RELATIVE COMPACTION: IN SEARCH OF A RATIONAL METHOD FOR SPECIFICATION

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1 INTRODUCTION

The primary purpose of compacting engineered fills is to expel water and air from the soil matrix to achieve an increase in stiffness, thereby reducing the likelihood of post construction settlement.

Engineers and earthwork contractors are accustomed to adopting ‘relative compaction’ as a means of compliance testing. Specifications relating to earthwork construction control are commonly expressed as:

\[ \frac{\gamma_d \text{field}}{\gamma_d \text{max}} \times 100 > R \% \]  

where \( \gamma_d \text{field} \) is the material density of the material measured in the field, \( \gamma_d \text{max} \) is the maximum dry density obtained from a known energy input and R(%) is the required relative compaction.

Despite being widely accepted, relative compaction does not have any direct correlation with the known properties of a material. Hence, there is no rational method for selecting an acceptable percentage R(%) for a particular purpose (Gue and Liew, 2001).

The intention of this paper is to investigate the rationale behind the perceived need within the construction industry to specify a minimum density ratio R(%) and consider what rational recourse a civil engineer or technician has when a compaction specification cannot be met.

1.1 BACKGROUND

Originally the energy input required to achieve \( \gamma_d \text{max} \) was that proposed by Proctor (1933), now referred to as the standard compaction test (AS1289.5.1.1-2003). The amount of energy input was later increased to keep up with increasingly heavy compaction plant, referred to as the modified compaction test (AS1289.5.2.1-2003). It is also customary for specifications to require the field material to be compacted at a moisture content within a specified range of the optimum moisture content (AS1289.5.2.1-2003).

Recommended levels of relative compaction for cohesionless soils provided by Australian Standard AS3798-1996 are given in Table 1. Also given in Table 1 is the maximum density index more commonly referred to as relative density,

\[ D_r = \frac{e_{\text{max}}-e}{e_{\text{max}}-e_{\text{min}}} \]  

Where \( D_r \) is the relative density (usually expressed as percent), \( e \) is the in situ void ratio, \( e_{\text{max}} \) is the void ratio of the soil in the loosest condition and \( e_{\text{min}} \) is the void ratio of the soil in the densest condition.

Table 1: Examples of minimum standard of compaction.

<table>
<thead>
<tr>
<th>Australian Standard: AS3798-1996</th>
<th>Maximum Density Ratio, % (cohesionless soils)</th>
<th>Maximum Density Index (cohesionless soils)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>95 std</td>
<td>65</td>
</tr>
<tr>
<td>Commercial</td>
<td>98 std</td>
<td>70</td>
</tr>
<tr>
<td>Pavement -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>subgrade</td>
<td>98 std</td>
<td>80</td>
</tr>
<tr>
<td>sub-base courses</td>
<td>95 mod</td>
<td>Na</td>
</tr>
<tr>
<td>base course – heavily loaded</td>
<td>98 mod</td>
<td>Na</td>
</tr>
<tr>
<td>base course – other</td>
<td>95 mod</td>
<td>Na</td>
</tr>
</tbody>
</table>

Unfortunately, AS3798-1996 provides no rational method of determining what level of compaction is adequate for a particular intended purpose. This is despite stating: “the designer should be conscious of not over-specifying the level of compaction required, simply for the sake of expediency.”

The following section describes a case study where an earthworks contractor was unable to meet the compaction specification and explores what recourse the engineer has when faced with the question: “will this level of compaction be adequate?”
2 CASE STUDY

This section presents a case study where the earthworks contractor was unable to meet the compaction specification during the construction of an underpass as part of the Southern Suburbs Railway.

The construction site was situated approximately 30km south of Perth over deep deposits of calcareous sand. The result of a CPT test undertaken within the envelope of the underpass is given in Figure 1.

The approximate foundation level of the underpass is shown in Figure 1 to be approximately RL 0.0 m AHD. The CPT result indicates that a layer of medium dense sand approximately four metres thick is located directly below the foundation level.

![Figure 1: CPT profile and approximate foundation location.](image)

The situation that arose was that the earthwork contractor was unable to achieve the required level of relative compaction, which was 98% maximum modified dry density (MMDD). Figure 2 shows the relationship between %MMDD achieved and number of passes with a vibratory roller. The asymptotic nature of the curve indicated that it would be very difficult to achieve 98% MMDD.

![Figure 2: Compaction achieved at two test locations after compaction with a vibratory roller.](image)
There are number of possible reasons why 98%MMDD was not achievable at this location. Two reasons that were considered were, first, that the stiffness of the underlying sand was not adequate to provide full reflection of the compaction effort (Hanna, 2003) and second, that particle breakdown had occurred in the laboratory samples during compaction and the field compaction results were essentially from a different material. Due to the calcareous nature of the sand it was quite possible that the second reason could have been be a contributing factor (Coop, 1990). The effect of particle breakage on the maximum achievable compaction is demonstrated in the following discussion.

The particle size distribution obtained from a sieve analysis before and after a modified compaction test is given in Figure 3 for similar sand to that identified at the base of the underpass excavation (Results from Arup file). The results demonstrate that there is a measurable change in particle size distribution after a modified compaction test has been carried out on a sample.

![Graph showing particle size distribution before and after compaction](image)

Figure 3: Particle size distribution before and after compaction testing of a sand derived from Tamala Limestone.

Variation in the particle size distribution would result in a different calculated relative density (Equation 2), so the compaction results obtained from the field may not correspond to those obtained in the laboratory. Indeed it is possible that continued attempts to compact the in situ material may be hindered because the in situ relative density may be approaching a $D_r$ of 100%.

### 3 THE 95% FIXATION

The common practice of earthwork specification has been likened to a “95% fixation” (Monohan 1986; Charles et al., 1998). In recent times the prolific specification of 98%MMDD could be viewed in a similar way. The following quotes highlight the frustrations of some researchers with the seemingly thoughtless processes which determine the way compaction specifications are handled:

Monohan (1986): “Since the reasonable but otherwise arbitrary choice of 95% Proctor densities as the target value for fill control work of the 1920s was made, there has developed a fixation on the part of specification writers to require this percentage compaction, irrespective of loadings, fill thickness, or other factors that should logically influence compaction requirements.”

Holtz and Kovacs (1981): “Since the objective of compaction is to stabilize soils and improve their engineering properties, it is important to keep in mind the desired engineering properties of the fill, not just its dry density and water content. This point is often lost in earthwork construction control.”

Although a compaction is a seemingly simple problem, it is important to keep in mind that compaction is directly related to cost and the unnecessary over specification of compaction adds to the cost. Conversely, too little compaction can result in expensive repair costs (Gue and Liew, 2001; Charles et al., 1998). Unfortunately there is very little information available to the engineer on which to base a decision.

In light of the apparent technical inadequacy of specifications the following section deals with the compressibility of compacted sands in relation to relative density.
4 COMPRESSIBILITY OF COMPACTED SAND

Since the primary purpose of compaction is to minimise post construction compression, it is worth examining some cases where the compressibility of granular material has been measured in relation to relative density.

Carrier (2000) demonstrated that the degree of compaction by itself may not achieve desired modulus. Figure 4 presents the results of five compression curves obtained from samples compacted to differing levels of relative compaction and moisture contents. The results demonstrate that the sample compacted to 99% MDD will exhibit much greater compressibility when compacted at a moisture content only a few degrees wet of the optimum moisture content.

Figure 4: Settlement of a cohesionless fill compacted under varying degrees of wetness (Carrier, 2000).

Cocks and Hillman (2003) observed that there was no difference in resilient modulus for CBR specimens compacted to 96% of MDD compared to 98% of MDD.

Hellweg and Rizkallah (1980) compacted sand specimens in an oedometer ring to varying degrees of relative density and applied a 50 kPa load. Once settlement of the sample had ceased the samples were flooded from the bottom up and any additional settlement was recorded. The degree of compaction versus total settlement curves are shown in Figure 5.

Figure 5: Degree of compaction versus total strain under a 50 kPa load for two different sand types (Hellweg and Rizkallah, 1980).

As would be expected the total settlement of the samples increased according to the degree of compaction (standard proctor). However, of most interest is the well defined increase in total settlement below a ‘threshold level of compaction’. The locations of increased total settlement are numbered, Point 1 and Point 2 in Figure 5, corresponding to ‘medium sand’ and ‘fine sand’ respectively. Point 1 corresponds to a ‘threshold level of compaction’ of
approximately 92% relative density for ‘medium sand’. Point 2 corresponds to a ‘threshold level of compaction’ of approximately 89% relative density for ‘fine sand’.

It is important to note that, for both the ‘medium sand’ and ‘fine sand’ tested by Hellweg and Rizkallah (1980), the ‘threshold levels of compaction’ are both below 95% relative density (standard proctor). The upshot of these results is that the ‘95% fixation’ concept may not be without a rational basis. However, due to the scarcity of similar published results, it is not possible to conclude whether the proximity ‘threshold level of compaction’ obtained by Hellweg and Rizkallah (1980) to 95% relative density is not simply a coincidence.

Given the shortage of available data relating to compacted sands there may be no recourse available to the engineer other than producing a correlation between the properties of compacted sands to in situ properties of natural sands. The simplest way to do this would be to adopt the properties of natural sands to compacted sands of a similar density index. Coop (1990) observed that the compressibility of over consolidated sand was found to be higher than that of identical sand compacted to the same void ratio. The difference is likely to be due to particle breakage and different contact stresses (Mitchell and Soga, 2005).

The above results demonstrate that relative compaction is not an ideal index for expressing the compressibility of sand. Interestingly other techniques are available for determining the stiffness of a soil, for instance the Clegg impact value (CIV) (AS 1289.9.6.1-2000) or the Briaud Plate Test (BPT), but unfortunately these are not referenced in AS3798 and hence the uptake of their use has been limited within Australia.

5 CONCLUSION

Due to the lack of a rational method of earth works quality control, density is still used as the governing criterion for compaction acceptance.

As discussed, particle breakage may influence the outcome of compaction testing particularly in calcareous sands. In such cases the engineer is provided with very little scope to accept a level of compaction other than that specified. This is despite the Australian Standard stating that over specifying compaction should be avoided.

The lack of a rational basis for specifying compaction based on relative compaction has led to a “95% fixation”.

Results of compression tests undertaken on compacted sand demonstrate that specifying density alone may not guarantee soil stiffness. The results by Hellweg and Rizkallah (1980) are of particular interest, as they show an apparent ‘yielding’ below a certain level of relative density. However, the ‘threshold level of compaction’ is likely to be highly material dependant.

Despite the existence of methods of testing in the field that produce direct correlations with compressibility, they have not been included in AS 3789, despite there being an Australian standard for determining CIV. While these methods continue to be omitted from the AS 3789 it is unlikely that they will be regularly used in earthwork specifications and the engineer will continue to struggle to answer the question: *will this level of compaction be adequate?*

6 REFERENCES

AS 1289.5.1.1-2003: Methods of testing soils for engineering purposes - Soil compaction and density tests - Determination of the dry density/moisture content relation of a soil using standard compactive effort.

AS 1289.5.2.1-2003: Methods of testing soils for engineering purposes - Soil compaction and density tests - Determination of the dry density or moisture content relation of a soil using modified compactive effort.


