Proceedings of the Second International Conference on Press-in Engineering 2021, Kochi, Japan – Matsumoto et al (eds)
© 2021 Taylor & Francis Group, London, ISBN 978-1-032-10414-0

Development of small-sized splice plates applied to steel sheet pile longitudinal joints

H. Nakayama & T. Momiyama
Nippon Steel Corporation, Tokyo, Japan

ABSTRACT: Steel sheet piles are longitudinally combined to form a longer pile in the course of driving them into the ground in places such as under bridge girders, where overhead clearance is limited. To connect piles, sheet piles are welded at each corresponding end, and splice plates are welded to fill a section shortage of the interlock where welding can't be applied. The splice plates tend to be larger and heavier according to the increase of size of sheet piles, and hence welding work becomes laborious. To reduce such burden, a small-sized splice plate that can keep the original splice plate in a like diamond shape was developed. The validity and effectiveness of the newly developed splice plate was confirmed through experiments and construction practices on site.

1 GENERAL INSTRUCTIONS

1.1 *Longitudinal joints for steel sheet piles*

Steel sheet piles are used as one of the main construction materials for many purposes, such as in retaining walls and in the reinforcement of ports, harbors, embankments, and piers, etc.

According to situations at construction sites or in transportation infrastructure where steel sheet piles are used or carried, the length of each steel sheet pile must be less than a certain level. For example, when it is necessary to set steel sheet piles to strengthen piers under bridge girders, the length of the steel sheet pile should be at least less than the distance between the ground surface and the underside of the bridge girder. Especially, the length needs to be much less at the construction site, where it is necessary to secure space for the driving machine used for installing the steel sheet pile. However, the steel sheet pile length as required by the construction design thus tends to be shorter than the necessary design length—which would be indispensable toward forming the structure. To cope with this kind of situation, the short steel sheet piles are longitudinally combined to make one long pile while these piles are driven into ground.

To form a longer pile consisting of shorter piles, a couple of steel sheet piles are respectively welded at each corresponding end. Because welding along the interlock should be avoided so as not to reduce the internal space of the interlock and so as not to cause deformation of the interlock, in order to secure smooth interlocking during driving, the total section where welding can be applied is less than the total cross-section of the steel sheet pile. The shortage of the cross-section area means a shortage in the strength and stiffness necessary for the steel sheet pile as a construction member. To fill the shortage of welding area, splice plates are commonly used (JASPP 2014). These are attached to the surfaces of the steel sheet piles in the form of bridging over two corresponding piles. Splice plates perform the role of reinforcing longitudinal joints. The reinforcement method using splice plates is very useful because of the simplicity of shape, and hence its handling is very easy when welding the plates onto the steel sheet pile.

In terms of industrial trends at construction sites, labor-saving has recently been required. In the case of steel sheet piles, welding longitudinal joints occupies a large amount of time throughout the driving period. When a larger size of steel sheet piles is used, the size of the splice plates also increases, and this makes the splice plates heavier, leading to longer welding time and then to longer construction time, making the welding task harder. Therefore, the present splice plate form was improved so as to alleviate welding work for longitudinal joints.

1.2 *Specifications of splice plates*

From a practical point of view, the positions of longitudinal joints are arranged alternately lengthwise along the wall direction so as to avoid stress concentration around the longitudinal joint area as a wall. The location of each longitudinal joint for the respective neighboring steel sheet piles is situated in a staggered form, as shown in Figure 1.

DOI: 10.1201/9781003215226-60

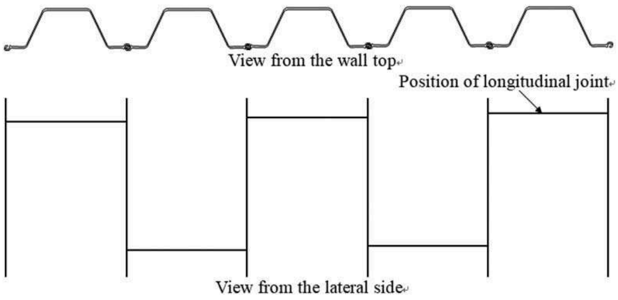


Figure 1. Position of longitudinal joints.

A longitudinal joint consists of two kinds of splice plates. One of them is attached to the surface of the web of the steel sheet pile, with the other attached to that of the arm. The latter parts are welded on both arms of the steel sheet pile. Figure 2 illustrates the location of each splice plate. By utilizing both web and arm surfaces where the distance from the neutral axis is almost the same for each, the position of the neutral axis of the steel sheet pile with a longitudinal joint is set to be similar to that of the original steel sheet pile.

The size of the splice plates is determined so as to secure a sufficient section area and capacity of bending moment.

With regard to the section area, the total cross-section area of the splice plates along the longitudinal joints needs to correspond to that of the interlocks where welding should be avoided. When a steel sheet pile is driven into the ground, tension force is repeatedly loaded along the pile in the course of the vertical motion applied from the driving machine.

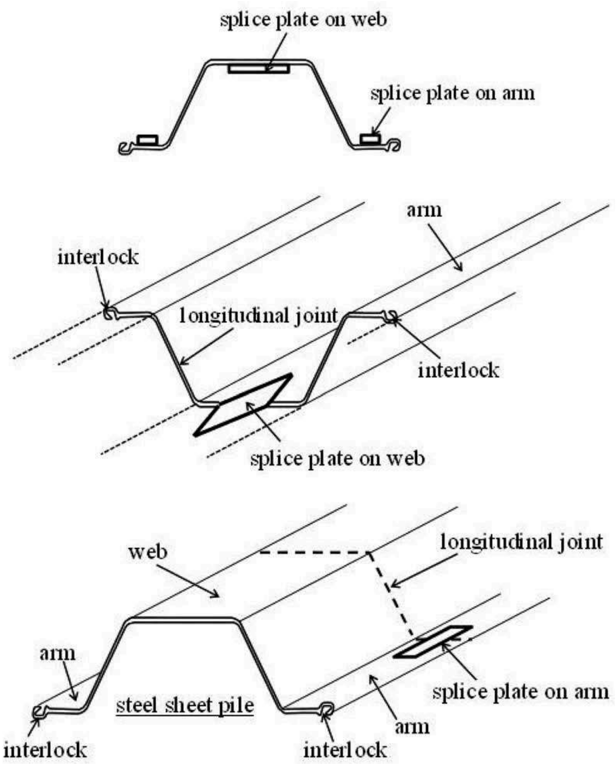


Figure 2. Splice plates.

This motion is necessary so as to realize smooth driving in order to avoid soil consolidation around the bottom of the pile and to reduce friction force along the side surfaces along the pile. Because the interlock can't be welded along the cross-sectional direction of the steel sheet pile, the total section area of the splice plates is designed to be larger than that of the interlocks positioned at the widthwise ends of the steel sheet pile. The sizes of the splice plates are determined by adjusting the thickness and width to match the required section area.

Concerning the capacity of bending moment, the sizes of the splice plates are set to secure the moment of inertia corresponding to the original steel sheet pile. Because longitudinal joints are arranged in a staggered form, the amount of moment of inertia is calculated as a combination of a pair of two steel sheet piles. One of the steel sheet piles is the complete form of the cross-section, which is the same as the original steel sheet pile, and the other is set with the longitudinal joint. The bending stress induced in the splice plate at the edge from the neutral axis is limited to less than the allowable stress.

The outline of splice plates attached to the web of steel sheet piles consists of a diamond-like shape. Because the splice plates are welded to the surface of the steel sheet piles, the amount of welding parts is arranged in order to make the stress level at the welding parts caused by both tension and bending moment less than the allowable stress. The size of throat depth along the welding lines is adjusted to satisfy this amount. On the other hand, it can be possible to reduce the weight of the splice plates, keeping the same amount of welding parts. Because the sizes of the splice plates tend to be larger according to the increase of the size of the steel sheet piles, the welding work would become more difficult if the weight of the splice plates is larger than the weight that one worker can carry/support during welding. Therefore, it is useful to use lighter splice plates so as to mitigate extra welding work. In terms of the shape of splice plates with a certain amount of welding parts, a diamond-like shape is more efficient than a rectangular shape with regard to the weight of the splice plate. As shown in Figure 3, when the perimeters of the diamond-like plate and rectangular plate are set to be the same, keeping the width at the widest part of the splice plate the same, which is noted as "b" in the figure, the area of the diamond-like shape becomes smaller than that of a rectangular plate, and this means that the diamond-shaped plate is lighter than the rectangular plate. Because the widest part of the splice plates is determined so as to secure a minimum area to cope with the tension force, the width cannot be reduced once the thickness of the splice plate is set. From the viewpoint of labor-saving and cost effectiveness, diamond-shaped splice plates are usually adopted for the splice plates attached to the web of steel sheet piles. Because the size of the splice plate attached to an arm is small enough for a single worker to handle, rectangular

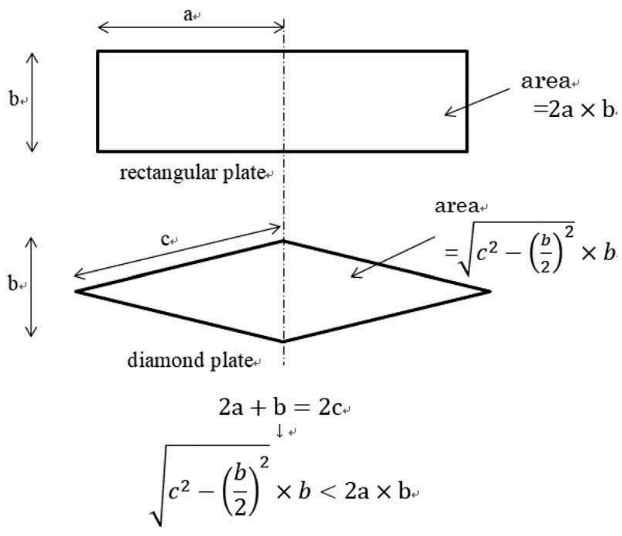


Figure 3. Comparison of the area of splice plates.

splice plates are sometimes used because the trimming of plates into rectangular form is easier than diamond-like form.

2 NEW TYPES OF SPLICE PLATES

2.1 *Half-size splice plates*

Even if diamond-shaped plates are used for the splice plates attached to the web of steel sheet piles, the weight is sometimes still too heavy to support considering workability on site. While welding work is carried out by one welder, the splice plate is usually supported by one hand of the worker, and the welding torch is handled by the other hand. It is normally regarded that one hand can support around 13 kg without worsening the conditions at the construction site. Therefore, it is effective to make the splice plate as light as possible so as to realize less load for welding work. Although the width of the splice plate positioned along the longitudinal line needs to be maintained, it is possible to lighten the splice plate itself by changing other parts. As the outline of the splice plate, the shape is freely decided as long as the perimeter is larger than the required length so as to cover the welding volume necessary for stress transmission between the splice plate and the steel sheet pile.

The present splice plate model consists of only one plate. However, the total weight of the splice plate can be reduced, keeping the total length of the perimeter, utilizing the characteristics of a diamond-like shape. As shown in Figure 4, one diamond-like shape can be divided into two parts, maintaining the total length of the perimeter. The total perimeter length of the present model is calculated as $c \times 4$. On the other hand, the proposed model is $c/2 \times 8$. These two equations produce the same result. The divided two small plates have a form similar to the original splice plate. The total weight of the divided two

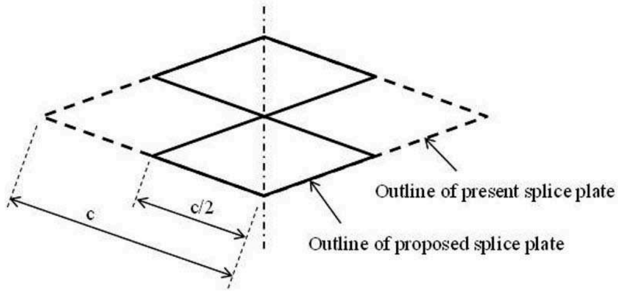


Figure 4. Small-sized splice plate.

plates becomes half that of the original plate, and this leads to 1/4th the weight of the original plate for each splice plate. This small-size type of splice plate is very effective toward realizing smooth welding work, especially when large-size steel sheet piles are used.

2.2 *Splice plates with one welding pass*

There is another way to reduce the load of welding work in using small-size splice plates. The purpose of the newly proposed model mentioned above is mainly to lighten the weight of the splice plate. On the other hand, the number of welds along the perimeter of the splice plate is also related to workability in terms of welding. Because the welding occupies almost all of the longitudinal joint work time, it is useful to save welding time for one steel sheet pile by reducing the weld amount for each splice plate. The reduction of weld time can lead to an increase in the number of steel sheet piles that can be driven into the ground in one day, and this would result in a decrease of construction cost.

The number of welds along the same line tends to increase according to the increase of the designed throat depth. Because the splice plates are welded by fillet welding along the perimeter of the splice plate, the size of welding volume necessary for stress transmission is decided by throat depth. The thickness of the welded part after one welding pass is limited due to the limitation of welding torch capacity. Therefore, the number of welding passes depends on the designed throat depth. The welding work needs to be repeated until the thickness of the welded part satisfies the designed throat depth. The total volume of the welded part sometimes gets larger than the designed volume. To minimize the welding time, it is effective to minimize the number of welding passes, preferably restraining the number to only one, though it is necessary to keep the total minimum volume of welding corresponding to the designed throat depth.

To reduce the throat depth to a point where it can be completed via only one welding pass, the size of the splice plate can be adjusted by widening the length of the longer side of the diamond-like shape from the first proposed model as shown in Figure 5. The shape of the splice plate, in other words the total

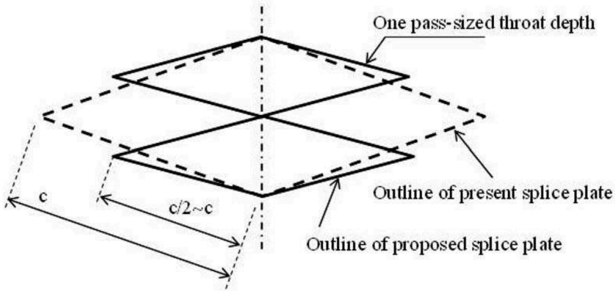


Figure 5. Small-sized splice plate with one welding pass.

length of the perimeter, with one welding pass is determined to secure the amount of welding parts necessary for stress transmission between the splice plate and the steel sheet pile. Even though the total weight of the splice plate for one longitudinal joint becomes heavier than the original splice plate, that of each splice plate can be reduced below a certain level compared with the original. This reduced weight leads to labor-savings, especially when a larger size of steel sheet pile is used.

2.3 *New splice plate for hat-type steel sheet piles*

Table 1 shows an example of our newly developed splice plate. There are mainly two types of steel sheet piles used in Japan: hat-type and U-type. Hat-type steel sheet piles are more cost-effective than U-type because of the location of the interlocks. In the case of U-type steel sheet piles, in which the interlocks are situated on the neutral axis, the whole shear force cannot be transmitted along the interlocks, and this requires a reduction in sectional properties, such as moment of inertia. On the other hand, no such reduction is required for hat-type steel sheet piles, as the interlocks are positioned at the outmost side of the section.

Therefore, hat-type steel sheet piles are mostly used where cost-effectiveness is demanded, so as to restrain construction costs. Being representative of steel sheet piles on which our new splice plate is attached, hat-type steel sheet piles are being focused on in this development. Because the new splice plate can be used effectively, especially for large-size steel sheet piles with high section properties, the two largest hat-type steel sheet piles, known as “45H” and “50H”, are being focused on.

For each steel sheet pile, three types of splice plates are as illustrated in Table 1, that is the present one, a half-size one, and a one-welding-pass model. The latter two models consist of our newly developed splice plate. For each splice plate, two pieces of information, the weight of each and the total set, and the total weld line length with a number of weld passes are added. Instead of throat depth, which can’t be directly measured, the leg length is alternatively checked after welding has been completed. The leg length for the respective model is also shown in the table.

When half-sized splice plates are used, the weight of each plate becomes 1/4th the present model and total weight becomes half. In the case of 50H, the weight of each plate is 5.2 kg and that of the total set is 10.4 kg, which is half of 20.7 kg for the present model. Because the splice plate length is adjusted in 10 mm units, the rounding error is neglected. It is quite hard to continue to carry and support a 20.7 kg plate by one hand all through the construction period during which a lot of longitudinal joint work is included. However, the labor burden can be allayed once the weight of each splice plate is reduced to 5.2 kg. The amount of the weld line length for 50H is totally the same between the present model and the proposed model, which is 6 to 8 m. Welding work of 3 to 4 passes is normally necessary to fill the 12 mm leg length.

To reduce the number of welding passes, the second model, the splice plate with a one-welding -pass model, is effective. In the case of 50H, the total weld line length is 3.4 m, which is a 43–57% reduction from the present and half-sized splice plate model. Although the weight of each splice plate of this model is larger than that of the half-sized splice plate model, the weight is 9.1 kg, which is less than half that of the present model. This weight reduction has great effect for labor-savings. From the viewpoint of total weight of the splice plate set, this model enables a 12% reduction from the present model, and this leads to cost reduction for material expenditures. As for one-pass welding, a 7 mm leg length is adopted, and hence the total length of the longer side of the diamond-like shape becomes larger compared with the half-sized splice plate model.

3 EVALUATION OF BENDING CAPACITY

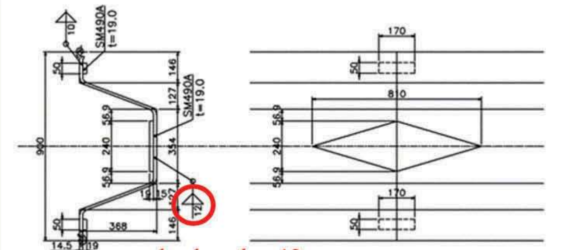
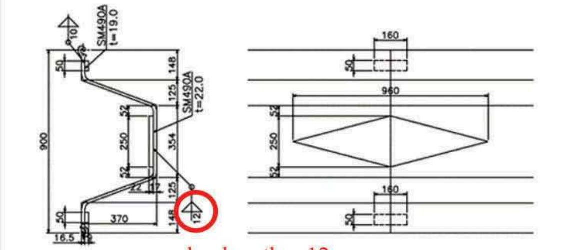
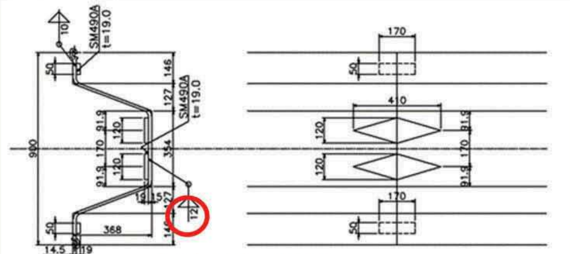
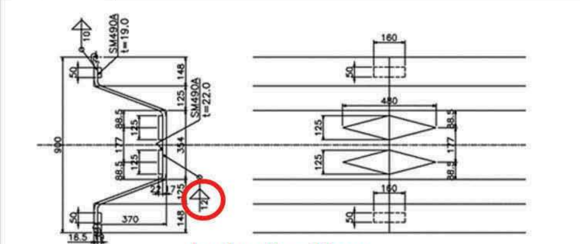
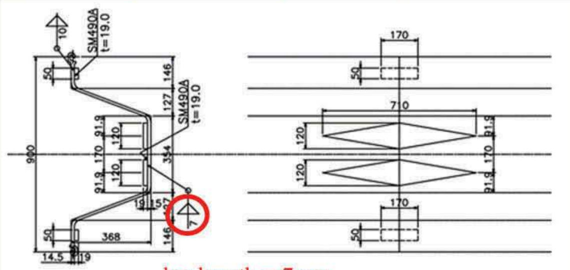
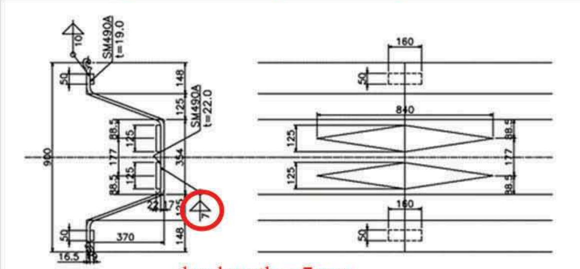
3.1 *Test conditions*

The capacity against bending moment for the newly developed splice plate was checked via a bending test (Momiyama 2019). It was expected that the bending stiffness and capacity of the new plate is larger than the designed values.

Two proposed models were investigated, comparing them with the present model. The splice plate positioned on the arm was set to be the same for all three models. The difference among the three models is the specification of the splice plate attached to the web. The details of each splice plate are shown in Table 1. For all three types, each splice plate was designed so as to make the designed bending capacity almost the same. As for the steel sheet pile, the largest hat-type, 50H, was used. The grade of steel of 50H was SWY295 and that of the splice plates was SM490.

Four-point bending tests were carried out, as shown in Figure 6. The longitudinal joint was located at the center of the test specimen, where only bending moment was loaded. In terms of the sectional direction of the steel sheet piles against the direction of force, denoted as “P” in Figure 6, two

Table 1. New splice plates for hat-type steel sheet piles.

		45H	50H
Present model		 leg length = 12mm	 leg length = 12mm
	weight	14.5kg ea×1 ea = 14.5kg per set	20.7kg ea×1 ea = 20.7kg per set
	weld line length	1.7m per perimeter×3∼4pass = 5.1∼6.8m per set	2.0m per perimeter×3∼4pass = 6∼8m per set
Half- sized splice plate		 leg length = 12mm	 leg length = 12mm
	weight	3.7kg ea×2 ea = 7.4kg per set 【Half the present model】	5.2kg ea×2 ea = 10.4kg per set 【Half the present model】
	weld line length	1.7m per perimeter×3∼4pass = 5.1∼6.8m per set 【the same as the present model】	2.0m per perimeter×3∼4pass = 6∼8m per set 【the same as the present model】
Splice plate with one welding pass		 leg length = 7mm	 leg length = 7mm
	weight	6.4kg ea×2 ea = 12.8kg per set 【12% less than the present model】	9.1kg ea×2 ea = 18.2kg per set 【12% less than the present model】
	weld line length	2.9m per perimeter×1pass = 2.9m per set 【43 to 57% less than the present model】	3.49m per perimeter×1pass = 3.4m per set 【43 to 57% less than the present model】

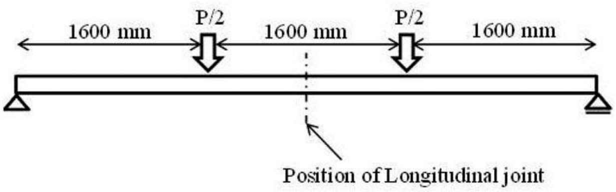


Figure 6. Side view of bending test.

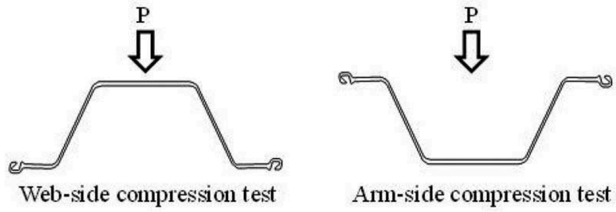


Figure 7. Sectional direction view of bending test.

series were investigated, respectively. One of them was a web-side compression test and the other was an arm-side compression test, as shown in Figure 7. Because the interlocks are not welded between corresponding two pile ends, different deformation and hence bending capacity were expected according to the position of the splice plates against the force direction.

3.2 *Test results*

The relationship between curvature and bending moment for all cases is shown in Figure 8. The designed values of yield moment and maximum moment calculated from both nominal stress and material test are also shown in the figure. The designed maximum moment is defined as a fully plastic moment. The respective values of bending stiffness, yield moment, and maximum moment obtained from the experiment are shown in Table 2. In this table, a comparison between the experimental results and the designed values is shown as well. In the case of the designed values, stress based on the material tests is used.

With regard to bending stiffness, the experimental results correspond to the designed values for all cases. Elastic behavior was kept until the force loaded on the test specimen reached yield moment based on nominal stress.

The capacity of bending moment obtained from the experiments surpassed the designed values for all splice plate models, for both yield moment and maximum moment. In any case, the value of the bending capacity for the arm-side compression tests outnumbered that for the web-side compression tests. The cause is considered to be derived from the compression effect for the interlock section in the arm-side compression tests. The surfaces of the intersection of the respective steel sheet piles touched each other, apparently making the entire cross-section area of the steel sheet piles resist the bending moment, which cannot happen in the web-side compression tests, where the interlock of the arm side is tensioned.

As for the pattern of deformation in the test specimens, a typical tendency was commonly observed for all test cases. At the final stage of the web-side compression tests, tension cracks occurred along the arm of the steel sheet pile and on the splice plate on the arm. As the origin of the breakage point, this crack emerged from the intersection without being welded. The deformation pattern is as shown in Figure 9. On the contrary, the local buckling of the arm of the steel sheet pile around the longitudinal joint line was the main reason to lower the bending capacity at the final stage in the arm-side compression tests, as shown in Figure 10. For all cases, there was no damage for the splice plates attached to the web of the steel sheet piles. Therefore, it can be concluded that the proposed splice plates do not affect the characteristics of the bending behavior of steel sheet piles.

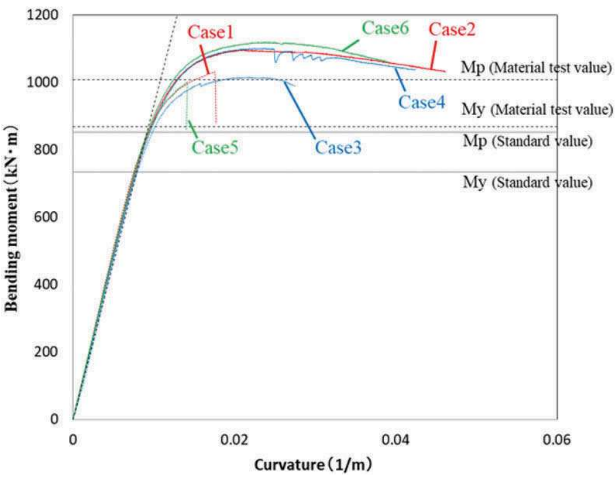


Figure 8. Curvature and bending moment relationship.

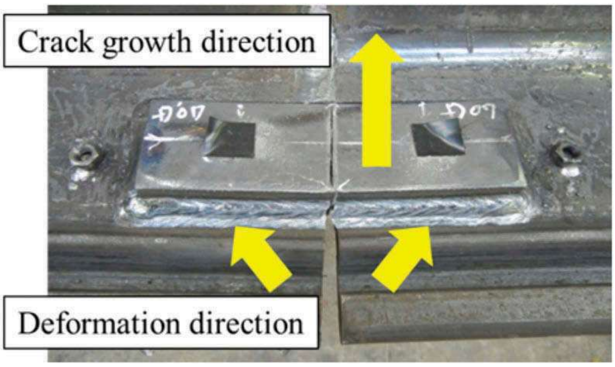


Figure 9. Deformation of splice plate welded on arm in web-side compression test (case1).

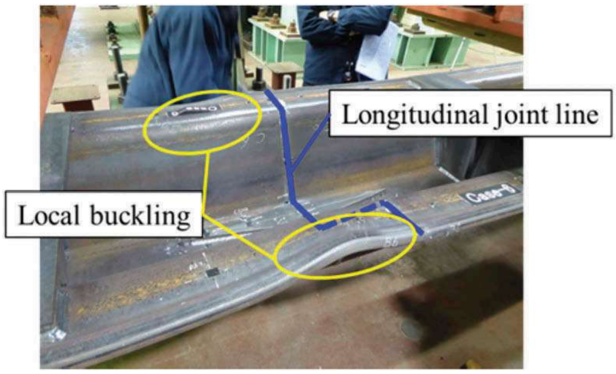


Figure 10. Deformation of arm in arm-side compression test (case4).

Table 2. List of bending test results.

No.	Splice plate model	Compression side	Experimental results: Bending stiffness (kN·m²)	Yield moment (kN·m)	Maximum moment (kN·m)	[Experimental result]/[designed value]: Bending stiffness	Yield moment	Maximum moment
Case1	Present	web	97093	948	1030	1.03	1.09	1.02
Case2		arm	95860	988	1098	1.01	1.14	1.09
Case3	Half-sized	web	92870	941	1016	0.98	1.08	1.01
Case4		arm	95941	1004	1102	1.01	1.16	1.09
Case5	One welding pass	web	92971	949	1008	0.98	1.09	1.00
Case6		arm	93637	1002	1120	0.99	1.15	1.11

4 FIELD TESTS

To check the validity of the new splice plate from a practical point of view, actual welding tests were carried out on site. Figure 11 shows the situation of the field tests. The time of welding is summarized in Table 3. The welding time consumed for the splice plates on the web of the steel sheet piles is separately shown in this table. The number of welding passes was differently set for each model. Three passes were carried out for the present model and for the half-size model. On the other hand, only one-pass welding was carried out for one welding pass model.

Because the total weld line length is the same for the present model and the half-size model, there is no difference in terms of welding time for both the splice plate and the entire section. However, it is confirmed that a one welding-pass model can reduce welding time. Concerning the welding time for the splice plate on the web, a 37% reduction from the present model was observed, leading to the entire welding time reduction by 25% compared with the present model.

Figure 11. Situation of field test.

Table 3. List of field test results.

Splice plate model (Number of welding pass)	Welding time: Time for splice plate on web (minute)	Welding time: Whole welding time (minute)
Present (3)	40	85
Half-Sized (3)	40 【the same as the present model】	85 【the same as the present model】
One welding pass (1)	25 【37% less than the present model】	64 【25% less than the present model】

5 CONCLUSIONS

The validity and effectiveness of the newly developed splice plate for steel sheet piles was confirmed through experiments and field tests. The most-noticeable issue of the new splice plate is the reduction of the weight of each splice plate type and the welding time for longitudinal joints, as this can contribute to labor-saving. A cost reduction for material is also expected. It can be confirmed that the proposed splice plate can maintain a necessary bending capacity similar to the steel sheet piles used on site.

REFERENCES

Japanese Technical Association for Steel Pipe Piles and Sheet Piles (JASPP). 2014. *Design and construction method for steel sheet piles*.

Momiyama, T., Nakayama, H., Kitahama, M., Takeno, M., Nishibe, K., Matsubara, H. 2019. Bending capacity evaluation of steel sheet piles with improved splice plates at longitudinal joint, *Japan society of civil engineers 2019 annual meeting*.