

**Field Investigation: Pre-Cracking of Soil-Cement Bases to  
Reduce Reflection Cracking**

By

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**ABSTRACT**

This paper describes a new approach to minimize the amount of shrinkage cracking in newly constructed soil-cement (S-C) bases. The approach, called microcracking, is demonstrated on three city streets constructed in October 2000 in a new subdivision of College Station, Texas. The bases on these streets were designed to meet TxDOT's specification 272 (1) requiring an unconfined compressive strength of 500 psi after 7 days moist cure. The base aggregate available in this area is a sandy gravel. To meet the TxDOT strength requirement requires a high cement content typically 6 – 8%. However with this cement content the City has experienced substantial shrinkage cracking.

In an attempt to mitigate this problem the microcracking approach was evaluated. Based on research from Austria (2) this requires a maximum of four passes of a steel wheel vibratory roller applied a few days after finishing. This introduced a network of hairline cracks into the base early in its life with the idea that these "micro-cracks" will minimize the major shrinkage cracks associated with S-C bases. Furthermore, as this is performed only a few days after placement, the microcracking will not impact the pavements overall structural capacity as the cracks will re-heal and the base will continue to gain strength with time. During this study the base stiffness was monitored with both the Humboldt Stiffness gauge and the Falling Weight Deflectometer. Large reductions in stiffness were monitored immediately after microcracking, but after 2 days recovery the base regained most of its initial stiffness. After 6 months a visual inspection was made and the structural strength was measured with a Falling Weight Deflectometer. The base was found to be very stiff and only minor amounts of cracking was found in each of the three monitor sections.

Based on this study draft specifications have been developed for incorporating microcracking in future projects. The S-C sections described in this report were all six inches thick and the work was completed in the fall with an air temperature ranging from 75 to 80 degrees. More work is needed to determine what changes will be required in the draft specifications when working with thicker bases, lower strength bases and or when construction occurs in either hot or cold weather.

## INTRODUCTION

The City of College Station has reported performance problems with several of its recently completed city streets. Examples of poor performance are shown in Figure 1, both of these sections were approximately 9 years old. These were from the Pebble-Creek subdivision and show problems with the two base types (flexible base and soil-cement) used by the city. Both pavement structures consist of a thin 2-inch Hot Mix Asphalt (HMA) surfacing with 6 inches of base over a 6-inch lime stabilized subgrade. The flexible base section was constructed with a high quality crushed limestone, typically transported over 100 miles to College Station from the Austin area. The S-C section was constructed with locally available river gravel. The city uses the Texas DOT's specifications for materials design and construction. For soil-cement materials (TxDOT item 272) requires a cement content which achieves a 7-day unconfined compressive strength of 500 psi, which for this marginal material results in relatively high cement content in the range of 6 to 8%.

In Figure 1 the flexible base section is exhibiting structural base failure caused by moisture entering the base, severely reducing its load bearing capacity. This moisture can enter the base through the surface defects or the longitudinal construction joints. Deterioration is accelerated if the top of the base is not adequately sealed. Rain is a concern but perhaps a bigger problem is the numerous sprinkler systems found in this residential area.

The soil-cement section in Figure 1 is showing a different distress pattern. The block crack pattern is normally associated with shrinkage of the base layer. This cracking occurs early in the life of the base and reflects through the HMA surface. The causes and cures of shrinkage cracking will be discussed later. Initially this is a cosmetic problem, but if the cracks are wide and moisture enters the lower layers then structural damage can occur. Wide cracks also can significantly impact the riding quality of the finished surface. The advantage of soil-cement bases is that they are not usually moisture susceptible and therefore the alligator cracking problems shown in the flexible section will not occur. However excessive shrinkage cracking early in the pavements life is also unacceptable, it is a concern to both city officials and street developers. In the summer of 2000 the early cracking in several newly constructed streets caused the City of College Station to consider mandating the use of only flexible base in future construction. The study described in this paper was initiated to attempt to mitigate these early shrinkage-cracking problems.

## CURRENT APPROACHES TO OF MINIMIZING SHRINKAGE CRACKING

The shrinkage of cement treated materials results from the loss of water by drying and from self-desiccation during the hydration of the cement. The factors which influence the severity and amount of cracking are numerous and complex. They include the amount of cement used, the water content used in the field, the aggregate properties, the adequacy of the curing procedures, weather conditions, the degree of subgrade restraint on the base and the type and time of placement of the final surfacing.

The causes and remedies for shrinkage cracking have been under investigation for over 50 years. Two excellent references on the subject can be found in the work of Williams (3) and George (4). Recent studies in Australia by Caltabiano (5) have focussed on material selection and mix design issues. Caltabiano proposed specifications which include limits on the linear bar shrinkage of the fines and the maximum amount passing the 200 sieve (7% max), together with the introduction of blended cements and the use of a linear shrinkage measurement on the S-C materials. These changes were reported to produce a more acceptable crack patterns. Other

ideas that are found in the literature are sometimes confusing, some authors promote early sealing of the base to promote curing, whereas other promote delayed surfacing to let the crack pattern develop prior to placing the final asphalt surfacing which will hopefully bridge the existing cracks.

Currently in Texas S-C bases are designed to meet a 7-day UCS value of 500 psi. With marginal materials high cement contents (6 to 8%) are usually required. This level of cement result in strong durable bases, which exhibit block cracks in the first few months after construction. (As a side note the 500-psi requirement is in current TxDOT specifications book, but it not widely used by TxDOT Districts. Many Districts are currently specifying between 200 and 300 psi in an attempt to mitigate cracking problems. TxDOT is currently reviewing this specification in a rewrite, which is scheduled for publication in 2002. Despite this anticipated change the 500-psi specification is widely used by many city and county highway agencies).

For construction of S-C bases in Texas it is recommended that the base be compacted at or below optimum moisture content and be adequately cured. Curing options include either a 3 day wet cure or an effective asphalt seal.

### **NEW APPROACHES TO MINIMIZING SHRINKAGE CRACKING**

Performance evaluations in Texas (6) have repeatedly found that the major problem with soil-cement is not strength or durability but shrinkage cracking. Soil-Cement bases were used widely in the 1960's and early 70's but their usage waned in the 80's and 90's. Several TxDOT Districts reported that they have many S-C sections which performed well, but they had experienced a few sections which had performed poorly. These sections were reported to crack excessively, give a rough ride and were difficult to maintain. With the current design criteria it was concluded that the construction techniques described above have provided limited success at mitigating the shrinkage-cracking problem.

Research studies to improve the performance of soil-cement bases have recently been undertaken at the Texas Transportation Institute (TTI). The focus of these studies has been on the following two approaches;

A) Improved mix design requirements (use less cement while maintaining durability)

Most designs procedures call for a high early strength S-C base. While these provide a strong durable base they do not necessarily provide good long-term performance. With S-C bases there is a poor correlation between base strength and perceived base performance. With 7-day 500 psi bases the ultimate strength in the field is often in excess of 1500 psi. These layers are stiff but also very brittle. A new design methodology has been proposed by TTI, which promotes the use of both strength and durability requirements rather than strength alone (7). The goal is to reduce strength but also maintain durability. A new test called the Tube Suction test has been developed as a simple durability test.

A limited laboratory study was conducted on the river gravel material discussed later in this paper (Edelweiss project). It was found that adequate strength (350 psi +) and good durability could be obtained with around 4.5% cement, significantly less than the 7% currently used.

B) Innovative construction techniques (Microcracking)

Austrian researchers, Litzka and Haslehner (2) first described this approach in 1995. Their paper stated, " The cement stabilized layer is loaded through several passes with

vibratory rollers after a time span of between 24 and 72 hours, thus creating a micro-cracked structure in the stabilized layer. Practical experience has shown that five roller passes leads to satisfactory results and the micro-cracked structure prevents the development of larger stress cracks. Thus reflective cracking does not appear in the asphalt overlay". They also found from deflection studies that the microcracking did not significantly impact the final pavement stiffness as the backcalculated moduli values corresponded very well with the design values. The one concern of these researchers was how to control the microcracking process? Their initial studies were conducted with Benkelman beams, but these were judged to be not practical for everyday use

Based on the Austrian results it was recommended that a section be constructed in College Station to determine if this approach could improved the initial performance of soil-cement pavements currently under construction. In August 2000 several meetings were held with the City Engineer (Bob Mosley P.E.) and the general contractors (Bill Thomas P.E. of Young Brothers Inc.). It was decided to try this approach on three city streets to be constructed in the Edelweiss Subdivision.

### **CONSTRUCTION OF THE EDELWEISS PAVEMENTS**

Three sections, Salzburg Court, Von Trapp and Newburg Court, were constructed in October 2000. The pavement structure consists of 6 inches of lime-stabilized subgrade, 6 inches of soil-cement and a 2-inch HMA surfacing. This was a wet period of the year, which delayed several phases of the construction. The first section on Salzburg was placed shortly after substantial rainfall. This section was cured for 24 hour, then pre-cracked as shown in Figure 2. A heavy 12-ton steel wheel roller was used, operating at a slow walking speed around 2 mph, with the vibrator set to maximum amplitude. It was difficult to see the impact of the rolling, but in a few locations it was possible to see a web of surface cracks. A typical example is shown in Figure 2.

The next sections on Von Trapp and Neuburg used a similar process, however on Von Trapp the section was left for 2 days before initiating the microcracking. A fourth section on Sophia Lane was constructed at the same time but not subjected to microcracking.

To monitor the changes in base stiffness the two techniques shown in Figure 3 were used. The first is the use of a Humboldt Stiffness gauge (8). This device imparts small displacements in the base at frequencies between 100 and 200 Hz. The force versus displacement is measured to compute the soil stiffness. The second approach was to use TxDOT's Falling Weight Deflectometer (FWD). The FWD is the main structural strength testing equipment used by TxDOT. The advantage of the FWD is that it can be used to estimate the base modulus (stiffness) both during construction and after placement of the final surfacing.

On each section four monitor locations were established for the Humboldt device and 10 for the FWD. Humboldt and FWD deflections were taken before microcracking, then after 2 and 4 passes of the vibratory roller. In this limited study it was concluded that the Humboldt Stiffness gauge worked well as a construction control device. The changes in average base stiffness are shown in Table 1.

From these data it was found that the average base stiffness decreased by approximately 30% after 2 passes of the roller and by and another 15 to 20% after two additional passes. After completion of the microcracking all of the sections were water cured for two days. The Salzburg section was retested after the two-day recovery period and the measured base stiffness had increased significantly indicating that the section was continuing to gain strength with time. The

stiffness had reduced to less than 50% of the initial stiffness after 4 passes of the roller, but this had recovered to 74% of the original stiffness after two days.

After completion of the microcracking the initial plan was to surface the sections as soon as possible after the curing period. However this was delayed for a period of 4 weeks because of heavy rain. This surfacing delay was one complicating factor in evaluating the performance of these sections.

## PERFORMANCE EVALUATION

The first detailed evaluation of performance was conducted 6 months after placement of the final surfacing. During this period the sections endured both a relatively cold wet winter and construction traffic, in-particular concrete trucks. After 6 months a visual survey and a repeat FWD survey were conducted on each street. The results of the visual survey are shown in Figure 4, and typical cracks found in the sections are shown in Figure 5. The average crack length information is tabulated in Table 2.

The FWD results are shown graphically in Figure 6 and 7. Two parameters are graphed namely the maximum surface deflection normalized to 9000 lbs and the surface curvature index (SCI) which is defined as the difference in deflection measured directly under the load to that measured one foot from the load. The surface curvature parameter is an indicator of the stiffness of the top 8 inches of the pavement. The lower the value the stiffer the base. For reference at a 9000lbs FWD load a concrete pavements will typically have a maximum deflection of 3 to 6 mils and SCI's of 1 to 2 mils. Flexible pavements with a similar structure to that used in College Station will typically have deflections in the 15 to 25 mils region and SCI's of between 8 and 12 mils. The data presented in these figures indicate that the pavement was very stiff after only one or two days curing (0 passes), however the stiffness reduced (increased deflection) substantially after the 4 passes of the vibratory roller. At that stage the stiffness was approaching that of a flexible base pavement. However after 6 month the pavement stiffness has fully recovered and the average deflection was significantly less than that measured before microcracking. The section clearly has continued to gain strength with time and the microcracking had little or no impact on the ultimate load bearing capacity.

The next step in the analysis was to back-calculate the modulus of the soil-cement layer from the FWD data. In general the higher the modulus the better the load carrying capacity of the pavement. To do this computation TxDOT's analysis program MODULUS 5.1 (9) was used. The results of this analysis are shown in Table 3.

For reference the typical moduli values found for Texas materials is as follows;

- Untreated Flexible Base 50 to 70 ksi
- Hot Mix 300 to 800 ksi (depends on temperature)
- Concrete 3000 to 6000 ksi

The moduli values obtained on the S-C bases are very high. After 4 passes the base stiffness dropped to close to the flexible base region. However after 6 months it recovered substantially. The S-C base on Von Trapp was computed to be approaching the stiffness associated with lean concrete. Clearly microcracking did not adversely affect load-carrying capability of these bases.

One word of warning on the moduli values shown in Table 3. The 6-month values are very high. The concern is that this base may be too stiff. The microcracking appears to have helped with the shrinkage-cracking problem. However with these pavements summer drying may cause cracking of the underlying soils. Bases this stiff may be too brittle to accommodate any substantial soil movement without cracking. One issue for consideration is that the current design and construction practices result in a pavement which is very strong. However, it may be feasible to reduce the initial strength requirement without significantly impacting the load bearing capability while significantly improving base flexibility.

## CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

- The microcracking process substantially reduced the amount of surface cracking in the three streets included in this study.
- Based on the data from Salzburg Court the pavements will rapidly regain strength. After two days the stiffness of the section was 75% of the pre-cracked stiffness.
- After 6 months it was found that all sections had minor cracking and very high base stiffness.
- The delay in placing the final HMA surface also helped in reducing the extent and severity of the surface cracking. This is based on the fact the surface cracking on the control section (Sophia Lane) was significantly less than cracking on similar jobs in College Station constructed with the same materials under similar conditions.
- The Humboldt Stiffness gauge was useful in controlling the cracking process.

### Recommendations

- Microcracking should be incorporated into future S-C jobs. A draft specification for microcracking has been developed and is shown in Figure 8. More studies are required to fine-tune these requirements for thicker sections and for different seasons of the year.
- The concept of delaying the final surfacing should be incorporated on future jobs. This could involve placing a chip seal on the cured section and the final HMA surface 2 to 4 months later.
- More work is needed to evaluate the reduced strength concept. The 7-day 500-psi strength requirement only guarantees a stiff material it does not guarantee and good performing pavement.

In summary, it appears that surface cracking of S-C bases can be minimized and perhaps eliminated if the City undertakes the following;

- a) reduces the design strength requirement (for example 500 to 300 psi),
- b) delays final surfacing as long as possible, (minimum 2 months)
- c) adheres to good curing practices, and
- d) adopts the microcracking specifications shown in Figure 8.

**ACKNOWLEDGEMENTS**

The City Engineer of College Station, Mr. Bob Mosely PE. and Bill Thomas P.E. of Young Bros. Construction were involved in all phases of this work. Their support is greatly appreciated. Spencer Guthrie of TTI conducted the Humboldt testing in the field and Stephen Sebesta of TTI conducted laboratory testing on the base materials. Darlene Geohl P.E. the pavement engineer of the Bryan District provided the FWD used in this study.

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**Table 1. Humboldt Stiffness Gauge Results. (MN/m).**  
(Average of 4 Locations per street).

Street	Age when Cracked (days)	Humboldt Measurement			
		Before Cracking	After 2 Passes	After 4 Passes	2 Day Recovery
Salzburg Court	1	56.5 (100%)	36.7 (65%)	27.7 (49%)	41.2 (74%)
Von Trapp	2	57.4 (100%)	43.6 (76%)	34.6 (60%)	
Neuburg CT	1	52.3 (100%)	33.7 (64%)	26.1 (50%)	

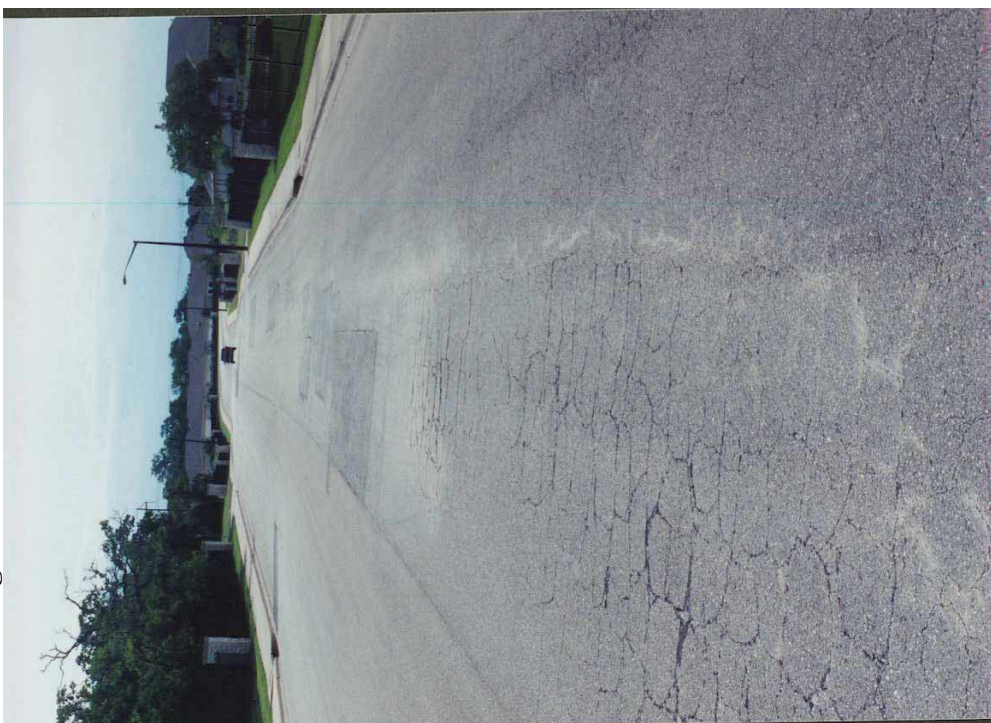
**Table 2. Summary of Shrinkage Cracking 6 Months After Surfacing.**

<b>Street</b>	<b>Crack Length in feet per 100 ft of pavement (2400 sq.ft.)</b>
Salzburg	5.6
Von Trapp	3.5
Neuburg	2.4
Control	27.3

**Table 3. Average S-CModuli (ksi) from FWD Data.**

<b>Street</b>	<b>Time</b>				
	<b>Before (Age)</b>	<b>After 2 Passes</b>	<b>After 4 Passes</b>	<b>After 2 Days Recovery</b>	<b>6 months</b>
Salzburg Ct	935 (1 day)	241	135	646	838
Von Trapp	1316 (2 days)	324	223	-	2334
Neuburg	1232 (1 day)	316	158	-	1964

**Figure 1. Pavement Problems in Pebble Creek Subdivision. –College Station, Texas – May 2001.**

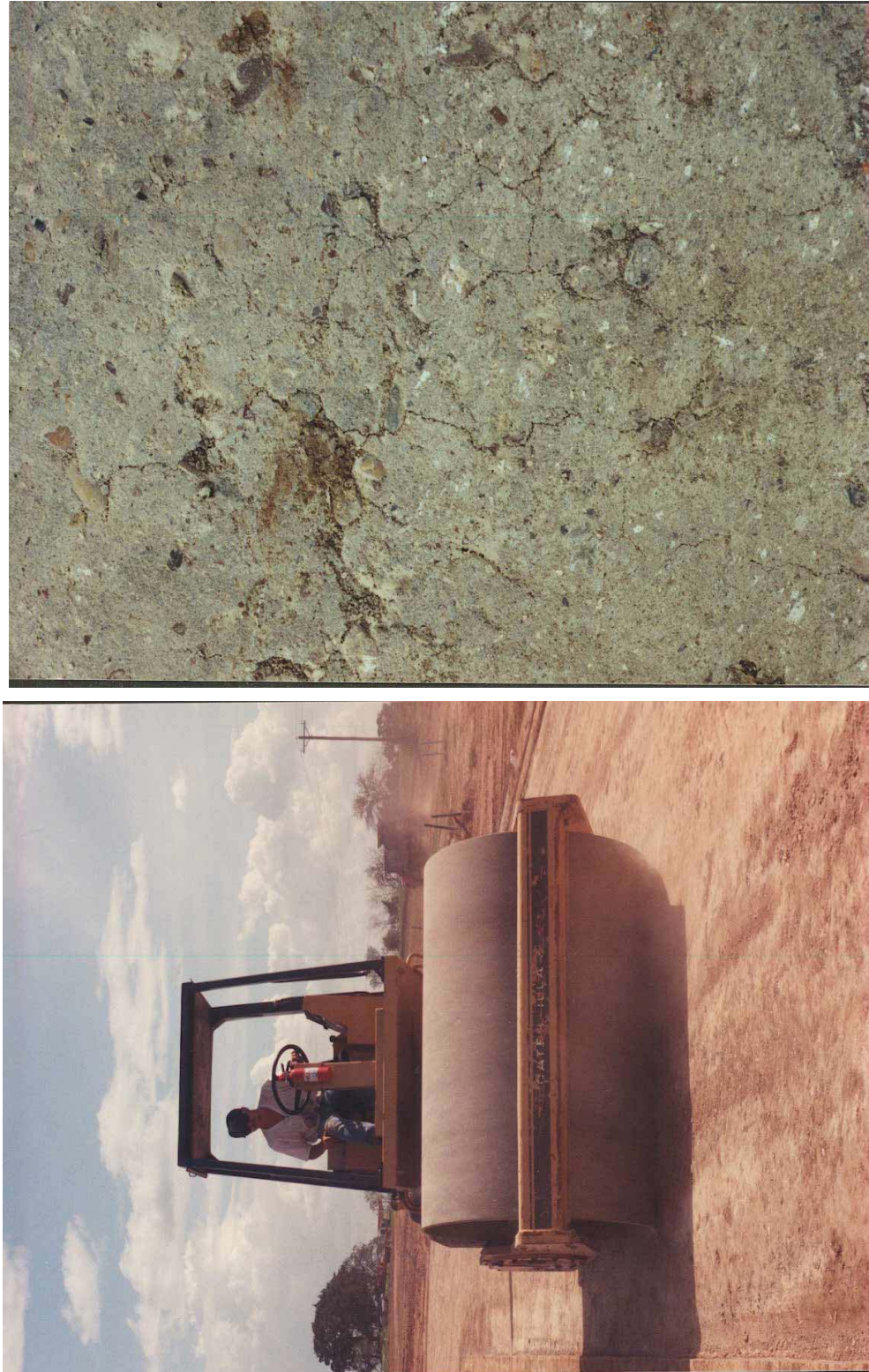


**a) Flexible Base Section**  
**(Moisture often enter base material via leaking construction joint. Lack of an effective seal over the base can accelerate deterioration. Sprinkler systems are also a concern.)**



**b) Soil-Cement Section**  
**(Excessive shrinkage of the stabilized base results in block cracking. This is initially cosmetic but can lead to secondary structural problems and loss of riding quality)**

**Figure 2. Microcracking of Soil-Cementin Edelweiss subdivision, Oct 2000.**



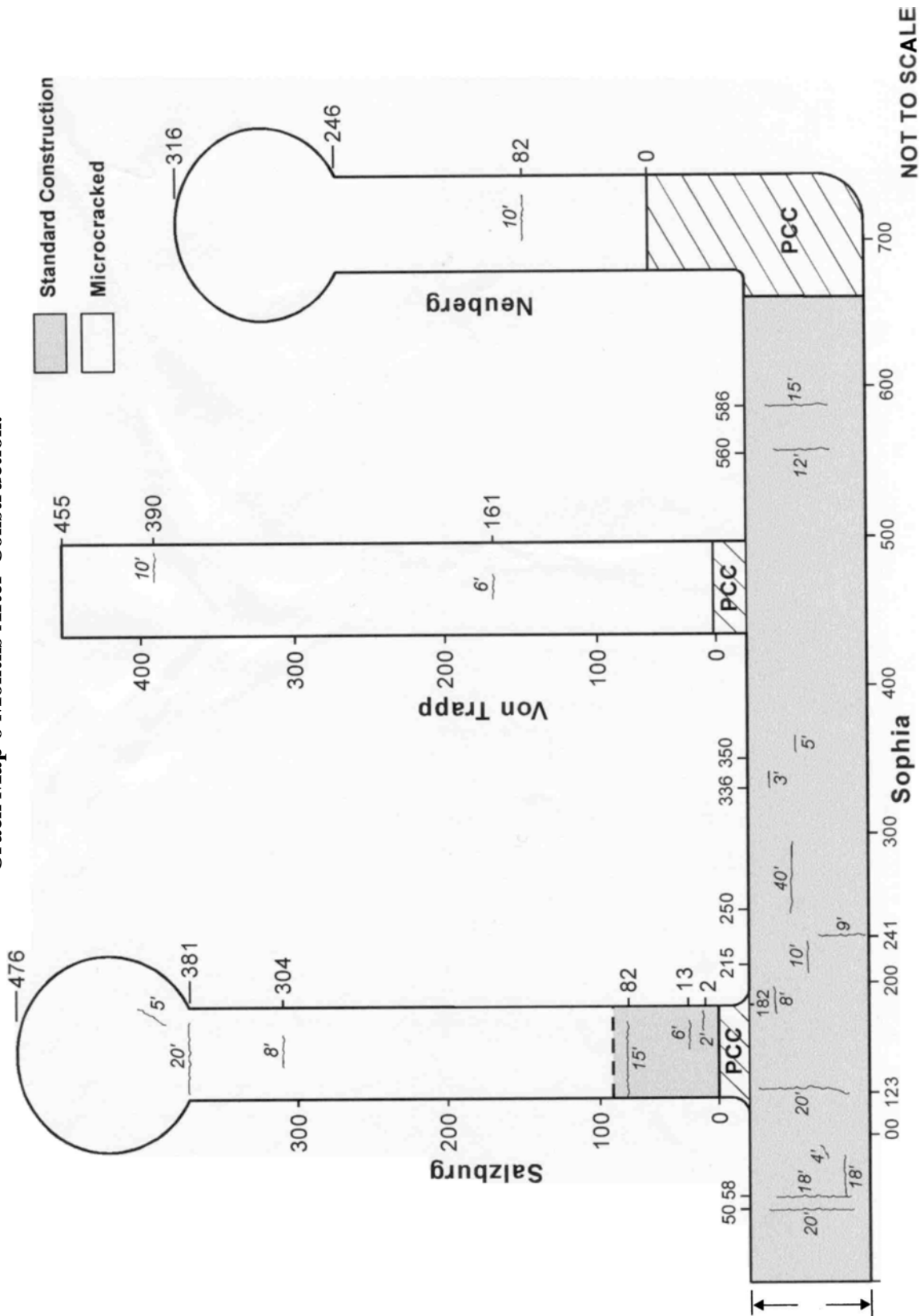
- **Introduces a network of microcracks into base to avoid major shrinkage cracks.**
- **First proposed in Austria in early 1990's**
- **Heavy Steel wheel vibratory roller applied to base 1-2 days after compaction followed by 2 days moist cure.**

**Figure 3. Monitoring Base Stiffness.**



- Stiffness measuring techniques used in study Humboldt stiffness gage and Falling Weight Deflectometer.
- Recommended to test section every 100 ft before and after 2 passes of vibratory roller.
- Target a 40% reduction in base stiffness (as measured by the Humboldt).

**Figure 4. Edelweiss Subdivision – Phase 14 & 16 – College Station, Texas  
Crack Map 6 Months After Construction.**



**Figure 5. 6 Month Condition Assessment. Minor Transverse Cracking in Section.**



**(b) Neuburg  
(only crack in section)**



**a) Von Trapp  
(Two cracks in 455-ft section)**

Figure 6. Falling Weight Deflectometer Data for Von Trapp.

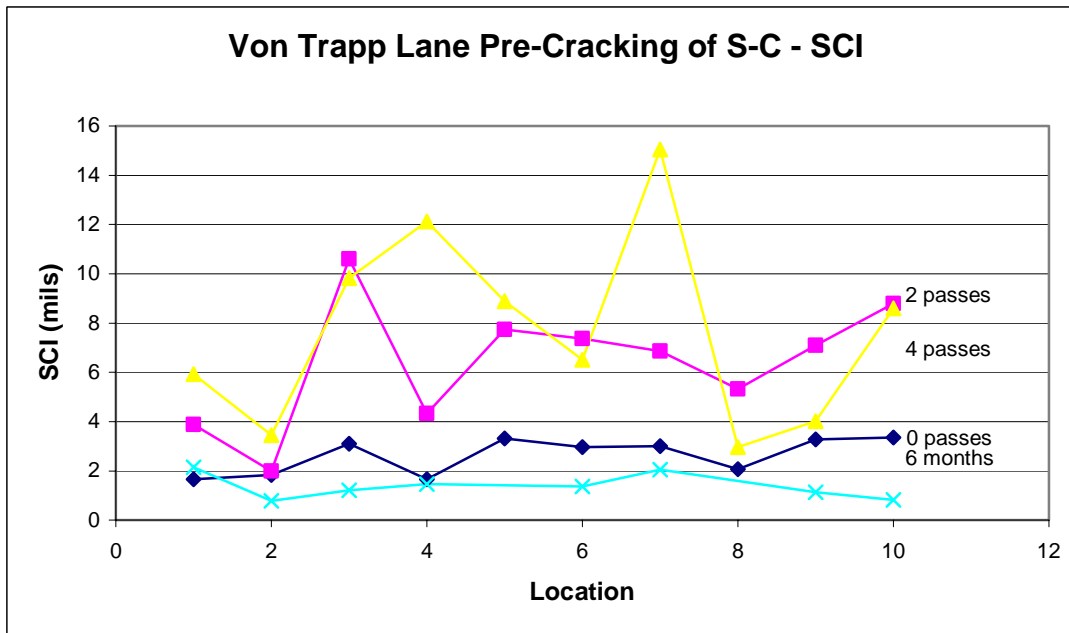
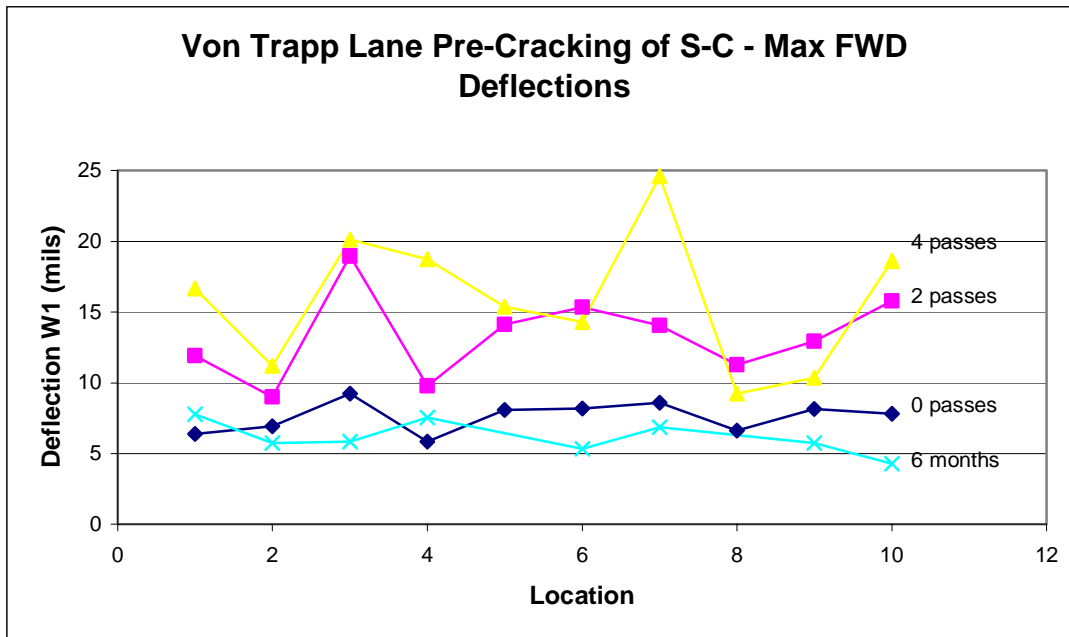
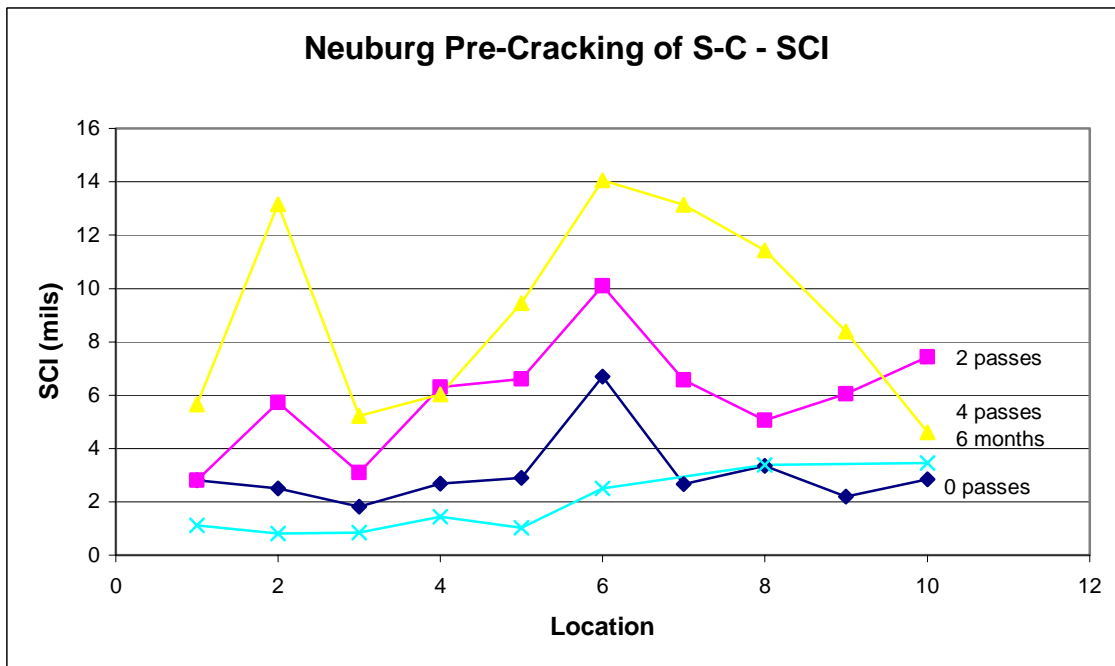
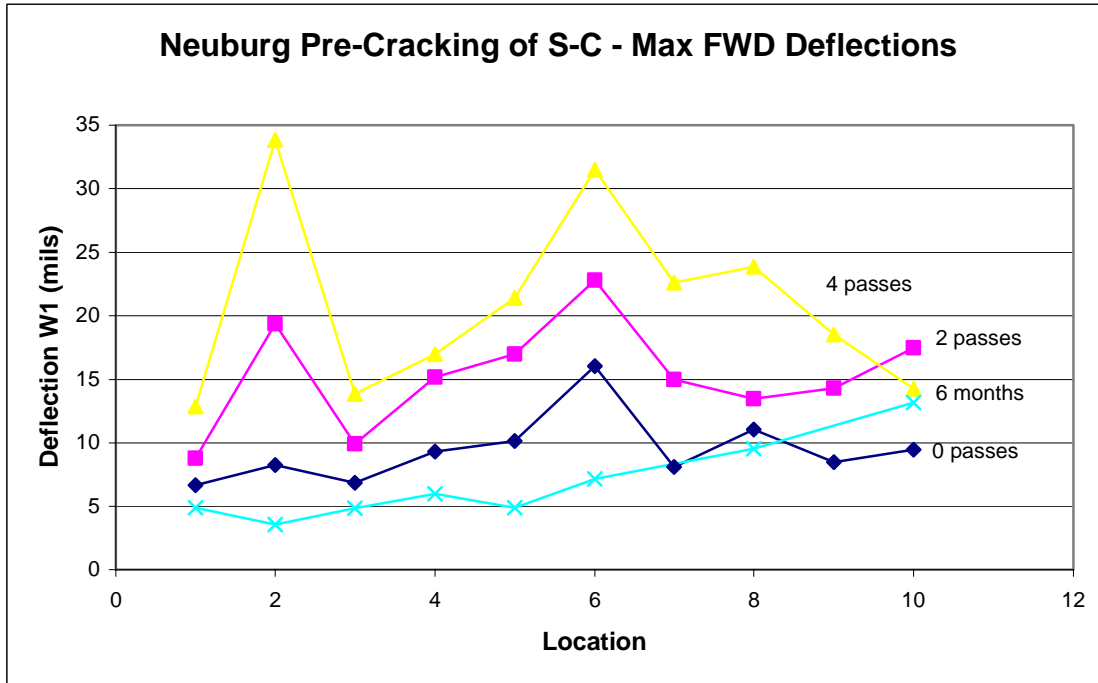


Figure 7. Falling Weight Deflectometer Data for Neuburg.



**Figure 8. Provisional Specifications for Microcracking.**

After compaction the finished soil-cement will be kept continuously moist for between 24 and 48 hours. The finished course shall then be vibrated with between 2 and 4 passes of a 12 ton steel-wheel vibratory roller, traveling at a speed of approximately 2 mph and vibrating at maximum amplitude (or as directed by Engineer). The section shall have 100% coverage exclusive of the outside 1 foot so as to induce minute cracks in the treated base course. Additional passes may be required to achieve the desired crack pattern or section modulus as directed by the Project Engineer. Rolling will be stopped when the average base stiffness has reduced by 40% or greater.

The following sequence shall be used unless otherwise directed by the Project Engineer.

- Step 1: The stiffness of the base course shall be determined by the contractor using an approved device, such as Humboldt stiffness gauge. One reading shall be taken in each 100 ft section along the project. The test points shall be marked for later retesting.
- Step 2: After two passes with the vibratory roller, the stiffness of the soil-cement course will determined and the section shall be inspected. Based on the target total stiffness reduction of 40%, it will decided if additional passes are required.
- Step 3: After two additional passes with the vibratory roller, the stiffness of the soil cement base course will determined and section shall be inspected. Rolling shall be stopped if the total stiffness reduction of 40% or greater is achieved. At this phase, it will be decided if additional passes are required.
- Step 4: After cessation of microcracking the section shall be moist cured for a period of 48 hours.

**Additional Notes**

- This specification is appropriate for S-C bases designed to have a 7-day UCS of 500 psi (TxDOT specification 272).
- These specifications are based on limited data from College Station. They may need to be adjusted for bases thicker than 6 inches and for construction in either very hot or cold weather.