The Performance of Light Structures founded in Expansive Clays following Active Moisture Recharge

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Summary Active moisture recharge is used on dry sites to restore the light structures on the sites to as near as built levels as possible. This process has been investigated as part of the research projects being carried out at Swinburne University of Technology over the last nine years. The performance of the structures during and subsequent to the moisture recharge shows that no additional damage is caused to the structures by the process, when it is adequately controlled. The long-term performance of the structures indicates that the process provides a permanent solution.

1. INTRODUCTION

Over the last few years, the climate in Victoria has been subjected to sustained dry periods. For the regions that have substantial areas of expansive soils, surface settlement has taken place, caused by drying out to depths of up to 3 m. Light structures founded on these soils have settled in a non-uniform manner, causing distress to the structure. The usual response is to provide underpinning for severely damaged structures.

Underpinning is not a long-term solution to the problem, unless the underpinning foundations are taken to a depth below moisture content change and isolated from movement of the upper layers of soil. Research has been conducted using an alternative method of raising the moisture content of the dry soil back to the content at the time of construction. The swelling pressures of the expansive soil have been harnessed to return the light structures to, at or about, the as-built levels.

This paper describes some of the techniques used in moisture recharge. The efficacy of the techniques is examined after review of the performance of the light structures over a number of years.

2. DRYING OF SOILS ON SITE

Once a light structure is constructed on an expansive soil site, there are two major influences on the drying of the soil beneath the structures. These are tree roots that have penetrated beneath or close to the structure, and the flow of air drying the soil underneath a structure supported on piers.

In the case of tree roots, the area of drying is limited to the spread of the roots in plan. In the case of native Australian drought-resistant trees, the boundary of this area is commonly taken as twice the mature height of the tree. Local influences, such as the presence of a constant water source, or the pressure of rock at a shallow depth, can influence this.

The drying of a soil beneath a structure supported on piers is generally limited to the plan view of the structure. Typically, the surface of the soil is dished, with the deepest part of the dish furthest from the outer edges of the structure.

2.1 Depth of Drying

Ultimately, the depth of drying is controlled by the local climate. The soil suction is a measure of the state of dryness in the soil. For the Melbourne region, for example, this change of soil suction occurs generally to a depth not exceeding 2 m. Drying beneath a light structure would not be expected to exceed this value in Melbourne.

Tree drying could be expected to be limited to this depth in most cases. The presence of a defined perch table could influence depth. Tree drying to a depth of 2.8 m has been observed in the Melbourne region (Brown, 1998).

2.2 Wet–Dry Cycles and Drying on Site

In an open field site, with no development, the surface of the site is free to move up and down as the soil swells and shrinks. This is related directly to the wet–dry cycles in the climate. If a structure is placed on the site, this interferes with this pattern. The area beneath the structure on piers begins to dry out continuously and the surface moves down. The site beyond the structure continues to respond to climate changes. This can have serious consequences for any structure linking the two areas.

If the structure is supported on a slab, the area under the inner portion of the slab wets up and achieves a higher moisture content than the surrounding site except in the wettest of periods. Except for appropriately stiff slabs, this results in relative movement being generated between the inner portion of the slab and the outer portions.

This implies that if the moisture regime beneath the structure can be altered, the difference in response between the soil on the open site and the soil beneath the structure can be reduced. For a structure on piers, the wetting up of the soil beneath the structure provides a potential solution. For a structure supported on a slab, the challenge is to stabilise the moisture content between the inner moist zone and the outer region where the soil moisture changes with the climate.

3. SHRINKING-INDUCED DAMAGE

Drying of the soil takes support from the foundations of the structure, causing the structure to follow the movement of the foundations downward. This can have some, or all, of the following effects on a structure:

- Floor bowing or tilting
- Doorways becoming out of shape
- Diagonal cracks in walls and over openings
- Outer walls tilting and bowing
- Foundations settling and tilting.

3.1. Underfloor Drying

The pattern observed in this situation is mainly associated with the differential settlement of the floor as it follows the piers downwards. The floor settlement is generally greatest in the centre of the structure. Walls supported off the floors follow the pattern and either tilt or are subjected to racking. Door frames are put out of shape and doors stick.

3.2 Tree Drying

Tree drying tends to affect a smaller portion of the structure than underfloor drying. The tilting of foundations is likely to be more prevalent with the associated tilting and bowing of outer walls and diagonal cracking of walls and over openings. This situation has greater potential for substantial damage to the structure.

4. WATER RECHARGE WELLS

For those situations where there is water deprivation, the possibility exists to remove the problem by replacing lost water. This is only available if the soil is expansive and has swelling pressure sufficient to raise the structure.

4.1 Well Installation

An early attempt to introduce water back into the soil was made using wells. These were installed using hand-held augers to a depth of two meters maximum. Relatively large volumes of water could be injected quickly and rapid response of the structure was obtained (Brown and McManus, 1996).

4.2. Effects of Recharge Wells

Uplifting of the structure could take place in as little as three months. This rebound was uncontrolled and the structure was subjected to movement that could result in brick joint lock up. The potential remained for the structure to sustain further damage under such a quick response.

The quick response induced a complacency in the minds of the owners, who, in spite of advice, regarded the operation as complete after this first swelling of the soil. They were not prepared to take seriously the need for long-term moisture maintenance.

5. DRIP INJECTION SYSTEM

This system replaces lost water in a much more controlled manner than the method using water recharge wells. This swelling pressure of the soil is used to lift the structure back into place, but in a more controlled manner and with the knowledgeable cooperation of the owner.

5.1 Drip Injection System Installation

The system is based on the use of standard drip-watering equipment for domestic gardens. Once the dry regions of the site are identified and the foundation elements that have settled are located, the location of the drip points can be planned (McManus and Brown, 1997). The flow rate of the system to recharge the moisture of the site is determined and an automatic timing system is installed. Alternatively the owner is instructed in the use of the system and given a watering program.

5.2 System Operation

In the situation where drying has occurred beneath a structure founded on piers, drip injection points are installed alongside the piers, at the depth of the pier base. One drip point is installed for each pier.

Measurements of the elevation of the settled floor are taken as a datum and the system is initiated. Regular monitoring by the foundation engineer and site owner is carried out to ensure that the response is smooth and all points are rebounding. If the system is not acting as predicted, it is possible to retrofit more drip points or close drip points down until the response is satisfactory. Thus, the response of the system can be fine tuned to take account of soil variability on the site.

6. CASE STUDIES

6.1 Case Study 1: Abbotsford

The property is a two-storey, full brick, federation style, built as two dwellings around the early 1900s. There is a party wall separating the north from the south section. The section reviewed was the north section and it, over the years, has undergone significant change. The southern section has remained fairly static in that time and its salient features are that it has a large concrete pavement around it and that it contains very few cracks from an external viewpoint. Surrounding the dwelling is a large number of plane trees in the front which are embedded in the footpath and have no means of natural watering as the footpath is sealed, the bluestone kerb and channel are concreted in and the road is fully sealed to the bluestones.

The adjoining property to the north is a vacant block of land with a swimming pool, a plantation of several groups of trees, bushes to the front and a very large elm tree at the rear. The foundation soil is residual clay derived from quaternary basalt. The soil was noted as highly reactive and the foundation of the building was detected at 750 mm, i.e. just below that of the filling which showed up in several of the bore logs.

Back in 1987 when the first review of this property was undertaken, which in turn was some two years after the redevelopment of the block to the north, inspection showed that cracks of up to 25 mm had occurred, primarily in the rear of the property, ie. the west. Levels, out-of-true of wall and brick-crack movements were noted. Also, a bore log taken at this time showed low moisture regimes and suctions very much on the dry side of expected.

At this stage, recommendations were made to remove the trees in the adjoining property. The removal was initiated and a watering system was placed along the northern side of the western section of the property using recharge wells. Watering was then carried out, but intermittently by the landlord, who did not have full and easy access to the property. The cracks were noted as closing very significantly in the first 12 months, particularly those cracks nearest the large tree that was removed.

Some three years later (at the end of 1989) the property was refurbished. Cracks were infilled and the property was re-let to another tenant. The water injection was maintained, although in an erratic manner.

In 1997 a further investigation was requested and it was noted that the western portion of the property had now been pulled down and rebuilt using a raft slab, which was now covering the old recharge wells. The elm tree in the rear of next door's property was still going very well and the new extension had dropped noticeably but not beyond 15 mm, causing minor cracking between it and the old construction. The front portion of the property had now moved substantially and was subjected to cracks much greater than 25 mm. Several doors were wedging.

Bore logs revealed that the moisture regimes were very low and the tree roots were present to great depths. Agreement was undertaken with the adjoining owner to remove most of the trees nearest the cracks, although they were small, and a soaker hose was implanted without drilling into the ground. This corrected most of the cracking by upwards of 70% in a matter of three months. However, it slowed down significantly and it was not until autumn, when the plane tree in the Council nature strip went into winter mode, that further recovery occurred.

Discussions are continuing with the Council to see if the plane tree can be either properly watered or removed. Also, a more permanent water system, installed with a self-timer to eliminate human intervention, is being considered by the owner at this time.

6.1.1 Lessons Learned

Owners with a good understanding of what is causing their problems can take quick and immediate action to reverse and correct their problems. On-site attention by somebody who cares always results in significant improvements to the property, and removal of what is directly causing violent differentials, namely trees, is an effective means of controlling differential movements, even in a strong drought environment.

6.2 Case Study 2: Mooroolbark

The property is a single-storey, standard brick veneer dwelling on strip footings, constructed in 1980. It has a series of underpins in and around its perimeter due to the presence of filling on the site. The timber stumps were also set slightly deeper than normal, at 800 mm, to again get below the filling. The foundation soil is from tertiary basalt deposits and is highly reactive, with increasing reactivity with depth. Surrounding the property is basic grassed area with some concrete pavement, and the ground has a moderate to strong slope. Other features are that there were many large trees in the adjoining property's front yard and in the rear of the investigated property.

At the time of reviewing this property several holes had been dug in the bank in an attempt to commence underpinning and this was terminated by one of the family members. These holes confirmed the soil testing of other parties that had been undertaken over the last five years.

The movement, which was measured by various means to be around 40–50 mm, was caused by the tree roots taking out moisture at depth (roots were detected at 2.8 m down) and initiating shrinkage of the clays, causing localised deformations and distress. This was further added to by the fact that moisture running down the strip footings would accumulate at the base of the various pins. Roots were noticeably attracted to these in the holes that were visible during the investigations.

The adjoining property owner agreed to prune and remove their trees, and the large trees in the rear of the yard were removed. Thereafter, the owners following instructions within the report drilled re-charge wells across the back of the property and down the side and in and around the front where the damage was most prevalent. Moisture was placed in accordance with directions and ultimate recovery of around 35–38 mm was achieved. Most of the recovery took place within three months of the trees being removed and continued for just over two and a half years until grit etc. in the cracks stopped further closure.

With this property there was an interested and actively involved owner who was willing to do the work himself and to initiate all of the necessary monitoring.

The degree of closure has been so good that the initial recommendation that the rear wall would need to be pulled down and rebuilt after recovery has now proved to be unnecessary. All that is necessary to finalise this property is the freeing-up of some wedged-together components and removal of minor grit from some of the cracks that have recovered 90%. The net cost of this repair, counting the owner's labour as zero, amounted to under $550. This compares with an estimated bill of over $6,000 for the underpins that were static and would not have corrected the problem and still would have required, for visual amenity, the removal and replacement of some 2,000 bricks and associated windows, frames, etc.

6.3 Lessons Learned

If we have active, educated and interested participants then moisture recharge can and does work remarkably well. Considering these examples where it has stumbled and/or has not worked well, it can only be concluded that it is because of the attitude and degree of commitment by those responsible for initiating the moisturising of the soil.

Both of these case studies, one over 11 years and the other over four years, proved conclusively that once you have an educated, willing and participating owner then recovery does occur and will do so very quickly. Proper control methodologies, once put into place, will maintain the corrections gained.

In both cases, replanting of trees has taken place but of a different size and species, and they are being positively watered in a manner that restricts their chances of having roots go beneath the building. Further negotiations are continuing with the local Council to see if they are willing to implement a watering system that is partially automatic.

This particular proposed methodology of watering the trees via trapping water in the kerb and channel and placing it at depth is being trialled in another municipality with regard to new trees being planted after errant trees have been removed.

7. CONCLUSIONS AND RECOMMENDATIONS

- The system can work in temperate climatic zones with distinct wet and dry periods where the period of drying exceeds the wetting-up period.
- The soils need to display swelling pressures in excess of the applied foundation pressures.
- The structures need to have sufficient articulation to accommodate the movement of the restoration.
- The use of small quantities of water injected at chosen locations gives more precise control of the restoration than the use of recharge wells filled with water on a regular basis.
- The location and depth of the injection points, and also the watering rates, need careful consideration and planning.
- Injection wells can be installed at any time during the climatic cycle.
- Structures of various degrees of articulation have been restored successfully and many have been standing for a long time.
- The influence of vegetation on drying has to be eliminated at the time of restoration and into the future for a successful outcome in the long term.
- Owner involvement and maintenance is a necessary requirement for a permanent result.

8. ACKNOWLEDGMENTS

Both authors wish to thank their staff, their families and assistants for their support and help in formulating this paper. A special thanks to both of the property owners involved, who have given us new hope of recommending cheap systems where the people concerned are able to implement them.

9. REFERENCES

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