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PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No./(Center No.) E-20-G16 (R6236-0A0) GTRC/GIT x DATE 1 / 8 / 87

Project Director: James S. Lai School/Lab CE

Sponsor: Georgia Department of Transportation

Agreement No.: Task Order #7 under BOA #90 dated 11/9/84

Award Period: From 10/14/86 To ~~12/31/86~~ 3-31-87 (Performance) 12/31/86 Reports

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	New With This Change	Total to Date
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Funded:	$ 9,944	$ 9,944

Cost Sharing No./(Center No.) N/A Cost Sharing: $ None

Title: Evaluation of Rutting Characteristics of Asphalt Mixes Using Loaded-Wheel Tester

ADMINISTRATIVE DATA

OCA Contact Brian J. Lindberg x. 4820

1) Sponsor Technical Contact:

Tom Stapler
Georgia Department of Transportation
Office of Materials and Research
15 Kennedy Drive
Forest Park, GA 30050
363-7567

2) Sponsor Issuing Office:

Percy B. Middlebrooks, Jr.
Georgia Department of Transportation
Office of Materials and Research
15 Kennedy Drive
Forest Park, GA 30050
363-7567

Military Security Classification: N/A
(or) Company/Industrial Proprietary: N/A

ONR Resident Rep. is ACO: ______ Yes X No
Defense Priority Rating: N/A

RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Sponsor. However, none proposed.

COMMENTS:

SPONSOR'S I.D. NO. 02.300.000.87.003

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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 3-19-87

Project No. E-20-G16 School/Lab CE

Includes Subproject No.(s) N/A

Project Director(s) James S. Lai GTRC / GIT

Sponsor Georgia Department of Transportation

Title Evaluation of Rutting Characteristics of Asphalt Mixes Using Loaded-Wheel Tester

Effective Completion Date: 3/31/87 (Performance) 3/31/87 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [X] Final Invoice or Final Fiscal Report - With Certification
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

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Angela DuBose
Russ Embry

FORM OCA 69.285

Contract Research

GaDOT Research Project No. 8609

FINAL REPORT

EVALUATION OF RUTTING CHARACTERISTICS OF ASPHALT MIXES USING LOADED-WHEEL TESTER

By

James S. Lai
Professor of Civil Engineering
School of Civil Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Prepared for

Georgia Department of Transportation
Office of Materials and Research

December, 1986

TABLE OF CONTENTS

Abstract

The purposes of this study are: 1) to assess the rutting potential of the GaDOT type B asphalt mixes and the six different modified mixes using aggregates from three different sources, and 2) to suggest the mix(es) that could provide better resistance to rutting. The modified mixes include the following:

- 3M: Adding 3% mineral filler from GA. Marble Co. @ Tate GA.
- 5M: Adding 5% mineral filler from GA. Marble Co. @ Tate Ga.
- 5T: Adding 5% mineral filler from Trenton Sand Co. @ Trenton Ga.
- 5S: Adding 5% Sylacauga Sand from Sylacauga, Alabama
- HM: Hand mixed gradation to increase minus #50 size particles
- 6K: Adding 6% Kraton polymer to asphalt cement

Prediction of rutting potential was based on a laboratory procedure in which the asphalt beam samples were made in the laboratory and were subjected to a repetitive wheel load to a certain prescribed number of repetitions. The rut-depth developed along the wheel path on the beam samples was measured and was used as the basis for evaluating the rutting potential of the mixes.

Comparision the ruting resistance of the standard Type B mixes determined in this study, the 3M and 5M modified mixes can improve rutting resistance, the effectiveness of the 5T and 5S modified mixes is mixed and requires further investigation, the benefit of using the HM modified mixes is significant, and the 6K modified mixes have the potential of improving rutting resistance.

CHAPTER 1
INTRODUCTION

This report summarizes the results and evaluations of the study of rutting characteristics of asphalt mixes conducted jointly by Georgia Department of Transportation, Office of Materials and Research, and Georgia Institute of Technology, School of Civil Engineering. The purpose of the study was to evaluate rutting characteristics of the Georgia coarse Type B asphalt mixes and several of the modified mixes using aggregates from three different sources. The standard mixes using the aggregates from the three sources were originally proposed to be used for the base course in a 30 mile roadway project. There was concern that these mixes as proposed could potentially develop excessive rutting. Several modified mixes were considered in an effort to reduce the potential rutting problem. This study was designed to evaluate if any of the modified mixes can indeed improve rutting resistance.

CHAPTER 2
MATERIALS

The aggregates used for this study were from Vulcan Materials Company at the following three plants:

Fairmount, GA	(F)
Dalton, GA	(D)
Chattanooga, TN	(C)

Ths standard gradations for the Type B binder course mixes for the three aggregates are given in Table 1A, 1B, and 1C. Modification to these standard gradations include:

3M: Adding 3% mineral filler from Ga. Marble Co. @ Tate Ga.

5M: Adding 5% mineral filler from Ga. Marble Co. @ Tate Ga.

5T: Adding 5% mineral filler from Trenton Sand Co. @ Trenton Ga.

5S: Adding 5% Sylacauga sand from Sylacauga, Alabama

HM: Hand mixed gradation to increase minus #50 size particles.

6K: Adding 6% Kraton polymer (by wt. of AC) to asphalt cement.

The gradations of these mixes are presented in Appendix A. The gradations of the mineral fillers from Ga. Marble Co., Trenton Sand Co., and Sylacauga Sand are given in Table 2.

The asphalt cement used was AMOCO AC-30, except the 6K Mixes in which the asphalt used was AC-20S from Shell Oil Co., the standard Shell AC-20 modified by adding 6% kraton polymer solids by weight of asphalt cement. The propertied of this modified asphalt are enclosed in Appendix B.

Table 3 in the following summarizes the 21 mixes used in this study.

TABLE 1A RUT STUDY - VULCAN MATERIALS @ FAIRMOUNT, GA.

COMBINATION	STANDARD MIX	3% MARBLE DUST	5% MARBLE DUST	5% SYLACAUGA SAND	5% TRENTON SAND	6% KRATON	HAND MADE GRADATION
BLEND:	49% - 67 10% - 89 16% - 810 24% - 777 1% - Lime	49% - 67 10% - 89 22% - 810 15% - 777 3% - Dust 1% - Lime	49% - 67 10% - 89 22% - 810 13% - 777 5% - Dust 1% - Lime	49% - 67 10% - 89 20% - 810 15% - 777 5% - Sand 1% - Lime	49% - 67 10% - 89 20% - 810 15% - 777 5% - Sand 1% - Lime	49% - 67 10% - 89 20% - 810 20% - 777 1% - Lime	49% - 67 10% - 89 20% - 810 20% - 777 1% - Lime
SIEVE GRADATION:							
1"	100	100	100	100	100	100	100
3/4	99	99	99	99	99	99	99
1/2	84	84	84	84	84	84	84
3/8	68	68	68	68	68	68	68
4	45	45	45	45	45	45	45
8	33	33	33	33	33	33	33
16	21	22	23	23	23	21	23
30	13	14	16	15	15	12	15
50	7	9	11	10	8	7	11
100	5	6	7	6	5	4	4
200	4	4	5	4	4	4	4
DESIGN DATA:							
Optimum A.C.(%)	4.9	4.0	4.0	4.1	4.2	4.9	4.3
Density (PCF)	150.7	152.2	152.9	153.0	152.2	150.2	152.0
Stability (lb.)	2490	2240	2400	2380	2460	2080	2110
Flow (.01")	12.3	8.8	11.2	12.9	10.2	13.4	10.8
Modified T/S (PSI)	35.0	46.8	49.5	45.3	46.0	38.9	29.5
Stiffness (lb./in.)	16381	20655	17451	18028	18486	15787	11913
Rut Depth (in.) after 2000 cycles	.088	.092	.071	.104	.103	.090	.063

TABLE 1B RUT STUDY - VULCAN MATERIALS @ DALTON, GA.

COMBINATION	STANDARD MIX	3% MARBLE DUST	5% MARBLE DUST	5% SYLACAUGA SAND	5% TRENTON SAND	6% KRATON	HAND MADE GRADATION
BLEND:	37% - 6 22% - 89 25% - 810 15% - 777 1% - Lime	37% - 6 23% - 89 22% - 810 14% - 777 3% - Dust 1% - Lime	37% - 6 24% - 89 19% - 810 14% - 777 5% - Dust 1% - Lime	37% - 6 23% - 89 22% - 810 12% - 777 5% - Sand 1% - Lime	37% - 6 20% - 89 26% - 810 9% - 777 5% - Sand 1% - Lime	37% - 6 22% - 89 25% - 810 15% - 777 1% - Lime	37% - 6 22% - 89 25% - 810 15% - 777 1% - Lime
SIEVE GRADATION:							
1"	100	100	100	100	100	100	100
3/4	99	99	99	99	99	99	99
1/2	74	74	74	74	74	74	74
3/8	66	66	66	66	66	66	66
4	46	46	46	46	46	46	46
8	33	33	33	33	33	33	33
16	20	21	22	21	21	20	22
30	13	15	16	15	15	13	15
50	9	11	12	11	10	9	12
100	7	8	8	8	7	7	7
200	5	5	5	5	5	5	5
DESIGN DATA:							
Optimum A.C.(%)	4.4	4.2	3.9	4.3	4.1	4.4	4.2
Density (PCF)	150.9	151.9	152.1	151.0	151.8	150.0	151.6
Stability (lb.)	2040	2550	2710	2110	2610	1900	1950
Flow (.01")	11.0	8.8	11.6	13.1	10.3	13.0	11.9
Modified T/S (PSI)	60.4	43.6	44.1	40.0	43.6	55.5	57.1
Stiffness (lb./in.)	22378	19336	21943	11602	21111	11743	21188
Rut Depth (in.) after 2000 cycles	.102	.076	.091	.126	.098	.067	.085

TABLE 1C. RUT STUDY - VULCAN MATERIALS @ CHATTANOOGA, TENN.

COMBINATION	STANDARD MIX	3% MARBLE DUST	5% MARBLE DUST	5% SYLACAUGA SAND	5% TRENTON SAND	6% KRATON	HAND MADE GRADATION
BLEND:	33% - 6 27% - 7 19% - M10 20% - 777 1% - Lime	33% - 6 27% - 7 21% - M10 15% - 777 3% - Dust 1% - Lime	33% - 6 27% - 7 19% - M10 15% - 777 5% - Dust 1% - Lime	33% - 6 27% - 7 19% - M10 15% - 777 5% - Sand 1% - Lime	33% - 6 27% - 7 19% - M10 15% - 777 5% - Sand 1% -Lime	33% - 6 27% - 7 19% - M10 20% - 777 1% - Lime	33% - 6 27% - 7 19% - M10 20% - 777 1% - Lime
SIEVE GRADATION:							
1"	100	100	100	100	100	100	100
3/4	99	99	99	99	99	99	99
1/2	78	78	78	78	78	78	78
3/8	63	63	63	63	63	63	63
4	42	42	42	42	42	42	42
8	33	33	33	33	33	33	33
16	20	21	22	22	22	20	21
30	14	16	17	16	16	14	16
50	9	11	12	11	10	9	12
100	6	8	8	8	7	6	6
200	5	5	5	5	4	5	5
DESIGN DATA:							
Optimum A.C.(%)	4.8	4.0	3.9	4.1	4.1	4.8	4.3
Density (PCF)	152.6	155.0	155.1	154.2	154.4	152.9	153.6
Stability (lb.)	2020	2620	2820	2760	2510	2330	1840
Flow (.01")	13.7	9.8	9.7	13.1	9.1	13.0	11.9
Modified T/S (PSI)	42.6	44.3	56.0	43.5	38.0	42.8	30.4
Stiffness (lb./in.)	14077	17988	19667	20680	14988	13662	10278
Rut Depth (in.) after 2000 cycles	.097	.085	.074	.058	.091	.058	.098

TABLE 2. MINERAL FILLER GRADATIONS FOR RUT STUDY

SOURCE:	GA. MARBLE 40 - 200 @ TATE, GA.	TRENTON MATERIALS @ TRENTON, GA.	GA. MARBLE @ SYLACAUGA, ALA.
SIEVE:			
3/8			100
4			98
8		100	95
16		93	87
30	100	82	78
50	89	42	66
100	48	13	40
200	18	1	10

Table 3. Asphalt Mixes Included in the Study

Agg. Sources / Modifications	Fairmount, Ga. (F)	Dalton, Ga. (D)	Chattanooga, TN (C)
Standard	FS	DS	CS
3% Marble Dust	F3M	D3M	C3M
5% Marble Dust	F5M	D5M	C5M
5% Trenton Sand	F5T	D5T	C5T
5% Sylacauga Sand	F5S	D5S	C5S
Hand Mixed	FHM	DHM	CHM
6% Kraton Polymer	F6K	D6K	C6K

CHAPTER 3

SAMPLE PREPARATION

Marshall mix design for the 21 mixes listed in Table 3 were performed at the GaDOT materials laboratory. Results of the Marshall mix design are summarized in Table 1A, 1B, and 1C. The optimum asphalt contents for each mix were based upon the air voids in the mix at approximately 4.5%.

The materials, aggregates and asphalt, needed to fabricate the 3"x3"x-15" beam samples for this study were provided by GaDOT. Based on the bulk density of each mix from the Marshall mix design, and the known volume of the beam mold, aggregate samples for 1/3 beam volume were batched for all the mixes. A total of 9 batches per mixes were prepared at GaDOT materials laboratory. During the preparation of the mixes, except for preparing the 6K mixes, aggregates and the asphalt cement were heated separately at 360^{0}F and 315^{0}F respectively. For the 6K mixes, aggregates and the asphalt cement were heated at 400^{0}F and 360^{0}F respectively.

The following describes the beam sample preparation procedures. The heated aggregates from the oven were poured into a mixing bowl and a 1% hydrated lime (by wt. of aggregates) was added to the aggregate. The aggregate and the lime were dry mixed and the optimum amount of asphalt was introduced and then the materials were thoroughly mixed by hand. The heated beam mold was placed on a sliding rack in the kneading compactor and the asphalt mix spooned into the mold. The 3"x1" loading foot of the kneading compactor was activated to compress the mix in the mold. During the compaction of the mixes in the beam mold, the beam was manually moved length-wise so that the entire beam would be subjected to an equal amount of compaction effort. Relatively low pressure was used initially and as the mix became more stable pressure gradually increased until the mix in the mold was compressed to the predetermined height. At this point, the next batch of asphalt mix was prepared and spooned into the beam mold and the compaction resumed. After the third batch of asphalt mix was in the mold and was compressed to approximately the required height, a thick loading plate 3"x15" in size was placed on top of the beam and a high pressure was applied on it to compress the mix in the mold to the final required height, flush with the 3 in. high side mold. This ensured that the beam prepared was compacted to the same density as that from the Marshall samples. Most of the beam samples, however, were unable to be compressed to the required 3 in. height. They were typically about 1/8 in. higher. As a result, the densities of the beams were lower than that of the Marshall samples. After the beam samples were allowed to cool overnight and were removed from the molds, the dimensions of each beam were measured and the bulk density was determined using the water displacement method. Results of the averaged bulk density of the beam samples and the corresponding bulk density from the Marshall samples are presented in Table 4. There is a substantial difference in the bulk density between these two types of samples. The potential effects of this on rutting will be discussed later in this report.

Most of the beam samples were quite porous in appearance. This is not surprising for Type B Mixes. There was concern that using the water displacement method in determining the bulk density on uncoated samples might introduce errors. To assess this possible source of error, 2 beam samples, which had the bulk density determined using the water displacement method, were coated with paraffin and the bulk density was determined again. It was found that the difference in the density determined with and without using the paraffin coating was less than 0.1 pcf.

Table 4. Bulk Density of Beam Samples and Marshall Samples

Mix Type	Bulk Density, pcf Marshall Samples	Beam Samples
FS	150.7	146.6
F3M	152.2	148.1
F5M	152.9	150.2
F5T	152.2	146.3
F5S	153.0	147.7
FHM	152.0	150.6
F6K	150.7	146.2
DS	150.9	145.8
D3M	151.9	147.3
D5M	152.1	147.3
D5T	151.8	144.4
D5S	151.0	147.6
DHM	151.6	148.1
D6K	150.0	145.2
CS	152.6	150.0
C3M	155.0	150.8
C5M	155.1	152.9
C5T	154.4	149.5
C5S	154.2	151.2
CHM	153.6	151.8
C6K	152.9	150.6

CHAPTER 4

MODIFIED LOADED-WHEEL TEST PRECEDURES AND RESULTS

The testing machine, the modified loaded-wheel tester, was described in the previous report entitled, "Development of a Simplified Test Method to Predict Rutting Characteristics of Asphalt Mixes", submitted to GaDOT in September, 1986. Some modifications were made on this machine in the course of this study mainly for the purpose of simplifying the setup and the data collection procedures.

The testing procedures used in this study were identical to that used in the previous study. The following were the test conditions:

Temperature:	95°F
Load:	100 lbs.
Contact pressure:	100 psi
Frequency:	22 cycles/min.

During the test, rutting profiles of the beam samples along the wheel path were measured at 0, 200, 500, 1000, and 2000 cycles. For some tests, additional rutting measurements were taken up to as far as 10,000 cycles. Table 5A, 5B and 5C summarized the test results. The test results presented in these tables were also presented in Appendic C in graphs.

TABLE 5A DOT Rutting Study-- Rutting Machine Test Data (Aggregate: Fairmount, GA)

Mix Design	MARSHALL DESIGN Density	Stability	Flow	Tensile	FD Stiffness	air voids	Unit Weight	BEAM RUT-DEPTH ,1/1000 IN. @ #Cycles 200	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
FS-1						7.77%	146.6	59	81	99	116	124	133	142					
FS-2						7.77%	146.6	44	60	70	82	90	99						
FS-3						7.77%	146.6	52	64	78	94	102	109						
FS	150.7	2490	12.3	35	16381		146.6	52	68	82	97	105	114						
F3M-1						7.47%	148.5	48	63	74	93	103	109						
F3M-2						7.47%	148.5	45	64	77	91	100	108						
F3M-3						8.29%	147.3	40	55	68	84	96	103	109	115	119	121	126	126
F3M	152.2	2240	8.8	46.8	20655		148.1	44	61	73	89	100	107						
F5M-1						5.36%	152.3	46	64	81	104	116	125	134	139	143	148	152	155
F5M-2						6.64%	150.4	33	45	58	72	80	87						
F5M-3						8.35%	147.9	27	42	52	70	80	87						
F5M	152.9	2400	11.2	49.5	17451		150.2	35	50	64	82	92	100						
F5T-1						8.75%	146.6	54	68	81	93								
F5T-2						9.17%	146.0	63	79	95	113								
F5T-3																			
F5T	152.2	2460	10.2	46	18486		146.3	59	74	88	103								
F6K-1						8.19%	146.0	56	73	81	89	96	100	101	105				
F6K-2						7.70%	146.7	54	67	78	91	102	111						
F6K-3						7.70%	146.7	31	43	51	62	69	80	85	86	93	95	97	99
F6K	150.7	2080	13.4	38.9	15787		146.2	47	61	70	81	89	97						
F5S-1						7.99%	148.5	72	90	107	127	137	147	154	160	167	173	179	184
F5S-2						8.42%	147.9	54	72	82	97	120	131						
F5S-3						9.30%	146.6	52	71	91	110	125	135						
F5S	153	2380	12.9	45.3	18028		147.7	59	78	93	111	127	138						
FHM-1						5.89%	150.6	38	44	52	61	66	71						
FHM-2						5.89%	150.6	34	44	53	65	76	84						
FHM-3						7.47%	148.3	47	63	75	90	107	117	124	130	136	140	146	146
FHM	152	2110	10.8	29.5	11913		150.6	40	50	60	72	83	91						

TABLE 5B DOT Rutting Study-- Rutting Machine Test Data (Aggregate: Dalton, GA)

Mix Design	MARSHALL DESIGN Density	Stability	Flow	Tensile	FD Stiffness	air voids	Unit Weight	BEAM RUT-DEPTH ,1/1000 IN. @ #Cycles 200	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
DS-1						9.61%	144.1	47	65	77	98	104	114	119	126	134			
DS-2						8.31%	146.0	52	76	91	105	116	126	133	139				
DS-3						7.44%	147.3	27	48	57	71	80	86	93	100				
DS	150.9	2040	11	60.4	22378		145.8	42	63	75	91	100	109	115					
D3M-1						8.12%	147.3	34	44	59	72								
D3M-2						7.69%	147.9	51	63	83	101								
D3M-3						8.55%	146.6	44	57	67	80	90	95						
D3M	151.9	2550	8.8	43.6	19336		147.3	43	55	70	84	90	95						
D5M-1						8.25%	147.3	68	77	82	92								
D5M-2						7.39%	148.5	44	62	74	90								
D5M-3						9.11%	146.0	31	44	54	67	77	83	88	93	96	100	103	106
D5M	152.1	2710	11.6	44.1	21943		147.3	48	61	70	83								
D5T-1						10.23%	144.1	54	71	85	96	106	125						
D5T-2						9.89%	144.6	51	66	76	99	108	121						
D5T-3						9.96%	144.5	42	52	62	75	86	94						
D5T	151.8	2610	10.3	43.6	21111		144.4	49	63	74	90	100	113						
D6K-1						8.27%	145.4	39	50	59	71	78	84						
D6K-2						8.69%	144.8	38	47	56	63	67	71						
D6K-3						8.27%	145.4	35	45	51	60	65	69	72	75	79	80	83	83
D6K	150	1900	13				145.2	37	47	55	65	70	75						
D5S-1						7.08%	147.9	64	85	101	116	127	130	138	143				
D5S-2						8.46%	145.9	65	93	113	135	148	153						
D5S-3						7.51%	147.3	48	65	82	103	115	122	130	137	142	146	196	220
D5S	151	2110	13.1	40	11602		147.6	59	81	99	118	130	135						
DHM-1						7.81%	147.8	29	38	47	57	61	65						
DHM-2						8.09%	147.4	42	60	70	88	94	103						
DHM-3						6.85%	149.2	36	52	65	82	91	95						
DHM	151.6	1950	11.9	57.1	21188		148.1	36	50	61	76	82	88						

TABLE 5C DOT Rutting Study-- Rutting Machine Test Data (Aggregate: Chattanooga, TN)

Mix Design	MARSHALL DESIGN Density	Stability	Flow	Tensile	FD Stiffness	air voids	Unit Weight	BEAM RUT-DEPTH ,1/1000 IN. @ #Cycles 200	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
CS-1						6.01%	151.0	56	72	86	102	110	124						
CS-2						7.73%	148.5	50	66	81	91	102	107	113	117				
CS-3						6.44%	150.4	45	59	74	92	102	111						
CS	152.6	2020	13.7	42.6	14077		150.0	50	66	80	95	105	114						
C3M-1						7.20%	151.6	43	55	68	83								
C3M-2						8.46%	149.8	52	73	91	117								
C3M-3						7.62%	151.0	43	56	74	86								
C3M	155	2620	9.8	44.3	17988		150.8	46	61	78	95								
C5M-1						6.42%	152.9	48	48	60	72	80	85	88	92				
C5M-2						7.68%	151.0	50	66	82	101	106	119	126	129				
C5M-3						5.16%	154.8	38	51	62	75	82	87						
C5M	155.1	2820	9.7	56	19667		152.9	45	55	68	83	89	97						
C5T-1						8.49%	149.1	49	64	78	93								
C5T-2						8.07%	149.8	37	51	68	89								
C5T-3						8.91%	148.5	36	49	60	73	88	95	101	106	111	121	124	128
C5T	154.4	2510	9.1	38	14988		149.5	41	55	69	85								
C6K-1						6.22%	151.0	48	62	71	83	87	84	87	86				
C6K-2						7.04%	149.8	38	45	52	59	63	65	66	68				
C6K-3						6.22%	151.0								62				
C6K	152.9	2330	11.3	42.8	13662		150.6	43	54	62	71	75	75	77	77				
C5S-1						6.66%	151.6	26	36	44	58	64	71	76	82	86	89	93	96
C5S-2						7.09%	151.0	37	45	52	66	75	81						
C5S-3						7.09%	151.0	25	34	42	51	59	61						
C5S	154.2	2760	13.1	43.5	20680		151.2	29	38	46	58	66	71						
CHM-1						6.28%	151.6	41	52	62	72	94	102						
CHM-2						5.81%	152.3	51	65	78	91	108	116						
CHM-3						6.28%	151.6	56	70	86	104	117	128						
CHM	153.6	1840	11.8	30.4	10278		151.8	49	62	75	89	106	115						

CHAPTER 5
ANALYSIS AND DISCUSSION

During the preparation of the beam samples it became apparent that it was much more difficultto made Type B mixes because of the coarseness of the gradation. For some mixes, it was very difficult to compact the mix to the required density. Also, the top surface of the beam samples was quite coarse in most cases. Variations of the densities from the beams within the same mix were typically within 1% (1.5 pcf), as shown in Tables 5A, 5B and 5C, although a few mixes such as mix F5M, F5S, D5M, CS and C5M had differences in densities exceeding that range. Air void contents in each beam sample shown in Tables 6A, 6B and 6C were computed from the bulk density of the beam as follows:

$$V_a = \frac{1.047\ G_m bm - G_m bb}{1.047\ G_m bm}$$

where G_{mbm} and G_{mbb} are the bulk density of the asphalt mix from the Marshall sample and the beam sample respectively. The computations were based on the assumption that the Marshall samples for each mix had 4.5% air voids and that the Marshall samples and the beam samples from the same mix had the same voidless mix density.

The air void contents ranged from 5% to slightly over 10% among all the beam samples. For the 21 mixes, 12 mixes had less than 1% difference of the air void contents within the same mix, 5 mixes had between 1% to 2% difference in air void content, and 4 mixes had between 2% to 3% difference in air void contents.

Besides the variation in density, perhaps nonuniformity in the distribution of the mix in the entire beam would alsoc contribute to the test variations. Nonuniformity in the distributions of the air voids which resulted in high porosity in certain areas of the beam samples was quite noticeable. Also on the tested beam samples, rutting along the "wheel path" was not uniform, quite frequently ridges and valleys were formed by the large aggregate particles in the mix. These test variations did not exist in the previous study in which standard Type E mix was used. Dsepite what seem to be relatively large testing errors in this study, the results shown in Tables 5A, 5B and 5C produce some very interesting trends. They are presented in the following.

Effects of 3M and 5M

Figures 1, 2 and 3 show the effects of 3M mixes and 5M mixes on the rutting characteristics of the asphalt mixes from the three aggregate sources. For the Fairmount aggregate, adding 3% and 5% marble dust resulted in proportionally reduction in rutting, with about 15% reduction in rutting for adding 5% marble dust as filler. For the Dalton aggregate, adding 3% and 5% marble dust resulted in an approximately 8% reduction in rutting. For the Chattanooga aggregate, adding 3% marble dust had little effect in improving rutting resistance while adding 5% marble dust resulted in approximately 15% reduction in rutting. Since the trends shown in these three figures are quite consistent, comparisons of the rutting characteristics can be represented by the rut-depth values at 2000 cycles for each mix. These results are presented in Table 7.

Except the C3M mix, the other 5 mixes with marble dust added to the standard gradation of the aggregates show positive improvement in reducing rutting. The marble dust from this source has very angular particle shape which should improve internal stability of the mixes and as a result, improve rutting resistance.

Effects of 5M, 5S and 5T

In this study, three types of mineral filler were used. The effectiveness of these different mineral fillers on the asphalt mixes are presented in Figures 4,5 and 6. Only the marble dust produced by the Georgia Marble Co. at Tate Plant showed consistent improvement in rutting resistance among all three aggregates. For the Chattanooga aggregate, adding 5% of Sylacauga sand and Trenton sand to the mix improved the rutting resistance. For the Dalton aggregate and the Fairmount aggregate, adding Sylacauga sand or Trenton sand to the mix rither exhibited no benefit, such as the D5T mix, or actually increase rutting, such as the F5T, F5S and D5S mixes. The gradations of the fillers, as shown in Table 2, as well as the particle shapes could be the important factors affecting the rutting characteristics. Unfortunately, information on the characteristics of the filler particles for the three fillers used in this study is not available, therefore any comments on this matter at this time is purely speculative.

Table 6A. Density and Air Void Contents

Aggregate Sources: Fairmount, GA
Air Voids in Marshall Samples: 4.5%

Mix Design	Marshall Density, pcf	Beam Density, pcf	Beam Air Voids
FS-1 **		146.6	7.77%
FS-2		146.6	7.77%
FS-3		146.6	7.77%
FS	150.7	146.6	
F3M-1		148.5	7.47%
F3M-2		148.5	7.47%
F3M-3 *		147.3	8.29%
F3M	152.2	148.1	
F5M-1 *		152.3	5.36%
F5M-2		150.4	6.64%
F5M-3		147.9	8.35%
F5M	152.9	150.2	
F5T-1		146.6	8.75%
F5T-2		146.0	9.17%
F5T-3 *			
F5T	152.2	146.3	
F6K-1		146.0	8.19%
F6K-2		146.7	7.70%
F6K-3 *		146.7	7.70%
F6K	150.2	146.2	
F5S-1 *		148.5	7.99%
F5S-2		147.9	8.42%
F5S-3		146.6	9.30%
F5S	153	147.7	
FHM-1		150.6	5.89%
FHM-2		150.6	5.89%
FHM-3 *		148.3	7.47%
FHM	152	150.6	

* Sample not tested
** Sample tested but the results not used

Table 6B. Density and Air Void Contents

Aggregate Sources: Dalton, GA
Air Voids in Marshall Samples: 4.5%

Mix Design	Marshall Density, pcf	Beam Density, pcf	Beam Air Voids
DS-1		144.1	9.61%
DS-2		146.0	8.31%
DS-3 *		147.3	7.44%
DS	150.9	145.8	
D3M-1		147.3	8.12%
D3M-2 **		147.9	7.69%
D3M-3		146.6	8.55%
D3M	151.9	147.3	
D5M-1		147.3	8.25%
D5M-2		148.5	7.39%
D5M-3 *		146.0	9.11%
D5M	152.1	147.3	
D5T-1		144.1	10.23%
D5T-2		144.6	9.89%
D5T-3 **		144.5	9.96%
D5T	151.8	144.4	
D6K-1		145.4	8.27%
D6K-2		144.8	8.69%
D6K-3 *		145.4	8.27%
D6K	150	145.2	
D5S-1		147.9	7.08%
D5S-2		145.9	8.46%
D5S-3 *		147.3	7.51%
D5S	151	147.6	
DHM-1 **		147.8	7.81%
DHM-2		147.4	8.09%
DHM-3		149.2	6.85%
DHM	151.6	148.1	

* Sample not tested
** Sample tested but the results not used

Table 6C. Density and Air Void Contents

Aggregate Sources: Chattanooga, TN
Air Voids in Marshall Samples: 4.5%

Mix Design	Marshall Density, pcf	Beam Density, pcf	Beam Air Voids
CS-1		151.0	6.01%
CS-2 *		148.5	7.73%
CS-3		150.4	6.44%
CS	152.6	150.0	
C3M-1		151.6	7.20%
C3M-2 **		149.8	8.46%
C3M-3		151.0	7.62%
C3M	155	150.8	
C5M-1		152.9	6.42%
C5M-2 **		151.0	7.68%
C5M-3		154.8	5.16%
C5M	155.1	152.9	
C5T-1		149.1	8.49%
C5T-2		149.8	8.07%
C5T-3 *		148.5	8.91%
C5T	154.4	149.5	
C6K-1		151.0	6.22%
C6K-2		149.8	7.04%
C6K-3 *		151.0	6.22%
C6K	152.9	150.6	
C5S-1 *		151.6	6.66%
C5S-2		151.0	7.09%
C5S-3		151.0	7.09%
C5S	154.2	151.2	
CHM-1		151.6	6.28%
CHM-2		152.3	5.81%
CHM-3		151.6	6.28%
CHM	153.6	151.8	

* Sample not tested
** Sample tested but the results not used

Table 7. Comparison of Rutting of 3M Mixes, 5M Mixes and the Standard Mixes

Mix Type	Rut @ 2000 Cycles 0.001 in.	% Reduction	Beam Density pcf	Average Beam Air Voids
FS	97		146.6	7.77%
F3M	89	8	148.1	7.74%
F5M	82	15	150.2	7.50%
DS	91		145.8	8.96%
D3M	84	8	147.3	8.34%
D5M	83	8	147.3	7.82%
CS	95		150	6.23%
C3M	95	0	150.8	7.41%
C5M	82	14	150.9	5.79%

Note: The averaged beam density and air voids are based on the beam samples tested and used in the analysis.

The gradations of the standard mixes, and the 5M, 5T and 5S mixes for the three aggregates are given in Table 1A, 1B and 1C and also in Appendix A. Comparing the gradations among these mixes indicates that the 5M mixes had 1% to 2% more fines (passing #50 sieve and #100 sieve) than the 5T mixes and the 5S mixes. This may contribute to the improved rutting resistance of the 5M mixes.

Effect of Hand Made Gradation

The effects of hand made gradation on the rutting resistance are shown in Figures 7, 8 and 9. For the Fairmount and the Dalton aggregates the improvement is significant while for the Chattanooga aggregate the effect is not as significant. Examing the gradations f hand made vs the standard gradation given in Table 1 and also summarized in Table 8 did not show any significant difference among the three aggregates in so far as the gradation is concern.

Effect of using Kraton Polymer in Asphalt Cement

Adding Kraton polymer into AC-20 asphalt cement raised the viscosity to higher than the AC-30 asphalt used for the other mixes. At 140^{o}F, the viscosity of the AC-20 S modified asphalt was 58,600 poises vs. 3000 ± 600 poises for AC-30; at 275^{o}F it was 1575 centistokes for AC-20 S vs. about 250 centistokes for AC-30. As a result, the mixing and compaction temperatures were increased for the 6K mixes. Also, the 6K mixes should be more resistant to rutting because of the binder was stiffer. Results presented in Figure 7, 8 and 9 show that the 6K mixes had significantly lower rutting than the corresponding standard mixes. It is interesting to note that the bulk density of the 6K mixes were nearly the same as that of the standard mixes as summarized below:

Mix Design	Marshall Density	Beam Density	Beam Air Voids
FS	150.7	146.6	7.77%
F6K	150.7	146.2	7.70%
DS	150.9	145.8	8.96%
D6K	150.0	145.2	8.50%
CS	152.6	150.0	6.23%
C6K	152.9	150.6	6.50%

Since the 6K mixes and the standard mixes had the same gradation, the same density among the Marshall samples and the beam samples implies that the compaction efforts in both mixes, standard mixes vs. 6K mixes, were comparable. It is also worth noting (see Tables 6A, 6B and 6C) that for each aggregate source, Fairmount, Dalton and Chattanooga, the standard mixes and the 6K mixes had the lowest density compared with other mixes modified with 3% and 5% mineral fillers. The only exception is the C5T mix; this mix also had the highest air voids among the mixes using Chattanooga aggregate.

Table 8. Effects of Hand Made Gradation on Rutting

Mix Type	Rut-Depth @ 2000 Cycles 0.001 in.	% Passing at #50 Sieve	#100 Sieve
FS	97	7	5
FHM	72	11	4
DS	91	9	7
DHM	76	12	7
CS	95	9	6
CHM	89	12	6

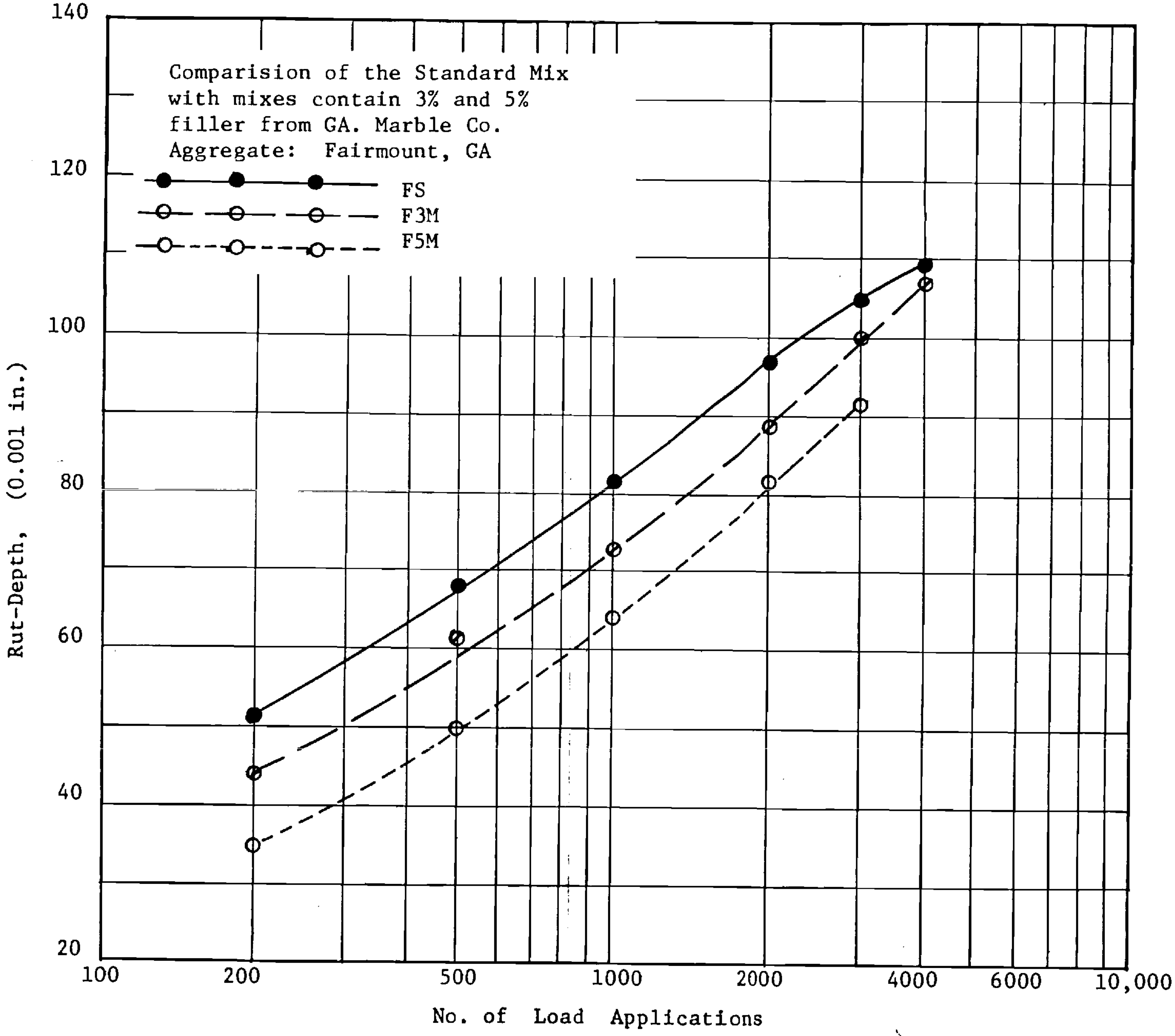

Comparision of the Standard Mix
with mixes contain 3% and 5%
filler from GA. Marble Co.
Aggregate: Fairmount, GA
FS
F3M
F5M
Rut-Depth, (0.001 in.)
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,000
No. of Load Applications

Figure 1.

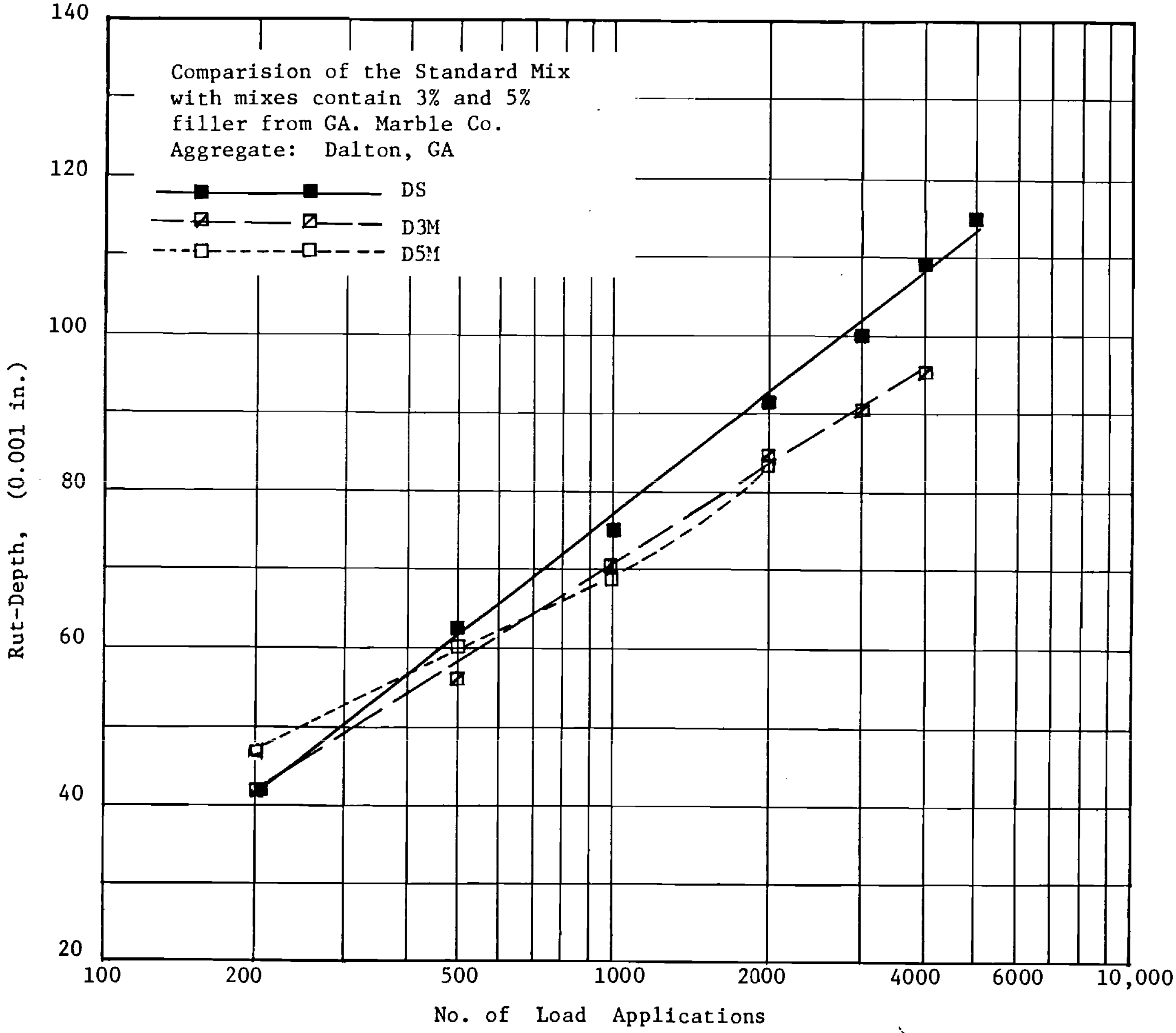

Comparision of the Standard Mix
with mixes contain 3% and 5%
filler from GA. Marble Co.
Aggregate: Dalton, GA
DS
D3M
D5M
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,000
No. of Load Applications

Figure 2.

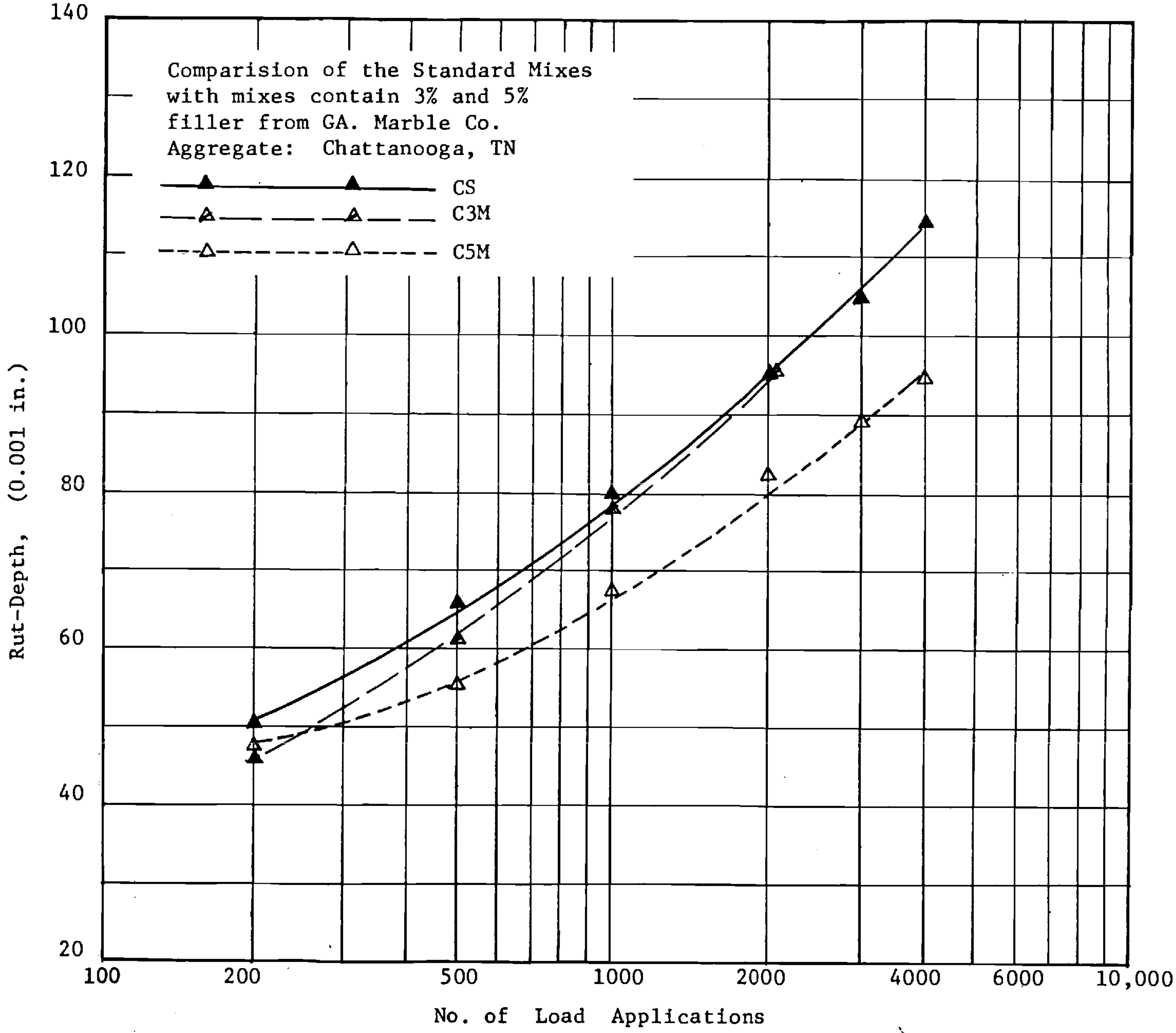

Comparision of the Standard Mixes
with mixes contain 3% and 5%
filler from GA. Marble Co.
Aggregate: Chattanooga, TN
CS
C3M
C5M
Rut-Depth, (0.001 in.)
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,000
No. of Load Applications

Figure 3.

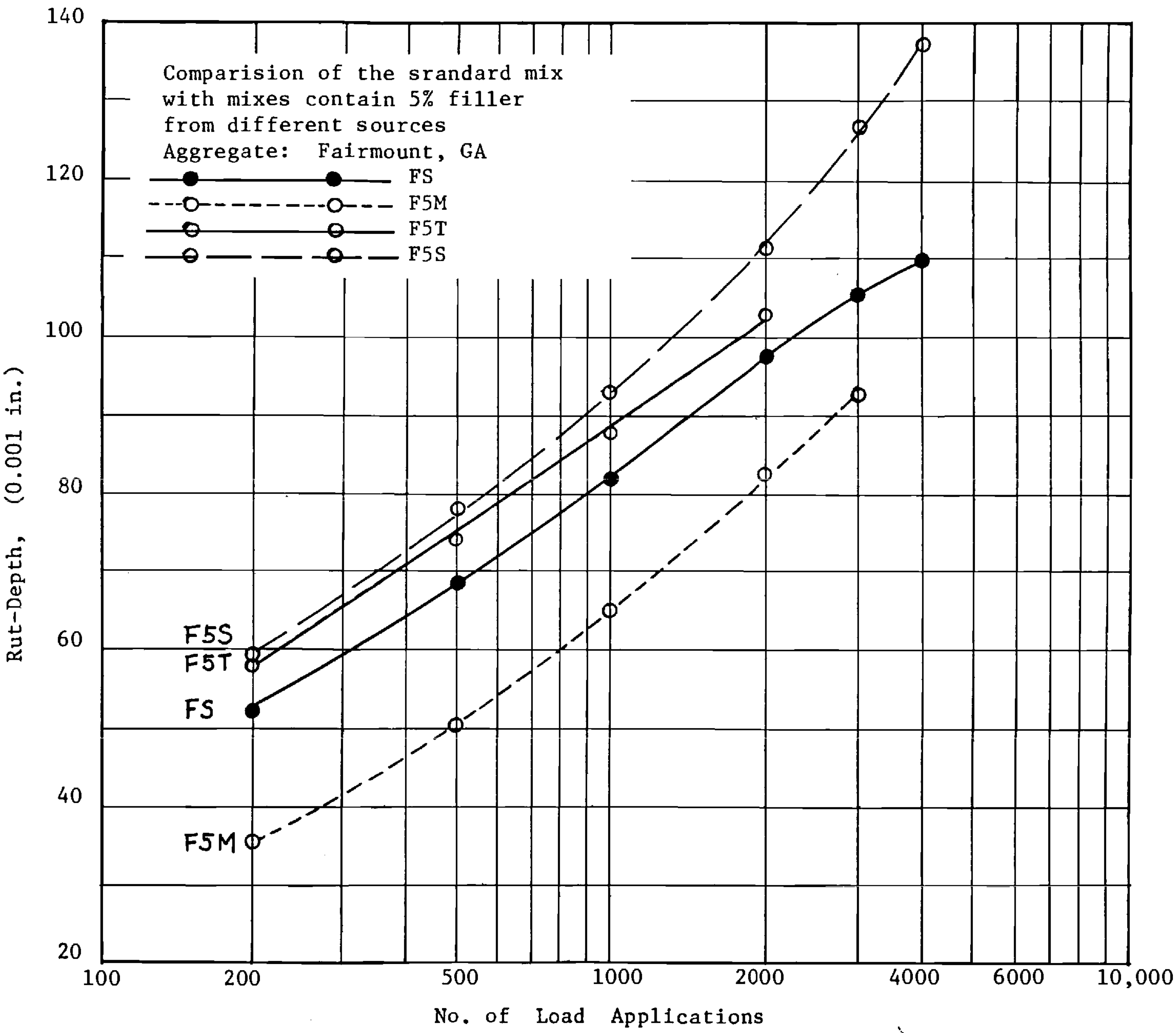
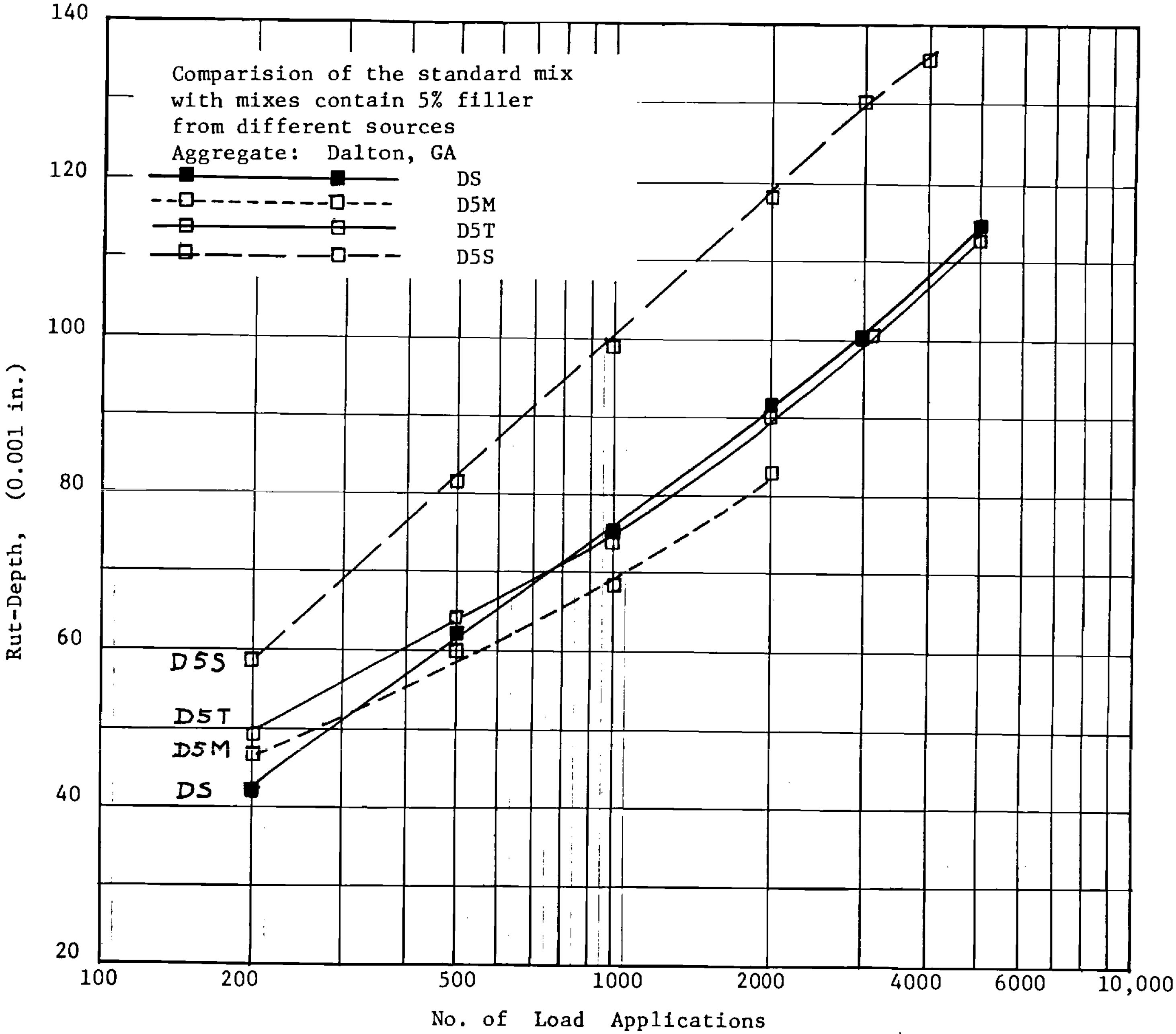

Comparision of the srandard mix
with mixes contain 5% filler
from different sources
Aggregate: Fairmount, GA
FS
F5M
F5T
F5S
F5S
F5T
FS
F5M
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,000
No. of Load Applications

Figure 4.



Comparision of the standard mix
with mixes contain 5% filler
from different sources
Aggregate: Dalton, GA
DS
D5M
D5T
D5S
Rut-Depth, (0.001 in.)
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,000
No. of Load Applications

Figure 5.

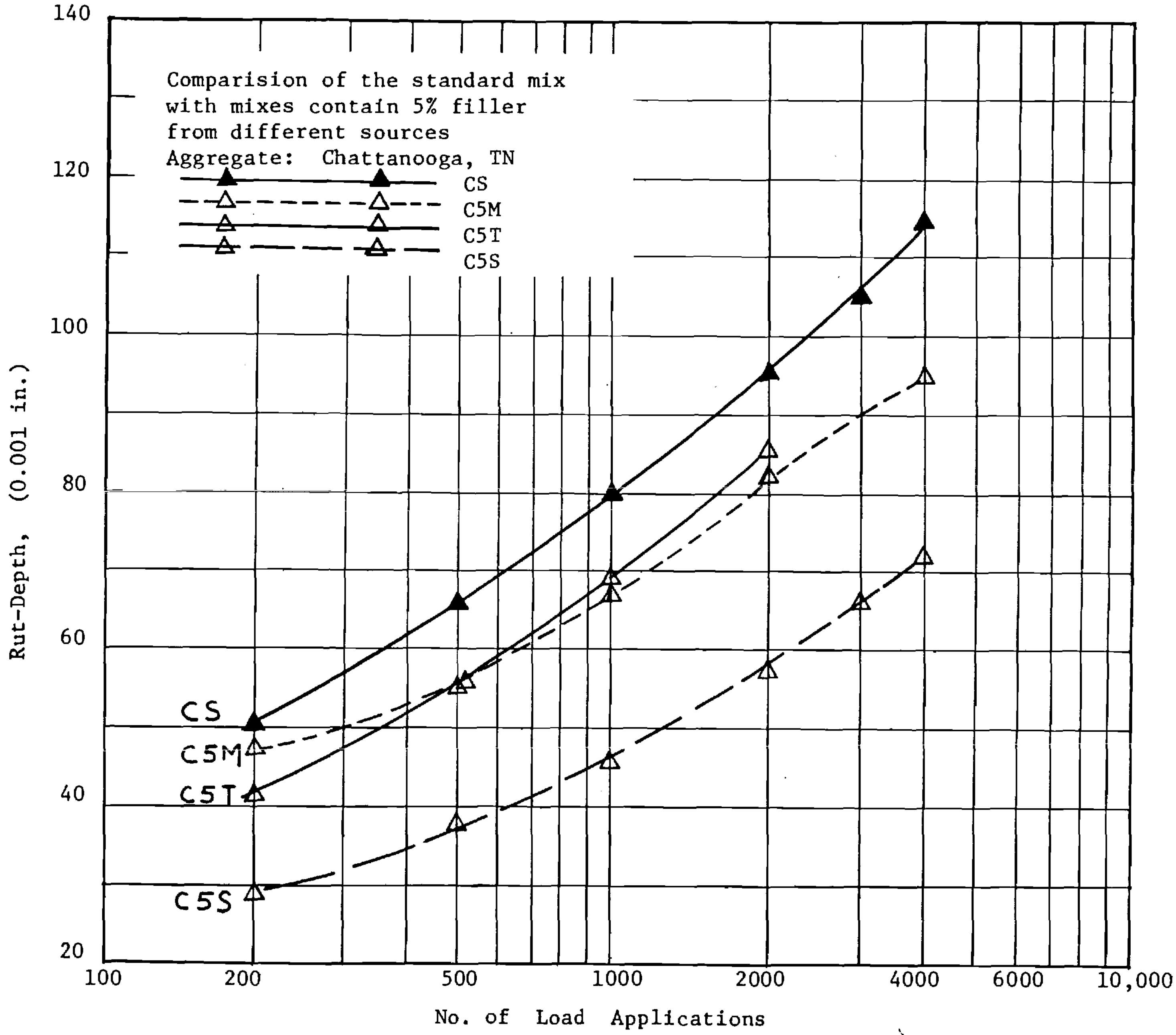

Comparision of the standard mix
with mixes contain 5% filler
from different sources
Aggregate: Chattanooga, TN
CS
C5M
C5T
C5S
Rut-Depth, (0.001 in.)
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,000
No. of Load Applications

Figure 6.

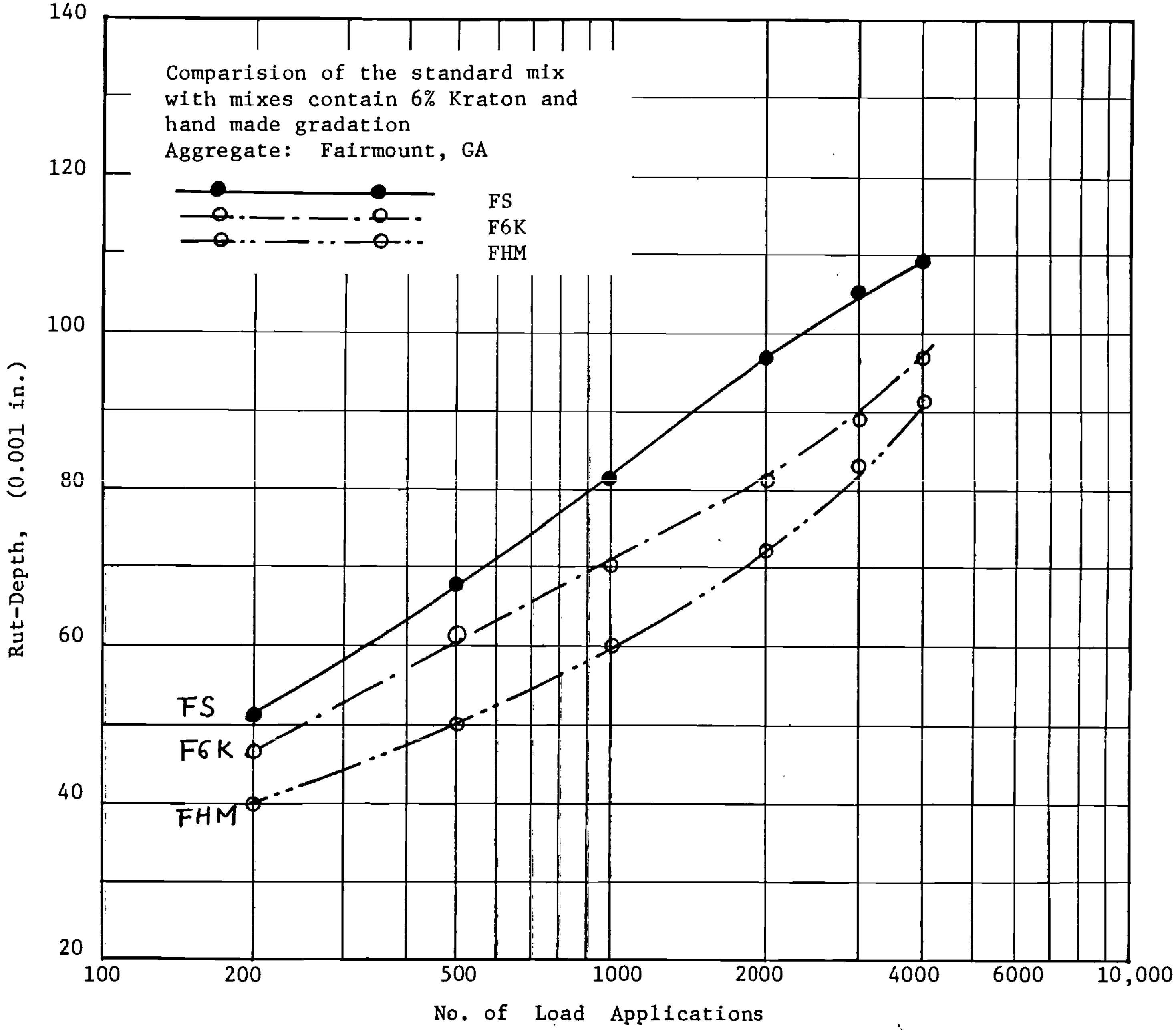
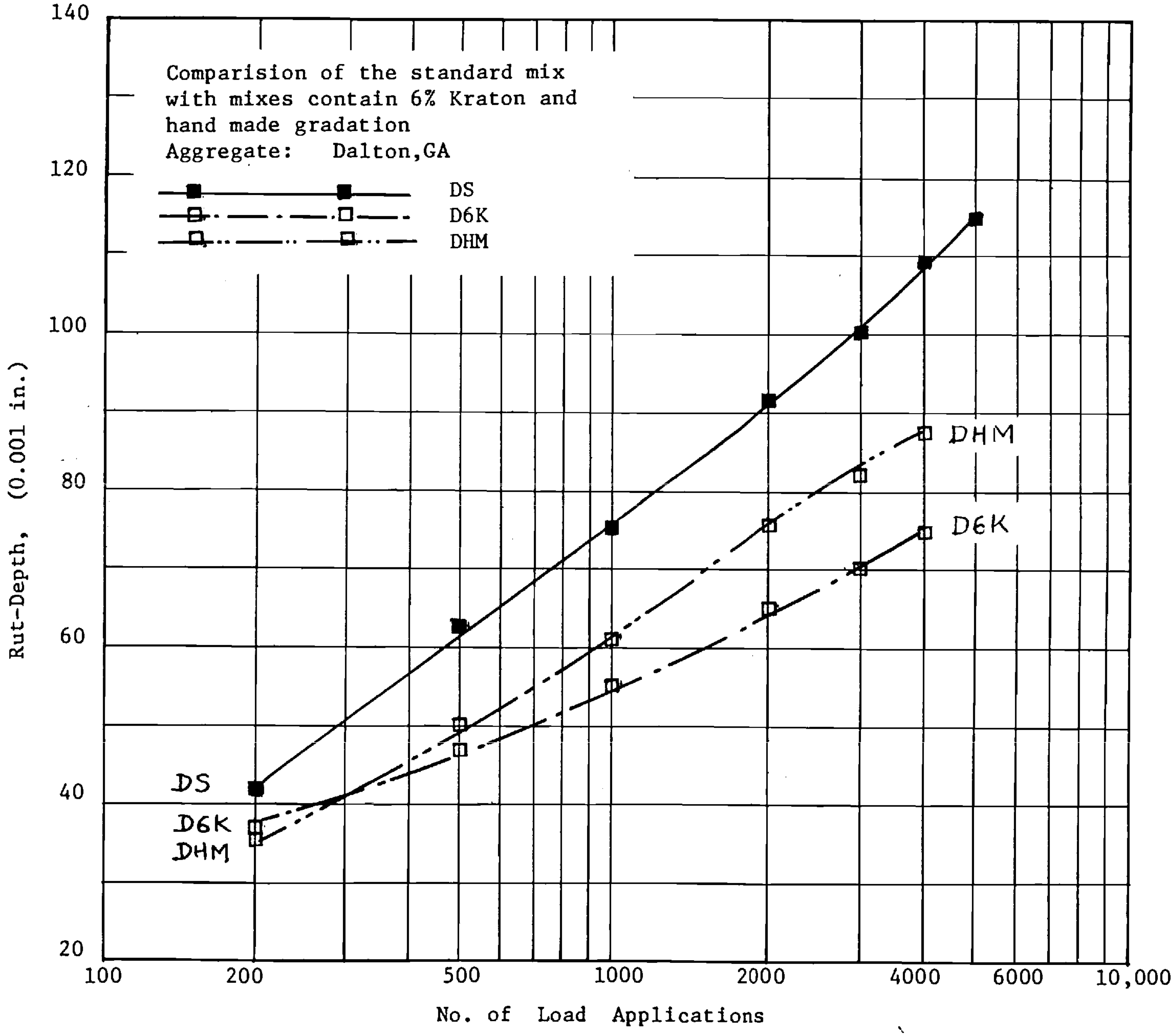

Comparision of the standard mix
with mixes contain 6% Kraton and
hand made gradation
Aggregate: Fairmount, GA
FS
F6K
FHM
FS
F6K
FHM
Rut-Depth, (0.001 in.)
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,000
No. of Load Applications

Figure 7.



Comparision of the standard mix
with mixes contain 6% Kraton and
hand made gradation
Aggregate: Dalton,GA
DS
D6K
DHM
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,000
No. of Load Applications
DS
D6K
DHM
DHM
D6K

Figure 8.

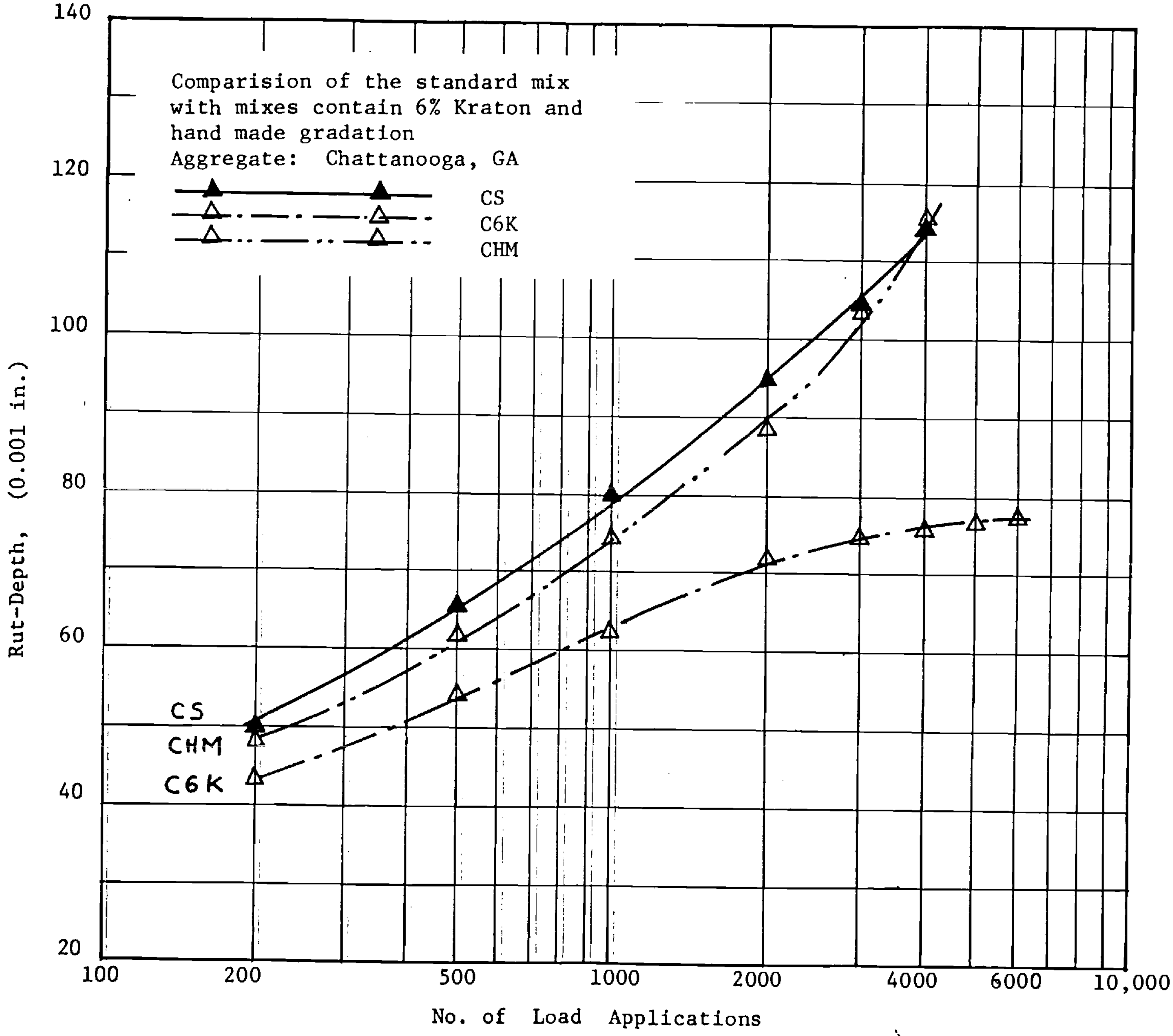

Comparision of the standard mix
with mixes contain 6% Kraton and
hand made gradation
Aggregate: Chattanooga, GA
CS
C6K
CHM
CS
CHM
C6K
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,000
No. of Load Applications

Figure 9.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study is to assess the rutting characteristics of certain asphalt mixes and to recommend the mix(es) that could provide better resistance to rutting. Prediction of rutting potential of the asphalt mixes was based on a laboratory procedure in which the asphalt beam samples were made in the laboratory and were subjected to a repetitive wheel load to certain prescribed number of repetitions. The rut-depth developed along the wheel path on the beam samples was measured and was used as the basis for evaluating the rutting potential of the mixes. From this study, the applicability of this simple laboratory testing method to assess the rutting characteristics of asphalt concrete has again been confirmed. Additional valuable information has been obtained and some deficiencies have been discovered. All of these will be incorporated in the future to further refine the testing method. Some of the deficiencies of the testing method in present form and improvement that will be addressed later in this section. The following are the conclusions and recommendations which can be drawn based on the results obtained in the course of this study.

CONCLUSIONS

1. Incorporating the mineral filler from Ga. Marble Co. at Tate Plant, which has very low fineness modulus and angular particle shape into asphalt mixes should improve the stability of the asphalt mixes. This has been demonstrated in the test results (See Figures 1, 2 and 3). It is worth noting that the Marshall stability values of the mixes modified with 3% and 5% of this type of filler were actually lower than that of the corresponding standard mixes, see Table 1A - FS vs. F3M and F5M; Table 1B - DS vs. D3M and D5M; and Table 1C - CS vs. C3M and C5M. This illustrates the deficiency of the Marshall test in assessing rutting potential. Based on the rutting test results, incorporating 5% of this type of filler in the asphalt mixes investigated should improve rutting resistance provided the other factors, such as asphalt content, etc. are adjusted accordingly.

2. The potential benefits of using mineral filler from Trenton sand

and from Sylacuga sand in improving rutting resistance require further study. Based on this study the effects were mixed.

3. The benefit of using the hand made mixes over the standard mixes in improving rutting is significant. This indicates the importance of the amount of material passing #50 sieve and #100 sieve sizes in the mix. Again, the Marshall stability values for the hand made mixes are lower than that of the standard mixes.

4. Use of AC-20S polymer modified asphalt cement could be beneficial in improving the rutting resistance. The problem of constructability in terms of higher mixing and compaction temperature requires further study.

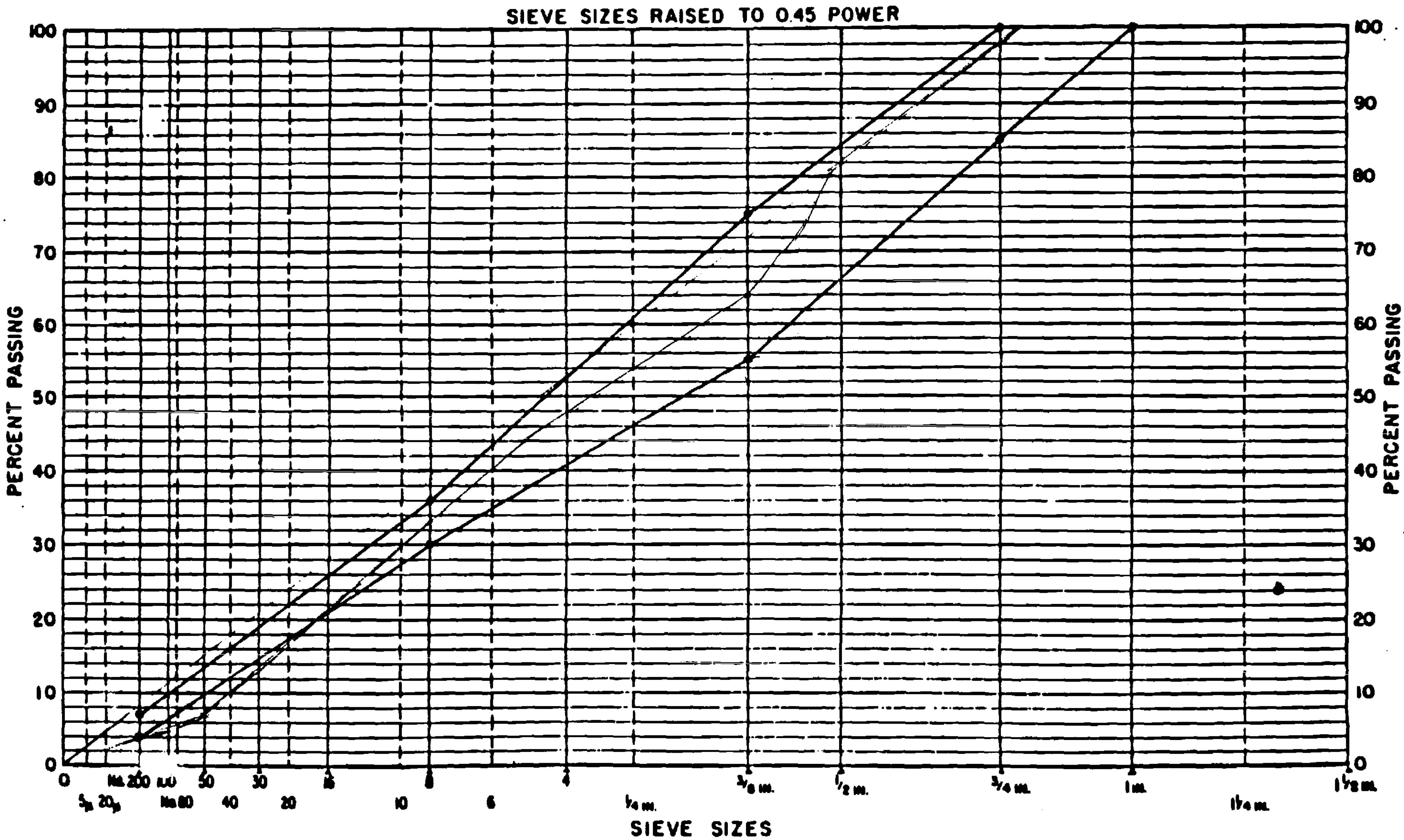
RECOMMENDATION

Several deficiencies pertaining to the test method have been observed in the course of this study. These include sample size, sample confinement, test temperature, and method of sample preparation. The present test method was originally developed for testing Type E or finer asphalt mixes. When Type B mix was used, several problems occurred which were not encountered in the previous study where Type E asphalt mix was used. The sample preparation was much more difficult due to the nature of the mix. Due to the rigid confinement on the sample, the coarse aggregate particles in the beam developed interlocking action and were constrained and as a result, plastic deformation and lateral shoving of the asphalt mix under the repeated loading were impeded. Because of this variability of the test results due to variations in sample preparations and testing could be accentuated. It is recommended that, in the future, when the similar test is to be performed on the coarse Tpye B mixes, due considerations should be given in using larger sample size in order to minimize the variability of the test results.

Appendix A

Gradation of the Aggregates

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Identification of gradations:

FS

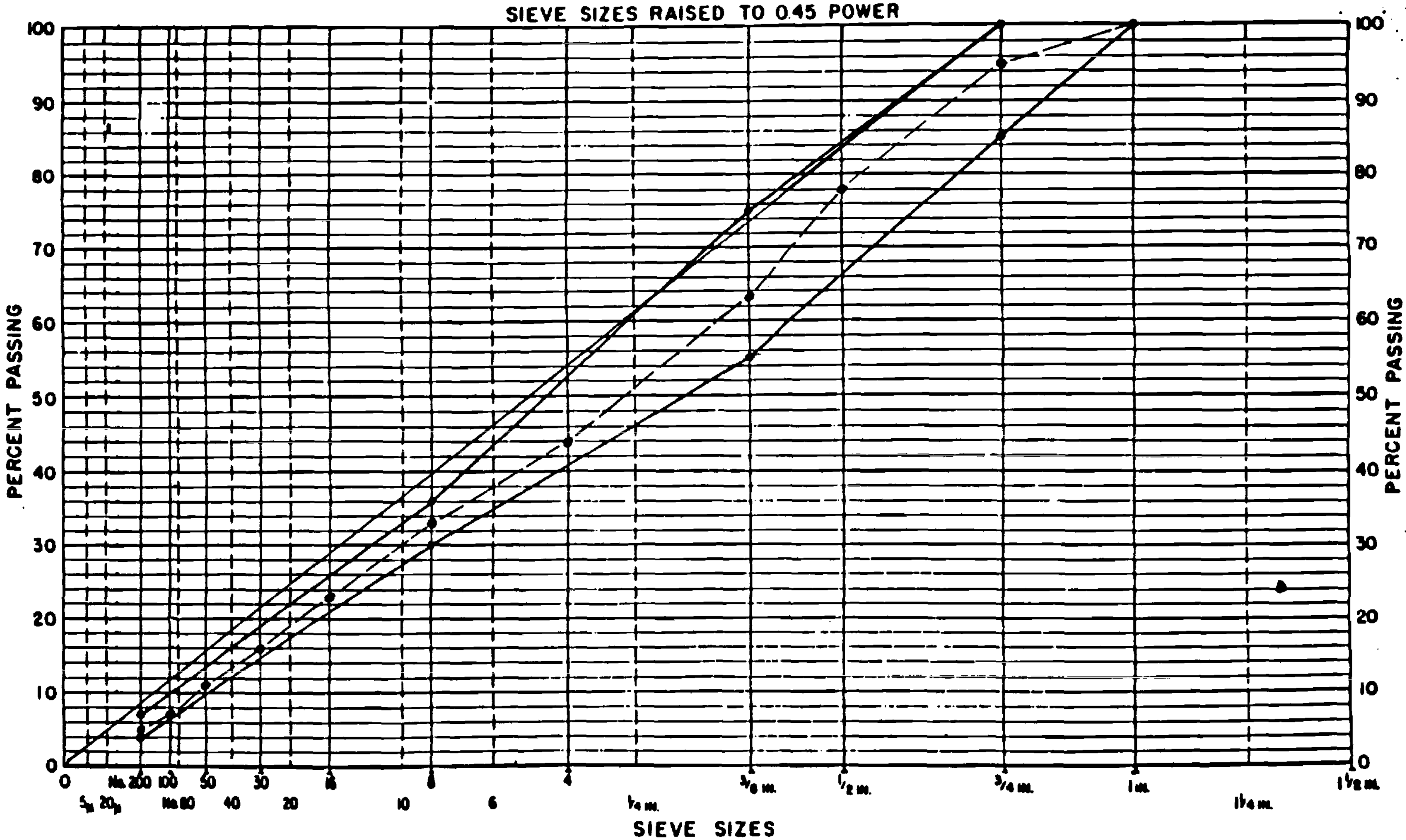
Sheet No.

Date

Form No. GC-2

THE ASPHALT INSTITUTE

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



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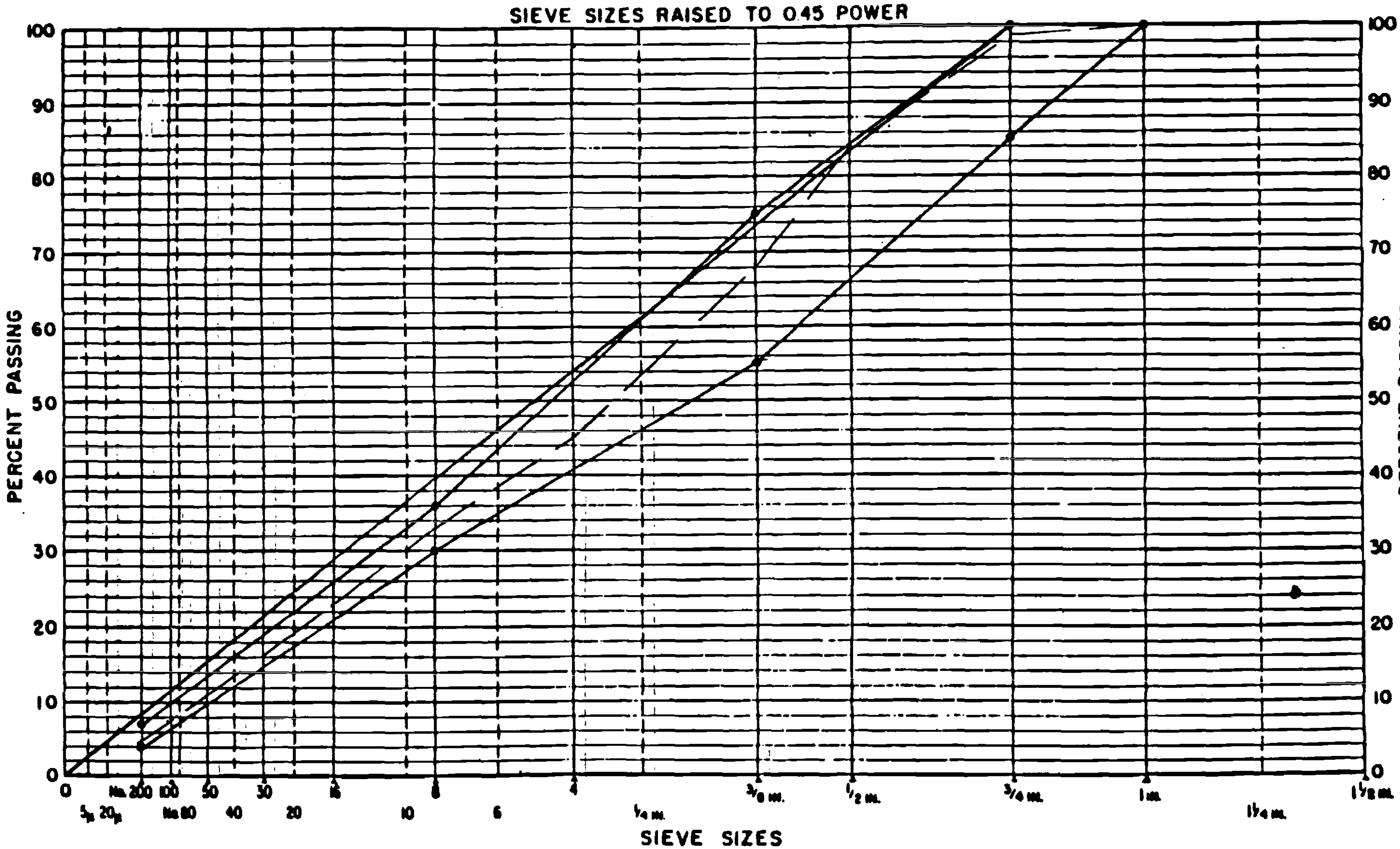
Form No. GC-3
THE ASPHALT INSTITUTE

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



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Identification of gradations:

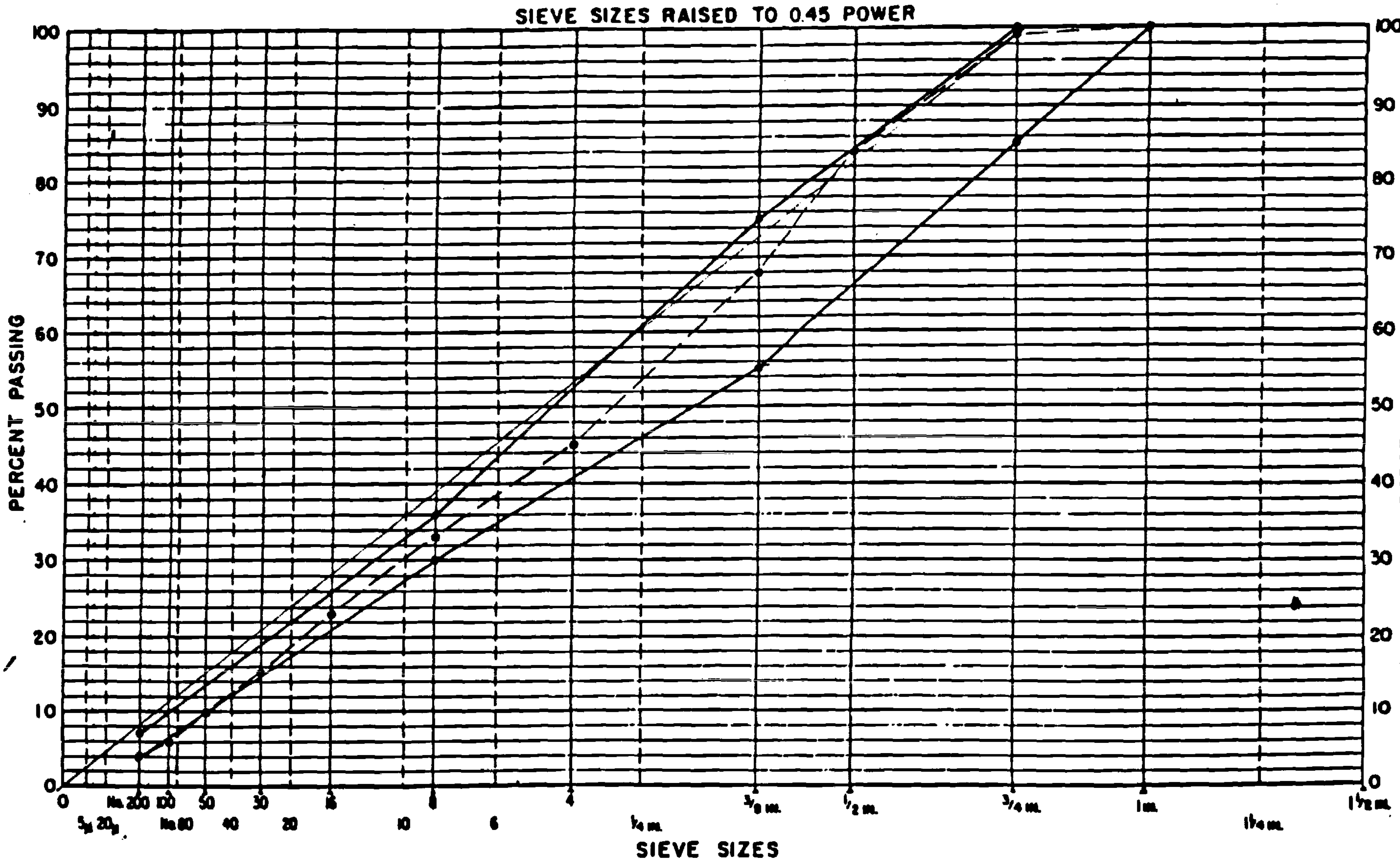
F5M

Sheet No.

Date

Form No. GC-3
THE ASPHALT INSTITUTE

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



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		Date

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THE ASPHALT INSTITUTE

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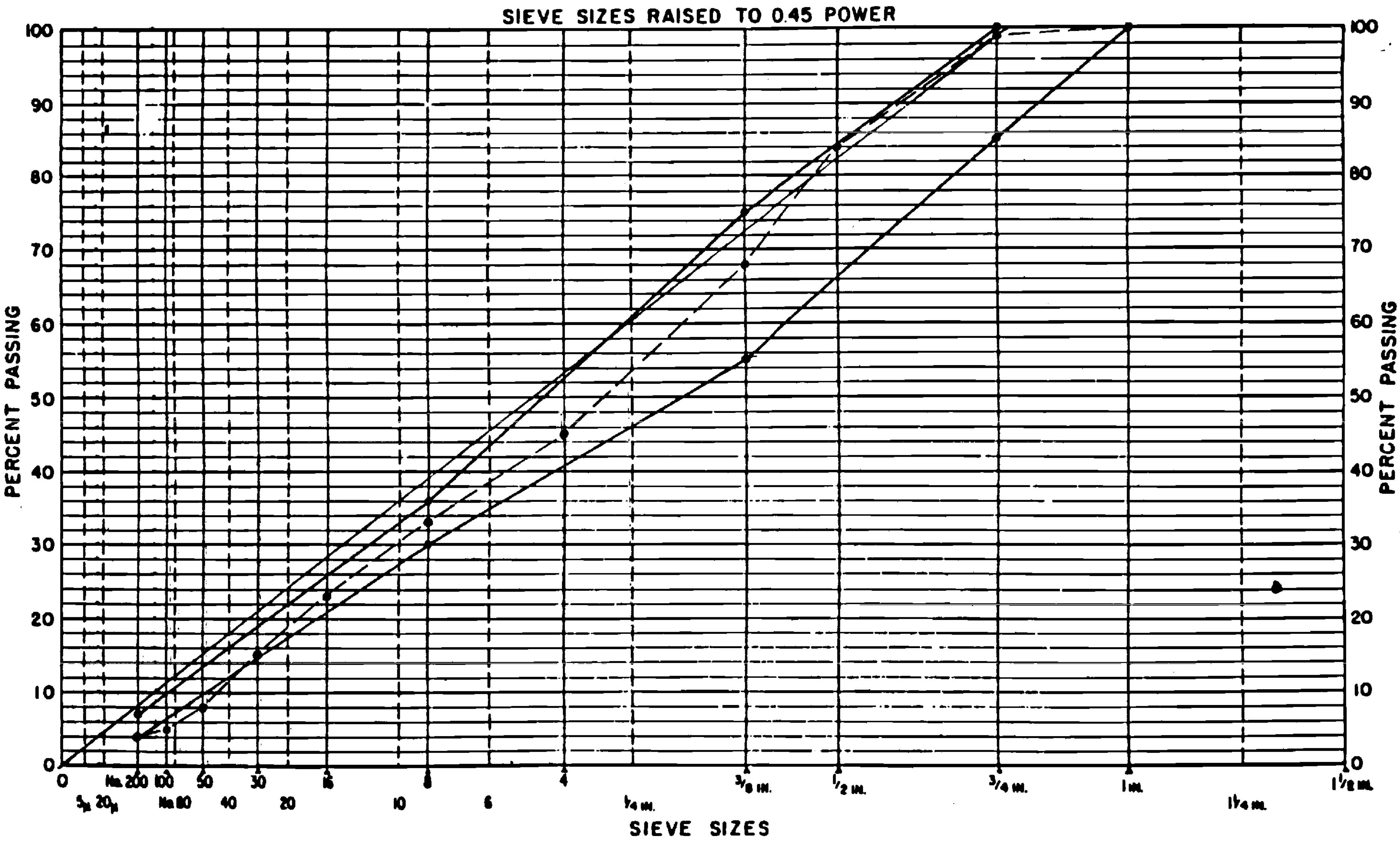

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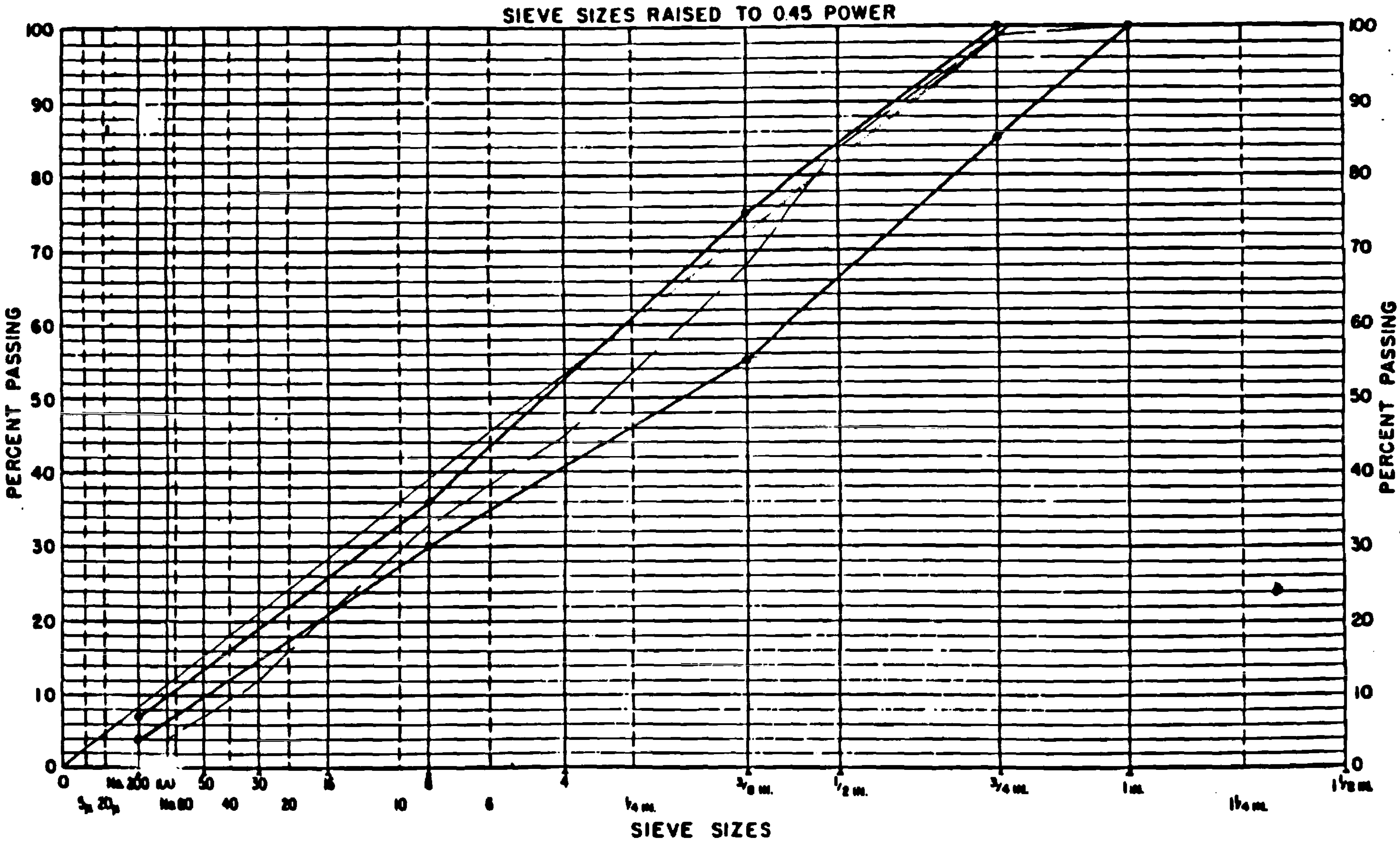
Sheet No.

Date

Form No. GC-3

THE ASPHALT INSTITUTE

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Identification of gradations:

F6K

Sheet No.

Date

Form No. GC-3

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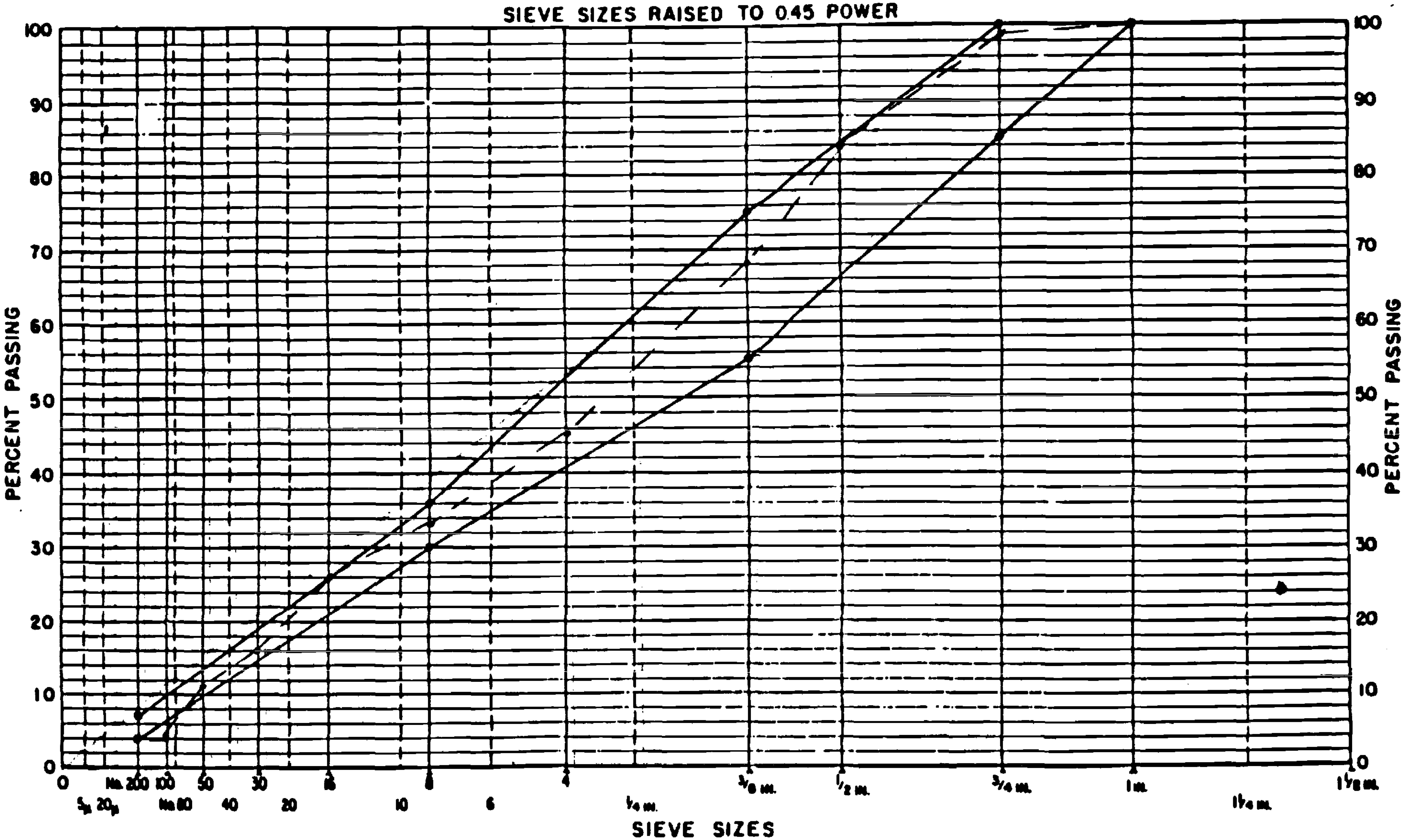
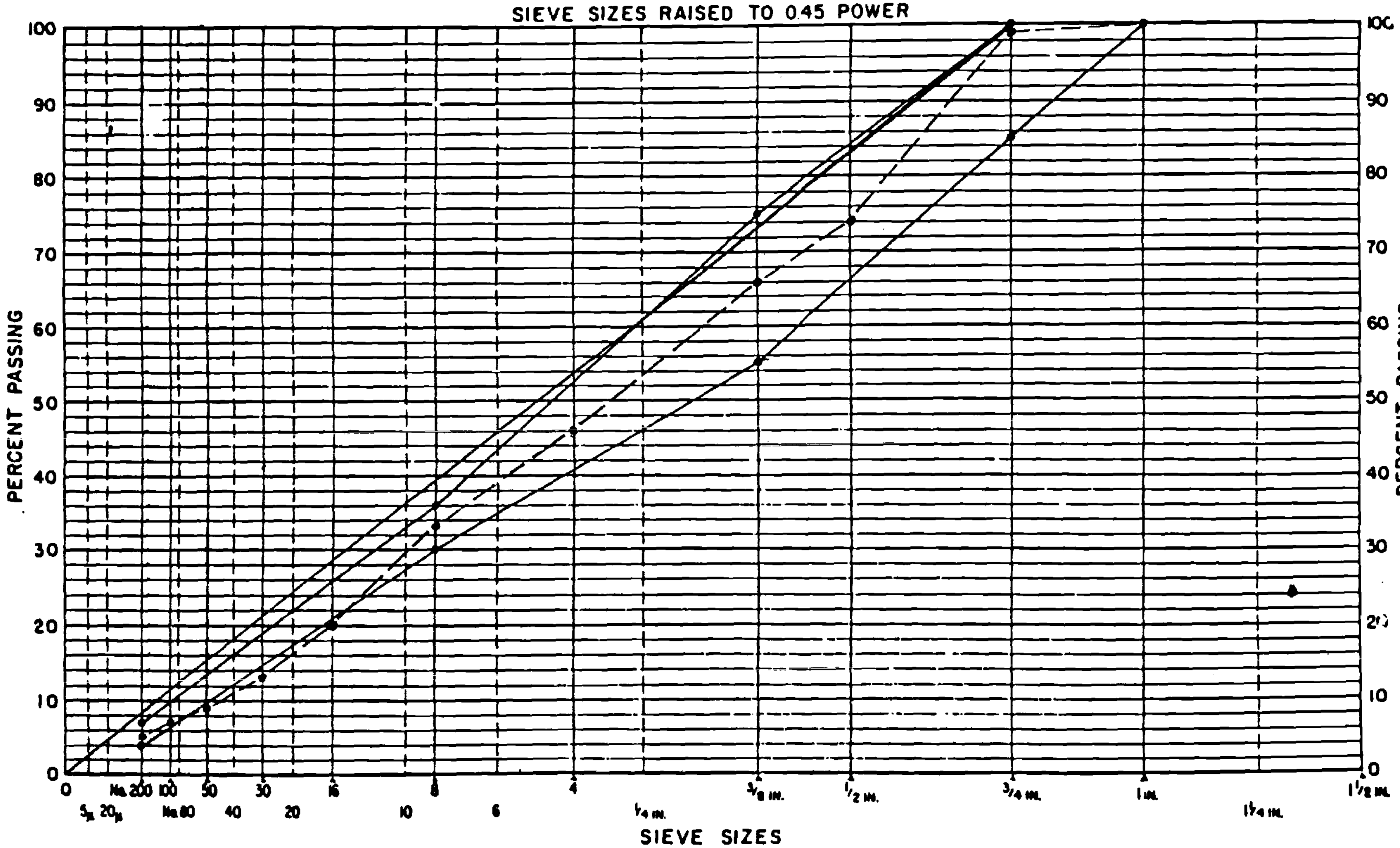
UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES	Identification of gradations: FHM	Sheet No. Date

Form No. GC-3
THE ASPHALT INSTITUTE

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Identification of gradations:

013-B1 DS 36125

Sheet No.

Date

Form No. GC-3

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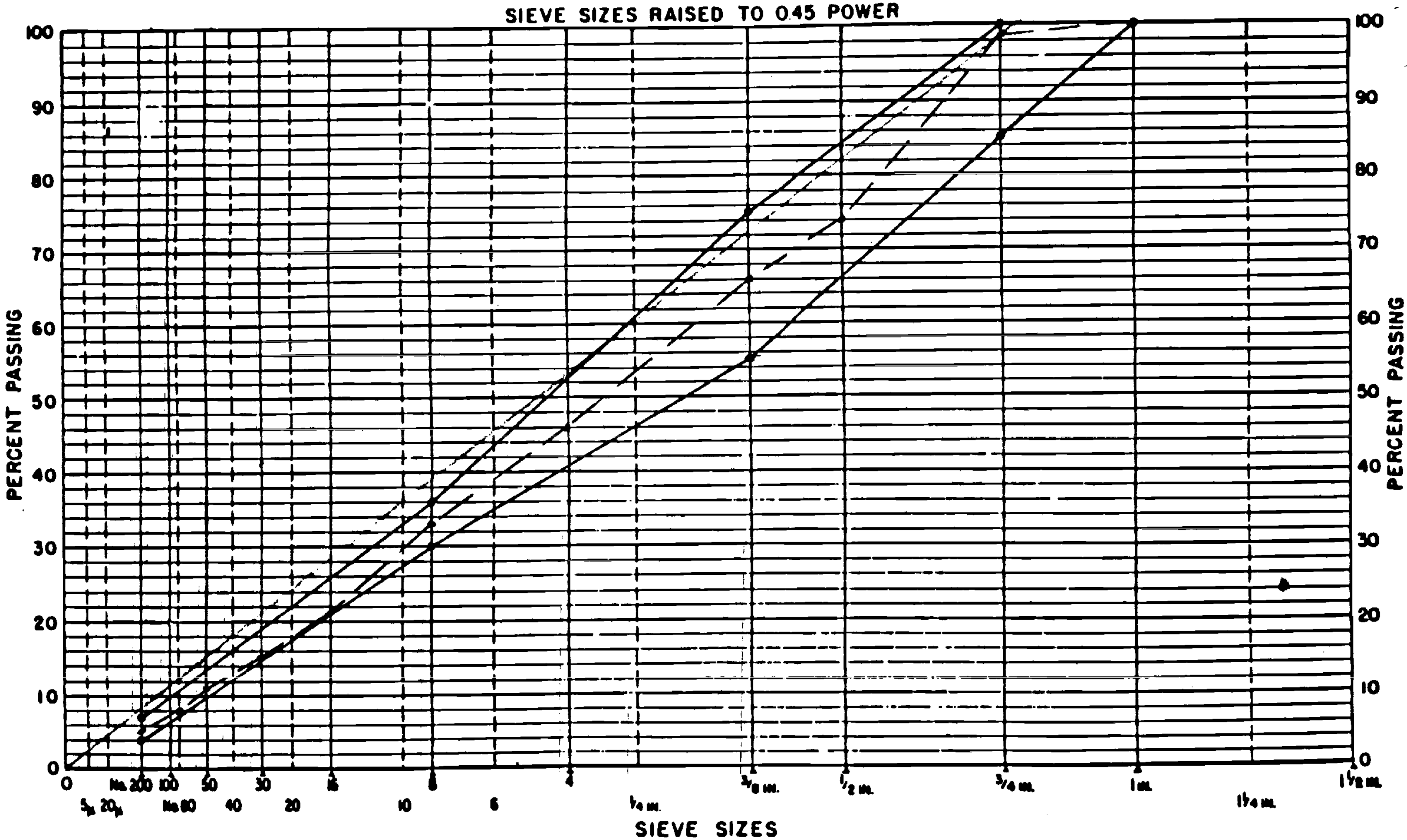
UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



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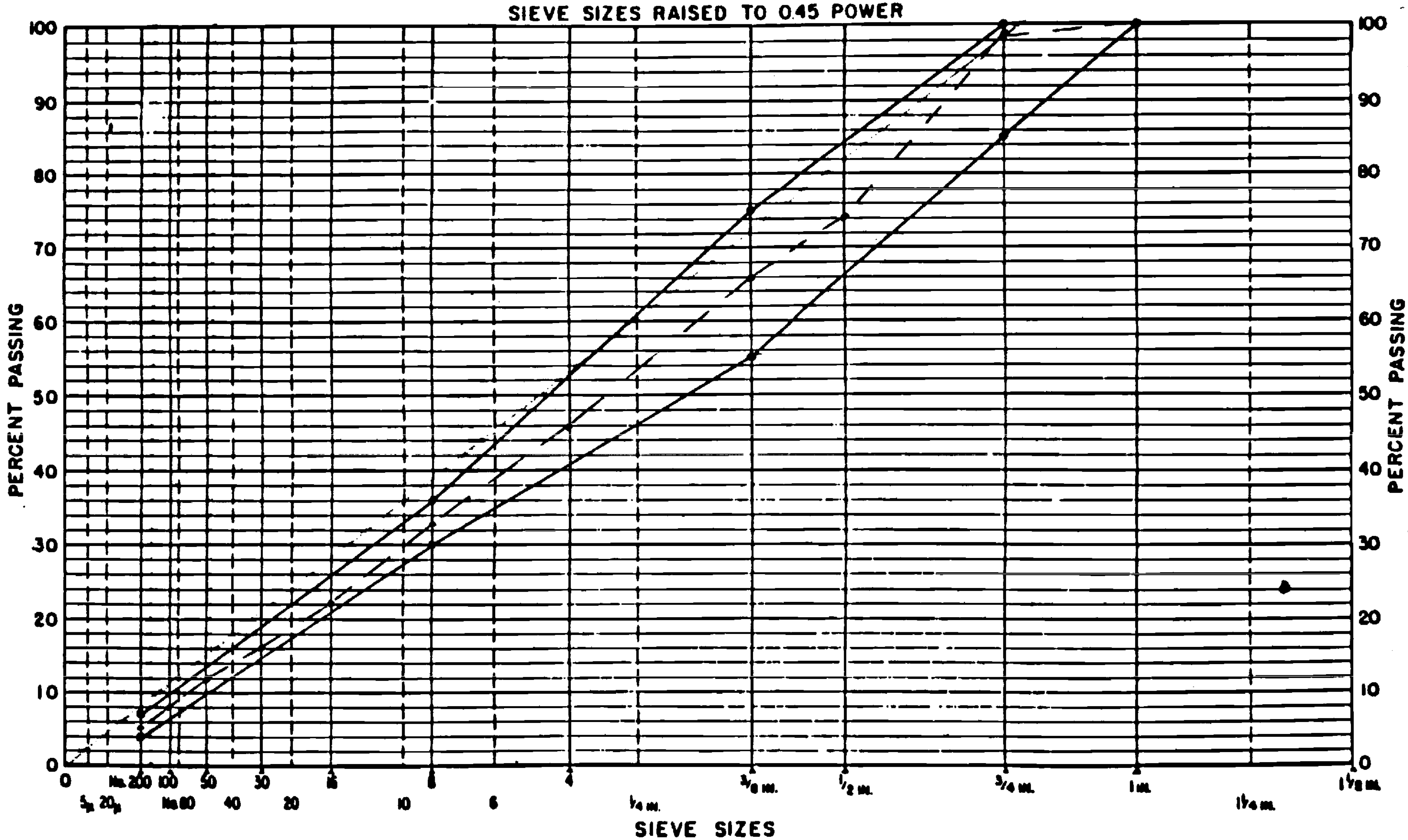
Form No. GC-3
THE ASPHALT INSTITUTE

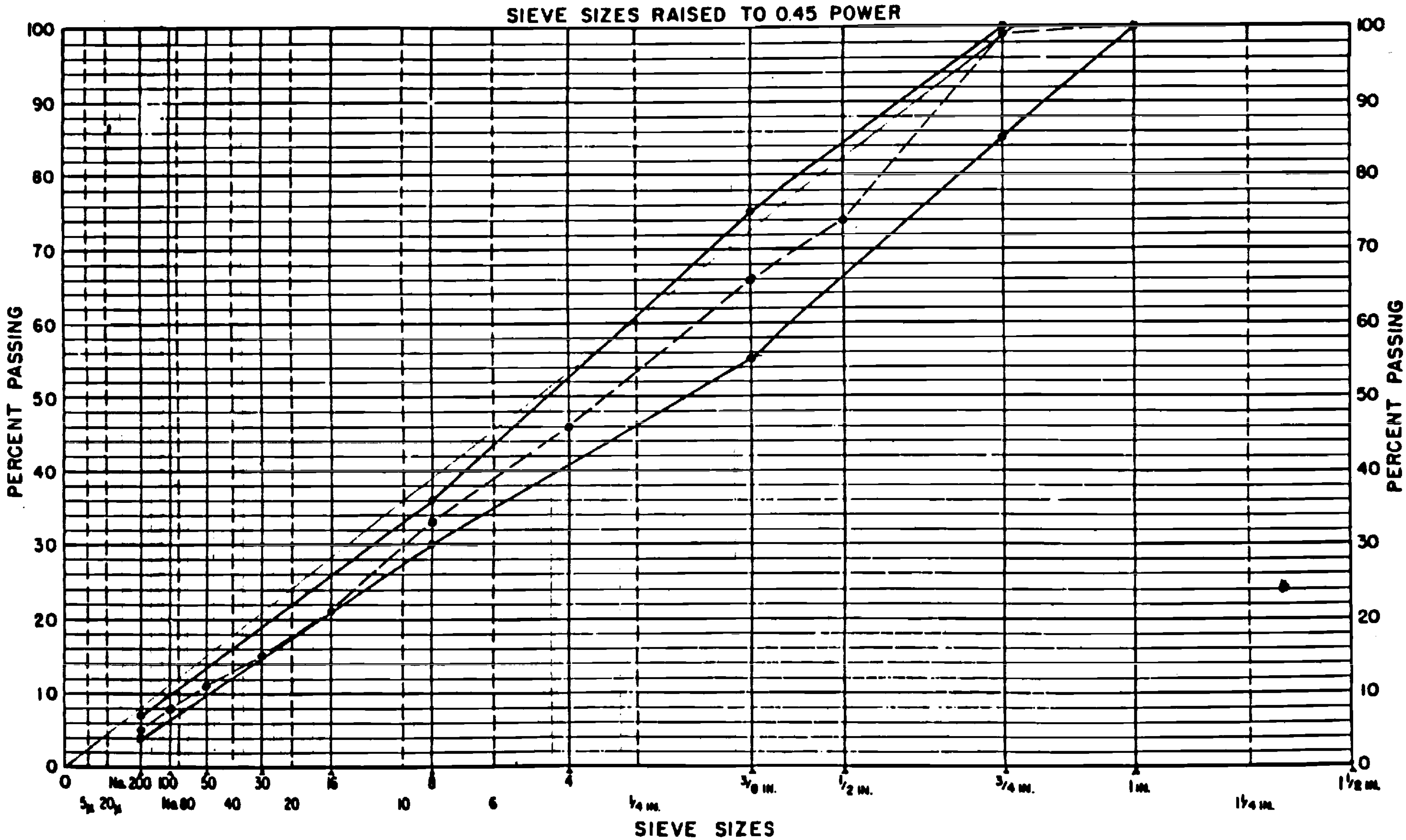
UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES	Identification of gradations: D5M	Sheet No. / Date

Form No. GC-3
THE ASPHALT INSTITUTE

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Identification of gradations:

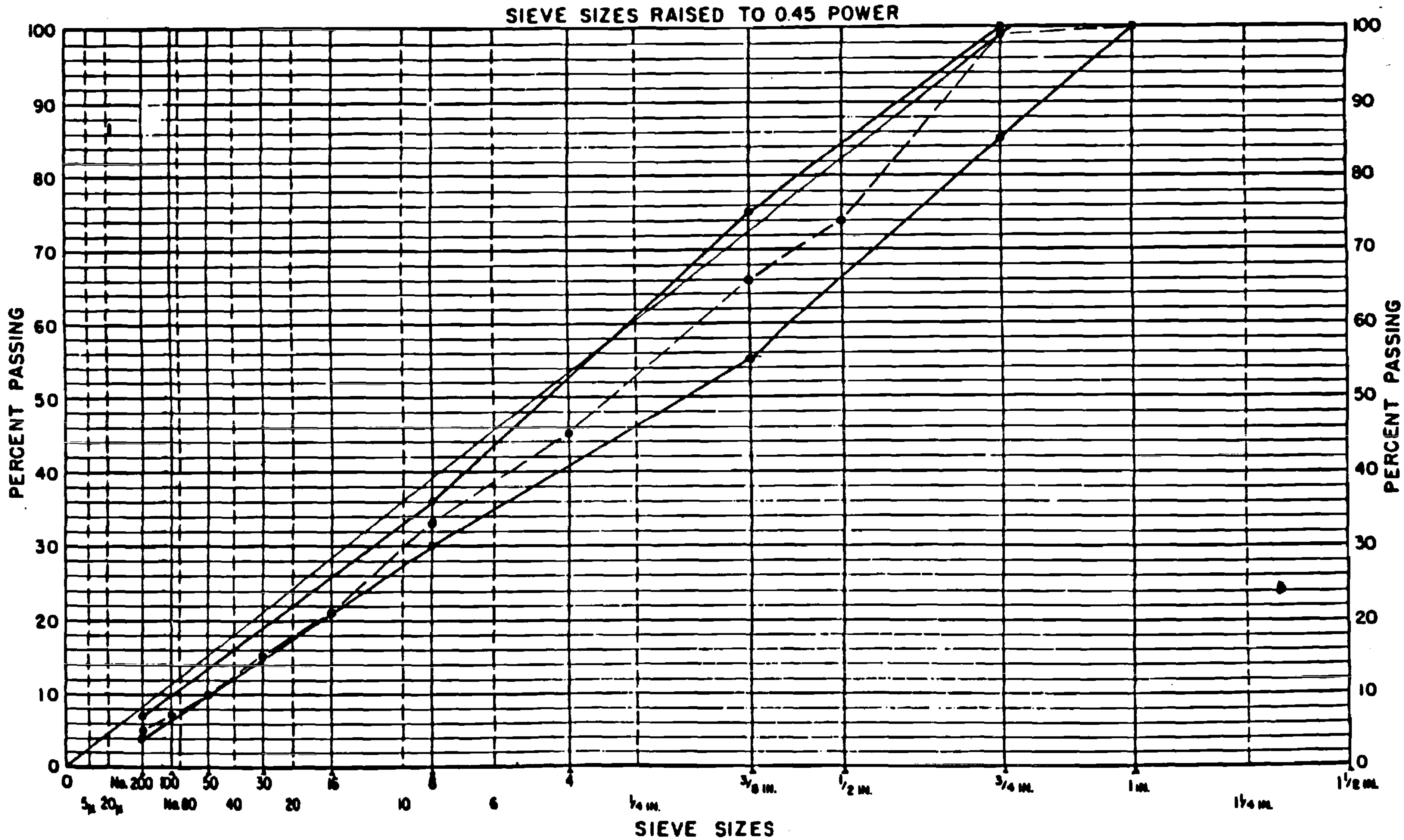
D 5S

Sheet No.

Date

Form No. GC-3
THE ASPHALT INSTITUTE

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



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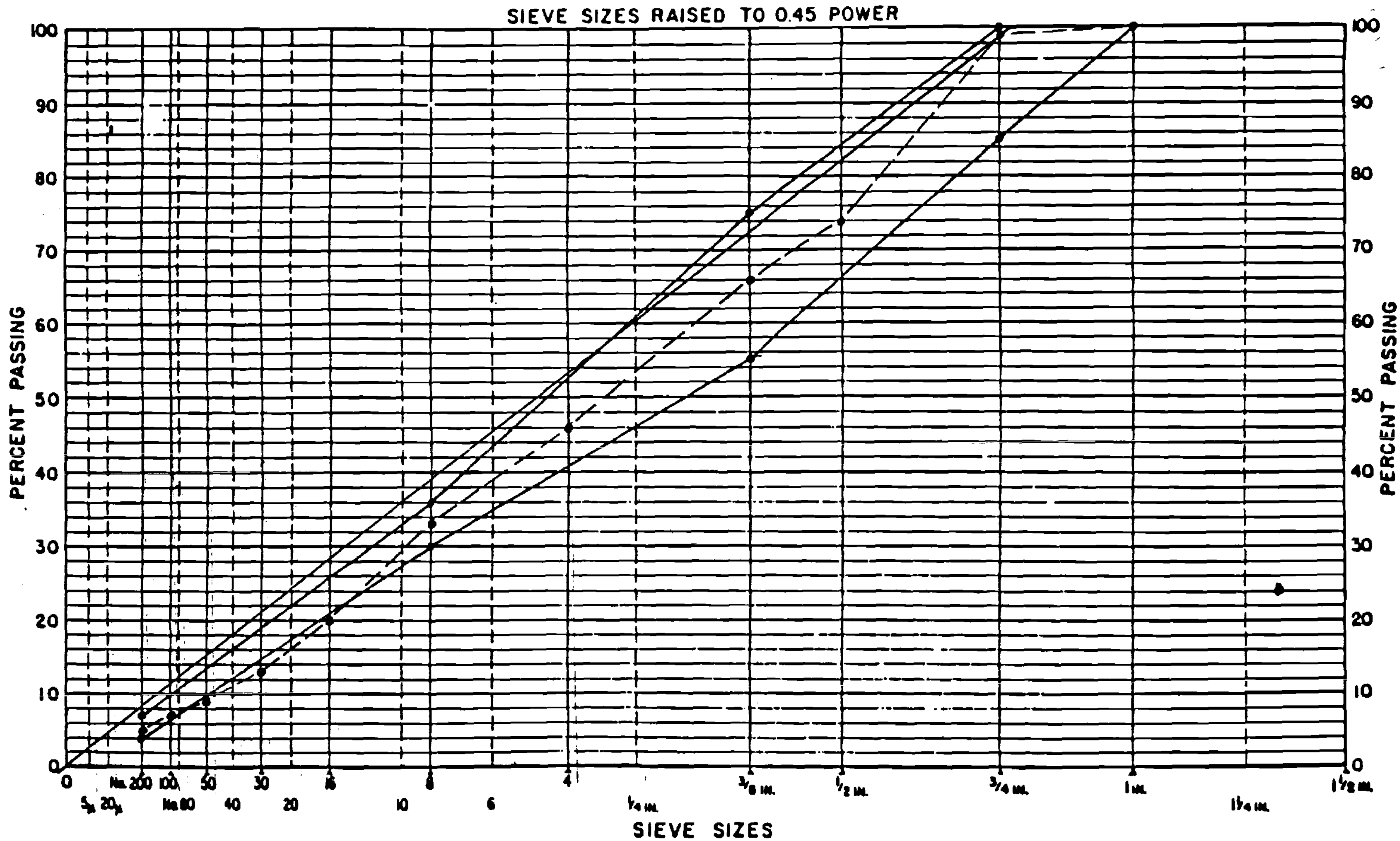
Form No. GC-3
THE ASPHALT INSTITUTE



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Identification of gradations:

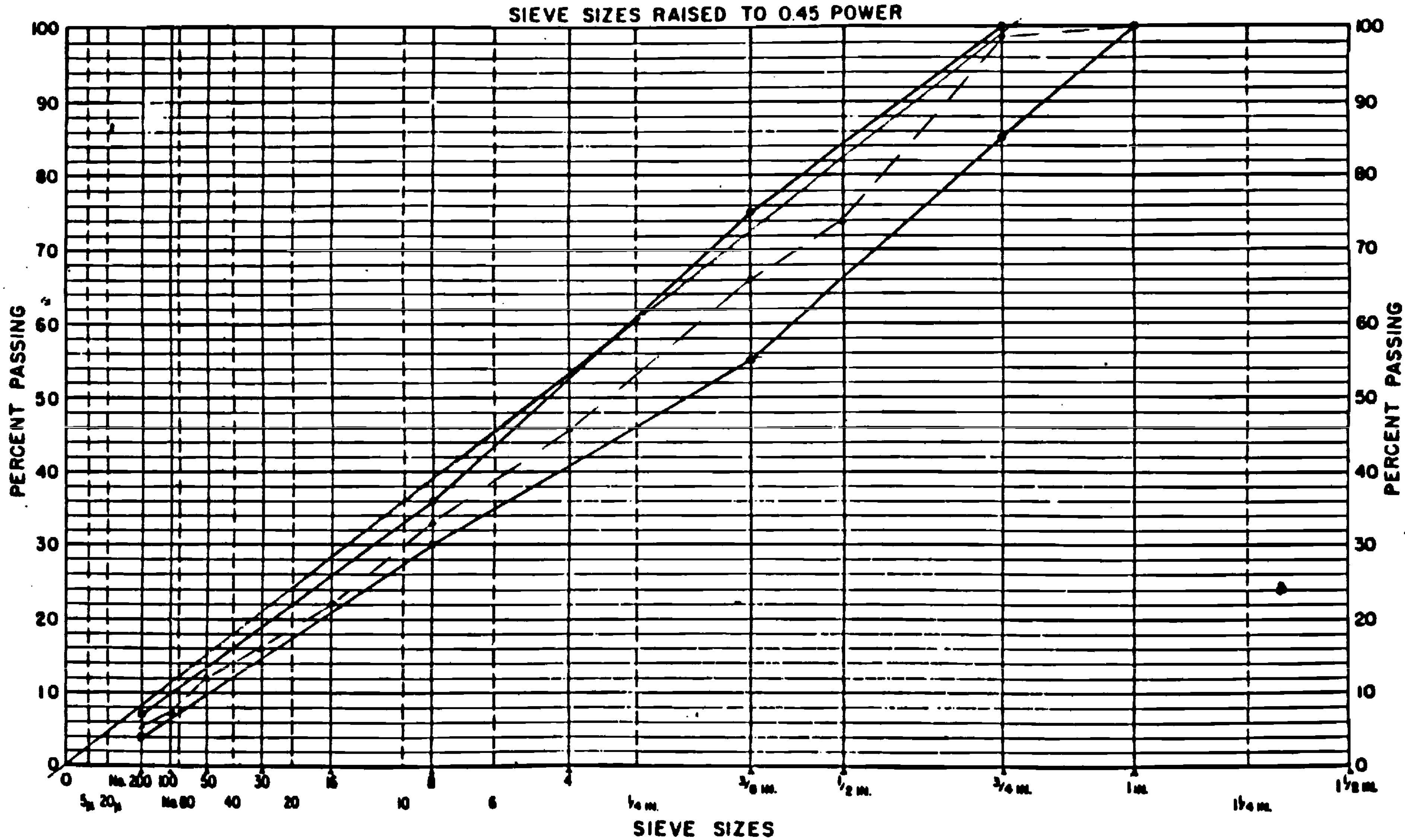
D6K

Sheet No.

Date

Form No. GC-3
THE ASPHALT INSTITUTE

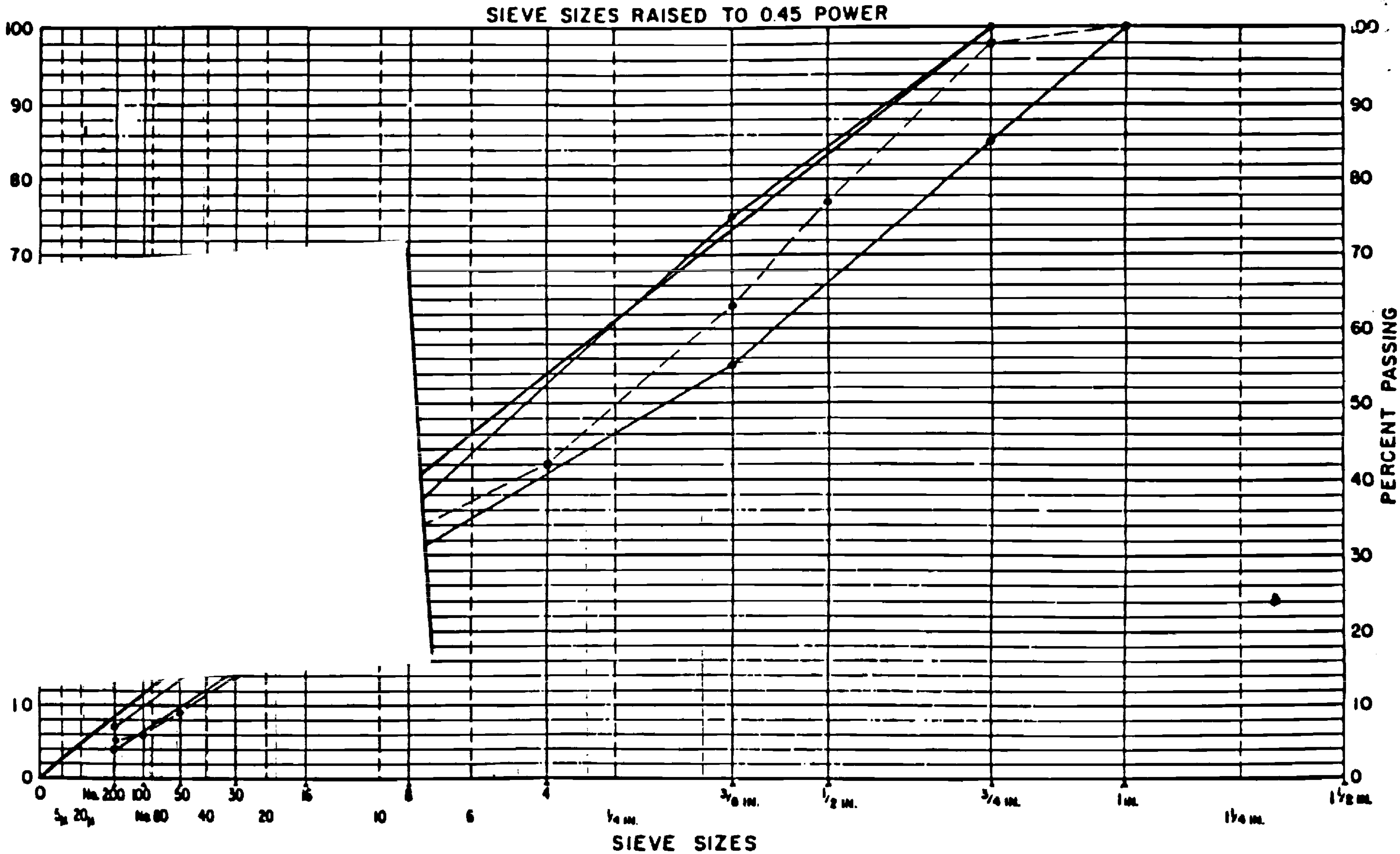
UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES	Identification of gradations: DHM	Sheet No. Date

Form No. GC-3
THE ASPHALT INSTITUTE

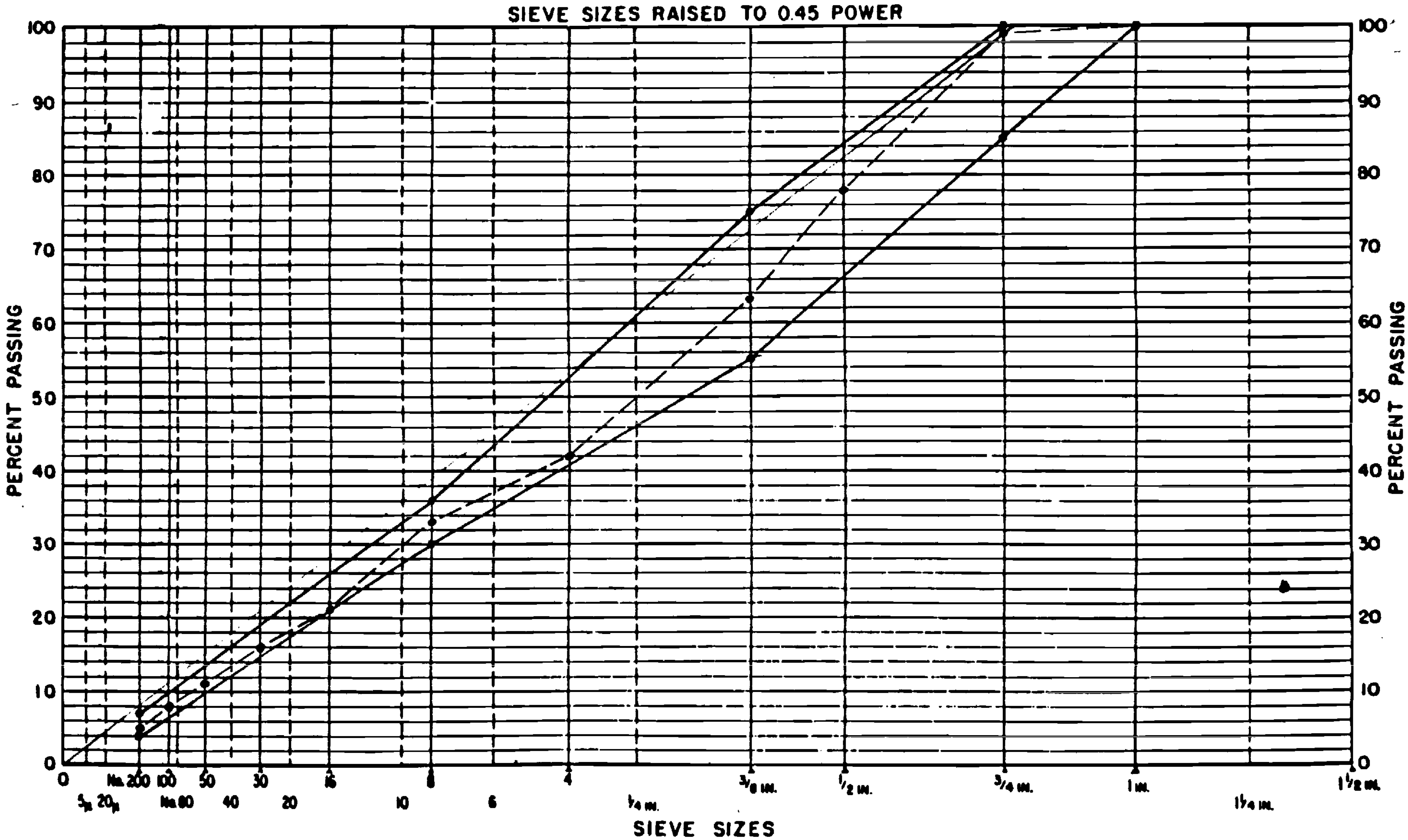
UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES	Identification of gradations: 043-B1 96280 CS	Sheet No. Date

Form No. QC-3
THE ASPHALT INSTITUTE

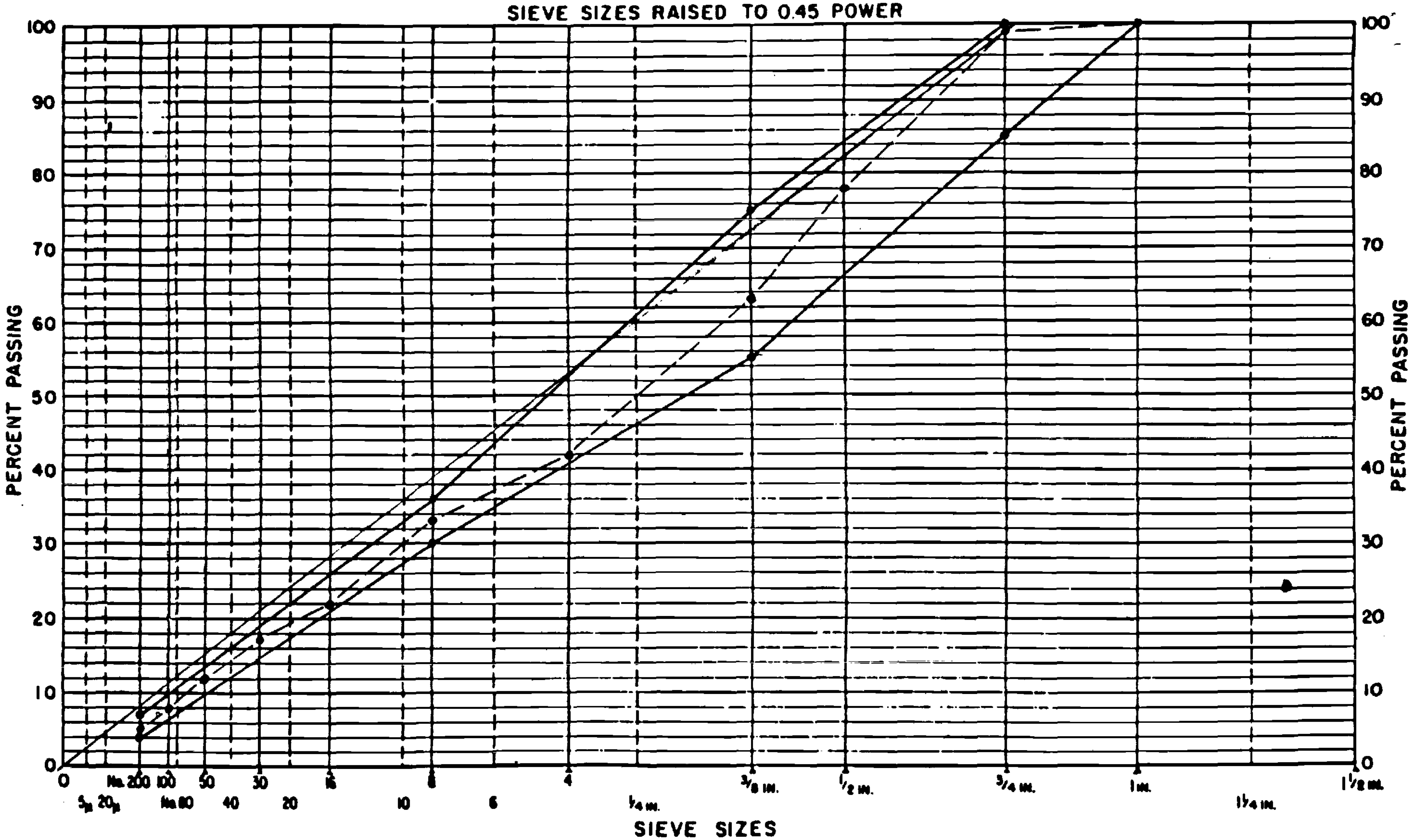
UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES	Identification of gradations: C 3M	Sheet No. / Date

Form No. GC-3
THE ASPHALT INSTITUTE

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

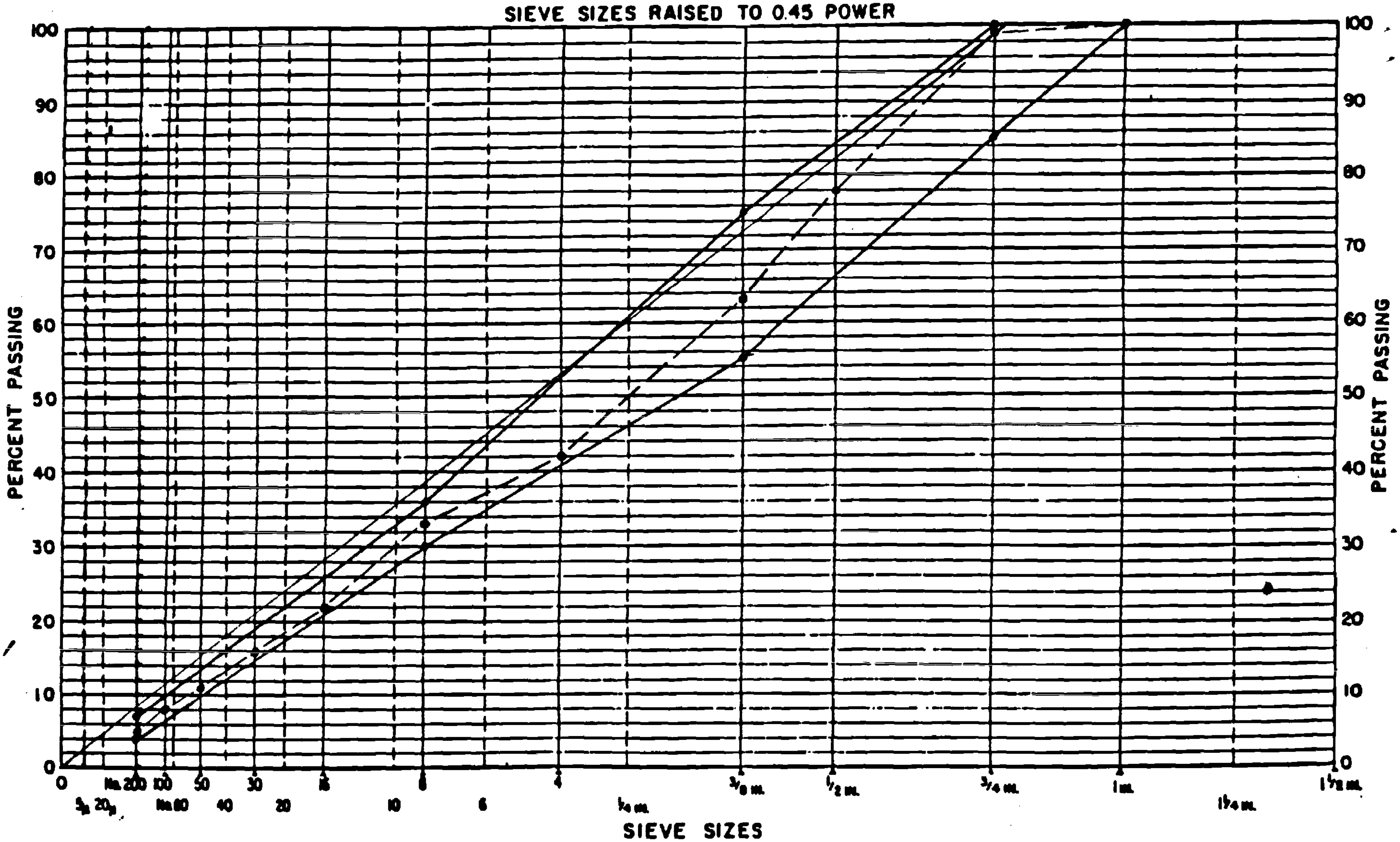
Identification of gradations: C5M

Sheet No.

Date

Form No. GC-3
THE ASPHALT INSTITUTE

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Identification of gradations:

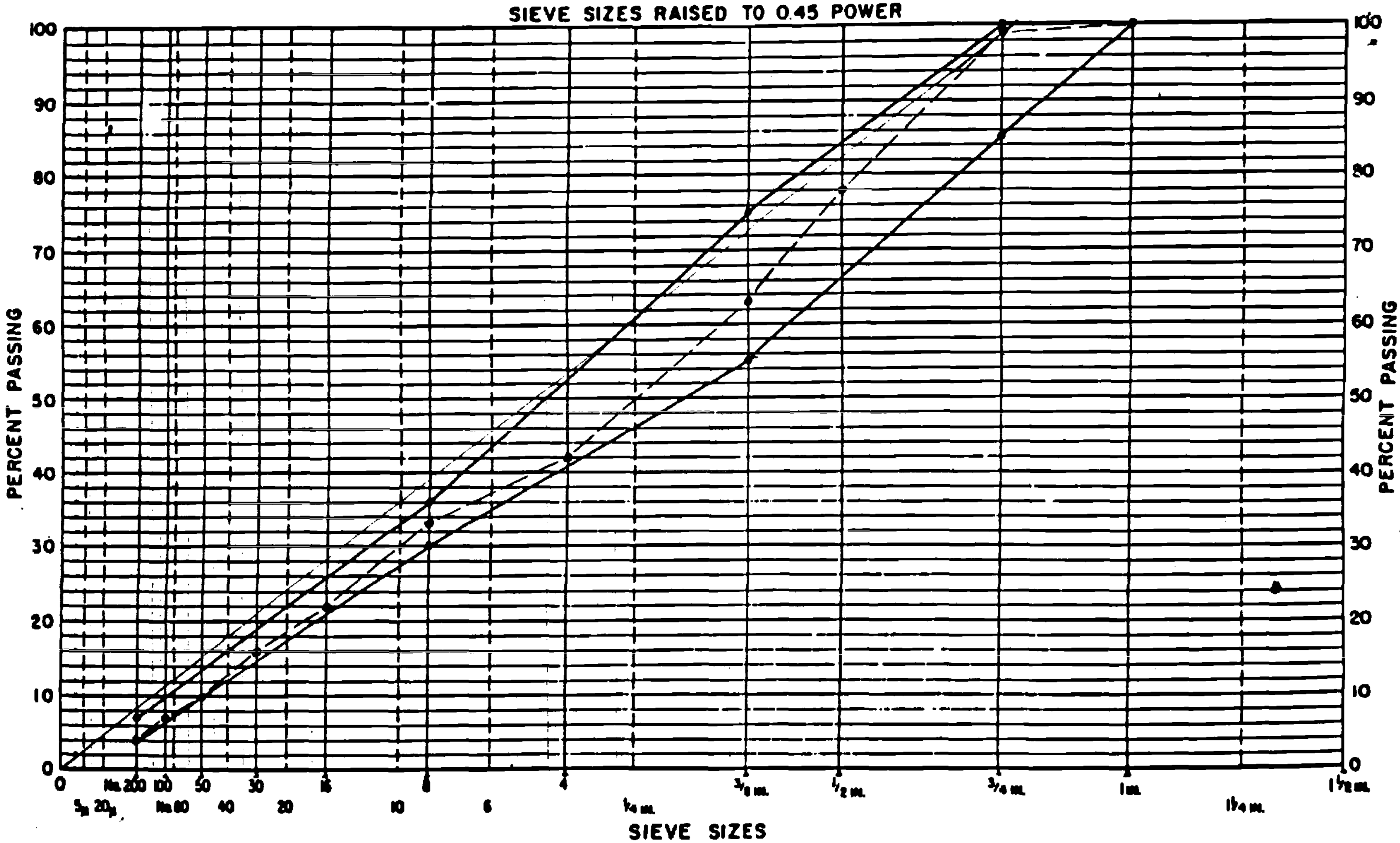
C5S

Sheet No.

Date

Form No. GC-3
THE ASPHALT INSTITUTE

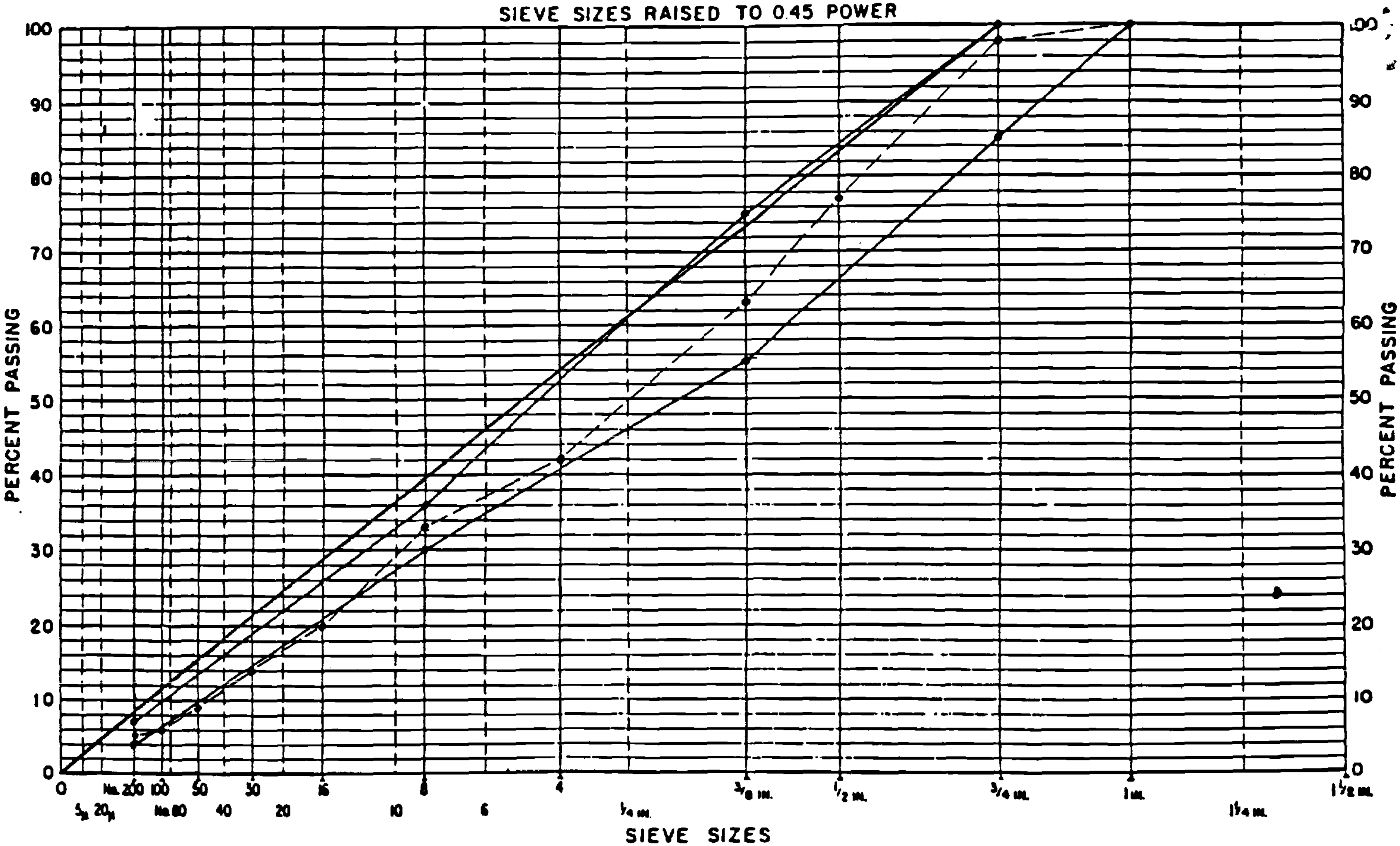
UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES	Identification of gradations: C5T	Sheet No. Date

Form No. GC-3
THE ASPHALT INSTITUTE

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Identification of gradations:

043-B1 96280 C6K

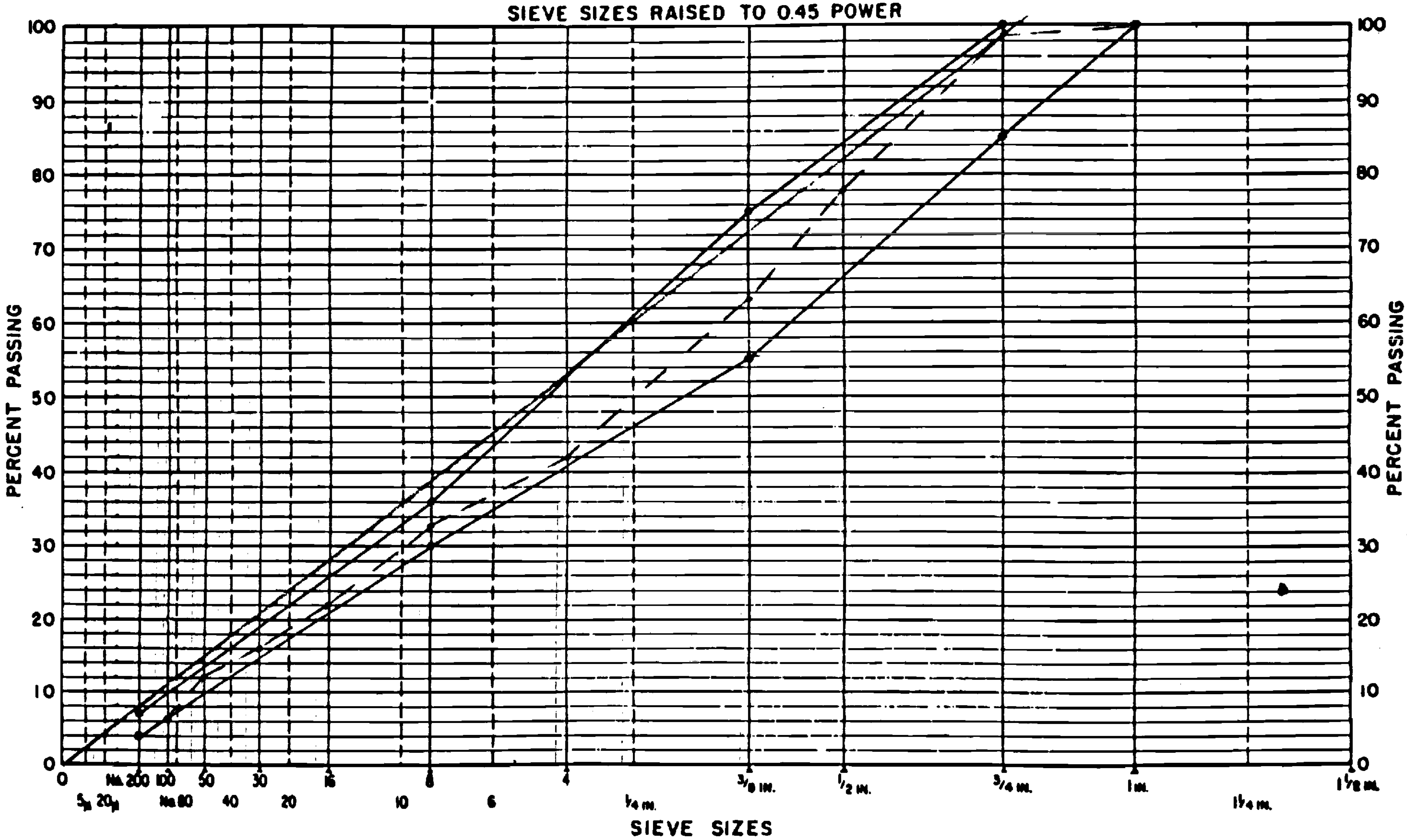
Sheet No.

Date

Form No. GC-3
THE ASPHALT INSTITUTE

Coarse D Mix

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES	Identification of gradations: CHM	Sheet No. / Date

Form No. GC-3
THE ASPHALT INSTITUTE

Appendix B

Properties of the Shell AC-20S Modified Asphalt

DEPARTMENT OF TRANSPORTATION

STATE OF GEORGIA

EVALUATION OF ASPHALT MODIFIER 11/21/86

MODIFIER NAME: KRATON MODIFIED ASPHALT TYPE:

MANUFACTURED BY: SHELL AT:

DISTRIBUTED BY: AT:

CONTACT PERSON: PHONE:

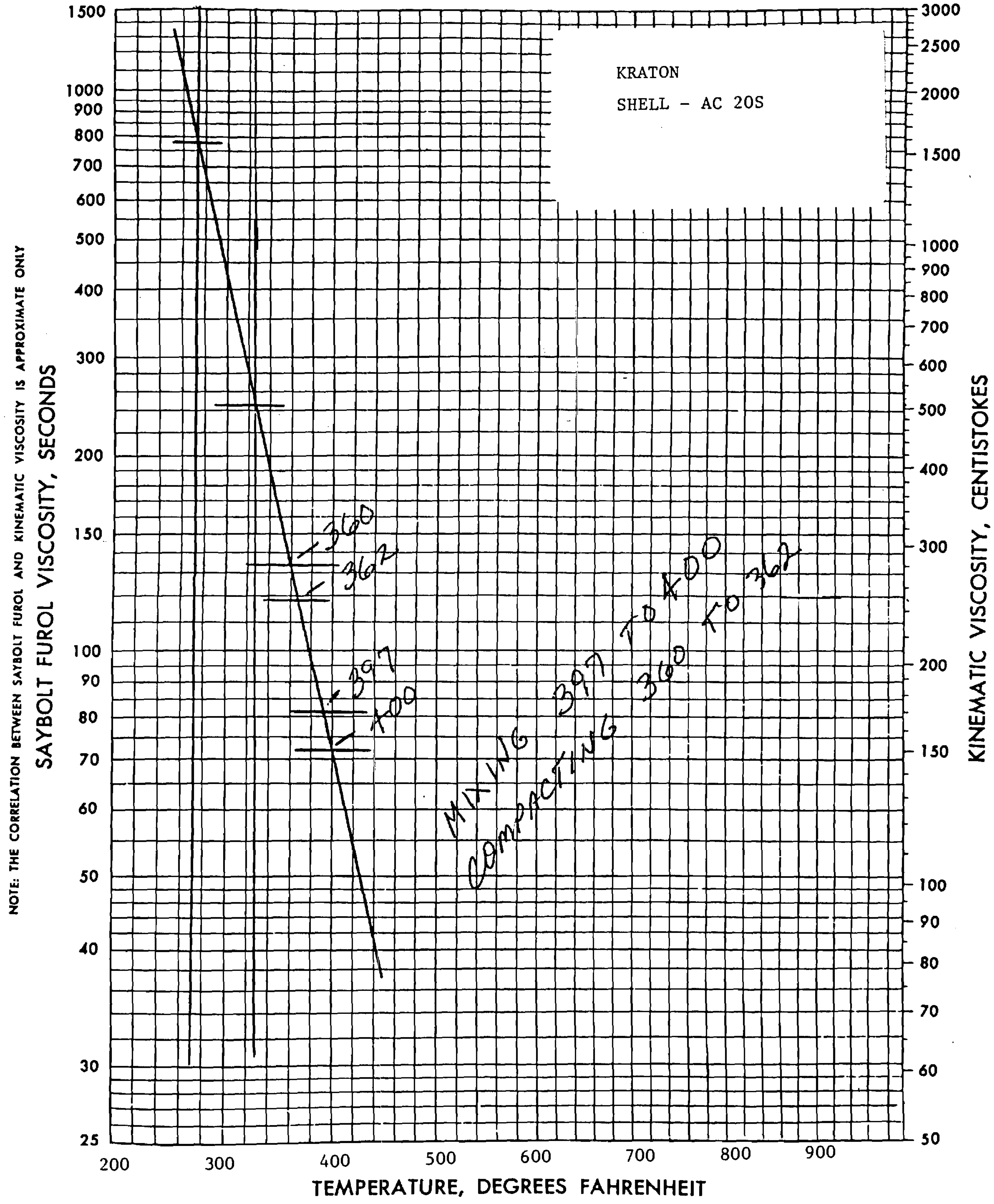
ASPHALT USED: SHELL AC-20S Modified by Shell Chemical Co GRADE:

MODIFIER CONCENTRATION: % BASED ON WEIGHT OF

TEST METHOD	MODIFIED ASPHALT	UNMODIFIED ASPHALT
Penetration @ 77°F	57	
Viscosity @ 140°F	58,642	
Viscosity @ 275°F	1,575	
Viscosity @ 325°F	515	
Mixing Temp. F°		
Compacting Temp. F°		
Tests on Residue (TFOT)		
Loss of Weight (%)		
Ductility @ 60°F		
Ductility @ 77°F		
PVN 140°F		
PVN 275°F		
Flexure		
Cohesiometer		

REMARKS: This is Additional Material received from Shell Chemical Co. for further design work. 11/21/86

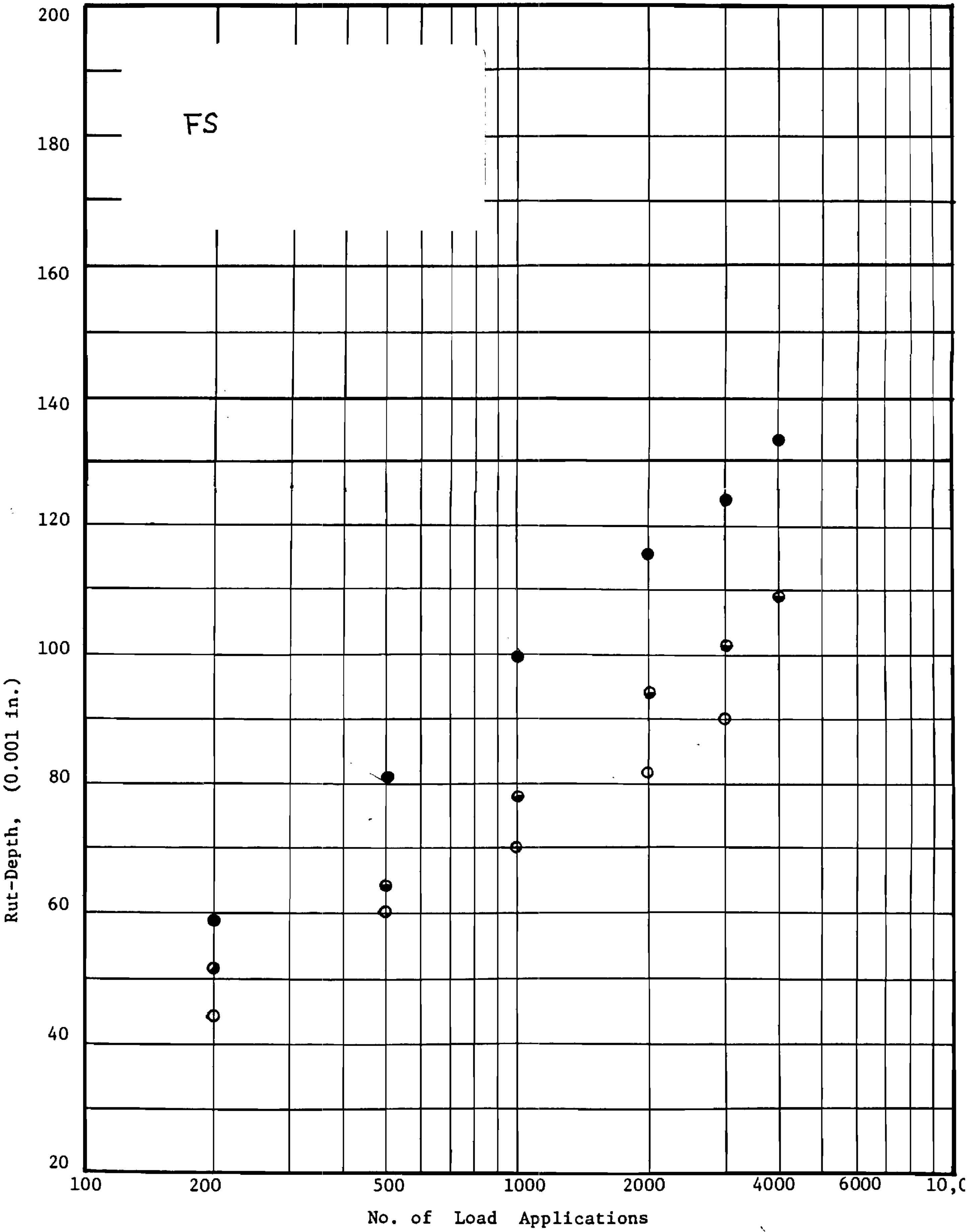
VISCOSITY VS. TEMPERATURE FOR ASPHALTS



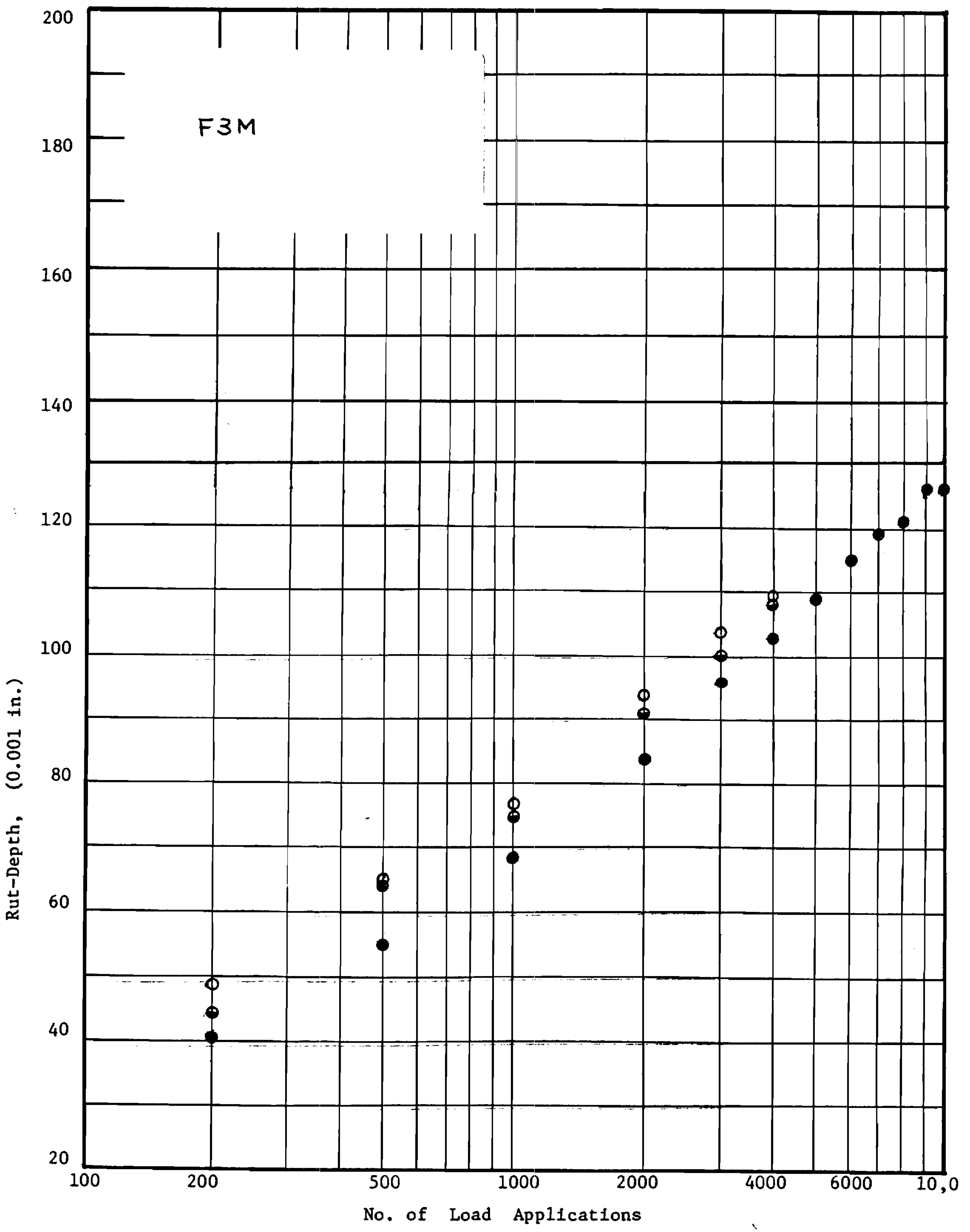
APPENDIX C

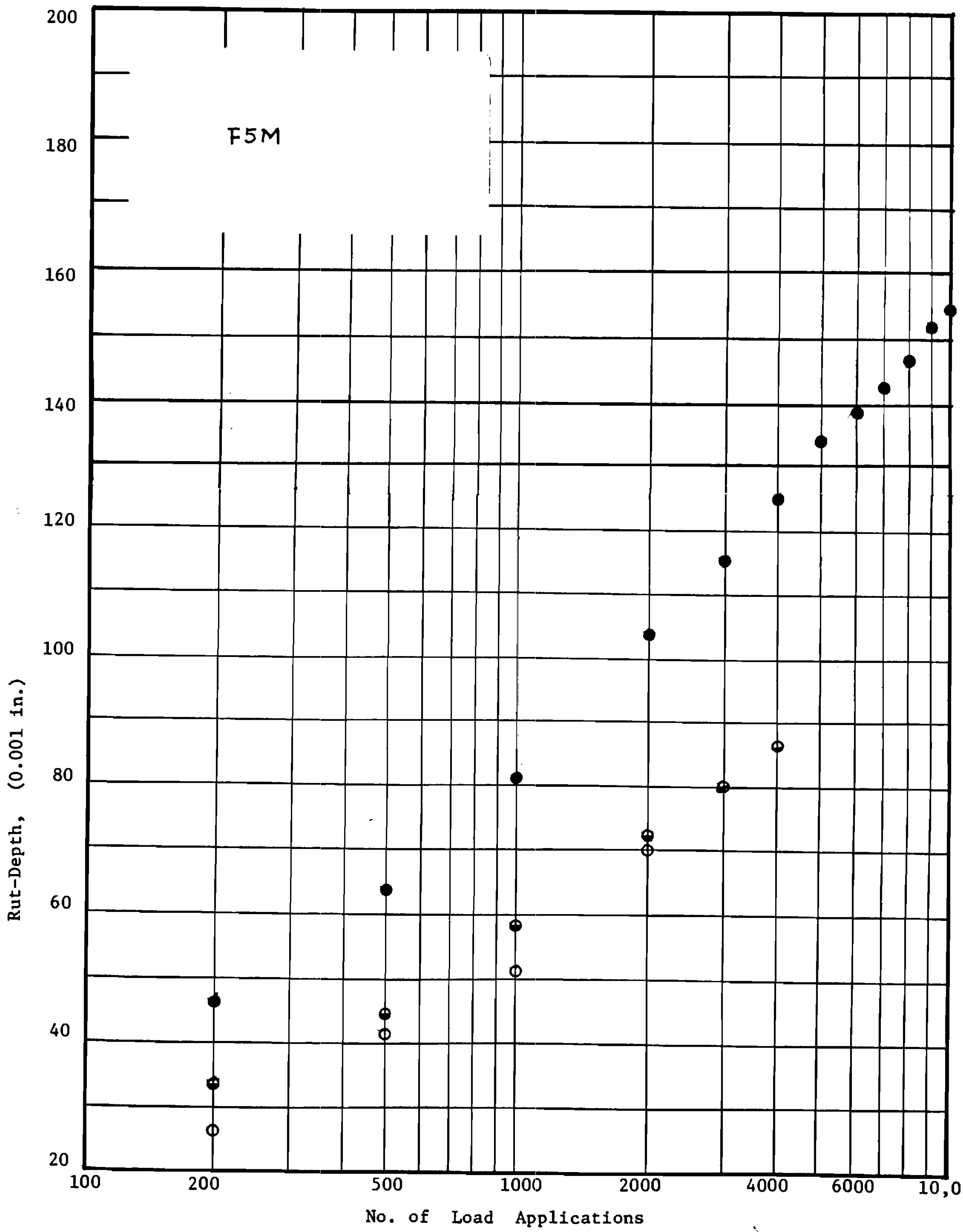
Graphs of Rut-Depth vs No. of Load Applications

for all the tests

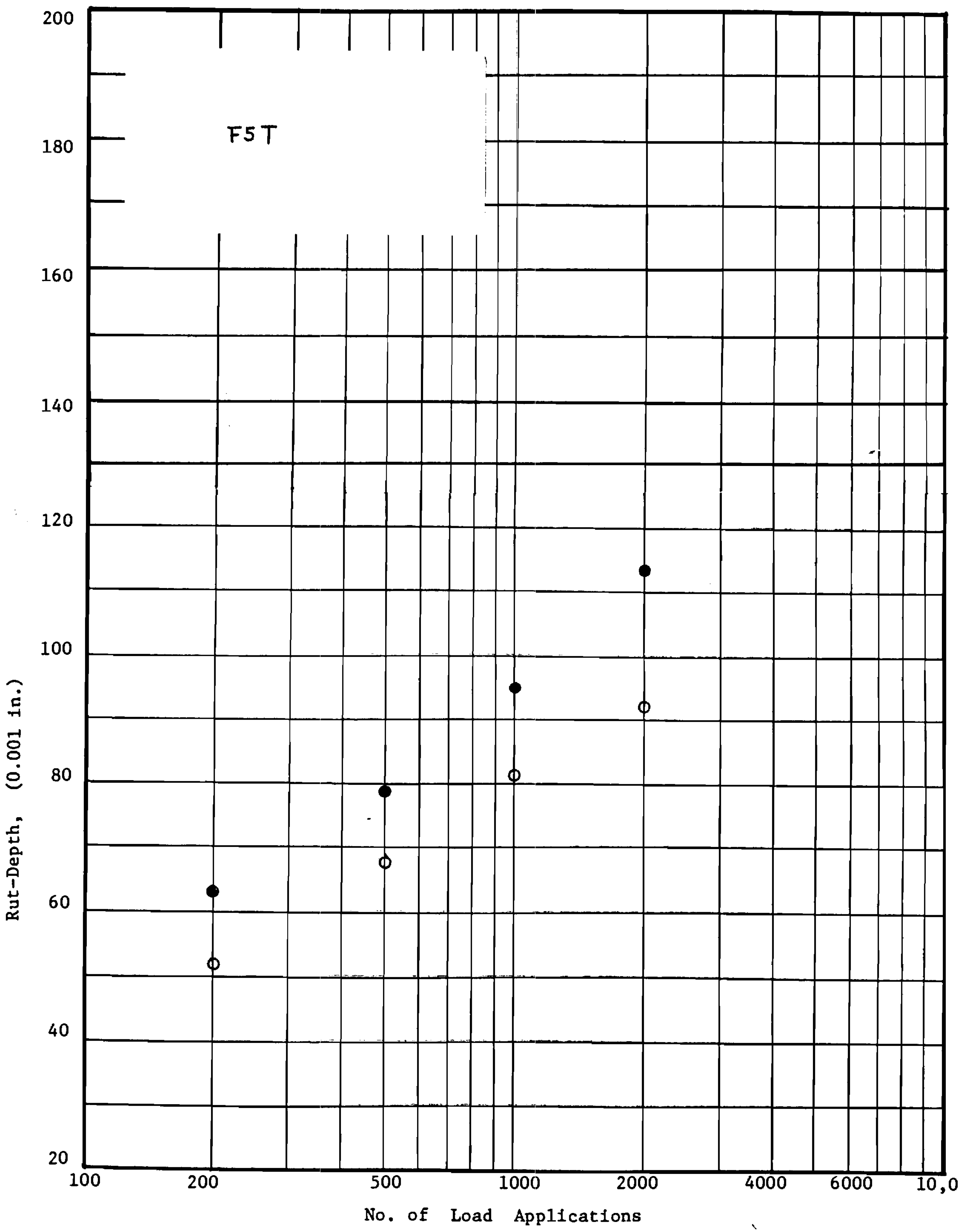


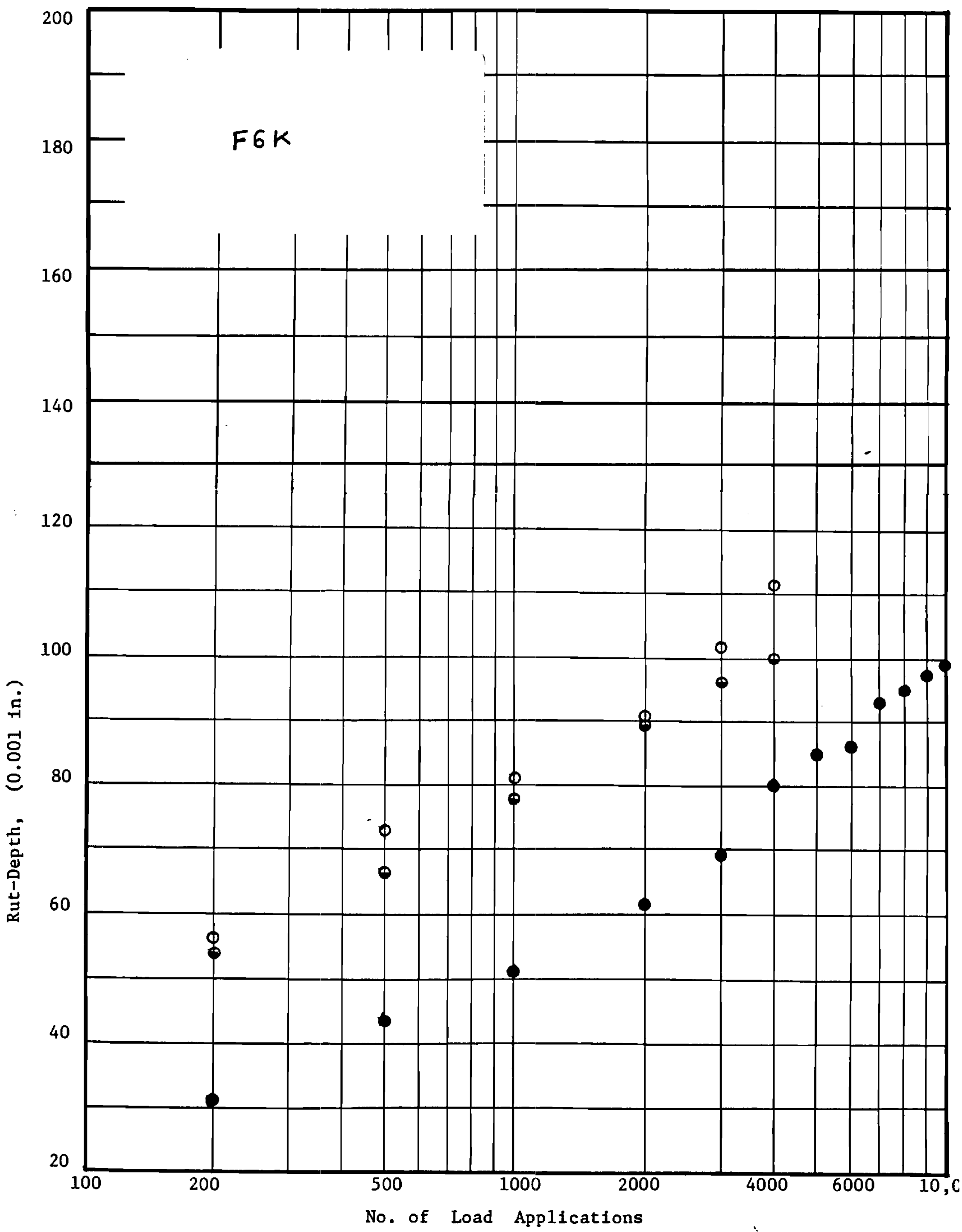
FS
Rut-Depth, (0.001 in.)
200
180
160
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
No. of Load Applications

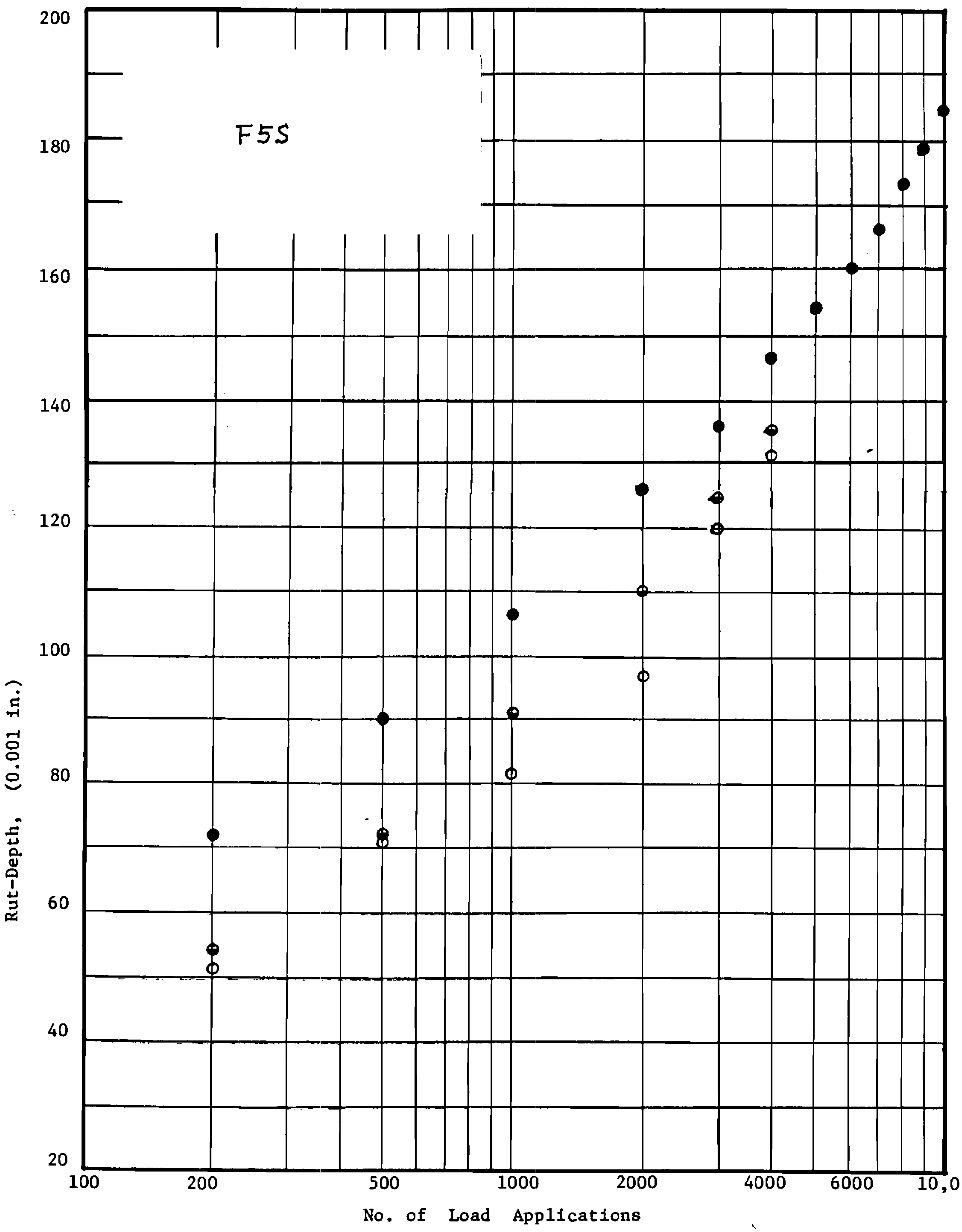

F3M
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications

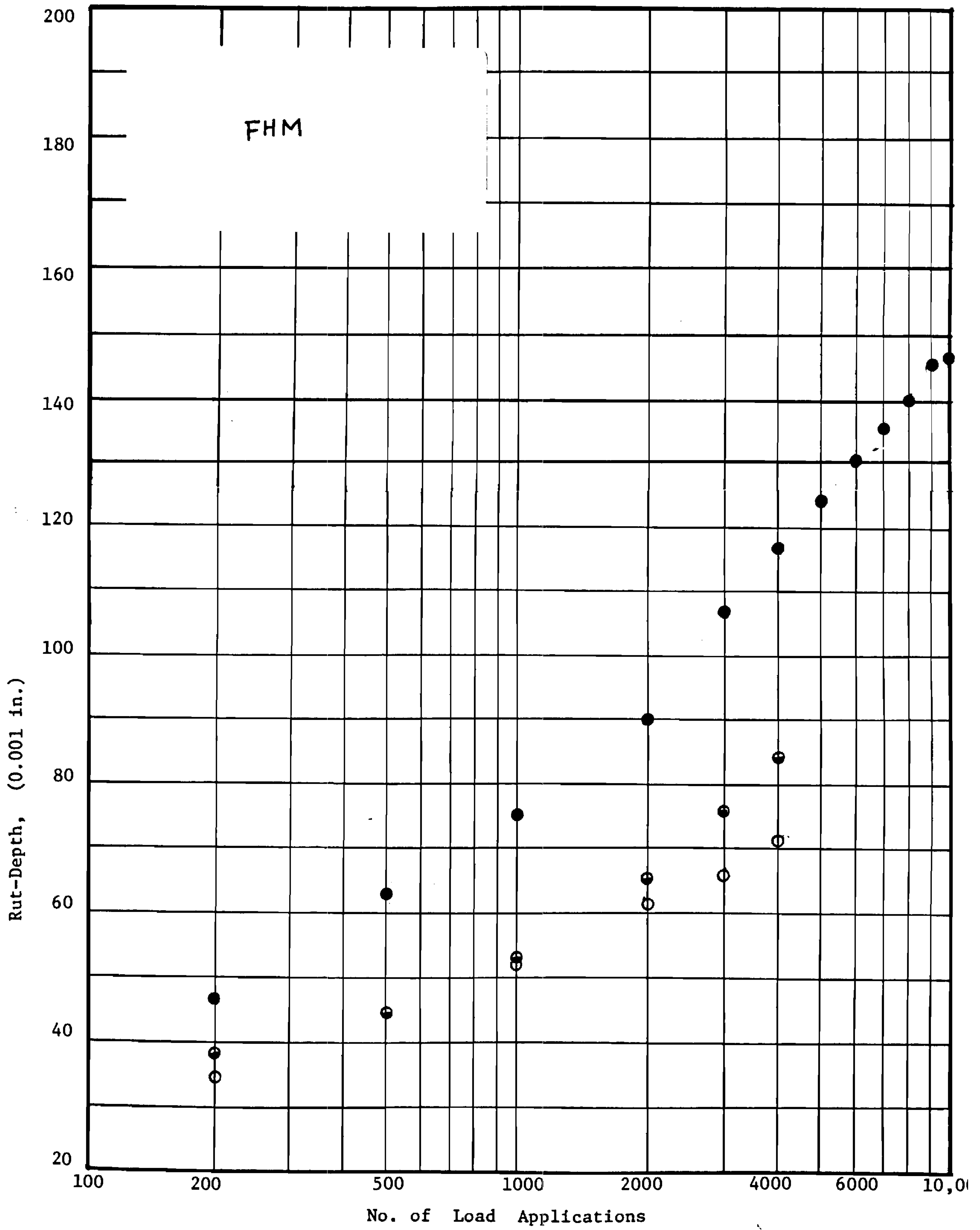


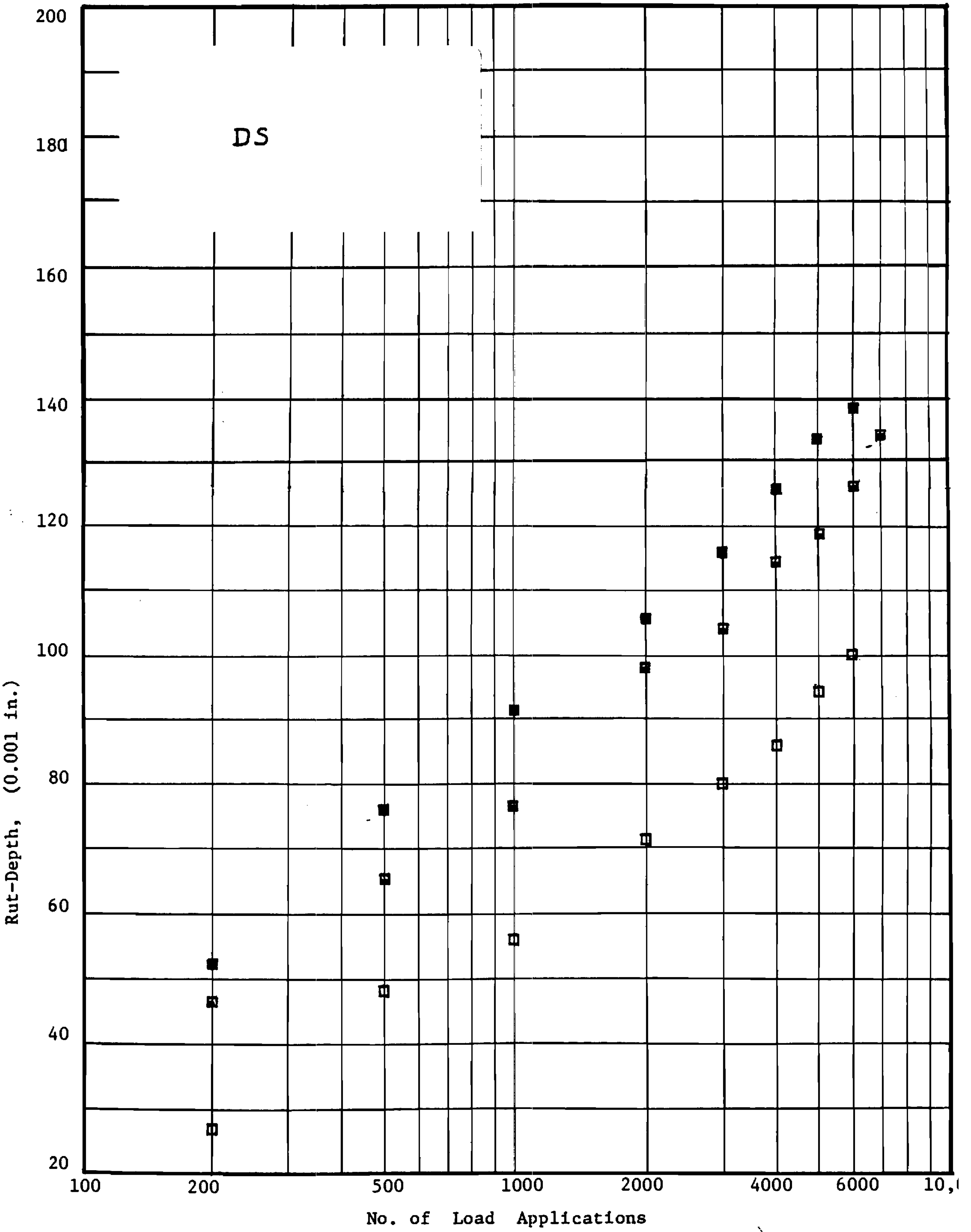
F5M
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications

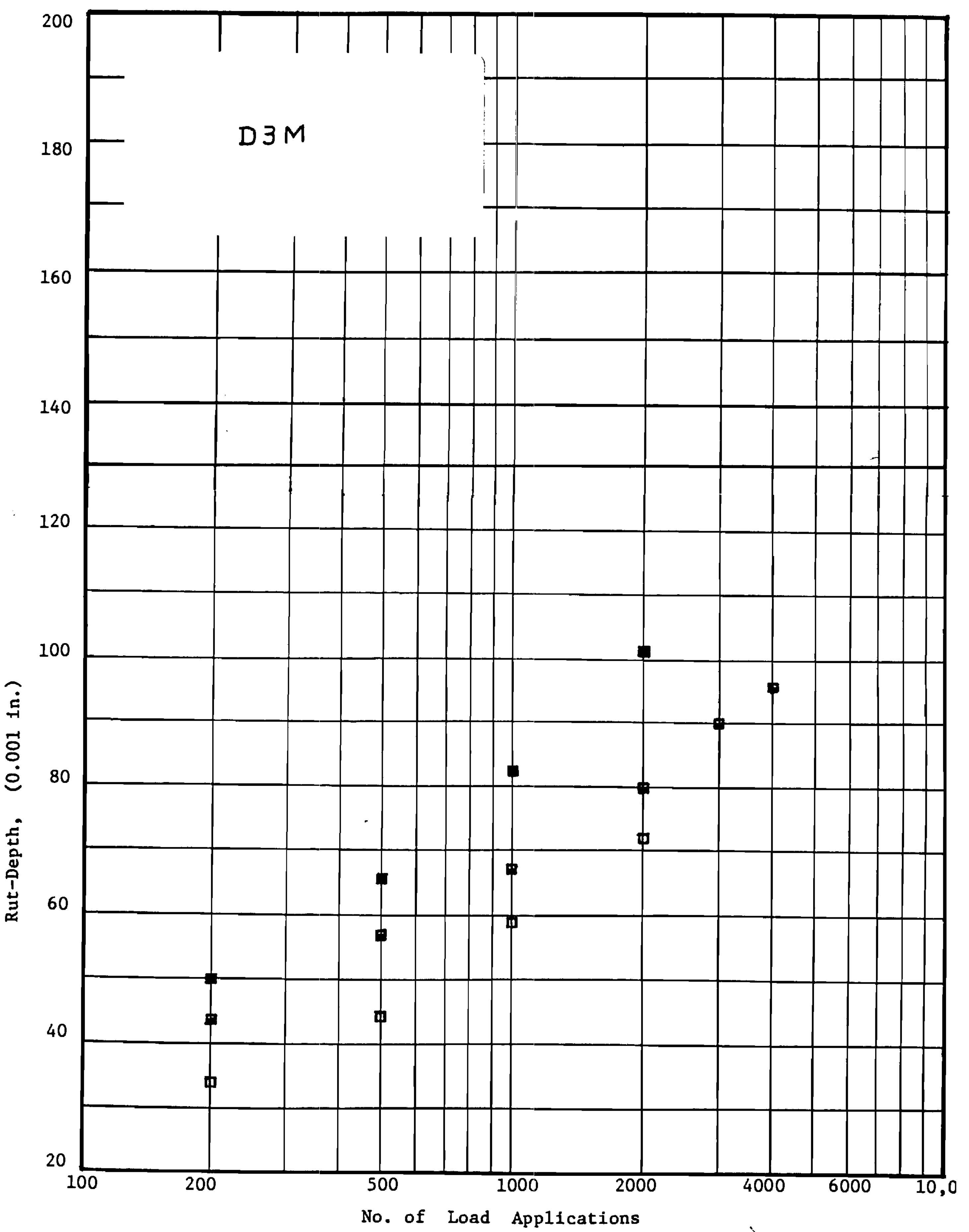

F5T
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications


F6K
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications

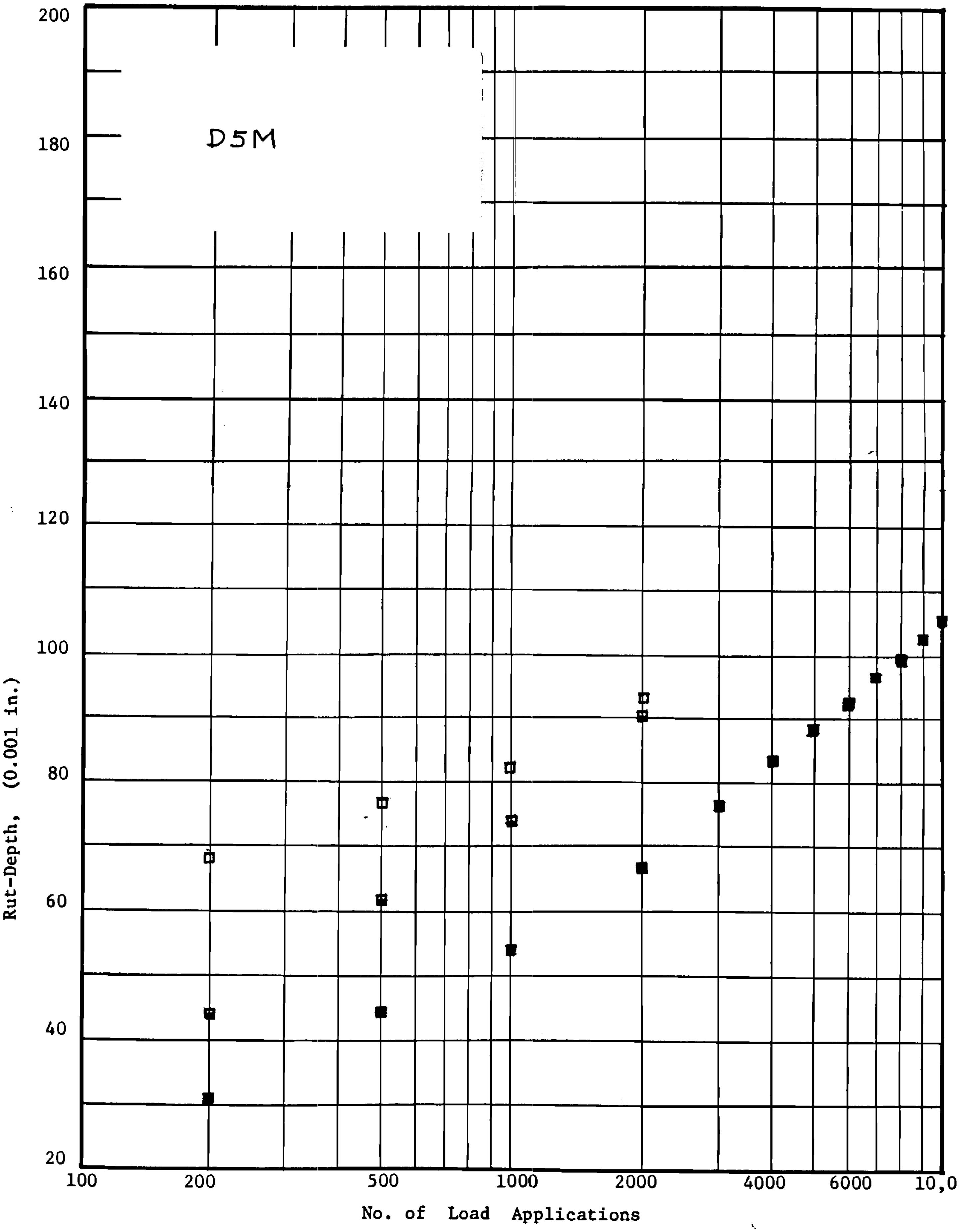

F5S
Rut-Depth, (0.001 in.)
200
180
160
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications

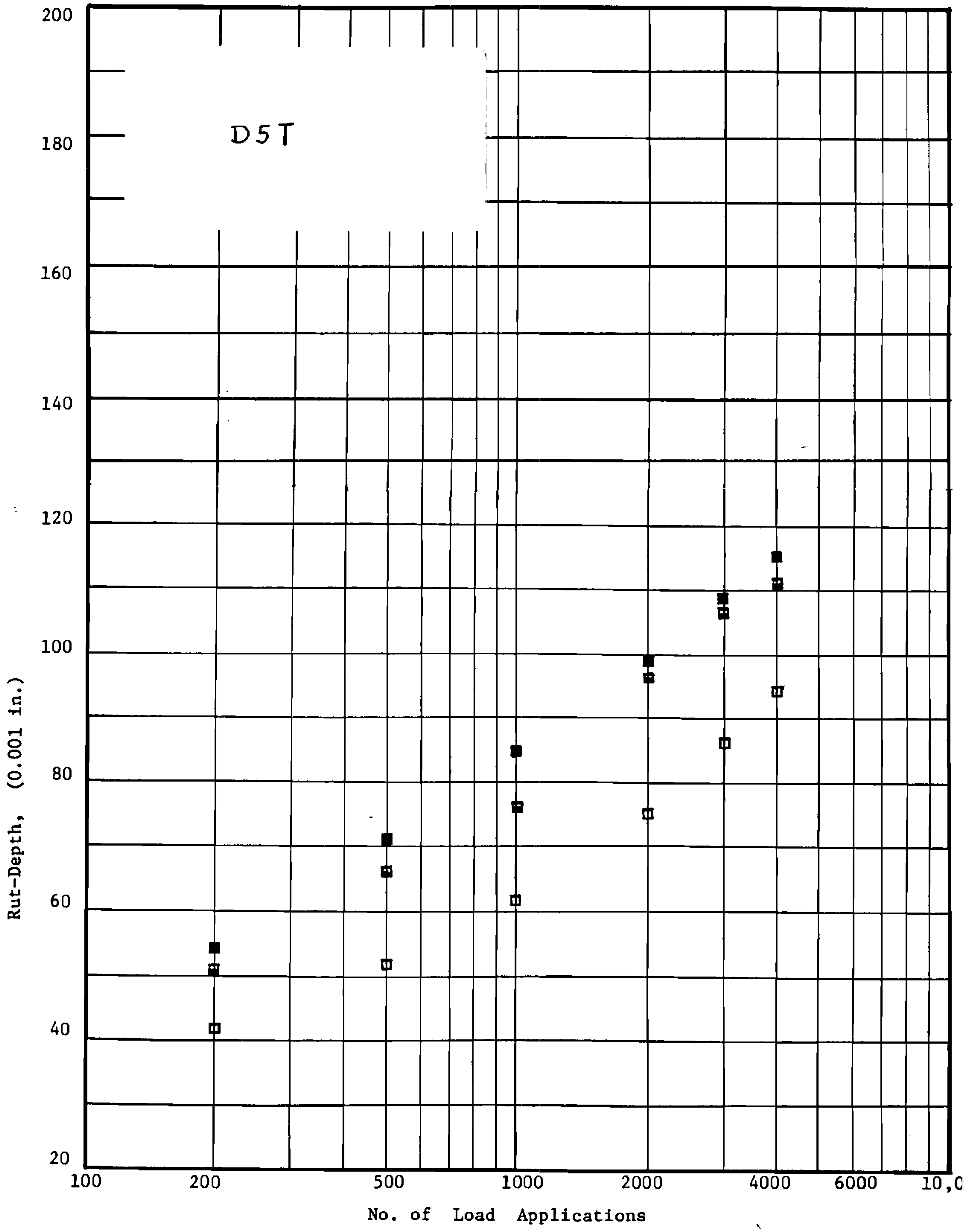

FHM
Rut-Depth, (0.001 in.)
200
180
160
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications

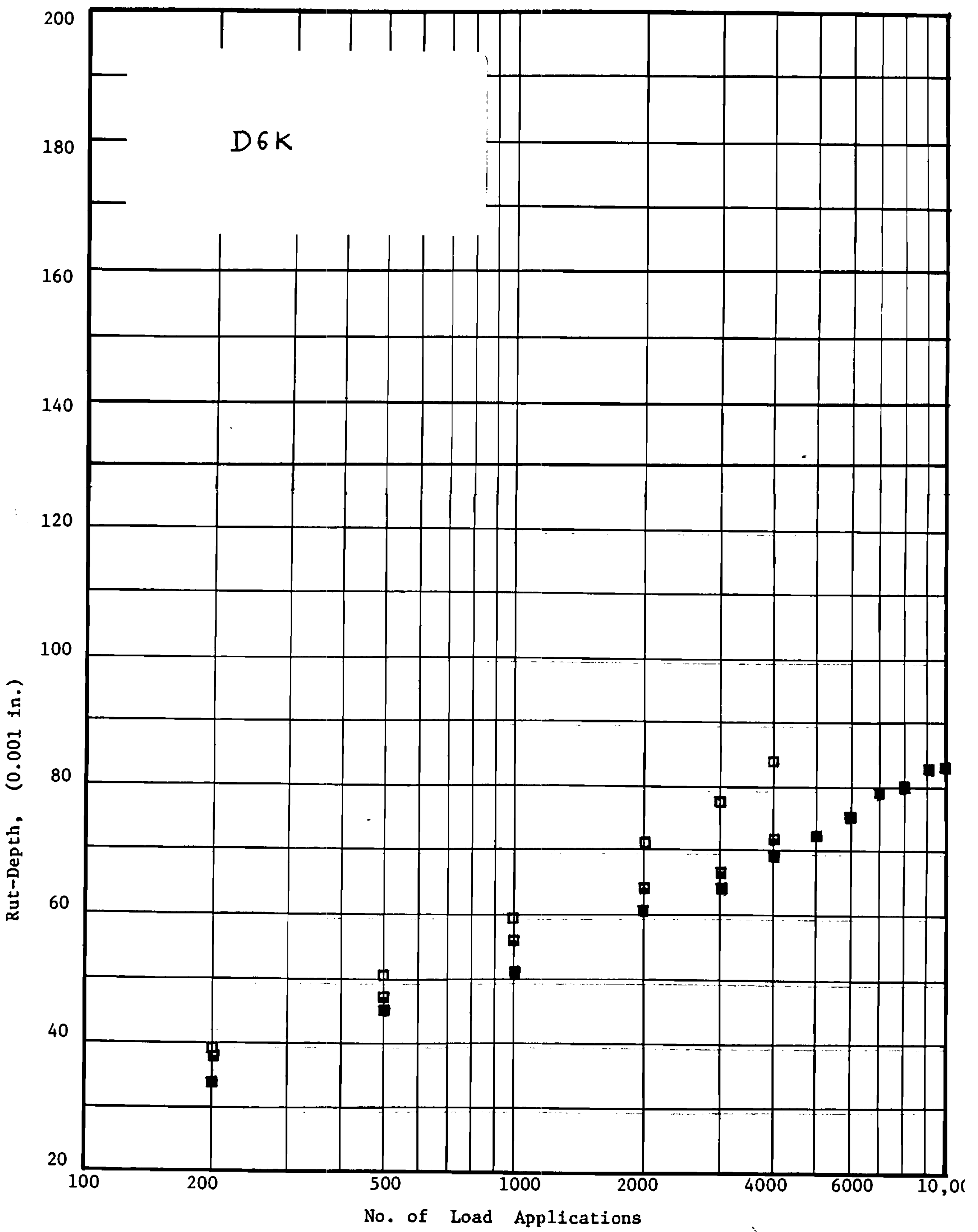

DS
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
No. of Load Applications

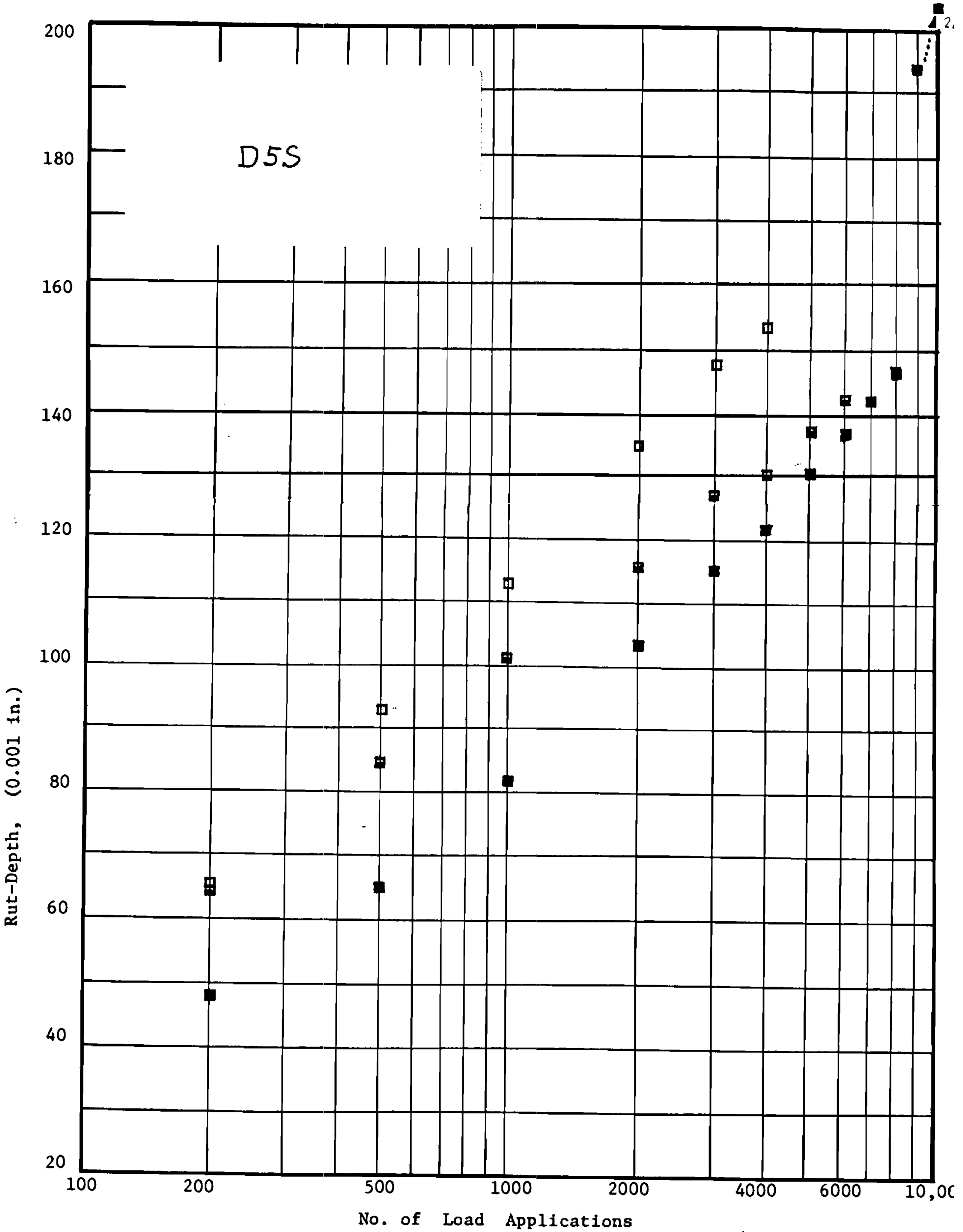


D3M
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
No. of Load Applications

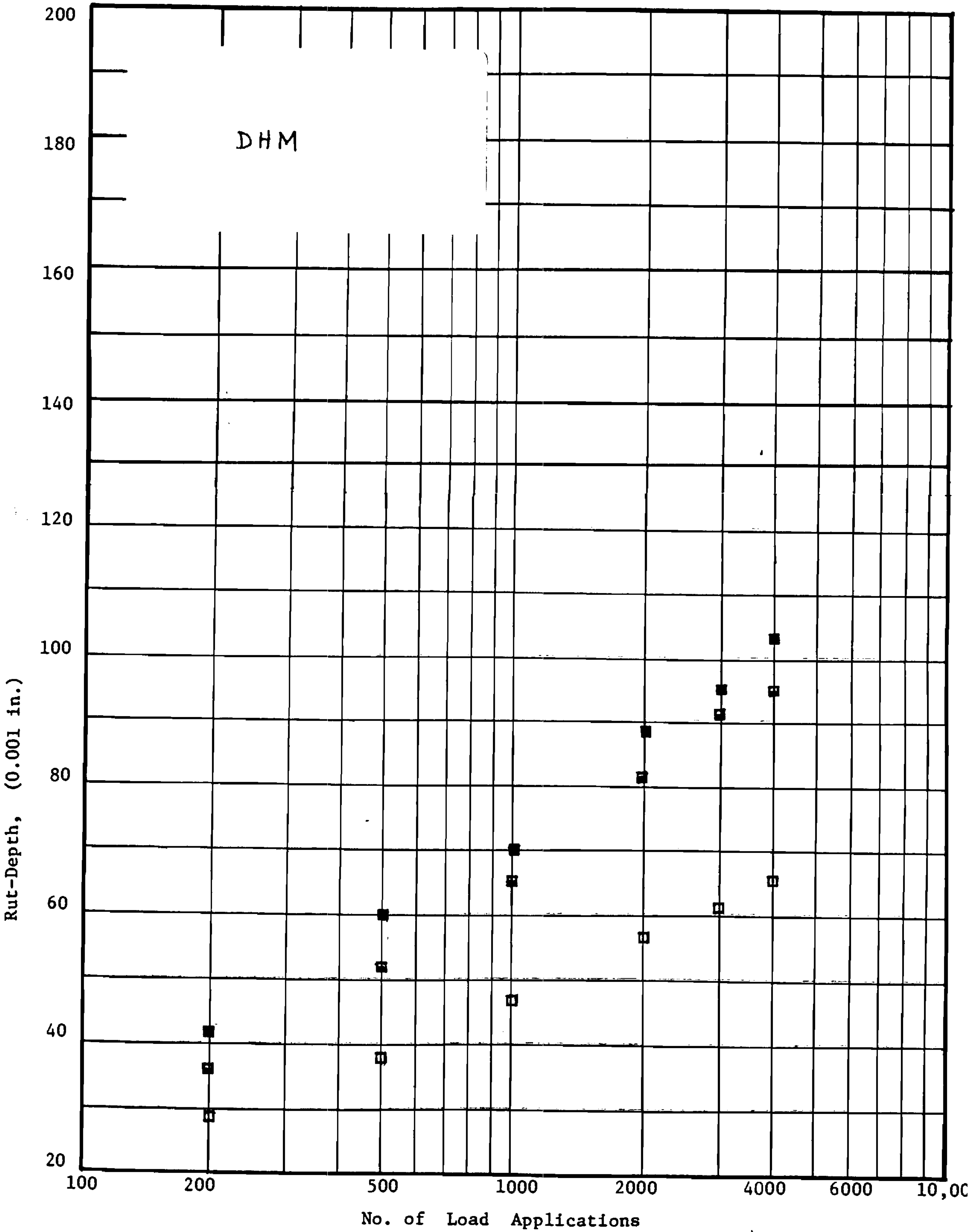

D5M
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications


D5T
Rut-Depth, (0.001 in.)
200
180
160
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications

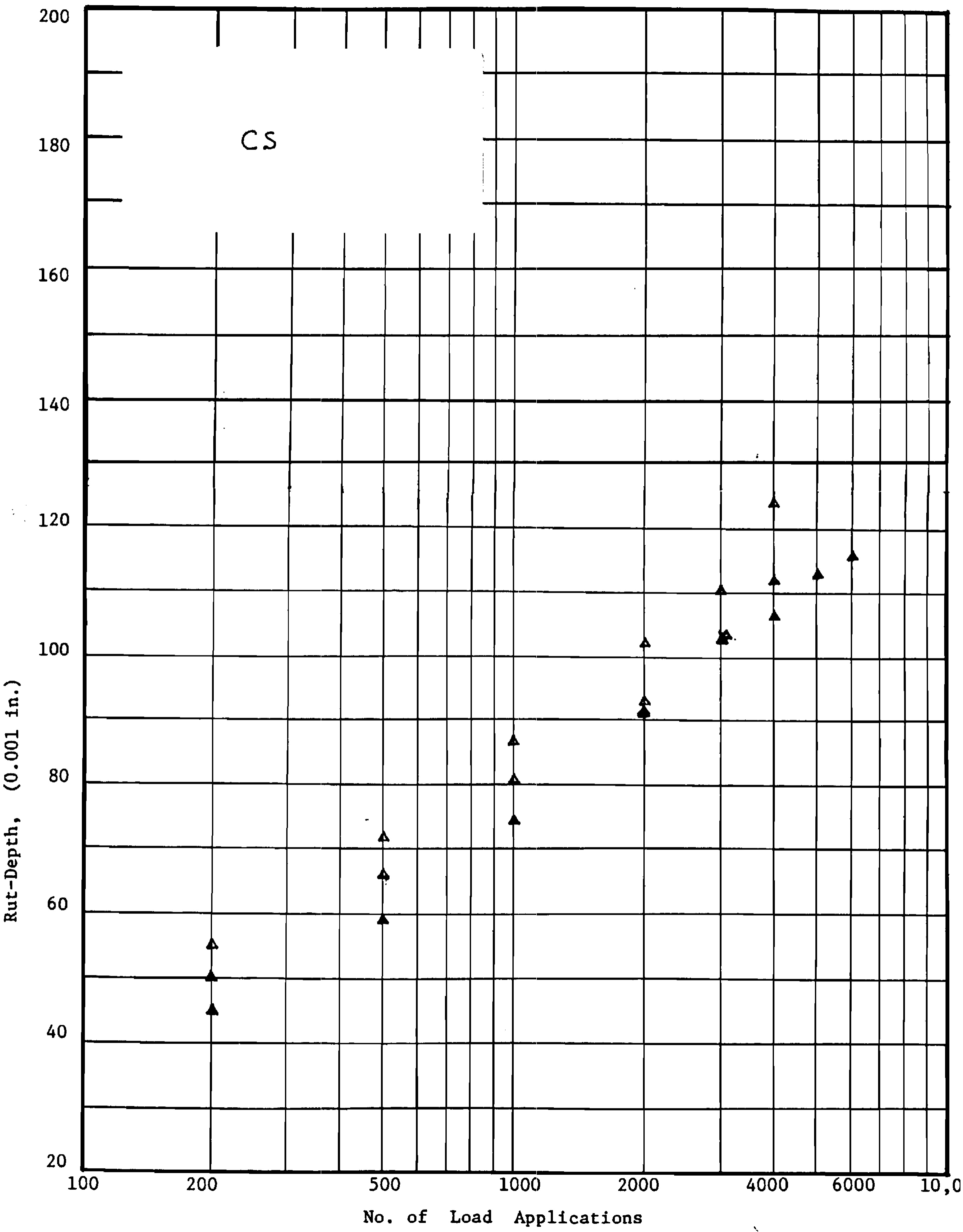

D6K
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,00
No. of Load Applications



D5S
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,00
No. of Load Applications



DHM
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,00
No. of Load Applications


CS
Rut-Depth, (0.001 in.)
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180
160
140
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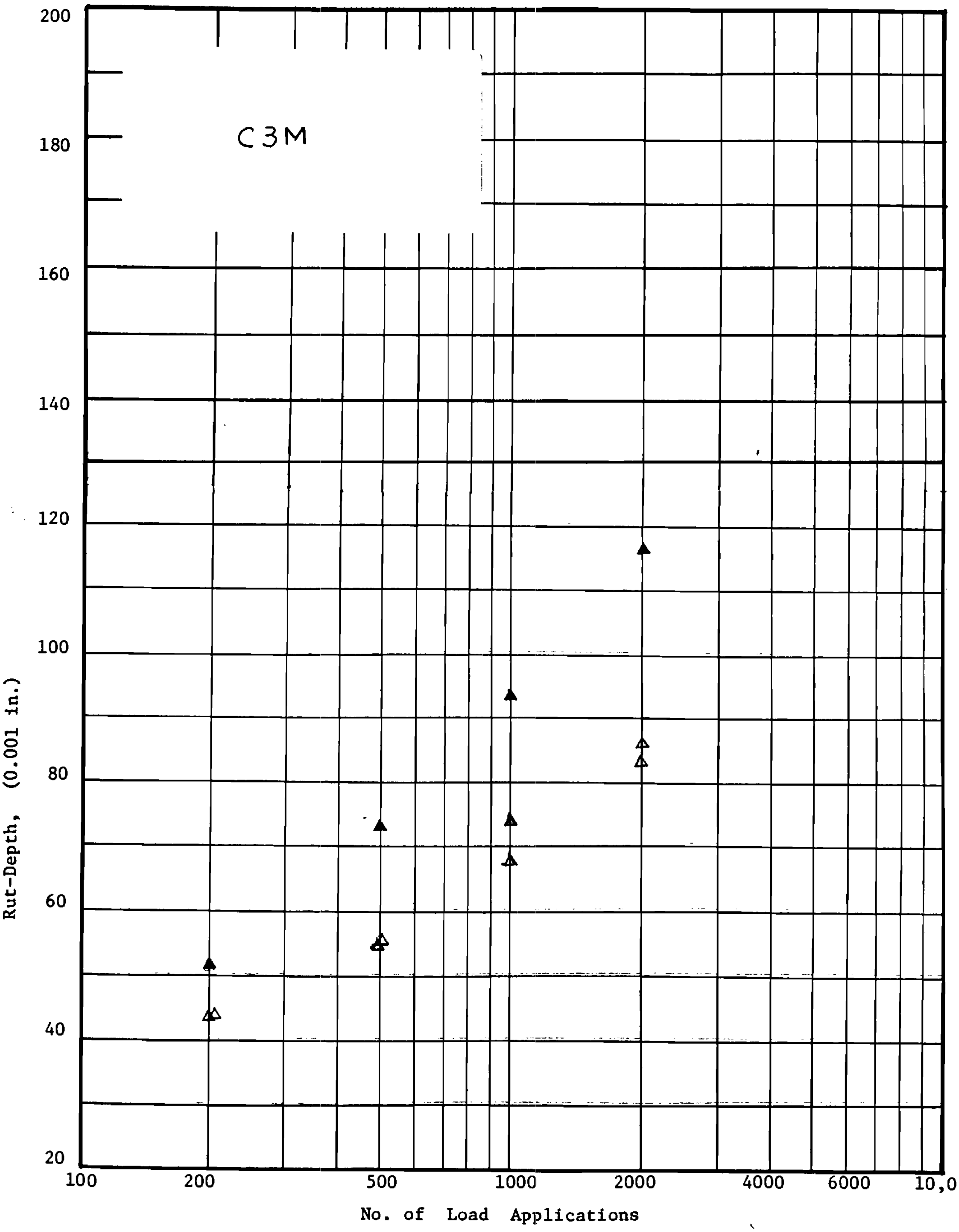
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications


C3M
Rut-Depth, (0.001 in.)
200
180
160
140
120
100
80
60
40
20
100
200
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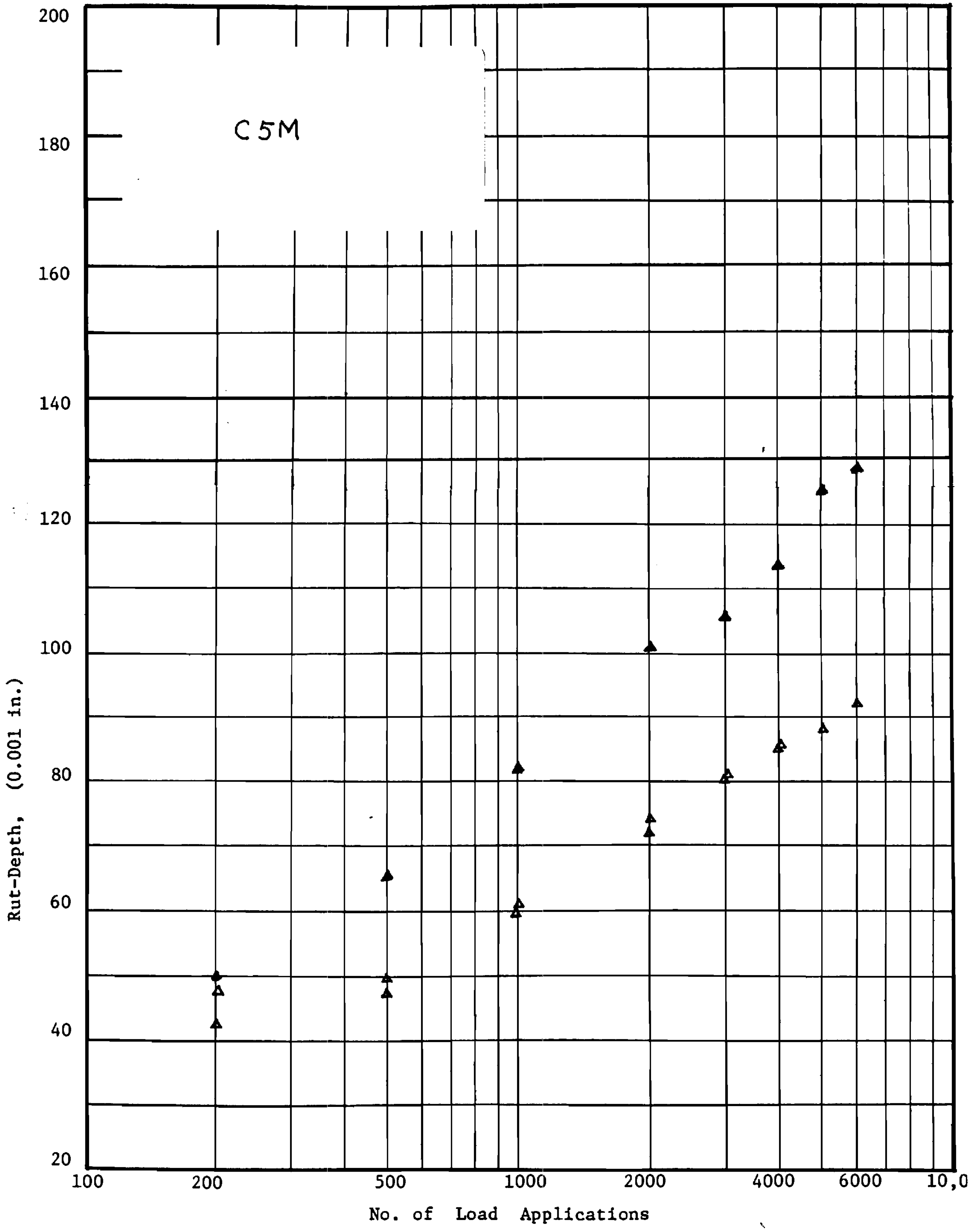
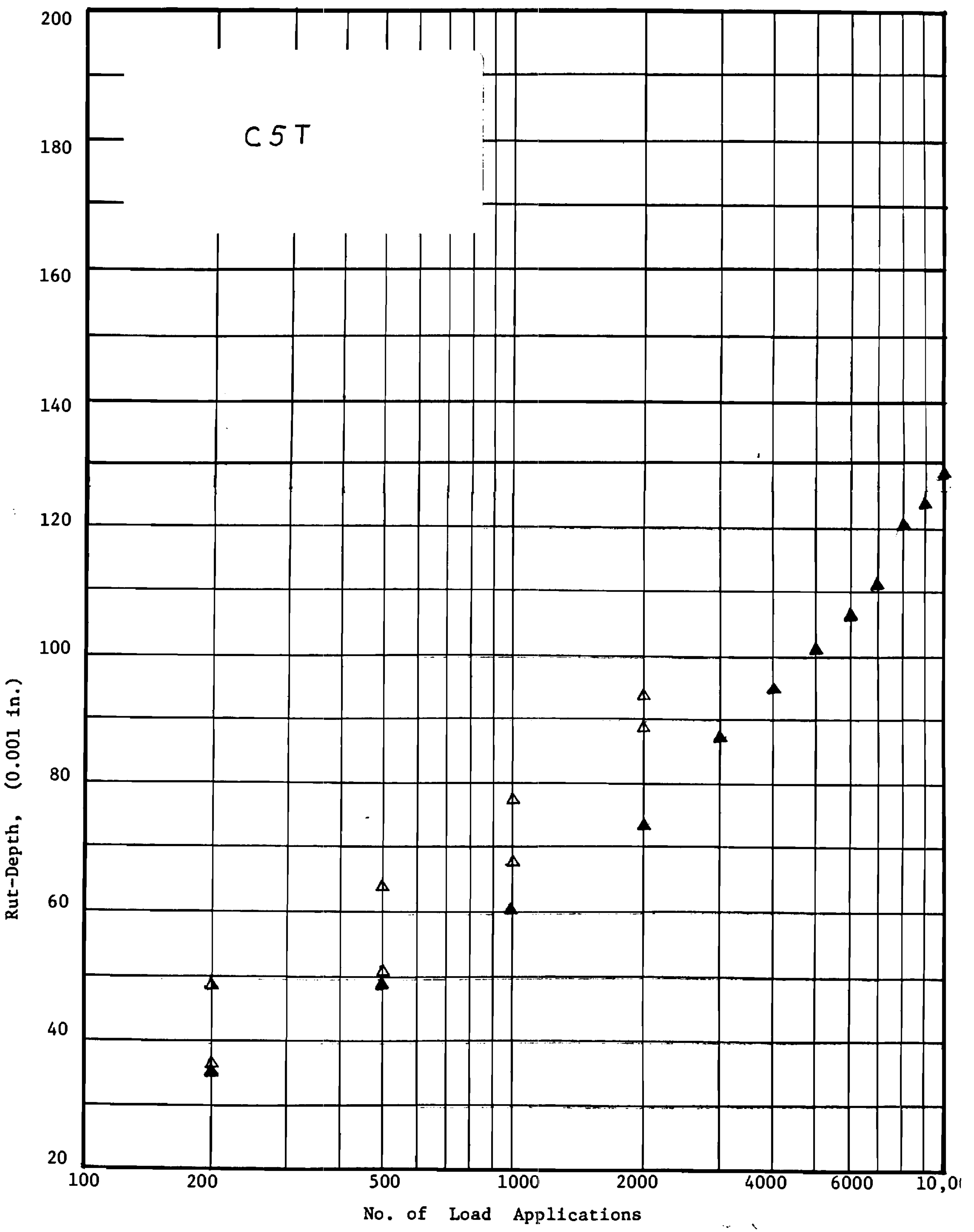
1000
2000
4000
6000
10,0
No. of Load Applications


C5M
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications



C5T
Rut-Depth, (0.001 in.)
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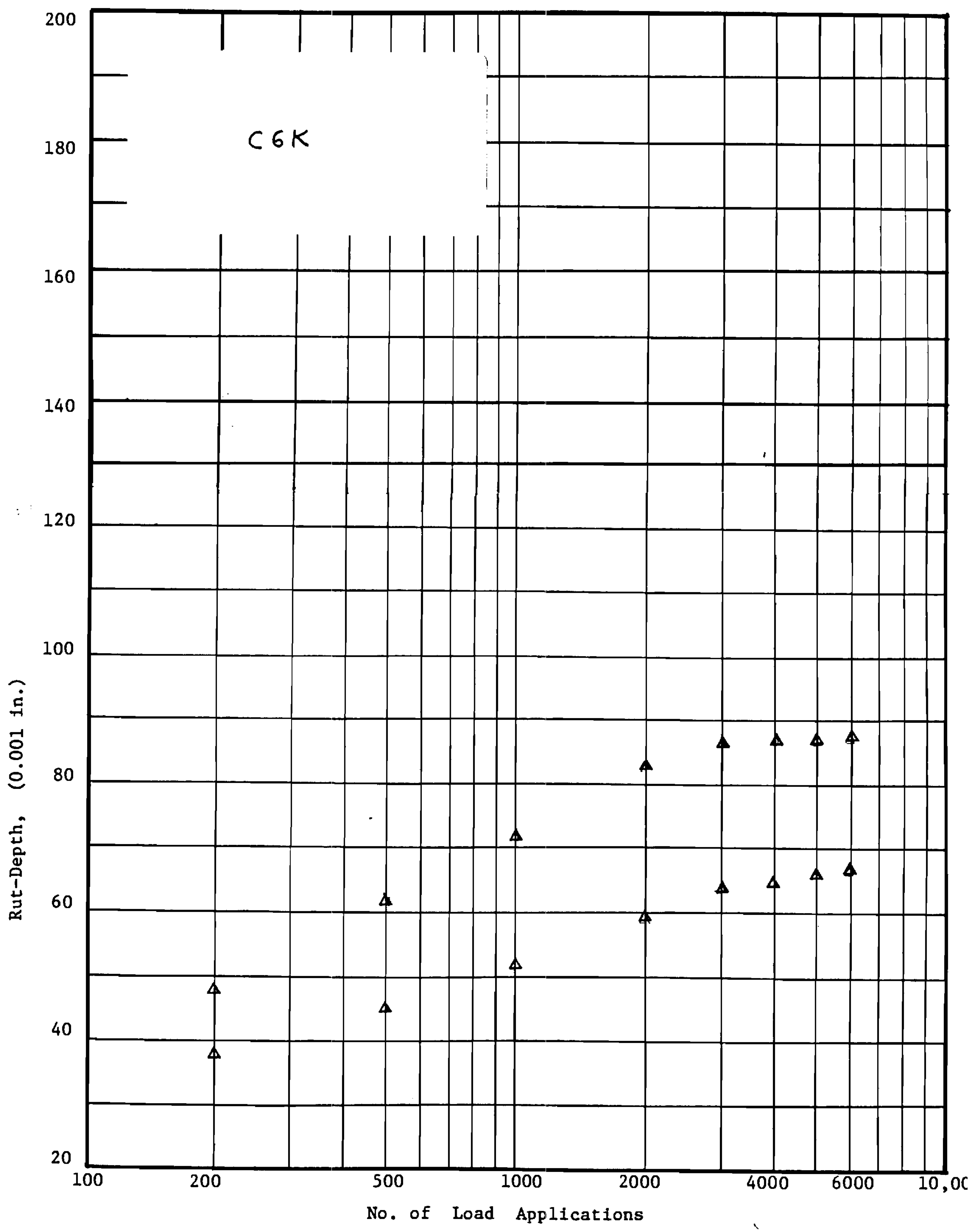
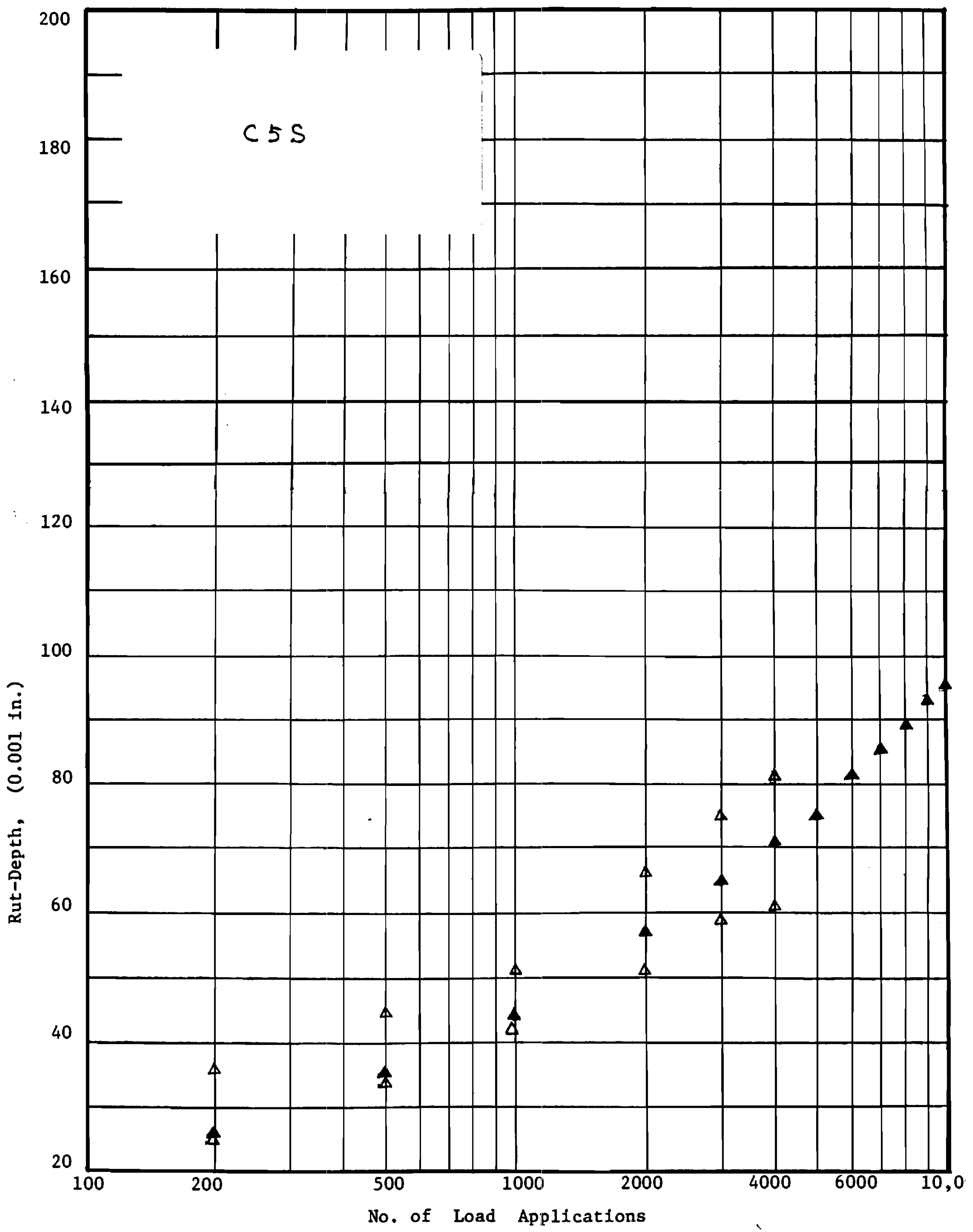
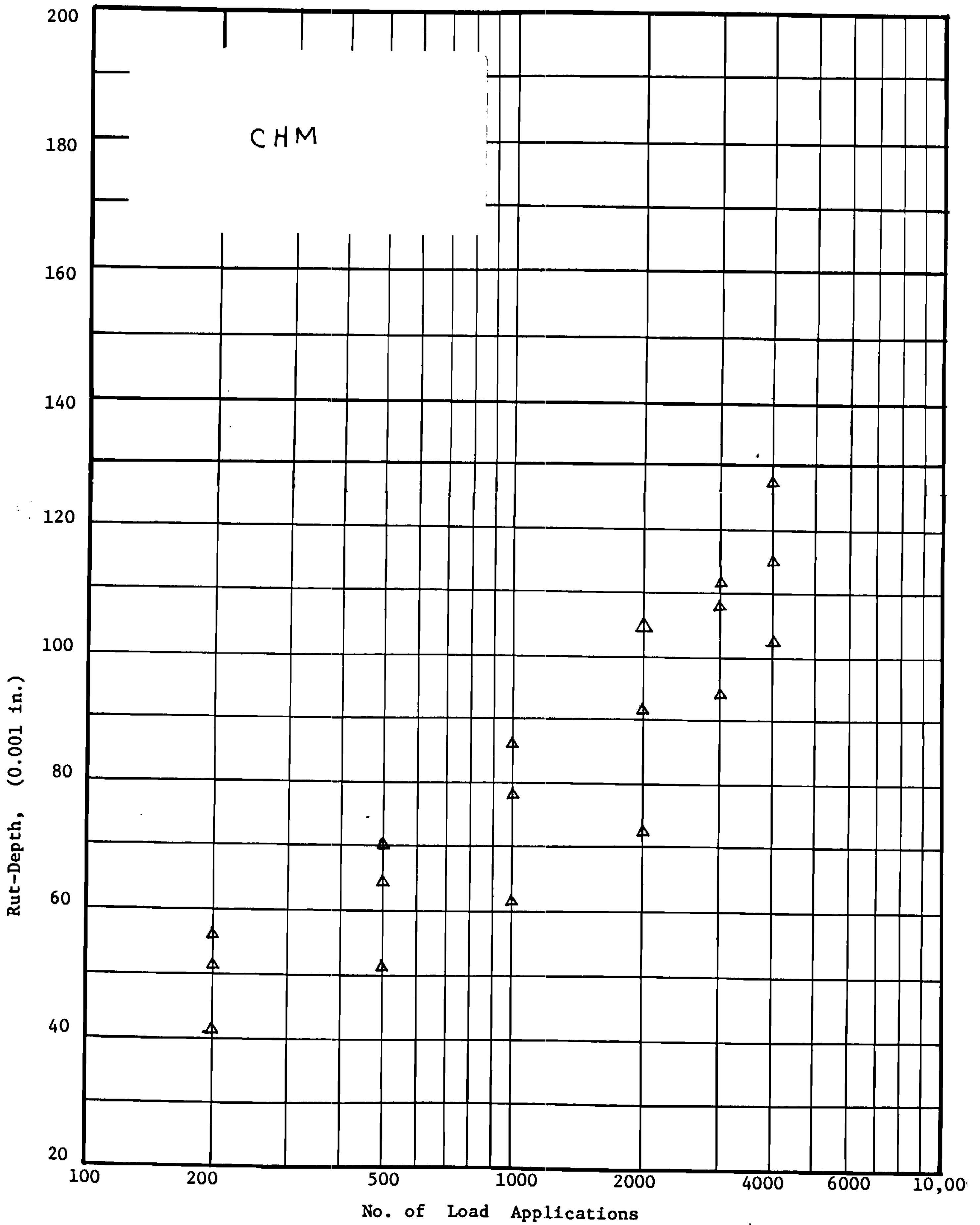
180
160
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications



C6K
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,00
No. of Load Applications


C5S
Rut-Depth, (0.001 in.)
200
180
160
140
120
100
80
60
40
20
100
200
500
1000
2000
4000
6000
10,0
No. of Load Applications



CHM
200
180
160
140
120
100
80
60
40
20
Rut-Depth, (0.001 in.)
100
200
500
1000
2000
4000
6000
10,000
No. of Load Applications