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Discussion: Predicting compaction properties of soils at different compaction efforts

Lucio Di Matteo PhD
Associate Professor, Department of Physics and Geology, University of Perugia, Perugia, Italy

Giovanni Spagnoli PhD, MBA
Global Project and Technology Manager Underground Construction, MBCC Group, Trostberg, Germany

Amin Soltani PhD
Lecturer, Institute of Innovation, Science and Sustainability, Federation University, Churchill, VIC, Australia; Honorary Fellow, Department of Infrastructure Engineering, Faculty of Engineering and Information Technology, The University of Melbourne, Parkville, VIC, Australia (Orcid:0000-0002-0483-7487) (corresponding author: a.soltani@federation.edu.au)

Mahdieh Azimi MSc
PhD candidate, College of Engineering and Aviation, School of Engineering and Technology, CQUniversity, Melbourne, VIC, Australia (Orcid:0000-0001-6061-7991)

Brendan C. O'Kelly PhD, FTCD
Associate Professor, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin, Dublin, Ireland (Orcid:0000-0002-1343-4428)

Contribution by Soltani, Azimi and O'Kelly

1. Introduction

Di Matteo and Spagnoli (2021) introduced a modelling framework (Equations 9–12 in their paper) for converting the optimum moisture content (OMC) and maximum dry unit weight (MDUW) between standard Proctor (SP) and modified Proctor (MP) compaction energy levels (CELs) for fine-grained soils. Their framework employs measured OMC and MDUW values for one of the CELs, together with the liquid limit (LL), to predict the corresponding values for the other CEL. Model development/calibration was performed using a database, comprising both SP and MP compaction test results for 49 fine-grained soils (LL = 17–98%), compiled entirely from various sources in the research literature. A second database of 14 SP:MP compaction data pairs, also compiled from different literature sources, was employed for validation of the model. The paper under discussion (Di Matteo and Spagnoli, 2021) offers a reasonably practical and more reliable alternative to the relatively poor prediction performance of traditional empirical correlations that rely solely on soil index properties (typically Atterberg limits and/or gradation information) for OMC and MDUW estimations. However, as demonstrated in this discussion contribution, it is the discussers' viewpoint that, when attempting to convert OMC and MDUW parameters between two CELs, the LL makes no or little contribution, but rather it restricts the SP⇆MP conversions to those soils falling specifically within the LL range used for model calibration. In other words, it is the discussers' viewpoint that reliable SP⇆MP conversions can be achieved without employing LL measurements.

2. The LL makes an insignificant contribution to the SP⇆MP conversion problem

Recent investigations (e.g. Khalid and Rehman, 2018; Shivaprakash and Sridharan, 2021) have demonstrated that reliable and consistent SP⇆MP conversions can be obtained through simple one-to-one linear correlations (without the need for any soil index properties). To explore/substantiate this viewpoint, employing the authors' compiled database of 49 SP:MP compaction data pairs (presented in Table 1 of the original paper), the discussers derived the following linear correlations:

13. $$\mathrm{OMC_{MP}} = 0.678 \times \mathrm{OMC_{SP}} + 1.654$$

14. $$\mathrm{MDUW_{MP}} = 0.845 \times \mathrm{MDUW_{SP}} + 4.262$$

In other words, the same dataset (see Tables 1 and 3 of the original paper) was used in generating and validating the SP⇆MP conversion models presented in both the authors' paper and this discussion contribution (i.e., Equations 13–16, reported herein). This approach allows valid comparisons of these models. Equations 13 and 14, both of which are approximately equal to those reported by Shivaprakash and Sridharan (2021) derived using a different database to that adopted by the authors, imply that having measured the OMC and MDUW of a fine-grained soil for SP compactive effort, the same can be predicted for the MP energy level (or vice versa) without the need for any additional soil properties. Note that the performance of the Khalid and Rehman (2018) and Shivaprakash and Sridharan (2021) correlations, being derived for larger datasets obtained for different soils (and having different LL calibration ranges) to those comprising the authors' database, was not compared to that of the authors' models.

It is noted that the statistical fit measures (R^2, root mean squared error (RMSE), ranking index (RI) and ranking

Table 5. Predictive performance of the OMC and MDUW models proposed by the authors

	MP→SP (reported by the authors)		SP→MP (calculated by the discussers)	
	OMC (Equation 9)	MDUW (Equation 10)	OMC (Equation 11)	MDUW (Equation 12)
Number of predictions, N	49	49	49	49
R^2	0.92	0.92	0.87	0.88
RMSE	1.30 wc%	0.43 kN/m^3	1.62 wc%	0.54 kN/m^3
RD	0.08	0.02	0.13	0.03
RI	0.11	0.03	0.16	0.04

wc, water content

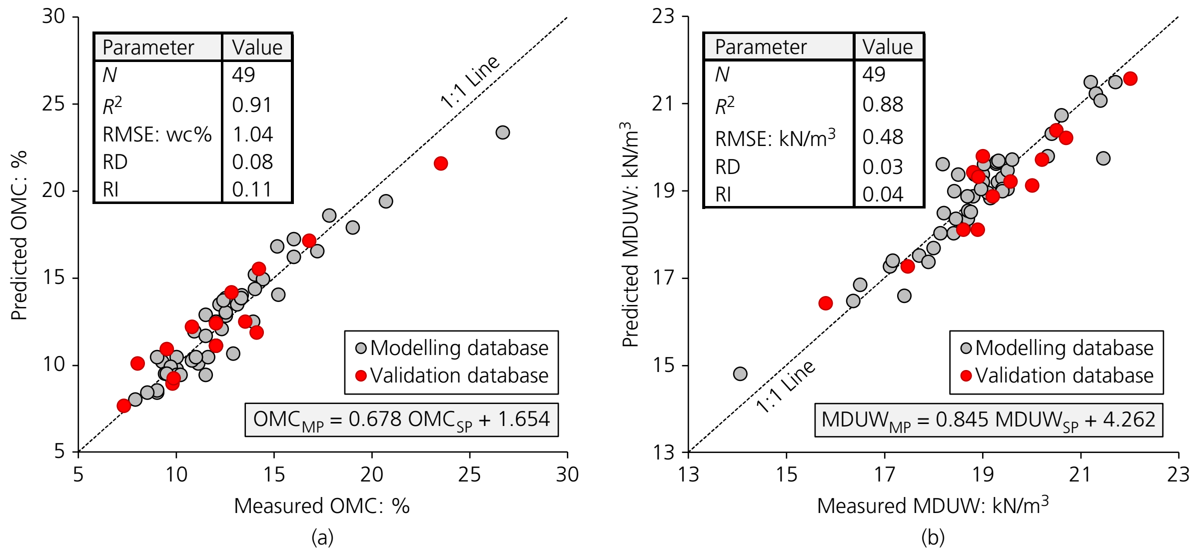

Figure 9. Correlation plots showing the level of agreement between predicted (using Equations 13 and 14 deduced by the discussers) and measured compaction parameters. The modelling database and validation database refer to the 49 SP:MP and 14 SP:MP compaction data pairs presented, respectively, in Tables 1 and 3 of the original paper

distance (RD)) reported in Table 4 of the original paper pertain to the MP→SP conversion problem (Equations 9 and 10 in the paper). Given the popularity of the SP test (and hence its measured data being more readily available) compared with the more labour-intensive MP test, it would be more fitting to consider the predictive performance of the authors' SP→MP models (their Equations 11 and 12) as the basis for further statistical comparisons with Equations 13 and 14. Employing the 49 SP:MP compaction data pairs listed in Table 1 of the original paper, the values of R^2, RMSE, RI and RD for Equations 11 and 12 (proposed by the authors) were calculated by the discussers and the results are summarised in Table 5 of this article. It is observed that the overall predictive performance is slightly lower than (but still comparable to) that reported by the authors for their MP→SP models (Equations 9 and 10 in the original paper).

Scatter plots illustrating the level of agreement between the predicted (by Equations 13 and 14 deduced by the discussers) and measured compaction parameters are provided in Figure 9. Judging by the R^2, RMSE, RD and RI values listed for OMC and MDUW in Figure 9, all values being either comparable to (or slightly better than) those calculated in Table 5 for the SP→MP conversion problem (Equations 11 and 12 in the original paper), one can conclude that reliable conversions/predictions can be achieved without having to rely on LL measurements. It should be noted that linear correlations having comparable predictive capabilities to Equations 9 and 10 proposed by the authors can also be obtained for the MP→SP conversion problem; that is (with $R^2 = 0.91$, RMSE = 1.46 wc%, RD = 0.10 and RI = 0.13) and (with $R^2 = 0.88$, RMSE = 0.53 kN/m^3, RD = 0.03 and RI = 0.04).

15. $$\mathrm{OMC_{SP}} = 1.336 \times \mathrm{OMC_{MP}} - 0.704$$

16. $$\mathrm{MDUW_{SP}} = 1.045 \times \mathrm{MDUW_{MP}} - 2.413$$

Table 6. Comparison of the predictive performance of the SP→MP models given by Equations 11 and 12 in the original paper and those introduced by the discussers (Equations 13 and 14 in this article) for soils with LL > 98%

Soil properties				Measured SP		Measured MP		Predicted MP (Equations 11 and 12)			Predicted MP (Equations 13 and 14)		
G_s	Clay: %	LL: %	Plasticity index: %	OMC: %	MDUW: kN/m^3	OMC: %	MDUW: kN/m^3	OMC: %	MDUW: kN/m^3	ODS: %	OMC: %	MDUW: kN/m^3	ODS: %
Horpibulsuk *et al.* (2008)													
2.58	59.4	150.5	111.3	28.5	13.8	20.8	15.7	17.1 (−3.7)	18.2 (+2.5)	111.8	21.0 (+0.2)	15.9 (+0.2)	91.8
2.60	56.6	152.8	104.6	32.6	13.1	23.9	15.0	21.0 (−2.9)	17.3 (+2.3)	116.0	23.8 (−0.1)	15.3 (+0.3)	93.1
2.66	58.1	256.3	217.1	33.8	12.8	27.4	14.1	14.0 (−13.4)	20.4 (+6.3)	134.0	24.6 (−2.8)	15.1 (+1.0)	89.5
Bera and Ghosh (2011)													
2.80	72.3	213.3	168.8	30.5	12.9	23.6	15.8	14.1 (−9.5)	19.0 (+3.3)	89.3	22.3 (−1.2)	15.1 (−0.6)	76.6

ODS = calculated optimum degree of saturation from MDUW and OMC for specific CEL; G_s = specific gravity
The numbers in parentheses represent the absolute prediction error (= predicted value − measured value)

The kaolinite and montmorillonitic clay (i.e., soils 43 and 34 having LL = 28.2% and 98.0%, respectively, as reported in Table 1 of the original paper) are used as demonstration examples for the two approaches. Note that the montmorillonitic clay has the highest LL among the calibration (and validation) datasets. For the kaolinite, with measured OMC_{SP}, OMC_{MP}, $MDUW_{SP}$ and $MDUW_{MP}$ of 18.31%, 15.21%, 15.55 and 17.16 kN/m^3, respectively, the discussers' Equations 13–16 predict values of 19.62%, 14.07%, 15.52 and 17.40 kN/m^3, respectively, while the authors' models (Equations 9–12) predict values of 17.90%, 16.55%, 16.23 and 16.29 kN/m^3, respectively, for the same soil. Similarly, for the montmorillonitic clay (measured OMC_{SP}, OMC_{MP}, $MDUW_{SP}$ and $MDUW_{MP}$ of 32.02%, 26.65%, 12.48 and 14.05 kN/m^3, respectively), the discussers' Equations 13-16 predict 34.90%, 23.36%, 12.27 and 14.81 kN/m^3, respectively, whereas the authors' Equations 9–12 predict 34.85%, 24.75%, 11.94 and 14.73 kN/m^3, respectively, for the same soil. In the given examples, the discussers' models provide slightly better predictions for the kaolinite, whereas the authors' models provide slightly better predictions for the montmorillonitic clay, with the levels of under- and over-predictions arising for the authors' and discussers' models dependent on the offsets of the measured data points (input values) from the model calibration equations.

3. The LL restricts the SP⇆MP conversions

Aside from being a statistically insignificant compaction predictor, it is the discussers' viewpoint that inclusion of the LL term has the effect of restricting the SP⇆MP conversions (in terms of achieving the same overall predictive performance) to those fine-grained soils falling specifically within the LL range used by the authors for their model development (LL = 17–98%). As typical examples, Table 6 compares the predictive performance of the SP→MP models proposed by the authors (Equations 11 and 12) with those introduced in this article (Equations 13 and 14) for some fine-grained soils with LL > 98% investigated by other researchers. Referring to this table, it can be observed that the authors' modelling framework is unable to make statistically significant and/or physically meaningful predictions (i.e., in terms of the calculated degree of saturation being limited to a maximum of 100%) when it is employed outside of the original LL calibration domain (of LL = 17–98%). Meanwhile, the simple linear correlations derived by the discussers are able to provide reasonably accurate and physically meaningful predictions, despite being calibrated for the same LL domain (of 17–98%). Hence, it is the discussers' viewpoint that these findings suggest the optimum compaction parameters for SP and MP compactive efforts are somewhat uniquely related and that the effects of soil index properties (LL in the present case) on soil compactability are adequately captured/explained by the measured OMC/MDUW value employed as an input/predictor for the SP⇆MP conversion. Further research on these aspects is merited.

Authors' reply

First of all, the authors thank the discussers for their interest in this topic. The authors' data presented in the original paper (Di Matteo and Spagnoli, 2021) were based on the pioneering work of Blotz *et al*. (1998) to convert the optimum compaction parameters obtained from one energy level to another. The authors used the encouragement provided by Blotz *et al*. (1998) to further validate and refine the method (based on energy ratio and the LL of soils) by analysing other soils not included in their database. The variation of the method employing compaction curves is slightly more precise, as Di Matteo and Spagnoli (2021) demonstrated, than the linear correlation SP⇆MP. The comparison between predicted and actual values in Figure 9(a) presented by the discussers shows that the values used for calibration and validation are underestimated for $OMC_{MP} > 20\%$. Therefore, although the RD presented by the discussers in Figure 9(a) is similar to that presented by the authors, it seems that the validity of the discussers' equation cannot be applied to all the database ranges. For example, for $OMC_{MP} = 26.65\%$, the predicted value obtained using Equation 9 of Di Matteo and Spagnoli (2021) is 24.75%, while the value obtained by the discussers using Equation 13 is 23.36% – that is, more than three percentage points lower than the actual value. Therefore, use of the LL does not restrict the SP⇆MP conversions as reported by the discussers. As suggested by Blotz *et al*. (1998) and confirmed by the authors' study, use of the LL produces slightly more precise SP⇆MP conversions.

Finally, the authors want to underline that if a 'reliable and consistent' SP⇆MP conversion exists, the discussers should apply the equations already presented by Khalid and Rehman (2018) and/or by Shivaprakash and Sridharan (2021). It seems that the discussers used the database of the authors to obtain new equations and not those proposed by the previously mentioned authors, which the discussers claim to be 'reliable and consistent'.

The authors warmly welcome the discussers to compile a novel database (i.e. with new data, not previously published) to support their criticism exposed in their discussion.

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