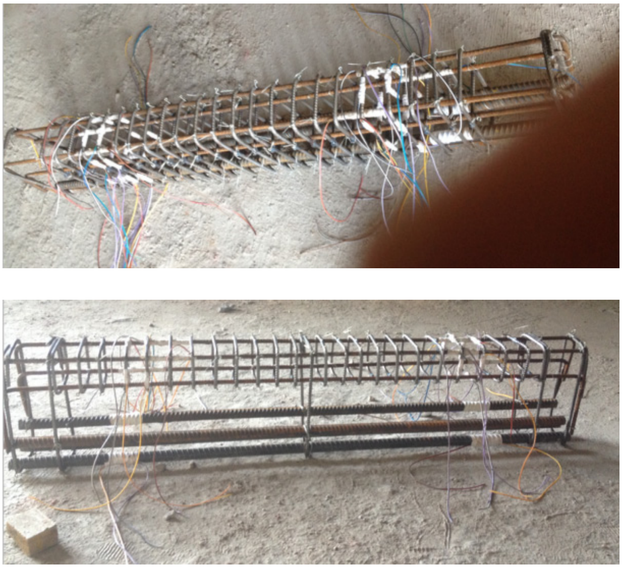
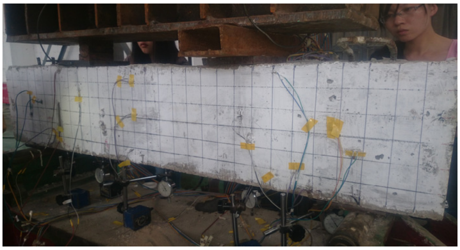
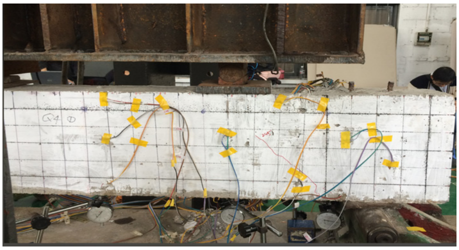


Fig. 3. Reinforcement cage

The experimental observations revealed that the cracking load of beams with three distinct stirrup configurations was consistent, approximately 60 kN. Prior to cracking, the stress distribution aligned with elastic analysis, as evidenced by the gradual strain development in longitudinal reinforcement (Figure 4). Furthermore, Figure 5 demonstrates negligible strain increments in ordinary stirrups of R1-1, R1-2, and N1-1 before cracking, indicating that the shear force was predominantly resisted by the concrete matrix during this phase. Given identical cross-sectional dimensions across all five beams, the similarity in cracking loads underscores the dominant role of concrete properties in initial shear resistance, independent of stirrup configurations.

(1)R1-1 (2)R1-2





(3)R1-3 (4)R1-4

(5)R1-5

Fig. 4. Beam loading site

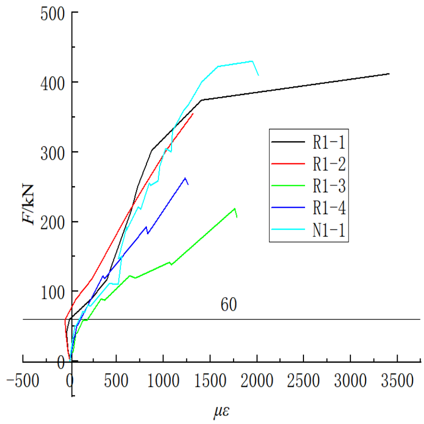


Fig. 5. Longitudinal Strain

Following concrete cracking, strain development in longitudinal reinforcement and ordinary stirrups accelerated across all beams, as evidenced by Figures 5 and 6. However, distinct strain patterns emerged in confined stirrups:

R1-1 and R1-2 (RCC beams with ordinary stirrups): Confined stirrup strain growth remained gradual (Figure 7), attributable to crack-width restraint provided by ordinary stirrups, which mitigated crack propagation into confined zones.

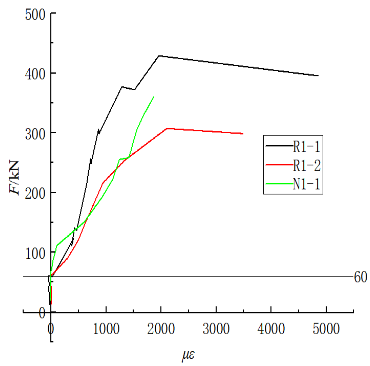


Fig. 6. Strain of Ordinary Hoop Reinforcement

R1-3 and R1-4 (RCC beams with confined stirrups only): Confined stirrup strain rates increased sharply post-cracking (Figure 7). The absence of ordinary stirrups eliminated crack-width control, enabling rapid crack extension into confined regions and triggering earlier activation of confined stirrups.

This contrast underscores the dual role of ordinary stirrups: (1) delaying crack progression and (2) redistributing shear demands to confined zones in a controlled manner.

Under incremental loading, strain rates in longitudinal reinforcement, ordinary stirrups, and confined stirrups accelerated significantly across all beams. However, confined stirrup strain development in R1-3 and R1-4 (beams with confined stirrups only) markedly outpaced that of R1-1 and R1-2 (beams with combined ordinary and confined stirrups). This divergence stems from distinct shear-resisting mechanisms:

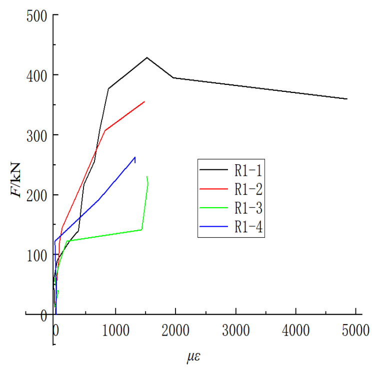


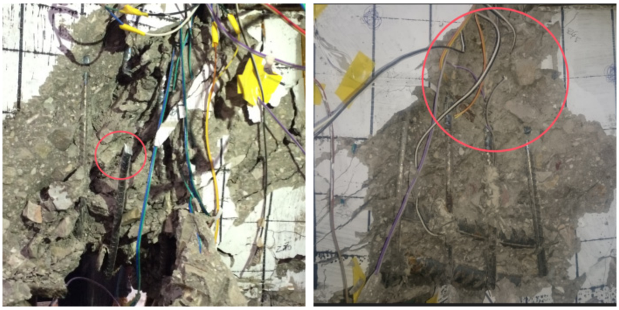
Fig. 7. Strain of Confining Stirrups

In R1-1 and R1-2, ordinary stirrups and shear-flexural zone concrete initially absorbed a portion of the shear force, delaying crack propagation toward confined regions.

In R1-3 and R1-4, the absence of ordinary stirrups forced shear resistance to rely solely on shear-flexural zone concrete, resulting in accelerated crack extension into confined regions under increasing loads. Consequently, confined stirrups in these beams experienced rapid strain accumulation as cracks penetrated confinement zones.

During early cracking stages, crack morphologies in R1-1 and R1-2 resembled those of the conventional RC beam (N1-1). However, R1-3 and R1-4 exhibited faster crack growth due to the lack of crack-width restraint from ordinary stirrups (Figure 8). In later loading stages, the confined zones in RCC beams (R1-1, R1-2) became active, effectively decelerating diagonal crack progression. For instance, R1-1 (with combined stirrups) demonstrated slower crack development than N1-1 under identical shear-span ratios, highlighting the synergistic effect of ordinary and confined stirrups in crack control.

At ultimate failure, even under shear-dominated failure mechanisms, the regionally confined concrete (RCC) beams (R1-1, R1-2, R1-3, and R1-4) exhibited enhanced ductility with a gradual failure progression, contrasting sharply with the abrupt collapse of the conventional RC beam (N1-1). As illustrated in Figure 6, the confined zones of all RCC beams maintained structural integrity at failure, whereas N1-1 experienced catastrophic separation into two segments due to a critical diagonal crack penetrating the entire cross-section.



(1) R1-1 (2) R1-2

(3) R1-3 (4) R1-4

(5) N1-1

Fig. 8. Beam failure modes

Notably, in R1-1, localized weld fractures occurred at stirrup joints during the final failure stage, likely attributable to stress concentrations at welded connections.

Experimental observations demonstrate that regionally confined concrete (RCC) beams exhibit behavior similar to conventional reinforced concrete (RC) beams during the initial loading stages. However, as loading progresses to intermediate and ultimate phases, the confined zones become activated, effectively restraining crack propagation rates and engaging confined stirrups in shear resistance. To ensure full utilization of confinement mechanisms, sufficient longitudinal tensile reinforcement must be provided to maintain stress transfer integrity within the confined regions.

4 Shear Bearing Capacity Calculation

The shear capacity of inclined sections is a critical parameter for assessing the performance of flexural members. In this study, the author evaluates selected beams by comparing calculated shear capacities with experimental results. This comparative analysis aims to validate the theoretical models outlined in the Technical Specification for Regionally Confined Concrete Structures and quantify the efficacy of regional confinement in enhancing shear resistance.

4.1 Formulas

As specified in the Code for Design of Concrete Structures (GB 50010–2010, hereafter referred to as the Code)[19], the shear capacity of reinforced concrete (RC) beams with stirrups only is calculated as follows:

$$V_{cs} = \alpha_{cv} b h_0 f_t + f_{yv} \frac{A_{sv}}{s} h_0 \tag{1}$$

α_{cv}: Coefficient for concrete shear resistance at inclined sections.

For general flexural members: α_{cv}=0.7. For independent beams under concentrated loads (where concentrated loads contribute ≥75% of the total shear at the support or joint edge):

$$\alpha_{cv} = \frac{1.75}{1+\lambda}$$

λ: Shear-span ratio, calculated as $\lambda = a/h_0$,where:

a: Distance from the concentrated load to the support/joint edge.

λ is bounded: 1.5≤λ≤3.0. If λ<1.5, use λ=1.5; if λ>3.0, use λ=3.0.

A_{sv}: Total cross-sectional area of stirrup legs in a single transverse section.

s: Spacing of stirrups along the beam axis.

f_{yv}: Tensile strength of stirrups.

The*Specification*provides the following equations for RCC beam shear capacity:

$$V \le V_{cs} + V_s \tag{2}$$

$$V_{cs} = \alpha_{cv} b(h_0 - x_{cc}) f_t + f_{yv} \frac{A_{sv}}{s} h_0 \tag{3}$$

$$V_s = b_1 x_{cc} f_{cv} \tag{4}$$

$$b_1 x_{cc} f_{cc} \le A_s f_y \tag{5}$$

V_{cs}: Design shear capacity contributed by the confinement assembly.

f_{cv}: Design shear strength of the confinement assembly, taken as $f_{cv} = 0.1 f_{cc}$.

b_1: Width of the confined core zone.

x_{cc}: Depth of the compression zone .

f_{cc}: Design compressive strength of the confinement assembly.

$$f_{cc} = (1+k) f_c \tag{6}$$

$$k = (f_y \rho_s + f_{yv} \rho_v) / f_c \tag{7}$$

And k≥0.48.

$$\frac{\rho_v}{\rho_s} \approx 1 \sim 1.5 \tag{8}$$

If $\rho_v \ge 1.5\rho_s$, use $\rho_v = 1.5\rho_s$; if $\rho_v \le \rho_s$, use $\rho_v = \rho_s$.

ρ_v : Volumetric ratio of confined stirrups, calculated as $\rho_v = \dfrac{A_{scl}\sum l_{cc}}{A_{cc}S}$.

ρ_s: Ratio of confined longitudinal reinforcement， calculated as $\rho_s = \dfrac{A_{sc}}{A_{cc}}$.

4.2 Comparative Analysis

The experimental study in Reference [14] was conducted at an earlier stage. Although the shear capacity of the beams was calculated in the original work, the methodology for regionally confined concrete (RCC) beams deviated from the Technical Specification, and certain parameter assumptions were suboptimal. To address these limitations, this study recalculates the shear capacity of both the test beams from Reference [14] and the beams tested in this work using the formulas prescribed in the Technical Specification for Regionally Confined Concrete Structures. For consistency with experimental results, standard values of axial compressive strength for concrete and measured steel strengths were adopted in the calculations. Specific values are listed in Table 3.

Table 3. Comparison of Calculated and Experimental Shear Capacities of Beams

Beam	f_{cuk} (MPa)	f_{ck} (MPa)	f_{tk} (MPa)	f_{yk} (MPa)	f_{yvk} (MPa)	f_{cck} (MPa)	f_{cvk} (mm)	λ	x_{cc} (mm)	h_0 (mm)	s (mm)	V_1 (kN)	V (kN)	V/V_1
R1-1	39.5	26.4	2.3	529.5	491	59.4	5.94	1.25	96	242.5	50	344.26	430	1.25
R1-2	39.5	26.4	2.3	529.5	491	59.4	5.94	1.44	96	239.5	50	340.56	355	1.04
R1-3	39.5	26.4	2.3	529.5	491	59.4	5.94	1.25	96	242.5	50	198.95	230	1.16
R1-4	39.5	26.4	2.3	529.5	491	59.4	5.94	1.24	96	239.5	50	198.23	310	1.56
N1-1	39.5	26.4	2.3	529.5	491	-	-	1.25	96	239.5	50	295.32	435	1.47
B-1	31.5	21.1	2.0	426	414	54.7	5.47	1.59	80	157	100	77.98	95	1.22
B-2	31.5	21.1	2.0	426	414	57.9	5.79	1.59	80	157	100	79.74	102.5	1.29
N-1	31.5	21.1	2.0	426	414	-	-	1.59	80	157	100	58.31	92.5	1.59

In the table, N-1, B-1, and B-2 are derived from the experimental data of Ma Jing [14]. V_1 represents the calculated shear capacity, where regionally confined concrete (RCC) beams are calculated using Equation (2-4) and conventional reinforced concrete (RC) beams are calculaComparative Analysis of Experimental and Calculated Results: Shear Capacity of Conventional RC Beam vs. RCC Beam:

The experimentally measured shear capacity of the conventional RC beam N1-1 was 435 kN, slightly exceeding that of the regionally confined concrete (RCC) beam R1-1 with the same shear-span ratio. However, a welded joint fracture in one stirrup of R1-1 during testing likely reduced its measured capacity. It is anticipated that improving welding quality would enhance R1-1's shear capacity.

In Reference [14], all RCC beams exhibited higher experimentally measured shear capacities than conventional RC beams, confirming that confinement effectively enhances shear resistance.

Safety Margin of the Technical Specification:

The V/V_1 ratios (experimental-to-calculated shear capacity) ranged from 1.04 to 1.56, demonstrating that the Technical Specification provides significant safety margins even when using material standard values.

Confinement Intensity and Shear Capacity:

The shear capacity of RCC beams increased proportionally with confinement enhancement (e.g., higher stirrup ratios, optimized confinement zones), validating the direct correlation between confinement design and structural performance.ted using Equation (1).

5 Conclusions

Based on comparative analysis of experimental observations and computational results, the following conclusions are drawn:

①Enhanced Shear Capacity and Ductility:

The application of confinement in shear-flexural zones improves the shear capacity of regionally confined concrete (RCC) beams and enhances ductility during shear failure.

The extent of ductility improvement requires further experimental quantification, as the post-peak behavior (descending branch of the load-displacement curve) was not captured in this study.

②Validation of Safety Margins:

Comparative analysis between calculated and experimental results confirms that the shear capacity calculation method in the Technical Specification provides sufficient safety margins, with safety factors ranging from 1.04 to 1.56 even when using material standard values.

③Critical Role of Longitudinal Reinforcement:

Adequate longitudinal tensile reinforcement must be sufficiently provided to activate confinement mechanisms and maximize shear capacity gains.

Acknowledgments

This work has been supported by Kaili University's 14th Five-Year Plan discipline professional platform"team"integrated construction plan(Grant No.YTH-XM2024012), National Natural Science Foundation of China(Grant No. 42307269),Guizhou Provincial Department of Education Higher Education Science Research Project (Grant No.

[2024]348), High-level Innovative Talents in Guizhou Province(GrantNo.[2025]202306) and Kaili University Integrated Research Project.(Grant No.YTH-TD202531).

References

1. Cao, X. M., and J. Bai. "Confined Concrete in Moment Element." Paper presented at the Conference on Structural Engineering, Changsha, China, 2004.
2. Hu, L. F., X. M. Cao, and W. D. Tang. "Curvature and Ductility Analysis of Sectionally Confined Concrete Shear Walls." Building Structure 52, no. S2 (2022): 968–974.
3. Zhang, Q., X. M. Cao, L. P. Xiao, et al. "Experimental Study on Seismic Performance of Steel Regionally Confined Concrete Columns." Building Structure 51, no. 2 (2021): 85–91.
4. Xiao Liping, Cao Xinming, and Ren Tingjian. "Mechanical Model of Regionally Confined Concrete Structures." Technology Innovation and Application 11, no. 24 (2021): 20-24.
5. Zhao Lei. Experimental Study on Rational Axial Compression Ratio of Regionally Confined Concrete Cylinders. Master's thesis, Guizhou University, 2021.
6. Chen Yunhao. Experimental Study on the Influence of Confinement Strength on Seismic Performance of Regionally Confined Concrete Shear Walls. Master's thesis, Guizhou University, 2021.
7. Chen Yunhao. "Effect of Axial Compression Ratio on Energy Dissipation Capacity of Regionally Confined Concrete Cylinders." China Water Transport (Second Half) 21, no. 6 (2021): 147-149.
8. Zhao Lei. "Experimental Study on Seismic Performance of Regionally Confined Concrete Cylinders under Different Stirrup Reinforcement Ratios." China Water Transport (Second Half) 21, no. 4 (2021): 161-162.
9. Li Tao. "Application Analysis of Regionally Confined Concrete in a Super High-Rise Building." Shanghai Construction Science and Technology, no. 1 (2025): 66-70.
10. Shang Mao, Li Lifeng, Zhang Xiaozhong, Peng Jing, and Yang Jianlin. "Research on Flexural Performance of Angle Steel-Regionally Confined Concrete Beams." Bulletin of Science and Technology 39, no. 10 (2023): 70-75.
11. Hu Lifeng, Cao Xinming, and Tang Weiduo. "Section Curvature and Ductility Analysis of Regionally Confined Concrete Shear Walls." Building Structure 52, S2 (2022): 968-974.
12. DBJ 52/T082-2016 Regional Confined Concrete Structure Technical Code. Technical standard. Guiyang: Guizhou Provincial Department of Housing and Urban-Rural Development, 2017. Published by China Architecture & Building Press, 2017.
13. Ding Jiajun. Experimental Study on Flexural Performance of Regionally Confined Concrete Beams. Master's thesis, Guizhou University, 2017.
14. Jiang Jitong, Liu Gaoming, and Du Derun. "Calculation and Evaluation of Flexural Performance of Regionally Confined Concrete Beams." Building Structure 50, S1 (2020): 799-803.
15. Zhou Jianying and Cao Xinming. "Stiffness Analysis of Regionally Confined Concrete Beams under Different Reinforcement Configurations." Journal of Guizhou University (Natural Sciences) 33, no. 6 (2016): 93-97.
16. Bo Jie. Experimental Study on Regionally Confined Concrete Beams. Master's thesis, Guizhou University, 2005.
17. Ma Jing. Experimental Study on Shear Performance of Regionally Confined Concrete Beams. Master's thesis, Guizhou University, 2008.

18. Guo Guyue, Cao Xinming, Zhou Jianying, et al. "Experimental Study and Finite Element Analysis on Shear Resistance of Regionally Confined Concrete Beams." Journal of Guizhou University (Natural Sciences) 34, no. 1 (2017): 108-114.
19. GB50010-2010 Code for Design of Concrete Structures. Technical standard. Beijing: Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2011. Published by China Architecture & Building Press, 2011.