Reduction of Pavement Damage from Expansive Soils using Moisture Barriers

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SUMMARY: Two field trials were carried out at an experimental site on the Sunraysia Highway, north-western Victoria, where the road had to be reconstructed because of the pavement damage caused by the effects of a Victorian semi-arid climate and trees on the expansive clay subgrade. Using a plastic geomembrane, a vertical moisture barrier was installed in each verge in order to stop the lateral migration of moisture to and from the subgrade. A barrier depth of 1.8 m below verge level was not deep enough to prevent the significant seasonal pavement movements being caused by roadside trees. However, a deeper barrier that was at least 2.5 m below verge level greatly reduced or virtually eliminated seasonal movements.

1. INTRODUCTION

In many countries, including Australia, the damage to structures and roads caused by expansive soils is greater than the damage caused by other natural hazards, such as earthquakes and floods. Road pavements on expansive clay subgrades are affected by seasonal wetting and drying, resulting in two main types of damage: (i) roughness or loss of shape and (ii) longitudinal cracking. The useable life of the pavement can be reduced to a small fraction of its design expectancy.

Loss of shape of the pavement is probably the most serious form of deterioration resulting from shrinking and swelling of expansive soils since this worsens the riding quality of the road and thereby diminishes public safety. It is not readily repairable and hence any remedial works are time consuming and costly. Other consequences of loss of shape are poor surface drainage and damage to existing drainage systems, both leading to ponding of water on, and adjacent to, the road and possible pavement damage.

The problems of loss of pavement shape and pavement cracking resulting from seasonal changes are exacerbated by the presence of roots from roadside trees and shrubs.

Various techniques have been tried with the aim of isolating the foundation soils from the surrounding soils thereby preventing seasonal migration of moisture to and from the pavement subgrade. Methods that have been employed include:

(a) deep, sand-backfilled, sub-surface drains (eg Steinberg, 1979);
(b) encapsulated pavement subgrades;
(c) pressure-injected curtains of lime grout; and
(d) various geomembrane applications, using horizontal, sloping or vertical plastic barriers (eg Steinberg, 1984).

In 1985, the Road Construction Authority (now called Roads Corporation of Victoria, VIC ROADS) commenced a research project at Morton Plains during the reconstruction of a length of the Sunraysia Highway. The aim of the project was to investigate the effect of vertical moisture barriers on the distortion of pavements on expansive soils.

2. ROLE OF VERTICAL MOISTURE BARRIER

Vertical moisture barriers were chosen as the best method for the field trials at Morton Plains because of their proven success in Texas (Picornell et al., 1984) and their prevention of invasion by roots of neighbouring trees (Nazer and Clark, 1982; 1983).

The role of a vertical moisture barrier has been described in detail by Picornell and Lytton (1986). Briefly, its role is to stop the seasonal lateral migration of moisture to and from the subgrade beneath the pavement in order to prevent the subgrade from expanding during wet periods and shrinking, and thereby cracking, during dry periods. To substantially stop the lateral moisture migration in the subgrade, the moisture barrier must extend below the depth of any crack which would provide an easy moisture path through the relatively impermeable clay. Obviously, a vertical barrier cannot stop any vertical moisture movement which may have a significant long-term effect on the expansive soil subgrade.

This long-term effect on the pavement depends upon the subgrade moisture conditions at the time of the barrier installation. To avoid any long-term movements in a new or reconstructed pavement, the soil moisture suction in the subgrade should be equal to the equilibrium suction, ie the value existing in the deeper foundation soils (Aitchison and Richards, 1965).

3. EXPERIMENTAL SECTION

The experimental section, shown in **Figure 1**, was located on the Sunraysia Highway at Morton Plains, 12 km south of Birchip, which is in the semi-arid Wimmera region of north-western Victoria. Between April and June 1985, the Sunraysia Highway at Morton Plains was reconstructed because the pavement had undergone serious loss of shape, with longitudinal cracking and longitudinal rutting up to 40 mm deep (Martin and Newbegin, 1989). This was only about ten years after the pavement was resheeted and the bituminous spray seal widened from 6.0 m to 7.4 m. The pavement (base/sub-base) comprised 170 to 300 mm depth of weathered sandstone.

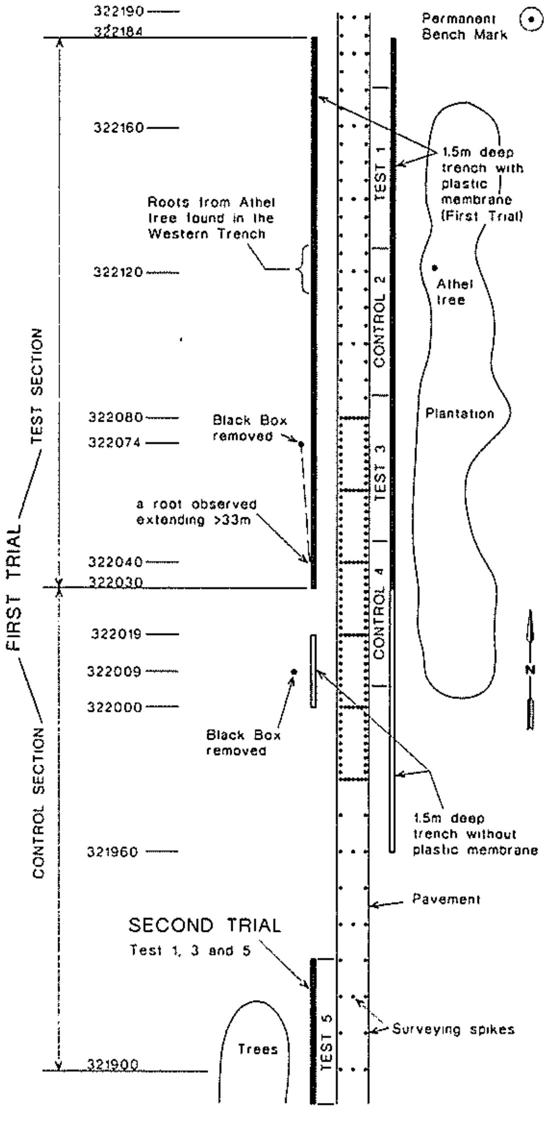

Fig. 1. Plan of Experimental Site

3.1 Geology and Site Conditions

Generally, the geology is similar to that in the Horsham area, where the soil profile consists of grey or black heavy clays to a depth of 0.6 to 2.2 m overlying light brown calcium heavy clays to a depth of up to 3.4 m, above a deep layer of white heavy clay (Kassiff and Holland, 1966). As the area is part of the Murray Basin, the more recent formation is most probably of alluvial origin and is known as "buried gilgai". The development and properties of gilgai are described by Kassiff and Holland (1966). The two characteristic properties of gilgai country are that as the depth increases the swelling potential increases and the permeability decreases. This area is characterised by the creation in winter of depressions known locally as crab holes or sink holes.

The area at the site is low-lying and poorly drained and in winter is flooded for long periods. In summer, through the combined actions of evaporation and tree roots, the soil dries and cracks extensively. An appreciation of the size and extent of the cracking can be gained from the report by Martin and Newbegin (1989).

3.2 Soil Properties

Tests were performed on samples of the subgrade taken from trenches on each side of the highway (Section 4.1). The results indicated that the soil was a highly expansive sandy clay with the following properties: LL = 82-86%, PL = 19-25%, PI = 57-67%, and LS = 21-22%. The moisture content ranged from 27 to 29%.

The base/sub-base material used in this area is weathered sandstone from a local pit. Sandstone in the Wimmera region typically performs well as pavement material but tends to degrade rapidly if it gets wet. Properties of the sandstone, sampled at the bottom of the sub-base, ie at a depth of 0.3 m, are LL = 29%, PL = 23%, PI = 6%, and LS = 4%.

3.3 Vegetation

The experimental section extends over a total distance of 284 m with trees occurring along most of its length. The eastern side of the road is host to a plantation of approximately 70 trees, while the western side has only a few trees, mainly near the southern extremity, and thick patches of lignum bushes and high grasses. There are five different dry-climate species of eucalyptus in the plantation, the trees ranging in height from around 3 m up to about 8 m. Standing some 10 m high, one other tree in the plantation is from the exotic species known as the Athel tree. The understorey is sparse with grasses making up the ground cover.

Two large Black Box trees (Eucalyptus Largiflorens) were removed from the western side of the highway during the reconstruction works in 1985. They were located at Chainages 322009 and 322074 m, as indicated in Figure 1.

4. FIRST FIELD TRIAL

The reconstruction of the Sunraysia Highway at Morton Plains was carried out at the start of the wet season between April and June, 1985, and the experimental section was established between Chainages 321900 and 322184 m (see Figure 1). This distance of 284 m consisted of a 130 m control section and a 154 m test section. In the test section of the first field trial, a thin plastic membrane was placed vertically in a trench on both the east and west sides of the highway.

4.1 Trench Excavation

As shown on the plan in Figure 1, trenches were excavated on both sides of the road about 8 m from the centre-line. On the east side of the road, the trench extended along the test section and well beyond the end of the plantation in the control section, whereas the west side trench was only along the test section and in front of the former site of the removed Black Box at Chainage 322009 m. The reason for the trenches (backfilled without a plastic membrane) in the control section was to sever any roots and thus remove the effect of this variable from the experiment. After the old road formation had been removed down to design subgrade level, the 0.4 m wide trenches were excavated by backhoe to a depth of 1.5 m below sub-base, ie a depth of about 1.5 m below natural surface (N.S.) level (see **Figure 2**).

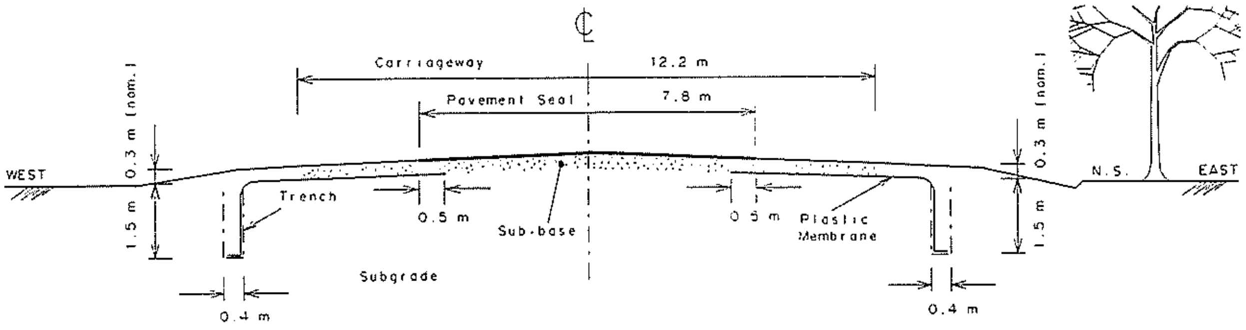

Fig. 2. Typical Cross-Section of Test Section (First Field Trial)

4.2 Placement of Membrane

The barrier chosen to minimise moisture variation beneath the pavement was a 0.2 mm thick black polythene membrane. When unrolled, each sheet was 50 m long by 4 m wide. Two sheets were joined longitudinally with adhesive tape to give a 7 m wide plastic sheet. This was then laid out along the shoulder of the road, so that it would extend 0.5 m under the edge of the future seal (Figure 2). The outer edge of the sheet lay across the bottom of the trench.

Due to the plastic membrane being so thin, several precautions were taken during its placement to avoid puncturing it. For example, sharp objects such as severed tree roots and large stones were removed from the inner face of the trench. Similarly, before placing the membrane horizontally across the shoulder/verge area, a relatively smooth level surface was produced with a grader. However, problems were experienced with the membrane, as discussed later.

Pavement base/sub-base material (weathered sandstone) was placed over the carriageway width on the plastic sheet and compacted in 100 mm layers to form a 300 mm thick pavement, which was surfaced with a 7.8 m wide primerseal.

4.3 Compaction of Backfill

The backfill, the excavated clay material, was shovelled into the trench to form layers of 100 mm (specified) up to about 150 mm thickness. Compaction was difficult due to the narrow width of the trench and the need to protect the plastic sheet. Limited densification of the lower layers of backfill was achieved by applying water from a water tanker. These nominal 100 mm layers were placed up to the top of the trench (ie to a depth of about 300 mm below the finished surface level). The final 300 mm of verge material was placed over the plastic sheet in one layer and compacted by a heavy roller.

4.4 Root Retardant Treatment

In order to eliminate the invasion of tree roots, the trenches were treated with a root retardant. The type chosen was Casoron, whose active ingredient (Dichlorobenil) has been shown to be effective for periods of at least 8 years (Nazer and Clark, 1983). The application of Casoron to each 100 mm layer of backfill followed the guidelines set out by Nazer and Clark (1982).

Root retardant was not placed in the trenches on the western side of the highway, but was placed in both the test and control sections on the eastern side. Also, no retardant was placed in the top 300 mm (ie above the plastic sheet) of the trench as this was compacted in one layer.

5. RESULTS FROM FIRST FIELD TRIAL

The movements of the road pavement were monitored by means of precise levelling (ie to 0.1 mm). To achieve this, the surveyors used a certain QS type bench mark, which was developed to provide a stable datum in expansive soils (Holden, 1987). After the construction works were completed, a number of 100 mm long deck spikes with a domed head were driven into the road pavement. They were placed at 2, 5 or 10 m spacing along the east and west edges of the road as well as at 20 m spacing along the centreline in accordance with the plan shown in Figure 1. A transverse line of 38 spikes at 200 mm spacing was placed at each of Chainages 321980, 322000, 322020, 322040, 322060 and 322080 m. Precise levelling of the spikes was first performed four weeks after completion of the construction works and after that at the end of each dry (summer) and wet (winter) period.

In their report on this project, Martin and Newbegin (1989) have presented all the plots of seasonal heave, seasonal shrinkage, and progressive movement for the east and west sides of the road and the centreline. They have also presented plots of seasonal movement for each of the six transverse lines or cross-sections.

A significant difference between the movements in the test section compared to those in the control section was expected. The movements within the control section should tend to fluctuate greatly due to the seasonal effects on the expansive soil subgrade, whereas in the test section the pavement should undergo a slow steady monotonic movement as the subgrade approaches its equilibrium soil suction. However, from the plots of seasonal heave in **Figure 3** and the plots of seasonal shrinkage, it can be seen that there is no appreciable difference in the magnitude of the seasonal movements between the test and control sections, alongside the plantation. This shows that there is still substantial wetting up and drying out occurring within the subgrade of the test section alongside the plantation.

The effect of the roadside trees can be seen in the typical cross-sections in **Figure 4**, where only the limits of seasonal movements are shown. The seasonal movement of the pavement at Chainages 321980 and 32200 m, where there were few trees set well back, was very small and relatively uniform across the road, over at least the first five years. On the other hand, the four cross-sections from Chainages 322020 to 322080 m show that the pavement was heaving (and shrinking) in a linearly decreasing manner across the road. The greatest

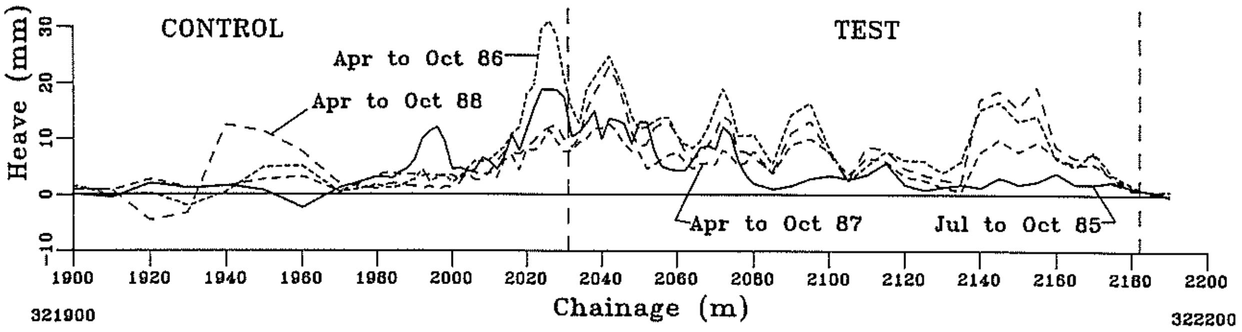

Fig. 3. Seasonal Heave - East Side of Road (First Field Trial)

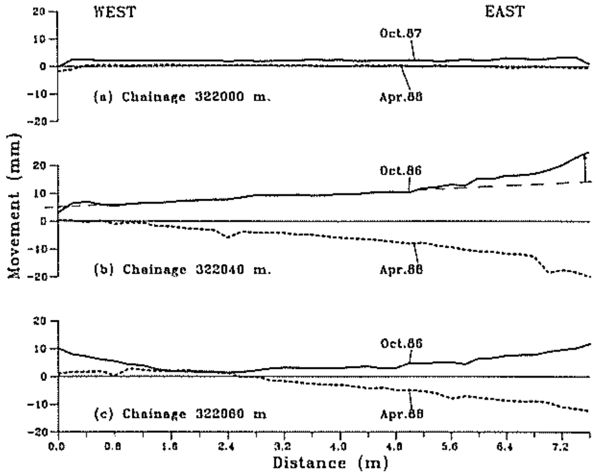

Fig. 4. Seasonal Pavement Movements for Three Cross-Sections (First Field Trial)

movement was always on the eastern side of the highway, where the plantation exists.

Superimposed on this linearly varying heave (and shrinkage) is a phenomenon known as "edge flapping", where the pavement edge moves vertically up or down according to the season. This effect, which can be clearly seen in Figure 4(b) and (c), extends up to 2 m from the pavement edge.

The cyclic movement of the pavement is shown in a typical plot of movement with time in **Figure** 5. From an examination of the rainfall figures for the area, the expected general influence of rainfall on the magnitude of seasonal movement was observed. The general trend in Figure 5 indicates that, in the Test Section, it took 3 to 4 years for the subgrade to seemingly recover after cutting the tree roots. This fact should be taken into account when planning a pavement rehabilitation which incorporates moisture/root barriers.

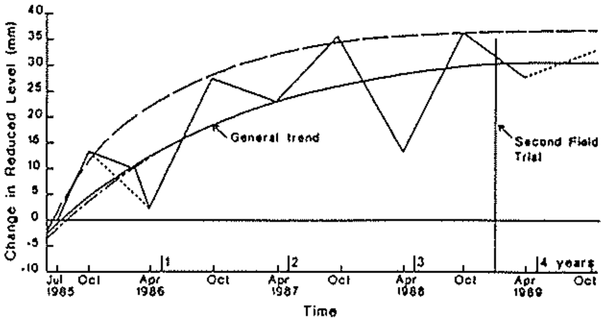

Fig. 5. Cyclic Movement of East Pavement Edge at Chainage 322042 m

6. SECOND FIELD TRIAL

In the First Field Trial, started in 1985, the junction between the test and control sections was selected to be at Chainage 322030 m, which was approximately half way along the worst section of the original deformed pavement. If the barriers worked, the effect should be shown clearly by contrasting results between the test and control sections. However, as demonstrated over the following 3.5 years, there appeared to be no significant difference between the two sections. Since seasonal movement continued alongside the plantation, it was surmised, after discussions with Prof. R. Lytton, Texas Transportation Institute, that the barrier had not been installed to a sufficient depth. Instead of merely replacing the barrier with a deeper one, it was decided to also relocate the test and control sections.

The Control Section in the First Trial was a poor choice because it had been mainly located in the region sparsely populated with trees on the east side of the highway. For statistical reasons, it was decided to create two separate control sections alternating with two separate test sections alongside the densely populated plantation (see Figure 1). This involved the removal of the vertical component of the plastic membrane from two areas on the east side of the highway, to produce two control sections, each 40 m in length.

The two test sections, on the eastern side only, involved the deepening of two vertical moisture barriers: Test Section 1 was 45 m long (between Chainages 322126 and 322171 m), and Test Section 3 was 40 m long (between Chainages 322046 and 322086 m). These barriers were installed to a depth approximately one metre lower than that previously used on the east side of the highway in 1985.

At the experimental site, a third test section (called Test Section 5), 40 m in length, was established on the western side of the highway between Chainages 321890 and 321930 m (see Figure 1). The pavement in this part of the original control section had undergone very large seasonal movements (Martin and Newbegin, 1989), because it was adjacent to some relatively large trees, and it was decided to determine the effect of a moisture barrier on these movements.

The three new test sections were completed in the order of numbers 5, 3, and 1 during December 1988 and January 1989.

6.1 The Three New Test Sections

During the installation or deepening of the 0.2 mm polythene moisture barriers along the three new test sections, a different approach was adopted for each section, each being an improvement on the previous one; these approaches are described in detail by Martin and Newbegin (1989).

In Test Section 5, a vertical barrier was installed in a trench 40 m long and 2.5 m deep below the road verge surface. There was no horizontal component of the barrier under the shoulder. Compaction of the top metre of backfill against the suspended vertical membrane was carried out with a vibratory rammer.

In Test Section 3, the 40 m long trench was carefully excavated in stages. The tree roots were recorded and an inspection of the original plastic was carried out. The excavation was continued to the new barrier depth of 2.5 m below the verge surface. The new membrane was attached to the old membrane using adhesive plastic tape. Backfilling and compaction to the verge surface level were then completed.

In Test Section 1, a new membrane was installed in a 45 m long trench excavated to 2.5 m below the existing horizontal membrane (ie to a slightly greater depth of approximately 2.8 m below verge level). At each end of the test section, the new plastic membrane was sealed to the wall of the trench, with a bituminous adhesive mixture, since it was thought that a significant horizontal flow of water had occurred in winter behind the old membrane via its ends. Backfilling and compaction were then carried out.

As with the first field trial, a fine granulated root retardant, Casoron, was placed during backfilling in each of the Test Sections 1, 3 and 5. In the top metre, it was sprinkled on successive soil layers which were about 200 mm except in the upper 400 mm where they were only 100 mm thick.

6.2 Observations During Trench Excavation

During the trench excavations for the Test Sections and for removing the vertical membrane from the Control Sections, the diameter, depth and frequency (number of roots per lineal metre) of severed tree roots were recorded and later reported by Martin and Newbegin (1989).

The majority of roots occurred within 400 mm of the surface, growing above the old membrane, with a frequency of up to 160 roots/m. The near-surface roots were generally small in diameter, viz. 1 to 5 mm, although they sometimes reached 10 mm.

Because an intact plastic membrane is impermeable to water, one may expect that roots normally would not have cause to penetrate the membrane. However, studies referred to by Landreth (1991) have shown that certain grass roots do penetrate the membrane used in our field trials. Nevertheless, we observed only that the tree roots, on reaching the membrane, had been diverted horizontally along it in their search for moisture. Some roots up to 18 mm diameter had grown through the membrane, but only at places where sharp stones had punctured holes in the plastic presumably at the time of laying. Those which had made their way through holes in the membrane formed, in some cases, an extensive network of roots behind the membrane. These networks extended horizontally and in some instances down toward the bottom of the trench. Great care was taken to ensure that there were no protruding stones or roots to pierce the new membrane and allow these problems to occur again.

The problems experienced with damage to the 0.2 mm polythene membrane forced us to use thicker membranes in later projects (Nunn et al., 1992).

It was thought that roots diverted by the plastic membrane may grow towards the bottom of the trench in their search for moisture. However, the diverted roots tended to travel horizontally, remaining within 400 mm of the surface. This can be attributed to one of two reasons: either surface roots rarely extend below a depth of 400 mm or the root retardant placed throughout the trench, except for about the top 300 mm, had achieved the desired effect.

7. RESULTS FROM SECOND FIELD TRIAL

As before, the various plots of pavement movement in the Second Field Trial have been presented in the report by Martin and Newbegin (1989).

By comparing these results with those of the first trial, an insight into the improvement in performance can be gained. When analysing the results of the second trial, it must be kept in mind that Control Sections 2 and 4 were not true controls because tree roots had been cut and the trenches backfilled with compacted clay, which,is less pervious than the fissured natural clay. The seasonal shrinkage that occurred over three consecutive summers (the last two in the second trial) has been presented for the east side of the road in **Figure 6**. These plots

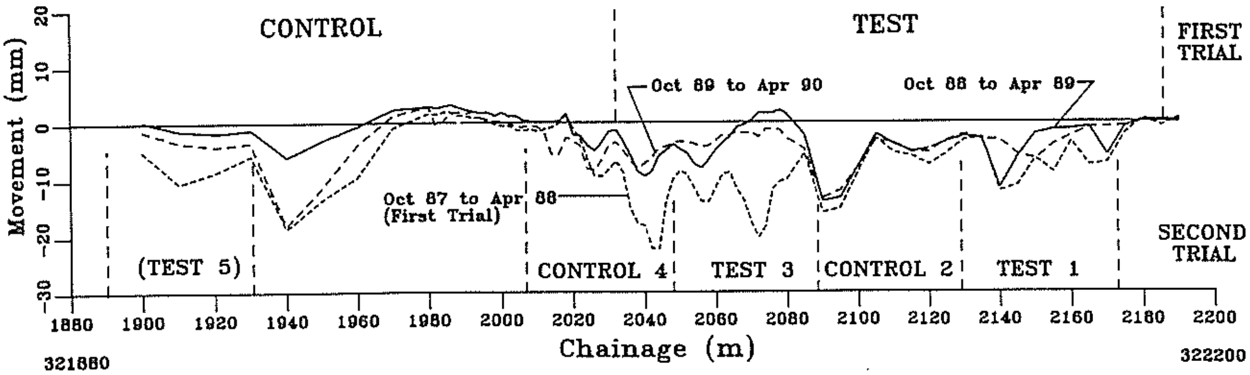

Fig. 6. Seasonal Shrinkage - East Side of Road

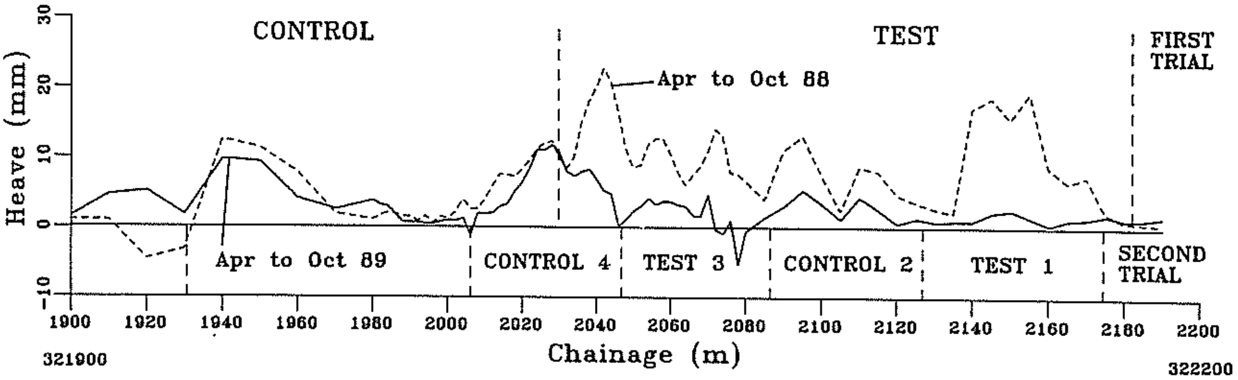

Fig. 7. Seasonal Heave - East Side of Road (First and Second Field Trials)

indicate that shrinkage over the summer has been reduced significantly by the deeper barriers, especially in Test Section 3 where it was only 0 to 2 mm at the centre. In comparison, the seasonal shrinkage for Control Section 2 has remained approximately the same.

The seasonal heave that occurred over two consecutive winters has been presented for the east side of the road in **Figure** 7. The heave over the winter has been reduced significantly by the deeper barriers, especially in Test Section 1, where the heave was almost eliminated. The partial reduction of heave observed in Control Section 2 and in the disturbed part of Control Section 4 is probably due to the fact that the plastic sheeting, which had some water flowing behind it during winter (see Martin and Newbegin, 1989, for the evidence), was replaced by a relatively impervious compacted clay.

The great value of these barriers can also be seen from the results of Test Section 5 on the western side of the highway (Martin and Newbegin, 1989). For example, the seasonal shrinkage was greatly reduced from a maximum of 43 mm during the summer of 1987/88 (ie without a barrier) to only 10 mm for 1988/89. Moreover in this section, the barrier did not have a horizontal component under the shoulder/verge and it reached to only about 1.7 m below the original natural surface.

8. CONCLUSIONS

Two field trials were carried out at a site on the Sunraysia Highway where the road had to be reconstructed because of the pavement damage caused by the effects of a Victorian semi-arid climate and trees on the expansive clay subgrade.

At this site, a vertical moisture barrier installed in the verge to a depth of 1.8 m below verge level (ie about 1.5 m below design subgrade or N.S. level) was not deep enough to prevent the significant seasonal pavement movements being caused by roadside trees. However, a deeper barrier that was at least 2.5 m below verge level (ie 2.2 m below N.S.) greatly reduced or virtually eliminated seasonal movements.

In a period of 3½ years, many tree roots up to 18 mm diameter had grown across the old trench through the verge material and some had entered the pavement subgrade through small existing puncture holes in the plastic membrane. Because of the risk of puncturing 0.2 mm polythene sheeting during installation, thicker plastic membranes have been used in later projects.

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