CHAPTER II

LITERATURE REVIEW

Soft soil; soil that has low compressive strength; is one of the common problems for geotechnical engineers. The abundant amount of soft soil making it as a concern in a construction field. If the strength of soil is not adequate enough to support structure above it, then it becomes a major problem. One of soft soil that can be found easily is marine clay. Seawater that penetrates into marine clay causing the clay to have large water content. This is one of the reason behind the low compressive strength of marine clay. Thus, soil improvement is needed in strengthen the clay. One of the method is cemented-soil pile by deep mixing. Researches about cemented soil that is exposed to seawater have been conducted by several researchers. Most of the researches resulted in the deterioration of soil pile because of the contact of the pile and seawater that contains sulfate. Therefore, the investigation leads to the effect of sulfate attack towards cemented-soil pile. Since the pile is placed in an extreme environment; marine area; the deterioration needs to be checked.

Reference [11] predicted about the lifecycle of soil-cement piles' bearing capacity. It also investigated about the deterioration depth on piles that were immerged in salt water. One of the content of salt water used is SO_4^{2-} or sulfate. The water content

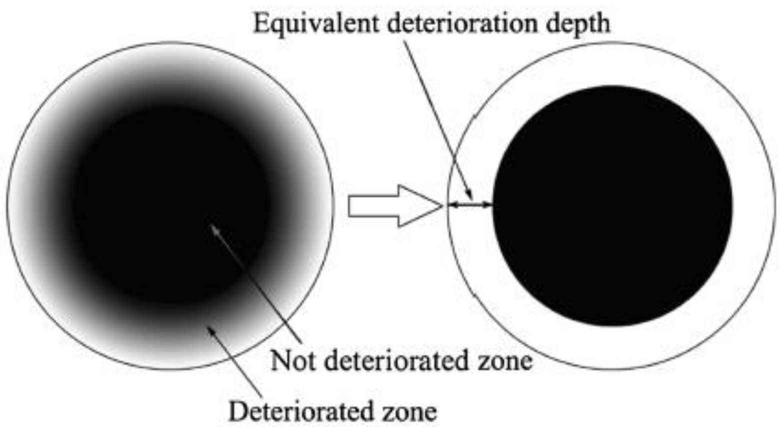


Figure 2. Scheme of partition in soil-cement pile [11].

of the sample was 30.4%. The cement that was used is OPC with 42.5 grade. The specimen was a cylinder with 50 mm height and 50 mm diameter which had 17.58% of cement content. The surface of the pile directly contacts the saltwater in the surrounding soil, so the corrosion of the soil-cements originates from the external part. The specimens then maintained under wet (under immersion) and dry (curing room) condition. The solution used for the immersion is the saltwater from the Yellow River Delta in China which having 1,122 mg/L SO_4^{2-} and 170.20 mg/L Mg^{2+}. The curing time took 7, 28, 90, 120, and 180 days. The test that was used is unconfined compression test (UCC). The result showed that the longer the curing time, the more compressive strength specimens had. It is just that the strength increment of dry-maintenance specimens is more significant compared to the ones on the immersion maintenance. Deterioration decreased the effective diameter of the soil-cement pile. The deteriorated area is shown in Figure. 2. There will be 2 zones which are deteriorated and undeteriorated zone. [11] predicted the deteriorated zone or depth using two equations:

$$D^2 q_{uw} = d^2 q_{uc} \quad (1)$$

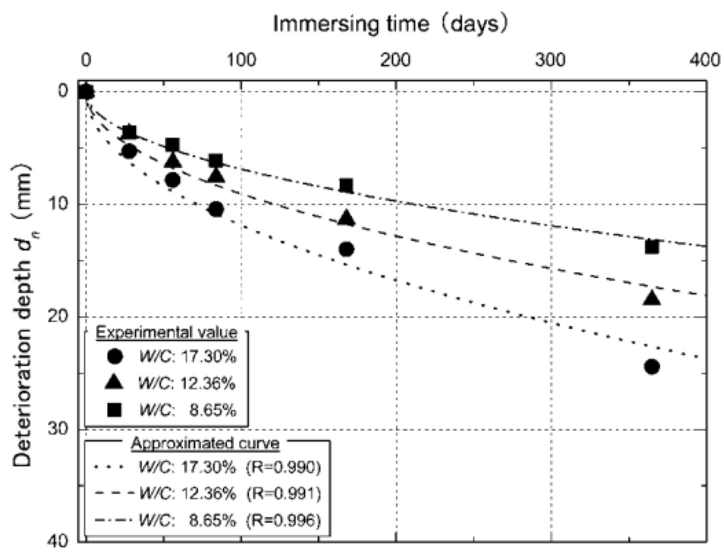
$$L = 0.5(D - d) \quad (2)$$

where q_{uw} = compressive strength of salty soil-cement under immersion maintenance; q_{uc} = strength of salty soil-cement under curing room maintenance; D = initial diameter of the salty soil-cement pile, in this study for the tested specimen, D is 50 mm; L = deterioration depth; and d = diameter of the internal undeteriorated part of the salty soil-cement pile. The final result of deterioration depth is 2.49, 2.76, and 3.17 mm at 90, 120, and 180 days respectively.

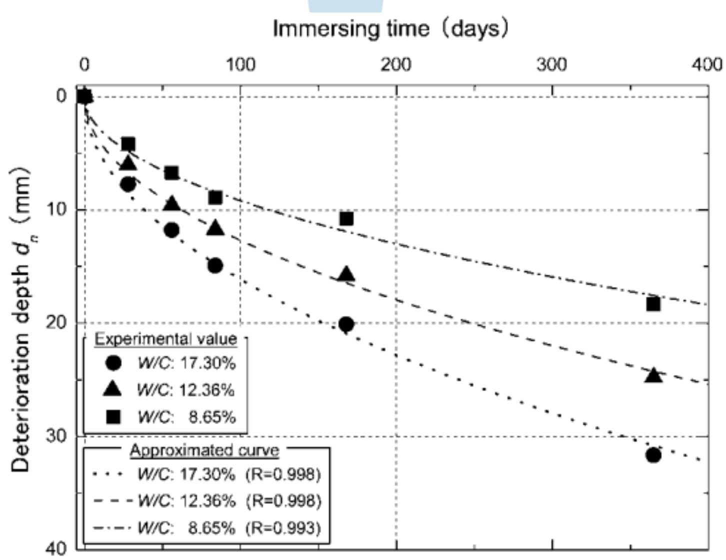
Reference [18] investigated about the deterioration of cement-treated Ariake clay in Japan under the immersion of seawater. They used natrium chloride or NaCl as the immersion solution. However, they found that Mg^{2+} has bigger impact of cement-treated clay's deterioration compared to NaCl. Thus, they predicted the deterioration depth using equation (3).

$$d_n = A\sqrt{t} \quad (3)$$

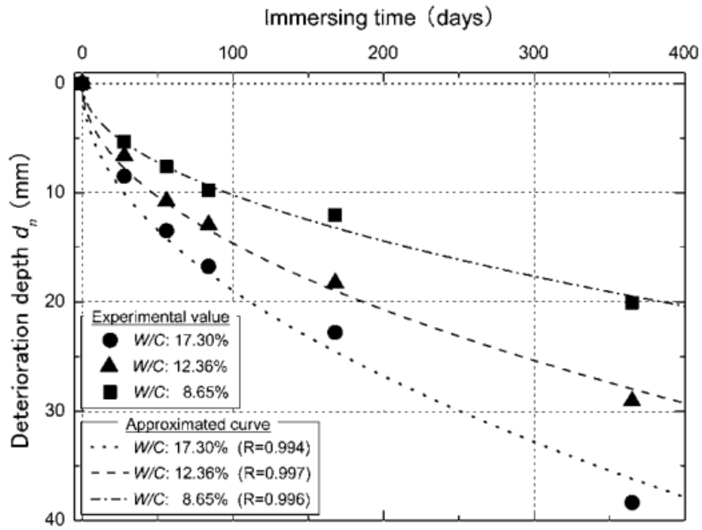
Where A represents the degradation rate coefficient and t represents the immersion time. Mg^{2+} concentrations were set to be 0.024%, 0.048%, and 0.072% while the water-cement ratios (W/C) were 17.30%, 12.36%, and 8.65%. They also varied the immersion time from 0 to 400 days. In Figure. 3, it can be obtained that the longer the immersion period, then the deterioration depth will be deeper. Furthermore, the larger the Mg^{2+} concentration, the more severe the deterioration was, and the higher the water-cement ratio, the less severe the deterioration was.



(a) Mg^{2+} concentration: 0.024%.



(b) Mg^{2+} concentration: 0.048%.



(c) Mg^{2+} concentration: 0.072%.

Figure 3. Approximated Curve of Deterioration Depth d_n. [18]

Amin, [10] conducted a research which resulted in compressive strength analysis of every specimens after the immersion in sulfate solution. The specimens were consisted of cement, sand, and water with the ratio of 2.5, 7.5, and 1.0. They were molded in the size of 150x150x150 mm and were imersed in sulfate solution with concentrations of 1%, 3%, and 5% for 3, 14, and 28 days. The curing time took at the room temperature. One of the tests that was conducted is compressive strength test. The result is shown at Figure. 4. It indicated that after long immersion time, the weaker sulfate concentration (1%) gave more efficient attack than the stronger concentrations gave during short periods. The more the MgSO4 concentration, the lower the compressive strength will be. At the 14th day of immersion, the compressive strength tend to be significantly lower than the ones at the 3rd and 28th day immersion.

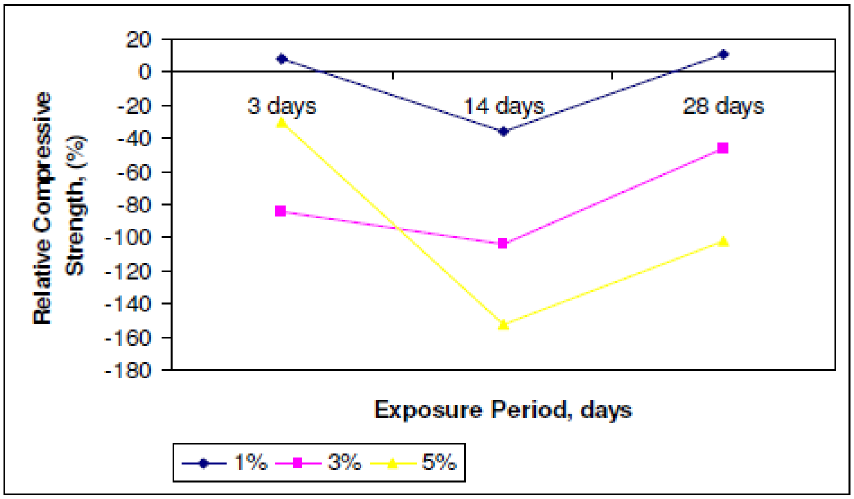


Figure 4. Relative Compressive Strength (%) After Exposure in 1, 3, and 5% $MgSO_4$ Solution for 3, 14, and 28 Days. [10]

Reference [19] studied the mechanism of cement stabilized soils polluted by different contents of magnesium sulfate. They used air dried silt soil as the material for specimens with liquid limit water content of 27.8%. As a binder, Portland cement (OPC) was used. The proportion of soil:cement:water is 100:20:50. Magnesium sulfate contents in cemented soil (CS) were 1.5, 4.5, 9.0, and 18 g/kg. They did not immerse the specimens into $MgSO_4$ solution, but instead they mixed the $MgSO_4$ with the specimens to get the attack both internally and externally. The specimens were put in 70.7mmx70.7mmx70.7 mm mold and were cured for 28 days in 20.9 °C temperature room with 90.7% relative humidity. Unconfined Compression Test (UCS) was conducted after the curing time. The result of UCS test is that the compressive strength of specimens increased as the magnesium sulfate increased until 4.5 g/kg. It is the peak of UCS value increment. However, UCS value decreased as the magnesium content got higher than 4.5 g/kg.

Khan [6] studied about the performance of cements blended with pozolanic materials in extreme marine environment. He made the specimens by mixing soil with its binder such as OPC, SRC (Sulfate Resistant Cement), slag cement, and blended OPC and SRC cement. But the OPC-mixed soil will mainly be discussed. The specimens were having cement and fine aggregate ratio of 1:5. Water cement ratio is fixed to be 0.5. Mixed-specimens were then cured. The compressive strengths of each specimens were measured at the 28^{th} day of curing time in tap water. The 28-days-measured samples were acted as the control specimens. The remaining samples were then immersed in sea water from Karachi beach for up to 180 days. At the 90^{th} day and 180^{th} day, the compression strength test was done in order to know the comparisons with the control specimens. The result showed a decrement in the compressive strength along with the increment of immersion period. In case of OPC-bound-specimen, the longer the specimen cured in the seawater, the lower the strength will be. Among the 3 periods which were 28, 90, and 180 days, the highest strength was obtained at the 28^{th} day of tap water cured specimen.

Yang [23] identified the deterioration depth of cemented-soil specimens that is immersed under seawater. The cement variations were 7% and 16% with the curing time of 30 until 720 days. Cement-soil mixture was put into a 14.5 mm wide and 11 mm height mold. Cone penetration test was done after the curing time, and Ca^{2+} and Mg^{2+} concentrations were determined along the depth direction. The result of the cone

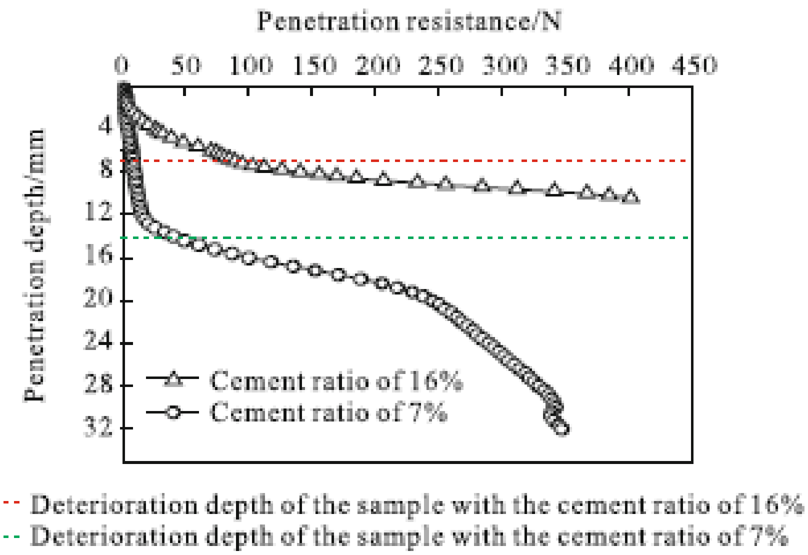


Figure 5. Results of Micro-Cone Penetration Test on The Samples With The Curing Time of 120d. [23]

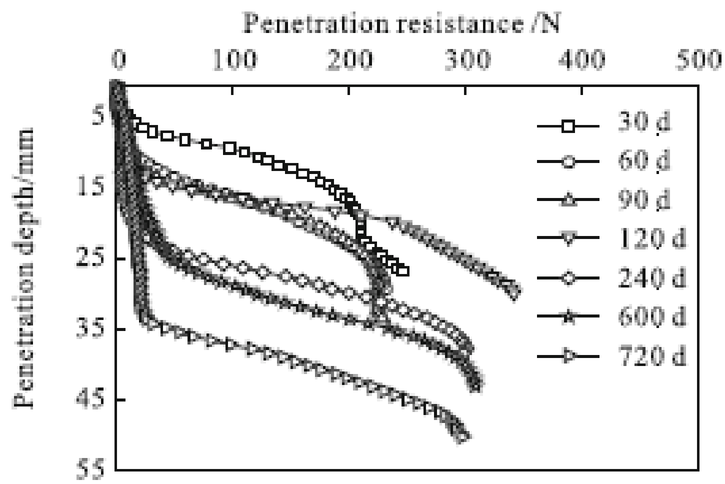


Figure 6. Results of Micro-Cone Penetration Test on The Samples With The Cement Ratio of 7%. [23]

penetration test is shown at Figure. 5 and Figure. 6. It can be concluded that as the curing period is longer, the deterioration depth is also bigger. Furthermore, as cement content increases, the deterioration depth is also bigger. This is due to the reaction where Mg^{2+} replaces Ca^{2+}. Since cement is consisted of mainly calcium, then the existence of ion Ca increases as the addition of cement increases. Thus, the more ion Ca available, the more chance exists for ion magnesium to replace the position of ion calcium. The replacement produces gypsum, a less hard material, that decreases the strength of the material. Yang [23] stated that Ca^{2+} dissolution is a vital cause for the reduction of soil strength. Therefore, it can be concluded that deterioration depth gets bigger as the addition of cement content. In Figure. 7 and Figure. 8 it can be seen that as the deep increases, the Ca^{2+} also increases. It shows that the deterioration minimizes at the inner part of the pile. While on the other side, Mg^{2+} decreases as the deeper the depth. This is because Mg^{2+} attack the outer part of the specimens as it directly exposed to seawater.

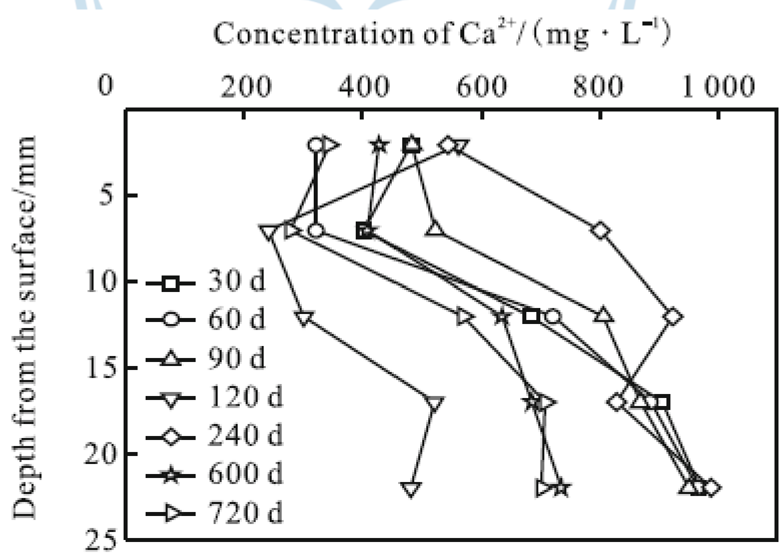


Figure 7. Concentration Distribution of Ca^{2+} With Depth.

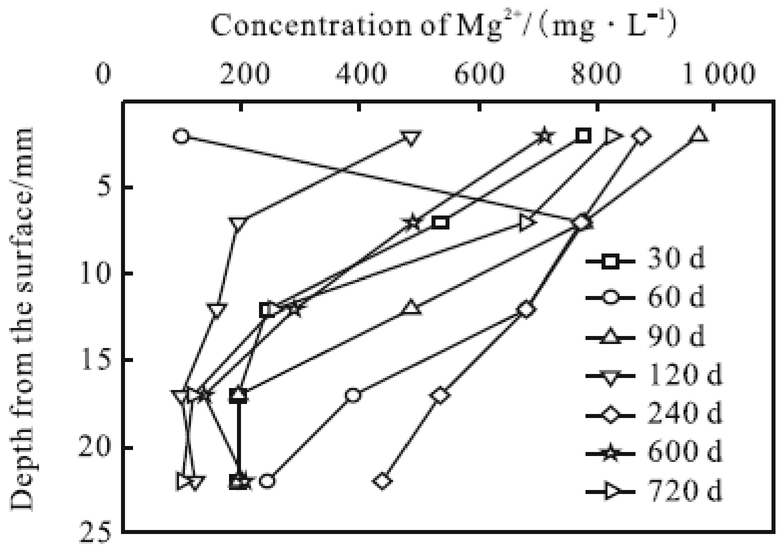


Figure 8. Concentration Distribution of Mg^{2+} With Depth.