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Localized corrosion of steel sheet piling

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ABSTRACT

When steel sheet piling suffers accelerated low water corrosion the webs and flange-web regions of individual piles often perforate first, for reasons not fully understood. To investigate this, samples of the cross-sections of typical U and Z profile sheet piling were exposed to natural seawater for 1, 2 and 3 years. They showed localized corrosion in the central region and also near the flange-web junctions. These locations were found to have more material defects and segregation and show composition differences. It is proposed these observations are linked to localized sheet pile perforation after long exposure to seawater.

1. Introduction

Accelerated low water corrosion (ALWC) of steel sheet and other piling is the term usually given to higher than expected corrosion loss in the region just below the mean low tide level compared to that elsewhere in the immersion zone [1]. In an advanced state, typically after many years exposure, this vertically oriented differential corrosion along the pile length causes localized perforation of the pile wall thickness. Such perforation and loss of pile wall thickness can have a significant effect on the structural capacity of the sheet piling. It has caused serious concern about the risks to marine infrastructure and the economic implications for its management [1].

Besides the vertically oriented differential effect associated with ALWC, there is also a horizontal aspect, at least for the steel pile profiles used in practice. When ALWC occurs, it also has been observed that actual perforation of the sheet wall occurs in localized areas, apparently randomly between piles, with some individual piles showing perforation and others not. However, where perforation does occur, the general pattern of perforation is a remarkably consistent. For U-profile sheet piling the perforations occur predominantly on the out-pans (Fig. 1) while for Z-profile piles perforation appears to occur predominantly as elongated slots on the web-flange junctions corners or in the web of the Z shape (Fig. 1). The reasons for these observations currently are not understood [2].

The next section reviews practical experience and observations about ALWC and pile wall perforation and summarizes recent research findings. These indicate that the horizontal localized corrosion effect is the direct result of metallurgical factors. The following section describes an investigation of this possibility using samples cut from commercial steel sheet piling and exposed to seawater, together with analyses of composition and grain structure of these samples. The results are compared with the corrosion observations. This is followed by discussion of the results and comparison of the experimental observations with field experience.

2. Practical observations and research background

Sheet pile walls in practice typically consist of individual steel piles of U, Z or I (flat web) cross-section. For U and Z profiles, every second length is reversed to create a vertically corrugated surface when installed. All sections interlock at their edges with adjacent piles to form the sheet pile wall system (Fig. 1). This form of construction suggests that there is a high degree of consistency in material and corrosion properties along the pile wall (i.e. in the horizontal direction).

In the vertical direction the high differential corrosion below low tide level has been termed accelerated low water corrosion (ALWC) and has long been associated with microbiologically influenced corrosion (MIC) [1,3]. Sulfate reducing bacteria and other microorganisms have been implicated. Typically their rate of production of aggressive species is proportional to their rate of metabolism, which in turn is a function of the rate of supply or availability of nutrients. Recently, good correlation has been demonstrated between the vertical corrosion profile associated with ALWC and elevated levels of nutrients (in particular dissolved inorganic nitrogen (DIN)) in the waters at or near steel piling [4,5]. Usually the nutrient supply is water borne and it is highly likely

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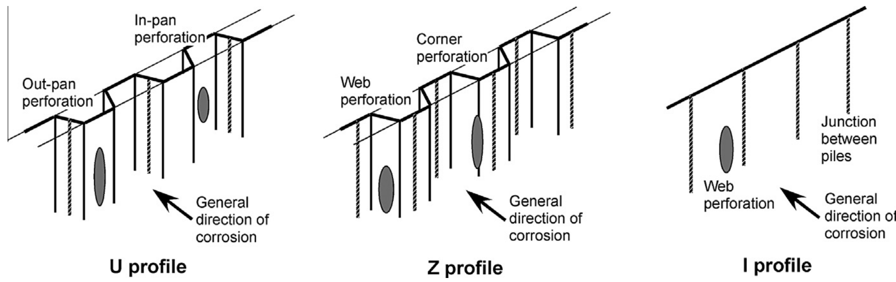

Fig. 1. Schematic view of sheet pile walls formed by U, Z and I profile piles and the types and locations of perforations commonly observed. Also shown is the general direction of corrosion attack from the seaward side of the pile wall.

that the nutrient concentration in the region immediately adjacent steel piles will be closely similar. This suggests that MIC is unlikely to be the primary cause of the different rates of corrosion between piles and on individual piles in the horizontal direction.

About 30% of commercially available U-profile pile sections have webs (pans) somewhat thinner than the remaining parts of the pile. This could be a reason for the earlier perforation of the webs. For U profile sheet piling the so-called out-pans (Fig. 1) typically are more exposed and this may be why they tend to perforate ahead of the in-pans. However, there are observations that sometimes the in-pans perforate first. It has been proposed [1] that this occurs when the out-pans are protected in some way, such as with timber piling but this clearly cannot be the general case. Similarly, while perforation at the corners or folds of the profile usually is associated with Z-profiles (Fig. 1) [6] similar perforation has been observed for some U-profile sheet piling (Fig. 2).

The rusts seen on sheet piling typically are a vivid orange or sometimes a yellowish or brownish soft and spongy layer that is easily removed by hand or simple hand-tool (Fig. 3a). Typically this reveals a thinner, sometimes gelatinous, loosely adherent slimy or viscous black paste. In some cases the yellow and black materials have been identified as lepidocrocite (γ-FeOOH) and hydrated magnetite $Fe_3O_4{\cdot}xH_2O$ respectively [6]. However, the black layer also has been associated with the iron sulfides (usually FeS_2), known as possible reaction products from the activity of sulfate reducing bacteria [3]. When wiped or scraped away the black layer usually reveals bright steel (Fig. 3b), often exhibiting a dished shape or showing extensive pitting [1,6]. The potential for bacterial involvement in the corrosion process (microbiologically influenced corrosion – MIC) has received much research attention but there have been few specific outcomes [3]. One research outcome is the model proposed by Gehrke and Sand [7] that attributes the ALWC phenomenon to the alternating involvement of different types of bacteria as a result of tidal seawater level fluctuation. The other research outcome is the recent demonstration of correlation between the presence of nutrients necessary for MIC and the vertical profile of steel strips [4,5]. However, neither of these findings provides an explanation for the observations summarized in Fig. 1, namely the differences in corrosion perforation in the horizontal direction, that is, along the pile wall.

Other structural steel pile sections, such as H piles, have been observed to corrode more severely at the flange ends. Circular steel piles typically corrode more severely along one vertical line (presumably the weld line). In addition, older (pre-Second World War) steel piles have been claimed to be more prone to ALWC [1]. Typically these older steels have higher carbon, sulfur, manganese and phosphorous contents and greater centreline segregation than is typical in modern hot rolled steel sections [8]. Steels with higher sulfur contents are known to be less resistant to corrosion in seawaters, although it also is known that small changes in composition of low alloy steels have little effect on corrosion, at least under oxygenated conditions [9]. Also, small changes in alloying tend to have a different effect for shorter term and for longer-term exposures (>2–5 years) [10]. Taken together, these observations suggest the possibility of material or metallurgical reasons for the horizontally oriented differences in localized perforation associated with ALWC.

Structural steel sheet and other piles are made by hot-rolling to the required profile. While there have been considerable improvements over earlier steel making, even in modern steels there remains a central core with segregation of metallic grain structure and small differences in metal composition compared to elsewhere on the cross-section [8,11]. In particular, the central region usually has slightly higher C, Mn, P and S content. Hot rolling to form a

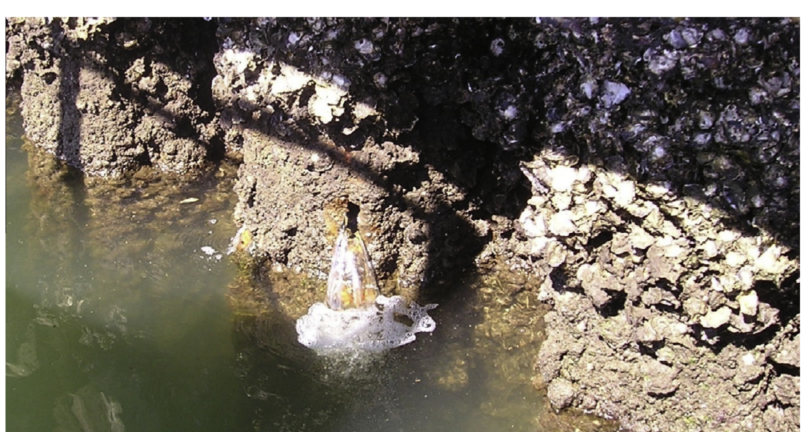

Fig. 2. Perforation and ground water draining into harbour waters at extreme low tide, showing perforation of a U profile pile near the junction between the web and the flange of the pile (Newcastle Harbour).