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Study on Anchorage Properties of Bundled Bars in Reinforced Concrete Beams

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Abstract: The first part of this paper describes the results of pull-out tests on 31 pieces of concrete specimens with bundled steel bars embedded. Based on the initial pull-out test results, a series of R.C. beam specimens that had been reinforced with bundled longitudinal steel bars were prepared and tested. The bond-anchorage characteristics and the major factors affecting the bond-anchorage properties of bundled steel bars in a R.C. beam, with comparisons to beams reinforced in the regular way, are discussed in detail. Formulas for calculating the required anchorage length of bundled steel bars are proposed. Calculated results from the proposed formulas agree well with the test results, and the design method of using bundled steel bars in beams is proposed. This proposal can be used as a reference for future revision of the Chinese Design Code.

Key words: bundled bars; anchorage properties; anchorage length

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Introduction

It is specified in the current Chinese Design Code and Chinese Construction Code for concrete structures that the longitudinal steel bars in concrete should be arranged singly and there should be sufficient spacing between these bars. In a heavily reinforced R.C. beam, the longitudinal steel bars may need to be placed in 2 or more rows according to the above specification. This may be difficult to accomplish in practice due to insufficient space in the beam. The bundled-bar method is a feasible way of solving the practical problem of insufficient spacing between longitudinal steel bars in a heavily reinforced R.C. beam. The anchorage strength of bundled bars in concrete is lower than the anchorage strength of singly placed bars in concrete. The required anchorage length of bundled bars in concrete should be increased appropriately.

1 Pull-out tests on specimens with bundled bars in concrete

1.1 Test specimens

In order to find out the bond-anchorage characteristics and the major factors affecting the bond-anchorage properties of bundled steel bars in concrete, pull-out tests were performed on 31 specimens. These specimens were cast with either a single bar or a bundle of bars in concrete. The test specimens are illustrated in Fig.1. Among the test specimens, 8 were cast with one single steel bar in each, 14 specimens were cast with a 2-bar bundle, and 9 specimens were cast with a 3-bar bundle. Details of the specimens are shown in Table 1.

1.2 Bond-anchorage characteristics of bundled steel bars in concrete

The results of pull-out tests on the specimens have indicated that the average bond-anchorage strength decreases with the increasing number of steel bars in a bundle. However, the characteristics of bond-slip is similar to those of the single-steel-bar specimens. The average bond-anchorage strength along the anchorage length may be expressed as

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Table 1 Pull - out test specimens

Specimen no.	Number of specimens	Number of embedded bars	Concrete cube strength range/MPa	Anchorage length range/mm
BA 1 ~ 3	8	1Φ12	21.6 ~ 31.1	80 ~ 200
BB 1 ~ 5	14	2Φ12	23.0 ~ 39.0	80 ~ 200
BB 1 ~ 3	9	3Φ12	23.5 ~ 31.3	80 ~ 250

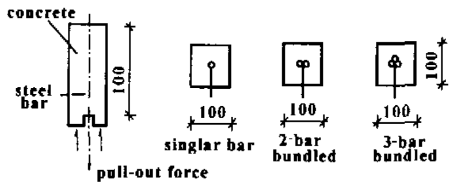


Fig.1 Test specimens

$$\tau = \frac{F}{l_a \cdot \sum \pi d}, \tag{1}$$

where τ is the average bond - anchorage strength along the anchorage length l_a, d is the diameter of the steel bars and F is the pull - out force. When the pull - out force F is increased to the maximum value F_u (i.e. when failure in the bond - anchorage occurs), the average bond - anchorage strength becomes the ultimate average bond - anchorage strength τ_u

$$\tau_u = \frac{F_u}{l_a \cdot \sum \pi d}. \tag{2}$$

Fig.2 shows the curves of bond - slip for three different specimens. Of these three specimens, one was cast with a single bar, the second one was with a 2 - bar bundle and the third one was with a 3 - bar bundle. It can be seen that the ultimate average bond - anchorage strength τ_u decreases with the increasing number of steel bars in a bundle. This is because the effective bond areas in the specimens with bundled steel bars are less than the total surface areas of the same number of singly placed steel bars acting together. The effective bonding surfaces for a 2 - bar bundle and a 3 - bar bundle are shown in Fig.3.

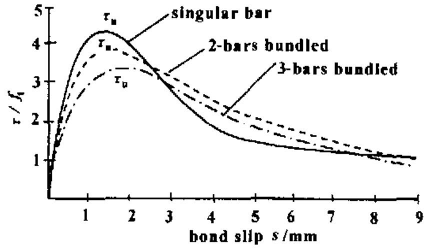


Fig.2 Curves of bond - slip

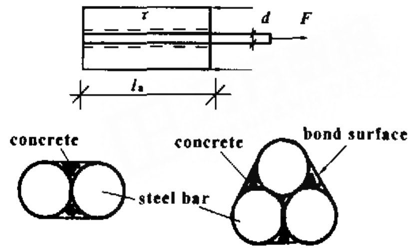


Fig.3 Effective bond surfaces of bundled steel bars

Statistical analysis of the results of pull - out tests (including other test results[2]) indicates that the ratio of the ultimate average bond - anchorage strengths for specimens with a single bar to specimens with a 2 - bar bundle and to specimens with a 3 - bar bundle is in the order of 1:0.719:0.562. This ratio may be expressed approximately as $1:1/\sqrt{2}:1/\sqrt{3} \approx 1:0.707:0.577$.

2 Anchorage properties of bundled steel bars in R.C. beams

2.1 Laboratory tests

In order to study the anchorage properties of R. C. beams reinforced with bundled steel bars, 18 beams were designed, cast and tested. Of the 18 beams tested, 12 were cast with 2 - bar bundles, 4 were cast with 3 - bar bundles and 2 were cast with singly placed bars. The arrangement of the set up for the tests is shown in Fig. 4 and the test results are shown in Table 2.

2.2 Bond - anchorage characteristics of R. C. beams

Fig.5 shows the test results of τ/f_t against the bond - slips for the beams with singly placed bars, with 2 - bar bundles and with 3 - bar bundles. The anchorage lengths are almost the same. It can be seen that the ultimate average bond - anchorage strength of the beam using singly placed bars is the highest. The beam with 2 - bar bundles is in the middle, and the beam with 3 - bar bundles is the lowest. The ultimate average bond - anchorage strength decreases with an increase in the number of bars in a bundle. The results obtained are similar to those obtained in the pull - out tests.

Table 2　Test results of beams using bundled bars

Specimen no.	f_{cu}/MPa	f_t/MPa	b/mm	h/mm	l_a/mm	Longitudinal steel bars	M_u/(kN·m)
BLⅡ 1 - 1	23.75	2.15	257	305	680	2Φ12×2	58.89
BLⅡ 1 - 2	23.75	2.15	232	301	480	2Φ12×2	37.74
BLⅡ 1 - 3	23.75	2.15	240	305	390	2Φ12×2	46.50
BLⅡ 1 - 4	23.75	2.15	224	307	280	2Φ12×2	24.85
BLⅡ 2 - 1	36.73	2.87	230	303	480	2Φ12×2	61.05
BLⅡ 2 - 2	36.73	2.87	210	303	390	2Φ12×2	39.53
BLⅡ 2 - 3	36.73	2.87	220	305	310	2Φ12×2	61.60
BLⅡ 2 - 4	36.73	2.87	187	305	210	2Φ12×2	22.20
BLⅡ 3 - 1	51.78	3.61	213	303	440	2Φ12×2	39.66
BLⅡ 3 - 2	51.78	3.61	204	303	310	2Φ12×2	42.35
BLⅡ 3 - 3	51.78	3.61	220	303	240	2Φ12×2	88.20
BLⅡ 3 - 4	51.78	3.61	205	303	180	2Φ12×2	38.25
BLⅢ 1 - 1	52.33	3.64	230	308	620	3Φ12×2	100.78
BLⅢ 1 - 2	52.33	3.64	222	301	510	3Φ12×2	76.05
BLⅢ 1 - 3	52.33	3.64	207	301	340	3Φ12×2	43.58
BLⅢ 1 - 4	52.33	3.64	212	308	210	3Φ12×2	32.49
DL 1 - 1	32.0	2.62	230	300	380	4Φ12	36.40
DL 1 - 2	32.0	2.62	220	299	280	4Φ12	94.55

Notes: ① f_{cu} is the cube strength of concrete, f_t is the tensile strength of concrete. ② Yield strength of longitudinal bars is 393.5 MPa. ③ M_u is the test value of the ultimate moment at failure.

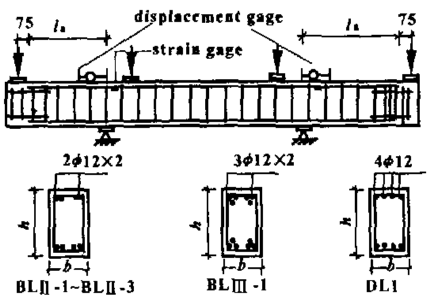


Fig.4　Arrangement of the set up for testing beams with bundled bars

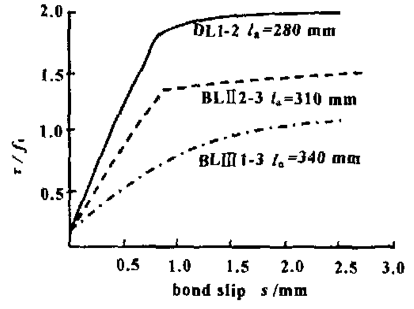


Fig.5　Curves of τ/f_t against bond - slip

Fig.6 shows the relationship between the stress in the longitudinal steel bars σ_s and the bond - slip s for 3 beams cast with 2 - bar bundles of different anchorage length. It can be seen that when the anchorage length is insufficient (BLⅡ 1 - 3, BLⅡ 1 - 4), the stress in the longitudinal bars is low and will not reach yielding. The ultimate moment is less than the flexural bearing capacity of the beam. The mode of failure is the bond - anchorage failure (Fig.7(a)).

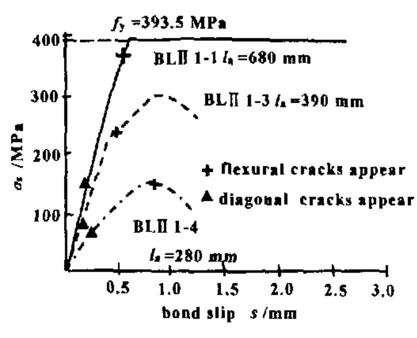
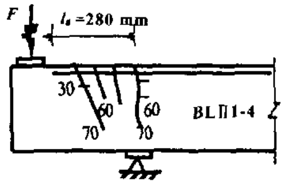
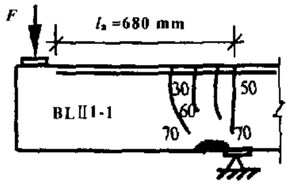


Fig.6　Curves of σ_t against bond - slip

When the anchorage length is sufficient (BLⅡ 1 - 1), the stress in the longitudinal bars is higher and the bars may yield. The ultimate moment is about the same as the calculated flexural bearing capacity of the beam. The mode of failure is of the flexural type(Fig,7(b)). It can, therefore, be deduced that by increasing the anchorage length of the bundled steel bars, the strength



(a) bond anchorage failure



(b) flexral failure

Fig.7 Modes of failure

of the anchorage and the bearing capacity of the beam can be ensured.

3 Design anchorage length of bundled bars in R.C. beams

The design anchorage length l_d of a steel bar in a R.C. beam is the minimum required length to ensure that anchorage failure will not occur before the stress in the longitudinal steel bars reaches the yield point. In beams with the longitudinal steel bars normally placed, the design anchorage length l_d is expressed as

$$l_d = \alpha \frac{f_y}{4\tau_u} d \ , \qquad (3)$$

where f_y is the tensile yielding strength of the longitudinal steel bars, τ_u is the ultimate average bond - anchorage strength (which varies with the tensile strength of the concrete), and α is a coefficient. In the current Chinese Design Code, the design anchorage lengths l_d for deformed steel bars (Ⅱ grade f_y = 310 MPa) are shown in Table 3.

Table 3 Design anchorage length
(for steel of Ⅱ grade f_y = 310 MPa)

Cube strength of concrete/MPa	15	20	25	30	40	50
l_d	$50d$	$40d$	$35d$	$30d$	$30d$	$25d$

In beams using bundled steel bars, the ultimate average bond - anchorage strength τ_u is less than that in the beams with the steel bars singly placed. The ratio of the ultimate average bond - anchorage strength for the beams with singly placed bars to that for the beams with 2 - bar bundles and to that for the beams with 3 - bar bundle may be taken to be $1:1/\sqrt{2}:1/\sqrt{3}$. Using formula (3), the design anchorage length for bundled steel bars may be expressed as

$$l_{d2} = (\sqrt{2})l_d \qquad (4)$$

and

$$l_{d3} = (\sqrt{3}l_d) \ , \qquad (5)$$

where l_{d2} and l_{d3} are the design anchorage length for bundled bars in beams with 2 - bar bundles and with 3 - bar bundles respectively.

Fig.8 shows the relationship between the flexural bearing capacity ratio M_u^t/M_u^c and the anchorage length l_d of bundled bars. M_u^t is the test value of the ultimate moment of the beams and M_u^c is the calculated ultimate moment by the formulas in the Chinese Design Code. When $M_u^t/M_u^c < 1$, the failure of the beam occurs in the bond - anchorage failure mode due to insufficient anchorage length of the bars. $M_u^t/M_u^c > 1$, the failure of the beam occurs in the flexural failure mode and the anchorage length provided is sufficient.

It can be deduced that if the design anchorage length of the bundled bars in a beam is sufficient, the strength of the anchorage and bearing capacity of the beams can be assured. Formulas (4) and (5) may be used as a reference for future revision of the Chinese Design Code.

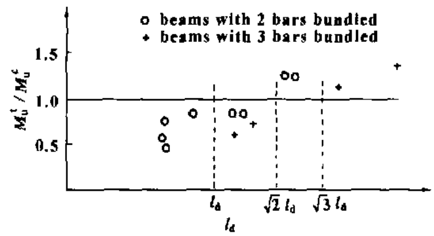


Fig.8 Design anchorage length of beams using bundled bars

4 Conclusion

The test result of pull - out concrete specimens and beams with a single bar and with 2 - bar bundle and 3 - bar bundle indicate that the ultimate bond - anchorage strength decreases with the increasing number of steel bars in a bundle. The ration may be expressed approximately as $1:1/\sqrt{2}:1/\sqrt{3}$. Increasing the required anchorage length of bundled steel bars in concrete beam. The anchorage and bearing capacity of the beams can be ensured.

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[1] GBJ 10 - 89, Chinese Design Code for Concrete Structures

[S].

[2] XU You - lin. Experimental studies on bond - anchorage and overlapped splice of deformed bars in concrete[J]. Proceeding of Concrete Structure, 1994(3):147 - 177.

钢筋混凝土并筋梁的粘结锚固及受力性能研究

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摘　要：为解决工程实践中当混凝土结构内钢筋用量较大时钢筋间距过小的问题,提出了将纵向受力钢筋并筋布置的方法.根据31个并筋粘结锚固拉拔试件验的结果,进行了17根钢筋混凝土并筋梁的受力性能试验,较详细地讨论了并筋梁粘结锚固的特点以及影响并筋粘结锚固的主要因素,并与一般梁进行了对比.试验研究结果表明,采用并筋后钢筋和混凝土之间的粘结锚固性能有所下降,但粘结滑移特性与一般梁相近,通过适当延长锚固长度即可保证并筋梁的锚固强度和承载力,从而使并筋梁可在工程实践中应用.给出了并筋锚固长度计算的建议公式,计算结果与试验结果符合良好.在可靠度分析的基础上提出了并筋梁的设计建议,可供我国混凝土结构设计规范修订时参考.

关键词：并筋；粘结锚固；锚固长度

河南省教育史上最大工程——郑州大学新校区破土动工

省委书记陈奎元、省长李克强参加了奠基仪式

8月28日上午,郑州国家新技术产业开发区彩旗飘扬,锣鼓喧天,一派节日气氛.我省教育史上最大的工程——郑州大学校区开工奠基仪式在这里隆重举行.我校师生与省市领导及中原区人民一起感受了这激动人心的历史性时刻.

去年7月10日,新郑州大学组建成立.为适应郑大发展的需要,省政府决定在高新技术产业开发区征地4200亩建设新校区,并将该工程列入河南省"十·五"规划重点工程.近一年来,李克强、范钦臣、王全书、张洪华、贾连朝、陈义初等省市领导多次于新校区现场办公,协调解决征地的有关问题.

郑大新校区位于高新技术产业开发区石佛镇沟赵乡,投资19亿.据负责新校区建设的邢莹副校长介绍,新校区设计规模为本专科生40000人,研究生2500人,工程建设周期5年,首批学生将于2002年9月进人新校区.

省市领导陈奎元、李克强、李成玉、王全书、李柏栓、李克、袁祖亮、张洪华、贾连朝、陈义初等出席奠基仪式.出席仪式的还有省直有关部门以及省内部分高校领导.

仪式由常务副校长申长雨主持.校党委书记蒋笃运代表学校向为郑州大学建设和发展倾注了大量心血、做出了巨大贡献的省市领导有关部门及新校区所在地群众致以感谢,并表示一定坚持面向现代化、面向世界、面向未来的原则,把郑州大学新校区建成河南高等教育的形象工程、精品工程和经典工程,以只争朝夕、求真务实、开拓创新的精神努力工作,使学校早日进人全国重点大学行列,为河南经济腾飞和社会进步做出贡献.

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