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# Structural behavior of self – drilling screws applied in steel structures of prefabricated buildings

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**Abstract.** Since the fast development of prefabricated building industry facilitate the light thin – walled steel application in both low residential building and fast construction, better understanding of the labour intensive fabrication of connection indicates the problems of optimized connection design and reduced manufacturing cost can be addressed. Several parameters such as number of screws and configurations of the screw layout were varied to study the impact on shear strength. Since the connection strength governs the structural behavior of the truss system which is the main part of modern thin – walled steel structure, the connection strength is calculated according to the American Iron and Steel Institute (AISI), Euro code, and Chinese specification respectively. The main failure mode occurred in self – drilling screw connections are found to be the tilting and bearing failure based on 84 single lap shear test. All testing specimens have experience four stages. When the spacing is fixed to certain number and the screw is less than six, the effect of configuration patten on the resistance capacity is very limited. In contrast, if the screw number is more than six, certain patten layout could lead to better overall strength compare with normal layout patten and the group effect factor is becoming as a constant. The strength of connection can be increased by enlarging the screw spacing with certain range.

## 1. Introduction

The first set of design equations for screw connections under shear, pull out and pull over failure was formulated by Peköz<sup>[1]</sup> with the data of more than 3500 tests. Different failure modes for steel to steel connection can be calculated from the provision released by the American Iron and Steel Institute<sup>[2]</sup>. Daudet and Laboube<sup>[3]</sup> conducted 264 shear test of screw connections to investigate the shear behavior of self – drilling screws and to compare their performance between normal ductility steel and steel with low ductility. In 2002, Laboube and Sokol<sup>[4]</sup> performed investigation of 200 single lap screw connections which varied in fastener configurations, spacing of screws, screw numbers. It is find that the connection strength decreased with the decrease of the distance between screws. Increasing number of the screws results in induced decrease in strength per screw which is defined as “group effect”. In 2003, Rogers, C.A, D. Yang and G.J. Hancock<sup>[5]</sup> studied stability and ductility of thin - walled high strength steel member and connections and found that 0.75 reduction factor taking into account the low ductility for high strength steel which specified in AISI<sup>[2]</sup> is not necessary. The test data indicates that safety factor specified in AISI<sup>[2]</sup> may not produce safe design if incorrectly interpreted. M.R. Bambach and K.J.R. Rasmussen<sup>[6]</sup> carried out investigation of 120 single lap screw connections which under combination of bending and shear loads since construction tolerance is



inevitable in practical construction. Parameters are also studies including screw configuration, overtightening, material type, thickness, screw size and rate of loading. An empirical equation is proposed for both American specification and Australian provisions regarding shear capacity of single screw connection, which apparently illustrated that screw capacity decreases linearly with increasing separation distance. Reynaud and Dean<sup>[7]</sup> studied the strength of the connection based on the strength of the steel sheet elements and strength of screw from which the screw are manufactured by three independent manufactures where indicates the strength of screw is significantly lower than the strength of connected components. S.S. Fairuz and H.H. Lau<sup>[8]</sup> also investigate the influence of screw spacing on the strength of self – drilling screw connections for the high strength cold – formed steel, in which number of screw, group effect reduction and spacing are varied. The experimental study demonstrated that connection strength increase proportionally to the number of screws in connection without expected group reduction outcome even the screw spacing is more than 3d. Furthermore, connection strength shows decreasing tendency when spacing is less than 3d which is in contrary to the finds made by Laboube and Sokol<sup>[4]</sup>. Francka and Laboube<sup>[9]</sup> implemented parameter studies by varying screw size, thickness of steel sheet elements, tensile strength and ductility among 84 tests, which resulted in two interaction equations to determine design capacity of screw connection. Corner<sup>[10]</sup> examined experiments on cold – formed steel in 2014 and found that screw tilting greatly affect the limit states of the connection. Failure mechanism as tilting was determined by pitch of fastener and thickness of the steel sheet, which was in direct contacted with screw head. Recommendation is provided to consider thickness of the steel sheet over screw pitch instead of the ratio between the thickness of the steel connected components due to the indication that specification in AISI predicts limit states inaccurately. At same year, another research is made by Haus<sup>[11]</sup>, who evaluated the performance of different types of screws in cold – formed steel sections. The testing of single screw connection is subjected to tension under monotonic and cyclic loading conditions. The typical load – displacement relationship of different failure modes of screw involved in three connection pairs with two different orientations was obtained. At the early stage, tilting occurs followed by tearing and bearing until screw pull out with induced final breaking of screw. In 2017, D.H. Bondok and H.A. Salim<sup>[12]</sup> performed investigation regarding failure capacities of cold – formed steel roof truss end – connections. The experimental program presented testing of 24 connection tests which includes symmetric and non – symmetric conditions determining failure capacities of end connections in truss under shear and tension loads. The ultimate failure of the connection was not due to the actual failure mode, but multiple modes of failure instead. Interaction of different failure modes is observed also in this experiment.

## 2. Experimental investigation

In accordance with test set up in provision of AISI<sup>[2]</sup>, a total of 84 test specimens of single lap connection were made up. The thickness of the test specimen is 1.5mm with involved self – drilling screw diameter 4.2 mm. The material property of the steel plate is derived from the tensile coupon test which can be seen in Table 1.

Table 1 Mechanical properties of steel plate

Specimen	Thickness/ t(mm)	Yield Strength/ $f_y$ (N/mm <sup>2</sup> )	Ultimate strength/ $f_u$ (N/mm <sup>2</sup> )	Young's Modulus/E (10 <sup>5</sup> N/mm <sup>2</sup> )	Elongation (%)
<b>SPCO - 01</b>	1.21	335.25	436.25	2.05	29
<b>SPCO - 02</b>	1.19	352.68	456.88	2.06	30
<b>SPCO - 03</b>	1.20	342.26	444..66	2.06	29

Shear test is carried out by Universal Testing Machine (UTM) by applying axial tension loads to the specimen and the deformation of the overall specimen was recorded every second during the test using data logger. The rate of loading was limited to no more than 2.5mm/min. Repeated testing specimen was prepared. The connection specimen was made up from two separated steel plate with thickness of 1.2mm. The testing specimens are denoted as SC2 - L1 - T2 - 3d – 1, where SC means

self – drilling screw numbers, L means the screw locating longitudinally, T means screw configured transversely, and 3d means the distance between the screws is three times of outer diameter of screw. The numerical digits following at the end means the repeated specimen with the same configurations.

### 3. Experimental results

During the load applying period, the self – drilling screw have tilting tendency and such tilting tendency become more severe after increasing the applied loads. Large plastic deformation can be observed at parental steel plate and connections eventually failure with sharp decreasing in load – displacement graph. When multiple screws are applied in connections, it is also noticed that starting from self – drilling screw tilting, the end tilting is initiating in the steel plate and screw group broke down due to that the head of the screw has been sheared off. Typical load – displacement curve can be seen in the figure 1, The whole process of connection under shear loading can be divided into four stages, which is elastic deformation stage, elastic – plastic stage, plastic stage and failure break. During the stage of elastic, the displacement increases linearly with load applying, the shear load is transformed through the contacting between the thread of screw and hole of the steel plate. After the elastic deformation, the stiffness slope is becoming lower, the non – linear increasing in load with respect to displacement can be obtained .

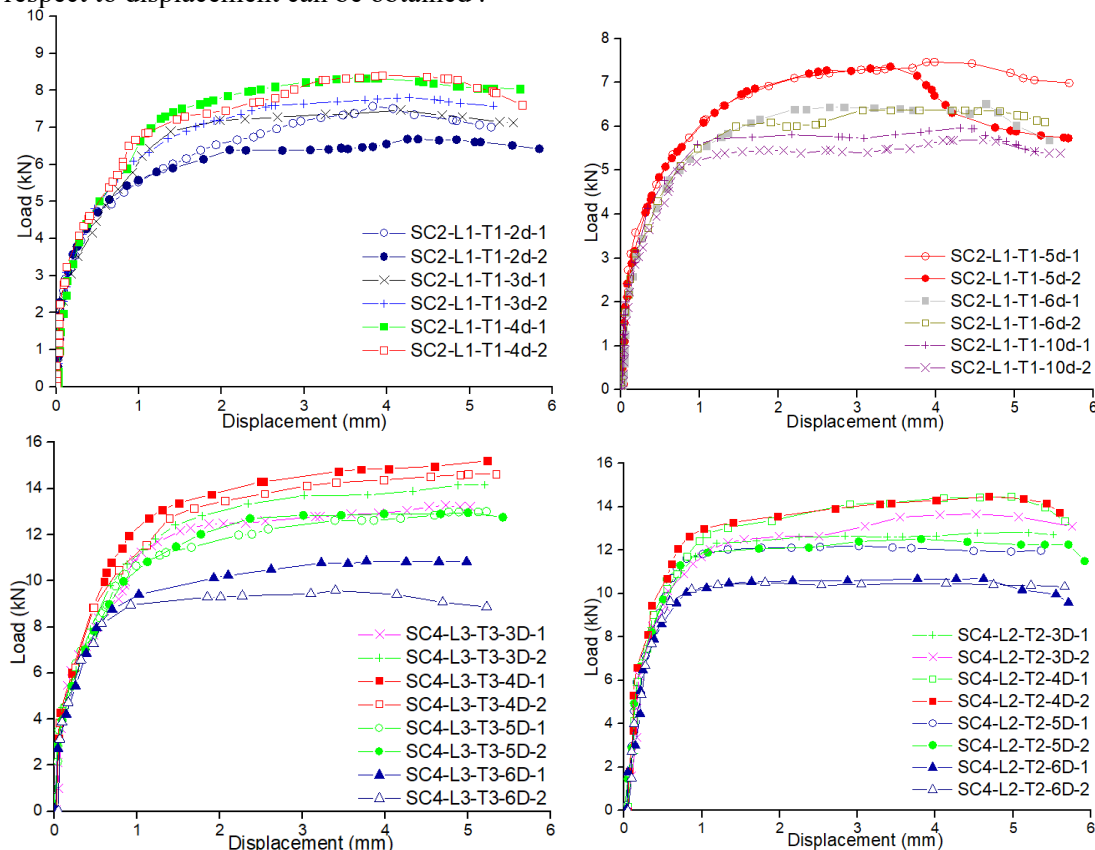


Figure 1. Load – displacement graph regarding two screws connection and 4 screw connection

The thread of the screw is tilted with plastic deformation in the hole of the steel plate and the end of the plate distorted. Furthermore, the curve is becoming stable that the displacement is continuously increasing without rising in load anymore during the stage of plastic process. The failure modes determine two common phenomena existing in the failure stage. In terms of the final failure mode of tilting or bearing break, there is no sharp decrease in the diagram of load – displacement curve. However, the sudden sharp decrease always accompanied with the failure mode screw head sheared off.

### 3.1 Screw spacing effect

Regarding the connection consists of 4 screw and 5 screws, five screw spacing parameters were investigated which varied from 3d to 6d and the largest spacing is 10d. The relation between the connection strength and screw numbers is illustrated in the figure below in Figure 2 with respect to connection consisting of 4 screws.

### 3.2 Comparison between experimental data and international provisions

The strength of self – drilling screw connection is derived according to the international provision, which is used to compare with the experimental value of single screw connected element.

As can be seen from the Table 2 that American provision AISI<sup>[13][14]</sup> and Chinese GB50018 – 2002<sup>[17]</sup> estimate better than other two provisions, which correlates well by ratio of 0.955 and 0.842 with certain safety conservation. However, Euro code 3<sup>[15]</sup> and Japanese design manual<sup>[16]</sup> give too much conservation in predicting shear resistance of self – drilling screw connections which will result in too much conservative cost in manufacturing and designing screw connections.

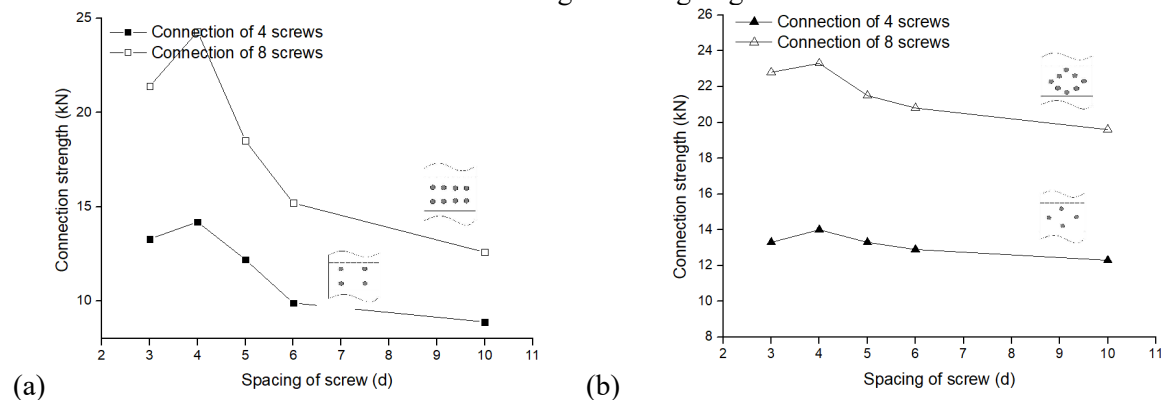


Figure 2. Relationships between connection capacity and screw spacing

shear resistance of self – drilling screw connections which will result in too much conservative cost in manufacturing and designing screw connections.

### 3.3 Influence of screw pattern on resistance capacity

The testing data has been summarized to investigate the influence of different screw layout on the resistance strength on screw connections, shown in Table 3. It can be noticed that the failure modes tend to behave similar if the testing specimen has similar configurations without big scatter in ultimate strength values. Furthermore, when the spacing between the screw and the number of the screw remains constant, the changing rate of the shear capacity is less than 8.5% when screw number is less than five. Apart from that it is very interesting that the group effect is diminished when certain layout pattern is applied with multiple screws (more than six screws), which can also be concluded from figure 2(b) and figure 3. It is concluded from figure 3 (a) that the left figure coincide well with the group effect theory. However, the curve is becoming stable with constant value without exponential decline when screw number increases more than six numbers with abnormal layout as seen in figure 3 (b). It indicates that when group of screws are applied in structural element, drilling the screw in the pattern with more columns and rows gives better resistance capacity.

## 4. Conclusion and recommendations

The main failure mode occurred in self – drilling screw connections are found to be the tilting and bearing failure based on 84 single lap shear test. All testing specimens have experience four stages. When the spacing is fixed to certain number and the screw is less than six, the effect of configuration.

Table 2 Comparison of the test data with international provision

Testing Specimens	Test strength	AISI strength	Euro code	Japan code	GB 50018 -2002	$P_{ns}^{AISI}$	$P_{ns}^{Eu}$	$P_{ns}^{JP}$	$P_{ns}^{Ch}$
						$P_{ns}^t$	$P_{ns}^t$	$P_{ns}^t$	$P_{ns}^t$
	$P_{ns}^t$ /kN	$P_{ns}^{AISI}$ /kN	$P_{ns}^{Eu}$ /kN	$P_{ns}^{JP}$ /kN	$P_{ns}^{Ch}$ /kN	-	-	-	-
SC-L1-T1 -1	5.264	5.023	3.674	1.764	4.426				
SC-L1-T1 -2	5.312	5.023	3.674	1.764	4.426				
SC-L1-T1 -3	5.198	5.023	3.674	1.764	4.426				
Average value	5.258	5.023	3.674	1.764	4.426	0.955	0.699	0.342	0.842

$P_{ns}^{AISI}$  is the shear strength determined from AISI code<sup>[13][14]</sup>

$P_{ns}^{Eu}$  is determined from Euro code 3<sup>[15]</sup>

$P_{ns}^{JP}$  is determined from steel structure manual of Japan<sup>[16]</sup>

$P_{ns}^{Ch}$  is determined from GB50018 – 2002<sup>[17]</sup>

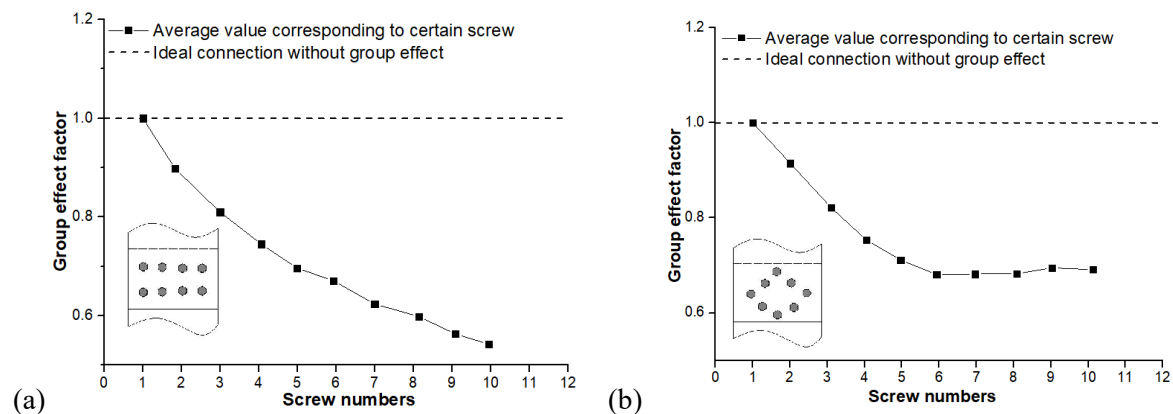


Figure 3. Comparison of group effect factor regarding different layout

patter on the resistance capacity is very limited within 7 percentage. In contrast, if the screw number is more than six, certain patter layout could lead to better overall strength compare with normal layout patter and the group effect factor is becoming as a constant. The strength of connection can be increased by enlarging the screw spacing with certain range. The strength is decreasing when the spacing is bigger than 4d. American AISI provision<sup>[13][14]</sup> and Chinese GB50018 – 2002<sup>[17]</sup> give better estimation in predicting the resistance capacity compare with overconservative value given by Euro code 3<sup>[15]</sup> and Japanese design manual<sup>[16]</sup>.

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