

Overview of Research on Shear Capacity of Self-tapping Screw Assembly Connection

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ABSTRACT: Taking the shear connection performance of self-tapping screws as the research object, the mechanical mechanism and several failure modes of self-supplement screws are briefly described. The basic methods of experimental research on the shear connection capacity of self-tapping screws are summarized. The design method of the self-tapping screw fastening steel plate-steel plate connection in the United States and Australia, and the research status of the shear connection performance of the self-tapping screw fastening steel plate-non-metal plate are summarized and analyzed. Finally pointed out the problems and the work that needs further research.

KEYWORDS: self-tapping screws; shear bearing capacity; steel plate-steel plate connection; steel plate-non-metal plate connection.

I. INTRODUCTION

With the improvement of the industrialization level of buildings and the promotion of the concept of “green energy conservation”, the development of fabricated light steel structural systems has received more and more attention. In the low-rise and multi-layer light steel structure system, the self-tapping screws are used as a main connecting piece, usually adopting the self-tapping self-drilling single-face fastening connection method, and the steel plate and steel plate, steel plate and wood board and other non-metal plates are tight. Solid together, it is widely used in metal roofing, steel-wood composite floor panels, steel-wood composite wall panels and beam-column connections. As with the way of bolt tightening, the shearing, tensioning and pulling-shearing combined forces are also the three typical methods of self-tapping bolts. Among them, the shearing connection is the most widely used. In this paper, the shear connection performance of self-tapping screws is taken as the research object. The design calculation theory and bearing capacity performance research of this type of connection are reviewed and reviewed, which provides a reference for the popularization and application of this type of connection.

II. FORCE TRANSMISSION MECHANISM AND FAILURE MODE OF SELF-TAPPING SCREWS BEING SHEARED

Due to the presence of the screw, the self-tapping screw can function as a tap. After the screw is screwed into the connecting plate, the connecting plate can be fastened together without the need of a nut. The typical self-tapping screws are subjected to shear connection. The force transmission mechanism and the type of force transmission mechanism of ordinary bolts rely on the self-shearing of the screws, the pressure of the screws and the top contact surface of the connecting parts to transmit the connecting parts. Shear force between.

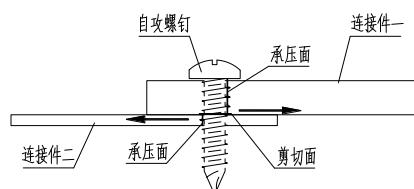


Fig. 1. Basic failure mode of self-tapping screw connection

Although the force transmission mechanism of the self-tapping screw shear connection is similar to that of the ordinary bolt, since the connecting plate usually has a small thickness, the connection failure mode is not only the common screw shearing of the common bolt, the hole wall crushing and the net cross-section damage of the connection, but also the inclination of the screw. Pulling out has become a common failure mode of this connection. Figures 2 and 3 show several typical failure modes of steel plate-steel plate and steel-OSB plate self-tapping screws.

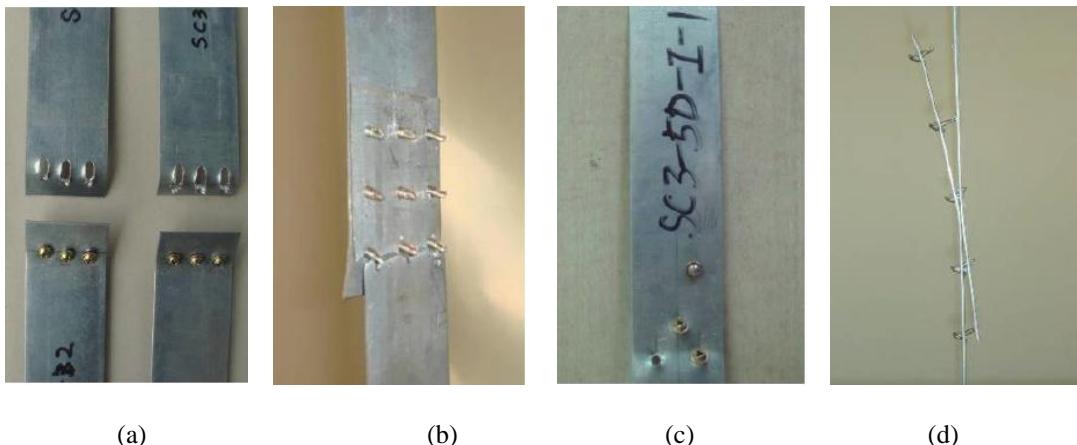


Fig. 2. Basic failure mode of self-tapping screw fastening steel plate to steel plate connection (a) Pressure reduction of the hole wall (b) Net section failure of the plate (c) Screw shearing (d) Pulling the screw obliquely

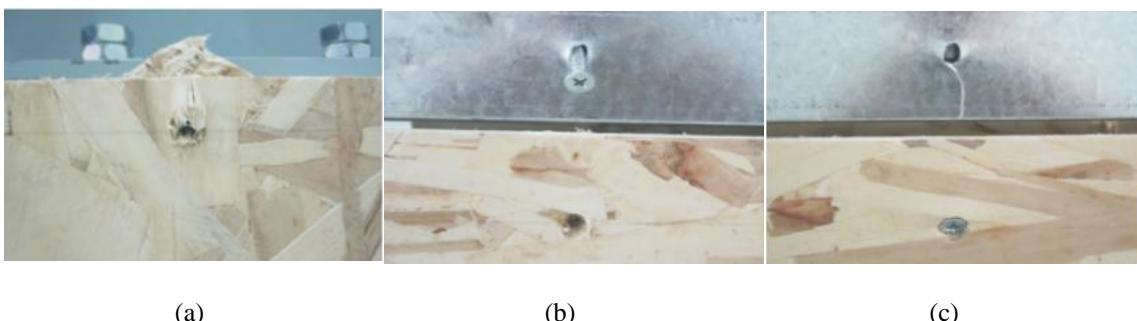


Fig. 3. Basic failure mode of self-tapping screwfastening steel plate to OSB plate connection (a) OSB board end tearing (b) Screw is pulled out from the OSB board (c) Screw slippage

III. DESIGN AND CALCULATION OF THE SHEAR CONNECTION OF SELF-TAPPING BOLTS IN VARIOUS COUNTRIES

The pressure-bearing surface of the self-tapping bolt and the connecting plate is complicated. The current research mainly focuses on the design and calculation of the steel-steel connection, and the force calculation mode is not perfect at present. Based on the results of the experimental research, the national regulations have made relevant regulations for the design calculation of the self-tapping screw steel plate-steel connection capacity.

(1) Chinese Code

China's current national standard "Technical Specifications for Cold-Formed Thin-Wall Steel Structures" (GB50018-2002)[1] is mainly based on the research of thin plates (thickness 2-6mm) with lower strength of Q235 and Q345. The design method for the shear bearing capacity of a single joint when the joint with self-tapping screws is sheared as follows:

$$\text{as } \frac{t_1}{t} = 1 , \quad N_{vf} = 3.7\sqrt{t^3 \cdot d \cdot f} , \quad \text{and } N_{vf} \leq 2.4t \cdot d \cdot f \quad (1)$$

$$\text{as } \frac{t_1}{t} \geq 2.5, \quad N_{vf} = 2.4t \cdot d \cdot f \quad (2)$$

and when in the between, take the middle interpolation. Where f is the tensile strength design value (N/mm²) of the joined steel plate; d is the screw diameter (mm); t_1 is the thickness (mm) of the thinner plate (the steel plate on the contact side of the nail head); t is the thickness (mm) of the thicker plate (the plate on the side of the nail head or the plate on the nail tip side).

(2) Japanese specification

The calculation of the Japanese steel structure design specification[2] for the self-tapping screw shear connection is as follows:

$$\text{for single screw shear failure load } P_s = f_r A = f_r \frac{\pi d^2}{4} \quad (3)$$

$$\text{for pressure-damaged load of wall panel: } P_c = \alpha f_c t d \quad (4)$$

In the formula, f_r is the shear strength for self-tapping screws, f_c is the permissible local compressive bearing capacity for wall panels (N/mm²); t is the thickness of the wall panel; When the screw is connected to the steel plate from the wall panel side, $\alpha = 1.0$.

(3) US, Australian and New Zealand specifications

The calculation methods for the load-bearing connection of self-tapping screws are basically the same in the United States[3], Australia and New Zealand[4]. The shear bearing capacity of a single bolt is determined as follows:

when $\frac{t_1}{t} = 1$, V_b take the minimum value of equation (5) to equation (7):

$$V_b = 4.2\sqrt{t_2^3 d_f} f_{u2} \quad (5)$$

$$V_b = 2.7t_1 d_f f_{u1} \quad (6)$$

$$V_b = 2.7t_2 d_f f_{u2} \quad (7)$$

when $\frac{t_1}{t} \geq 2.5$, V_b take the minimum value of equation (5) to equation (7);

And when in the between, take the middle interpolation.

In the equation, f_{u1} is the tensile strength of the steel plate adjacent to the screw head; f_{u2} is the tensile capacity of steel plates not adjacent to screw heads (N/mm²). t_1 is the thickness of the steel plate adjacent to the screw head (mm); t_2 is the thickness of the steel plate not adjacent to the screw head (mm); d_f is the nominal diameter of the screw.

(4) European normative calculation method

European specification (EC3) [5] single bolt shear capacity is determined by the following method:

a) Pressure bearing capacity

$$F_{b,Rd} = \frac{\alpha f_u d t}{\gamma_{M2}} \quad (8)$$

b) Net section bearing capacity

$$F_{n,Rd} = \frac{A_{net} f_u}{\gamma_{M2}} \quad (9)$$

c) Shear failure bearing capacity

$$F_{v,Rd} \geq 1.2 F_{b,Rd}, \text{ 且 } F_{v,Rd} \geq 1.2 F_{n,Rd} \quad (10)$$

Where t is the thickness of the thinner plate when the screw is connected; t_1 is the thickness of the thicker plate when the screw is connected; d is the nominal diameter of the screw connection; γ_{M2} is Influence coefficient, take 1.25; f_u is the ultimate bearing capacity of screw joints; α Value as follows: when $t = t_1$, $\alpha = 3.2\sqrt{t/d}$, and $\alpha \leq 2.1$; when $t_1 \geq 2.5t$, $\alpha = 2.1$; when $t < t_1 \leq 2.5t$, taking the linear interpolation. For the design shear capacity of the overall connection, take the minimum of equation(8), equation(9) and equation(10).

IV. TEST METHOD FOR BEARING CAPACITY OF SELF-TAPPING BOLTS WITH SINGLE SHEAR CONNECTION

Aiming at the experimental research on the bearing capacity of self-tapping screws, the current experimental research methods are also available in various ways. Figure 4 summarizes three common steel-steel-plate joint test methods. In the figure, L is the joint of the connecting plates. Total length (excluding the clamping portion); Ls is the length of the single connecting plate (excluding the clamping portion); W is the width of the connecting plate; e is the end distance; t is the thickness of the connecting plate. During the test, the following points should be taken into account:

- 1) In order to ensure that the load applied by the device in the test passes through the center of the lap joint, a spacer should be placed at the test chuck. In order to control the failure mode of the connection to the screw being cut, the connecting plate in the test shall be steel plate; and the thickness of the steel plate shall be greater than the diameter of the self-tapping screw; the self-tapping screw shall have at least 3 turns of thread through the steel plate.
- 2) For the connecting steel plate in the test piece, the end distance and the margin of the self-tapping screw shall not be less than 3 times the screw diameter and greater than 20 mm; the width of the connecting plate shall not be less than 6 times the screw diameter and greater than 40 mm. The length of the single connecting plate (excluding the clamping part of the chuck) should be 100mm, and the total length of the connecting plate after lap jointing (excluding the clamping portion of the chuck) should not be less than 160mm. When the steel plate is thick, in order to ensure that the self-tapping screw can be fastened in place, the hole should be pre-opened on the steel plate, and the nominal diameter of the screw with a diameter of 0.9 times is pre-opened.

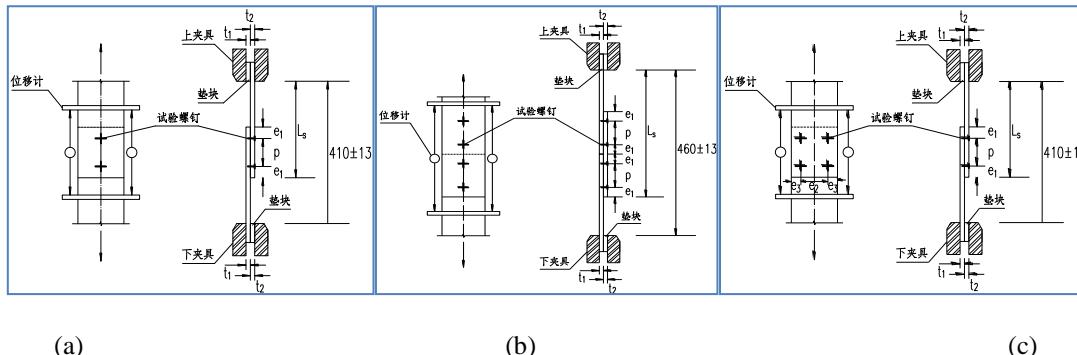


Fig. 4. Basic test method for bearing shear capacity of self-tapping screws (a)Single row two nail connection; (b) Single row four nail connection
(c) Double row four nail connection

V. RESEARCH STATUS OF SHEAR CONNECTION OF THIN-WALLED STEEL SHEETS AND NON-METAL PLATE SELF-TAPPING SCREWS

In addition to the fastening of lap connections between steel plates and steel plates, self-tapping bolts are often used for lap fastening of steel to non-metal plates. In view of the shear capacity of lap connection of steel to non-metal plates, scholars at home and abroad have also conducted extensive research.

FIORINO et al [6] studied the shear performance and failure mode of self-tapping screws connections of OSB to GWB plate, pointing out that the plate type, loading direction, end distance and loading mode have different effects on shear strength and stiffness.

For the self-tapping screw connection between the calcium silicate wall panel and the cold-formed thin-walled steel keel, NITHYADHARAN et al [7] discussed the in-plane shear strength under different loading methods, and the influence of failure mode, screw end spacing and plate thickness on shear behavior based on experimental research. The load-displacement curve of the shear connection and the calculation formula of the ultimate shear strength are given.

YE et Al [8] conducted a test study on a total of 51 sets of test pieces which connected to the steel plate to GTB, BMG, CSB, and OSB through self-tapping screws, and the following conclusions were drawn: Obvious brittle failure will occur on the CSB board; the shear bearing capacity and deformation resistance of the specimen under monotonic loading are higher than the hysteretic loading; the shear bearing capacity is obviously affected by the end distance of the screw, except for CSB board, the loading direction has little effect on shear resistance.

The test results of Dong Jun et al.[9] showed that the performance of the self-tapping connection between the NAFC,LCFC plates and the steel keel has a clear correspondence with the performance of the plate, and the bearing capacity is mainly controlled by the bearing strength of the self-tapping bolt hole side plate.

Teng Xuefeng et al.[10] conducted a static test on a full-scale model of cold-formed thin-walled steel-OSB board composite floor, and the results show that, the self-tapping screw-connected crimped C-shaped steel and OSB board can work together and have a high Bearing capacity and better ductility.

Shi Yu et al. [11-12] test research shows that the bearing capacity of self-tapping screw connection steel plate-oriented particle board is higher than that of steel plate-gypsum board connection, and they are all directional; the shear bearing capacity of the specimen will increase with the thickness of the board Increase, increase the screw tip distance, but increasing the loading rate will reduce the shear bearing capacity of the specimen. A design method of the shear bearing capacity of the connection between a steel plate and a non-steel for single self-tapping screw is given based on the experimental study.

Hao Jiping [13] found through experiments that, for the self-tapping screws connection of the steel plate and the OSB plate, the excessive tilt failure of the self-tapping screw and the splitting failure of the OSB plate is the main failure mode; while, for connection between steel plate and calcium silicate plate, the net cross-section of the calcium silicate plate, the main failure mode is net section failure of the calcium silicate plate. The influence of the thickness of the steel plate, the stress direction of the plate, the loading speed, and the screw end distance on the specimen's shear bearing capacity is similar to the literature [11].

Through the experimental study on the mechanical properties of the self-tapping screws connection between the cold-bent thin-walled steel keel and OSB plates subjected to monotonous and low-cycle reciprocating shear loads, Li Yuanqi et al [14] analyzed the influence of the loading rate, panel layout direction, screw end distance and keel wall thickness on the seismic performance of this type of connection. The results of the study show that: the test loading rate and the orientation of the OSB board have no significant effect on its shear performance; as the end distance of the screw increases within the range of the test, the load and deformation capacity are greatly improved; as the wall thickness of the keel increases, the peak load has increased to a certain extent, while the deformation capacity has no obvious change rule. Finally, based on the test results, a restoring force model for the self-tapping screws connection between the steel keel and the OSB plate was established, which provided the basic parameters for the numerical simulation of the keel composite wall and the overall seismic performance of the building.

In summary, domestic and foreign scholars have conducted in-depth research on the design method of the shear bearing capacity of self-tapping screws. However, due to the complex hole wall contact surface between self-tapping screws and connected members, it has caused greater difficulty for theoretical analysis which also make it difficult to form a unified self-tapping screw calculation model and calculation formula so far. Although there are design calculation methods related to the bearing capacity of self-tapping screws in national codes, they are basically determined according to the test results.

VI. CONCLUSION

In retrospect, the research on the bearing capacity of self-tapping screws with shear connection shows that there are many experimental studies on the shear joint performance of steel-steel plates. The national regulations also address the relevant regulations on the performance of this type of joint shear capacity. There has been relatively little research on steel-non-metal plate joints for shear joints. For example, for the steel-wood board shear connection, there is no perfect design calculation method at present, and as the most basic assembly connection method of the steel-wood composite structure, the analysis and analysis of the steel-wood board connection performance is of great significance. For the shear connection performance of self-tapping screws, it is recommended to strengthen the research in several aspects in the future:

- (1) Research on the bearing capacity performance and energy dissipation capacity of self-tapping screws under reciprocating load. At present, the relevant research situation is not mature, and further research is needed to meet the actual needs of the project.
- (2) For the bearing capacity of steel-non-metal plate connection, due to the complex performance of the connecting plate, there is no unified and mature design calculation method, and a large number of systematic experimental research and analysis are needed.
- (3) The performance analysis of the self-tapping bolt's shear capacity is mainly based on experimental research. The current experimental research method is mainly considered for the one-way force situation, but there is no standard test for the determination of the connection performance under the reciprocating force. The research method, if the stress performance under the reciprocating load of the self-tapping bolt is obtained simply and accurately, the experimental research method needs to be further analyzed and discussed.



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