Main issues of pile foundation at waterfront development and its prevention method

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Abstract. Pile foundation is widely used in construction and building marine structures. This is because pile foundation is an important structure and should have long-term durability. However, in waterfront development, a lot of issues from the seawater should be considered distinctively because it consists of many problems that can affect the building structure especially the foundation of the building. Thus, a research should be conducted to identify issues of pile foundation at waterfront development and determine its prevention methods. The research was carried out through interviews with the developers and contractors from the projects of Lexis Hibiscus at Port Dickson, Negeri Sembilan and Redevelopment for Deep-Water Facilities at Quay 6 in Pasir Gudang, Johor, Malaysia. The objectives of this research are to identify issues of pile foundation and to determine the prevention methods of pile foundation issues at waterfront development. All respondents agreed that the main issues of pile foundations at waterfront development are the wave and tide condition. The prevention methods of the issue faced at waterfront development that are most frequently used for the pile foundation are coating system and concrete cover. This research is beneficial to all developers and contractors to ensure pile foundations at waterfront development can be protected by using the prevention methods.

1. Introduction
Houses, condominiums, bridge, resorts, jetties, and high-rise buildings are all constructed by using pile foundation. Therefore, pile foundation is believed as an important structure and should have long-term durability. Pile foundation is widely used in construction and building marine structures. This is because, nowadays, people think and believe that concrete is a long lasting material no matter what is the environment it exposed to [1-6].

Waterfront development includes the development of existing ports, harbours and beach for residential or tourism purpose. However, in waterfront development, a lot of issues from the seawater should be considered distinctively. During designing of pile foundation, it is important to ensure that structure made from concrete is strong and able to support the load. Therefore, provision of prevention methods to pile foundation can reduce the problem of pile foundation at waterfront development.

Moreover, waterfront development is already a well-established phenomenon internationally. Therefore, many cities are not in the financial position to acquire land and construct public amenities. Often, the synergy between private uses, such as retail and entertainment, and public open spaces have reinforced each other and maximized public enjoyment of the waterfront [7]. Development of waterfront areas is controversial however, the growing of human population that requires job demands the
development of these areas. On the other hand, biologists and environmentalists is struggling to preserved habitats, but the developer and investor need to develop a new place for the public [8]. This is because beachfront area is near to the coastal area and marine environment. It consists of many issues and problems that can affected the building structure especially the foundation of the building.

One of the issues of pile foundation at waterfront development is cause by seawater. Dissolved salt in seawater contains chloride and sodium that will essentially affect the concrete to a certain extent like corrosion. Issues for the seawater is physically attack which is due to the chloride and sulphate ions weakening the concrete surface. It happens when the seawater soaks into the concrete, then the corrosion process begins. Besides, another issue from the seawater is called chemical attack. This is when the salinity containing chloride and naturally occurring sulphates of sodium, potassium, calcium or magnesium in the seawater will have a chemical change [9].

Besides seawater at the coastal area, wave also is a body of seawater and it caused by wind. The size of the wave is largely dependent on the distance that wind can blow the seawater without interruption and the movement of seawater caused by the rotation of earth [8]. Therefore, the forces of waves need to be concerned because it can destroy the structural of pile foundation at the coastal area. Furthermore, wave also bring the floating object to the coastal area and it well cause the floating object to hit the pile foundation and caused cracking and fractures.

Another issue of pile foundation at waterfront development that should be concerned is tide. Tide is the daily movement of water toward and away from the coastal area caused by the force of gravitational from sun and moon [8]. For this reason, general daily tide levels are important to be understood and hence influence the design of pile foundation. In that case, contractor needs to spend more time to construct the pile foundation because of low and high tide.

The main purpose for this research was to study the issues and prevention methods on pile foundation at waterfront development. Thus, this paper aims of two objectives that is to identify the issues of pile foundation at waterfront development and to determine the prevention methods of pile foundation issues at waterfront development. The area of this study is at Lexis Hibiscus, Port Dickson and Redevelopment for Deep-Water Facilities at Quay 6, Pasir Gudang. Lexis Hibiscus, Port Dickson is located in Negeri Sembilan, Malaysia and it was designed by world renowned architect Broadway Malyan and developed by Lexis Hotel Group and Kuala Lumpur Metro Sdn. Bhd. Redevelopment for Deep-Water Facilities is situated in Pasir Gudang, Johor, Malaysia and it was inspired by Malaysia Marine and Heavy Engineering Sdn Bhd. Therefore, Redevelopment for Deep-Water Facilities at Quay 6 was a wide spectrum of offshore construction, offshore conversion and marine repair services at two yards in Pasir Gudang, Malaysia. This research is vital in bringing up the awareness of issues and prevention method of pile foundation at waterfront development. Secondly, this research would also give benefits to various parties involving developers, contractors, architects, engineers and most important parties, which are the users.

2. Literature Review
Damage to buildings by pile structure is one of the phenomena that often occur in the construction industry. As can be seen, it is left without any solution that may lead to more serious consequences to the building structure as well as consumers. The definition of waterfront has several meaning and different interpretations. Although the word waterfront is clear but still can use different words to replace it, which is city port, harbour front, riverside, beachfront and river edge and riverfront. Waterfront can be defined as the part of a town or city adjoining a river, lake, beach and harbour. Waterfront also refers to a land fronting on to water in common use [7]. The use of waterfront development includes tourism and residential. The commercial space ensures the feasibility of the design which provides the appropriate balance of land use and access to the landscape [10].

The meaning of waterfront development has difference in term of understandings. The content of waterfront development has greatly varied the characteristics of sites and cities. These development levels are common of different fields [11]. Waterfront development is evaluated as urban planning field [7]. The urban waterfront development is widely regarded as a frontier on contemporary urban
development, which considered as an attracting investment and publicity [12]. Moreover, the waterfront development stimulated the modern development in the cities [13].

According to Wrenn (1983), waterfront developments have been divided into five categories, explained below the first two lines are at coastal cities and another three lines is inland ones: 1) Area located on a bay, 2) Area located on peninsula, 3) Area located on banks of a river, 4) Area located on a large body of water, and 5) Area located on banks of intersecting rivers [8].

As can be seen, the difference understanding in waterfront development concept is always confusing. This is because waterfront development is greatly varying according to the characteristics of cities and sites. Therefore, waterfront development projects have followed a number of conventional approaches which is: 1. Waterfront as tourist destination, 2. Waterfront as a new residential district, 3. Waterfront as extension of the financial district, and 4. Waterfront as a platform for ecologically sensitive and sustainable development.

Pile foundation can be defined as a column inserted into the ground to transmit the structural loads to a lower level of subsoil. Hence, piles foundations are mainly used to support structures under lateral and vertical loads [14]. Pile foundation offer several benefits that are widely used in coastal environments. The type of pile foundation is often constructed of treated wood timbers, steel pipes, or pre-cast concrete and other materials [15]. Table 1 shows the prevention method and its description.

| System        | Description                                                                 |
|---------------|-----------------------------------------------------------------------------|
| Coating System| - Divided into two broad groups; metallic and non-metallic                   |
|               | - Objective to isolate the underlying metal from the corrosive media.         |
|               | - Tested at bioreactors using bacteria and shown good protection against     |
|               |   corrosion                                                                  |
| Cathodic Protection| - Using electrochemical reactions to prevent the corrosion of steel structures |
|               | - Deterioration of the protective coating occurs with time, depending on     |
|               |   deposition of protective calcium and magnesium salts                       |
| Concrete cover | - It is use to cover the surface of pile and protect it from being hit by     |
|               |   wave and effect from salinity                                              |
|               | - Restricted to the splash zone. However, in some cases, splash and tidal    |
|               |   zones can be protected by extending the encasement                        |
| Inhibitors    | - Normally used in closed systems                                           |
|               | - Objective to control corrosion and bio-fouling                            |
|               | - Inhibitors could leach from the coating and controls the corrosion         |

The method of installation is a major consideration in the structural integrity of pile foundation [15]. Installation of pile foundation can be divided into two categories and based on their method. Therefore, the first category consists of driven piles, which displace and disturb the soil. The second category consists of piles that are installed without soil displacement which is in situ displacement pile. Thus, steel, precast concrete and wood or timber pile belong to the first category. In the second category, soil is removed by drilling, and concrete is cast in the borehole to form the pile [14]. However, this study is well focusing on the driven pile.

Driven pile is the piles which driven into the ground by holding them in the correct position against the piling frame and applying hammer blows to the head of the piles. In this category, the pile is held in place with leads while a single-acting, double-acting diesel or air-powered hammer drives the pile into the ground [14]. Besides, the methods for installing piles include driving, augering, and jetting. A combination of methods may also be used. For example, piles may be placed in augered holes and then driven to their final depth. Combining installation methods can increase the achievable embedment depth. With increased depths, a pile’s resistance to lateral and vertical loads can be increased, and its vulnerability to scour and erosion will be reduced [16].
In-situ displacement pile is constructed by advancing a displacement boring tool into the ground with a rotary drilling rig using both torque and crowd force. The precondition for the successful deployment are modern rotary drilling rigs offering high levels of torque, downward thrust and retraction force, as well as a tall torsion-resistant drill mast [18].

2.1 Issues of Pile Foundation at Waterfront Development

At waterfront development, marine structures are subjected to damage and deterioration during their service life because of continuous exposures to aggressive environment. As a result, the performance and the intended functions of the pile foundation are affected. For several reasons, many issues are well affected the durability of pile foundation and cause corrosion processes begin.

Salinity is the saltiness or dissolved salt in seawater [19]. Salt itself contains chloride and sodium. In addition, magnesium, sulphate and calcium are the major component for seawater then if add together with chloride and sodium that will present an attack to concrete or pile foundation to a certain degree. Therefore, salinity can produce two types of effect to the pile foundation which are chemical attack and physical attack.

Salinity contains chloride and naturally occurring sulphates of sodium, potassium, calcium or magnesium in the seawater will have a chemical change and these sulphates can chemically attack the pile foundation at coastal areas [9]. Chemical attack is caused by the sulphates. Sulphate is quite simply, a salt of sulphuric acid. They can found in all natural waters, which are major dissolved component of rain. Sulphate attack typically involves a reaction between the sulphate and constituents of the concrete to form product by ettringite [20]. The salts in seawater are the primary source of chlorides introduced into concrete. Chlorides are also a major player in the corrosion of reinforcement, as they pierce the thin, protective iron oxide layer surrounding the reinforcement and initiate a corrosive reaction in the steel.

Wave is a body of seawater and it caused by wind. The size of the wave action is largely dependent on the distance that wind can blow the seawater without interruption and the movement of seawater caused by the rotation of earth [8]. Wave forces on the marine structures are the major contribution to the total forces experienced by such structures, particularly in rough weather. In addition, structural engineers have also carried out research on piles foundation, considering pile capacity and the effects of the structural loads on piles foundation at coastal areas [21].

Tide is the daily movement of water toward and away from the coastal area caused by the force of gravitational from sun and moon [8]. Tide conditions at different locations and different bodies of water such as oceans, rivers, tidal estuaries and tidal straits.

Foundations in coastal areas must elevate buildings above the base flood elevation, while withstanding flood forces, high winds, scour of wave, salinity erosion, and floating debris. Besides, foundations used for inland construction are generally not suitable for coastal areas to construct. Thus, pile foundation at coastal area also need to provide a sufficient length of pile to develop the fixity depth, stiffness for long unsupported length, and toe of pile needed to provide passive resistance.

2.2 Prevention Method of Pile Foundation Issues

There are many issues that can cause pile foundation corrosion at marine environment. Henceforth, we need to find comprehensive alternative of prevention methods in order to protect and control corrosion for the pile foundation. The prevention methods of issues on pile foundation can be divided into four primary methods to control the corrosion problem for the pile foundation.

Coating system for corrosion protection can be divided into two broad groups’ metallic and non-metallic such as organic and inorganic. Therefore, any types of coating are generally same to isolate the underlying metal from the corrosive media. These high build durable coatings have been tested in a range of environments including bioreactor tests in the presence of bacteria and have shown good protection against localised corrosion at the low water level especially at Japan and Europe [22]. The concept of metallic coating is applying the noble metal coating on an active metal takes advantage for the greater corrosive resistance of the noble metal [22]. An example metallic coating is zinc rich epoxy primers. Zinc rich epoxy is the most effective in maintaining the damaged areas and breakdown of the...
coatings systems applied at new construction. It is compatible with alternate methods of surface preparation such as power tool cleaning [23].

The primary function of organic coatings in corrosion protection is to isolate the metal from the corrosive environment [23]. In addition, to form a barrier layer to stifle corrosion, the organic coating can contain corrosion inhibitors. Therefore, an example for organic coating is high build epoxy coatings. This coating is generally more abrasion and chemical resistant than primers and topcoats and in this case protect not only the substrate itself, but the zinc primer as well from all of these detrimental factors [23].

Like organic coatings, inorganic coatings for corrosion applications serve as barrier coatings [22]. The most effective are inorganic zinc silicate primers which is essentially become anodic to the steel in a corrosion cycle. The primary advantage of this type of coating is that it will arrest rust creep, or undercutting of the coatings surrounding the damaged area, and confine corrosion to the point of the damage. These coatings also provide a high degree of resistance to heat and chemical spills [23].

The preferred technique for mitigating marine corrosion, based on historical performance and measurable results, is cathodic protection. Therefore, the practice of using electrochemical reactions are to prevent the corrosion of steel structures and another reason for increased acceptance, cathodic protection prevents corrosion on under water structures [23]. Besides, cathodic protection can be achieved by two application methods, which differ based on the source of the protective current [22].

Concrete encasement can also be referred to concrete cover. Concrete encasement can be used to protect piles in soils or marine environments. In soils and seawater, concrete is not always free from deterioration problems. The concrete should have the correct composition and compaction with a depth of cover appropriate for the environment as recommended in the appropriate standard [24]. It is use to cover the surface of pile and protect it hit by wave and effect from salinity. In marine environments, often the use of concrete encasement is restricted to the splash zone. However, in some circumstances, both splash and tidal zones are protected by extending the encasement to below the lowest low water level [24].

The use of inhibitors is favoured in closed systems where the necessary concentration of inhibitor is more readily maintained. Besides, inhibitor water-treatment packages can control the corrosion and bio fouling which can be incorporated in a protective coating or in a primer for the coating [22]. At a defect in the coating, the inhibitor leaches from the coating and controls the corrosion. Other inhibitors specifically affect either the anodic or cathodic process and still have others in promoting the formation of protective films on the metal surface.

3. Research Methodology
The population of this study is the developers and contractors involved in waterfront development in Malaysia. Case study of this research is at Lexis Hibiscus Port Dickson and Redevelopment for Deep-Water Facilities, therefore the samples for this study involves developers and contractors at this site. Semi structured questions were submitted to the respondents. The research data that was obtained have been analysed using content analysis to obtain information. After the interview session, the researcher will be able to detect patterns of answers given by respondents. All data and information gathered will be compiled into a systematically tables. Finally, the data obtained will be categorized according to the questions to get the results of the analysis.

4. Result and analysis
4.1 Respondent’s Background
A series of interviews were conducted among two developers and two contractors to determine the issues of pile foundation at waterfront development and its prevention methods. Table 2 shows the background of respondents have been interviewed for this research data analysis. Additionally, the four respondents which have been interviewed have more than five years’ experience regarding pile foundation at waterfront development. All of them know well about the pile foundation in theory and were willing to share their experience. In addition, R1 have cooperation with R2 as the developer and contractor for a project as well as the R3 also have the cooperation experience with R4.
Table 2. Respondent’s background

| Respondents | R1                  | R2                  | R3                  | R4                  |
|-------------|---------------------|---------------------|---------------------|---------------------|
| Position    | Senior Project      | Managing            | Civil and           | Director            |
|             | Director            | Director            | Structure Engineer  |                     |
| Years of experience | 31                 | 20                  | 10                  | 10                  |
| Experience in constructing at waterfront development | Yes                | Yes                 | Yes                 | Yes                 |

4.2 Data Analysis Objective 1: Identify the issues of pile foundation at waterfront development
The objective of this part is to identify the issues of pile foundation at waterfront development. Hence, the scope of this objective may be too large, thus only those data which had been emphasized will be taken into account and will be further discussed. Table 3 shows that the overview issues on pile foundation summary based on their perspectives.

Table 3. Overview Issues on Pile Foundation Summary table

| Category                              | R1                                                                 | R2                                                                 | R3                                                                 | R4                                                                 |
|---------------------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------|
| Issues of pile foundation             | • Seawater                                                          | • Seawater                                                          | • Seawater                                                          | • Tide                                                              |
|                                       | • Tide                                                              | • Tide                                                              | • Tide                                                              | • Wave                                                              |
|                                       | • Wave                                                              | • Installation techniques                                          | • Installation techniques                                          |                                                                    |
| Problems faced during constructing    | • Setting piling point                                              | • Balance barge                                                    | • Limited time of work                                              | • Balance barge                                                    |
|                                       | • Pitching the pile                                                | • Accuracy of pile                                                | • Wave condition                                                    | • Wave condition                                                    |
|                                       | • Balance barge                                                    | • Setting pile point                                              | • Balance barge                                                    |                                                                    |
|                                       | • Transfer pile                                                    |                                                                    |                                                                    |                                                                    |
| Serious problem can affect the pile   | • Installation techniques                                          | • Workmanship                                                     | • Tide condition                                                   | • Support for pile                                                  |
|                                       |                                                                    | • Force of wave                                                   | • Wave condition                                                   | • Structure loading                                                 |
| Environmental factor affect the pile  | • Sea condition                                                    | • Salinity problem                                                | • Tide condition                                                   | • Salinity problem                                                  |
| foundation                            |                                                                    |                                                                    | • Wave condition                                                   |                                                                    |
| Environmental problem contribute to   | • Salinity problem                                                 | • seawater                                                        | • seawater                                                         | • Salinity problem                                                  |
| the corroding                         |                                                                    |                                                                    |                                                                    |                                                                    |

(a) Issues of pile foundation at waterfront development

All the respondents are agreed and mentioned that the tide condition and wave condition were the main issues. The strength of wave was caused by the force of wind and it affects the pile during installation. Thus, tide condition was caused by the gravitational force of the earth and it will affect the limited time for installation work of the pile foundation at waterfront development.
R1, R2 and R3 also agreed that seawater condition like salinity was a common issue of pile foundation at waterfront development. This statement can be found out from the literature review which proves that salinity was one of common issue and may be associated with two types of conditions such as chemical attack and physical attack. This issue is not necessarily affects all pile foundations, but it can happen when the piles have cracks or were corroded. However, by implementing the prevention methods on pile foundation, it can control and protect the pile before it becomes serious.

Furthermore, it can be seen that R1, R2 and R4 were more concerned about the techniques for installation as one of the issues that can affect the pile foundation at waterfront development. In the design stage, the client and engineers had to decide which techniques to be used to install pile at waterfront development, whether to use a driven pile or in situ displacement pile which was stated in the literature review. After the installation of the pile, if any unexpected problem were to happen, the contractor or project manager must respond quickly by making a decision before it becomes a big issue.

(b) Problem Face When Constructed Pile Foundation

Perspectives from the R1 and R2 were concerned about techniques for installation at the site and they were pay more attention during installation because they believed that the installation work was an important process for the pile and if any mistake that can directly affects the stability and strength of pile foundation. Besides that, set out the pile point and pitching the pile also can influence the piles and the balance of barge was affecting the accuracy of the pile. In addition, R1 has mentioned another problem as the transfer the pile from pile stock to sea because they needed balance the barge and control it does not being hit the other piles had been installed.

However, R3 and R4 were more afraid the force of wave can affect the pile during installation. A wave is a part of the body from the seawater and it’s caused of wind. According to Florence (2010), the size of wave action is largely dependent on the distance that wind can blow the sea water without interruption and the movement of seawater caused by the rotation of earth then the force of wave is unpredictable during installation of pile [8].

(c) The Serious Problem Can Affect the Pile Foundation

Based on Table 3 shows that the perspectives of all respondents were totally different and they had their own experience about the serious problem in their previous project about the pile foundation at waterfront development. R1 has mentioned that techniques to install the pile was the most serious problem can affect the pile foundation. This is because all the setting out and pitching of the pile into the position can influenced the stability of the pile and also the strength to support the main structure. Therefore, R1 stated that it is needed to use GPS system to set the survey instrument and pile point during installation of the pile foundation.

R2 and R3 also agreed wave condition was a serious problem can have affected the pile foundation at waterfront development. This statement can be found out from the literature review to prove that wave was a common issue. It can affect the barge at the sea during the installation. This problem can directly affect the pile installation since it influenced the balance of barge. Moreover, it is also difficult to set the pile point and no easy to pitching the pile into the seabed. R2 also has stated that poor workmanship for installing pile foundation would become a serious problem. This is because, during the installation if there is any negligence and careless would affect the stability and quality of the pile.

R4 was more concerned about the support and structure loading of pile foundation at waterfront development because pile was the main support for the structure of the building. Therefore, they need to calculate which types of pile was more suitable for the structure and it required enough of strength to support the building. If overloading may cause structural failure, and hence such possibility should have been considered in the design stage.
(d) Environmental Factor Affect the Pile Foundation

Salinity problem was a part of seawater and it consists of two types effect which were physical attack due to the chloride and sulphate ions weakening the concrete surface. It happens when the seawater soaks into the concrete, then the corrosion process would begin. Chemical attack happens when the salinity containing chloride and naturally occurring sulphates of sodium, potassium, calcium or magnesium in the seawater would have a chemical change [9]. However, R3 has a different perspective for this, whereby, wave and tide condition were the environmental factors that can affect the pile foundation during installation. Low and high tide in a day can caused limited time of work for the pile installation and caused the installation needed used more times to construct.

(e) Environmental Problem Contribute to The Corroding of Pile Foundation

R1 and R4 has the same perspective about the concrete casting need to have good condition so that it can avoid the crack to protect the pile foundation. If poor condition for the casting would cause the concrete crack, then seawater would have infiltrated into the pile inside then the corrosion would begin. The perspectives of R2 was supported by R3. If the seawater infiltrated into inside the pile it would corrode the steel bar and exposed the steel bars in the sea. However, provide the prevention method to the pile foundation surface can protected the pile to avoided salinity problems become more serious. Besides, good workmanship for the workers and supervised by site supervisor or project manager can ensure the installation work and avoided any carelessness and negligence for the installation work and achieved the requirement had set by the early stage.

4.3 Data Analysis Objective 2: Determine the Prevention Method of Pile Foundation Issues at Waterfront Development

The objective of this part was to determine the prevention method of pile foundation issues at waterfront development. Table 4 shows that the Summary of Prevention Method for Pile Foundation was obtained and based on the perspectives from developers and contractors.

Table 4. Summary of Prevention Method for issues of pile foundation

| Category                  | R1                                      | R2                                      | R3                                      | R4                                      |
|---------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|
| Prevention method         | Spin pile                               | Spin pile                               | Coating system                         | Coating system                         |
|                           | Concrete cover                          | Concrete cover                          | Concrete cover                         |
|                           | Good workmanship                        | Coating system                          |                                        |
| Implemented currently in the industry | Concrete cover                          | Integrity test                          | Integrity test                         | Coating system                         |
|                           | Clerk of Work inspection                 |                                        | Coating system                          |                                        |
|                           | Coating system                          |                                        | Concrete cover                          |                                        |
|                           | Check and balance                       |                                        |                                        |                                        |
| Most effective method     | Concrete cover                          | Concrete cover                          | Check and balance                       | Cost effective                         |
|                           | Clerk of Work inspection                 | Good workmanship                        |                                        |                                        |
|                           | Warning sign                            |                                        |                                        |                                        |
Prevention method in other countries

| Prevention method in other countries |
|-------------------------------------|
| Check and balance                   |
| Check and balance                   |
| Good workmanship                    |
| Coating system                      |
| Coating system                      |
| Check and balance                   |
| Cost-effective                      |

(a) Prevention Method

Based on Table 4, those statements given by R1 and R2 have a similar perspective to use spun pile as the pile foundation. However, R3 and R4 were consistent in using coating system to prevent pile foundation issues at waterfront development. Reinforcement pile (RC pile) consists of steel bars inside the pile and covered by high-grade concrete. It is almost the same with RC pile, but it is hollow inside. Besides, concrete cover also had been mentioned by R1 and R2, which can be used to protect the pile from corrosion. R3 also stated coating system is another prevention method that can use for corrosion control of pile foundation and steel structures such as offshore platforms, bridges and underground pipelines.

However, R3 have a common opinion as R4. R3 mentioned that his company also used coating system and concrete cover as a prevention method of pile foundation during construction to prevent the rust and corrosion. R1, R2 and R3 also mentioned on the concrete cover as one of the prevention methods for the pile foundation at waterfront development. Furthermore, the concrete cover also can refer as concrete encasement as already mentioned in chapter 2 in the literature review. It can be used to cover the surface of pile to protect if being hit by the waves and the effect of salinity.

(b) Preventive Method Has Been Implemented Currently in The Industry

In the construction industry, a lot the prevention methods of pile foundation had been implemented currently in the industry. R1 have stated many preventive methods for pile foundation, but he stressed about the check and balance was a special method. The check and balance was a process to conduct after installation of pile complete. According to R1, this process can ensure the pile installation has been followed all the specifications, requirements and standard for the pile foundation. If there were any problem, then they can immediately take action.

Meanwhile, R2 and R3 were having the same opinions about this statement. The R3 has explained briefly about preventive methods had been implemented currently in the industry. Based on both respondents’ opinions, integrity test was a method have been implemented in the industry. According to R2, integrity test can check the stability of every piles and to discover such flaws before they can cause any damage. If there were any damage, then can immediately take action or abandon the pile. One of the coating system examples given by R4 was auto blasting coating. According to Sherief (2011), it is an epoxy material for the metallic coating system and can maintain the damaged areas and breakdown of the coating systems applied in new construction [23]. Besides, R4 stated concrete cover also can be used to cover the surface of pile to protect it.

(c) Most Effective Method

From the opinion, R1 more concerned about procedure of installation work for the pile foundation and quality of work during pile foundation installation at waterfront development. Therefore, Clerk of Work (CoW) inspection can ensure that the quality of both materials and workmanship were in accordance with the design information such as specification, engineering drawings and achieved quality standards.

During construction or installation on pile foundation, the good workmanship can affect the stability and quality of the pile. It can be explained if more actions are taken during installation, it can reduce...
risk of damage and care less for the pile foundation. By all means, R2 more pay attention to the process of installation. Moreover, R2 was care about the boat at coastal area would being hit the pile foundation and damage to the pile. Therefore, R2 think to put the warning sign in coastal area so that accident can be avoided and remind other peoples that the place is having a construction.

According to R3, check and balance was a process involves the client, contractor and sub-contractor. It is for checking the pile work and ensure its followed all the specifications, stability and standard for the pile foundation. This can ensure the quality of work during installation pile foundation at waterfront development. In addition, R4 comment about each issues have different measurement and have their own prevention based on the situation. Thus, they would have a meeting to discuss and make decision to solve the problem.

From the R4 opinion, R4 emphasized to not have the most effective method because everything is needed based on the situation on site to make a decision. Therefore, R4 mentioned about the cost-effective was used to solve the problem. Cost-effective was a different answer from the interview and this also was a different kind of method for the pile foundation at waterfront development.

(d) Prevention Method in Other Countries

The prevention method in other countries would need to accord from all respondents’ perspectives with their experiences and knowledge. Check and balance was more efficient and effective for the work for the R1. This practice need to hire another contractor to become a quality controller to ensure the work have achieved the quality and all the specifications have been set in the design stage. R2 mentioned that some countries are more concerned about quality of work and the workmanship for the workers contribute the pile during installation. Then R2 also stated that other countries have many different types of coating system, that provide to pile foundation and the last one was check and balance. R2 thinks the quality of work was very important then check and balance in order to check the work had been completed and accepted by the client and contractor.

Based on the literature review, Physical Vapour Deposition coating (PVD) was one of the metallic coating in coating protection system. PVD coating was an environmental friendly coating. Besides, there is no hazardous by resulting brilliant decorative finishes with excellent wear and corrosion resistance for the pile foundation. However, R4 still believed that cost-effective concept has been applied in other countries. For example, certain people tend to save time and cost to do construction pile foundation, the reclamation process can be used to create a new land for construct the pile foundation. Besides, platform can be used to construct a pile foundation so that the wave and tide condition has no effect to the pile.

5. Discussion and conclusion

In this research, the issues and prevention methods of pile foundation at waterfront development were determined. From the analysis, all respondents agreed that the wave condition and tide condition were the main issues of pile foundation at waterfront development. For the prevention methods, coating system and concrete cover has been chosen by the respondents as the main prevention methods of pile foundation at waterfront development. In contrast, all respondents also mentioned that the workmanship and check and balance were some other prevention methods of pile foundation issues which means they believed that during construction and installation, the workmanship can control the quality of work. The check and balance determined the work after completing the installation following the requirements and standards have been set in the design stage.

In conclusion, this research has been successfully implemented with both the objectives being achieved which identifying issues of pile foundation at waterfront development and determines the prevention methods of pile foundation issues at waterfront development. From this research, issues and prevention methods of pile foundation at waterfront development was identified through interviews with the respondents whom involved in the process of analysed data that had been obtained. Data analysis and discussions in chapters 4 and 5 has provided a clear understanding with an explanation of the objectives and results for this research.
Lastly, this research is very important for developers and contractors so that they know and understand the issues of pile foundation at waterfront development as well as in determining the prevention methods of pile foundation issues at waterfront development. This is to ensure and improve the quality of the projects development. It is also can help in project development to increase the confidence of the buyers or users. It is hoped that this research will provide more information on safety measures. Especially, it is required by the parties involved in the construction sector such as developers, engineers and contractors. Lastly, this research can act as a reference for students and as a guide in future studies.

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