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THE EFFECTS OF CRUSHED PARTICLES IN ASPHALT MIXTURES

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Iowa Department of Transportation
Research Project MLR-88-16
and Research Project HR-311

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Highway Division
Iowa Department of Transportation

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DISCLAIMER

ABSTRACT

One of the most serious impediments to the continued successful use of hot mix asphalt (HMA) pavements is rutting. The Iowa Department of Transportation has required 85% crushed particles and 75 blow Marshall mix design in an effort to prevent rutting on interstate roadways. The objective of this research and report is to develop relationships between the percent of crushed particles and resistance to rutting in pavement through the use of various laboratory test procedures.

HMA mixtures were made with 0, 30, 60, 85 and 100% crushed gravel, crushed limestone and crushed quartzite combined with uncrushed sand and gravel. These aggregate combinations were used with 4, 5 and 6% asphalt cement (ac).

Laboratory testing included Marshall stability, resilient modulus, indirect tensile and creep. A creep resistance factor (CRF) was developed to provide a single numeric value for creep test results. The CRF values relate well to the amount of crushed particles and the perceived resistance to rutting. The indirect tensile test is highly dependent on the ac with a small effect from the percent of crushed particles. The Marshall stability from 75 blow compaction relates well to the percent of crushed particles. The resilient modulus in some cases is highly affected by grade of ac.

INTRODUCTION

Hot mix asphalt concrete has been used to produce high quality pavements for both high and low volume roadways. Approximately 94% of the paved roads in the United States are asphalt surfaced. Properly designed and constructed, the asphalt pavements have provided smooth, durable roads and streets.

In recent years, rutting of HMA pavements on high truck volume roadways has resulted in premature failure and the need for rehabilitation or reconstruction. On the other hand, some roadways constructed of HMA have carried large volumes of truck traffic with very little rutting. Severe rutting on high volume interstate HMA pavements has caused some concern as to whether HMA is an appropriate construction material for these roadways. Rutting is a major impediment to the continued successful use of HMA pavements. The fact that some HMA pavements have performed well on high volume interstate roadways leads the authors to believe that with the proper specifications, materials, design and construction HMA can be used on high volume roads without rutting.

Some people seem to believe that using a harder grade of ac will increase the capacity of a HMA pavement to carry load. Even AC 20, a hard ac, will not retain its shape at room temperature (70°F), but will plastic flow. Without aggregate, the AC 20 will not support a load of significant magnitude without deformation.

In recent years, the Iowa DOT has specified a minimum of 85% crushed particles including a 75 blow Marshall design in HMA used on interstate roadways in an effort to reduce the problem of rutting (1, 2, 3). A general review of projects with increased percent of crushed particles would indicate that they are not as prone to rutting. The increased amount of crushed particles has resulted in some change in the contractor's operation. To obtain density, the compaction rolling has been moved closer to the laydown machine and 40,000 pound and higher rubber roller weights are being used. In general, these 85% crushed particle HMA mixtures have been very effective in resisting rutting. Unfortunately, there is very little research available relating % of crushed particles, current test results and actual field performance.

OBJECTIVE

The objective of this research and report is to develop relationships between the percent of crushed particles and resistance to rutting in the pavement through the use of various laboratory test procedures.

MATERIALS

There are numerous factors that affect the load carrying capacity of HMA. One very important factor is the material. Therefore, an essential part of this project was to locate an uncrushed material that would produce a crushed material of similar rock type. In Iowa, the best quality gravels are found on the Mississippi River. Aggrecon Corporation operates the Turner Pit (approximately 90% igneous) (NE 1/4, Section 7, Township 84N, Range 7E) near Sabula, Iowa in Jackson County (Sp.Gr.=2.63). Tests on the gravel portion yield absorptions of about 1.05%, Los Angeles abrasions of about 15 and an Iowa DOT "A" freeze and thaw loss of 1. This source was selected because the production uses no crushing and all size selection is accomplished by screening.

A windblown hillside deposit blow sand (Woodbury County west of Floyd Boulevard, Section 15, Township 47, Range 89) was used to provide the balance of the required uncrushed sand retained on the #200 and #100 screens. This was a rounded sandy material which for this research was better than using an earthy type #100 and #200 sized material.

The crushed limestone (Sp.Gr.=2.59) was from the Kaser Corporation, Sully Mine in Jasper County (SE 1/4, Section 16, Township 79N, Range 17W). The material was from beds 36 through 41. Tests yield absorptions of about 3.85%, Los Angeles abrasions of about 33 and an Iowa DOT "A" freeze and thaw loss of 1.

Crushed Quartzite (Sp.Gr.=2.64) was obtained from the Everist Inc. Minnehaha County Quarry at Del Rapids, South Dakota

(SW 1/4, Section 10, Township 104N, Range 49W). Tests yield absorptions of about 0.22%, Los Angeles abrasions of about 21 and an Iowa DOT "A" freeze and thaw of 1.

Unless otherwise noted, the ac was an AC 10 from Koch Refining Company at St. Paul, Minnesota. A few specimens for comparison were made using AC 2.5 and AC 20 grade Koch Refining Company ac.

GENERAL MIX DESIGN CRITERIA

Again, there are a number of factors that will affect the results of this research. It is, therefore, necessary to limit the scope. The research was aimed at the type of mix design currently being used by the Iowa DOT on interstate highways. All specimens were made using 75 blow Marshall compaction. In addition to the 4%, 5% and 6% ac contents used in the mix design, an ac content intended to yield 4% calculated voids was used to make a series of specimens.

The target aggregate gradation for all asphalt mixtures was 100% passing the 3/4 inch, 42% passing the #4 and 4% passing the #200. The complete gradation is given in Table 1 and a 0.45 power graphical plot in Figure 1.

Both the crushed and uncrushed materials essentially met the intended gradation with actual gradations included in Table 1. Most crushed gravel material was obtained by crushing material passing a 3 inch screen and retained on a 1 inch screen. In all cases, the crushed material passed a screen at least 1/4 inch smaller than the screen on which the uncrushed material had been retained.

The intent was to test asphalt mixtures containing 0, 30, 60, 85 and 100% crushed particles.

PREPARATION OF AGGREGATE

All materials were dry screened on all individual screen sizes noted in Table 1. It was recognized that even in a relatively dry condition, some fine material would adhere to larger particles.

To obtain the crushed gravel, the uncrushed gravel passing the 3 inch screen and retained on the 1 inch screen was crushed in a small laboratory jaw crusher with the jaws set relatively wide open (3/4 to 1 inch). All crushed gravel was dry screened and saved by screen size. The partially crushed material retained on the 3/4 inch screen was returned to the jaw crusher. After sufficient amounts of the larger sized crushed gravel was obtained, the jaw opening was reduced to produce finer material.

The crushed limestone was produced using a hammer mill at the production site. This product was dry screened in the laboratory.

Everist Inc. produced the crushed quartzite in a cone crusher. It again was sized in the laboratory by dry screening.

Recognizing that fines would adhere to the larger particles, percentages of each screen size were added to yield a 1000 gram sample. A washed gradation of the built up 1000 gram sample was conducted. Based on the resulting gradation, the percentages used in 1000 gram sample were adjusted to more closely produce the desired gradation. Percentages of dry screened material that would yield the desired washed gradation were determined. The resulting gradations are shown in Table 1.

TESTING EQUIPMENT

Marshall Equipment

The hammer used to compact the Marshall specimen for the study was an Iowa DOT Materials Lab fabricated mechanical hammer with a flat face and stationary concrete base. The mechanical hammer is calibrated every three months by correlating with a hand held Marshall hammer of the type described in AASHTO T245-82.

The stability equipment was a Rainhart load frame and stability head and a Heath Model SR-207 X-Y recorder. This equipment is calibrated weekly with a proving ring and dial gauge.

<u>Resilient Modulus Apparatus</u>

The resilient modulus testing for this study was performed using a Retsina Mark VI Resilient Modulus Non-Destructive Testing Device, purchased in 1988 from the Retsina Co., Oakland, California. The Retsina Device was selected among numerous resilient modulus testing systems due to its low cost, simplicity, and ease of operation. As described in ASTM D-4123, for a cylindrical specimen, diametral loading results in a horizontal deformation which is related to resilient modulus by the formula:

$$M = \frac{P(\nu+0.2734)}{t(d)}$$

where: M = resilient modulus

P = vertical load

ν = poissons ratio

t = specimen thickness

d = horizontal deformation

The device operates by applying a load pulse (0 to 1000 lb range) diametrically through the specimen. Load duration (0.05 or 0.10 sec.) and frequency (0.33, 0.5, or 1.0 hz) are controlled by the operator. Horizontal deformations are sensed by transducers mounted on a yoke connected to the specimen. The number of cycles to be used in a test can be set by the operator. Results are calculated by a microprocessor and are presented both by printer and digital display.

Indirect Tensile Apparatus

For indirect tensile strength determination, the Iowa DOT Materials Laboratory Machine Shop fabricated the indirect tensile device developed by Dr. Gilbert Y. Baladi, Michigan State University (4). The device consists of a load piston and four frictionless guide pins inserted through a framework of upper and lower stationary plates. The sample rests diametrically within the frame on a 1/2 inch loading bar. The load piston then rests on top of the specimen and the entire apparatus is positioned in a Marshall loading frame where a load is applied at the standard rate of 2.0 inches per minute and the maximum compressive load is recorded on an X-Y plotter.

The Baladi device was chosen for this test due to the anticipation that the frictionless guide system prevents rocking or rotation of the upper load strip and thus yield more accurate results than are achievable using previously available indirect tensile testing equipment.

Creep Test Device

The creep test device used in this study was fabricated by Iowa DOT Materials Lab Machine Shop and Instrumentation personnel. The device consists of three pneumatically actuated load units mounted on a load frame, and is capable of simultaneously testing three samples. An air regulator with digital display is capable of delivering pressure from 0 to 120 psi to the load units. The load units have 12.4 to 1 force/pressure conversion ratio and a maximum output of 1500 lbs. in the linear range. A compression load cell was used to calibrate the load units and develop the force/pressure conversion ratios. A brass load plate is centered on the frame directly under each of the load unit rams. A specimen is centered on the load plate and another load plate is placed on top of the specimen. The specimen and top load plate are aligned directly beneath a load unit ram through which a vertical force of from 0 to 1500 lbs. can be applied. Dial gauges readable to 0.001 inch are mounted to the load unit rams, and vertical deformation of the specimen as a function of time, is determined. The lower load frame and test specimens are contained in an insulated tank containing a temperature controlled water bath. The operational range of the water bath is from 25°F to 140°F.

TEST PROCEDURES

Specimen Preparation and Marshall Testing

The test specimens were prepared in accordance with AASHTO T245-82 except that four specimens are made from a 13,000 gram batch. Maximum specific gravity of the mixes were determined in accordance with AASHTO T-209 using a volumetric flask and bulk specific gravities were determined using AASHTO T166-83, Method A.

Resilient Modulus Testing

Testing temperature for resilient modulus was targeted at 77±2°F. The only temperature control utilized was the ambient air temperature of the lab itself. The temperature of the specimen was determined by sandwiching a thermocouple wire between two specimen. If the indicated temperature was not 77°F±2, the test was not performed.

After confirming the temperature was within the desire range, a template was used to mark three 60° divisions on the diameter of the specimen. Specimen thickness was determined to .01 inch using a height comparator. Each specimen was placed in the frame and tested with the transducers directly opposite each other. After an individual test was completed, the specimen was reoriented by rotating 60° and the test was repeated. Each specimen was again rotated 60°, resulting in a total of three tests per specimen each at an orientation of 60° from the other two.

Each test consisted of twenty load cycles of 0.10 sec. and a frequency of 0.33 hz. Prior to this study, it was determined that preconditioning by subjecting the sample to a number of the cyclic loads had no effect on the outcome, consequently, the practice of preconditioning as recommended in ASTM D-4123 was not utilized. The three sets of twenty cycles were each repeated at loads of 50 and 75 pounds.

This same testing pattern was performed on each of the three specimens of an individual asphalt content for a particular mix design. All results were then averaged to yield a single resilient modulus value for each asphalt content. Final results were expressed in terms of thousands of pounds per square inch (ksi).

Since the resilient modulus test is considered nondestructive at low loadings and moderate temperatures (the key factor being low horizontal deformation and accumulated deformation), when resilient modulus testing was completed, the same Marshall specimens were then used for the creep test procedure.

<u>Indirect Tensile Test Procedure</u>

Indirect tensile strength was determined only for Marshall specimens of mixes at asphalt contents intended to produce 4.0% voids. From the time they were compacted until the testing was conducted, all specimen were stored in open air at room temperature. For testing, the samples were immersed in a 77°F water bath for thirty minutes. Each sample was removed from the water bath, dried with a damp towel, and tested with the Baladi apparatus in the Rainhart Marshall stability loading machine within a 30 second time period. The load was applied at a rate of 2.0 inches per minute until the maximum compressive strength was achieved as indicated by a peak on the X-Y recorder. Since the Baladi device employs 1/2 inch steel loading strips, the tensile strength was calculated using the formula found in AASHTO T283-85 Section 11.1;

$$St = \frac{2P}{\pi t D}$$

where:

St = tensile strength, psi

P = maximum load, pounds

t = specimen thickness, inches

D = specimen diameter, inches

Indirect tensile strength results were calculated for each of three specimen in a set, and those results were averaged to provide a single indirect tensile strength number for a particular mix.

Creep Test Procedure

Specimen faces were first polished by laying them on a belt sander using #50 grit paper. This was done to remove surface irregularities that would result in uneven, internal stress distribution, and to allow the surface to be made as frictionless as possible. Surface friction reduction was further enhanced by the application of a mixture of #2 graphite flakes and water/temperature resistant silicon gel lubricant to the polished specimen faces.

Sets of three specimen of the same mix design and asphalt content were tested simultaneously. Testing temperature was 104°F, and the specimen were conditioned in 104°F water for 1/2 hour prior to testing.

The specimen were then subjected to a preload of 15 psi contact pressure for 2 minutes. In order to achieve contact pressures as high as 200 psi, a 3 inch diameter top load plate was used instead of a 4 inch diameter plate. After preloading, which was intended to properly seat the specimen, load plates and ram, and compress any final minute surface protrusions, the specimen are removed from the apparatus and their height measured to the nearest 0.0001 inch using a height comparator. The samples are then placed back in the apparatus, dial gauges are adjusted to read 0.500 inch, and the creep loads are applied.

Contact pressure is increased from 0 to 40 psi in step loads of 8 psi applied for 1 minute each (Figure 2). After 40 psi is reached, the dial gauges are read at ten minute intervals until 1 hour has passed. At this time, 8 psi step loads of one minute duration are again applied until a contact pressure of 80 psi is attained. Dial gauge readings are again taken at ten minute intervals for one hour. This entire sequence is repeated until the final step of 200 psi for 1 hour is achieved, or specimen failure occurs. Specimen failure is indicated by a rapid increase in height reduction or change in height of more than 0.05 inch. Total elapsed time (min.), the applied pressure at the time of failure and the measured reduction in height just prior to failure are recorded. If failure does not occur, total reduction in height at the end of the test (325 minutes) is used to calculate the creep resistance factor (CRF). The CRF was developed by the Iowa DOT to provide a single quantitative number value to creep test results. The formula for the CRF is:

$$CRF = \frac{t}{325}\,[100 - c(1000)]$$

where: CRF is Creep Resistance Factor

t is time in minutes at failure , 0.05 inch height change, or 325 if failure did not occur.

c is change in height in inches or 0.05 inch if failure occurred.

For example, if failure did not occur, but total change in height was 0.037 inch, then

$$CRF = \frac{325}{325} [100-(0.037)(1000)]$$

$$= 63$$

In another example, if failure occurred at 265 minutes, then

$$CRF = \frac{265}{325} [100-(0.050)(1000)]$$

$$= 41$$

DISCUSSION OF RESULTS

Using 100% crushed gravel, the outer edges of the specimens were somewhat friable. With 100% crushed gravel (Table 2), 5.85% ac could be used to obtain approximately 4% voids (3.80%). Only 3.40% ac was used to obtain 4.40% voids in the 100% uncrushed gravel mix. The percent of ac which results in 4% voids is very dependent on the amount of crushed particles. The greater angularity of the crushed particles yielded much greater voids (8.85%) at low ac contents than the uncrushed materials (2.89% voids).

The voids of the limestone mixes (Table 3) were similar, but slightly higher, ranging from 1.20 at 6% ac and 0% crushed to 11.02% voids at 4% ac and 100% crushed. There was difficulty in selecting the proper ac content to yield 4% voids. For construction project control, another mix would have been made to select an ac content that would more closely yield 4% voids. Due to a very limited amount of material, no additional mixes were made. The greater angularity of the limestone yielded slightly greater void contents than the crushed gravel with other factors being equal.

Somewhat surprisingly, with other factors being constant, the quartzite (Table 4) produced lower void contents than the crushed gravel. The 6% ac content in the quartzite mixes yielded void contents below 2% which is well below the Iowa DOT design criteria.

Density

The densities (Tables 1, 2 & 3) vary from 2.27 to 2.45 grams per cubic centimeter. The laboratory densities seem to have very little significance in regard to the stability or the capacity to carry load. The 100% uncrushed yields the highest densities, but the lowest Marshall stabilities and Creep Resistance Factors. The densities of the limestone mixes are in general just slightly lower, but yield the highest Marshall stabilities. The lab densities (Figure 3) are inversely related to the percent of crushed aggregate.

Even though the laboratory density and voids do not correlate with stability or strength, the proper void content is important in HMA pavement in preventing bleeding and instability during hot weather. Adequate field compaction to obtain high density and laboratory voids is essential.

Marshall Stability

The Marshall stability is a relatively good measure of the potential load carrying capacity of an asphalt mixture. Unfortunately, argillaceous limestone aggregate will yield stabilities higher than nonargillaceous limestone with other factors remaining the same. The aggregates used in this research were relatively hard, high quality aggregates.

The Marshall stabilities of all mixes ranged from 575 to 4020 pounds. For the crushed gravel (Figure 4), it increased from 900 pounds at 0% crushed to almost 2500 pounds for 100% crushed. The percentage of ac had very little effect on the Marshall stability until at 6% ac the mixture became highly over asphalted with 30% or less crushed gravel. With that exception, the 4, 5 and 6% ac mixtures yield nearly the same stabilities.

The crushed quartzite mixes (Figure 5) yielded Marshall Stabilities very similar to the crushed gravel, ranging from 900 to 2300 pounds. Again, in general, until the mixtures became highly over asphalted, the percent of ac had very little effect on the stabilities.

With 30% or more crushed limestone (Figure 6), the Marshall stabilities were much higher than those of the crushed gravel or quartzite. The percent of ac in the limestone mixtures had a greater influence on the resulting stabilities. The 4% ac yielded Marshall stabilities approximately 400 pounds higher than those for the 6% ac. The amount of crushed material was again the dominate factor with an increase of approximately 400 pounds for each additional 10% of crushed limestone.

Three pairs of mixes (two limestone and one quartzite) were made and tested to determine the effect of the grade of ac (Tables 3 & 4). AC 20 produced stabilities approximately 400 pounds greater than those of the AC 2.5 mixture (Figure 7). This is again very small when compared to the effect of crushed particles in the mixture.

Resilient Modulus

The resilient modulus of the crushed gravel mixes (Figure 8) increases with increasing crushed material from 0 to 60%. Above 60% crushed gravel, the resilient modulus decreases.

With crushed limestone (Figure 9) there again was a relatively uniform increase of resilient modulus up to 60% crushed and then a more gradual increase.

The crushed quartzite mixes yielded relatively low resilient moduli (Figure 10) with less relationship to amount of crushed material than the gravel and limestone mixtures.

With 5% asphalt cement in all mixtures (Figure 11), the resilient modulus exhibits a straight line increase up to 60% crushed material. Crushed limestone mixtures yield resilient moduli substantially higher than those for crushed gravel or crushed quartzite. Over the 0 to 60% crushed aggregate range the resilient modulus does not correlate well with percent of crushed material.

Based on the limestone mixtures (Table 3), the resilient modulus is highly dependent on the grade of asphalt cement. AC 2.5 yields resilient moduli of about 200 ksi. AC 10 resilient moduli are about 450 ksi and AC 20 resilient moduli are about 900 ksi. Resilient moduli are more dependent on grade of asphalt cement than percent of crushed aggregate.

Indirect Tensile

Indirect tensile testing (Tables 2, 3 & 4) was conducted on only one mix of each crushed to uncrushed proportion. The values ranged from 104 to 148 with the highest values from the limestone mixes and the lowest from the quartzite mixes. A greater range (62 to 205) results from the use of AC 2.5 and AC 20 grade ac. The indirect tensile values are highly dependent on the ac and relatively unaffected by the percentage of crushed particles. Again, this data does not seem to indicate that the indirect tensile values are related to load carrying capacity.

Creep Resistance Factor

Creep testing (5) is new to the Iowa DOT in 1989. The CRF was developed to provide a quantitative number value for the results of the test. The creep test is a very time consuming test (7 hours) with completion of one mixture (three specimens) per day.

The CRF data looks very promising in regard to evaluating a mixture's resistance to rutting. The CRF (Tables 2, 3 & 4) ranged from less than 21 for 100% uncrushed gravel to 83 or above for 4 and 5% asphalt cement with 100% crushed gravel or limestone.

The CRF is highly dependent on the percent of crushed materials (Figure 12) with only minor dependence on the percent or grade of asphalt cement (Table 3). With crushed gravel, the CRF exhibits a gradual increase with increased crushed material to about 75%. There is a more rapid increase of CRF's above 75% crushed gravel.

In general, the crushed limestone mixtures (Figure 13) yield higher CRF's than crushed gravel or quartzite. HMA mixtures with 60% or more crushed limestone yield relatively high CRF's.

Increasing percentage of crushed quartzite yields a gradual increase in CRF's. The CRF's of crushed quartzite mixtures (Figure 14) seem to be more adversely effected by increased asphalt cement content or decreased crushed material than are the gravel or limestone mixtures. The maximum CRF for quartzite was 84 with 5.5% ac and 100% crushed (Table 4). With 100% crushed and 5.0% ac, the CRF was 73. All other quartzite CRF's were 52 or less.

With 5% asphalt cement in all HMA mixtures, the CRF's ranged from 16 with 0% crushed aggregate to near 80 with 100% crushed material (Figure 15). The crushed limestone yields the highest CRF's and the quartzite yields the lowest.

The creep test should be a more severe test than the Marshall stability. The limited amount of data available would show that it relates to Marshall stability when considering crushed gravel, limestone or quartzite separately, but would not correlate because of substantial differences between crushed gravel and limestone mixtures.

In a study to follow this laboratory research, field core samples have been taken from pavements that have experienced rutting and others that have performed well without rutting.

These will be used to assist in relating the CRF to minimum criteria necessary to alleviate rutting on high traffic volume roadways.

CONCLUSIONS

This research supports the following conclusions in regard to crushed particles in asphalt mixtures and tests thereon:

1. Strengths or stabilities of asphalt mixtures are inversely related to laboratory densities of 75 blow Marshall compacted specimens.

2. The Marshall stabilities are directly related to the percent of crushed particles in the mixture. Increased percent of crushed particles yields a substantial increase in stabilities.

3. The percent of ac in the mixture has minimal affect on Marshall stabilities until there is an excess of ac.

4. A harder grade of ac will yield a small increase in Marshall stability in comparison to larger stability increases caused by higher percentages of crushed particles.

5. Crushed limestones yield much higher Marshall stabilities than crushed gravel or crushed quartzite.

6. The resilient modulus data does not correlate with percent of crushed aggregate or perceived resistance to rutting.

7. The resilient modulus and indirect tensile test are highly dependent on the grade of ac.

8. The CRF is directly related and very dependent on the percent of crushed aggregate.

9. The grade or content (unless highly over asphalted) of asphalt cement has a relatively small affect on the CRF.

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TABLE TITLES

TABLE 1

Gradations of Aggregates Used for Hot Mix Asphalt Mixtures

Sieve Size	Intended	% Passing Uncrushed Gravel	Crushed Gravel	Limestone	Quartzite
3/4"	100	100	100	100	100
1/2"	85	86	85	85	85
3/8"	64	64	64	63	64
4	42	43	43	42	41
8	27	30	29	27	28
16	20	21	21	19	20
30	13	14	14	12	12
50	8	8.6	8.7	7.7	7.9
100	6	5.8	6.1	6.0	5.8
200	4	3.9	4.1	4.2	3.6

TABLE 2

Summary of Results With Crushed Gravel and Uncrushed Gravel

Uncrushed Gravel %	Crushed Gravel %	% of A.C.	Lab. Density lbs/cu.cm	Calc. Voids %	Marshall Stability Pounds	Flow inx100	Resilient Modulus ksi	Indirect Tensile psi	Creep Resistance Factor
0	100	4.00	2.27	8.85	2460	10	229		85
0	100	5.00	2.30	6.56	2335	12	252		89
0	100	5.85	2.33	3.80	2490	11	243		90
0	100	6.00	2.33	3.76	2480	12	260		77
15	85	4.00	2.29	8.14	2175	8	257		57
15	85	5.00	2.32	5.52	2150	10	250		70
15	85	5.25	2.34	4.44	2167	11	244	124.5	53
15	85	6.00	2.35	3.03	2165	12	248		44
40	60	4.00	2.32	7.24	2050	8	362		54
40	60	4.85	2.37	4.33	1925	10	345	124.5	55
40	60	5.00	2.36	4.32	2035	10	350		39
40	60	6.00	2.37	2.38	2110	10	361		37

TABLE 2 (CONT.)

Summary of Results With Crushed Gravel and Uncrushed Gravel

Uncrushed Gravel %	Crushed Gravel %	% of A.C.	Lab. Density lbs/cu.cm	Calc. Voids %	Marshall Stability Pounds	Flow inx100	Resilient Modulus ksi	Indirect Tensile psi	Creep Resistance Factor
70	30	3.75	2.38	5.41	1708	7	415	108.9	27
70	30	4.00	2.39	4.70	1605	7	326		31
70	30	5.00	2.41	2.67	1568	9	220		29
70	30	6.00	2.39	1.89	832	14	126		24
100	0	3.40	2.43	4.40	1283	6	341	121.7	19
100	0	4.00	2.45	2.89	995	8	219		21
100	0	5.00	2.44	1.88	860	12	132		16
100	0	6.00	2.42	1.20	575	6	81		12

TABLE 3

Summary of Results With Crushed Limestone and Uncrushed Gravel

Uncrushed Gravel %	Limestone %	% of A.C.	Lab. Density lbs/cu.cm	Calc. Voids %	Marshall Stability Pounds	Flow inx100	Resilient Modulus ksi	Indirect Tensile psi	Creep Resistance Factor
0	100	4.00	2.28	11.02	4020	9	633		84
0	100	5.00	2.30	8.93	3610	9	693		83
0	100	6.00	2.32	6.58	3935	11	543		84
0	100	6.25	2.35	5.26	3708	12	356	148.2	80
15	85	4.00	2.30	9.93	3920	9	487		79
15	85	5.00	2.33	7.55	3850	10	557		74
15	85	5.85	2.36	4.95	3185	10	425	148.1	72
15	85	6.00	2.36	5.06	3435	11	453		78
40	60	4.00	2.35	7.71	2810	7	635		83
40	60	4.70	2.38	5.69	2667	8	575	134.5	69
40	60	5.00	2.38	4.94	2515	7	550		76
40	60	6.00	2.39	3.14	2350	10	375		50

TABLE 3 (CONT.)

Summary of Results With Crushed Limestone and Uncrushed Gravel

Uncrushed Gravel %	Limestone %	% of A.C.	Lab. Density lbs/cu.cm	Calc. Voids %	Marshall Stability Pounds	Flow inx100	Resilient Modulus ksi	Indirect Tensile psi	Creep Resistance Factor
70	30	3.70	2.39	6.24	1762	8	473	130.0	38
70	30	4.00	2.41	4.98	1813	7	394		23
70	30	5.00	2.41	3.22	1663	8	340		32
70	30	6.00	2.41	2.10	1427	10	153		16
15	85 (2.5)	5.85	2.37	2.22	3480	10	198	87.4	77
15	85 (20)	5.85	2.35	3.25	3712	12	889	205.0	83
70	30 (2.5)	3.70	2.39	6.03	1577	6	208	61.8	30
70	30 (20)	3.70	2.37	6.70	2000	7	960	131.7	44

TABLE 4

Summary of Results With Crushed Quartzite and Uncrushed Gravel

Uncrushed Gravel %	Quartzite %	% of A.C.	Lab. Density lbs/cu.cm	Calc. Voids %	Marshall Stability Pounds	Flow inx100	Resilient Modulus ksi	Indirect Tensile psi	Creep Resistance Factor
0	100	4.00	2.31	7.00	2255	9	146		52
0	100	5.00	2.35	4.20	2240	12	131		73
0	100	5.30	2.36	3.13	2223	10	128	104.3	84
0	100	6.00	2.37	1.90	2375	12	105		40
15	85	4.00	2.32	6.74	1910	10	212		52
15	85	5.00	2.36	3.98	1873	11	132		50
15	85	5.10	2.37	3.22	2042	11	197	116.5	51
15	85	6.00	2.37	1.96	1693	10	93		25
40	60	4.00	2.36	5.69	2035	8	255		33
40	60	4.45	2.39	3.61	1833	8	236	109.1	42
40	60	5.00	2.40	2.71	1945	9	217		34
40	60	6.00	2.39	1.49	1510	12	145		27
70	30	4.00	2.41	6.51	1903	7	283		24
70	30	5.00	2.41	3.87	1265	8	179		20
70	30	6.00	2.41	2.48	1095	11	120		13
70	30	(2.5)3.70	2.39	5.87	1492	5	193	69.9	
70	30	(20)3.70	2.38	6.51	1903	7	223	156.8	

FIGURE CAPTIONS

Figure 1
A 0.45 Power Plot of the Intended Gradation

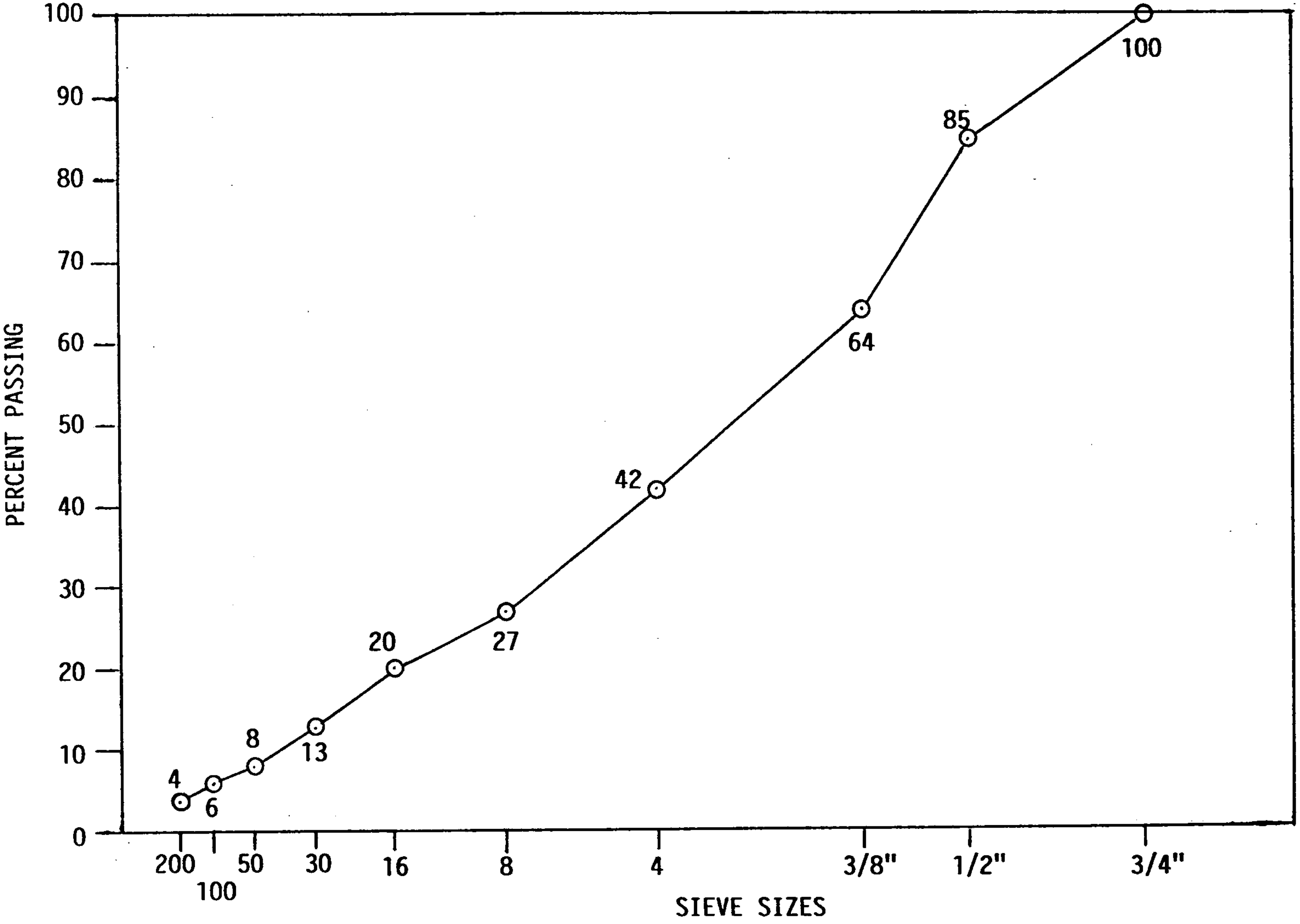

Figure 2
Change in Height Plotted Against Time for a Creep Test
CREEP CURVE - STEP LOADS

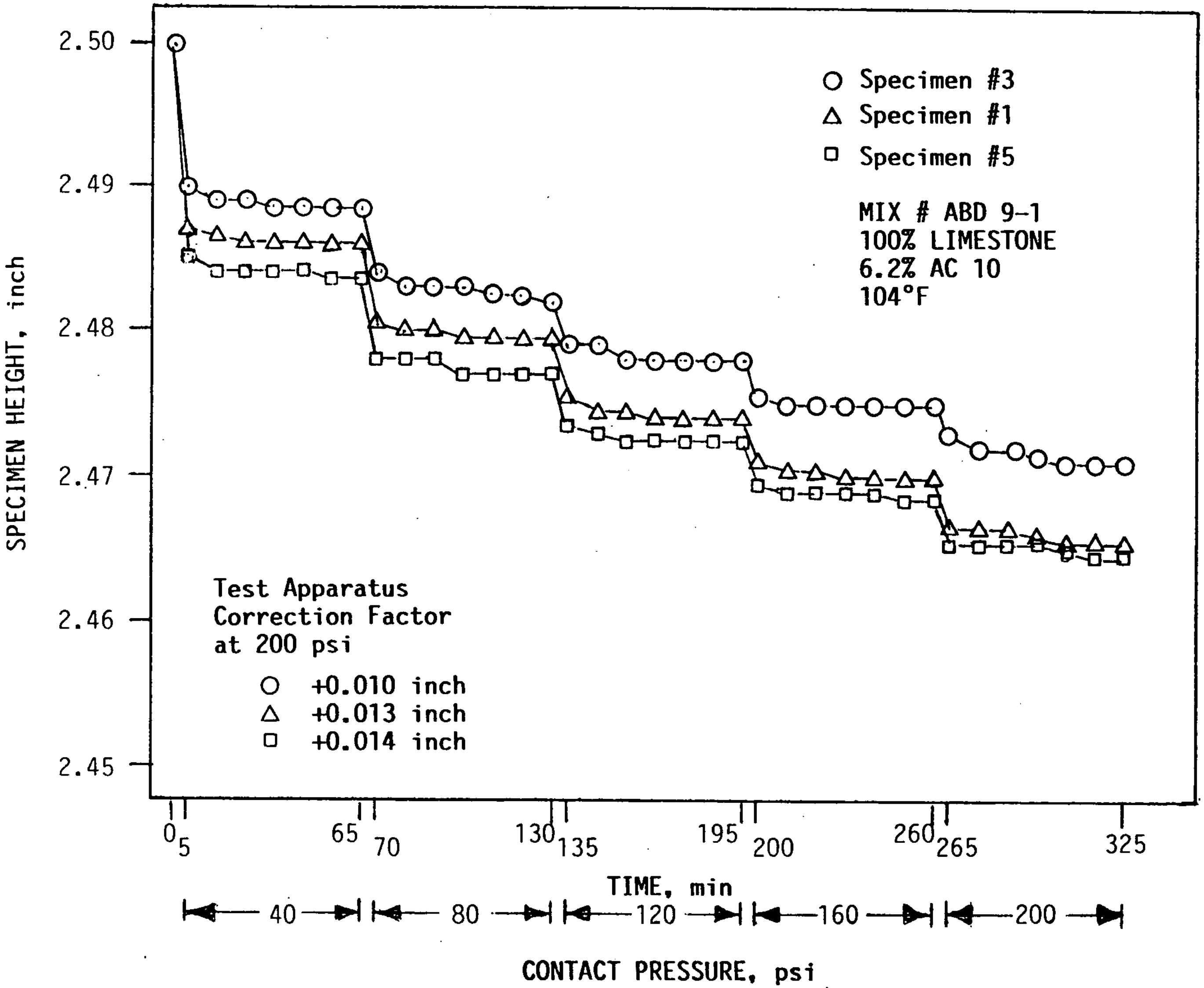

Figure 3

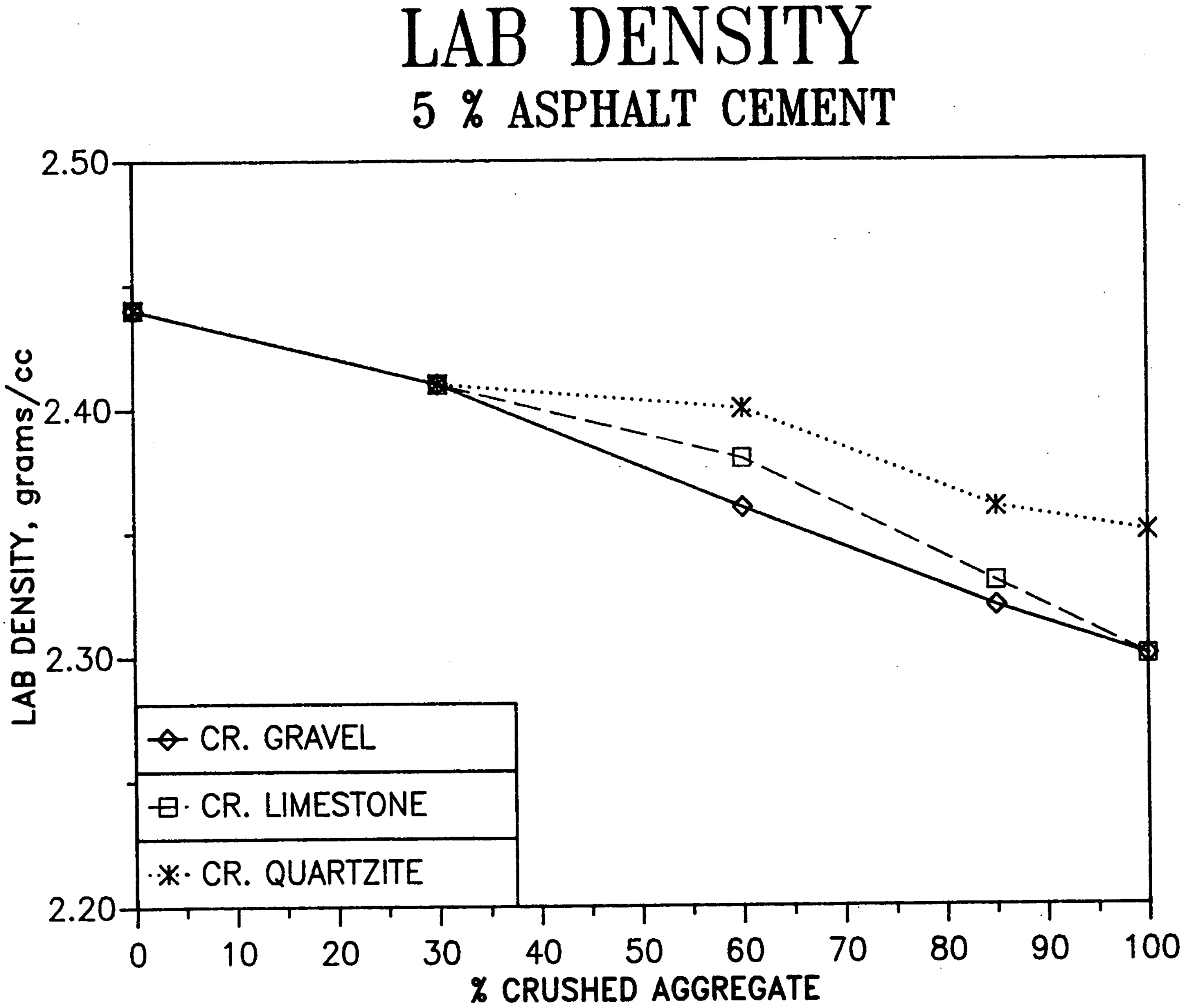
LAB DENSITY
5 % ASPHALT CEMENT
2.50
2.40
2.30
2.20
LAB DENSITY, grams/cc
CR. GRAVEL
CR. LIMESTONE
CR. QUARTZITE
0
10
20
30
40
50
60
70
80
90
100
% CRUSHED AGGREGATE

Figure 4

MARSHALL STABILITY
BALANCE OF AGGREGATE UNCRUSHED GRAVEL

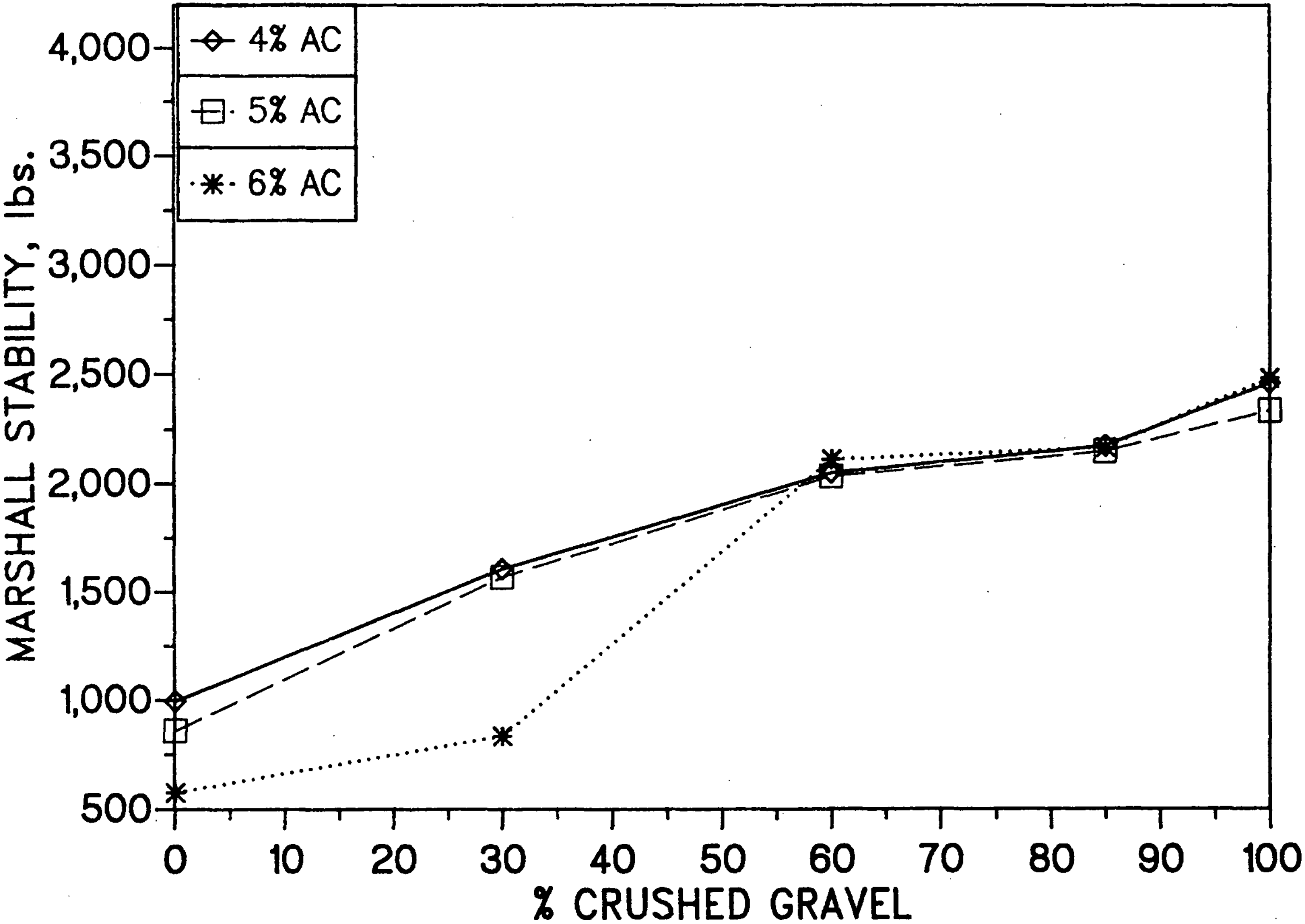

Figure 5

MARSHALL STABILITY

BALANCE OF AGGREGATE UNCRUSHED GRAVEL

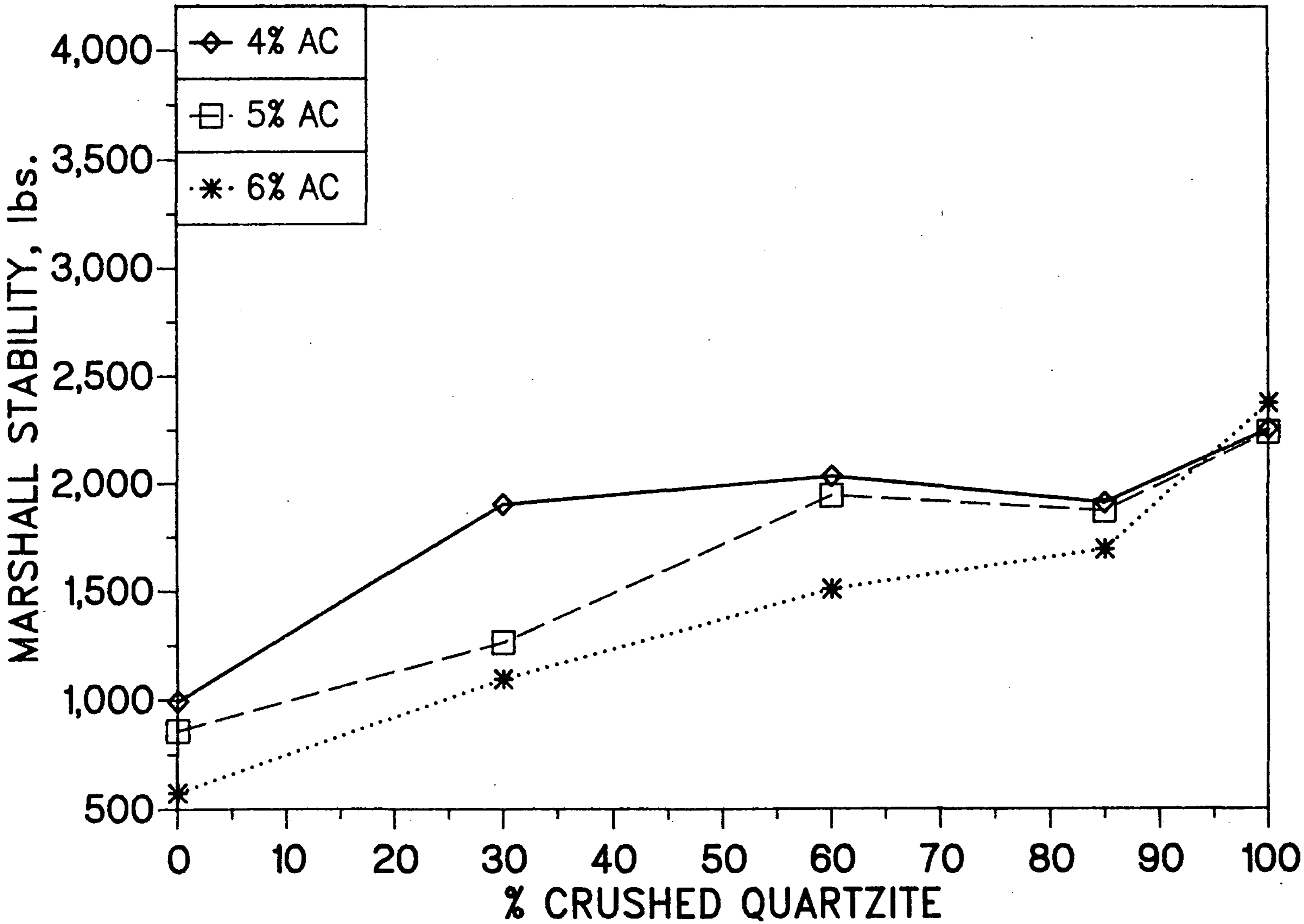

Figure 6

MARSHALL STABILITY

BALANCE OF AGGREGATE UNCRUSHED GRAVEL

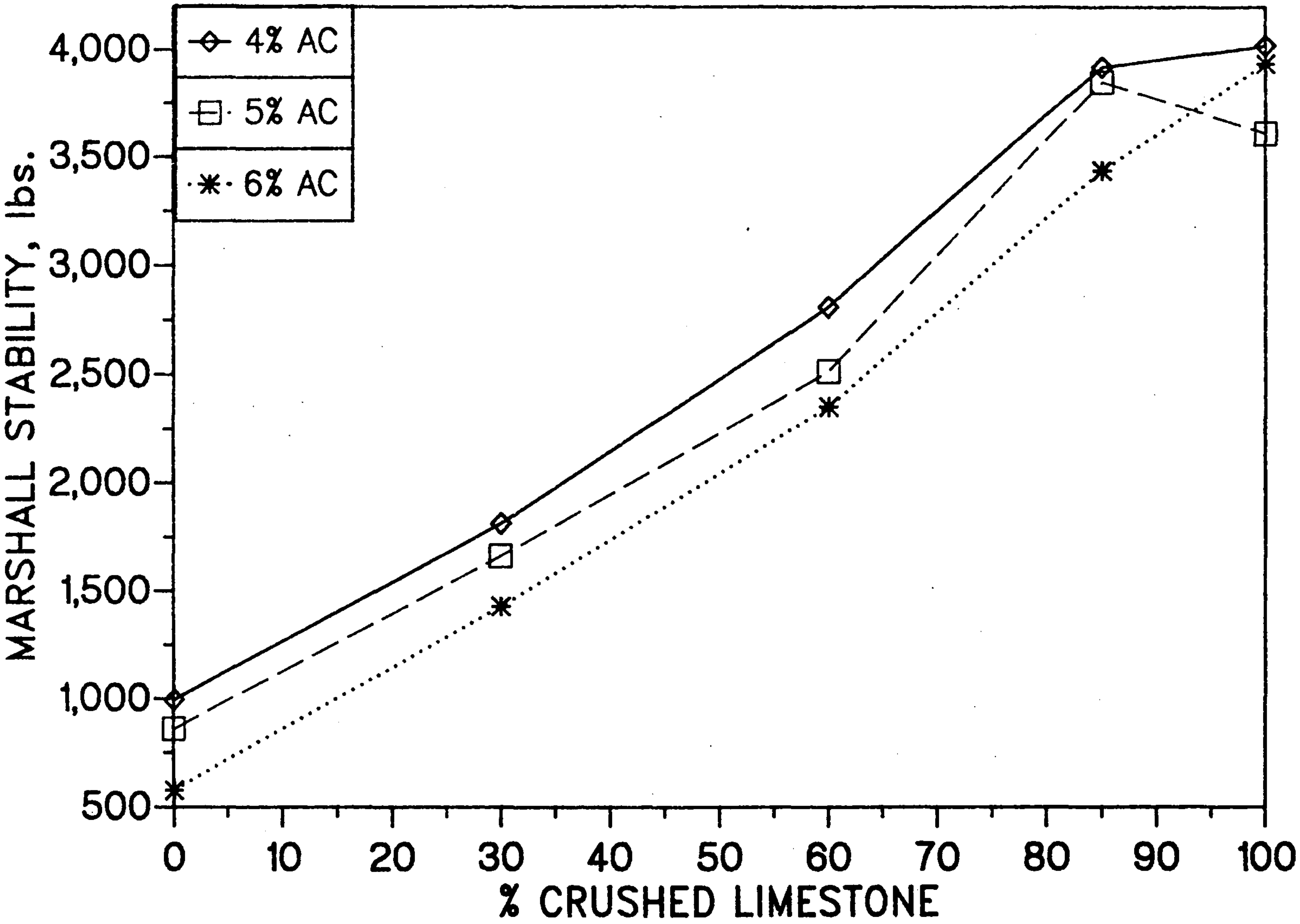

Figure 7

MARSHALL STABILITY

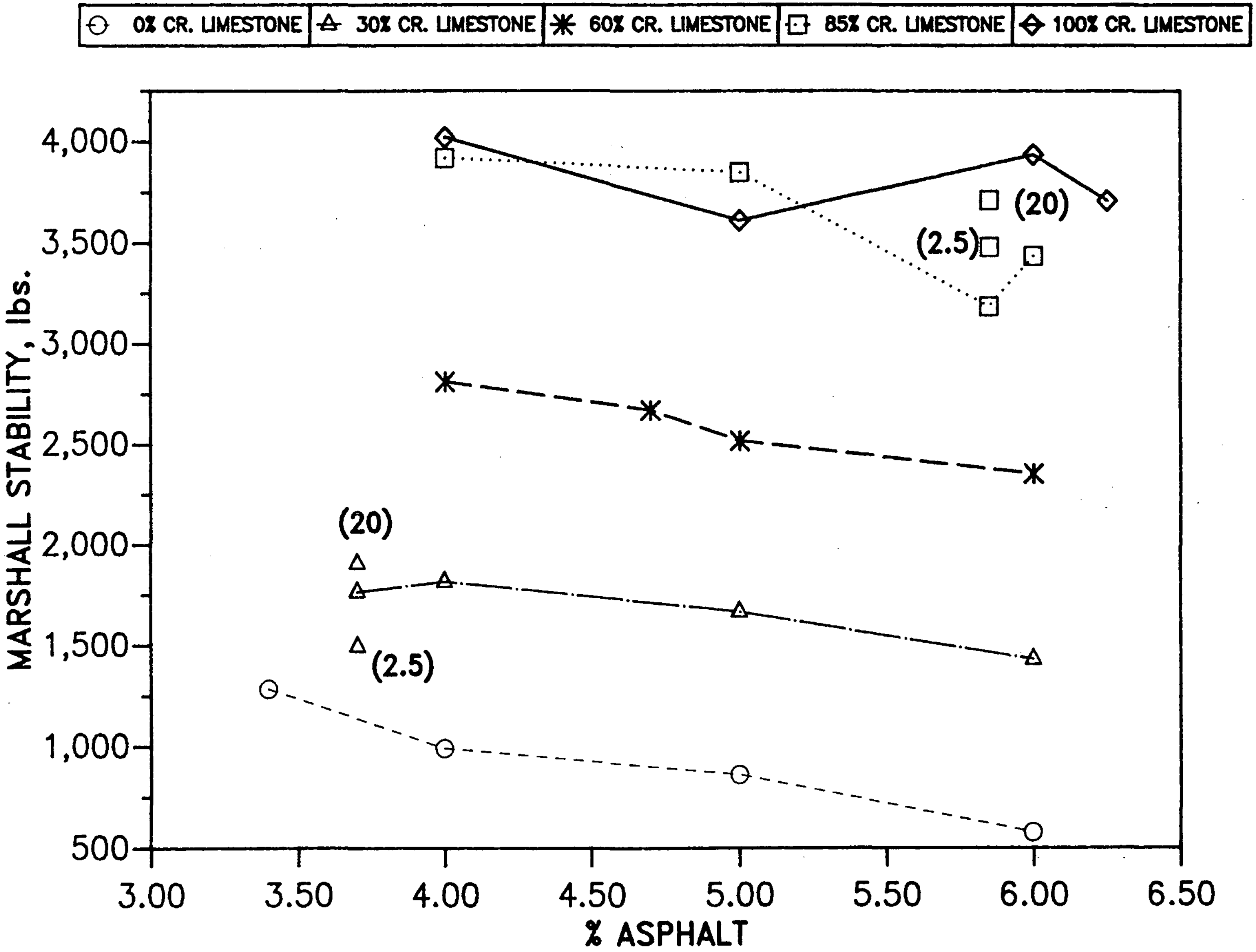

Figure 8

RESILIENT MODULUS

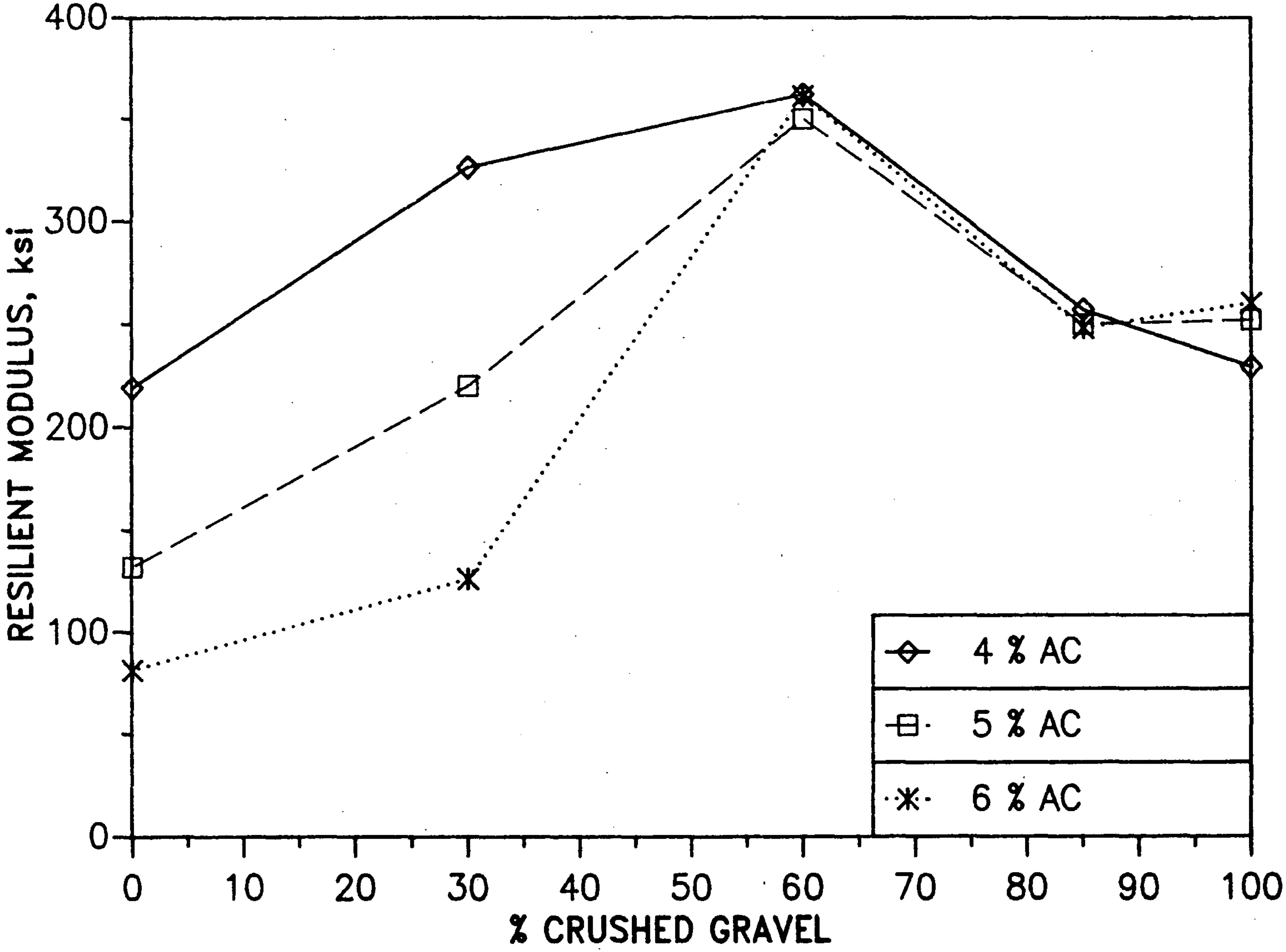

Figure 9

RESILIENT MODULUS

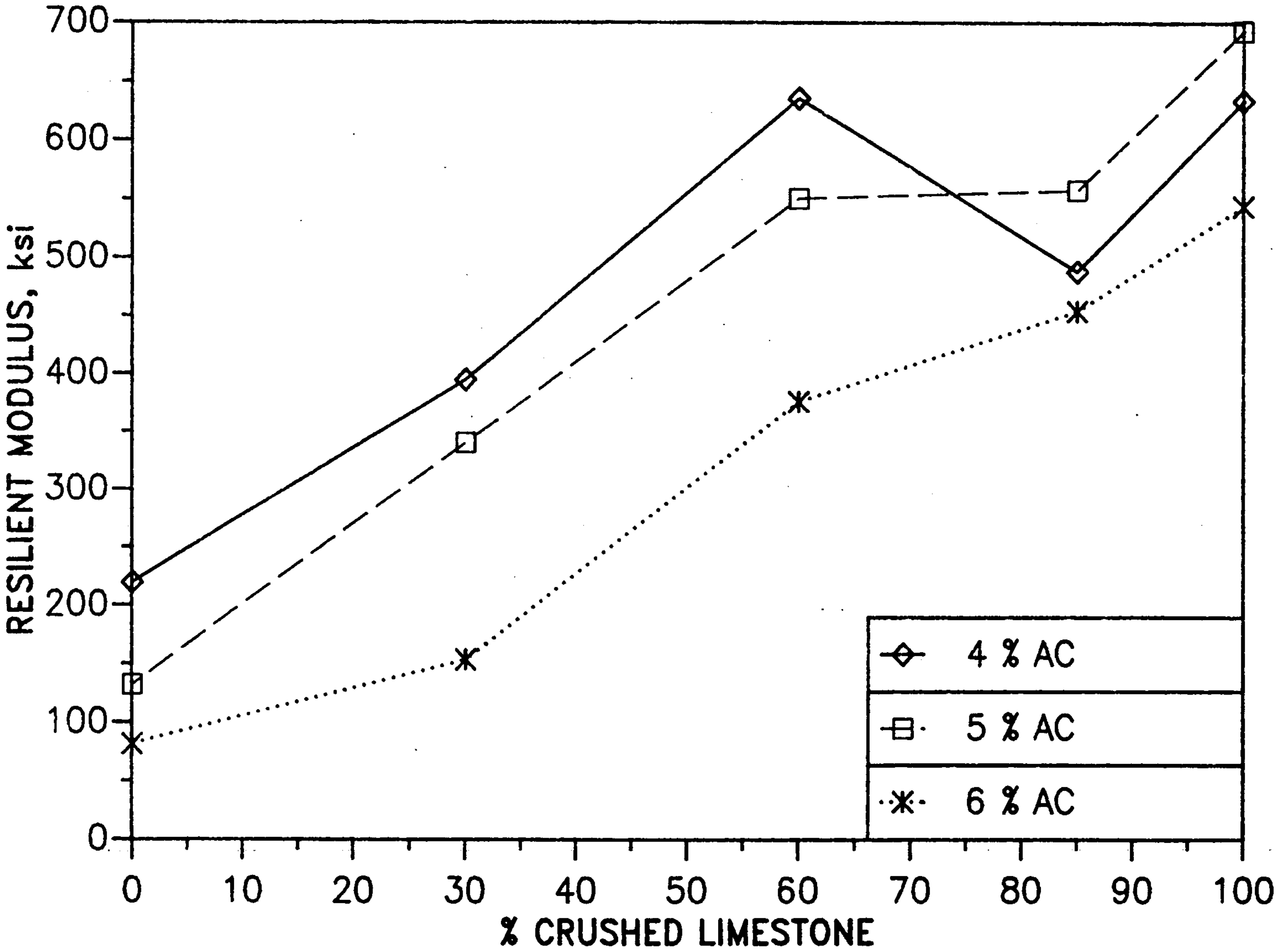

Figure 10

RESILIENT MODULUS

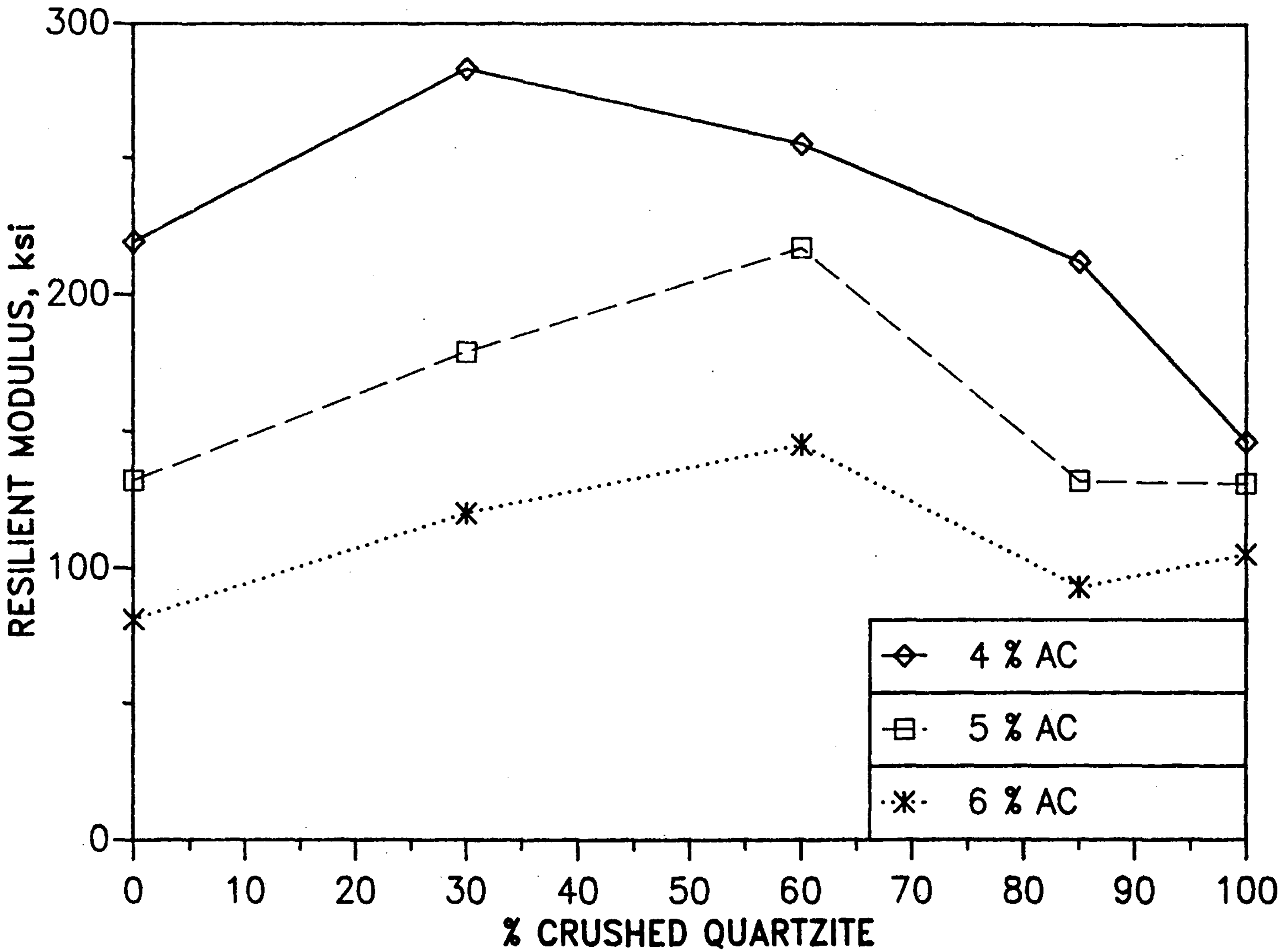

Figure 11

RESILIENT MODULUS

5 % ASPHALT CEMENT

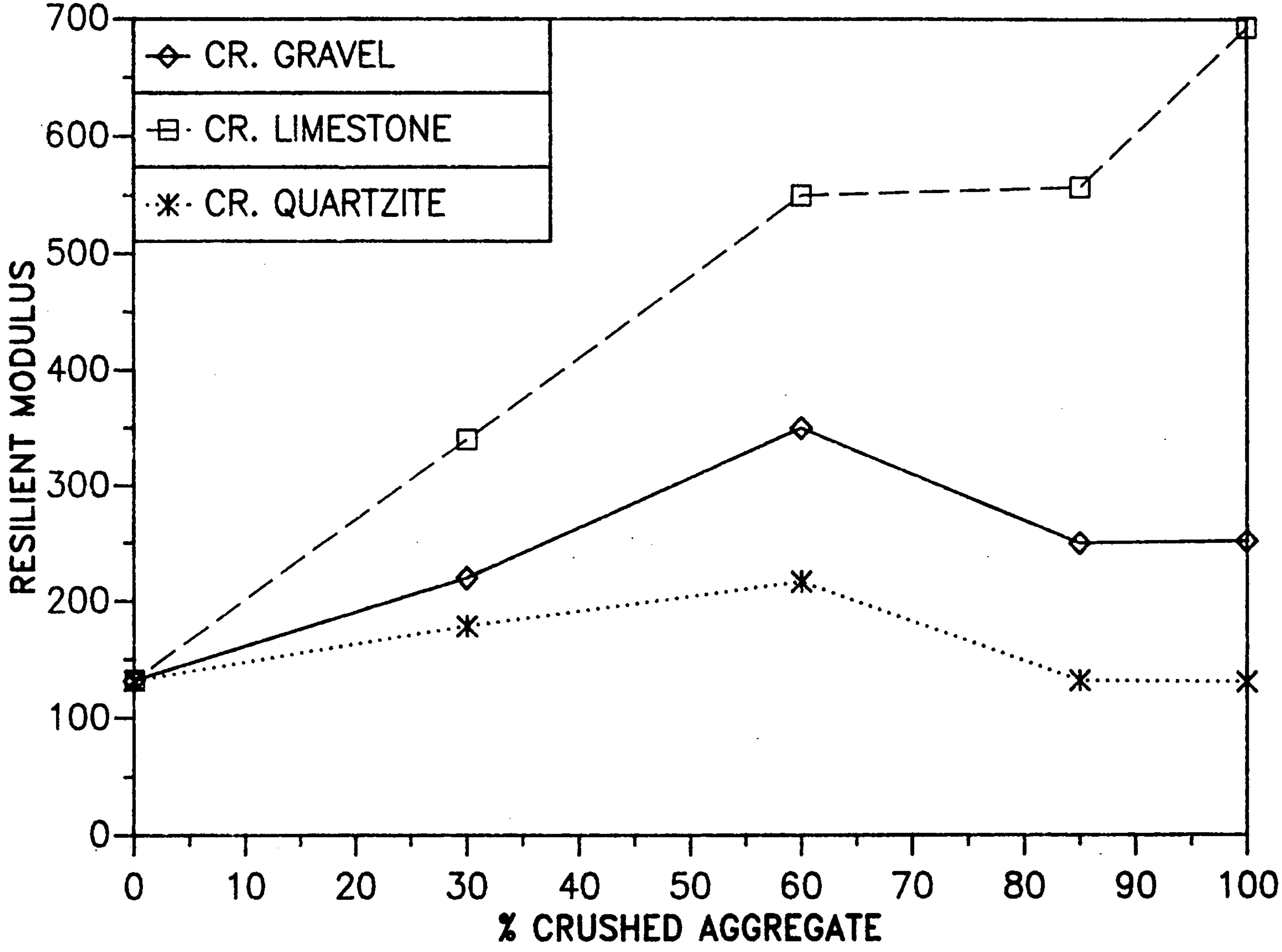

Figure 12

CREEP RESISTANCE FACTOR

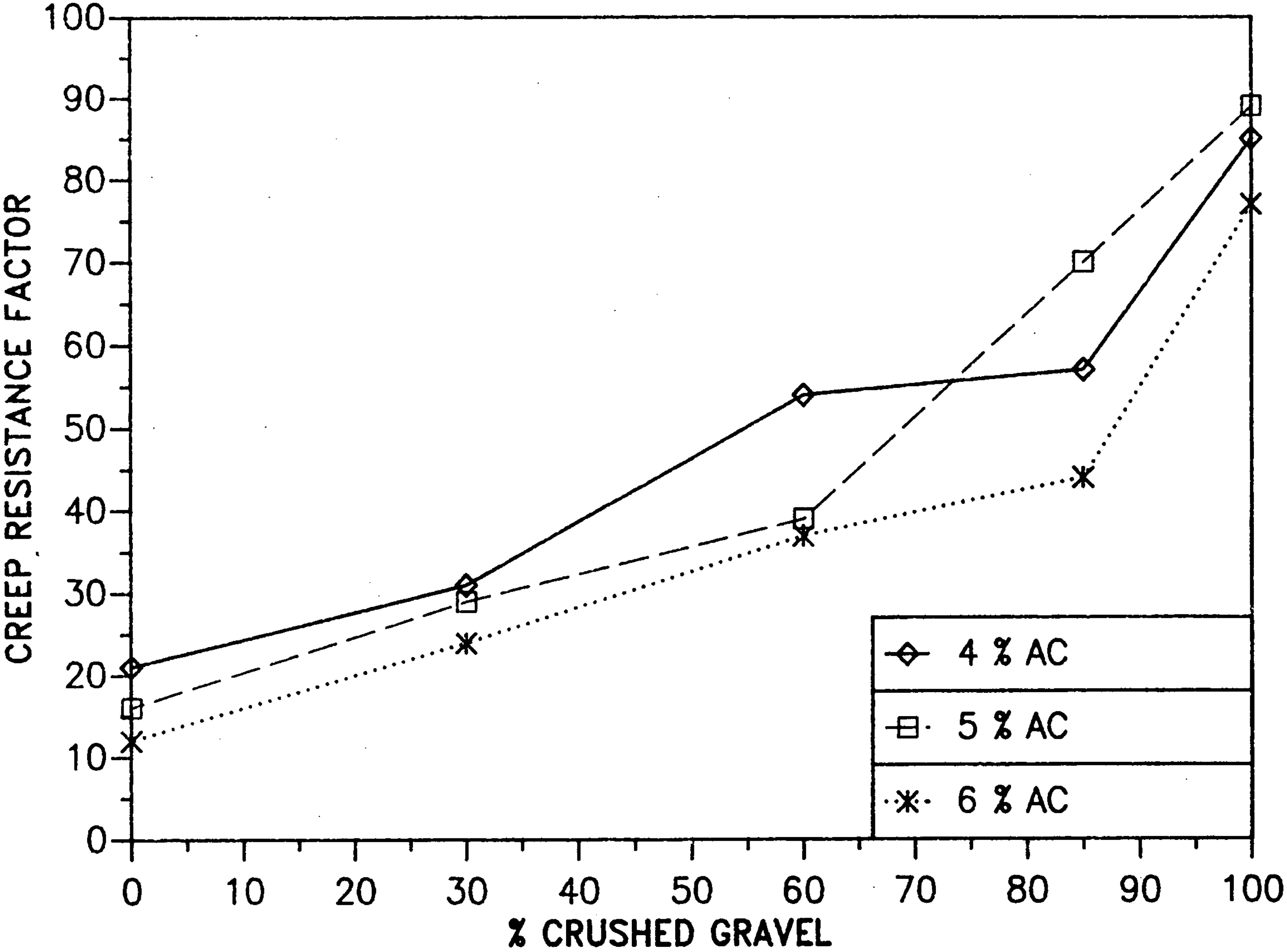

Figure 13

CREEP RESISTANCE FACTOR

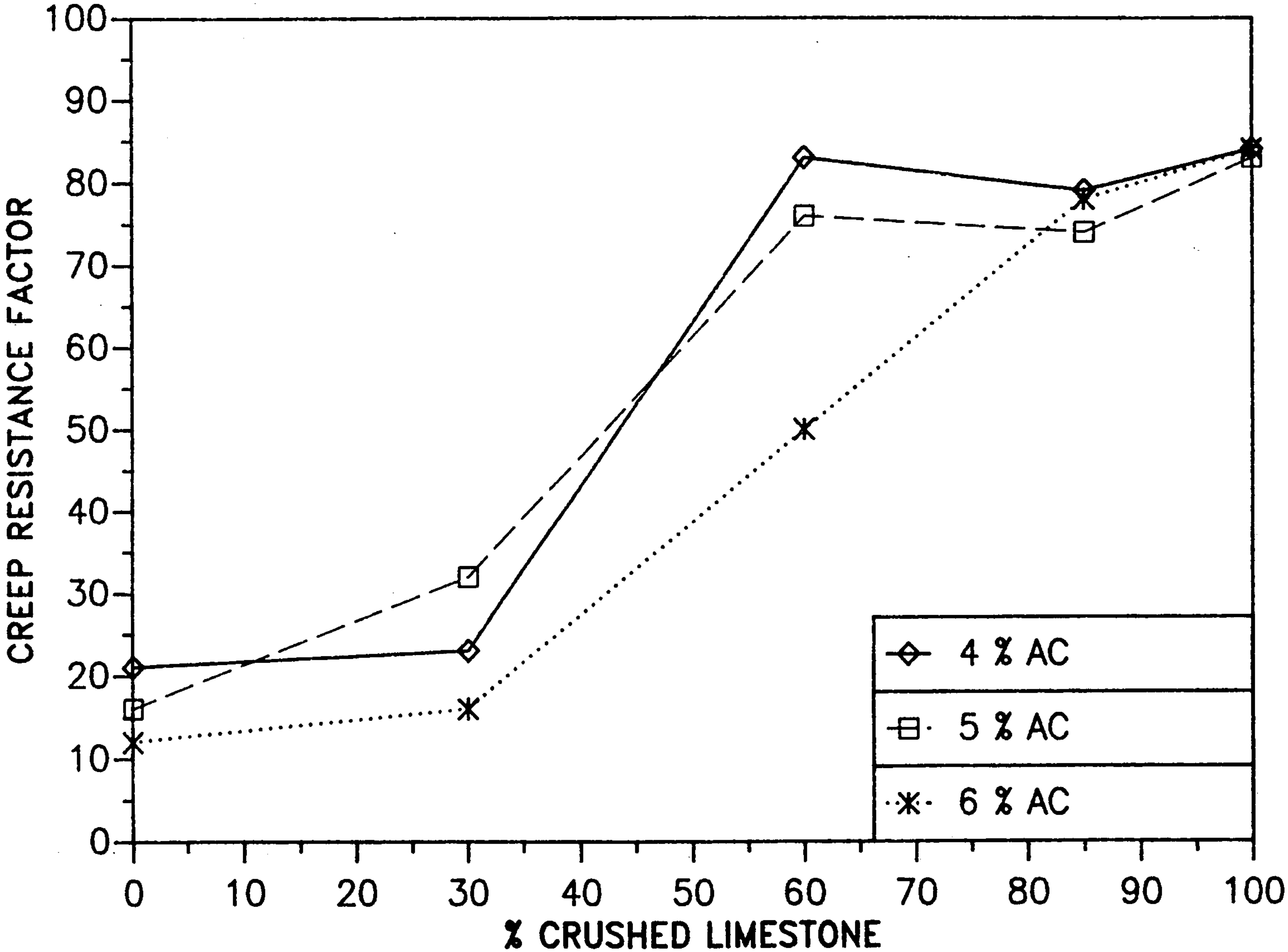

Figure 14

CREEP RESISTANCE FACTOR

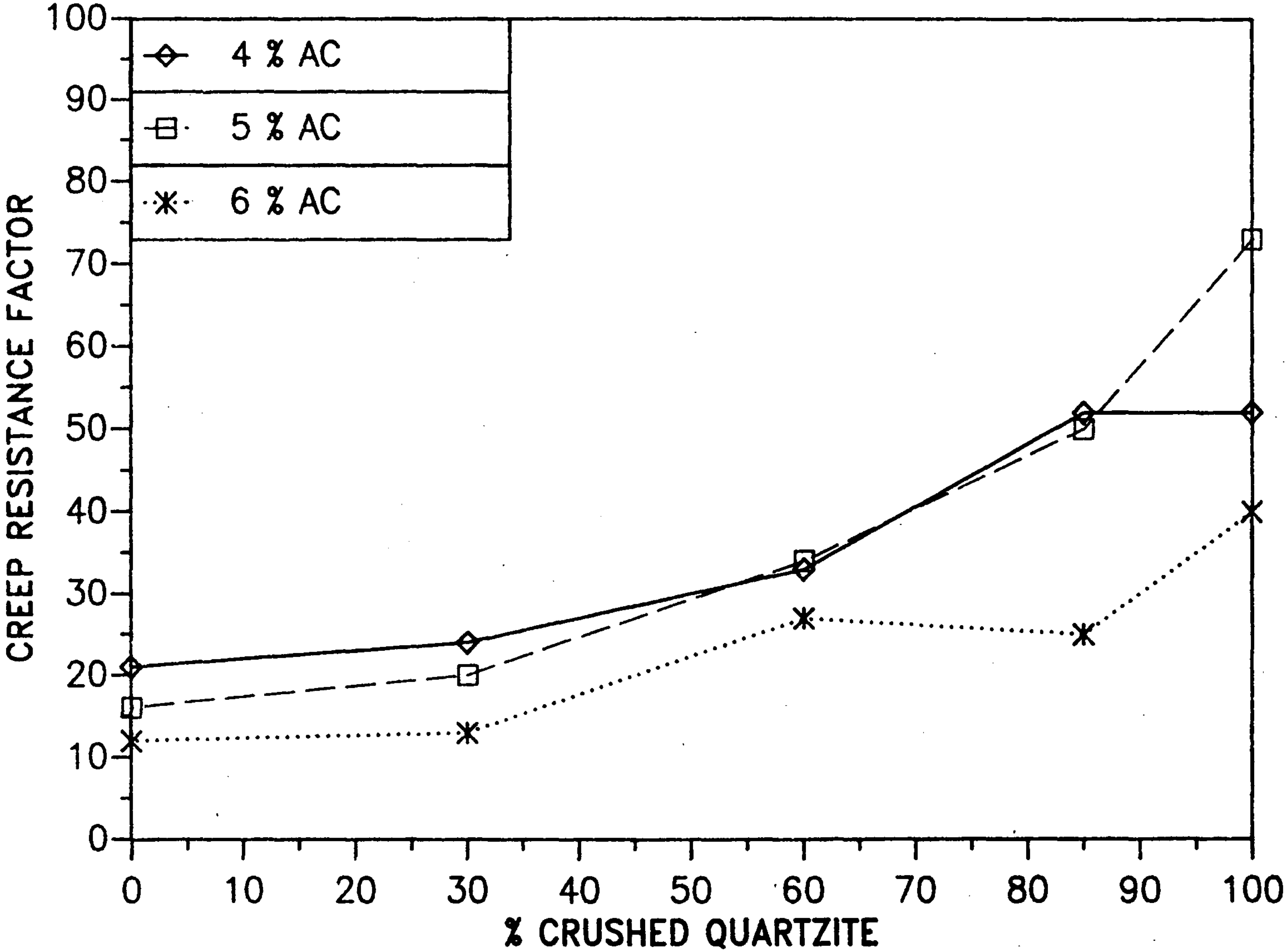

Figure 15

CREEP RESISTANCE FACTOR
5% ASPHALT CEMENT