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Experimental Study on Mechanical Performance of an Oval Steel Anchorage Connector

FANKUI ZENG AND JIE TANG
School of Civil Engineering, Xi'an Technological University, Xi'an, Shaanxi, CHINA
Email: *fankuizeng@126.com*

Abstract: To solve the problem that the quality of concrete poured cannot be guaranteed due to a dense distribution of steel bars in beam column joints of reinforced concrete structures, we designed an oval steel anchorage connector. The mechanical performance test was conducted for traditional 90° hooked bars and oval steel anchorage connectors on plain concrete. The results showed that the bar was pulled off and the concrete was locally destroyed in the drawing destruction. Mechanical performance of specimen with oval steel anchorage connectors is better than specimen with 90° hooked bars, while they all satisfy the requirement of related specification. The weight of the single oval steel anchorage connector is about 1.01 kg less than that of the 90° hooked bar, which greatly reduces project cost, and promotes the sustainable development of construction industry in China.

Keywords: *Reinforced Concrete Structure, Steel Anchorage Connector, Mechanical Performance, Experimental Study.*

1. Introduction

For reinforced concrete structures, steel bar anchorage aims to enhance bonds between rebars and concrete, which will improve structure reliability. Bond is composed of four forces: adhesive force, friction, mechanical interaction, and anchoring force at the bar end. The primary means for mechanical anchorage are hooks, soldering, heads, and anchorage head. Compared to 90-degree hooked bars, anchorage heads overcomes the shortages of steel congestion and inconvenient construction, thus providing higher engineering quality as well as better anchoring performance. What is more, with less demand for steel, the use of anchorage heads can reduce construction costs. However, there are still some practical problems. For example, the bearing plane of existing round anchorage heads is so large that bar spacing cannot be determined accurately; concrete may be poured unevenly, which increases construction difficulty; the in-situ fabrication of anchorage heads is as time-consuming as lowering working efficiency. As the construction industry expands, the bar connection technology gains breakthroughs. The application of concrete sleeves shortens half lap length than before to a certain extent. This economical apparatus is adaptable to all existing kinds of bar materials regardless of their components, albeit in the way that the bond between bars and concrete is weakened. Zhibin Li introduced two types of bar connectors that had been developed in and applied to America: HRC headed bar with high-speed friction welding (Figure 1), which is rarely used as a bulky equipment; and ERICO headed bar connected by taper threads (Figure 2), which has received widespread application due to its good performance. The CABR headed bar developed by China Academy of Building Research has amassed multiple patents, but finds unfavorable market expansion. According to the current Code for Design of Concrete Structures (GB50010-2010) in China, the cross section of steel bars with mechanical anchorage can be round, oval or square. This paper designed an oval steel anchorage connector, and conducted experimental research on its mechanical properties.

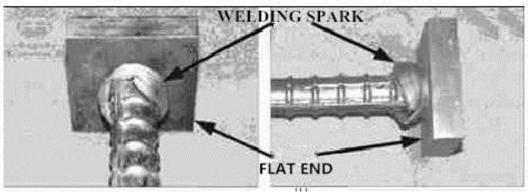

Figure 1.*HRC headed bar connector*

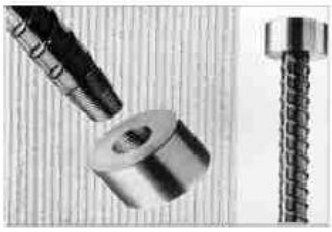

Figure 2.*ERICO headed bar*

Figure 3.*CABR headed bar*

2. Design of the oval steel anchorage connector

The oval steel anchorage connector (Figure 4-6) comprises anchorage head, back-up member, and sleeve. Below the soffit of the anchorage head welds the first steel bar that connects to the second steel bar through a sleeve. Back-up members are installed on both sides of the minor axis of the oval cross section for the anchorage head. When this connector is fabricated to a beam column joint, the first steel bar connects to the second steel bar through a sleeve, the second steel bar connects to the third steel bar through a sleeve, and so on. The anchorage head corresponds to the steel bar. The minor axis shares the same direction with the column body. Several anchorage heads in the column connect to one another along the direction of the minor axis. And on the premise of meeting the requirement of steel bar spacing, the anchor plates are uniformly arranged. There is the first frustum on the top surface of the anchorage head.

In addition, the sleeve is thin at both ends, but slightly thicker in the middle. At the ends of the sleeve are the first column and the second column, respectively. These hollow columns have the same external diameter that is smaller than the sleeve counterpart. The second hollow frustum is installed co-axially between the first column and the sleeve body. The third hollow frustum is installed co-axially between the second column and the sleeve body. Both the sleeve and the rebar are curved internally and externally with threads. By integrating the sleeve and the rebar into a whole, the correspondingly constructed reinforced concrete structure has its seismic performance improved, which reduces the rate of house collapse. Compared to the conventional techniques of lap splicing and welding, the performance of the oval steel anchorage connector designed is more reliable to reach the joint standard of Technical Rules for Mechanical Connection of Steel Bars(JGJ107-2010). This superior apparatus is unaffected by climate or welding skills, and also achieves high working efficiency because it spares the efforts for constructors to allow for bar weldability. The stronger sleeve gives full play to the rebar’s ductility and strength, and will not fail before steel bar failure. So the sleeve is larger than one level of steel bar.

Fourteen grooves on the surface of the first frustum enlarge the contact area between the first frustum and concrete. This frustum has its bottom diameter as long as the minor axis, the height equal to the thickness of the anchorage head, and a back-up member as thick as the anchorage head. The proportion of the major axis and the minor one is 1.38:1. Too large proportion may spur shear failure of the rebar easily, and further reduce or even lost the anchorage force at the beam column joint.

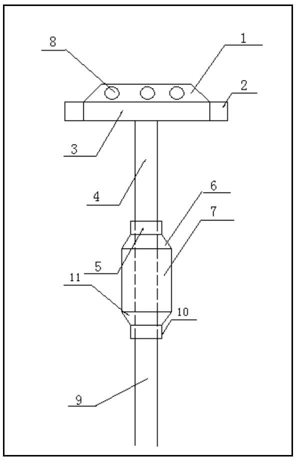

Figure 4.*Front view of the connector*

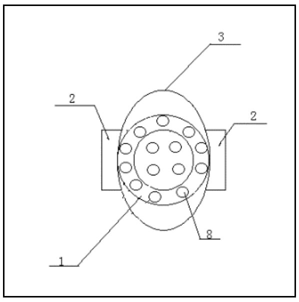

Figure 5.*Plan view of the connector*

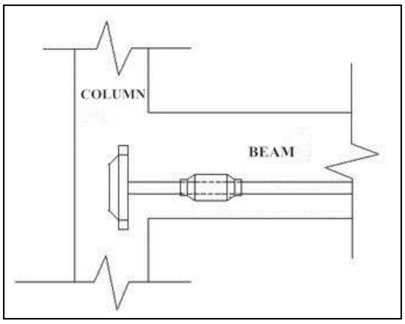

Figure 6.*Sketch map of connector application*

(1—the first frustum, 2—back-up member, 3—anchorage head, 4—the first rebar, 5—column, 6—the second frustum, 7—column body, 8—groove, 9—the second rebar, 10—the second column, 11—the third frustum.)

3. Characteristics of the oval steel anchorage connector

Compared to existing technologies, this connector is characterized by

(1) The anchorage head is oval, which means that its minor axis is shorter than the diameter of a conventional round anchorage head with the same cross section. In this case, some spacing is guaranteed between adjacent rebars, which not only improves pouring evenness, but also allows more steel bars to be installed along the direction of the minor axis.

(2) The back-up members at each side of the minor axis is used to gauge the spacing between neighboring reinforcing bars, facilitating constructors who install steel bars according to requirements in the design paper.
(3) The existence of the first frustum and grooves increase the contact area between the anchorage head and concrete, thus further enhancing the adhesive force acted on them.
(4) The sleeve is designed with thin ends and a thicker body, which strengthens the bond between the sleeve and concrete. Accordingly, the anchorage performance at beam column joints is improved effectively.

4. Test of the mechanical performance of the connector

4.1. Test conditions

The test materials are Ø25 HRB400 and commercial concrete C35. The size of the specimen is 700mm×700mm×700mm. The minor axis, the major axis, and the overall thickness of the anchorage connector are 50mm, 69mm and 25mm, respectively (Figure 7). We prepare two sets of specimens, six for each set. The first set uses 90° hooked bars whose internal diameter is 4d=100mm. The anchorage length is 321.2mm, and the length of the straight part is 15d=375mm. (According to the Code, in the beam column joint area, the straight part of a bended longitudinal steel bar at the lower beam part and at the upper part of an interlayer beam shall be no shorter than 15d; the 90-degree end hook, if specifically required, shall have the internal diameter of 4d and the straight length of 12d.) The second set is poured with the oval steel anchorage connector. Figure 8 is the sketch map of the pair of sets. Figure 9 is the specimen.

4.2. Test result analysis

During the test, we used a pull out apparatus to load the specimens until they conform to requirements in Code for Design of Concrete Structures (China Architecture& Building Press, 2010). By way of graded loading, 10% of limit load expected is one class, gradually loading, each stage of loading 1min~2min. After 10 min dead load, we observed the change of load reduction. In this way, we comparatively analyzed the anchorage behaviors of the pair of sets. Table 1 shows the average value of specimens in each set.

(a)

(b)

Figure 7.*The oval steel anchorage connector (a, b)*

Figure 8.*Two types of reinforcing bar*

Figure 9.*The specimen*

Table 1: *Test result*

eel	Steel bar Specification (mm)	Set	Dead Load (KN)	Ultimate Reduction (KN)	Percentage of Differential Pressure Reduction (%)	Actual bar yield (KN)
Ⅲ	25	Anchorage connector	196.4	184.6	0.060	228.2
		90° hook	196.2	178.5	0.090	219.6

The combined usage of relatively large volume of concrete block, high strength concrete, and the pullout apparatus plays a positive role in preventing the formation of concrete cracks. Therefore, either the rebar with mechanical anchorage or the one with 90-degree hooks meets the demands for bond anchorage strength. They both pull off in the pullout test, accompanied by local concrete failure. The anchorage performance of headed steel bar is not lower than the one of 90-degree hooked bar, and can satisfies the requirement in Code for Design of Concrete Structure. Compared to the 90-degree hooked bar, each of the oval steel anchorage connector saves about 1.01kg steel bar, which greatly reduces project cost.

5. Conclusion

The safety and durability of a reinforced concrete structure rests on the bond between rebar and concrete. There exist several shortages for the traditional usage of 90-degree hooked bar, such as interference between hook layout and rebar layout, serous steel congestion, lack of structure space, and insufficient space for installation of hooked beam bar. The oval steel anchorage connector designed in this paper obtained the utility model patent No. ZL201520539243.2. A mechanical performance test is conducted for traditional 90° hooked bars and oval steel anchorage connectors on plain concrete. The results shows that the bar is pulled off and the concrete is locally destroyed in the drawing destruction. Mechanical performance of specimen with oval steel anchorage connectors is better than specimen with 90° hooked bars, while they all satisfy the requirement of Code for Design of Concrete Structure.

The weight of the single oval steel anchorage connector is about 1.01 kg less than that of the 90° hooked bar, which greatly reduces project cost and steel volume, as well as addresses the problem of steel congestion. These advantages of the connector designed fit for the advocacy of "green construction" in modern Chinese society, and comply with our Chinese national conditions. The development of the connector can also promote healthy growth of the construction industry in China.

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