EQUILIBRIUM MOISTURE CONTENT OF VOLUMETRICALLY ACTIVE CLAY EARTHWORKS IN QUEENSLAND

B. G. Look
Connell Wagner Pty Ltd, Brisbane

ABSTRACT

The water changes of volumetrically active clays result in movement of the overlying pavements and in a change in the subgrade strength. This adverse effect results in damage to roads and buildings, with over one-third of Queensland covered with such clays.

This paper discusses the equilibrium moisture content (EMC) operating range in southeast Queensland, and the philosophy behind the procedures for assessment and design on reactive clay earthworks. Two important considerations for wet environments with highly reactive clays are 1) the EMC is wet of the Optimum Moisture Content (OMC), and 2) the long-term density is below the Maximum Dry Density (MDD). If this placement condition is not targeted, then movements can be expected in the early years. This may result in damage to overlying structures irrespective of the design subgrade strength adopted. Targeting the OMC and MDD in such cases is building in future long term movement.

This EMC condition must be considered together with construction issues.

1 INTRODUCTION

Reactive clays cover over one third of Queensland (Figure 1) with the greatest distribution occurring in western Queensland and the Darling Downs region. The economics of using this available local material provides a significant cost saving during construction where cut and fill is required.

Figure 1: Distribution of reactive clays in Australia (Richards, 1990).

However, the cost of maintenance is often considerably higher at sites where reactive clay earthworks have been used. This higher cost is due to environmental changes producing early distress to the pavement and/or structures on reactive clays. Damage results from movement of such clays, and the extent of movement is controlled by the inherent properties of the clays, its soils suction characteristics and its design application. This paper discusses the equilibrium
moisture content (EMC) of the soil, but the corresponding movement is also implied. Movement can be calculated using the shrink swell procedures as provided in AS 2870 (1996) and discussed in Fityus et al. (2005).

Soil suction while a useful design concept is yet to be implemented as a construction control parameter. The soil suction is directly related to the moisture content, which is the parameter used in control testing. The moisture content is discussed in this paper as manifested in various forms. These are moisture content at the plastic limit, liquid limit, and consequently plasticity index, the optimum moisture content (OMC) and the moisture content at its current state. The OMC varies from Standard or Modified Compaction.

Studies of road embankments monitored over several wet/dry cycles are presented to show the measured EMC and the zone of seasonal influence. The long-term moisture conditions in southeast Queensland are shown to be wet of Standard optimum moisture content (SOMC) with a corresponding density below the Standard Maximum Dry Density (SMDD). This has significant consequences in terms of placement of earthworks.

2 DISTRESS IN PAVEMENTS AND ITS ASSOCIATED COSTS

Structural distress in pavements results in cracking and permanent deformation. The various forms of distress are categorised in Finn and Monismith (1984), with the cause being traffic-load associated or non-traffic load associated. In Australia, the environmental factors (climate and soil types) account for 60% of total network maintenance costs and traffic effect account for 40% of costs (Kneebone, 1993). However, pavement distress is not only due to the effects of traffic and environmental factors in isolation. Once damage is initiated, the two factors occurring in tandem produce the total damage to the pavement.

The climatic factors, which affect pavement performance, are usually evaluated in terms of temperature and moisture. This paper focuses on the latter only.

Figure 2 shows the time scale relationship between reactive clays and other forms of land instability. The slow rate of movement makes this form of instability less dramatic and not directly responsible for loss of human life. Because the process works so slowly, damage is not always obvious and the actual annual cost to society may exceed SUS 10 billion dollars (1989 dollar values). Fifty percent of the damage affects highways and streets, while 14 percent affects family dwellings or commercial buildings (Bryant, 1991). The hazard is most evident in the semi-arid states of California and Texas, which are similar to many areas of the Queensland environment.

The cost of earthwork construction is low when the material is used in balanced cut and fills. Conversely, the cost may be high when material is imported. The use of readily available material is therefore preferred even when the material involved is subject to in service volume changes. The real costs of using volumetrically active clays in embankments include the maintenance costs over the design life in addition to the construction costs. Pavement cracking and distortion usually occur within a few years after construction, resulting in increased maintenance costs.
The maintenance cost for roadways on reactive subgrades has been quoted as roughly ten times greater than that for a non-reactive subgrade (Snethen, 1979) in the United States. However that number was derived from a survey of maintenance engineers. Look (1995) quantified the various contributing cost factors for the Queensland road network in terms of “normal” ground (~ 50%), reactive clays (30% - 40%), soft clays (< 5 %) and rock (5% to 10%). This analysis showed the following:

- Construction costs were not significantly different between “normal” ground and reactive clay ground on a per kilometre basis
- Soft clay sites while the least cost classification because of their limited areal extent, were the largest construction cost on a per kilometre basis
- The total maintenance cost of roads on reactive clays is two and a half times the cost for roads on other soil types in Queensland. When considered on a per km basis then the factor increases to 3.25.
- The road user costs were the dominating cost factor, and there was not a significant difference for the various ground conditions on a per km basis.

3 COMPACTION

Traditionally, specifications require that soils be compacted at their optimum moisture content (OMC) and maximum dry density (MDD) as determined by the Standard Proctor compaction. The MDD is based on a specified test procedure and values above that “maximum” can be obtained in the field. The MC is usually specified as a range about the OMC, while the density is specified a minimum % of MDD (say 95%). Variations using the modified compaction tests were introduced to account for heavier compaction equipment. The actual compaction achieved in the field varies depending on the soil type, equipment and construction procedures used. There is no universal relationship between the standard and modified compaction MDD or OMC, although the energy of compaction can be compared. Further discussion on this issue can be obtained in Ervin (1993).

The OMC and MDD (whether standard or modified) is simply a reference unit of measure upon which to calibrate the action of compaction in the field. Heavy equipment (higher compactive effort) produces a higher dry density, but at a lower OMC. Dry of OMC compaction is preferred in arid environments where water is a scarce resource. The high density can be achieved with heavy compaction equipment. Lighter compaction equipment may not achieve the required density and introduces the possibility of collapse settlement, as well as lower strengths and modulus. Therefore the moisture content is one variable as a means to the achievement of the required strength, through the process of densification.

However, while strength and modulus may improve during construction for a dry of OMC placement, this may not represent its in service condition. In drier climates little may change while in wetter climates the soil may wet up with a corresponding drop in strength and modulus during the design life. Therefore, there are instances when the “optimum” moisture content and the “maximum” density are not desirable conditions for construction. In applying levels of compaction and moisture conditioning, the designer must therefore distinguish between the following:

- The movement tolerance and geometry of the structure / infrastructure being developed
- As constructed strength and modulus versus in service strength and modulus
- Climatic Conditions, expressed in terms of rainfall in this paper
- Soil Types, expressed in terms of Weighted Plasticity Index (WPI) in this paper

The WPI is the Plasticity Index (PI) times the percentage passing the 425micron sieve. The PI by itself can be misleading as the test is performed only on the percentage passing the 425micron sieve (A.S.1289, 1995), and this quantity can vary considerably. Look (1995) showed the case at the Mt Walker site where a PI of 43% would have classified the site as highly expansive, yet 97% of the bulk material was not used in the test. Given that the test procedure is based on using the percentage passing the 425micron sieve, it was thought that by reporting that value there would be little effort (and cost) to have the WPI parameter. However, many laboratories carry out a sieve analysis separately with an added laboratory test cost to obtain a WPI value.

In the case of volumetrically active clays, the shrink / swell behaviour often governs the design and strength is not the only criteria in the design. For these soil types, the attainment of the equilibrium moisture content (EMC) must be paramount in the design and construction process to minimise future movements. In addition, the CBR must be based on the EMC and not on the OMC. The soaked CBR at the OMC and MDD is the state of play for design, although design philosophies based on EMC have been advocated for some time. For example, Luttrell and Reeves (1984) discuss the issues with road construction on reactive clays with the EMC in western Queensland and procedures for obtaining the design moisture content as discussed in the Queensland Pavement Design Manual (1990).
Many designs by using a soaked CBR test assume it is a conservative approach. The alternative of determining the likely EMC and density and compacting the sample accordingly before carrying out a CBR test is more time consuming (and costly). The “savings” in field and laboratory testing and basing the pavement design only on a soaked CBR value may result in higher pavement cost or an inadequate pavement unless correction factors area applied. Mulholland et al. (1986) show that 25% of test sites have an in situ CBR less than the soaked CBR and provide correction factors to be applied to the CBR value to estimate the equilibrium in situ CBR as given in Table 1.

Table 1: Correction Factor to soaked CBR to estimate the equilibrium in situ CBR (Mulholland et al., 1985).

<table>
<thead>
<tr>
<th>Climatic Zone</th>
<th>Soil Type</th>
<th>Soil with PI &lt; 11</th>
<th>Soil with PI &gt; 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall ≤ 600 mm</td>
<td>1.0 – 1.5</td>
<td>1.4 – 1.8</td>
<td></td>
</tr>
<tr>
<td>600 mm &lt; Rainfall ≤ 1000 mm</td>
<td>0.6 – 1.1</td>
<td>1.0 – 1.4</td>
<td></td>
</tr>
<tr>
<td>Rainfall &gt; 1000 mm</td>
<td>0.4 – 0.9</td>
<td>0.6 – 1.0</td>
<td></td>
</tr>
</tbody>
</table>

This procedure has subsequently been adopted in some Pavement Design Manuals e.g. ARRB (1995). However, this still has not captured the movement potential of the subgrade. The pavement can still suffer cracking and deformation, even if its strength is adequately or conservatively designed.

This is analogous to current codes which advocate both ultimate and serviceability limit states for walls and foundations. The ultimate limit state accounts for strength, while the serviceability considers movements as an explicit design consideration.

The discussion that follows uses only standard compaction as a reference unit. A few authorities prefer using only modified compaction. This confuses the issue even further with respect to considerations on reactive clays, as the modified compaction shifts the moisture density curve to a higher MDD at a lower OMC. These two factors contribute to an increased swell potential in volumetrically active clay environments. Dineen et al. (1999) showed an increase of soil suction from 200 kPa (3.3 pF) to 1000 kPa (4.0 pF) for the Standard OMC and the Modified OMC, respectively for the soil tested.

**4 REACTIVE CLAYS IN EMBANKMENT CONSTRUCTION**

The terms, reactive clays, swelling clays, shrinkage clays, plastic clays, and active clays are often used interchangeably. However the process is a reversible one and implicitly describes a material that exhibits shrink/swell behaviour, that is clays that are subject to volume changes with variations in moisture content.

The mechanisms causing distress and the solutions to control such distress differ between reactive clay subgrades in cuttings and embankments. Remoulded and compacted soil samples often have a shrink or swell potential two or more times greater than undisturbed soil samples, (Parcher and Liu, 1965; Jones, 1976; El-Sohby and Elleboudy, 1993). For embankments placed dry of equilibrium, an overall heave results. The higher swell potential of remoulded compacted clays has been attributed to (Komornik, 1969):

1) The energy of compaction stored in the remoulded material which causes higher swelling and
2) Minute fissures in the internal structure of the undisturbed clay that allow some swelling forces to dissipate.

Pavements in cuttings are exposed to direct seasonal influences (rainfall and evaporation) only from the surface, while embankments have additional exposure on the sloping faces. The seasonal shrink/swell condition associated with the large exposed faces results in higher differential edge effects, which may produce heaving and longitudinal cracking. The soil near the top of embankments is generally unsaturated, while in deep cuttings the subgrade soil would be closer to saturation due to the increased moisture flow to the low point at the pavement subgrade level. Note that saturated here does not refer to 100% degree of saturation, but to its performance as if it is in a saturated state. This “saturated” performance occurs for values typically greater than 85% for clays and even less for other materials (Jennings and Burland, 1962).

An illustration of the effect of over-compaction of remoulded clay samples can be shown using the AS2870 procedure. Section 3 of this paper described an in-built suction difference of 0.7 pF for modified versus standard compaction. If the soil has an equilibrium density near SOMC and SMDD, then 0.7 pF soil suction change is required for the soil to achieve its equilibration state. Using this value, for the full profile depth, results in a rectangular suction profile for the short-term equilibration as compared to the AS2870 (1995) seasonal triangular distribution. Assuming a typical value of 2%/pF, and a nominal 2.0 m active zone assumed with a 0.6 m pavement overlying with a cracked zone of half the full depth, then the site would be classified as a moderately reactive state (20 mm to 40 mm). This would be the change...
that could occur initially, while the seasonal variations (with the standard triangular distribution) would occur over its life.

5 EQUILIBRIUM MOISTURE CONTENT IN QUEENSLAND

Data from various reported studies at Queensland sites were compiled to evaluate the equilibrium moisture conditions likely for different climatic regions. This compilation of data from various road sites was provided in Look (1995) and summarised in Figures 3 and 4, as the ratio of moisture content to plastic limit (MC/PL) and moisture content to standard optimum moisture content (MC/OMC) versus annual rainfall, respectively. These site data did not specifically investigate the EMC, but provided data on moisture content across the road profile for assessment of various subgrade conditions under the pavement.

As discussed previously, the PI data by itself can provide inconsistencies and the WPI provides a much more meaningful result in assessment of clay movement potential. Figures 3 and 4 were plotted using the weighted plasticity index (WPI) to assess any differences in trends based on that criteria. The dividing line separates the material with WPI < 1000. However, no data points were available for WPI in the range 1000 to 2000, and the dividing line would therefore apply equally for WPI < 2000. The results obtained using the WPI criteria are different from those obtained using PI alone.

![Figure 3: Relationship of MC/PL with annual rainfall.](image)

The MC/PL ratio shows little dependency on annual rainfall, while the MC/OMC ratio shows a climatic dependency. In each case, the relationship is stronger for the higher WPI values. The curvilinear trend line for the higher WPI is also shown on Figure 4. The more reactive soils, with WPI > 2000, tended to be sensitive to climate, while the non reactive material, with WPI < 1000 was less sensitive. The MC/OMC is here termed the moisture ratio.

Based on the above trends, the data from Look (1995) is investigated further in Figure 5 with additional data and now shows:

1) For WPI < 1200, the equilibrium moisture ratio is dry of OMC
2) For WPI = 1200 – 3200, the equilibrium moisture ratio shows some dependency on climatic influences
3) For WPI > 3200, the equilibrium moisture ratio is sensitive to climate. Therefore if such material does not have the EMC as a design consideration significant changes in moisture (and hence movement) can be expected. The data varies from dry of OMC for rainfall less 500 mm, to wet of OMC for rainfall greater than 1000 mm.
Table 2 summarises these considerations for the trend line. While the equilibrium condition should be the target construction condition, this may not be practical in certain instances. For example, where equilibrium corresponds to conditions very wet of optimum (say 140% OMC), the target moisture content for construction purposes may be significantly different from the equilibrium conditions. In such instances, the use of equilibration periods needs to be considered prior to placement of the final pavement layers. An example of such a procedure is given in Look et al. (1994).

Table 2 provides guidance on the stable EMC expected at depth or at areas below the pavement sufficiently away from the edge so as not to be affected by seasonal variations. Above the stable zone, the MC of the soil varies considerably and is dependent on the rainfall conditions prior to testing and the season when testing occurred. The following sections illustrate these MC differences for a site monitored over several years.
Table 2: Equilibrium Moisture Conditions trends in the annual rainfall range of 400 mm to 1700 mm.

<table>
<thead>
<tr>
<th>Median Annual Rainfall (mm)</th>
<th>WPI &lt; 1200 (Low correlation)</th>
<th>WPI = 1200 – 3200 (Medium correlation)</th>
<th>WPI &gt; 3200 (High correlation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median value for all Rainfall</td>
<td>80%</td>
<td>100%</td>
<td>115%</td>
</tr>
<tr>
<td>≤ 500</td>
<td>50%* to 90% OMC</td>
<td>70% to 100% OMC</td>
<td>50% to 80% OMC</td>
</tr>
<tr>
<td>500 – 1000</td>
<td>70% to 120% OMC</td>
<td>100% to 130% OMC</td>
<td>70% to 120% OMC</td>
</tr>
<tr>
<td>1000 – 1500</td>
<td>70% to 110% OMC</td>
<td>100% to 130% OMC</td>
<td>110% to 140% OMC</td>
</tr>
<tr>
<td>≥ 1500</td>
<td>70% to 110% OMC</td>
<td>100% to 130% OMC</td>
<td>130% to 160%* OMC</td>
</tr>
</tbody>
</table>

* Beyond practical construction limits

A unique value of EMC is unlikely to be obtained due to natural material variability and minor changes in offset and depth can result in a change in moisture content value. This is compounded by the testing precision where MTRD (1994) showed that the OMC of clay would have 13% of the mean for repeatability and 19% of the mean for reproducibility. Based on this practical consideration, an operating range for the EMC is more relevant rather than a unique value.

The earthworks design must consider two distinct conditions. These are

1) A stable EMC where the core of the embankment is protected from seasonal variations.
2) An unstable outer zone which is responsive to seasonal variations.

The former occurs in the first few years while the latter occurs over the life of the embankment.

6 LONG TERM MONITORING OF EXISTING EMBANKMENTS AT COOROY

The earthworks for the proposed 7.15 km Cooroy Bypass deviation, located approximately 120 km north of Brisbane, involved cut and fill operations in clays, which, based on classification tests, were highly reactive with a WPI of 2200 to 3200. The initial moisture studies were undertaken using Time Domain Reflectometry (TDR) instrumentation (Look and Reeves, 1992a). The TDR probes were installed in late 1990, in two trenches designated T1 and T2, within existing embankments, to monitor long term seasonal moisture fluctuations (Look and Reeves, 1992b). The TDR measures volumetric moisture content (VMC) and the dry density of the soil must also be measured to convert to the gravimetric moisture content. At the time of the TDR probe installation, samples were obtained to determine the SOMC and SMDD at each probe location.

The monitoring data were also integrated with the laboratory test results to establish design conditions for the earthworks on the proposed Bypass project. The boundary between the active and stable zones was also based on the results of oedometer testing aimed at establishing the swell characteristics of samples at various depths. Only the field monitoring is discussed further herein.

The results of the monitoring at T1 and T2 suggest that the moisture content from greater depths showed fewer and smoother irregularities than those at lesser depths (Figures 6 and 7). A 1.5 m active zone was assumed at the time of installation of the TDR probes. The depths shown are from top of the edge of the pavement. The Figures show that the active moisture zone, which is affected by seasonal variations, extends to below a depth of 1.8 m. Reactive clays placed within this zone undergo moisture changes due to seasonal moisture variations. However, the swelling test results show that, although some moisture changes occur at 1.8 m depth, the movement is likely to be suppressed by the overburden pressure. Reference to the stable zone in this paper (eg Figure 7), therefore implies a no movement zone, even though minor moisture content changes may occur in that zone. The EMC is therefore an operating range rather than a unique value and applies to the stable zone only.

Using soil suction – moisture content relationship established for this site, a soil suction change of 0.8 pF at just below the 0.6 m deep pavement occurred over the few years of monitoring. The near zero soil suction change (extrapolated) is at 2.0 m for these road embankments, while 1.0 pF (extrapolated) occurs at the surface. This can be compared with the ground surface 1.2 pF soil suction change (wet to dry state) and 1.5 m to 2.3 m active zones suggested in A.S. 2870. The depth of active zone is comparable, but there is a difference in the soil suction (1.2 pF vs 1.0 pF), and this can be due either to the non-site specific nature of the Standard or the partial pavement cover and embankment exposure. The probes were installed at the edge of the travelled lane, with a paved shoulder, therefore being “protected” from direct seasonal influences from 3 sides, but with the embankment batter exposure.
Using the SOMC obtained initially, and converting from the volumetric moisture measurements to the gravimetric moisture content, the monitoring showed that the in-service moisture condition is 1.2 to 1.3 times the SOMC in the stable zone (Figure 6). These 2 trenches were over 7 km apart but constructed of similar clays, with measurements showing a similarity in their response to moisture changes. Reactive clays placed drier than this condition would be expected to wet up and expand over time. Design should therefore allow for the potential volume changes and the accompanying reduction in strength.

The peak volumetric moisture content was about 42% to 43% in both the active and stable zones. Here the peak moisture content corresponded to the peak of a 50-day moving average of the rainfall preceding the day of monitoring. This was established by comparing a range of moving averages of the rainfall with the measured volumetric moisture contents. While the peak of the wetting phase corresponds to the 50-day moving average rainfall, the base of the drying phase corresponded to the 300-day moving average rainfall pattern. The density in the stable zone for both T1 and T2
varied from 92% to 94% of the SMDD, although these embankments had been constructed at its MDD. The relationship between the EMC and equilibrium density is discussed in Look et al. (1994).

7 COOROY TRIAL EMBANKMENT

These moisture studies in the area indicated that the equilibrium conditions were well above the SOMC and the density was lower than the MDD. Consequently, it was necessary for design and construction specifications to anticipate and limit the likely damaging effects of volume change over the life of the roadway.

Based on these results of moisture monitoring, in situ testing and the analysis of laboratory test data, the following design parameters and conditions were recommended for these earthworks with the reactive clays:

1) A design subgrade California bearing ratio (CBR) of 3%.
2) A target density between 92% and 94% of standard MDD.
3) Characteristic densities between 90% and 96% MDD.
4) A target moisture condition between 110% and 130% of SOMC.

A trial embankment was used to test these recommendations. It was constructed in three sections each with different initial moisture conditions but with the same target density. The moisture contents targeted were 1.0 OMC, 1.2 OMC and as wet as possible (1.2+ OMC). Again TDR probes were used for long term monitoring, and these measure the volumetric moisture content. The Figures therefore show this VMC measurement, but appropriate conversions to gravimetric moisture contents had to be made.

The results of that trial are presented in Look and Reeves (1992b), and summarised in Figure 8. Figures 8a and 8b show the results for the inner wheel path (IWP) and outer wheel path (OWP), respectively. The IWP would be more stable while the OWP is less stable. The probes are also at different heights, which would provide added variation. The results show that irrespective of the moisture content of the trial embankment, the embankments all converged to an approximately similar VMC at 9 months (Figure 8a) with a more significant variation in the active OWP. In this trial the EMC is in the range of 35% to 38% VMC. This stable moisture content range compares with the 37% to 43% VMC measured in T1 and T2 described previously. When appropriate conversions to gravimetric moisture content and applying the appropriate SOMC at this location, then the moisture ratio is again 110% to 130% of SOMC.

The trial confirmed the viability of the specifications, and the limitations of construction equipment on wet fills. The introduction of an upper characteristic value implies that in such earthworks a material can fail its quality control testing if compacted at or above MDD. The lower characteristic value provides the density (and strength) requirement for subgrade support. The specification for earthworks on reactive clays is discussed further in Look et al. (1994), and Look (1995). Design and construction considerations on reactive clay fill sites should consider:

1) Zonal strategies
2) Specification limits with a failure for over-compaction as well as under-compaction
3) Targeting the EMC
4) Curing Periods to achieve the EMC before placement of the final paving layers
5) Not using heavy rollers, to avoid over-compaction
Figure 8: Moisture Variations in the a) stable inner wheel path and b) active outer wheel path of the trial embankment.

8 CONSTRUCTION MONITORING

During construction TDR probes were installed to control the curing period. This instrumentation provided data on when sufficient time had passed for moisture equilibration before placement of the critical overlying pavement layers. This would minimise any damage from movements associated with moisture equilibration. Horizontal profile gauges (HPG) were also installed to evaluate the corresponding movements. That data is discussed elsewhere (Look, 1995).

Figure 9 shows the results of monitoring at various chainages during construction, when 1.2OMC was targeted, which was the upper limit of practical moisture placement but still under the EMC. Again this monitoring confirmed the design should target the equilibrium condition. In this case the equilibration occurred in a shorter period than the trial embankment due to both a higher rainfall at the time of construction and the procedure adopted.
CONCLUSION

This paper provides data to show the importance of the EMC on volumetrically active clays. Compacted clays (in embankments) have a higher swell potential than undisturbed clays at the same moisture content and density. Environmental induced distress accounts for more pavement damage than traffic loading.

The cost attributed to reactive clays has been compared to those due to other hazards. Because damage due to reactive clays occurs slowly and undramatically, the damage to the infrastructure is not always obvious. The indirect costs to the road user far outweigh the direct construction and maintenance costs to the road authority. The maintenance cost of roads on reactive clays is two and a half times the cost for roads on other soils types in Queensland.

Volumetrically active clays are sensitive to the effects of moisture change, which is the most significant factor determining pavement life and maintenance requirements. The variation of equilibrium moisture conditions in the various climatic regions of Queensland has been described. For volumetrically active clays in the wet regions of the State, the equilibrium condition is wet of optimum, while in the arid and semi-arid regions the equilibrium condition is dry of optimum. For soils with WPI less than 1200, the equilibrium conditions are at or dry of optimum in all climatic regions.

The weighted plasticity index represents the soil composition factor controlling movement and the state of the soil is represented by the moisture ratio. These two parameters should be used to evaluate and control moisture movements.

ACKNOWLEDGMENTS

Most of the data was obtained as part of a research project while the author was at the Queensland Main Roads Department. The project was under the direction of Ian Reeves. The views expressed do not necessarily reflect those of the Department.

REFERENCES


