APPLICATION OF SHEET PILES IN ONSHORE AND MARINE STRUCTURES

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ABSTRACT

Sheet piles, particularly steel sheet piles, in marine jetty are used as ship berthing structures in ports or harbors for mooring vessels. The aim of this paper is to explain the application of sheet piles. Also, explaining the different types of materials used in sheet piles, such as wooden, concrete and steel. The usages of them in different applications, then the types of sheet pile sections like U-section and Z-section, which are commonly used in the world, are another aim of this paper. The concern of this research is approached in different steps. Firstly, by reviewing the existing recent studies which determine the types of sheet piles performance in onshore structures. Secondly, it studied the factors affecting the design of sheet piles that are obtained from penetration, type of structures and section modulus, in order to resistance against rotations as well as the stability of sheet piles against overturning moments and horizontal force. Thirdly, it determines the best sections of sheet piles that have the main role to minimize project cost and performance period. Finally, the procedures used to drive the sheet piles and their disadvantages are also mentioned.

Keywords: Sheet piles, materials, retaining walls, marine structures, soil, horizontal force.

INTRODUCTION

Generally, sheet piles are designed to resist the horizontal forces (lateral loads) due to soil or water pressures. Also, they are performed as a retaining wall system. In the civil engineering projects, sheet piles are used in many applications, for instance: river revetments, port piers and to resist ground subsidence. Moreover, they can be made of different types of materials, such as wood, aluminum, concrete and steel. Determining of suitable material for construction of sheet pile retaining walls depends on some factors like applications and the type of soil layers. Commonly steel sheet piles are used due to its advantage within strength, workability and easy to drive in various soil layers (Eskandari and Kalantari, 2011). The selection of the section of sheet piles is the most important issue. Z-section and U-section are the two main types of the section are being used depending on the types and positions of the projects (Byfield and Mawer, 2003). Similarly, there are few other types such as Straight Web and Hat-type section in order to reduce construction cost and duration (Grabe, 2008). In the UK, U-section steel sheet piles have been used since 20^{th} century and widely spread throughout of the world especially in seawater construction retaining-walls and to perform of any maritime environmental project (Byfield and Mawer, 2003). On the other hand, meanwhile sheet piles are used as temporary structures as well as cofferdams. The cofferdam is a box-dam which is an application of sheet pile retaining walls, which it uses to enclose the desired area from water or soil and to create a dry environment in order to provide a safer workplace, for example in construction pier of bridges in rivers that it is always installed temporary (Grabe, 2008). Additionally, sheet piles designing particularly in cofferdam

dependents on some factors, such as soil layers, depth of excavation, water condition, weather and period of the project (Mohamed, 2014).

According to Neghabat and Stark, 1971 in the USA, the use of the sheet piles especially circular one is the best to minimize the cost of projects and shorten the project duration. They also mentioned that this type is commonly used for high heads and larger projects (Neghabat and Stark, 1971).

Usage Of Sheet Piles

Nowadays, Sheet piles play a vital role in civil engineering supporting structures that widely used in large and small waterfront structures (horizontal pressures types), ranging from small pleasure boat launching facilities to large dock structures of ocean sailing ships. On the other hand, the Sheet piles are also used for beach protection against erosion, which assists in the stabilization of ground slopes, and also for shoring walls of trenches and other excavations (Eskandari & Kalantari, 2011).

Moreover, sheet piles are used in the construction of deep foundation where the subsoil is close to the surface and bearing capacity of the soil cannot carry the imposed loads of the structures (Kalantari and Roohbakhshan, 2015).

Sheet Piles Category

In general retaining wall sheet piles are classified into two main categories; as Anchored sheet piles and Cantilevered sheet piles (Eskandari and Kalantari, 2011).

Different Kinds of Materials Used in the Manufacture Sheet Piles

Wooden sheet piles

Traditionally, this is considered the first type of sheet pile used in history for temporary light structures. The wooden sheets are damaged due to its age, particularly when they remained for long period in inappropriate environmental conditions like dryness and wetness. Although, wooden sheet piles are still in use, however, the wooden sheets are required to be either fully covered or chemically treated. (Eskandari and Kalantari, 2011).

Concrete sheet piles

Mostly, precast concrete sheet piles are used as retaining walls. For that reason, the driving processes are not easy because of its heavyweight. Prime usage of this type was used in bulkheads in both salt and fresh water (Eskandari and Kalantari, 2011).

Steel sheet pile

At the present time, steel sheet piles are the most extensively used due to their strong load resistance, easiness of transporting (because of their light weight), and easy to drive in various types of soil layers during construction. In addition, steel sheet piles furthermore advantages such as improved water tightness, toughness, efficiency and it needs small area while construction. Consequently, they are used in temporary and permanent structures which include soil consolidation, breakwaters and harbor projects (Guang-Ghong et al., 2013).

Various cross-section steel sheet piles are available according to their application, safety, and economy. Steel sheet piles have some corrosion issues but coating with a suitable thin material can prevent it. Moreover, their thickness ranged from ten to thirteen millimeters. The acceptable stress is between (170 -210) MPa. Additionally, extra advantages of steel sheet piles that have a long service life, resistant to high driving stress, lightweight, reusability;

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easy to elongate by welding, less deform occur at joints; and can be used as a watertight barrier (Eskandari and Kalantari, 2011).

Also, steel sheet pile walls are broadly used in the modern projects. Two main sections are used: "U-section" and "Z-section" they are connected together by interlock joints along with the length of the piles which allow the section to be fitted together to form as one continuous wall (Byfield and Mawer, 2003).

U-Section and Z-Section Shapes

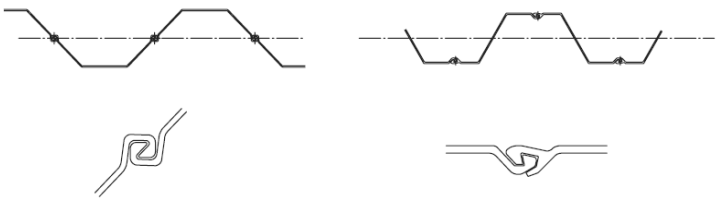
The most common sheet pile shapes are:

a. "Z" section

Z-sections are considered to be one of the most effective and operational piles available nowadays. It is commonly used for both intermediate and deep wall applications. Z- Piles are generally used for cantilevered, bridge abutments, tieback systems and Additional applications (Eskandari and Kalantari, 2011).

b. "U" section

U-section and Z-section Sheet piles are almost similar in terms of usage (Eskandari and Kalantari, 2011). U-section steel sheet piles are usually used to construct retaining walls in marine environments and were widely used throughout the 20^{th} century. Recently, concerns have been raised about its bending issue, because U-section piles are connected together by interlocking joints located along the center line of the pile (Byfield and Mawer, 2003).



a- U-section sheet pile b- Z-section sheet pile

Figure 1. Main types of sheet pile sections (Grabe, 2008).

Differences Between Z- Section And U- Section Steel Sheet Piles

In order to select the best type of steel sheet pile section, this article is trying to scientifically compare the two common sections: Z-Section always drives in corrugated and welded sheet piles combined together. Additionally, Z-sections are used more than U-sections in port-maritime constructions and deep excavation because of its greater modulus. Also, the two main properties of Z-section are the form of the web that is continuous and the location of the interlocking joints symmetrically distributed on both sides of the neutral axis, which improves the modulus of the section.

Although, when the same section modulus is used, the Z- sections have a smaller mass per square meter compare to U-sections. Therefore Z-sections have a bigger width, which means a fewer number of sheets are needed to minimize the installation cost and excavation, it is also considered as a perfect type in terms of water tightness. Moreover, Z-sections can be placed as infill together with steel pipes and H beams to achieve greater modulus. The

resistance of the section dependents on its modulus (Coastal Engineering Research Center, 1984).

Table 1. Properties of some steel sheet pile shapes introduced by United State Steel Corporation (Das, 2007).

Type	$Driving\ distance$ (in.)	Designation	Moment of inertia I (in^4/ft) of wall	Section modulus S (in^3/ft) of wall
Z	18	PZ – 38	280.8	46.8
	21	PZ – 32	220.4	38.3
	18	PZ –27	184.2	30.2
U	16	PDA – 27	39.8	10.7
	19.6	PMA – 22	13.7	5.4
	16	PSA – 28	4.5	2.5
	16	PSA -28	4.1	2.4
Straight Web	16.5	PSX – 32	3.7	2.4
	15	PS – 32	2.9	1.9
	15	PS – 28	2.8	1.9

Interlock Joints

The crucial part of sheet pile sections is interlocking joint which tightens the sheets together. The selection of the shape of interlock section is essential because it affects the overall design process that includes the size of the structure (Guang-Ghong et al., 2013).

In order to create one form of a complete wall, the individual sheet piles have to be joined all together in one piece. When welded/crimped interlocks used, the maximum permissible bending moment is 2-3 times greater than the single sheet pile. Interlock joints played a key role during the driving process even though these joints between the sheet piles are not watertight (Grabe, 2008).

Choosing Section of Sheet Piles

Recently, the section of sheet piles is directly related to the project cost. Using wide section reduces the number of piles that result in minimizing the cost of installations. Furthermore, properties of cross-section depend on depth and thickness of the piles. Similarly, it is effective to drive-in of the. The bigger cross-section means the bigger driving forces. Hence, the appropriate section should be selected based on the soil layers where piles are installed to resist deflection. Finally, previous experiences should be considered to pick the cross-section sheet piles.

Construction Procedures of Sheet Piles

Sheet piles are usually placed into the ground depending on the soil layer types, a vibrated method for sand type and hammer method for clay type.

a. Placing sheet pile sections one by one, and interlocking them carefully.

b. Individually driving the sheet piles to the desired depth.

c. Then driving the next sheet pile with the joint interlocks between the first sheet pile and second "locked".

d. Repeating steps 2 & 3 until the wall perimeter is completed.

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e. Finally, Use connector features when more complex shapes are used (Eskandari and Kalantari, 2011), (Kalantari and Roohbakhshan, 2015).

Disadvantages of Sheet Piles

The disadvantages of sheet piles are:

a. It is not suitable to use in permanent construction.

b. Driving of sheet piles is not easy in soils that have cobblestone and boulders. Thus, the desired wall depths may not be reached.

c. Excavation forms should be suited to the sheet pile shapes and interlocking elements.

d. Driving process of sheet piles causes a lot of noise for the neighborhood.

e. Sometimes Settlements may occur in adjacent positions due to the effect of vibration. (Eskandari and Kalantari, 2011).

Applications of Sheet Piles

As mentioned before, different types of materials are used for the manufacture of sheet piles such as wooden, concrete and steel. The selection of sheet pile materials depends on their applications and design. The common application of the sheet piles is retaining of soil mass due to resistance for lateral forces by long thin elements connected by interlocking joints. When sheet piles are compared with heavyweight walls stone or concrete, sheet piles are measured as flexible structures. Some of the common applications are shown in Figure 1 (Eskandari and Kalantari, 2011).

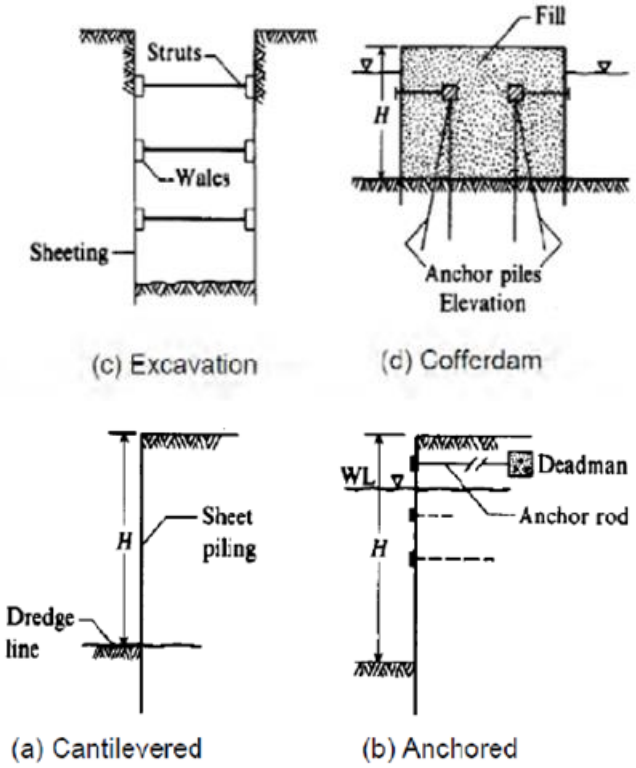

Figure 2. Applications of sheet piles (Eskandari and Kalantari, 2011).

Cantilever sheet piles

In practice, cantilever sheet piles as retaining structures are used to prevent permanent and temporary excavation in many project fields such as landslides, sanitation and highway. Moreover, Cantilever sheet piles are usually used for an excavation that is as high as 6m from dredge line. As shown in Figure 2a (Eskandari and Kalantari, 2011).

Cantilever sheet piles are always used in order to protect soil from the short depth and in granular soil type for both river protection sheet walls and excavation. Besides they are used in foundation structures such as temporary protection (Babu and Basha, 2008).

Anchored sheet piles

Anchored sheet piles are used as an economic strategy, for the depth not exceeding six meters, this type of sheet piles are anchored at the top of bracing the sheet pile (see Figure 2b). Anchored sheet piles have less depth of penetration. If anchored walls are carefully constructed, less horizontal deflection will occur than braced walls and also anchored sheet piles protect the back-slope subsidence. Moreover, for installation anchor requires only a small excavation.

The functioning of Anchored walls is always close to the prestressed concrete members. Because of the anchors, the whole backfilling behind it change for compression zone, thus creates a massive gravity wall. The only disadvantage of the anchor is the possibility of occurrence of vertical sediment of the sheet caused by the vertical component of forces (Eskandari and Kalantari, 2011).

Excavation

In order to prevent excavation side soils, Sheet-piling systems will be developed with either an interlocking and\or overlapping joint (see Figure 2c). To support excavation sides, cantilevered sheet piles use, depending on the depth of excavation and lateral loads, or they can be chosen by a special design.

During the excavation of the ground, anchors are gradually installed. As a result, the soil behind sheets will be stable and change to ‘reinforced earth zone’. Therefore, any excavation can be safe in a wide range of ground conditions (Eskandari and Kalantari, 2011).

Cofferdams

Coffer-box means box dam that can be used as a temporary protection structure to remove the water and soil from the field of work, such as a bridge foundation or other structures in maritime condition, as it is illustrated in Figure 2d. To provide the dry and suitable work environment and a safer workplace, cofferdams are used. Sheet piles are placed around the work field, then the voids between sheet piles and the ground are treated by plain concrete to prevent leakage (Eskandari and Kalantari, 2011).

Usage of Steel Sheet Piles in Coastal (Onshore) Structures

Sheet piles particularly steel sheet piles in jetties are used as ship berthing structures, which are used in port or harbor for mooring vessels. The main purpose of this application is its facility for loading and unloading ships. Moreover, sheet piles should resist the ship impacts, therefore, during the design of sheet piles, some key points should be considered. Firstly, sheet piles should penetrate into the ground at least one-third of their lengths. Secondly, some of the piles are usually installed in an inclined position. Finally, sheet piles should be braced laterally by extra-retaining walls as shown in Figure 3 (Sadeghi, 2011).

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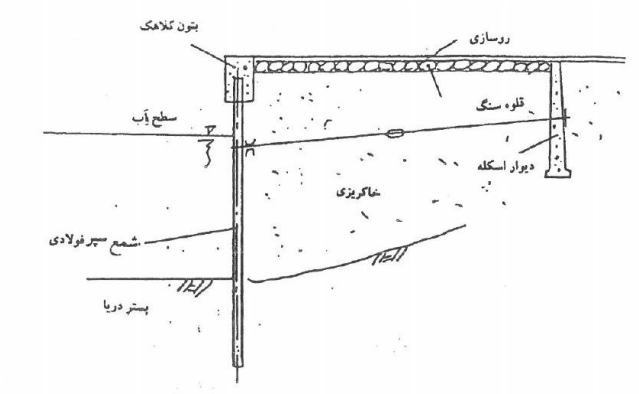

Figure 3. Sheet pile jetty as onshore structure (Sadeghi, 2011).

Design of Steel Sheet Piles

Usually, the main procedure to design the steel sheet piles are obtained from penetration depth and steel section modulus in order to resistance against rotations. Besides, the stability of sheet piles against overturning moments and horizontal forces depending on penetration depth (Babu and Basha, 2008).

In design sheet piles several features should be considered. Such as geotechnical situation: if the backfill soil is weak should be replaced by coarse type with high bearing capacity, a load of the truck and movable crane load behind the sheet piles walls also service lifetime of sheet pile. The widest types of the section are used in harbor structures are Z-section and U-section. Moreover, for steel sheet piles, the used steel grade minimum yield ranged 240-260 MPa. The standard thickness between 6 to 20mm flanges and 8 to 16 mm webs and maximum rolling length changes from 16 to 32m. Also, one-third of the length of sheet pile should penetrate to ground or seabed because at this depth maximum bending moment will be very accurate. Correspondingly, the designer should consider all factors that influence the corrosion like temperature, oxygen etc. (Wall and Wadsö, 2013).

Steel Sheet Piles and Earthquake

Harbor structures are same time suffered from earthquake actions that are causes to hazard in economic field because of interrupting trading process. For this purpose, the designer should consider the positions that sheet piles are installed, for instance, the investigation about earthquake line. On the other hand, the designer should select the type of the sheet piles according to earthquake line.

Same main factors are affected to occur big shaking on sheet piles at the time of earthquake: liquefaction of backfill solid, ground settlement due to cracking in the concrete apron, water pressure near the wall (Gazetas et al., 2016).

Steel Sheet Piles and Waves

For additional information on the environmental data together with necessary formulas and the data needed for design and analysis of such structures, the instructions, data and recommendations given by (Kaiser et al., 2013), (DNV Technical Report, 1996), (Jerman, 2015), (API, 2010), (Sadeghi, 1989, 2001, 2004, 2007a, 2007b, 2008 and 2013), (US Army Coastal Engineering Research Center, 1980), (US Army Corps of Engineers, 2002), Muyiwa and Sadeghi, 2007), (Sadeghi and Aleali, 2008) (Nouban and Sadeghi, 2013 and 2014), (US Army Corps of Engineers, 2011), (Nouban, 2016), (Nouban et al., 2016) and (Nouban et al., 2017) can be used.

CONCLUSIONS

Sheet pile retaining walls are used in order to resist the lateral forces (horizontal forces), they consist of various materials, which are selected according to the situation of the construction: type of the soil layers, depth of the excavation, water condition, weather and period of construction. Wooden sheet piles are used for temporary and the small and light constructions but it will be destroyed if exposed to water and high temperature. It is not a suitable type to be used in marine structures. Concrete sheet piles have the high strength to resist lateral loads, durable and heavyweight, but it is quite expensive for temporary constructions. Steel sheet piles have the good advantage like high strength, durability, workability, reusable and easy to drive in various types of soil particularly in the boulder or cobble layers.

About the sections of sheet piles, the research suggests that to use Z- section steel piles because it has some properties such as firstly, Z-section steel piles are used for marine and deep excavations as mentioned above. Secondly, they have bigger section modulus than U-sections because in Z-section the location of interlock joints are symmetrically distributed on both sides of the neutral axis, thus improve modulus of their sections. Even, the resistances of the section depend on section modulus as mentioned above in Table 1, when the driving distance, designation and moment of inertia are constant for both Z and U sections. Thirdly, when using the same modulus, the Z-sections have the smaller mass per square meter if compared to the U-sections. Fourthly, Z-sections have bigger widths. It means that less number of sheets are needed. Thus, minimize the cost and excavation occurs. Finally, Z-sections can be used together with steel pipes and H-beams to achieve higher modulus.

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