Trends in Shrink–Swell Test Results in the Newcastle region

S. G. Fityus
B.E.,B.Sc.
Postgraduate Student, The University of Newcastle, Australia
J. C. Welbourne
B.E.

Summary Shrink-Swell test results obtained in the Newcastle, Lake Macquarie and lower Hunter Valley regions have been studied. A total of 902 individual results, obtained from two local consultants and the Newcastle University Civil Engineering Department, have been compiled in a database. The recorded results date from 1981 to 1995. Efforts were made to record all of the available test data associated with each result. Important trends in both the local practice and the local conditions are examined. An attempt to establish a useful correlation between the Instability Index, I_{SS}, and the moisture content at the end of the swell test failed to yield any generally useful results.

1. INTRODUCTION

This paper summarises the trends observed in a database of shrink–swell soil reactivity test results for 902 soil samples in the Newcastle area. The database was created as a final year project by the second author, while a student in the Department of Civil Engineering and Surveying at the University of Newcastle.

The aim of the database was to assemble the substantial but relatively inaccessible volume of shrink-swell test data which has been generated in the Newcastle region over the past 13 to 14 years. Amongst the general aims of the project were assessments of the types and depths of soils sampled and the typical ranges for results. More specific aims were to analyse trends in other recorded parameters in an attempt to find a useable correlation between the I_{SS} value and other more easily measured quantities.

A similar database of 580 results was compiled by Taylor in 1993 as part of a Masters research program on reactive clay soils in the Newcastle area. That study examined only the statistical and geographical distribution of I_{SS} values and attempted to infer typical site classifications throughout the area based on the results for particular geological sub-groups. The database compiled for the present study is more comprehensive in that it includes all useful test data recorded with each collected test result. Its research potential extends well beyond this paper.

The test results were mostly collected from the records of two of the larger geotechnical consulting firms practicing in the Newcastle region. Sets of 241 and 616 test results were obtained from the two consultants. The remainder of the results were taken from testing records of the University of Newcastle's geomechanics laboratory, which undertakes shrink–swell testing on occasions.

2. SAMPLING STRATEGY

2.1 Geographical and Geological Range

In formulating this project, it was acknowledged that the collection of all available data for the local region was beyond its present scope. It was thus decided that the data should be sampled on a suburb by suburb basis, taking all available data for each of the targeted suburbs. Figure 1 shows the distribution of the targeted suburbs, and gives an indication of the geographical extent of the database.

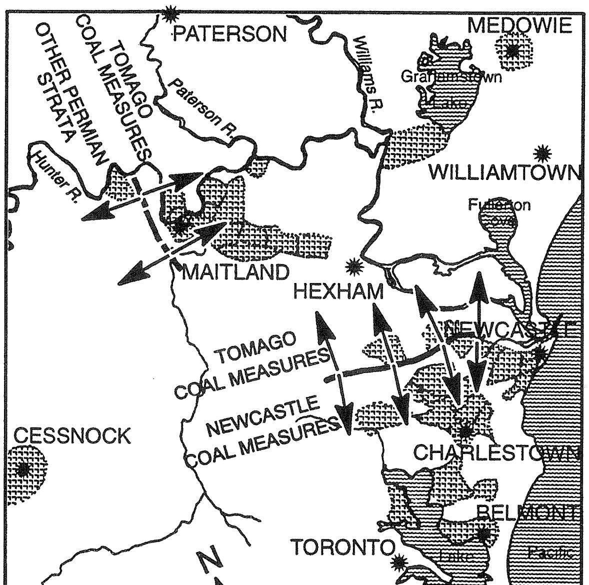

Figure 1. Approximate areas covered by samples in this study.

The suburbs sampled were selected on the basis of test frequency and geological providence. Suburbs with a greater number of results were sampled in preference to those with few results. Suburbs were also selected to give good representations of geological formations which commonly weather to produce reactive clays, as well as alluvial clay areas. The implications of geology are summarised briefly in section 3. Note that efforts were made to select suburbs without bias: the suburbs selected are considered to fairly represent both the higher and lower typical soil reactivities in the region.

2.2 Form of the database

The database was set up to accommodate up to 30 fields of data for each test result. Any useful test information recorded by the consultants was included so that the database would be the most comprehensive source of factual shrink-swell data possible.

Fields include measured test quantities such as sample strains, moisture contents, densities and shrinkage limits as well as data on sample depth, sample location and testing operator. Note that variations in the quoted sample sizes reflect missing values in the source data.

3. REACTIVE SOILS IN THE NEWCASTLE REGION

Reactive soil phenomena in the Newcastle Region differ significantly from those in Melbourne and Adelaide. The Newcastle reactive soil profiles are generally shallow and the climate is temperate (Smith and Allman, 1995). The range and distribution of soil reactivities is strongly influenced by the local coal measures geology. This unique influence is discussed in detail by Fityus and Delaney(1995). Only the main features will be summarised here.

- The Newcastle, Lake Macquarie and Lower Hunter Valley areas are underlain by Permian coal measures sequences with intervening marine formations.
- Newcastle and Lake Macquarie are mostly underlain by the Newcastle Coal Measures, while suburbs to the immediate north, and most of the Maitland area, are underlain by the older Tomago Coal Measures. (refer to Figure 1)
- The coal measures consist of a highly variable sedimentary geology of mudstone, siltstone, sandstone and coal. Hunter Valley coal measures (the Newcastle Coal Measures in particular) also contain frequent units of tuffaceous claystone and conglomerate. These rock types weather to produce a wide range of soils ranging from very reactive clays to inert gravelly sands.
- The coal measures are made up from as many as 200 individual units which can vary greatly in thickness, and even disappear, across the region. There is no consistent succession of rock types; strata producing very reactive clays are often in direct contact with units which produce inert soils.
- The regional structure of the coal measures is typically gently dipping (4°, roughly south) to horizontally bedded, with frequent and unpredictable localised variations.
- Flat-lying areas are usually underlain by Quaternary alluvial clays which also exhibit a range of reactive potentials.

The origin of samples whose results form this database is summarised in Figure 2

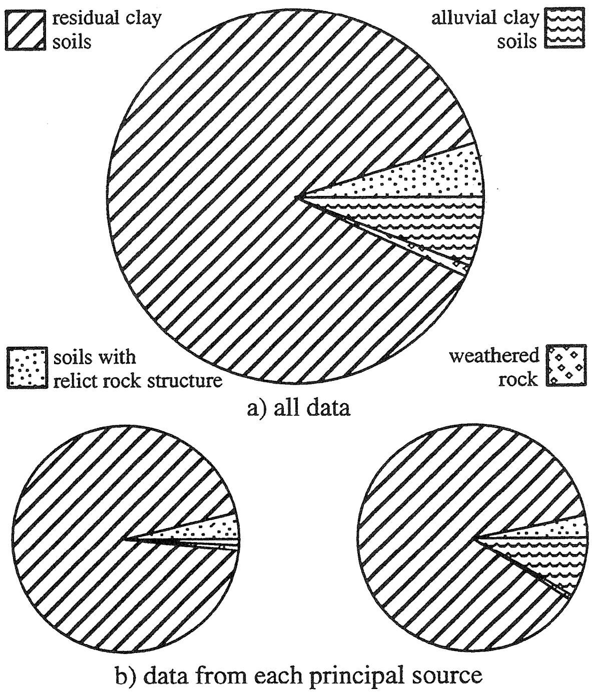

Figure 2. Origin of the soil samples corresponding to the results presented in this study.

Figure 2 shows that around 90 percent of all soils tested derived directly from weathering of the underlying Permian Geology.

A broader implication of the local geology is the inherent unpredictability of subsurface conditions. This results from the interaction of a flat-lying, variable geology with a typically undulating surface terrain.(Fityus and Delaney 1995) Because of this unpredictability, the broad categorisation or zoning of wide areas of the Newcastle area according to soil reactivity is not generally feasible. Categorisation is seldom reliable beyond the recognition that sites, underlain by certain geological units or formations, are more or less likely to be affected by reactive soil phenomena.

4. REACTIVE SOILS ENGINEERING IN THE NEWCASTLE AREA

The inherent variability of the local geology has long been recognised by the local consulting industry. Local methods of assessing reactive soil potential have thus evolved with a much stronger emphasis on individual site testing, than those used in other centres in Australia where broad regional trends and visual assessment are acceptably reliable. As such, the classification of clay sites for reactive soil potential in local practice usually involves some laboratory testing. This is typically of "undisturbed" 50mm. diameter soil samples, according to the method in AS1289-7.1.1.-1992.

The earliest test records located in the study date from 1981 and consist of an unconstrained shrink test only. Tests as early as 1983 comprise both shrink and swell test components, although the early tests reported the instability index simply as the sum of the shrink and swell strains. From about 1986, with the release of the first reactive soils standard, AS2870–1986, the reported instability index assumed its current form; that is, with the swell strain divided by 2 to account for lateral confinement, and the total strain divided by an assumed change in suction of 1.8 pF units. It should be noted that the I_{SS} values considered here have all been recalculated in the database in accordance with this approach, from the recorded shrink and swell strains.

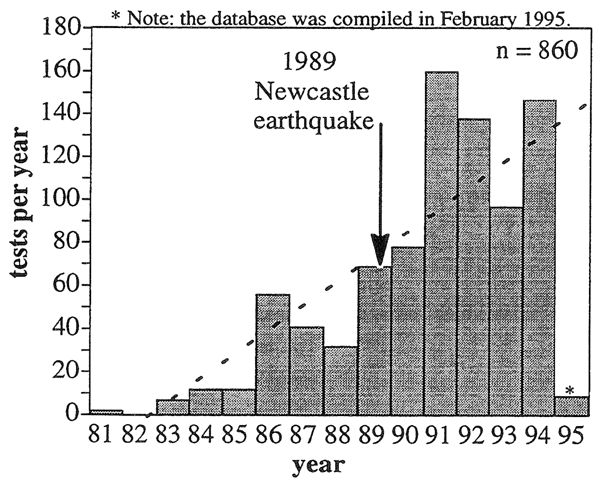

Figure 3. Number of shrink–swell tests per year.

Figure 3 shows the temporal trend in test frequency since the testing began in 1981. It is obvious from this figure that awareness of reactive soils phenomena has been increasing steadily since it became prominent in the early 1980's, and that it continues to increase. Of particular interest is the localised increase in 1991–92. This increase results from the occurrence of the December 1989 Newcastle earthquake, which caused widespread damage to residential structures throughout the region. The 1 to 2 year delay between the earthquake and the increase in testing is an interesting and explainable anomaly. Damage which was reported immediately after the earthquake was repaired by insurance companies with little or no investigation to confirm its cause. However, in the wet and then dry periods which followed the earthquake, much of the repaired damage recurred. Many of the claims for recurring damage were subsequently investigated for other causes, and in many cases this involved an assessment of the potential for damage due to reactive soil movements. It may be of interest, that in the experience of the first author, the potential for reactive soils to have caused both the original and recurring damage was identified in a large number of the cases investigated.

5. TRENDS IN SOIL REACTIVITY

5.1 Range and spread of I_{SS} values

A histogram of all 902 I_{SS} records is presented in Figure 4

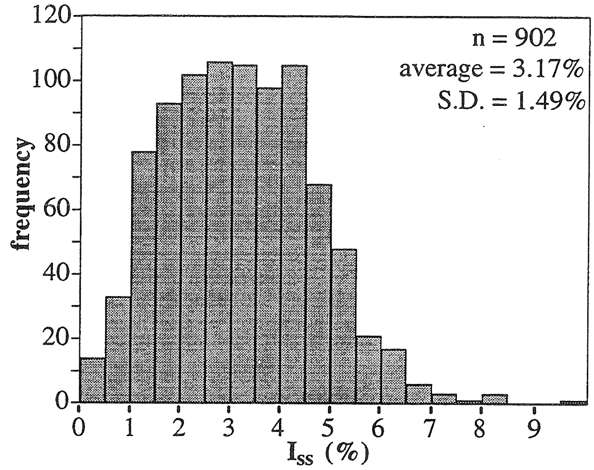

Figure 4. Histogram of all recorded I_{SS} results (902 results, all sources)

It is apparent that the clay soils in the greater Newcastle region span a wide range from very low to very high I_{SS} values. It is also apparent that there is a similar likelihood of encountering I_{SS} values anywhere from 1 to 5 percent for any randomly selected site. For a clay profile up to 1.5 m. in depth (the active depth for the Newcastle region), this implies similar likelihoods of encountering slightly, moderately or highly reactive sites. Thus, the adoption of average values, or the common assumption of a moderately reactive site, each hold significant likelihoods of over or under design. Further, the likelihood of an inappropriate design is greater than the likelihood of an appropriate design, if a classification is randomly assumed. The data thus confirms the necessity for frequent testing by the local consulting industry.

5.2 Depth of testing

Figure 5 shows a histogram of the depth of samples taken in the Newcastle region for shrink swell testing.

While most samples are taken from within the 1.5 m. active depth, a small number of samples are taken from deeper levels. These mostly correspond to the areas of Maitland and Cessnock, which are both inland and for which a greater active depth can be argued. Maitland in particular, has areas which are underlain by deep alluvial clays which are observed to crack to great depth.

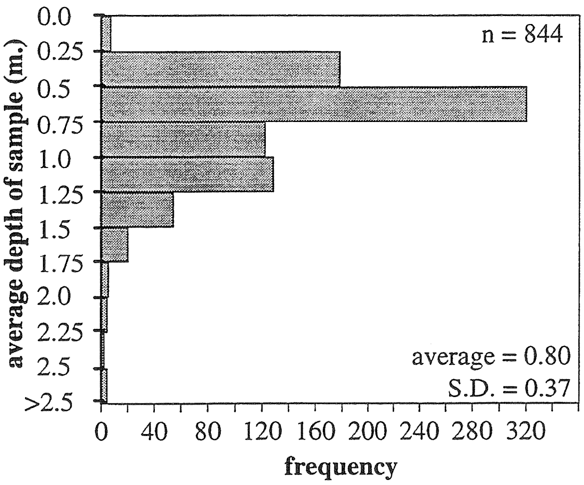

Figure 5. Distribution of average sampling depth. (all data)

Also obvious from Figure 5 is an appropriate scarcity of testing at depths less than 0.25 m. This is consistent with the presence of 0.2 to 0.3 m. of relatively non reactive topsoil in most areas.

5.3 Variations in I_{ss} with depth

The data has also been used to assess the trends in I_{ss} with depth. It was suspected that the I_{ss} might vary with the depth of sampling due to a decrease in the degree of weathering, as rock is approached in residual soil profiles. Residual clay profiles, derived from the underlying Permian coal measures strata, typically exhibit little or no obvious stratification apart from the presence of a well defined silty or sandy topsoil layer. Visual and textural changes in the residual clay itself are often perfectly gradational. Soils may vary from biologically and climatically altered clays at the base of the topsoil, to extremely weathered rock, over depths of as little as 1m., without any identifiable interfaces between different materials. This would suggest

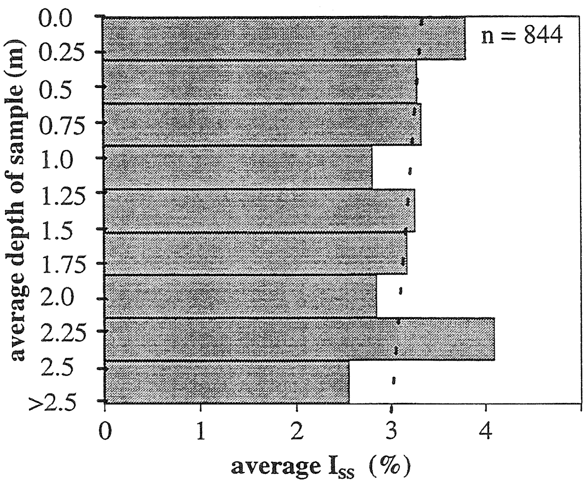

Figure 6. Distribution of average I_{ss} vs. average sampling depth. (all data)

that samples from deeper levels in the profile might be less weathered and thus have had less of their original mineral content converted to potentially reactive clay. This idea is assessed in Figure 6.

Figure 6 shows that there is only a slight decreasing trend in I_{ss} with increasing depth. This suggests that the weathering process which produces clay soils from local Permian rocks has little effect of the types or amounts of clay present. As such, the main effects of the weathering process appear to be the reversal of the cementation and compaction processes which occurred during diagenesis.

5.4 Comparison of results from the Newcastle and Tomago Coal Measures

Figure 7 compares the distribution of I_{ss} results for residual soils derived from the Newcastle and Tomago Coal Measures.

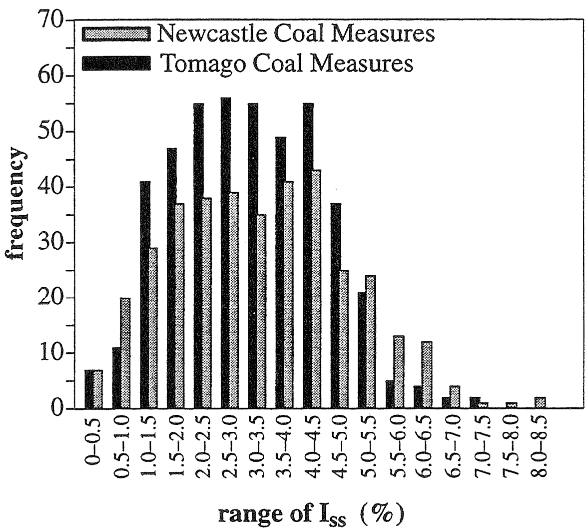

Figure 7. Distributions of I_{ss} values for residual soils derived from the Newcastle and Tomago C.M.

Table 1 presents the statistics for these distributions. It is interesting to note that despite the greater abundance of potentially reactive claystones in the Newcastle Coal Measures, the mean reactivities of soils produced by each is similar. From Figure 7, the results for the Newcastle Coal Measures do appear to be more broadly distributed; the greater spread confirmed by a larger standard deviation. It appears that the greater proportion of very reactive clays derived from the tuffaceous claystones is probably offset by a larger relative proportion of less reactive soils derived from conglomerates, thus spreading the results without greatly shifting the mean.

Table 1. Statistics for I_{ss} values of soils derived from different geological formations.

Newcastle Coal Measures			Tomago Coal Measures		
n	av.(%)	S.D.	n	av.(%)	S.D.
371	3.29	1.60	449	3.11	1.35

5.5 Alluvial and Residual Soils

The data was also used to compare the range of reactivities determined in the alluvial soils with the range of reactivities in the soils derived, in situ, from the local Permian geology. The latter data set includes all residual clays, soils with relict rock structure and extremely weathered rock. The results are shown in Figure 8, and the statistics are given in Table 2.

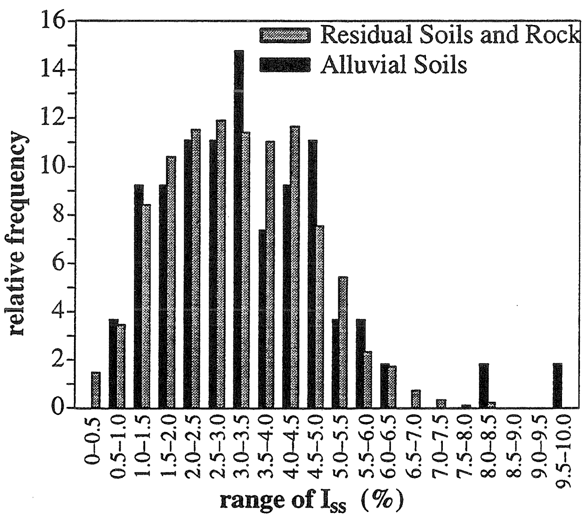

Figure 8. Distributions of I_{ss} values for soils from different genetic origins.

The distributions are relatively similar, apart from a peak and trough in the alluvial results between 3 and 4% I_{ss}, and two peaks above 8%. It is worth noting that these high peaks (>8% I_{ss}) in the alluvial results are not as significant as they might appear as they represent only one test result in each case: the alluvial sample size of 55 is relatively small.

Table 2. Statistics for Alluvial and Residual soil subsets.

Residual Soils.			Alluvial Soils.		
n	av.(%)	S.D.	n	av.(%)	S.D.
847	3.18	1.46	55	3.38	1.72

The spread in alluvial results is surprising given the degree of mixing and reworking which occurs during the transportation and deposition of sediments. Some of this is perhaps due to the differences in the providences of sediments sampled in different catchments.

Also surprising, is the similarity between the distributions of alluvial and residual soil results. The distribution of results for residual soils reflects the varied origin of materials contributing to the different Permian strata. This is strongly influenced by sediment which was supplied, in varying proportions, by an explosive volcanic source (Diessel, 1985), as well as an eroding geology which was certainly different to that which outcrops in the Hunter catchment today. In contrast, the alluvial soils are derived from areas in the wider Hunter catchment, many of which are remote from outcropping Permian strata.

6. POSSIBLE EMPIRICAL CORRELATIONS

A number of the properties recorded with the shrink-swell results were explored to see whether some other easily measured property might have a unique and well defined relationship to I_{ss}. In particular it was proposed that the saturated moisture content of a clay could be used as a quantitative indicator of a soil's reactive potential. This proposition was based on the observation that both volume change and degree of saturation were strongly dependent upon the amount of water absorbed by a soil. This is in turn a function of the proportions and types of clays present in the soil.

This proposition was tested, in part, by Aitchison and Richards (1965). They established that for soils of similar origin, prepared to a given total suction, those with greater clay contents had higher moisture contents.

It was also tested in part by Kay (1990) who attempted to correlate volume change with liquid limit; a quantity somewhat related to the mineralogy of the clay fraction of a soil.

Figure 9 tests the proposition in full. The saturated moisture content plotted below is the moisture content of the swell sample at the end of the swell test.

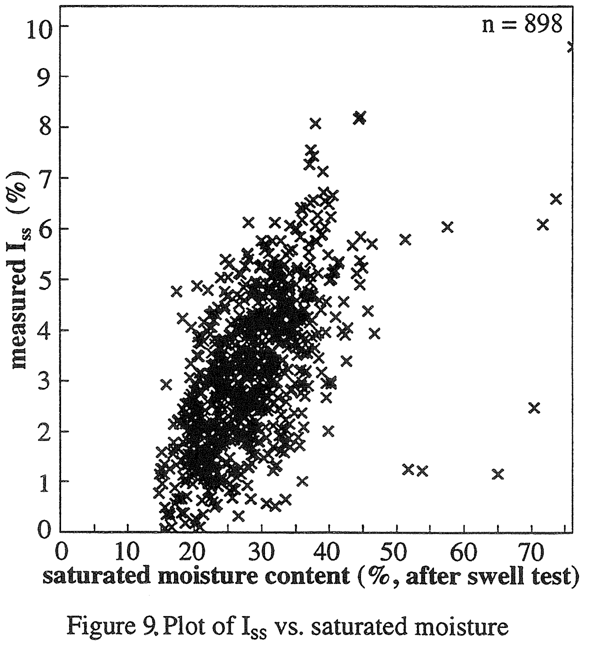

Figure 9. Plot of I_{ss} vs. saturated moisture content.

While there is indeed an obvious trend between the saturated moisture content and the I_{ss}, the correlation is very scattered. For any given moisture content, there is an equal chance of the I_{ss} value lying anywhere in a range of about 3%. The correlation is thus not useable, as the expected error in a best fit estimate is as much as 1.5%: enough to result in a change in site classification in most cases.

It is interesting to note that the scatter in this correlation is similar in magnitude to that found by Kay (1990).

A large number of correlations were also examined for data subsets defined by criteria such as geological origin(8), same suburb(28), same site(10) and restricted ranges of initial moisture content and sampling depth. The correlations were at best, consistent, and at worst, vague. No useable correlations were found, even for the most restricted of subsets.

A possible reason for the persistence of scatter was identified in recent experimental findings by Fityus (1996), in a study of the effect of initial sample moisture content on I_{SS}. In this study, it was found that the moisture contents of the swell samples at the end of the swell test are dependent upon the initial sample moisture content. In some cases higher initial moisture contents produce higher final moistures. In other cases, the opposite is observed.

An attempt to correlate I_{SS} with the saturated moisture content (after the swell test) failed to produce a useful correlation.

7. CONCLUSIONS

The reactive potential of clay soils in the greater Newcastle region exhibit a wide range of reactive potentials. Local site classification practice is typically based on a calculated characteristic surface movement which is calculated from Instability Index (I_{SS}) values determined by laboratory testing of "undisturbed" site samples. This practice, which differs from that in centres such as Adelaide and Melbourne, is justified by local conditions which are also different. These comprise a range of typically encountered I_{SS} values between 1 and 5%, but as high as 10%, and a subsurface geology which is highly variable.

Despite some significant differences in their geological assemblages, the Newcastle and Tomago Coal Measures generate residual clays which exhibit similar ranges of reactivity, and with similar means. However, the distribution of I_{SS} values in the Newcastle Coal Measures is slightly more spread due to the increased presence of claystones and conglomerates.

While only 6% of soils tested were of an alluvial origin, they exhibit a range and distribution of reactivities similar to the residual soils derived from the local Permian coal measures geology.

Clays tested in the Newcastle region are mostly sampled from within the assumed 1.5 m. active depth for the area. There seems to be little or no trend of either increasing or decreasing reactivity with depth, despite weathered rock being typically encountered between about 1 and 2 m. below the surface.

8. ACKNOWLEDGMENTS

This research has been carried out with the permission of two local geotechnical consulting firms. Financial support for this research from the Mine Subsidence Board of New South Wales, Robert Carr and Associates and the Australian Research Council is also appreciated.

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