King Sheet Piling (KSP®) - Technical Guidance

The following information is provided for the guidance of designers and installers using the KSP system. This is for information only and designers and installers are responsible for satisfying themselves of the adequacy and applicability of their design or installation methods. Users should ensure they download a current version of this document.

DESIGNERS PLEASE NOTE *– There is no restriction on you designing a KSP wall. A licence is required at the construction stage only and is normally obtained by the main contractor or the sheet piling subcontractor. All we require is that you inform us that you are using a KSP design and that you have notes on the drawings about KSP's patented status. See Guidance to Users.*

Contents

Design Guidance 2

Sheet Pile Profile for KSP 3

Wall Design – Single Pair of Intermediates 3

Other KSP Configurations 4

Design Deflections 4

Sizing the Kings 4

Steel Grade 5

Intermediate Design 5

Section Lengths 6

Water Pressure Relief 6

Water Cut-off Options 6

Designing KSP for Watercourses or Marine Applications 7

Installation Method 7

Crimped Pairs 8

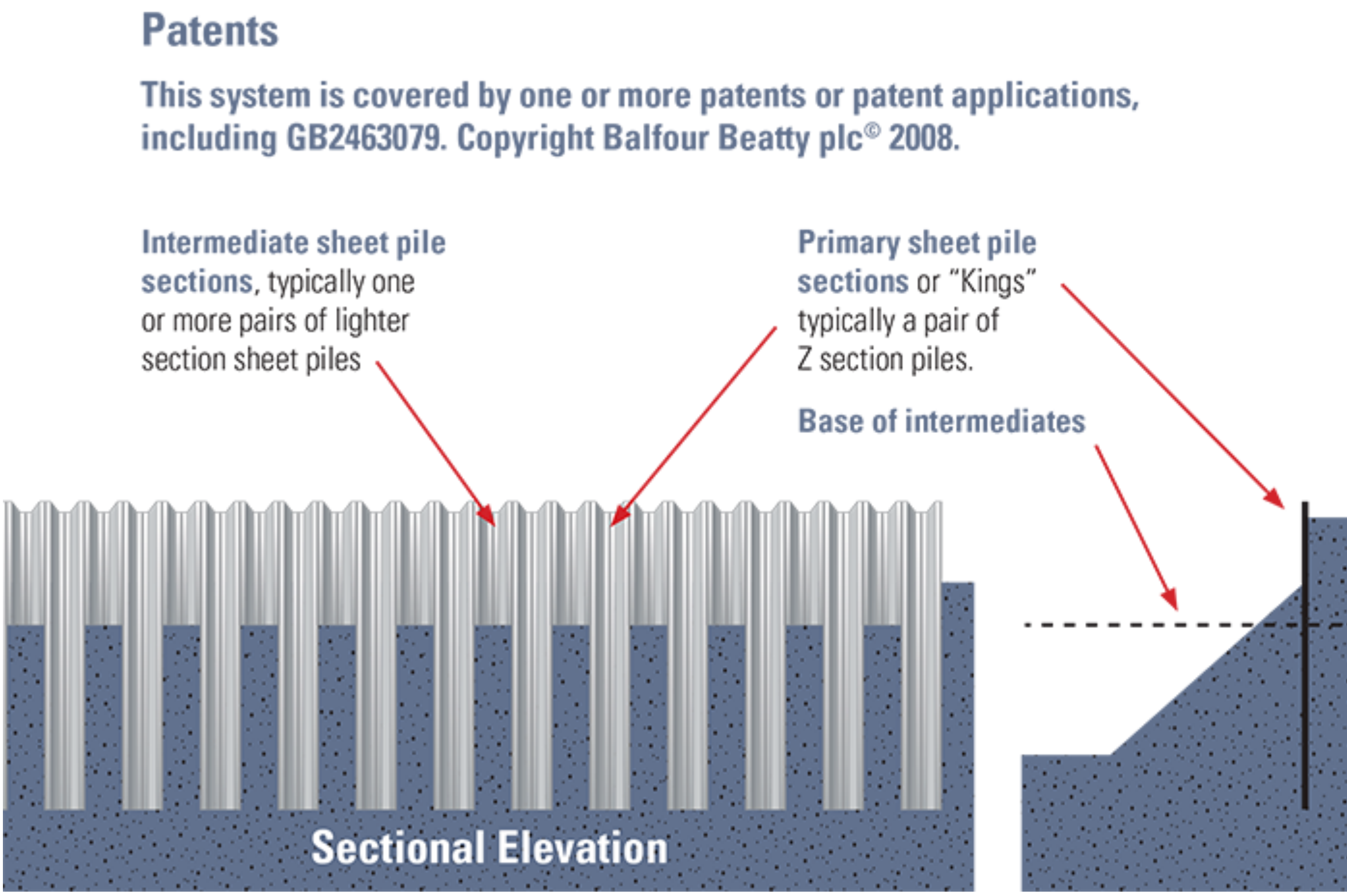
Installation using Pressing 8

Pre-augering in Hard Ground & Weak Rock 8

References 9

Design Guidance

Design of a KSP wall is relatively straightforward and no different in essence to design of a conventional sheet pile retaining wall except that the wall stiffness and structural properties are reduced in proportion to the ratio of the length of the wall made up of kings. The reduced stiffness of a KSP wall typically has only a relatively small effect on wall deflections.



KSP walls are normally designed for use with Z piles. U piles do not work efficiently in a non-continuous wall.

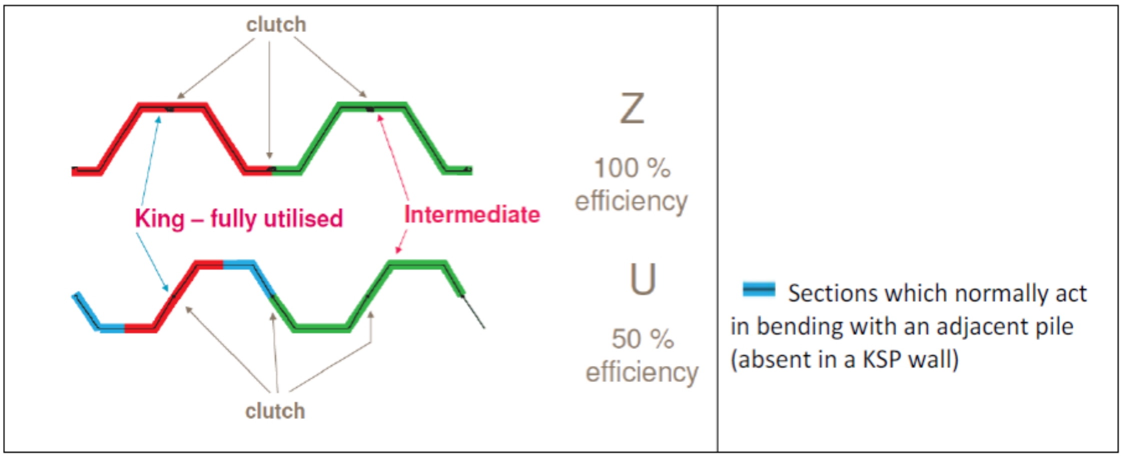
The simplest and most efficient form of KSP wall consists of pairs of crimped Z piles as kings, with pairs of the lightest practicable Z piles, as intermediates.

For more detailed guidance on the design and specification of a KSP wall, including options for water cut-offs, see the detailed Technical Guidance below.

Sheet Pile Profile for KSP

Standard KSP walls are designed to use hot rolled Z profile piles, as defined in BS EN 1993-5: 2007 Eurocode 3, Table 1-2, with clutches manufactured in accordance with BS EN10248. To view Z pile sections from the current ArcelorMittal range click here .

U profile piles are inefficient for KSP walls. They would only be used in special cases where there is a particular reason to do so, e.g. a stock of U piles to be used up, and then they can only be used in combinations that are less efficient than an equivalent Z pile KSP wall. The reason is that U piles, being clutched on the neutral axis in the middle of the equivalent "webs" of the wall, rather than the equivalent "flanges", as in Z piles, depend on adjacent U piles to generate their full capacity in bending. The end half of each combination of U piles forming a king is ignored as it would normally be bending through an adjacent "web" which is not present. This is illustrated in the diagram below. This simplified approach avoids complex structural analysis to determine how much of the blue sections in the diagram can safely be treated as contributing to bending through the single web (red) without over-stressing the piles. Note that if a designer chooses to use U piles, accepting reduced efficiency, the U piles should be driven as pairs, with clutches either crimped or welded so as to avoid reduced structural capacity due to clutch slippage. Reduced capacity and increased deflection due to potential oblique bending, particularly in the active zone of the wall, must also be considered.



Wall Design – Single Pair of Intermediates

Design of a KSP wall is straightforward and no different in essence to design of a conventional sheet pile retaining wall. The designer first selects the minimum section for the Kings, based on accepted guidelines for sheet pile selection for a continuous sheet pile wall. When designing a KSP wall from the start, the designer will input equivalent reduced wall stiffness properties into a retaining wall program such as Wallap or Frew based on pro-rata adjustment of the wall properties for the proposed spacing of the Kings. For the most common application, that of a pair of Z piles as intermediates and a pair of Z piles as Kings, the spacing of the Kings is substantially less than the 3D centre to centre spacing rule of thumb commonly adopted in the design of king post walls.

Where a KSP wall is being considered in place of a pre-designed conventional cantilever sheet pile wall, the reduced stiffness of the KSP wall is not normally a significant factor in terms of soil structure interaction and any increase in wall deflection is relatively small. A sensitivity analysis carried out using the retaining wall analysis program, Wallap, for a wide range of wall and ground properties showed that dividing the wall stiffness by a factor of 2.1 (Change from SP wall to KSP wall using 1 pair of AZ 770 intermediates) typically increases cantilever wall deflection by about 5 mm.

In evaluating the structural properties of the wall, due allowance must be made for loss of section due to corrosion over the design life of the wall.

Other KSP Configurations

KSP walls may also consist of:

- **Double intermediates** - Pairs of Z section piles as kings with 2 pairs of Z section piles as intermediates. This configuration may require welding of the clutches between intermediate pairs or other restraint measures to limit rotation and deflection of the intermediates. For these reasons and the additional structural demand imposed on the sheet piles forming the kings, this configuration is not commonly used but may be considered for low retained height walls.
- **Single Z sections** - Single Z section piles as kings alternating with single Z section piles as intermediates would appear ideally suited to installation by silent pressing. This configuration is not recommended, however, due to potential problems of oblique bending if the piles are not adequately restrained by a combination of the ground and the torsional resistance of the kings.
- **U section piles** - Combinations using U section piles are possible but inefficient (see above) and are normally only used in rare circumstances where there is a stock of U piles to be used up.

Design Deflections

Design limiting deflections will depend on the particular application and the sensitivity to movement of any structures or services that may be affected. In the UK, KSP walls on a number of Smart Motorway schemes have been designed using a maximum deflection of 75 mm. This takes into account: (a) permissible differential settlements along the carriageway, (b) recognition that settlement associated with wall deflections generally varies gradually with distance along the wall and back from it (and does not lead to large localised differential settlements) and (c) recognition that a significant proportion of the movement takes place during construction and before completion of the pavement.

Sizing the Kings

The minimum pile section for the kings is chosen based on industry guidelines for sheet pile selection for driveability for a continuous sheet pile wall. Section 11 of the ArcelorMittal Piling Handbook (9th Ed), for example, contains detailed guidelines for sizing sheet piles based on the method of installation, the driven pile length and the ground conditions. These are in the form of semi-empirical equations, charts or tables which take into account pile length, ground resistance and hammer energy.

A nomogram relating driven length, ground conditions and pile section is also provided in Figure 11.24 of Section 11. Understanding this chart can be improved by sketching in approximate contours through entries of common section modulus value (e.g. 12, 18, 26, 32, 39 and 48). Based on guidance elsewhere in Section 11, the approximate bounding values of strata stiffness or relative density are as follows:

Driving Conditions	Cohesive Ground	Cohesionless Ground
Easy	Su < 15 kPa	SPT N < 20
Normal	Su 16 to 50 kPa	SPT N 21 to 40
Hard	Su > 50 kPa	SPT N > 40

Approximate bounding ground conditions in Figure 11.24 of Piling Handbook (9th Ed.)

The nomograph is a guide only and must be treated with caution. UK piling subcontractors may sometimes propose pile sections which are more conservative than the guidance in the nomograph. This is not necessarily unreasonable in the context of experience driving AZ 28 sheet piles on the M25 in very stiff clay, when the pile heads were bending at a driven depth of 13m.

Steel Grade

To cope with difficult driving conditions, it is normally more economical to increase the steel grade than to increase the section size. A minimum steel grade of S355 GP is recommended for kings in KSP walls. Increasing to S430 GP for the kings is an economical way of increasing both the resistance to impact driving and the bending capacity of a KSP wall. Intermediates can be grade S270 GP unless deeper driving is required for structures such as basements or to achieve a cut-off.

Intermediate Design

To function structurally in the normal range of soils, there is no requirement for intermediates to extend below the ground level in front of the wall. A nominal penetration depth of 0.5m to 1.0m below this level is normally specified to cater for practical tolerances in design, construction and pile supplied length. The designer must allow for any uncertainties in level s when specifying penetration depths. In cohesionless ground, the designer needs to pay particular attention to the combination of intermediate penetration length and drainage measures on both sides of the wall to ensure there is no risk of flow of water eroding material from behind the wall. In very soft soils, the designer must check that the penetration depth is sufficient to avoid squeezing of soft soil beneath the intermediate.

Designers of cantilever walls up to 4m high have typically approached intermediate design on an empirical basis. The lightest section, e.g. an AZ 12-770 is normally used for cantilever walls where penetration is limited. A heavier section may be required for drivability in other applications, such as basements. Where piles are to be pressed as singles, an AZ12-700 would be the lightest section practicable but an AZ 17-700 may be more appropriate to cope with pressing forces, unless a heavier section is advisable for the penetration needed.

In cantilever walls up to 4m high, water pressure on the wall is normally relieved by a combination of weep holes and drainage measures behind the wall. Because of arching in the ground, sustained ground loading on the intermediate sections is limited, as they are effectively supporting only a localised arc of ground between the kings. Standard Larssen type clutches, manufactured in accordance with EN10248, are commonly used in combined walls retaining significant heights of material or water. Any tendency for the intermediates to deflect under load will initiate the arching action in the ground, relieving loading on the intermediates.

For more heavily loaded intermediates, e.g. in basements or pumping stations, analysis may be carried out using the approach suggested for combined walls in BS EN 1993-5: 2007 Eurocode 3 – Design of steel structures – Part 5: Piling. Where clutches are welded for water-tightness in basements, design considerations are simplified.

Section Lengths

Section lengths should be specified to the nearest 0.5m. This is to suit the practicalities of cutting to size in the mill and handling and tracking the sections thereafter. Taking normal mill cutting tolerances into account (+/- 200mm in length), this ensures that the specified section lengths are easily recognised and differentiated from other similar section lengths.

Water Pressure Relief

KSP is ideal for ensuring the flow of groundwater across the line of the wall is not impeded. It is particularly beneficial in avoiding the build-up of differential water pressures in the active and passive zones of the wall. Water pressure equalisation on both sides of the wall can lead to substantial economies in wall design.

Where it is desirable to ensure drainage in the zone restrained by the intermediates, this can be achieved by a combination of weep holes and drainage measures behind the wall. In cuttings, in the right ground conditions, use of band drains could also be considered. These would be driven with the intermediates with a purpose-made shoe fixed to the bottom of the intermediate. The band drain would extend the full height of the retained ground to above the water table and would wrap around the intermediate on the passive side, extending up to ground level where it can discharge naturally or be led into drainage material.

Water Cut-off Options

KSP is ideal where it is desirable to allow the flow of groundwater across the line of the wall or where groundwater is not a design issue. A KSP wall can also be used to advantage where a cut-off is required by:

- Driving intermediates deeper to cut-off into a low permeability stratum.
- Constructing a KSP wall along the line of a pre-formed cement-bentonite cut-off wall.

- Using a purpose-made mandrel in the form of a thickened sheet pile pair of the same profile as an intermediate. The mandrel is clutched to the previous king and driven with grout tubes attached. As the mandrel is withdrawn, cement bentonite is injected to fill the gap left by the mandrel. (This technique uses the same principle as in a Vib-Wall cut-off, which is formed by driving and withdrawing an I beam in an overlapping sequence whilst grouting through attached grout tubes). The mandrel is withdrawn and grouted only after the subsequent king has been driven. It is then replaced by a standard shallower intermediate.

Designing KSP for Watercourses or Marine Applications

KSP walls may be used for flood protection, beach erosion defences or for retaining any development adjacent to water. This is subject to its applicability being confirmed for the ground and groundwater conditions. Where the intermediates extend sufficiently into cohesive material to form a cut-off or where ground water pressures are naturally equalised either side of the wall, a KSP wall is normally feasible.

The intermediates need to extend beyond the potential depth of erosion or scour. Some designers may be minded to avoid use of KSP walls where there may be any uncertainty over the potential erosion depth. These concerns should not be a blocker for use of KSP in these situations, however. A rational and safe KSP design which saves money, resources and installation time may be designed using the following rationale:

- The sheet pile wall will be designed to support the ground or bank/beach defences in the event of a particular design level of erosion or scour on the water side of the wall. This design erosion level will be selected in accordance with accepted conservative state-of-the-art practice.
- The wall then has to function with the accepted normal design factors of safety for this erosion level.
- The wall designer can also check how much deeper the erosion would have to be before the FOS of the wall reduced to 1.0, i.e. the point of failure of the wall.
- The KSP wall can then be designed with the intermediates extending to or just below this unrealistic erosion level. This would build-in an appropriate factor of safety against undermining beneath the base of the intermediates.
- The KSP design would be robust and could not be criticised as, if erosion were to occur to this unexpected depth, the wall would fail in overturning anyway.

Installation Method

KSP is ideally suited to installation by pitch and drive as the short intermediates minimise clutch friction, eliminate problems of forward lean, makes control of alignment simple. Safety is improved as the method minimises working at height. Experience in cantilever walls up to 4m retained height is that KSP walls are readily kept on line by routine adjustment when placing each intermediate and king. This speeds the installation process considerably.

Where a subcontractor has elected to install by panel driving, some down-drag of short intermediates has occasionally taken place but this was readily rectified by pulling the intermediates back up. Pitch and drive is the recommended installation method for KSP walls.

Crimped Pairs

For installation using a vibratory or percussive hammer, piles should be ordered as crimped pairs. When pairs of Z piles are driven percussively un-crimped, oscillation can develop in the clutch, leading to loss of energy, inefficient driving and excessive vibration and noise. Where a stock of un-crimped pairs is sourced, the pairs should be tack-welded before percussive driving.

Where there is a possibility that piles may be installed by pressing, the piles should be ordered un-crimped and tack welded if percussive driving is to be used instead.

Installation using Pressing

Pairs of 700 mm wide Z sections may be installed by pressing singles to form alternating long pairs (kings) and short pairs (intermediates). A press such as the Giken ECO700S can press Z piles up to 700 mm wide. Hence AZ 12-700s rather than AZ 12-770s are required for the intermediates. The benefits noted above for pitch and drive extend to walls installed by pressing. Control of verticality is improved and pressing is easier through reduced clutch friction. The practicability of pressing two adjacent, short, single, Z piles to form intermediates using techniques such as tack welding intermediates to the previous kings or use of a temporary pile alongside has been established. Further information can be supplied on request.

Pre-augering in Hard Ground & Weak Rock

Providing the right pre-augering equipment and techniques are used, KSP walls can be reliably installed to full depth with confidence in very hard ground. KSP walls were successfully installed in very hard ground on M5 J4A-6 using vibratory driving only, with no need for impact driving. Typical ground conditions over the driven lengths were:

- 7m long sheet piles driven through 5 m of sand (weathered sandstone) then 3.5 m into extremely weak and very weak Bromsgrove sandstone gravel (SPT N 100 blows/265 mm at 5 m depth).
- 10m long sheet piles driven through 5 m of firm becoming stiff clay (1m of Made Ground over weathered Mercia Mudstone Grade IVA (2m firm clay) then Grade III (2m stiff clay), then 5 m into extremely weak Mercia Mudstone Grade III (SPT N in blows/penetration in mm of 100/225, 100/170, 100/145).

Pre-augering was generally carried out to toe level using 450 mm diameter holes centred on the clutches of the kings. The key to this success is pre-augering with a cased auger to ensure verticality, together with use of heavy-enough vibratory driving equipment, in this case an ABI TM22 piling rig with circa 15 tonne m torque and a MRZV 30VV hammer operating at ultra-high frequencies. Cased CFA augering can achieve a vertical tolerance of up to 1:250 compared to 1:75 for a conventional CFA auger. It is important that the pre-augering does not proceed more than 20 to 25 m ahead of the sheet piling to ensure the pre-augered holes are in the right positions.

With pre-augering and percussive driving, KSP kings can be installed into harder ground and to greater depths.

References

ArcelorMittal (2016), Piling Handbook, 9th Edition.

BS EN 1993-5: 2007 Eurocode 3 – Design of steel structures – Part 5: Piling.

BS EN 12063: 1999 Execution of special geotechnical work - Sheet-pile walls.

BS EN 10248-1: 1996 Hot rolled sheet piling of non alloy steels – Part 1 Technical delivery conditions.

BS EN 10248-2: 1996 Hot rolled sheet piling of non alloy steels – Part 2 Tolerances on shape and dimensions.