SUGGESTIONS ON THE REINFORCEMENT DETAILING OF REINFORCED CONCRETE BLOCK MASONRY

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ABSTRACT

This paper is an investigation of reinforceing anchorage and lap length in mortar joints, grout cells and bond beam, based on the specifications of Code for Design of Masonry Structures (Enquiry Document). The bar detailing of reinforced concrete masonry is summarized and analysed. Testing data are provided for compiling codes and improving suggestions of reinforcement detailing are presented.

Key words: reinforced concrete masonry, mortar joint, grout cells, bond beam, reinforcement detailing

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INTRODUCTION

Reinforced masonry structure is a newly popular structural system now actively used in China. Compared to reinforced concrete structure, reinforced masonry structure is more complicated, requiring an understanding of material choice, material properties, structural detailing and construction technology. Based on the theoretic analysis and testing, the technology and material relating to reinforced masonry has been established in recent years. However, bar anchorage and lap length provided in the Code for Design Masonry Structures (Enquiry Document), hereinafter called the "Code", is not only conservative and arbitrary, but also lacking of test data. In order to make the code reliable, experimentation on the bar anchorage and lap length in the bed joints, grout cells and bond beam was carried out. Finally, the code requirement on the anchorage and lap length was modified and reasonable suggestions are presented in the paper.

TESTING OUTLINE

Specimen

Based on the feedback opinion and the provision presented in the code, the bar anchorage and lap length is very conservative, and there was not adequate testing data available. More than 71 group pullout specimens were tested and the anchorage and lap behavior of reinforcement in bed joints, grouted cells and bond beams was investigated. Detailed explanation follows:

The specimens of bar anchorage in bed joints were divided into two series. Series1 included 11 group specimens (ungrouted cells). The bars were embedded horizontally in the bed joint, and embedded fully in mortar. The bar anchorage length had a hook with a 90-degree bent plus an extension at the free end of the bar. Series 2 included 13 group specimens (grouted cells). The bars were embedded horizontally in the bed joint, and the hook was embedded in mortar and grout or in vertical grout cells. The bar anchorage length was designed at 325mm, 390mm for ungrouted cells, 260mm, 325mm for grouted cells and the hook length was 130mm and 195mm, respectively. The joint reinforcement diameter is 6.5mm for grade HRB235, 4mm for cold-rolled-deformed bar. The mortar was grade M10, M15, M20 and M25, respectively. The compressive stress normal to bed joint was applied, which was 0.1MPa, 0.5Mpa, 0.76Mpa, 1.0Mpa, 1.5Mpa and 2.0Mpa.

27 group specimens of bar anchorage in grouted cells were tested, which included 9 group bar anchorage specimens and 18 group bar lap specimens. The deformed bar was grade HRB335 and HRB400. The bars, which were used in the design as principal reinforcement in hollow concrete masonry unit construction, should be long enough for anchorage and lap. The anchorage specimens, where the bars were embedded in grouted cells, were tested considering the effect of the bars diameter, anchorage length and loading mode. The bar diameter was 14mm, 16mm, 18mm and 20mm, respectively. The anchorage length was 40, 35, 30 bar diameters, respectively. The grout grade ranged from grade C25 to C40. For the lap specimens, the effect of several parameters was investigated, which included the bars diameter, lap length and lap mode. For the bar lap splice, there are two lap modes, contact lap

and noncontact lap. The contact lap length was 44, 39, 34and 29 bar diameters, respectively. The lap length was 48,43 bar diameters for the space 75mm and 44, 39 bar diameters for the space 150mm. The range of the bar diameters and the grout grade was the same as that of the grouted cells anchorage specimens.

20 group bond beam specimens were tested, which included 14 group bar anchorage specimens and 6 group bar lap specimens. The grout was grade DY-5series. The bar lap specimens were designed considering the effect of bar diameter and lap length. The bar diameter was 12mm and 14mm. The lap length was 50, 40, 35 and 30 bar diameters, respectively. The grout ranged from grade C20 to C40. The bar anchorage specimens were designed considering the effect of diameter, anchorage length and anchorage mode. Two anchorage modes were adopted. One mode is that the anchorage length with a 90-degree bent hook plus an extension was embedded in bond beam at the free end of the bar. The second mode used grouted cells. The anchorage length was 45, 40, 35, 30 and 25 bar diameters, respectively. The hook length was 35, 30, 25, 20 and 15 bar diameters, respectively. The range of the bar diameter and grout grades was the same as those of the grouted cells anchorage specimens.

Properties of material

The hollow concrete masonry unit was grade MU10. The grout was grade DY-5 series. The mortar was grade DY-4 series. The bar was grade HRB235, HRB335, HRB400 and cold-rolled bar, respectively. The properties were measured by testing the standard specimens, specifically yet concurrently, and the details of the reinforcement properties are given in Table 1.

Table1. Practical Mechanical Criterion of Reinforcement

Grade	Diameter mm	Section area mm^2	Yield strength f_y N/mm^2	Ultimate strength f_u N/mm^2	Modulus of elasticity E_S N/mm^2	Ductile ratio %
Cold-rolled 650	4.0	12.60	822.0	1127.0	2.79×10^5	
HRB235	6.5	33.20	300.4	417.8	2.13×10^5	22.3
HRB335	1 2	113.1	423.5	658.7	2.00×10^5	31.0
HRB335	1 4	153.9	389.2	573.7	1.92×10^5	32.1
HRB335	1 6	201.1	400.3	579.3	1.97×10^5	31.3
HRB400	1 8	254.5	463.7	730.8	1.79×10^5	22.2
HRB335	2 0	314.2	397.8	614.3	2.04×10^5	29.5

Test setup and procedure

The pullout load was measured by a BLR-1 type mechanical sensor, and the displacement was measured by a 300mm displacement sensor.

All testing was monitored using an UCAM-70A data recorder and acquisition system. During the testing course, the pullout bar was fixed, and loaded evenly using a hydraulic pressure jack. The load-deflection curve was drawn and recorded by the UCAM-70A.

FAILURE COURSE AND TESTING RESULT ANALYSIS

Joint reinforcement anchorage in mortar

The load-deflection curve of the pullout bar is shown in figure 1. The curve of the bar is similar to the bar stress-strain curve. As the load increased, the bar arrived at yielding strength and the curve reached the level stage. Upon further loading, the bar came into the harden stage. Subsequently, the slippage between the bar and mortar took place at the bar loading end and the mortar surface brought about cracking. When the bar slippage of the loading end reached approximately made 36mm, the load decreased abruptly. As well, the bar loading end lost bond strength and brought about bond failure. Then the hook began to bear load. If the load increased continually, the curve began to rise again. The bar strength exceeded yield strength again and reached the hardened stage, but did not reach ultimate strength. The bar hook (free end) began to slip and bond strength was lost completely. All specimens did not have any obvious yielding point. During the whole testing process, the loading end did not show any obvious slippage. The phenomenon of failure indicated that the bar stretched in the axis of tension and finally snapped in two.

The strength curve of the ungrouted specimen when subjected to crossing-stress is shown in figure 2, this indicated that the influence of the bar yielding strength subjected to crossing-stress was not obvious. The failure strength increased as the crossing-stress became greater and the failure strength ranged between the bar yielding strength and the ultimate strength.

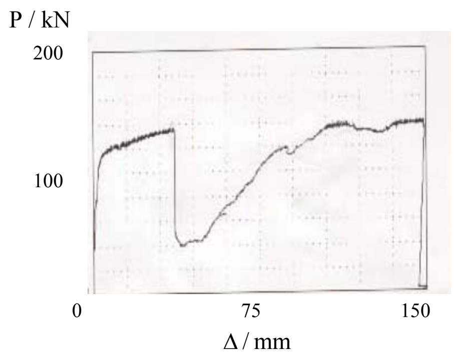

Fig.1Strain-stress curve of the specimen HF5

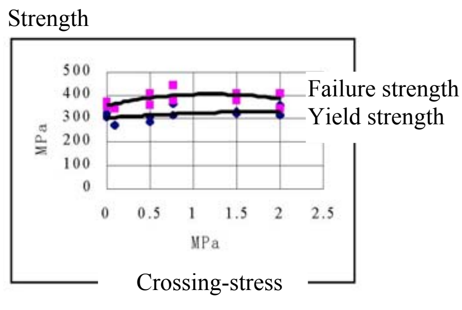

Fig.2 Influence curve of bar anchorage strength subjected to crossing-stress

Joint reinforcement anchorage in grouted masonry

The bed joint reinforcement was a bar free end bent to 90 degrees, plus an extension embedded in the mortar and grout of bed joint. The vertical joint reinforcement was a bar free end bent to 90 degrees, plus an extension embedded in the grouted cells. The load-deflection curve of a typical specimen HF21 is shown in figure 3, this indicated that the loading-deflection curve is similar to the bar stress-strain curve. The slippage between the bar and mortar did not occur at the bar loading end before the bar yielded. The grout surface did not lead to obvious cracking. As loading increased, and the bar reached hardened stage, bar deflection increased quickly. Slipping occurred at the bar loading end, and the mortar surface cracked. During the whole testing course, slippage did not occur in the free end (hook part). The phenomenon of failure indicated that the bar stretched in the axis of tension and finally snapped in two, not leading to bond failure and the bar reached ultimate strength.

The strength curve of the grouted specimen subjected to crossing-stress is shown in figure 4, showing that the yielding strength and ultimate strength of the bar changed.

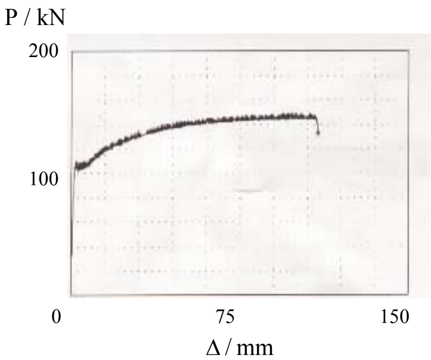

Fig.3 Strain-stress curve of the specimen HF5

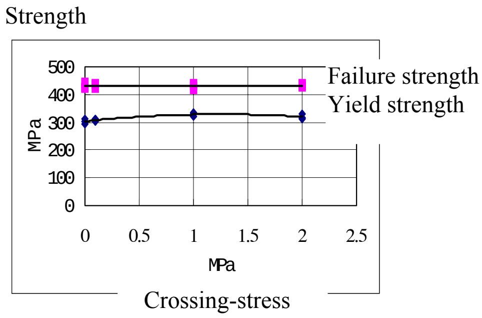

Fig.4 Influence curve of bar anchorage strength subjected to crossing-stress

Bar anchorage in grouted cells

During the testing course, the loading-deflection curve of the grouted specimen is similar to the bar stress-strain curve. Obvious slippage and cracking did not occur between the bar loading end and the grouted concrete. When the bar reached hardened stage, the top surface of the concrete gradually cracked as bar deflection increased. The bar free end did not lead to slippage and bond failure did not occur. Individual specimen tests were terminated because the local pressure of the masonry strength was insufficient, but the failure strength of all grouted specimens reached yielding strength.

Bar contact and noncontact lap in grouted cells

The testing result showed that the curve of the contact lap specimen was similar to the bar stress-strain curve. During the testing course, at the joint between masonry and the fixed base cracking occurred when the load reached 60 percent of the ultimate strength. When the specimen failed, the width of crack ranged from 50mm to 70mm. The bar loading end did not slip before the bar yielded. Only when the bar reached hardened stage did the concrete fail. When these specimens failed, all bars reached yielding strength and most of reached ultimate strength, as well.

With the noncontact specimens, the bar load-deflection curve was similar to the bar stress-strain curve at the initial stage. The intersection of the masonry and the fixed base cracked when the load reached 60 percent of the ultimate strength. When the specimen failed, the range of cracking was from 70mm to 100mm. Due to the eccentricity and increase of deflection, the noncontact bar specimen, whose space is 75mm, inclined so as to lose the capacity of bearing. When the noncontact lap bars, whose space was150mm, failed, the specimen inclined much greater than those whose space was 75mm, and failure occurred abruptly. The test results showed that all the pullout bars reached yielding strength, and the specimens did not lead to bond failure after the bars exceeded yielding strength.

Bar anchorage in bond beam

The load-deflection curves of all specimens were similar to the bar stress-strain curve. During the testing course, obvious slipping did not arise between the bar and concrete. Only when the bar reached hardened stage did slippage occur and the concrete was failed and all bars reached ultimate strength. In addition, the slippage at the free end (hook part) did not occur, and then the specimens did not lead to bond failure. The results of failure also indicated that the bar stretched in the axis of tension and finally snapped in two and all bars reached ultimate strength.

Bar lap splice in bond beam

During the testing course, the load-deflection curve of two bars contacting each other was drawn, respectively. At the initial loading stage, both the curves were similar. As the load increased, especially when the bar reached hardened stage, the two curves showed some difference. One bar deflection increased faster than the other and the bar, which deflected faster, stretched in the axis of tension and finally snapped in two.

During the loading course, when the bars of all specimens reached hardened stage, slippage occurred between the two loading ends of the bars and grout. Finally, the phenomenon of failure indicated that the bar stretched in the axis of tension and finally snapped in two and the specimen did not lead to bond failure. Due to fixture failure or bad construction quality, several tests were not completed, but the failure strength of all specimens exceeded bar yielding strength.

DETERMINATION OF ANCHORAGE AND LAP LENGTH

In engineering design and practice the bar anchorage and lap length of reinforced masonry in the mortar joint, grouted cells and bond beam is very important. The anchorage length must be sufficient enough to insure no bar failure. At the same time, the bar lap splice must have enough length. This is necessary to transfer the inside force between bars through bond stress so that the bar strength can be exerted fully. In consideration of safety factors, the pullout bar yielding strength is used to determine the ultimate anchorage length, in this paper, and that the strength increase is used to assure safety under the condition of quick slippage at a later stage. Based on the test results, the anchorage and lap length is determined as follows:

Joint reinforcement anchorage length for ungrouted masonry

Article 8.4.5 of the Code described that the bar anchorage length is 70 bar diameters. For this test, the bar diameter is 6mm and the anchorage length is 325mm and 390mm (equivalent to 50d and 60d), whose hook length is 130mm and 195mm, respectively. The testing data showed that all specimens failed after the pullout bars yielded. Hence, an allowable minimum anchorage length in mortar joint is 50 bar diameters, and the hook length be not less than 20 diameters or 150mm.

Joint reinforcement anchorage length for grouted masonry

There are two-anchorage modes, bed anchorage and vertical anchorage. The bed joint reinforcement was a bar free end bent at 90 degrees and the bar was embedded in mortar. The vertical joint reinforcement was a bar free end bent at 90 degrees and the bar was embedded in the grouted cells. In the test, the bars anchorage length was 260mm and 325mm, which was equivalent to 40 bar diameters and 50 bar diameters, whose hook length was 130mm and 195mm, respectively. The testing data showed that all the specimens failed after the bars yielded. Hence, an allowable minimum anchorage length of both the anchorage modes should be 40 bar diameters, and that the hook length is not less than 20 bar diameters or 150mm.

Joint reinforcement anchorage length for cold-rolled bars ($d \leqslant 5mm$)

For the test, two types of anchorage lengths were used 260mm and 325mm, respectively. The testing results showed that all pullout bars of the specimens were stretched in the axis of tension and finally snapped in two after those reaching ultimate strength. Considering the higher strength of bars and the influence of construction quality, the anchorage length shows unfavorable results when shorter. Hence, an allowable minimum anchorage length is 300mm, and that the hook length is not less than 150mm.

Bar anchorage length l_a for grouted masonry

The bar anchorage length for grade HRB335 should be no less than 40 bar diameters. For grade HRB400 and RRB400 should be no less than 45 bar diameters, which is prescribed in Article 8.4.3 of the Code. Based on the testing result, when the bar anchorage length is 40 bar diameters, the bars of diameter 14 and 16 were stretched in the axis of tension and finally snapped in two. All specimens' bars reached ultimate strength, and the specimens did not lead to bond failure. Similarly, the bars whose anchorage length is 35 bar diameters and 30 bar diameters reached ultimate strength and the specimens did not lead to bond failure. Hence, an allowable minimum anchorage length in grouted masonry is 30 bar diameters, which is the same as that prescribed in Code for Design of Concrete Structures (GBJ10-89) under the condition of grade Ⅱ bar and concrete over grade C30.

Bar contact and noncontact lap length l_a

Based on Article 8.4.4 of the Code, the contact bar lap length is $1.1l_a$, which is equivalent to 44 diameters (HRB335). Using bars ranging from 25 diameters to 44 diameters, all pullout bars reached yielding strength most of which reached ultimate strength. Hence, taking into account safety factors and by averaging the bar diameter length specimens, we arrived at an allowable minimum lap length is 35 bar diameters (equivalent to l_a+$5d$).

Based on Article 8.4.4 of the Code, the noncontact bar lap length is $1.2l_a$, which is equivalent to 48 bar diameters for grade HRB335. The space of two bars is 75mm and 150mm, respectively. The lap length is 48, 43 bar diameters for 75mm, and the lap length is 44, 39 bar diameters for 150mm. The testing result showed that all pullout bars reached yielding strength. Hence, an allowable minimum lap length is 40 bar diameters (equivalent to l_a+$10d$), and the space of the bars, which is more than 150mm, should not be adopted.

Bar anchorage and lap length in bond beam

The testing anchorage length was 25, 30, 35, 40 and 45 bar diameters, respectively and the hook length was 15, 20, 25, 30 and 35 bar diameters. The testing result showed that some individual specimens, which did not reach ultimate strength, failed because the top surface of the masonry block was sheared or due to the fixture failure. Others failed when the bars reached ultimate strength and then did not lead to bond failure. Hence, an allowable minimum anchorage length should be 30 bar diameters, and that the hook length is not less than 15 bar diameters or 200mm.

Based on Article 8.4.5 of the Code, the bar lap length in bond beams is 50 bar diameters. The testing anchorage length was 25, 30, 35, 40, 45 and 50 bar diameters, respectively. All the pullout bars of the specimens reached yielding strength. Several specimens failed because the top surface of the masonry unit was sheared or the fixture failed. The others failed when the bars reached ultimate strength and did not lead to bond failure. Hence, an allowable minimum anchorage length is 35 bar diameters (equivalent to l_a+$5\ d$).

SUGGESTIONS FOR BAR ANCHORAGE AND LAP LENGTH

Based on theoretical analysis and test results, suggestions for the bar anchorage and lap length in reinforced masonry are as follows:

1. For ungrouted masonry, joint reinforcement shall be fully embedded in mortar. The anchorage length of the joint reinforcement shall be 50 bar diameters and have a hook with a 90-degree bent, plus an extension of not less than 20 diameters or 150mm.
2. For grouted masonry, joint reinforcement shall be fully embedded in mortar, grout or both. The anchorage length shall be 40 bar diameters and have a hook with a 90-degree bent, plus an extension of not less than 20 diameters or 150mm.
3. For smaller diameter cold-rolled bar, the anchorage length shall be 300mm and have a hook with a 90-degree bent, plus an extension of not less than 150mm.
4. For grouted cells, the bar anchorage length shall be 30 bar diameters, the bar lap length shall be 35 bar diameters (l_a+$5d$) for contact lap, 40 bar diameters (l_a+$10d$) for noncontact lap and the bar space should not exceed 75mm.
5. For bond beam, the bar anchorage length shall be 30 bar diameters and have a hook with a 90-degree bent, plus an extension of not less than 15 diameters or 200mm. The bar

lap length shall be 35 bar diameters.

To sum up, the anchorage and lap length should be decreased from *5d* to *20d* compared to the length prescribed in the Code. The length of anchorage and splice is greater than the required development length of the bars. It is desirable that a splice shall be capable of developing the ultimate strength but practical limitation makes this ideal condition difficult to attain. In this paper, the length of anchorage or lap, based upon yield strength of the pullout bar, is to insure safety in a splice so that bond failure can be avoided.

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