

# Investigation of Rutting Potential Using Static Creep Testing on Polymer-Modified Asphalt Concrete Mixtures

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In recent years, polymer-modified asphalt mixtures have been increasingly used in the construction of flexible pavements. These products have gained popularity because of their ability to increase pavement performance in both cold and hot environments. The increased elasticity from the polymer imparted to the mixtures at cold temperature increases the pavement's ability to resist thermal cracking. The increased stiffness, as well as the increased elasticity, of these mixtures at warm temperatures has shown an improved resistance to rutting. The increased resistance to rutting in warm climates was of particular interest for construction projects in the hot desert climate of southern Nevada. To investigate the potential benefits of these polymer-modified materials, the Nevada Department of Transportation (NDOT) placed six polymer-modified experimental test sections between Las Vegas, Nevada, and the Arizona border in December 1989. The University of Nevada, Reno, in conjunction with NDOT, developed a research program to rank the rutting potential of the various mixtures and the increased rutting potential in the presence of moisture. Conclusions from this research were that strains observed in creep testing depend on the location of instrumentation and boundary conditions imposed on the sample. Results showed that a ranking of the materials (lowest to highest strain) was the same for 8-in.-high samples instrumented over the center third or over full depth. A finite element analysis showed that the magnitude of strains observed depends on the area of instrumentation. End friction in the sample can give rise to substantial difference in the creep strain measurements made. Conclusions also indicate that the permanent strains after moisture conditioning appear to be a good indicator of possible moisture damage.

In recent years, polymer-modified asphalt mixtures have been increasingly used in the construction of flexible pavements. These products have gained popularity because of their ability to increase pavement performance in both cold and hot environments. The increased elasticity from the polymers imparted to the mixtures at cold temperature increases the pavement's ability to resist thermal cracking. The increased stiffness and increased elasticity of these mixtures at warm temperatures have improved resistance to rutting. The increased resistance to rutting in warm climates is particularly important for construction projects in the hot desert climate of southern Nevada.

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## RESEARCH PROGRAM

The objectives of the research program were to

1. Evaluate differences between the various polymer-modified mixtures;
2. Evaluate the impact of moisture on the rutting potential of the mixtures; and
3. Undertake a limited investigation of the impact of sample size and instrumentation location.

NDOT collected samples behind the paver from each of the six experimental test sections placed on I-15 between the Arizona state line and 5.3 miles east of the state line (toward Las Vegas). The variables between the test sections were limited to the binder; both the aggregate source and gradation remained constant.

Permanent deformation (i.e., creep) characteristics were measured using a static unconfined creep test currently under development for adoption by ASTM. Both 4-in.-diameter by 8-in.-high (typical triaxial cell size) samples and 4-in.-diameter by 2.5-in.-high (conventional mix design size) samples were prepared. Deformation was measured over both the full depth and center third of the 8-in. samples. The deformation of the 2.5-in. samples was measured over the full depth only.

The impact of moisture on the permanent deformation was evaluated using the Lottman accelerated conditioning procedure for only the 8-in. samples.

## MATERIALS USED IN CONSTRUCTION

The binders used in each of the sections were

- AR4000-R,
- AC-20-RL (L indicates low modifier content),
- AC-20-RH (H indicates high modifier content),
- AC-20-PM,
- AR4000-PM, and
- AC-20-P (control section).

AC-20-R was designated the control section because it is the product currently used by NDOT.

The modifiers used for each of the test sections were listed as proprietary; as of the writing of this paper, specific information has not been released.

The aggregate gradation met a Type II NDOT specification; this is similar to the ASTM D3515 dense-mixture specification of 3/4-in. maximum nominal size.

## SAMPLE PREPARATION AND TEST METHOD

### Sample Preparation

Loose-mix materials were sampled by NDOT during construction and delivered to the university in sealed canisters. This material was reheated and split into individual 1,100-g samples. Each sample was then reheated to 230°F for 2 hr prior to compaction. All samples were compacted with a California kneading compactor using sufficient compactive effort (30 blows at 250 psi) to produce samples with air voids between 6 and 8 percent.

The 8-in. samples were compacted in three lifts of 1,100-g batches placed consecutively on top of each other. Approximately 2.5 in. of the sample was built with each lift. Each lift received the same compactive effort (30 blows at 250 psi). After compaction, samples were placed in a 140°F oven for 1½ hr prior to the application of a 5,000-lb leveling load.

The 2.5-in samples (conventional mix design size) consisted of one 1,100-g batch compacted with 30 blows at 250 psi before being placed in a 140°F oven for 1½ hr prior to the application of a 11,600-lb leveling load.

All samples, regardless of size, were extruded and cooled to 77°F. The heights and bulk specific gravities were then determined according to ASTM D3549 and D2726, respectively.

### Creep Testing

The creep test selected was a uniaxial, static, unconfined test. A Satec "Cats" closed-loop system was used for all creep tests. The testing setup for 2.5-in. and 8-in. samples is shown in Figure 1. Sample ends were well greased with a graphite-based lubricant prior to the seating of the loading platens in order to reduce friction between the sample and the platen.

All tests consisted of a static preconditioning followed by a static load. Preconditioning consisted of the application of a 628.5-lb (50-psi) step load for 2 min followed by a 5-min rest period. Testing started immediately at the end of this rest period and consisted of another 628.5-lb (50-psi) static step load applied for 60 min. This step was followed by a 15-min rest period to allow for elastic recovery. Vertical deformations were measured continuously for all samples, but the location of instrumentation varied for the different sample sizes. All samples were tested at 77°F.

The 2.5-in. samples were instrumented over the entire height of the sample with two linear variable differential transducers (LVDTs) placed 180 degrees apart (Figure 1 (top)). These deformations were electronically averaged and recorded every 60 sec throughout the test.

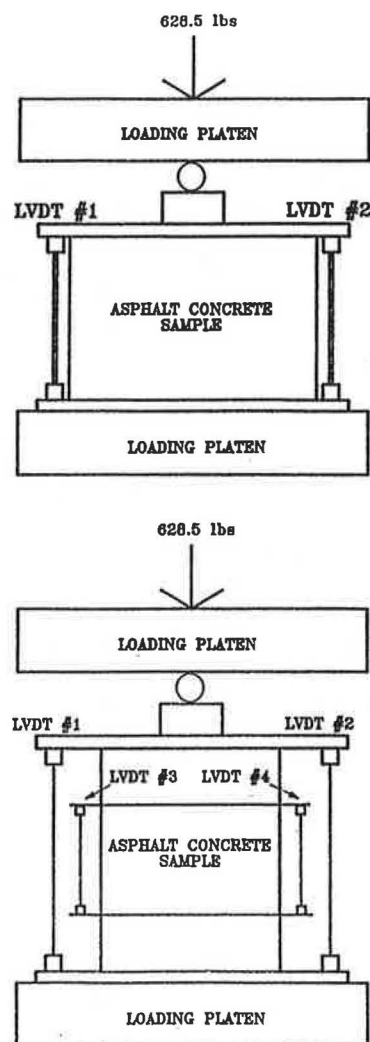


FIGURE 1 Test setup for conventional (top) and unconventional (bottom) size samples.

The 8-in. samples were instrumented in two locations: (a) over the entire height of the sample, and (b) over the center 3 in. In each location, the deformations were measured on both sides of the sample, 180 degrees apart (Figure 1 (bottom)). These deformations were electronically averaged and recorded every 60 sec throughout the test.

The data were then used to calculate compressive strains over the instrumented length:

$$\epsilon(t) = [(d(t)/H_o)]$$

where

$\epsilon(t)$  = strain at time  $t$ , in./in.;

$H_o$  = original height of the sample or gauge length, in.; and

$d(t)$  = deformation over the instrumented length at time  $t$ , in.

This equation was used for both unconditioned and moisture-conditioned samples.

## Moisture Conditioning

Selected samples were moisture conditioned consistent with Lottman's procedure for accelerated conditioning used to determine the retained strengths of asphalt concrete materials (1). Briefly, this procedure consists of immersing the samples in water and applying a vacuum of 24 in. Hg for 10 min to achieve a minimum of 90 percent saturation. Samples are wrapped in plastic and placed in a 0°F freezer for a minimum of 15 hr. Samples are then unwrapped and transferred to a 140°F water bath for  $24 \pm 0.5$  hr and immediately placed in a 77°F water bath for 2 hr in order to cool to test temperature.

## TESTING PROGRAM

A total of seven samples from each of the six test sections were prepared: three 8-in. samples were tested unconditioned, two 8-in. samples were tested after moisture conditioning, and two 2.5-in. samples were tested unconditioned. The number of samples was restricted because of the limited quantity of material on hand. Although the number of samples was not ideal, sufficient data were obtained to estimate standard deviation, variance, and coefficient of variation as well as to evaluate the differences between the binders.

## ANALYSIS OF UNCONDITIONED TEST RESULTS

### 8-in. Samples

#### *Instrumented over the Full Depth*

Typical test results over the duration of both the loading and unloading period are shown in Figure 2. The ranking (lowest to highest permanent deformation) of the various materials was as follows:

Binder	Avg Permanent Strain
AC-20-RL	0.002636
AC-20-RH	0.003166
AR4000-R	0.005519
AC-20-PM	0.008942
AC-20-P (Control)	0.011277
AR4000-PM	0.011364

It appears that AC-20-RL and AC-20-RH behave similarly. It also appears that AC-20-RL and AC-20-RH and AR4000-R could be expected to exhibit less rutting in the field than either AC-20-P or AR4000-PM.

For the 8-in. samples instrumented over the full depth, within-sample set variance was calculated and an average variance was determined (Table 1). The resulting within-sample set standard deviation (i.e., square root of the average variance) was 0.002175 strain.

#### *Instrumented over the Center Third*

The typical data collected over the duration of both the loading and unloading period are shown in Figure 3. The data recorded over the center third for a set of three samples of the same material are much more variable than those recorded

over the full depth. After an examination of the test setup, it was concluded that the method of mounting the third-point LVDTs made the electronics sensitive to both machine vibrations and drafts. The impact from drafts can be seen in the discontinuity of the one line; this phenomenon was evident once in most of the sets of three. Therefore, for the analysis, the data with this discontinuity were removed from the data base.

The ranking (lowest to highest permanent deformation) of the various materials for the remaining set of two samples was as follows:

Binder	Avg Permanent Strain
AC-20-RL	0.001785
AC-20-RH	0.002263
AR4000-R	0.003529
AC-20-PM	0.004844
AC-20-P (Control)	0.009385
AR4000-PM	0.010131

This ranking is identical to that obtained for the full-depth instrumentation, even with the increased fluctuation of the third-point readings. The conclusions are also similar: the AC-20-RL and AC-20-RH behave similarly, and the AC-20-RL and AC-20-RH, and the AR4000-R could be expected to exhibit less rutting in the field than either the AC-20-P or the AR4000-PM.

For the 8-in. samples instrumented over the center third, within-sample set variance was calculated and an average variance was determined (Table 2). Only two of the three samples tested were instrumented over the center third. The resulting within-sample set standard deviation (i.e., square root of the average variance) was 0.002799 strain.

### 2.5-in. Samples

#### *Instrumented over the Full Depth*

For the 2.5-in. samples instrumented over the full depth, within-sample set variance was calculated and an average variance was determined (Table 3). Graphical representation of a typical set of samples is shown in Figure 4. The resulting within-sample set standard deviation (i.e., square root of the average variance) was 0.000889 strain. The ranking (lowest to highest permanent deformation) of the various materials was as follows:

Binder	Avg Permanent Strain
AC-20-P (Control)	0.001924
AR4000-R	0.002574
AR4000-PM	0.003272
AC-20-RL	0.003507
AC-20-RH	0.003514
AC-20-PM	0.004243

The ranking of lowest to highest permanent deformation is considerably different from that obtained from either method of instrumenting the 8-in. samples. The AC-20-P and the AR4000-PM mixtures exhibited the most deformation when 8-in. samples were tested and the lowest strains when 2.5-in. samples were used. The AC-20-RL, AC-20-RH, and the AR4000-R exhibited essentially identical permanent deformation characteristics when the 2.5-in. samples were used for testing.

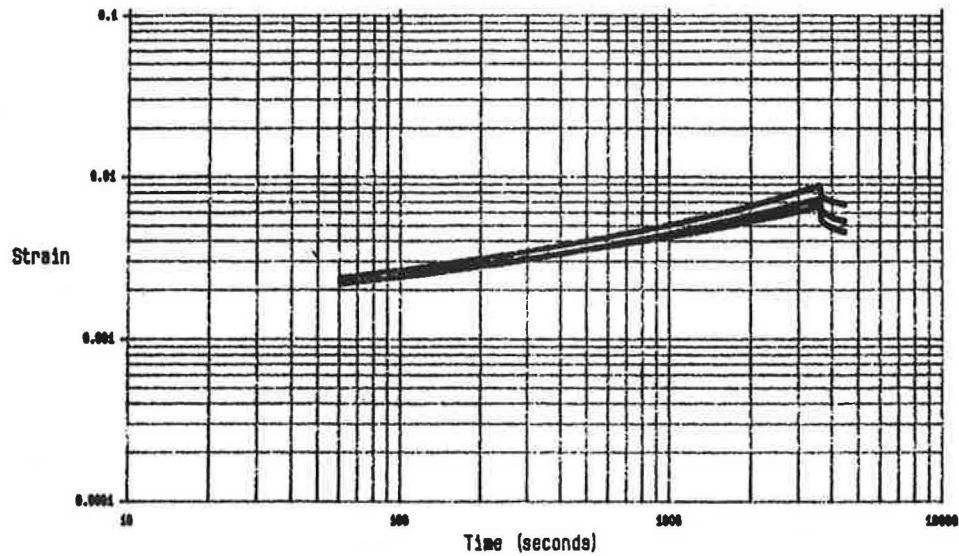


FIGURE 2 Graphical representation of typical set of three unconventional samples, full-depth strain.

TABLE 1 STATISTICAL ANALYSIS OF PERMANENT DEFORMATION FROM 8-in. SAMPLES, FULL-DEPTH STRAIN

Sample Set	Test Number			Ave. Perm. Strain	Variance	Standard Deviation
	1	2	3			
AR4000-R	0.005286	0.006727	0.004545	0.005519	1.23E-06	0.001109
AC-20-RL	0.003920	0.002911	0.002669	0.003166	4.40E-07	0.000663
AC-20-RH	0.000684	0.003314	0.003911	0.002636	2.95E-06	0.001716
AC-20-PM	0.004957	0.008993	0.012877	0.008942	1.57E-05	0.003960
AR4000-PM	0.008019	0.011110	0.014964	0.011364	1.21E-05	0.003479
AC-20-P	0.009452	0.010769	0.013610	0.011277	4.52E-06	0.002125
AVERAGE				0.007151	6.15E-06	0.002175

TABLE 2 STATISTICAL ANALYSIS OF PERMANENT DEFORMATION FROM 8-in. SAMPLES, CENTER THIRD STRAIN

Sample Set	Test Number		Ave. Perm. Strain	Variance	Standard Deviation
	1	2			
AR4000-R	0.003016	0.004042	0.003529	5.26E-07	0.000725
AC-20-RL	0.002427	0.001143	0.001785	8.24E-07	0.000907
AC-20-RH	0.002540	0.001987	0.002263	1.53E-07	0.000391
AC-20-PM	0.003261	0.006427	0.004844	5.01E-06	0.002238
AR4000-PM	0.006013	0.014249	0.010131	3.39E-05	0.005823
AC-20-P	0.004641	0.014129	0.009385	4.50E-06	0.006709
AVERAGE			0.005322	1.42E-05	0.002799

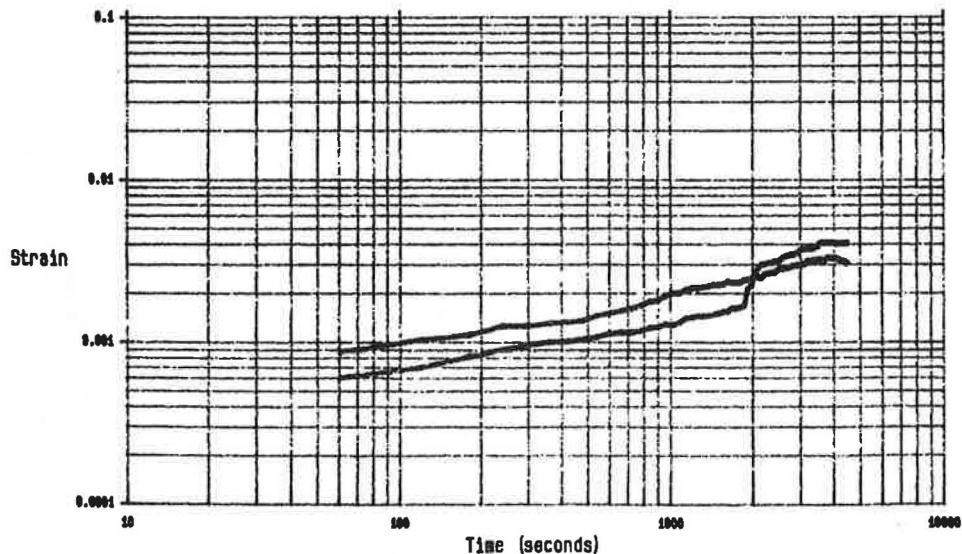


FIGURE 3 Graphical representation of typical set of two unconventional samples, center third strain.

TABLE 3 STATISTICAL ANALYSIS OF PERMANENT DEFORMATION FROM 2.5-in. SAMPLES, FULL-DEPTH STRAIN

Sample Set	Test Number		Ave. Perm. Strain	Variance	Standard Deviation
	1	2			
AR4000-R	0.002045	0.003103	0.002574	5.60E-07	0.000748
AC-20-RL	0.004154	0.002661	0.003407	1.11E-06	0.001055
AC-20-RH	0.002707	0.004321	0.003514	1.30E-06	0.001141
AC-20-PM	0.004127	0.004360	0.004243	2.71E-08	0.000164
AR4000-PM	0.003354	0.003191	0.003272	1.33E-08	0.000115
AC-20-P	0.000429	0.003419	0.001924	4.47E-06	0.002114
AVERAGE			0.003155	1.25E-06	0.000889

### Comparison of Test Results for the Two Sample Sizes

While instrumenting an 8-in. sample over either the full depth or the center third generates the identical ranking of the materials, testing the 2.5-in. samples generates a completely different, almost reverse, ranking. Historically, the height-to-width ratio of axially compressed specimens has been 2:1 because of the effect of end constraints. Based on this information, an assumption was made that the testing from the 8-in. samples would generate the more accurate reflection of relative ranking of the material. Once this decision was made, the impact of end constraint influence on the deformation measurements over both the full depth and the center third of the sample needed to be assessed. A finite element method was chosen to perform this analysis.

### FINITE ELEMENT ANALYSIS OF 8-in. SAMPLE

A preliminary investigation into the effects on nonuniform stress/strain field in the 8-in. sample using the finite element

method was undertaken. If the stress/strain conditions developed under the imposed loading are uniform within the sample, the strain results from both measurements (full depth and center 3 in.) should be the same. When the asphalt concrete sample is axially loaded using the closed-loop testing system, the stresses and strains developed at various points in the sample vary depending on the boundary conditions at the top and bottom of the sample. The nonuniform stress/strain field in the sample may be responsible for the difference in strain measurements obtained for the whole sample and at the middle of the sample. A preliminary investigation using the finite element method into the nonuniform stress/strain field in the sample is presented below.

### Finite Element Description and Loading

Different boundary conditions between the sample and the top and bottom loading plates can exist. They are

1. No-slip interface condition (Case 1),
2. Smooth interface condition (Case 2), and
3. Partial slip at the interfaces (Case 3).

The third case can be viewed as an intermediate condition between Case 1 and Case 2. Though a coating of lubricant is used at the top and bottom of the sample, smooth interface conditions may not be present. The stress/strain field developed under all three boundary conditions can be calculated using the finite element method.

The finite element method has been successfully used in many engineering problems to evaluate stresses, strains, and deformations of bodies subjected to loading. This method is a very effective tool because it takes into account the variability in the geometry and properties of the materials and the

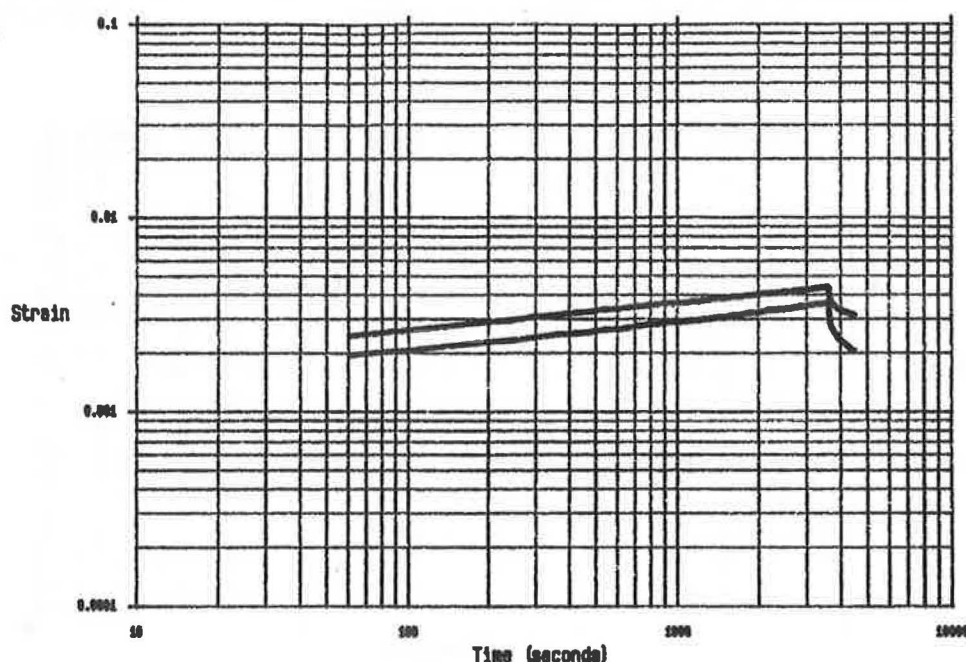


FIGURE 4 Graphical representation of typical set of three conventional samples, full-depth strain.



various boundary conditions. In this method, the entire domain of interest is assumed to be an assembly of a finite number of elements that are connected at the nodal points. By assuming a reasonable variation for displacements within an individual element, it is possible to generate a load-displacement relationship for the entire domain.

A widely used finite element-based program, IMAGES-3D (2), was used to analyze the sample behavior under axial loading with the three types of boundary conditions. The axisymmetric finite element discretization and the boundary conditions are shown in Figures 5 and 6. The entire sample was divided into 580 elements of 0.25 in.  $\times$  0.1 in. in size. In Case 1 (see Figure 6) the bottom nodes have freedom to move only vertically, thus simulating a no-slip condition at the interface. At the top face, the nodes are fixed. In Case 2, the top and bottom nodes are free to move without resistance (smooth condition) in the radial direction. On the other

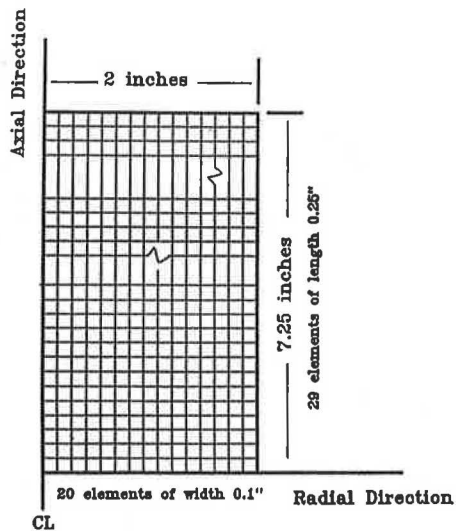


FIGURE 5 Axisymmetric finite element discretization (580 elements, 630 nodes).

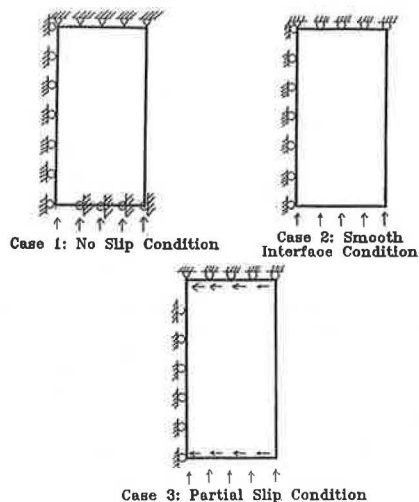


FIGURE 6 Boundary conditions used with the finite element analysis.

hand, the third case represents partial slip in which the interface resistance is obtained by multiplying the applied pressure by the coefficient of friction ( $\mu$ ). A value of 0.1 was used in this paper. Material properties in terms of Young's modulus ( $E$ ) and Poisson's ratio ( $\nu$ ) are necessary to use the finite element program. Representative values of  $E = 300,000$  psi and  $\nu = 0.35$  were used. Table 4 gives sample properties and loading used in the computer runs. In all cases, a vertical pressure of 50 psi was applied at the bottom face.

### Analysis of Finite Element Method Results

The IMAGES-3D program gives displacements at the nodes and stresses and strains at the middle of the elements. The nodal displacements can be used to compute average strains in the sample between any two points. The overall compressive strain in the sample ( $\epsilon_z$ )<sub>s</sub> can be calculated using

$$(\epsilon_z)_s = [(u_{top})_{ave} - (u_{bot})_{ave}]/L$$

where  $(u_{top})_{ave}$  and  $(u_{bot})_{ave}$  are the average vertical displacements at the top and bottom of the sample, and  $L$  is the sample length. A similar procedure can be adopted to compare compressive axial strain at the middle of the sample,  $(\epsilon_z)_m$  using displacements given by the program at two points separated by 3 in. near the middle of the sample. These strain values are shown in Table 5 for all three cases considered in the study. Using the element strain data, it is possible to evaluate the range of maximum and minimum principal normal strains and shear strains in the sample. These values are also shown in the table.

A number of observations can be made from the results in the table. In Case 2 (smooth interface), the strain field in the

TABLE 4 SAMPLE PROPERTIES AND LOADING

Sample Size	
Sample Length	7.25 inches
Sample Radius	2 inches
Material Properties	
Young's Modulus	300,000 psi
Poisson's Ratio	0.35
Loading	
Vertical Pressure	50 psi
Coefficient of Friction	0.1

TABLE 5 RESULTS FROM FINITE ELEMENT ANALYSIS

Computed Strain Response	Case #1	Case #2	Case #3
Axial Compression for Whole Sample (ave.) (10 <sup>-6</sup> m/m)	162	167	165
Axial Compressive Strain at Middle of Sample (ave.) (10 <sup>-6</sup> m/m)	173	167	170
Range of Maximum Principal Strain (10 <sup>-6</sup> m/m)	99 to 185	167 to 167	128 to 176
Range of Minimum Principal Strain (10 <sup>-6</sup> m/m)	-7 to -74	-58 to -58	-22 to -62
Range of Maximum Principal Shear Strain (10 <sup>-6</sup> m/m)	266 to 107	225 to 225	237 to 153

Computed Normal Strain is Considered Positive

sample is uniform and therefore gives identical results for strains computed based on end displacements and those computed using the middle-of-sample displacements. However, there are differences between the strain values in the other two cases (Cases 1 and 3). The difference is within 6.8 percent. Larger compressive strains are obtained when using the middle-of-sample displacements. It should be noted that Case 3, which is a partial friction case, gives results between Case 1 (no slip) and Case 2 (smooth) in all categories.

The range of principal strains (normal and shear) gives a measure of the nonuniformity. In Case 2, the strain field is again uniform, while Cases 1 and 3 give nonuniform strain field. The ranges obtained for strain values in Cases 1 and 3 are quite wide. For example, in Case 1, the maximum principal shear strain range is 107 to 266  $\mu$ . In other words, the strain difference between any two points in the sample can differ by as much as 2.5 times. In Case 3, which may be a more realistic representation of the testing conditions, the difference is within 1.6 times.

It is clear from the finite element studies that the nonuniform stress conditions can be present if smooth sample end conditions do not exist. However, though friction may be present, the analysis indicates that the compressive strains obtained for the whole and middle of the sample differ only by a small percentage. It should be recalled that the finite element analysis is based on linear-elastic properties for asphalt concrete. It may be argued that viscoelastic behavior in the asphalt concrete may be responsible for the difference in strain measurements. Though asphalt concrete is viscoelastic, the behavior immediately after the application of the load is linear elastic.

It should be noted that the creep behavior monitored long after the load application can result in much different strain measurements for the whole sample and middle of the sample. This is because the creep behavior, which is mainly a time-varying shear behavior (3), varies from point to point in the sample. The difference in shear behavior is brought on by the nonuniform shear strain field present in the sample. The strain obtained for the whole sample is caused by creep behavior of the entire sample; the strain in the middle is caused by creep behavior of the middle region. This is why the difference in strain measurements is not uniform from the start to finish of the creep sample.

#### ANALYSIS OF MOISTURE-CONDITIONED TEST RESULTS

Previous research conducted for NDOT (4) showed that moisture sensitivity, a typical problem for Nevada mixtures, could contribute to increased permanent strain. Because of the limited amount of materials, only 8-in. samples were tested after moisture conditioning. Two samples from each of the six experimental test sections were subjected to moisture conditioning before testing. The resulting data for the full depth and the center 3 in. are shown in Tables 6 and 7. To reduce the number of variables in the experiment, the method of instrumentation, load, and temperature were consistent with the unconditioned data base.

TABLE 6 STATISTICAL ANALYSIS OF PERMANENT DEFORMATION FROM 8-in. SAMPLES, MOISTURE-CONDITIONED, FULL-DEPTH STRAIN

Sample Set	Test Number		Ave. Perm. Strain	Variance	Standard Deviation
	1	2			
AR4000-R	0.009810	0.006646	0.008228	5.01E-06	0.002237
AC-20-RL	0.008715	0.008661	0.008688	1.09E-09	0.000033
AC-20-RH	0.007116	0.007533	0.007324	6.25E-08	0.000255
AC-20-PM	0.009108	0.009304	0.009206	1.92E-08	0.000138
AR4000-PM	0.008611	0.007532	0.008071	4.37E-07	0.000660
AC-20-P	0.010328	0.006149	0.008238	8.73E-06	0.002954
AVERAGE			0.008292	2.38E-06	0.001046

TABLE 7 STATISTICAL ANALYSIS OF PERMANENT DEFORMATION FROM 8-in. SAMPLES, MOISTURE-CONDITIONED, CENTER THIRD STRAIN

Sample Set	Test Number		Ave. Perm. Strain	Variance	Standard Deviation
	1	2			
AR4000-R	0.011839	0.005497	0.008668	2.01E-05	0.004484
AC-20-RL	0.008728	0.006487	0.007607	1.88E-06	0.001372
AC-20-RH	0.005263	0.005550	0.005406	3.09E-08	0.000175
AC-20-PM	0.006491	0.009632	0.008061	4.93E-06	0.002221
AR4000-PM	0.006504	0.007432	0.006968	3.23E-07	0.000568
AC-20-P	0.007686	0.004670	0.006178	4.55E-06	0.002132
AVERAGE			0.007148	5.30E-06	0.001825

#### Instrumented Over the Full Depth

After moisture conditioning, the ranking of the mixtures was as follows:

Binder	Avg Permanent Strain
AC-20-RH	0.007324
AR4000-PM	0.008071
AR4000-R	0.008228
AC-20-P (Control)	0.008238
AC-20-RL	0.008688
AC-20-PM	0.009206

Although the ranking has changed from the unconditioned test results, there is so little variation between the results that there is essentially no difference between the permanent deformation characteristics of the mixtures. Therefore, all mixtures could be expected to exhibit similar rutting distress in the presence of moisture. Previous research has shown that the permanent deformation characteristics after moisture conditioning vary greatly between construction projects; therefore it is hypothesized that the "stripping" potential of the aggregate, not the binder, is the governing factor. Therefore, mixtures prepared with the same aggregate source and gradation, but with different binders, could be expected to exhibit similar permanent deformation characteristics after moisture conditioning.

The within-sample set variance for full-depth and center third instrumentation was calculated and an average variance was determined. The resulting standard deviations were 0.001046 and 0.001825, respectively.

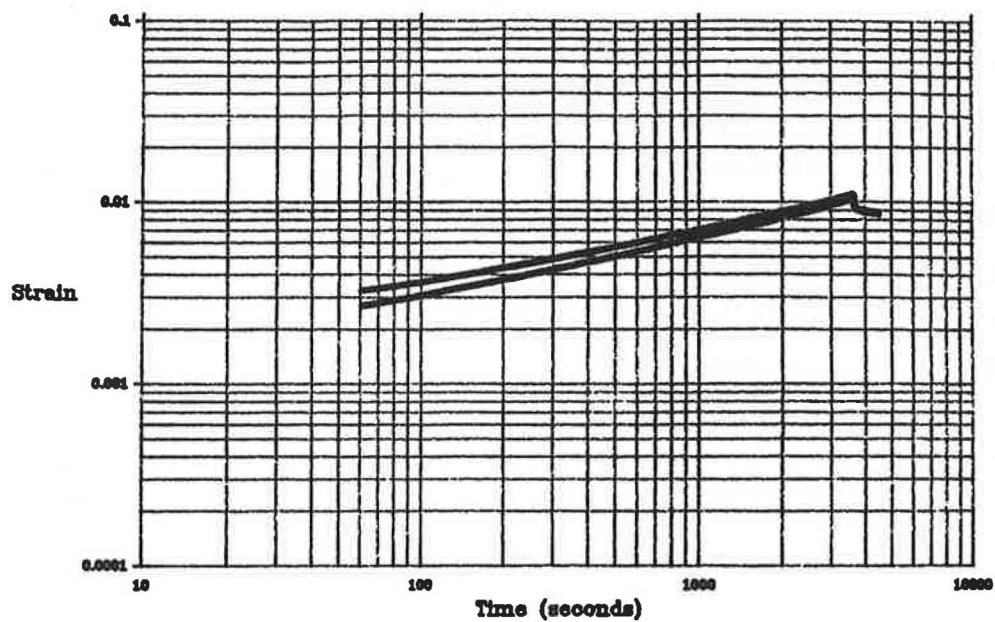


FIGURE 7 Graphical representation of typical conditioned unconventional samples, full-depth strain.

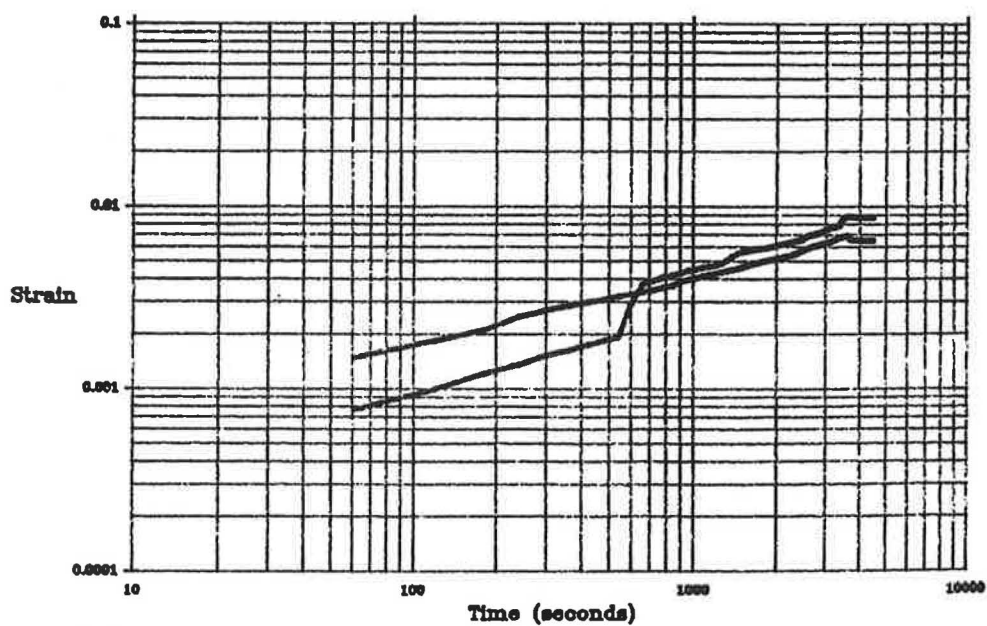


FIGURE 8 Graphical representation of typical unconventional samples, center third strain.



Figures 7 and 8 show typical ranges of data for each area of instrumentation (full depth and center 3 in.). Again, the discontinuity occurring on one of the center third data sets can be seen.

### Instrumented Over the Center Third

After moisture conditioning, the ranking of the mixtures was:

Binder	Avg Permanent Strain
AC-20-RH	0.005406
AC-20-P (Control)	0.006178
AR4000-PM	0.006968
AC-20-RL	0.007607
AC-20-PM	0.008061
AR4000-R	0.008668

Although the ranking has changed from both the full-depth instrumentation and the unconditioned test center point results, there is still little variation between the results.

The within-sample set variance for full-depth and center third instrumentation was calculated and an average variance was determined. The resulting standard deviations were 0.001825 and 0.002799, respectively.

### CONCLUSIONS

The following conclusions can be drawn:

1. The ranking of lowest to highest permanent strain for the various binders used in this project was the same for 8-in. samples instrumented over either the full depth or the center third of the sample.
2. There was no correlation between the relative ranking obtained from the 8-in. and the 2.5-in. data.
3. The finite element analysis of the 8-in. sample configuration showed that:

- The strains observed in creep testing depend on the location of instrumentation and boundary conditions imposed on the sample; and

- The presence of friction at the ends can result in nonuniform stress/strain fields in the sample. The end friction can give rise to a substantial difference in creep strain measurements made at the ends (full depth) and center of the sample.

4. Moisture conditioning the 8-in. specimens and then determining the permanent deformation resulted in a fairly consistent permanent deformation for all mixtures, regardless of binder.

5. The research conducted in this program consisted of a very small data base because of the limited availability of material. Future research should be conducted to confirm any conclusions suggested here.

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