A CLIMATE-BASED DESIGN DEPTH OF MOISTURE CHANGE MAP OF QUEENSLAND AND THE USE OF SUCH MAPS TO CLASSIFY SITES UNDER AS 2870-1996.

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ABSTRACT

The informal correlation between Thornthwaite Moisture Index and depth of soil suction change has been used to produce a climate zone map of Queensland to assist in the classification of sites under AS 2870-1996. The map complements previous work in other States, and a discussion of the use of such maps, with a worked example, will assist practitioners in all States in the calculation of characteristic surface movement.

Keywords: Thornthwaite Moisture Index, soil suction, characteristic surface movement, climate, site classification, reactive clay.

1 INTRODUCTION

In many parts of Australia the most commonly used method for site classification under AS 2870-1996 Residential slabs and footings of sites containing reactive clay is by estimation of the characteristic surface movement ($y_s$). Calculation of $y_s$ for any particular site requires knowledge of the reactivity of the clay on the site, the amount of clay present and of the moisture change likely within the clay.

The reactivity of clay is described by the instability index ($I_p$), which is the percent vertical strain per unit change in suction. Methods for the measurement of $I_p$ are given in AS 2870-1996, and comprehensive comparison and discussion of the different methods are provided in Cameron (1989) and Walsh and Cameron (1997). Further discussion of $I_p$ is beyond the scope of this paper.

The moisture change within the unsaturated soil profile on a site is expressed in terms of soil suction variation, and some knowledge of this variation is required for calculation of soil surface movement due to reactive clay volume change. While numerous techniques are available for measurement of soil suction they are not simple, and considerable care is required to achieve reliable results. Further, soil suction changes continually with weather, land management and site development. A singular soil suction profile measurement may provide a useful lower bound, but it does not indicate temporal variation. Accordingly it is not practical to “measure” the design soil suction profile for the purposes of particular site classification, and reliance must be placed on historic or other data.

For various locations around Australia AS 2870-1996 provides figures for suction change ($\Delta u$) at the soil surface and depth of suction change ($H_d$). However the list of locations is not exhaustive and for some locations the Standard provides a range for the parameter.

An indication of soil suction parameters over large areas of country can be obtained by utilising the commonly accepted (but informal) correlation between soil suction distribution and the Thornthwaite Moisture Index (TMI). The TMI was presented by C.W. Thornthwaite (1948), a consulting climatologist, in 1948 in order to quantify the answer to the question implicit in Thornthwaite’s statements: “We cannot tell whether a climate is moist or dry by knowing the precipitation alone. We must know whether precipitation is greater or less than the water needed for evaporation and transpiration.” Positive values of TMI indicate a net surplus of water (a humid climate), and negative values of TMI indicate a net deficit of water (an arid climate). It is generally held that increasing aridity (as indicated by lower values of TMI) means deeper soil suction changes.

The correlation between TMI and soil suction should not be overstated as it is based primarily on empirical evidence, and researchers in some parts of the world have found the correlation to be unreliable in arid areas. Blight (1997), based on the research of others, states: “... for arid and semi-arid areas ... Thornthwaite’s equation is completely unrealistic ...”. Nonetheless the empirical evidence supporting useful correlation is strong. In the USA the PTI slab design method (PTI, 1980), first published in 1980 and used extensively since then throughout semi-arid and arid areas of the country, relies heavily on TMI for design soil suction determination and for estimation of design edge distance. A design standard for residential foundations currently being developed by the ASCE (ASCE, 1997) relies in part on a climate rating derived directly from the TMI.
In Australia TMI-based climate maps exploiting the correlation between TMI and soil suction profile for use in residential site classification have been developed for a number of regions. Smith (1993) published maps of Victoria and Melbourne. (These maps have subsequently been incorporated in AS 2870-1996 as Figures D1 and D2). Fityus et al (1998) published a map of the Hunter Valley. Barnett and Kingsland (1999) published a map of New South Wales. Walsh et al (1998) published maps of South-east Queensland and South-west Western Australia. With the exception of the Hunter Valley map all these maps were based on the work of Aitchison and Richards (1965), who published their TMI map of Australia in 1965. Early indications are that the correlation, for example as expressed for Victoria in Figures D1 and D2 of AS 2870-1996, is a useful tool for site classification purposes and the results obtained are similar to those derived by other methods.

Very little firm data on soil suction profiles in Queensland are available, and in the light of continuing concern in some areas regarding site classification practice the decision was taken to produce a TMI-based climate map of the State.

2 THE SOIL SUCTION PROFILE MAP OF QUEENSLAND

The climate map of Queensland is presented as Figure 1. The soil suction parameters corresponding to the climate zones 1 to 5 are consistent with those used in Appendix D of AS 2870-1996, and climate zone 6 has been added. The zone parameters are:

<table>
<thead>
<tr>
<th>Climatic zone</th>
<th>Description</th>
<th>$H_s$ (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alpine/wet coastal</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>Wet temperate</td>
<td>1.8</td>
</tr>
<tr>
<td>3</td>
<td>Temperate</td>
<td>2.3</td>
</tr>
<tr>
<td>4</td>
<td>Dry temperate</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>Semi-arid</td>
<td>4.0</td>
</tr>
<tr>
<td>6</td>
<td>Arid</td>
<td>&gt; 4.0</td>
</tr>
</tbody>
</table>

Table 1 value of $H_s$ for climate zones
Figure 1 Climate zone map of Queensland
The map provides sufficient data to determine the depth of design suction change, $H_s$. However, a value for surface suction change ($\Delta u$) is required to enable the idealised soil suction profile of AS 2870-1996 to be generated. For Queensland, the value of $\Delta u$ is taken to be 1.2 pF, and the resulting design soil suction profile is shown in Figure 2.

![Diagram of soil suction profile](image)

Figure 2 Soil suction profile derived from map

### 2.1 DERIVATION

Examination of the informal data upon which the Aitchison and Richards map (1965) was based reveals that the Queensland section of the map was plotted from 69 data points, out of more than 600 Australia-wide. This was considered to be an insufficient number of data points on which to base a new map, particularly in light of the more than thirty years additional data now available and the potential use of modern computer tools for data analysis. Accordingly, the current map is based on calculation of TMI from first principles, using the most recent data available from the Bureau of Meteorology.

Details of the development of the TMI are contained in Thornthwaite (1948), and a recent detailed discussion is contained in Fityus et al. (1998). However, for present purposes, it is sufficient to state that the method requires both rainfall and temperature data for each station, and AS 2870-1996 Amendment 2 requires that such calculations be based on at least 20 years of climate data.

The map has been plotted from the results of TMI calculations for 154 stations in Queensland where both temperature and rainfall data are available for at least twenty years. The full record was used at each station, with the result that the period covered by individual stations varies from 22 to 147 years, with the mean being 88 years. The TMI was calculated using the method outlined by McKeen and Johnson (1990). Using the terminology of Fityus et al. (1998) the calculation method selected was “year by year”, which means that the TMI was calculated for each station for each year of record, with the stated station TMI being the mean of all years. Further details of the actual calculation method and results obtained are beyond the scope of this paper.

Fityus et al. (1998) note the suggestion that a sixth zone (“arid”) be added to the five previously used on such Australian climate maps, with the zone applying to regions with TMI < -40, and this zone has been added to the present map. Note that a specific $H_s$ figure has not been given for zone 6 (ie. "> 4.0") as firm data are not available. In a review of available data on depth of suction change in Queensland Henderson (1988) noted that researchers have suggested depths of 6 to 8 metres in western Queensland.

### 2.2 PRINCIPAL FEATURES

The most striking aspect of the map is the preponderance of dry temperate, semi-arid and arid land. These dry climate types include about eighty-five percent of the State and in some locations continue full width of the State, from the western border to the coast. Approximately thirty-five percent of the State is “arid”. “Wet coastal” climate occurs only intermittently along the coast, with substantial areas occurring only around Cairns, and the Gold and Sunshine Coasts and hinterland.
Of considerable concern is the complexity of the climate map in the economically important southeast of the State. For example the Brisbane River valley has areas of zones 1, 2 and 3 and is known to contain soil types including clays of considerable reactivity. This supports the anecdotal evidence of experienced practitioners in the region that the potential surface movement in the Greater Brisbane area varies markedly. Unfortunately more detailed examination of the climate in this area is beyond the scope of the present project.

Another region of rapid climate change is the area west of Cairns, where four different zones occur in a line of about sixty to seventy kilometres, indicating a markedly different climate in Dimbulah, for example, from that of Cairns.

2.3 COMPARISON WITH PREVIOUS WORK

Previous work on TMI mapping of Queensland appears confined to the work of Aitchison and Richards (1965). The more recent map of South-east Queensland by Walsh et al (1998) derived climate zones for use in estimating $H_w$ from the Aitchison and Richards (1965) data. Comparison of the present map and that of Aitchison and Richards (1965) reveals significant similarities in detail and broad variations in some areas.

The detail in the Greater Brisbane area, with the relatively dry region around the Brisbane River and towards the southwest, the relatively humid area west of Miriam Vale, and the arid "tongue" that captures the Emerald area are very similar. The arid region, as denoted by zone 6 on the present map, follows the "40" TMI isopleth of Aitchison and Richards (1965) map closely. Further, the points where the isopleths intersect the State borders are generally quite close.

However there is considerable variation in the intermediate zones. The Gulf country around Burketown and Normanton would be "wet temperate" based on the Aitchison and Richards (1965) map, but is "semi arid" on the present map. Of perhaps more concern is the sub-tropical region north from Gympie and west to about Moura, where the present work indicates significantly drier conditions than previously indicated. Specific examples are towns such as Gayndah, Mundubbera, Biloela and Moura, which would be "zone 3 temperate", based on previous work, but which are "zone 4 dry temperate" on the present map. Bundaberg itself is borderline between zones 2 and 3, but adjacent areas (for example Bundaberg airport) are distinctly zone 3.

3 USE OF THE SOIL SUCTION PROFILE MAP

At all times it should be borne in mind that the map is based on analysis of climate data and an empirical, informal correlation with soil suction parameters. Priority always should be given to specific soil suction data for a particular site or region where these are available.

The formula for calculation of the characteristic surface movement ($y_s$) is given in Clause F1 of AS 2870-1996:

$$y_s = \frac{1}{100} \frac{H_t}{I_{ps}} \Delta u \Delta h$$

The depth of design suction change $H_t$ is in metres, and is obtained by searching the map for the locality and identifying the climate zone for that point. The legend above is then used to get the $H_t$ figure for that zone. The instability index $I_{st}$ normally is derived from the shrinkage index ($I_{ps}$), which in turn is obtained by laboratory testing soil from the site. The relationship between the two is:

$$I_{ps} = \alpha \times I_{ps}$$

$\alpha$ is a correction factor to allow for the lateral restraining effect of the soil mass and the vertical effect of overburden, and clause F2 of AS 2870-1996 recommends values, with some knowledge of the depth of soil cracking required for its estimation. AS 2870-1996 suggests that the depth of cracking be taken as $0.33H_t$ to $H_{so}$, with specific values being determined on the basis of climate. The Standard recommends $0.5H_t$ for the Brisbane/Ipswich region, however correlation between depth of cracking and climate is beyond the scope of the present project, and little other research has been done. If cracking investigation has been carried out in a subject region it is recommended that those figures be used.

$\Delta u$, the design surface soil suction change, is normally taken to be 1.2 pF throughout Queensland, however local practices do vary and further research is to be encouraged.

A numerical example of the use of the map to calculate $y_s$ is given in Appendix A.
CONCLUSION

The TMI-based climate zone map provides a valuable site classification tool for practitioners throughout Queensland, and it complements previous work in other States. Experience has highlighted problems in the calculation of characteristic surface movement with many practitioners in all States. The discussion and worked example will be a useful guide to correct practice.

ACKNOWLEDGMENTS

The research on which the map is based was carried out with the support of the Construction Industry Advisory Council. Stephen Fityus, Robert Smith, Ken Boddie and John Simmons contributed valuable advice and assistance on various technical points.

REFERENCES


American Society of Civil Engineers, 1997: Design standard for residential foundation structures on expansive soil, uninculated Committee Draft.


APPENDIX A: EXAMPLE OF Ys CALCULATION USING THE MAP

**Aim:** To estimate the characteristic surface movement, $y_s$, for a house site at Biloela (24.38S, 150.52E), with the following soils data. Boreholes to 4m deep indicate 1m of natural silty clay (for which laboratory testing has indicated a shrink-swelling index, $I_s$, of 2.5%) overlying clay ($I_s$ 3.5%) to the limit of excavation. The site appears typical of the region and contains no apparent geological, topographical or drainage anomalies.

**STEP 1: COLLECT DATA**

**Regional.**
Reference to Figure 1 indicates the site to be in climate zone 4. In the absence of any over-riding specific data accept from Table 1 that $H_s$ for the site is 3.0m, and that the depth of cracking is $0.75H_s$ or 2.25m. The design surface suction change is 1.2pF.

**Site specific.**
From the boreholes there are two strata within the active zone: 1m of $I_s$ 2.5% and 2m of $I_s$ 3.5%.

**STEP 2: DEVELOP SITE PROFILE**

From the above data:

**STEP 3: IDENTIFY PROPERTIES OF LAYERS**

Divide the profile into layers of like properties. In this example there will be three: the upper soil stratum, and the lower stratum, which will be divided into two layers, one within the crack zone, the other below the crack zone. The properties to be used are those at the mid-height of the respective layer. The geometry becomes:
STEP 4: CALCULATION OF $Y_s$

The formula given in the Standard for calculation of $y_s$ (F1 in AS 2870-1996), and quoted above, indicates that $y_s$ is the integral of incremental contributions to surface movement over the depth $H_s$. This is not practical in actual application, and $y_s$ is calculated as the sum of surface movement contributions from a number of discrete layers. The formula becomes, for “n” layers and assuming shrink-swell testing is used to estimate $I_{ps}$:

$$ y_s = \frac{1}{100} \sum_{1}^{n} \alpha_n I_{ssn} \Delta u_n \Delta h_n $$

The calculation is:

<table>
<thead>
<tr>
<th>Layer</th>
<th>$\alpha_n$</th>
<th>$I_{ssn}$</th>
<th>$\Delta u_n$</th>
<th>$\Delta h_n$</th>
<th>$(\alpha_n I_{ssn} \Delta u_n \Delta h_n)/100$</th>
<th>$y_s$ contrib. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>2.5</td>
<td>(2.5/3.0)1.2 = 1.0</td>
<td>1.0</td>
<td>(1x2.5x1x1000)/100</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>3.5</td>
<td>(1.375/3.0)1.2 = 0.55</td>
<td>1.25</td>
<td>(1x3.5x0.55x1250)/100</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>(2-2.625/5) = 1.475</td>
<td>3.5</td>
<td>(0.375/3.0)1.2 = 0.15</td>
<td>0.75</td>
<td>(1.475x3.5x0.15x750)/100</td>
<td>6</td>
</tr>
<tr>
<td>Σ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>55</td>
</tr>
</tbody>
</table>

The characteristic surface movement for the site is thus 55mm after rounding to the nearest 5mm in accordance with AS 2870 Supp1-1996, clause C2.2.3(c), and the site is class “H”.