A R C H I W U M   I N S T Y T U T U   I N Ż Y N I E R I I   L Ą D O W E J
Nr 1 ARCHIVES OF INSTITUTE OF CIVIL ENGINEERING 2007

AN EXPERIMENTAL VERIFICATION OF THE IMPROVED BOLTING ARRANGEMENT

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Abstract

Even though the corrugated steel plate structures are designed by the Ring Compression theory, But the bending deformation may occur during backfilling. It may allow that the deflection of the structure is about 5% reduction in the rise caused by overburden pressure. But the crack at the seam would take place even when the deflection in the rise is less than 5%. It may be caused by the incorrect bolt arrangement. There are only three arrangements of bolts for longitudinal seams in the 152 by 51 corrugated plates; these arrangements, two, three and four bolts per pitch and 2-row. But the arrangment with four bolts per pitch length makes the seam too brittle and is not recommended for use in soil-steel bridges. Sometimes, high-overburden pressure caused by high level earth cover or an unpredictable vehichle load requires high level strength seams made by increasing the number of bolts at the longitudinal seams. For this reason, this paper devised the flexural strength and the compression strength over 3-bolt/pitch at the correct arrangement and verified it experimentally.

Key words: Correct, Improved, arrangement, Flexural Strength

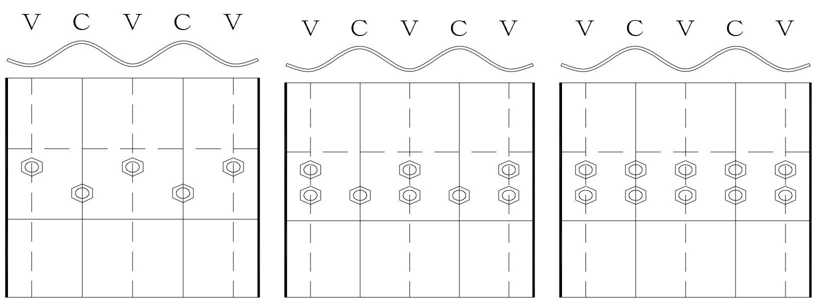
1. INTRODUCTION

An arch structure using corrugated steel plates makes compressive deformation and is designed by Ring Compression theory, but 'bending deformation', which occurs during or after back filling, is an important point to be reviewed in order to secure structural stability of a structure. Therefore, considering the characteristics, bolt arrangement is needed to secure structural stability to resist overburden pressure and deformation performance of corrugated steel plate, which is a structural steel plate having repetitively uniform pitches. In addition, such a steel plate may have 2, 3 or up to 4 bolts/pitch. However, to secure the deformation performance of corrugated steel plate, two per pitch bolting arrangement has been used(Lee, R.W.S. and Kennedy, D.J.L., 1988). Even in the arrangement, it is recommended to use Correct arrangement(Mikhailovsky and Kennedy, D.J.K., 1992). The Incorrect arrangement may show the same strength with that of the Correct arrangement against compression performance, but it uses 2 bolts/pitch because of relatively enough flexural performance. With the reason, This study devised the bolt arrangement to secure the characteristics of the Correct arrangement and the compression strength over 3 bolts/pitch and verified it experimentally.

2. OBJECTIVES

2.1 Present Bolting Arrangement

As pesented in Figure 1, longitudinal seam of 152×51mm(6×2 in) corrugated steel plate may generally have three types of bolt arrangement; 2-bolt, 3-bolt or 4-bolt/pitch. However, 4-bolt/pitch is not recommended for corrugated steel plate because it may too brittle to accept the allowable deflection. Because of the Incorrect bolt arrangement, the crack at the seam would take place even when the deflection in the rise is less than 5%. In addition, such a crack may lead corruption due to over deformation of the structure. Therefore, it is necessary to have structure stability by using a desirable bolt arrangement so that longitudinal bolt seam does not have any crack against bending deformation within the scope of deflection control.



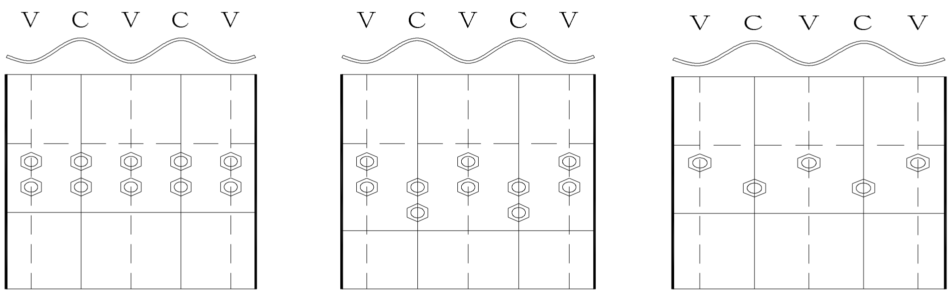
(a) 2-Bolt/Pitch (b) 3-Bolt/Pitch (c) 4-Bolt/Pitch

Figure 1. Standard bolt hole arrangement

2.2 Improved Bolting Arrangement

The seam with 152×51mm(6×2 in) corrugated steel plate, which is currently used, is applied with 2-row bolt arrangement. With the reason, if applying 4-bolt arrangement in two rows may be weak against bending deformation of the Incorrect bolt arrangement. However, it is often necessary to apply a heavy load

to a structure as the increase of the number of bolts requires the increased compressive strength. To overcome the above shortcomings and consider advantages, the bolt arrangement is devised as in Figure 2.(b).
Bolt arrangement row increases from 2 to 3 and it is cross-arranged considering the Correct bolt arrangement.



(a) Present arrangement (b) Improved arrangemnt (c) Correct arrangement

Figure 2. Comparison to the Present and Improve arrangements

3. EXPERIMENTAL TEST

The specimens used in the performance test of corrugated steel plate seam is defined by the criteria of Table 1. And, the types of the specimens used in the study are summarized in Table 2.

Table 1. Definition of the Specimens

B or C - M or P - 4B 01 - 700

700	Thickness of the specimen.
4B 01	The number of specimen based on 4-bolt.
M or P	A kind of the bolt arrangement. For example, the Modified or Present bolt arrangement.
B or C	A kind of the test. For examples, the Bending or Compression test

Table 2. Summary of the specimens

Test Case	The Number of Bolt / Pitch	The test Number	Thickness (mm)	The Name of Each Test
Bending	P-3.0	01	4.50	BP-3B01-450
	P-3.0	02	4.50	BP-3B02-450
	P-3.0	03	4.50	BP-3B03-450
	P-3.0	01	7.00	BP-3B01-700
	P-3.0	02	7.00	BP-3B02-700
	P-3.0	03	7.00	BP-3B03-700
	P-4.0	01	4.50	BP-4B01-450
	P-4.0	02	4.50	BP-4B02-450
	P-4.0	03	4.50	BP-4B03-450
	M-4.0	01	4.00	BM-4B01-450
	M-4.0	02	4.00	BM-4B02-450
	M-4.0	03	4.00	BM-4B03-450
	P-4.0	01	7.00	BP-4B01-700
	P-4.0	02	7.00	BP-4B02-700
	P-4.0	03	7.00	BP-4B03-700
	M-4.0	01	7.00	BM-4B01-700
	M-4.0	02	7.00	BM-4B02-700
	M-4.0	03	7.00	BM-4B03-700
Compression	P-4.0	01	4.50	CP-4B01-450
	P-4.0	02	4.50	CP-4B02-450
	P-4.0	03	4.50	CP-4B03-450
	M-4.0	01	4.00	CM-4B01-450
	M-4.0	02	4.00	CM-4B02-450
	M-4.0	03	4.00	CM-4B03-450
	P-4.0	01	7.00	CP-4B01-700
	P-4.0	02	7.00	CP-4B02-700
	P-4.0	03	7.00	CP-4B03-700
	M-4.0	01	7.00	CM-4B01-700
	M-4.0	02	7.00	CM-4B02-700
	M-4.0	03	7.00	CM-4B03-700

3.1 Bending Test of the Seam

As the bending tester of corrugated steel plate seam, UTM(Universal Test Machine) with the max. capacity of 300 MT was used and for the test, 2 LVDT (Linear Variable Differential Transformer) systems were installed on the position of loading and another one was installed on the center of the bottom on the steel plate in the displacement control method, measuring the displacement.

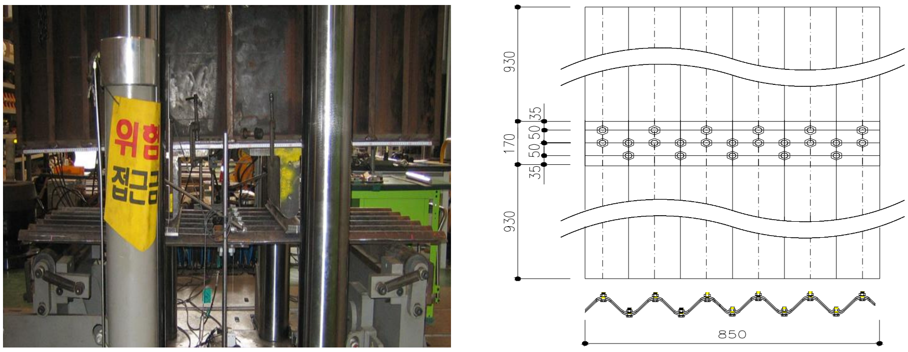


Figure 3. The View of the Bending Test

3.2 Compressing Test of the Seam

The compressing tester of the corrugated steel plate was as same as one used in the bending tester and at the same time, the tightness torque of bolting was between 350Nm~400Nm, meeting the current construction standard (200Nm ~ 400Nm) of the corrugated steel plate.

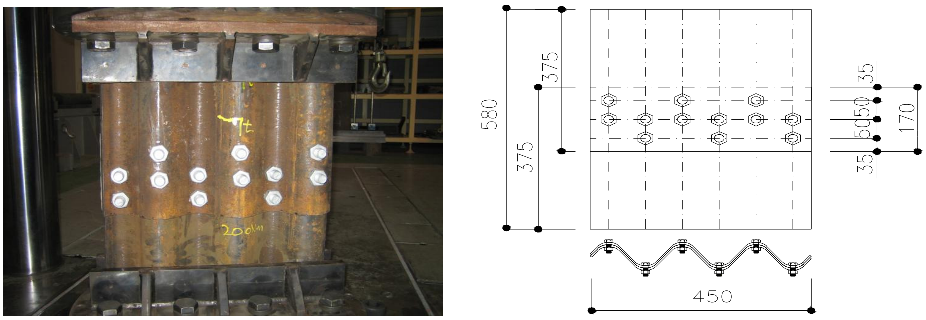


Figure 4. The View of the Compressing Test

4. TEST RESULTS

4.1 Bending Test

The test results of bending the corrugated steel plate are presented in Figure 5 through 7 with the correlation of load and displacement. The existing 2-row 4-bolt corrugated steel plate shows the max. load of about 15 ton and the displacement of about 80mm. As seen in Figure 5, the currently used 4-bolt arrangement does not accept any additional deformation later than the max. load. That is, the seam may not accept any deformation as soon as the load is reduced. It could not meet the behavior of corrugated steel plate, which should have ductile behavior.

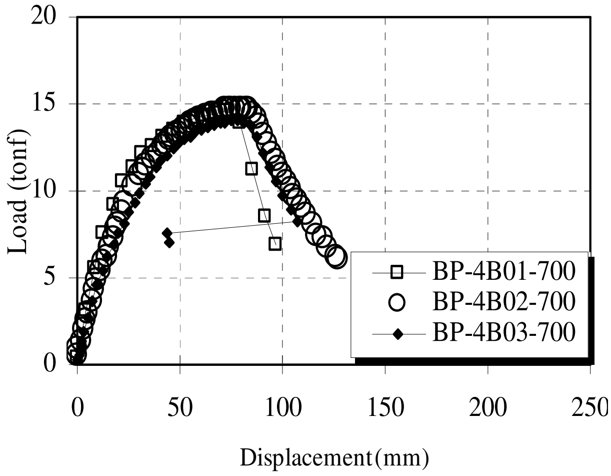


Figure 5. The result of the present 4-bolt seam

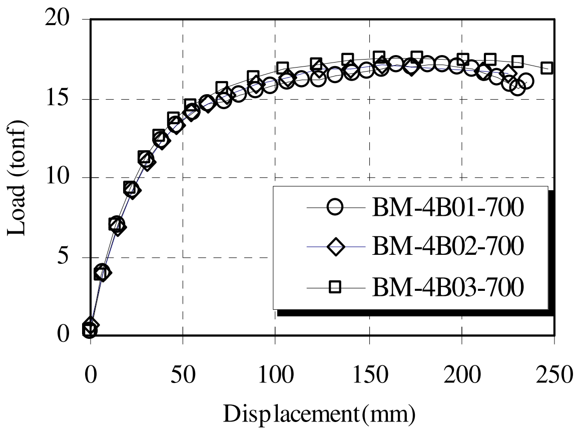


Figure 6. The result of the modified 4 bolt seam

However, the improved bolt seam of 3-row 4-bolt arrangement, as presented in Figure 6, shows the behavioral characteristics accepting the deformation with increased load, showing that the improved 3-row 4-bolt corrugated steel plate bolt seam may secure excellent seam strength and flexural performance.

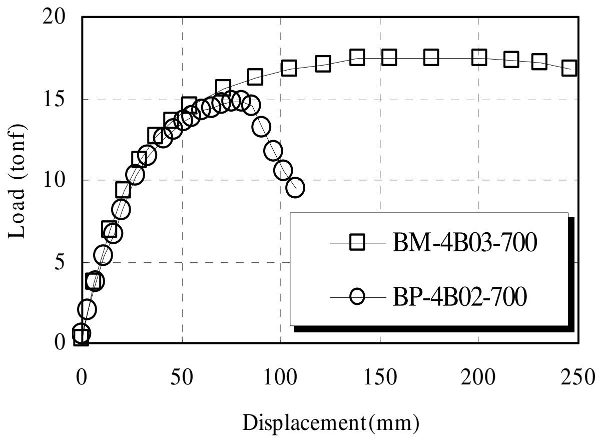


Figure 7. Comparison to the present and modified seam tests

Figure 7 compares the correlation between load and displacement of two types of bolt arrangement previously described. It was found that the seam with same steel plate thickness has excellent load and deformation performance in 3-row and 4-bolt arrangement than 2-row and 4-bolt arrangement. In addition, in case of 7.0mm steel plate, as presented in Figure 8, the existing 4-bolt had a crack in the seam but the improved bolt arrangement did not make any crack although it suffered from the max. deformation, with which it could be found that the improved 4-bolt arrangement may have the characteristics of the Correct arrangement.

(a) the present 4 bolt – cracks

(b) the modified 4 bolt – non crack

Figure 8. The Crack Check of Each Type of the Bolting Seam

4.2 Compressing Test

By evaluating the flexural performance of seam depending on the bolt arrangement types of corrugated steel plate, the study verified whether the improved corrugated steel plate may have the strength found in the existing 2-bolt or 4-bolt arrangement and higher. The specimens of the improved steel plate had twist during loading as seen in Figure 9 and might not have enough compressive strength. It is also determined that such phenomenon may be affected by asymmetrical bolt arrangment as seen in the Figure 9 (a). So, The improved bolting compressive strength is relatively smaller than the existing 4-bolt arrangment showing at Figure 11. However, considering that the improved 4-bolt seam also shows the compressive strength value is higher than the design value, demonstrating that it has the stability of seam performance. It is also planned to verify whether the additional test considering symmetrical bolt arrangement may have the value higher than the current test strength value.

(a) the front view of the specimen (b) the side view of the specimen

Figure 9. Torsion bending During Compressing tests

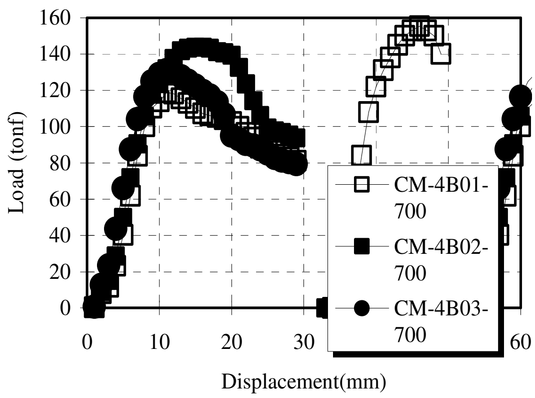


Figure 10. The result of the modified 4-bolt seam

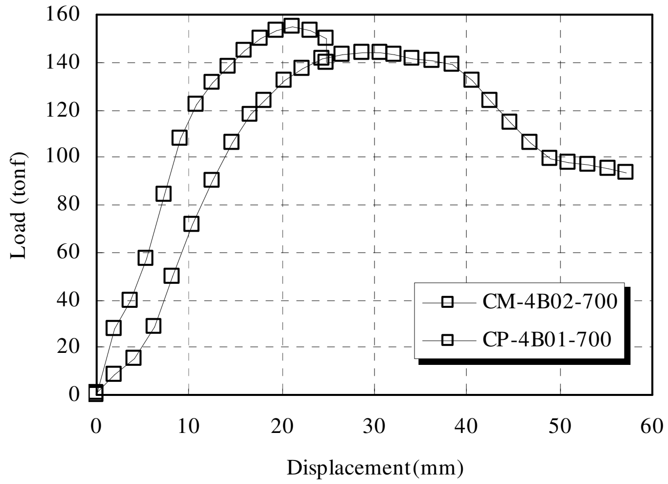


Figure 11. Comparison to the present and modified seam tests

4.3 Test Results and Discussions

The results in the test with improved bolt seam are summarized in the following tables, in which it is found that the increased the number of bolt would have increased compressive strength of seam, which is also demonstrated in the improved 4-bolt/pitch. As presented in Table 3, 7.0mm corrugated steel plate has a value smaller than that of the existing 4-bolt compression strength, which probably means that it would be resulted from torsion bending of the specimens that occur during the compressing test. The results of bending test are prepared with the max. Load and dispacement in Table 4. In the bending test, it was found that the max. load is within the similar scope regardless of the number of bolt and that in case of 4.5mm thick steel plate, the max. displacement of 2-bolt / pitch had about 56% and 62% of 3-bolt/pitch and 4-bolt/pitch, respectively. That shows in the currently used bolt arrangement, the increase of bolts may have a huge influence on the flexural performance. With the results, in the test with 7.0 mm thick steel plate of the improved bolt arrangement, the max. displacement was approximately 182.72mm, showing 237% of the max. displacement of the existing 2-row 4-bolt arrangement, which was 77.11mm. Therefore, it is found that the improved 3-row 4-bolt arrangement may secure appropriate joint compressive strength and flexural performance.

Table 3. Compression Test Results

Thickness	2 Bolt / Pitch	3 Bolt / Pitch	4 Bolt / Pitch	M4 Bolt
4.0 mm	1084.8 N/mm	1431.9 N/mm	1644.2 N/mm	1794.7 N/mm
7.0 mm	2533.4 N/mm	3045.8 N/mm	3382.2 N/mm	3286.9 N/mm

Table 4. Bending Test Results

Thickness	2 Bolt / Pitch		3 Bolt / Pitch	
	Max Load	Displacement	Max Load	Displacement
4.0 mm	-	-	-	-
4.5 mm	96.40 N/mm	154.07 mm	89.70 N/mm	67.58 mm
6.0 mm	143.90 N/mm	180.41 mm	-	-
7.0 mm	-	-	142.80 N/mm	74.77 mm
Thickness	4 Bolt / Pitch		M4 Bolt / Pitch	
	Max Load	Displacement	Max Load	Displacement
4.0 mm	-	-	79.58 N/mm	112.00 mm
4.5 mm	84.87 N/mm	53.35 mm	-	-
6.0 mm	-	-	-	-
7.0 mm	137.78 N/mm	77.11 mm	167.8 N/mm	182.72 mm

5. CONCLUSIONS

The 2-bolt arrangement of the currently used 152×51mm(6×2 in) corrugated steel plate is intended to secure the flexural performace according to the ductile behavior of the corrugated steel plate, but 3-bolt or 4-bolt arrangement over the above may increase compressive strength but rarely secure the ductile behavior of corrugated steel plate owing to the reduced flexural performance. However, it is determined that the bolt arrangement proposed in the study may maximize the flexural performance with the increased compressive strength of seam and that it may secure the safety against any possible excessive deformation during the construction of corrugated steel plate.

In addition, a factor of safety of the seam, one of items to determine the thickness of corrugated steel plate design is relatively large and the strength reduction coefficient of seam is also large, so it has the most influence on the determination of steel plate thickness. Therefore, to secure the factor of safety of seam, the thickness of steel plate often needs relatively increasing. However, the bolt arrangement suggested in the study shows the enough safety rate of seam, so it does not need to increase the thickness any more. Then, it is possible to reasonably determine the thickness of corrugated steel plate structure. Finally, The study may be summarized with the following conclusion.

(1) Improved 4-bolt arrangement increases the compressive strength of seam.
(2) Improved 4-bolt arrangement increases the flexural strengh of seam.
(3) Improved 4-bolt increases the flexural performance of seam.
(4) Improved 4-bolt arrangement may secure the additional safety rate to determine the thickness of steel plate.

6. REFERENCES

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EKSPERYMENTALNA WERYFIKACJA UDOSKONALONEGO
ZŁĄCZA ŚRUBOWEGO

Streszczenie

Nawet jeśli wymiaruje się konstrukcję z blach falistych w oparciu o teorię ściskania pierścieniowego należy pamiętać, że w trakcie zasypywania poddawane są one deformacji wskutek zginania. Może dojść do tego, że ugięcie konstrukcji wyniesie około 5% wysokości konstrukcji w wyniku przyłożonego obciążenia zewnętrznego. Jednak do zerwania złącza śrubowego może dojść nawet w przypadku, gdy ugięcie jest mniejsze od 5%. Dla złączy śrubowych w konstrukcjach o fali 152*51 istnieją trzy rodzaje układów śrub: 2 śruby na falę, 3 śruby na falę oraz 4 śruby na falę (dwurzędowo). Układ 4 śrub na falę powoduje kruchość złącza śrubowego i nie jest zalecany w konstrukcjach z blach falistych. Niekiedy pojawiają się obciążenia wyjątkowe z postaci bardzo wysokiego naziomu lub dużych obciążeń ruchomych przy niskim naziomie i wtedy wymagane jest zastosowanie zwiększonej ilości śrub w złączu poziomym. Dla tych celów referat opisuje określenie nośności giętnej i wytrzymałości na ściskanie układu 3- śrubowego rozmieszczonego w odpowiedni sposób oraz jego weryfikację eksperymentalną.

Słowa kluczowe: udoskonalony układ złącza śrubowego, nośność giętna