IS SOIL SCIENCE RELEVANT TO ROAD INFRASTRUCTURE?

A.J.W. Biggs[1] and K.M. Mahony[2]
South West Region, Department of Natural Resources, Mines and Energy, Toowoomba, Australia.
Southern Queensland Region, Department of Main Roads, Toowoomba, Australia.

Abstract
Soil is a primary engineering material for road construction and maintenance. Most road authorities successfully identify and manage the physical properties of soil when undertaking road construction and maintenance. However, identification and management of soil chemical properties and soil landscape processes, and in particular, how they may influence road construction and maintenance now, and in the future, is highly variable.

Using soil as an engineering medium requires the removal of biological properties, alteration of chemical properties and reduction/removal of the physical properties (e.g. bulk density, water entry rate, porosity and hydraulic conductivity) of a soil. However, soil physico-chemical properties may present hazards to engineering, and these risks need to be identified and managed as part of project design, assessment, maintenance and management. Soil chemical properties such as acidity, sodicity and salinity may corrode concrete and steel structures and road furniture or cause land degradation in the area of the road. Assessment of these properties, and the soil and landscape processes that affect them will be essential to the future integrity of road assets.

Additional Keywords : sodic, acidification, salinity, road, Queensland, construction

Introduction

Soil science and civil engineering, in particular road engineering, are well established disciplines that are applied to a variety of industries. Interactions between soil science and road engineering have predominately occurred in the area of soil physics. This may have resulted in soil science not identifying important issues relevant to engineering, and the civil engineering discipline not adequately assessing and managing one of its primary materials. Using soil as a road engineering material may require the removal of biological properties, alteration of chemical properties and reduction or removal of some of the physical properties, in order for the road asset to meet it's intended design life and cause minimal impact (*or vice versa*) on the immediate and surrounding landscapes. Consequently, soil science is applicable to road planning and design, material source identification, road construction/maintenance and erosion control and rehabilitation of the road reserve.

In southern Queensland, recent work by road authorities and other government departments has been raising the awareness of the importance of soil science to road infrastructure development and asset maintenance with both soil scientists and engineers. This paper will address:

1. how soil chemical properties and soil landscape processes may influence road planning and design. This will include how land use adjoining road reserves may influence the design assumptions that are used during road planning and design. For example structure design may need to consider that the soil may be more acidic or saline at some future point in the design life of the structure.
2. solutions, monitoring methodologies and technologies that can be applied to road construction and asset maintenance to address soil properties and therefore minimise road reserve and road asset degradation.
3. importance of co-operation between government agencies and the community in managing the implications of soil chemical properties and soil landscape processes on road infrastructure.

Background

The main properties required of a road embankment are minimal potential for movement and erosion. The main properties for a road pavement are strength, durability, impermeability, volume stability, wear resistance and workability during construction. In addition to these properties, road structures require non-aggressive soil environments that is, low chloride, low sulphate, pH neutral and low potential for erosion of the material surrounding the structure. The soil parameters to be assessed and managed to meet these requirements are from quite different fields in soil science. Historically, road infrastructure development has relied on assessment of the physical properties of soils, with minimal assessment of soil morphology or chemistry. As such, road authorities have considerable experience and skill in the assessment, understanding and management of the physical properties of soils but less experience in soil chemistry assessment and management. Soil science, although thoroughly understanding both the physical and chemical properties of soils, has traditionally dealt with agriculture environments. As such minimal work has been conducted in relation to the impact of soil physio-chemical and chemical properties and their implications for road infrastructure. Specifically, how the parameters of sodicity, salinity, pH and waterlogging affect road infrastructure.

Southern Queensland contains large areas of soils with specific characteristics relevant to the road environment. These include, but are not limited to:

1. Thin, infertile, poorly structured surface horizons.
2. Sharp increase in clay content and associated “hostile”chemistry in the subsoil
3. Clay soils with high salt contents (both NaCl and $CaSO_4$)
4. Very large areas of cracking clays (Vertosols). These are relatively fertile but possess physical and chemical limitations.

Coupled with the climate found in southern Queensland (sub-tropical, with episodic, high intensity rainfall), these soil properties lead to considerable difficulty in both management of the road reserve, and use of soil material for construction purposes.

Sodicity

Soils can be eroded by either mechanical or chemical erosion. Chemical erosion is often referred to as dispersion. A sodic soil is a soil with a high percentage of sodium ions relative to other cations in the soil water solution. Simply, when a soil is saturated, the pores are filled with a solution containing varying amounts of cations (e.g. calcium and sodium) and anions (e.g. chloride and sulphate). In a non-dispersive soil, these cations and anions are in balance with the negatively charged clay particles. In a dispersive soil, the ionic bond is weak, and therefore the clay particles lose their cohesiveness and readily disperse into the pore spaces. Dispersion can occur in sodic soils without disturbance, as long as there is a non-saline moisture source. Non-dispersive undisturbed soils can also become dispersive when remoulded (Emerson 2002). If dispersion has occurred, the permeability of the soil is reduced and erosion can readily occur. Sodic soils can form hardsetting crusts, which are impermeable when dry. Sodic soils also suffer from poor aeration, waterlogging and erosion, and normally have low wet bearing strengths. The inherent nature of sodic soils also makes revegetation of the road reserve difficult.

Location of Sodic Soils in Southern Queensland

Sodicity can occur in many different soil types and at any depth in the soil profile. Sodicity is an inherent feature of most southern Queensland landscapes. Most clay soils, with the exception of those of basaltic origin, have an exchangeable sodium percentage (ESP) >6 in the subsoil, and values of >15 are common at depths as shallow as 0.3 m. Subsoil ESP values in excess of 40 are not uncommon. Gradational, duplex or uniform soil profiles can all potentially be sodic but duplex soils are most likely to be sodic. There are two types of sodicity – primary and secondary. Primary sodicity is a consequence of the parent material or and soil forming/landscape processes. Secondary sodicity is a consequence of change salinity associated with change in land use. Drainage and leaching of salt affected areas can result in removal of chloride, but retention of sodium. The relationship between electrical conductivity (EC) and ESP is an important aspect that has not been explored in the context of disturbed environments. In the natural environment, these two aspects are in equilibrium, governed by clay content, clay type and rainfall (SALCON 1997). In the agricultural environments, removal of perennial vegetation and associated change in hydrology will leach chloride, the dominant salt in most soils (Tolmie *et al*. 2003). As the EC of the soil declines, the EC/ESP relationship is altered, and the soil typically becomes less stable. Eventually a new equilibrium is achieved.

Issues Associated with Using Sodic Materials

The lack of non-sodic materials across much of the southern Queensland landscape has resulted in sodic materials frequently being used to construct embankments, and often used as a pavement material. The long-term success of such practices is now being questioned. This is because, sodic embankments (either cuts or fills) are often very difficult to stabilise, and rilling, tunnelling, gullying and slumping are common forms of failure. Dispersion of sodic materials abutting rigid structures e.g. culverts, bridges, road furniture is also a problem in many areas. It is apparent that the difference in rigidity between compacted soil material and concrete can result in sufficient gaps/cracks forming for water to enter and cause dispersion. Major failures of structures can result as holes and tunnels develop. There are numerous examples of this in southern Queensland. On average the problems develop over long periods of time (i.e. 3-10 years), however some significant problems have developed as soon as 8 months after the completion of construction.

Potential Mitigation Measures

Mitigation measures for sodicity have to be considered at all stages of road infrastructure development to minimise the financial and environmental impacts of using sodic soil as a primary engineering material. These mitigation measures include:

Planning stage

1. Using existing soils mapping and minimal field investigation, the sodicity of the soils in the surrounding landscape are determined. This provides a risk assessment for the project manager, and allows project cost estimates to be altered accordingly.
2. If the road project falls within a medium to high risk area (ESP >10) for sodicity, a detailed soil survey will be undertaken to the depth of the soil profile that will be disturbed. This assessment will also include off site material sources. Sampled soils are analysed at an accredited lab for dispersion, pH, EC, cations, and cation exchange capacity (CEC).
3. If the road project falls within a low risk area (ESP<10) for sodicity, existing mapping, field indicators and the sodicity test, as described in Managing Sodic, Acidic and Saline Soils by the CRC for Soil and Land Management will be applied. Road infrastructure planners accept that this is a screening test that should be undertaken before laboratory tests are undertaken, in areas where it is possible, not probable that sodic soils are present.

Design stage

Once the level of sodicity of the material is determined, design decisions regarding cross- and longitudinal drainage, structure type, cut and fill slope and vertical and horizontal alignment may all need to be modified to address the implications of a sodic soil. In some cases, this will mean minor changes, while in other cases, significant changes will be required. For example

1. Steel structures may need to be replaced with concrete structures designed for a chloride or sulphate rich environment. Particular attention also needs to be made to hydraulic design to ensure the culvert outlet is not designed to create a "scour hole" to manage downstream velocity. This may result in a significant tunnel or dispersion point that may undermine the structure. Such problems are currently occurring in a number of locations in southern Queensland.
2. If it is uneconomical or unfeasible to treat the cut slopes and fill batters, longitudinal drainage needs to be altered to allow material to be collected in the table drains. This has meant changing kerb and channel to wide parabolic or v shaped drains. This allows for easy collection of sediment during the operation of the road and reduces maintenance costs. If it is feasible to treat the slopes (i.e. they can be constructed at a reduced slope) protective layers can be applied to minimise dispersion of the sodic material exposed on cut slopes and fill embankments. In the past, combinations of the following techniques have been utilised on road infrastructure in southern Queensland:
    a. aeration and gypsum applied at a calculated rate which is dependent on the degree of sodicity (refer Table 1). Gypsum is generally applied in a liquid form as this is the easiest form of application for road infrastructure when considering the time it needs to be applied and the slope constraints of the site;
    b. clay capping (0.05 m) and/or top soil (0.15 m – 0.30 m minimum) replacement in combination with revegetation (grasses or shallow rooted shrubs) or rock mulch (0.05 m)or wood chip (depth is dependent on production capacity of the project site, which is dependent of existing vegetation cover);
    c. concrete or concrete mattresses.
    d. if the project has limited quantities of sodic material, entombment in accordance with Figure 1 may be undertaken.
    e. compaction of a sodic soil is not a feasible long term option for the road environment. It is also difficult to implement in the road environment due the slopes of the embankment and construction issues around the road pavement area. It is also costly to maintain.

A significant limitation to using these treatments is the slope of the cut or fill embankment. As a decreased slope has an increased cost in additional earthworks, the design options selected will often be dependent on this factor. Recently we have also become aware that although the use of gypsum is beneficial for the control of sodicity, it may have a detrimental impact on structures, as it may cause sulphate attack of concrete and steel.

Table 1. Example gypsum requirement calculation sheet

Soil	ESP		Ca:Mg	Treatment area					Calcium requirements for treated area					
	Existing	Target	ratio Target	Area (sq m)	Depth (m)	Vol. (m^3)	BD g/cc	Mass (t)	(meq/100g soil)	(mg/100g soil)	(kg/t soil)	(kg/m^3 soil)	(kg/total volume)	(kg/ha)
1	11.1	6.0	3.5	2000	0.5	1000	1.5	1500	0.0	0.9	0.01	0.01	13.8	2.8
2	10.5	2.0	0.8	2000	0.2	400	1.5	600	0.2	3.2	0.03	0.05	19.5	3.9

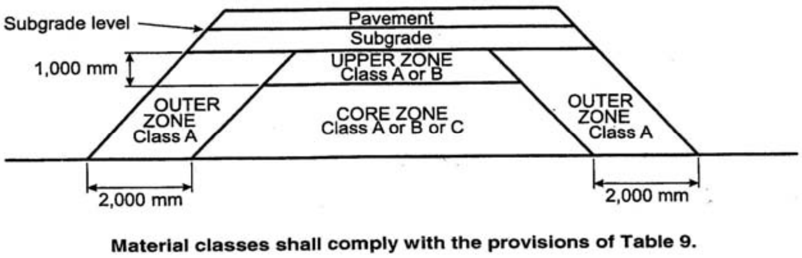

Figure 1. Sodic material entombment design

Construction stage
In most cases, by the time a construction project commences, the issues associated with sodicity should be resolved and well described in contract documentation. It is essential that project engineers understand the risk to the project that sodic soils pose, and the importance of not altering design. However, inherent properties of a sodic soil may significantly affect the construction of a project. Dispersion and associated soil loss during the construction phase may require significant reconstruction of the embankment if it has not yet reached practical completion, and therefore not stabilised with one of the methods outlined above. Furthermore, sodic soils easily become waterlogged and take significant times to dry out. This results in increased downtime for construction crews following wet weather and may increase the cost of the project. Sodic soils often dry to form a hard setting surface. These are difficult to work and cause increased construction dust which is nuisance to surrounding businesses and residences. It is generally not possible to use compaction as a treatment to minimise dispersion and erosion in the road environment, due to difficulties with utilisation of heavy machinery on steep batters and close to new pavement surfaces and structures. However, the most critical impact of sodic soils on construction is the difficulties they pose for revegetation of the project area.

Maintenance stage
Sodic soils pose a constant problem in maintenance of the road environment. Some of the common issues are:
1. increased production and deposition of sediment in structures which increases the frequency of the clean out of the structures;
2. increased erosion in the road reserve to be controlled. This control may be required to improve road safety, protect the road asset, prevent undermining of road furniture, fencing and structures and reduce or prevent land degradation in the road reserve and adjoining private property; and
3. increased corrosion of road furniture such as steel posts, road signs, guard rail.

In southern Queensland, programs have been established to record locations that are actively dispersing as a result of sodicity. Many of these locations would be classed as significant erosion problems but it is important to note that in some cases that pose a significant threat to the road asset. The cost of rehabilitating these sites ranges from $5000 to $125 000 and this is undertaken on a risk priority basis. In summary, sodic soils have a significant impact on the planning, development and construction of road infrastructure. Although many potential options exist, the availability of financial (e.g. cost of ameliorants, transportation distance) and physical (e.g. topsoil availability) resources are the main limitations to the management of sodic soils in southern Queensland.

Salinity (primary and secondary) and waterlogging
Salinity is simply defined as a high level of soluble salts in the soil water solution. Primary salinity generally causes problems due to the presence of salts in soils or rocks that are then combined into road structures.

Secondary salinity however, is usually always associated with waterlogging. Both primary and secondary salinity are common in southern Queensland, although the extent of the latter is restricted to certain landscapes.

Primary or secondary salinity in the road environment (formation and road reserve) can cause a number of issues that include but are not limited to:

1. Potential to degrade the pavement material. The presence of water (permanent or seasonal) in the road environment may have a far more deleterious impact on the road formation than salts present in the water. The depth at which water tables rise to is critical, and dependant on the soil type. However, if the water table is between 1 m and 6 m below the ground surface, the weight of the embankment, in combination with traffic travelling on the road, can act to bring soil moisture up to the road formation. This moisture can rapidly degrade the pavement and result in minor and major pavement failures.
2. Water rising to the surface may also bring soluble salts, and these may accumulate in the road formation and cause problems with dispersion, and stripping of the bitumen seal. At present neither of these problems appear significant or extensive in southern Queensland, although further investigation is required.
3. Roads may also cause/exacerbate secondary salinity. Waterlogging is caused when the rate of water entry into a soil is greater than the rate of exit, either as surface, lateral flow or deep drainage. The rate at which water moves through soils is dependant upon a number of basic attributes such as clay content, clay type and structure. These in turn influence parameters such as porosity, tortuosity and hydraulic conductivity. Construction of roads and associated infrastructure can strongly influence these and other soil/landscape properties, resulting in changes to the surface and near-surface hydrology in a local environment. It is apparent that both road pavements and infrastructure such as culverts and inverts may prevent or restrict lateral flow through the landscape. Good surface hydrology design should minimise the occurrence of surface water ponding, but poor maintenance and/or sedimentation associated with erosion of embankments and waterways can increase the frequency of occurrence. Both surface ponding and restriction of lateral flow can lead to increased evaporative concentration of salts at the soil surface, with resultant decline in vegetation upstream of the road and potentially damage to road infrastructure. Loss of vegetation within the road reserve may have direct impacts on biodiversity, erosion potential and landscape amenity.
4. The degradation of structures in the road environment as a result of salinity is evident in some locations. The largest potential impact of salinity in southern Queensland in the next decade will be on structures, due to their location in lower parts of the landscape and their financial value.
5. Degradation of pavements and stripping of bitumen seals through the use of saline water during pavement compaction. Failure to determine the salt content of water used during the construction phase can lead to the incorporation of salts in the pavement material. Upon crystallisation, these salts cause problems such as blistering of the bitumen seal.

The impact of salinity on road infrastructure can be considerable if not considered in planning, design and maintenance. The following measures are currently being applied in southern Queensland to manage the emerging issues of salinity.

1. Assessing the potential of the embankment/paving materials to possess soluble salts that are the result of either primary or secondary salinity.
2. Assessing the soluble salt content of all water that may be used during road construction
3. Reviewing existing groundwater databases to determine if water tables may present a problem for the road embankment, and if so alter design accordingly with drainage blankets and other measures.
4. Reviewing the potential for the landscape to be affected by primary or secondary salinity over the design life of the structure (25-100 years). If salinity will be an issue, structure types that will withstand chloride or sulphate attack must be selected. This may include the use of protective coatings.
5. Ensure plants selected for revegetation are able to withstand changing moisture and salt content.
6. Assessing that road infrastructure will not cause a localised catchment restriction and consequent waterlogging and salinity expression. This is essential to ensure that adverse impacts do not occur on adjoining property and other infrastructure within the road reserve (telecommunications, gas pipelines etc).

The implementation of these measures is essential at this stage of the salinity timeline in southern Queensland. The development of monitoring frameworks for salinity is still under way. While there is significant groundwater monitoring infrastructure already located within the road reserve in some areas, there are large areas of land that are not suitably monitored. There are only a small number of structures that possess either surface or groundwater monitoring facilities. Increased exchange of data between the agency that collects the data (NRM&E) and MRD is an essential requirement in the future, as is increased monitoring of water quality (specifically salinity) in groundwater areas around major road infrastructure. Expanded monitoring programs for salinity will be essential, as there is growing recognition that the road environment is often strongly affected by land management practices throughout the whole surrounding catchment.

Acidity and Alkalinity

Most soils have a pH between 3.5 and 10. Values depend on parent material, weathering state and other factors. Younger soils, particularly those formed on basic parent materials such as basalt are usually alkaline (e.g. eastern Darling Downs Vertosols). Older, more weathered soils or those formed on more siliceous materials such as granites or quartzose sandstones are often acid in nature (e.g. Stanthorpe Tenosols, Kingaroy Ferrosols). Soil pH varies vertically as well as horizontally. Some soils become alkaline with depth, while others become strongly acidic (e.g. Vertosols on the western Darling Downs). These changes can occur over small depths and can be quite significant e.g pH 9 to ph 4.5 over <0.1 m. Alkaline soils are widespread in southern Queensland, but the do not present a significant risk *per se* to road infrastructure. They can however cause problems in revegetation of road corridors, and in some cases, the prevalence of some declared pests who prefer alkaline soil conditions.

The rate of pH change is controlled by the buffering capacity of the soils. The pH of a soil can be changed in relatively short periods of time by changes in oxidation state. The extreme examples of these are acid sulphate soils in coastal areas and inland acid sulphate soils, although the latter have a limited extent. Soils have also been acidified through agricultural practices. Agricultural production increases acidity through unbalanced nitrogen cycling (excessive use of nitrogen fertilisers and nitrogen leaching) and the continued removal of alkaline plant material. Unlike alkaline soils, acid soils present a significant risk to road infrastructure, in particular steel structures. In some recent cases the accelerated corrosion of a structure has resulted in its collapse and therefore closure of the road. Acidic soils are also difficult to revegetate, and like alkaline soils can be restored to neutral pH by the use of soil ameliorants. In soils where acidification is occurring as a result of agricultural practices, consultation with land owners and regular monitoring of structures is undertaken. If this strategy is unable to protect structures, protective coatings are utilised and steel avoided.

Importance of Government and Community Cooperation

Road infrastructure traverses many different landscapes with a variety of landscape attributes. Road authorities, although responsible for the road reserve, also have a duty of care to adjoining property owners and vice versa. The land management decisions of one organisation and/or individual can have significant implications for another organisation and/or individual. For example, gullying as a result of poor sodic soil management in the road reserve can affect many hectares of an adjoining property owners land, or the clearing decisions of a group of property owners may cause secondary salinity that will directly impact on the road as it traverses the catchment. As such, the co-operation of these groups is essential to ensure that the land management responsibilities and asset investment of both parties is managed now and in the future.

Intergovernmental co-operation within southern Queensland and between states will be essential to ensure that maximum cooperation and minimum duplication occurs in resolving the many soil and landscape process issues presently challenging us. Different organisations bring differing skills, experiences and knowledge concerning managing these basic issues. Collaboration provides new knowledge and understanding of the assessment and management of soil and landscape issues. This is best demonstrated by the following example from southern Queensland: "One of the most common management tools for managing sodicity in agriculture is the additional of gypsum. However, its use in road infrastructure is limited as construction processes do no allow easy application and gypsum may result in structure degradation due to sulphate attack."

Conclusion

Soil attributes that affect embankment stability are consistency (shrink-swell), plasticity, low wet-bearing strengths and acidity, high sodicity and. These attributes are further exacerbated by soil and landscape processes such as acidification, secondary salinity and high or perched water tables (seasonal and permanent). Assessment of both current and future soil and landscape factors and processes is essential to ensure that road assets are constructed and maintained appropriately and achieve their design life. In order to accomplish this, the discipline of soil science needs to make itself more relevant to road infrastructure, and the discipline of engineering needs to embrace soil science.

References

Emerson, W.W. (2002). Emerson Dispersion Test. In "Soil Physical Measurement and Interpretation for Land Evaluation". (Eds McKenzie, N., Coughlan, K. and Cresswell, H.) p190-199. CSIRO Publishing: Collingwood.
SALCON (1997). Salinity Management Handbook. Salinity and Contaminant Hydrology Group, Department of Natural Resources, Brisbane. DNRQ97109.
Tolmie, P.E., Silburn, D.M. and Biggs, A.J.W. (2003). Estimating deep drainage in the Queensland Murray-Darling Basin using soil chloride. Department of Natural Resources and Mines, Queensland. QNRM03020.