Comparing Vibratory and Impact Laboratory Compaction Methods

La Comparaison du Vibrateur et l'Impact de la method de Compaction

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ABSTRACT
Laboratory analysis carried out on different soils shows that vibratory and impact compaction produce different results. Standard methods based on BS 1377: 1975 using the vibratory hammer and mod AASHTO for impact were applied. Results obtained for maximum dry density and optimum moisture content were compared for each soil. It was found that the vibratory method was more suitable than impact for non-cohesive soils and gravels. Cohesive soils reached maximum compaction at higher moisture contents using vibration as opposed to impact, but at lower densities. It is clear that field densities under vibratory compaction would be difficult to achieve where the laboratory control method was based on impact.

RÉSUMÉ
Texte du résumé L' alanyse faite siu les differnts solsmentre que la vibration et l' impact de la compaction preduit des differents resultals. La methode basée siu BS 1377 : 1975 pour la vibrateur et la modification AASHTO pour l' impact fut employé. Les resultats obtenus poui le maximum de densité seche et l' optimum humidité furent comparé pour chaque sol. On a censtaté que le morteau vibrant est mileux adapté pour les sols pulveruleuts que les gravels. Le sol cohésif atleint le maximumde compaction a un plus liant degré d' humidité se servant de la vibration a l' impact, mais a une densité plus basse. C' est evident que sous la compaction du vibrateur sua difficele a altteindie, si la methode du laboratoire est basée sui l' impacte.

Keywords : vibratory compaction, impact, density, moisture content, soil compaction.

1 INTRODUCTION

The main sub-problem identified in this research project will be dealt with in this paper. Research (Lange, 2005) was carried out to test the following hypothesis: "The vibrating hammer method of compacting soil in the laboratory is suitable for certain soil types used in the construction of roads and embankments." The investigation was conducted on a total of five different soils found in the Greater Johannesburg region in Gauteng province of South Africa. Standard procedures were first followed for the engineering classification of each soil and then, the compaction properties were determined, using the vibrating hammer according to BS 1377: 1975 and also the Mod. AASHTO impact method (British Standards, 1978).

The effectiveness of both methods of compaction for each soil was studied by way of a comparison of the results obtained for *MDD* and *OMC*. This was illustrated by tabulating the numerical values and plotting the curves together on the same set of axes. The results for each soil were recorded separately before summaries of the numerical comparisons were made. This paper presents the results of that exercise.

2 DISCUSSION OF RESULTS

In the section below, the results of the compaction tests for each soil were studied and compared. Primary consideration was given to the manner in which the vibratory compaction properties differed from those of impact. Where possible explanations were given for each significant difference observed.

2.1 *Comparison of maximum dry densities*

In General, it was found that Vibratory compaction significantly reduced air voids in non-cohesive soils. Table 1 provides details of the compaction characteristics for each soil.

Table 1. Summary of Compaction Characteristics for all soils

Sample	Mode	MDD	OMC	Vib MDD as % of Imp MDD	Air Voids	PI
R01A	Imp	2091	4.99	102.53	0.13	4
	Vib	2144	5.99		0.08	
R01B	Imp	2055	2.78	104.72	0.19	4
	Vib	2152	4.75		0.11	
R02A	Imp	1736	16.6	93.78	0.09	7
	Vib	1628	23.2		0.03	
R02B	Imp	1897	14.5	67.42	0.04	27
	Vib	1279	14.8		0.35	
R04	Imp	1888	14.3	97.14	0.03	11
	Vib	1834	14.4		0.06	
R05A	Imp	1784	15.2	63.45	0.09	15
	Vib	1132	16.6		0.40	
R05B	Imp	1795	18.2	65.18	0.03	15
	Vib	1170	18.8		0.36	
R06A	Imp	2114	7.4	95.32	0.05	3
	Vib	2015	7.8		0.09	
R06B	Imp	2123	7.95	92.09	0.03	3
	Vib	1955	10.4		0.06	

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Figure 2 provides a graphical illustration of the data given in the above table. The densities obtained by both the impact and vibratory methods as percentages of saturated dry density (SDD) of each sample are shown. In addition the vibratory *MDD* expressed as a percentage of the impact *MDD* is also shown.

The plasticity index (PI) of each soil is given in order to indicate the relative cohesiveness. This enables a view of the effectiveness of either compaction mode in relation to soil type. It should be noted that the vibratory mode produced a reasonable reduction in air voids for all soils with a PI less than 11, that is, for 6 of the 10 samples. In these cases the air voids ranged from 0.03 to 0.11, with a mean of 0.07, compared with the mean obtained through impact of 0.087 for the same samples. Whereas samples with a PI of 15 and higher performed poorly, under vibratory compaction. Here the air voids ranged from 0.35 to 0.40.

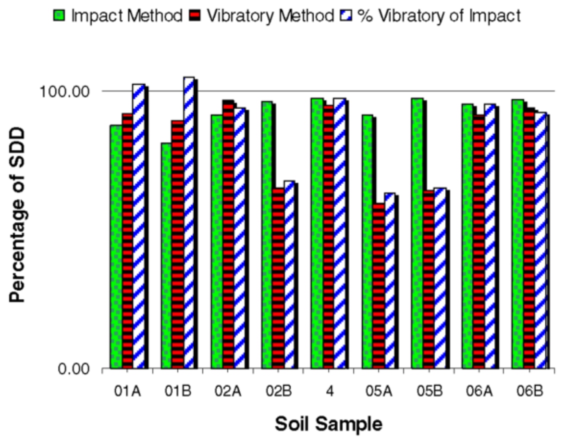

Figure 1. Comparison of Compaction Results for all Soils

2.2 *Good void reduction through impact compaction on cohesive soils*

The data was further summarized by plotting the maximum dry density obtained for each soil by vibratory compaction against the respective percentage of mod. AASHTO maximum dry density. Figure 2 below demonstrates the trend obtained.

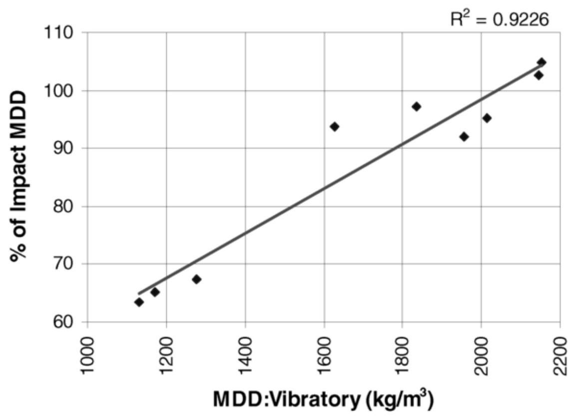

Figure 2. Correlation Between Percentage of *MDD* (Impact Compaction) and *MDD* (Vibratory Compaction) for all Soils.

In addition, the relationship between maximum dry density: impact and maximum dry density: vibratory was considered in Figure 3.

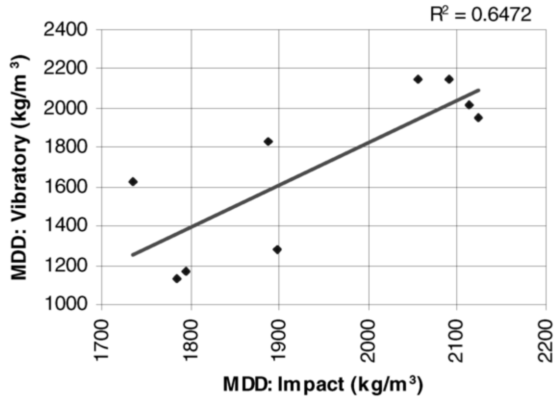

Figure 3. Correlation Between *MDD* (Vibratory Compaction) and *MDD* (Impact Compaction) for all Soils.

These two figures illustrate the large difference obtained between the two modes of compaction on the four cohesive samples. Vibratory compaction produced maximum dry densities on these samples which ranged from 65.45 % to 67.42 % of that for impact. The respective void ratios had a mean of 0.365. However, the mean void ratio achieved through impact was as low as 0.043, showing that this mode was most suited to clayey soils due to the kneading action that was produced in conjunction with the impact forces. It may be possible to conclude that the operating frequency of the vibratory hammer was much higher than the natural frequencies of these soils.

2.3 *Vibratory compaction well suited to certain soils*

The results show that the vibratory compaction test would be well-suited to the R01A and R01B soils. The percentage of vibratory over impact compaction, for the maximum dry densities obtained, were 102.53 and 104.72 % respectively. With a *PI* of 4.0 and a gravelly sand texture the Midrand soil would have a relatively high natural frequency and should compact readily under forces produced through compaction from this particular type of vibratory hammer as required by BS 1377.

2.4 *Impact compaction achieved the highest dry densities in most cases*

The two soils that compacted well through the vibratory method (R01A and R01B) had a *PI* of 4.0, a linear shrinkage (*LS*) of 0.00 and were also classified as highly suitable for use as a road subgrade (A-1-a on the AASHTO system). The other soils in the research had *PIs* ranging from 3 to 27 and *LLs* of 2.0 to 11.0. These soils all performed better under the impact mode of compaction.

2.5 *OMC for vibratory was greater than that for impact in all cases*

Table 2 below provides details of the differences in the *OMCs* obtained for both impact and vibratory compaction for all of the soils in the research. This difference recorded as a percentage, ranged from +0.70% to +70.86%.

2.6 *The curve for vibratory compaction had the better fit for most samples*

Table 3 below contains the coefficients of determination (R^2 – value) which relate to the curves fitted to the compaction data for each sample.

Table 2. Comparison of Optimum Moisture Contents Obtained for all Soils

Sample Number	OMC		% Variance
	IMP.	VIB.	
R01A	4.99	5.99	+20.04
R01B	2.78	4.75	+70.86
R02A	16.10	23.20	+44.10
R02B	14.49	14.75	+1.79
R04	14.25	14.35	+0.70
R05A	15.15	16.60	+9.57
R05B	18.15	18.78	+3.47
R06A	7.35	7.76	+5.58
R06B	7.95	10.40	+30.82

Table 3. Comparison of Moisture / Density Relationships (R^2 Values)

SAMPLE Number	R^2 Value	
	IMPACT	VIBRATORY
R01A	0.6928	0.6686
R01B	0.8457	1.0000
R02A	0.9663	0.9728
R02B	0.8486	0.9738
R04	0.9609	0.9968
R05A	0.9636	0.9069
R05B	0.9973	0.5409
R06A	0.9063	0.9916
R06B	0.8868	0.9568
MEAN VALUE	0.8974	0.8898

Despite the fact that the mean values suggest that the moisture / density curves for impact compaction corresponded more satisfactorily with the compaction data, a study of the R^2 values for vibratory compaction showed that in most cases this data was more easily matched to a curve. This fact suggests that good consistency was obtained using this method. Possible reasons for the poor fit obtained for the two samples (R01A and R05B) for vibratory compaction, were:

2.6.1 *Effect that removal of the gravel fraction had on R01A*

This sample had the fraction greater than 4.75 mm removed before compaction. This alteration of the grading structure had an adverse effect on the compaction properties of the soil. It should be noted that the R^2 value for impact compaction was also low.

2.6.2 *Need for vibratory compaction at a lower frequency for R05 B*

This sample was compacted in its natural form with the fraction greater than 4.75 mm still part of the grading structure. However, as the *PI* was relatively high, it was likely that vibratory compaction at a lower frequency would be closer to the soil's natural frequency than that of the vibrating hammer. This phenomenon suggests that the internal cohesive forces due to the presence of the plastic fines in the soil, prevented the vibratory forces from causing closer packing of the coarser particles in the soil.

It should be noted that the R^2 value for the same soil using impact compaction was one of the highest recorded in the experiment.

2.7 *Effect of removal of fraction greater than 4.75 mm*

The removal of the gravel fraction greater than 4.75 mm from the soils before vibratory compaction had varying effects on the compaction properties. The sections below provide details:

2.7.1 *Reduction in maximum dry density*

For samples R01A and R05A the maximum dry densities were decreased by -0.37% and -3.25%, respectively.

2.7.2 *Increase in maximum dry density*

For the sample RO6A there was an increase in maximum dry density of +3.07%.

2.7.3 *Increase in optimum moisture content*

For the sample R05A there was an increase in optimum moisture content of +26.11%.

2.7.4 *Decrease in optimum moisture content*

For samples R05A and R06A there was a decrease in optimum moisture content of -11.61% and -28.27% respectively.

2.8 *Confining effect of the mould during compaction*

2.8.1 *The case of vibratory compaction*

The constant pressure of the tamper, coupled with the dynamic forces generated during vibratory compaction, are likely to introduce lateral forces in the soil which are resisted by the confining wall of the mould. This occurrence could be related to the Poisson effect which is likely to set up a system of friction forces between the mould and the soil which restrict the compression of the soil under the tamper. It would be more prominent with the "sticky" plastic soils due to adhesion of soil particles to the sides of the mould. This condition would not be a problem in the vibratory compaction of soil in layers on site as the lateral forces would dissipate into the layer.

2.8.2 *The case of impact compaction*

Impact compaction in the mould causes a vertical shearing effect on the soil under each blow of the tamper which would be large enough to easily overcome any side friction. Therefore, this condition should not affect the dry densities obtained as much as that experienced with vibratory compaction.

3 CONCLUSIONS

3.1 *Importance of the control of layer thickness during compaction*

Good control of layer thickness would be necessary for consistent results in the case of both vibratory and impact compaction. A likely reason for the better R^2 – values obtained for most of the vibratory compaction results could be that, the tamper foot left a smooth surface after compaction of each layer, making it easy to take height readings to determine layer thickness. Hence the operator would always be well informed on whether results were within the specification or not, and apply appropriate controls. Whereas with impact compaction, due to the hammer's puncturing of the surface with each blow, the layer thickness could only be roughly estimated, making this task difficult to carry out.

An example of the consequences of poor control of layer thickness can be seen in the vibratory compaction results on the R01B sample.

3.2 *Possible features of a modified vibratory compaction test*

A primary purpose of a laboratory compaction test would be to apply compaction forces which could produce the highest possible dry densities for a given soil. Certain modifications could be made to the vibratory compaction test to improve on its abilities to fulfill this purpose.

3.2.1 *Allow for compaction of thinner layers*

It should be possible that a modified version of the vibratory compaction test could have an increased number of layers to be compacted, thus reducing their thickness. Four, five or six layers would reduce to thicknesses of 31.75 mm, 25.4 mm and 21.17 mm respectively, compared with the 42.5 mm obtained using the current BS specification, which requires only 3 layers of 38 to 42mm thickness each.

3.2.2 *Vary the frequency*

The addition of a variable speed controller to regulate the operating frequency of the hammer could be installed. This improvement would make it possible for soils to be compacted at frequencies close to their natural frequencies. (Semmelink, 1987) This alteration however could cause the energy output to be reduced. This situation could be compensated for by compacting layers of lesser thickness.

3.2.3 *Reduce cycle times*

The problem of de-densification due to over compaction needs to be studied. Compaction for periods shorter than the specified 60 seconds per layer should be experimented with to determine optimum cycle times. During the vibratory compaction tests it was observed that, for most of the soils tested the point of maximum compaction was reached well within the standard time required.

3.3 *Standard compaction test needed to monitor vibratory compaction on site*

The existing practice in use by engineers was to monitor and control vibratory compaction on site using the Mod. AASHTO (Impact) test in the laboratory. The findings in this research experiment show clearly that this approach has obvious flaws. In particular, it has been demonstrated that some plastic soils compacted using the vibratory method in the laboratory, tended to have much higher optimum moisture contents than when compacted using the impact method. It stands to reason that efforts on site to achieve high dry densities with these soils at lower moisture contents, would be futile. There is need to develop a standard test for the purpose of monitoring vibratory compaction on site.

3.4 *Applications of these findings to typical soil compaction solutions*

In the design and construction of embankments for roads, runways, dams, mine tip walls and other similar structures, it is essential that the designer can accurately model the soil mass in its actual compacted state. Structures of this type depend on the inter-particle forces set up in the compaction process which increase the soil's ability to perform appropriately under the loads applied.

Of particular interest to the authors, reinforced soil structures (in the form of stabilized slopes and embankments and basally reinforced soil foundations) have a specific requirement for the ability of the soil to transfer stresses to the geosynthetic reinforcing elements. This transfer of stress is largely dependent on cohesion and internal friction in the soil (Scotto and Naughton, 2008). These two properties are directly dependent on the degree of compaction and the functions of density (or reduction in the void ratio which can also be interpreted in terms of volumetric strain) and moisture condition. All reinforced soil designs are therefore directly influenced by the accuracy of the description of the soil's compacted state both before construction at the design stage, and post construction during the working life of the structure. It is clear that not only durability and integrity are at stake but also a clear-headed prediction by the designer of the horizontal and vertical movement expected, and subsequent control of this characteristic in terms of allowable tolerances.

REFERENCES

British Standards Institution. 1978. Vibrating Hammer Method for Compaction of Soil, Test 14 of BS 1377: 1975.

Lange, DP. 2005. Validation of the Vibrating Hammer for Soil Compaction Control, University of Johannesburg, South Africa. April 2005. Chapters 4 and 5.

Scotto, M., Naughton, P. 2008. Design of basal reinforcemnent for embankments over soft soils, Maccaferri SA Lecture Series, Johannesburg, South Africa. April 2008.

Semmelink, C. 1987. Calibration of the Vibratory Compaction Table, Technical Note: TC/14/87, National Institute for Transport and Road Research, CSIR, South Africa, March 1987, pp. 1 to 12.