Experimental Research on Anchoring Behavior of Chemical Anchor Bolt under Repeated Loading

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Abstract. To study the anchoring behavior of chemical anchors under repeated loading, 33 test pieces were designed and fabricated based on the specifications. Each 3 test pieces were 1 set, that is, 1 set of comparative test pieces and 10 sets of test pieces, respectively, for static force. Bonding and anchoring performance tests for loading and reloading. Through the analysis of the test phenomena and results, the following conclusions are drawn: when the loading load exceeded 0.9 times the ultimate bearing capacity of the anchor; when the loading load was equal to 0.6 or 0.75 times, the test piece would undergo splitting damage after the set number of loading times, and its bearing capacity would increase. As the number of loading increase, the energy consumption would gradually decrease, and the decreasing amplitude would gradually increase. Compared with constant amplitude loading and variable amplitude loading, it is found that the slip value of variable amplitude loading increased by 42.1% and the bearing capacity decrease by 12%, which indicated that variable amplitude loading has a great influence on the bonding and anchoring performance of specimens.

Keywords. Anchoring behavior, repeated loading, bond anchoring property, ultimate load.

1. Introduction

Chemical anchors technology is a new construction technology in the modern construction industry. This technology is mainly applied in the construction of main structure, without first embedding the component, but the use of chemical anchor bolt can effectively realize the connection between the concrete structure of the building and the structural component of the tensile edge and the non-structural component of the lifeline project [1]. It has the advantages of fast construction speed, reliable anchorage capacity and so on, and has been widely used in curtain wall engineering.

At present, domestic and foreign scholars have conducted a lot of experiments and theoretical studies on the anchoring performance of chemical anchors in concrete. Xiao et al. [2] carried out the pull-out test on 102 chemical anchoring specimens, studied the concrete strength, bolt diameter, hole diameter, embedment depth on the influence of the chemical anchor bolt bearing capacity, through compared with embedded steel bearing capacity, the results said chemical anchoring reinforcement and embedded reinforcement concrete reinforced this two ways to achieve the same effect. Xie et al. [3-4] studied on the force of group anchor bending shear was carried out, analyzed the influence of edge distance and spacing on the bearing capacity and failure mode of chemical anchor group. Xu et al. [5] and Cheng et al. [6] studied the shear capacity of chemical anchor bolt and carried out the finite element simulation, proposed that the construction of chemical planting reinforcement can effectively increase the load transfer efficiency of concrete interface. Wan et al. [7] and Xing et al. [8] studied the mechanical properties of chemical anchor bolt after high temperature and under high temperature. Put forward the
calculation formula of the pull-out force of chemical anchor bolt changing with temperature after high temperature and obtained the relationship between the bond strength and temperature of chemical anchor bolt under high temperature. Richardson et al. [9] Studied the influence of temperature and fiber in concrete on the bearing capacity of chemical anchorage specimen. The results showed that the bearing capacity increased with the increase of temperature (the highest temperature is 20 ℃), steel fiber and polypropylene fiber have little effect on the bearing capacity of chemical anchorage specimens. The above research is mainly about the anchoring performance of chemical anchor bolt under monotonic static load. In reality, the curtain wall bears a strong wind and earthquake [10-12], and the force transmitted to chemical anchor bolt not only bears monotonic load, but also is a kind of repeated loading and unloading. Based on few scholars to study, thus to study the chemical anchors bolt anchorage performance under repeated load is very meaningful.

Based on the central pull-out test, this paper considered the influence of loading mode, stress level and loading time on the anchoring performance of chemical anchor bolts.

2. Experimental Program

2.1. Specimen Design

To study anchorage performance of chemical anchor bolt under repeated load, a total of 11 sets of 33 concrete cube specimens were made in this test. Test piece size is 150 mm × 150 mm × 150 mm, the parameter of the specimen is shown in table 1. Anchor bolt size is 12 mm × 250 mm, refer to “German Huiyu Building Anchoring Technical Manual”, the drilling diameter is 14mm, and the drilling depth is 110 mm, ensure the effective anchorage depth of the anchor bolt in the C40 concrete test block is 105mm, the anchorage specimen is shown in figure 1.

![Anchoring specimen](image1)

Figure 1. Anchoring specimen.

2.2. Material Tests

According to the “standard for test methods of mechanical properties of ordinary concrete (GB/T50081-2002)”, reserved 3 cubes of C40 concrete for curing under the same conditions as the test piece. The average compressive strength of concrete measured was 41MPa. According to the requirements of “tensile test method for metallic materials at room temperature (GB/T228.1-2010)”, one group of 3 anchor bolts test samples shall be made. Uniaxial tensile test of metal in civil engineering experimental center of Wuhan University of Science and Technology. Table 2 shows the mechanical parameters of anchor bolts.

2.3. Test Device and Loading Scheme

In this test, static pull-out and repeated pull-out loading tests were carried out on chemical anchor bolts. This test adopts microcomputer controlled electro-hydraulic testing service universal testing machine, model: WAW-1000. Firstly, through the static test of chemical anchor bolt, the average ultimate bearing capacity (Fₘ) corresponding to chemical anchorage failure was measured, it used to determine the
applied force corresponding to different stress levels. When the set load value is reached, the tester would automatically unload to 0, and then enter the next cycle. After this cycle to the set number of times, the static pull-out to anchor failure. It could be divided into four loading modes, three of which were equal amplitude loading, the stress level was 60% \(F_m\), 75% \(F_m\) and 90% \(F_m\) respectively, 30 times, 50 times and 100 times; one is variable amplitude loading, increasing 5kN step by step, 5 times for each load cycle [13-14]. The following principles shall be followed when the pull-out test is stopped: the anchor bolt is pulled out; there is a large slip at the loading end or a large slip occurred when the load reached the peak load; the concrete test block is cracked.

**Table 1. Parameter of the specimen.**

| Specimen number | Drilling diameter (mm) | Anchor diameter (mm) | Depth (mm) | Effective anchorage depth (mm) |
|-----------------|------------------------|----------------------|------------|-----------------------------|
| A0              | 14                     | 12                   | 110        | 105                         |
| A1-30           | 14                     | 12                   | 110        | 105                         |
| A1-50           | 14                     | 12                   | 110        | 105                         |
| A1-100          | 14                     | 12                   | 110        | 105                         |
| A2-30           | 14                     | 12                   | 110        | 105                         |
| A2-50           | 14                     | 12                   | 110        | 105                         |
| A2-100          | 14                     | 12                   | 110        | 105                         |
| A3-30           | 14                     | 12                   | 110        | 105                         |
| A3-50           | 14                     | 12                   | 110        | 105                         |
| A3-100          | 14                     | 12                   | 110        | 105                         |
| B-5             | 14                     | 12                   | 110        | 105                         |

Notes: \(A_1\)-30: \(A_1\) is equal amplitude repeated loading stress level 60% \(F_m\), 30 means load 30 times; \(A_0\), \(A_2\), \(A_3\) represent static loading and equal amplitude repeated loading stress levels of 75% \(F_m\), 90% \(F_m\). \(B\)-5: \(B\) means variable amplitude loading, increasing 5kN step by step; 5 means 5 times of loading per level.

**Table 2. Bolting test.**

| Anchor diameter (mm) | Yield strength \(f_y\) (MPa) | Ultimate strength \(f_u\) (MPa) | Elongation (%) |
|----------------------|------------------------------|---------------------------------|----------------|
| 12                   | 449                          | 610                             | 12.2           |

This test was carried out in the civil engineering experimental center of Wuhan University of Science and Technology. The loading device in the test is shown in figure 2.
3. Test Phenomenon and Result Analysis

3.1. Test Phenomenon
Monotonic static test piece $A_0$, at the beginning of loading, the surface of anchor bolt and concrete test block had no change. With the increasing of applied force, cracks beginning to appear at the anchorage of anchor bolts and gradually extended to the bottom of the test block, and the slip of anchor bolts increased slowly. When the slip value of anchor bolt was between 0-1.25 mm, the load increased linearly; when the slip value was between 1.25-3.22 mm, the load growth slowed down; when the slip value was between 3.22-4.5mm, the bearing capacity dropped rapidly; when the slip value was over 4.5mm, the load dropped slowly, and the anchor bolt was pulled out finally. Repeated loading test pieces $A_{1-30}$, $A_{1-50}$, $A_{1-100}$, $A_{2-30}$, $A_{2-50}$, $A_{2-100}$, $A_{3-30}$, $A_{3-50}$, $A_{3-100}$, B-5, except for test pieces $A_{3-30}$, $A_{3-50}$, $A_{3-100}$, apart from the pull out failure due to the number of cycles not completed, the splitting failure occurred. When the stress level was 90% $F_m$, the preload was carried out first to eliminate the influence of the upper clamp slip in the anchor bolt and loading device, and then the cyclic load was applied to 39kN(90% of the static pull out ultimate load), at the 5th, 7th and 26th cycles respectively, the test pieces failed to pull-out (since the chemical anchoring test pieces failed to complete the set loading times at the stress level of 90% $F_m$, $A_{3-30}$, $A_{3-50}$ and $A_{3-100}$ were all represented by $A_3$ in the following paper), there was no change on the surface of the concrete test block. The transverse rib of the anchor bolt was filled with anchoring glue, and the transverse rib of the anchor bolt had no obvious deformation. At this time, the chemical adsorption force between the anchoring glue and the concrete interface played a leading role, and the displacement at the loading end of the failure point was 2.86 mm. When the stress level was 60% $F_m$, 75% $F_m$ and variable amplitude loading, concrete splitting occurred. With the increase of loading time, cracks appeared at the joint of anchor bolt and concrete test block, and then gradually spread to the bottom of the test block. With a loud bang, the test block broke, the anchorage system failed, and the bearing capacity of chemical anchorage dropped rapidly. At this time, the mechanical bite force played a leading role in the bond strength between anchor bolt and anchorage glue, in which the test piece that was not completely broken depends on the anchorage glue and concrete With the loading of the testing machine, the bearing capacity of the soil increased a little, and then the anchor bolt was pulled out slowly. The chemical anchorage failure diagram was shown in figure 3.

![Figure 3. Chemical anchorage failure diagram.](image)

3.2. Test Result

3.2.1. Load-displacement Curve. The load displacement curve is shown in figure 4. It could be seen from the comparison between the curve obtained from repeated loading test and the monotonic static loading curve: At the stress level of 60% $F_m$ and 75% $F_m$, the bearing capacity would rise slightly after
30, 50 and 100 times of repeated loading; when the stress level was 90% $F_m$ and the set number of cycles (30, 50, 100) was not completed, the anchor bolt was pulled out and the bearing capacity was reduced by about 28%; in the equal amplitude stress loading, the peak displacement corresponding to the peak stress had little change compared with the monotonic static load. As can be seen in figure 4d, under variable amplitude loading, splitting failure occurred in the chemical anchorage specimen. Compared with the monotonic static pull-out specimen $A_0$, the bearing capacity decreased by 12%, and the peak displacement increased by 42.1%. In conclusion, in the repeated loading test, the variable amplitude loading system had a greater impact on the bond and anchorage performance of chemical anchorage specimens than the equal amplitude loading system.

![Load displacement curve of anchorage specimen under repeated load.](image)

**Figure 4.** Load displacement curve of anchorage specimen under repeated load.

### 3.2.2. Hysteresis Curve Analysis.

The drawing and unloading hysteresis curves of $A_1$-100, $A_2$-100, $A_3$ and $B$-5 are shown in figure 5. It can be seen that the hysteresis curves of $A_1$-100, $A_2$-100 and $A_3$ have some same characteristics. After repeated loading with equal amplitude, the slope and area of the hysteresis curve were decreasing, and the residual slip was increasing after unloading. This is because the interface between the anchorage adhesive and the concrete was damaged and the anchoring force is decreasing after repeated loading with equal amplitude. For $B$-5, the slope of the hysteresis curve decreased with the increase of amplitude, and the residual slip increased after unloading. The hysteresis curves of $A_1$-100, $A_2$-100, $A_3$ and $B$-5 are shuttled like, without obvious pinching phenomenon, which indicated that the plastic deformation and energy dissipation capacity of the chemical anchoring specimen are strong when it bears repeated load.

### 3.2.3. Influence of Loading Times on Energy Consumption.

Under the repeated loading system, the bond slip curve between the loading section and the unloading section forms a closed hysteresis loop. Hysteresis loop area is the energy dissipated in one cycle (the area of the hysteresis loop kN/mm) [15]. Figure 6 shows the relationship between energy consumption and repeated loading time.
Figure 5. Loading unloading hysteresis curve of each test piece.

As can be seen from figure 6, with the increase of repeated load time, the energy consumption of A1-100 and A2-100 decreased slowly and tended to be stable. Finally, in the process of equal amplitude loading, the energy dissipation of stress level of 60% $F_m$ and 75% $F_m$ was stable at about 6.19kN/mm and 7.32 kN/mm respectively. When stress level was 90% $F_m$, the set loading times were not completed, and the energy dissipation before loading failure was 14.2 kN/mm. The decrease stiffness of energy dissipation of test piece A3 was greater than that of test pieces A1-100 and A2-100. It showed that the chemical anchorage has good and stable energy dissipation capacity with the increase of loading times when the repeated load is 60% $F_m$ and 75% $F_m$. However, when the cycle load reached 90% $F_m$, the energy consumption was stable at 1-15 cycles, and at 15-25 cycles, the energy consumption started to decrease significantly.

Figure 6. Cyclic loading energy consumption diagram.
3.2.4. Influence of Loading Times on Loading and Unloading Stiffness. It can be seen from figure 7, the loading and unloading stiffness decreased with the increase of cycle time, and finally tend to be stable. The constant amplitude repeated loading and unloading stiffness of test piece A3 decreased rapidly because the applied load is slightly less than the bond force of the interface between the anchorage adhesive and the concrete. After multiple loading, the interface was damaged, resulting in irreversible sliding, the stiffness continues to decrease, and finally it was pulled out. The loading and unloading rigidity of test pieces A1-100 and A2-100 were relatively stable, and the surface of the test piece hasn't changed after 100 time of loading. Through observation, the interface slipped between the anchorage adhesive and the concrete is small, Thus, at the stress level of 60% Fm and 75% Fm, the loading times have little influence on the loading and unloading stiffness of the chemical anchorage specimens, and at the stress level of 90% Fm, the loading times have great influence on the loading and unloading stiffness of the chemical anchorage specimens.

![Figure 7. Cycle section stiffness.](image)

4. Summary and Conclusions

Based on the analysis of the test phenomena and results, the following conclusions are drawn:

(1) When the loading load was more than 0.9 times of the ultimate bearing capacity of the anchor bolt, the chemical anchor bolt pull-out failure occurs suddenly; when the loading stress was equal to 0.6 or 0.75 times of the ultimate bearing capacity of the anchor bolt, the splitting failure occurred after the completion of the set loading times, and the bearing capacity increased.

(2) With the increase of loading times, the energy consumption decreased and the decreasing range increased;

(3) Comparing the constant amplitude loading with the variable amplitude loading, it was found that the sliding value of the variable amplitude loading increases by about 42.1%, and the bearing capacity decreased by about 12%, which showed that the variable amplitude loading had a great influence on the bond anchorage performance of specimen.

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References

[1] Technical specification for post-installed fastenings in concrete structures JGJ145-2013
[2] Xiao C Z, Tian W L, Sun W J and Liu B 2010 Experimental research on the bonding properties of chemically post-installed bar in concrete Journal of Wuhan University of Technology 32 (14) 126-131
[3] Xie Q and Lu Z D 2007 Experimental study on behavior of bonded in reinforcement anchorage group under combined of moment and shear loading Journal of Building Structures 2007 (S1) 247-251
[4] Bing T and Xie Q 2007 Design comparison of cast-in-place and post-installed anchorage connections under combinations of moment and shear loading Industrial Construction 37 (z1) 280-282
[5] Liu Y L, Xu F Q, Xie J and Xiong C H 2018 Experimental study on shear behavior of anchor steel connections Journal of Building Structures 39 (S2) 374-379
[6] Cheng M L, Zhang L and Li Q 2019 Experiment and numerical simulation of shear performance of concrete interface for bonded rebars Building Structure 49 (15) 104-109
[7] Wan Z S, Xia Y X and Han R C 2013 Experimental research on mechanic behavior under high temperature of chemistry anchor bolts Journal of Chang’an University (Natural Science Edition) (01) 63-66
[8] Wan Z S, Xia Y X and Han R C 2010 Ultimate uplift capacity experivent study of new type chemical anchoring bolts under high temperature Concrete (08) 71-72+79
[9] Richardson A E, Dawson S, Campbell L, Moore G and Mckenzie C 2019 Temperature related pull-out performance of chemical anchor bolts in fibre concrete Construction and Building Materials p 196
[10] Peng S, Xu C X, Lu M X and Yang J M 2018 Experimental research and finite element analysis on seismic behavior of CFRP-strengthened seismic-damaged composite steel-concrete frame columns Engineering Structure 155 50-60
[11] Xu C X, Peng S, Wang C F and Ma Z T 2020 Influence of the degree of damage and confinement materials on the seismic behavior of RC beam-SRC column composite joints Composite Structures 231 111002
[12] Peng S, Xu C X and Liu X Q 2019 Truss-arch model for shear strength of seismic-damaged SRC frame columns strengthened with CFRP sheets Frontiers of Structural and Civil Engineering 13 (6) 1324-1337
[13] Jin Q P, Chen P X, Liang T Y and Wang G B 2019 Bond behavior between GFRP bars and concrete under variable range cyclic loading and unloading Industrial Construction 49 (03) 12-17+23
[14] Gao Y H, Shen J Y, Jin Q P, Wang G B and Xiang Y N 2018 Bonding behavior between GFRP bars and concrete under cyclic loading condition China Plastics 32 (07) 100-104
[15] He Z and Sun Y 2006 Bond behavior between GFRP rod and concrete subjected to high stress reversals Acta Materiae Compositae Sinica (06) 149-157