# CHAPTER II

# LITERATURE REVIEW AND BASIC THEORIES

## II.1 Literature Review

Clough (1981) did research about soil behavior stabilized by cement, the result is amount and cement characteristic, confining pressure, relative density, gradation, and soil structure are variable that need to be concerned when studying cemented sand-soil stress-strain behavior.

Rad and Clough (1982) suggest there is co-relation between ultimate bearing capacity ($q_u$) with soil cementation content. Soil with $q_u$ between 100 kPa to 300 kPa declared as weakly cemented, while soil with ultimate bearing capacity value lower than 100 kPa declared as very weakly cemented soil.

Halstead (1986), two major classes of fly ash are specified in ASTM C 618 on the basis of their chemical composition resulting from the type of coal burned; these are designated Class F and Class C. class F is a fly ash normally produced from burning anthracite or bituminous coal, and Class C is normally produced from the burning of subbituminous coal and lignite (as are found in some of the western states of the United States). Class C fly ash usually has cementitious properties in addition to pozzolanic properties due to free lime, whereas Class F is rarely cementitious when mixed with water alone.

Sularno (1990).Clay stabilization using cement and lime are already learned and used. Cement, if used to soil stabilization appears to less efficient because cement that functioned as binding material appears unable to bind soil grain well, especially refined grain soil.

Leroueil (1990) suggest a conceptual approaching to describe a soil stress-strain behavior which shows similar characteristic with cemented sand-soil. Structure influence on soil behavior similar with consolidation behavior that occur on clay soil. Classic soil mechanical theory put an initial density parameter and stress history on soil. But, nowadays is already known that shear force and soil natural stiffness and weak stones is not enough explained with that concept, rather structure and the influence on soil behavior should be calculated when make a base concept of mechanical theory that occur on cemented soil.

Chang and Woods (1992) generally tell that on certain stress level, shear stress of cemented sand-soil can be presented in Mohr circle diagram where the shear parameters should calculated the cement content. Which soil cohesion is a unique soil cementation function (cement contents on soil). But, friction angle value is not influenced by cementation.

Based on Clarke (1992) studied that: (a) fly ash particle size can be bigger or smaller than cements particle that is between 1 – 150 micron and mostly are silt, (b) fly ash has the non-plastic characteristic, and has specific gravity between 1.90 - 2.72 and dry density around 1.09 – 1.60 $Mg/m^3$ which depend to used coal source, (c) fly ash is a material with pozzolanic characteristic.

Cripwell (1992), application of fly ash on civil engineering are as follow: (a) as mixture material on concrete, (b) as mixture on cement production, (c) geotechnical sector, as mixture on soil compaction, (d) strengthening material on steel production, (e) productions of bricks and ceramics with the addition of fly ash reach 70%, (f) others application, such as in highway construction as base soil stabilizer and soil bearing wall.

Atkinson (1993) shows that soil stress-strain behavior which is cemented naturally or artificially, basically depend on initial condition, and its connection with liquid limit curve. Cemented sand behavior idealized with grouping in 3 classifications: (a) occur when soil reaches its melt condition while isotropic pressure happens. In this case, shear will produce similar behavior with undisturbed soil, (b) occur on mid-stress where union will broken when accept the shear, (c) sheared soil with relative small circumference stress compared with binding strength.

Gens (1993) found that soil behavior is influenced by geological history and stress-strain history, also influenced by strain level, temperature, and major stress direction.

Hapsoro (1996). Research about clay soil stabilization using fly ash + GEOSTA has been done, the result as follow: (a) increasing sand fraction and silt, also decreasing clay fraction, (b) increasing maximum density, (c) decreasing optimum water content, (d) decreasing liquid limit and increasing plastic limit, (e) decreasing index of plasticity, (f) increasing CBR value, and (g) increasing swelling potency and swelling pressure.

Hapsoro (1996), research about clay soil stability with fly ash and GEOSTA as the mixture. Fly ash content 13% from soil weight, GEOSTA content has variation to 15% (0, 1, 5, 8, 10, and 15). The result shows that 8% of

GEOSTA is the optimum content, soil shear force increase about 25%, maximum dry density increase about 28%, followed by optimum water content decrease.

Vatsala, Nova, and Srinivasa Murthy (2001) made a model of cemented soil on a framework of plasticity theory on strain hardening condition. The model based on concept that cemented soil strength formed from 2 components: soil strength, and binding strength of soil with cement. Soil deformation connected with stress components of soil without consider the binding strength; meanwhile, the cement union give resistance on strain level given. All soil response when stressed can be defined into 2 parallel stiffness with strain unit given. Separately, stress-strain connections defined as 2 components and then combined that finally gives all stress-strain response. Soil stress-strain connections visualized with "Cam-Clay" model. Simple model with use elastoplasticity concept on cemented soil, finally suggested with existing assumption.

Hatmoko (2004) research about artificially cemented soil shear behavior using triaxial test apparatus. The outcome shows that ultimate bearing capacity increase with addition of cement content on soil. Co-relation between cementation degrees with ultimate bearing capacity is a linear. Co-relation between cementation degrees with soil cohesion is positive, with linear co-relation. Differ with inner shear angle value, where there is no clear co-relation between cementation degrees with cemented soil deep friction angle value. Cemented soil shear force which is tested with conventional triaxial is a function of ultimate bearing capacity and inner shear angle for un-cemented soil. Modulus of elasticity and Sekan modulus for cemented soil not significantly influenced by confining pressure. There is direct co-relation between modulus of elasticity and Sekan modulus with cement content on soil.

Abadi, Taufan Candra (2007). The result by using cement as a stabilized material show that the shear strength significantly increases at the optimum and wet conditions, where the percentage of cement to be added is 20%. For wet conditions 15% of cement produces a good condition. The highest improvement is 687.82% at the cement percentage of 20% for the wet condition. The result of unconfined compression strength test at the dry, optimum and wet conditions shows that the highest shear strength is attained at 28 day curing time. Optimum percentage for fly ash that can be used for optimum and wet conditions is 5%, while for dry condition is 10% according to the compaction test.

Muhardi, Reni Suryanita, Alsaidi (2007). Clay bricks are bricks made from clay with or without other material mixtures passed the combustion process with high temperature so that they do not break into pieces if soaked in water. They have o more than 15% holes area compared to the plane area. This research aims at improving the brick characteristics with the addition of fly ash until 80%. Based on the compressive strength test to the brick, where the clay is taken from Klim, Pekanbaru and fly ash from PT. RAPP, Kerinci, Riau, with 10% - 80% mixtures, it is obtained that the maximum addition of fly ash is 50%. The increases in compressive strength are 25.27%; 26.40% and 20.37% at the ages of 7, 14, and 28 days respectively, with respect to compressive strength without fly ash. The maximum compressive strength occurs at 40% fly ash addition with the increase in the compressive strength of 36.69%; 39.32% and 48.37% at the ages of 7, 14, and 28 days respectively. When the addition of fly ash is more than 50%, the compressive strength decreases compared to the one without fly ash. The physical characteristic of brick with fly ash is lighter, smaller water absorption and more compact compared to the ordinary brick.

## II.2 Basic Theories

### II.2.1 Clay

II.2.1.1 Clay Definition

Clay minerals are predominantly silicates of aluminum and/or iron and magnesium. Some of them also contain alkalies and/or alkaline earths as essential components. These minerals predominantly crystalline in that the atoms composing them are arranged in definite geometric patterns. Most of the clay minerals have sheet or layered structures. A few have elongated tubular or fibrous structures.

Clay minerals are very small (less than 2 μm) and very electrochemically active particles which can be seen using electron microscope only with difficulty. In spite of their small size, however, the clay minerals have studied extensively (Grimm, 1968; Mitchell, 1976) because of their economic importance, particularly in ceramics, metal molding, oil field usage, and engineering soil mechanics. The clay minerals exhibit characteristics of affinity for water and resulting plasticity not exhibited by other materials even though they may be of the clay size or smaller.

A clay mineral also has hydroxyl (OH) at its surface. This hydroxyl has ability to release itself from clay particles, as described in this reaction below;

$$SiOH \xrightarrow{H_2O} SiO^- + H^+$$

At the mixture of clay and fly ash, there will be reaction that called pozzolanic reaction, described as the reaction between calcium particle with silica or alumina to build cementing agent. This cementing agent is a rough and rigid mass, almost the same as the result of Portland cement hydration. The reaction velocity of pozzolanic not only depends on the time, but also influenced by the materials that react and the temperature also.

II.2.1.2 Soil Properties

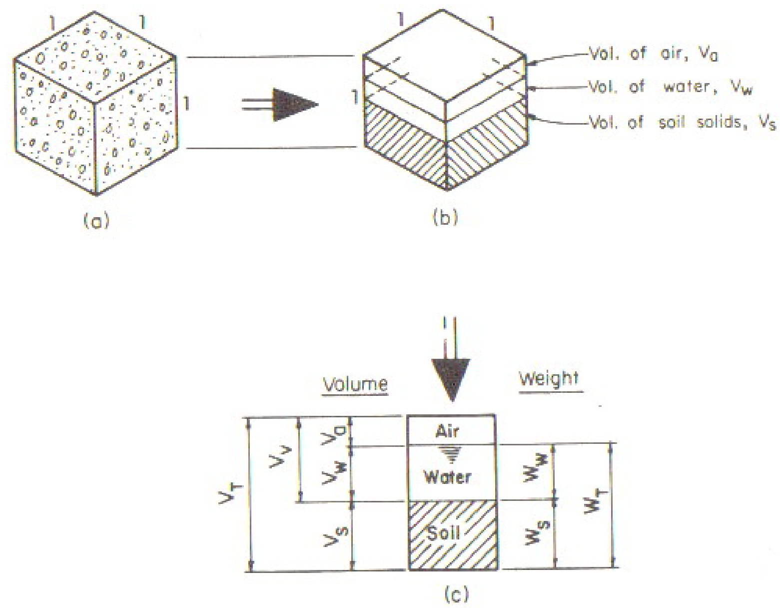
a. Void ratio ($e$)

Void ratio is defined as the ratio between void volume and solid grain volume.

$$e = \frac{V_v}{V_s}$$

The possible range of $e$ is $0 < e \leq \infty$

Typical values for cohesive soils from 0.7 to 1.1.




b. Porosity ($n$)

Porosity defined as the ratio between void volume and total soil volume.

$$n = \frac{V_v}{V_T} \times 100$$

The range of $n$ is $0 \leq n \leq 1$\

c. Water content ($w$)

Water content defined as the ratio of the weight unit of water in soil compared to the solid weight of the soil.

$$w = \frac{W_w}{W_s} \times 100$$

The range of $w$ is $0 < w$, percent $\leq \infty$

d. Degree of saturation (*S*)

Degree of saturation defined as the ratio of water volume and void volume.

$$S = \frac{V_w}{V_v} \times 100$$

The range of *S* is $0 < S$, percent $\leq 100$

e. Specific gravity (*G*)

Specific gravity defined as the ratio of a unit weight of material to the unit weight of water.

$$G = \frac{weight\ of\ unit\ volume\ of\ any\ material}{weight\ of\ unit\ volume\ of\ water\ at\ 4°C}$$

Specific gravity of soil grains (solids) ($G_s$)

$$G_s = \frac{\gamma_s}{\gamma_w} = \frac{W_s}{V_s \gamma_w}$$

Where $\gamma_s$ = unit weight of the soil solids. Typical values of $G_s$ for soil solids are 2.65 to 2.72.

II.2.1.3 Clay Characteristics

The general characteristics of clay:

a. Hydrated shape

Clay particles are almost always hydrated which mean always covered by minimum 2 layers of water molecules that is quite thick, called as diffusion layer.

b. Clay activity

Clay activity is a ratio between plasticity index (PI) with clay percentage (grain fraction with diameter < 2 micron) on soil. This activity also directly connected with soil's water content. Bowles, 1988; typical value of clay soil as follow: kaolinite 0.40 – 0.50; illite 0.50 – 1.00; montmorillonite 1.00 – 7.00.

c. Water effects

A particular phenomenon of clay is that a clay mass which has dried from some initial water content form a mass which has considerable strength. If these lumps are broken down to elemental particles, the material behaves as a cohesionless particulate medium. When water is again added, the material becomes plastic with some strength intermediate to the dry lump strength. The role of water in this phenomenon is not fully understood, although in drying, surface tension certainly pulls the particles into maximum contact with the very minimum of interparticle spacing so that the interparticle forces are a maximum. It appears that the higher density resulting from packing and the close spacing resulting in the maximum effect of interparticle force attraction give this very high strength. We can readily observe that the strength of the clay varies from a very low value at $S$ = 100% to a very high value at $S$ = 0.

### II.2.2 Fly Ash

II.2.2.1 Fly Ash Definition

Fly ash is a small grain material, had a uniform gradation, and came from a residue of coal burning. About 80% of ash formed from coal burning which come out from fireplace, fly ash pass through chimney (smokestack), while rough residue on the bottom of fireplace called as bottom ash. Fly ash include as a pozzolanic material because fly ash consist of pozzolan material such as: silica ($SiO_2$), ferrit oxide ($Fe_2O_3$), aluminium oxide ($Al_2O_3$), calcium oxide (CaO), magnesium oxide (MgO), and sulphat ($SO_4$) (Hausmann, 1990).

According to ASTM C618 – 91 (1994), in the application, fly ash divided into two class, thats are: (a) F class, are the results of the burning of coal type of anthracite/bituminous, are pozzolanic character and low chemical CaO containing smaller than 10%, (b) C class, are the results of the burning of coal type lignite/sub-bituminous, have high CaO containin (more than 10%), and have characteristic of pozzolanic and cementitious also.

The qualities of fly ash are various depend on:

- Quality and type of coal
- Burning efficiency and the refinement of coal powder
- Fireplace dimension of coal burning
- Fly ash capture methods from coal burning

II.2.2.2 Fly Ash Chemical Element

According to Davidson (1961), chemical analysis result of fly ash have different size and unburned element such as $SiO_2$, $AI_2O$, $Fe_2O_3$, inclined in refined size particles, while carbon elements generally determined by loss ignition is dominant in rough particles, so weight percentage that get through No. 325 sieve (ASTM) generally could be used as carbon content indicator.

Chemical characteristic of fly ash influenced by the type of burned coal and the saving technique, so is the curing. There are 2 types of fly ash, Class C and Class F.

Table 2.1 Fly ash chemical element

| Component | Bituminous Class F (%) | Sub-bituminous Class C (%) | Lignite (%) |
|---|---|---|---|
| $SiO_2$ | 20 – 60 | 40 – 60 | 15 – 45 |
| $Al_2O_3$ | 5 – 35 | 20 – 30 | 10 - 25 |
| $Fe_2O_3$ | 10 – 40 | 4 – 10 | 4 – 15 |
| CaO | 1 – 12 | 5 – 30 | 15 – 40 |
| MgO | 0 – 5 | 1 – 6 | 3 – 10 |
| $SO_3$ | 0 – 4 | 0 – 2 | 0 – 10 |
| $Na_3O$ | 0 – 4 | 0 – 2 | 0 – 6 |
| $K_3O$ | 0 – 3 | 0 – 4 | 0 – 4 |
| LOI | 0 - 15 | 0 – 3 | 0 - 5 |

II.2.2.3 Fly Ash Physical Attributes and Characteristics

According to ACI committee 226.3R-87, size and shape characteristic of fly ash particles depend on origin place and the similarity with coal, crushing degree before burning process, the level of burning, and solid hollowed system type, described as *Cenosphere*, and rounded that consist less of fly ash, called *Plerospheres*. This fly ash material have grey colour if produced directly from less oxygen coal burning. This colour can be changed from light grey to black. Coal burning process have very important role, because better fly ash will be produced if the burning are close to perfect. Fly ash will be blackish colour if the temperature when burning is less than 1000º C (unperfected burning), because still a lot of carbon contained that not burned yet; and will be greyed if the burning done at 1000º C temperature (perfect burning). Unperfected burning will produce blackish fly ash. This matter caused by bigger amount unburned carbon content exists on fly ash.

II.2.2.4 Fly Ash Influence to Soil

The purpose of the addition of fly ash to soil is to build pozzolanic reaction, which is reaction between Calcium and Silica. Silica and Alumina obtained from soil, while fly ash addition will give Calcium element (CaO) that will result of pozzolanic reaction. Besides that, the addition of fly ash will riches Alumina and Silica element at soil because of fly ash gradation is larger than soil, so with the addition of fly ash the soil will get better gradation, increase the workability of the soil. The heat that produced from fly ash also can decrease the water content on wet soil. Soil with pozzolan contain will be greatly combined with fly ash to build a rigid and rough mass.

### II.2.3 Soil Stabilization

Bowles, Joseph E. (1984). When the soils at a site are loose or highly compressible, or when they have unsuitable consistency indices, too high permeability, or any other undesirable property making them unsuitable for use in a construction project, they may have to be stabilized. Stabilization may consist of any of the following:

1. Increase the soil density
2. Adding inert materials to increase the apparent cohesion and/or friction resistance
3. Adding materials to effect a chemical and/or physical change in the soil material
4. Lowering the water table (soil drainage)
5. Removal and/or replacement of the poor soils

Soil stabilization may be any, or a combination of one or more, of the following:

1. Mechanical, densification with various types of mechanical equipment as rollers falling weights, explosives, static pressure, fabrics, freezing, heating, etc.
2. Additives, gravel, to cohesive soils; clay, to granular soils; and chemical additives such as portland cement, lime, fly ash (byproduct from coal burning), often with lime and/or Portland cement, asphalt cement, sodium and calcium chlorides, paper mill wastes, and others (sodium silicate, polyphosphates, etc.)

According to Bowles (1984), soil-cement and lime-fly ash (LFA) are very commonly used in soil stabilization. Laboratory procedures are specified by ASTM, AASHTO, PCA (1959) and for LFA in a U.S. Department of

Transportation publication (DOT, 1976). These stabilization procedures are used worldwide with select modifications for local climate and soil peculiarities.

Basically the field stabilization criteria for density and percent of admixture (cement, lime, fly ash, etc) based on dry weight of soil is established in the laboratory. Admixture percentages for fly ash are usually in the range of 12% – 30%, with larger percentages for poorer soils.