

**Use of Microcracking to Reduce Shrinkage Cracking in Cement Treated Bases**  
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## ABSTRACT

Shrinkage cracking occurs in cement-treated bases due to desiccation and cement hydration; eventually these cracks start to reflect through the pavement surfacing. While initially considered cosmetic in nature, these cracks open the pavement to water infiltration and increase the likelihood of accelerated pavement distress. Although numerous options exist for minimizing the amount of reflective cracks that appear, this paper focuses on the performance of controlled test sections utilizing a promising approach termed "microcracking." The microcracking concept can be defined as the application of several vibratory roller passes to the cement treated base at a short curing stage, typically after one to three days, to create a fine network of cracks. In addition to the microcracked test sites, the contractor constructed moist cured, dry cured, and asphalt curing membrane sites for comparison. Researchers used falling weight deflectometer (FWD) tests to control the microcracking process, periodic crack surveys to monitor crack performance, and FWD tests through time to track base moduli. Microcracking proved quite effective at reducing shrinkage cracking problems in the base; applying the procedure with three passes of the roller after two to three days curing resulted in the best performance. Additionally, researchers observed that without microcracking, excessively high cement contents result in problematic cracking in the base even if cured according to good construction practice. Microcracking did not result in pavement damage or diminished in-service modulus; thus, microcracking should be considered a viable and inexpensive option to incorporate shrinkage crack control into construction of cement-treated bases.

## INTRODUCTION

Over the years much work has been performed regarding cracking in cement-treated road base. Shrinkage cracks occur when the tensile stress in the base exceeds the tensile strength (1,2). These shrinkage cracks eventually reflect through the pavement surfacing. Although initially thought to be cosmetic in nature, these cracks allow water into the pavement which accelerates the rate of pavement deterioration. Faced with both negative public perception due to the cracking and the risk of early pavement distress, agencies and researchers alike continue their quest for solutions to the shrinkage cracking problem to this day. While numerous approaches to minimize shrinkage cracking exist, this paper discusses a controlled experiment for evaluating the microcracking technique for minimizing shrinkage cracking problems in cement-treated base.

## BACKGROUND

Shrinkage of cement-treated materials can be divided into two categories: autogenous shrinkage (shrinkage resulting from the hydration of the cement) and drying shrinkage. K.P. George and H.E. Bofinger studied the shrinkage cracking phenomenon extensively and concluded drying causes the majority of the shrinkage (3,4). Other factors also contribute to how much shrinkage cracking cement-treated materials exhibit. Tensile strength of the base (3,4), restraint by friction between the base and subgrade (5,6), creep characteristics of the base (4,7), shrinkage with decreasing temperature (5,6), amount and type of clay in the treated material (3), and pre-treatment and molding moisture content (4) all influence how much cracking takes place. While cement content historically is believed to significantly influence shrinkage, some researchers concluded shrinkage decreased with increasing cement content (4), others noted an optimal cement content existed where total shrinkage was minimized (3,8), and yet others found no relationship between cement content and shrinkage (9).

With the developed background on factors causing shrinkage in cement-treated bases, recent efforts for minimizing the shrinkage cracking problem focus on design and construction aspects. The Portland Cement Association currently recommends 7-day unconfined compressive strengths in the range of 300-400 psi in the design phase, and during construction they recommend compaction at or slightly below optimal moisture content and moist curing until a moisture barrier is placed (10).

While most initial methods for reducing shrinkage cracking in cement-treated materials focused on controlling desiccation through moist curing or asphalt curing membranes, more recently other techniques examined the utility of stress relief layers such as chip seals, geosynthetics, or thin unbound granular base layers to reduce reflective cracking. Although these designs will reduce the likelihood of reflective cracking, they require a substantial additional step in the construction process. In Austria, an innovative concept originated to use the vibratory smooth drum roller to create a microcracked structure in the cement-treated layer early in the curing stage (11). The researchers reported this "microcracking" process prevents the development of larger stress cracks (11). According to Litzka (pers. comm.), microcracking typically is performed by 3 passes of a roller 24 to 48 hours after compaction. Brandl (12) reported that, of available options for minimizing cracking on the Austrian-Hungarian Highway, the microcracking technique was most suitable. Microcracking can be defined as the application of several vibratory roller passes to the cement treated base at a short curing stage, typically after one to three days, to create a fine network of cracks.

Based upon the promising work utilizing microcracking in Austria, work in Texas was initiated as early as 2000 to investigate the microcracking concept. Scullion (13) described these first efforts and presented a draft specification for the microcracking process. Although the initial studies showed favorable results using the microcracking procedure, the test sites were residential streets utilizing cement contents and target strengths that are now believed excessive (7% cement and 500 psi (3,447 kPa) 7-day strength). Thus, researchers organized the construction of controlled microcracking test sections utilizing a laboratory mix design and controlled applications of the microcracking process.

## RESEARCH METHODS

The microcracking test facility was constructed at Texas A&M's Riverside Campus on September 8, 2003, and utilized a 6 inch (152.4 mm) layer of the same marginal gravel base as the residential streets described by Scullion. Figure 1 shows the gradation of the material. The maximum dry density determined by Test Method Tex-113-E is 136.5 pcf (2,186 kg/m<sup>3</sup>) at 7 percent water. A laboratory mix design based upon a 7-day strength target of 300 psi (2,068 kPa) and a final dielectric value after the Tube Suction Test of no greater than 10 determined the optimal cement content was 4 percent. The Tube Suction Test is a capillary soak test for moisture susceptibility (currently being implemented statewide by TxDOT) and is described elsewhere (14-16). Table 1 shows the results from the mixture design tests.

To evaluate crack control techniques, researchers planned six treatments to apply to the designed base. Additionally, a mirror site with the same treatments but 8 percent cement was constructed to represent the historic treatment level with this material. Figure 2 shows the layout of the test sites and the treatments applied. The contractor scheduled a seal coat for placement on Day 4 but due to rain could not place the seal coat until the following week. The rock did not stick well, and the majority of the rock has been broomed off leaving only the primed base exposed.

To apply the microcracking procedure, the same 2001 model year Vibromax W1105 D, 11,100 kg (12.2 ton) roller used for compaction was utilized vibrating at high amplitude and 36 Hz. The roller drum width was 84 inches (2.13 m) and the roller was operated at 2-3 mph (3.2-4.8 km/hr). To control the microcracking process, a Texas Department of Transportation (TxDOT) falling weight deflectometer (FWD) was used to measure the base modulus immediately before applying the microcracking procedure, then after rolling the FWD was employed to verify at least a 40 percent drop in base modulus was achieved. The research team then performed crack surveys and FWD tests periodically to monitor the progression of cracking in the base and track the base moduli.

## CRACKING PERFORMANCE

Researchers conducted the first crack survey the morning after placement of the base; cracks that existed at this time would not be preventable regardless of treatment. The research team conducted the most recent survey on June 28, 2004. Figures 3 and 4 illustrate the current status of the cracking, and Table 2 summarizes the crack length statistics for the sites. Several observations are evident from the surveys:

- In general, the sites with 8 percent cement exhibited more total cracking than their counterpart treatments with 4 percent cement. The most drastic differences exist in the dry cured and prime cured sections.
- Of the sites with 4 percent cement, the site microcracked at two days cure currently has the best cracking performance.
- Of the sites with 8 percent cement, the site moist cured currently has the least amount of total cracking; however, microcracking at 3 days cure was most effective at preventing additional cracks from occurring. For example, the site cracked after 3 days already had 80 feet (24.4 m) of cracks per 100 linear feet (30.5 m) road before microcracking; after treatment the total crack length has increased by only 10 percent. In contrast, the moist cured section initially had no cracks in it but over time has progressively shown a steadily increasing amount of cracking.
- At the site with 8 percent cement, a prime coat curing membrane was ineffective at controlling cracking.

Two mechanisms exist by which microcracking can reduce shrinkage cracking problems. First, microcracking can reduce the total amount of cracking; second, microcracking can reduce the severity (width) of the cracks. Table 2 shows microcracking substantially reduced preventable crack length in the site with 8 percent cement. The only major reduction in total crack length at the site with 4 percent cement is with the section microcracked after 2 days cure. However, drastic differences in crack severity exist in the site with 4 percent cement. As noted in Table 2, the crack width in sections that were wet cured or dry cured is such that spalling is starting to occur. In contrast, the cracks in sections that were microcracked are less severe. Figure 5 contrasts the

widest to the tightest cracks in the sections with 4 percent cement. In some cases (see Figure 5b) some of the cracks are so tight they are barely visible. Differences in crack severity also exist in the site with 8 percent cement, with cracks in the microcracked sections less severe than others. In general the research team observed crack severity decreased with microcracking as compared to the dry cured, wet cured, and prime cured sections. Thus the performance of the sites indicate that in some cases, especially on bases with high cement contents, microcracking will significantly reduce the amount of cracking in the base; however, even if total crack length is not substantially reduced, crack severity is significantly reduced by microcracking, regardless of mixture design.

## FWD RESULTS

Figure 6 illustrates the typical pattern of changes in base modulus with the microcracking procedure. As curing proceeds, the base modulus increases. The change from Day 0 to Day 1 in Figure 6 shows this increase. Then, during the initial passes of microcracking (one pass is down and back), minimal change in the base modulus takes place. Figure 6 shows how after 2 passes the modulus only decreased 25 percent. Then, with one additional pass, the base modulus suddenly drops drastically. At this point the base is satisfactorily microcracked. The base modulus then recovers quickly since microcracking takes place early in the curing stage of the material.

Two key questions arise regarding the modulus of the base from microcracking. First, since time and equipment limitations prevent the use of a FWD on every microcracking project, field engineers need to know how much rolling to perform. Second, the in-service modulus of the microcracked layer must be satisfactory. Regarding the amount of rolling, the contractor applied 3 passes to each of the microcracked sections with 4 percent cement and achieved an average reduction in base modulus of 60 percent, with a range of 51 to 70 percent reduction. At the site with 8 percent cement, the contractor applied 2.5 to 4 passes and achieved an average reduction in base modulus of 65 percent with a range of 58 to 69 percent reduction. Thus, field experience at these test sites indicates 3 passes of the vibratory roller should be sufficient to obtain the desired results. With respect to eventual in-service base modulus, Figure 7 shows the average base moduli of the test sites from the most recent FWD measurements (June 28, 2004). Figure 7 illustrates both the observed sample mean (the square marker) and the 95 percent confidence interval for the population mean (the vertical lines) for each section. These data show:

- Microcracking has not resulted in reduced layer moduli when compared to the control (moist cured). Statistical tests show no significant difference exists in the mean base modulus between the microcracked sections and the moist cured section at the site with 4 percent cement. At the site with 8 percent cement, the section cracked after one day, and the section cracked after 3 days, both have statistically significant greater mean moduli values than the moist cured section.
- With the exception of the dry-cured sections and the sections cracked at one day, currently no difference in mean modulus value exists between the two cement contents when constructed and cured with identical techniques. The higher cement content in general has not resulted in a significantly increased in-service modulus.

A secondary issue that arose from this work was questions regarding how quickly traffic can be allowed on cement-treated layers. TxDOT specifications require a 3 day moist cure; however in instances of emergency repairs TxDOT needs to open the road sooner. Figure 8 shows the distribution of observed moduli for the sites the afternoon of placement, representing a curing time of approximately 4 hours, and the morning after placement, representing approximately 20 hours curing. The site with 4 percent cement had an average base modulus on the day of placement of 362 ksi (2,496 MPa), and 90 percent of these observations were greater than 65 ksi (448 MPa). The morning after placement the average modulus at this site was 874 ksi (6,026 MPa) with 90 percent of observations greater than 200 ksi (1,379 MPa). With 8 percent cement, the average base modulus was 436 ksi (3,006 MPa) the day of placement, and 90 percent of these observations were greater than 100 ksi (689 MPa). This average modulus value increased to 1690 ksi (11,652 MPa) the morning after placement, with 90 percent of observations at least 650 ksi (4,482 MPa). For reference, a typical Texas flexible base has an in-service resilient modulus value in the range of 40-100 ksi (276-689 MPa). The data indicate earlier trafficking of this cement-treated base than what is typically allowed should not pose a problem. Similarly, work performed by Guthrie et. al. recently indicated trafficking could be permitted as early as after 8 hours curing on a section constructed with full-depth recycling and 2 percent cement (17).

## APPLICATION OF MICROCRACKING IN CONSTRUCTION

Based upon the reported positive results from microcracking in Austria and the positive results of microcracking at the controlled test sites described in this paper, microcracking provides a valid means of reducing the severity of

cracking problems in cement treated bases. A summary of the recommended process based on Texas experience follows:

- Use laboratory tests to design the mixture. Inclusion of both a strength and moisture susceptibility test is recommended. If using solely compressive strength, target 300 psi (2,068 kPa) unconfined at 7 days cure.
- After satisfactorily compacting and blue topping the base in the field, wet cure the base to an age of 2 to 3 days.
- Using the same roller (or same tonnage roller) employed for compaction, apply 3 passes over the section with the roller vibrating at maximum amplitude and traveling at approximately walking speed (approximately 2-3 mph (3.2-4.8 km/h)) to apply the microcracking procedure. Although surface damage should not occur, inspect the process for verification.
- Continue to wet cure the section through a curing age of 3 days

## CONCLUSIONS

Construction of test sites at Texas A&M's Riverside Campus provided an excellent opportunity to investigate the microcracking concept on a cement-treated aggregate base material in a controlled setting. The research team had full control over the construction, from start to finish, and the location provided an opportunity to leave the base exposed so cracking in the base could easily be investigated. The observations to date support the following:

- Without microcracking, excessively high cement contents result in problematic cracking in the cement-treated aggregate base.
- An asphalt curing membrane was minimally effective at reducing cracking problems.
- Microcracking reduces the severity of shrinkage cracks in the base, regardless of cement content, and in some cases also significantly reduces total crack length.
- The positive effect of microcracking on cement-treated aggregate base means the technique is a valid method for reducing the risk of reflective cracking through the roadway surfacing.
- When properly applied, microcracking does not result in pavement damage. The surface does not break up and the base modulus recovers.
- Proper lab design combined with microcracking by 3 passes of the vibratory roller at high amplitude after two to three days cure has provided a marked reduction in shrinkage cracking problems with the cement-treated aggregate base used at the test sites.

Based on the promising results from the controlled experiment described in this paper, and the consistency of findings among researchers investigating the microcracking concept, agencies should consider microcracking a viable construction technique for reducing the severity of shrinkage cracking in cement-treated aggregate bases. Of critical importance, however, is a proper mixture design of the material. Excessively high target strengths and cement contents typically result in more total crack length and more severe (wider) cracks.

## ACKNOWLEDGEMENT

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**TABLE 1 Results from Mixture Design Tests for Gravel Base**

<b>Cement Content (%)</b>	<b>Final <math>\epsilon</math> after Tube Suction Test</b>	<b>7 Day UCS (psi)</b>
2	12.0	267
3	11.2	298
4	6.1	383
5	5.7	466
6	5.3	492

*1psi = 6.89 kPa*

**TABLE 2 Summary of Cracking Performance of Test Sites**

Cement Content (%)	Treatment	Crack Length per 100 Feet						Comment
		9/9/2003	9/15/2003	1/28/2004	3/29/2004	6/28/2004	6/28/2004*	
4	Dry Cure	9	43	57	57	89	89	cracks spalling
	Prime Cure	18	29	51	59	78	60	
	Crack 1 Day	14	35	35	45	76	62	
	Crack 2 Day	0	0	17	19	34	34	
	Crack 3 Day	0	6	6	19	81	81	some cracks close in heat of day
	Moist Cure	0	8	50	50	50	50	cracks spalling
8	Dry Cure	29	29	46	76	277	277	cracks spalling
	Prime Cure	0	48	89	125	328	328	
	Crack 1 Day	31	62	62	92	92	62	
	Crack 2 Day	58	58	58	73	105	47	
	Crack 3 Day	80	80	80	80	88	8	
	Moist Cure	0	0	15	33	70	70	cracks spalling

\*This column is only the crack length of preventable cracks

1 foot = 0.305 m

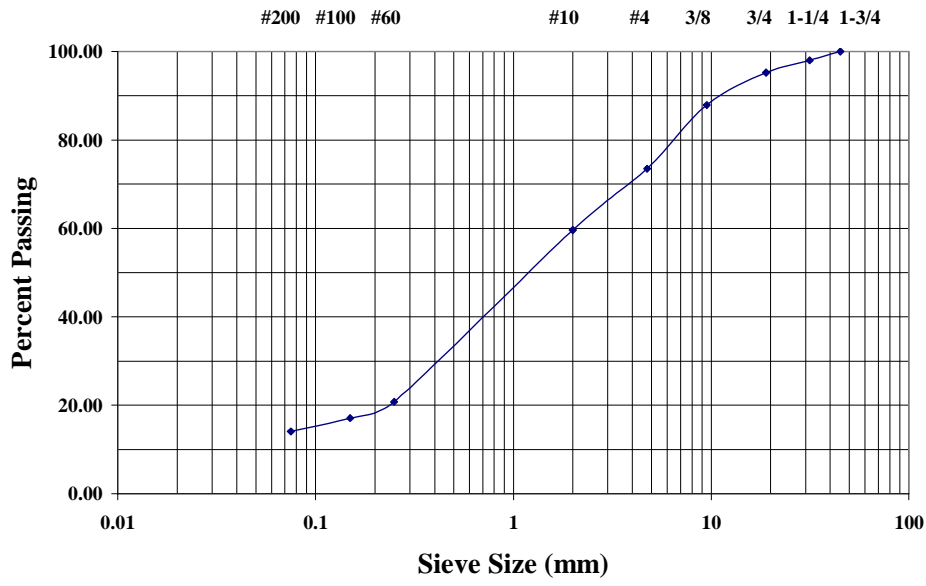


FIGURE 1 Gradation of Gravel Base used at Test Sites

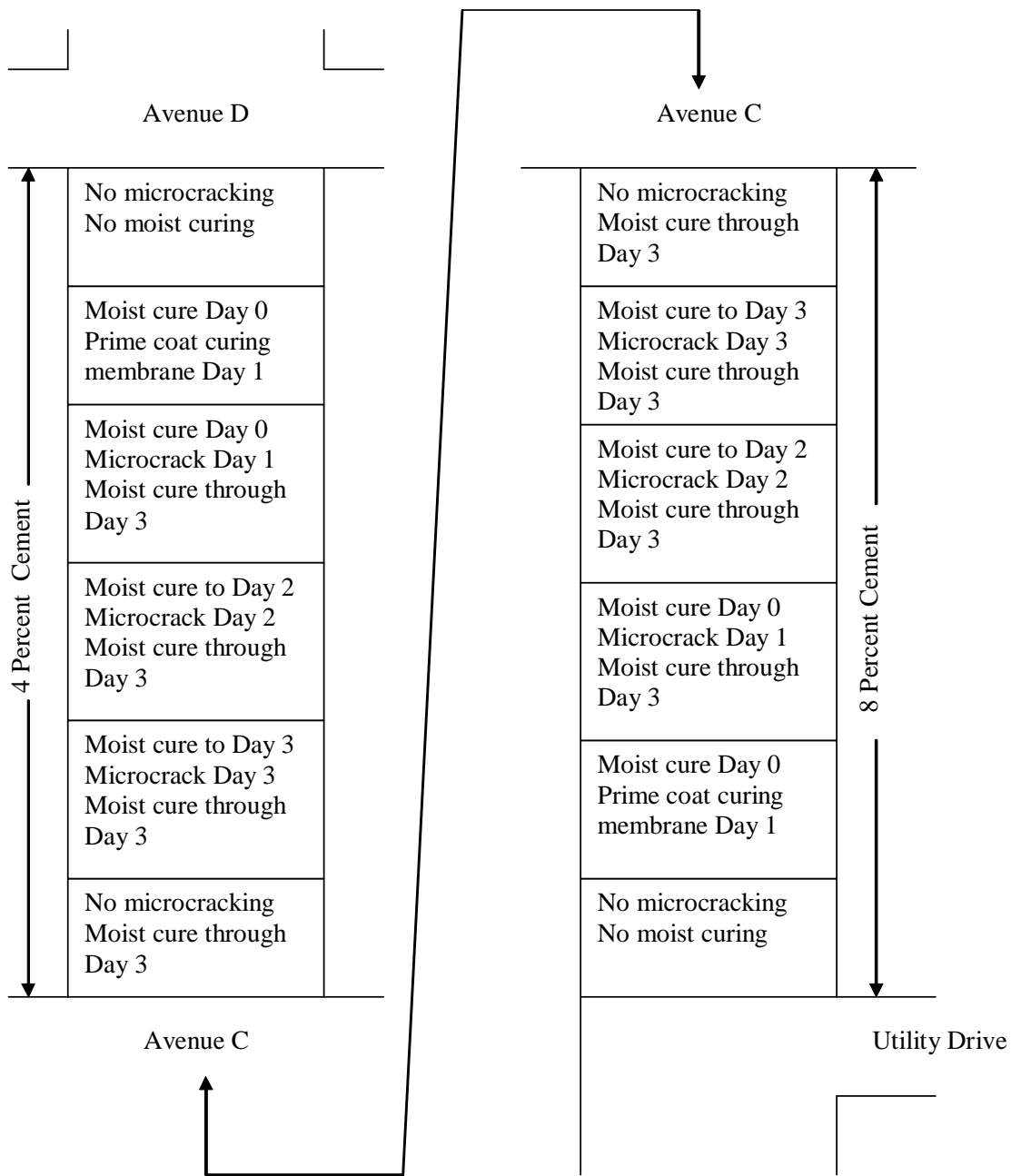


FIGURE 2 Layout of Test Sites

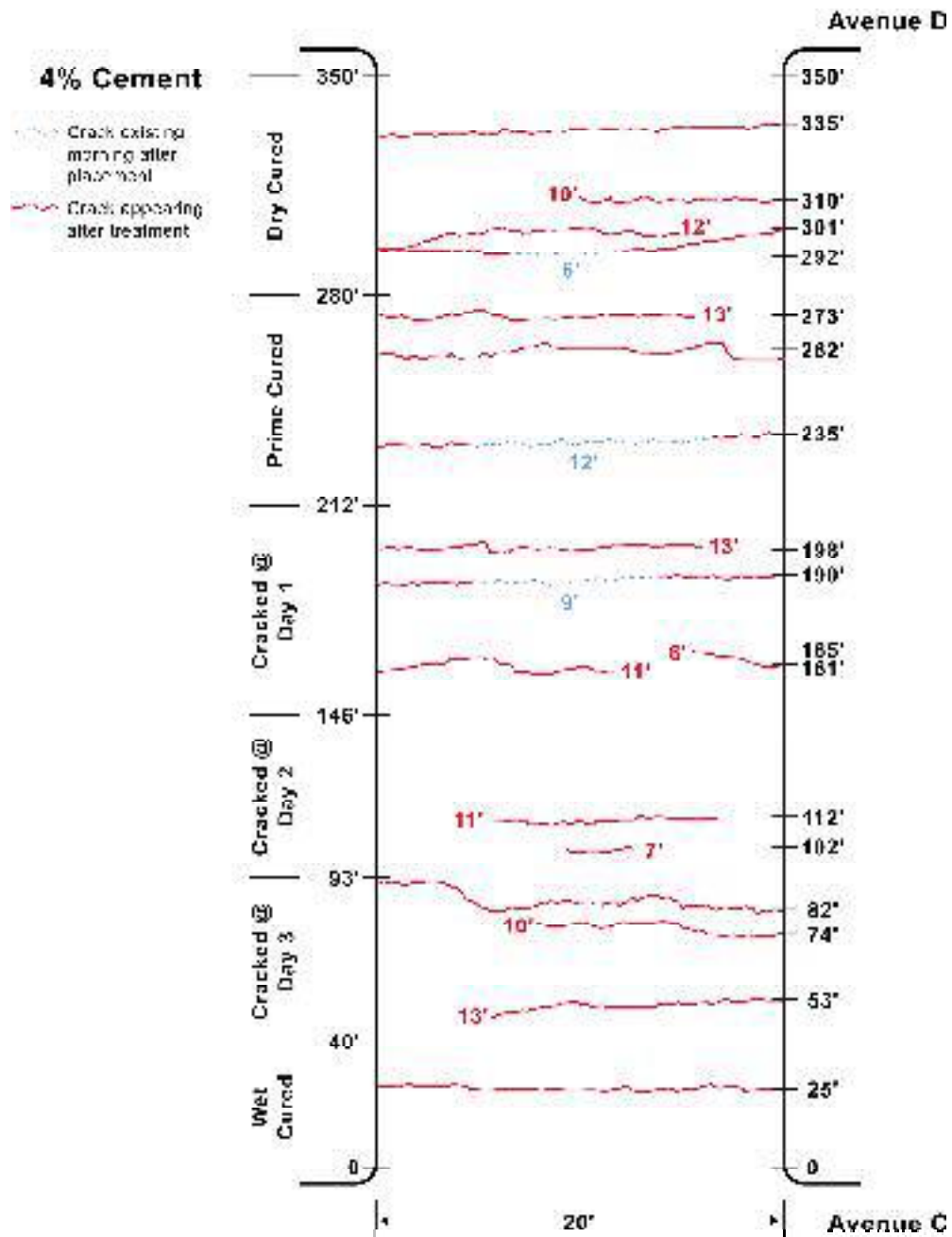


FIGURE 3 Crack Map of Site with 4 Percent Cement

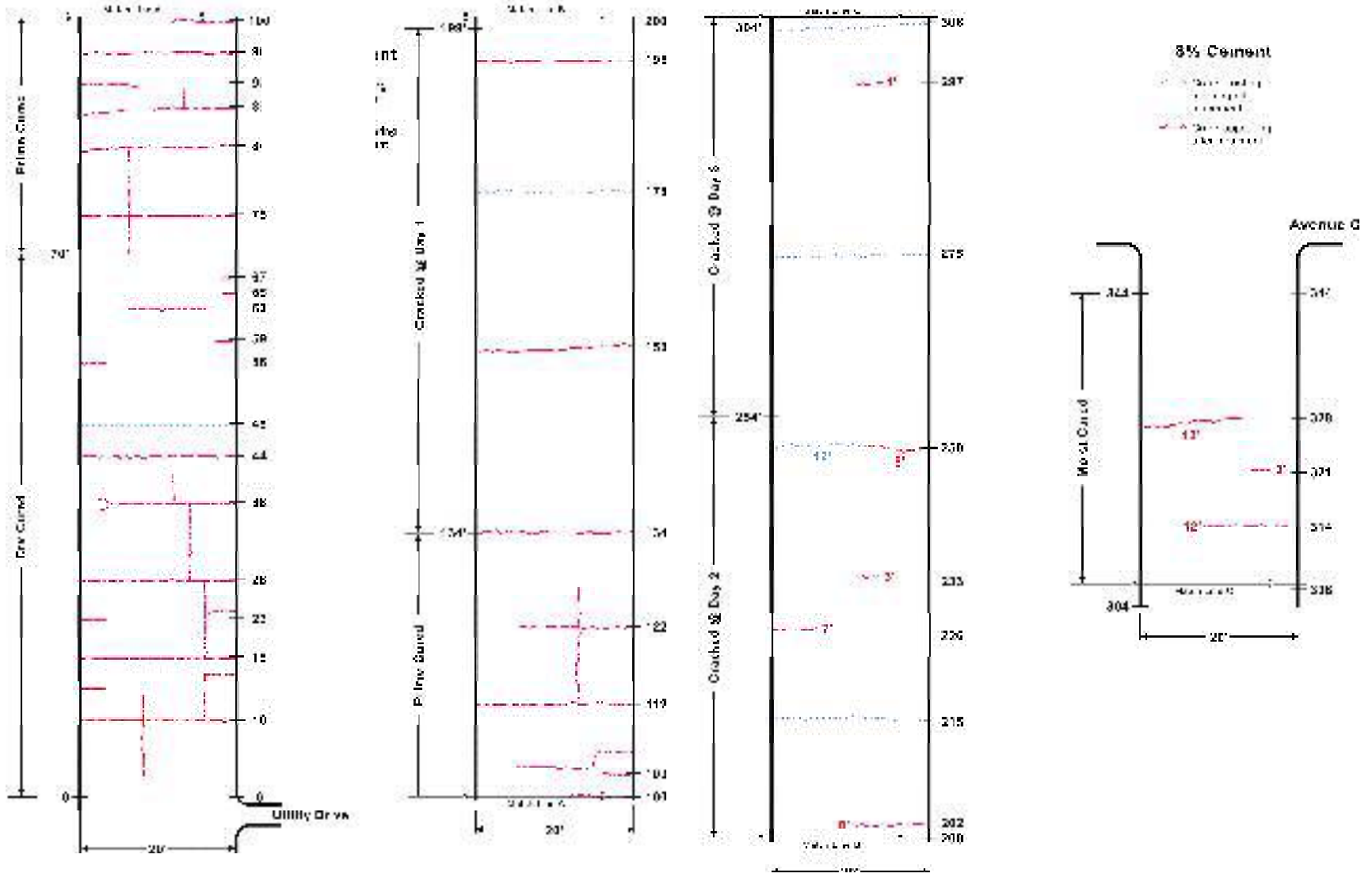


FIGURE 4 Crack Map of Site with 8 Percent Cement



**(a) Dry Cured**



**(b) Microcracked at 3 Days Cure**

**FIGURE 5 Worst (a) and Least (b) Severe Cracks in 4 Percent Cement Test Site**

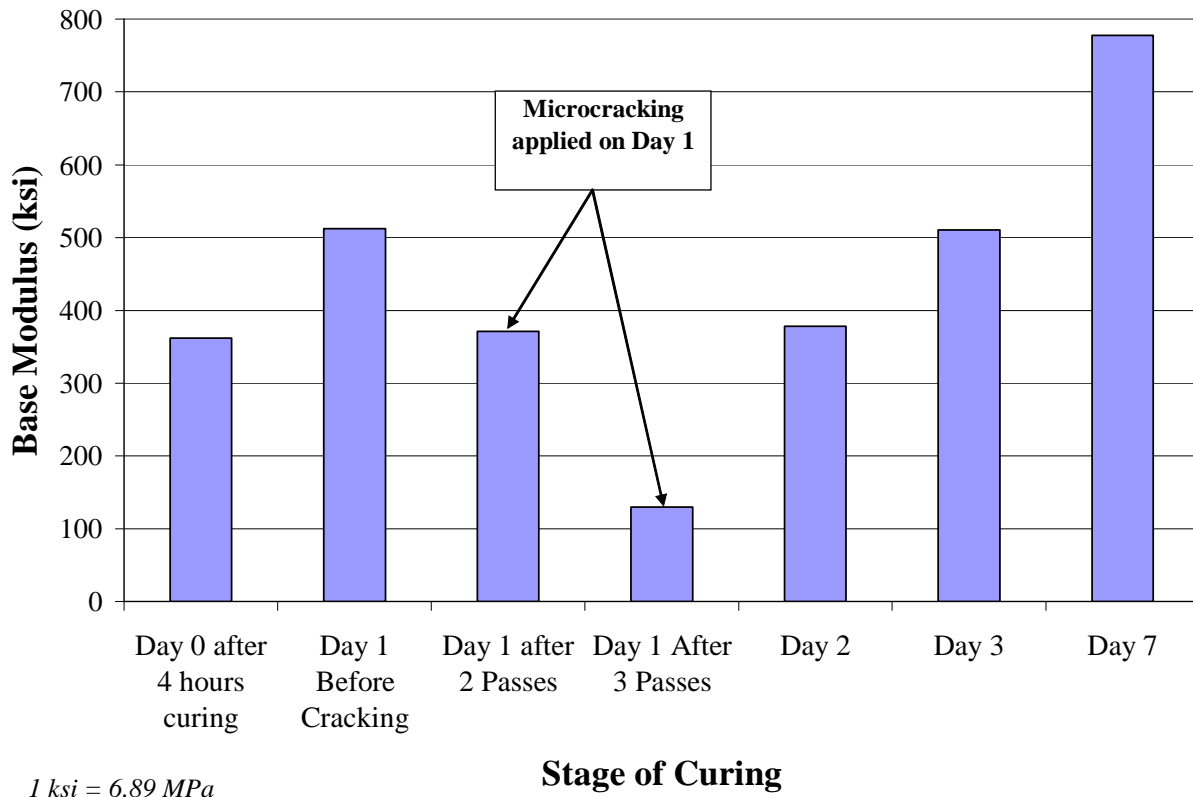


FIGURE 6 Typical Pattern of Base Modulus Changes with Microcracking

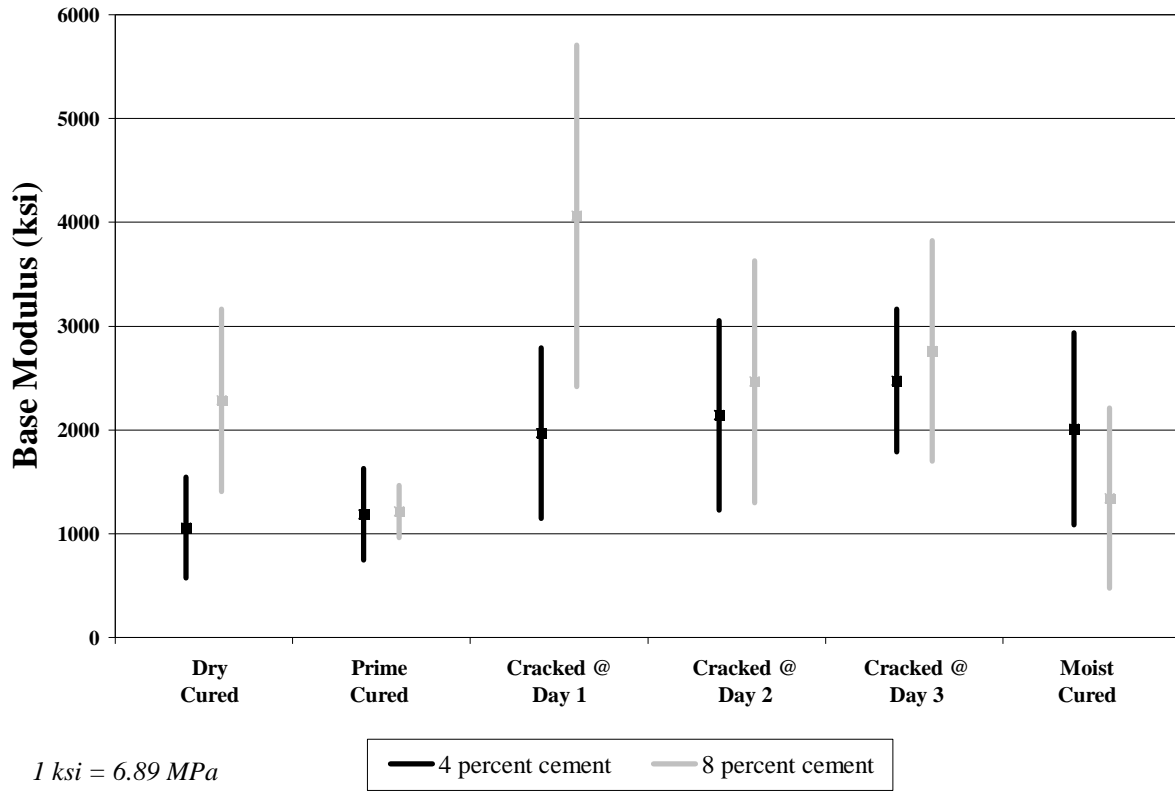
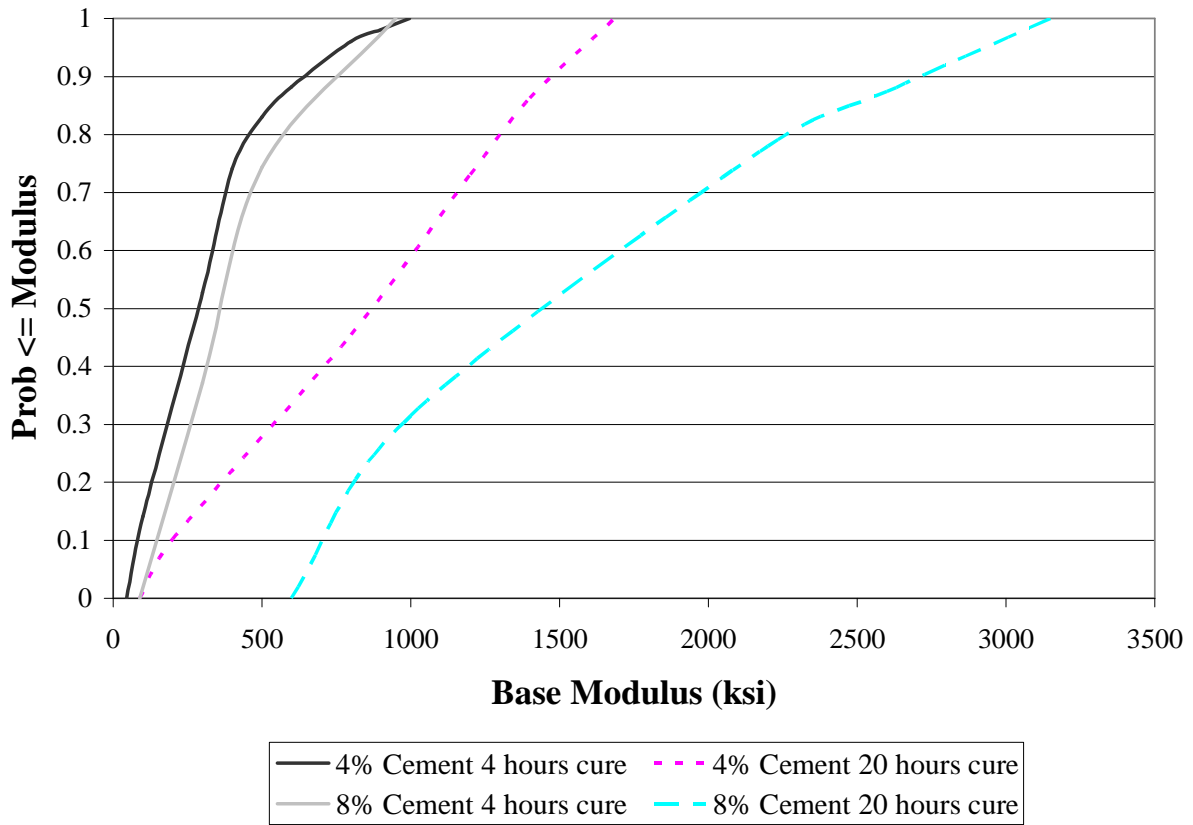


FIGURE 7 Average Base Moduli for Riverside Test Sites, June 2004



**FIGURE 8 Distributions of Base Moduli in Test Sites after 4 and 20 Hours Curing**