Quick Methods of Measurement of Relative Compaction and Moisture Content

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ABSTRACT

The need of compaction control is well-recognized to ensure safety and satisfactory performance of fill body. Minimum relative compaction is commonly used in the end-product specification for earthworks. The Hilf method is a way to determine the relative compaction and deviation from optimum moisture content without the need to know the moisture content of soil. Infrared with convection heating is a drying method to dry soil rapidly (within 3.5 hours for common fill materials in Hong Kong). These two methods facilitate the quick determination of the relative compaction. This paper examines these two quick methods. It also presents the review of the applicability of the Hilf method in fill compaction control based on 271 pairs of results conducted in public works projects and the effectiveness of the infrared with convection drying in measuring moisture content of soil based on 167 sets of test results. The results showed that there is a reasonably good correlation between the relative compaction determined from the Hilf method and sand replacement test, with an absolute difference in relative compaction mainly within 3%; while the moisture content obtained from the infrared with convection drying and the conventional oven drying method are statistically identical with majority of the results having differences less than 0.4% which is considered practically insignificant for geotechnical engineering applications.

Keywords: Fill Compaction, Hilf Method, Infrared Drying

1 Introduction

1.1 Background

The need of compaction control is well-recognized to ensure safety and satisfactory performance of fill body. Minimum relative compaction (RC), which is a ratio of field dry density (ρ_d) to maximum dry density (ρ_{dm}) of the compacted soil, is commonly used in the end-product specification for earthworks. Field moisture content (w_f) within a specific range from the optimum moisture content (w_o) (also called optimum water content) may also be specified in compaction control of fill materials. In Hong Kong, ρ_{dm} is determined using Proctor compaction test method in laboratory while ρ_d is calculated using the equation "$\rho_d = \rho_w /(1 + w_f)$", where field wet density (ρ_w) (also known as in-situ bulk density) and w_f are measured by sand replacement test (SRT) and conventional oven drying method, respectively. SRT has been used for many decades, which is a reliable and economic method. Conventional oven drying method for measuring moisture content usually takes at least 24 hours to complete. In practice, Additional time is required due to following reasons: (i) delivering samples from field to the laboratory; (ii) non-operating hours of laboratory; and (iii) administrative procedures and quality control process in the laboratory, such as checking of all relevant test results. Consequently, the information on RC may only be available at least 2 days after the SRT, which is highly undesirable to construction works especially during the wet seasons. It is imperative if the field compaction results could be obtained as soon as possible, in particular for large-scale backfilling works such as fill reclamation.

Hilf (1957 and 1961) proposed a method to determine the RC and the deviation of w_f from w_o without the need to determine w_f of the soil. Usually, the results of only three additional Proctor

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compaction tests are required after the SRT and these can be completed in less than two hours. The Hilf method has been widely used in the USA since its development in 1957. Subsequently, it has been codified as testing standard in Australia (AS, 2006), Brazil (ABNT 1991) and the USA (USBR 1990 & 2012; ASTM 2017). Historically, the method was introduced for cohesive soil and was used in compaction control on such soil satisfactorily (Hilf 1961). As specified in some testing standards, the method is applicable on wider range of soils. For example, in ASTM (2017), the test method is normally performed for soils containing more than 15% fines. In Hong Kong, the Hilf method has been included in General Specification for Civil Engineering Works (GS) (HKG 1992) as an alternative method to determine RC, ρ_{dm} and w_o of compacted fill with particles retained on 37.5 mm BS test sieve not exceeding 20%. However, the Hilf method receives little attention in local construction industry. The reason of not adopting the method in the past three decades by the practitioners is not known.

Another way to determine RC quickly is to shorten the duration to obtain w_f. Convection heating is adopted in conventional oven drying method. Heat is transferred through air inside the oven to soil specimens and this takes relatively long period to supply enough thermal energy to extract moisture out of the specimens. While for infrared (IR) heating, radiation is transmitted to soil specimens and water inside directly without the presence of a heating medium (e.g. air). Since there is no significant loss of energy to the ambient, the efficiency of energy transfer can be maximized, in particular if the peak output wavelength of the IR source matches with the absorption band of the material being heated. Natural wavelength of water molecule is close to that of intermediate and far IR (i.e., 1 μm to 10 μm), indicating that IR is an effective heat source for water heating. IR heating has an extensive application in manufacturing sectors, such as food, polymer and mineral processing industry. Drying of materials by combined convection and IR heating has also been studied (Masanobu et al 1988, Mortaza 2016). The drying rate is found to be remarkably increased under hybrid heating method comparing to those by convection heating alone. The use of convection heating with IR heating enhances the IR drying rate as the diffusion rate of the water vapor and the heating rate of the material would be increased (Tiller and Garber 1942). It is considered that a more stable and uniform temperature distribution and energy efficiency of IR drying process can be elevated by combined use of convection oven with IR heating source.

This paper examines the above two quick methods. It also presents the review of the applicability of the Hilf method in compaction control based on the tests conducted in public works projects and the effectiveness of the IR with convection drying in measuring moisture content of local soils.

2 The Hilf Method

2.1 The Theory

RC can either be expressed as a function of wet density or dry density, see Figure 1.

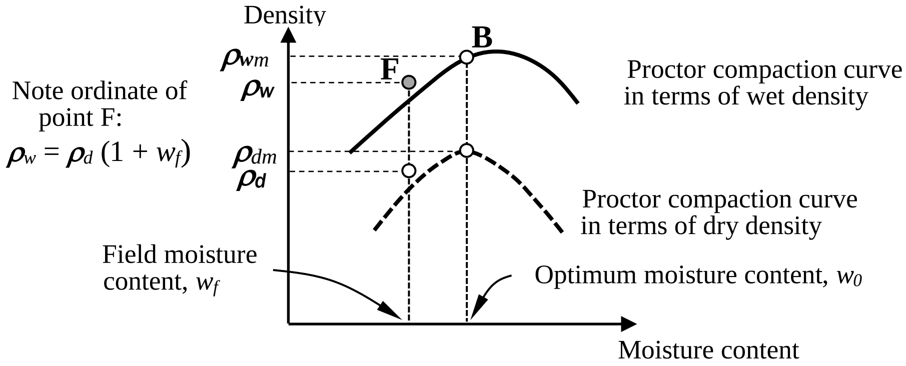

Figure 1: Proctor compaction curve

$$RC = \frac{\rho_d}{\rho_{dm}} = \frac{\rho_d(1+w_f)}{\rho_{dm}(1+w_f)} \tag{1}$$

After the SRT in the field, additional soil samples surrounding the SRT spot are taken. When the soils are transported back to the laboratory, typically three compaction tests using Proctor equipment are conducted on the soil samples to obtain the wet densities. The moisture content of the three specimens for the compaction tests is normally pitched at z = 0, ±2%, ±4%, where z is defined as the added/removed water in reference to w_f in percentage of soil wet mass before adding any water in laboratory (see Equation (2)). The "±" sign depends on whether w_f is estimated to be less than or greater than w_o. For example, if w_f is estimated to be less than the w_o, then the three moisture contents could be z = 0, +2% and +4%.

$$z = \frac{wM_s - w_f M_s}{M_s(1+w_f)} = \frac{w - w_f}{1+w_f} \tag{2}$$

where M_s is the dry mass of soil and w is the moisture content of soil. Rearranging Equation (2) gives 1 + z as shown below:

$$1 + z = \frac{1+w}{1+w_f} \tag{3}$$

Each soil compaction test on the additional soils taken from the field gives a point on a plot with wet density as ordinate and z as abscissa (see P1, P2 and P3 in Figure 2, assume positive z). For each of these three points, the ordinate is divided by (1 + z) to obtain a so-called converted wet density (also known as converted bulk density). A parabola may be fitted to the three converted wet density data points. The maximum value of this parabola can then be obtained (see point A in Figure 2). The converted wet density (CWD) is calculated from dividing the wet density of soil by (1 + z),

$$\mathrm{CWD} = \frac{\text{wet density}}{1+z} = \frac{\rho_d\,(1+w)}{1+z} = \frac{\rho_d(1+w)}{\frac{1+w}{1+w_f}} = \rho_d\,(1+w_f) \tag{4}$$

Since w_f is a constant, the maximum value of the CWD (i.e., the vertex of the parabola, MCWD) must be $\rho_{dm}(1+w_f)$, i.e. point A in Figure 2. Equation (4) also shows that when $w = w_o$,

$$\frac{\rho_{dm}\,(1+w_o)}{1+z_m} = \rho_{dm}(1+w_f) \tag{5}$$

where z_m is the abscissa of point A.

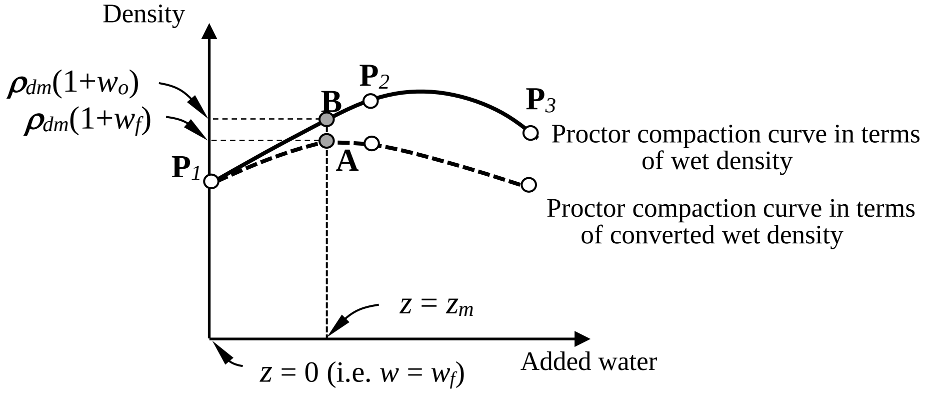

Figure 2: The Hilf method compaction curve

RC (also known as ratio D in Hilf method) can now be obtained from ordinates of Point F in Figure 1 and Point A in Figure 2:

$$\text{RC or D} = \frac{\rho_d}{\rho_{dm}} = \frac{\rho_d\,(1+w_f)}{\rho_{dm}\,(1+w_f)} = \frac{\text{ordinate of Point F (Figure 1)}}{\text{ordinate of Point A (Figure 2)}} \quad \textbf{(6)}$$

As far as density control of fill compaction is concerned, in addition to a specified minimum RC, many specifications also require w_f be close to w_o, for example, a tolerance of ± 3% of w_o. The Hilf method provides information of the difference between w_f and w_o (i.e., $w_f - w_o$) without the determination of the w_f of the compacted fill material. Refer to the converted wet density curve in Figure 2, the z value corresponds to the peak point (A) is z_m. Rearrange Equation (5) and from the definition of z_m to give:

$$w_o - w_f = \frac{z_m}{1+z_m}(1+w_o) \quad \textbf{(7)}$$

The right-hand side of Equation (7) cannot be evaluated unless w_o is known or estimated. Hilf then made use of about 1,300 data set compiled by the Bureau of Reclamation of US to establish a correlation between the maximum wet density (ρ_{wm}) and w_o. As Point B (i.e., ρ_{wm}) shown in Figure 1 and Figure 2 are known, the corresponding w_o can be estimated from the correlation. The correlation between ρ_{wm} and w_o can also be developed based on the results of Proctor tests in Hong Kong (see Figure 6). The difference between w_f and w_o (i.e., w_o - w_f) is then calculated from Equation (7).

2.2 Test Programme

A total of 102 field trials were conducted in 40 different construction sites. Amongst the field trials, 77 of them used 2.5 kg rammer in Proctor compaction test while the remaining adopted 4.5 kg rammer. Usually, more than one SRT is carried out for one batch of fill compaction works according to GS (HKSAR 2020). Therefore, in total, 271 pairs of results were obtained from these trials to compare the RC values calculated from the Hilf method with that determined from SRT. Analysis of the difference between w_f and w_o determined from the Hilf method and conventional oven drying method was also carried out.

Distribution of the data set collected from the trials in terms of soil types and compaction efforts in Proctor tests is presented in Table 1. The fill materials covered in the study were mainly coarse-grained soils and classified as sandy GRAVEL or gravelly SAND. The distribution of ρ_{dm} and the corresponding ρ_{wm} at w_o against w_o are presented in Figure 3. As shown in the Figure, fill material in this study had ρ_{dm} and w_o close to the relationship between ρ_{dm} and w_o (i.e., $\rho_{dm} = 3.703\ w_o^{-0.266}$) for sandy GRAVEL, gravelly SAND and silty/clayey SAND proposed by Chung & Chu (2020).

Table 1: Distribution of Soil Types in Field Trial

Soil Type	Compaction Effort Used in Proctor Test	Number of Data Set Collected from Trials	Percentage in Entire Set of Data
sandy SILT/CLAY	2.5 kg	22	8.1%
silty/clayey SAND	2.5 kg	18	6.6%
gravelly SAND	2.5 kg	128	47.2%
sandy GRAVEL	2.5 kg	46	17.0%
sandy GRAVEL	4.5 kg	57	21.0%
Total number of data set		271	100%

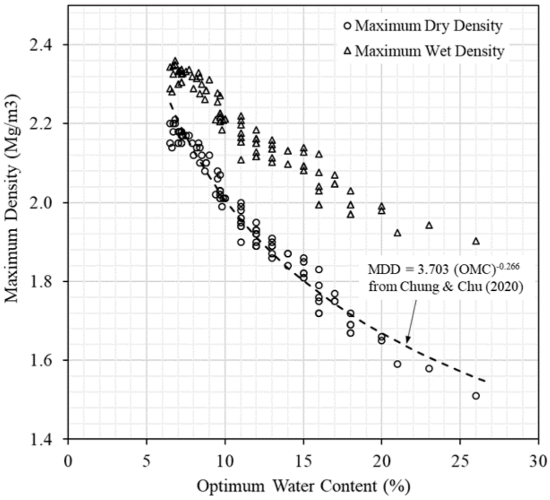

Figure 3: Maximum density versus optimum moisture content of soils in the study

For each trial, sufficient soil from the compaction layer near one of the locations of SRTs was collected for the additional Proctor compaction tests under the Hilf method. The soil was kept in a sealed plastic bag to preserve its field moisture content, w_f. Upon returning to the laboratory, the soil was screened over 20 mm BS test sieve and subdivided into equal portions. First portion of the soil was compacted at its w_f in a standard cylindrical mould according to the procedure of the Proctor test. The rammer used in the Hilf method followed the one used to determine ρ_{dm} through Proctor test for the calculation of RC.

Specific amount of water which equaled to certain percentage of the wet mass of the soil was added to or removed from other portions of the soil (e.g., z = ± 2%). The soil with adjusted water content was compacted in the same way. Converted wet density was then calculated from the wet density divided by (1 + z). For each trial, the w_f was also determined from oven drying method so that assessment on the applicability of the Hilf method in prediction of the difference between w_f and w_o can be made. In general, 3 to 4 compaction tests were carried out for each trial. It took about 2 hours to complete sample preparation and additional compaction tests in the laboratory. With the use of Hilf method, the information on RC may be available within 0.5 to 1 day after the SRT.

2.3 Density Control by the Hilf Method

Relative compaction value (D) obtained from the Hilf method was compared with the RC value obtained from SRT (Figure 4). In general, D value increased with the increase of RC value. Regression analysis was conducted. A linear relationship between D and RC values with the R-squared of 0.71 was determined. Most of the results had the absolute difference between D and RC values within 3% (84%

of the data). The mean of the difference ($\overline{X}_{D\text{-}RC}$) and the standard deviation of the difference ($S_{D\text{-}RC}$) were 0.32% and 2.22% respectively.

The distribution of the difference between D and RC values was further evaluated based on soil type and compaction effort used in the compaction test. As shown in Figure 5, the differences were concentrated within ± 3% irrespective of soil type and level of compaction effort used (i.e., 2.5 kg and 4.5 kg). The trend of the relationship between D and RC values for different soil types and compaction efforts were similar to the data considered in one single group. If RC ≥ 95% is adopted as the compliance criterion in fill compaction control, only a very small proportion of data (about 2.9% bounded by the red dashed box) was interpreted as compliance results based on the Hilf method but non-compliance in accordance with the SRT results.

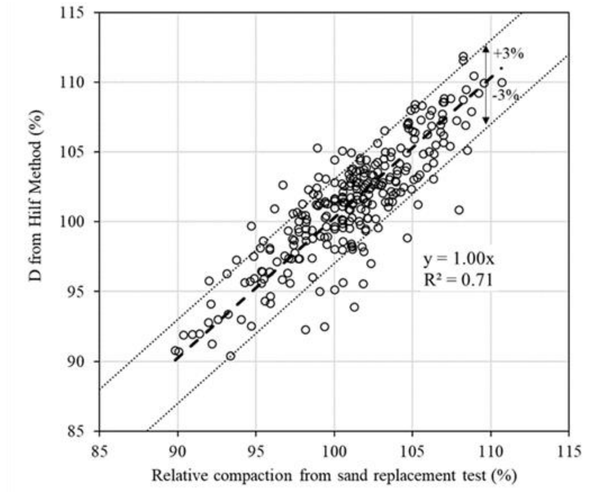

Figure 4: D values versus RC values

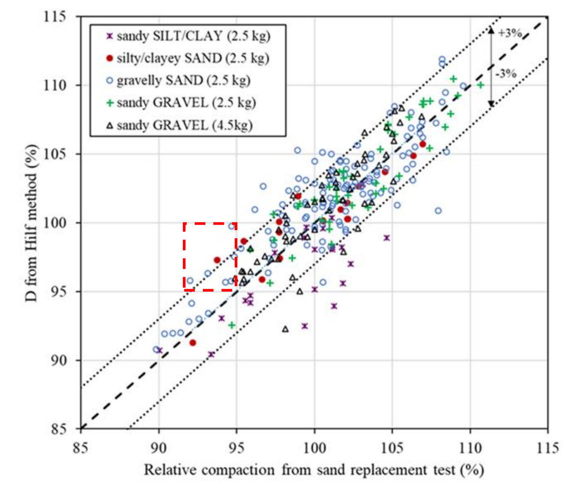

Figure 5: D values versus RC values for different soil types and compaction efforts

2.4 Moisture Content Control by the Hilf Method

The applicability of the Hilf method for moisture content control was evaluated. In the Hilf method, the deviation of w_f from w_o is estimated based on a relationship between ρ_{wm} and w_o without knowing w_f or w_o for each in-situ density test. Local ρ_{wm} - w_o relationships were used in this study. The relationships were determined from a review of 15,952 results of Proctor tests conducted between 2014 and 2018 under public works projects in Hong Kong. Relationships between ρ_{dm} and w_o were first established for 4 different soil types and 2 different compaction efforts. Then the relationships between ρ_{wm} at w_o and w_o with the highest R-squared were determined. The relationships are presented in Table 2. Figure 6 shows the distribution of data for four soil types in two different compaction efforts. With the measured ρ_{wm}, w_o was calculated based on these relationships. (w_f - w_o) was then determined using Equation (7) based on z_m and w_o.

Table 2: Local Relationships between ρ_{wm} at w_o and w_o

Soil Type	Rammer Used in Proctor Test	Best-fit Relationship	R-squared	Number of Proctor Test
sandy SILT/CLAY	2.5 kg	$\rho_{wm} = -0.021\ (w_o) + 2.399$	0.789	965
silty/clayey SAND	2.5 kg	$\rho_{wm} = 2.385\ e^{-0.009\ w_o}$	0.752	2626
gravelly SAND	2.5 kg	$\rho_{wm} = 2.996\ (w_o)^{-0.134}$	0.756	8084
sandy GRAVEL	2.5 kg	$\rho_{wm} = 2.514\ e^{-0.012\ w_o}$	0.691	1487

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sandy GRAVEL	4.5 kg	ρ_{wm} = 2.491 e $^{-0.01\,wo}$	0.467	2790

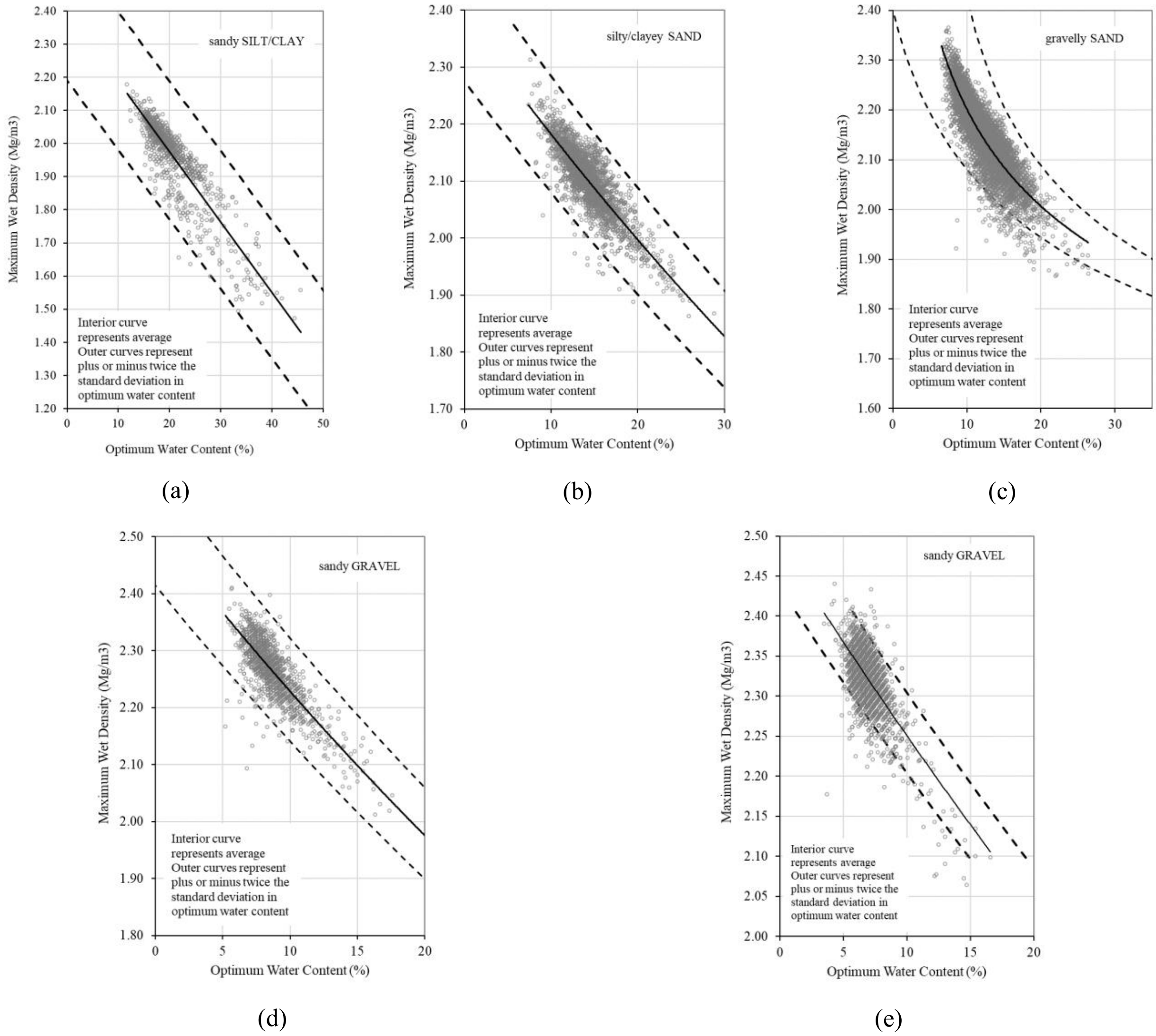

Figure 6: ρ_{wm} - w_o Relationship for (a) sandy SILT/CLAY (2.5 kg); (b) silty/clayey SAND (2.5 kg) ;(c) gravelly SAND (2.5 kg); (d) sandy GRAVEL (2.5 kg); and (e) sandy GRAVEL (4.5 kg)

The values of (w_f - w_o) determined from the Hilf method based on local ρ_{wm}-w_o relationships were plotted against the values of (w_f - w_o) with w_f determined from oven drying method and w_o from Proctor test (see Figure 7). The values of (w_f - w_o) determined from the Hilf method and oven drying method showed a linear relationship. Regression analysis showed that more that 90% of the data (w_f - w_o) were negative indicating that w_f at the time of carrying out SRT was mostly on the dry side of the w_o. About 50% of the data had w_f less than w_o more than 3%. This observation matched with the review carried out by Chung & Chu (2020) which showed that about 37% of 42,191 SRTs conducted under public works projects had w_f less than w_o more than 3%. The best fit curve established between (w_f - w_o) from the Hilf method and (w_f - w_o) from oven drying method and Proctor test attained a high R-squared of 0.844.

Similar to the comparison between D and RC values, the data of (w_f - w_o) from the Hilf method and oven drying method was re-analyzed based on soil types and compaction efforts used in the compaction tests. As shown in Figure 8, the differences were concentrated within ± 3% for all soil types and compaction efforts. About 11% of the data (as highlighted in red dash box) indicated that the compacted fill had w_f meeting the requirement in GS (i.e. w_f within ± 3% from w_o) while the compaction did not meet the requirements based on the results from oven drying method (i.e. $w_f < w_o$-3%).

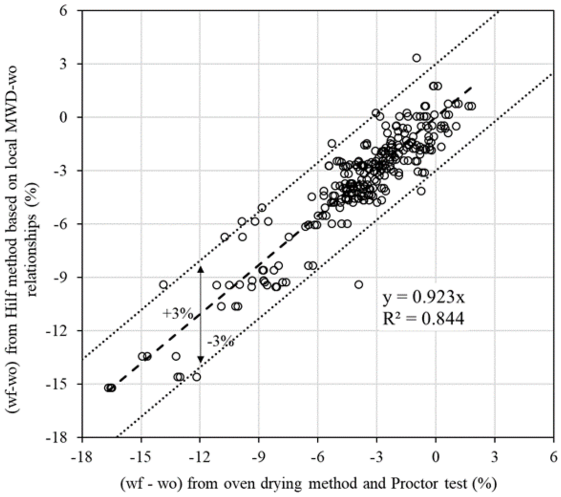

Figure 7: (w_f - w_o) determined from the Hilf method (based on local ρ_{wm} - w_o relationships) and oven drying method

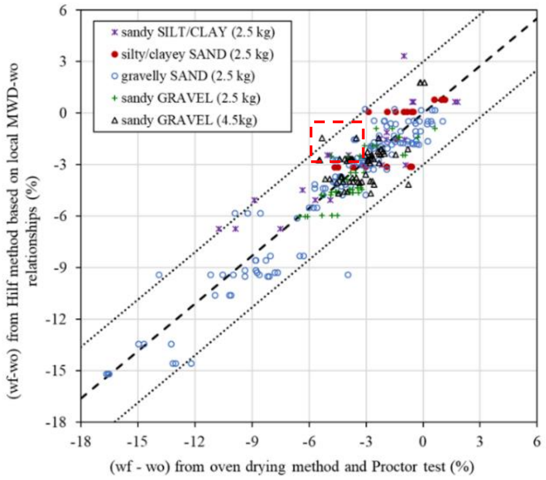

Figure 8: (w_f - w_o) determined from the Hilf method (based on local ρ_{wm} - w_o relationships) and oven drying method in different soil types

2.5 Review on the use of the Hilf Method

The results show that there is a reasonably good correlation between "degree of compaction" from the Hilf method and SRT. There is also no significantly difference in "deviation from optimum moisture content" determined from the Hilf method and oven drying method. The findings suggested that the Hilf method can provide an alternative option for density control and moisture content control in compaction works should quick results are required. The use of the Hilf method may increase certain uncertainty of the compaction works and hence the engineer's risk. Therefore, it is suggested that the Hilf method should not replace all the compaction control tests using RC and oven drying method as routine procedure. The Engineer/designer may decide an appropriate frequency of using the Hilf method taking into consideration of (a) the acceptance level of the uncertainty in compaction works; and (b) the calibration results of D (from Hilf method) and RC (from SRT) in the course of construction.

3 Infrared with Convection Drying Method

3.1 Heating Mechanism and Performance of the Oven with Hybrid Heating

The oven to be reviewed in the study adopts hybrid heating method with mid to far-IR radiation and convection heating. 16 pieces of IR panels are installed at top and bottom sides. Each IR panel is 0.2 kW and the total power of all panels is 6.4 kW. The interior of the oven is shown in Figure 9. There are two K thermocouples for the IR heater built in the center and one double K thermocouple for unit body temperature control using Proportional-Integral-Derivative (PID) controller. PID controller uses a control loop feedback mechanism to control process variables. It receives information from temperature sensors as input and compares the actual temperature to the target temperature, then provides output to control the heating sources. In this study, the target temperature of the convection heating source and IR panels were both set at 105ºC. Distribution of temperature inside the hybrid oven was reviewed based on the method of calculating the temperature deviation of the oven following a method suggested by Hong Kong Accreditation Service (HKAS) (HKAS 2019). The temperature deviation was found to fell within 1.79ºC and 2.17ºC with 60 minutes of pre-heating time; while ranged between 1.12ºC and 1.36ºC with 90 minutes of pre-heating time. These deviations well satisfy the requirement of ± 5ºC from 105ºC as specified in GEOSPEC 3 (GEO 2017).

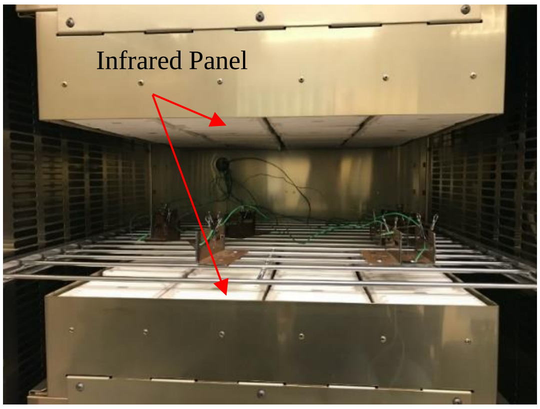

Figure 9: Internal Space of Hybrid Oven

Efficiency of the oven was also reviewed based on its ability to evaporate water. Following the Public Works Laboratories (PWL) Checking Procedure for Oven (PWL 2013), the average evaporation rate of the hybrid oven with convection and IR heating was about 50% to 57% higher than that of conventional oven with average measured temperature at 105.5ºC. Besides, dry uniform sand with particle size between 63 μm and 600 μm was used to review the capability of the oven to maintain the soil temperature without overshooting above 110ºC. As shown in Figure 10, temperature of all sand specimens achieved a mean temperature of about 105 ºC after 100 minutes then levelled off.

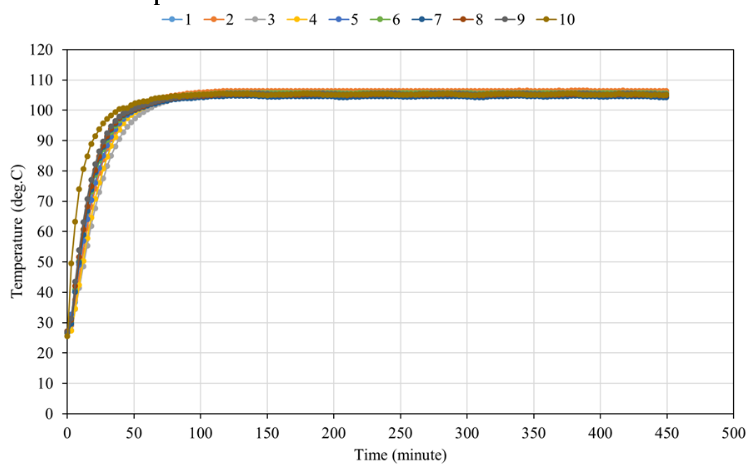

Figure 10: Temperature of dry uniform sand during drying period in hybrid oven

3.2 Test Programme

Ten soil types, ranged from fine-grained to coarse-grained, were prepared for the study. The finest soil had 100% of particles passing 63 μm test sieve whereas the coarsest soil has 10% of particles larger than 37.5 mm with the maximum particle size limited to 50 mm. Fine soil with all particles passing 63 μm test sieve is considered rarely in use for fill compaction works in Hong Kong and this soil type probably represents a worse composition of materials in local filling works in practice. All soils were mixed with a specific amount of water to achieve a moisture content of about 3% above OMC in this study. Each specimen was prepared with a minimum mass of soil according to GEOSPEC 3 (GEO 2017) based on its particle size distribution.

The successive masses of the specimens after 3 hours and 3.5 hours under hybrid heating (with IR and convection heating at the same time) were measured and the mass of specimen after 3.5 hours of drying was used to determine the moisture content of the specimens. Afterwards, the specimens were transferred to conventional oven with temperature set at 105 ± 5ºC for further drying of 24 hours. In this period of time, the specimens were subject to convection heating solely which was same as that in routine moisture content test according to GEOSPEC 3 (GEO 2017). Moisture content of the specimens after drying in conventional oven was determined. Hybrid heating is considered acceptable for rapid moisture content determination with drying time of 3.5 hours if there is no significant difference between moisture content values obtained from hybrid heating and subsequent conventional heating. The drying criterion of hybrid heating (i.e., difference in any two successive weighings of the specimens, taken after 3 hours and 3.5 hours of drying, less than 0.1% of the initial soil mass) was examined as well.

3.3 Test results

Three fine-grained soil types, with a total of 54 specimens, were tested. For specimens with initial mass of at least 30 g, the differences in successive weighings of most specimens after hybrid oven and conventional oven drying ranged between -0.09 g to 0.07 g, except one with value of 0.24 g. The differences led a small variation of less than 0.4% in moisture contents between two drying methods for most of the specimens (about 93% of the specimens). The small variation in moisture content indicated that moisture in fine-grained soils were successfully removed within 3.5 hours using hybrid drying method. 7 out of 54 specimens (about 13% of specimens) did not meet the drying criterion for hybrid oven drying. The difference in successive weighings was more than 0.1% of the initial soil mass with the largest value of 0.42% (equivalent to 0.13 g).

Five medium-grained soil types, with a total of 105 specimens, were tested. The differences in successive weighing of specimens after hybrid oven and conventional oven drying fell within a range of 0.01 g to 0.92 g for specimens with minimum initial mass of 300 g. The differences resulted in changes of less than 0.4% in moisture contents determined from two oven drying methods for most of the specimens. The small changes revealed that moisture in medium-grained soils were successfully removed within 3.5 hours using hybrid drying method. Similar to fine-grained soil, small proportion of specimens (about 17%) had successive mass difference between 3 hours and 3.5 hours of drying more than 0.1% of the initial soil mass, with highest value of 0.6% (equivalent to 1.8 g). While for coarse-grained soil, 8 specimens in three soil types were tested. The changes in successive weighting of specimens after drying in two ovens were between -0.9 g and 5.3 g for specimens with minimum initial mass of 3000 g. These changes caused the differences were less than 0.3% in moisture contents determined from two oven drying methods. The test results indicated that moisture in coarse-grained soil was also successfully removed by hybrid drying method. Only one specimen slightly deviated from the drying criterion for hybrid oven with value of 0.16% (equivalent to 4.8 g). Throughout the drying process, temperature of all specimens was well controlled below 110 ºC.

3.4 Discussions

Based on the experimental test results, the oven with hybrid drying method (IR with convection heating) was capable to maintain the target temperature with a deviation less than that required in conventional drying method stipulated in GEOSPEC 3 (GEO 2017). The higher evaporation rate of about 50% more than that of conventional oven indicated that the performance of the hybrid oven was elevated in terms of the efficiency of removing water. The requirement of maintaining soil temperature without exceedance of 110ºC was also satisfied.

Drying method with the adoption of both IR and convection heating was applicable to determine moisture content of fine-grained to coarse-grained soil rapidly, within 3.5 hours of drying, if soil has a moisture content 3% above the OMC. Figure 11 shows the moisture content determined from hybrid oven drying and subsequent convection oven drying for all soils in this study. A linear relationship between moisture content from two drying methods with the R-squared of 1 was determined. The mean and the standard deviation of the difference between two moisture contents were only 0.01% and 0.17% respectively. The test statistic was 0.837 which was lower than the critical value of 1.974 for significant level of 0.05 and with degree of freedom of 166. The null hypothesis for no difference in moisture content determined from two drying methods could not be rejected. In other words, the moisture contents determined from these two drying methods could be considered as statistically identical for a significant level of 5%. Besides, the difference between the moisture content determined from hybrid oven and conventional oven drying was in general less than 0.4% for different soil types. The difference is considered practically insignificant for geotechnical engineering applications.

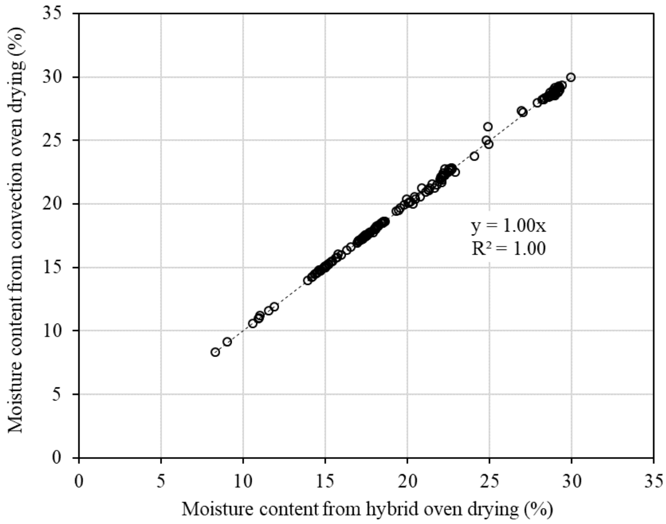

Figure 11: Moisture Content Determined from Hybrid Oven Drying versus Moisture Content Determined from Convection Oven Drying

Regarding the termination criterion for IR and convection heating method, the comparison illustrated that soil could be deemed to be dried if the successive weights of specimens taken half-hourly after 3 hours of drying with IR and convection heating was less than 0.1% of the original mass of the specimen. For some specimens which cannot meet this drying criterion, it is recommended that the specimens to be returned to the hybrid oven for successive drying and weighted at half-hourly intervals until the drying criterion is satisfied. It is expected that the difference in moisture contents between two oven drying methods would be further reduced, less than 0.4%. To provide more effective drying, it is suggested that soil specimen should be crumbled and placed loosely in the container. As the temperature during drying process is up to 110ºC, the method is considered not suitable for soils containing gypsum, calcareous or organic matter. Drying by other means (e.g., in convection oven at 45ºC) is considered more appropriate.

4 Conclusion

This paper examined two quick methods in measuring RC and moisture content. 271 pairs of results from 102 field trials conducted in public works project showed that there is a reasonably good correlation between “degree of compaction” from the Hilf method and sand replacement test. There is also no significant difference in “deviation from optimum moisture content” determined from the Hilf method and oven drying method. The findings of the review suggested that the Hilf method can provide an alternative option for density control and moisture content control in compaction works for fine to coarse-grained soil should quick results be required.

There was practically no difference in the moisture content results determined from the hybrid oven and conventional oven based on 167 test results on 10 soil types from fine to coarse-grained soils. The results also showed that moisture content test with hybrid drying could be completed within 3.5 hours for soils with moisture content of about 3% above optimum moisture content. The study demonstrated that hybrid drying with IR and convection heating is a reliable and quick alternative method to determine moisture content for most of the soils encountered in compaction works in Hong Kong.

5. Declarations

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5.2 Publisher's Note

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