The Press-in Method Assisted with Augering: Case studies of Single U and Double Z Shaped Piles in the United Kingdom

Masafumi YAMAGUCHI
Deputy Manager, Press-in Technologies Support Department, GIKEN LTD., Tokyo, Japan
Email: yamaguchi@giken.com
Kensei YAMADA
Technical Manager, Technical Department, GIKEN Europe B.V, London, England

ABSTRACT

One of the key issues of pile installations is ground condition. In the case where the ground condition is stiff or hard, much efforts are required to secure the pile drivability of piles, workability of construction plant, and stiff response of retaining walls. Since the Press-in Method was developed in 1975 in Japan, efforts had been made to develop the penetration technique assisted by augering. Finally, a pressing-in machine against hard ground was manufactured in 1997. Since then, the machine has been improved until now and this penetration technique has been recently utilized in the UK as well. This paper introduces the penetration technique of the Press-in Method assisted with augering and the use of it in two case studies, A465 Heads of the Valleys Road Section 2 in Wales and the Thames Tideway tunnel in the central London. Finally, the installation of single U and double Z shaped sheet piles by Press-in assisted with augering are compared in terms of their pile drivability, workability and wall stiffness.

Key words: *Press-in assisted with augering, single U piles, double Z piles, augering area*

1. Introduction

The Press-in Method was developed in 1975 with the world's first "reaction based" (GIKEN, 2008) hydraulic steel sheet pile jacking machine. Since then, this unique piling technique has been achieving environmentally friendly and suitable pile installations. Particularly, due to the demand of installations into stiff ground, the Press-in Method assisted with augering has recently become popular all over the world. On the other hand, there are various types of prefabricated piles nowadays (i.e. steel sheet pile, tubular piles, H beams and others) in the world, and the latest pressing-in machines can be applied to them.

This paper describes two types of steel sheet piles currently popular in the global market, the penetration technique of the Press-in assisted with augering and two case studies of the installation of single U-shaped steel sheet piles (Hereafter, U piles) or double Z-shaped pair steel sheet piles (Hereafter, Z piles) in the UK, which are often utilized as walls and/or foundations in today's construction industry, thus we describe some advantages of them.

2. Applicable prefabricated piles

Most of the pre-fabricated piles on the global market can be applied to the Press-in Method. Among them, two popular and typical sections of steel sheet piles are introduced as follows.

2.1. U shaped steel sheet piles / U Piles

Among steel sheet piles, U piles are available in many sizes, typically effective width of 400, 500 and 600mm (**Fig. 1**). They are used e.g., for levee protection and road retaining walls. In Japan, they are often utilized for temporary cofferdams and earth retaining walls due to their durability against repeated use. As the cross section is symmetrical, they can form a continuous wall with an effective sheet pile height twice as long as that of a single sheet pile. However, care must be taken since the

interlocks come on the neutral axis where the shear stress reaches the maximum value. It is necessary to consider interlock efficiency to reduce sectional performance due to insufficient shear transmission at the interlock (IPA, 2016).

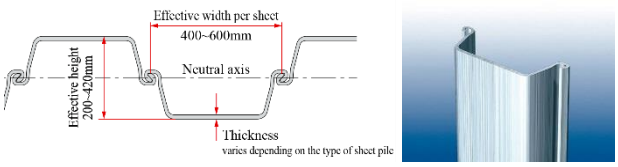

Fig. 1 Typical cross-section of U piles

2.2. Z shaped Steel Sheet Piles / Z Piles

Z pile comes in superior in terms of cost efficiency since the interlocks are positioned farthest away from the neutral axis, it is not necessary to consider the interlock efficiency and the amount of steel per unit wall can be reduced. The piling of Z piles is often conducted with two previously interlocked piles mostly fabricated in a factory or occasionally done on site, which is called double Z piles (**Fig. 2**). Double Z piles have more efficiency in cost and productivity when compared with single piles (IPA, 2016).

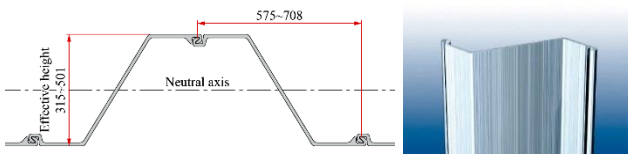

Fig. 2 Typical cross-section of Z piles

3. Penetration technique

3.1. Selection of driving assistance

In the Press-in Method, standard press-in operation for soft ground conditions, or those with driving assistance such as water jetting for medium dense or stiff ground conditions, augering or rotary cutting for hard ground condition are selected according to the ground condition and embedded length. The primary purpose of these driving assistances is reduction of the toe resistance, which could also reduce the noise and vibration during the operation.

3.2. Press-in assisted with augering

3.2.1. Press-in operation with simultaneous augering

Augering is driving assistance by a Pile auger , which is a part of a pressing machine, to reduce penetration resistance. The technique is classified into two; simultaneous augering and pre-augering.

As shown in **Fig. 3**, in the simultaneous augering, the hard ground at the pile toe is bored by a smaller auger head than widths of sheet piles, and a hollow space is created. Piles/sheet piles are then pressed-in while extracting the auger, which is termed "Press-in operation with simultaneous augering". The technique can minimize the range of excavation and can reduce the risk of settlement of surrounding ground (IPA, 2016).

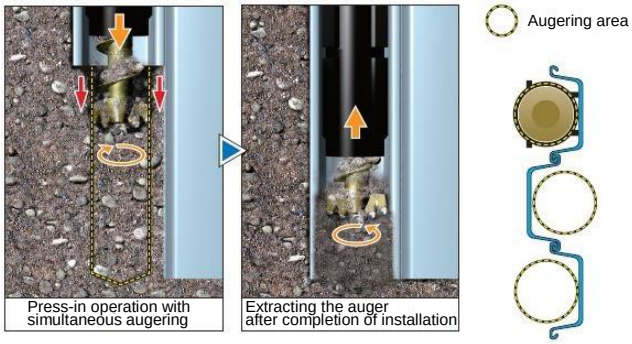

Fig. 3 Procedure of Press-in operation with sumultaneous augering

3.2.2. Press-in operation with pre-augering

For ground and rock mass with a converted SPT *N*-value* over 75, pile installation is conducted by the "Press-in operation with pre-augering". The Press-in operation with pre-augering is a technique that installs piles/sheet pile in two steps. The first procedure is pre-augering with an auger with the diameter covering most of the section of the sheet piles down to the necessary depth and backfilling while extracting the auger. The second step is the pile installation with simultaneous augering with a smaller diameter auger, as explained in 3.2.1. The procedure is shown in **Fig. 4** (IPA, 2016).

3.3. Selection of auger heads

Several auger heads can be selected based on the soil layer and stiffness to secure the drivability of it.

Note: A converted N-value is applied for an N-value greater than 50 where converted N-value = N value (at 50 strokes) x 30 (cm) / penetration depth after 50 strokes (cm).

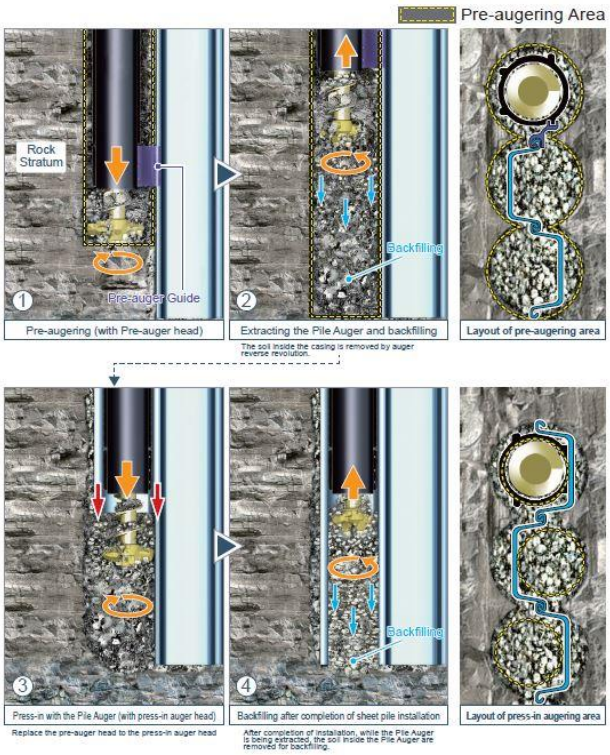

Fig. 4 Procedure of Press-in operation with pre-augering
1) Pre-augering by a large diameter auger head; 2) Extraction of auger (backfilling by reversed rotation of auger); 3) Changing to a small diameter auger head, and pile installation with simultaneous augering; and 4) Completion of Press-in operation (extraction of the small diameter auger and backfilling).

3.3.1. Auger heads for press-in operation with simultaneous augering

Fig. 5 shows a simultaneous auger head, which has two wings, to install 600mm width single U piles. The diameter is 400mm as it shall be extracted after installing a sheet pile. Generally, this type of auger head can be applicable for medium dense, relatively stiff ground which consists of sand and gravel with the SPT *N* value less than 50.

3.3.2. Auger heads for press-in operation with pre-augering

The installation of sheet piles into extremely stiff ground such as rock mass or buried obstructions are often required due to the site condition. In that case, the tough and durable auger heads should be essential.

An auger head utilized for a Press-in operation with pre-augering for 600mm width single U piles is shown in **Fig. 6**. It can drill into stiff grounds, using three wings equipped with hard teeth.

3.3.3. Auger heads with zooming blades

Pre-auger heads are quite useful for drilling into stiff ground, however, they should be replaced with simultaneous auger heads before the installation of sheet piles due to their size, unless it cannot be extracted after the completion of the process of the Press-in operation with simultaneous augering. The replacement requires some time, which may decrease the productivity.

For such a case, auger heads with zooming blades were developed (**Fig. 7**). Essentialy, these auger heads are utilized in the Press-in operation with simultaneous augering. While a sheet pile is being pressed-in, the auger head is rotating clockwise and the zooming blades are spreading, which enables the augering area to widen, e.g. 685mm diameter augering area for 600mm width single U piles. On the other hand, the Pile auger can be extracted by the auger head rotating anti-clockwise which enables the zooming blades to close. It means that the replacement of the auger heads is not required and the productivity is improved. Note that auger heads with zooming blades may not be applicable for extremely hard ground conditions as their joints between the main body and the wings be damaged.

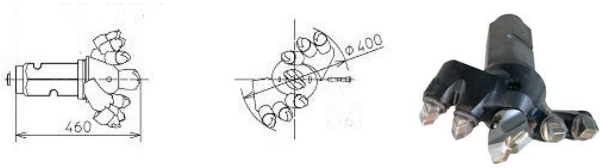

Fig. 5 Simultaneous auger head for 600mm width U piles

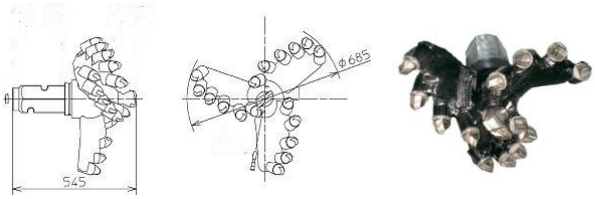

Fig. 6 Pre-auger head for 685mm width U piles

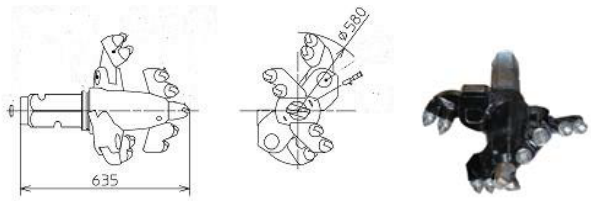

Fig. 7 Auger heads with zooming blades for 600mm width U piles

3.4. Selection of pressing machines

Since the first world's "reaction based" machine was developed in 1975, various machines exclusively applicable for pre-fabricated steel/concrete piles have been manufactured (GIKEN, 2017).

This section introduces a couple of machine models in Super crush mode for 600mm width single U piles and 1,400mm width Double Z piles, which are popular on the global market at present.

3.4.1. Silent Piler ECO700S in super crush mode

Silent Piler ECO700S is capable to install either 600-750mm width single U piles or 575-708mm single Z piles by the change of the Chuck and Lower assembly parts. Also, this model provides greater performance in various ground conditions and site environments through the Versatile Penetration system, which are Standard mode, Water jetting mode and Super crush mode, with optional auxiliary accessories.

Table 1 and **Fig. 8** show the machine specification and the machine schematic diagram.

That in Super crush mode consists of a machine main body, a Pile auger including a motor, casings, augers and auger head, a Casing chuck and a Hose Reel.

3.4.2. Super Crush SCZ675WMG

Super Crush SCZ675WMG was developed to install 1,060-1,416mm width double Z piles (580-708mm per pile), 1,200mm and 1,400mm width double U piles (600 and 700mm per pile). Unfortunately, only Standard and Water jetting mode can be applicable for double U piles at present, however, Super Crush mode can be applicable for installations of double Z piles.

Table 2 and **Fig. 9** show the machine outlook and the technical specification. Due to the size of double Z piles, the machine size grows bigger and heavier than ones for single U piles, meaning a wider working space is essential. On the other hand, productivity is improved by installing two single piles at the same time.

Table 1. Specification of ECO700S in Supe crush mode

SILENT PILER GV-ECO700S (Main body)	
Max. Press-in Force	820kN(84t)
Max. Extraction Force	1,200kN(122t)
Total Weight*	18,450kg
Pile Auger	
Auger torque	28 - 62 kN.m
Total Pile Auger Weight(for 21 m pile)	11,000 kg

Table 2. Specification of Super crush SCZ675WMG

Super Crush SCZ-675WMG (Mainbody)	
Max. Press-in Force	1,300kN(133t)
Max. Extraction Force	1,400kN(143t)
Total Weight	27,400 kg
Pile Auger	
Auger torque	100 kN.m
Total Pile Auger Weight(for 21 m pile)	18,400 kg

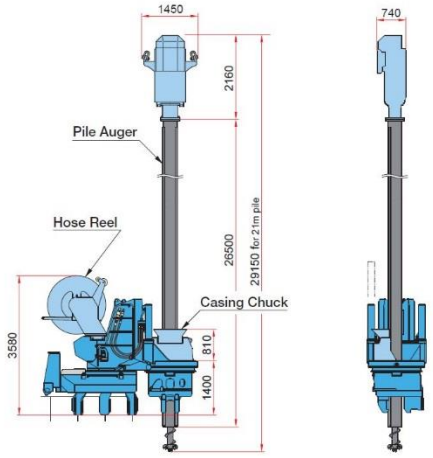

Fig. 8 Figure of ECO700S in Super crush mode

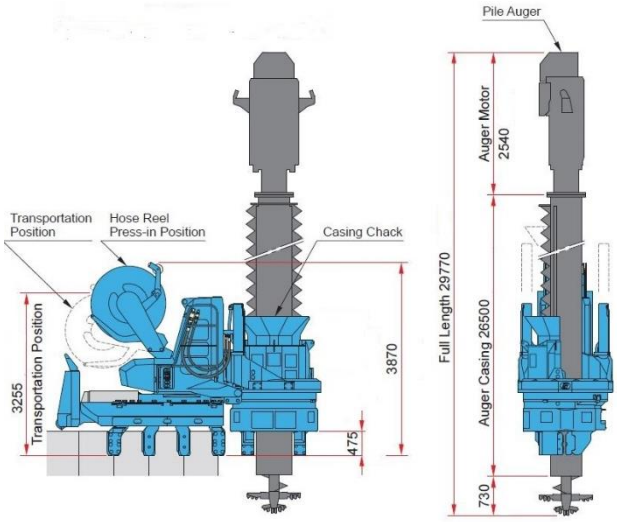

Fig. 9 Figure of Super Crush SCZ-675WMG

4. Case studeies in the UK

4.1. Case study 1: A465 Heads of the Valleys Road Section 2

4.1.1. Summary of the site

The A465 is recognised in the Welsh Governments National Transport Plan as a strategically important route. The scheme extends for 8.1km from Brynmawr in the West to Gilwern in the East, and includes the construction of 14 major structures, over 12.5km of various types of retaining walls as well as excavation of over 1.2 million m^3 of earthworks. All this was done through on a narrow rock gorge with a river on one side while maintaining current traffic flows on the existing route.

The main purpose of the site where two ECO700S in Super crush mode was to widen the existing roads from three to four lanes. Constructing the road retaining wall, approximately 717 no. 9.5-12.0m long single PU32 piles had to be installed into mudstone or sandstone in double lines from October 2016 to April 2017.

4.1.2. Site condition

Photo 1 shows the narrow working space between the existing road and the valley. The working width is approximately 7.0 meters which was the minimal size for the crawler crane operation. Then, one of the double lines was on a slope (**Photo 2**). If the conventional piling method based on the crawler and drill unit had been utilized, temporary work (i.e. platform, reclamation) would have been essential to set the rig on the installation line.

4.1.3. Issues and solutions

The main issue was to install steel sheet piles into hard rock mass. **Fig. 10-a, 10-b** show bore hole logs at this site. According to the soil investigation report, the upper made ground included boulders, and it was written that the value of unconfined compressive strength (Hereafter, UCS) of lower mudstone/siltstone is 60.7Mpa, and the UCS of the lowest Sandstone is 92.9Mpa, meaning extremely hard ground conditions. 685mm diameter pre-auger heads were first utilized in the UK, solving this issue. This type of auger head was developed for rock mass. The situation of discharging the crushed rocks from the window of the casing was shown in **Photo 3**. Some rocks crushed by pre-augering may be seen. From this photo, the Press-in operation with pre-augering was effective against rock mass. After pre-augering, the steel sheet pile was successfully installed by simultaneous augering.

Photo 1. Narrow working space

Photo 2. Piling on slope

Photo 3. Arising from the window of casing

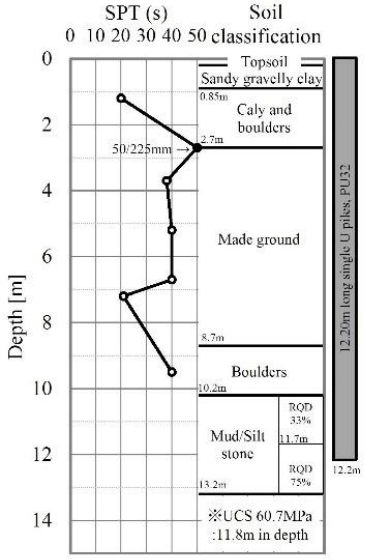

Fig. 10-a Bore hole logs of A465 Heads of the Valleys Road section 2

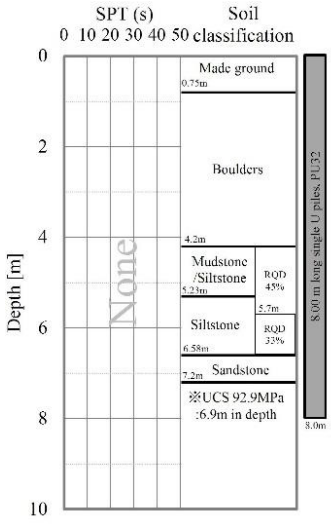

Fig. 10-b Bore hole logs of A465 Heads of the Valleys Road section 2

4.2. Case study 2: Thames Tideway tunnel -east-

4.2.1. Summary of the Site

The Thames Tideway Tunnel is an under-construction 25 km tunnel running mostly under the tidal section of the Thames through central London, which will provide capture, storage and conveyance of almost all the combined raw sewage and rainwater discharges that currently overflow into the river.

At Chambers wharf, which is one of the site of this huge project, two units of Super crush SCZ676WMG were utilized to install 321 no. 17.7-22.6m long double AZ36-700N piles to build twin sheet pile cofferdams for the construction of the shaft being utilized as a relay station of the tunnel. The piling duration was approximately 5 months from July to November 2016, using two units for the pressing-in machines.

4.2.2. Site condition

First of all, this site is located near Tower Bridge in central London, so the noise and vibration generated by piling works were to be minimized as much as possible, due to the city's strict regulations. Further, the ground consisted of stiff clay with occasional cobbles whose converted max SPT *N*-value is 125 (**Fig. 11**). In addition, since the Thames is a tidal river, the projecting length above the riverbed is approximately 9meters at low tide whilst the operation is on water at high tide. Solving all the above requirement, the Press-in Method was adopted (**Photo 4**).

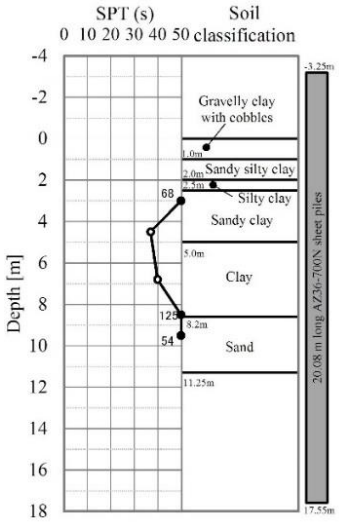

Fig. 11 Bore hole log of Chambers wharf

Note that two service cranes per unit were utilized: one on land to feed a double Z pile to the pressing machine whilst the other one on a pontoon to support the Pile auger, due to the installation of 22.6m long double Z piles.

4.2.3. Issues and Solutions

In this project, the construction duration including the piling work had to be minimized as much as possible. Hence, the following measures were adopted.

- Installation of double Z piles
- Piling by two units
- Use of the auger head with zooming blades

From the view of the pile installation, one of the advantages of double Z piles, the productivity is literally

"double" that of the installation of single piles. Then, as double Z piles in two rows, inner and outer, could be installed separately (**Fig. 12**), the duration of the piling work was dramatically shortened. Note that it might have taken 20 months if one pressing-in machine (instead of two) for single piles (instead of double) had been utilized.

Also, another way to improve productivity is to utilize the auger head with zooming blades. As described in 3.2., an auger head replacement shall be required between the pre-augering and simultaneous augering. However, it is not necessary if using the auger head with zooming blades. Usually, it takes approximately 20 minutes per pile to change auger heads, which could be cut from the piling work.

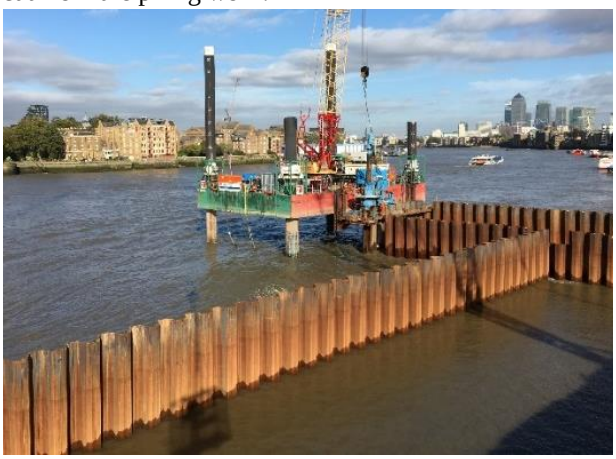

Photo 4. Press-in operation on water

Fig. 12 Two units working

5. Comparison of installation of single U piles and double Z piles

Below, the pros and cons of the installation of both single U and double Z piles in the Press-in operation assisted with augering will be summarized.

5.1. Pile drivability

Fig. 13-a shows the typical augering areas of 600mm width single U piles, whilst **Fig. 13-b** shows the ones of 1,400mm width double Z piles. It may be seen that the 580mm diameter augering areas of U piles covers the whole section. On the other hand, 980mm diameter augering areas of the double Z piles don't cover the whole section. Since their pile drivability is logically improved by the reduction of their toe resistance, single U piles should be considered to be superior to double Z piles, particularly into hard rocks and buried obstructions. Note that stiff and very stiff ground condition should be no problem for double Z piles based on the case studies such as the Thames Tideway tunnel.

5.2. Horizontal response of wall

While installing double Z piles, most augering takes place on the in-pan side, meaning that the ground disturbance on the out-pan side, which is also the passive side, of double Z piles could actually be minimized.

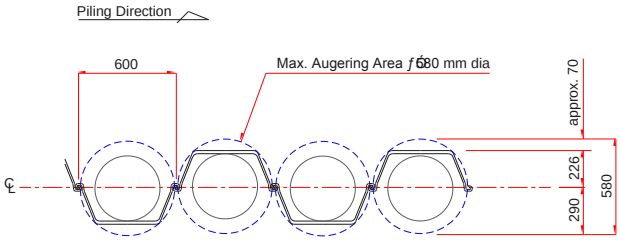

Fig. 13-a 580mm dia. augering area for single U piles

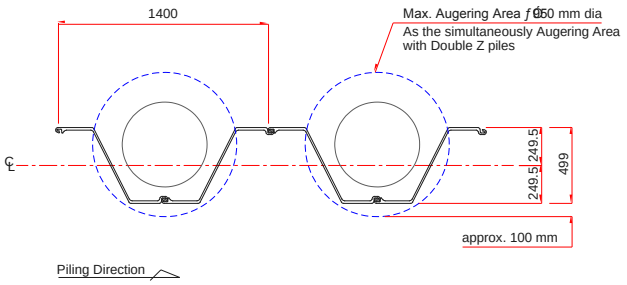

Fig. 13-b 980mm dia. augering area for double Z piles

Note: The augering area is shown by a blue dashed line in each drawing.

Then, according to the Euro code 3 part 5 in BSI British Standards (2007) : piling , reduction factorsfor β shall be applied to U piles due to the possible lack of shear

force transmission at the interlocks (**Table 3**). The values of β of single and uncrimped piles in the table is 0.40 to 0.80 subject to the number of structural support levels and ground conditions, which means the wall stiffness may be reduced by half. In contrast, no reduction is required in sectional properties of Z piles because interlocks are located at the far edge of the wall, which means that the shear force does not occur in the interlocks.

Table 3. Reduction factors for U shaped sheet piles

Type of U-pile unit	Number of structural support levels (see Note 1)	Reduction factors β_B and β_D referred to in 5.2.2 (2); 5.2.2 (9); 5.2.3 (2); 6.4 (3) (see Notes 2, 3, 4, and 5)					
		Highly unfavourable conditions (see Note 6)		Unfavourable conditions (see Note 7)		Favourable conditions (see Note 8)	
		β_B	β_D	β_B	β_D	β_B	β_D
Singles or uncrimped doubles	0	0,40	0,30	0,50	0,35	0,60	0,40
	1	0,55	0,35	0,60	0,40	0,70	0,45
	>1	0,65	0,45	0,70	0,50	0,80	0,55
Crimped or welded doubles	0	0,70	0,60	0,75	0,65	0,80	0,70
	1	0,80	0,70	0,85	0,75	0,95	0,80
	>1	0,90	0,80	0,95	0,85	1,00	0,90

Based on the above mentioned two reasons, the wall constructed of double Z piles should show stiffer response than that of single U piles.

5.3. Workability in narrow space

Essentially, construction plants become larger and sections of steel sheet piles become bigger due to the length and weight of steel sheet piles. For instance, one 50ton crawler crane should be enough to lift one 12.0m long single PU32 piles whose weight is 1.37tons, whilst one 100ton crawler crane should be necessary to lift one 22.6m double AZ36-700N pile whose weight is 5.36tons.

Thus, as described in table 1 and 2, the pressing-in machine for single U piles is bigger and heavier than the one for double Z piles.

From this point of view, single U piles should be preferable in narrow spaces where conventional pile drivers could not be set.

6. Concluding remarks

This report introduces Press-in assisted with augering based on two types of steel sheet piles and two case studies in the UK. Also, the characteristics of the installation of single U and double Z piles are described. Based on them, the following conclusions can be drawn:

1. The Press-in operation with augering can be applicable for stiff to hard ground conditions. Particularly, the augering of single U piles should be more effective in hard ground conditions such as siltstones with 92.9Mpa in UCS.
2. Double Z piles installed by the Press-in assisted with augering should be more effective to wall stiffness due to the augering on passive side and reduction factor β specified in Euro code 3 part 5.
3. The workability of the operation to install single U piles should be better as its construction plant is relatively small. It means single U piles can be more applicable to narrow working conditions.

Since the Press-in Method assisted with augering was developed in 1997 in Japan, this piling technique has spread all over the world. I hope this paper will be useful for someone wishing to understand its characteristics.

7. Acknowledgements

The authors are grateful to Mr Simon King and Mr Andy King of Ivor King (Civil Engineering Contractors) Ltd and Mr Robert Law of AGD Equipment Limited for the collaboration with GIKEN Europe B.V in the UK and checking materials used to write this paper.

References

International Press-in Association. 2016. Press in retaining structures: a handbook.

GIKEN LTD. 2018. Hard Ground Press-in Method Silent Piler ECO400S Techniqueal Brochure.

GIKEN LTD. 2016. Silent Piler Silent Piler ECO700S/ 1400S Brochure.

GIKEN LTD. 2008. Silent Piling Piling Technologes 2008.

Constructing Excellence in Wales. 2017. Design stage case study A465 Heads of the Valleys Section 2 Gilwern to Brynmawr: http://www.cewales.org.uk/files/2114/9812/2528/A465_Heads_of_the_Valleys_Section_2_Gilwern_to_Brynmawr_Design_Stage.pdf.

Tideway. 2018. The Web site of the Thames Tideway Tunnel: https://www.tideway.london/.

ArcelorMittal. 2016. Piling Handbook 9th edition. ISBN 978-99959-0-194-3.

BSI British Standards. 2007. UK National Annex to Eurocode 3: Design of steel structures – Part 5: Piling. NA to BS EN 1993-5:2007.