

IN-SITU WASTE CHARACTERISATION FOR PRIMARY SETTLEMENT ASSESSMENT FOR HIGH EMBANKMENT BUILT OVER MUNICIPAL SOLID WASTE

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ABSTRACT

Due to land restriction, some sections of several highway and railway projects have to be constructed over poor and uncommon foundation such as waste materials placed as part of the preceding landfill operation. Waste/Municipal Solid Waste (MSW) materials especially those comprising high amount of organic and readily degradable materials are highly compressible and have high variability in composition and void distribution. Conventional geotechnical laboratory testing and limited in-situ testing are often insufficient to characterise waste material. A design of field trial to understand the settlement characteristics will also require a reasonable understanding of the properties of waste materials.

This paper presents a basic methodology for in-situ characterisation of waste materials to enable the assessment of geotechnical properties of these materials on the basis of their composition and organic content. This includes the selection of suitable drilling method to allow for a good quality and continuous waste sample recovery. From such characterisation, a dimensionless Waste Compressibility Index (WCI) can then be derived based on procedures given in the published literature. The WCI value can then be correlated with compression ratio used to analyse primary consolidation settlement.

A case study is presented in this paper where a railway embankment was to be built over a landfill foundation consisting of existing Municipal Solid Waste (MSW) in the east coast of Australia. The foundation was treated by means of high surcharge. The abovementioned methodology has been used in the design to characterise MSW materials and assess primary settlements. The back-analysis by using settlement monitoring data indicate a reasonable agreement between the WCI related to the back-analysed compression ratio and the estimated WCI values. This agreement was obtained despite the variability in the aforementioned correlation. It shows that a basic methodology for in-situ waste characterisation on the recovered waste sample was able to provide a reasonable estimate of compressibility parameters for the purpose of analysing primary settlements.

1 INTRODUCTION

It becomes increasingly inevitable for the routes of new highway and railway infrastructures to traverse area underlain by poor or unconventional foundation materials. This area includes landfill where waste materials have been previously placed in subdivided cells. The majority of landfills were used as dumping ground for Municipal Solid Waste (MSW) with heterogeneous content and large proportion of organic materials. Consequently, the compressibility of MSW materials is relatively high and variable in comparison with the compressibility of conventional soft soil. As a result, ground improvement is usually required to limit the post construction settlements to which these infrastructures are subjected (Van Impe and Bouazza, 1997). For the design of such ground improvements, it is essential to estimate compression ratio to assess primary consolidation settlements. Magnitude and completion of the primary settlements including large void collapse are important information which will be required to assess the remaining post construction settlements.

However, the estimate of compression ratio (CR) will require the characterisation of MSW materials to allow for their treatment as geomaterials. The conventional laboratory testing is not usually practical due to large size and irregular shape of the samples, limited availability of equipment to measure large strain due to large void collapse (Landva et al., 2000), as well as health and safety issue. In-situ testing such as cone penetration testing, pressuremeter or dilatometer may not be sufficient if they are not undertaken in large quantity and in conjunction with investigations which involve sample recovery. The undertaking field trial is useful to assess the settlement characteristics but the design of such trial will require an understanding on the properties of MSW materials.

Various literatures have presented unique relationship between CR and various geotechnical properties (organic content, moisture content and density) of MSW materials. CR has been reported to decrease with the decrease in the organic content (Sower 1973; Chen et al. 2009). CR has also been observed to increase with the increase in moisture content

(Reddy et al. 2009; Wall and Zeiss 1995). An increase in MSW density has been reported to have an influence in a decrease in the compression index (C_c) of MSW materials (Landva et al. 2000; Chen et al. 2009).

It is worth noting that the primary settlement assessed by using CR is related to the physical and mechanical process involving the reorientation of particles, movement of the fine materials into larger voids and collapse of void spaces (Sharma and De 2007) under a given load. In most cases, the primary compression of MSW materials was not a result of dissipation of excess pore water pressure due to relatively high permeability and unsaturated condition of MSW materials (Wall and Zeiss 1995; Bareither et al. 2012). As organic solids are typically more compressible than other MSW constituents and consequently tend to form weaker structures around voids, the relative influence of organic solid content to the primary settlement is considered to be significantly higher in comparison to other MSW constituents.

This paper presents a basic methodology for the in-situ waste characterisation to estimate compression ratio required to assess the primary settlements. A discussion is presented on the proposed basic investigation scope to allow for a good recovery, identification and assessment of MSW constituents. Then, some equations are given to assess the equivalent geomaterial properties of MSW. The MSW materials can then be characterised by using a dimensionless index suggested by Bareither et al. (2012). This index allows an estimate of compression ratio (CR). To demonstrate the aforementioned technique, a case study is presented which involves an estimate of a compression ratio for MSW materials on which a proposed railway embankment was to be built in the east coast of Australia.

2 GEOTECHNICAL SITE INVESTIGATION

2.1 PLANNING OF INVESTIGATION

Prior to the undertaking of fieldwork investigation, it is a good practice to conduct a desktop study as part of the planning process. Depending on available information, this study may comprise the review of historical aerial photographs, waste placement records, survey record and operational records (i.e. leachate circulation, gas monitoring, etc). It is useful to obtain information regarding the type and volume of MSW constituents, landfill depth, thickness/interval of cover layers and age of landfill. Details of such planning work are given in Landva and Clark (1990).

2.2 BASIC INVESTIGATION METHODOLOGY

The majority of landfill comprise highly variable MSW materials with varying degree of placement compaction (Zekkos et al., 2006). As the MSW characterisation requires a continuous exposure of MSW sample, a suitable investigation technique should be employed. An open excavation pit may be suitable for relatively shallow landfill formation. On the other hand, an unsuitable drilling technique may result in poor sample recovery or difficulty in locally penetrating solid objects.

As most of landfill can be expected to be thicker than 5 m, and obstructions within landfills may cause difficulties to conventional drilling, it may be necessary to adopt other investigation techniques such as sonic drilling. In sonic drilling (ref. Figure 1), the core barrel is typically advanced by using a high-frequency energy transferred downwards to the drill face. This energy generated at sonic frequency liquefies the surrounding materials hence reducing frictional resistance against the barrel. The casing is then advanced around the core barrel to protect it from collapsing hole. The core barrel is then extracted along with the samples.



Figure 1: Typical sonic drilling and MSW samples recovered during sonic drilling

Physical measurements should be taken on each sample run to obtain total length, sample diameter and approximate sample weight (with or without water). Detailed inspection on the sample should then be carried out to allow for classification of materials forming the MSW materials. This includes the constituent material type, proportion (i.e. measured by thickness or area and weight), odour and colour. Where possible, notes should also be recorded on the material density, moisture condition and state of decomposition. High resolution photographs of MSW samples along with a ruler should be taken to allow for further analysis following the fieldwork completion.

Landva and Clark (1990) proposed the following classification of MSW materials based on the biodegradation potential:

- Organic Putrescible (OP) comprising readily biodegradable materials such as food waste, garden waste.
- Organic Non-putrescible (ON) comprising slowly biodegradable materials such as paper, wood, textiles, oil.
- Inorganic Degradable (ID) comprising metal with potential degradation due to corrosion
- Inorganic Non-degradable (IN) comprising typical inert materials such as construction rubbles, soil, ash, glass, ceramics.

It is imperative that the quantity and properties of OP materials are sufficiently obtained from the investigation as these and their associated changes over time will affect the compressibility and strength characteristics of MSW materials. The OP materials have high water absorption capacity and are highly compressible. As described above, the compressibility of MSW materials is typically governed by the organic solid content (OP), moisture content and density at the time of the load application.

For the purpose of primary settlement assessment, it would be necessary to obtain several geomaterial properties including bulk unit weight (γ_b) and compression ratio (CR). Once the detail of MSW constituents are obtained, the dry density (γ_d) can be obtained by the following equation (Landva and Clark, 1990):

$$\gamma_d = \frac{1}{\sum_1^n \frac{w_{si}}{w_{sc}} \times \frac{1}{\gamma_{di}}} \quad (1)$$

Where γ_d = average dry density of landfill (kN/m³); w_{si} = solid weight of waste constituent (kg); w_{ci} = total solid weight of waste samples (kg); γ_{di} = typical dry density of waste constituent (kN/m³). Depending on shape and condition of recovered waste materials, it could be more practical to estimate the volume of waste constituent or the volume of whole sample. This estimate can be done by physical measurement with or without the use of water as the displaced medium. Where these volumes can be reasonably estimated, the dry density can be analysed as follows:

$$\gamma_d = \frac{1}{v_t} \sum_1^n v_{si} \times \gamma_{di} \quad (2)$$

Where v_{si} = approximate volume of waste constituent (m³ or litre); v_{si} = approximate volume of waste constituent (m³ or litre). For practical purpose, γ_{di} for a specific material type can either be obtained from published data or representative laboratory testing. Moisture content of sample (m_d) is typically needed to estimate γ_b for a typical geomaterial. Such estimate in the field could potentially be challenging due to the use of drilling fluid and the varying absorption capacity of various waste constituents. Two possible methods are proposed. The first method involves the measurement of moisture content for representative sample for each waste constituent which is capable of absorbing water. Equation (3) below can be adopted (Landva and Clark, 1990).

$$\gamma_b = \gamma_d (1 + m_d) = \gamma_d \left(1 + \sum_1^n \frac{w_{si}}{w_{sc}} \times \frac{\Delta\gamma_{di}}{\gamma_{di}} \right) \quad (3)$$

Where $\Delta\gamma_{di}$ is the increase in unit weight of waste constituent (kN/m³). The second component of the sum in the bracket in the equation (3) essentially describes the average of moisture content of various waste constituents. Alternatively, it is possible to estimate moisture content (by dry weight) on the basis of its correlation with organic content which typically has a high capacity of water absorbance. This correlation, which was developed based on field observation, was originally presented Landva and Clark, 1990 and Park et al. 2011. In this study, additional data from published literatures were added as shown in Figure 2 below. The variability in the estimate should be noted in the selection of appropriate value of moisture content. Detailed sensitivity or reliability studies may be required as part of the design. A comparison against available literature (Zekkos et al., 2006) presenting comprehensive database of landfill unit weight is also worthwhile.

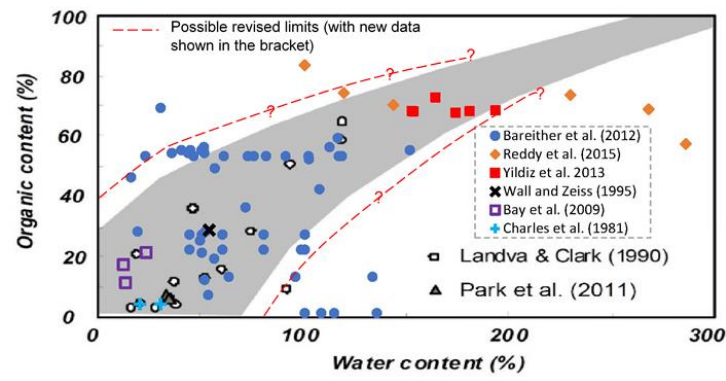


Figure 2: Extended relationship between organic content in waste materials and moisture content (Base figure from Landva and Clark, 1990)

3 ESTIMATE OF PRIMARY SETTLEMENTS

Bareither et al. (2012) proposed a dimensionless Waste Compressibility Index (WCI) based on the percentage of biodegradable materials, moisture content and MSW density.

$$WCI = m_d \left(\frac{\gamma_w}{\gamma_d} \right) \left(\frac{OP}{100 - OP} \right) \quad (4)$$

Where OP is the percentage of biodegradable materials (taken as organic putrescible materials); m_d is dry weight moisture content; γ_d is dry unit weight (kN/m^3); γ_w is unit weight of water. In soil mechanics, dry weight moisture content is equivalent to the moisture content where weight of solid excludes water.

By carrying a regression analysis on a large database of test results available in the literature and their own experiments, Bareither et al. (2012) developed a relationship to estimate compression ratio (CR) from WCI.

$$CR = 0.26 + 0.058 \log_{10} WCI \quad (5)$$

Where CR = compression ratio ($C_c / (1 + e_0)$); C_c = compression index. It should be noted that the estimate of CR can be carried out with a range of ± 0.087 for each value of WCI. Similar to the variation in the correlation between organic content and moisture content, the estimate of CR will require a judgement and, if warranted, may involve sensitivity or reliability study.

The above estimate is proposed for MSW layers where organic content is present and governs the primary compression of the MSW materials due to its higher compressibility and tendency to form weaker structures around voids. The use of WCI is also capable of capturing the variation in the organic content with time due to the decomposition of MSW materials. Where organic content becomes smaller (i.e. WCI approaches 0 %), the corresponding CR becomes relatively smaller. In the complete absence of organic content, the use of WCI is no longer applicable.

4 CASE STUDY – RAILWAY PROJECT IN EAST COAST OF AUSTRALIA

4.1 OVERVIEW

A rail embankment was to be built in the eastern coast of Australia. A section of the proposed alignment with an approximate length of 200 m had to be built over the buried landfill cells. Ground improvement in the form of surcharging was employed to reduce the post construction settlements. The ground improvements in the forms of rigid and semi-rigid inclusions as well as dynamic compaction were not adopted due to a risk of damage to the existing landfill features including the leachate circulation system and liner.

The high surcharge embankment and waiting period were designed to induce the primary settlement (reduction in void ratio) and consequently reduce the post construction settlement via the decrease of creep strain rate ($C_{\alpha\epsilon}$). It is shown that the decrease in $C_{\alpha\epsilon}$ has a distinct correlation with the reduction in void ratio (Siddiqui et al., 2013). As part of the design, the performance of ground improvement was assessed by monitoring the settlements due to the surcharge loading. Ground settlement were monitored by using Settlement Plates (SPL) and Hydrostatic Profiling Gauges (HPG) as shown in Fig. 3.

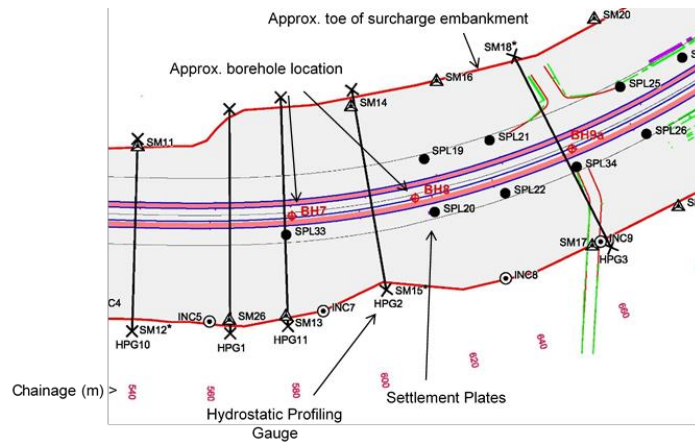


Figure 3: Plan view showing subject area (vicinity of BH7, BH8 and BH9a)

As part of pre-design investigation, several boreholes were drilled. Three boreholes BH7, BH8 and BH9a were selected for this study due to their proximity to the settlement monitoring points. Boreholes BH7 and BH8 were drilled using sonic technique with excellent sample recovery. Borehole BH9a was drilled by using conventional rotary drilling technique with Standard Penetration Test (SPT) at every 1.5 m interval. Only partial sample recovery was achieved in borehole BH9a. The majority of SPT testing resulted in refusal or blow count of over 50 per 300 mm penetration. Locations of BH7, BH8 and BH9a are shown in Figure 3.

Additionally, the settlement monitoring of a field trial conducted earlier in 1985 was also considered in the study. This field trial was conducted for other purpose in nearby area located just about 100 m to the south of area shown in Figure 3. Prior to the field trial, the investigation was undertaken by means of a test pit excavated to 5 m deep below the then ground surface. A circular trial embankment was built by using uncompacted crushed sandstone to a total height of 3 m with a top diameter of about 3 to 4 m. The settlement was monitored by means of settlement plates. Further details are available in Siahaan et al. (2014).

4.2 IN-SITU WASTE CHARACTERISATION

MSW characterisations for BH7, BH8 and BH9a have been carried out as per the method described above. The MSW composition by weight is given in Figure 4 below.

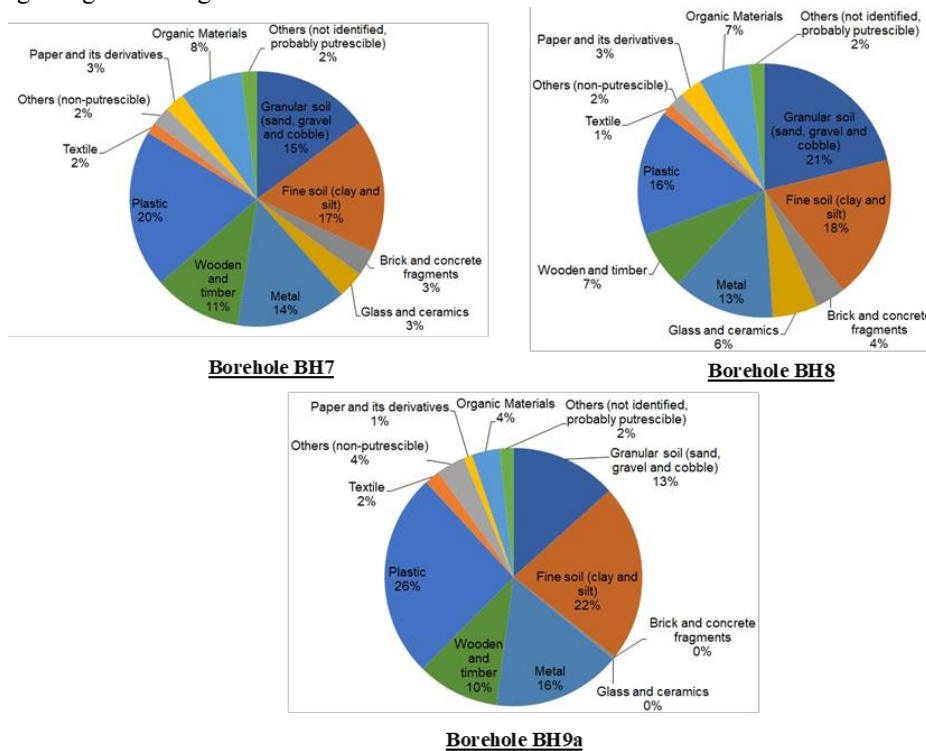


Figure 4: Assessed MSW composition by weight for BH7, BH8 and BH9a

4.3 SETTLEMENT MONITORING DATA

Results of settlement monitoring at points which were located at closest proximity to BH7, BH8, BH9a and 1985 Trial location are given in Figure 5 below. Two mechanisms of primary consolidation of MSW materials were considered to assess the end of primary consolidation. The first mechanism involves the reduction of void ratio due to particle rearrangement. The second mechanism involves the collapse of larger voids held up by weak structure. As MSW generally has high permeability, the completion of first mechanism is typically immediate. However, the completion of second mechanism may take slightly longer time than the first mechanism due to possible progressive weakening of the void structure under the given load. In general, various literatures have reported that both mechanisms were completed within 1 to 4 months (Wall and Zeiss 1995, Sharma and De 2007). Further settlements due to secondary consolidation are not shown in Figure 5 for clarity purpose.

For BH7, BH8 and BH9a, the end of primary consolidation was analysed by means of graphical assessment of settlement curve. As the primary consolidation of MSW materials under the surcharge load was not induced by the dissipation of excess pore pressure, it was not possible to reasonably undertake the back-analysis by considering the time-dependent behaviour (e.g. using pore pressure data, etc). Therefore, the end of primary consolidation was deemed to have finished by observing the following conditions:

- The secondary (creep) settlement became apparent in a semi log plot (i.e. no noticeable change in general curvature)
- Localised change in settlement curvature (i.e. sign of possible sudden void collapse) has stopped.

The assessed end of primary consolidation was generally about 3 months from the start of monitoring or about 2.5 months from the reference time which took into consideration the staged placement of fill materials.

For the 1985 Trial, the completion of primary condition could not be readily assessed particularly with respect to the end of void collapse. Due to the shallow embankment with smaller dimension and uncompacted fill, the collapse of larger and stronger voids under given load possibly have not occurred until the end of monitoring. As a result, the settlement value was extrapolated to about 3 months from the end of filling which is consistent with typical periods reported in literature and those observed in BH7, BH8 and BH9a.

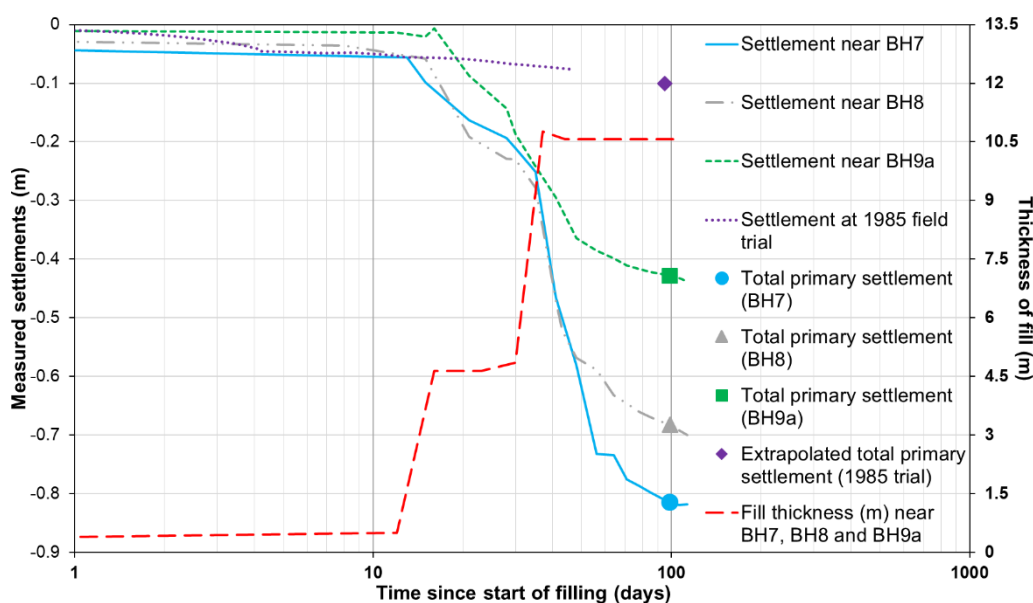


Figure 5: Settlement monitoring results and fill placement

4.4 BACK-ANALYSIS OF COMPRESSION RATIO

Subsequent to the characterisation of MSW materials, an average dry density (γ_d) was obtained for the entire MSW depth of each borehole. The γ_d value was calculated by using equation (2) and typical dry density values of individual MSW constituent (Landva and Clark, 1990). These values are consistent with those presented in Zekkos et al. (2006). Then, moisture content values of MSW were assessed based on the approximate organic content (Figure 2). As this correlation yields a range of moisture content values for a given value of organic content (OP), a range of WCI was consequently estimated for each respective borehole. The assessed WCI values are given in Table 1.

As each value of WCI is also related to a range of compression ratio CR resulting from regression analysis carried out by Bareither et al. 2012, a multi-dimensional range of WCI and CR will result in greater extent of variability. Therefore, it is necessary to initially back-analyse the compression ratio (CR) from the settlement data to limit the range of CR. The compression ratio were assessed from the measured settlements given in Fig. 5. Subsequently, each assessed CR value was plotted with a range of WCI along with the “most likely value” of the WCI. This procedure allowed a sensitivity analysis to be conducted on the variation WCI which is related directly with the variability in MSW materials.

The compression ratio (CR) was back-analysed by means of the following equation for one-dimensional settlement analysis:

$$S_{prim} = S_{prim (non-waste)} + S_{prim (waste WCI)} = \Delta\sigma_v \frac{H_{nw}}{D} + CR H_{w-WCI} \log_{10} \frac{\sigma'_v + \Delta\sigma_v}{\sigma'_v} \quad (6)$$

where, D = constrained modulus (kPa), $\Delta\sigma_v$ = additional pressure (kPa) due to surcharge embankment, H_{nw} = thickness (m) of non-waste layers not considered in the WCI calculation, H_{w-WCI} = thickness of waste layers considered in WCI calculation, σ'_v = initial effective stress (kPa). The non-waste layers (cover layers) which contributed to the term $S_{prim (non-waste)}$ for BH7, BH8 and BH9a were located above the founding levels of the SPLs and HPGs. As a result, the monitoring results registered at SPLs and HPGs were only applicable to the back-analysis of waste layers considered in the WCI calculation ($S_{prim (waste WCI)}$).

Based on settlement data shown in Figure 5, the back-analysed compression ratio for BH7, BH8, BH9a and 1985 Trial are 0.14, 0.13, 0.0875 and 0.12, respectively. Each of CR value was then plotted against the range of assessed WCI for respective location. These plots are shown in Figure 5 along with the range of relationship between CR and WCI.

As expected and shown in Figure 6, the back-analysed compression ratio are higher with higher content of organic materials (OP) with the exception of the 1985 Trial. Such observation for the 1985 Trial was possibly related to the inadequacy of data used for the assessment of WCI and other information for the 1985 Trial. As the information from 1985 Trial was obtained from a 5-m deep test pit, limitations in the investigation depth and sampling quality would have applied in the assessment of the MSW properties. This highlights the importance of a selection of appropriate investigation technique to obtain good quality MSW samples from most or entire depth coverage.

Results in Figure 6 also shows that the range of WCI for given compression ratio generally fall within the relationship given by Bareither et al (2012). It can also be seen from Figure 6 that back-analysed compression ratio for BH7 and BH8 are generally closer to and have proportional gradient to the mean line. As previously noted, the quality of recovered samples from BH7 and BH8 was generally higher than that of borehole BH9a and the test pit in 1985 Trial. This implies that a good sample recovery is beneficial to allow for a robust MSW characterisations.

Table 1: Assessed range of Waste Compressibility Index

Borehole ID	MSW thickness inferred from borehole depth (m)	Assessed organic content (%)	Dry unit weight (kN/m ³)	Assessed range of moisture content (%)	Assessed range of Waste Compressibility Index
BH7	12	12.5	11	5 – 40 (most likely value = 20)	0.0065 – 0.052
BH8	11.5	11.3	12.2	5 – 40 (most likely value = 20)	0.0052 – 0.042
BH9a	12.5	6.3	11.5	5 – 40 (most likely value = 20)	0.0029 – 0.023
1985 Trial	10*	>30	8.5	10 – 50 (most likely value = 30)	0.063 – 0.32*

Note:
* Thickness including up to 3 m of non-waste materials. Value of non-waste material was excluded in the WCI estimate.

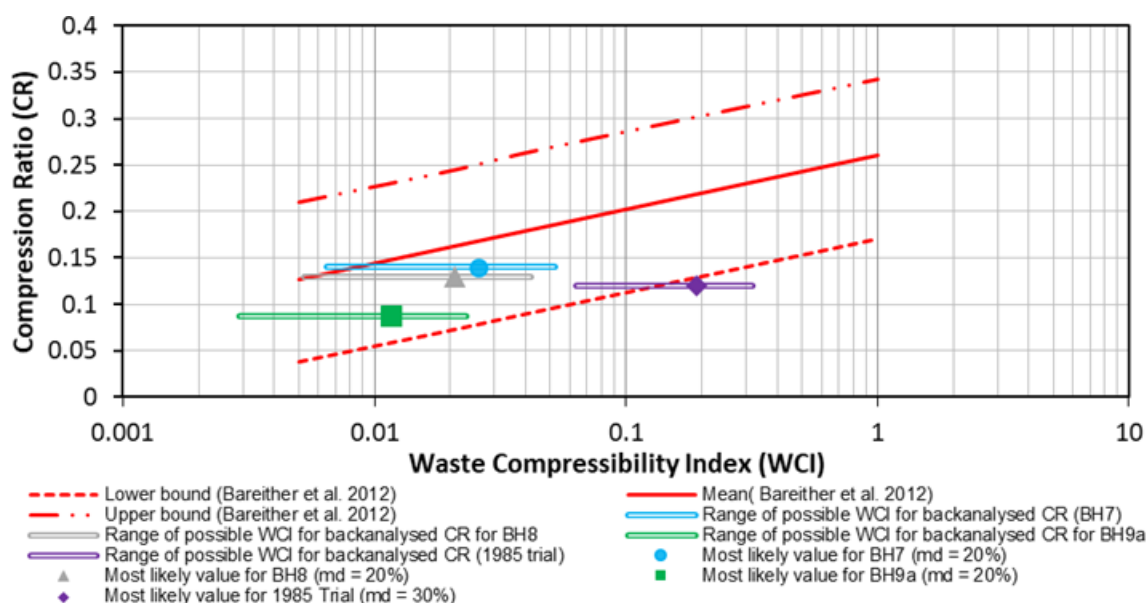


Figure 6: Plots of back-analysed compression ratio and range of WCI (Base CR-WCI relationship denoted by red lines is based on Bareither et al., 2012)

Despite its usefulness, the relationship was developed by Bareither et al. (2012) by using available database of compressibility parameters at the time of publication. Therefore, it is a good practice that this relationship is used thoughtfully especially for the range of WCI where less available data were used in regression analysis.

As indicated in Figure 5, the time taken for the completion of primary settlement is 2.5 months from the reference time which took into consideration the placement of fill materials. This period is consistent with times observed in literatures (Edil et al. 1990, Walls and Zeiss 1995, Andersen et al. 2004, Sharma and De 2007). Although the secondary settlement is not shown in Figure 5, the completion of primary consolidation requires monitoring of subsequent settlements to ensure that the curvature of settlement does not generally change in the linear-log type of semi-log graph. This practice is to ensure that larger voids, which can induce differential settlements, have collapsed under the given load. Such monitoring of void collapse can also be improved by adopting line measurement of settlements by using HPG.

5 CONCLUSIONS

This paper presents an overview of a basic investigation methodology which can be adopted for the in-situ waste (MSW) characterisation and subsequent processing of the characterised waste to obtain the compression ratio (CR) required for the estimate of primary consolidation settlement. The primary compression of MSW materials can be relatively high compared to the uncontrolled soil fill and is typically governed by the highly compressible organic solids content. The estimate of primary settlement is useful for the assessment of construction settlement as well as the design of ground improvement extent to achieve required reduction in void ratio and collapse of large critical voids.

A case study involving a railway embankment built over buried landfill cells was presented. In this case study, the ground improvement in the form of surcharging was adopted due to project requirements. The in-situ waste characterisation was carried out using sonic drilling and conventional drilling methods. A comparison against the 1985 Trial was also presented as part of this case study. The compression ratio which were back-analysed in the case study were found to be consistent with the published relationship between Waste Compressibility Index and compression ratio. In this relationship, higher organic content is typically proportional with higher compression ratio.

Given the variability in waste properties and also a range of parameters assessed from the discussed correlations, it is imperative that the basic investigation is carried out in a sufficient quantity and, where possible, should be supplemented by additional investigation. Additional assessments, such as but not limited to sensitivity, reliability and risk assessments, should also be considered in the design process. It is also a good practice to undertake an observational technique where the waste behaviour in terms of settlements was monitored during the construction or earlier operational period of a typical infrastructure. This will allow a further refinement in the settlement prediction and manage risk.

6 ACKNOWLEDGEMENT

Authors are grateful for the support provided by their colleagues at Coffey Services Australia Pty Ltd.

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