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Elements of roadway specifications for residual soils

Eléments des spécifications routières pour les sols résiduels

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ABSTRACT: Technical specifications provide guidance on quality levels and documents the procedures to be followed to achieve an acceptable standard. Road specifications integrates experiences and proven construction methodologies, which blends theory with practice and must consider variability in geology and climate. Australia's wide climate variation, geology and land area means that specifications between State Road Authorities do vary. The large area of Australia is similar to the European countries combined. Residual soils is the dominant type in Australia, with significant areas of expansive clays. The performance of these soils depends on climate, while non-expansive materials do not show the same sensitivity to climate.

Data from trial embankments and long-term roadway monitoring of these soils are shown, and how that data was used to influence the State Road specifications. The equilibrium moisture content (EMC) is targeted to avoid volume changes after construction. The EMC can be significantly different than the Optimum Moisture Content (OMC) typically used as a key reference for quality control. Distinguishing between a strength based and movement-based pavement criteria is a critical design consideration. Over compaction of an expansive clay should be avoided. An upper characteristic value and zonation should be considered in wet climatic environments. Even in non-expansive soil strength degradation is shown to occur from excessive compaction of residuals soils from in situ shear test measurements.

RÉSUMÉ: Les spécifications techniques fournissent des orientations sur les niveaux de qualité et documente les procédures à suivre pour parvenir à une norme acceptable. Les spécifications routières intègrent des expériences et des méthodologies de construction éprouvées, qui mélangent la théorie à la pratique et doivent tenir compte de la variabilité de la géologie et du climat. La vaste variation climatique, la géologie et la superficie terrestre de l'Australie signifient que les spécifications entre les autorités routières de l'État varient. La grande région de l'Australie est similaire à celle des pays européens réunis. Les sols résiduels sont le type dominant en Australie, avec des zones significatives d'argiles expansibles. La performance de ces sols dépend du climat, tandis que les matériaux non expansifs ne présentent pas la même sensibilité au climat.

Les données des talus d'essai et la surveillance à long terme des chaussées de ces sols sont montrées, et comment ces données ont été utilisées pour influencer les spécifications de la route nationale. La teneur en humidité d'équilibre (CEM) est ciblée pour éviter les changements de volume après la construction. La CEM peut être significativement différente de la teneur en humidité optimale (MOC) généralement utilisée comme référence clé pour le contrôle de la qualité. La distinction entre un critère de chaussée basé sur la force et le mouvement est une considération critique pour la conception. Il faut éviter le compactage d'une argile expansible. Une valeur de caractéristique supérieure et une zonation doivent être prises en compte dans les environnements climatiques humides. Même dans la dégradation de la force du sol non expansible, il est démontré qu'il se produit du compactage excessif des résidus des sols à partir de mesures de test de cisaillement in situ.

Keywords: Residual Soils; Australia; Specifications; Monitoring; Compaction

1 INTRODUCTION

Technical specifications provide guidance on quality levels and documents the procedures to be followed to achieve an acceptable standard. Road specifications varies between States and countries as each specification represents the accumulation of local experiences and issues that are unique to that environment. Any standardisation must capture both key fundamentals and the unique climate, geology and practices of that region. These variations may be even significant for large size State or countries. Vallejo and Ferrer (2011) describe the variation in earth fill for Spanish and French codes for these adjacent countries.

Similarly, Look (2018) shows the dichotomy of recognising the complexity of the situation and yet providing simplicity in a procedural regional specification based approach for the state of Queensland, Australia. The state has an area of 1,727,000 square kilometres, and is the second largest state in Australia. Queensland is nearly seven times the size of Great Britain and almaost half the size of Europe. In comparison Europe‘s area is 3,483,000 square kilometres (Figure 1).

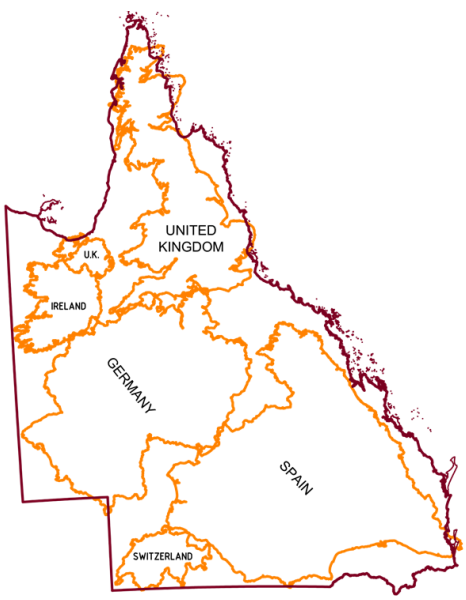


Figure 1. Queensland relative size

The climate in Queensland varies from tropical and subtropical climates to temperate, semi-arid and arid regions. Large distances to high quality materials requires using in situ or nearby materials as much as possible.

One-third of these materials could be subject to volume change behaviour. These soils are known as expansive clays, but both shrink and swell occurs. In Australia, the term “Reactive Clays“ is used to describe this volume chnage bahaviour. Different climates have different soil suction profiles, which influence that soil movement. The equilibrium moisture content (EMC) at placement has been found to be more important than the optimum moisture content (OMC) for reactive clays.

In Queensland about 80% of soils are residual soils. The stony nature of such soils provides a special consideration, even when basic and standard tests are applied. Compaction and CBR tests require oversize corrections to be valid and are invalid for large oversize proportions.

The testing that is appropriate in transported soils may not be appropraite to residual soils. Addditionally the placement in such climates requires considerations not typicaly adopted in temperate European conditions

A summary of these key differences is provided in Figure 2. These are just a few variables that must be considered and is not exhaustive. These factors are discussed briefly in this paper, to show how engineering considerations are affected.

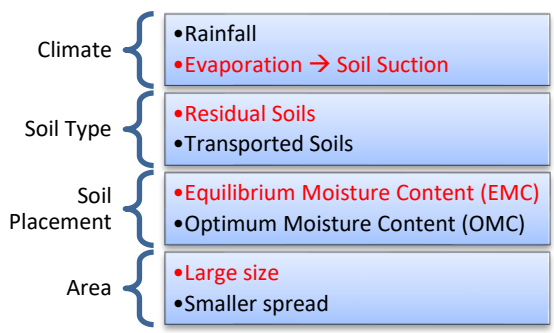


Figure 2. Queensland key attributes compared

2 QUEENSLAND CLIMATE

Figure 3 shows the various climatic regions which range from tropical areas to the north, sub tropical in the south east coastal regions with temperate climates to the south. The inland area varies from temperate to sub-arid to arid. Mining and farming occur in the inland areas.

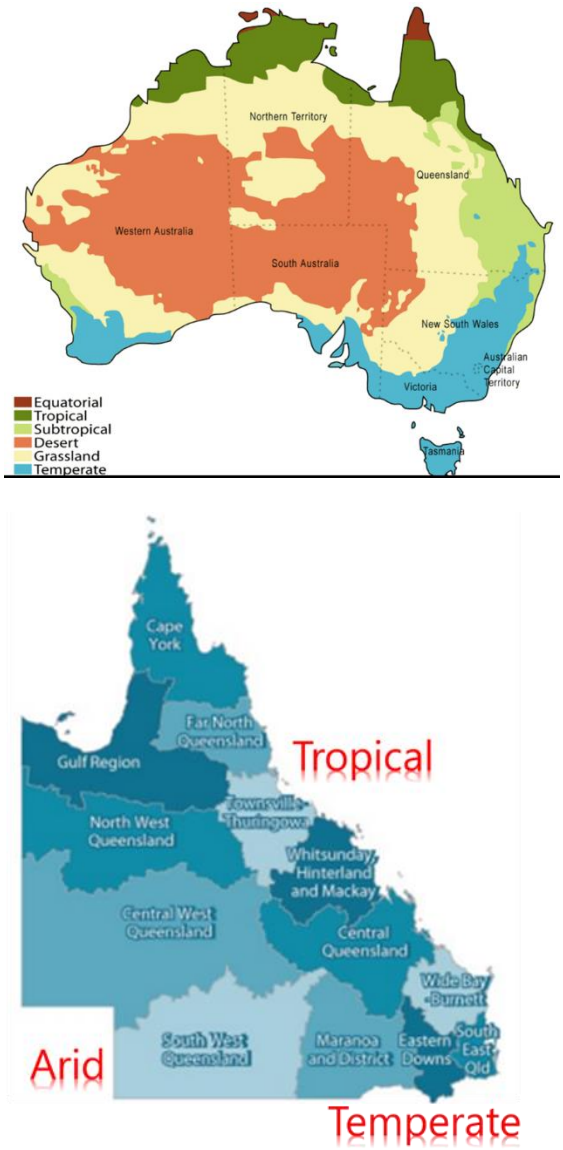


Figure 3. Australia and Queensland Climatic Regions

Rainfall over 1500mm/ year occurs in the wet tropical regions. However, in the temperate and sub tropical regions over 1500mm / year of evaporation occurs with rainfalls varying from 500 to 1200mm for the major Capital cities. This is a net water loss, with seasonal soil suction ocuring from wet to dry seasons.

The high temperatures and rainfall results in deep zones of weathering. The high evaporation results in high soil suctions and deep active zones. These active zones where suction changes occurs vary from 1.5m at the coastal areas to 4.0m in the arid regions.

The active zone is divided into an upper cracked zone and a lower uncracked zone. The dessication cracking occurs during the dry periods and heals during the wet period (Figure 4). Swelling then occurs in the wet periods.

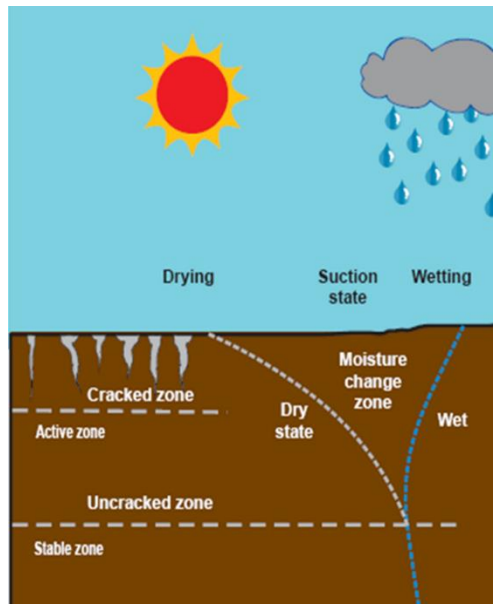


Figure 4. Soil Suction states in the active zone

This seasonal variation needs to be accounted for in both design and construction as the soil suction changes may result in significant movements (heave and shrinkage) for light structues such as residential buildings and road pavements.

3 SOIL CLASSIFICATION

The climatic conditions results in deep weathering profiles and typically the in-situ rock weathering has a deep cover of residual soil materials. These residual soils are the principal soil types in Queensland (approximnaterly 80% of land area) although the cities along coastal areas developed over transportd soils.

Due to their in-situ formation, residual soils generally are heterogeneous and progressively grade to the characteristics of their parent rock. A transition occurs between XW (extremely weathered) rock and residual soils with no clear layering, although an interpretative line is drawn on the borelogs. In comparison, alluvial soils have been sorted during transportation and likely to be more uniform in composition with distinct layers. Reactive clays may be derived from these residuals soils. The economics of using available local reactive clays provide a cost saving during construction where cut and fill is required.

The Atterberg Limits are used for soil classification for road works in assessment of the quality of fill. The Plasticity Index (PI) has then been traditionally used as an indicator of the soil's volume change potential when exposed or deprived of water. However, the PI value often provides "false positives" in residual clays. This was found to be due to the removal of the fraction coarser than the 425 micron sieve as part of the test procedure – a large portion in residual clays.

The term weighted plasticity index (WPI) was therefore adapted to clearly differentiate from the PI and is the product of the plasticity index and the number percentage passing the 425 micron sieve. Thus a PI = 22% with 100% passing has a WPI of 2200, and would be considered less expansive than a PI = 32% material with 50% passing (WPI = 1600). The classification in Table 1 has been adopted for classification of expansive clay materials (Look, 2016).

Approximately half of all residual soil values are low volume change material, with an approximately similar amount (14% to 18%) of medium, high and very high expansive materials. Using values based on PI only on residual material has the greater potential to (mis) classify as an expansive material.

Table 1. Comparison of potential for volume change using WPI and PI criteria

Plasticity (PI) Criteria		**Weighted Plasticity Index (WPI)**		**Potential for Volume Change**
Range	Likeli-hood	Range	Likeli-hood	
< 12%	20.2%	< 1200	51.4%	Low
12% - 22%	31.8%	1200 - 2200	17.9%	Medium
22% - 32%	21.6%	2200 - 3200	13.9%	High
≥ 32%	26.4%	≥ 3200	16.8%	Very High

Figures 5 and 6 compare the distribution of data using the PI and the WPI, respectively. A lognormal and exponent Probability Distribution Function (PDF) applies to the PI and WPI data, respectively. In the PI tests, typically 60% of the samples was used in a residual soil profile from the 292 samples examined. This accounts for the difference and over classification when using the PI only as an index of volume change. This illustrates why the use of the PI test may not be representative in residual soil profiles, due to the high percentage discarded in carrying out the test.

This WPI screening criteria can then be used to classify materials both during investigations and in quality control during construction.

4 STANDARD COMPACTION TESTS

The density ratio (Field Density / Maximum Dry Dnsity) is widely used in compaction control for Quality Assurance (QA) of earthworks. The California Bearing Ratio (CBR) test is also used to assess the material strength and modulus.

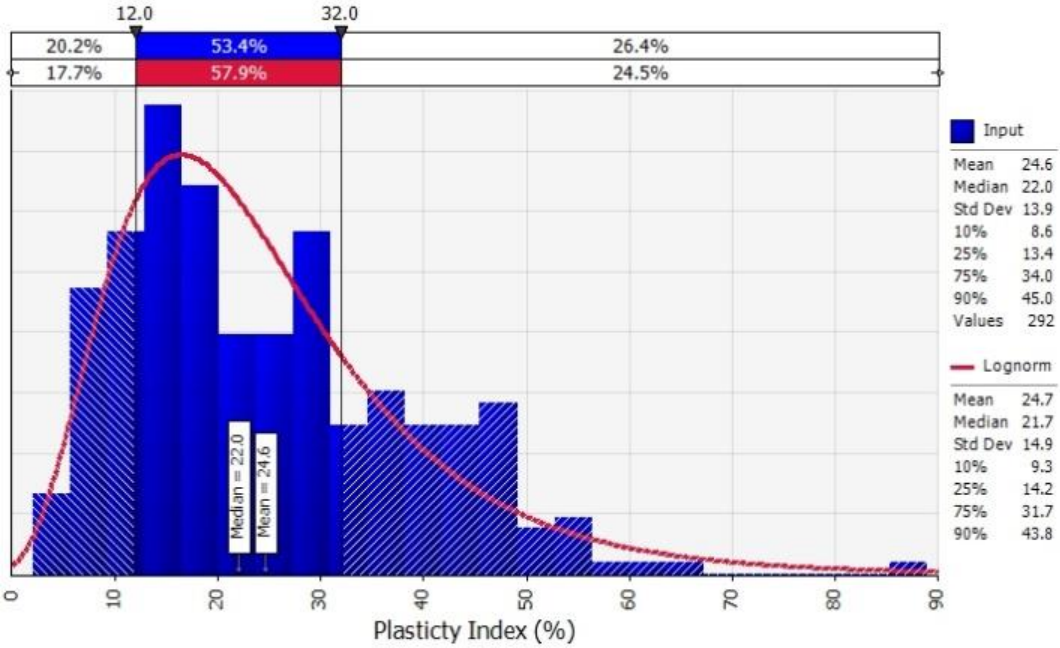


Figure 5. Plasticity Index Distribution

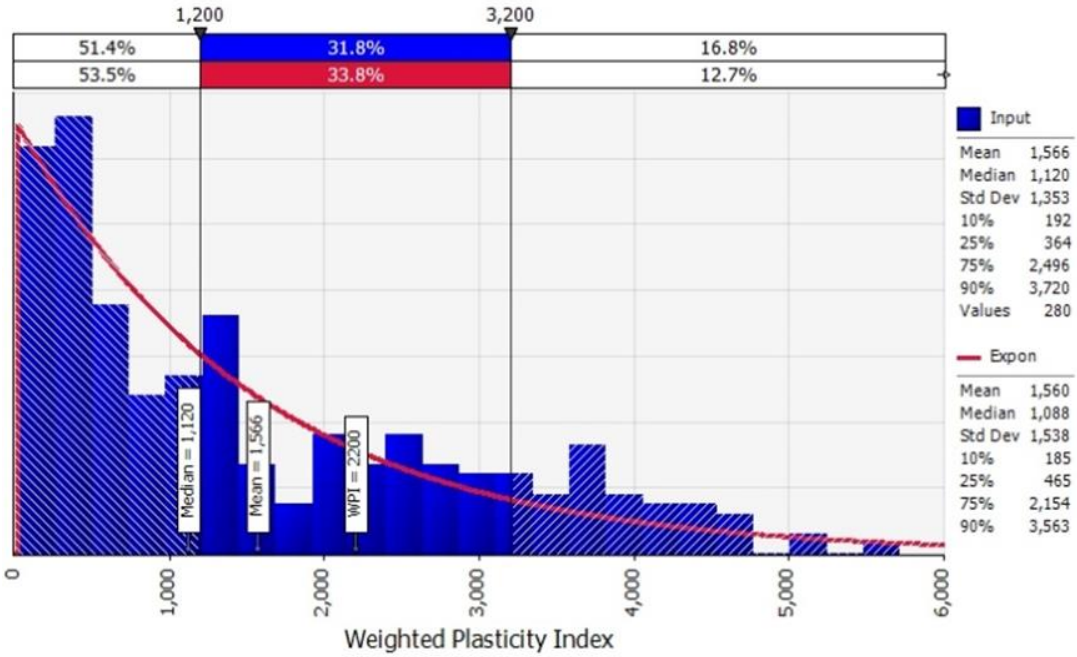


Figure 6. WPI Distribution

Look at al. (2018) and Look (2018) highlight correlations errors or assumptions in using density ratios. Excessive compaction may result in strength degradation although density ratio may be increasing (Look, 2017).

Standards require a density oversize correction. This applies for up to 20% of material exceeds 19 mm or 38 mm for Mould A and B size, respectively. The test is not applicable for greater than 20% oversize. Look (2016) shows that for the residual soils in Australia with a high stone content, the larger size materials are being discarded in the density and CBR test without a correction factor being applied. This provides a non representative (conservative) strength.

Look (2016) found that 23% of test reports used in QA did not account for that over size correction, and this data was from completed projects. Thus, the reported density or CBR value may be invalid without accounting for the significant ovrersize in residual soils.

For this residual soil data set, the percentage fines is typically passing 0.75 times the percentage passing the 425 micron sieve i.e. percentage of whole sample used in the test (Figure 7). The percentage passing the 19mm sieve is also shown. This value represents the "oversize" associated with the compaction tests.

Above 20% oversize (80% passing the 425 micron) represents increasing errors associated with using that test result in compaction or CBR tests. Figure 7 shows that over 50% passing the 425 micron sieve is required to remove having oversize corrections from consideration in compacted or CBR tests. If less than 67% or 50% of the sample is used in the PI test then less than 50% to 35%, respectively is likely to be fines. The material is likely "coarse grained".

When the larger sizes are discarded in the CBR test, then the obvious discrepancy occurs, that a laboratory CBR for the residual soil overlying the XW rock woud have the same CBR as the rock itself. The soaked CBR plateaus as the "strong" oversize material is discarded during the CBR test (Figure 8 from Lacey et al., 2016).

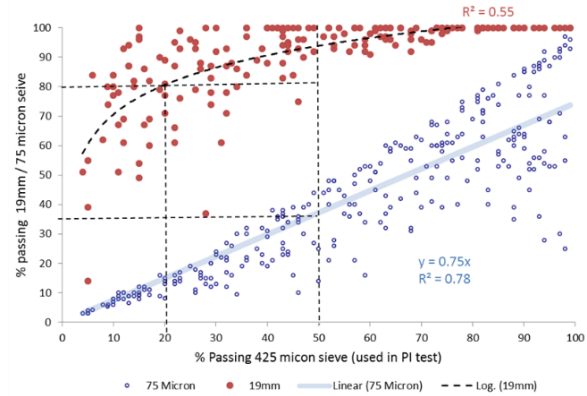


Figure 7. Ratio of percentage fines to percentage used in PI test for typical residual soil.

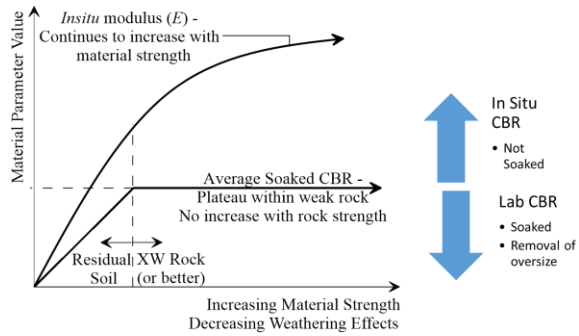


Figure 8. Lab CBR vs field values on residual soils

During compaction the 'strong' oversize material may break down, resulting in a reduction in MDD (Figure 9) and loss of friction (Figure 10) as reported in Look (2018).

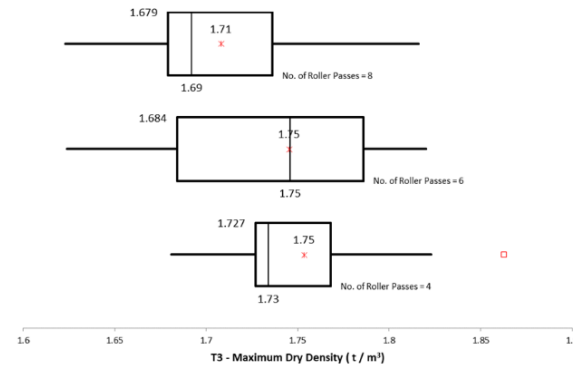


Figure 9. MDD with number of roller passes.

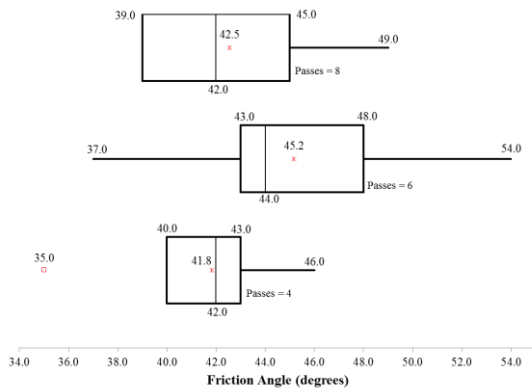


Figure 10. In-situ friction with number of passes.

5 PLACEMENT MOSITURE CONTENT

The compaction moisture content is a useful recommendation target for minimising effort in the field, but should not be used as a pass and fail criteria as discussed in Look (2005, 2018).

Look (2005) shows the long-term equilibrium condition (EMC) is more important than a short-term OMC construction compaction target. The EMC in terms of the moisture ratio varies with climate environment (Look et al., 1994). Long term monitoring of several embankments using Time Domain Reflectometry showed the embankments constructed near OMC changed within 2 to 3 years to an EMC. A summary result is shown in Figure 11.

For highly expansive clays with high WPI, the movement rather than the strength governs the design. Annual rainfall in the 500 to 1,00mm range would have the OMC ~ EMC. However tropical and arid climates constructing or targeting the OMC may be convenient for construction, but is likely to result in long term heave or shrinkage, respectively.

Look (2016) shows the process flowchart (Figure 12) to combine the considerations of material classification (WPI), climate (rainfall) and the EMC in developing a Quensland specifications. Once the material is classified as high WPI, and the climate identified then placement may involve some of the following:

- An upper characteriostic value (UCV) to avoid over compaction of high WPI materials in wet environments
- EMC for high WPI materials. Note EMC ~ OMC in certain rainfall environment
- Zonal embankments to utilise high WPI materials within an inner zone and away from the seasonal active zone.

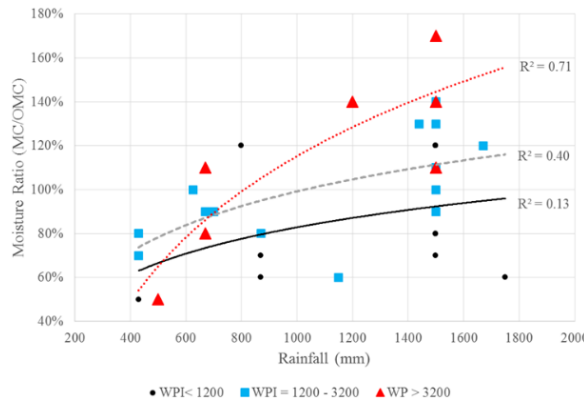


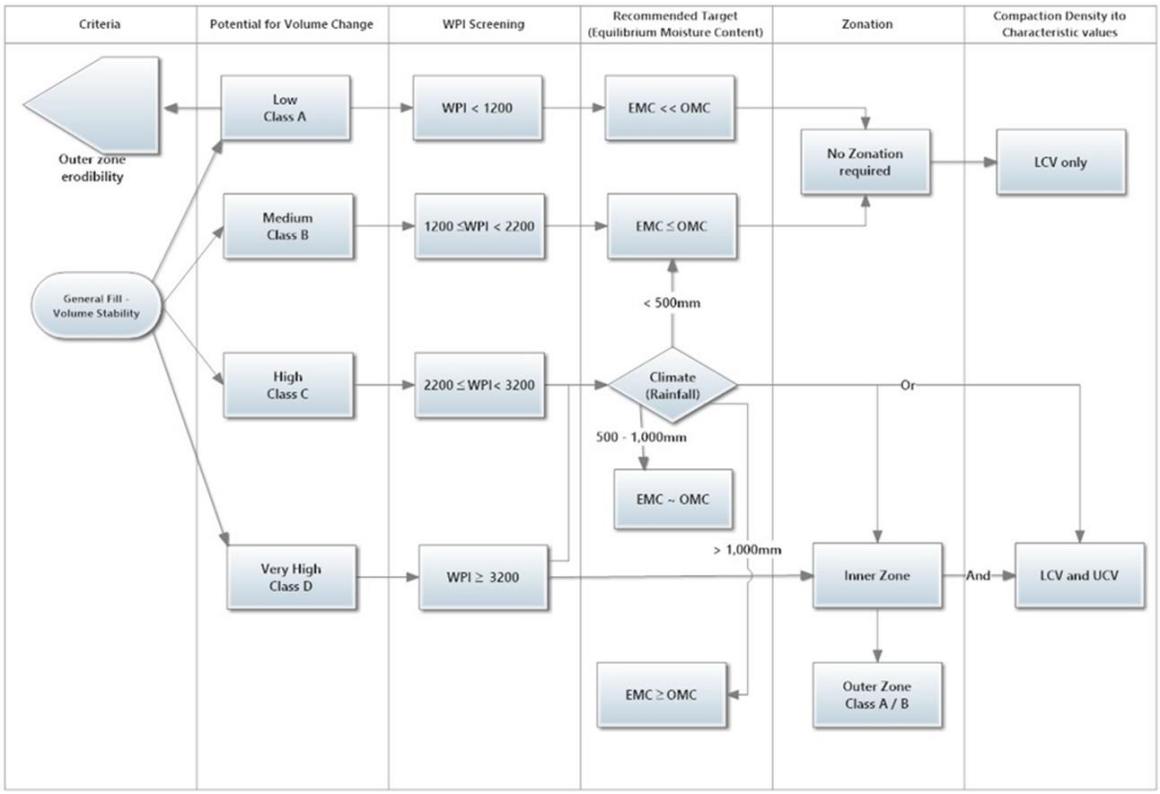
Figure 11. Equilibrium Moisture Content.

6 CONCLUSIONS

Climate and soil type affect specifications. The specifications for residual soils should be different from those in transported soils.

Basic classification tests need to be interpreted differently as well as the compaction and CBR tests. This is due to the significant oversize present on residual soils. Over compaction may destroy the strength of such materials and may also induce excessive heave in residual clays.

Constructing to the equlibrium mositure content is more important than the OMC which is short term construction expedient. This avoids long term volume changes which may occur some time after construction. The EMC ~ OMC for climates with 500mm to 1,000mm annual rainfall. Thus countries or States with that rainfall range would use the OMC criteria without adverse effects.



Figur 12. Design and construction process based on material type and climate

7 REFERENCES

Lacey, D.W., Look B.G. and Marks D.F. 2016. Use of the Light Falling Weight Deflectometer (LFWD) as a site investigation tool for residual soils and weak rock. *5th International conference on geotechnical and geophysical site characterisation*, Gold Coast, Australia.

Look, B G., Reeves I. N. and Williams D. J. 1994. Development of a specification for expansive clay road embankments. *17th Australian Road Research Board Conference*, August, Part 2, pp 249-264.

Look, B. G. 2005. Equilibrium Moisture Content of volumetrically active clay earthworks in Queensland. *Australian Geomechanics Journal*, **40**, No. 3, pp 55 – 66.

Look, B.G. 2016. The Weighted Plasticity Index in Road Design and Construction. *Australian Geomechanics Journal*, **51**, No. 3, pp 55 – 66.

Look, B.G. 2016. MRTS 04 Earthworks - Background Research incorporated into the specification. *Engineering Technology Forum*, Queensland Transport and Main Roads.

Look, B.G. and Lacey, D.W. 2017. Dynamic Monitoring and Modulus based specifications with deep lift compaction. *19th International Conference on Soil Mechanics and Foundation Engineering, Seoul*.

Look, B. G. 2018. Elements of an expansive clay roadway specifications. *Australian Geomechanics Journal*, **53**, 1, pp 109 – 124.

Vallejo, Luis Gonzalez and Ferrer, Mercedes 2011. *Geological Engineering*. CRC Press.