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**16. ABSTRACT**

The results of a California Department of Transportation study to evaluate the structural properties of asphalt treated permeable base (ATPB) and open graded asphalt concrete (OGAC) are presented. Both laboratory and field investigations were used to determine the stiffness of ATPB and OGAC. The field investigation consisted of using Dynaflect deflection measurements before and after placement of an ATPB layer and comparing the percentage change in deflection to a section of pavement without ATPB. The results of these measurements show that the ATPB has a gravel equivalent factor equal to that of a dense graded AC pavement. Laboratory testing included both resilient modulus and R-value. The results from the resilient modulus tests show the modulus to average 141,000 psi for ATPB and 156,000 psi for OGAC. The results from the R-value tests were not used due to the low values obtained which were not consistent with the conclusions from the resilient modulus tests and the Dynaflect deflection measurements.

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STATE OF CALIFORNIA
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# STRUCTURAL VALUE OF ASPHALT TREATED PERMEABLE BASE AND OPEN GRADED ASPHALT CONCRETE

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## CONVERSION FACTORS

### English to Metric System (SI) of Measurement

| Quality | English unit | Multiply by | To get metric equivalent |
|---|---|---|---|
| Length | inches (in)or(") | 25.40<br>.02540 | millimetres (mm)<br>metres (m) |
| | feet (ft)or(') | .3048 | metres (m) |
| | miles (mi) | 1.609 | kilometres (km) |
| Area | square inches ($in^2$)<br>square feet ($ft^2$)<br>acres | $6.432 \times 10^{-4}$<br>.09290<br>.4047 | square metres ($m^2$)<br>square metres ($m^2$)<br>hectares (ha) |
| Volume | gallons (gal)<br>cubic feet ($ft^3$)<br>cubic yards ($yd^3$) | 3.785<br>.02832<br>.7646 | litre (l)<br>cubic metres ($m^3$)<br>cubic metres ($m^3$) |
| Volume/Time (Flow) | cubic feet per second ($ft^3/s$ | 28.317 | litres per second 1/s) |
| | gallons per minute (gal/min) | .06309 | litres per second (1/s) |
| Mass | pounds (lb) | .4536 | kilograms (kg) |
| Velocity | miles per hour (mph)<br>feet per second (fps) | .4470<br>.3048 | metres per second (m/s)<br>metres per second (m/s) |
| Acceleration | feet per second squared ($ft/s^2$) | .3048 | metres per second squared ($m/s^2$) |
| | acceleration due to force of gravity (G) ($ft/s^2$) | 9.807 | metres per second squared ($m/s^2$) |
| Density | ($lb/ft^3$) | 16.02 | kilograms per cubic metre ($kg/m^3$) |
| Force | pounds (lbs)<br>(1000 lbs) kips | 4.448<br>4448 | newtons (N)<br>newtons (N) |
| Thermal Energy | British thermal unit (BTU) | 1055 | joules (J) |
| Mechanical Energy | foot-pounds (ft-lb)<br>foot-kips (ft-k) | 1.356<br>1356 | joules (J)<br>joules (J) |
| Bending Moment or Torque | inch-pounds (in-lbs)<br>foot-pounds (ft-lbs) | .1130<br>1.356 | newton-metres (Nm)<br>newton-metres (Nm) |
| Pressure | pounds per square inch (psi) | 6895 | pascals (Pa) |
| | pounds per square foot (psf) | 47.88 | pascals (Pa) |
| Stress Intensity | kips per square inch square root inch ($ksi\sqrt{in}$) | 1.0988 | mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$) |
| | pounds per square inch square root inch ($psi\sqrt{in}$) | 1.0988 | kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$) |
| Plane Angle | degrees (°) | 0.0175 | radians (rad) |
| Temperature | degrees fahrenheit (F) | $\frac{+F - 32}{1.8} = +C$ | degrees celsius (°C) |
| Concentration | parts per million (ppm) | 1 | milligrams per kilogram (mg/kg) |

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## INTRODUCTION

The California Department of Transportation procedure for designing flexible pavement (1) is dependent upon knowing the relative strength of the various pavement layers making up the structural section. In the Caltrans procedure, these relative strength values are expressed as gravel equivalent factors ($G_f$) and vary from 1.0 for aggregate subbase to as high as 2.5 for asphalt concrete (AC) on low traffic volume roads. The $G_f$ values assigned to most materials have been developed and/or verified by various laboratory tests such as cohesiometer, R-value and unconfined compressive strength, along with test roads and field experience.

Two materials, asphalt treated permeable base (ATPB) and open graded asphalt concrete (OGAC), which are both widely used by Caltrans, were not used at the time the Gf values for other materials were developed. The 1.4 value currently assigned to these materials is an estimation based on limited data. Although these materials are used specifically to remove excess water, they do contribute to the total load support strength of the structural section. To design the most cost effective structural section, the correct $G_f$ of each layer must be known.

The objective of this research was to determine the $G_f$ values as well as other structural properties of the ATPB and OGAC. Both laboratory and field measurements were included in the study.

## CONCLUSIONS

1. When overlayed with a dense graded AC pavement, an ATPB drainage layer is as effective in reducing the deflection level as an equal thickness of AC.

2. The resilient modulus of ATPB and OGAC at 70°F averaged 141,000 psi and 156,000 psi, respectively. As a comparison, dense graded AC at 70°F averages 300,000 psi and aggregate base (AB) ranges from 10,000 psi to 100,000 psi depending on stress level.

3. The R-value test is not an appropriate test for ATPB. Laboratory tests indicate a value of only 64 which does not correlate with the results of the resilient modulus test and the deflection measurements. The low R-values for this material are due, in part, to the high void content of the mix.

## RECOMMENDATIONS

1. Assign the same gravel equivalent factor to ATPB and OGAC as dense graded AC.

2. Assign a resilient modulus of 141,000 psi to ATPB and 156,000 psi to OGAC.

3. Do not assign an R-value to ATPB.

4. Construct test sections designed with the gravel equivalent factors suggested in (1) to determine the minimum cover of AC required for satisfactory performance and to substantiate the results of this research.

## IMPLEMENTATION

Construct test sections using the suggested gravel equivalent factors form this research and monitor the performance under a future research project.

## BACKGROUND

### Gravel Equivalent Factors

No direct method has been developed for determining the $G_f$ of materials. It has, therefore, been necessary to develop relative values based on test track data, correlation with cohesiometer values and correlation with pavement deflection measurements.

The test track data came mainly from the American Association of State Highway Officials (AASHO) road test in the 1960's and consisted of comparing wedge-shaped thicknesses of a given material to a given thickness of aggregate subbase (AS). The thickness of material which gave the same performance as the AS was used to establish the $G_f$ of that material.

The cohesiometer (California Test 306) measures the cohesion of a material by breaking cores or laboratory-compacted specimens under controlled conditions. Prior to 1964, the cohesion values of paving materials were used in the design equation. When the results of the AASHO road test were published, the existing cohesiometer values for the various structural section elements were correlated to the $G_f$ values determined from the road test. In 1964, Caltrans revised the design procedures to include $G_f$ in lieu of cohesiometer values. As a result, cohesiometer values are no longer used except for special studies.

The use of deflection measurements to determine the $G_f$ for various paving materials came from research performed by the Transportation Laboratory (Translab) between 1955 and 1979 (2,3,4). This research established a correlation between the level of pavement performance and deflection. These studies also established a correlation between the gravel equivalent increase resulting from an AC overlay or pavement rehabilitation and the percentage decrease in pavement deflection. Figure 1 shows this relationship and is part of California Test 356 "Methods of Test to Determine Overlay Requirements by Pavement Deflection Measurements."

Earlier research beginning in 1938 established tolerable deflection criteria for various thicknesses of pavement and Traffic Indices (TI) from both laboratory and field measurements. The Tolerable Deflection Chart (Figure 2), was the result of this earlier research and is also part of California Test 356.

Two other tests which are sometimes used to evaluate the load bearing qualities of structural section materials are the Resistance (R) value test (California Test 301) and the Resilient Modulus test (AASHTO T274-82).

The R-value test is used to measure the capacity of soils and aggregates to resist lateral deformation when subjected to a vertical load. R-value is a primary factor in the Caltrans design procedure where it is used to determine the required thickness of the structural section.

The resilient modulus test provides a measure of the recoverable strain of structural section materials. The value is used in conjunction with the Poisson ratio for use in elastic layer theory models.

ATPB

Asphalt treated drainage layers were first used in California in 1967. At that time, Humboldt County used asphalt to stabilize the open graded aggregate layer of a two-layer drainage blanket. Shortly after, in 1968, Caltrans installed its first asphalt treated drainage layer on a project which was also in Humboldt County. Because of the success of these projects, Caltrans began to apply the process to other drainage layers around the state. The material subsequently became known as asphalt treated permeable material (ATPM).

In 1974, TransLab reported the results of a study (5) to evaluate the performance of seven highly efficient two-layer drainage systems on which the open graded drainage layer had been stabilized with 1.5 to 2.0 percent paving grade asphalt. One conclusion of that study was that the asphalt stabilized layer eliminates the problem of excessive displacement during placement of overlying elements of the structural section.

No attempt was made to establish the structural value of the asphalt treated drainage layer until 1979. At that time, a minor research project (6) was initiated in an effort to determine a $G_f$ value for both ATPM and OGAC. A project in Tehama county was selected for this study. During the summer of 1979, two structural sections were constructed using ATPM. Another section which did not include ATPM was constructed to serve as a control.

One test section consisting of 0.4 foot AC, 0.25 foot ATPM and 1.4 feet of AB was constructed over a relatively low quality basement soil with an R-value of 17. The second test section was similar except that the thickness of the AB was reduced to 0.75 foot because of the 34 R-value basement soil in that area. The control section which was placed over a 19 R-value basement soil consisted of 0.4 foot AC over 1.65 feet of AB. Thus, the ATPM was assumed to have the same structural value as the AB and was substituted on a one-for-one basis.

Deflection measurements were taken upon completion of the AB, ATPM and AC layers in each of the three areas. Deflection measurements were also taken on the AC in November 1979, April 1980, and January 1981. Since the deflections on the AB layer of the control section were nearly the same as the deflections on the test section with 1.4 feet of AB, these two sections were selected for comparison. Based on this evaluation, which was reported in a TransLab minor research report (6), the ATPM had an apparent $G_f$ of 1.4. The author of that report noted, however, that this value was sensitive to the initial deflection level. He also suggested that future research include projects which have a higher initial deflection to overcome the sensitivity (or lack thereof) of the Dynaflect device used to make the measurements.

Since ATPM was first used, the specifications have been revised to improve its structural value. The most significant change was the addition of the requirement that 90% of the aggregate be crushed. The name of the material was also changed to asphalt treated permeable base (ATPB) to more accurately reflect its principal usage, i.e., a base. The latest ATPB specification was first adopted in late 1984 as Standard Special Provision 29.01. The same specification was later included in the 1988 Standard Specifications and was in effect for all of the construction projects included in this study. A comparison of the original ATPM and the current ATPB specifications is presented in Table 1.

Table 1

COMPARISON OF ATPM AND ATPB SPECIFICATIONS
Percentage Passing

| Sieve Size | ATPM-1967 | ATPM-1979 | ATPM-1984 | ATPB-1988 |
|---|---|---|---|---|
| 1" | 100 | 100 | 100 | 100 |
| 3/4" | 90-100 | 92-100 | 50-100 | 90-100 |
| 1/2" | - | 54-63 | - | 35-65 |
| 3/8" | 40-70 | 29-42 | 15-50 | 20-45 |
| No. 4 | 0-10 | 4-6 | 0-5 | 0-10 |
| No. 8 | 0-5 | 0-1 | 0-5 | 0-5 |
| No. 200 | - | 0-1 | 0-2 | 0-2 |

In addition to the above gradation for the 1988 specification, ATPB aggregate must also conform to the following quality requirements prior to the addition of the asphalt:

| | California Test Number | Requirement |
|---|---|---|
| Percentage of Crushed Particles (min.) ......... | 205 | 90% |
| Los Angeles Rattler Loss at 500 Rev. (max.)..... | 211 | 45% |
| Cleanness Value (min.) ......................... | 227 | 57 |
| Film Stripping (max.) .......................... | 302 | 25% |

OGAC

Open graded asphalt concrete (OGAC) has been used in some areas of California since the early 1960's. Its purpose is to provide an open textured pavement through which excess water can escape from under vehicle tires and reduce the potential for hydroplaning. The material has functioned satisfactorily for this purpose but its contribution to the load bearing capability of the structural section has not been satisfactorily defined.

An attempt was made to establish the $G_f$ for OGAC in 1979 and the results were reported in the same study (6) referred to previously. An overlay project in Glenn county was selected for evaluation of OGAC. The project was constructed during the summer of 1979 and consisted of overlaying the existing pavement with 0.15 foot dense graded AC followed by 0.06 foot of 3/8 inch maximum OGAC conforming to the 1975 Standard Specifications.

The OGAC section was compared to a 1000 foot control section of 0.20 foot AC without OGAC. Again, Dynaflect deflection measurements were used to compare the OGAC section to the AC control section.

No conclusions on the strength of the OGAC could be made due to the small change in deflection resulting from the OGAC. The author recommended that future investigations study only pavements having a greater thickness of OGAC.

## DISCUSSION

The work plan for this study called for both laboratory and field testing to evaluate the structural properties of the ATPB and OGAC materials.

R-value (California Test 301) and resilient modulus (AASHTO T274-82) were selected as the laboratory tests most suited to the evaluation of ATPB. Only the resilient modulus test was used for the OGAC. In the field, deflection measurements were again used to determine the difference in stiffness of the alternative structural sections.

## FIELD EVALUATIONS

It was originally anticipated that materials from six construction projects would be used in the evaluations. However, due to construction constraints, only three projects were suitable for field testing the ATPB. None of the OGAC projects were of value because of insufficient OGAC thickness.

The three projects that were used to evaluate the ATPB represented a wide range of basement soils and climatic conditions. One was in the Sierra Nevada foothills where the annual rainfall is approximately 50 inches. Another was on the mud flats of a coastal bay and the third was in southern California. Descriptions of these three projects are presented below:

3-Nev-20-R6.3/R12.2

This realignment of State Route 20 between Penn Valley and Grass Valley was constructed between 1982 and 1984. The structural section of the mainline served as the control since ATPB was not included in the design. Two test sections having ATPB were constructed in the westbound lane. Both the control and test sections were designed based on a Traffic Index of 9.5 and a subgrade R-value of 40. For this project, the ATPB was substituted for an equal thickness of AB, thus assuming a $G_f$ of only 1.1. The structural sections are shown below:

Structural Section
Layer Thickness-feet

| Layer | Control Section | ATPB Section |
|---|---|---|
| AC | 0.45 | 0.45 |
| ATPB | - | 0.25 |
| AB | 0.90 | 0.65 |

Deflection measurements were taken on the AB layer and the first AC layer in August 1984. Measurements were also taken in April 1985 on the final surface. The results of the AB and final AC lift deflection measurements are shown below.

AVERAGE DYNAFLECT DEFLECTION
(in. x $10^{-3}$)

| Test Date | Layer | Control Section | ATPB Section |
|---|---|---|---|
| 8-13-84 | AB | 1.05 | 1.08 |
| 8-24-84 | AC (0.15' thick) | 0.92 | 0.93 |
| 4-30-85 | AC (0.45' thick) | 0.74 | 0.52 |

The percentage change in deflection from measurements on the AB to the final AC lift was 30 for the control section and 52 for the ATPB section. The $G_f$ for the ATPB can be determined using the following relationship:

$$\frac{52}{G_{f1}(T_{AC}) + G_{f2}(T_{ATPB})} = \frac{30}{G_{f1}(T_{AC})}$$

where: $G_{f1}$ = gravel equivalent factor of AC
$G_{f2}$ = gravel equivalent factor of ATPB
$T_{ATPB}$ = ATPB thickness
$T_{AC}$ = AC thickness

Substituting the thicknesses of the AC and ATPB in the above equation and using 1.9 for the gravel equivalent factor for AC, the ATPB gravel equivalent factor for this project was 2.5.

4-Ala-84-R0.7/R3.0

This realignment of the approach to the Dumbarton Bridge was constructed in 1984. The structural section required the use of select material (SM) having an R-value of 30 because of the low R-value of the existing subgrade. The structural section was based on the R-value of this material and a TI of 13. Since the structural section already included ATPB, a 200 foot control section was built for comparison. The ATPB was replaced for an equal thickness of AC for the control section. The structural sections are shown below:

Structural Section
Layer Thickness-feet

| Layer | Control Section | ATPB Section |
|---|---|---|
| AC | 0.95 | 0.70 |
| ATPB | - | 0.25 |
| SM | 1.00 | 1.00 |

Deflection measurements were taken at the following times and on the following surfaces:

| DATE OF MEASUREMENT | ATPB SECTION | CONTROL SECTION |
|---|---|---|
| 8-30-84 | 1.00′ SM | 1.00′ SM |
| 9-17-84 | 0.25′ ATPB/SM | 1.00′ SM |
| 10-1-84 | 0.50′ AC/0.25′ ATPB/SM | 0.75′ AC/SM |
| 5-6-85 | 0.70′ AC/0.25′ ATPB/SM | 0.95′ AC/SM |

The results of the above measurements are shown below:

AVERAGE DYNAFLECT DEFLECTION
(in. x $10^{-3}$)
4-Ala-84-R0.7/R3.0

| Section Description | 8-30-84* | 9-17-84 | 10-1-84 | 5-6-85 |
|---|---|---|---|---|
| CONTROL-#1 LANE | 0.63 | 0.68 | 0.60 | 0.50 |
| CONTROL-#2 LANE | 0.54 | 0.61 | 0.40 | 0.50 |
| ATPB-#1 LANE | 0.55 | 0.52 | 0.63 | 0.40 |
| ATPB-#2 LANE | 0.59 | 0.54 | 0.41 | 0.43 |

* Date of measurement

The above results show that the initial deflection for each test section was extremely low. This presented a problem in determining the percentage reduction in deflection since the error of the Dynaflect is $\pm 0.05 \times 10^{-3}$ inches or approximately 20% of the initial deflection. Even though there was no significant reduction in deflection, the results of these tests are still valuable for determining the Gf of ATPB. It is important to note also that there was no significant increase in deflection because of the inclusion of ATPB in the stuctural section.

8-SBd-71-0.0/8.4

This pavement rehabilitation project was constructed in 1984. The design for the pavement structural section of the mainline was 0.30 foot AC over the existing pavement in the fill areas and 0.20 foot AC over 0.25 foot ATPB over the existing pavement in the cut areas. This design was based on the results of California Test 356 and a TI of 10.0. Four test sections in the cut areas served as ATPB test sections and one test section in the fill area served as a control. Cores taken in each of the four ATPB test sections soon after construction showed the average AC thickness was 0.32′ and the average ATPB thickness was 0.20′. A core taken in the control section showed that the AC thickness was 0.35′. The results of the Dynaflect deflection measurements are as follows:

AVERAGE DYNAFLECT DEFLECTION
(in. x $10^{-3}$)
8-SBd-71-0.0/8.4)

| Section Description | 8-29-84 (Exist AC surface) | 11-7-85 (New AC surface) | Percent Reduction in Deflection |
|---|---|---|---|
| ATPB 1 | 1.63 | 0.83 | 49 |
| ATPB 2 | 2.11 | 0.86 | 59 |
| ATPB 3 | 2.62 | 1.37 | 48 |
| ATPB 4 | 2.06 | 1.24 | 40 |
| CONTROL | 2.05 | 1.45 | 29 |

Using an average percent reduction of 49 for the ATPB test sections and 29 for the control section, the $G_f$ of ATPB for this project was calculated as follows:

$$\frac{49}{(1.9)(0.32') + G_{f2}(0.20')} = \frac{29}{(1.9)(0.35')}$$

where: $G_{f2}$= gravel equivalent factor of ATPB

The $G_f$ for ATPB for this project was calculated to be 2.6.

## LABORATORY TESTING

The R-value test and the resilient modulus test were used to evlauate ATPB, whereas, only the resilient modulus test was used to evaluate the OGAC. The ATPB samples used for the R-value test were prepared entirely in the laboratory so that the grading, percentage of crushed particles and asphalt content could be precisely controlled. ATPB and OGAC samples used in the resilient modulus tests were taken from ongoing Caltrans projects.

The first series of R-value tests was completed in 1984. The aggregate was sized and batched in the laboratory to conform to the coarse and fine limits of the ATPM grading specifications that were in effect at the time (see Table 1, page 5). Natural and crushed aggregates were blended so that crushed particles made up exactly 25 percent of each size fraction. Two percent AR-4000 asphalt was added to the treated test specimens but replicate samples were also prepared and tested without asphalt. The test specimens were compacted according to the R-value procedures using a kneading compactor applying a pressure of 350 psi. Paper baskets were used to contain the mix and facilitate transferring the test specimen from the compaction mold to the stabilometer. During compaction, a rubber disk was placed on the top and bottom of the sample to reduce crushing of the aggregate.

The asphalt treated specimens were heated to 230°F immediately prior to compaction. The compacted specimens were cooled to room temperature (approximately 72°F) prior to performing the stabilometer portion of the test.

The results of these series of tests are presented in Table 2.

Table 2

R-VALUE TESTS OF ATPM

| Sieve Size | Specification Limit* | Test Sample Grading (Percent Passing) #1 | #2 | #3 | #4 | #5 | #6 | #7 | #8 |
|---|---|---|---|---|---|---|---|---|---|
| 1" | 100 | 100 | 100 | 100 | 100 | | | | |
| 3/4" | 50-100 | 50 | 50 | 50 | 50 | 100 | 100 | 100 | 100 |
| 1/2" | - | 28 | 28 | 28 | 28 | 63 | 63 | 63 | 63 |
| 3/8" | 15-50 | 15 | 15 | 15 | 15 | 50 | 50 | 50 | 50 |
| No. 4 | 0-5 | 0 | 0 | 0 | 0 | 5 | 5 | 5 | 5 |
| No. 8 | 0-5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No. 200 | 0-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| % Crushed Particles | 25 min. | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| % Asphalt | | 2.0 | 2.0 | 0.0 | 0.0 | 2.0 | 2.0 | 0.0 | 0.0 |
| Test Results | | | | | | | | | |
| Turns Displ. | | 7.5 | 7.5 | 9.3 | 9.3 | 4.9 | 4.9 | 8.2 | 8.2 |
| Ph @ 2000 lbs | | 37 | 38 | 32 | 28 | 44 | 39 | 28 | 26 |
| R-value | | 52 | 51 | 52 | 56 | 57 | 61 | 62 | 61 |

*Specification from 1984 Standard Special Provisions.
Ph-Horizontal pressure

The low R-values of the samples were attributed to the large voids in the mix which in turn resulted in a high number of turns displacement. The turns displacement is used in the R-value equation as a way of normalizing surface irregularities in the sidewall of the sample. A lower R-value results from a greater number of turns. As the number of turns displacement increases, the R-value decreases. However, the validity of the turns displacement measurement is questionable on materials such as ATPB which has excessive surface voids. It is reasoned that a significant portion of the measurement is due to the stabilometer diaphragm being forced into the surface voids.

After the specification for ATPB was changed to require 90% crushed aggregate (Table 1) additional R-value tests were performed using the middle of the new gradation limits. The procedure for compacting and testing the samples was the same as used previously. The gradation of the mix and the test data are shown in Table 3.

Table 3

R-VALUE TESTS OF ATPB

| Sieve Size | Specication Limits* | Test Sample Grading (Percent Passing) #1 | #2 | #3 | #4 | #5 | #6 |
|---|---|---|---|---|---|---|---|
| 1" | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 3/4" | 90-100 | 95 | 95 | 95 | 95 | 95 | 95 |
| 1/2" | 35-65 | 50 | 50 | 50 | 50 | 50 | 50 |
| 3/8" | 20-40 | 32 | 32 | 32 | 32 | 32 | 32 |
| No. 4 | 0-10 | 5 | 5 | 5 | 5 | 5 | 5 |
| No. 8 | 0-5 | 0 | 0 | 0 | 0 | 0 | 0 |
| No. 200 | 0-2 | 0 | 0 | 0 | 0 | 0 | 0 |
| % Crushed Particles | 90 min. | 90 | 90 | 90 | 90 | 90 | 90 |
| % Asphalt | | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Test Results | | | | | | | |
| Turns Displ. | | 5.7 | 6.0 | 6.2 | 5.8 | 5.7 | 6.1 |
| Ph @ 2000 lbs | | 32 | 34 | 28 | 28 | 32 | 24 |
| R-value | | 63 | 60 | 65 | 66 | 63 | 67 |

Ph-Horizontal pressure

* Specification from 1988 California Standard Specifications

The average of the six tests was 64. This is higher than any of the previous tests, but still lower than a Class 2 AB which has a specified minimum R-value of 78. As stated above, the high void content probably increased the displacement measurement which, in turn, caused the R-value to be unrealistically low.

Resilient modulus testing of the ATPB and OGAC was done in accordance with AASHTO T274-82 with modifications suggested by the Institute of Pavement Studies at the University of California at Berkeley.

The procedure consisted of the following steps:

1. The ATPB and OGAC were heated to 230°F prior to compaction.

2. Compaction was accomplished with a kneading compactor applying a pressure of 350 psi.

3. The 8-inch high test specimens were compacted in four 2-inch layers.

4. Test specimens were cooled to room temperature (approximately 70°F) prior to testing.

5. Preconditioning of the test specimens was accomplished by applying 100 repetitions of each of the pressures shown in Table 4.

6. Testing included 50 repetitions of each of the stress combinations shown in Table 5.

Table 4

STRESS SEQUENCE FOR PRECONDITIONING SAMPLE

| Deviator Stress (psi) | Confining Pressure (psi) |
|---|---|
| 12 | 10 |
| 30 | 10 |
| 30 | 15 |
| 45 | 15 |
| 45 | 20 |
| 60 | 20 |
| 60 | 30 |
| 60* | 30 |

* This pressure was reduced from UCB's recommended 90 psi to 60 psi due to constraints on the machine.

Table 5

STRESS SEQUENCE FOR RESILIENT MODULUS TESTS

| Sequence No. | Deviator Stress (psi) | Confining Pressure (psi) |
|---|---|---|
| 1 | 12 | 10 |
| 2 | 20 | 10 |
| 3 | 30 | 10 |
| 4 | 16 | 15 |
| 5 | 30 | 15 |
| 6 | 45 | 15 |
| 7 | 20 | 20 |
| 8 | 40 | 20 |
| 9 | 60 | 20 |
| 10 | 30 | 30 |
| 11 | 60 | 30 |
| 12 | 60* | 30 |
| 13 | 40 | 20 |
| 14 | 20 | 10 |
| 15 | 12 | 5 |
| 16 | 20 | 5 |
| 17 | 12 | 5 |
| 18 | 20 | 10 |
| 19 | 40 | 20 |
| 20 | 60* | 30 |
| 21 | 60 | 30 |
| 22 | 30 | 30 |
| 23 | 60 | 20 |
| 24 | 40 | 20 |
| 25 | 20 | 20 |
| 26 | 45 | 15 |
| 27 | 30 | 15 |
| 28 | 16 | 15 |
| 29 | 30 | 10 |
| 30 | 20 | 10 |
| 31 | 12 | 10 |

* This pressure was reduced from UCB's recommended 90 psi to 60 psi due to constraints on the machine.

The average of the recoverable deformations recorded during the last five repetitions was used to determine the resilient modulus (Mr) using the following relationship:

$$Mr = \sigma_D / \varepsilon$$

where:

Mr = resilient modulus
$\sigma_D$ = deviator stress
$\varepsilon$ = recoverable strain

The results of the resilient modulus tests on the ATPB are shown in Table 6 and tests on the OGAC are shown in Table 7. Figures 3 to 27 show plots of Mr versus the sum of the principal stresses. The poor coefficient of correlation ($R^2$) of many of the test samples is probably due to the large voids in the ATPB and OGAC mixes.

Table 6

RESILIENT MODULUS TEST RESULTS
ATPB

| Sample Description | Average Mr, psi | Standard Deviation, psi | Coeff. of Corr. $R^2$ |
|---|---|---|---|
| Station 380+00 #1 | 155,149 | 26,751 | .18 |
| Station 380+00 #2 | 117,513 | 19,989 | .05 |
| Station 380+00 #3 | 127,251 | 13,762 | .10 |
| Station 172+50 #1 | 164,810 | 48,677 | .27 |
| Station 172+50 #2 | 118,245 | 22,151 | .32 |
| Station 177+00 | 147,870 | 17,812 | .58 |
| Station 198+00 #1 | 174,754 | 25,929 | .48 |
| Station 198+00 #2 | 114,601 | 15,770 | .25 |
| Station 537+00 #1 | 133,489 | 18,170 | .49 |
| Station 537+00 #2 | 113,181 | 19,390 | .26 |
| Station 537+00 #3 | 113,978 | 17,706 | .59 |
| Station 852+00 #1 | 201,656 | 34,283 | .13 |
| Station 852+00 #2 | 139,595 | 18,442 | .41 |
| Station 852+00 #3 | 149,575 | 25,163 | .32 |
| Combined | 140,833 | 35,652 | .34 |

Table 7

RESILIENT MODULUS TEST RESULTS
OGAC

| Sample Description | Average Mr, psi | Standard Deviation, psi | Coeff. of Corr. $R^2$ |
|---|---|---|---|
| Baker #1 | 162,082 | 30,601 | .32 |
| Baker #2 | 130,129 | 15,295 | .24 |
| Station 494+00 #1 | 163,146 | 23,669 | .35 |
| Station 494+50 #2 | 169,129 | 20,797 | .04 |
| Station 9+75 #1 | 138,910 | 21,662 | .25 |
| Station 9+75 #2 | 102,265 | 13,531 | .61 |
| SBD-15-#1 | 157,774 | 19,447 | .38 |
| SBD-15-#2 | 229,818 | 29,465 | .26 |
| Combined | 156,657 | 41,261 | .28 |

The results of the OGAC agrees closely with research done by others (7,8). Monismith, et. al., showed that the resilient modulus for open-graded AC mixtures using partially crushed gravel averaged 522,000 psi for samples tested at 40°F and 159,000 psi for samples tested at 72°F. Research by Hicks, et. al., showed the modulus averaged 70,000 psi at 90°F. and 155,000 to 270,000 at 75°F depending on confining pressure.

## SUMMARY

The average gravel equivalent factor of ATPB as determined by deflection measurements was 2.5. The percentage reduction in deflection for the ATPB section was higher than the AC section for the same given thickness. This would infer that ATPB is stronger than the AC and should, therefore, be assigned a higher gravel equivalent factor than the presently used value of 1.4.

The results of the laboratory tests were conflicting. The R-value tests showed the ATPB to have less stiffness than AB whereas the resilient modulus tests showed that both ATPB and OGAC have greater stiffness than AB. This discrepancy could be attributed to the different nature of the tests. The R-value test uses a much lower confining pressure than the resilient modulus test which would influence the results for materials such as ATPB. Another difference between the two tests is the turns displacement used in the R-value test. The irregular shape of materials such as ATPB causes a high number of turns displacement which results in an even lower R-value. It appears, therefore, that more credence should be given to the the results of the resilient modulus tests than to the R-value tests. No direct correlation is available between resilient modulus and gravel equivalent. However, a correlation does exist between resilient modulus and AASHTO's structural coefficient. For the resilient modulus values determined from this research, the structural coefficient was 0.25 which is comparable to a low strength dense graded AC. (The structural coefficient for dense graded AC is 0.44). This compares to another report by Hicks, et. al. (9), who showed the structural coefficient of OGAC to average 0.40 which is nearly equal to dense graded AC.

Since the resilient modulus tests indicated that the strength of ATPB was nearly equal to dense graded AC and deflection measurements indicated that the strength was greater, it follows that the Gf assigned to ATPB should be equal to dense graded AC. The calculated average Gf of 2.5 for ATPB is higher than the Gf assigned to dense graded AC for TI's greater than 5.0. Therefore, it is recommended that the ATPB be assigned a Gf equal to the Gf of AC. It is further recommended that the ATPB be substituted on a 1:1 basis for dense graded AC up to a maximum of 0.25 foot thick. To further support this conclusion, recent Caltrans projects using thin layers of AC over ATPB are performing well after 2 to 3 years of service. These projects contained structural sections which were designed to have thinner AC layers than the normal Caltrans design method.

Since the OGAC had nearly the same resilient modulus value as ATPB, it should also be given the same Gf as dense graded AC.

The results of the R-value test will not be used due to the reasons stated above.

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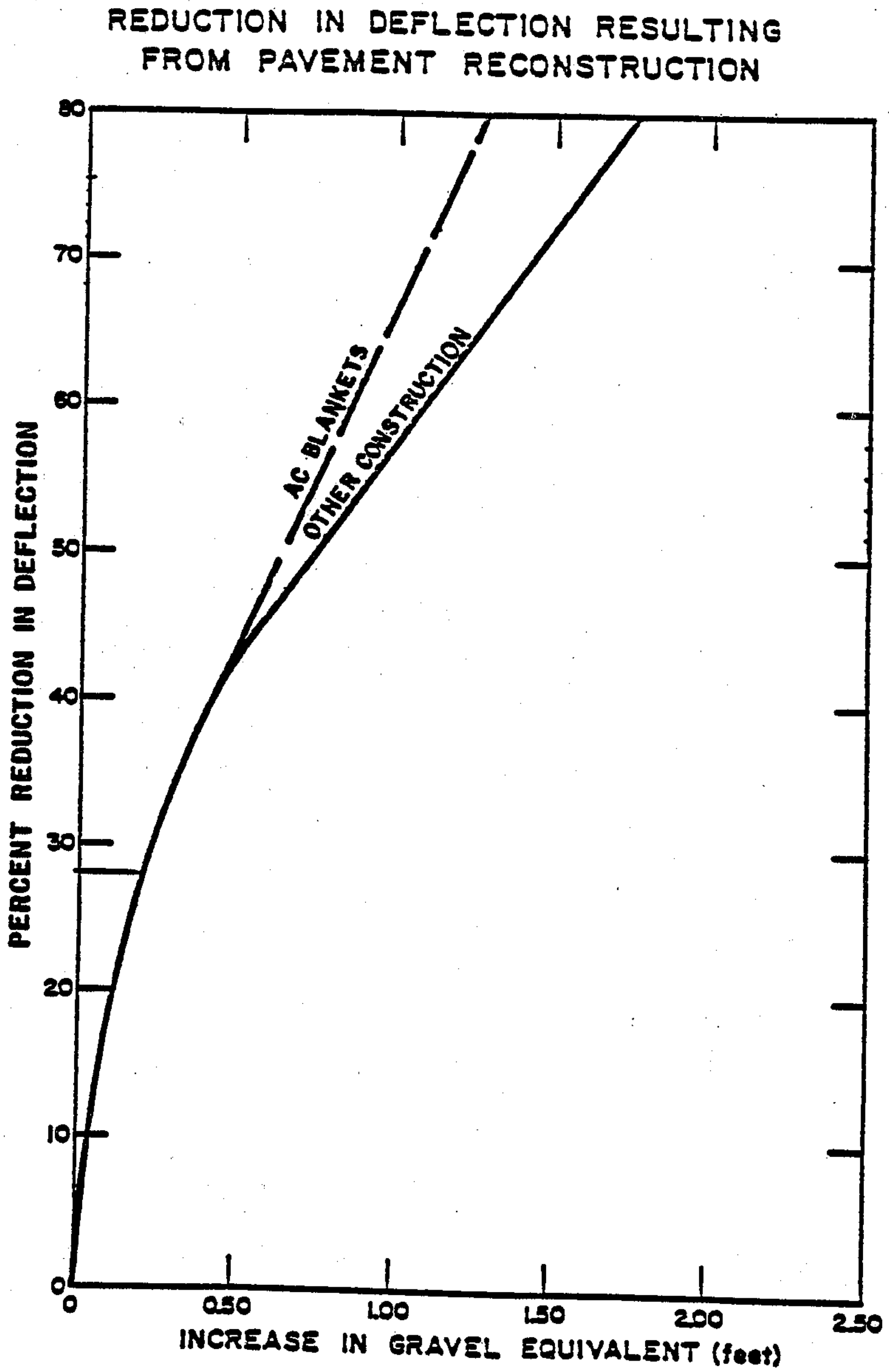
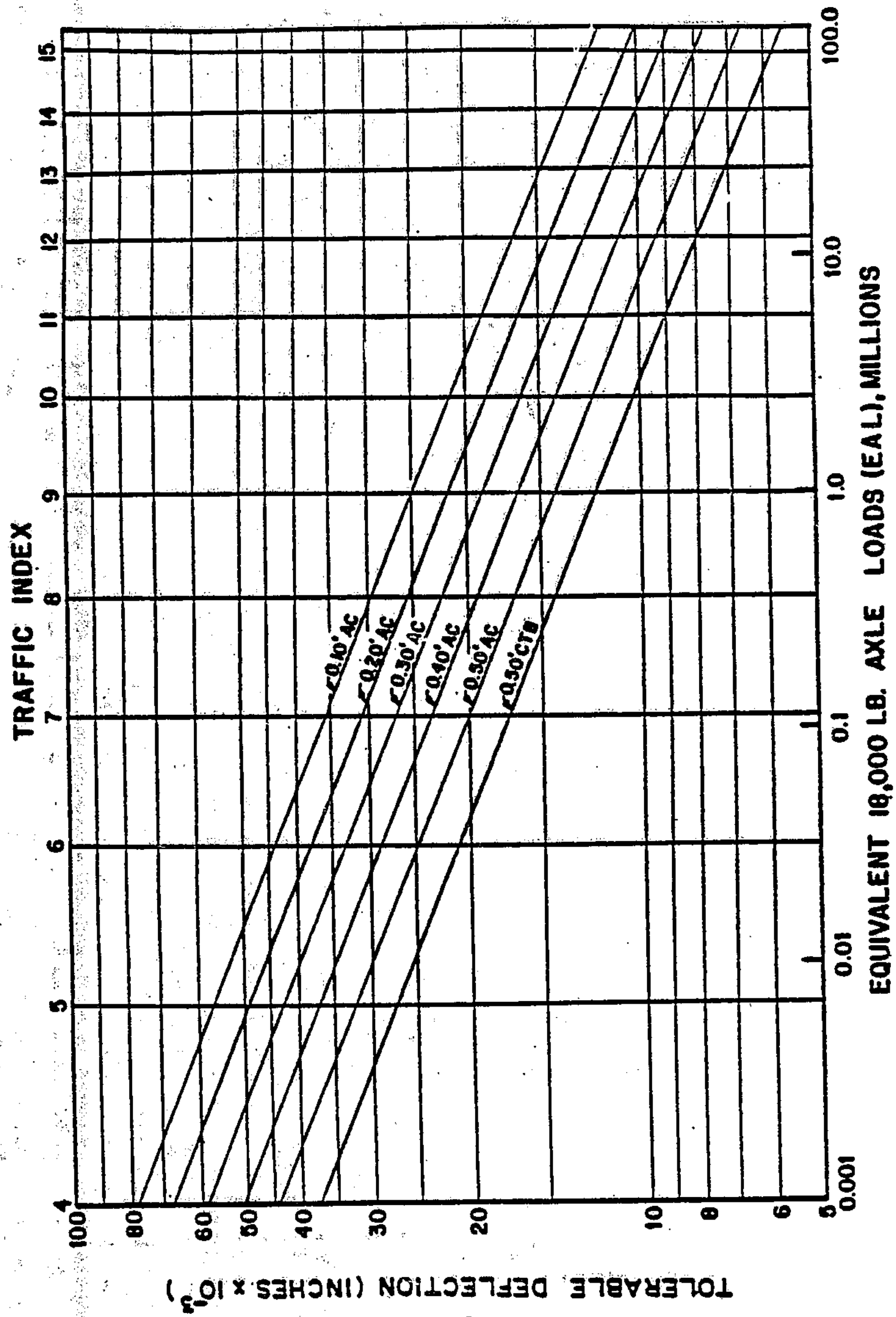
8. Hicks, R.G., L.E. Santucci, D.G. Fink and R. Williamson, "Performance Evaluation of Open-Graded Emulsified Asphalt Pavements," Presented at the Annual Meeting of Asphalt Paving Technologists, Atlanta, Georgia, February 28, March 1-2, 1983.

9. Hicks, R.G., L.E. Santucci, D.G. Fink and R. Williamson, "Effect of Laboratory Curing and C mpaction Methods on the Stress-Strain Behavior of Open-Graded Emulsion Mixes," Prepared for Presentation and Publication at the 1979 Annual Meeting of the Transportation Research Board, Washington D.C. Janduary 1979.

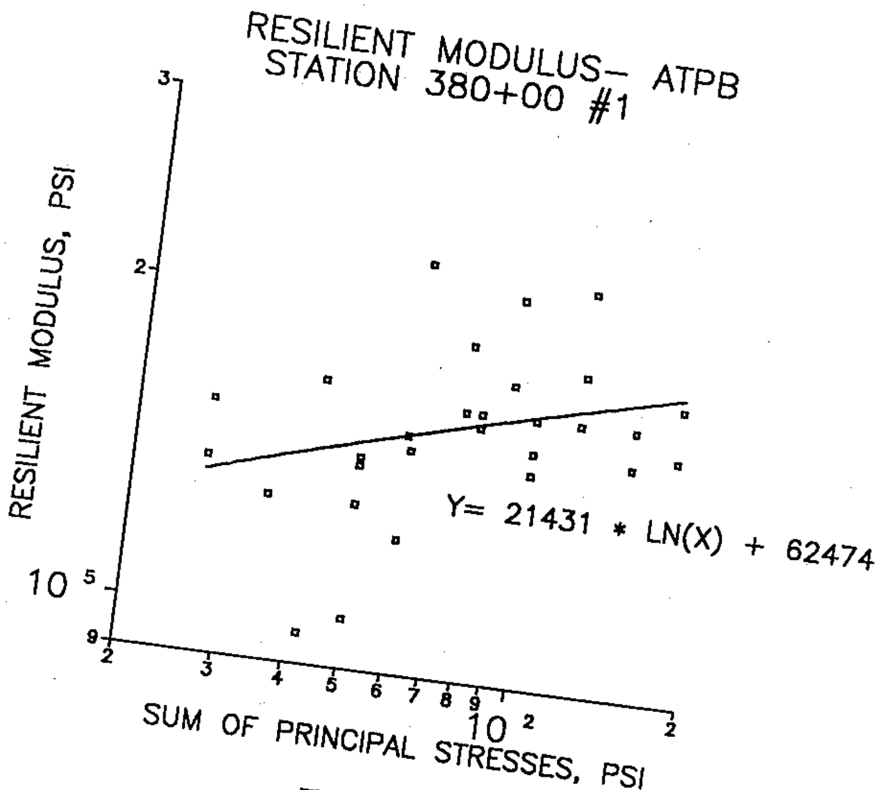
Figure 1


REDUCTION IN DEFLECTION RESULTING
FROM PAVEMENT RECONSTRUCTION
PERCENT REDUCTION IN DEFLECTION
0
10
20
30
40
50
60
70
80
0
0.50
1.00
1.50
2.00
2.50
INCREASE IN GRAVEL EQUIVALENT (feet)
AC BLANKETS
OTHER CONSTRUCTION




TOLERABLE DEFLECTION CHART

Figure 2

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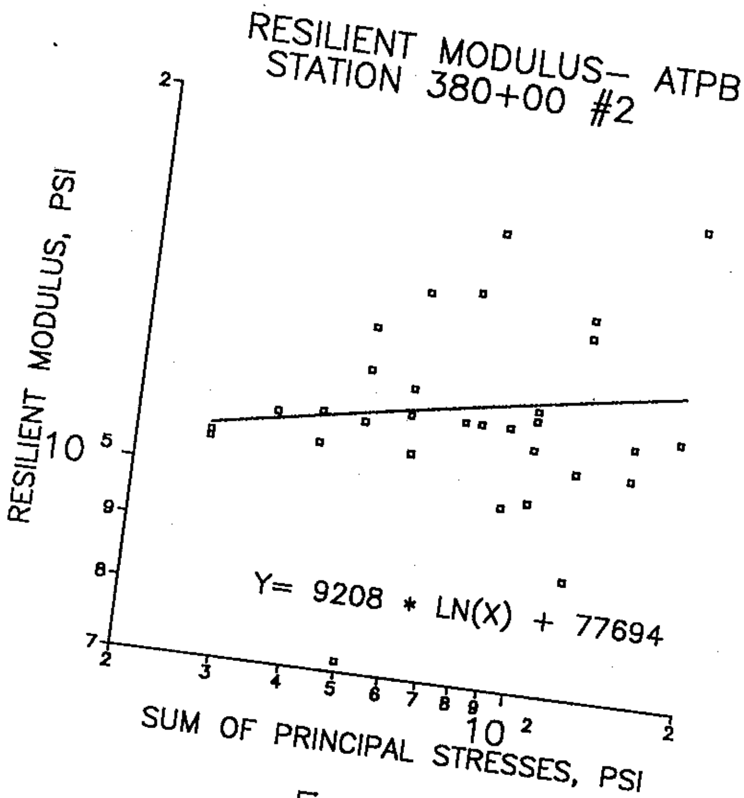


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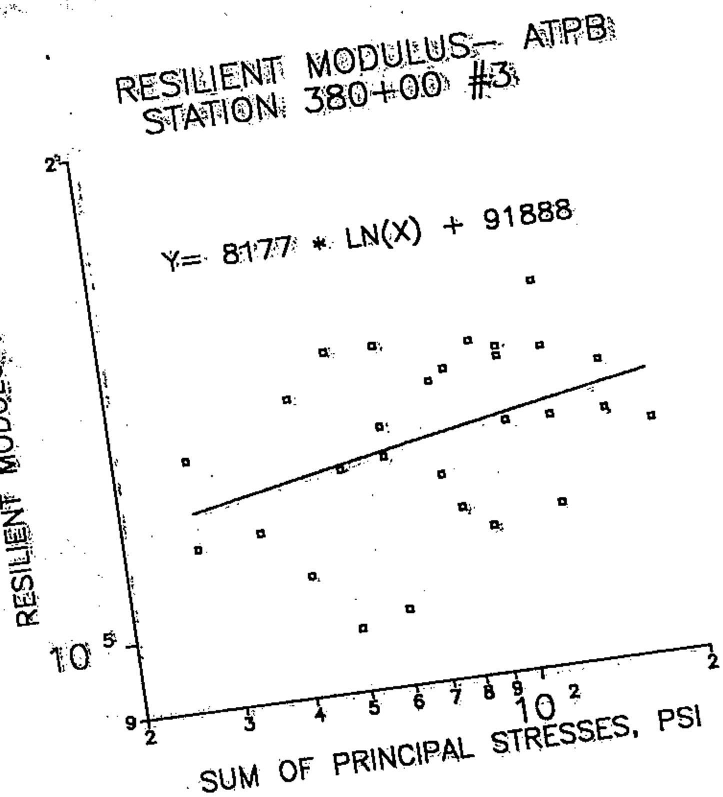


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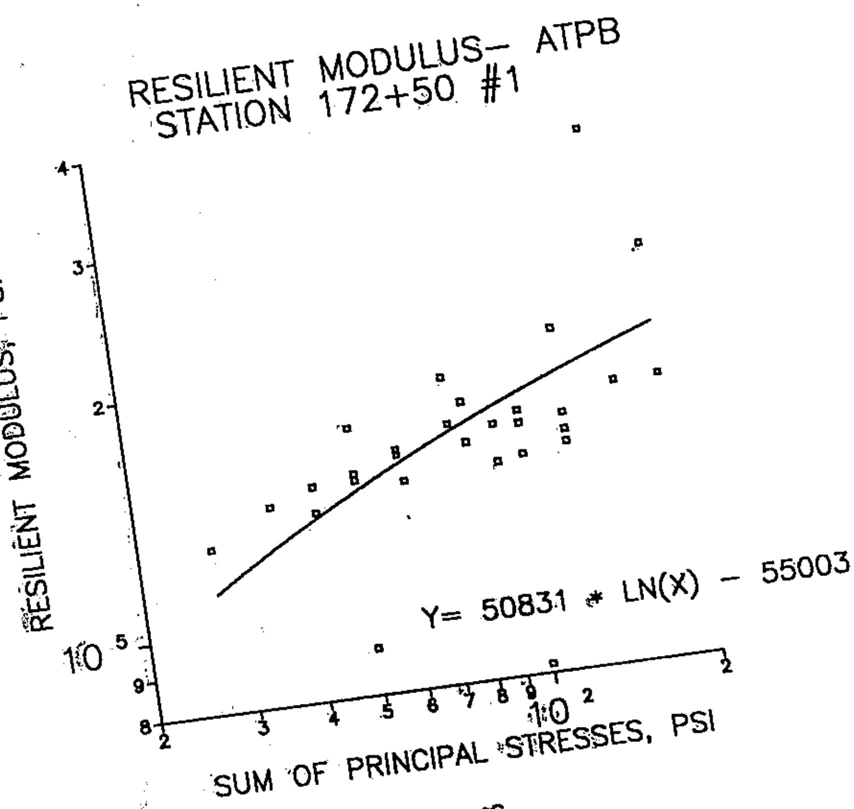


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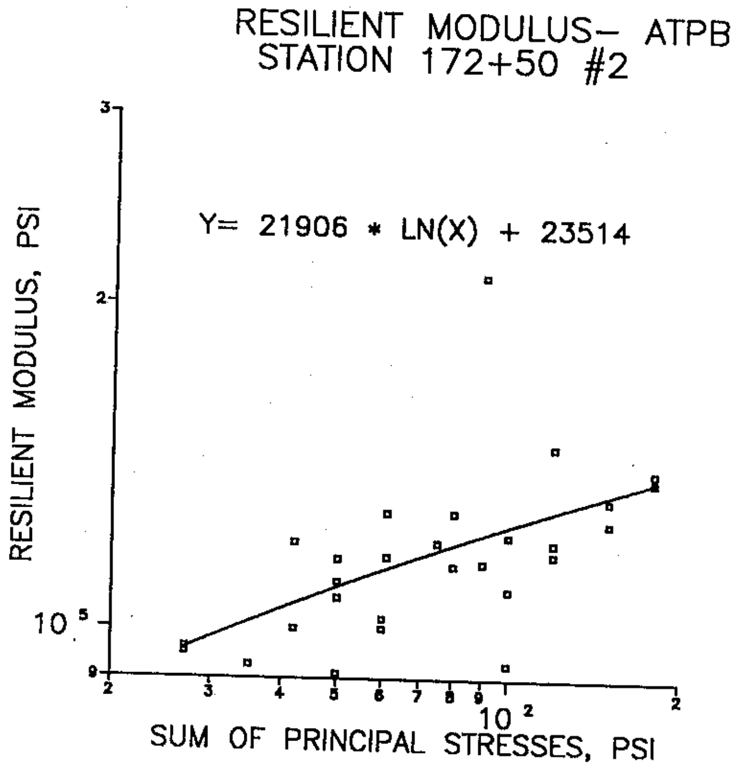


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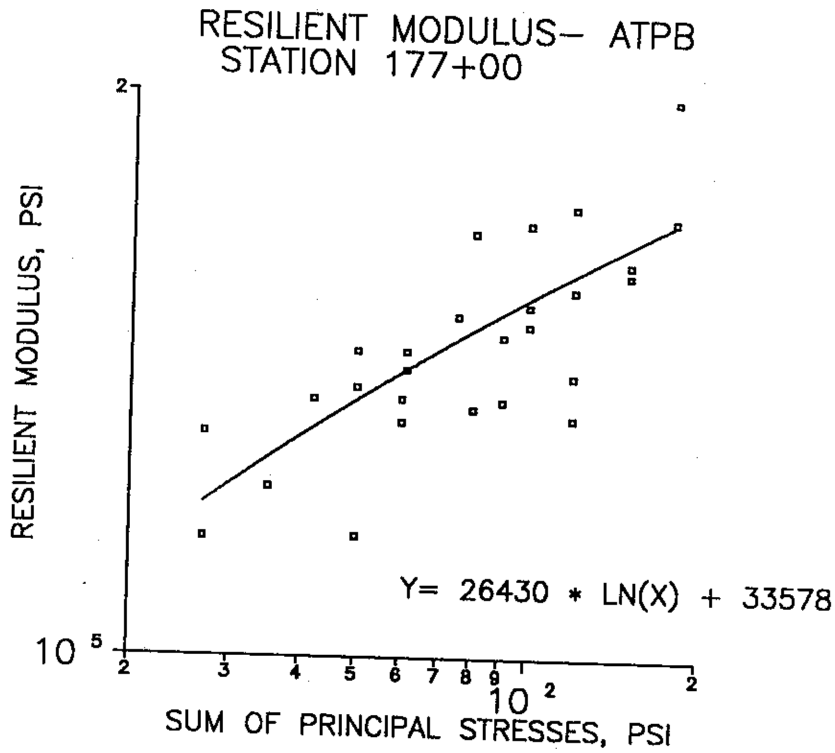


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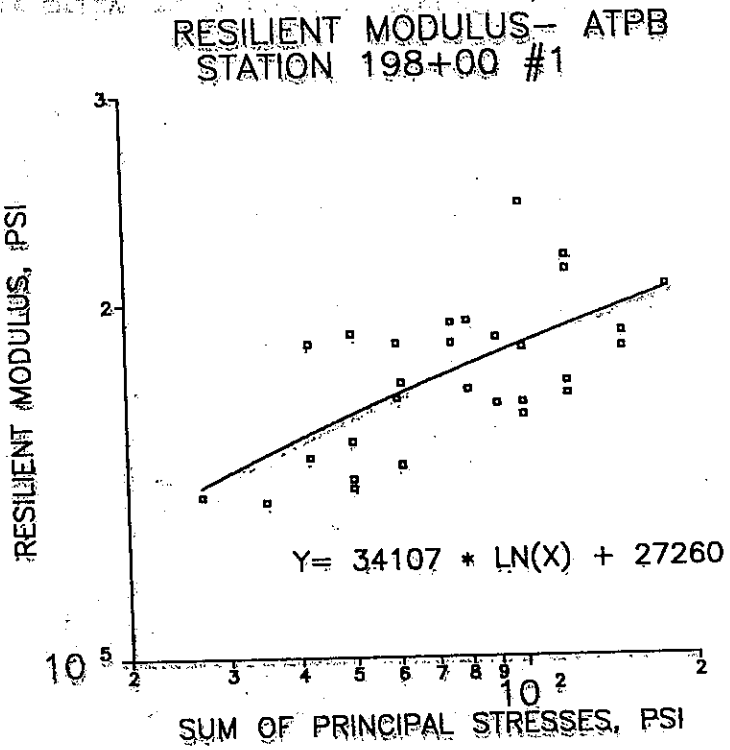


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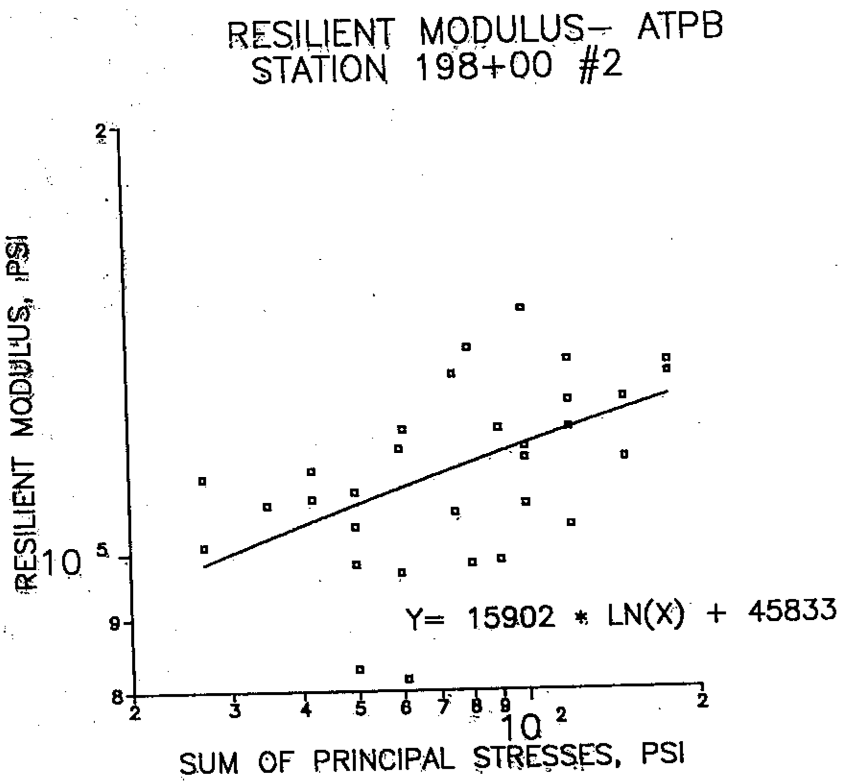


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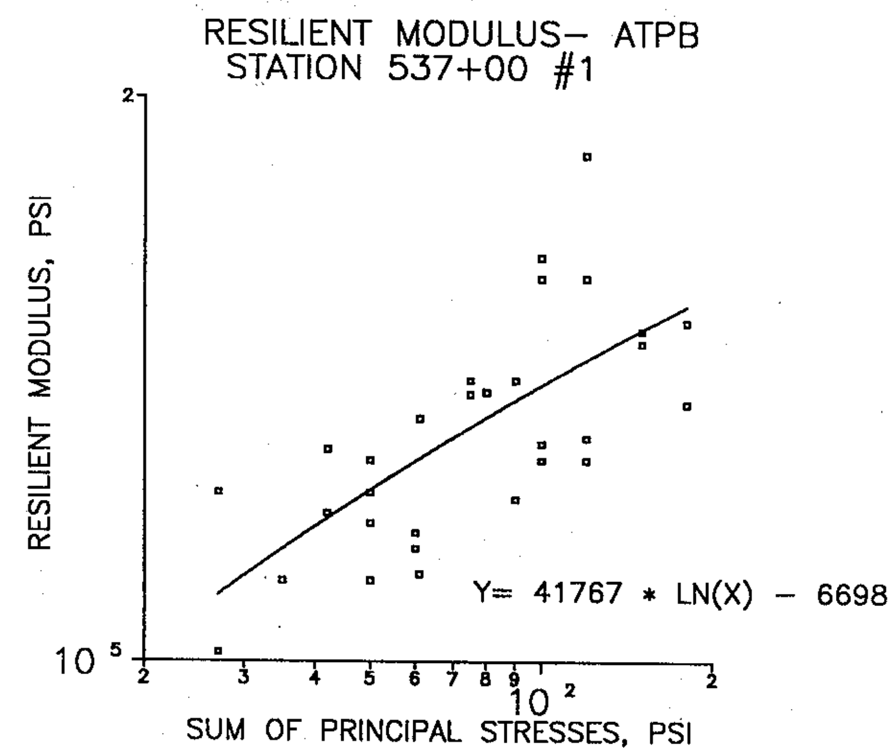


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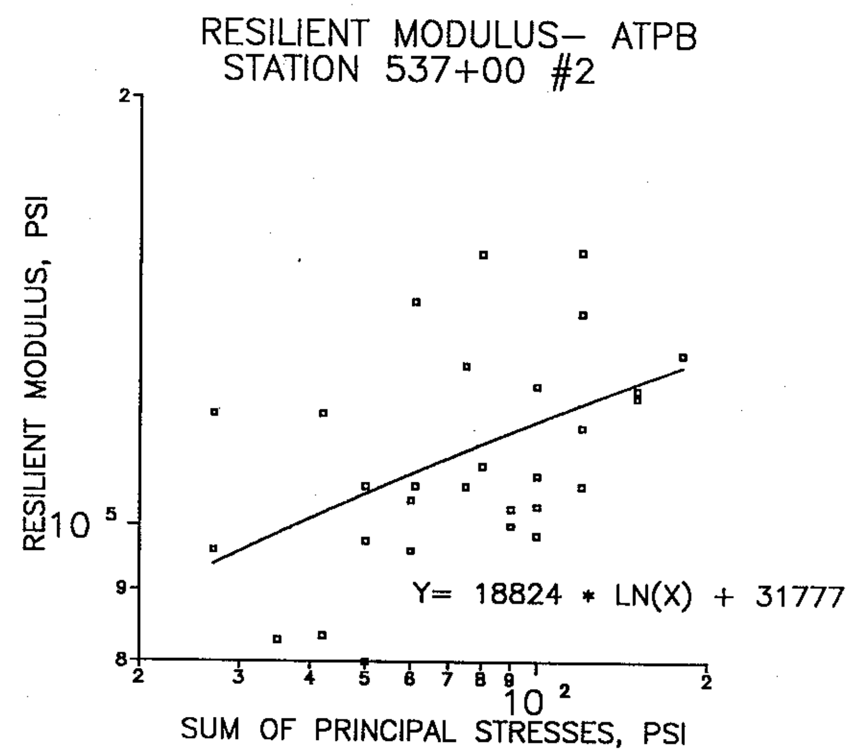


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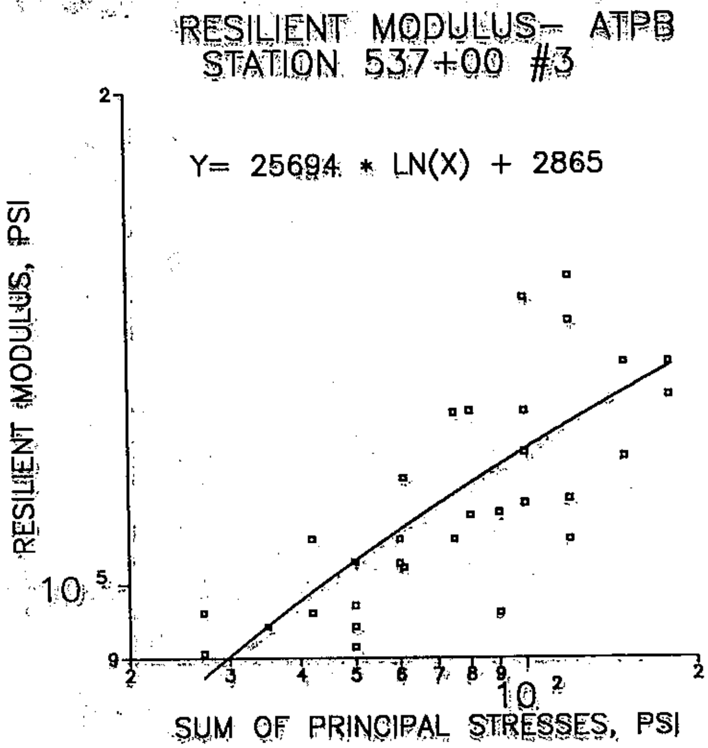


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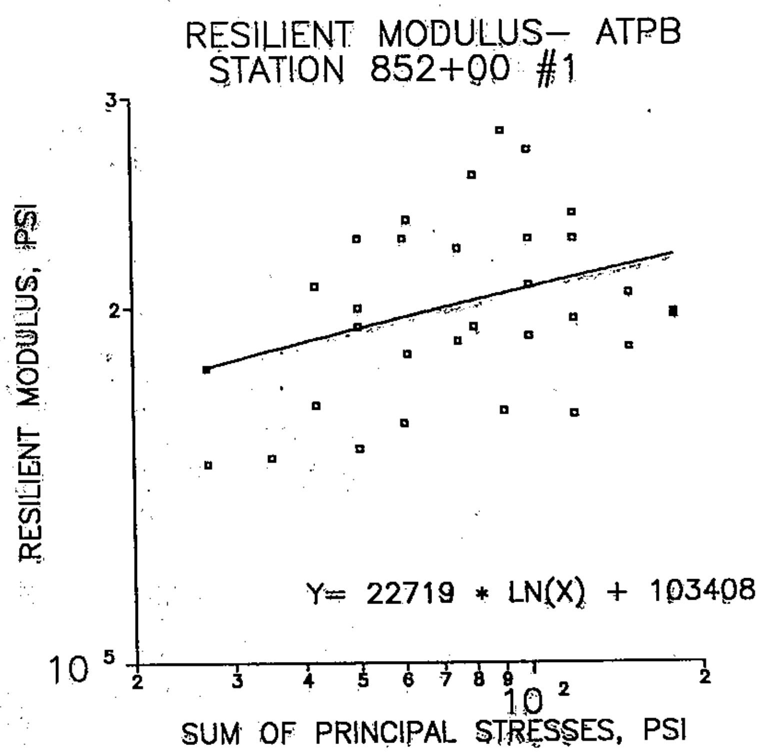


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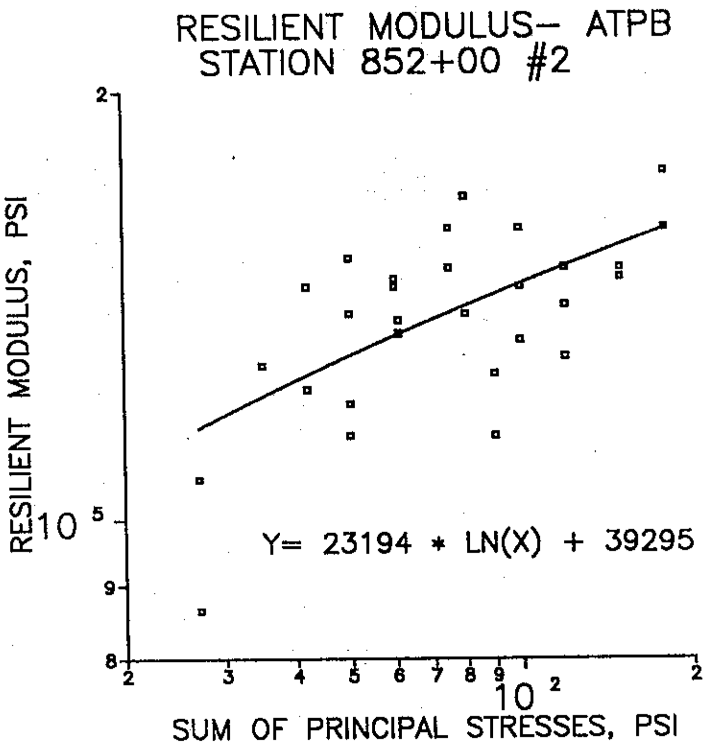


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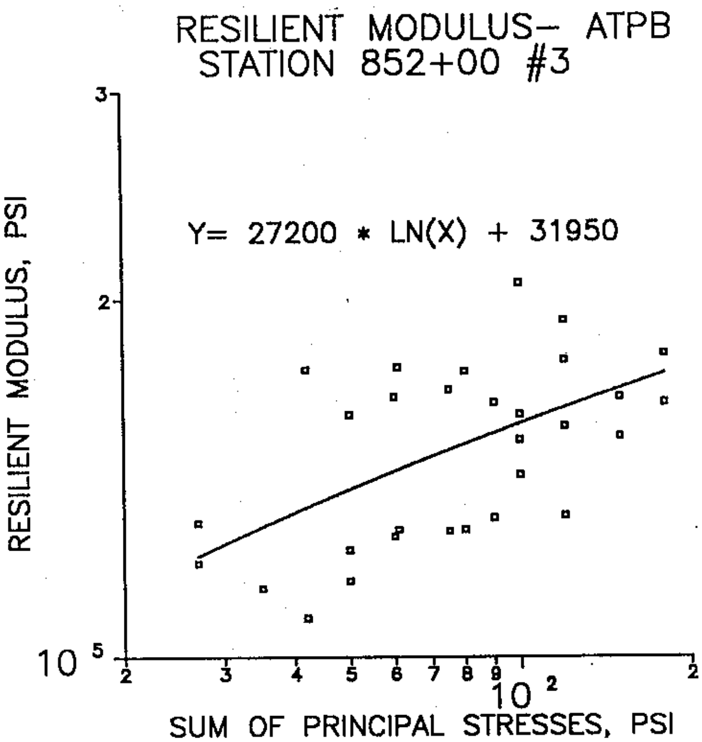


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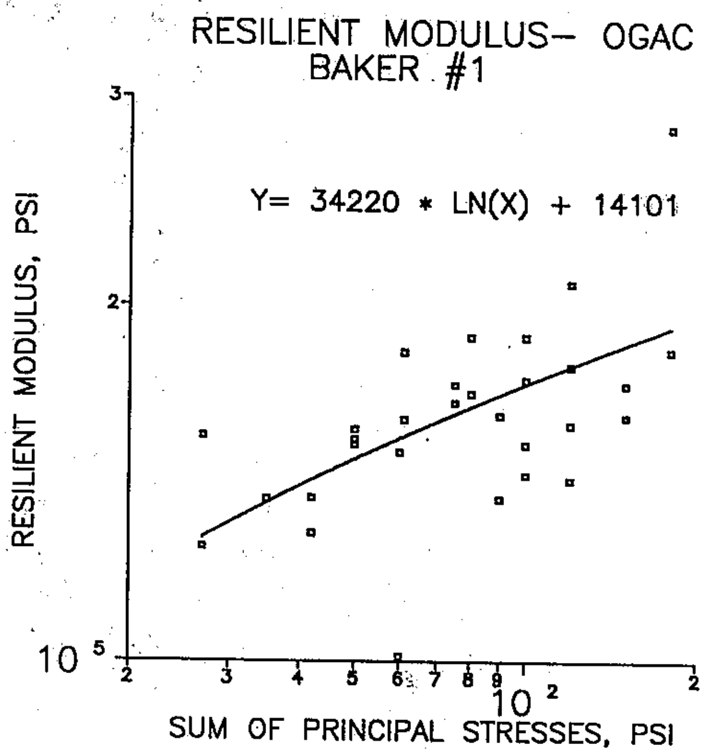


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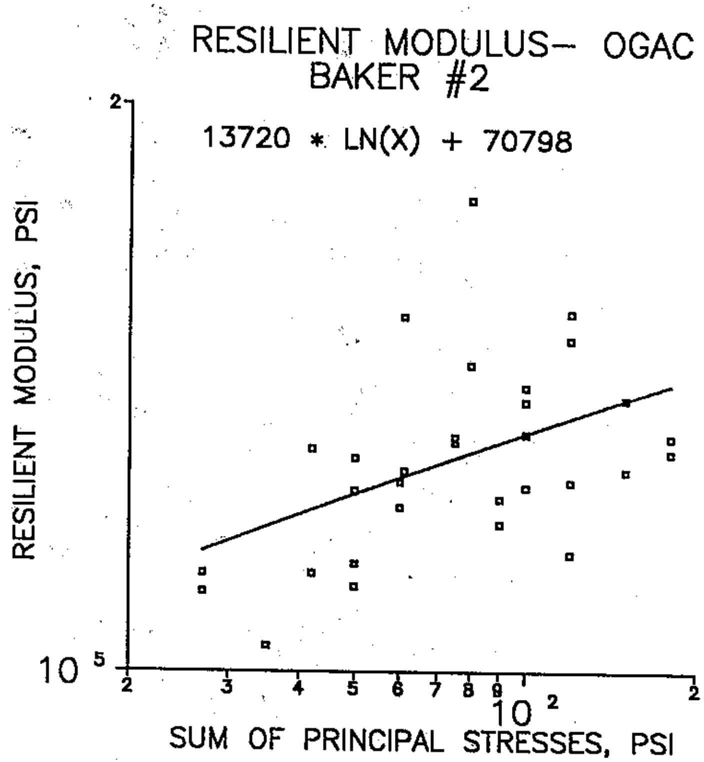


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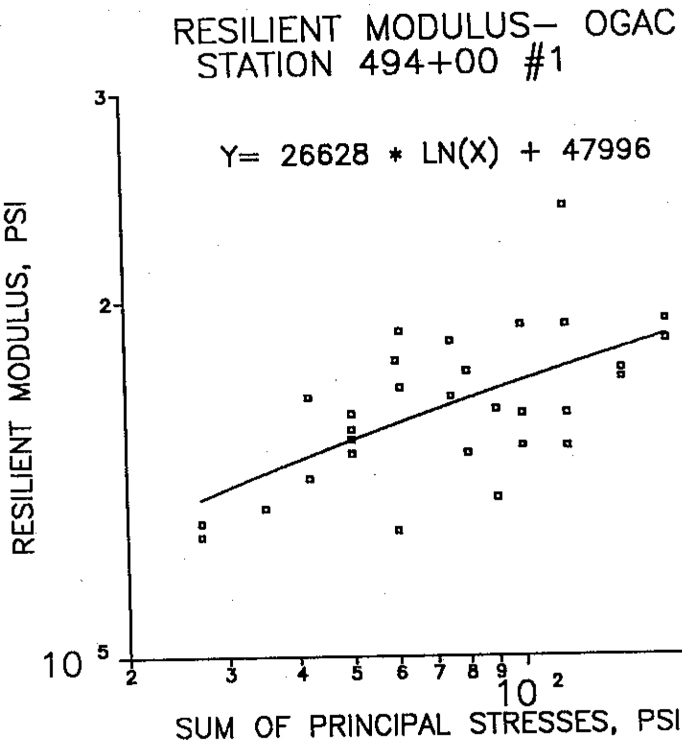


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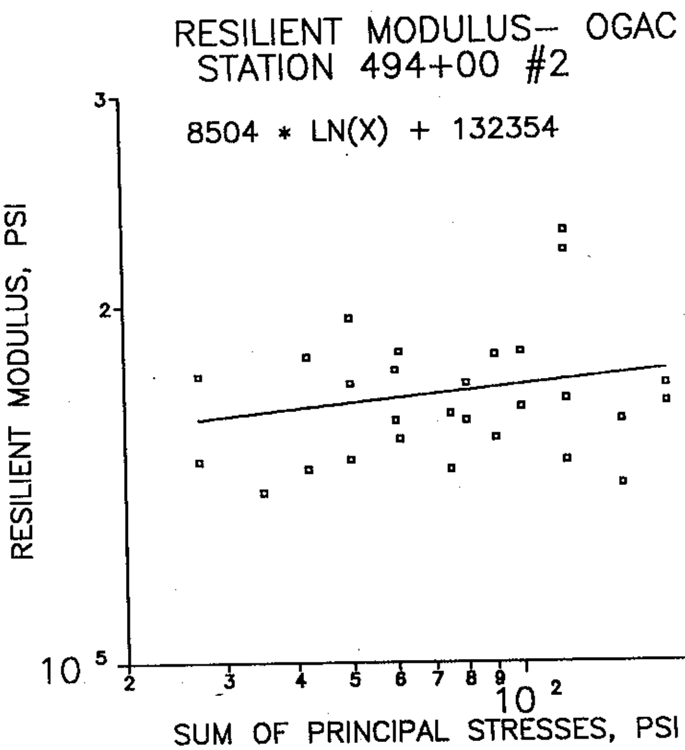


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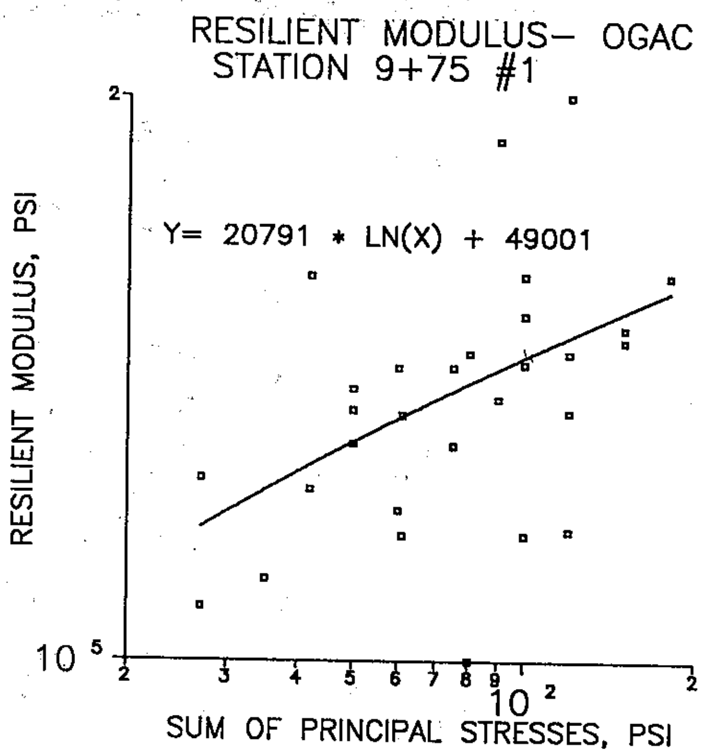


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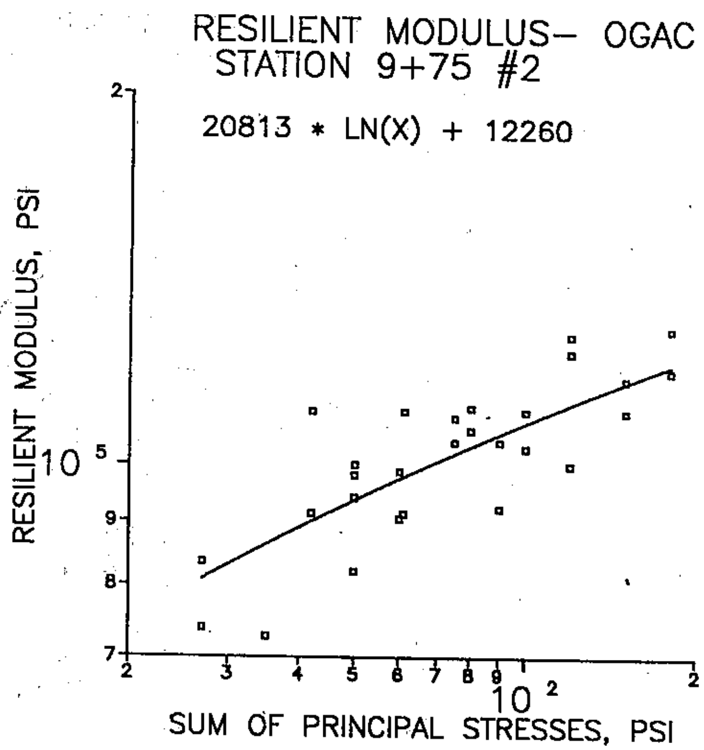


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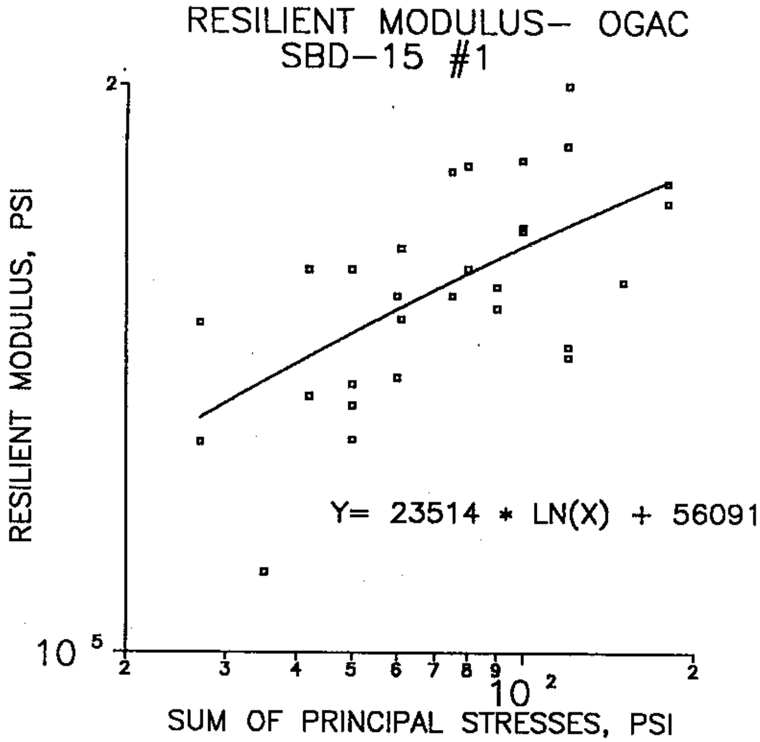


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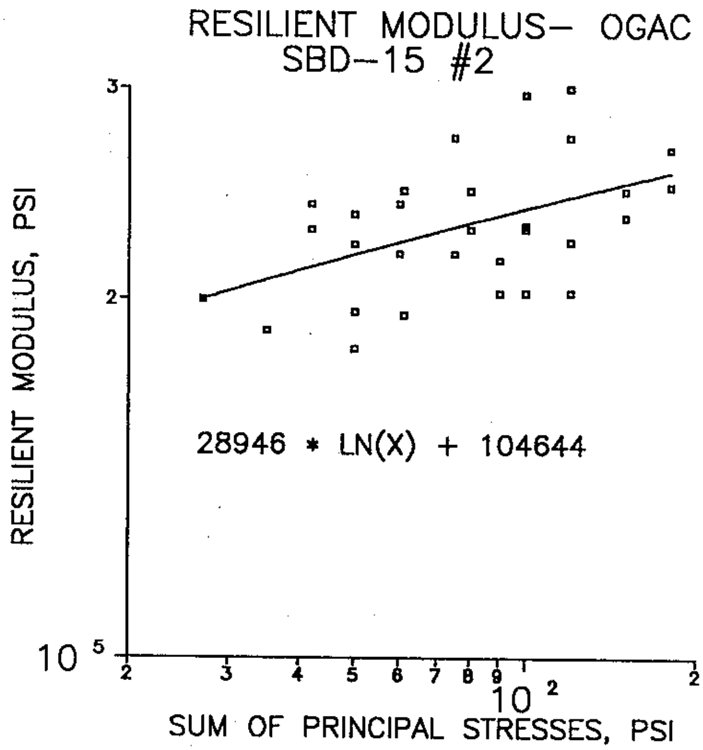


Figure 24