Experimental Research on Anchoring Performance of Chemical Anchor Bolt in Building Curtain Wall Engineering

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Abstract. To study the anchoring performance of chemical anchor bolts in building curtain wall, anchoring performance affected by chemical anchoring in concrete grade and anchor bolt diameter were considered. Based on the existing code, 48 standard specimens were made. After analysing the drawing force and the load-displacement curve, the results revealed that when the concrete strength grades are the same, the drawing force of specimen increases while the increasing of chemical anchor bolt diameter; when the chemical anchor bolts have the same diameter, the drawing force of each specimen increases while the increasing of the concrete strength grades; when the concrete strength grade is C40 and the chemical anchor bolt diameter is M14, the concrete splitting damage degree of specimen is the weakest.

Keywords. Building curtain wall engineering, chemical anchor bolt, anchoring performance, drawing capacity, splitting damage.

1. Introduction
The building curtain wall consists of supporting structures and panels, which can be used for the external wall envelope of the building. In recent years, building curtain walls have been widely used in housing construction due to their beauty, energy saving and easy maintenance. During seismic events [1, 2], the building curtain wall is damaged in varying degrees. Therefore, researching its mechanical property becomes very important [3]. The force of the curtain wall is transmitted to the anchor bolt through the keel, and finally to the main structure through the anchor bolt [4]. Compared with traditional embedded anchors, chemical anchors have the advantages of flexible design, convenient construction, economical and reasonable reality, and adapting to engineering changes [5], so they have been widely used in engineering practice.

Scholars from home and abroad have carried out experimental research and theoretical research on chemical anchoring properties. Xiong et al. [6] uses three burial depths of 10d, 15d, and 20d to study the effect of anchoring depth on the pullout force of the planting bar. The conclusion is that specimens with a steel reinforcement depth of 10d often suffered concrete cone failure; Specimens with a steel reinforcement depth of 15d often suffered mixed failure; Specimens with steel reinforcement depth of 20d often suffered tensile yield of reinforcement. He et al. [7] uses a double-reinforcement pull test to study the effects of anchoring depth and steel bar spacing on anchoring performance. The conclusion is that when the bar spacing is bigger than 20 cm. Unaffected between anchor bars .Lu et al. [8] studies the group anchoring force, the combined shear and bending shear forces, and analyze the group anchors failure mode and bearing capacity. Quan et al. [9] study the anchoring performance of a single anchor, double anchor and four anchors, and derive their failure modes in shear. The American Ronald A. Cook et al. [10-12] derive the formulas for the bearing capacity of the post-anchor system under...
different failure modes in the post-reinforcement anchoring, and analyze the influence of the anchoring depth on the failure mode and bearing capacity of the post-anchor system. The above studies mainly focused on the areas of structural reinforcement and bridge design, but there are few related studies on building curtain wall engineering.

Based on four concrete strength grades (C30, C40, C50, C60) and four chemicals anchor bolt diameters (M12, M14, M16, M18) commonly used in building curtain walls, 48 standard test pieces were made and divided into 16 groups. The purpose is to use a static pull test to study the effect of concrete strength grade and chemical anchor bolt diameter to its anchoring performance.

2. Experimental Methods

2.1. Test Specimen

With reference to the “Huiyu Construction Anchor Technology Manual”, four types of chemical anchors, M12, M14, M16, and M18 were used for anchoring in C30, C40, C50, and C60 concrete substrates. A 150 mm × 150 mm × 150 mm concrete cube test block was used. The anchor bolt was made of stainless steel extension bolt, as shown in figure 1. According to different types of anchor bolts and different strength of concrete, a total of 48 concrete specimens were anchored, divided into 16 groups. The main parameters of the test pieces are given in table 1.

![Anchor test specimen section](image1)

![Anchoring specimen elevation](image2)

Figure 1. Finished product.

2.2. Material Properties

The base material is made of a set of 150 mm ×150 mm × 150 mm concrete cube test blocks according to the Standard for Test Methods of Mechanical Properties of Common Concrete (GB/T 50081-2002), and the same conditions are used for curing the test pieces. See table 2 for the average measured compressive strength of concrete. Using standard test methods, three standard specimens were used from each diameter for anchor bolts of different diameters for tensile testing of the reinforcing bars. See table 3 for the yield strength, tensile strength and elongation of steel bars measured according to the “Room Temperature Tensile Test Method for Metal Materials” (GB/T228-2002). In this test, the anchoring adhesive was used as the epoxy-based anchoring adhesive. The actual performance indicators are shown in table 4.

2.3. Test Device

The central drawing test method was used to study the anchoring performance of chemical anchor bolts. The pulling test with loading device used a microcomputer to control the electro-hydraulic servo universal testing machine, and the pulling test piece was fixed on the universal testing machine through the upper and lower clamps of the testing machine [13], as shown in figure 2. The loading speed is controlled to 2 mm/min according to the Standard for Test Methods of Concrete Structures, and the loading is performed automatically by the computer [14]. During the test, the universal testing machine recorded the slip and loads for every 0.05 s. When measuring the amount of slippage in the band during breakage, a dial indicator on the upper part of the test piece was installed.
Table 1. Main parameters of test pieces.

| Specimen number | Drilling diameter (mm) | Anchor bolt diameter (mm) | Buried depth (mm) | Effective anchoring depth (mm) |
|-----------------|------------------------|---------------------------|------------------|-----------------------------|
| A-M12           | 14                     | 12                        | 110              | 105                         |
| B-M12           | 14                     | 12                        | 110              | 105                         |
| C-M12           | 14                     | 12                        | 110              | 105                         |
| D-M12           | 14                     | 12                        | 110              | 105                         |
| A-M14           | 16                     | 14                        | 120              | 115                         |
| B-M14           | 16                     | 14                        | 120              | 115                         |
| C-M14           | 16                     | 14                        | 120              | 115                         |
| D-M14           | 16                     | 14                        | 120              | 115                         |
| A-M16           | 18                     | 16                        | 125              | 120                         |
| B-M16           | 18                     | 16                        | 125              | 120                         |
| C-M16           | 18                     | 16                        | 125              | 120                         |
| D-M16           | 18                     | 16                        | 125              | 120                         |
| A-M18           | 20                     | 18                        | 145              | 140                         |
| B-M18           | 20                     | 18                        | 145              | 140                         |
| C-M18           | 20                     | 18                        | 145              | 140                         |
| D-M18           | 20                     | 18                        | 145              | 140                         |

Note: A-M12: A represents C30 concrete, M12 represents anchor bolt diameter of 12 mm; B-M12: B represents C40 concrete; C-M12: C represents C50 concrete; D-M12: D represents C60 concrete.

Table 2. Measured values of concrete compressive strength.

| Grade | C30 | C40 | C50 | C60 |
|-------|-----|-----|-----|-----|
| Load/kN | 700  | 768.4 | 943  | 901  | 927  | 1152 | 1138 | 1195 | 1350 | 1373 | 1379 |
| Pressure/MPa | 31.1  | 34.1  | 29.4 | 41.9 | 40.0 | 41.2 | 51.2 | 50.6 | 53.1 | 60.0 | 61 | 61.3 |
| Average/MPa | 31.5  | 41  | 51.6 | 60.8 |

Table 3. Measured values of anchor bolt properties.

| Anchor Bolt Diameter d (mm) | Yield Strength f_y (MPa) | Tensile strength f_u (MPa) | Elongation δ (%) |
|-----------------------------|--------------------------|---------------------------|------------------|
| 12                          | 449                      | 610                       | 12.2             |
| 14                          | 410                      | 615                       | 13.4             |
| 16                          | 435                      | 605                       | 14.3             |
| 18                          | 455                      | 601                       | 15.2             |

Table 4. Performance index of epoxy anchor.

| Project | Performance                                                                 |
|---------|-----------------------------------------------------------------------------|
| Physical Properties | Viscosity (25 °C) 4500-75000mpa x s, installation temperature is normal curing within -5 °C-40 °C, curing time is adjustable. |
|          | Standard value of compressive strength f_{bc, k} ≥ 60 N/mm²                  |
|          | Standard value of tensile strength f_{bt, k} ≥ 18 N/mm²                     |
|          | Tensile elastic modulus E ≥ 5.2 × 103 N/mm²                                 |
|          | Tensile deformation limit ε_u ≥ 0.01                                       |

| Experiment method |
|-------------------|
| “Adhesive viscosity measurement method” GB2794-81 |
| “Compression Test Method for Plastics” GB1041-79 |
| “Plastic tensile test method” GB1040-79 |
3. Experimental and Analysis

3.1 Experimental Phenomena and Failure Modes

With the continuous loading of the universal testing machine during the drawing process, the drawing force gradually increases. When the value reaches the ultimate bearing capacity, the test piece is damaged. Two types of breakage occurred in the specimens of the above test, as showed in figures 3 and 4.

(1) Anchor bolt pullout breakage: During the drawing process of A-M12, A-M14, B-M12, and B-M14 specimens, the anchor bolt is slowly pulled out as the pulling force continues to increase, the pulling force reached its peak value at 27kN, 25kN, 32kN, 44kN, after that the pulling force gradually decreased until the anchor bolt was completely pulled out.

(2) Concrete splitting breakage: During the drawing process at A-M16, A-M18, B-M16, B-M18, C-M12, C-M14, C-M16, C-M18, D-M12, D-M14, D -M16, D-M18, there is no obvious change in the anchor bolt bonding position with the increase of the drawing force, the pullout force reached its peak at 57 kN, 36 kN, 57 kN, 44 kN, 47 kN, 50 kN, 54 kN, 66 kN, 54 kN, and 72 kN. At this time, the concrete test block was instantaneously broken, cracks occurred on three sides from the anchorage of the anchor bolt, and the cracks extended from coarse to fine to the bottom surface of the concrete test block as showed in figure 5. The pulling force at the moment of breakage is close to 0, and then the pulling force rises again to about 20% of the peak value, but not rise again until the anchor bolt is completely pulled out.
3.2 Load Displacement Curve

As shown in figure 6, in the M12 and M14 anchor bolts, the A-M12, A-M14, B-M12, and B-M14 specimens load-displacement curves smoothly decrease after reaching the peak value, and the bolts are pulled out and damaged; C-M12, C-M14, D-M12, D-M14 load-displacement curve reached the peak after the cliff-type decline, concrete splitting failure occurred. M16, M18 anchor bolts in all concrete grade substrates, concrete cracks occurred.

![Load Displacement Curves](image)

(a) M12 chemical anchor  (b) M14 chemical anchor  (c) M16 chemical anchor  (d) M18 chemical anchor

**Figure 6.** Load displacement curves of different concrete substrates under the same model.

As showed in figure 7, when the concrete substrate grades are A and B, A-M12, A-M14, B-M12, and B-M14 specimens are pulled out and damaged by anchor bolts. A-M16, A-M18, B-M16, B-M18 test specimens suffered concrete splitting damage; when the concrete substrate grades reached C, D, the concrete test blocks of all types of test specimens suffered splitting breakage.

![Load Displacement Curves](image)

(a) C30 concrete  (b) C40 concrete  (c) C50 concrete  (d) C60 concrete

**Figure 7.** Load displacement curves of different diameters in the same concrete substrate.

3.3 Drawing Capacity

The results of the test pieces in the pull test are shown in table 5. See table 6 for orthogonal analysis of its drawing limit.

1. In the case of the same anchor bolt type, the drawing capacity of the M12, M14, and M18 test specimens increase with the increase of the concrete grade. The concrete grade in the M16 test specimen has a small effect on the specimen as showed in figure 8a.
(2) In the case of the same concrete substrate, when using A and B concrete substrates, the pull-out bearing capacity increases with the increase of the anchor bolt model. When the model reaches M16, the bearing capacity reaches the maximum and then decreases; using C for concrete substrates such as D, the drawing bearing capacity increases with the increase of the anchor bolt model, as shown in figure 8b.

According to the “Technical Regulations for Anchorage of Concrete Structures after Anchorage” (JGJ145-2013) [15], the theoretical calculation values for the design value of the bearing capacity of the concrete substrate in the drawing process are given in table 7.

| Specimen number | Pulling capacity (kN) | Peak point average displacement (mm) | Average bond strength (MPa) | Destruction form          |
|-----------------|------------------------|--------------------------------------|-----------------------------|---------------------------|
| A-M12           | 27                     | 4.2                                  | 6.8                         | Anchor pull out damage    |
| B-M12           | 32                     | 5.7                                  | 8.1                         | Anchor pull out damage    |
| C-M12           | 47                     | 0.52                                 | 11.9                        | Concrete splitting failure|
| D-M12           | 54                     | 0.57                                 | 13.6                        | Concrete splitting failure|
| A-M14           | 25                     | 5.1                                  | 4.9                         | Anchor pull out damage    |
| B-M14           | 44                     | 5.9                                  | 8.7                         | Anchor pull out damage    |
| C-M14           | 50                     | 0.62                                 | 9.9                         | Concrete splitting failure|
| D-M14           | 66                     | 0.69                                 | 13                          | Concrete splitting failure|
| A-M16           | 57                     | 0.67                                 | 9.5                         | Concrete splitting failure|
| B-M16           | 57                     | 0.65                                 | 9.5                         | Concrete splitting failure|
| C-M16           | 54                     | 0.59                                 | 8.9                         | Concrete splitting failure|
| D-M16           | 66                     | 0.66                                 | 10.9                        | Concrete splitting failure|
| A-M18           | 36                     | 0.52                                 | 4.5                         | Concrete splitting failure|
| B-M18           | 44                     | 0.62                                 | 5.6                         | Concrete splitting failure|
| C-M18           | 66                     | 0.44                                 | 8.3                         | Concrete splitting failure|
| D-M18           | 72                     | 0.42                                 | 9.1                         | Concrete splitting failure|

**Table 5.** Test results of test specimens after static pull.

![Figure 8. Ultimate load of each test piece.](image)

**Table 6.** Measured drawing limit value of test piece (kN).

| Specimen number | M12 | M14 | M16 | M18 |
|-----------------|-----|-----|-----|-----|
| A               | 27  | 25  | 57  | 36  |
| B               | 32  | 44  | 57  | 44  |
| C               | 47  | 50  | 54  | 66  |
| D               | 54  | 66  | 66  | 72  |
Table 7. Design value of bearing capacity for failure of concrete substrate (kN).

|       | M12 | M14 | M16 | M18 |
|-------|-----|-----|-----|-----|
| A     | 42.6| 47.5| 50  | 60.3|
| B     | 49.2| 54.8| 57  | 69.7|
| C     | 55  | 61.3| 64.5| 77.9|
| D     | 60.2| 67.1| 70.7| 85.3|

It can be known from above that when the concrete substrates are the same. The tensile bearing capacity of chemical anchoring is generated by the adhesive force between the anchor and the concrete substrate with the vinyl resin as the main raw material. Increasing the diameter of the anchor bolt increases the bonding surface area. When the anchoring adhesive force is lower than the tensile strength of the concrete, the pull-out failure of the anchor occurs, conversely, the concrete splitting breakage occurs.

It can be known from tables 6 and 7 that in the A and B concrete substrates, the measured values of the tensile bearing capacity of the test pieces A-M12, A-M14, B-M12, and B-M14 are smaller than the theoretical values of the tensile strength of the concrete. The actual measured pull-out bearing capacity of A-M16 and B-M16 is greater than the theoretical value of concrete tensile strength, so concrete cracking occurs during the test, which is in line with the test phenomenon. The specimens A-M18 and B-M18 caused cracks in the concrete base material due to the large drilling diameter (see table 1), resulting in a decrease in the tensile strength of the base material, and eventually concrete cracking and failure occurred. According to the “Technical Specification for High-rise Building Concrete Structures” (JGJ3-2010), in order to avoid structural cracks, the strength grade of cast-in-place concrete should not be more than C40. C and D concrete substrate test specimens all suffered concrete splitting failure, and the test phenomenon complied with the requirements of the specification.

According to comprehensive regulations and test results, the suitable concrete substrate grades in the above several combinations are C30 and C40, and the chemical anchor bolt models are M12 and M14; and the C40 concrete substrate anchor M14 type chemical anchor bolt combination is most suitable. At the same time, the mechanical properties of concrete and anchoring rubber are fully exerted.

4. Conclusions

The following conclusions were got through experimental phenomena and data analysis:

1. When the anchor bolt model is M12, M14, M18, the pull capacity of chemical anchoring increases with the increase of the concrete base material grade; when the anchor bolt model is M16, the concrete grade change has little effect on the anchor strength. When the concrete grade is C30, C40, the pull-out bearing capacity in the same concrete substrate increases with the diameter of the anchor bolt, and it reaches the maximum when the diameter increases to 16mm; when the concrete grade is C50, C60, increasing the size of the anchor bolt has a slow effect on the increase of anchoring strength.

2. When the concrete substrate grade is C30, C40, the chemical anchors of the anchors M12 and M14 are pulled out and damaged, and chemical anchors of the anchors M16 and M18 are broken by the concrete. When the concrete base material grade is C50, C60, all types of chemical anchor bolts anchored the test specimens, and concrete cracking occurred.

3. The curtain wall project in the C40 concrete substrate uses the chemical method to anchor the M14 anchor bolt, which can fully exert the mechanical properties of the substrate and the anchoring glue. When the fixed load is below 9kN, there is no damage to the anchorage; when a load such as a strong wind or earthquake occurs, the load limit value is 44kN, beyond that the anchor bolt will be pulled out and damaged. It can be seen that the chemical anchorage damage in this form have retardant property, which has certain safety and feasibility under strong wind, earthquake and other environments.
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