

Research Article

Feasibility Experimental Analysis of a New Anchorage in Reconstruction of Pre-stressed Structure

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Abstract: In this study, a new anchorage used for reconstructive engineering of pre-stressed structure is mainly introduced. Pre-stressed concrete structures began to appear at the end of the 19th century. The structure form of pre-stressed concrete expresses outstanding advantages and gets a wide application, no matter in the functional form or structural properties as well as in construction or investment benefit. Facing functional changes and a situation that structure opening is often inevitable on the floor; the ordinary anchorage cannot fully meet the requirements of the reconstructive engineering. It's urgent to test the new anchorage whose outstanding characteristic is higher anchoring coefficient, separated anchoring cup, participating of retaining bolt. Combined with several data analysis of anchorage test, a comprehensive study of the anchorage is indispensable to explore the feasibility of engineering applications.

Keywords: Anchorage, concrete structure, experiment, pre-stressing, reconstruction

INTRODUCTION

With the development of high efficiently pre-stressed technology in recent years, the structure form of pre-stressed concrete technology expresses outstanding advantages and gets a wide application, no matter in the functional form or structural properties as well as in engineering construction or investment benefit (Feng and Yu, 2012). However, in practical application, as a result of multi-span continuous arrangement of pre-stressing steel in the floor slab generally with a rather complicated reinforcement situation, it greatly increases the degree of difficulty in construction. Furthermore, it is frequently needed that open hole in pre-stressed floor when new stair, elevator, piping shaft and pipeline facilities are constructed. After structure opening, with the concrete eliminating and pre-stressed steel disrupting, corresponding balanced load completely lost at this time (Liu and Gao, 2012). If supporting measures are not provided on time to the related plate of pre-stressed reinforcement, the problem such as plate cracking or even collapse will be inevitable (Zhang, 2003). Although structural reinforcing has been adopted in the surrounding of the hole according to relevant regulations in the current design and construction, but supporting in the construction is still indispensable to ensure the integrity of the structure after the truncation of the pre-stressed steel strand. There are still many problems remain to be solved in further research. At present, stress

performance for pre-stressed plate structure opening in China is still scarce, so it is necessary to carry out a series of research (Song, 2006).

The purpose of this research is to develop a new anchorage in the pre-stressed structure opening when pre-stressed steel wires can be cut off with little supporting or even no supporting. Based on widely collected and analyzed data, a systematic study about anchorage structure opening of unbonded pre-stressed concrete is made with a combination of theoretical analysis and experimental research. The specific idea is installing two open anchorages on both sides of the pre-stressed steel of the hole before the pre-stressed steel cutting off. With a new anchorage called XDQM anchorage applied, pre-stressed reinforcement truncation won't cause great loss in pre-stress of the pre-stressed structure. Meanwhile, we can keep the integrity of the structure and also save a lot of manpower, material resources and time, which have important guiding significance for the future design and construction.

ANCHORAGE ILLUSTRATION

Detail of XDQM anchorage: XDQM anchorage is a tapered anchorage, which is consisted of the anchoring cup and the clip. Using a structure style of two-piece clip with steel traveler, the outstanding characteristic of the anchorage is wrapping Angle, nearly close to 180°. With the contact area of steel wires increasing, each

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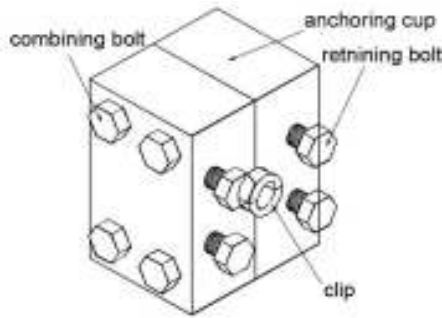


Fig. 1: Isometric drawing of XDQM anchorage



Fig. 2: Physical drawing of XDQM anchorage

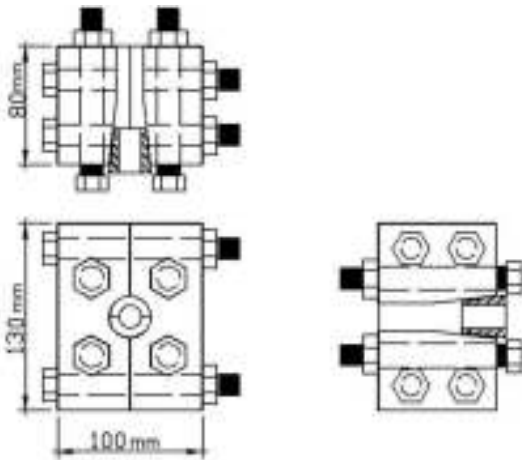


Fig. 3: Isometric projection drawing of XDQM anchorage

piece of clip can be stuck in steel wires, which increases the friction force indirectly. Through the theoretical mechanical calculation of the anchorage combined with the processing requirement of mechanical technics, XDQM anchorage takes a special structure design with 4 grades 8.8 (China Industrial Standards) high-intensity bolts whose diameter are 16 mm as a combining bolt and 4 same bolts as retaining bolt. Choosing QM15 anchoring shaped clip, the machining process and heat treatment process of XDQM anchorage is strictly regulated (Fig. 1).

Working principle of XDQM anchorage: Pre-stressed steel strand tapered anchorage employ wedge

theory. Under strong lateral pressure and friction force, the clip is thrust into the sleeve in order to clamp the pre-stressed steel. Furthermore, taking advantage of mechanical bite and friction that result from the surface physical effects between anchorage and reinforcement, the clip is applied to fulfill the anchoring performance (Zhao, 2012).

XDQM anchorage cup choose standardized clip products with specific selecting of wedge Angle for $6^{\circ} 30'$. Zigzag design can prevent clip's sliding out and facilitate following up of the clip. Through the reasonable selection of angle, the embedded depth of steel strand should be satisfied in order to keep the equivalent angle of friction between the steel strand and the clip greater than the sum of the clamping wedge angle and the equivalent angle of friction between the anchorage plate and the clip, which effectively guarantee the anchoring performance (Fig. 2).

Technological superiority of XDQM anchorage: Profiting from the reasonably determination of bottom diameter of the thread and better fitment, the self-anchorage property has been greatly improved for the reason that even when there is no jacking, the jaw of anchorage can follow up in order automatically. During the period, even the friction appearance of two clip is different and the trend of irregularities appears, two clamping piece fastened together with the steel traveler will still firmly followed the steel strand anchorage (Xiong, 2005) to maintain the favorable anchorage performance, driven by the steel traveler which shows strong stiffness and higher resistance to shear. It's especially convenient for the anchorage when making an anchorage quitting. Before cutting off the steel strand when the steel strand is tensioned, implemental anchorage is installed where the steel strand is exposed. After the reconstruction, the implemental anchorage is substituted for permanent anchorage by stretching the anchorage cup with other tools (Fig. 3).

Test-bed of XDQM anchorage: Pre-stressed concrete structure is widely suitable for large-span structure. However, due to the limitation of the test condition, the test specimen of full size is impossible in actual test. The floor of text-bed in this experiment is designed on existing conditions, combined with the design standard. Simulated in structure opening of large-span board, the plate finish setting ducts for pre-stressed reinforcement with the corrugated tube or UPVC pipe. Above all, the duct is straight with unbonded pre-stressed reinforcement in it. To prevent local compression damage of concrete slab, 15 mm thick steel plate 0is installed in both anchoring place and tensioning place, which also play the role of limit board. Moulded and assembled in laboratory, the text-bed is made of C40 (China standard) commodity concrete, which is curing for 28 days. Reinforcement and section size are shown in Fig. 4.

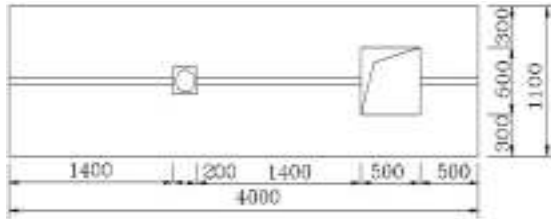


Fig. 4: Detail drawing of experimental table

EXPERIMENTAL STUDY

On the basis of designing and developing the pre-stressed anchorage, the topic make an exploratory study about the feasibility in engineering of the pre-stressed structural reinforcement and reconstruction by taking static load anchoring test, cyclic loading test, internal shrinkage test and anchorage friction losing test in accordance with the requirements of the national standards of quality inspection and assessment.

Static anchoring performance test: The function of the structure is to withstand structural loads and ensure structural safety, serviceability and durability. Anchorage should have a reliable anchoring performance, adequate carrying capacity and good applicability to give full play to the role of the pre-stressed steel strand and safety pre-energizer operating. It is precisely because of this, the static anchoring performance test is extremely important for the anchorage to analysis its validity.

Static load test of XDQM anchorage without retaining bolt: Tensile force in practical pre-stressed engineering in China is not greater than 75% of standard value f_{pk} of steel wire tensile strength and will not exceed 70% of the maximum in practice (Xiong, 2005). So in this experiment feed-through jack is used to stretching to 75% of the tensile strength limit of steel strand with three level constant velocity (100 MPa/min) on the basis of tensile strength standard value f_{pk} of 40 and 60% of the steel strand. Only by doing three groups of trials can we reduce the contingency.

Feed-through jack, pressure sensor, XDQM anchorage, steel strand, test-bed and other test equipment are assembled according to Fig. 5. Firstly, the installation of XDQM anchorage is begun until the sensor reading of stretching end reaching the advanced calibrated figure when tensioning the jack. In addition, the anchorage is an open anchorage and 90 N·M moment is needed to tighten the combine bolt with torque wrench. Next, two clips are installed after the combining bolt is tighten. Then comes the installation of two clips. There will be the situation of stress non-uniform if the clip is not abreast followed by the consequence of local destroy or break of steel strand. Finally, it's appropriate to measure the indicators when feed-through jack is relaxed with XDQM anchorage began to tighten and clip began to shrink.

Static load test with retaining bolt: Tensile force in practical pre-stressed engineering in china is not greater than 75% of standard value f_{pk} of steel wire tensile strength and will not exceed 70% of the maximum in practice. So in this experiment feed-through jack is used to stretching to 75% of the tensile strength limit of steel strand with three level constant tension (100 MPa/min) on the basis of the steel strand tensile strength standard value f_{pk} of 40 and 60%. Only by doing three groups of trials can we reduce the contingency.

Feed-through jack, pressure sensor, XDQM anchorage, steel strand, test-bed and other test equipment are assembled according to Fig. 5. The tensile process of static load test with retaining bolt is basically the same with the tensile process of static load test without retaining bolt. The only difference is the installation of retaining bolt comes after the installation of the clips. When installing the retaining bolt, 90 N·M moment is exerted to tighten the retaining bolt with torque wrench. In this process, the clip shrink to the inner part of the anchorage cup with the retaining bolt tightened. So the shrinkage of the clip in the tension process is finished ahead of time leading to a decrease of pre-stress loss. It's appropriate to measure the same indicators as them in the static load test of XDQM

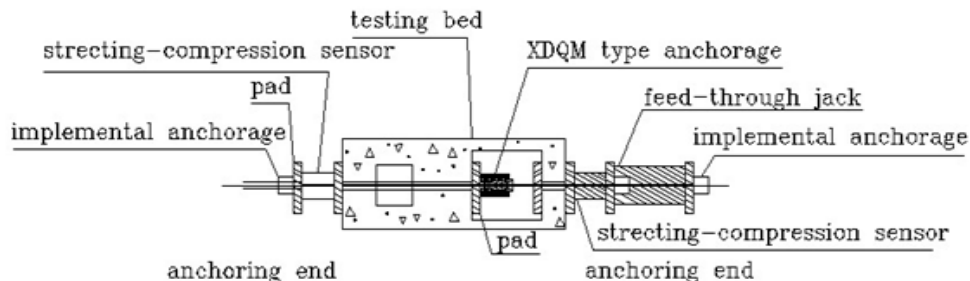


Fig. 5: Static test sketch without retaining bolt

anchorage without retaining bolt when feed-through jack is relaxed with XDQM anchorage began to tighten and clip began to shrink.

Measure indicators:

- Tension force
- Shrinkage of the steel strand
- Strain of XDQM anchorage

Conventional static load test: Tensile force in practical pre-stressed engineering in china is not greater than 75% of standard value f_{pk} of steel wire tensile strength and will not exceed 70% of the maximum in practice. However, according to technology application rules for pre-stressed anchorage, grip and connector JGJ 85-2002, conventional anchors should be loaded to 80% of f_{pk} . So in this experiment feed-through jack is used to stretching to 75% of the tensile strength limit of steel strand with four level constant tension (100 MPa/min) on the basis of 20, 40, 60%, respectively of tensile strength standard value f_{pk} of the steel strand. Only by doing three groups of trials can we reduce the contingency.

Feed-through jack, pressure sensor, XDQM anchorage, steel strand, test-bed and other test equipment are assembled according to Fig. 5. After the installation of anchorage is finished, 90 N·M moment is exerted to tighten the combining bolt with torque wrench before installing the clip. A measurement about the indicators is made when the sensor reading of stretching end reaching the advanced calibrated figure.

Measure indicators:

- Tension force
- Shrinkage of the steel strand
- Strain of XDQM anchorage

Cyclic loading test: Being an earthquake-prone area, many important structures have seismic requirements. As the application of pre-stressed structural reinforcement and renovation project, cyclic loading test is very necessary for XDQM anchorage.

According to technology application rules for pre-stressed anchorage, grip and connector JGJ 85-2002, conventional anchors should be loaded to 80%. So the maximum stress of cyclic loading test chooses to be 80% of his standard value of the tensile strength of the strand steel, while the minimum stress of cyclic loading test comes to be 40% of the standard value of the tensile strength of the strand steel in this test according to the regulation. In this experiment, feed-through jack is used to stretching to 80% of the tensile strength limit

of steel strand and then returning 40 and 80% again for 50 times cycling with four level constant velocity (100 MPa/min) on the basis of 20, 40, 60%, respectively of tensile strength standard value of the steel strand.

Feed-through jack, pressure sensor, XDQM anchorage, steel strand, test-bed and other test equipment are assembled according to Fig. 5. After the installation of anchorage is finished, 90 N·M moment is exerted to tighten the combining bolt with torque wrench before installing the clip. A measurement about the indicators is made when the sensor reading of stretching end reaching the advanced calibrated figure:

- Tension force
- Shrinkage of the steel strand
- Strain of XDQM anchorage

Internal shrinkage test: The shrinkage test here utilizes the loading system of the static load test, that is, 75 and 80% of the standard value of the tensile strength of the steel strand. The grading tension setting of internal shrinkage test is the same as the setting in static load test.

Feed-through jack, pressure sensor, XDQM anchorage, steel strand, test-bed and other test equipment are assembled according to Fig. 5. After the installation of anchorage is finished, 90 N·M moment is exerted to tighten the combining bolt with torque wrench before installing the clip. A measurement about the indicators is made when the sensor reading of stretching end reaching the advanced calibrated figure.

Measured indicators:

- Tension force
- Shrinkage of the steel strand
- Strain of XDQM anchorage

Anchorage friction-losing test: The anchorage friction losing test here utilizes the loading system of the static load test, that is, 75 and 80% of the standard value of the tensile strength of the steel strand. The grading tension setting of anchorage friction losing test is the same as the setting in static load test.

Feed-through jack, pressure sensor, XDQM anchorage, steel strand, test-bed and other test equipment are assembled according to Fig. 5. After the installation of anchorage is finished, 90 N·M moment is exerted to tighten the combining bolt with torque wrench before installing the clip. A measurement about the indicators is made when the sensor reading of stretching end reaching the advanced calibrated figure.

Measured indicators:

- Tension force
- Shrinkage of the steel strand
- Strain of XDQM anchorage

TEST RESULT AND ANALYSIS

Analysis of static anchoring performance test: As can be seen from three groups of test (Table 1), the total strain of the device of steel strand anchorage is relatively small due to the large size of XDQM anchor. The strain gauge reading is increased basically as the stress increases. Compared with the static loading test with retaining bolt, the pre-stress losing and coefficient of anchoring efficiency in static loading test is far from satisfied, while the retaining bolt is very helpful in decreasing the internal shrinkage, which improve the anchorage performance and reduce the loss of pre-stress efficiently. With the help of retaining bolt, a part of the shrinkage of the clip is finished in advance which significantly reduces the loss of pre-stress in the anchorage.

Analysis of cyclic load test: As can be seen from cyclic load test (Fig. 6), specimen of cyclic load test is under larger force in the first few cycles. The reading

of No. 3 strain gauge keeps a maximum while the reading of No. 5 strain gauge keeps a minimum that illustrates a phenomenon that edge stress is larger at the fringe. Furthermore, after 50 times cyclic loading, the stress tends to be mean basically that is to say the anchorage force tends to be stable. Above all, the data obtained from cyclic load test well fits the theoretical analysis results.

Analysis of internal shrinkage test: As can be seen from the internal shrinkage test (Table 2), the maximum of the internal shrinkage is conventional test clip and the three groups internal shrinkage of the steel strands tend to be average. The reason for that is there is no pressure in anchorage clip and the stress being exerted is much larger. Moreover, compared with the test without retaining bolt and the test with retaining bolt, clip of the test without retaining bolt makes a larger shrinkage during the two groups. It is precisely because the internal shrinkage of the clip with retaining bolt is finished before anchoring leading to higher anchoring efficiency and less pre-stress losing.

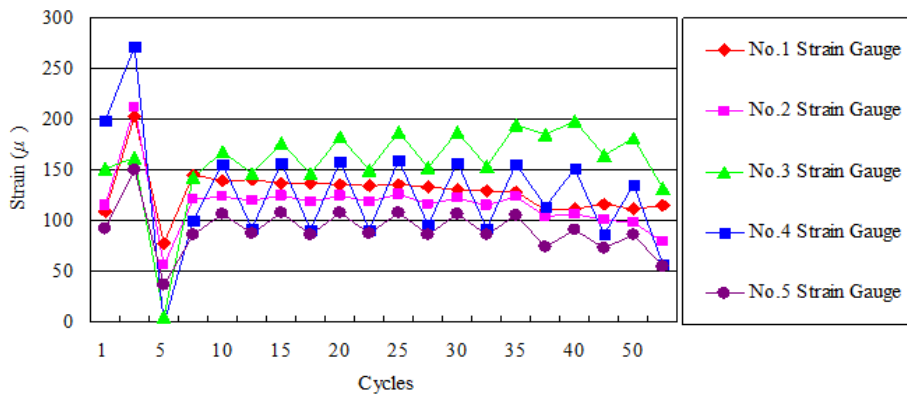


Fig. 6: Result of cycle load test

Table 1: Experimental summary of static load test

	Calculated ultimate tension of strand (KN)			Measured ultimate tension of strand (KN)			Coefficient of anchoring efficiency (%)			Total strain (%)		
Without retaining	190.21	191.56	192.78	121.59	127.61	119.47	63.92	66.62	61.97	0.31	0.37	0.49
With retaining	194.00	194.00	194.00	166.63	173.44	165.43	85.89	89.40	85.27	0.32	0.34	0.27
Conventional	207.00	207.00	207.00	198.38	204.08	198.38	96.35	98.93	95.83	0.51	0.76	0.63

Table 2: Experimental data of internal shrinkage test

	Internal shrinkage of clip (mm)			Mean value of internal shrinkage (mm)
Without retaining bolt	6.75	6.19	7.41	6.78
With retaining bolt	2.80	3.21	2.70	2.90
Conventional	9.20	11.56	10.54	10.43

Table 3: Experimental data of friction loss test

	Tension difference of steel strand (KN)			Value of friction losing (%)			Mean value of friction losing (%)
Without retaining bolt	68.62	63.95	73.31	36.08	33.38	38.03	35.83
With retaining bolt	27.37	20.56	28.57	14.11	11.60	14.73	13.48
Conventional	7.56	2.92	8.63	3.65	1.07	4.17	2.96

Analysis of anchorage friction losing test: It can be obtained that the losing of pre-stress in conventional static load test is the least from the data of anchorage friction losing test (Table 3). Used as closed anchorage in anchoring end, the losing of pre-stress in the test with retaining bolt is much satisfied than the one without retaining bolt, which obviously highlights the affection of retaining bolt.

CONCLUSION

The most innovated feature of XDQM anchorage is participating four high-intensity bolts as retaining bolt. The core of the test is a relatively comparison of anchorage efficiency coefficient of XDQM anchorage between the static load test without retaining bolt, static load test with retaining bolt and conventional static load test. As conventional anchorage, efficiency coefficient of XDQM anchorage reaches 97.04% meeting the national standard requirement. For the important role of retaining bolt, XDQM anchorage makes an average of 86.52% in efficiency coefficient. With the help of retaining bolt, a part of the shrinkage of the clip is finished in advance which significantly reduces the loss of pre-stress in the anchorage and improves anchoring performance effectively lengthening the anchorage efficiency coefficient. Making little pre-stress losing of original structure in reconstruction and reinforced process, which protect the integrity of the building in

the largest extent, XDQM anchorage developed in the subject exhibits prominent engineering significance.

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