TECHNICAL NOTE 009

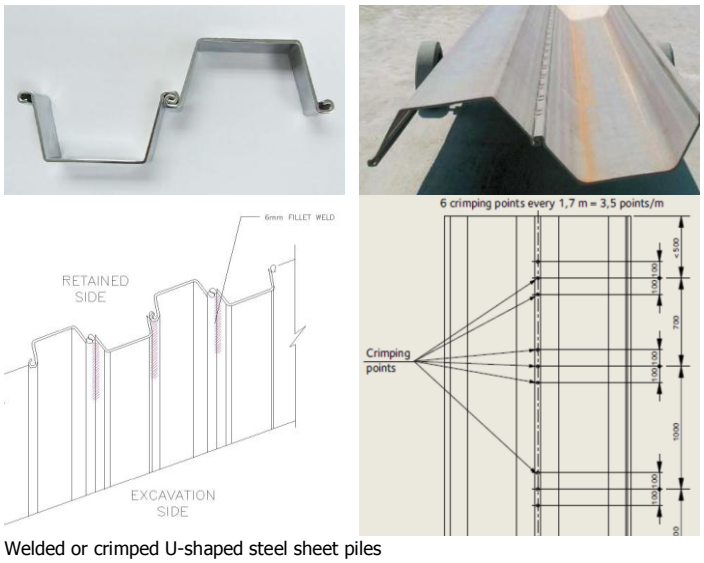
Watch Out! Clutch-Welding: Conservatism in Steel Sheet Pile Wall Design

Keywords
Clutch-welding, clutch-crimping, reduction in stiffness and moment capacity, misinterpretation of reduction factors

Synopsis
Clutch-welding or crimping has been specified recently in continuous steel sheet pile walls to enhance the interlocking performance between individual sheet pile sections. Buildings Department (BD), following the approach in Eurocode BS EN 1993-5:2007, has imposed reduction factors for stiffness and bending strength of sheet pile walls. The criteria are however slightly different from those in the Eurocode, leading to possible misinterpretation of these factors in ELS design. In a recent ELS design prepared by a Contractor's Designer, the clutches of all the steel sheet piles were specified to be intermittently welded along the full length of the sheet pile sections, leading to substantial cost and time impacts on the project.

1.0 Introduction

U-shaped (or Z-shaped) steel sheet piles are commonly used as the vertical retaining elements in ELS works. They are connected together via interlocking clutches along the length of the sheet pile sections. To prevent inter-pile movement under lateral load effects, the clutches may be crimped or welded together (see figures below) in order that full composite bending stiffness and strength can be achieved.



Welded or crimped U-shaped steel sheet piles

If the paired-up sheet pile sections are left uncrimped or unwelded, the stiffness and strength of the pile sections are required to be reduced, depending on how the sections are installed and the number of layers of lateral support specified.

2.0 Conservative Use of Reduction Factors

The interpretation of the reduction factors required for stiffness and strength varies between designers, leading to some very conservative (or even disruptive) construction requirements during ELS installation and bulk excavation. One of such examples is explained below.

2.1 Design by The Engineer

In The Engineer's tender design, it was stated that *"the interlocks of single U-piles should be connected after installation by a structural weld (minimum 6mm fillet) near the top. The minimum length of the weld should be **500mm**."* It was further stated that *"Reduction factors for moment of inertia and section modulus of sheet piles to be **0.55**."*

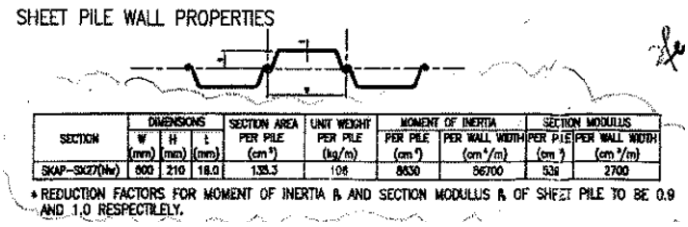
The use of reduction factor of 0.55 for both the stiffness and strength of the sheet piles is conservative when referenced to the said Eurocode. However, at least, the requirements were stated on the Tender Drawings and all tenderers, if they noticed these subtle requirements, were pricing on the same basis.

2.2 1st Design by Contractor's Designer

In the ELS design (submitted to BD) by a Contractor's Designer after contract award, the reduction factors had been lifted up to **0.9** and **1.0** for stiffness and strength, improving the structural efficiency of the sheet pile walls. However, this was achieved at the expense of having intermittent 6mm fillet welds (150mm welds; 300mm gaps) along the full length of the interlock between each sheet pile, and this activity has to be sequenced with the bulk excavation. As can be imagined, this additional welding requirement is costly and disruptive.

2.3 2nd Design by Contractor's Designer

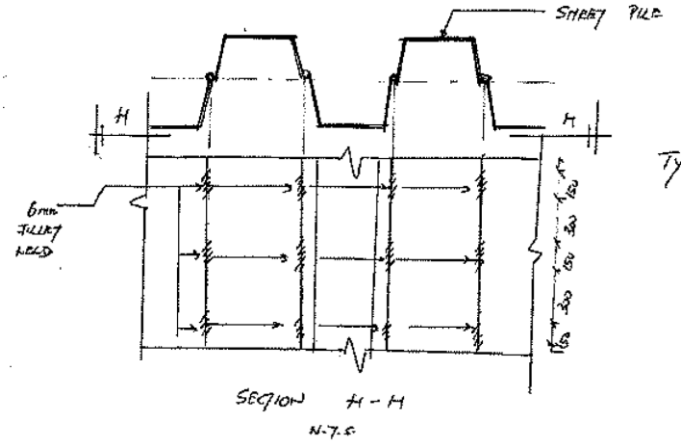
After an internal review regarding the application of the reduction factors and a follow-up meeting with the Contractor's Designer, a BD amendment submission was made in that the reduction factors were modified to **0.85** and **1.0** for stiffness and strength, and the clutch-welding of the sheet piles was kept to the top **500mm** only. As a result, the Contractor's proposed sheet pile sections could be maintained whilst the clutch-welding requirement was no worse than that shown on the Tender Drawings.



SHEET PILE WALL PROPERTIES

SECTION	DIMENSIONS W (mm)	H (mm)	t (mm)	SECTION AREA PER PILE (cm²)	UNIT WEIGHT PER PILE (kg/m)	MOMENT OF INERTIA PER PILE (cm⁴)	MOMENT OF INERTIA PER WALL WIDTH (cm⁴/m)	SECTION MODULUS PER PILE (cm³)	SECTION MODULUS PER WALL WIDTH (cm³/m)
SKAP-SX27(Hw)	600	210	18.0	133.3	106	8630	86700	539	2700

* REDUCTION FACTORS FOR MOMENT OF INERTIA I_B AND SECTION MODULUS I_B OF SHEET PILE TO BE 0.9 AND 1.0 RESPECTIVELY.



Images showing the section properties, reduction factors adopted and clutch-welding requirements for steel sheet pile walls in BD Submission (1st Design by Contractor's Designer)

3.0 Eurocode 3 – Requirements of Reduction Factors

The original requirements of reduction factors, β_B (for strength) and β_D (for stiffness), are stated in **Eurocode 3: Design of steel structures** – Part 5: Piling. The table extracted from EC3, tabulating the various reduction factors is shown below for reference.

NB – The requirements shown in the table below are not fully adopted by BD in Hong Kong. Please see Section 4 for BD requirements.

Table NA.2 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

NOTE 1 Any restraint device which leads to the shear force changing from positive to negative or vice versa may be considered as a structural support. The toe of the piles should not be considered as a restraint. The benefit of the restraint should only be taken into account for design situations following installation of the restraint. Restraints may be regarded as structural supports only when designed as such in accordance with relevant standards.

NOTE 2 If interlocks are not treated with sealants or lubricants, the coefficients may be increased by +0,05 (to a maximum value of 1,0).

NOTE 3 The interlocks of single or uncrimped U-piles should be connected after installation by a structural weld (minimum 6 mm fillet) near the top. The minimum length of this weld should be 100 mm for walls with retained heights up to 2,5 m; for greater retained heights, an additional 100 mm of weld should be provided for every additional 1 m of retained height, up to a maximum of 500 mm (applies to retained heights above 6,5 m). Provision of this weld permits the β_B coefficients to be increased by +0,1, 0,15 or 0,2 respectively for highly unfavourable, unfavourable and favourable conditions (to a maximum value of 1,0); and the β_D coefficients likewise by +0,15, 0,2 or 0,25 (to a maximum value of 1,0).

NOTE 4 The enhancement of β values by additional methods may be considered by the designer subject to demonstration, by calculation, testing or by other means, that the appropriate degree of shear force transmission will take place to justify higher coefficients than those values obtained from this table and notes.

NOTE 5 The β_B and β_D coefficients for the entire pile should be selected according to the most unfavourable conditions that apply.

NOTE 6 Highly unfavourable conditions are:

- *retaining substantial depths of free water;*
- *significant presence of very low strength fine soil or very loose coarse soil (as defined in BS EN ISO 14688-1) below formation;*
- *artificial loosening by pre-augering in fine soil below final excavation level (unless it can be demonstrated by testing or other means, that the pre-augered soil offers friction equivalent to or better than that of a low strength fine soil or loose coarse soil, in which case better conditions may be assumed);*
- *artificial loosening of fine soil by water jetting at a rate exceeding 240 l/min (see Annex D.2 of BS EN 12063:1999); or*
- *artificial loosening of coarse soil by water jetting at a rate exceeding 480 litres per minute (see Annex D.2 of BS EN 12063:1999).*

NOTE 7 Unfavourable conditions are:

- *significant presence of low strength fine soil or loose coarse soil (as defined in BS EN ISO 14688-1) below formation;*
- *artificial loosening by pre-augering in coarse soil below final excavation level (unless it can be demonstrated by testing or other means, that the pre-augered soil offers friction equivalent to or better than that of a medium dense soil, in which case better conditions may be assumed); or*
- *artificial loosening of fine soil by water jetting at a rate between 60 l/min and 240 l/min (see Annex D.2 of BS EN 12063:1999) or when coarse soil has been artificially loosened at a rate between 240 l/min and 480 l/min.*

NOTE 8 Favourable conditions may be assumed if none of the highly unfavourable or unfavourable conditions apply.

4.0 BD Requirements of Reduction Factors

It is understood that the reduction factors adopted by BD are documented in their in-house Engineering Manual. The relevant table is shown below for reference only.

Table 1 – Reduction factors for steel sheet piles

Type of Steel Sheet Pile Unit	Number of Lateral Support Layers (Note 2)	Reduction factors β_B and β_D (Note 3)			
		Category 1 (Note 1)		Category 2 (Note 1)	
		β_B	β_D	β_B	β_D
Singles or uncrimped doubles (i.e. free interlock) (Note 4)	0	0.40	0.30	0.60	0.40
	1	0.55	0.35	0.70	0.45
	> 1	0.65	0.45	0.80	0.55
Crimped or welded doubles (i.e. double steel sheet pile) (Note 5)	0	0.70	0.60	0.80	0.70
	1	0.80	0.70	0.95	0.80
	> 1	0.90	0.80	1.00	0.90

Conditions defining which 'Category' to be considered are also outlined in the manual.

5.0 Recommendation

In ELS design for deep excavation entailing long perimeter length of sheet pile walls, the correct use of reduction factors is important, noting that the reduction factors could be as low as **0.30** to **0.40**. It is recommended that the Technical Department should be consulted if one comes across the above situation.

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