# The Effect of Cement Stabilization on the Strength of the Bawen’s Siltstone

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# Introduction

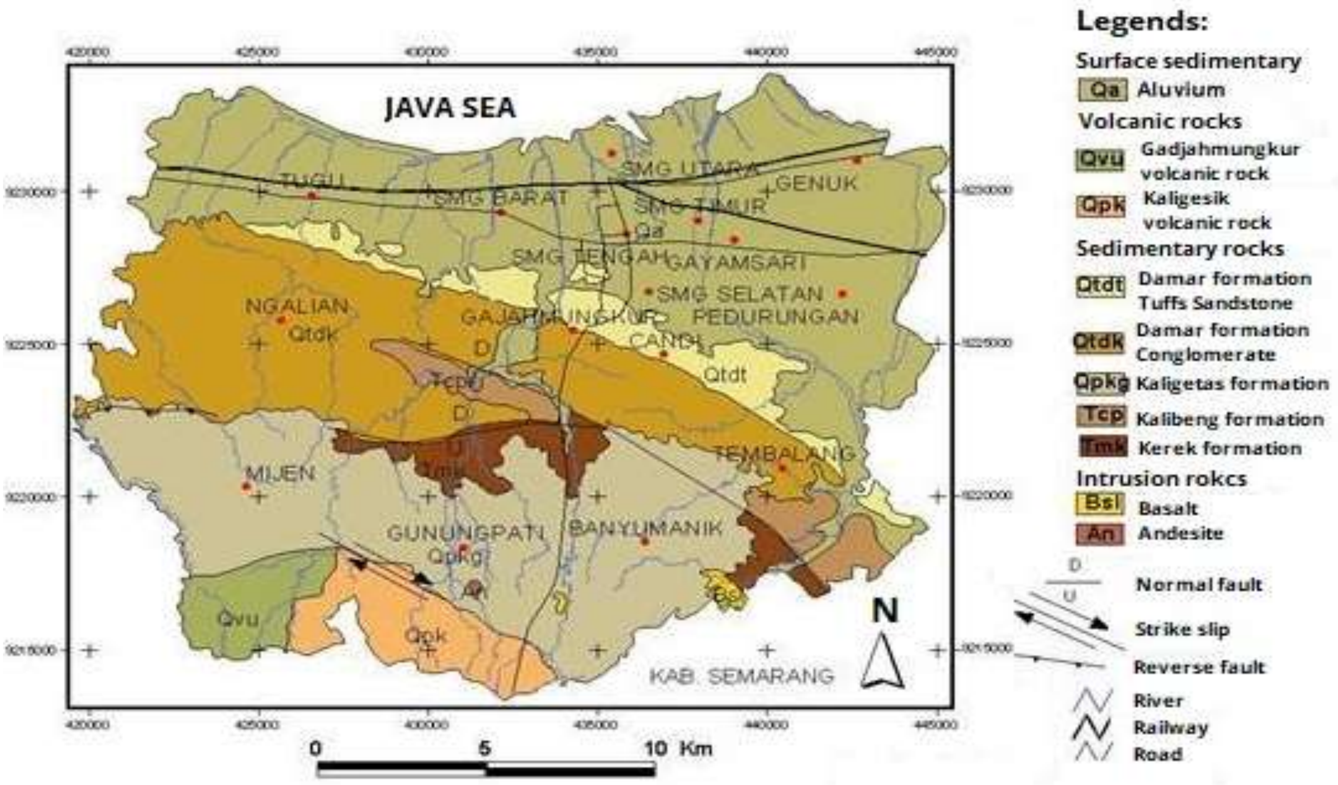


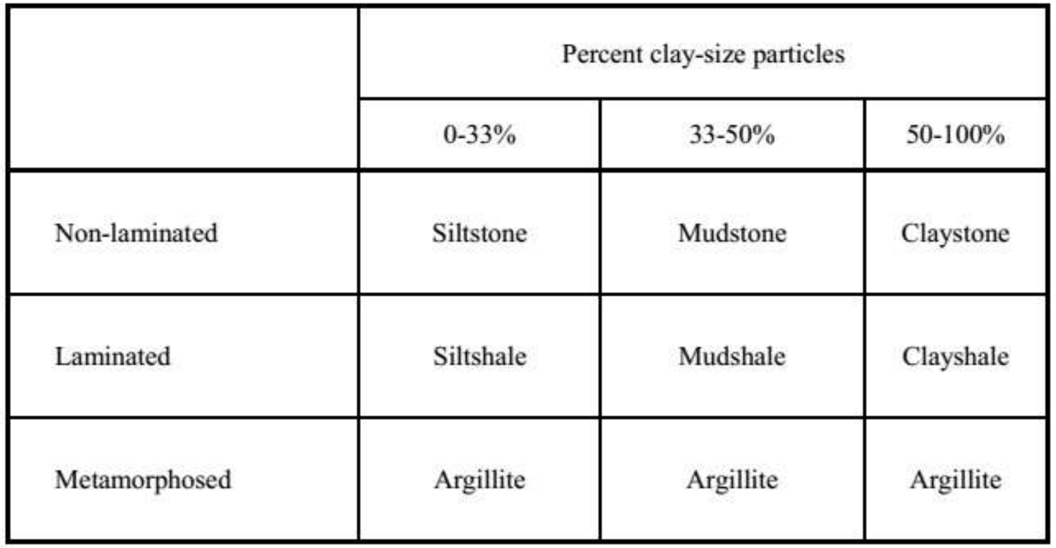
**Fig.1.** Geology maps of the Semarang area

Siltstone, claystone and clayshale known as mudstone are found along the toll bawen-semarang. The rock is easy undergoes weathering if exposed and undergo repeated wetting and drying process even in just one cycle [4]. Muhroji and Wardani [5] reported that the typical mudrock, such as shale along the toll road has a high SPT value, but they generated instability of the roadway embankment.

In the process of road construction, it is often necessary to excavate and cut the slope. If the excavation is performed on the type of rock, it will affect the stability, either as a slope or a road body. Some cases of road settlement are caused by the lack of soil compaction and increasing the saturation. Soil stabilization are needed to improve the integrity of the soil layer to extend the lifetime of the construction. Stabilization with cement or cement with other materials, proven to be effective.

# Classification

Table 1.1: Geological classification of mudrocks (Modified after Potter et al., 1980, by Dick and Shakoor, 1992).



| | Percent clay-size particles | | |
|---|---|---|---|
| | 0-33% | 33-50% | 50-100% |
| Non-laminated | Siltstone | Mudstone | Claystone |
| Laminated | Siltshale | Mudshale | Clayshale |
| Metamorphosed | Argillite | Argillite | Argillite |

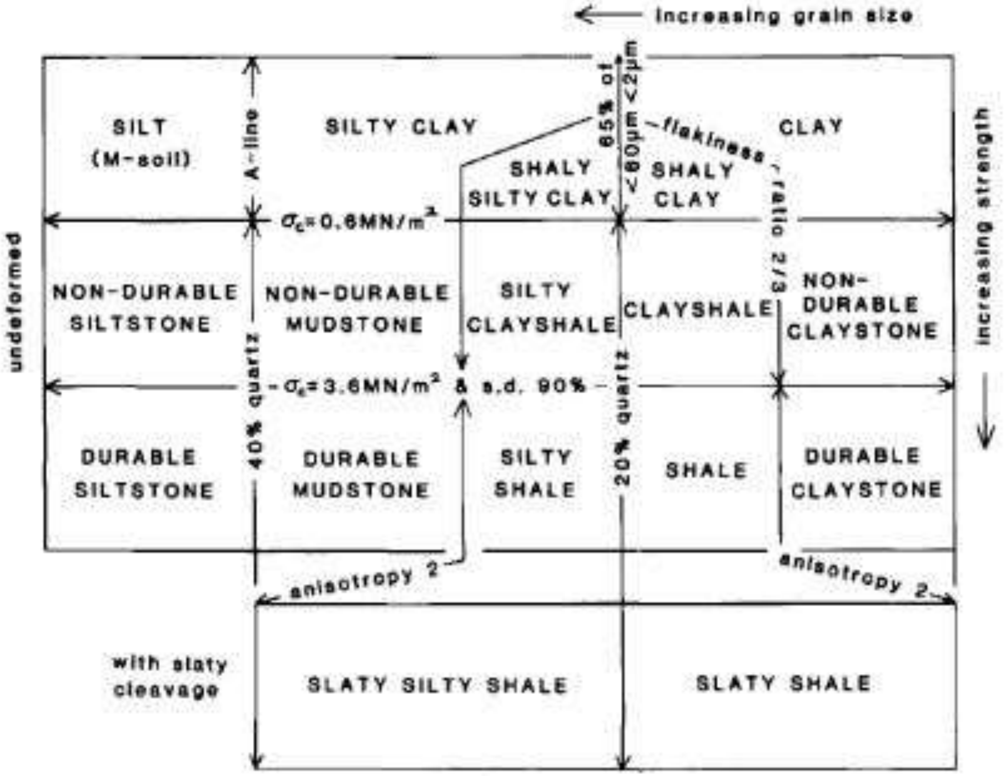


Fig 2a. Classification of Mudrock by Grainger, 1984

Table 1.1 shows the classification of mudrocks by Potter et al. (1980), modified by Dick and Shakoor (1992) which will be employed here. However, the classification proposed by Potter et al. (1980), which is based on the amount of clay content, presence or absence of fissility (tendency of mudrocks to split along planes of weakness), and degree of metamorphism, is widely accepted in engineering practice.

According to this classification, siltstones contain less than 33 percent clay-size material and not laminated. Figure 2a shows the mudrock classification by Grainger, 1984, which is based on the amount of grain size, mineral content and strength

# Experimental Method

Table 2. Properties of the Soil Samples

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Specific gravity, Gs | 2.58 | Soil fraction: | |
| Liquid limit, LL (%) | 38 | Clay size (%) | 12.5 |
| Plastic limit, PL (%) | 22 | Silt size (%) | 38.3 |
| Plasticity index, PI (%) | 16 | Sand (%) | 49.2 |
| Maximum dry density, MDD (kN/m$^3$) | 14.8 | Optimum moisture content, OMC (%) | 25 |

**Fig.2b** Geology maps of the Semarang area

One of the mudrocks type used in this study is siltstone which was taken from the slope side of the Bawen toll road. The typical siltstones sizes are shown in Fig. 2b. After pulverizing, the soil consists of 51% of fines grain fraction; the rest is coarse grain fraction. Furthermore, the fragment is categorized as siltstones according to the criteria of Dick and Shakoor [15]. The plasticity index test indicates that the fines fraction is classified into low plasticity clay. Thus, the soil sample can be classified into A-6 group by AASHTO.

# Experimental Method

Table 3 Laboratory testing design

| Specimens | Code | Test Type | | | |
|---|---|---|---|---|---|
| | | Att. | PSD | UCS | CBR |
| Soil | S | ● | ● | ●●● | ●● |
| Soil + 2% PC | SC2 | ● | ● | ●●● | ●● |
| Soil + 5% PC | SC5 | ● | ● | ●●● | ●● |
| Soil + 7% PC | SC7 | ● | ● | ●●● | ●● |
| Soil + 10% PC | SC10 | ● | ● | ●●● | ●● |
| Soil + 12% PC | SC12 | ● | ● | ●●● | ●● |

Notes: Att. = Atterberg limits; PSD = particle size distribution; UCS = unconfined compressive strength; CBR = California bearing ratio;
● = number of specimen

A series of laboratory tests were performed including index properties (Atterberg limits, particle size distribution), compaction, and unconfined compressive strength, and California Bearing Ratio tests. The soil was mixed with various cement content from 2% to 12%. The testing design of this experiment is presented in Table 3. The specimens were prepared according to ASTM D4609 [17] which recommended the tests after seven days curing at high humidity. Since the strength of soil is affected by the initial water content, then the UCS and CBR specimens were mixed at the same moisture content of the OMC of unstabilized soil. The liquid limit, plastic limit, and plasticity index were tested according to the ASTM D4318 [18]. The particle size distribution of the stabilized soils was performed as stated in ASTM D422 [19].

# Results and Discussion

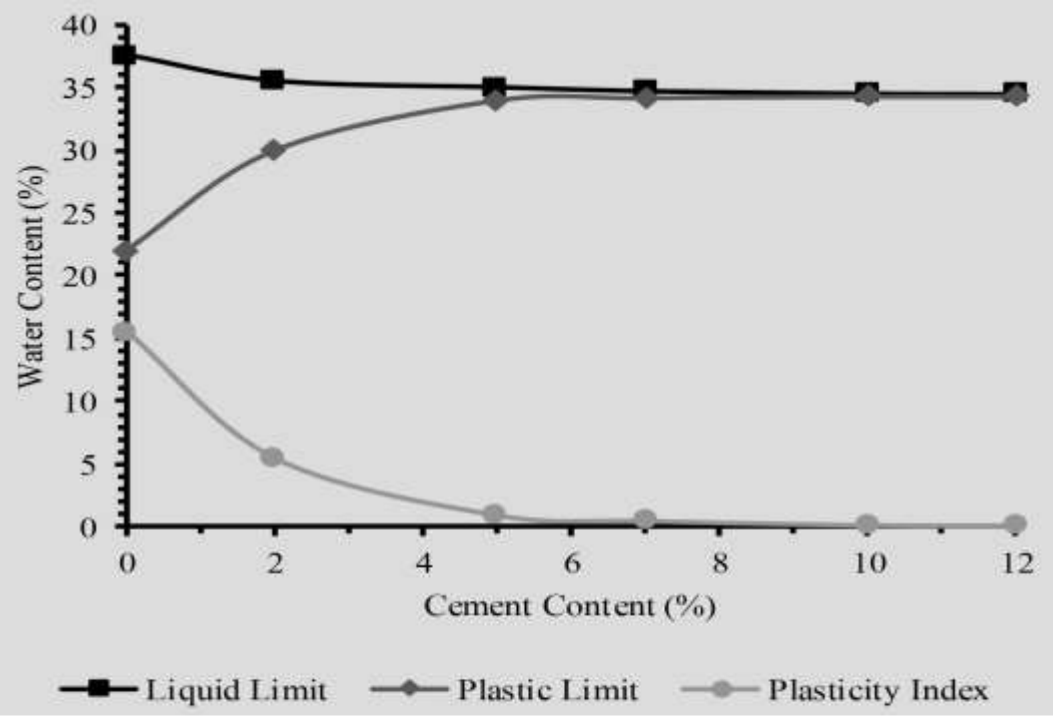


**Fig. 3**. Variation of consistency limits of the soil-cement mixtures

The results in Fig. 3, it appears that if the cement content increases, the liquid limit decreases and the plastic limit increases, so the plasticity index decreases. The consistency limits change significantly by adding the cement up to 5%. The results mean, that the stabilization of cement on siltstone is quite effective in reducing the soil plasticity. Decreasing in plasticity index is an indicator of stabilization [17]. Principally, consistency limit relates to the affinity of clay to water

# Results and Discussion

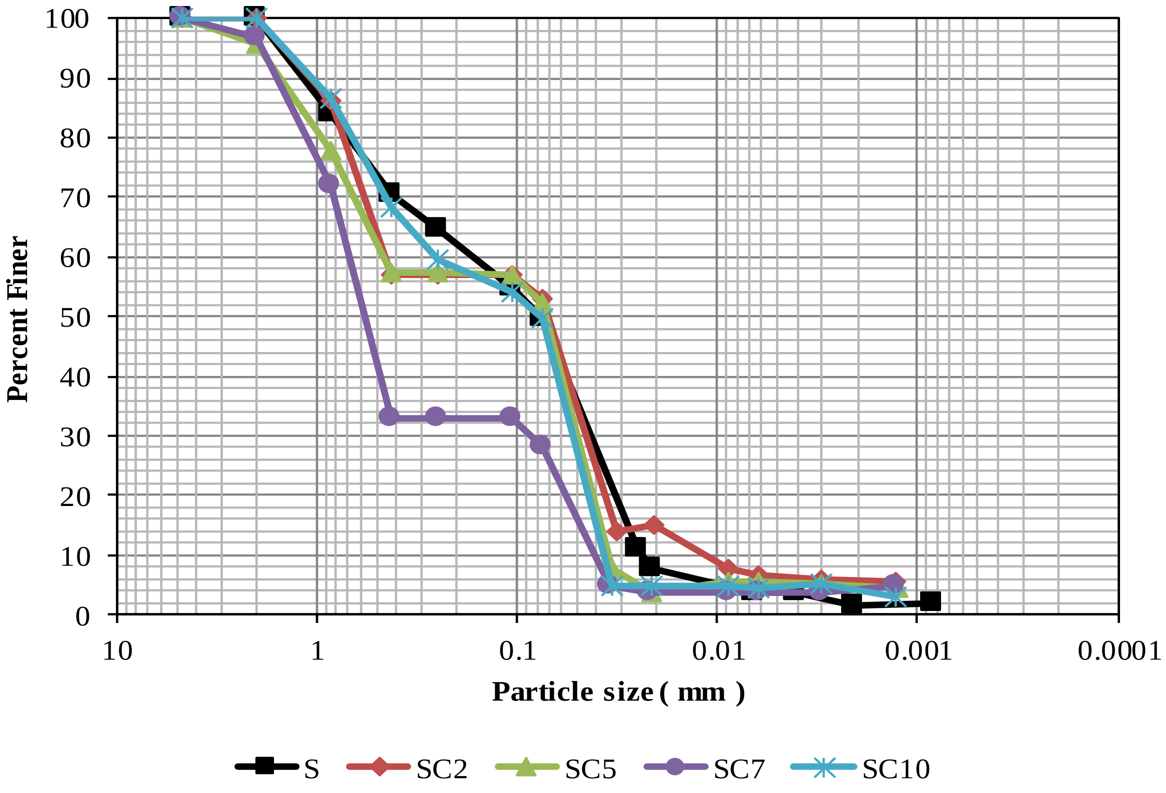


**Fig. 4**. Particle size distribution of the soil-cement mixtures

Fig. 4 illustrates that cement alters the particle size distribution of soil. The fine-grained fraction change to be a coarser grain. The characteristic indicates that agglomeration takes places in the cement-modified soil.

Reduction in affinities of clay soil for moisture content can be attributed to three mechanisms: (a) destruction of clay-mineral structures in reaction with cement, (b) cementation of fine mineral particles into aggregates, and (c) modification and masking of the surface, and support of restraint of particles by cementitious reaction products [8].

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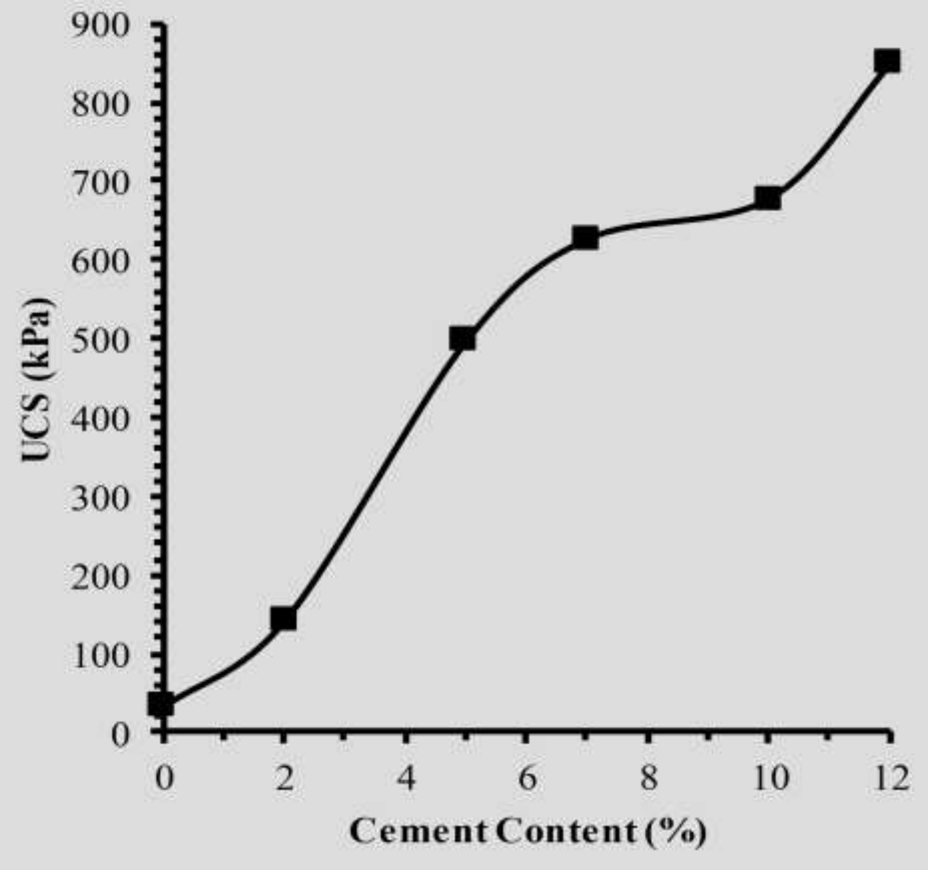

**Fig. 5a**. Effect of cement content on the variation of UCS

Fig. 5a shows the effect of cement content on the unconfined compressive strength of soil. The figure indicates that the UCS increases almost linearly with the increasing of cement. The UCS increases from 34 kPa to 849 kPa by the addition of 12% cement. Based on the Indonesian Standard for cement-treated base [22], the minimum UCS for base course layer is 600 kPa. Thus, this study recommends that addition of 7% cement be suitable to improve he siltstone as base course layer. This result is consistent with Ilori [13].

Increasing in UCS can be attributed to the reaction product in the soil-cement mixture. Wardani and Muntohar (2018) explain that in the cement-stabilized soil will produce the main products of tricalcium silicate and secondary products of calcium silicate hydrate and calcium aluminate hydrate. The main products harden into high strength additives. The secondary process increases the strength and durability of soil-cement by producing an additional cementation agent to increase the bonding strength between the particles. Several other parameters may control the increase the UCS such as dry density, water content, and water to cement ratio [24].

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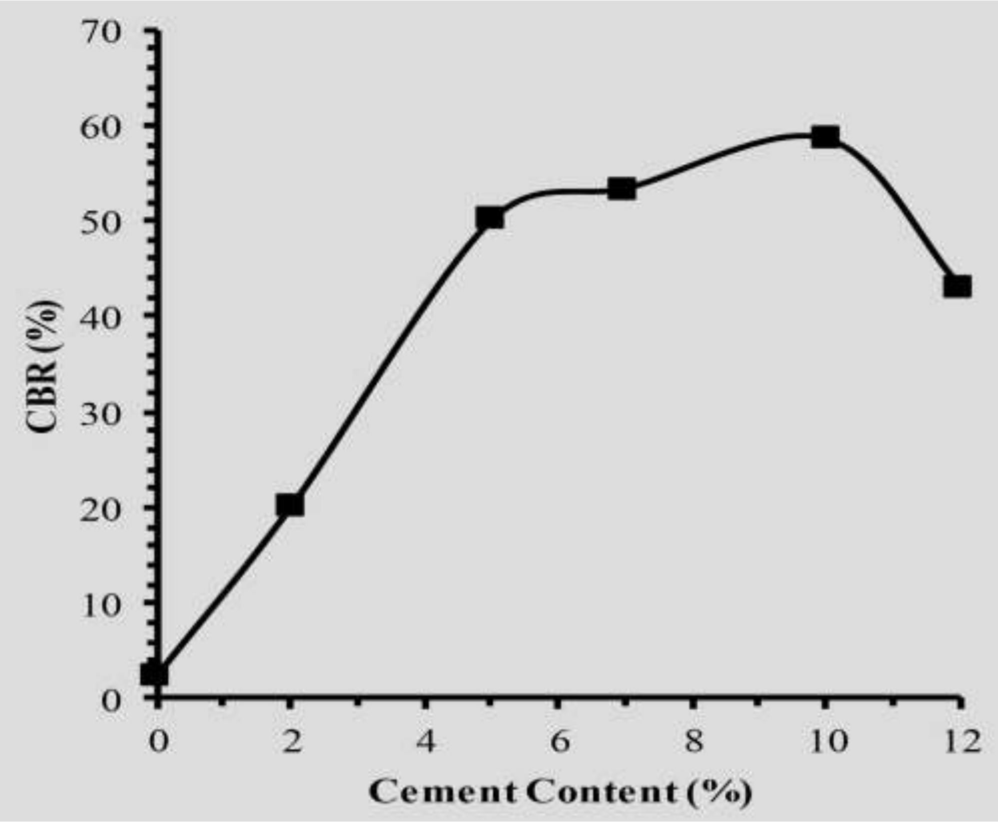

**Fig. 5b**. Effect of cement content on the variation of CBR

Fig. 5b presents the relationship between CBR and the cement content in the soil-cement mixtures. The figure shows that the CBR increases almost linearly with the increases in cement content up to 10%. Hereafter, the CBR tends to decrease after addition of 10% cement. The CBR increases significantly from 2.54% to 59% by the addition 10% of cement. CBR is commonly used as the requirement for subgrade design of road pavement.

In this research, the UCS specimens were controlled their moisture and density. All specimens were compacted at the same moisture, and compacted statically to controlled their density. But, the CBR was performed by means controlling their moisture. Then, the specimens were compacted using modified compaction procedures. As a result, the density is possible to vary depending the compaction energy.

In this research, there was no swelling observed for four days soaking of unstabilized soil. It is because of no-swelling clay mineral in the soil origin. During soaking, the specimen absorbs water and result in increases in moisture content. Then, this mechanism reduces the CBR value of the cement-stabilized soil.

# Conclusion

- The research has been successfully conducted to evaluate the effectiveness of cement for the siltstone stabilization.
- The experiments show that the use of cement improves the geotechnical engineering of the siltstones significantly. Addition of cement up to 5% decreases the plasticity index of soil significantly.
- For stabilization, 7% cement addition is suitable to alter the soil particle size and fulfill the requirement for subgrade and base-course layer of the paved road according to Indonesian Standard [22, 23]. This study found that the UCS and CBR value of stabilized-soil increases about four times by addition of 7% cement.