# Evaluation of Compression Index of Tamil Nadu Clays from their Engineering Characteristics

*by*

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## Introduction

OF all the various tests performed on soil, the most time consuming one is the laboratory test for consolidation. *The test, essentially, consists* of determining the time-compression relation under constant loading of a laterally confined soil mass and is intended for estimating the probable magnitude and time rate of settlement of foundations to be expected under loading imposed by structures. From the consolidation tests conducted on clay soil-samples, $C_v$—the coefficient of consolidation and $C_c$—the compression index are evaluated from the time—settlement graph and the $e$—log $p$ curves respectively. Before designing a foundation for a particular soil condition, the practical interest of a foundation engineer is in the determination of the full-settlement of the structure and in selecting such contact pressure on the soil as would not cause intolerable settlement. Therefore, he is more interested in the value of $C_c$ than $C_v$ at the design stage.

The compression index $C_c$ is determined through a time consuming and expensive consolidation test ; the test requires expert observations also.

Therefore, several attempts by various scientists have already been made to forecast the compression index with the aid of other soil characteristic ; A.W. Skempton (1948) has established $C_c = 0{\cdot}009$ (L.L.—10) and Hough (1957) evolved $C_c = 0{\cdot}3\,(e_o - 0{\cdot}27)$ for clayey soil. Recently Cozzolino (1961) has brought out the following equations for certain silty clays in Brazil :

(*i*) For heavy medium clays and silts :

$$C_c = 0{\cdot}256 \text{ Plus } 0{\cdot}00106\,(\text{L.L.} - 65) \text{ Plus } 0{\cdot}32\,(e - 0{\cdot}84) \text{ Plus or Minus } 0{\cdot}063 \quad (A)$$

(*ii*) For soft clays and silts :

$$C_c = 1{\cdot}21 \text{ Plus } 0{\cdot}0072\,(L.L. - 95) \text{ Plus } 0{\cdot}53\,(e - 1{\cdot}87) \text{ Plus or Minus } 0{\cdot}32 \quad (B).$$

* Highway Research Station, Guindy, Madras-25 (Tamil Nadu).

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When these equations were applied to the various clays of Tamil Nadu, large variations in $C_c$ values were observed. Therefore, detailed studies were made on clay samples from different parts of the state for establishing relationships between $C_c$ and the engineering characteristics of soils which can easily be determined.

## The Experimental Study

Undisturbed clayey soil samples were obtained from bores of different soil investigation works undertaken by the Highways Research Station, Madras, for the foundation design of different structures.

Tests for their engineering characteristics were carried out and also systematic consolidation tests were run on the undisturbed soil samples, $e-\log p$ curves plotted, and compression indexes $C_c$ evaluated.

The compression index values are plotted against (*i*) the liquid limit, (*ii*) $e_o$—the natural void ratio and (*iii*) the N.M.C.—the natural moisture content of the soils and for each of above, a straight line of "best fit" is obtained through "Linear Regression". The plots are shown in Figures 1, 2 and 3. The following equations have been established :

(*i*) $C_c = 0{\cdot}0087 \text{ L.L.} - 0{\cdot}089$

$$= 0{\cdot}0087\,(\text{L.L.} - 10) \quad \ldots(1)$$

(*ii*) $C_c = 0{\cdot}39\, e_o - 0{\cdot}03$

$$= 0{\cdot}39\,(e_o - 0{\cdot}08) \quad \ldots(2)$$

(*iii*) $C_c = 0{\cdot}0093 \text{ N.M.C. Plus } 0{\cdot}0142$

$$= 0{\cdot}0093 \text{ N.M.C.}$$

$$= 0{\cdot}9 \frac{\text{N.M.C.}}{100} \quad \ldots(3)$$

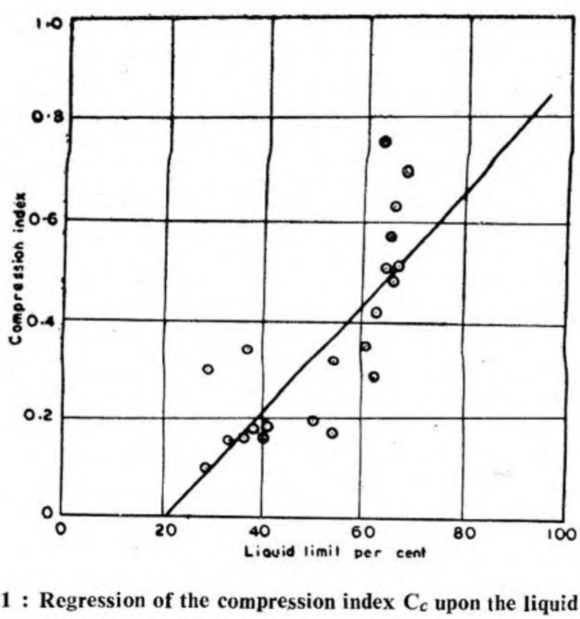


**FIGURE 1 : Regression of the compression index $C_c$ upon the liquid limit LL.**

**TABLE**

**$C_c$-Values through derived expressions and compared**

| Sl. No. | Liquid limit | Natural moisture content N.M.C. | Initial voids ratio—$e_o$ | Laboratory value of compression index—$C_c$ | Skempton's expression—$C_c$ | Hough's expression—$C_c$ | Cozzolino's equation $(A)$ $C_c$ | Cozzolino's equation $(B)$ $C_c$ |
|---|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| 1. | 29 | 30 | 0·945 | 0·29 | 0·171 | 0·203 | 0·252 | 0·245 |
| 2. | 30 | 18 | 0·500 | 0·10 | 0·180 | 0·069 | 0·110 | 0·016 |
| 3. | 33 | 18 | 0·536 | 0·15 | 0·207 | 0·080 | 0·125 | 0·057 |
| 4. | 37 | 41 | 1·198 | 0·34 | 0·243 | 0·278 | 0·341 | 0·430 |
| 5. | 38 | 28 | 0·799 | 0·17 | 0·252 | 0·159 | 0·214 | 0·232 |
| 6. | 50 | 20 | 0·724 | 0·19 | 0·360 | 0·136 | 0·203 | 0·279 |
| 7. | 40 | 23 | 0·587 | 0·16 | 0·270 | 0·095 | 0·149 | 0·134 |
| 8. | 36 | 22 | 0·575 | 0·16 | 0·234 | 0·091 | 0·141 | 0·009 |
| 9. | 41 | 19 | 0·634 | 0·18 | 0·279 | 0·169 | 0·165 | 0·166 |
| 10. | 35 | 19 | 0·739 | 0·19 | 0·225 | 0·141 | 0·192 | 0·179 |
| 11. | 54 | 21 | 0·901 | 0·31 | 0·396 | 0·189 | 0·264 | 0·409 |
| 12. | 54 | 25 | 0·592 | 0·17 | 0·396 | 0·097 | 0·165 | 0·237 |
| 13. | 61 | 43 | 1·000 | 0·35 | 0·459 | 0·219 | 0·303 | 0·504 |
| 14. | 62 | 32 | 0·730 | 0·28 | 0·468 | 0·138 | 0·218 | 0·368 |
| 15. | 63 | 81 | 2.077 | 0·75 | 0·477 | 0·543 | 0·650 | 1·089 |
| 16. | 64 | 47 | 1·257 | 0·51 | 0·486 | 0·297 | 0·388 | 0·662 |
| 17. | 65 | 52 | 1·500 | 0·57 | 0·495 | 0·369 | 0·467 | 0·798 |
| 18. | 66 | 59 | 1·261 | 0·63 | 0·504 | 0·297 | 0·392 | 0·678 |
| 19. | 68 | 70 | 1·681 | 0·70 | 0·522 | 0·423 | 0·528 | 0·915 |
| 20. | 63 | 30 | 0·754 | 0·42 | 0·477 | 0·147 | 0·226 | 0·388 |

1. Skempton's Equation $C_c=0{\cdot}009$ (L.L.—10)
2. Hough's Expression $C_c=0{\cdot}3\ (e_o-0{\cdot}27)$

*Cozzolino's Equation*

3. For heavy medium clays silts $C_c=0{\cdot}255+0{\cdot}00106$ (L.L.—65) $+0{\cdot}32\ (e-0{\cdot}84)=0.063$(A)
4. For soft clays and silts $C_c=1{\cdot}21+0{\cdot}0072$ (L.L.—95) $+0{\cdot}53\ (e-1{\cdot}87)+0{\cdot}32$

*By Linear Regression Method*

5. $C_c=0{\cdot}0087$ (L.L.—10)
6. $C_c=0{\cdot}39\ (e_o-0{\cdot}08)$

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**with the other existing expressions.**

| $C_c=0\cdot0087$ (11=10) | New Derivations | | | | | |
|---|---|---|---|---|---|---|
| | $C_c=0\cdot39$ $(e_o=0\ 08)$ | $C_c=0\cdot9\ \frac{\text{N.M.C}\ \%}{100}$ | Multiple regression analysis $C_c=0\ 0038$ (L L.)+ 0 0086 (N.M.C.) —0·1323 | Multiple regression analysis $C_c=0\cdot0033$ (L.L.)+ 0·0086 (N.M.C.)— 0.1323 | Normal equation $C_c=0\cdot0044$ (L.L.)+ 0 3435 $e_o$— 0·2143 | Normal equation $C_c=0\ 0028$ (L.L.)+ 0.009 (N.M.C.) —0·1215 |
| (10) | (11) | (12) | (13) | (14) | (15) | (16) |
| 0·171 | 0·339 | 0·27 | 0·234 | 0 260 | 0·239 | 0·2210 |
| 0·180 | 0·164 | 0·16 | 0·084 | 0·146 | 0·091 | 0·1220 |
| 0 207 | 0·179 | 0·16 | 0·110 | 0·149 | 0·116 | 0·1310 |
| 0·243 | 0·437 | 0 37 | 0·359 | 0·375 | 0·361 | 0·342 |
| 0·252 | 0·281 | 0·25 | 0·225 | 0·251 | 0·229 | 0·234 |
| 0·360 | 0 150 | 0·18 | 0·255 | 0·189 | 0·256 | 0·205 |
| 0·270 | 0·199 | 0·21 | 0·160 | 0·206 | 0·165 | 0·198 |
| 0·234 | 0·195 | 0·20 | 0·138 | 0·191 | 0·143 | 0·176 |
| 0·279 | 0·215 | 0·17 | 0·182 | 0·168 | 0·185 | 0·166 |
| 0·225 | 0·257 | 0·17 | 0·190 | 0·161 | 0·195 | 0·148 |
| 0·396 | 0·316 | 0·19 | 0·336 | 0·203 | 0·335 | 0·227 |
| 0·396 | 0·199 | 0·23 | 0·228 | 0·242 | 0·228 | 0·261 |
| 0·459 | 0·359 | 0·39 | 0·403 | 0·423 | 0·400 | 0·439 |
| 0·468 | 0·254 | 0 29 | 0·314 | 0·318 | 0·311 | 0·348 |
| 0·477 | 0·780 | 0·73 | 0·786 | 0·790 | 0·779 | 0·772 |
| 0·486 | 0·460 | 0·42 | 0·506 | 0·465 | 0·501 | 0·493 |
| 0·495 | 0·554 | 0·47 | 0·595 | 0·514 | 0·589 | 0·529 |
| 0·504 | 0·460 | 0·53 | 0·517 | 0·582 | 0·521 | 0·593 |
| 0·522 | 0·684 | 0·63 | 0·692 | 0·690 | 0·665 | 0·694 |
| 0·477 | 0·262 | 0·27 | 0·327 | 0·302 | 0·324 | 0·334 |

7. $C_c=0\cdot9\ \frac{\text{N.M.C.}}{100}\%$

*By Multiple Regression Analysis*

8. $C_c=0\cdot0047$ (L.L.)+0·3473 $(e_o)$—0.2312
9. $C_c=0\cdot0033$ (L.L.)+0·0086 (N.M.C.)—0 1323

*By Normal Equations*

10. $C_c=0\cdot0044$ (L.L.)+0·3435 $(e_o)$—0·2143
11. $C_c=0\cdot0028$ (L.L.)+0·009 (N.M.C.)—0·1215

**TABLE II**

**Percentage errors of the derived expressions.**

| Sl. No. | Skempton's equations | Hough's expressions | Cozzolino's equation (*A*) | Cozzolino's equation (*B*) | $C_c=0{\cdot}0087$ (L.L.—10) | $C_c=0.39$ $(e_o-0{\cdot}08)$ | $C_c=0{\cdot}9\,\frac{\text{N.M.C.}\%}{100}$ | Multiple regression $C_c$, L.L., $e_o$ | Multiple regression $C_c$, L.L., N.M.C. | Normal equation $C_c$, L.L., $e_o$ | Normal equation $C_c$, L.L., N.M.C. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percentage error | Percentage error | Percentage error | Percentage error | Percentage error | Percentage error | Percentage error | Percentage error | Percentage error | Percentage error | Percentage error |
| 1. | 41·4 | 31·0 | 13·8 | 13·8 | 41·4 | 17·25 | 6·9 | 20·7 | 10·35 | 17·25 | 20·7 |
| 2. | 80·0 | 30·0 | 10·0 | 80·0 | 80·0 | 60·0 | 60·0 | 20·0 | 50·0 | 10·0 | 20·0 |
| 3. | 40·0 | 46·7 | 20·0 | 60·0 | 40·0 | 20·0 | 6·66 | 26·7 | — | 20·0 | 13·35 |
| 4. | 29·4 | 17·65 | — | 29·4 | 29·4 | 29·4 | 8·83 | 5·28 | 11·76 | 5·88 | — |
| 5. | 47·0 | 5·88 | 20·35 | 35·3 | 47·0 | 64·7 | 47·0 | 35·3 | 47·0 | 35·3 | 35·3 |
| 6. | 89·4 | 26·3 | 5·26 | 42·1 | 89·4 | 21·05 | 5·26 | 36·9 | — | 36·0 | 10·51 |
| 7. | 68·8 | 37·5 | 6·25 | 18·75 | 68·8 | 25·0 | 31·25 | — | 31·25 | — | 25·0 |
| 8. | 43·75 | 43·75 | 12·50 | 37·50 | 43·75 | 25·0 | 25·0 | 12·5 | 18·75 | 12·5 | 12·5 |
| 9. | 55·50 | 5·55 | 11·10 | 5·55 | 55·5 | 22·2 | 5·55 | — | 5·55 | 5·55 | 5·55 |
| 10. | 21·04 | 26·30 | — | 5·26 | 21·04 | 36·82 | 10·52 | — | 15·78 | — | 21·04 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11. | 29·07 | 38·76 | 16·15 | 32·25 | 29·07 | 3·23 | 38·76 | 9·69 | 35·53 | 6·46 | 25·8 |
| 12. | 135·2 | 41·16 | 5·88 | 41·16 | 135·2 | 17·64 | 35·28 | 35·28 | 41·16 | 35·28 | 53·0 |
| 13. | 31·46 | 37·18 | 14·30 | 42·90 | 31·46 | 2·86 | 11·44 | 14·3 | 20·02 | 14·30 | 25·74 |
| 14. | 67·9 | 50·0 | 21·42 | 32·13 | 67·9 | 10·71 | 3·57 | 10·71 | 44 28 | 10·71 | 25·0 |
| 15. | 36·0 | 28·0 | 13·34 | 45·30 | 36·0 | 4·00 | 2·668 | 5·336 | 5·336 | 4·0 | 2·67 |
| 16. | 3·92 | 41·2 | 23·50 | 29·40 | 3.92 | 9·80 | 17·64 | — | 7·84 | 1·96 | 3·92 |
| 17. | 12·28 | 35·1 | 17·55 | 40·30 | 12·20 | 3·51 | 17·55 | 5·26 | 10·52 | 3·51 | 7·02 |
| 18. | 20·6 | 52·4 | 38·10 | 7·54 | 20·60 | 27·00 | 15·88 | 17·45 | 7·94 | 17·45 | 6·35 |
| 19. | 25·7 | 40·0 | 24·30 | 31·40 | 25·70 | 11·44 | 10·0 | 4·285 | 1·43 | 5·72 | 1·43 |
| 20. | 14·3 | 64·3 | 45·30 | 7·14 | 14·28 | 38·15 | 35·7 | 21·42 | 28·56 | 23 8 | 21·4 |
| Error-Range | Nos. % | Nos. % | Nos. % | Nos. % | Nos. % | Nos. % | Nos. % | Nos. % | Nos. % | Nos. % | Nos. % |
| 0—10% | 1 5 | 2 10 | 6 30 | 4 20 | 1 5 | 5 25 | 8 40 | 9 45 | 7 35 | 10 50 | 7 35 |
| 0—20% | 3 15 | 3 15 | 14 70 | 6 30 | 3 15 | 10 50 | 13 65 | 14 70 | 13 65 | 16 80 | 11 55 |
| 0—30% | 8 40 | 7 35 | 18 90 | 8 40 | 8 40 | 16 80 | 14 70 | 17 85 | 15 75 | 17 85 | 18 90 |
| 0—40% | 11 55 | 13 65 | 19 85 | 13 65 | 11 55 | 18 90 | 18 90 | 20 100 | 17 85 | 20 100 | 19 95 |
| 0—50% | 14 70 | 18 90 | 20 100 | 18 90 | 14 70 | 19 95 | 19 95 | 20 100 | 20 100 | 20 100 | 19 95 |

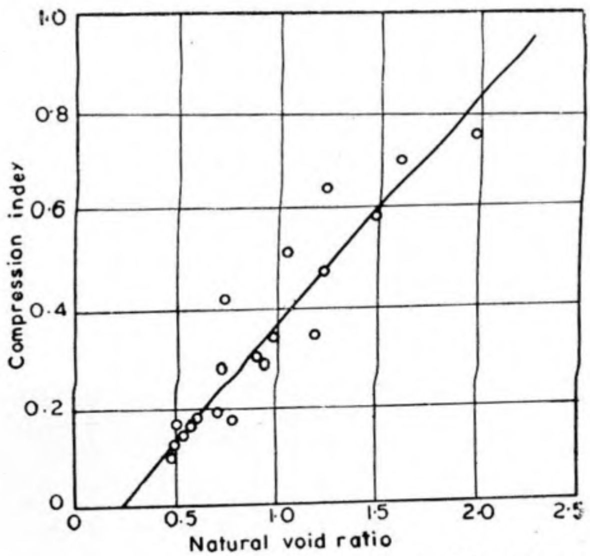


**FIGURE 2 : Regression of the compression index $C_c$ upon the natural void ratio e.**

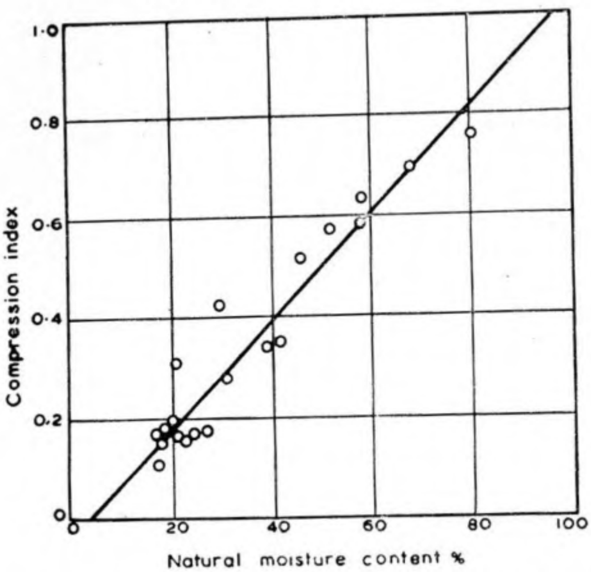


**FIGURE 3 : Regression of the compression index $C_c$ upon the natural moisture content M.**

Even though it is possible to arrive at a relation between either compression index $C_c$ and L.L. or $C_c$ and $e_o$ or $C_c$ and N.M.C., it is not reasonable to consider such relationships alone as fully correct. For, consolidation is a process of compression depending upon the moisture content or $e_o$ as well as on the physical characteristic of soil such as L.L. Hence, a relationship between $C_c$ on one side and L.L. and $e_o$ or L.L. and N.M.C. on other side will be more significant and representative. Hence, statistical correlations through "Multiple Regression" connecting (*i*) $C_c$, L.L. and $e_o$, and (*ii*) $C_c$, L.L. and N.M.C. have been obtained.

Relationships between (*i*) $C_c$, L.L. and $e_o$, and (*ii*) $C_c$, L.L. and N.M.C. have aiso been established through normal equations such as $y=ax_1$ Plus $bx_2$ plus $C$.

The relationships through "Multiple Regression" analysis (4) are :

$$C_c = \text{Plus } 0{\cdot}0047 \text{ (L.L.) Plus } 0{\cdot}3473 \; e_o = 0.2312 \quad \ldots(4)$$

$$C_c = \text{Plus } 0\,0033 \text{ L.L. Plus } 0{\cdot}0086 \text{ (N.M.C.)} - 0{\cdot}1323 \quad \ldots(5)$$

The equations established through normal equations are :

$$C_c = 0{\cdot}0044 \text{ L.L. Plus } 0{\cdot}3435\, e_o - 0{\cdot}2143 \quad \ldots(6)$$

$$C_c = 0{\cdot}0028 \text{ L.L. Plus } 0{\cdot}009 \text{ N.M.C.} - 0{\cdot}1215 \quad \ldots(7)$$

The $C_c$ values determined through the above different equations along with the soil characteristics are given in Table I.

The percentages of error from the observed values of $C_c$ obtained using the derived expressions as compared to the already established equations in vogue are given in Table II. In this table, the error range for each equation is shown.

## Conclusion

The comparision of the equations and their error range indicates that the derived Equations (3, 4, 5, 6 and 7) give out the $C_c$ values with minimum error range. These equations compare well with the Cozzolino Equation (*A*). As a more approximation the equation $C_c = \frac{0\,9}{100}$N.M.C. (Equation 3) can be used to determine the $C_c$ value with more case using the value of N.M.C. only. The efficiency of these equations has been observed to be satisfactory by having conducted further consolidation tests on a few more soil samples from different sources.

## References

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