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An Experimental Investigation on the Effect of Calcium Chloride As Dust Suppressant on the Strength of Unpaved Road

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Abstract: The quality of the gravel used in road construction has a profound positive impact on road service life. The potential use of calcium chloride as a dust control agent and material for stabilizing the base of unpaved roads has been researched. However, the quality of the gravel may be impacted if calcium chloride is introduced as a dust suppressant into it. The main aim of this research is to examine the increase in strength of soil specimens treated with calcium chloride and to evaluate how different proportions of calcium chloride as a dust suppressant and base stabilizer affect the California Bearing Ratio value of the soil samples. Mixtures of natural gravel and gravel with varying amounts of calcium chloride were analyzed for their Atterberg limits, grading, maximum dry density, CBR properties, and optimum moisture content. The changes in the characteristics of the gravel - calcium chloride mixtures were analyzed. It was found that the particle size distribution and Atterberg limits remained largely unchanged. However, the optimum moisture content (OMC) decreased from 9.2% to 7.6%, 7.4%, and 7.2% with calcium chloride added at percentages of 2 percent, 3 percent, and 4 percent per volume of dry soil, respectively. Observation of the mixture revealed an increase in the maximum dry density (MDD) as the ratios of calcium chloride were altered. The maximum dry density significantly increased from 2.15 Mg / m^3 to 2.31 Mg/m^3, 2.35 Mg/m^3, and 2.36 Mg/m^3, respectively. Along with this, the California Bearing Ratio (CBR) demonstrated an improvement of 25% to 29%, 32%, and 36% at 95% compaction with an increase in the ratios of calcium chloride. The increase in dry density can be explained by the improved bonding between particles and the reduction of air voids. This increase in dry density, in turn, positively influences the California Bearing Ratio by transforming soil structure from a dispersed state to a flocculated state. It can be inferred from the results that calcium chloride has the potential to function as a stabilizer for unpaved roads. The findings of this study are expected to reduced life cycle costs for unpaved roads, provide insights for the best approach to materials analysis for unpaved roads, and contribute to environmental benefits by minimizing dust emissions into the atmosphere and reducing the release of chemicals into nature.

Keywords: Calcium chloride, unpaved roads, engineering properties, dust suppressant, gravel, lignosulphonate, Uganda

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1. Introduction

Developing countries predominantly have unpaved road systems, as highlighted by Overby & Pinard (2008). These unpaved roads are typically constructed by grading and compacting the existing soil to create a roadbed, as noted by Gillies et al. (2005). In their study, Gillies et al. (1999) reported that the street network in Uganda, which is estimated to be 129,469 kilometre long, is primarily composed of unpaved roads, accounting for approximately 80% of the total network. The main reason behind this is the exorbitant expenses involved in developing these roads to rigid or flexible pavement. However, Unpaved roads have deteriorated significantly due to an increase in traffic resulting from economic developments in developing countries. Thus, effective strategies are needed to address this challenge (Overby & Pinard, 2008; Gillies et al., 1999; Gillies et al., 2005)

Automobiles movement on unpaved roads creates forces that displace fine particles from the road surface, resulting in the formation of defects such as corrugations and potholes (Ministry of Works and Transport, 2017; Nicholson et al., 1989). These fine soil particles are released into the atmosphere as dust. With increased automobiles on unpaved roads, there is a buildup of dust in the atmosphere due to the accumulation of these displaced particles (Ministry of Works and Transport, 2017).

According to Broken et al. (2005), The spread of dust into the air as a result of vehicles traveling on unpaved roadways have a substantial effects on health, maintenance costs, safety and the overall standard of living. However, the implementation of efficient dust control measures can reduce the aforementioned impacts, resulting in enhanced safety, improved health, superior quality of life, and reduced maintenance expense.

Several traditional techniques have been employed to manage dust on unpaved roads, such as installation of windbreakers such as roadside trees and vegetation to mitigate wind erosion, regular watering of road surfaces, periodic re-graveling and speed reduction measures like speed humps, (Edvardsson & Kungliga Tekniska Högskolan, 2010) However, recent research has unveiled alternative methods for managing dust on unpaved roads. According to Ken Skorseth and Ali A. Selim (2000), a technique for dust control is to utilize hygroscopic salts like calcium chloride and magnesium chloride. The moisture-attracting properties of these salts improve soil adhesion, leading to a reduction in dust. This method can be effective for up to a year without requiring reapplication of the salts (Thompson & Visser, 2007). Other methods include the use of organic polymers with binders, tackifiers, soil stabilizers, and resins (Chunhua, 1992), all aimed at mitigating dust emissions from unpaved roads.

In 1992, Kirchner and Gall carried out a study in which they assessed the efficiency of 3 dust control substances, namely organic polymer plus binder, calcium chloride and magnesium chloride, on 51 road test sections located in the southwest regions of Minnesota, northwest and east central, USA. The traffic flow on these roadways varied from twenty-five to seven hundred automobile per day, while the gravel materials employed remained largely constant throughout the test sections. The road surface was evenly sprayed with dust control materials using a tank truck. Dust were monitored and the research concluded that the use of these products effectively managed dust.

However, there is a dearth of comprehensive data regarding the influence of soil adhesives, this study has been conducted to analyze the influence of materials like calcium chloride on crucial engineering properties of gravel, such as its particle size distribution and bearing strength. The aim of this research is to assess how using calcium chloride as a soil adhesive affects the engineering characteristics of gravel, which is frequently utilized in unpaved roads found in developing nations. This study aims to fill the existing knowledge gap and offer valuable insights into the effects of calcium chloride on gravel properties within the specific context of unpaved roads in developing countries.

2. Literature Review

Calcium chloride possesses additional properties that enhance the performance and effectiveness of unpaved roads. Calcium chloride has higher surface tension, a stronger moisture film, lower freezing point and lower vapor pressure compared to plain water. These combined properties allow calcium chloride to keep unpaved surfaces consistently damp and effectively control tiny or fines dust particles from becoming airborne (Tiwari et al., 2020).

Numerous researchers have argued that expansive soils, which exhibit frequent volume variations with changes in moisture content, pose critical challenges for civil engineering structures such as pavements (Akinmusuru et al., 2016). Many trials are being conducted worldwide to monitor the swell-shrink behavior of expansive soils. Pavements constructed on these soils often show signs of continuous damage during their service life, resulting in increased maintenance costs.

The study examined various engineering properties such as unsoaked California bearing ratio, Atterberg limits, specific gravity, compaction, soaked, unconfined compressive strength, and natural water content. The research also investigated how these properties behaved when stabilized with different percentages of sodium chloride, ranging from 0 to 2.5. The study results indicated a decrease in the liquid limit, specific gravity, plasticity index, linear shrinkage, free swell index, plastic limit, and optimum water content values of the stabilized soil. On the other hand, an increase in the California bearing ratio, maximum dry density, and unconfined compressive strength values was observed. Ganesh et al. (2017) reported that treatment of the soil with various percentages of sodium chloride resulted in reductions in the values of linear shrinkage, plastic limit, plasticity index, free swell index, liquid limit, and optimal water content, with the highest reduction percentages achieved at 42.86 %, 60.42 %, 66.64 %, 83.43 %, 71.26 %, and 28.57 %, respectively. The maximum percentage increase in unsoaked CBR, soaked CBR, maximum dry density, and unconfined compressive strength were 31.78 %, 257.67 %, 11.38 %, and 26.98 %, respectively, with soil treatment using 1.5% sodium chloride by weight. As a result of sodium chloride treatment, soil strength was enhanced and swelling potential was reduced.

The distress caused by the shrinkage and swell cycles of expansive soils has posed a significant challenge for geotechnical engineers in adopting appropriate control measures. The characterization and selection of suitable foundations are crucial when dealing with problematic soils. Ongoing research is being conducted to investigate solutions for expansive soils, such as black cotton soils. Among the various approaches available, treating expansive soils with electrolytes has shown promise in improving their behavior. Experimental investigations were carried out in the laboratory, under controlled conditions, as part of this research, the properties of gravel commonly used on unpaved roads will be examined, with a specific focus on the impact of electrolytes, particularly calcium chloride. In 1997, Brown David Elton documented that a methodical process was conducted to examine the influence of various electrolytes, including calcium chloride, on the physical and engineering properties of expansive soil. The findings indicated that the addition of calcium chloride resulted in significant improvements, with the highest enhancement observed among all the electrolytes tested. This research sheds light on the potential of calcium chloride as a treatment for expansive soils in unpaved road construction.

In the past decade, numerous methods have been explored for stabilizing expansive subgrade soil. Chemical stabilization techniques have gained prominence due to their ease of adaptability and applicability. Calcium chloride, a widely available waste product, has been tested for its potential to alter the characteristics of expansive soil due to its cementing properties. However, According to Brown David Elton (1997), The experimental studies showed that there were no substantial changes in calcium chloride, the plasticity index of the gravel material and the mixture of gravel.

3. Methodology

3.1 Research Materials

In order to meet the research goals, the necessary materials were procured and examined, as outlined in the following sections. Gravel and calcium chloride were the main materials used in this study.

3.2 Gravel

Samples of gravel were obtained from the quarry and sent to the laboratory for testing purposes. These samples were cautiously stored in the laboratory for the duration of the testing period.

Sampling Procedure:

1. After identifying a suitable point in the borrow pit, the surface was thoroughly cleared.
2. The gravel was scooped out with a spade and digging was performed using a pickaxe.
3. The gravel samples were meticulously placed in sacks and adequately covered to prevent loss of moisture and any form of contamination.
4. Representative samples of the gravel were then transported to the laboratory for further testing.

3.3 Calcium Chloride

The calcium chloride (CaCl2) used in this research was a commercial product with 98% purity. In order to attain a weight concentration of 32%, water was used to dissolve anhydrous calcium chloride. Precisely, 32 grams of calcium chloride were completely dissolved in 100 milliliters of pure water.

The selection of dry or liquid calcium chloride was influenced by factors such as economic viability, availability of storage, mixing, and application equipment. According to Brown David Elton (1997), the preference was for liquid calcium chloride with a weight concentration of 32% over dry calcium chloride, primarily because of its capacity to uniformly distribute the chemical in the gravel. The gravel was mixed with different ratios of liquid calcium chloride, as shown in Table 1.

3.4 Mixing

The gravel specimens, which had been air-dried was blended with calcium chloride in the ratios specified in Table 1, In accordance with the 1976 maintenance manual instructions provided by the American Association of State Highway and Transportation Officials (AASHTO).

According to the guidelines provided by the American Association of State Highway and Transportation Officials (AASHTO) in their 1976 maintenance manual, it was determined that calcium chloride solutions with concentrations of 30%, 32%, and 38% are effective for dust control when the percentage of calcium chloride by weight is within the range of 2% to 3%. This information was used as the basis for determining the mix ratios in this study (AASHTO, 1976).

Table 1 - Differences in the mixtures of gravel and calcium chloride

Air-dried gravel by mass (%) Mass of air-dried gravel	Calcium Chloride			
	The volume of liquid calcium chloride with a weight concentration of 32%..			
	0.0 Ltrs	1 Ltrs	1.5 Ltrs	2.0 Ltrs
	Mass of calcium chloride with 32% concentration			
(50 kilogram)	0 kilogram	0.32 kilogram	0.48 kilogram	0.64 kilogram
	Percentage of calcium chloride by mass (%)			
	0	2.0	3.0	4.0
100				
98.0				
97.0				
96.0				

- Neat sample
- Mix ratio 1
- Mix ratio 2
- Mix ratio 3

3.5 Testing

Table 2 illustrate summary of the various tests performed to evaluate the strength and grading of the gravel.

Table 2 - Tests on gravel and gravel-calcium chloride mixtures

Tests	References	Materials
Moisture content determination	BS 1377: Part 2: 1990	Gravel
Particle size distribution (Wet sieving)	BS 1377: Part 2: 1990	Gravel, Gravel- calcium chloride mixtures
Determination of Atterberg limits (liquid limit, plastic limit, Plasticity Index)	BS 1377: Part 2: 1990	Gravel, Gravel- calcium chloride mixtures
Linear shrinkage	BS 1377: Part 2: 1990	Gravel, Gravel- calcium chloride mixtures
Dry Density- Moisture content relationship	BS 1377: Part 4: 1990	Gravel, Gravel- calcium chloride mixtures
California Bearing Ratio (Three-point Method)	BS 1377: Part 4: 1990	Gravel, Gravel- calcium chloride mixtures

4. Results and Discussion

4.1 Neat Gravel Sample Classification

The gravel material was categorized by analyzing the amount of fines that passed through the No. 200 sieve, as specified by the gradation curve of the initial sample. The engineering properties of the neat sample were evaluated and reported in Table 3

Table 3 - Neat gravel characteristics

Test	Test Reference	Result
Natural Moisture Content	BS 1377 Part 2:1990	6.42 %
Grading Modulus	BS 1377 Part 2:1990	2.12
% Passing 0.075mm	BS 1377 Part 2:1990	22 %
Liquid limit	BS 1377 Part 2:1990	38.70 %
Plastic limit	BS 1377 Part 2:1990	20.00 %
Plasticity Index	BS 1377 Part 2:1990	18.7 %

Linear Shrinkage	BS 1377 Part 2:1990	10.30 %
Shrinkage Product	BS 1377 Part 2:1990	290
MDD	BS 1377 Part 4:1990	2.15 Mg/m^3
OMC	BS 1377 Part 4:1990	9.20 %
CBR	BS 1377 Part 4:1990	25 %
Swell Index	BS 1377 Part 4:1990	0.0201 %

Table 3 presents the outcomes of testing several characteristics of the gravel sample, such as its liquid limit, CBR, linear shrinkage, MDD/OMC, plastic limit, plasticity index, and swell index. Table 4 presents a summary of the standards used to classify the sample according to plasticity index, particle Size Distribution and liquid limit.

Table 4 - AASHTO classification of the neat sample

% Passing Sieve No. 200	22 %
LL	38.7 %
PI	18.7 %
Group classification	A- 2-6
Group index (GI)	1

A road subgrade material should consist of gravel material that has a classification of A-2-6 and less than 35% of its particles passing through the 0.075mm aperture sieve, and the identified gravel material meets these criteria, thus making it suitable for use as a road subgrade material. With a group index of 1, the gravel material exhibits excellent performance characteristics, making it a suitable choice for road construction. A lower group index value indicates even better performance, with values ranging from 0 to 20. A desirable condition for subgrade in paved roadways and gravel wearing courses in unpaved roadways is to have a group index of zero.

The formula below represents the calculation for the GI

$$GI = 0.01(F - 15)(PI - 10) \quad (1)$$

Where;

F = percentage of neat gravel material passing sieve No. 0.075mm
PI = Plasticity Index

4.2 Distribution of Particle Size

The gravel samples, both neat and mixed with different ratios of calcium chloride, were graded to assess the effects of the added chemical. The results, including sieve size and other relevant information, are presented in Table 5, with additional findings illustrated in Figure 1.

Table 5 - Particle size distribution

Size of Sieve	Passing sieve			
	Neat sample%	Mix ratio 1%	Mix ratio 2%	Mix ratio 3%
63.0 mm	100	100	100	100
37.5 mm	100	100	100	100
20.0 mm	99	99	99	99
5.0 mm	62	51	59	65
2.00 mm	39	31	38	38
0.425 mm	28	24	28	27
0.075 mm	22	20	22	22

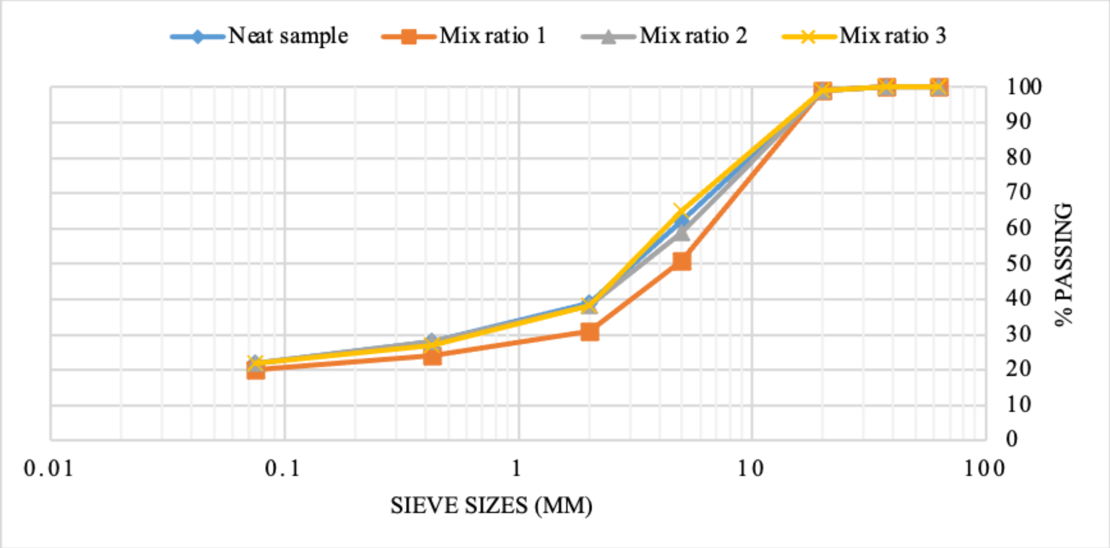

Fig. 1 - Grading curves of neat sample and gravel- calcium chloride mixtures

4.3 Atterberg Limits

The purpose of this experiment was to determine the liquid limits, plasticity index, linear shrinkage values, and plastic limits of the gravel, as well as the gravel-calcium chloride mixtures. The results are presented in Table 6, with additional information shown in Figure 2.

Table 6 - The neat gravel sample and gravel- calcium chloride mixtures Atterberg limits

Mix Ratios	Neat Sample	Mix Ratio 1	Mix Ratio 2	Mix Ratio 3
Liquid limit.	39 %	34 %	33.5%	33.8%
Plastic limit.	20.0%	15.2%	15.6%	15.4%
Plasticity Index.	18.7%	18.4%	17.9%	18.4%
Linear Shrinkage.	10.3%	10.2%	9.8%	10.1%
% Passing 0.425mm sieve.	28	24	28	27
Shrinkage Product, SP.	290	245.1	274	271.9

Plasticity index (bs 1377 part 2: 1990)

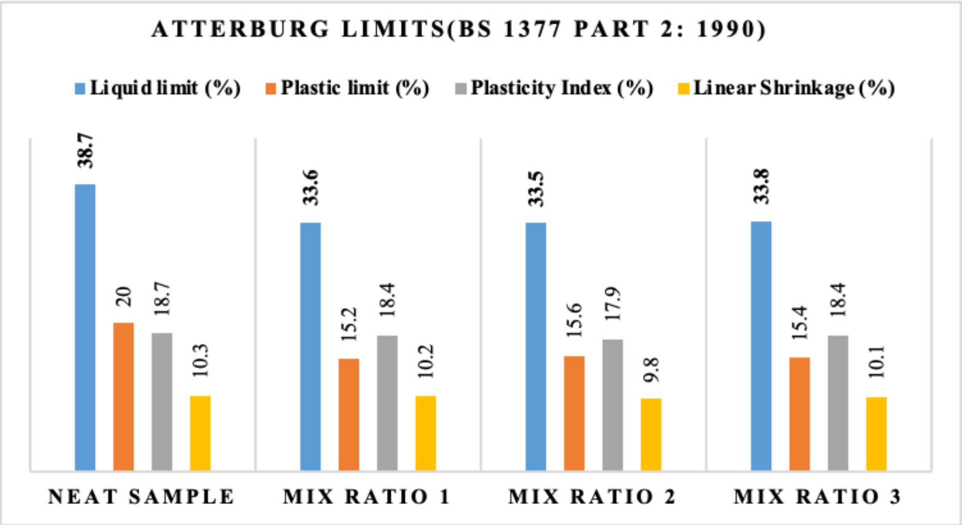

Fig. 2 - Variation of the Atterberg limits for gravel- calcium chloride mixtures and the neat sample

4.4 Dry Density- Moisture Content Relationship

The experimental findings presented above established a correlation between the moisture content and dry density for the original sample as well as various mixing ratios. This correlation is documented in Table 7 and Figure 3 below, based on the findings obtained from the conducted experiments.

Table 7 - The relationship between moisture content and dry density for the neat sample and various mix ratios

Neat Sample		Mix Ratio 1		Mix Ratio 2		Mix Ratio 3	
Moisture content (%)	Dry Density (Mg/m3)	Moisture Content (%)	Dry Density (Mg/m3)	Moisture Content (%)	Dry Density (Mg/m3)	Moisture Content (%)	Dry Density (Mg/m3)
6.7	2.092	4.8	1.992	4.2	2.053	4.2	2.015
8.1	2.132	5.5	2.132	5.7	2.159	5.2	2.120
10.3	2.137	6.2	2.252	6.3	2.268	6.3	2.333
11.0	2.122	7.3	2.310	6.9	2.329	7.2	2.312
11.8	2.098	7.9	2.276	7.9	2.287	8.3	2.304

Dry density- moisture content relationship (bs 1377 part 4: 1990)

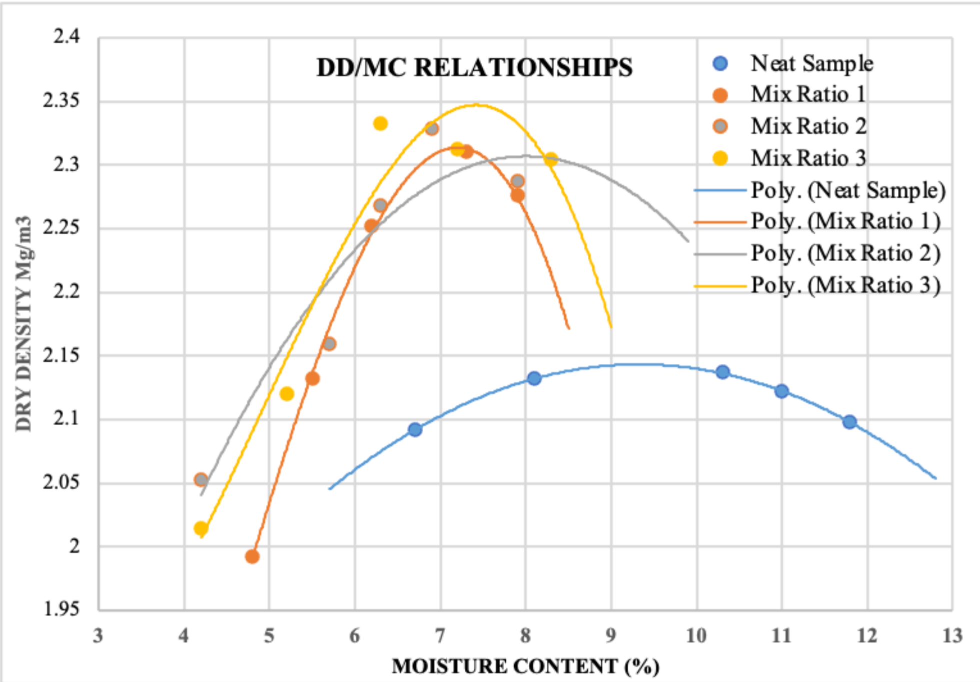

Fig. 3 - Variation of dry density and moisture content

Table 8 summarizes the maximum dry densities (MDD) and their corresponding optimum moisture contents (OMC) for both the original sample and various mixing ratios, as per the laboratory results presented above. The variation of MDD and OMC was further illustrated in Figure 4 through a graphical representation.

Table 8 - Relationship between dry density and moisture content

MIX RATIOS.	MDD (Mg/m3)	INCREASE IN MDD	OMC	% DECREASE IN OMC
Neat Sample.	2.15		9.2%	
Mix Ratio 1.	2.31	7.44%	7.6%	17.4
Mix Ratio 2.	2.34	8.84%	7.4%	19.6

Mix Ratio 3.	2.35	9.30**%**	7.2**%**	21.7

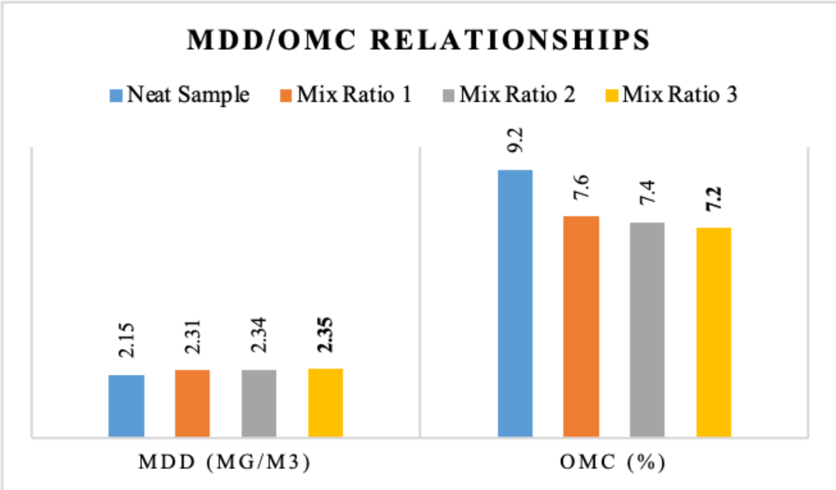

Fig. 4 - Variation of Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)

Figure 4 clearly shows that the optimum moisture content decreased slightly, with the neat gravel sample having an optimum moisture content of 9.2%, while the gravel-calcium chloride mixture exhibited a reduced optimum moisture content of 7.2% (a decrease of 21.7%). This decrease can be attributed to the hygroscopic nature of calcium chloride, which tends to absorb moisture from the environment. This absorption results in a lower optimum moisture content in the mixture. This information is also summarized in Table 8.

4.5 California Bearing Ratio (CBR)

Table 9 presents a summary of the CBR (California Bearing Ratio) values for BS (British Standard) heavy compaction at different percentages of MDD (Maximum Dry Density), including 93%, 95%, and 98%.

Table 9 - Gravel- calcium chloride mixtures and neat gravel sample CBR values

	CBR @ 93% COMPACTION.	**CBR @ 95% COMPACTION.**	**CBR @ 98% COMPACTION.**
NEAT SAMPLE.	22	25	33
MIX RATIO 1.	21	29	39
MIX RATIO 2.	25	32	41
MIX RATIO 3.	28	36	48

California bearing ratio (bs 1377 part 4: 1990)

Table 9 presents the CBR test results, which were graphically analyzed in Figure 5 to assess the fluctuations in CBR values at various percentages of compaction for the different mix ratios and neat sample.

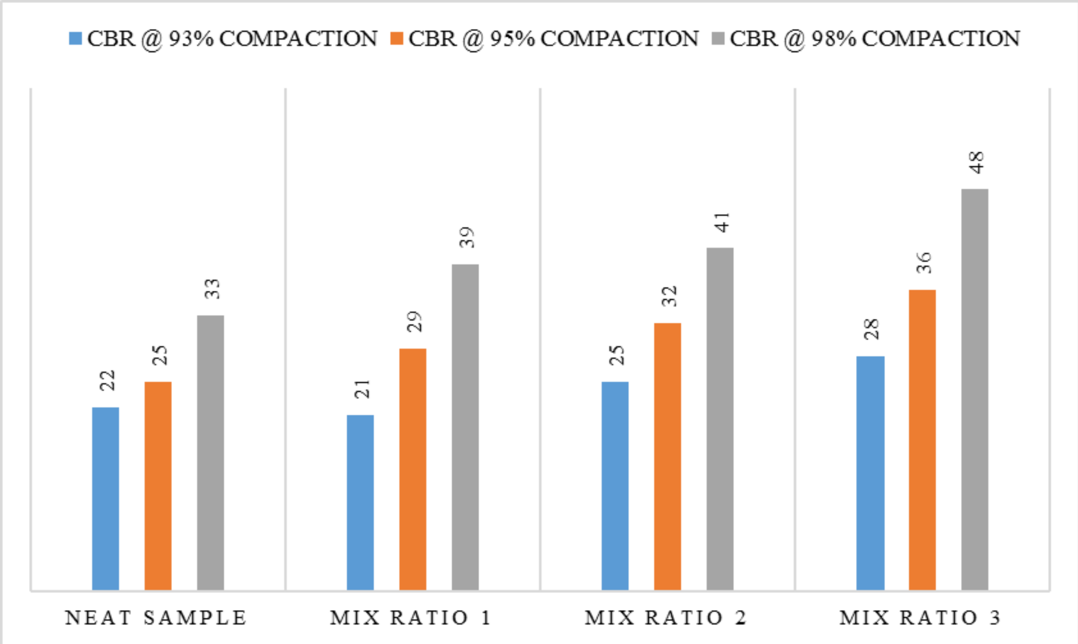

Fig. 5 - Variation in CBR for the different mix ratios and neat sample

As depicted in Figure 5, the CBR values showed a gradual increase with the addition of more calcium chloride to the gravel. Table 9 illustrates how this pattern was noted across various mixing ratios and different percentages of compaction.

5. Conclusions

Table 4 presents the classification of the material through the utilization of the AASHTO soil classification system, which resulted in an A-2-6 group classification with a group index of 1. Furthermore, a CBR value of 25% with the gravel material is suitable for multiple uses, including improving subgrade, the gravel material is utilized in both road construction as asphalt binder course, wearing course and sub-base for unpaved roadways. The criteria mentioned comply with the standard guidelines for constructing roads and bridges that are outlined in the MoWT manual series 3000.

In line with the laboratory experimental results recorded, it can be noted that the addition of calcium chloride resulted in a significant increase in the MDD of the gravel material. Specifically, the maximum dry density increased from 2.15 Mg/m3 to 2.35 Mg/m^3. Additional calcium chloride added gradually increased the MDD. As a result, the CBR of the material improved due to the increase in dry density caused by the addition of calcium chloride from 2.15 Mg/m3 to 2.35 Mg/m3, and further additions led to a gradual increase in MDD. This increase in dry density resulted in a remarkable improvement in the California Bearing Ratio of the same material. The noteworthy increase in the CBR value, which saw a rise from 25% to 36% (representing a 44% increase), serves as clear evidence that the incorporation of calcium chloride can serve as a potent chemical stabilizer for different types of road construction materials. By doing so, this stabilizer has the ability to improve the quality of gravel wearing courses utilized for unpaved roadways and enhance the subbase and subgrade materials used for paved roadways. These findings underscore the potential of calcium chloride in enhancing the performance and strength of road construction materials.

After examining the laboratory tests, it was found that the wet sieving method did not significantly alter the particle size distribution. However, it was evident that the particles exhibited physical bonding, resulting in a reduction in the fines content and an elevation in the dry density. By utilizing wet sieving, the bonded and flocculated material were successfully separated and dispersed during the washing process. Furthermore, there was a consistent stability observed in the plasticity index of both the gravel material and the gravel-calcium chloride mixture.

The addition of calcium chloride enhances the bonding of fine particles, resulting in increased density and improved bearing capacity. The utilization of calcium chloride can be deemed as a viable technique for chemically stabilizing various road materials, especially for unpaved road gravel wearing courses, and to improve the subgrade and subbase materials of paved roads. However, to gain a comprehensive understanding of the influence of calcium chloride, it is necessary to evaluate other significant characteristics, such as mineral composition, surface texture, and porosity.

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