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# ON THE COEFFICIENT OF CONSOLIDATION OF COMPACTED SOILS

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**ABSTRACT:** The present experimental investigation deals with the determination and comparison of $c_v$ of compacted soils by different methods. The values of $c_v$ were determined by the conventional $\delta$-$\sqrt{t}$ & $\delta$-log t methods, in addition to rectangular hyperbola, log $\delta$ - log t and one point methods. The compacted soils are characterised by the presence of yield stress, which is akin to the preconsolidation stress of undisturbed soils. The paper discusses the feasibility of these methods in the pre-yield region, transition region and the post-yield region of the compressibility behavior of compacted soils. A comparative study of the values of $c_v$ obtained from the $\delta$ - $\sqrt{t}$, $\delta$ - log t, rectangular hyperbola & log $\delta$ - log t methods with those obtained from one point method has also been done. The study indicates that the one point method predicts comparable values of $c_v$ for compacted soils and hence, recommended in view of its simplicity.

## INTRODUCTION

The time rate of settlement analysis of foundations built on a compressible soil mass requires the value of coefficient of consolidation ($c_v$) of the soil mass. Most of the curve fitting procedures available in the literature for the determination of $c_v$ from the laboratory one dimensional consolidation test data are based on Terzaghi's theory. Among them, Taylor's $\delta - \sqrt{t}$ and Casagrande's $\delta$ – log t methods are considered as conventional methods. Inspite of their popularity and wide usage, they have their own limitations [1]. In view of this, rectangular hyperbola method (RH method) [1, 2, 3], log $\delta$ – log t method [4] and one point method [5] are becoming popular these days. This technical paper deals with the comparative study of $c_v$ values obtained from $\delta - \sqrt{t}$, $\delta$ – log t, RH, log $\delta$ – log t and one point methods.

## ONE POINT METHOD

The procedure adopted in this method is as follows.

i) Consider the value of compression corresponding to the end of loading period as final compression ($\delta_f$).
ii) Knowing $\delta_f$ , obtain the compression corresponding to 50% consolidation (i.e., $\delta_{50} = 0.5\ \delta_f$ ) along with the corresponding time $t_{50}$.
iii) Calculate the value of $c_v$ corresponding to the time noted.

$$\text{i.e.,}\quad c_{vp} = \frac{T_{50} H^2}{t_{50}} \qquad (1)$$

The one point method is simple and does not involve any curve fitting procedure. The review of the documented geotechnical engineering literature reveals that one point method gives values of $c_v$ free from the effects of initial and secondary compressions [5, 6]. Due to its inbuilt merits, one point method is considered as the reference method in this study.

## MATERIALS AND METHODS

Four soils from the field and one commercially available kaolinite clay mineral (i.e., China clay) passing 425 μm sieve were used in the present experimental investigation (Table 1). Indian standard light compaction tests [7] were conducted on these soils to obtain OMC and $\rho_{dmax}$ values. One dimensional consolidation tests were conducted on these soils compacted at three levels: compacted to $\rho_{dmax}$, compacted to 0.95 $\rho_{dmax}$ on the dry side of optimum and compacted to 0.95 $\rho_{dmax}$ on the wet side of optimum. Due to want of space only typical test results are presented in this paper.

## $\delta$ – log t CURVES OF COMPACTED SOILS

Fig. 1 presents a typical e – log $\sigma'$ curve of a compacted soil from the present study. From this figure, it can be noticed that the e – log curve of a compacted soil is characterized by the presence of yield stress, which is akin to the pre-consolidation stress of undisturbed soils. With the result, the e – log $\sigma'$ curve of a compacted soil can be considered to have three regions: pre-yield region, which corresponds to over consolidated state, zone involving the transition from over consolidated state to normally consolidated state (i.e., transition region) and post-yield region, which corresponds to normally consolidated state.

Fig. 2 presents typical $\delta$ – log t curves of a compacted soil from the present study. From the study of $\delta$ –log t curves of all soils studied in the present work in the pre-yield region, transition region and post-yield region, following observations have been made.

**Table 1** Physical Properties of Soils Studied

| Sl. No. | Soil | Specific Gravity | Liquid limit ($w_L$), % | Plastic limit ($w_P$), % | Shrinkage limit ($w_S$), % | Grain Size Distribution, % | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Clay size | Silt size | Sand Size |
| 1 | Kollegala soil | 2.74 | 55 | 26 | 15.9 | 37.0 | 34.5 | 28.5 |
| 2 | Kuderu soil | 2.85 | 54 | 26 | 11.5 | 39.0 | 21.0 | 40.0 |
| 3 | Bannur soil | 2.69 | 67 | 30 | 16.1 | 45.0 | 55.0 | – |
| 4 | CFTRI soil | 2.72 | 68 | 33 | 13.9 | 51.0 | 49.0 | – |
| 5 | China clay | 2.67 | 68 | 30 | 24.8 | 63.0 | 37.0 | – |

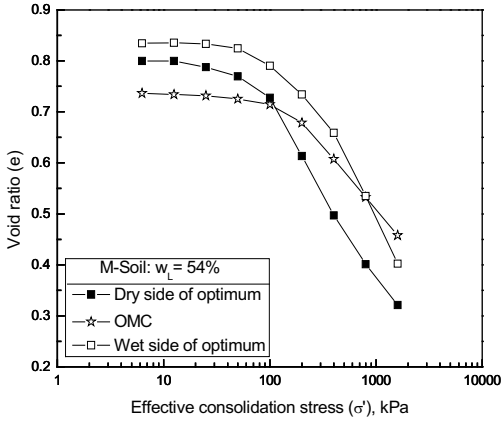


**Fig. 1** Typical e-log σ' curves of compacted soils from the present study

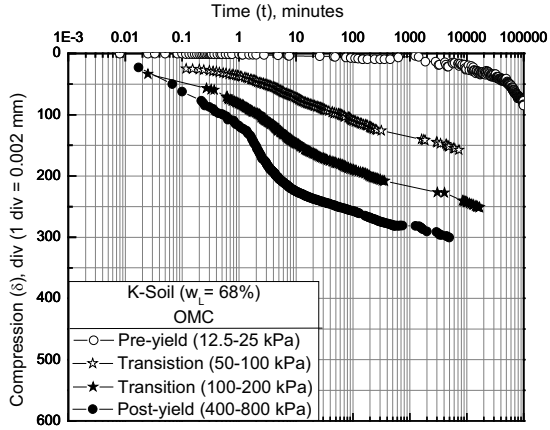


**Fig. 2** Typical δ-log t curves of a compacted soil from the present study

- The δ-log t curves of the pre-yield zone are characterised by the delayed compression. This is manifested by the initial linear portion of the δ-log t curve over a considerable time interval, followed by concave down curve. In spite of stress increment ratio being one, majority of the δ - log t curves in the pre-yield zone do not exhibit conventional reverse S-shaped curve, which is typical of over consolidated soils. Due to this fact, it is not possible to apply logarithm of time fitting method to calculate coefficient of consolidation in such cases.
- The tendency of delayed compression gets reduced over the transition zone and well defined reverse S-shaped curves result in the post-yield zone of consolidation loading. The results show clearly the gradual transformation in the shape of the δ - log t curve from that of over consolidated soil to that of normally consolidated soil.

## $c_v$ OF COMPACTED SOILS

The values of $c_v$ corresponding to different stress increments coming under pre-yield, transition and post-yield regions were determined from the conventional δ - √t & δ - log t methods (wherever possible) as well as from RH, log δ - log t and one point methods.

Figs. 3 – 6 illustrate the comparison of the values of cv obtained during the pre-yield, transitional and post-yield regions of compressibility behaviour of compacted soils obtained from δ-log t methodδ-√t method, rectangular hyperbola method (i.e., RH method) and log δ - log t method respectively with those obtained from one point method. It can be seen that the one point method has better correlation with δ - log t method (Fig. 3) than with any other method.

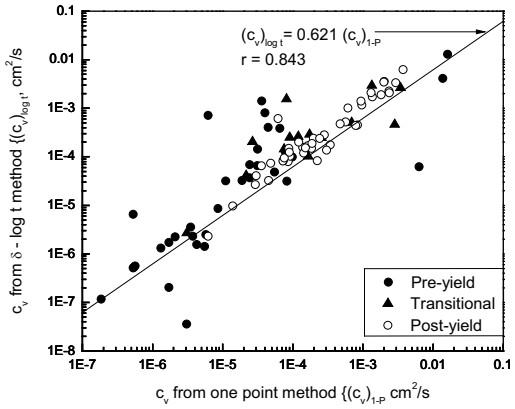


**Fig. 3** Comparison of values of $c_v$ obtained from logarithm of time fitting method with those from one point method

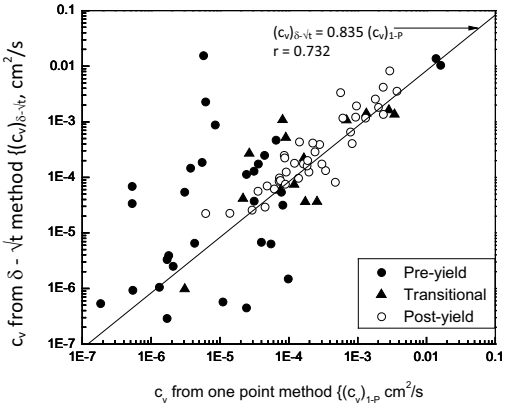


**Fig. 4** Comparison of values of $c_v$ obtained from square root of time fitting method with those from one point method

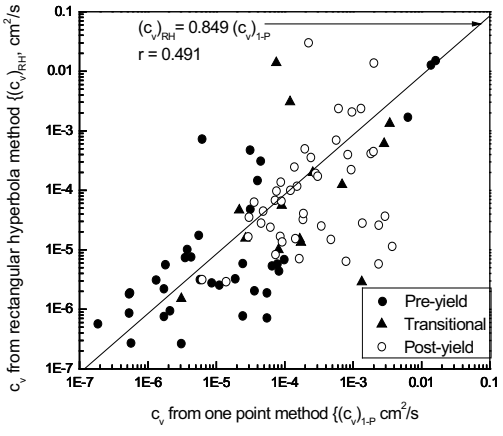


**Fig. 5** Comparison of values of $c_v$ obtained from RH method with those from one point method

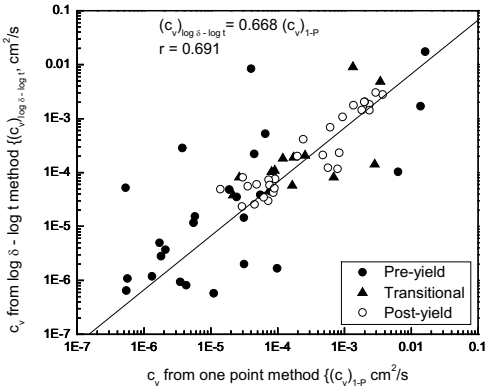


**Fig. 6** Comparison of values of $c_v$ obtained from log δ - log t method with those from one point method

Table 2 present the results of the statistical analysis carried out for the data of Fig. 3 through Fig. 6.

Study of Table 2 reveals the following.

- In the pre-yield region, correlation of $c_v$ values obtained from one point method with those obtained from rectangular hyperbola method appears to be good.
- In the transitional region, the values of $c_v$ obtained from δ-√t method and one point method correlate very well.
- The overall comparison of all the five methods considered in the present analysis indicates that one point method, on an average, results in higher values of $c_v$ for compacted soils when compared with δ-log t, δ-√t, Rectangular hyperbola and log δ-log t methods.

Table 2 also presents the comparison of $c_v$ values obtained from the conventional δ-log t method with those obtained from the conventional δ-√t method. Considering this comparison it can be concluded that the values of $c_v$ obtained from one point method are well within the range of values obtained from the conventional δ-log t and δ-√t methods.

## CONCLUSIONS

Due to the presence of a characteristic yield stress on the e-log σ′ curve, compacted soils exhibit $c_v$ values of varying magnitude in the three regions namely pre-yield region, transition region and post yield region. The comparative study of $c_v$ values obtained from different commonly adopted curve fitting procedures indicates that one point method predicts higher values of $c_v$ for compacted soils, on an average. The documented geotechnical engineering literature indicates that the value of $c_v$ of the soils in the field are quite high when compared with the values obtained for the same soils in the laboratory [8, 9]. In view of this, the prediction of

**Table 2** Comparison of values of $c_v$ obtained from different methods over different stages of loading – A statistical analysis

| Fig. No. | Data coverage | Regression equation | Co-efficient of determination (r) |
|---|---|---|---|
| 3 | • Pre-yield region | $(c_v)_{logt} = 0.542(c_v)_{1-p}$ | 0.877 |
| | • Transitional region | $(c_v)_{logt} = 0.669(c_v)_{1-p}$ | 0.731 |
| | • Post-yield region | $(c_v)_{logt} = 1.326(c_v)_{1-p}$ | 0.964 |
| | • Overall | $(c_v)_{logt} = 0.621(c_v)_{1-p}$ | 0.843 |
| 4 | • Pre-yield region | $(c_v)_{\delta-\sqrt{t}} = 0.788(c_v)_{1-p}$ | 0.721 |
| | • Transitional region | $(c_v)_{\delta-\sqrt{t}} = 0.543(c_v)_{1-p}$ | 0.846 |
| | • Post-yield region | $(c_v)_{\delta-\sqrt{t}} = 1.414(c_v)_{1-p}$ | 0.857 |
| | • Overall | $(c_v)_{\delta-\sqrt{t}} = 0.835(c_v)_{1-p}$ | 0.732 |
| 5 | • Pre-yield region | $(c_v)_{RH} = 0.875(c_v)_{1-p}$ | 0.978 |
| | • Transitional region | $(c_v)_{RH} = 0.350(c_v)_{1-p}$ | 0.116 |
| | • Post-yield region | $(c_v)_{RH} = 0.824(c_v)_{1-p}$ | 0.182 |
| | • Overall | $(c_v)_{RH} = 0.849(c_v)_{1-p}$ | 0.491 |
| 6 | • Pre-yield region | $(c_v)_{log\delta-logt} = 0.622\ (c_v)_{1-p}$ | 0.710 |
| | • Transitional region | $(c_v)_{log\delta-logt} = 1.307(c_v)_{1-p}$ | 0.604 |
| | • Post-yield region | $(c_v)_{log\delta-logt} = 0.841\ (c_v)_{1-p}$ | 0.968 |
| | • Overall | $(c_v)_{log\delta-logt} = 0.668(c_v)_{1-p}$ | 0.691 |
| – | • Pre-yield region | $(c_v)_{logt} = 4.419(c_v)_{\delta-\sqrt{t}}$ | 0.997 |
| | • Transitional region | $(c_v)_{logt} = 1.190(c_v)_{\delta-\sqrt{t}}$ | 0.814 |
| | • Post-yield region | $(c_v)_{logt} = 0.144(c_v)_{\delta-\sqrt{t}}$ | 0.479 |
| | • Overall | $(c_v)_{logt} = 4.151(c_v)_{\delta-\sqrt{t}}$ | 0.967 |

higher values of $c_v$ of compacted soils is an added advantage of the one point method which has already been proved to have inbuilt merits such as simplicity, not getting affected by the initial and secondary compressions and absence of any curve fitting process. It has also been observed that the value of $c_v$ obtained from one point method are within the range of values of $c_v$ obtained from the conventional δ-log t and δ-√t methods. Further, one point method performs equally well with other methods. In view of its simplicity and less time requirement, one point method is recommended for use in practice.

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