Queensland Government
Department of Main Roads
Road System & Engineering

EXPANSIVE SOILS IN

WQ37

DRAINAGE STRUCTURES ON WESTERN QUEENSLAND

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1 Introduction

This Technical Note is one of a series regarding road construction issues in Cloncurry, Barcaldine and Roma District. Details of these notes can be found in the Preface to WQ Technical Notes. It may also be applied to adjacent Districts with similar soils or conditions, but the parts to which it is applicable have not been determined.

This Technical Note addresses:

multiple reinforced concrete box culverts (RCBC) and slab link box culverts (SLBC)

multiple reinforced concrete culverts (RCC)

with a total length greater than 10m along the road centreline in expansive soil conditions.

This Technical Note does not address the following situations: pipe culverts;

RCBC and SLBC installations with a total length less than 10m along the road centreline.

For these smaller structures, useful advice based on proven practices is reported in Luttrell and Reeves (1984). A separate Technical Note will address the smaller culverts in more detail.

2 Background

The location of expansive soils in Western Queensland is detailed in Technical Note WQ32, where they are described as cracking clays.

Except for main stream crossings where bridges are constructed, it has generally been considered that the most cost effective drainage structures are reinforced concrete box culverts (RCBC) and slab link box culverts (SLBC). These structures are relatively simple to construct. An insitu reinforced concrete base slab is constructed in accordance with Standard Drawings 1317 and 1318. Precast concrete box culvert segments are then trucked to the site and placed relatively quickly to form the completed structure.

Visual evidence of damaged culverts (Plate 1) and other unsatisfactory performance such as culverts which appear to rise above their original level, approaches to culverts that deform, and pavement distress over culverts, are often the result of volume changes in expansive soil foundations and embankments. With differential ground movements taking place at culvert/approach interfaces, heavy vehicle studies show that high axle impact factors can be obtained. The design load of culverts is influenced more by high impact loads of individual axles rather than the behaviour of the entire vehicle. High impacts on structures can dramatically reduce service lives.

2.1 Expansive Soil Potential

Expansive soils pose particular problems in civil engineering works due to shrink-swell behaviour. This is caused by moisture movement brought about by climate changes producing moisture variations from extreme wet to extreme dry or vice versa. Examples are:

soils in arid climates, usually in a desiccated state i.e. cracked, which are subjected to occasional unusually high rainfall or prolonged inundation causing the soil to saturate and expand;

soils in semi-arid climates where the moisture conditions of the soil reflect the wet-dry seasonal cycle and may be subjected to occasional climate extremes of drought and flood;

predominantly wet soils which from time to time are subjected to a prolonged period of drought and exhibit drying shrinkage.

Soils in Western Queensland fall into the first two categories. A simple soil classification approach would seem to be useful in addressing culvert issues. However, there has not yet evolved a universal classification procedure for the characterisation of the expansive potential. This has been made difficult by the fact that these volume change phenomena are controlled by three major factors viz. intrinsic expansiveness of the soil (generally characterised by shrink-swell index for the soil), suction change (site specific and dependent on the atmospheric conditions) and applied stress. Changes in soil moisture produce suction changes, which in turn produce a loading/unloading effect on the soils and result in volume changes in the soil. The two most important site-specific issues with regard to suction are:

the postulated suction change at the surface;

the depth over which the suction change manifests, called the active depth (generally between 2-5m).

The empirical correlations generally fail to distinguish between these factors. AS 2870 Residential Slabs and Footings addresses this problem for house construction and requires sitespecific testing.

Whilst some guidance is available for expansive soil embankments in road construction (e.g. Technical Note WQ35), the problem with drainage structures in expansive soils is different in that it is a soil/structure interaction condition.

Local experience has shown that expansive soil problems generally tend to occur with soil which has Linear Shrinkage greater than 8% and/or swell strains greater than 5% at OMC (based on a multi-point soaked CBR test). For example at Douglas Ponds, Skeleton Creek and Jessamine Creek, where culverts have been damaged, the foundation soils show linear shrinkage values in excess of 8%. In the Unified Soil Classification these soils range from SC/CL to CH and are not necessarily restricted to high plasticity CH clays.

Therefore particular design and/or construction considerations need to be adopted to avert damage to culverts where expansive soils are exposed to significant long term moisture changes.

2.2 Postulated Mechanism of Distress

The observed movement in some large culverts is generally a movement of the outer edges of the culvert relative to the central section of the culvert, which is generally immune to the movement. Figure 1 in the Appendix to this Technical Note depicts this failure mechanism for Jessamine Creek and Douglas Ponds culvert sites. Most small culverts are generally satisfactory or exhibit a uniform heave due to their inherent geometric stiffness.

It is considered most likely that the outer edges i.e. apron slabs, are subjected to extremes of wetting/ drying phenomena which produce either high swelling pressures or lack of base support.

3 Current Design Methodology

3.1 Standard Drawings

Standard Drawings Roads has Standard Drawings for culvert bases. Drawings issued up until Amendment 28, 10/97 do not state the design assumptions on which the drawings are based and, most importantly, situations when the drawings are inappropriate for use.

The design assumptions on which those drawings are based include:

the base slabs are designed as a beam on a moisture insensitive, elastic foundation, i.e. differential settlement due to moisture changes are not a design consideration in the standard drawing; and the minimum ultimate bearing capacity of the strata under the culvert base is at least 150 kPa but preferably in excess of 200 kPa. Meeting these bearing requirements is generally not problematical in Western Queensland.

Sites subject to large settlements or large differential settlements, arising out of moderate or highly expansive soils below the culvert base, are outside the design method of these Standard Drawings.

3.2 Improvement to Standard Drawings

Until the Standard Drawings 1179, 1317 and 1318 are amended, the following procedure should be adopted.

For culverts with a base >10m along road centreline, specialist advice should be obtained where highly reactive or expansive clay soils (linear shrinkage > 8% and/or CBR swell >5%) occur below the culvert bases. This is to determine if non-standard base slabs or other foundation treatments are required.

4 Foundation Investigation

An appropriate, special investigation for culvert bases on expansive soils should be undertaken in a similar manner to the proven need for special bridge site investigations. This work should be undertaken under the direction of specialist geotechnical engineers and geologists as appropriate. This is required only if preliminary testing indicates the subgrade to be expansive (i.e. LS > 8% and/or CBR swell > 5%). This preliminary testing can be undertaken at the District level with specialist geotechnical advice.

It is imperative that a vertical profile is established to determine the extent of the actual expansive zone. A field investigation should include:

Trenching or drilling to 2 m depth under or in the vicinity of the proposed culvert location;

In-situ moisture content (Q102A) and density testing (Q111A) at every 300 mm in depth or at change of soil horizon, whichever is earlier, to determine the active zone. (Below the active zone, no significant moisture content changes occur over time). Due to lack of data, AS 2870 - 1996 gives little guidance on active depths for Queensland conditions. For most other States e.g. Victoria, where the reactivity of clay profiles has been the subject of extensive research, useful guidance is available;

50 mm undisturbed tubes taken from each soil horizon, for shrink-swell index testing and filter paper suction measurements.

Adequate materials to be sourced from each location for the following laboratory tests.

A laboratory investigation is required to determine, for each soil horizon:-

Parameter	Test Method
Particle size distribution (Sieve analysis)	Q103A
Liquid Limit	Q104A
Plastic Limit	Q105
Linear Shrinkage	Q106
Shrink-swell index*	AS 2870 - 1996
Filter paper suction measurement*	BRE - IP 4/93

* To be carried out at the Herston laboratories.

If instrumented sites are established in different soil/climatic regions, enabling a rational classification of soil/climatic behaviour response patterns, the level of testing can be reduced in the future.

5 Options for the Control of Distress - Culverts

For drainage structures using culvert bases, special measures need to be undertaken to avert distress. Options for control of distress of culvert bases may be categorised into either geotechnical alternatives or structural alternatives. In many cases, geotechnical methods may be used successfully in conjunction with structural methods.

5.1 Geotechnical Methods

There are broadly two geotechnical methods for limiting damage to light structures such as culverts constructed on expansive soil foundations. These either reduce the expansive potential of the soil or minimise the seasonal fluctuations of the subgrade moisture.

5.1.1 Reducing Expansive Potential of the Foundation - Volume Stability

Methods for reducing the expansive potential of the foundation may include one of the following:

excavation of the foundation and replacement with a low permeability granular or non-swelling material,

chemically treating the natural material (e.g. lime stabilisation),

ripping, scarifying and then compacting the soil with moisture and/or density control,

These processes are carried out to a depth beyond the level of seasonal moisture variation within the soil. The areas to be treated would be under the aprons and 1m beyond the cut-off wall of the apron.

5.1.2 Control of Foundation Moisture Fluctuations - Moisture Stability

The aim of these methods is to control the moisture fluctuations in the foundation within acceptable limits. Methods of control may include one of the following:

pre-wetting or ponding a foundation prior to construction.

stabilisation of foundation moisture conditions by a physical limit e.g. vertical moisture barriers. This involves the placement of a geomembrane (generally a waterproof fabric) in a trench along the perimeter of the slab to the limit of the estimated active zone depth. These vertical barriers minimise seasonal lateral migration of moisture to and from the foundation soils beneath the foundation slab. Details of backfilling and other technical issues will need to be covered by supplementary specifications.

extending the concrete apron with a flexible apron e.g. grout-filled erosion mattress (~3m width) underlain by an impermeable membrane (horizontal moisture barrier). This is aimed at shifting the moisture fluctuation zone to be under the extended apron, thus shielding the concrete apron slab from the edge effects.

Prediction of moisture infiltration under sealed areas by numerical methods may be used in estimating the required lateral extent that needs to be provided by the flexible apron.

5.2 Structural Methods

The structural options to control distress of culvert bases are as follows:

5.2.1 Improved Layout of Culverts

The risk of damage to culvert bases may in some circumstances be reduced by limiting the size of banks of culverts. In wide flood plains, it is considered that a number of banks of culverts distributed across the water course will result in a better hydraulic and structural solution.

5.2.2 Other Structural Solutions

The use of stiffened raft foundations (AS 2870) are technically proven solutions widely used in the building industry. As the culvert distress is commonly observed within the apron area of the slab, any stiffening needs only be confined to the apron slab. Swell pressures can be as much as 200 kPa, i.e. much greater than the applied pressure at the base of the slab. (typically up to 50 kPa in Western Queensland). Each case has to be considered on its own merit.

6 Other Options - Bridges

Consideration should be given to using short span bridges founded on free standing piles extending to the stable material below the active zone. Due to the limited nature of contact between the volumetrically active soil and the foundation elements i.e. the free standing piles, limited upward thrusts are transmitted to the deck. Therefore, these foundation systems are less influenced by the movement of the ground and allow such designs to be optimised. However, expansive soil issues with bridge abutments and general bridge maintenance requirements would still need to be resolved.

Bridges would not be a practical option for low height structures, but the actual height limit has not currently been determined, and it may vary for different sites.

7 Discussion

The long term moisture stability of the culvert foundation is critical. Western Queensland is subject to long term seasonal changes which may exist for a number of years. Consequently over time it is reasonable to expect that the moisture content of the surrounding soil will vary.

This is a complex issue which has been barely acknowledged by the engineering community. Very little research effort has been directed towards resolving these problems, although a reasonable amount of work has been undertaken in the housing sector for residential slabs and footings, e.g. AS2870. It is considered prudent to adopt the housing industry approach as a preliminary basis, subject to refinement as we gather more factual data and observational evidence. This in turn will lead to reduction in investigation costs in the future.

Due to the larger surface area in contact with swelling/shrinking soil, the edge regions of flexible culvert foundation systems may be subjected to significant upward thrusts due to swelling, or suffer from reduced contact pressures due to shrinkage.

Geotechnical solutions of volume stability and moisture stability need to be capable of offering long term (10 to 20 year) solutions. Some of these options, e.g. pre-wetting, need to be decided during construction, depending on the relative moisture condition at the time.

Chemically treating the natural material, or excavation and replacement of the natural material and replacing with a non-swelling material would be influenced by availability of suitable materials and suitable plant (e.g. equipment for lime stabilisation or lime injection). Chemical processes may also be constrained by drainage and environmental considerations in watercourses.

In the absence of geotechnical controls, structural options can be considered. In the broader context of life cycle costs, the use of short span bridges (subject to available clearance and meeting the hydraulic requirements) may provide the most economical solution. This removes the need to construct moisture control procedures which may be difficult in a waterway.

In determining which of these options (or a combination of) are appropriate, it is necessary to examine the conditions which are specific to a job. This will include economic and practical considerations. Specialist advice should be obtained for geotechnical and structural issues.

8 Improved Construction Practice

Consideration should be given to restricting construction practices which adversely affect the moisture content of the soil. The following practices should be excluded:

Placement of permeable fill behind the culvert (either granular or cement stabilised sand);

Opening a culvert base up for a prolonged period when the moisture content is low;

Not allowing adequate time for the culvert base to reduce moisture content after a prolonged wet period.

Supplementary specifications may be required in such situations, and may require specialist input from Transport Technology.

9 Author

This Technical Note has been written by Ross Pritchard, Senior Engineer (Bridge Design) and Vasantha Wijeyakulasuriya, Principal Engineer (Geotechnical).

10 References

Luttrell, B. J. and Reeves, I. N., (1984). *Experiences and Developments with Road Construction on Expansive Clay Soils in North West Queensland*. Proc. 5th International Conference on Expansive Soils, pp 340-347.

Pritchard, R.W., Wijeyakulasuriya, C.V., Vanderstaay, A.B.G., (1999) *Problems and Cost Efficient Solutions for Drainage Structures in Expansive Soils*, Proc. Main Roads Central Symposium, 31p.

11 Appendices

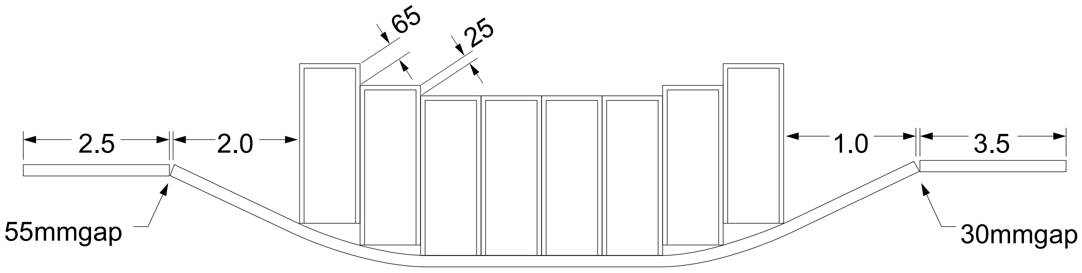
The following are appended:

Close-up of typical crack in apron slab.

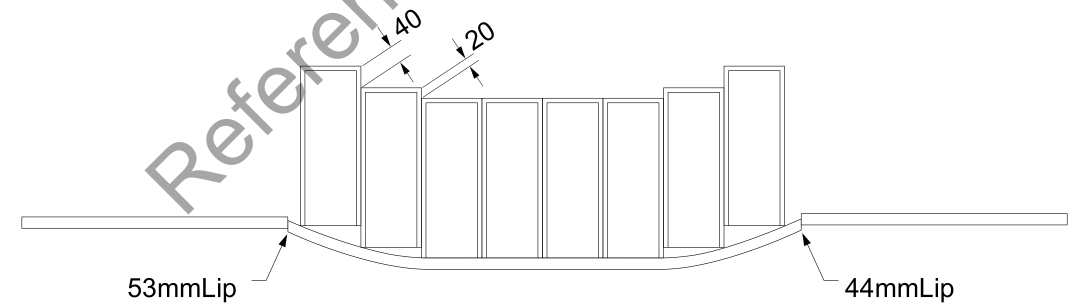
Typical crack in apron slab; note the crack stops at the slab which forms the footing of the wing wall, the apron slab has risen relative to the wingwall slab. The outer edge of the apron slab has appeared to drop and now slopes away from the culvert.

Typical apron slab crack near the wing wall slab. Note the vertical displacement across the break, and the rise of the apron slab relative to the wingwall slab.

Plate 1Damaged Culverts at Jessamine Creek



Failure at Jessamine Creek



Failure at Douglas Ponds

Figure 1 Diagram Depicting Culvert Failures at Jessamine Creek and Douglas Ponds