

# Research Review on Embedded Fittings in Reinforced Concrete Structures

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## Abstract

Driven by the rapid development of prefabricated construction and steel-concrete composite structures, reinforced concrete embedded fittings – serving as critical connection elements – have experienced significant expansion in their range of applications. These components play vital roles across diverse fields including building curtain walls and tunnel engineering. This paper systematically reviews and evaluates research achievements by domestic and international scholars concerning reinforced concrete embedded fittings. It outlines current research hotspots and technological advancements, elucidates the structural configurations of various types of embedded fittings, and provides an in-depth analysis of their mechanical performance characteristics under different loading conditions.

## Keywords

**Reinforced Concrete; Embedded Fittings; Prefabricated Structures; Anchorage Behavior; Mechanical Behavior.**

## 1. Introduction

Traditional cast-in-place concrete structures increasingly fail to meet the green and high-quality development objectives of the construction industry due to protracted construction cycles, significant resource consumption, and pronounced adverse environmental impacts [1]. Conversely, prefabricated structures – demonstrating reduced pollution, higher resource utilization efficiency, and enhanced construction productivity – have gained substantial policy impetus by advancing construction industrialization and enabling low-carbon sustainable building practices [2]. Within this context, the structural systems of prefabricated structures and their connection technologies (particularly efficient and reliable joint detailing methods) have emerged as major contemporary research topics [3-4].

Embedded fittings refer to metallic components (typically fabricated from steel reinforcement or plates) pre-installed at designated locations prior to concrete placement [5]. Serving as universally adopted construction elements in building engineering, they primarily transfer loads from superstructures to substructures, ensuring reliable interconnections between both systems. Multiple scholars have conducted in-depth investigations into their mechanical behavior: Wang M. investigated the response characteristics of embedded steel elements within concrete shear walls under tensile loading [6]. Cook R.A. and Klingner R.E. examined the ductile behavior of multi-anchor embedded fittings in concrete and their shear capacity under cyclic loading [7]. Makato Obata elucidated the fracture mechanisms and tensile pullout strength features of anchor reinforcement installed near free edges [8]. Jeremy T. Deason, Gokhan Tunc and Bahram M. Shahrooz focused specifically on the load-transfer mechanisms of embedded fittings connecting outrigger steel beams to concrete walls in hybrid structures subjected to seismic cyclic loading [9]. J. Pertold and R.Y. Xiao collaboratively performed experimental validation and numerical simulation studies on column-base embedded connections. These

investigations collectively establish a robust foundation for understanding embedded fitting performance. [10]

## 2. Commonly Used Embedded Fitting Types in Concrete Section Headings

Embedded fittings in concrete structures exhibit diverse configurations, with the most representative types being composite embedded fittings (comprising anchor plates and anchoring elements) and channel-type fittings. Both categories are extensively employed for securing building equipment, installing decorative components, and on-site assembly of precast elements.

**Composite Embedded Fittings:** The core components consist of an anchor plate (typically steel) and affixed anchors (rebar or studs). Their shear failure modes are critically dependent on connection methods and anchor material properties. The Code for Design of Concrete Structures (GB 50010-2010) specifies two primary design models: (1) Anchor plate with symmetrically configured straight anchors (2) Anchor plate utilizing both symmetrically arranged bent anchors and straight anchors to collectively resist shear forces (see Fig. 1).

**Channel-Type Fittings:** Demonstrate relatively complex failure mechanisms, where failure may result from either concrete breakout or channel-specific failures (e.g., channel deformation fracture).

**Other Fitting Types:** Beyond the principal types, specialized variants address specific engineering demands: (1) U-Shaped Fittings: Fabricated from steel plate-angle steel assemblies to facilitate heavy equipment anchoring with enhanced non-slip stability; (2) Anchor Rod Systems: Provide high load-carrying capacity for securing large-scale walls/slabs, adaptable through parameter adjustments; (3) Plate/T-Bolt Embedded Connectors: Enable rapid column-beam connections in steel-framed industrial buildings; (4) Anchor Bolt Assemblies: Engineered to withstand significant vertical/horizontal loads for critical equipment foundations.

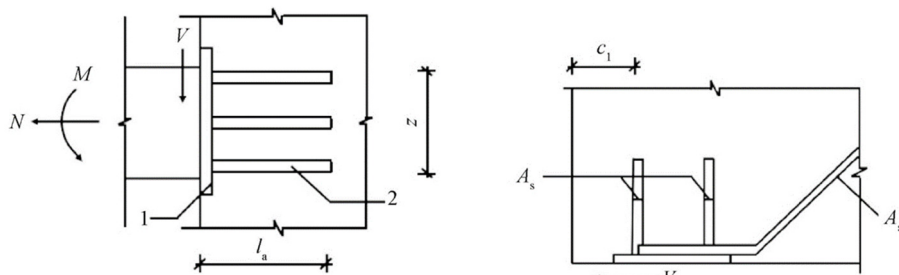


Fig 1. Embedded Fitting with Combined Bent and Straight Anchors Resisting Shear

## 3. Mechanical Property Analysis of Embedded Parts

### 3.1. Response Under Pure Shear Load

When subjected to unidirectional shear force, research has shown that the mechanical response of embedded parts can be roughly divided into three continuous stages:

**Elastic stage (before  $\approx 60\%$  ultimate load):** The external shear force is mainly borne by the compressive reaction force of the concrete at the bottom edge of the anchor plate and the bonding strength between the anchor plate and the concrete interface. At this point, the relative deformation is minimal, and the values of anchor bar stress, concrete bearing force under anchor bar, and interfacial friction force are all low.

**Elastic plastic stage (exceeding 60% ultimate load):** The concrete below the bottom edge of the anchor plate begins to crack due to compressive stress concentration, and the interfacial bonding effect gradually fails. The stress of the anchor bar significantly increases, and the

external shear force gradually changes to be mainly resisted by the compressive force of the concrete under the anchor bar and the friction mechanism between it and the concrete.

**Destruction stage (exceeding 80% ultimate load):** The concrete near the root of the anchor bar reaches its ultimate compressive strength first, resulting in stress redistribution, and the peak compressive stress area migrates into the interior of the concrete. The continued increase in load will lead to a wider range of concrete compression failure. At the same time, the anchor bars themselves can reach their tensile strength and form plastic hinges at the most unfavorable stress points. At this time, the deformation of the embedded parts increases sharply, and the concrete below the anchor bar undergoes local pressure cracking and splits along the shear direction, ultimately losing its bearing capacity. The noteworthy rule is that small diameter anchor bars ( $d \leq 14\text{mm}$ ) are prone to tensile or shear fracture in the welding heat affected zone due to stress concentration; For large-diameter anchor bars ( $d \geq 20\text{mm}$ ), the main manifestation is that the bottom concrete is crushed and damaged, while the reinforcement material itself remains intact (under the premise of qualified welding quality). Therefore, the main factors determining the bearing capacity of embedded parts are often attributed to the strength parameters of anchor bars and concrete.

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### **3.2. Response under Tensile Shear Composite Load**

Under the combined load of tension and shear, the working state of the embedded parts is similar to that of the pure shear state in stages, but exhibits unique features:

**Stress characteristics of anchor bars:** The principal stress is the combination of tensile stress and bending stress. As the load angle  $\alpha$  (the angle between the external load and the anchor plate plane) increases, the dominant effect of tensile stress becomes more pronounced. In the early stage, there is a stress difference between the upper and lower rows of anchor bars, but

in the later stage, due to the redistribution of internal forces, they tend to be even and can reach tensile strength.

**Deformation characteristics:** Horizontal cracks usually appear more widely at lower load levels (about 50% of the limit value). The horizontal displacement during the final failure stage increases significantly compared to the pure shear state (up to 5-7mm), while the vertical displacement is similar or slightly larger (except at a load angle of 90 °).

**Load angle influence:** The test results confirm that load angle is a key parameter affecting the bearing capacity. Within the range of  $\alpha \leq 90^\circ$ , the bearing capacity increases with the increase of  $\alpha$ , which is due to the transition of the bearing mode from shear dominated to tensile dominated, and the pure tensile bearing capacity of such specimens is usually higher than that of pure shear. The relationship between the bearing capacity and the load angle follows a nonlinear law.

**Anchor bar anchorage length:** The effective length of the anchor bar under tensile stress is extended compared to the pure shear state, and its anchorage length requirement is positively correlated with  $\alpha$  (usually distributed between 15d and 20d). No pull-out failure of the reinforcement was observed in the relevant tests (anchorage length  $\geq 20$  days, load angle  $\leq 60^\circ$ ). Suggested anchor length estimation can refer to the formula:  $l_m \approx 15d (1 + \sin \alpha)$ .

**Anchor plate function:** The strength and stiffness of the anchor plate are crucial for the efficiency of tension transmission. In practical design, it is feasible and conservative to calculate the strength and stiffness of a single directional plate with both ends fixed to anchor bars. The effect of adding stiffeners is equivalent to that of ribbed plates, and the measured deformation is minimal.

**Low cycle repeated load characteristics:** Unidirectional reciprocating tensile shear action is more advantageous than pure bending or pure shear repeated action. The bearing capacity repeatedly pulled and cut shall not be less than 0.74-0.98 times that of monotonic loading.

### 3.3. Response under Bending Shear Composite Load

The performance of embedded parts under bending shear loads is highly dependent on the force arm ratio  $e/Z_0$  ( $e$  is the eccentricity,  $Z_0$  is the internal force arm): the force arm ratio is linked to the failure mode:

$E/Z_0 \leq 0.4$ : The failure mode is similar to pure shear and is controlled by the concrete crushing in the compression zone. Compressive anchor bars are mainly subjected to bending stress, while tensile anchor bars are mainly subjected to tensile force (including bending moment contribution).

$E/Z_0 > 0.7$ : The dominant failure mode shifts to the tensile anchor bar breaking, and its stress can reach the ultimate tensile strength. The stress level of the compressed anchor bar is relatively low.

$0.4 < e/Z_0 \leq 0.7$ : The failure mode exhibits transitional characteristics, or it may be concrete crushing or anchor bar tensile failure.

The force arm ratio is related to displacement: the overall vertical displacement is smaller than that in the pure shear state. The key feature is the horizontal displacement at the root of the tension anchor, which significantly increases with the increase of  $e/Z_0$ . The vertical displacement decreases slightly with the increase of  $e/Z_0$ .

**Force arm ratio and compression zone characteristics:** The compression zone of concrete is mainly concentrated below the bottom edge of the cow leg, and the compressive stress becomes more concentrated and increases with the increase of  $e/Z_0$ . The pressure center in the compression zone is usually slightly lower than the bottom edge of the cow leg. The actual calculation can take the internal force arm  $Z_0 \approx Z$  ( $Z$  is the distance from the center of the tension anchor bar to the bottom edge).

Repetitive bending shear characteristics: This working condition is the most unfavorable, as it simultaneously bears repeated shear forces and bending moments (or tension compression). Its average bearing capacity under low cycle repeated loads is only about 0.67 times that of the monotonic bending shear state.

#### 4. Conclusion

The technology of reinforced concrete embedded parts has established a relatively complete research and application system in the international academic and engineering fields, and the relevant experimental research, theoretical models, and design specifications have a high level of maturity. In contrast, China still needs to strengthen in this field: the design specifications and application standard system of embedded parts products still need to be improved and unified; The theoretical coverage of bearing capacity calculation in current standards is not comprehensive enough, and some articles focus more on guiding structural measures, lacking systematic theoretical support; In addition, there is still room for improvement in the diversity of optional embedded parts products in China, and the understanding of their failure mechanisms and their collaborative performance (interaction mechanisms) with the main structural framework is not sufficient. Corresponding refined and executable design regulations also need to be established. Therefore, deepening theoretical exploration and sufficient experimental verification of the embedded parts system is an urgent direction for future research and development.

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