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Reliability Estimation of Strength Properties in Black Cotton Soils Stabilized with Glass Powder

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ABSTRACT:In this paper, laboratory results for compacted Black Cotton Soil partially replaced with glass powder were used to obtain reliability estimation of characteristic strength. Data obtained from Unconfined Compressive Strength and California Bearing Ratio results together with preliminary test were used to produce a predictive model. The reliability index values were obtained using a First Order Reliability Method (FORM) via a FORTRAN program. All variable factors such as liquid limit, optimum moisture content, glass powder, maximum dry density, produced safety indices less than 1 at Coefficient of Variation (COV) ranging from 0 -100 per cent. The result of the correlation shows that only glass powder shows a strong correlation with the Unconfined Compressive Strength with correlation coefficient value of 79% while the California Bearing Ratio shows a strong negative correlation with the maximum dry density with correlation coefficient value of -79%. The result of the reliability index shows for Unconfined Compressive Strength as the Coefficient of Variation increases safety index increases while for California Bearing Ratio, safety index decreases with increase in Coefficient of Variation.

KEYWORDS: Reliability analysis, Black cotton soil, Glass powder, California Bearing Ratio, Unconfined Compressive Stress.

I. INTRODUCTION

Reliability estimation carried out on a given soil sample ensures that the probability of the soil sample will perform its specified mission satisfactorily for the specified time when used according to the specified condition (Hamiduet *al.*, (2015); Sani *et al.*, (2017)).

The First Order Reliability Method (FORM) is one the prominent methods used in determining the reliability evaluations in structural and geotechnical reliability theories. The use of FORM method is widely utilized in engineering programming (for code calibrations) and in practice. This enable engineers to reduce the uncertainties associated with the design and construction of geotechnical structures. A good reliability study increases safety and cost of carrying out projects associated with the soil.

This paper focuses on the determining the best condition in which Black Cotton Soil (BCD) stabilized with glass powder will meet up to the energy level of British Standard Light (BSL).

II. RELATED WORK

Waste glass has been used as stabilizer for black cotton soils or as partial replacements for engineering materials such as concrete cubes as seen in concrete tiles as seen in Ayeni P, Babatunde O.A and Dahunsi B.O (2019). Subash et al (2016) went further to stabilize black cotton soil with glass and plastic granules. The need employ reliability to these results obtained becomes important, as they provide a safe working design and construction criteria when working with glass as a stabilizer or as a partial replacement product in the field or while coding design software packages as required.

The reliability theory can be applied to cater for uncertainties in engineering designs. Also, the theory can be used to predict the effects of alterations these conditions can cause on its performance. This view is in line with researchers like Yisa and Sani (2014), Sani *et al.*, (2014), Yohannaet *al.*, (2019), Sani *et al.*, (2018).

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The swelling and shrinking characteristics of black cotton soil makes it known as an expansive soil. They are majorly sited in Northern Nigeria (Ola, 1983), however, India is home to the largest deposit of black cotton soil globally. According Ingles and Metcalf (1972) gave requirement of 687 – 1373 kN/m² for sub base materials. This is a heavy clay soil, varying from clay to loam with clay contents of 40 to 50% (Mishra, 2013).

III. METHODOLOGY AND MATERIALS

The soil used in this study is dark grey in Colour and is known as black cotton soil, it was obtained along Gombe—Biu road in YamatuDeba local government Area of Gombe state using the method of disturbed sampling. The location lies along (latitude 10degrees 19’N and longitude 11degrees 30’E).

Reliability Analysis: The various parameters that are associated with strength were measured while carrying out the experiments in the laboratory. These measured parameters include Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), glass powder, Maximum Dry Density (MDD), Liquid Limit (LL), Optimum Moisture Content (OMC). According to Eberemu (2008), Stephen (2010) and Nwaiwuet *al.*, (2009), the MDD, Strength, and water content are normally assumed to have a lognormal distribution, while glass powder will have a normal distribution. Thus, a regression model for predicting laboratory UCS and CBR results was produced.

The regression equations for both UCS and CBR are given in equations 1 and 2 respectively. Microsoft Excel 2016 was used as the tool for carrying out the required statistical analysis.

$$UCS = 1702.03 - 0.51GLASS + 491.69MDD - 5.22OMC - 28.92LL \dots eqn1$$

$$CBR = 96.23 - 0.19GLASS - 20.48MDD - 0.58OMC - 0.65LL \dots eqn2$$

In order to generate a field based predictive model for UCS, the essential statistical properties for BCS partially replaced with glass powder were incorporated into FORM 5, a FORTRAN programmer used to predict and evaluate the reliability levels of UCS. Table 1 shows the data used for the reliability analysis for Unconfined Compressive Strength.

Table 1: Unconfined Compressive Strength data used for FORM5 reliability analysis

S/N	Variables	Distribution Type	Mean E(x)	Standard Deviation S(x)	Coefficient of Variation COV (%)
1	Unconfined compressive strength	Lognormal	1.108E2	3.885E1	35.06
2	Glass Powder	Normal	4E0	3.16E0	79.00
3	Optimum Water Content	Lognormal	1.996E1	1.494E0	3.27
4	Maximum Dry Density	Lognormal	1.532E0	4.604E-2	7.52
5	Liquid Limit	Normal	7.74E1	1.129E0	16.48

Furthermore, to generate a field based predictive model for CBR, the essential statistical properties for BCS partially replaced with glass powder were also incorporated into FORM 5, which was used to predict and evaluate the reliability levels of CBR. Table 2 shows the data used for the reliability analysis for California Bearing Ratio.

Table 2: California Bearing Ratio data used for FORM5 reliability analysis

S/N	Variables	Distribution Type	Mean E(x)	Standard Deviation S(x)	Coefficient of Variation COV (%)
1	California Bearing Ratio	Lognormal	1.96E0	1.141E0	58.16
2	Glass Powder	Normal	4E0	3.16E0	79.00
3	Optimum Water Content	Lognormal	1.996E1	1.494E0	3.27
4	Maximum Dry Density	Lognormal	1.532E0	4.604E-2	7.52
5	Liquid Limit	Normal	7.74E1	1.129E0	16.48

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IV. RESULTS AND DISCUSSION

Degree of Correlation on Glass Powder: The result produced a very strong correlation indicated that glass powder had a significant influence on the unconfined compressive strength of the stabilized black cotton soil. Fig. 1 shows a strong correlation value of 79% percent which is gotten by finding the square root of coefficient of determination R^2 shown in the graph. Therefore, positive relationship exists between the glass powder and the UCS values, while weak relationship exists between the glass powder and the CBR values. Fig. 2 shows a correlation value of 6.93%, this indicates a weak positive relationship exist. The trend line equations for both UCS and CBR graphs is in conformation with this view.

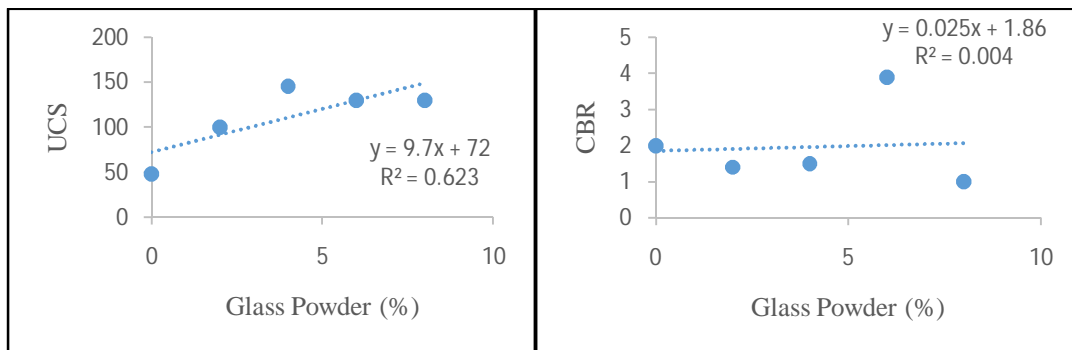


Fig. 1: Correlation of Glass powder on Unconfined Compressive Strength

Fig. 2: Correlation of Glass powder on California Bearing Ratio

Degree of Correlation on Liquid Limit: Fig. 3 shows that a strong negative relationship exist between the liquid limit and UCS values. A correlation value of -0.74 was calculated for the influence of liquid limit on UCS values. However, Fig. 4 indicates a moderate negative relationship exists between the liquid limit and the CBR value of the glass stabilized black cotton soil. A correlation value of -0.578 was obtained.

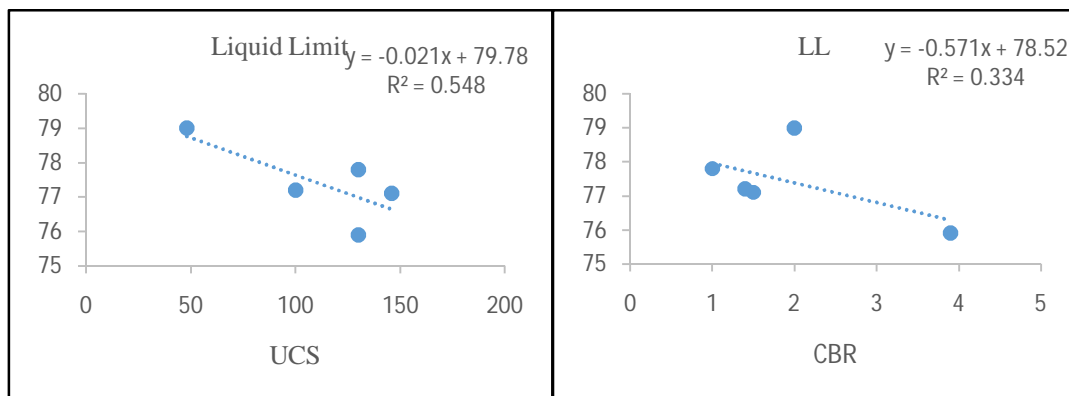


Fig. 3: Correlation of liquid limit on Unconfined Compressive Strength

Fig. 4: Correlation of liquid limit on California Bearing Ratio

Degree of Correlation on Maximum Dry Density: Fig. 5 shows a moderate positive correlation ($R = 52\%$) existing between the maximum dry density and the UCS values, while in terms of the CBR values, a strong negative correlation ($R = -79\%$) exists between the maximum dry density and CBR values of the stabilized black cotton soil, as illustrated in Fig. 6

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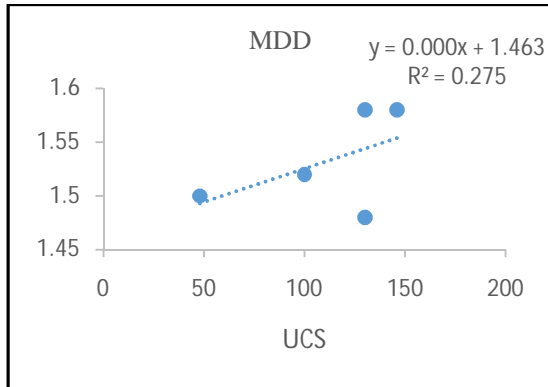


Fig. 5: Correlation of Maximum Dry Density on Unconfined Compressive Strength

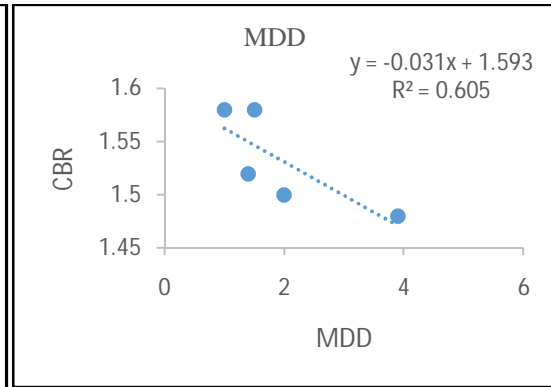


Fig. 6: Correlation of Maximum Dry Density on California Bearing Ratio

Degree of Correlation on Optimum Moisture Content: Fig. 7 shows that a moderately negative relationship exist between the optimum moisture content and the UCS values. A correlation value of -0.52 was calculated for the influence of optimum moisture content on USC values. However, Fig. 8 indicates no relationship exist between the optimum moisture content and the CBR value of the glass stabilized black cotton soil. A correlation value of -0.03 was record.

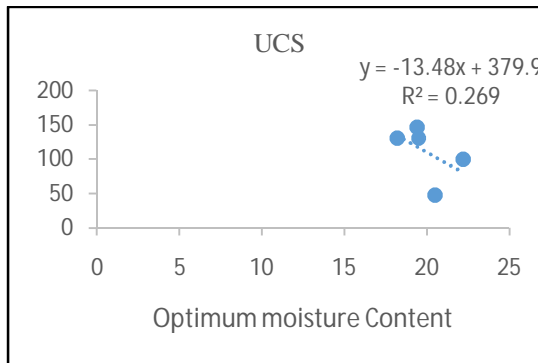


Fig. 9: Correlation of Optimum moisture content on Unconfined Compressive Strength

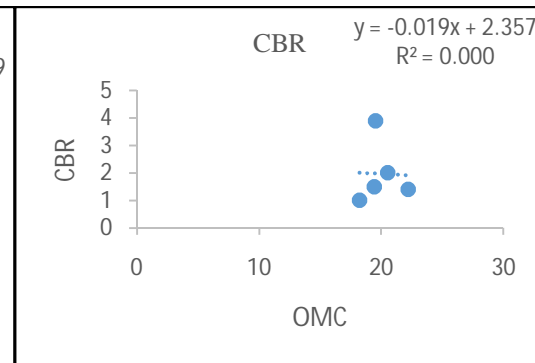


Fig. 10: Correlation of optimum moisture content on California Bearing Ratio

Sensitivity of Black Cotton Soils stabilized with Glass powder: The sensitivity analysis for each of the independent variable that affects the strength of glass stabilized black cotton soil was performed by varying the assumed coefficient of variation (COV) ranging from 0-100% to obtain reliability indices. This β -value for the five independent variables that influences the strength includes the water content relative to optimum (WRO), maximum dry density, Liquid limit, Glass powder and plastic limit at compaction energy level of British standard light was obtained.

Effect of Unconfined Compressive Strength on Reliability Index: In Fig. 11, increase in safety indices were recorded with increase in the coefficient of variation. For various coefficient of variation used, a negative safety indices were produced. A significant increase in safety indices, from -12.6 to -2.29 were recorded for a corresponding 0 to 50% range of COV. However, minimal changes were recorded from 50 to 100 per cent variation of COV. This range of change in safety index indicates that the variability of unconfined compressive strength does not affect the safety indices. Similar trend of increase in safety index with increase in COV for unconfined compressive strength is recorded by Sani *et al.*, ((2018)

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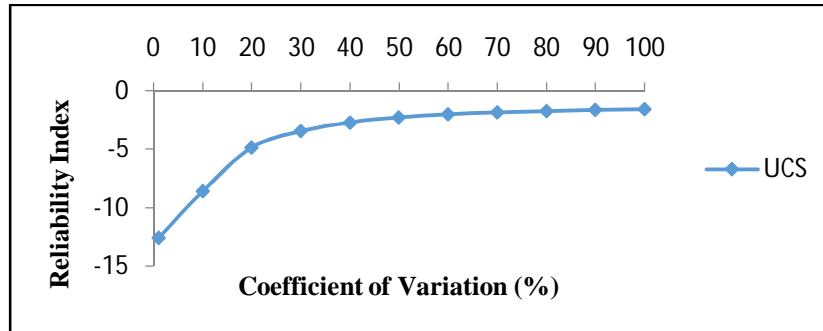


Fig. 11: Variation of reliability index with coefficient of variation for 7 days unconfined compressive strength.

Effect of Glass powder on Reliability Index of the 7 days unconfined compressive strength: Fig. 12 shows the effect of glass powder on the reliability index as the variation of coefficient of variation. A constant β -value of -11.3 was recorded as COV increases from 0 – 100%. The constant value of reliability index, indicates that the variability of the glass powder has no severe effect on the safety index.

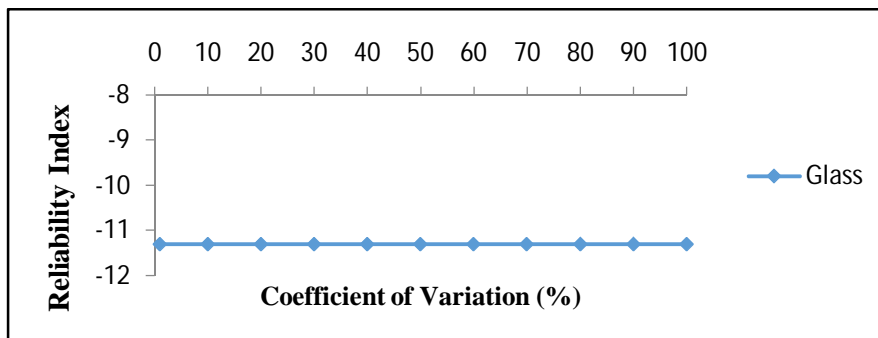


Fig. 12: Variation of reliability index with coefficient of variation for Glass powder.

Effect of Liquid Limit on Reliability Index of the 7 days unconfined compressive strength: In Fig. 13, the effect of varying the COV on the reliability indices has been presented. The β -value changes with increase in the COV from 0 to 100 percent. The highest β -value was recorded at -1.16, for a corresponding 100 per cent coefficient of variation readings.

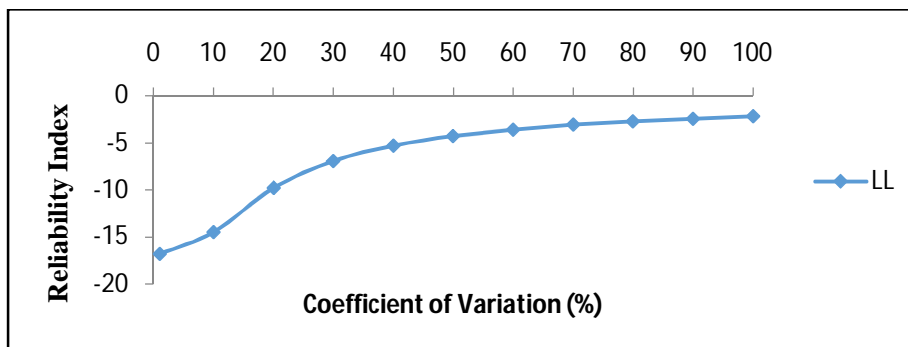


Fig. 13: Variation of reliability index with coefficient of variation for Liquid Limit

Effect of Maximum Dry Density on Reliability Index of the 7 days unconfined compressive strength: The effect of maximum dry density on the reliability index on the unconfined compressive strength shows that, increase in the COV produces a corresponding increase in the β -value (see Fig. 14). The β -value ranges from -11.6 to -5.03 for a

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variation of 0 to 100 COV. The highest β -value was recorded at -.503 for 100 percent COV value. Fig. 14 shows that, increase in the variability of maximum dry density do not produce a radical change in the safety index. Similar trend of increase in safety index with increase in COV for maximum dry density is recorded by Sani *et al.*, ((2018).

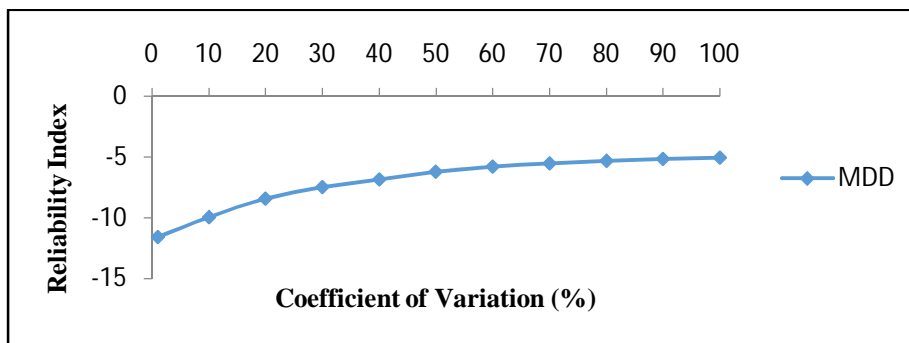


Fig. 14: Variation of reliability index with coefficient of variation for Maximum Dry Density.

Effect of Optimum water content on Reliability Index of the 7 days unconfined compressive strength: Fig. 15 indicates a constant β -value of -11.3, for 0 to 10% COV. This β -value is same with that of glass powder. An increase in the β -value occurs from 20 to 100 percent COV, with 100 percent COV having the highest β -value of -3.38. Similar trend of increase in safety index with increase in COV for maximum dry density is recorded by Sani *et al.*, ((2018)

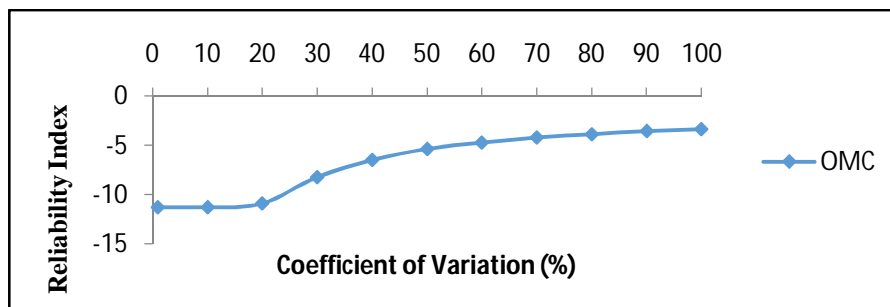


Fig. 16 Variation of reliability index with coefficient of variation for optimum moisture content.

Effect of California Bearing Ratio on Reliability Index: Fig. 17 shows the effect of California Bearing Ratio on the reliability index as the variation of coefficient of variation. The graph shows an initial increase in the β -value from -0.292 to -0.203, for 0-10 percent variation of COV. From 10 to 100 percent variation of COV, a general decrease in β -value was recorded. Additionally, an increase in the variability of CBR value produces a drastic change in the safety index. Similar trend of increase in safety index with increase in COV for maximum dry density is recorded by Sani *et al.*, ((2014)

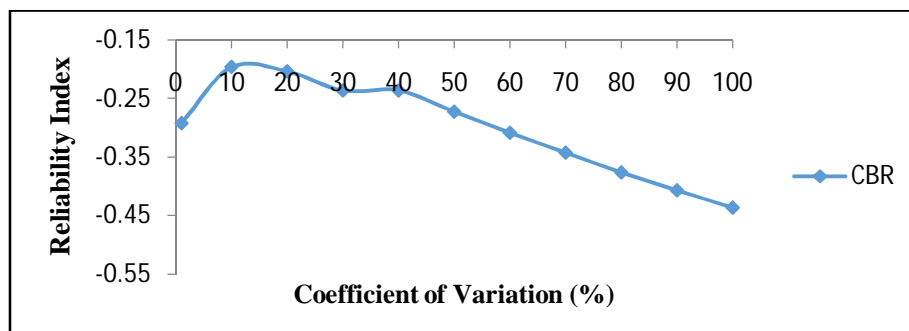


Fig. 17 Variation of reliability index with coefficient of variation for California Bearing Ratio.

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Effect of Glass powder on Reliability Index on California Bearing Ratio: Fig. 18 shows the effect of glass powder on the reliability index as the variation of coefficient of variation. A general increase in the β -value was observed for 0 to 100 per cent variation of COV. 100 per cent variability of COV produced the highest safety index of -0.27.

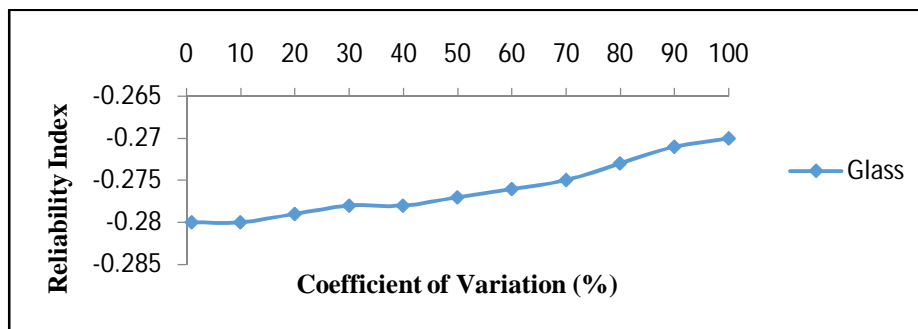


Fig. 18 Variation of reliability index with coefficient of variation for Glass powder.

Effect of Maximum Dry Density on Reliability Index on California Bearing Ratio: Fig. 19 shows the effect of California Bearing Ratio on the reliability index as the variation of coefficient of variation. The graph shows an initial increase in the β -value from -0.292 to -0.203, for 0-10 percent variation of COV. From 10 to 100 percent variation of COV, a general decrease in β -value was recorded. Additionally, an increase in the variability of CBR value produces a drastic change in the safety index.

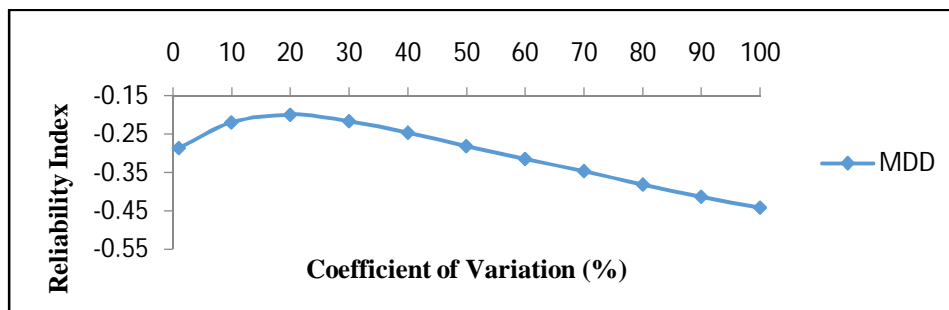


Fig. 19: Variation of reliability index with coefficient of variation for maximum dry density.

Effect of Liquid Limit on Reliability Index on California Bearing Ratio: Fig. 20The graph shows a general increase in the β -value from -0.394 to -0.062, for 0-100 percent variation of COV. Additionally, an increase in the variability of liquid limit value produces non drastic change in the safety index.

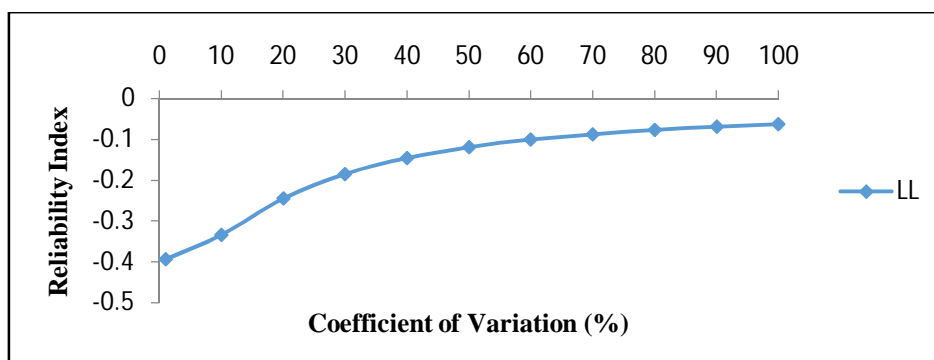


Fig. 20: Variation of reliability index with coefficient of variation for Liquid Limit.

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Effect of Optimum moisture content on Reliability Index on California Bearing Ratio: Fig. 21 shows the effect of California Bearing Ratio on the reliability index as the variation of coefficient of variation. The graph shows an initial increase in the β -value from -0.276 to -0.271, for 0-20 percent variation of COV. From 30 to 100 percent variation of COV, a general decrease in β -value was recorded. Additionally, an increase in the variability of optimum moisture content value produces a drastic change in the safety index.

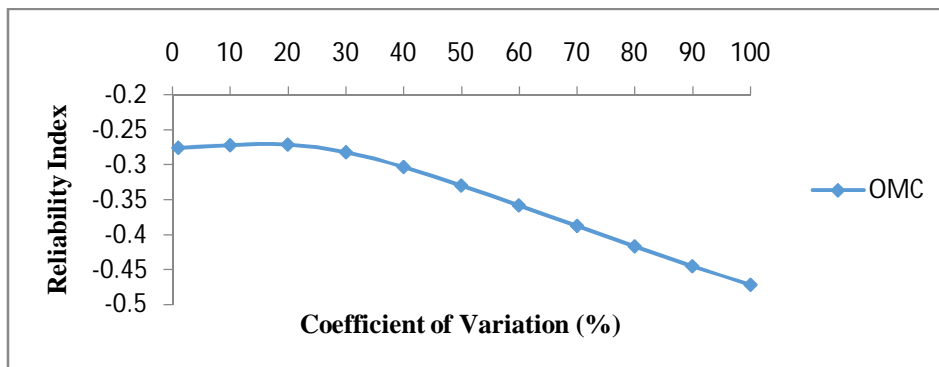


Fig. 20: Variation of reliability index with coefficient of variation for Optimum moisture content.

Stochastically Model Assessment on the 7 days unconfined compressive strength: NKB report (1978) specified a safety index value of 1.0 as the minimum value for serviceability limit state design of structural components. Table 3 presents a summary of all safety index values of variable factors. For unconfined compressive strength, none of the variable factors meets the value of 1.0.

Table 3: Stochastic Model Assessment of Acceptable Safety Index for Unconfined compressive strength

S/N	Variable Factors	Highest β -value	Acceptable Range of COV (%)
1	UCS (7 days Curing)	-1.59	Nil
2	Glass Powder	-11.3	Nil
3	Optimum Water Content	-3.38	Nil
4	Maximum Dry Density	-5.03	Nil
5	Liquid Limit	-2.16	Nil

NKB report (1978) specified a safety index value of 1.0 as the minimum value for serviceability limit state design of structural components. Table 4 presents a summary of all safety index values of variable factors. For California Bearing Ratio, none of the variable factors meets the value of 1.0.

Table 4: Stochastic Model Assessment of Acceptable Safety Index for California Bearing Ratio

S/N	Variable Factors	β -value	Acceptable Range of COV (%)
1	California Bearing Ratio	-0.196	Nil
2	Glass Powder	-0.270	Nil
3	Optimum Water Content	-0.271	Nil
4	Maximum Dry Density	-0.199	Nil
5	Liquid Limit	-0.062	Nil

V. CONCLUSION

A careful study of all safety index values obtained, indicates non-satisfactory safety indices. It is observed that all maximum β -value were significantly less than 1.0. A β -value ≥ 1.0 is required for serviceability limit state design. The

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trends indicate that variable factors for CBR values such as MDD and OMC must be strictly controlled when CBR is being considered in terms of variability of their COV. However, in considering UCS values, variable factors such as LL, MDD and OMC are not affected by COV as these factors are responsible for the strength gain in the stabilized black cotton soils.

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APPENDIX

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PROGRAM FLOOR
C THIS PROGRAM EVALUATES THE RELIABILITY ANALYSIS OF GLASS
C POWDER ON ENGINEERING PROPERTIES OF BLACK COTTON SOIL
C BY USING UNCONFED COMPRESSION STRENGTH
  IMPLICIT DOUBLE PRECISION (A-H,O-Z)
  EXTERNAL GFLOOR
DIMENSION X(5),EX(5),SX(5),VP(10,5),COV(5,5),ZES(3),
+          UU(5),EIVEC(5,5),IV(2,5),des(5)
CHARACTER*10 PRT
COMMON/CFLOOR/E
DATA EX/6.87D2,4.0D0,1.53D0,1.996D1,1.8146D1/,
+ SX/3.885D1,3.16D0,5.0D-2,1.5D0,2.99D0/,
+ N/5/,NC/5/,NE/5/,IRHO/0/
WRITE(*,*)ENTER THE COEFF. OF VAR. FOR X(5) IN %....>
READ(*,*)VAR
SX(5)=VAR*EX(5)/100.
```

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do 707 k=1,8
NAUS=7
ICRT=0
OPEN(7,FILE='TIMI.RES',STATUS='OLD',ERR=10)
GOTO 20
10 OPEN(7,FILE='TIMI.RES',STATUS='NEW')
20 CALL YINIT (N,IV,VP,IRHO,COV,NC)
IV(1,1)=3
IV(1,2)=2
IV(1,3)=3
IV(1,4)=3
IV(1,5)=2
DO 100 I=1,N
X(I) = EX(I)
VP(8,I)=1.D0
100 CONTINUE
V1=1.D0
BETA=1.D0
WRITE (NAUS,5000)
5000 FORMAT (///,6X,70('*'),/,30X,F O R M 5',/,6X,70('*'),/,
+'SAFETY CHECK ON TREATED FOUNDRY, 5 VARIABLES:')
CALL YKOPF (NAUS, N, IV, EX, SX, VP, IRHO)
WRITE (ICRT,*) ' START OF FORM5'
WRITE (ICRT,*) ' STOCHASTIC MODEL :'
CALL YKOPF (ICRT, N, IV, EX, SX, VP, IRHO)
PRT=' COV '
CALL YMAUS (NAUS,NC,N,COV,PRT)
CALL FORM5 (N, IV, EX, SX, VP, GFLOOR, IRHO, COV, NC,
+ EIVEC, NE, V1, NAUS, BETA, X, UU, ZES, IER)
C
C POTENTIAL LOSS IS HERE DETERMINED
PF = YPHINF(-BETA)
PL = (0.95*(1.0-EXP(-50.*PF)))*PF*100.
C WRITE(*,*)'POTENTIAL LOSS =' ,PL
C WRITE(NAUS,*)'POTENTIAL LOSS =' ,PF
PRT=' UU '
CALL YFAUS (NAUS,N,UU,PRT)
PRT=' ZES '
CALL YFAUS (NAUS,6,ZES,PRT)
do 777 i=1,n
des(i)=x(i)/ex(i)
777 continue
write(naus,888)(des(i),i=1,n),E
WRITE(NAUS,504)
write(NAUS,505)(uu(i)/beta,i=1,n)
504 FORMAT(/,3X,'ALPHA VECTOR:')
505 format(3x,/3X,6(2X,E10.2)/)
888 format(3x,/,7f10.2/3x,6f10.2/3x,'aspect ratio for joist =' ,f8.2/
+ 10x,10('*')/)
C
WRITE(NAUS,*)'POTENTIAL LOSS =' ,PL
WRITE(NAUS,*)'POTENTIAL FAILURE=' ,PF
707 continue

WRITE (ICRT,*) ' END OF FORM5 : IER =' ,IER
WRITE (ICRT,*) ' RESULTS SEE FILE TIMI.RES'
STOP
END

SUBROUTINE GFLOOR (N, X, FX, IER)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION X(N)
COMMON /CFLOOR/E
IF (X(1).GT.0.)THEN
FX =(X(1))-(1702.03-0.51*X(2)+491.69*X(3)-5.22*X(4)-

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+ 28.92*X(5))
IER = 0
ELSE
  FX = 1.D+20
  IER = 1
ENDIF
RETURN
END

PROGRAM FLOOR
C THIS PROGRAM EVALUATES THE RELIABILITY ANALYSIS OF GLASS
C POWDER ON ENGINEERING PROPERTIES OF BLACK COTTON SOIL
C BY USING CALIFORNIA BEARING RATIO
  IMPLICIT DOUBLE PRECISION (A-H,O-Z)
  EXTERNAL GFLOOR
DIMENSION X(5),EX(5),SX(5),VP(10,5),COV(5,5),ZES(3),
+  UU(5),EIVEC(5,5),IV(2,5),des(5)
  CHARACTER*10 PRT
  COMMON/CFLOOR/E
  DATA EX/4.0D1,4.0D0,1.53D0,1.996D1,1.8146D1/,
+  SX/1.145D0,3.16D0,5.0D-2,1.5D0,2.99D0/,
+  N/5/,NC/5/,NE/5/,IRHO/0/
WRITE(*,*)'ENTER THE COEFF. OF VAR. FOR X(5) IN %....>'
READ(*,*)VAR
  SX(5)=VAR*EX(5)/100.
  do 707 k=1,8
  NAUS=7
  ICRT=0
  OPEN(7,FILE='TIMI2.RES',STATUS='OLD',ERR=10)
  GOTO 20
10 OPEN(7,FILE='TIMI2.RES',STATUS='NEW')
20 CALL YINIT (N,IV,VP,IRHO,COV,NC)
IV(1,1)=3
IV(1,2)=2
IV(1,3)=3
IV(1,4)=3
IV(1,5)=2
  DO 100 I=1,N
  X(I) = EX(I)
  VP(8,I)=1.D0
100 CONTINUE
  V1=1.D0
  BETA=1.D0
  WRITE (NAUS,5000)
5000 FORMAT (////,6X,70(*),/,30X,'F O R M 5',/,6X,70(*),/,
+ 'SAFETY CHECK ON TREATED FOUNDRY, 5 VARIABLES:')
  CALL YKOPF (NAUS, N, IV, EX, SX, VP, IRHO)
  WRITE (ICRT,*) ' START OF FORM5'
  WRITE (ICRT,*) ' STOCHASTIC MODEL : '
  CALL YKOPF (ICRT, N, IV, EX, SX, VP, IRHO)
  PRT=' COV '
  CALL YMAUS (NAUS,NC,N,COV,PRT)
  CALL FORM5 (N, IV, EX, SX, VP, GFLOOR, IRHO, COV, NC,
+  EIVEC, NE, V1, NAUS, BETA, X, UU, ZES, IER)
C
C POTENTIAL LOSS IS HERE DETERMINED
  PF = YPHINF(-BETA)
  PL = (0.95*(1.0-EXP(-50.*PF)))*PF*100.
C WRITE(*,*)'POTENTIAL LOSS =',PL
C WRITE(NAUS,*)'POTENTIAL LOSS =',PF
  PRT=' UU '
  CALL YFAUS (NAUS,N,UU,PRT)
  PRT=' ZES '
  CALL YFAUS (NAUS,6,ZES,PRT)
  do 777 i=1,n
  des(i)=x(i)/ex(i)

```

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```
777 continue
  write(naus,888)(des(i),i=1,n),E
  WRITE(NAUS,504)
  write(NAUS,505)(uu(i)/beta,i=1,n)
504 FORMAT(/,3X,'ALPHA VECTOR:')
505 format(3x,/3X,6(2X,E10.2)/)
888 format(3x,/'7f10.2/3x,6f10.2/3x,'aspect ratio for joist =',f8.2/
+ 10x,10('*')/)
C
  WRITE(NAUS,*)'POTENTIAL LOSS =',PL
  WRITE(NAUS,*)'POTENTIAL FAILURE=',PF
707 continue

WRITE (ICRT,*) ' END OF FORM5 : IER =',IER
WRITE (ICRT,*) ' RESULTS SEE FILE TIMI2.RES'
STOP
END

SUBROUTINE GFLOOR (N, X, FX, IER)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION X(N)
COMMON /CFLOOR/E
IF (X(1).GT.0.)THEN
FX =(X(1))-(96.23-0.186*X(2))-20.475*X(3)-0.584*X(4)-
+ 0.652*X(5)
IER = 0
ELSE
  FX = 1.D+20
  IER = 1
ENDIF
RETURN
END
```