

THE MICHIGAN DEPARTMENT OF TRANSPORTATION
CIRCULAR WEAR TRACK—RESULTS OF
PRELIMINARY AGGREGATE POLISHING TESTS

First Progress Report

R. W. Muethel

Research Laboratory Section
Testing and Research Division
Research Project 71 C-13
(Phase 2)
Research Report No. R-1098

Michigan Department of Transportation
Hannes Meyers, Jr., Chairman;
Carl V. Pellonpaa, Weston E. Vivian
John P. Woodford, Director
Lansing, March 1979

The information contained in this report was compiled exclusively for the use of the Michigan Department of Transportation. Recommendations contained herein are based upon the research data obtained and the expertise of the researchers, and are not necessarily to be construed as Department policy. No material contained herein is to be reproduced—wholly or in part—without the expressed permission of the Engineer of Testing and Research.

SUMMARY

This report presents the results of preliminary aggregate polishing tests completed on the MDOT circular wear track constructed by the Research Laboratory Section under Phase 2 of Research Project 71 C-13, "A Study of Aggregate and Mix Requirements for Durable and Skid-Resistant Bituminous Mixtures." The wear track was developed to study the effect of simulated traffic polish on various aggregates for use in bituminous pavements.

Completed tests include material from 16 carbonate rock quarries, seven glacial gravel sources, and two slag producers. Additional tests have been completed on 24 rock types sorted from glacial gravels, and two blends of high-polishing carbonate rock with crushed gravel.

The test results indicate that the polish resistance of aggregates can be readily differentiated by wear track testing. Mineral hardness, degree of cementation of mineral grains, and surface texture of the aggregate particles are shown to be major factors in polish resistance. Several types of aggregate appear to maintain polish resistance by sacrificial loss of surface grains.

The preliminary wear track test results suggest that high-polishing carbonate aggregate can be blended with polish-resistant material to produce a composite aggregate which will provide acceptable polishing resistance.

Future wear track tests are planned to evaluate various polish-resistant aggregates and blends with carbonates. The testing of bituminous pavement specimens is also being considered.

INTRODUCTION

Between 1957 and 1961 the Michigan Department of Transportation conducted skid surveys on approximately 261 portland cement concrete, 129 limestone bituminous concrete, and 109 gravel bituminous projects, using the Department's skid test vehicle. Results of these surveys, conducted in accordance with ASTM Standard E 274, indicated that bituminous pavements containing high percentages of limestone in the wearing course were exhibiting skid coefficients below a proposed acceptable minimum range of 0.35 to 0.40.

In 1965 the Department's Standard Specifications for Road and Bridge Construction were revised to include a ban on the use of crushed limestone in the wearing course of bituminous concrete (4.12) mixes, and a 70 percent carbonate limit on crushed gravel for these mixes. These restrictions, however, resulted in severe aggregate supply problems, particularly in the northern lower peninsula where local aggregates are primarily high-carbonate gravels and quarried carbonates.

In 1971 the Department initiated a study at the request of the gravel producers to evaluate the ban on using crushed limestone in the wearing course of bituminous concrete (4.12) mixes, and the 70 percent carbonate limit on crushed gravel for these mixes. The study, titled "Study of Aggregate and Mix Requirements for Durable and Skid Resistant Bituminous Mixtures" (Research Project 71 C-13), included the design and construction of a circular wear track under Phase 2, for the study of the effect of simulated traffic polish on various aggregates for use in bituminous pavements.

Construction of the wear track was completed in 1974 and the first experimental polishing tests were scheduled. A total of eight series of tests were completed between 1974 and 1977 at which time the wear track was dismantled for relocation in the Department's new Testing and Research Laboratory building. Reconstruction of the wear track at the new laboratory location was completed in 1978.

Purpose and Scope of the Project

The wear track was constructed for initially evaluating the polishing resistance of aggregates, primarily quarried carbonates, high carbonate gravels, and skidproof blending materials. The preliminary wear track test results discussed in this report investigate the interplay of smooth tread test tires with exposed aggregates graded to a standard size, and tested under controlled indoor laboratory conditions.

The wear track and static skid tester were designed and constructed by the Research Laboratory Section, and specialized procedures were developed for specimen preparation and operation of the wear track and skid tester.

TEST AGGREGATES

The following aggregates were tested in Series 1 through 8:

- 1) quarried carbonates from 16 major quarries in Michigan and adjacent states,
- 2) glacial gravel from seven local sources,
- 3) blast furnace slag from one source,
- 4) reverberatory furnace slag from one source, and
- 5) twenty-four rock types sorted from a statewide sampling of glacial gravels.

Detailed tabulations of the aggregate sources are included in Tables A-1 and A-2 of Appendix A. Each test series consisted of 16 slabs, usually containing eight different aggregate sources in pairs.

TESTS AND PROCEDURES

Test Slab Preparation

It was decided to begin the test program using No. 4 through 3/8-in. size stone particles embedded in a portland cement mortar. This would result in basic polishing data on the stone component of either 4.12 or 4.11 mixes. It had also been shown by many agencies that the coarse aggregate properties have the greatest influence on the skid resistance of bituminous mixtures. Preparation of the wear track test slabs is accomplished in the following sequence:

- 1) gradation of selected aggregate to passing 3/8-in., retained No. 4 size,
- 2) precoating of steel specimen molds with a medium-etch cement retarding compound,

- 3) placement of aggregate particles in etch-treated molds,
- 4) placement of portland cement mortar and wire mesh reinforcement in dual steel mold and briefly vibrate,
- 5) removal of etched cement and fine aggregate by washing and brushing test surfaces after a 24-hr cure, and
- 6) cure for 7 days in moist room and 14 days in air.

The test slab dimensions describe a trapezoidal concrete specimen 1-1/2 in. thick with parallel sides of approximately 15-1/2 in. and 19-1/2 in., and non-parallel sides of 11 in. (Fig. 1).

The etching process used in the fabrication of the test slabs results in the exposure of test aggregates approximately 2 mm above the etched concrete surface.

Figure 1 shows the specimen molds and vibratory table for consolidating the concrete slabs.

Wear Track Tests

The wear track polishing apparatus is comprised of a circular test bed approximately 7 ft in diameter set on a concrete pedestal. A complete series of test specimens contains 16 test slabs which are clamped securely in place. Polishing is accomplished by two 15-in. smooth tread tires (ASTM E-524) mounted on a horizontal cross-arm powered by a 10 hp a-c motor. Each polishing wheel is spring-loaded to approximately 800 lb to simulate vehicular weight. Wheel passes are recorded by an electro-mechanical counter preset to stop the test at 500,000 wheel pass intervals (250,000 revolutions).

A view of the wear track installation is shown in Figure 2.

Skid Tests

At intervals of 500,000 wheel passes of wear track polishing the specimens are skid-tested on a static skid test device containing a 15-in. smooth tread test tire (ASTM E-524) mounted in a framework containing a calibrated load cell. A skid test involves spinning the wheel to 40 mph for a drop-contact with the test slab. The torque generated by the tire-slab contact is recorded by a high-speed oscillograph. All skid tests are conducted with the specimens wetted by a recirculating water sprayer. The skid tester is shown in Figure 3.

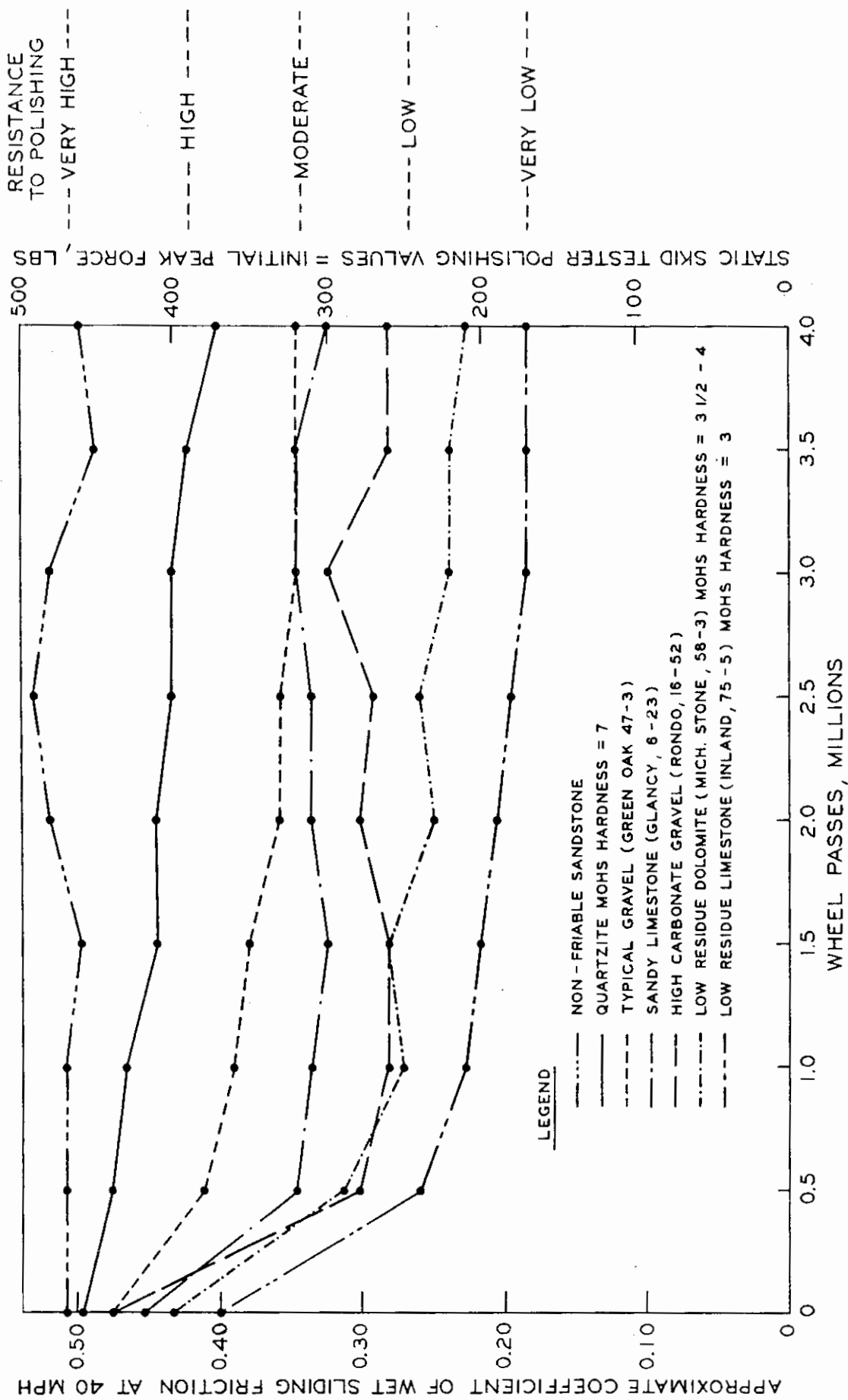


Figure 4. Examples of wear track polishing.

Although the wear track tests were intended to provide general polishing data, the test results suggest that several specific factors in aggregate polishing appear to be the mineral hardness of the rock constituents, the degree of cementation of mineral grains, and the roughness of the aggregate particle surfaces.

Figure 4 contains examples of hardness-related variations in polishing resistance. Quartzite (Mohs hardness 7) exhibits high resistance to polishing; Inland limestone (Mohs hardness 3) exhibits very low resistance to polishing. Oscillograms included in Appendix B also indicate the relationship between hardness and polishing resistance. The high resistance to polishing of such materials as friable sandstone and siltstone suggests that a continued rough surface texture is maintained by a minor loss of abraded material during wear track testing.

The effect of roughness (aggregate particle grain size) upon skid resistance is indicated by variations in initial skid test values. Non-friable sandstone (medium to fine-grained) exhibits a high initial skid value; Inland limestone (very fine grained to microcrystalline) exhibits a considerably lower initial skid value.

The tabulations include several aggregates which are highly resistant to wear track polishing. An example of such material is non-friable sandstone, which recorded a 2 percent decrease from the initial test value. The highly polish-resistant aggregates display very slight visual evidence of wear track polishing. None of the test slabs exhibited any evidence of rutting or scouring due to wear track polishing.

Supplemental skid tests were conducted on a highly polished smooth textured concrete test surface for comparison with the normal open-graded test surfaces of the wear track test slabs. As shown in Appendix B, oscillograms B-1, B and B-2, B show that both types of surfaces produce similar skid test results when highly polished.

Field Correlation Tests

The static skid tester used for measuring the effect of wear track tire polishing has been field tested for correlation with the Research Laboratory's GM skid test vehicle. In July of 1976 and May of 1977, the skid tester was installed in a portable frame and transported to field test locations for comparison tests with the skid test vehicle. Tests conducted on several portland cement concrete pavements and experimental test surfaces produced a correlation coefficient of 0.94 (Appendix C).

Figure 4 presents examples of wear track polishing results expressed as coefficients of wet sliding friction at 40 mph based upon the field correlation study. Pavements containing exposed coarse aggregate with a similar gradation could be expected to perform similarly. However, the presence of fine aggregate or bituminous material could cause considerable variation in skid performance of a pavement containing a given coarse aggregate.

Statistical Analysis of Test Data

Data from the skid testing of the wear track slabs containing the two control aggregates, Green Oak crushed gravel and Inland limestone, were submitted to the Research Laboratory Statistical Analysis Group for evaluation.*

The following comments summarize the results of the statistical analysis.

1) Future wear track studies should continue the present format of two replicate test slabs for each test aggregate.

2) Skid testing of one location per test slab would provide representative data for each slab.

3) The present format of three skid test trials per test slab location should be continued.

4) Wear track polishing beyond 2 or 2-1/2 million wheel passes provides minimal additional data. More frequent skid test intervals early in the testing would provide more detailed data during the period in which the greatest changes take place on the test slabs.

5) The continuation of the use of control aggregates in each test series does not appear to be necessary. Periodic checking of the skid tester could be accomplished with a standard reference test slab.

* A statistical evaluation report is being prepared.

CONCLUSIONS

The preliminary wear track polishing tests indicate that aggregates can be readily classified according to polishing resistance based upon wear track performance. Figure 4 presents an example of a classification which could be utilized for selecting aggregates for use in pavement wearing course mixtures.

The excellent polishing resistance of such aggregates as sandstone and siltstone suggests that these materials would serve as ideal blending agents. Also, the sacrificial effect which contributes to long-term resistance to polishing can be expected to be a characteristic of aggregates that contain considerable percentages of soft and non-durable material. A greater allowable percentage of such material in bituminous wearing course aggregates would be expected to result in greater skid resistance.

FUTURE TESTS

The wear track is scheduled for the following categories of testing:

- 1) evaluation of various skid resistant aggregates and blends with carbonates,
- 2) evaluation of siliceous carbonates for polishing resistance,
- 3) evaluation of selected crushed gravels and slags for polishing resistance, and
- 4) experimental testing of bituminous pavement core specimens of about 8-in. diameter mounted in a reinforced portland cement mortar base.

The fabrication of laboratory prepared bituminous mixture test slabs for wear track testing is being developed in cooperation with the Testing Laboratory's Bituminous Unit. These will allow the controlled testing of various mix parameters in addition to the coarse aggregate variables.

APPENDIX A
TABULATED RESULTS OF WEAR
TRACK POLISHING TESTS

TABLE A-1
RESULTS OF WEAR TRACK POLISHING TESTS
COMPLETED ON AGGREGATES FROM SELECTED
MICHIGAN AND OUT-OF-STATE SOURCES
(SERIES 1 THROUGH 5)

Aggregate Type and Composition	No. of Test Slabs	Wear Track Polishing Values		
		Initial Value	0.5 Million Wheel Passes	4.0 Million ¹ Wheel Passes
<u>Crushed Gravel approximately 40% Carbonate</u>				
Green Oak Pit No. 47-3 (Control Gravel)	15	440	380	320 (0.45)
G. R. Gravel Co. Pit No. 41-38	2	420	380	300 (0.41)
<u>Crushed Gravel, High Carbonate</u>				
Rondo Pit No. 16-52 (82% Carbonate)	2	440	280	260 (0.36)
Pierce Pit No. 45-19 (90% Carbonate)	2	460	350	250
Big Cut Pit No. 71-15 (90% Carbonate)	2	430	330	240 (0.34)
<u>Natural Gravel</u>				
Hodgkiss and Douma Pit No. 5-74 (7% Shale Content)	2	390	330	270 (0.37)
Day Pit No. 40-1 (3% Shale Content)	2	400	320	240 (0.34)
<u>Quarried Carbonates</u>				
Weldum Pit No. 21-54 Shaley LS. and Siltstone	2	460	390	330 (0.46)
Glancy Pit No. 6-23 Aren. LS., Produced ²	2	420	340	320
Wallace Pit No. 32-4 Aren. LS., BR ²	2	440	350	310
Glancy Pit No. 6-23 Aren. LS., Top 12 ft ²	2	420	320	300
Wallace Pit No. 32-4 Aren. LS., Produced ²	2	430	380	290
France Pit No. 58-2 Aren. Dol. ²	2	470	370	290
Peterson Pit No. 55-95 Dol.	2	470	370	290
Wallace Pit No. 32-4 Aren. LS., FF ²	2	450	360	290
France Pit No. 58-1 Dol. and Calc. Dol.	2	460	360	270
Material Services, Thornton, Ill. Dol., Vuggy	2	450	360	260 (0.36)
Bichler Pit No. 21-46 Arg. LS.	2	470	350	250
Thornton Pit No. 21-67 Dol. and Calc. Dol.	2	460	340	230
France, Waterville, OH Dol.	2	450	310	230
Nat. Lime, Findlay, OH Dol.	2	390	300	210
Michigan Stone Pit No. 58-3 Dol. and Calc. Dol.	2	400	290	210
Drum. Dol Pit No. 17-66 Dol.	3	410	280	200
Hendricks Pit No. 49-7 Dolomitic LS.	2	400	260	180
Presque Isle Pit No. 71-47 LS.	2	400	260	180
Inland Pit No. 75-5 (Control Limestone)	15	370	240	170 (0.24)
<u>Slag</u>				
E. C. Levy Blast Furnace	2	520	450	340 (0.47)
White Pine Copper Co. Reverb. Furnace	2	420	330	290 (0.40)
<u>Blended Aggregates</u>				
(Green Oak Pit No. 47-3 and Inland Pit No. 75-5)				
Cr. Gravel: Limestone, 50:50 (70% Tot. Carb.)	1	440	280	240 (0.34)
Cr. Gravel: Limestone, 20:80 (88% Tot. Carb.)	2	430	280	220 (0.31)

Polishing Value = average initial peak force, lb, measured on wear track skid tester.

¹ Numbers in parentheses indicate the approximate 40 mph coefficients of wet sliding friction based upon preliminary field correlation tests.

² Material contains greater than 10 percent insoluble residue coarser than No. 200 sieve.

NOTE: Control gravel and limestone values determined from Series 1 through 8 data.

TABLE A-2
RESULTS OF WEAR TRACK POLISHING TESTS
COMPLETED ON ROCK TYPES SORTED FROM
SELECTED MICHIGAN AGGREGATES
(SERIES 5 THROUGH 8)

Rock Type	No. of Test Slabs	Wear Track Polishing Values		
		Initial Value	0.5 Million Wheel Passes	4.0 Million ¹ Wheel Passes
Crushed Gravel Control Aggregate (Green Oak Pit No. 47-3)	15	440	380	320(0.45)
<u>Igneous</u>				
Diorite	2	480	450	360(0.49)
Granite	2	460	450	350
Gabbro	2	480	430	350
Felsite ²	2	440	400	320
Basalt	2	420	380	310(0.42)
<u>Metamorphic</u>				
Quartzite	2	460	440	370(0.51)
Schist	2	410	390	350
Metasediments	2	450	410	340
Tillite	2	440	400	320(0.45)
<u>Sedimentary</u>				
Friable Sandstone	2	530	540	520(0.70)
Non-Friable Sandstone	2	470	470	460
Siltstone	2	470	460	450
Crag	2	500	420	410
Vitreous and Dark Dull Chert	2	400	360	340
Mottled Chert	2	400	360	330
Shale	2	370	320	320(0.45)
Light Dull Chert	2	410	320	310
Clay Ironstone, Outer Shells	2	430	320	290
Clay Ironstone, Fossiliferous	2	420	300	270
Clay Ironstone, Hard Centers	2	410	270	250
Clay Ironstone, Massive-Laminated	2	390	300	250
Dolomite ³ (Drummond Island Pit No. 17-66)	3	410	280	200
Dolomitic Limestone ³ (Hendricks Pit No. 49-7)	2	400	260	180(0.25)
Limestone ³ Control Aggregate (Inland Pit No. 75-5)	15	370	240	170(0.24)

Polishing Value = average initial peak force, lb, measured on wear track skid tester.

¹ Numbers in parentheses indicate the approximate 40 mph coefficients of wet sliding friction based upon preliminary field correlation tests.

² Includes rock outcrop material

³ Quarried material

NOTE: Control gravel and limestone values determined from Series 1 through 8 data.

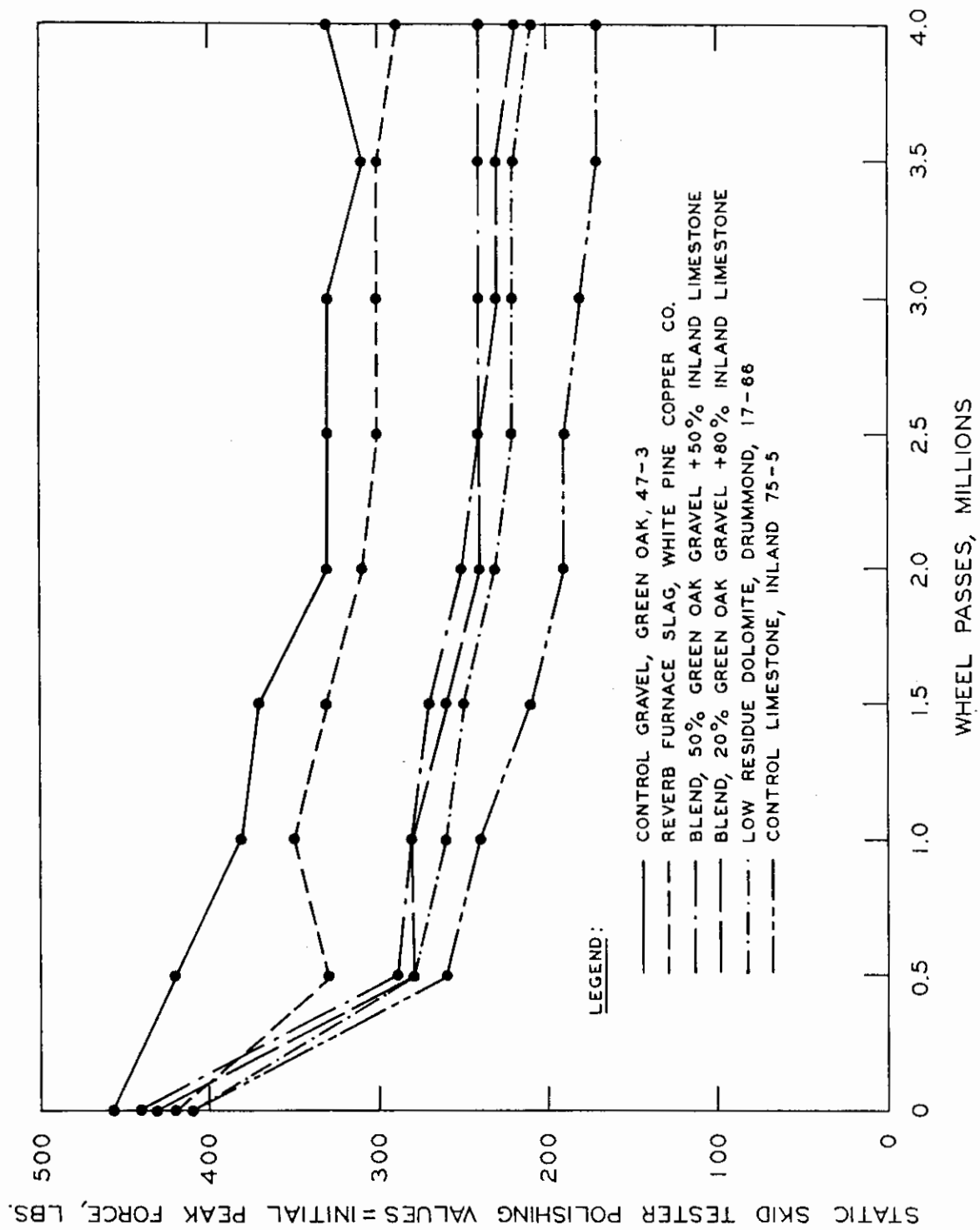


Figure A-1. Wear track test series No. 1.

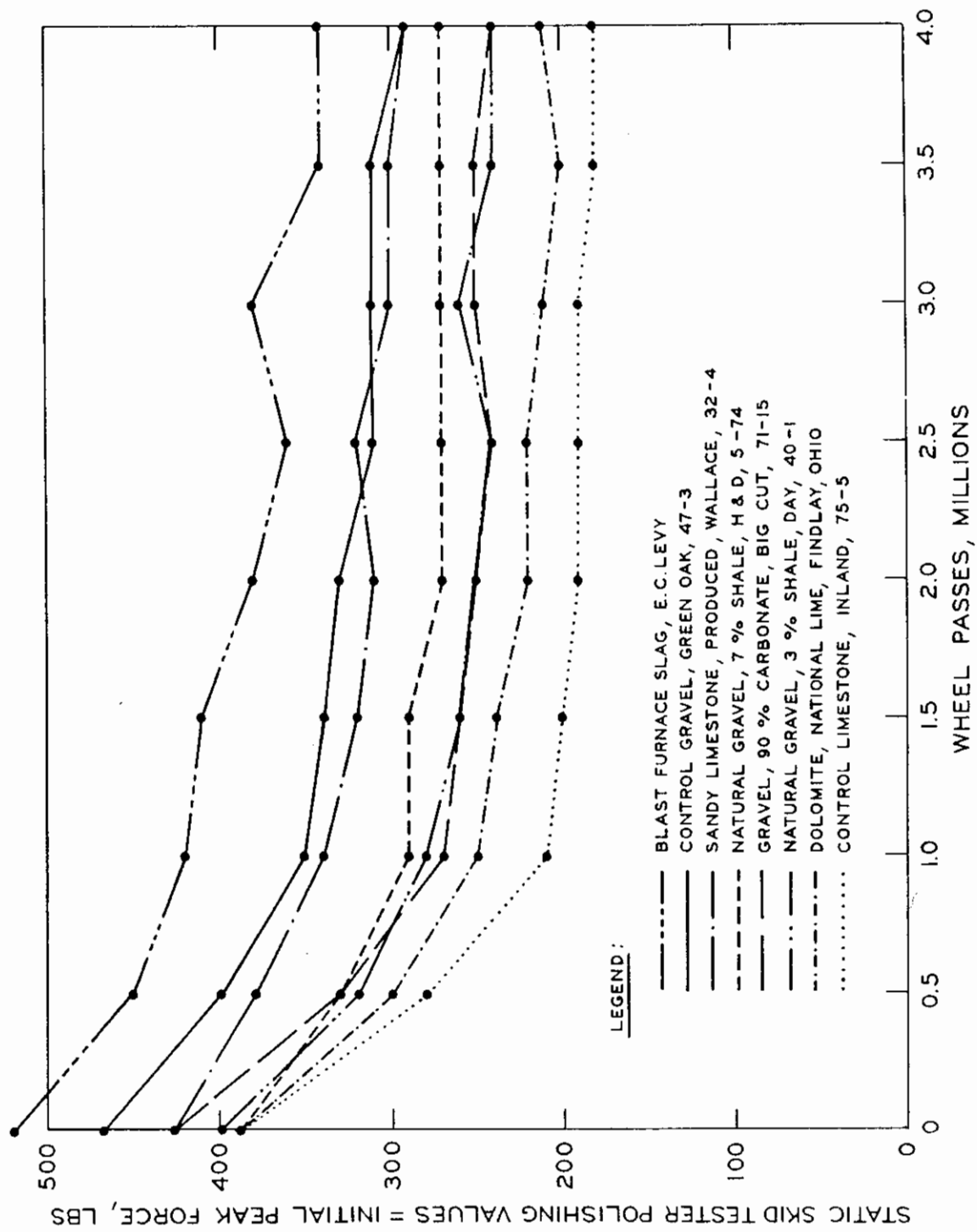


Figure A-2. Wear track test series No. 2.

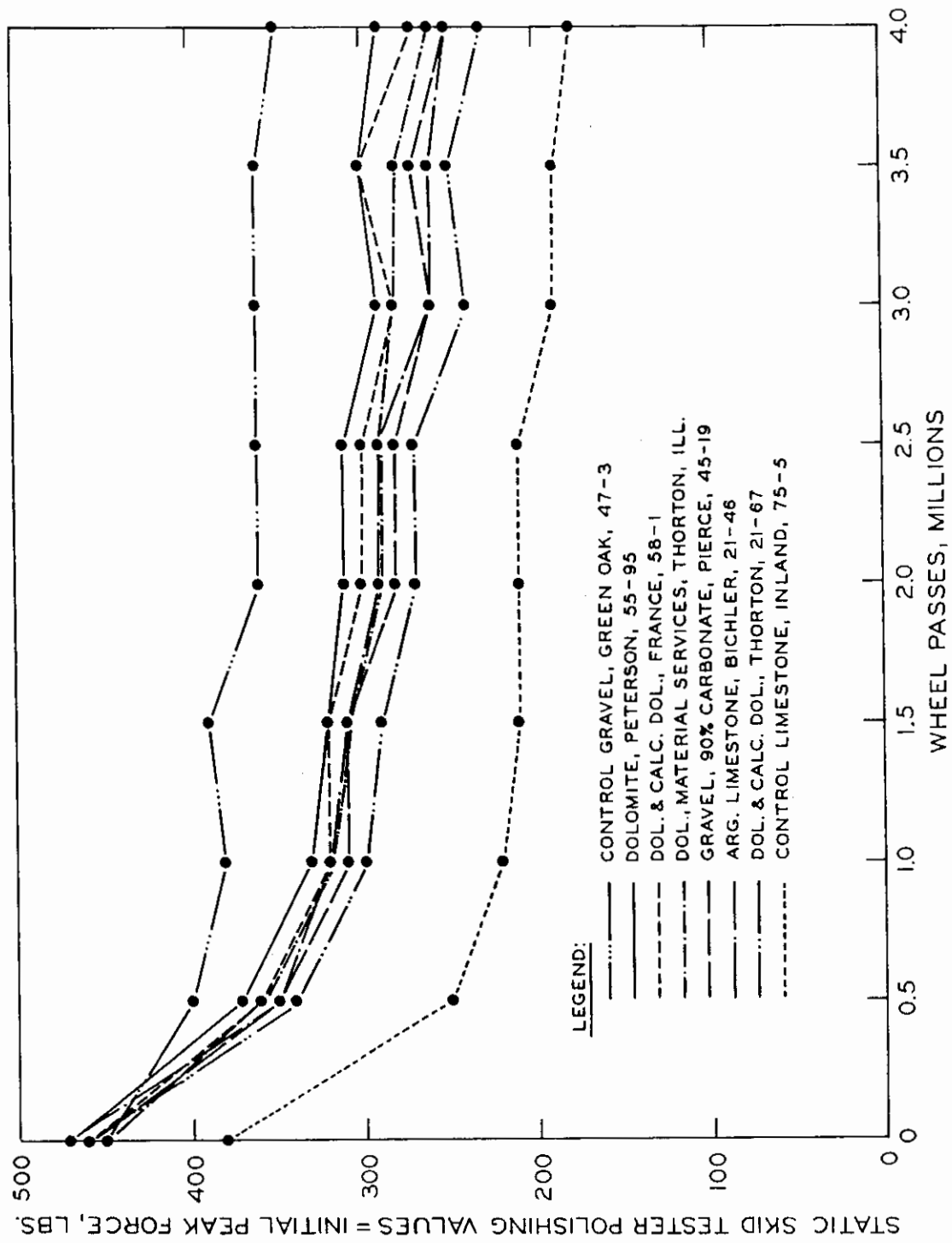


Figure A-3. Wear track test series No. 3.

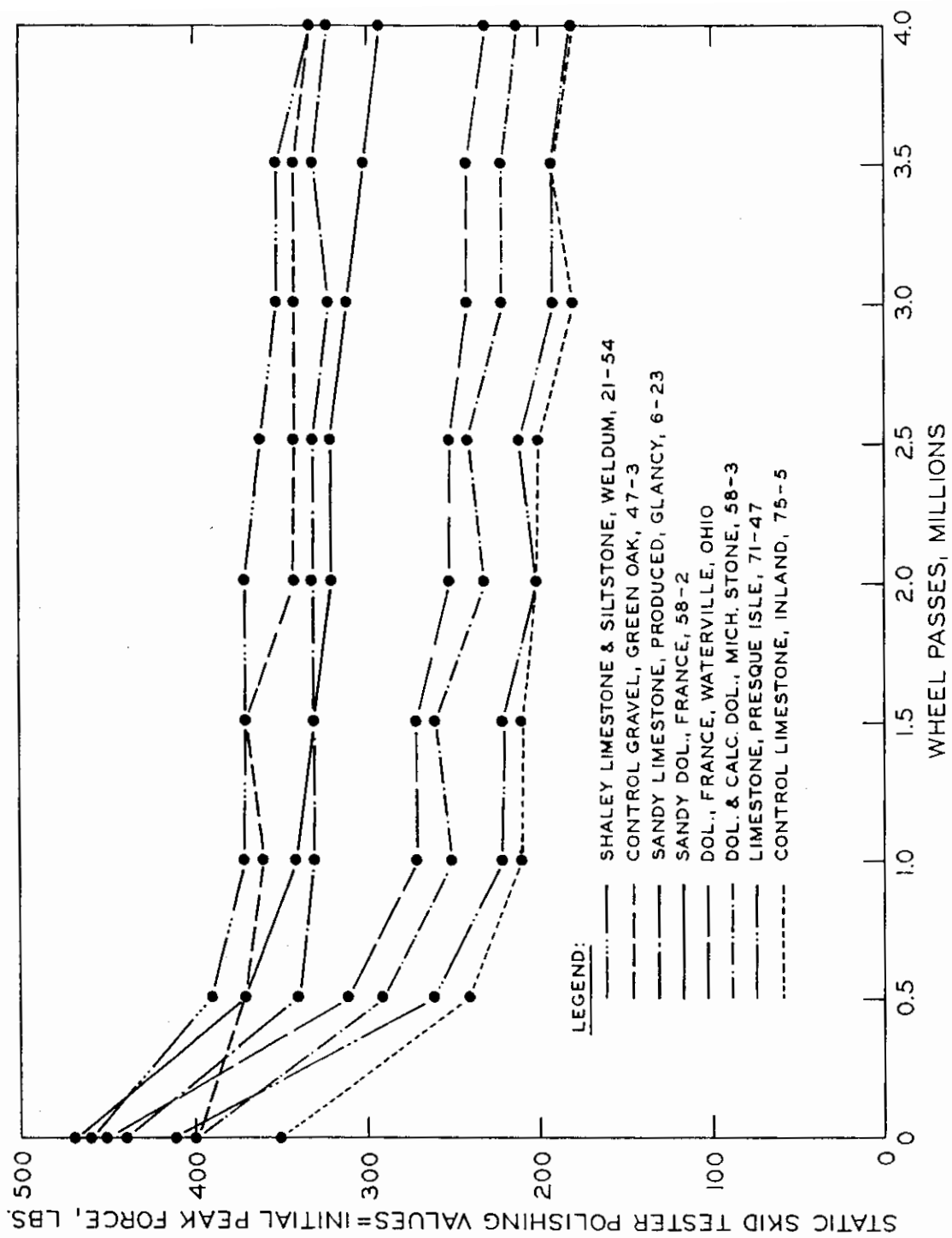


Figure A-4. Wear track test series No. 4.

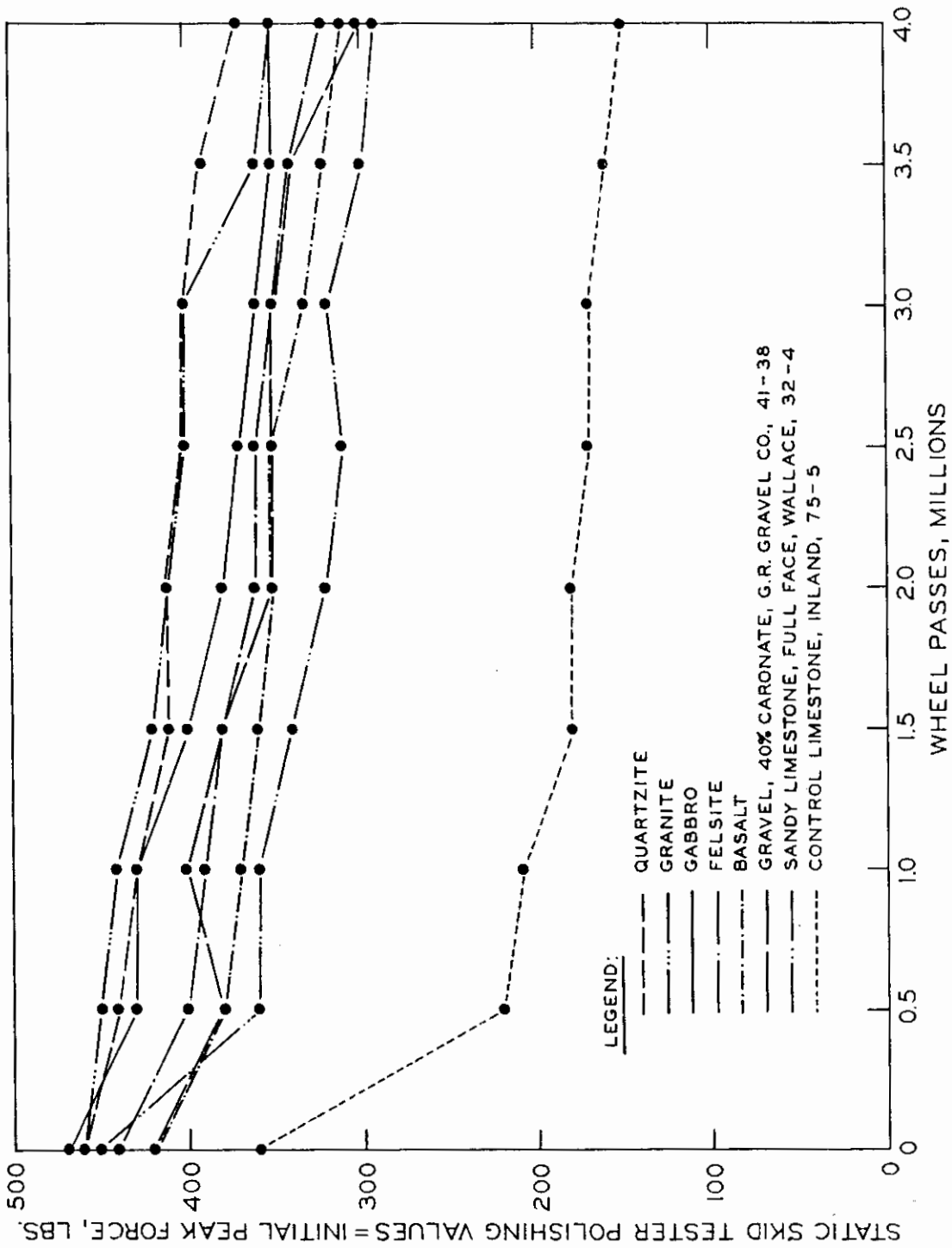


Figure A-5a. Wear track test series No. 5 and 7.

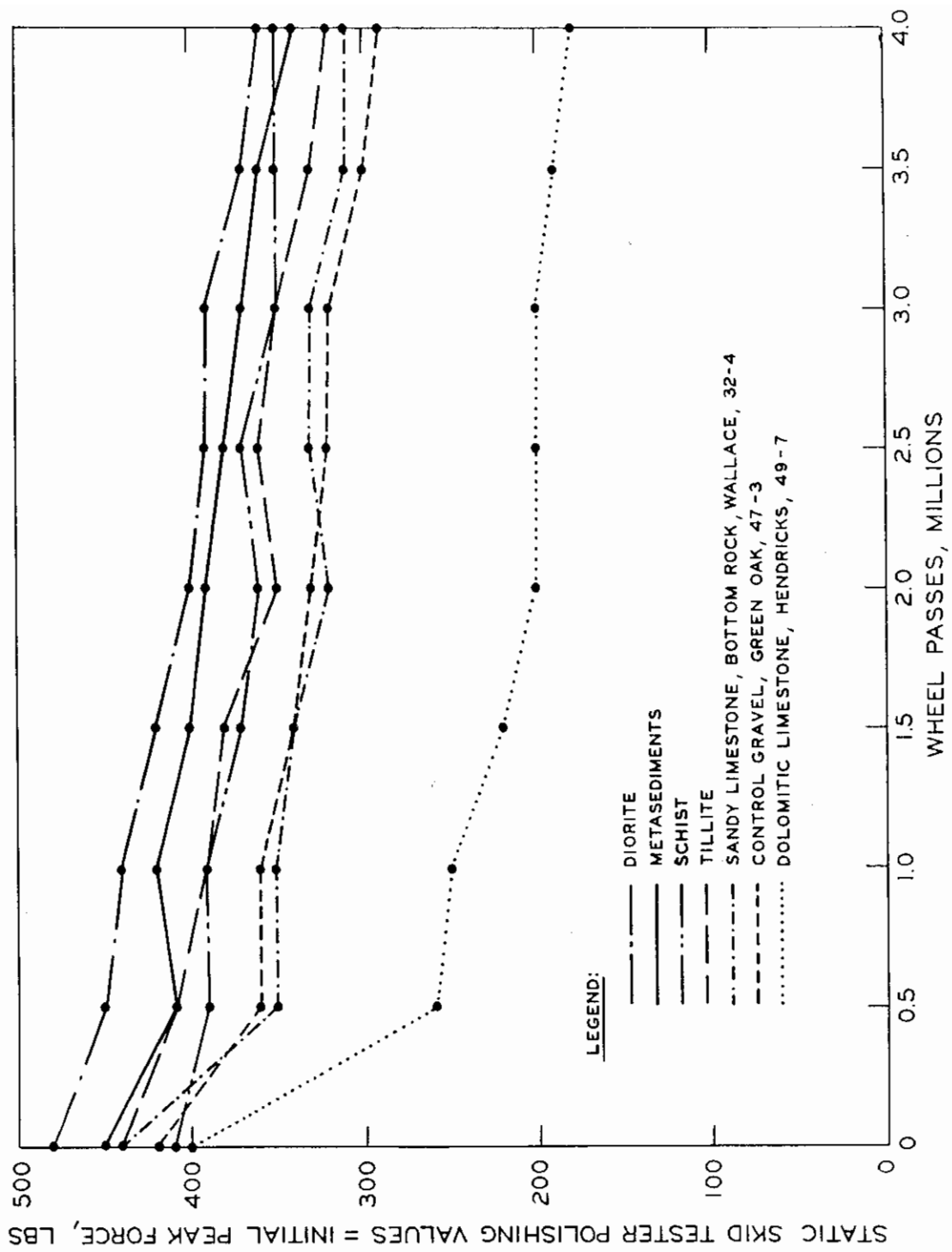


Figure A-5b. Wear track test series No. 5 and 7, continued.

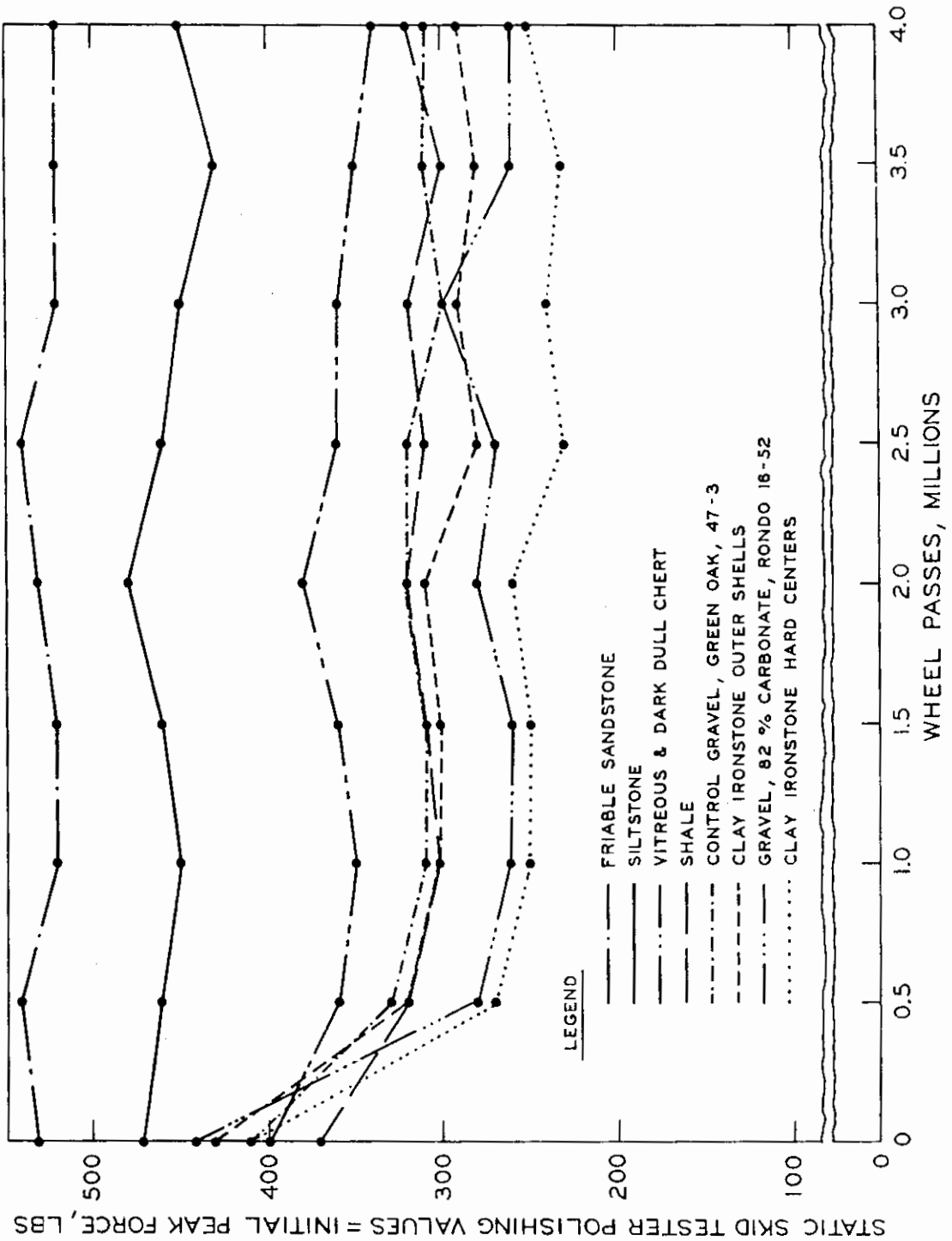


Figure A-6a. Wear track test series No. 6 and 8.

APPENDIX C

FIELD CORRELATION TESTS, GM UNIT SKID
TEST VEHICLE vs. STATIC SKID TESTER



OFFICE MEMORANDUM

DATE: October 14, 1977

TO: L. T. Oehler
Engineer of Research

FROM: L. E. DeFrain

SUBJECT: Field Calibration Device for Static Skid Tester.
Research Project 75 TI-320.

The purpose of this letter is to report the procedures and results of the subject project.

Background and Purpose

The wear track is currently used to determine the wear properties of selected aggregates. As part of this work, the skid resistance of the test samples is also determined. These skid data provide a measure of the degree of aggregate polishing. The test is performed by dropping a standard test tire, revolving at 40 mph, onto the wetted test sample and recording the resultant drag force, on the wheel assembly, on a high speed chart recorder.

The purpose of the field calibration reported below is to determine if a correlation exists between some characteristic of the drag force of the laboratory test and the dynamic skid coefficients currently being measured in the field by our Skidometer.

Procedure

Several concrete and bituminous roadway test sites were selected to provide a wide dynamic range of skid values. At each site skidometer tests were performed and the actual skid path marked. Subsequently, the portable version of the laboratory static skid tester was placed on the marked path and the drag force on the wheel assembly measured. Approximately five such tests were performed along the marked wheel track of each dynamic test. A typical plot of drag force versus time is shown in Figure 1.



Figure 1. Typical wheel stopping forces obtained from static skid tester.

Results and Conclusions

Tests were performed during July of 1976 and May of 1977. Vehicle speeds of 20 and 40 mph were used in the dynamic measurements and 21 tests were performed, ranging in value from 0.05 to 0.72.

Since the static tests produced an analog trace of drag versus time, it was possible to investigate several measures of stopping force.

- 1) Initial peak force (multiple peaks from some tests)
- 2) Average force
- 3) Total work to stop wheel
- 4) Time required for wheel to stop.


Of these four potential test parameters; the initial peak force was found to have the most favorable correlation with the dynamic skid values.

The results of the correlation analysis are shown in Figure 2. The standard error of estimate for the dynamic skid instrument is 0.01. A linear regression analysis of the static skid instrument indicates that the standard error of estimate is ± 75 lb with a correlation coefficient of 0.94. Using Figure 2, this allows determination of the skid coefficient with a resolution of ± 0.06 .

October 14, 1977

This analysis indicates that the peak initial drag force obtained from laboratory tests using the static skid tester can be related to pavement skid coefficients.

TESTING AND RESEARCH DIVISION



Supervisor - Instrumentation and
Data Systems Group

LED:bf

cc: F. Copple
G. H. Gallup
M. G. Brown
R. W. Muethel

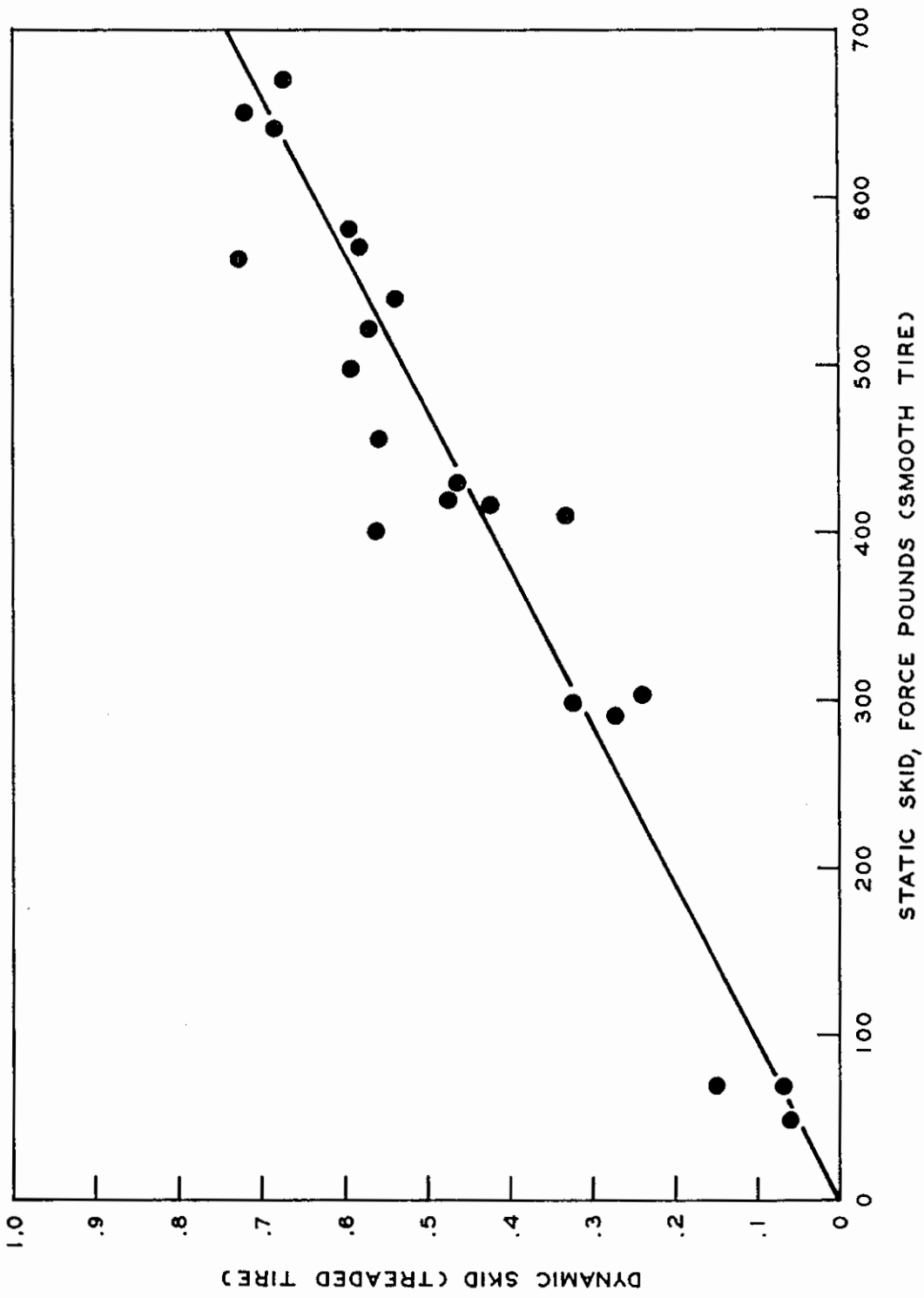


Figure 2. Correlation study: GM Unit skid test vs. static wheel.