Optimization of replacement fines in roads base materials by cement/ lime

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Abstract The road networks in Iraq suffer from the increase in the proportion of highly carriage trucks and vehicle growth rates, which requires improving the layer's characteristics and using protective methods accomplished with suitable costs to achieve high quality and fewer cost treatments. This paper investigates the effect of modifying sand - gravel soil as a base layer by using cement or/ lime as a replacement to the original filler. The mechanical properties of the mix were evaluated based on compaction, CBR, and compression strength tests. The results for the CBR test suggested that there was an increase in bearing ratio when replacing a percent of filler by cement or lime as compared with the origin material, and the percent of replacement by cement or lime was 30% of origin filler. The results for the compression strength show that there is an increase with increasing percent of filler replacement by Cement, on the contrary, the Lime increase reveals a decrease in strength. The replacement with cement was better than that of lime. Lime should be used in less than 30% from point of view cost and strength. The findings of this paper suggested that adopting the method will result in decreasing the thickness of the pavement layer. The best results obtained when adopting 100% replacement by cement (10% by total weight) which gave the best reduction in the required thickness by about 62%. Regarding the lime use, the results revealed optimal percent of lime to be used is about 3% of total weight.

Keyword: flexible pavement, optimization, CBR, sand-gravel, lime.

1. INTRODUCTION

The road network in Iraq suffers from the increase in the proportion of highly carriage trucks and vehicle numbers growth rates, which requires improving the layer's characteristics and using protective methods accomplished with suitable costs to achieve the high quality less costly treatments.

The road's base layer has an important role in the pavement resistance to applied stresses and equalizing them to the subgrade bearing capacity. To achieve this, either by using sufficient materials, or increasing the layer thickness, or using methods to increase the strength. However, the best alternative should depend on the most economical solution among them. Many methods have been used to treat, modify or stabilize the base soil and the Portland cement or lime most chemicals used. Mixing cement and lime with base materials gave more stability with better strength and high elasticity modulus [1]. Roads service life was prolonged when cement and lime are used with aggregate in roads and provide better load transfer to the beneath layers. The layer thickness was reduced which consequently reduced the cost [2, 3], enhancing the flexural strength, and considered the best choice to resist the effect of water [3].

Ghani et al [4] used cement as an additive to the base material with a percent's up to 15% by total weight. The CBR% was increased by 100% and the compression strength was increased by about 7 Mpa. Adding Cement and lime together by more than 10% has increased the strength by 6.8 mph [1].

Research works [1-4] involved pavement base materials treatment by cement and/or lime with amounts from 5-15% as an additive to original material, but not a replacement to the fillers.
materials, causing raising these fines amounts in some cases more than their limits and remaining the effect of clays on cement without a reduction in their amount.

This paper focuses on finding the optimum percent of cement and lime treated base material by evaluating the mechanical and economical effect of using a method to modify sand-gravel soil as a base layer using cement or/and lime as a replacement to the original filler without any change in filler quantity. The paper also investigates the effect of reducing the clays or plastic mineral materials on mechanical properties. Also, the paper highlights the differences between cement and lime treatment.

2. Materials and experimental work:
The natural gravel-sand soil was used as base course material; its grade complies with the requirement of the Iraqi standard specifications (SCRB)⁶ and the re-grade had done to achieve the middle of the specification limits as shown in Figure 1. Two kinds of chemical agents were used which are Portland cement (sulfates resistant) and hydrated lime, Tables 1 and 2 show the physical and chemical properties of these two materials. The method of modifying was by replacing the original filler dust at (30, 50, and 100 %) from its content in total mixture by the same percent from cement or lime. As observed that the chemical agent amount was too little not exceeded 10% of the total mix.

The following tests were conducted on the samples depending on ASTM [7] standards test methods:

1- Sieve analysis according to ASTMC 136 to prepare the gradation satisfying the Iraqi standard specifications required for the base layer.
2. Liquid and plastic limits according to ASTM D 4318. The origin material has a 17% liquid limit with a 3% plasticity index.
3- Moisture-density relationship according to ASTM D 1557 to find the maximum dry density and optimum moisture content for the CBR test.
4-California bearing ratio according to ASTM D 1883 which is one of the parameters required for pavement structural design (unbonded soil).
5- Compression strength according to ASTMD 1633 at 7th day cured in water, it's one of the parameters which is required for pavement structural design (stabilized soil).

![Figure 1. The aggregate gradation compared to the Iraqi standard specification (SCRB) gradation limits for base course materials](image-url)
TABLE 1. Chemical and physical characteristics of cement used

| Oxide composition | Oxide content % | Initial setting time (Vicat) (min) | Final setting time (Vicat) (Hrs:min) |
|-------------------|-----------------|-----------------------------------|-------------------------------------|
| CaO               | 62.11           |                                   | 115                                 |
| SiO₂              | 22.02           |                                   | 5.40                                |
| Al₂O₃             | 5.27            |                                   | 3 days                               |
| Fe₂O₃             | 3.4             | 7 days                            | 13                                  |
| MgO               | 2.71            |                                   |                                     |
| SO₃               | 2.41            |                                   |                                     |
| Free CaO          | 1.46            | C₃S                               | 45.17                               |
| L.O.I             | 1.47            | C₃S                               | 29.13                               |
| I.R               | 0.29            | C₃A                               | 7.97                                |
| L.S.F             | 0.86            | C₄AF                              | 10.35                               |

Table 2. Chemical analysis of Limestone Powder

| Oxide   | Content % |
|---------|-----------|
| CaO     | 50.12     |
| Fe₂O₃   | 0.43      |
| Al₂O₃   | 1.57      |
| SiO₂    | 4.16      |
| MgO     | 2.24      |
| SO₃     | 1.64      |
| L.O.I   | 39.83     |

3. Results and discussions

3.1 California Bearing Ratio (CBR %) Test

All samples were cured in water by immersing them four days, and to obtain more accurate results, the number of study samples were increased to consist additional percent of the additives, the origin material samples gave 60% CBR, thus it doesn't comply with the Iraqi specification requirements (SCRB)[6] for base course. As shown in Figure 2; the CBR values had increased when replacing the amounts of filler with cement or lime as compared with the original material due to reduction in plasticity and pozzolanic bonds forming. The higher result has got when replacing the origin filler with 30% cement, which represented the optimum for treatment with cement, the results also revealed that the optimum lime was 30%. The CBR results of treatment by lime were less than that in cement treatment due to the slow reaction and setting of lime, the plasticity of lime paste, and low density.

When comparing with the control sample, the 30% replacement with cement and lime raising the CBR to 4.3 and 3.5 times respectively.

In returning to the CBR results by Ghani et al[4] when they used the gravel -sand soil as base materials treated by adding cement to 10% by total weight, the CBR test results were about 90% while in the present study was about 190% (2.11 times much higher) for the same amount of
cement. This high value is due to the replacement of the origin filler by cement. It is also possible to use 3% cement to get CBR of 260% (2.88 times higher) only when removing 30% of dust (original filler), the cement is less than that used in Bandara et al [5] and getting higher CBR value. While Mohsen and Jawad [8] found the optimum cement percent is 6% by total weight added to gravel-sand soil to get 100% CBR. However, the results show that the base course treatment by lime and cement enhance and satisfy the Iraqi requirements for the base course to achieve more than 80% CBR.

![Figure 2. CBR test results influenced by the additives](image)

### 3.2 The Compression Strength Test Results:
This test is used for stabilized materials due to increasing tension strength, Bandara et al [5]. The study approved that there is no relation between cement and CBR or CBR with compression strength. Researchers [1-5] adopted it in the evaluation, analysis, and pavement design; therefore this test was implemented in this study.

The samples were cured in water and tested on the 7th day. Figure 3 shows that the compression strength increased with increasing the percent of filler replacement by cement due to increasing bonds and reduction in the clays because the presence of clays had a negative impact on cement activity (in contrast to what appeared in the CBR test), on the other hand, there is a decrease in compression strength results with increasing percent of replacement the original filler by lime, it could be due to the slow action of lime in bonding, the stabilization process needs to years [9, 10]. Also; the lime reacts mainly with clay rather than granular materials and permanently transforms them into a strong cementitious matrix [11], and it alone can react with soils containing as little as 7% clay [11], which's clearly shown at 100% lime sample (0% original filler) which is even less than the original sample. However, replacement by 100% cement in the present study gave higher strength values than the other similar studies Azadegan et al [1], Ghani et al [4], and Bandara et al [5].

According to the requirements of the Iraqi specification (for treatment by lime and cement) and the results obtained, more than 50% original filler replacement by cement is required to satisfy the Iraqi specifications, on the other hand; for treatment with lime, more than 50% lime doesn't satisfy the requirements as illustrated in Figure 3.
4. Pavement Design
The estimation of thickness design for pavement was conducted by adopting the AASHTO 1993 [12] method for structural design. The parameters used in the design were fixed for some layers properties used in Iraqi highways. The surface layer was hot mix asphalt and the subbase was gravel-sand soil with a resilient modulus of 450000 and 52500 Psi respectively. The UCS test results were adopted in the design for cement or lime stabilized base materials. The results showed that a reduction occurs in base course thickness of more than 60% when increasing cement content to 100%.
The 30% content of lime reduces the thickness of the layer, however, it is increased at 100% lime due to the reduction in strength parameter, as shown in Figures 4-6.
5. Conclusions
This paper investigated the effect of using an innovative method to modify sand-gravel soil as a base layer by using cement or lime as a replacement to the original filler. The mechanical properties of the mix were evaluated based on compaction, CBR, and unconfined compression strength tests.

The results for the CBR test suggested that there was an increase in bearing ratio when replacing a percent of filler by cement or lime as compared with that of the original material. The better results were obtained when the percent of replacement by cement or lime was 30% of origin filler. The results for the compression strength show that there is an increase with increasing percent of filler replacement by cement. In contrast, there is a decrease in strength with increasing percent of replacement of the original filler by lime. The replacement with cement was better than that of lime; lime should be used in less than 30% from point of view of cost and strength.

The findings of the paper suggested that adopting this method resulted in decreasing the thickness of the pavement layer. The best result was obtained when adopting 100% replacement by cement (10% by total weight) which gave the best reduction in the required thickness by about 62%. Regarding lime use, the results revealed that its optimal percent is about 3% of the total weight.
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