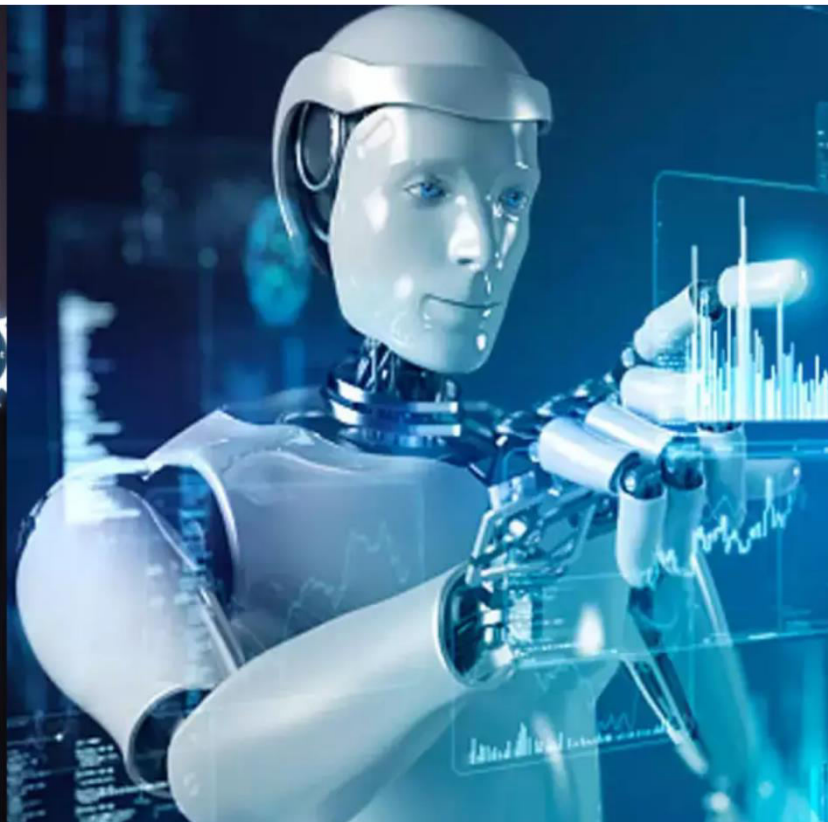




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# Comparative Analysis of Two Detachable Connectors (HSFGB and ENBC) for Steel-Concrete Composite Beams

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**ABSTRACT:** This paper briefly describes the significance of steel-concrete composite beams in modern architecture and bridge engineering, introduces two detachable connectors, HSFGB and ENBC, and aims to conduct a comparative analysis of these two connectors in terms of force mechanism, failure mode, and design methods, with the expectation of providing references for engineering design.

**KEYWORDS:** Steel-concrete composite beams, HSFGB connectors, ENBC connectors, Force mechanism, Failure mode, Design method.

## I. INTRODUCTION

With the in-depth implementation of the sustainable development concept in the construction industry, higher requirements have been put forward for the disassemblability and reusability of building structures[1]. As a key component for achieving the sustainable development of steel-concrete composite beams, the performance of detachable connectors directly affects the structural performance, service life and the efficiency of recycling and reuse after demolition of the composite beams. Steel-concrete composite beams using detachable connectors can be conveniently and quickly dismantled when the building structure reaches its service life or needs to be renovated, reducing the generation of construction waste, lowering the impact on the environment, and at the same time realizing the recycling and reuse of materials such as steel and concrete, which is in line with the development trend of resource conservation and environmental protection.

HSFGBC (High-Strength Friction-Grip Bolts Connector, high-strength friction grip bolt connector) and ENBC (Embedded Nut Bolts Connector, embedded nut bolts connector) are two common types of detachable connectors. They have significant differences in connection methods, working principles, and performance characteristics. In-depth research on these two types of detachable connectors is of great practical significance for optimizing the structural design of steel-concrete composite beams, improving their performance and reliability. Through comparative analysis, their respective advantages and disadvantages as well as applicable scenarios can be clearly identified, providing a scientific basis for the selection of connectors in engineering practice. This can enhance project quality, reduce project costs, and promote the sustainable development of prefabricated buildings in civil engineering.

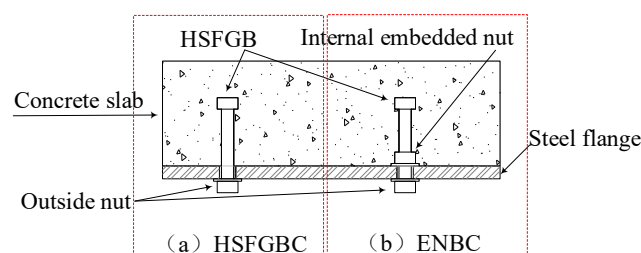


Fig. 1. Two Typical Structural Forms of High-Strength Bolt Connections for Composite Beams (a) Friction-type shear connector (HSFGB) (b) Embedded nut type shear connection (ENBC)

II. COMPARISON OF THE MECHANISM OF FORCE APPLICATION AND THE FORM OF FAILURE

The HSFGBC connection piece is based on the strong preload force exerted by the bolts, which generates compressive force between the contact surfaces of the connected components, thereby forming a large friction force perpendicular to the screw direction. This enables the steel beam and the concrete slab to work collaboratively. The connection structure is shown in Figure 1(a). By summarizing and analyzing the existing research results[2-3], it can be found that the shear resistance of the HSFGBC connection can be divided into five stages as shown in Figure 2:.

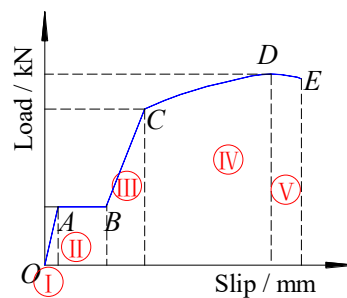


Fig. 2. Division of Five Loading Stages for HSFGBC

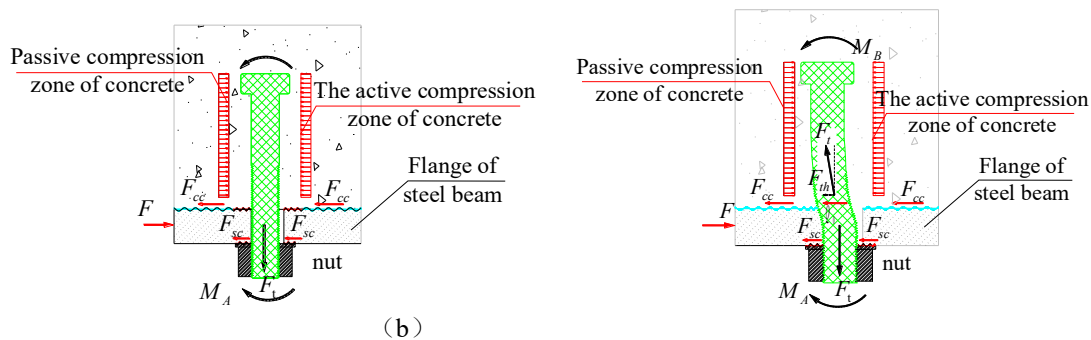


Fig. 3. Load Transfer Mechanism of HSFGBC (a) Stages I to III (b) Stages IV to V

**Stage I: Friction-Dominated Phase (OA Segment)**

Due to the anti-slip action between contact surfaces, the load-slip curve remains in the linear phase. In this stage, the force resisting the external load  $F$  is primarily provided by the friction ( $F_{sc}$ 、 $F_{cc}$ ) between the steel beam, nut, and concrete slab. The slip amount is minimal, but the stiffness is high (as shown in Figure 3(a)).

**Stage II: Sliding Phase (AB Segment)**

In this phase, clearances exist between the steel beam bolt hole walls and the bolt shank, as well as between the concrete hole walls. After the friction ( $F_{sc}$ 、 $F_{cc}$ ) reaches its limit, relative sliding begins between the steel beam and concrete, causing the load growth to slow down or almost stop. The cumulative slip amount in this stage is approximately equal to the distance between the bolt and the concrete hole wall.

**Stage III: Elastic Loading Phase of Bolt Shank (BC Segment)**

Once the bolt shank comes into contact with the concrete and steel beam, it gradually starts to provide shear resistance in addition to friction. As the slip amount increases, the bolt shank tilts, generating a horizontal force along the sliding direction derived from the bolt’s axial force, which contributes to the shear capacity.

**Stage IV: Elastoplastic Loading Phase of Bolt Shank (CD Segment)**

The force mechanism in this stage is similar to Stage III, but due to steel yielding, the force growth no longer



follows a linear pattern. As the load increases, plastic deformation of the bolt shank becomes more significant (as shown in Figure 3(b)).

**Stage V: Failure Phase (DE Segment)**

When the external load exceeds the connection’s resistance capacity, failure occurs. If the concrete slab strength is lower than C30, crushing failure of the concrete typically occurs. If the concrete strength exceeds C50, shear failure of the bolt generally occurs.

Embedded Nut Shear Connector (ENBC) is an improvement over the HSFGB connector, with a tightening nut added to the side of the steel beam flange adjacent to the concrete slab (as shown in Figure 1(b)). By incorporating the embedded nut, this connector achieves two key functions: 1) Fixing the pre-tensioned high-strength bolt connector to prevent tilting and misalignment of the bolt shank during construction; 2) Effectively reducing bending deformation of the bolt shank to enhance connection stiffness. The load transfer mechanism of ENBC also differs significantly from that of friction-type high-strength bolt connections. Existing research results indicate that the load behavior of ENBC shear connections can be divided into the following four stages as shown in Figure 4[4]:

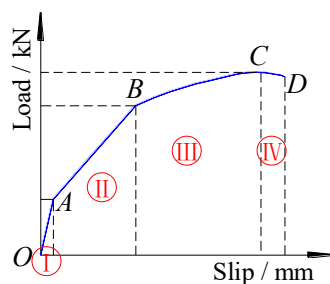


Fig. 4. Division of Four Loading Stages for ENBC

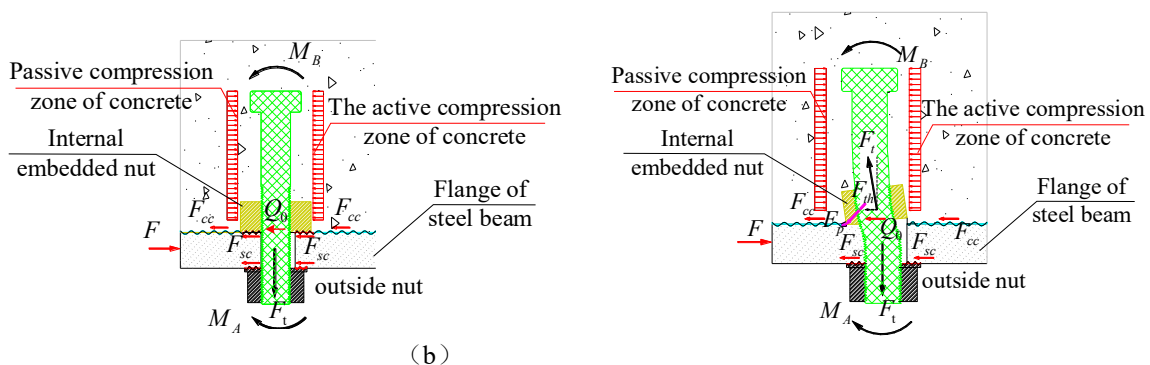


Fig. 5. Load Transfer Mechanism of ENBC (a) Stages I to II (b) Stages III to IV

**Stage VI: Friction-Dominated Phase (OA Segment)**

In this stage, the load behavior of the connection is fundamentally consistent with that of friction-type high-strength bolt connections. The resistance is primarily derived from the friction forces  $F_{sc}$  and  $F_{cc}$  between the steel beam, nut, and concrete slab. Due to the embedded nut in the concrete flange, friction forces exist on both sides of the steel beam flange under bolt pre-tension (as shown in Figure 5(a)). At this stage, the resistance and initial stiffness of ENBC connections with the same diameter are greater than those of HSFGB-type connections.

**Stage VII: Elastic Loading Phase of Bolt Shank (AB Segment)**

As slip occurs in the ENBC connection, the bolt shank begins to provide shear resistance  $Q_0$ . The load behavior is similar to that of HSFGB-type connections. Although slip increases in this stage, it remains significantly smaller

than that of HSFGB-type connections. The overall load-slip curve exhibits no distinct slip plateau, and the bolt shank remains in the elastic state.

**Stage VIII: Elastoplastic Loading Phase of Bolt Shank (BC Segment)**

The most prominent feature of this stage is that the embedded nut penetrates into the steel beam flange, generating cutting resistance. The bolt enters the elastoplastic state, experiencing significant bending deformation (as shown in Figure 5(b)). With the addition of cutting resistance, the connection’s load-carrying capacity increases notably, but deformation becomes more pronounced, and stiffness continues to decline. The load-slip curve of the connection demonstrates nonlinear behavior.

**Stage IX: Failure Phase (CD Segment)**

The ultimate failure modes of ENBC connections are similar to those of HSFGB-type connections, including two primary forms: 1) Bolt shear failure when the shear resistance of the bolt reaches its limit; 2) Concrete crushing failure when the concrete strength is insufficient.

Based on the comparative analysis above, the main performance comparison of the two connection types is summarized in Table 1.

Table 1 Performance Comparison of ENBC and HSFGB Connections

Performance Indicators	HSFGB	ENBC
Load-Carrying Capacity	Low (approximately 79% of ENBC)	High (close to stud connectors)
Stiffness	Low	High (99% higher than HSFGB)
Slip Amount	Large (3–4 times that of ENBC)	Small (no distinct slip plateau)
Demountability	Excellent (no pre-embedding required)	Excellent (quick disassembly)
Construction Convenience	Convenient (installation via pre-drilled holes)	High prefabrication precision required
Cost-Effectiveness	Low (but requires increased quantity)	High (high material cost)

**III. COMPARISON OF DESIGN SHEAR CAPACITY**

As an important index for the assessment of the high strength connector shear performance, the ultimate shear resistance should be determined within the design procedures. However, the shear capacities of a connector are different for various failure modes, and the actual ultimate shear strength depends on the weakest one (corresponding to the most likely failure mode). Therefore, the designers should check all possible modes of failure for a ENB, e.g., connector fracture, concrete pry-out, and hole elongation. Based on the existing research results, Table 2 conducts a comparative analysis of the calculation methods for the shear bearing capacity of the connection between HSFGB and ENBC.

Table 2 Calculation of shear capacity of two types of connection

connector type	Source of the formula	computational formula	Formula specification
HSFGBC	ACI 318 (2019)[5]	$P_{(1)} = 0.6A_s f_u$	$A_s$ is the effective cross-sectional area of the bolted shear plane; $f_u$ is the ultimate tensile strength of bolts.
	Eurocode 3 (2010)[6]	$P_{(2)} = \alpha_v A_s f_u$	$\alpha_v$ is the coefficients related to bolt grades, equalled to 0.6 for Grade 4.6, 5.6 and 8.8, and 0.5 for Grade 4.8, 5.8, 6.8 and 10.9.
	Kwon[7]	$P_{(3)} = 0.5A_s f_u$	Suitable for normal concrete with compressive strength less than 25 MPa
	Zhang[8]	$P_{(4)} = 0.62A_s f_u$	Suitable for Grade 10.9 HSFGBs embedded in C50 normal concrete
	Yang[9]	$P_{(5)} = 0.6\alpha_1 A_s f_u$	Suitable Grade 8.8 HSFGBs in groups in C50 normal concrete, $\alpha_1$ is the coefficient considering multiple

			bolts effect, equalled to 1.0 for grouped HSFGBs arranged in double rows, and 0.9 for three rows condition.
ENBC	Kwon[7]	$P_{(2)} = 0.5A_s f_u$	Suitable for Grade 10.9 DENB (double embedded nut bolts in normal concrete with compressive strength less than 25 MPa)
	Chen[4]	$\begin{cases} P_{(2)} = F_c \leq F_{EN} \\ F_c = 0.605\phi_s A_b \sqrt{f_{cd} E_c} \\ F_{EN} = 1.25\phi_s A_b f_u' \end{cases}$	$F_u$ is the design shear capacity of the connection; $F_c$ is the concrete-controlled partial design shear capacity; $F_{EN}$ is the bolt-controlled partial shear capacity considering the cutting action between the nut and steel beam flange; $\phi_s$ is the partial safety factor for resistance. When the diameter-to-width ratio of the embedded nut is between 1.4 and 1.8, $\phi_s = 1.0$ ; otherwise, $\phi_s = 0.76$ ; $A_b$ is the effective cross-sectional area of the bolt (mm <sup>2</sup> ); $f_{cd}$ is the design value of concrete compressive strength (MPa); $E_c$ is the elastic modulus of concrete; $f_u'$ is the design value of the bolt material's tensile strength (MPa).

It can be clearly seen from the comparative analysis of the bearing capacity calculation formulas in the table that no unified calculation formulas have been established for the shear bearing capacity of HSFGB and ENBC connections. The applicable scope of existing formulas is limited, and further in-depth research in this area is still needed.

conclusion

Through a comparative analysis of the load transfer mechanisms, failure modes, and bearing capacity design methods of HSFGB and ENBC demountable connections, it is found that ENBC connections exhibit greater connection stiffness and shear bearing capacity than HSFGB connections, though the former are relatively more complex to construct. Existing calculation methods for shear bearing capacity vary significantly and have limited applicability, indicating that the design calculations for connection shear resistance require further in-depth research.

#### IV. ACKNOWLEDGEMENTS

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