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Effects of Limestone Dust on Geotechnical Properties of an Expansive Soil

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Abstract
Effects of limestone dust (LSD) on Atterberg's limits, compaction properties, unconfined compressive strength(UCS), soaked California bearing ratio(CBR), shear strength parameters, hydraulic conductivity and swelling pressure of an expansive soil have been discussed in this paper. LSD has been added to an expansive soil up to 12% at an increment of 3%. Analysis of test results reveals that there was a continuous decrease in liquid limit, plasticity index, maximum dry density, hydraulic conductivity, swelling pressure and continuous increase in plastic limit, shrinkage limit, and optimum moisture content up to 12% addition of LSD. The UCS, soaked CBR, cohesion and angle of internal friction however had maximum values when the percentage addition of LSD was 9%. The optimum percentage of LSD for stabilization of expansive soil was found to be 9%. At the optimum percentage addition of LSD, substantial improvements in geotechnical properties of the expansive soil were found out.

Keywords: Effects, Limestone Dust, Expansive Soil, Soaked California bearing ratio, Swelling Pressure.

Introduction

In arid and semi-arid regions of the world expansive soils are mostly found. Around 20% of total area of India is covered by this type of soil. Serious damages occur to lightly loaded structures founded on this type of soil because of its cyclic swell-shrink behaviour. Some prominent construction techniques normally adopted by civil engineers while dealing with construction in expansive soil are i) adoption of under reamed pile foundation ii) placement of, sand cushion/ cohesive non swelling soil (CNS) cushion/ stabilized solid waste cushion iii) construction of granular pile anchor iv) provision of moisture barrier v) stabilization using lime/cement/ chemicals and/or solid wastes etc. Expansive soil has been successfully stabilized using different types of mineral solid wastes. Some of them are, quarry dust [1],[2],marble dust[3]-[5],baryte powder[6], pyroclastic dust [7], granite dust[8],[9],mine tailings[10].

Limestone dust (LSD) is the dust produced during the processing of limestone, mostly consists of $CaCO_3$ in its chemical composition. Approximately 20% of LSD wastes are produced by the processing of limestone [11]. In paper [12] the author had stabilized expansive soil by adding crushed limestone dust from 2 to 10% at an increment of 2%.Reduction in plasticity index and significant decrease in expansion were found out.

From the review of literature it is found that the study, regarding the effects of limestone dust on geotechnical properties of expansive soil is limited.

The objective of the present investigation is to study the effects of LSD on Atterberg's Limits, Optimum Moisture Content(OMC), Maximum Dry Density(MDD), Unconfined Compressive Strength(UCS), soaked California Bearing Ratio (CBR),Cohesion, Angle of Internal Friction, Hydraulic conductivity and Swelling Pressure of an expansive soil.

Materials and Methods

Material

The materials used in the experiment are mainly, Expansive soil and LSD.

Expansive Soil

The expansive soil used in the experimental programme was brought from a place 250 km away from Bhubaneswar. The geotechnical properties of the expansive soil are given in Table1.

TABLE 1.Geotechnical Properties of Expansive soil

Properties	Values
1)Grain Size Analysis	
Sand size(%)	12
Silt size(%)	24
Clay size(%)	64
2) Atterberg's Limit	
Liquid Limit(%)	60
Plastic Limit (%)	31
Shrinkage Limit (%)	11
3)Compaction Properties	
OMC (%)	22
MDD (kN/m^3)	16.2
4) UCS (kN/m^2)	86
5) Soaked CBR(%)	1.62
Swelling Pressure (kN/m^2)	132

Lime Stone Dust (LSD)

LSD (having CaO=5.4% and $CaCO_3$ =82.51%) used in the experimental programme was purchased from the local market, it was crushed into powder form, those passing 425µ IS sieve were used in the experimental programme.

Testing Procedure

Different specimens of expansive soil-LSD were made by addition of LSD from 0 to 12% at an increment of 3% by dry weight of soil. Liquid Limit, Plastic Limit, Shrinkage Limit Standard Proctor Compaction, UCS, soaked CBR, Triaxial Compression, Hydraulic Conductivity, and Swelling Pressure tests were conducted according to the relevant IS Codes. UCS, Triaxial Compression, Hydraulic Conductivity and Swelling Pressure tests were conducted after 7 days of curing, and soaked CBR tests were conducted after 7 days of curing and 4 days of soaking under a surcharge of 5Kg.

Analysis of Test Results and Discussion

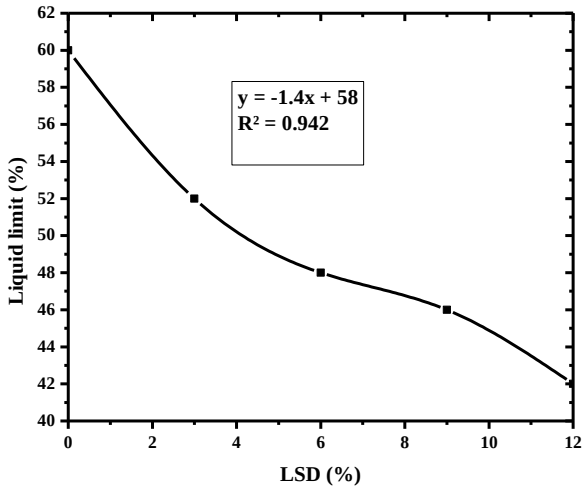

Fig.1(a) Variation of Liquid Limit of Expansive Soil with LSD(%)

Variation of Liquid Limit of the expansive soil with LSD(%) has been shown in Fig.1(a).With increase in LSD percentage the Liquid Limit goes on decreasing. The Liquid Limit decreased to 42% from 60% when the LSD increased to 12%. A linear Regression model has been developed to predict the liquid limit of expansive soil stabilized with different percentages of LSD. The model is,

$Y=-1.4X+58$, R^2 =0.942,R=0.97

Where,
Y= Liquid Limit (%) of the stabilized soil
X= LSD (%)
R= Coefficient of Correlation and R^2= Coefficient of

Variation of Plastic Limit of the expansive soil with LSD(%) has been shown Fig.1(b) The Plastic Limit goes on increasing with increase in percentage of LSD. The Plastic Limit increased to 36% from 31% when the LSD increased to 12%. A Regression model has been developed to predict the Plastic Limit of the expansive soil stabilized with different percentages of LSD. The model is

$Y=-0.001X^4+0.034X^3-0.379X^2+1.861X+31$, R^2 =1, R=1

Where,
Y= Plastic Limit (%) of the stabilized soil
X= LSD (%)

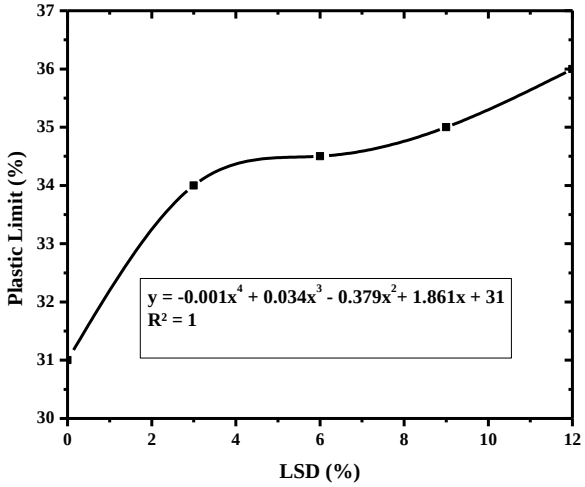

Fig.1(b) Variation of Plastic Limit of Expansive Soil with LSD(%)

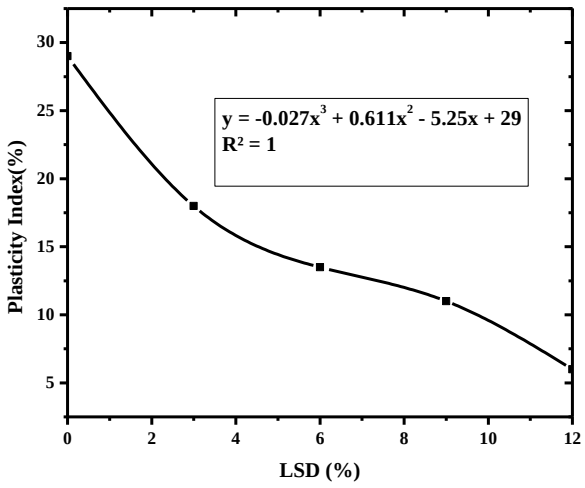

Fig.1(c) Variation of Plasticity Index of Expansive Soil with LSD (%)

Variation of Plasticity Index of the expansive soil with LSD (%) has been shown Fig. 1(c). The Plasticity Index goes on decreasing with increase in percentage of LSD. The Plasticity Index decreased to 6% from 29 % when the LSD increased to 12%.

A model has been developed to predict the Plasticity Index of the expansive soil stabilized with different percentages of LSD. The model is,

$Y=-0.027X^3+0.611X^2 - 5.25X +29$, $R^2=1$, R=1

Where,
Y= Plasticity Index (%) of the stabilized soil
X= LSD (%)

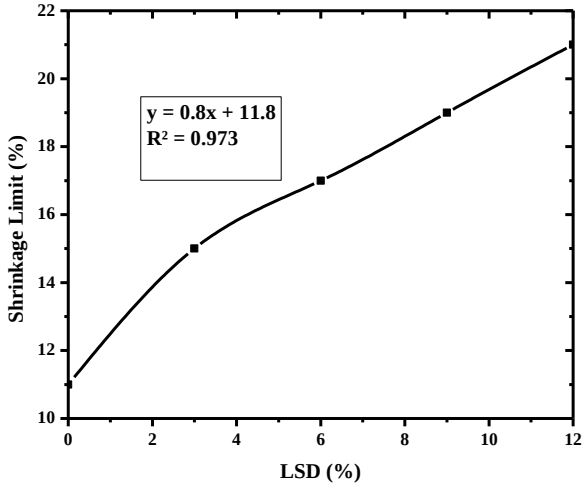

Fig.1(d) Variation of Shrinkage Limit of Expansive Soil with LSD(%)

The variation of Shrinkage Limit of expansive soil with LSD(%) has been shown Fig. 1(d). With increase in LSD percentage the Shrinkage Limit of soil goes on increasing. The Shrinkage limit increased to 21% from 11% when the LSD increased to 12%.
A linear regression model has been developed to predict the Shrinkage Limit of the expansive soil stabilized with different percentages of LSD. The model is,

$Y=-0.8X+11.8$, $R^2=0.973$, R=0.986
Where,
Y= Shrinkage Limit (%) of the stabilized soil
X= LSD (%)

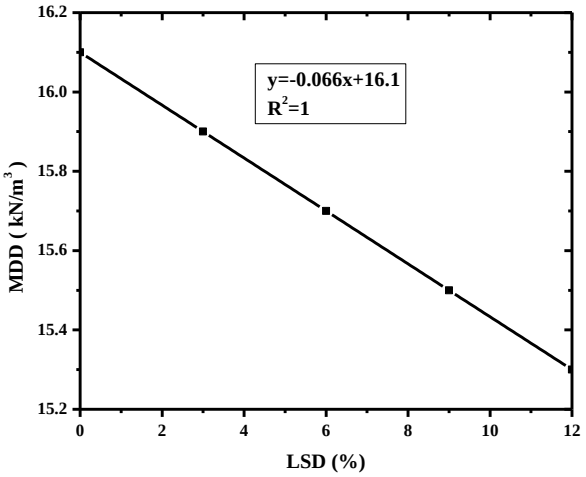

Fig.2. Variation of MDD of Expansive Soil with LSD(%)

Variation of MDD of the expansive soil with LSD (%) has been shown in Fig.2. The MDD of soil goes on decreasing with increase in percentage of LSD. The MDD decreased to 15.3
kN /m^3 from 16.1 kN /m^3 when the LSD increased to 12%.
A linear regression model has been developed to predict the MDD of the expansive soil stabilized with different percentages of LSD. The model is,

$Y=-0.066X+16.1$, $R^2=1$, R=1

Where,
Y= MDD (kN /m^3) of the stabilized soil
X= LSD (%)

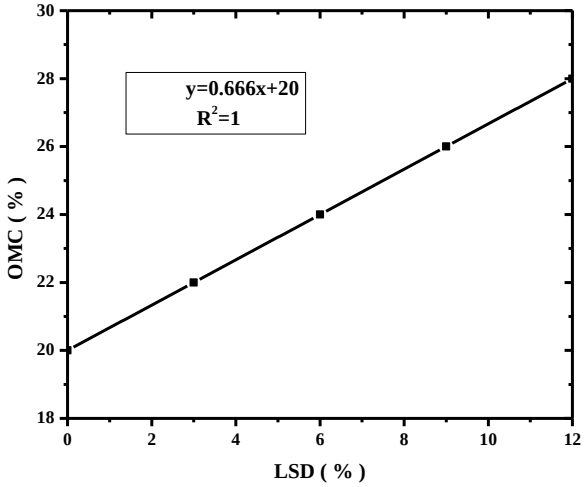

Fig. 3. Variation of OMC of Expansive Soil with LSD(%)

Variation of OMC of the expansive soil with LSD(%) has been shown in Fig.3.With increase in LSD percentage the OMC of soil goes on increasing. The OMC increased to 28% from 20% when the LSD increased to 12%.

A linear regression model has been developed to predict the OMC of the expansive soil stabilized with different percentages of LSD. The model is,

$Y=0.666X+20$, $R^2=1$, $R=1$

Where,
Y= OMC (%) of the stabilized soil
X= LSD (%)

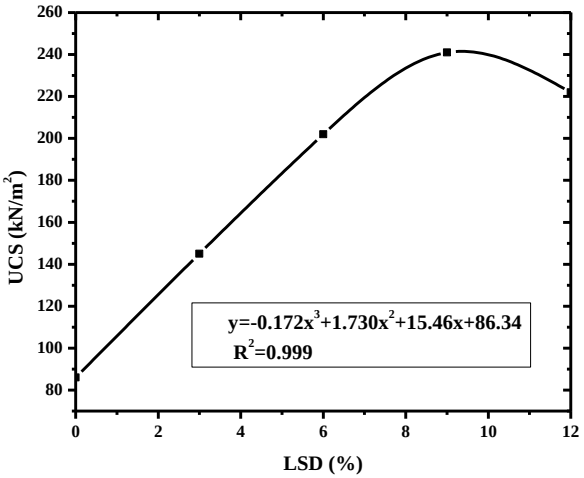

Fig.4. Variation of UCS of Expansive Soil with LSD(%)

The variation of UCS of the expansive soil with LSD(%) has been shown in Fig.4.With increase in percentage addition of LSD, the UCS of soil goes on increasing. The UCS increased to 241 kN/m^2 from 86 kN/m^2 when the percentage addition of LSD is 9% thereafter it decreased. The maximum increase in UCS is 180% as compared to the UCS of virgin expansive soil when the percentage addition of LSD is 9%.
A Regression model has been developed to predict the UCS of the expansive soil stabilized with different percentage of LSD. The model is,
$Y=-0.172X^3+1.730X^2+15.46X+86.34$,
$R^2=0.999$ and $R=0.999$

Where,
Y=UCS **(**kN /m^2) of the stabilized soil
X=LSD (%)

Variation of soaked CBR of the expansive soil with LSD (%) has been shown in Fig.5.With increase in percentage addition of LSD the soaked CBR of soil goes on increasing. The soaked CBR increased to 5.23% from 1.62 % when the percentage addition of LSD is 9%, thereafter it decreased. The maximum increase in percentage of soaked CBR is 222% as compared to the soaked CBR of virgin expansive soil when the percentage addition of LSD is 9 %.
A Regression model has been developed to predict the soaked CBR of the expansive soil stabilized with different percentage of LSD. The model is,

$Y=-0.003X^3+0.033X^2+0.390X+1.644$

$R^2=0.995$ and $R=0.997$

Where,
Y= soaked CBR(%) of the stabilized soil
X= LSD (%)

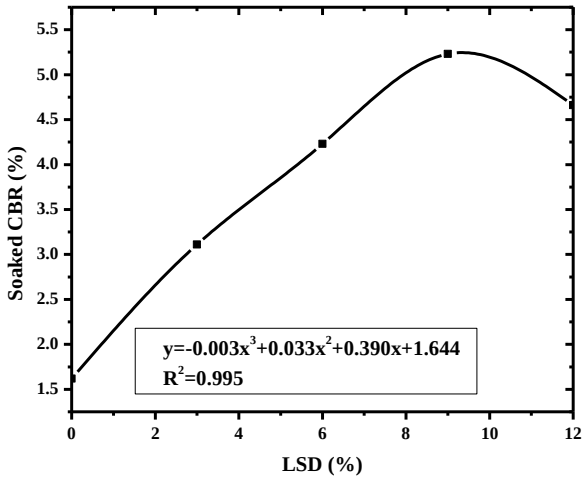

Fig.5. Variation of Soaked CBR of Expansive Soil with LSD(%)

The variation of Cohesion of the expansive soil with LSD(%) has been shown in Fig.6.With increase in percentage addition of LSD, the Cohesion of soil goes on increasing. The Cohesion increased to 25 kN/m^2 from 18 kN/m^2 when the percentage addition of LSD is 9% thereafter it decreased. The maximum increase in Cohesion is 38.8 % as compared to the Cohesion of virgin expansive soil when the percentage addition of LSD is 9%.
A Regression model has been developed to predict the Cohesion of the expansive soil stabilized with different percentage of LSD. The model is,
$Y= -0.003X^4+ 0.071X^3 - 0.412X^2+ 1.361X + 18$

$R^2=1$ and $R=1$

Where,
Y= Cohesion (kN /m^2) of the stabilized soil
X=LSD(%)

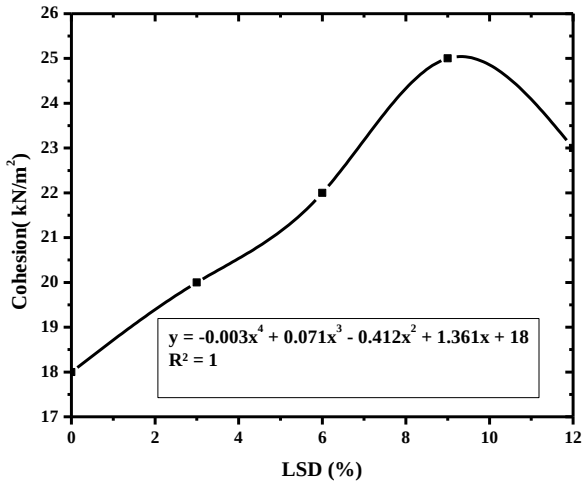

Fig.6. Variation of Cohesion of Expansive Soil with LSD(%)

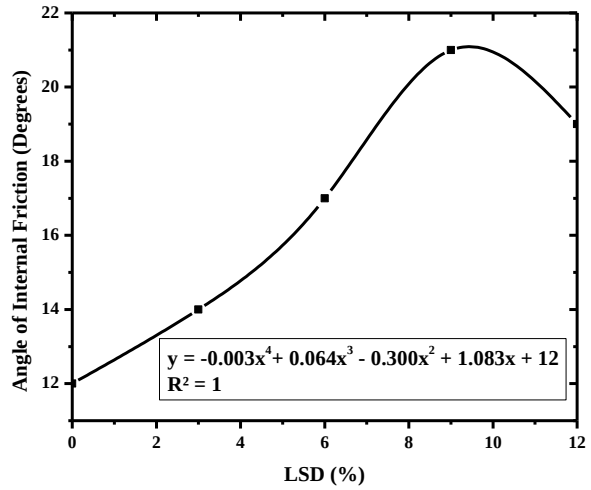

Fig.7. Variation of Angle of Internal Friction of Expansive Soil with LSD(%)

Fig.7 shows the variation of Angle of Internal Friction of the expansive soil with LSD (%).With increase in percentage addition of LSD, the Angle of Internal Friction of soil goes on increasing. The Angle of Internal Friction increased to 21º from 12º when the percentage addition of LSD is 9% thereafter it decreased. The maximum increase in Angle of Internal Friction is 75% as compared to the Angle of Internal Friction of virgin expansive soil when the percentage addition of LSD is 9%.

A Regression model has been developed to predict the Angle of Internal Friction of the expansive soil stabilized with different percentage of LSD. The model is,

$Y= -0.003X^4 + 0.064X^3 - 0.300X^2 + 1.083X + 12$

$R^2=1$ and R=1

Where,

Y= Angle of Internal Friction (Degree) of the stabilized soil

X=LSD(%)

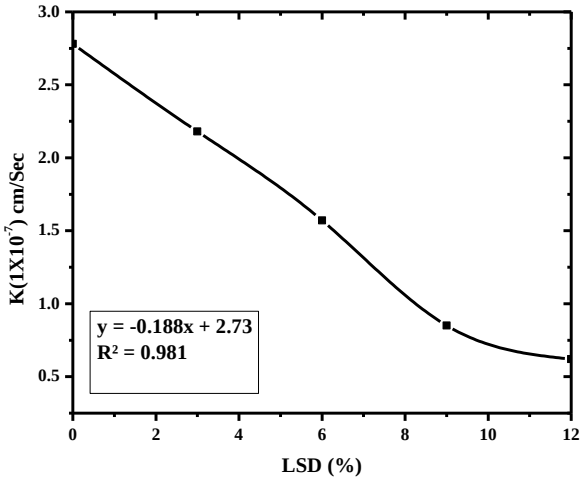

Fig.8. Variation of Hydraulic Conductivity of Expansive Soil with LSD(%)

The variation of Hydraulic Conductivity of the expansive soil with LSD(%) has been shown in Fig.8.With increase in percentage addition of LSD the Hydraulic Conductivity of soil goes on decreasing. The Hydraulic Conductivity decreased to $0.62x\ 10^{-7}$ cm/sec. from $2.78x\ 10^{-7}$ cm/sec. when the percentage of addition of LSD is 12%. There is 77.7% decrease in Hydraulic Conductivity as compared to virgin expansive soil.

A Regression model has been developed to predict the Hydraulic Conductivity of the expansive soil stabilized with different percentage of LSD. The model is,

Y= -0.188X+2.73

R^2=0.981 and R=0.99

Where,

Y= Hydraulic Conductivity (cm/sec.) of the stabilized soil

X= LSD(%)

The variation of Swelling Pressure of the expansive soil with LSD(%) has been shown in Fig.9. With increase in percentage addition of LSD the swelling pressure of soil goes on decreasing. The Swelling pressure decreased to 12 kN /m^2 from 132 kN/m^2 when the percentage of addition of LSD is 12%. There is 90.91% decrease in Swelling Pressure as compared to the Swelling Pressure of virgin expansive soil.

A Regression model has been developed to predict the Swelling Pressure of the expansive soil stabilized with different percentage of LSD. The model is,

Y= -10.53X+130.8

R^2=0.983 and R=0.991

Where,

Y= Swelling Pressure (kN /m^2) of the stabilized soil

X= LSD (%)

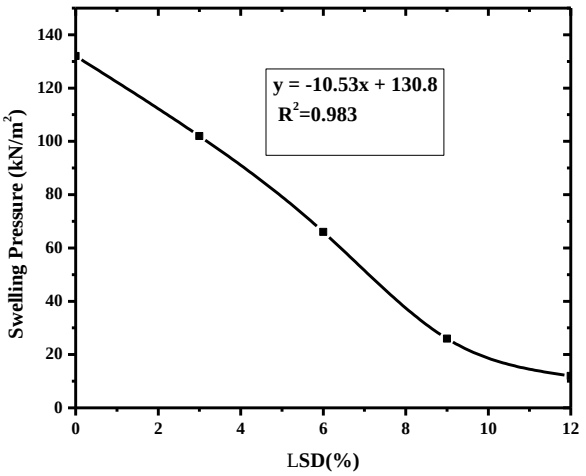

Fig.9. Variation of Swelling Pressure of Expansive Soil with LSD (%)

Conclusion

The following conclusions are drawn from this study.

- The Liquid Limit goes on decreasing, the Plastic Limit and Shrinkage Limit go on increasing, Plasticity Index goes on decreasing with increase in percentage addition of LSD .The Liquid Limit decreased to 42 %, the Plastic Limit increased to 36%, Plasticity Index decreased to 6% and Shrinkage Limit increased to 21% from 60 %, 31 %, 29% and 11% respectively when the percentage addition of LSD is 12%.
- The MDD of soil goes on decreasing with increase in percentage addition of LSD. The MDD decreased to 15.3 kN/m^3 from 16.1 kN/m^3 when the percentage addition of LSD is 12%.
- The OMC of soil goes on increasing with increase in percentage addition of LSD. The OMC increased to 28% from 20% when the percentage addition of LSD is 12%.
- The UCS of soil goes on increasing with increase in percentage addition of LSD. The UCS increased to 241 kN/m^2 from 86 kN/m^2 when the percentage addition of LSD is 9% thereafter it decreased. The maximum increase in UCS is 180% as compared to the UCS of virgin expansive soil when the percentage addition of LSD is 9%.
- The soaked CBR of soil goes on increasing with increase in percentage addition of LSD. The soaked CBR increased to 5.23% from 1.62%when the percentage addition of LSD is 9% thereafter it decreased. The maximum increase in percentage of soaked CBR is 222 % as compared to the soaked CBR of virgin expansive soil when the percentage addition of LSD is 9 %.
- The Cohesion of soil goes on increasing with increase in percentage addition of LSD. The Cohesion increased to 25 kN/m^2 from 18 kN/m^2 when the percentage addition of LSD is 9% thereafter it decreased. The maximum increase in Cohesion is 38.8% as compared to the Cohesion of virgin expansive soil when the percentage addition of LSD is 9 %.
- The Angle of Internal Friction of soil goes on increasing with increase in percentage addition of LSD. The Angle of Internal Friction increased to 21º from 12º when the percentage addition of LSD is 9% thereafter it decreased. The maximum increase in Angle of Internal Friction is 75% as compared to the Angle of Internal Friction of virgin expansive soil when the percentage addition of LSD is 9%.
- The Hydraulic Conductivity of soil goes on decreasing with increase in percentage addition of LSD. The Hydraulic Conductivity decreased to 0.62x 10^{-7} cm/sec. from 2.78x 10^{-7} cm/sec. when the percentage of addition of LSD is 12%. There is 77.7% decrease in Hydraulic Conductivity as compared to the Hydraulic Conductivity of virgin expansive soil
- The Swelling Pressure of soil goes on decreasing with increase in percentage addition of LSD. The Swelling Pressure decreased to 12 kN/m^2 from 132 kN/m^2 when the percentage of addition of LSD is 12%. There is 90.91% decrease in Swelling Pressure as compared to the Swelling Pressure of virgin expansive soil
- The optimum percentage of LSD for stabilization of expansive soil is found to be 9%.
- The models developed to predict Atterberg's Limits, Compaction properties, UCS, Soaked CBR, Shear Strength Parameters, Hydraulic Conductivity and Swelling Pressure of LSD stabilized expansive soil is found to be very accurate judged based on coefficient of correlation.

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