RRD-33

PB

REPORT NO. FRA/ORD-77/32

# BALLAST AND SUBGRADE MATERIALS EVALUATION

FAST

FACILITY FOR ACCELERATED SERVICE TESTING

INTERIM REPORT
DECEMBER 1977

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

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Prepared for

**U.S. DEPARTMENT OF TRANSPORTATION**
**FEDERAL RAILROAD ADMINISTRATION**
**Office of Research and Development**
**Washington, D.C. 20590**

NOTICE



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TECHNICAL REPORT STANDARD TITLE PAGE

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| FRA/ORD-77/32 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| FAST Ballast and Subgrade Materials Evaluation - Ballast and Foundation Materials Research Program | December 1977 |
| | 6. Performing Organization Code |
| 7. Author(s) | 8. Performing Organization Report No. |
| M. R. Thompson | |
| 9. Performing Organization Name and Address | 10. Work Unit No. |
| Department of Civil Engineering<br>University of Illinois, Urbana-Champaign Campus<br>Urbana, Illinois 61801 | 11. Contract or Grant No.<br>DOT-FR-30038 |
| | 13. Type of Report and Period Covered<br>Test Report |
| 12. Sponsoring Agency Name and Address<br>Office of Research and Development<br>Federal Railroad Administration, U.S. Dept. of Trans.<br>2100 2nd Street, S.W.<br>Washington, D. C. 20590 | 14. Sponsoring Agency Code |

15. Supplementary Notes

16. Abstract


The ballast, subballast, and subgrade materials from the FAST Project at Pueblo, Colorado were evaluated. Conventional characterization testing and repeated load triaxial testing were conducted with the various materials.

The data included in this report were developed for bulk material samples forwarded to the University of Illinois. The test results do not reflect any "material variability" which would be encountered in the completed FAST Project.


| 17. Key Words | 18. Distribution Statement |
|---|---|
| Ballast, Subgrade, Ballast Performance, Conventional Railway Track Support System, Materials Testing, Material Properties | Document is available to the U.S. Public throught the National Technical Information Service, Springfield, Virginia 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 40 | |

Form DOT F 1700.7 (8-69)

## PREFACE

This report has been generated as part of a sub-contract between the Association of American Railroads Research and Test Department and the University of Illinois.

This sub-contract is part of a larger contract which is a cooperative effort between the Federal Railroad Administration and the Association of American Railroads on improved track structures. The entire program is in response to recognition of the desire for a more durable track structure. To this end, the program is a multi-task effort involving (1) the development of empirical and analytical tools for the description of the track structure so that the economic trade-offs among track construction parameters such as tie size, rail size, ballast depth, cross section and type, subgrade type and stiffness may be determined, (2) methodologies to upgrade the existing track structures to withstand new demands in loading, (3) development of performance specifications for track components, and (4) investigating the effects of various levels of maintenance.

This particular report presents the evaluation of the ballast, subballast, and subgrade materials from the FAST Project at Pueblo, Colorado. Conventional characterization testing and repeated load triaxial testing have been conducted with the various materials.

A special note of thanks is given to Mr. William S. Autrey, Chief Engineer of Santa Fe, Mr. R. M. Brown, Chief Engineer of Union Pacific, Mr. F. L. Peckover, Geotechnical Consultant, Mr. C. E. Webb, Asst. Vice President of Southern Railway System, as they have served in the capacity of members of the Technical Review Committee for this Ballast and Foundation Materials Research Program, and Dr. R. M. McCafferty as the Contracting Officer's Technical Representative of the FRA on the entire research program.

W. So
Manager and Principal Investigator
Track Structures Research Program
Association of American Railroads

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# INTRODUCTION

Characterization and testing of the FAST Project ballast, subballast, and subgrade materials were included as a part of the contract extension activities of the Ballast and Foundation Materials Research Program. Conventional testing (ASTM or British Standard Procedures) and repeated load triaxial testing (in accordance with techniques previously developed in the research program) were conducted.

This report describes the testing program and presents the data developed. Data interpretation and material comparisons are beyond the scope of the present study and are not considered.

# MATERIALS

Representative samples of the various ballast and subballast materials and the subgrade soil were forwarded to the University of Illinois by the ballast suppliers or the FAST Project Staff. Five ballast samples, a subballast sample, and a subgrade sample were included in the test program. A listing of the materials, their source, and a brief description are presented in Table 1.

# TEST PROCEDURES

## Characterization Tests

Standard characterization tests were conducted with the materials. The tests conducted and the procedures utilized are summarized in Table 2.

## Repeated Load Triaxial Tests

Resilient and permanent deformation responses of the materials to repeated load triaxial testing were determined. Test procedures developed in the Ballast and Foundation Materials Research Program (1)* were utilized.

Specimen Preparation - To minimize segregation and to insure gradation control, each specimen was weighted out by thirds for each of the size

* Numbers in parentheses refer to entries in the List of References.

Table 1. Material Samples

| MATERIAL | SOURCE | GENERAL DESCRIPTION |
|---|---|---|
| Wyoming Granite | Union Pacific Railroad Company | Crushed graded granite ballast used extensively by the Union Pacific |
| McCook Limestone | Vulcan Materials Co. Chicago, Illinois | Crushed dolomitic limestone |
| Pennsylvania Basalt | Dwyer Quarry Co. Birdsboro, Pennsylvania | Crushed traprock |
| Indiana Limestone | Newton County Stone Co. Inc. Kentland, Indiana | Crushed dolomitic limestone |
| CF & I Slag | The Fountain Sand & Gravel Company Pueblo, Colorado | Crushed blast furnace slag |
| Subballast | The Fountain Sand & Gravel Company Pueblo, Colorado | Crushed and Screened River Gravel |
| Subgrade | FAST Site Pueblo, Colorado | Sand |

Table 2. Characterization Tests Conducted

| Test | Test Designation | | Materials Evaluated | | |
|---|---|---|---|---|---|
| | ASTM[a] | British Standard[b] | Ballast | Subballast | Subgrade |
| Particle Index | D3398 | | ✓ | | |
| Bulk Specific Gravity | C127 | | ✓ | | |
| Los Angeles Abrasion | C131 | | ✓ | | |
| Gradation | C136 | | ✓ | ✓ | ✓ |
| Flakiness Index | | 812-15 | ✓ | | |
| Soundness | C88 | | ✓ | | |
| Crushing Value | | 812-34 | ✓ | | |
| Absorption Capacity | C127 | | ✓ | | |
| Plasticity Index | D424 | | | ✓ | ✓ |

(a) American Society for Testing and Materials

(b) British Standard 812, "Methods for Sampling and Testing of Mineral Aggregates, Sands, and Filters," British Standards Institution, 1967.

fractions and each third was placed in a separate container. Ballast and subballast samples were prepared in an "air-dry" moisture condition and the subgrade sample was prepared at a water content of approximately 8% which is in the water content range determined at the time of FAST subsurface instrumentation installation (private communication, E. T. Selig).

The specimens were prepared in three layers in a split mold (20 cm (8 in.) diameter, 41 cm (16 in.) length) clamped to the base of the triaxial cell. A rubber membrane was placed inside the mold and a vacuum was applied to hold the membrane against the mold.

Compaction was accomplished with a vibratory hammer having a compaction foot slightly smaller in diameter than that of the mold. Each of the three layers was compacted for a period of 5 seconds. After compaction, the height of the specimen was recorded, the load cap was placed, and a vacuum was applied to the specimen. The mold was then removed, and a second membrane was placed over the specimen because almost without exception the original membrane was punctured during compaction. The triaxial cell was then assembled and placed in the loading frame.

Repeated Triaxial Loading - Confining pressure was supplied by air and was not cycled during the tests. The repeated deviator stress was applied by a hydraulically actuated piston; control was by means of a closed loop electronic system. Input for the load control was provided by a function generator connected through electronic controls to the hydraulic actuator.

To satisfy the constraints of the equipment and to approximate in-service conditions, a frequency of 50 applications per minute and a haversine load pulse of 0.15 seconds duration were selected.

The triaxial chamber pressure was monitored by a gauge on the air supply line. The axial load was monitored by means of a load cell mounted between the hydraulic actuator and the loading rod. A two-channel high speed strip chart recorder was used to monitor the output of the load cell.

Two methods were used to observe the axial deformations. The primary method for measuring the resilient deformation was by two electronic-optical scanners which measured the vertical motion of targets placed at the upper and lower quarter points of the specimen. The targets consisted of one black and one white rectangular strip, 32 mm by 64 mm (1 1/2 by 2 1/2 inches) each, which were held to the specimen membrane by double-sided tape. The chamber confining pressure insured the membrane was molded firmly to the specimen thereby eliminating slippage between specimen and targets. The movements of the targets were sensed by the optical heads and converted into an electrical signal; the difference in movements was recorded as output on the strip recorder.

A backup for measuring axial deformation was provided by a linear variable differential transformer (LVDT) mounted at the top of the hydraulic actuator. The LVDT signal was recorded simultaneously with the collimator signal. The LVDT measured deformations over the entire specimen length, and therefore the output included specimen end effects.

The ballast and subballast specimens were initially conditioned at a deviator stress of 310 kN/m$^2$ (45 psi) and a confining pressure of 103 kN/m$^2$ (15 psi) for 5000 load applications. After conditioning, each specimen was tested for resilient modulus at each of 7 stress levels as follows:

| Deviator Stress, kN/m$^2$ (psi) | Confining Pressure, kN/m$^2$ (psi) |
|---|---|
| 310 (45) | 103 (15) |
| 207 (30) | 103 (15) |
| 276 (40) | 69 (10) |
| 138 (20) | 69 (10) |
| 138 (20) | 34 (5) |
| 103 (15) | 34 (5) |
| 69 (10) | 34 (5) |

The subgrade sample was initially conditioned at a deviator stress of 130 kN/$m^2$ (15 psi) and a confining pressure 34 kN/$m^2$ (5 psi) for 5000 load applications. After conditioning, the specimen was tested for resilient modulus at the following stress levels:

| Deviator Stress, kN/$m^2$ (psi) | Confining Pressure, kN/$m^2$ (psi) |
|---|---|
| 34 (5) | 34 (5) |
| 69 (10) | 34 (5) |
| 34 (5) | 34 (5) |
| 34 (5) | 69 (10) |
| 69 (10) | 69 (10) |
| 138 (20) | 69 (10) |
| 172 (25) | 69 (10) |

Resilient modulus values were calculated for the various stress states according to the equation:

$$E_R = \frac{\sigma_D}{\varepsilon_R}$$

where

$E_R$ = Resilient modulus

$\sigma_D$ = Repeated deviator stress

$\varepsilon_R$ = Recoverable (resilient) axial strain based on electronic optical scanner deflection measurements

Following the resilient testing sequence, additional repeated loading ($\sigma_D$ = 310 kN/$m^2$, $\sigma_3$ = 103 kN/$m^2$) was applied to the ballast and subballast samples to achieve (in all cases except the CF & I Slag) $10^6$ load applications. Additional repeated loading ($\sigma_D$ = 103 kN/$m^2$, $\sigma_3$ = 34 kN/$m^2$) was also applied to the subgrade sample to achieve 50,000 load applications. Permanent strain was periodically monitored during the extended loading period.

Sieve analyses of the ballast specimens were conducted following long term repeated loading. Comparison of the "before" and "after" testing gradation data provides a measure of the particle degradation tendencies of the various ballast materials.

Subgrade Strength Tests

In the conduct of the repeated triaxial testing of the subgrade material, a "cementing" tendency was noted. Even though the subgrade is non-plastic, it was apparent that the material did display a "cementing potential". A series of 2 inch (51 mm) diameter by 4 inch (107 mm) specimens were compacted (8% water content, dry density of 112 pcf (1795 kg/m$^3$)) and cured under various conditions.

## RESULTS

Table 3 is a summary of the material characterization data. A summary of the physical properties of the various specimens subjected to repeated triaxial testing is presented in Table 4.

Particle size distribution curves for the ballast, subballast, and subgrade samples are shown in Figures 1, 2, and 3, respectively.

Data collected from the resilient response testing were used in regression analyses to develop equations of the following type:

$$E_r = K\Theta^n$$

where

$E_r$ = resilient modulus,

n, K = constants representing slope and intercept, respectively on a log-log plot, and

$\Theta$ = the first stress invariant = $\sigma_1 + \sigma_2 + \sigma_3$

(Note: $\Theta = \sigma_1 + 2\sigma_3$ in the triaxial test)

Figures 4 through 10 present the results, including regression analyses, for the specimens tested. All of the regression equations were significant at $\alpha = 0.01$.

Table 3. Characterization Test Results

| | Wyoming Granite | Pennsylvania Basalt | McCook Limestone | Indiana Limestone | CF & I Slag | Subballast | Subgrade |
|---|---|---|---|---|---|---|---|
| Particle Index | 14.2 | 16.4 | 12.2 | 15.4 | 10.5 | — | — |
| Flakiness Index | 20.8 | 22.7 | 9.4 | 10.8 | 5.9 | — | — |
| Soundness, % | 0.77 | 0.55 | 11.9 | 6.3 | 1.6 | — | — |
| L.A. Abrasion (% Wear) | 18.8 | 13.2 | 25.7 | 26.3 | 28.8 | — | — |
| Bulk Specific Gravity | 2.67 | 2.94 | 2.65 | 2.71 | 2.52 | — | — |
| Absorption Capacity, % | 0.40 | 0.20 | 1.65 | 1.95 | 1.60 | — | — |
| Crushing Value | 18.4 | 13.1 | 19.3 | 22.2 | 29.2 | — | — |
| Plasticity Index | — | — | — | — | — | NP | NP |

Table 4. Moisture-Density Data for Triaxial Test Specimens

| Specimen | Compacted Density | | Water Content, % |
|---|---|---|---|
| | $kg/m^3$ | pcf | |
| Wyoming Granite | 1605 | 100.2 | "Air-Dry" |
| McCook Limestone | 1511 | 94.3 | "Air-Dry" |
| Pennsylvania Basalt | 1551 | 96.8 | "Air-Dry" |
| Indiana Limestone | 1511 | 94.3 | "Air-Dry" |
| CF & I Slag | 1296 | 80.9 | "Air-Dry" |
| Subballast | 1730 | 108.0 | "Air-Dry" |
| Subgrade | 1626 | 101.5(a) | 8% |

Notes:

a - Dry density

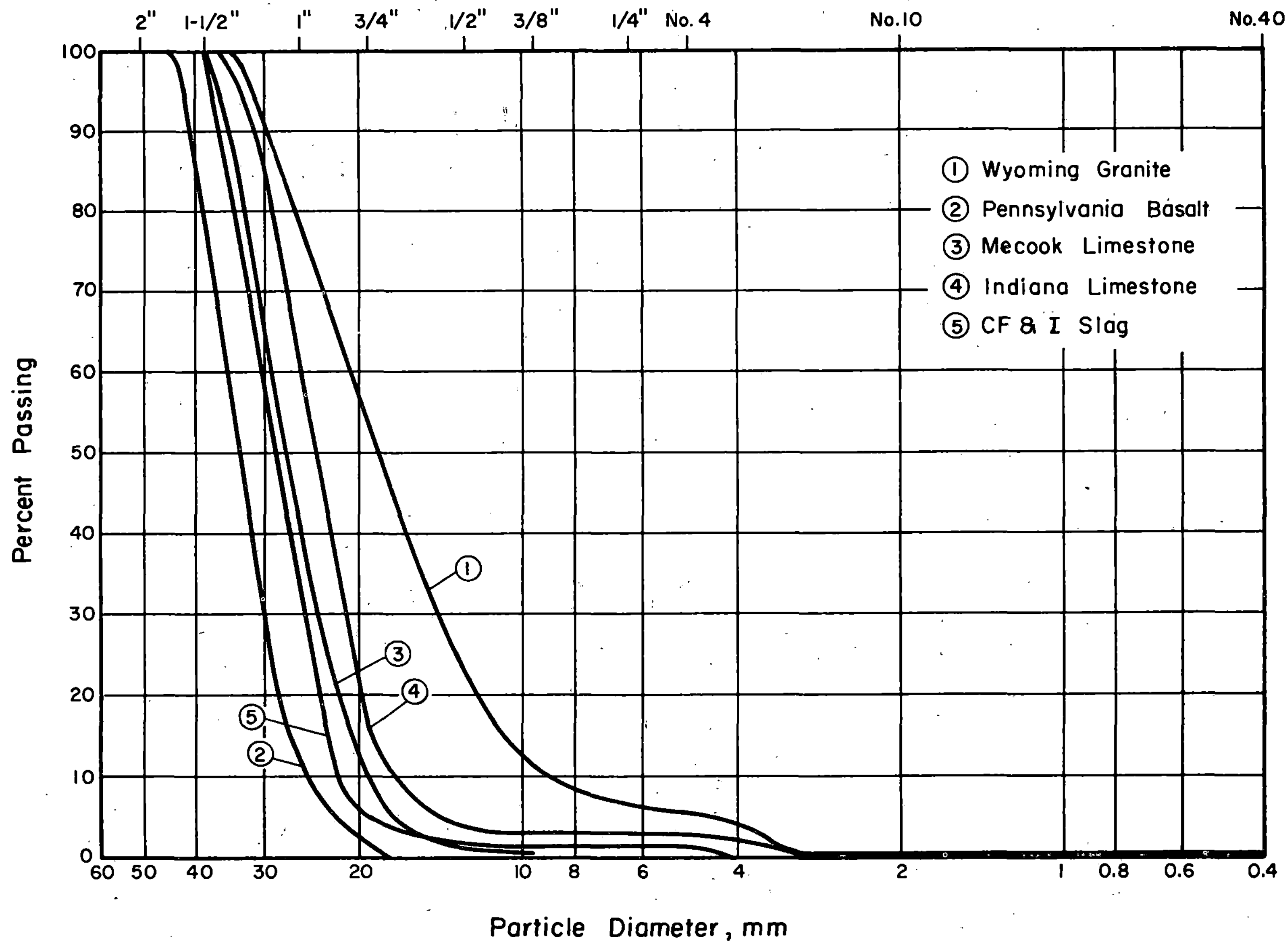


Figure 1. Particle Size Distribution for FAST Ballast Materials.

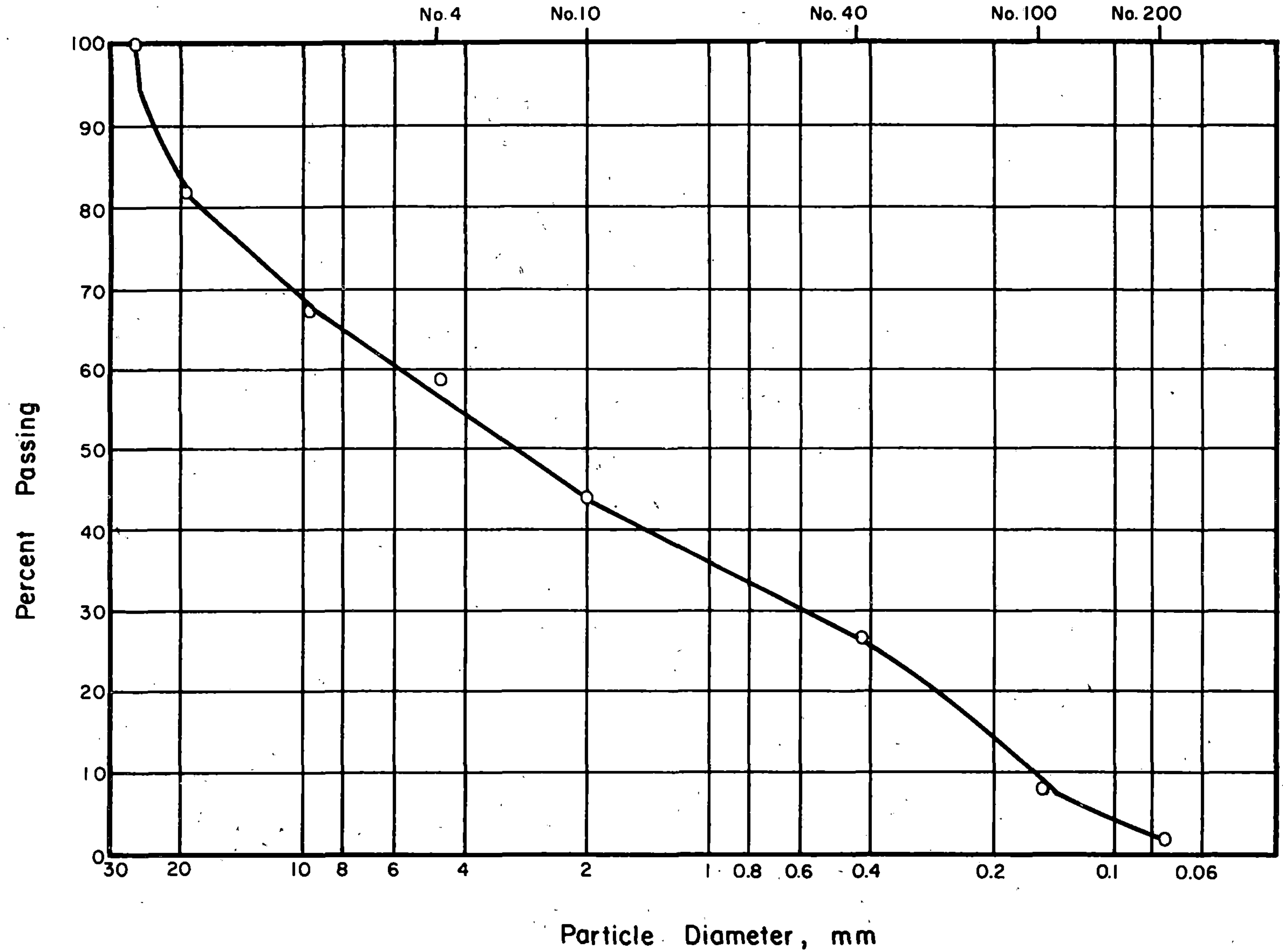


Figure 2. Particle Size Distribution for FAST Subballast Material.

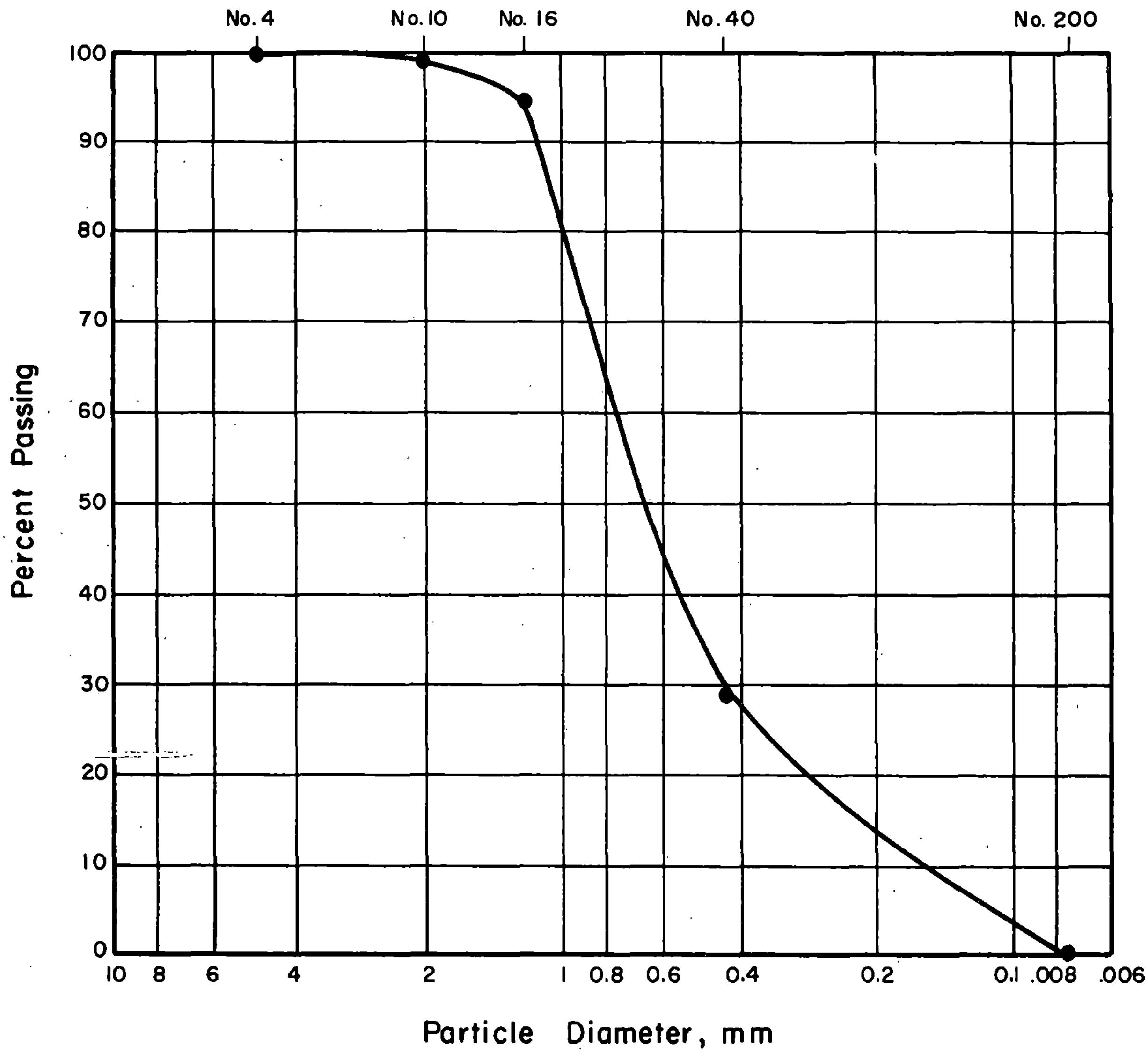


Figure 3. Particle Size Distribution for FAST Subgrade.

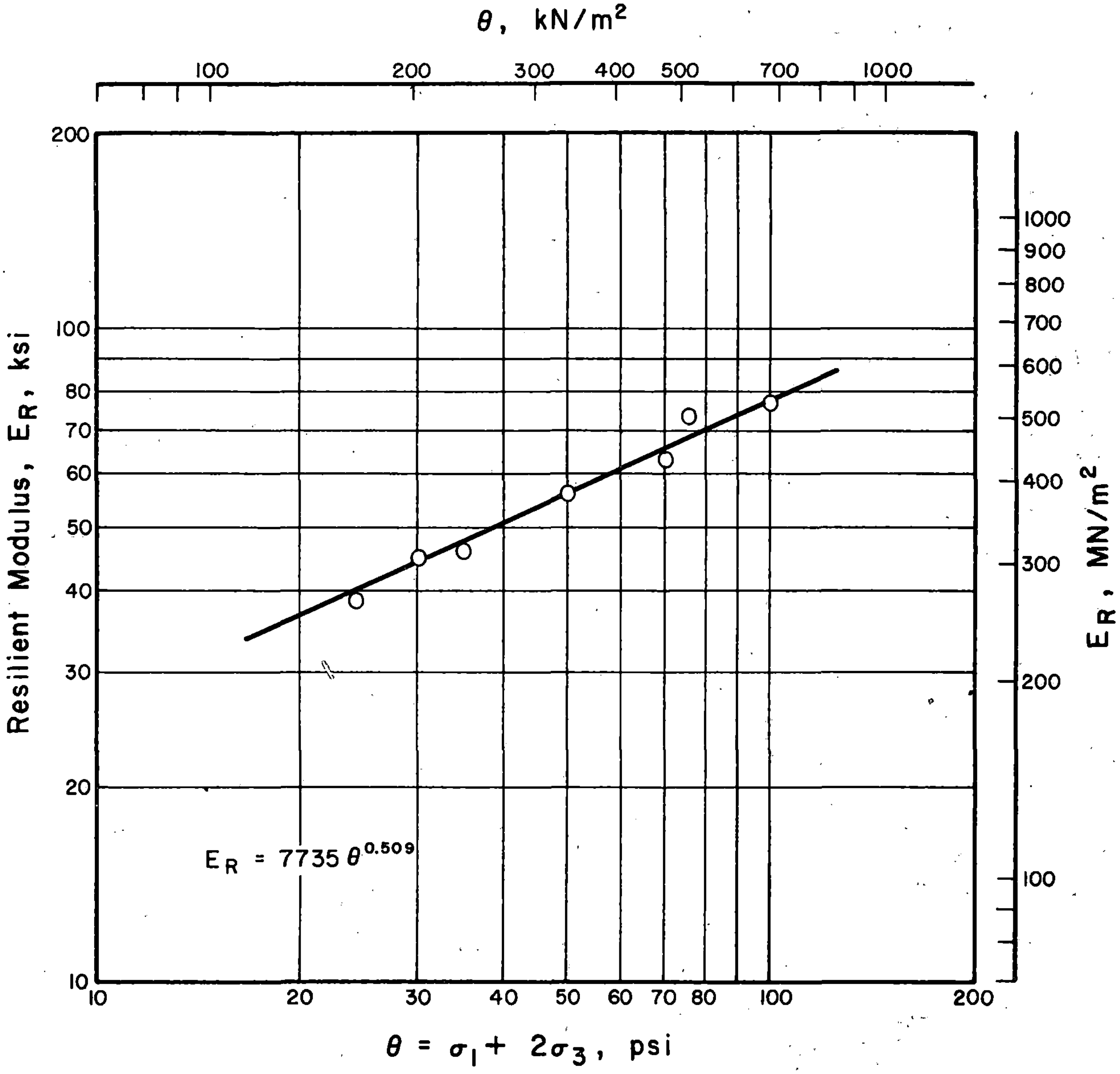


Figure 4. $E_R$-θ Relationship for Wyoming Granite Ballast.

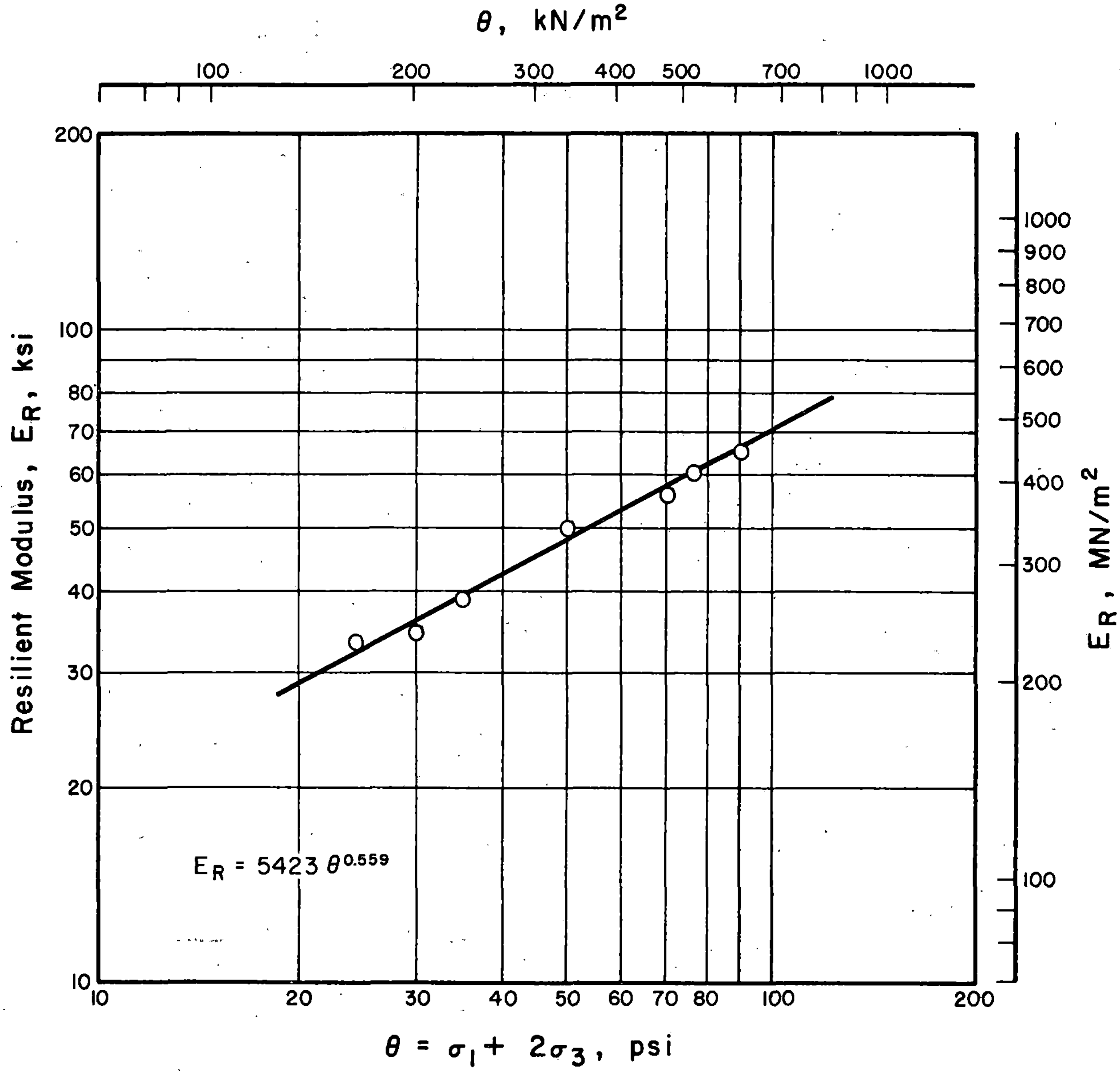


Figure 5. $E_R$-θ Relationship for McCook Limestone Ballast.

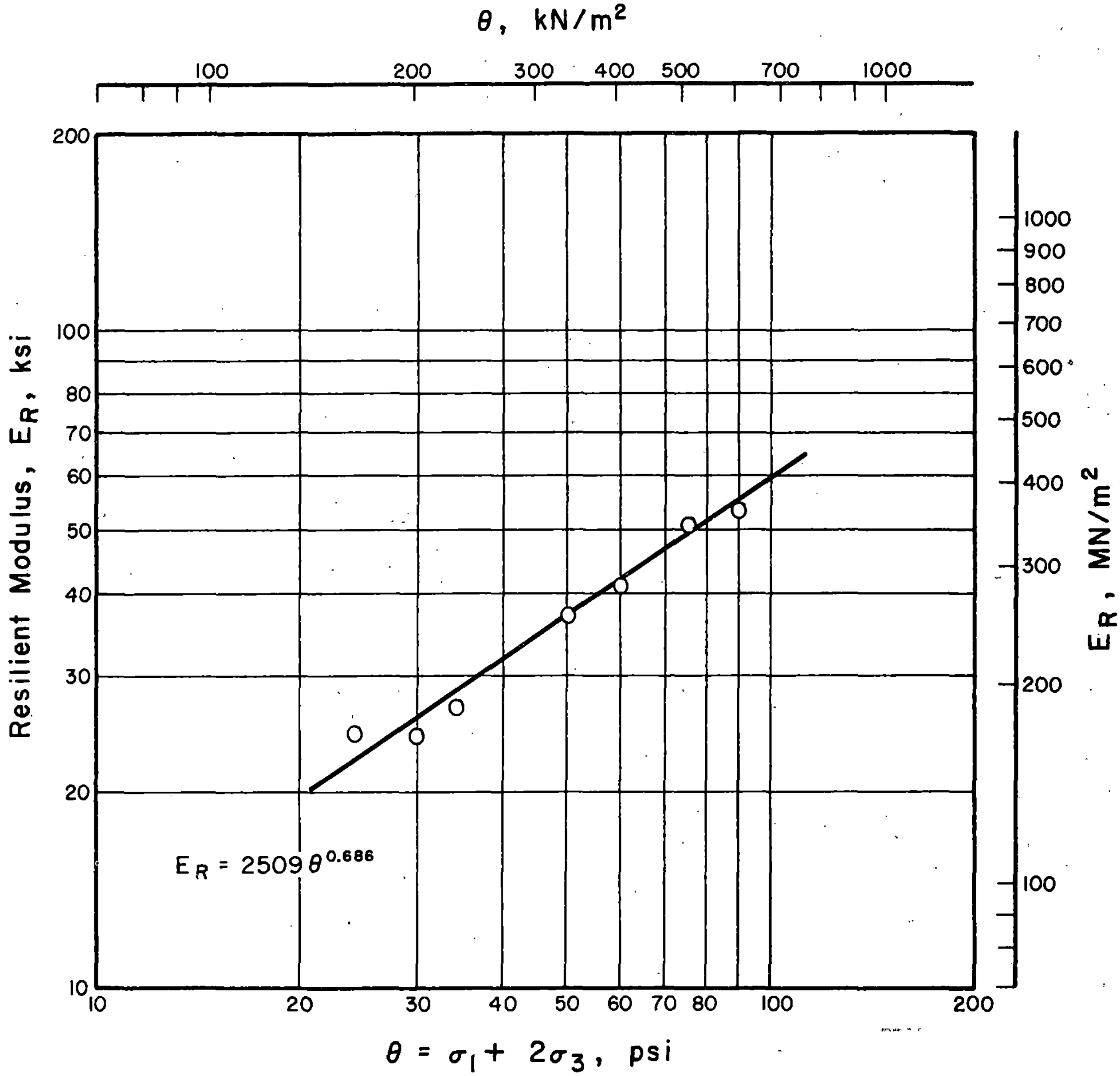


Figure 6. $E_R$-θ Relationship for Pennsylvania Basalt Ballast.

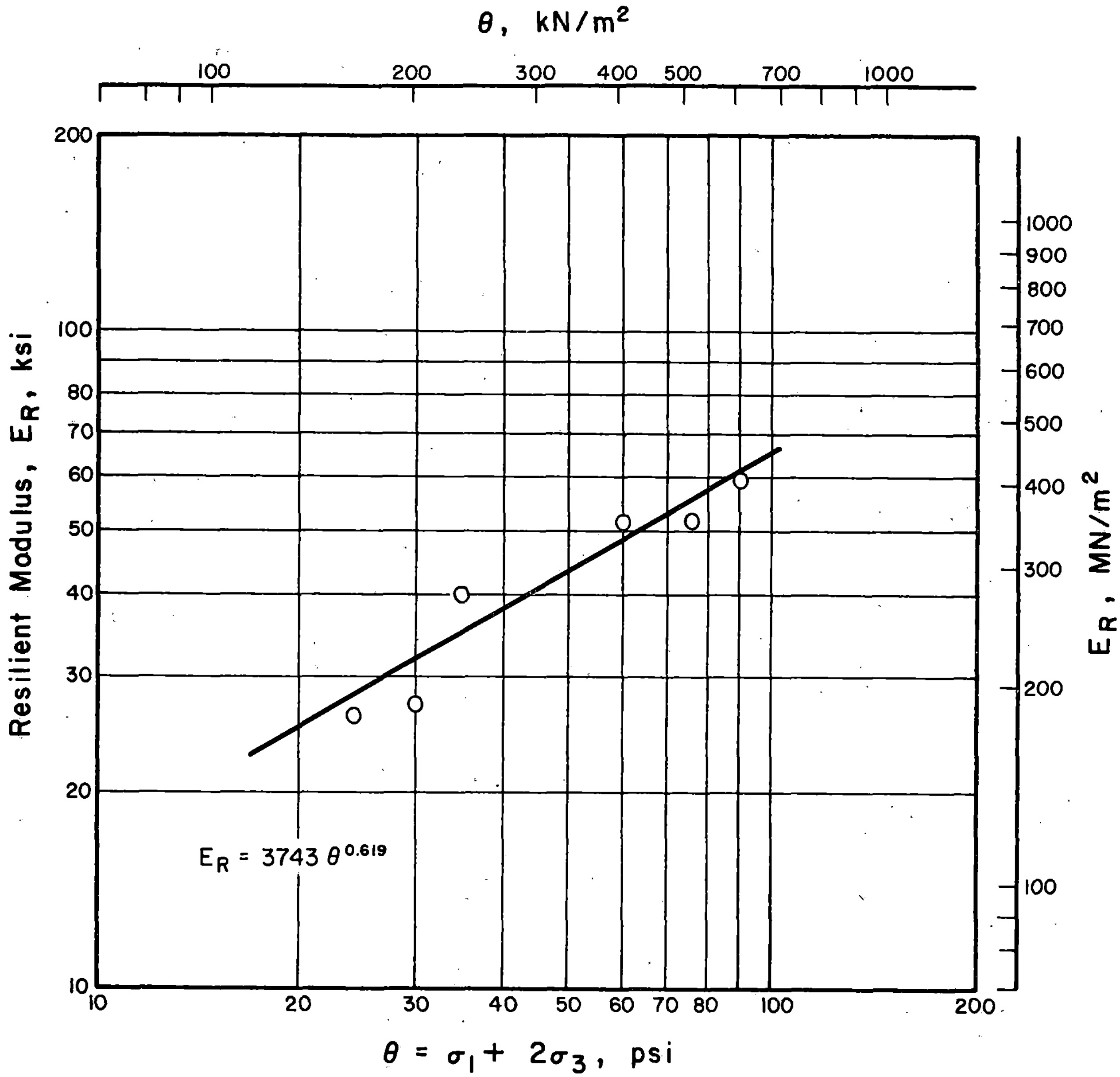


Figure 7. $E_R$-θ Relationship for Indiana Limestone Ballast.

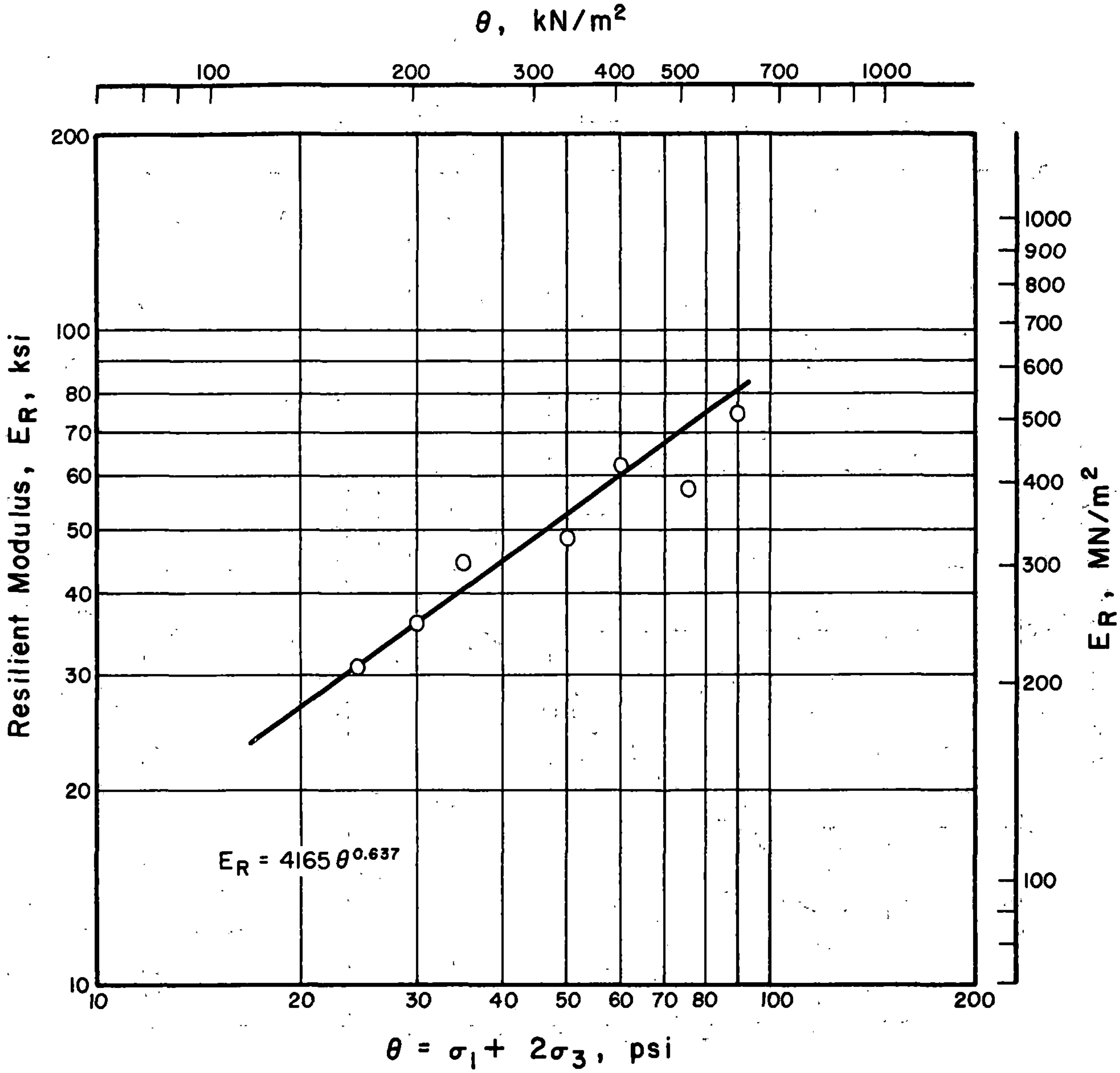


Figure 8. $E_R$-θ Relationship for CF&I Slag Ballast.

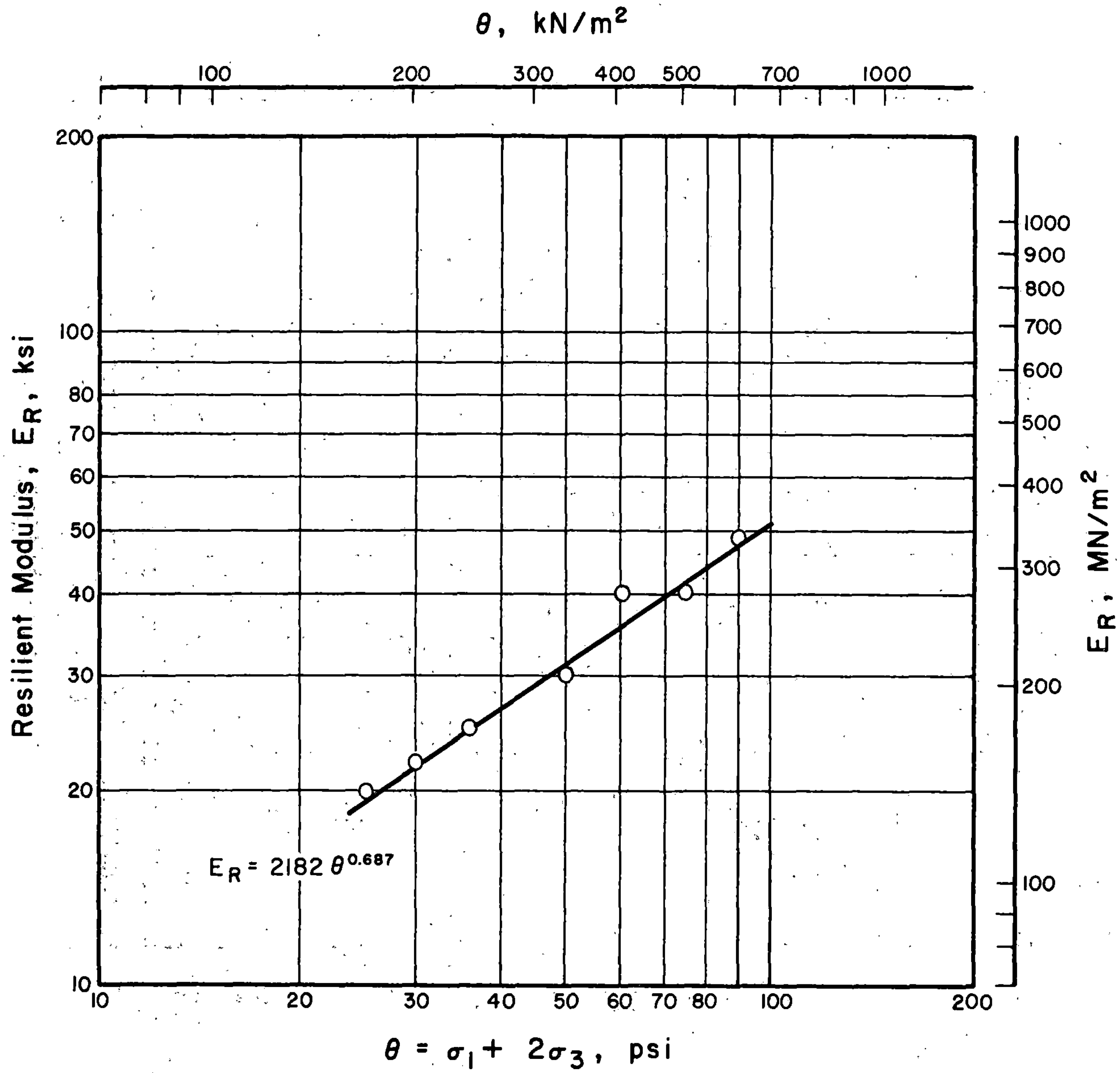


Figure 9. $E_R$-θ Relationship for FAST Subballast Material.

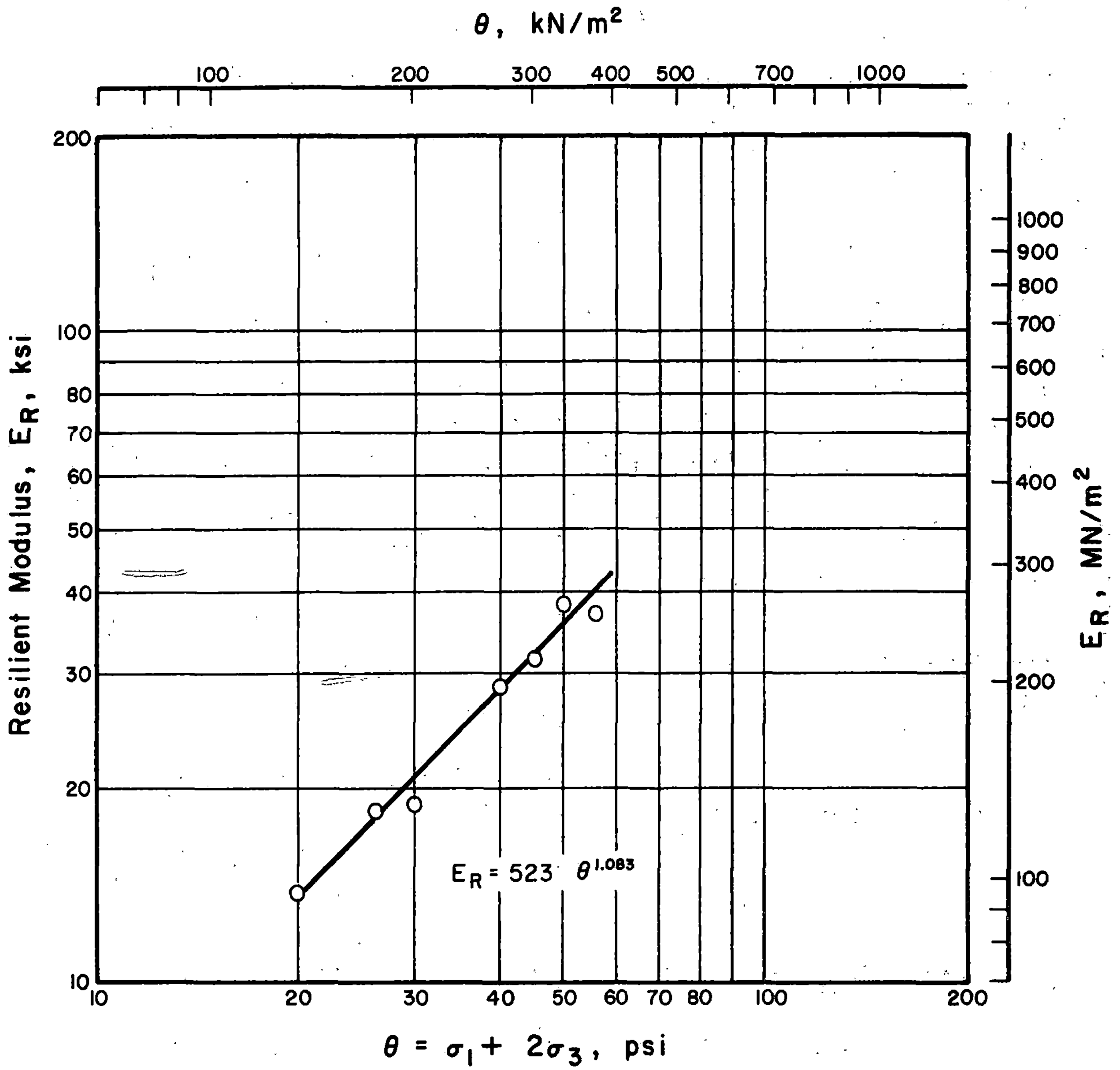


Figure 10. $E_R$-$\theta$ Relationship for FAST Subgrade.

Previous research in the Ballast and Foundation Materials Research Program (2) indicated that a semi-log plot (permanent strain versus logarithm of number of cycles) best represented permanent deformation behavior of ballast type materials. Figures 11 through 17 are plots of permanent strain (LVDT deformation measurements) versus logarithm of the number of load cycles for the ballast, subballast and subgrade materials.

Table 5 is a summary of the gradation analyses (before and after repeated triaxial testing) for the ballast specimens. For comparison purposes, AREA gradation requirements for No. 4 and No. 5 ballast are shown in Table 6.

Subgrade unconfined compressive strength and moisture content data for the various curing conditions are summarized in Table 7. It is important to note that the compressive strength increases with a decrease in moisture content. For the driest sample (moisture content of 0.4%) a compressive strength of 124 psi (854 $kN/m^2$) was achieved (hardly characteristic of a nonplastic sand).

## SUMMARY

The ballast, subballast, and subgrade materials from the FAST Project at Pueblo, Colorado were evaluated. Conventional characterization testing and repeated load triaxial testing were conducted with the various materials.

It is emphasized that the data included in this report were developed for the bulk material samples forwarded to the University of Illinois. The test results do not reflect any "material variability" which would be encountered in the completed FAST Project.

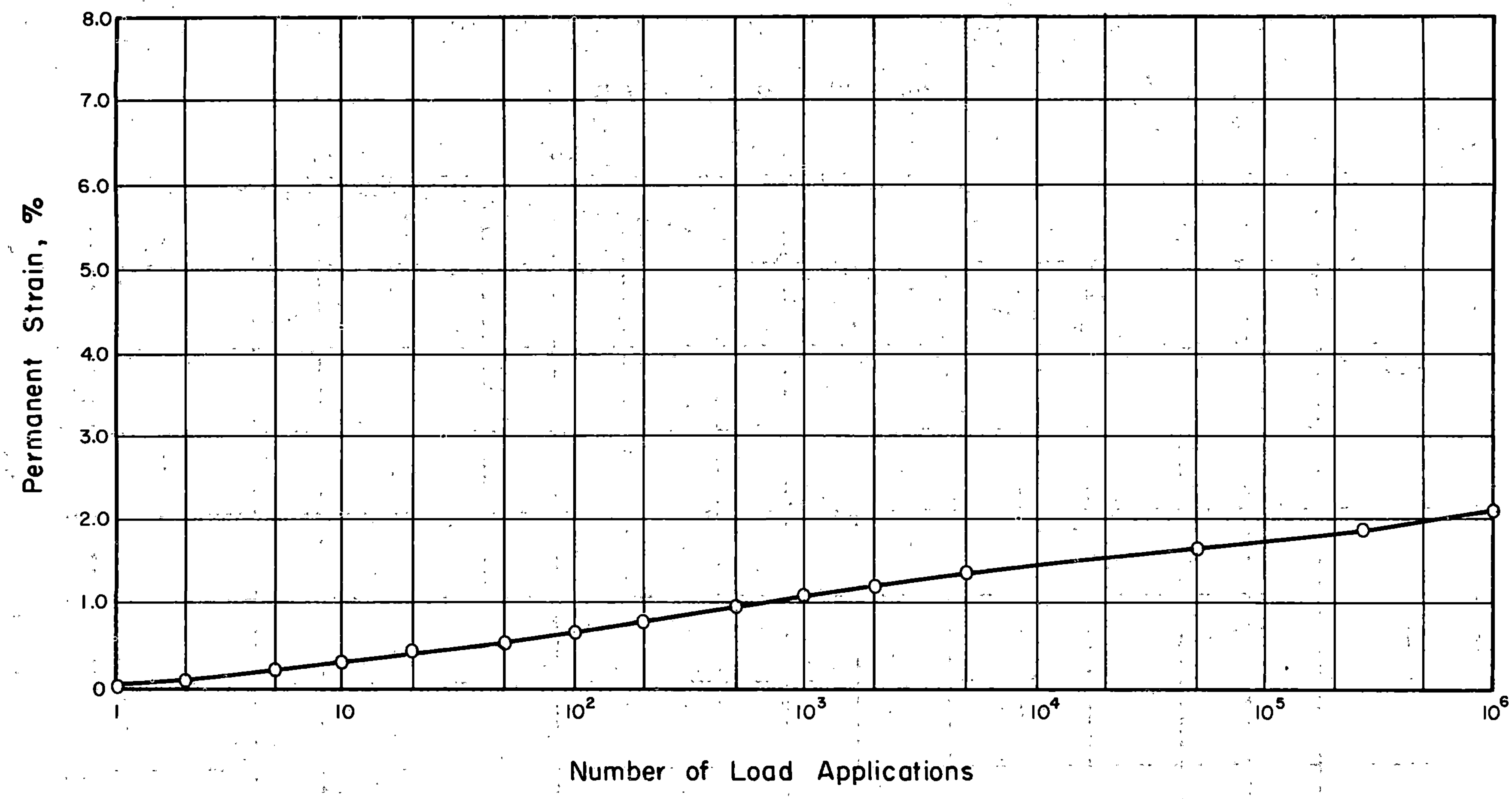


Figure 11. Permanent Strain-Number of Loads Relationship for Wyoming Granite Ballast.

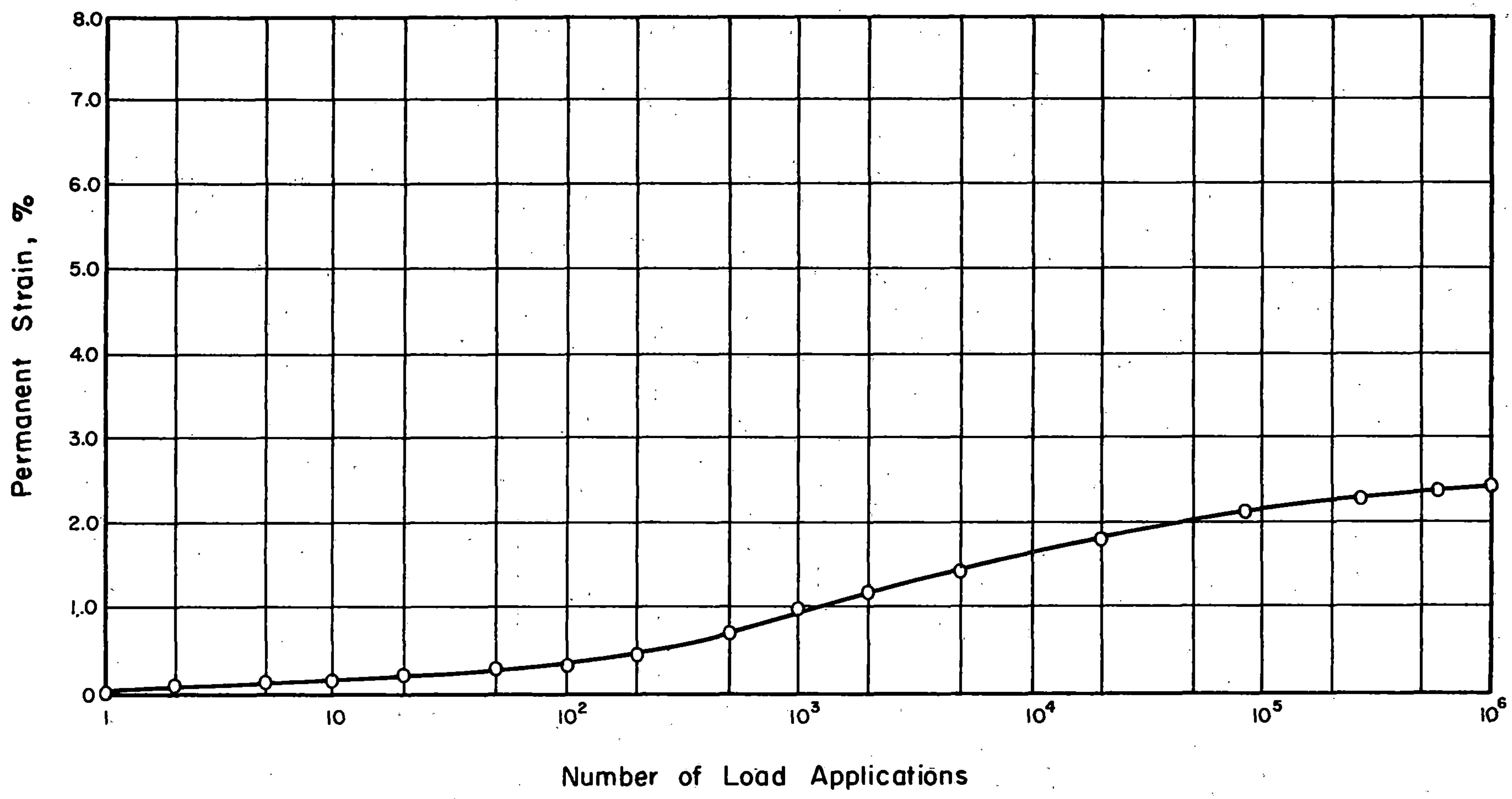


Figure 12. Permanent Strain-Number of Loads Relationship for McCook Limestone Ballast.

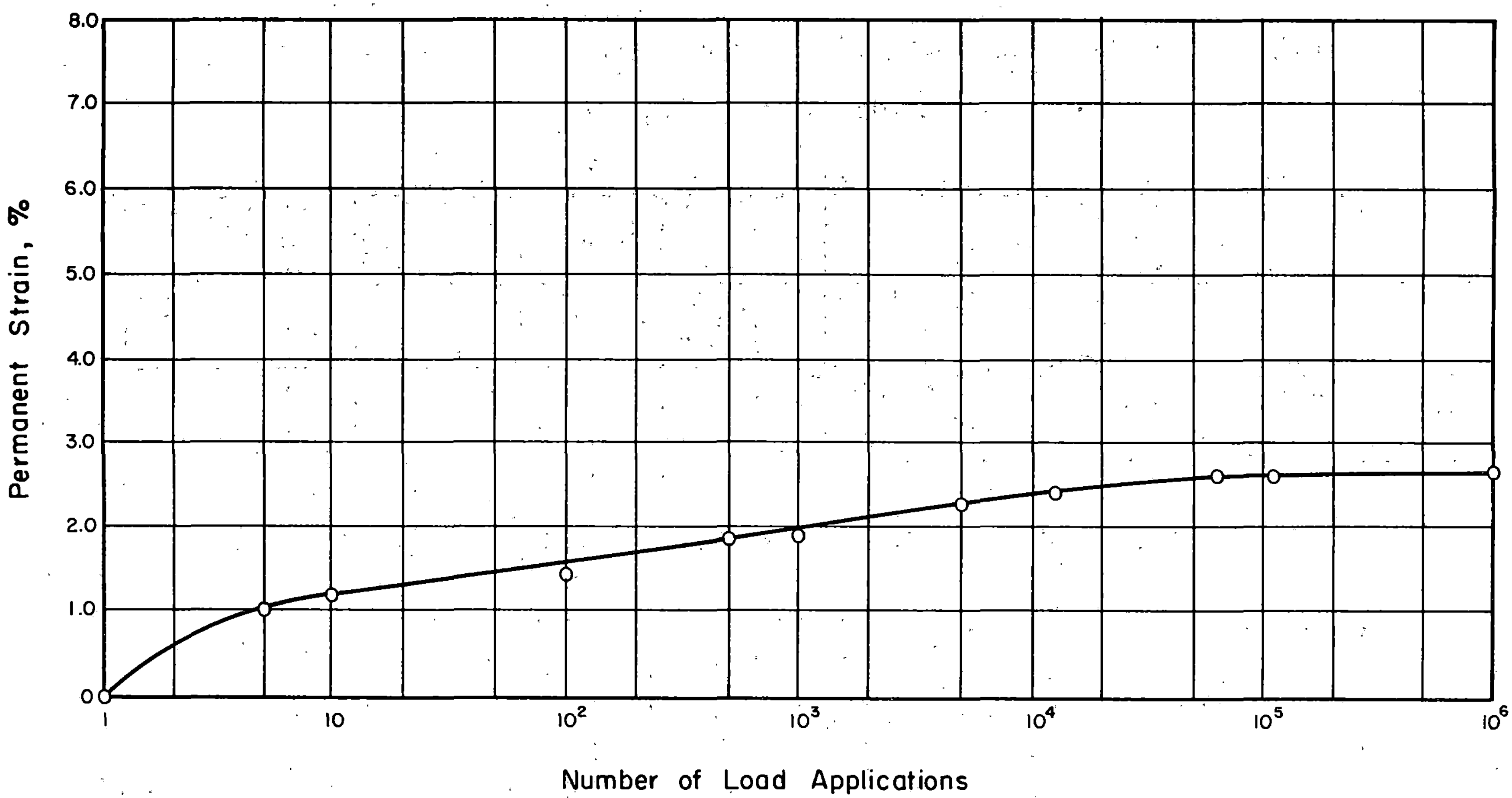


Figure 13. Permanent Strain-Number of Loads Relationship for Pennsylvania Basalt Ballast.

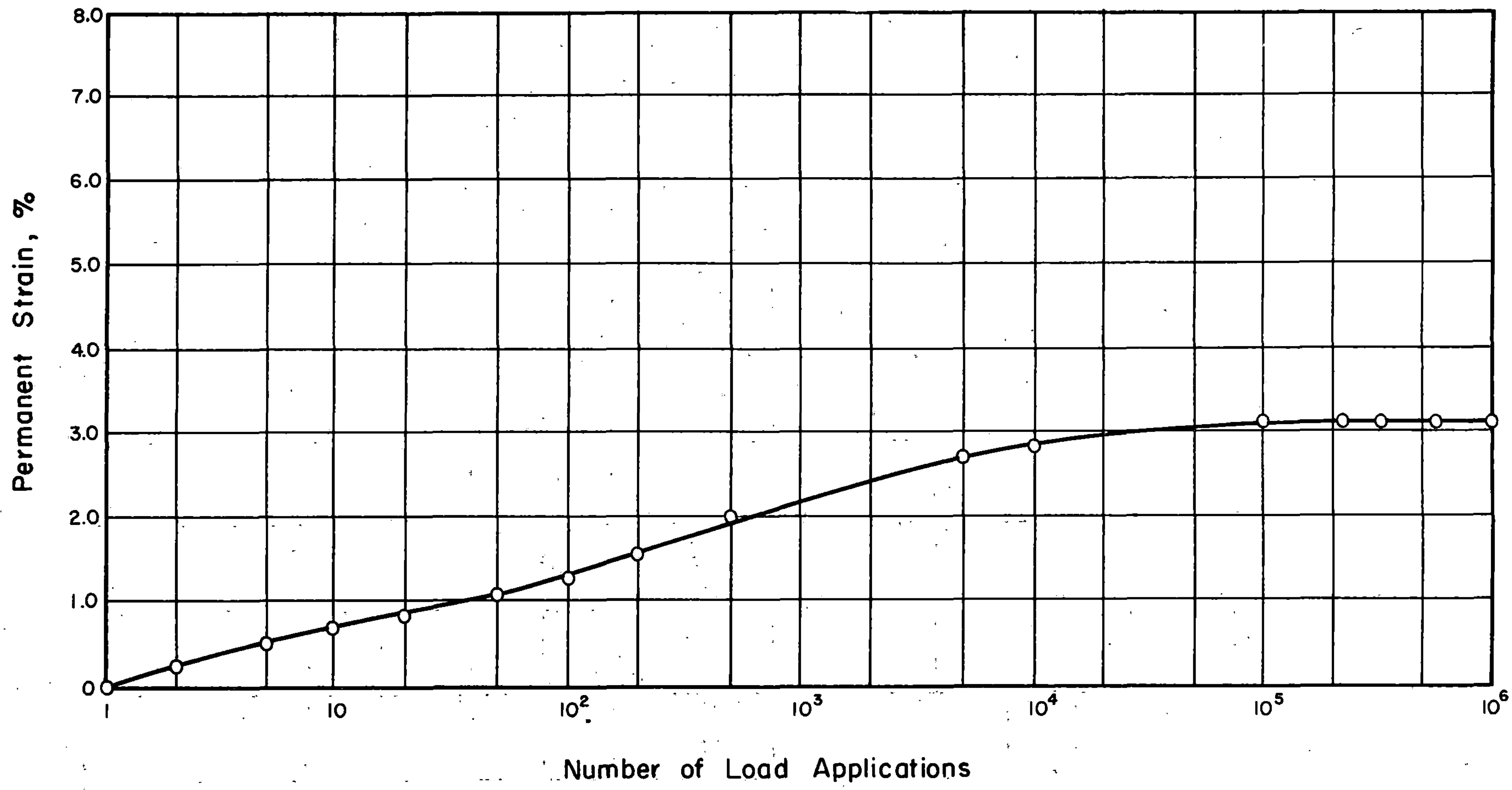


Figure 14. Permanent Strain-Number of Loads Relationship for Indiana Limestone Ballast.

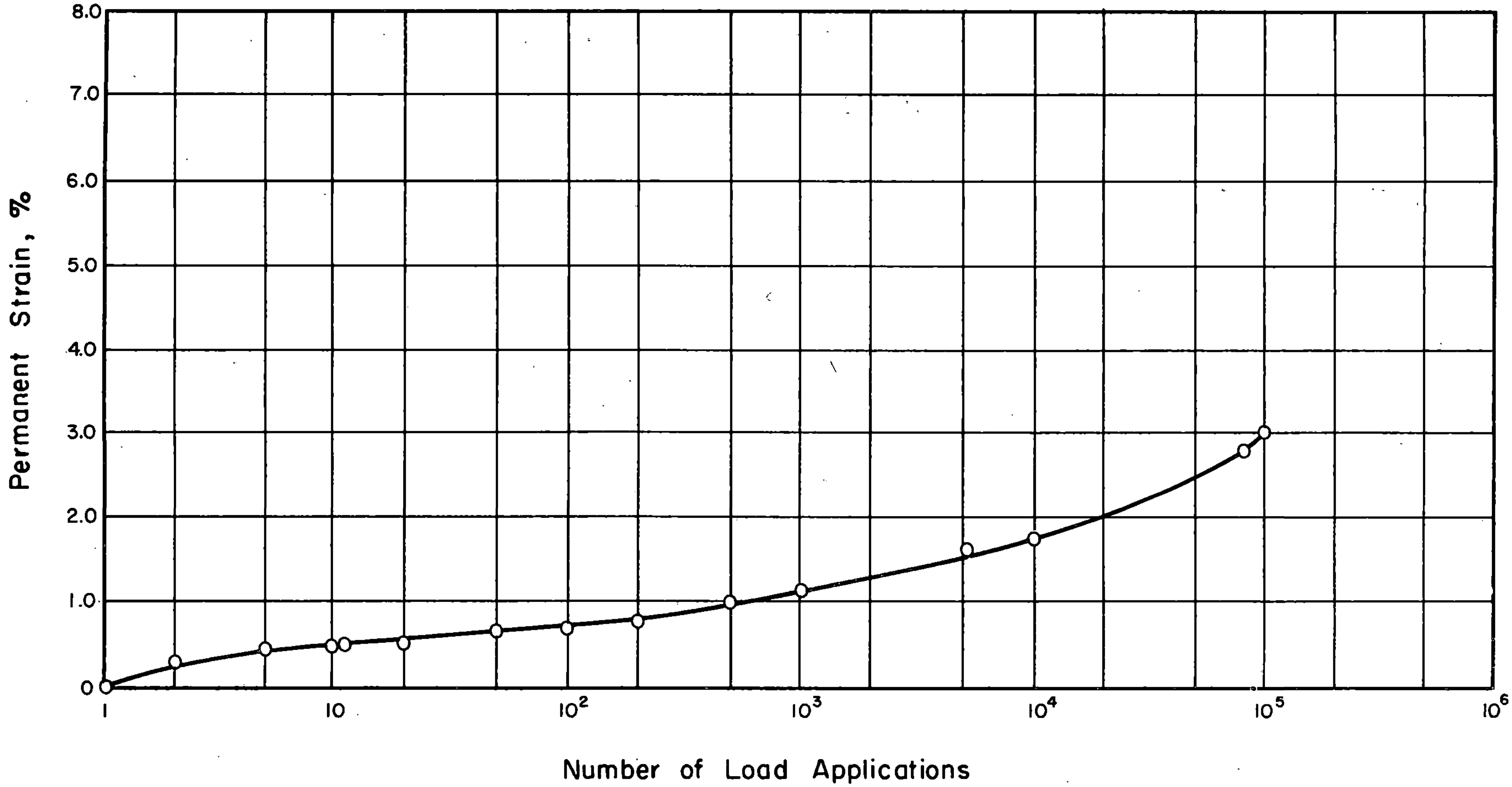


Figure 15. Permanent Strain-Number of Loads Relationship for CF & I Slag Ballast.

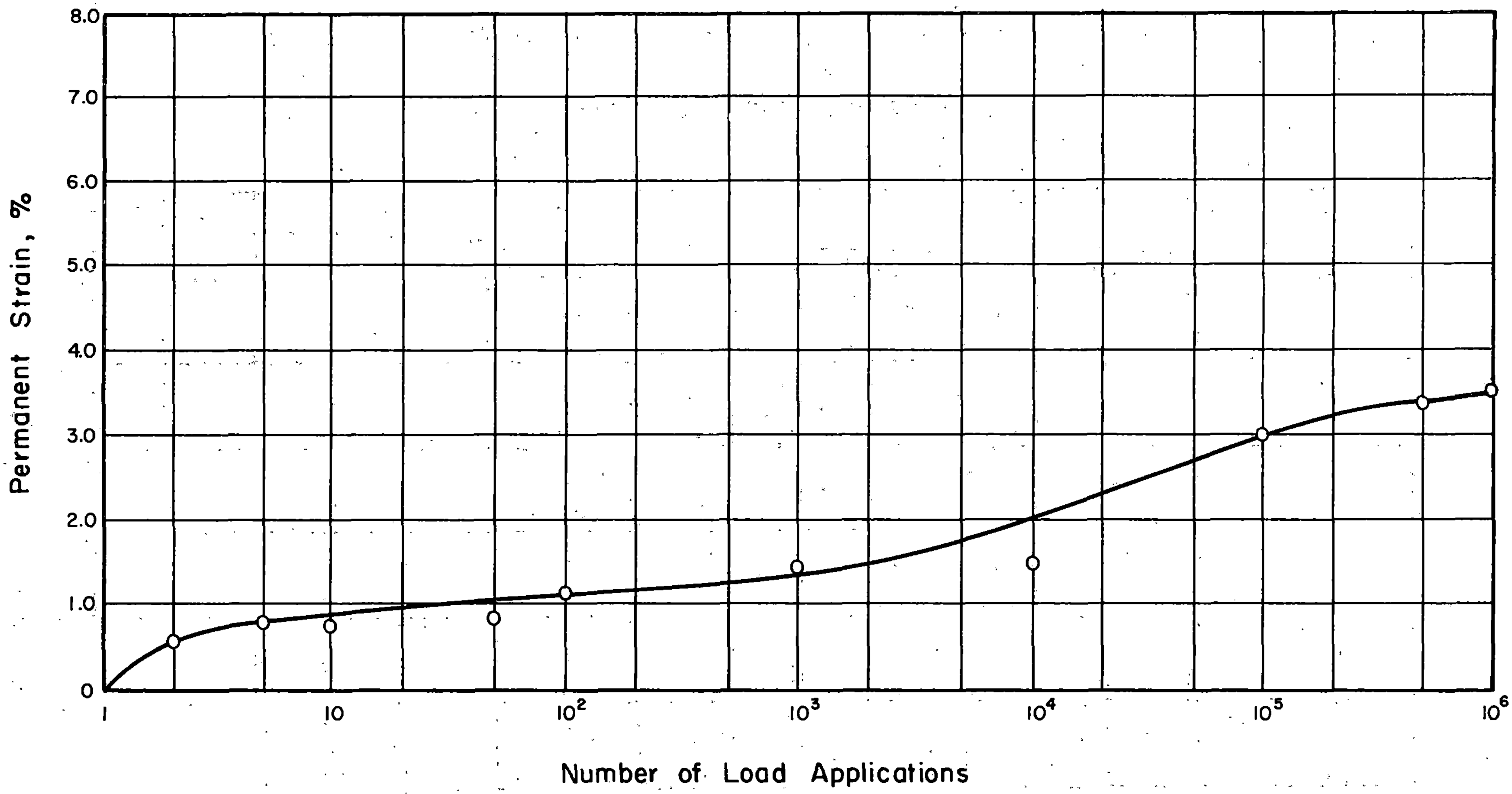


Figure 16. Permanent Strain - Number of Loads Relationship for FAST Subballast.

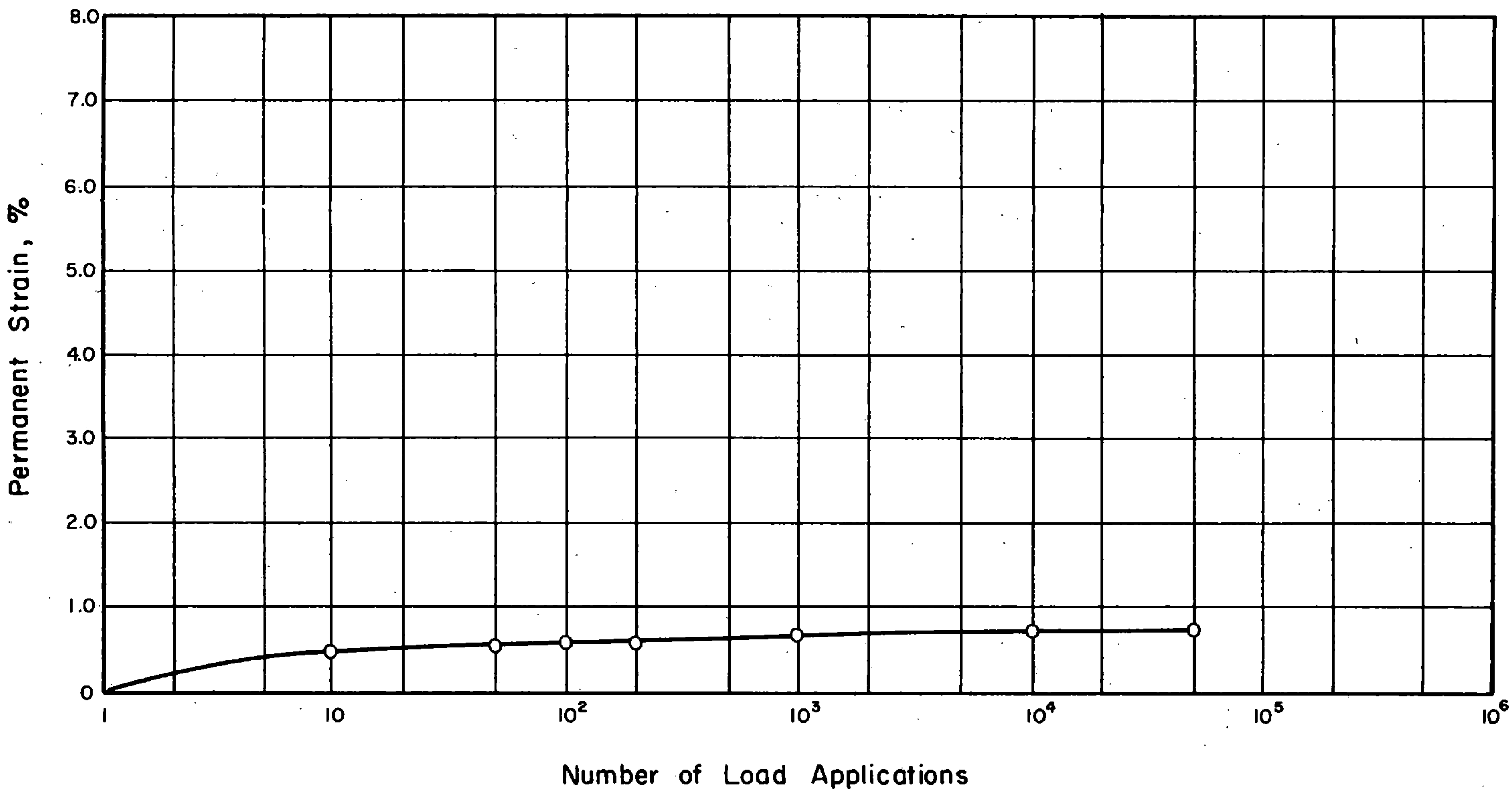


Figure 17. Permanent Strain - Number of Loads Relationship for FAST Subgrade.

Table 5. Ballast Gradation Data for Repeated Triaxial Samples

| Sieve Size | | | Percent Passing | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Wyoning Granite | | Pennsylvania Basalt | | McCook Limestone | | Indiana Limestone | | CF & I Slag | |
| | | Number of Loads (a) | 0 | $10^6$ | 0 | $10^6$ | 0 | $10^6$ | 0 | $10^6$ | 0 | $10^{5(b)}$ |
| inches | mm | | | | | | | | | | | |
| 2 | 50.8 | | 100.0 | | 100.0 | | | | | | | |
| 1 1/2 | 38.1 | | 99.1 | 99.1 | 77.9 | 83.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1 | 25.4 | | 77.9 | 78.9 | 11.2 | 12.5 | 38.4 | 39.9 | 57.7 | 58.8 | 31.1 | 39.9 |
| 3/4 | 19.0 | | 53.8 | 54.3 | 0.8 | 1.3 | 8.1 | 9.8 | 14.0 | 15.8 | 4.4 | 10.3 |
| 1/2 | 12.7 | | 24.0 | 24.7 | 0 | 0.3 | 1.1 | 1.2 | 3.2 | 3.6 | 1.7 | 4.3 |
| 3/8 | 9.5 | | 11.2 | 11.9 | | 0.3 | 0.3 | 0.7 | 2.7 | 2.7 | 1.6 | 4.0 |
| #4 | 4.76 | | 5.3 | 5.5 | | 0.2 | 0 | 0.6 | 1.9 | 2.5 | 1.5 | 3.3 |
| #10 | 2.00 | | 0 | 3.0 | | 0.2 | | 0.6 | 0 | 2.1 | | 3.2 |
| #40 | 0.42 | | | 0.3 | | 0.2 | | 0.5 | | 1.8 | | 2.3 |
| #200 | 0.075 | | | 0.2 | | 0.1 | | 0.4 | | 1.4 | | 1.7 |

Notes:

(a) - 0 loads is the original gradation of the sample.
(b) - Membrane puncture developed after $10^5$ load applications and testing was terminated.

Table 6. AREA Ballast Gradation Requirements

| | % Passing | |
|---|---|---|
| Sieve Size | No. 4 | No. 5 |
| 2 inches | 100 | --- |
| 1 1/2 inches | 90-100 | 100 |
| 1 inch | 20-55 | 90-100 |
| 3/4 inch | 0-15 | 40-75 |
| 1/2 inch | --- | 15-35 |
| 3/8 inch | 0-5 | 0-15 |
| No. 4 | --- | 0-5 |

Table 7. Unconfined Compressive Strength Data for FAST Subgrade Material

| Moisture Content at Test, % | Unconfined Compressive Strength* | |
|---|---|---|
| | $kN/m^2$ | psi |
| 7.3 | 20 | 2.9 |
| 7.1 | 27 | 3.9 |
| 6.6 | 25 | 3.7 |
| 5.7 | 57 | 8.3 |
| 5.5 | 68 | 9.8 |
| 5.1 | 57 | 8.3 |
| 3.2 | 127 | 18.4 |
| 0.4 | 859 | 124.5 |

*Average based on 3 specimens

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☆U.S. GOVERNMENT PRINTING OFFICE: 1978-261-264/26

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