CHAPTER 7

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

Capping layers are used in railway/pavement substructures to improve the structural stability where the in-situ materials can not sustain the imposed loads adequately especially without undue permanent deformations. It is essential that these capping layers be properly characterised for use in any design practices.

Methods of characterising railway substructure materials have first been reviewed in detail in this thesis. An economical method, both in terms of testing effort and cost of evaluating the capping layer material properties using penetration tests on specimens contained in a California Bearing Ratio (CBR) test mould coupled with a finite element modelling based backcalculation technique has been developed. The finite element based backcalculation of material properties has been achieved by incorporating stress-dependent tangent modulus and friction angle to modify the Drucker-Prager model. An explicit finite element code coupled with adaptive re-meshing technique was used to model the large vertical penetration relative to the height of the specimen without mesh distortion or any other form of numerical instability. However, whilst the explicit algorithm models the global behaviour adequately, it does not provide an accurate measure of the distribution of internal stresses within the specimens. Although more involved methods of importing the explicit solution into implicit algorithms for achieving acceptable internal stress distribution are available, such a procedure was not adopted as the main objective of the thesis was to evaluate representative upper and lower bound values of the properties of capping layer material only. Furthermore the backcalculation method used was also a trail and error approach, although there is an emerging trend of using genetic algorithm search techniques for such inverse problems. Once again the adoption of approximate methods in preference to advanced techniques/ procedures is due to the practical objective of the thesis for developing a simple and economical method to determine the upper and lower bound properties of the capping layer materials which allow the practitioner to make reasonable assessments of the likely field performance of capping material.

The robustness of the evaluated material properties has been examined by applying the data to unfamiliar situation where the material layer was kept under plane strain condition with limited lateral confinement. The predicted behaviour of the capping layer material under plane strain condition has been validated using large-scale tests.

7.2 Major Conclusions

The following are some important conclusions made from this thesis:

(1) The simple penetration test termed 'Semi Confined Test (SCT)' coupled with the explicit finite element technique based backcalculation procedure is capable of characterising the material well. Methodology proposed in this thesis could be used to determine broad characteristics of the capping material for assessing their suitability.

(2) For this procedure to work well, both the tangent moduli and friction angle should be regarded as confining pressure dependent. A limited number (3) of drained

triaxial tests and uniaxial tests are required for the determination of initial trial values of elastic moduli, coefficient of friction, cohesion, and hardening modulus to be used in the backcalculation procedure. Capping layer material could be modelled as an elasto-plastic continuum represented by the Drucker-Prager failure criterion modified for the pressure dependent tangent modulus and friction angle to determine the level of permanent deformation under loading.

(3) Acceptable predictions of upper and lower bounds of capping layer tangent moduli, friction angles, cohesion, dilation angle and hardening modulus were obtained from the simulations using the constitutive model based on Drucker-Prager theory of plasticity coupled with a stress dependent tangent modulus and a friction angle.

(4) Other than the degree of compaction, the main external parameter that affects the properties of material is the level of moisture. Moisture level in capping layers adversely affects their properties more than the effects of load cycle or loading rate. Saturation tends to soften the material and dryness tends to stiffen the material relative to the behaviour of the material with optimum moisture content (OMC) in the low level of penetration (≤ 20mm). Beyond this level, the softening – remoulding – hardening behaviour of the capping layer within the highly confined CBR mould is less pronounced for saturated specimens and significantly highly pronounced for dry specimens.

(5) From the limited number of large scale plane strain modelling of capping layer material carried out, it may be inferred that specifying a good quality material for

the capping layer for railway substructure is more important in practice than improved thickness design criteria or models. The importance of characterisation of the material advocated in this thesis could be re-emphasised based on this conclusion.

(6) Although large scale plane strain testing could be used for backcalculating the properties of the capping layer materials as they more closely resemble the field condition than the CBR mould test, considering the costs and efforts associated with the large scale testing, it can be concluded the semi confined testing in CBR mould is the most economical testing base although the testing generates very high levels of confining stresses that do not get generated in practice.

7.3 Specific Conclusions

The following conclusions are specific to the capping layer material tested in this thesis:

1. Three distinctive groups of properties were predicted from the experimental based finite element backcalculation process for dry, OMC and saturated state of the capping layer material given in Table 7.1.

Table 7.1 Summary of predicted capping layer properties

		Elastic			Plastic	
		$E_0 \le E_t \le E_{max}$ (MPa)	$\phi_{min} \le \phi \le \phi_{max}$ (^{0})	c (kPa)	ψ (^{0})	H_p (kPa)
Dry	Lower bound	$80 \le E_t \le 100$	$40 \le \phi \le 43$	500	2	200
	Upper bound	$345 \le E_t \le 350$	$40 \le \phi \le 43$	500	2	200
OMC	Lower bound	$30 \le E_t \le 80$	$35 \le \phi \le 38$	300	4	300
	Upper bound	$80 \le E_t \le 130$	$35 \le \phi \le 38$	350	7	300
Saturated	Lower bound	$20 \le E_t \le 45$	$33 \le \phi \le 35$	300	7.5	300
	Upper bound	$55 \le E_t \le 80$	$33 \le \phi \le 35$	300	6.7	300

2. For the capping layer material considered in the thesis, it was found that with the increase in moisture content the tangent moduli, friction angle (all elastic properties) and cohesion decreased whilst the dilation angle and hardening modulus (both plastic properties) increased.

3. The large scale plane strain testing, modelling and analysis carried out indicated that

   (i) the 300mm capping layer resisted the penetration with higher resistance than the 600mm layer did

   (ii) the 300mm layer sustained failure beyond 15mm penetration irrespective of the quality of the material (upper bound or high quality & lower bound or poor quality)

   (iii) the 600mm layer made from lower bound material sustained failure beyond 30mm penetration whilst the 600mm layer made from upper bound material did not fail up to 50mm penetration for which the analysis was made.

4. Although thicker capping layer reduce the stresses in the layers below; it was evident from the above results that the thicker capping layers made from lower bound materials do not provide better behaviour than a corresponding thinner layer. Therefore, anticipated improvements by providing a thicker layer may not be the right approach in a rail track design where low quality materials are to be used.

7.4 Recommendations for Future Studies

There is much scope for further advancement of the modelling details. Some potential future improvements to the analytical procedures and to our overall understanding of capping layer behaviour are presented below.

- Extension to SCT – In the SCT, only granular materials were tested. It is worthwhile to further investigate the behaviour of cohesive material using the current experimental method and extend the constitutive model. As more knowledge becomes available, the constitutive model can be improved to describe what has been observed in the laboratory and in engineering practice.
- Extensions to constitutive model – The present material constitutive relationships consider an *isotropic hardening model* where the loading surface expands uniformly (or isotropically), and it cannot account for the Bauschinger effect (Chen and Mizuno 1990) exhibited by material subjected to cyclic loading. Therefore the present constitutive model might usefully be extended to a *kinematic hardening model* which can predict cyclic loading which is more relevant to railway loading conditions.

  The friction angle is also a stress-dependent parameter (Selig and Waters 2000), therefore the present material constitutive relationships can be improved by incorporating a yield function that includes first and third stress invariants which are related to soil shear strength or friction angle (Yang and Elgamal 2004).

  The material strength parameters were drastically changed according to the degree of saturation, from dry to fully saturated. As much as they depend on the stress conditions, they also depend on the moisture levels. Therefore, this study can be improved by incorporating a factor for the moisture levels in the constitutive model.

- Extensions to validation experiments – The validation experiments can be extended for more realistic situations, especially by varying the base boundary conditions as capping layers are provided when natural ground or fill has lower strength parameters than the capping layer. Extending experiments to such scenarios will provide valuable information on the behaviour of the capping layer and the applicability of SCT predicted material parameters via finite element modelling.
- Parameter data base and design charts – Little is known of the capping layer materials used in Australia. Typically, broadly graded sandy gravel with a feeble plastic binder is used as a capping layer. Further research is required to examine the effect of these materials simulating in-service conditions. After extensive investigations a data base or design charts can be produced using different boundary conditions.