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The Unified Calculation Method for Shear Capacity of Reinforced Concrete Flexural Members

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Abstract: Based on the systematic analysis of the shear behavior for reinforced concrete beams, the paper presents an experimental investigation involving 24 reinforced concrete beams subjected to concentrated and uniformly distributed loads. Four main factors are considered, namely shear-span ratio ($\lambda=a/h_0$), span-depth ratio (l_0/h), horizontal and vertical web reinforcement ratio (ρ_{sh} & ρ_{sv}). According to the test results, the working behavior, shear failure modes, the action of concrete compression zone as well as shear (web) reinforcement (including of horizontal and vertical web reinforcement) are further elaborated. Furthermore, the unified calculation method for shear capacity of beams is presented, which can be used to calculate the shear capacity of deep beams, short beams and even normal beams. The proposed formulas' calculation results are in good agreement with the test results.

Key words: reinforced concrete; shear capacity; deep beam; short beam

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Introduction

Reinforced concrete short beams have a wide range of applications in structural engineering, such as pile caps, foundations, bridge girders, and offshore structures, as well as transfer girders in tall buildings.

The current design practice "Design Code for Concrete Structures (GBJ 10-89)"[1] indicated that deep beam was defined as span-depth ratio l_0/h is less than 2 (simply supported deep beam) or 2.5 (continuous span deep beam), normal beam was defined as span-depth ratio l_0/h is more than 5 (i.e. $l_0/h>5$), short beam was defined as span-depth ratio l_0/h is between 2 (or 2.5) and 5 ($l_0/h=2$ (or 2.5) ~5). The shear capacity of deep beams and normal beams can be calculated according to the relevant GBJ 10-89 equations. But there is no formula can be applied to calculate the short beam's shear capacity.

In this paper, the author tested 24 simply supported beams which subjected to the top concentrated load and uniformed distributed load. According to the study of test results, the unified calculation method for shear capacity of reinforced concrete beams was presented, which can be applied to estimate the shear capacity of deep beams, short beams and normal beams.

1 Experimental Program

1.1 Test specimens

The 24 simply supported beam specimens had the same across dimensions of 150 mm × 300 mm, all of them had web reinforcement, 12 specimens of them supported top concentrated loads and the others supported uniformly distributed loads. The relevant properties of the beams are given in Tab.1.

The notation adopted for identification of the beam is as follows. The first letter "s" refers to the short beam. The second letter refers to the type of load, namely, "c" for beams supported concentrated load,

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"u" for beams supported a uniformly distributed load. The third letter denotes horizontal or vertical web reinforcement. The last two numbers are span-depth ratio and shear-depth ratio respectively.

Tab.1 Properties and test results of beam specimens

beam no.	f_{cu}/MPa	ρ_{sv}/%	ρ_{sh}/%	V_{cr}/kN	V_u/kN	failure mode
sch-2-1	24.83	—	0.295	37.9	155.4	DC
scv-2-1	24.67	0.236	—	35.4	160.4	DC
sch-4-2	24.79	—	0.295	33.2	50.7	SC
scv-4-2	25.48	0.236	—	28.2	85.7	SC
sch-5-1.5	26.12	—	0.295	30.9	85.9	SC
scv-5-1.5	32.67	0.236	—	35.93	120.93	SC
sch-5-2.5	27.23		0.295	18.4	53.4	DT
scv-5-2.5	23.78	0.236	—	28.4	73.4	SC
sch-6-3	27.63	—	0.295	33.5	46.0	DT
scv-6-3	28.67	0.236	—	18.5	68.5	SC
schv-5-1	31.66	0.236	0.295	35.9	170.9	DC
schv-5-1.5	23.53	0.236	0.295	36.0	101.0	SC
suh-2	27.72	—	0.295	61.1	316.1	DC
suv-2	26.89	0.236	—	70.9	295.9	DC
suh-3	28.67	—	0.295	68.6	276.1	SC
suv-3	29.16	0.236	—	71.1	306.1	DC
suh-4	32.00	—	0.295	51.3	261.3	SC
suv-4	29.04	0.236	—	66.2	276.2	DC
suh-5	27.01	—	0.295	58.7	156.2	SC
suv-5	25.97	0.236	—	56.2	216.2	SC
suh-6	28.52		0.295	46.6	151.6	SC
suv-6	32.98	0.236	—	31.2	176.2	SC
suh-8	25.88	—	0.295	36.9	81.9	SC
suv-8	27.29	0.236	—	36.9	161.9	FL

Note: f_{cu}=cubic compression strength of concrete; ρ_{sv}, ρ_{sh}=vertical and horizontal stirrup ratio respectively; ρ= 2.92%, longitudinal reinforcement ratio; f_{yv}=f_{yh}=336.9 MPa, the yield strength of web reinforcement; V_{cr}=experimental cracking load; V_u= experimental shear force; DC=diagonal compression failure; SC=shear compression failure; DT=diagonal tensile failure; FL=failure in flexure.

1.2 Test procedure

For the concentrated loading beams, we applied symmetrically two points load on the top surface of beams. For the uniformly distributed loading beams, we applied eight equal loading points on the top surface of beams. For longitudinal reinforcement, strain gages were located at the midspan as well as 1/4 span position. As to web reinforcement, the strain gages were laid out near the line connecting the support and the loading point (concentrated loading beams) or 1/4 span position (uniformly distributed loading beams).

The tests were all started with applying the one-tenth estimated failure load. Meanwhile, the data from the load cells (7∪13), and strain gages were captured and stored in the computer.

2 Test Results and Discussions

Tab.1 shows the failure loads and failure modes. Fig.1 illustrates the relationship between the strains of web reinforcement and the shear capacity of specimens' beams.

2.1 Test phenomena

The first crack to form was always the flexural crack. It started to propagate from the bottom of the beam or at midspan at a load of approximately 15% of the ultimate load. The first inclined crack, in the middle of the shear-span, formed at a load of approximately from 20% to 40% of the ultimate load.

As the load increased, the first diagonal crack would then appear at approximately from 30% to 60% of the ultimate load.

In general, the flexural crack widths tended to stabilize or even reduce slightly after the formation of the diagonal crack. The formation of the diagonal crack was rather sudden. The initial diagonal crack width was at least 0.02 mm when first measured, and it increased rapidly with additional load.

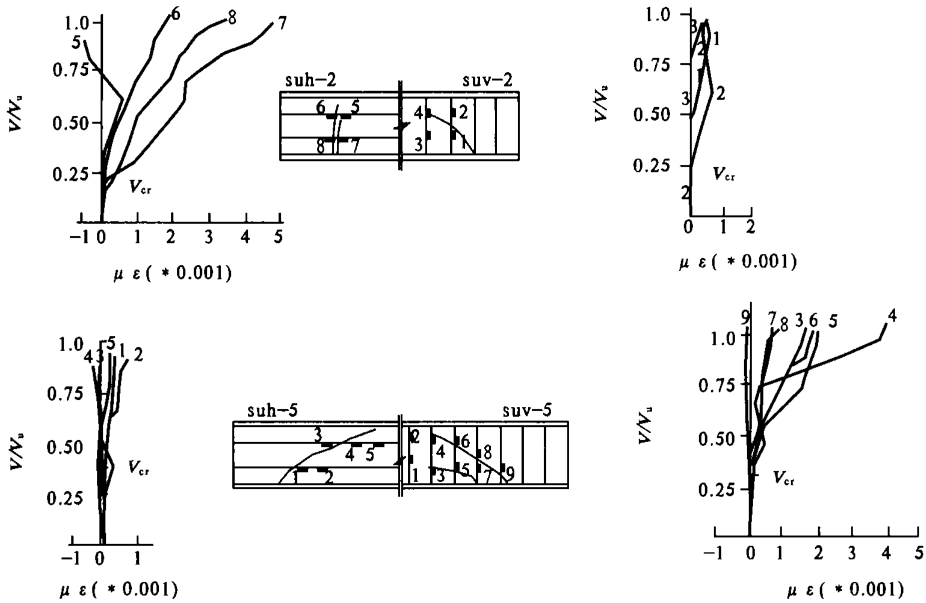

Fig. 1　The relationship between the strains of web reinforcement and the shear capacity of partial specimen beams

In general, the working of test beams experienced three stages from loading to failure. The first is elastic-working stage. The second is working stage with crack and the third is failure stage. The failure modes have to do with shear span-depth ratio and span-depth ratio. The diagonal compression failure usually occurs when shear span-depth ratio is less than 1.0 or span—depth ratio is less than 4. The shear compression failure usually occurs when shear span-depth ratio is between 1 and 3 or span—depth ratio is between 4 and 8.

2.2　Concrete contribution to shear capacity

The shear capacity of concrete compression zone is affected by shear span-depth ratio and span—depth ratio[2].

The shear capacity without web reinforcement beams decreases with the increasing of shear span-depth ratio. Fig. 2 shows the changing tendency of 581 beams collected[3], in which we can see that the changing is not obvious when $\lambda \leqslant 1.0$ or $\lambda \geqslant 3.0$, but the shear capacity decreases largely with the increasing of shear span—depth ratio λ, when λ is between 1.0 and 3.0. As for uniformly distributed loading beams, the shear capacity decreases with the increasing of span-depth ratio (l_0/h).

Fig. 3 illustrates the changing tendency of 201 beams collected[3]. When span-depth ratio is $l_0/h \leqslant 2$ or $l_0/h \geqslant 8$, there is little changing of shear capacity; but $l_0/h = 2 \sim 5$, the changing of shear capacity is quite obvious.

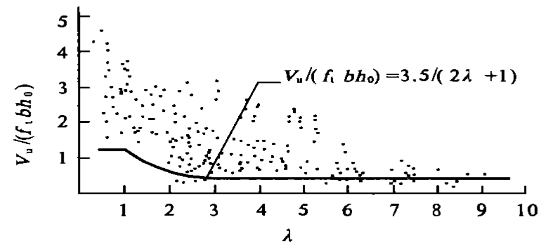

Fig.2　Variation of shear strength with λ

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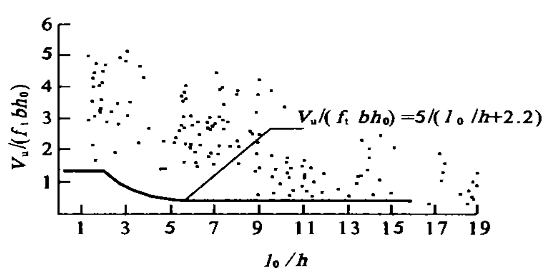

Fig. 3　Variation of shear strength with l_0/h

2.3　Web reinforcement contribution to shear capacity

Fig. 1 shows the curves of shear capacity versus web reinforcement strain of partial beams.

(1) Before diagonal crack occurred, the strains of web reinforcement were very small. For example, the strains of vertical stirrups of suv—2 beam were negative, which indicated the vertical stirrups were com-

pressive working stage. However, the strains of horizontal web reinforcement of suh-2 beam were positive, which illustrated that the horizontal web reinforcement was tension-working stage.

(2) After diagonal crack occurred, both vertical stirrups and horizontal web reinforcement entered tensile working stage gradually with load increasing, and their action was almost same.

(3) When shear span-depth ratio is between 1 and 3 ($1<\lambda<3$) or span-depth ratio is greater than 5 ($l_0/h>5$), the strains of vertical stirrups were greater than that of horizontal web reinforcement, except for the vertical stirrups laid near the loading point or the support. The stress of vertical stirrups across diagonal cracks can reach yielding strength at the ultimate load.

3 Calculation for Shear Capacity

3.1 General principle

As for beams which are reinforced only for flexural tension, the nominal shear capacity is equal to that provided by concrete.

$$V_u = V_c. \tag{1}$$

For a section with web reinforcement, the total nominal shear resistance is the sum of that provided by concrete and that provided by web reinforcement.

$$V_u = V_c + V_{sv} + V_{sh}. \tag{2}$$

Where V_u is ultimate shear capacity; V_c is concrete's contribution; V_{sv} and V_{sh} are the contribution of the vertical and horizontal web reinforcement respectively.

3.2 Proposed calculation method

Based on the above analyses, the following calculation method is proposed.

Concentrated loading beams:

$$V_u = \frac{3.5}{2\lambda+1} f_t b h_0 + \frac{5}{12}\left(\frac{l_0}{h}-2\right) f_{yv} \frac{A_{sv}}{s_h} h_0 + \frac{1}{6}\left(5-\frac{l_0}{h}\right) f_{yh} \frac{A_{sh}}{s_v} h_0. \tag{3}$$

Uniformed loading beams:

$$V_u = \frac{5}{\frac{l_0}{h}+2.2} f_t b h_0 + \frac{5}{12}\left(\frac{l_0}{h}-2\right) f_{yv} \frac{V_{sv}}{s_h} h_0 + \frac{1}{6}\left(5-\frac{l_0}{h}\right) f_{yh} \frac{A_{sh}}{s_v} h_0. \tag{4}$$

Where λ is shear span-depth ratio with a value from 1.0 to 3.0; $\frac{l_0}{h}$ is span-depth ratio with a value from 2.0 to 5.0; f_t is axial tensile strength of concrete; f_{yv}, f_{yh} are yield strength of vertical and horizontal web reinforcement respectively; A_{sv}, A_{sh} is area of vertical and horizontal web reinforcement respectively; S_h, S_v is spacing of vertical and horizontal web reinforcement respectively; b is width of section; h_0 is effective depth of section.

Acknowledgements

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钢筋混凝土受弯构件受剪承载力统一计算

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摘 要:在系统分析钢筋混凝土梁受剪性能的基础上,进行了24根承受集中荷载和均布荷载的钢筋混凝土梁的受剪性能试验,主要考虑的因素有剪跨比($\lambda=a/h_0$)、跨高比(l_0/h)、水平和垂直腹筋配筋率(ρ_{sh}和ρ_{sv}).详细阐述了梁的受剪特性、破坏形态、受压区混凝土的作用以及腹筋的作用(包括水平腹筋和垂直腹筋),并最终提出了钢筋混凝土梁斜截面受剪承载力统一计算方法.该方法可用于计算深梁、短梁及浅梁的斜截面承载力,计算结果与试验结果符合良好.

关键词:钢筋混凝土;受剪承载力;深梁;短梁