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LIMITED EVALUATION OF EXPERIMENTAL AND STANDARD TRACTOR DOZER BLADES

by

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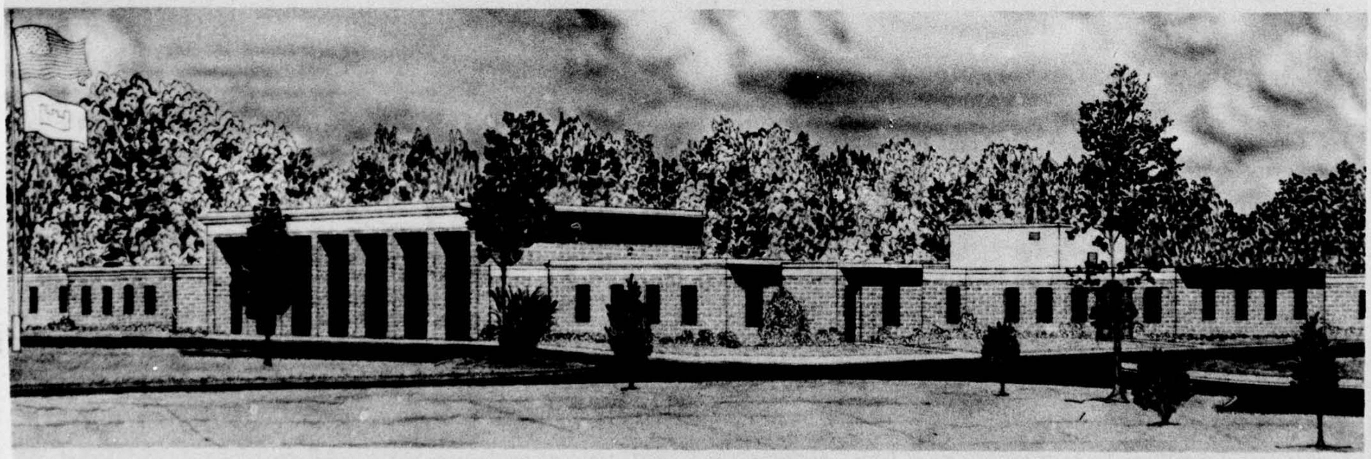

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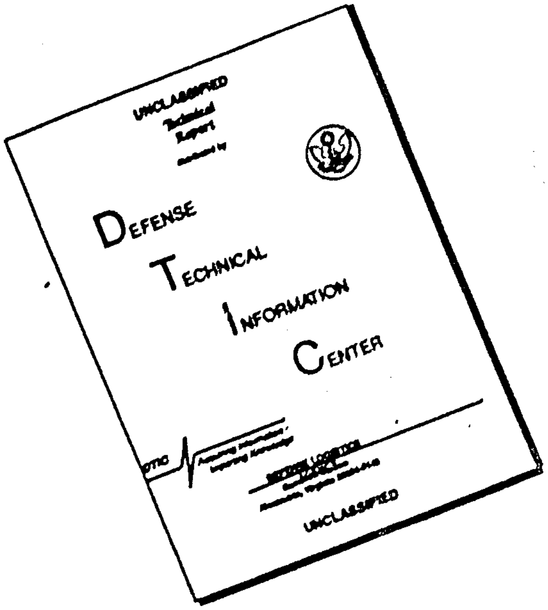

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This study was conducted to make a limited evaluation of experimental and standard tractor dozer blades. A field test program was conducted in the southeastern part of Kansas on strip-mined areas where the spoil banks are parallel with crest-to-crest distances between 90 and 120 ft and maximum dozing distances usually less than 50 ft. This evaluation was a part of an overall joint Pittsburg and Midway Mining Company--U. S. Bureau of Mines (USBM) Specialized Reclamation Field Test Program primarily centered on the field → next page

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testing of experimental high-volume lateral relocation blades. The three blades evaluated were the 60-ft-wide angle (A) blade mounted on two 41B tractors, a 48-ft-wide A blade mounted on two D9H tractors, and a 13-ft-wide reclamation universal (Rec U) blade mounted on a D9H tractor. In addition to the experimental blades, three commercially available blades were tested: A 20-ft universal (U) blade mounted on two side-by-side (SxS) D9H tractors; a 20-ft U blade mounted on a 41B tractor; and a 12-ft straight (S) blade mounted on a D8H tractor.

The dozer blade evaluations compared measured blade performance with soil and other site characteristics and with estimated earthmoving performance rates based on earthmoving methodology that accounts for the traction and speed of the tractor. The earthmoving methodology was also validated with data collected during this program.

FOREWORD

This report was prepared by the U. S. Army Engineer Waterways Experiment Station (WES), Mobility and Environmental Systems Laboratory, P. O. Box 631, Vicksburg, Mississippi 39180, under USBM Contract Number H0252009. The contract was initiated under the Advancing Coal Mining Technology/Surface Mining Equipment Program. It was administered under the technical direction of the Spokane Mining Research Center with Mr. John Goris acting as Technical Project Officer. Mr. Monte Camp was the contract administrator for Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period from July 1976 to July 1977. This report was submitted by the authors November 1977.

Mr. W. G. Shockley, Chief, Mobility and Environmental Systems Laboratory (MESL), and Mr. A. A. Rula, former Chief, Mobility Systems Division (MSD), MESL, were general supervisors of the study; Mr. E. S. Rush, former Chief, Mobility Investigations Branch (MIB), MSD, now Chief of MSD, MESL, directed it. Mr. B. G. Schreiner, MIB, directed the field data collection program; and Mr. W. E. Willoughby, MIB, directed the data analysis. Messrs. Rush, Schreiner, and Willoughby wrote the report.

Acknowledgements are made to the following for cooperation and assistance in conducting the program:

Mr. John Goris, Spokane Mining Research Center
Mr. Jake Howland, Pittsburg and Midway Mining Company
Mr. Ken Cassidy, Pittsburg and Midway Mining Company

COL J. L. Cannon, CE, was Commander and Director of WES during the study and report preparation. Mr. F. R. Brown was Technical Director.

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CHAPTER 1: SUMMARY

Soil and site characteristics did not vary enough to determine their influence on tractor dozer performance. Comparisons of maximum blade and operating blade capacities showed that all blades were operating at less than 67 percent maximum capacity, but the U blades operated at a higher percentage of maximum capacities than the A blades. These percentages would change with changes in soil and site characteristics.

The earthmoving production model based on traction capabilities has validity because all measured earthmoving production values were below computed optimum values. Using computed optimum production at measured speed as 100 percent efficiency, the tractor dozers measured production averaged 56 percent (based on dozing time only) with neither blade type (A, U, or S) being significantly more efficient than another. However, in terms of volume of material moved, the 60-ft blade moved an average of 6513 loose cubic yards per hour (LCY/hr), which was an 86 percent increase over the next largest blade, the 48-ft A blade. A good correlation existed between the horsepower and the average acres of spoil reclaimed per hour of dozing time.

Based on the drawbar pull-slip tests the maximum tractive force used in the earthmoving production model is too low for crawler tractors. The effects of the lower values are not considered significant; however, if the new maximum drawbar pull values were used in the model, the computed optimum production rates would be slightly higher and occur at slightly lower speeds.

The report contains two appendices: Appendix A discusses the earthmoving production model used in making estimates of production rates; and Appendix B presents a table of the conversion factors used.

CHAPTER 2: INTRODUCTION

Background

The U. S. Bureau of Mines (USBM) as part of its overall energy research program is developing and demonstrating advanced surface mining equipment and systems capable of producing coal at optimum cost and safety with minimum environmental change and maximum use of the nation's coal reserves. As part of the overall program, the USBM in cooperation with the Pittsburg and Midway Coal Mining Company conducted a Specialized Reclamation Field Test project aimed at developing specialized reclamation equipment and techniques for leveling area mined spoil banks. The objective of the project was to provide tools and techniques that will enable the surface coal mining industry to meet land reclamation requirements within an acceptable time frame and at a reasonable cost.

Three principal experimental tools tested under this project included:

- a. A 48-ft angle (A) blade mounted on two side-by-side D9H tractors.
- b. A 60-ft variable A blade mounted on a 41B tractor with a tow assist from a second 41B tractor.
- c. A 14-ft reclamation universal (Rec U) blade mounted on a D9H tractor.

In addition, the following three conventional dozer blades were used at the test site as support equipment:

- a. A 23-ft universal (U) blade mounted on two side-by-side D9H tractors.
- b. A 20-ft U blade mounted on a 41B tractor.
- c. A 13-ft straight (S) blade mounted on a D8H tractor.

As part of the evaluation of both the experimental and standard blades, the USBM, through an interagency agreement, engaged the U. S. Army Engineer Waterways Experiment Station (WES) to evaluate these tools at the test site in southeastern Kansas. The selection of WES stems from an earlier project in which WES conducted for USBM a feasibility study of using large tractor dozers for moving earth during strip mining reclamation activities.* During this study, estimates were made of earthmoving rates and costs for a range of existing standard tractor dozers as well as a few concept tractor dozers in the 1000- to 5000-hp range. The basis for the estimated earthmoving rates was the verified analytical models developed by WES that relate the performance capabilities of ground vehicles to the terrain conditions on which they are required to perform. In the original WES models, traction capabilities of the vehicles were of prime importance since they could be converted to tractive force, speed, etc.; however, in the large tractor dozer feasibility study, the WES models were extended to convert tractive force and speed into estimates of optimum earthmoving rates for each tractor. The current evaluation study reported herein presents earthmoving rates and other pertinent data as measured during field exercises to compare with estimated rates computed using existing technology.

The field test program was conducted in the southeastern part of Kansas on strip-mined areas where the spoilbanks are parallel with crest-to-crest distance between 90 and 120 ft and maximum dozing distance is usually less than 50 ft. The participation by WES was a small part of an overall joint Pittsburg and Midway Mining Company-USBM Specialized Reclamation Field Test Program "primarily centered on the field test and evaluation of high-volume lateral relocation blades, designed to improve dirt-handling efficiency in short distance (less than 50 ft) relocation ranges associated with leveling area-mined spoil banks."**

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* E. S. Rush and W. E. Willoughby, "Feasibility of Using Large Tractor Dozers in the Surface Mining of Coal and the Reclamation of Mined Areas," Miscellaneous Paper M-76-4, Mar 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

** J. Goris and J. W. Howland, "Effective Utilization of Horsepower in Mined Land Reclamation Efforts (Part 3)," presentation at the Earthmoving Industry Conference, Society of Automotive Engineers, Peoria, Ill., 19 Apr 1977.

Objectives

The overall objective was to evaluate performance of six specialized and standard crawler tractor blades tested in leveling surface-mined spoil piles in southeastern Kansas as outlined below:

a. Collect soil and other terrain data as required in modeling terrain/equipment interactions in areas being reclaimed after coal extraction using the area strip mining method.

b. Measure dozer blade earthmoving performance rates in several areas exhibiting differences in earth material properties.

c. Relate the performance rates of the experimental and standard dozer blades to pertinent equipment/terrain parameters.

d. Compare measured performance data with optimized earthmoving performance rates computed with methodology presented in the feasibility study and reviewed in Appendix A.

e. Discuss production efficiencies during practical application of tractor dozers in leveling spoil banks.

f. Present limited tests of drawbar pull-slip for two tractors.

CHAPTER 3: EQUIPMENT EVALUATED AND DATA COLLECTED

Equipment Evaluated

The tractors used in dozer evaluations were manufactured by Caterpillar (D8H and D9H) and Fiat-Allis (41B). Characteristics of the evaluated equipment are summarized in Table 1 and discussed briefly in the following paragraphs.

D8H/S blade

The D8H (Figure 1) was the smallest of the tractors used, and it was equipped with a 13-ft S blade that is 8 in. less in height but the same width as the U blade usually recommended for reclamation activities. The main differences are that this U blade has a greater maximum concavity and side panels to hold more material in front of the blade.

D9H/Rec-U blade

The D9H tractors (Figure 2) have track-width options of 24, 27, and 30 in.; the one evaluated had the 30-in.-wide tracks. The Rec-U blade is the same height as the S blade, also made for the D9H, but about 1 ft wider. The Rec-U blade also has side panels for holding material in front while dozing. It is considered to be one of the experimental blades.

41B/U blade

The 41B with 20-ft U blade (Figure 3) at 160,000 lb was the largest single tractor dozer evaluated during this study.

SxS D9H/U blade

This equipment consists of two D9H tractors attached in the front to a single 24-ft U dozer blade and in the rear by a steel-tubing attachment that keeps the tractors in a basic parallelogram configuration (Figure 4). The unit is operated by one operator with movements of the two tractors synchronized hydraulically. The total weight of this configuration is 187,400 lb. The tractors when operated side-by-side use 27-in.-wide tracks that give a ground pressure of 13.0 psi.

SxS D9H/A blade

This equipment configuration (Figure 5) uses the same two tractors

Table 1

Tractor Dozer Characteristics

	Tractor/Dozer Blade					
		D9H/		SxS D9H		Two 41B's
Specifications	D8H/ S Blade	Rec-U Blade	41B/ U Blade	Universal Blade	Angle Blade	with 60-ft Angle Blade
Gross weight, lb	67,800	92,900	160,000	187,400	190,000	327,000
Area of tracks in contact with ground, sq in.	5,520	7,980	9,184	14,364	14,364	18,368
Track width, in.	24	30	36	27	27	32
No. of road wheels per side	7	9	9	9	9	9
Ground clearance, in.	--	24	24	24	24	24
Horsepower	270	410	524	820	820	1,048
Transmission*	PS	PS	PS	PS	PS	PS
Blade						
type**	S	Rec-U	U	U	A	A
width, in.	164	164	240	288	576	720
maximum height, in.	54	72	86	86	79	93
maximum concavity, in.	6	13	16	17	17 (est)	17
maximum capacity, cu yd†	9	14	30	35.6	48	84

* PS - power shift.

** S - straignt; U - universal; A - angle; Rec-U - reclamation U.

† Measured during field test program.

Figure 1. D8H/S blade

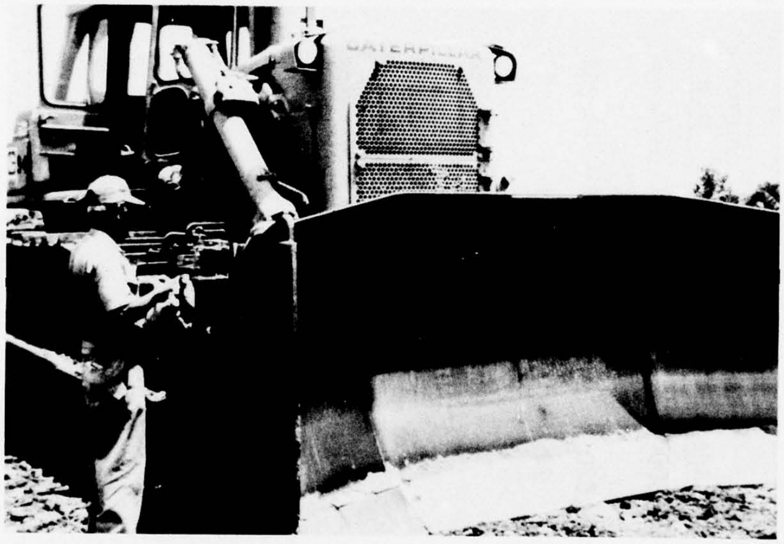


Figure 2. D9H/Rec-U blade

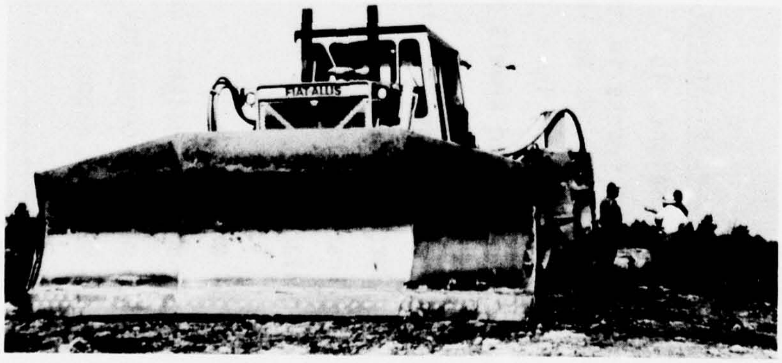
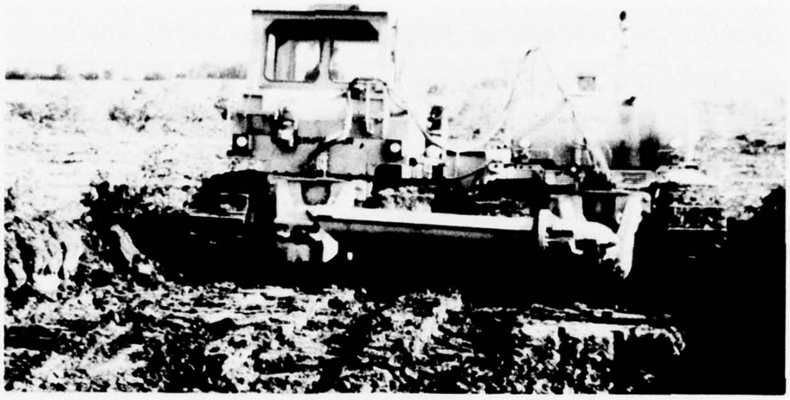


Figure 3. 41B/U blade



a. Rear view

b. Front U blade

Figure 4. SxS D9H/U blade

Figure 5. SxS D9H/A blade

described above, the difference being the blade size, shape, and angle of attack. The blade angle is fixed at 46 deg with the leading edge of the tractors, and the blade width is 48 ft. This is one of the experimental blades built specially for the overall field program.

Two 41B/A blade

This equipment (Figure 6) consists of two 41B tractors and an experimental variable angle blade 60 ft wide. The rear tractor carries approximately 60 percent of the total system, and the lead tractor carries the remaining weight and assists the rear tractor by towing the blade. During the tests, the blade was operated at angles between 40 and 85 deg.

Location and Description of Test Areas

The test areas are located in the same strip-mined area reported in the feasibility study report.* Figures 7 and 8 show the specific test areas for the study reported herein. The mined area is located in Cherokee County in the extreme southeastern corner of Kansas. The natural relief in the surrounding areas is not great, less than 80 ft; however, in the mined areas, spoil banks from coal mining operations have commonly exceeded the total natural relief. Some 20,000 acres have been stripped in the vicinity of the test areas that were located on land currently owned by the Pittsburg and Midway Mining Company.** The spoil bank crestline-to-crestline distances range from 90 to 120 ft and the heights from original ground level from 20 to 80 ft.

Test areas 1 through 5, 1A through 4A, 1B, 3B, and 4B were on 90-ft crestline-to-crestline spoil banks, and test areas 6, 7, 8, 9, 10A, 10B, 11, 12A, 12B, 13, and 14 were on 120-ft crestline-to-crestline spoil banks. For all test areas, the tests were begun after the peak of the spoil bank had been leveled by one pass of a U- or S-blade dozer to make a working platform for the test dozers. Earthmoving procedures varied with dozer configurations and will be discussed later.

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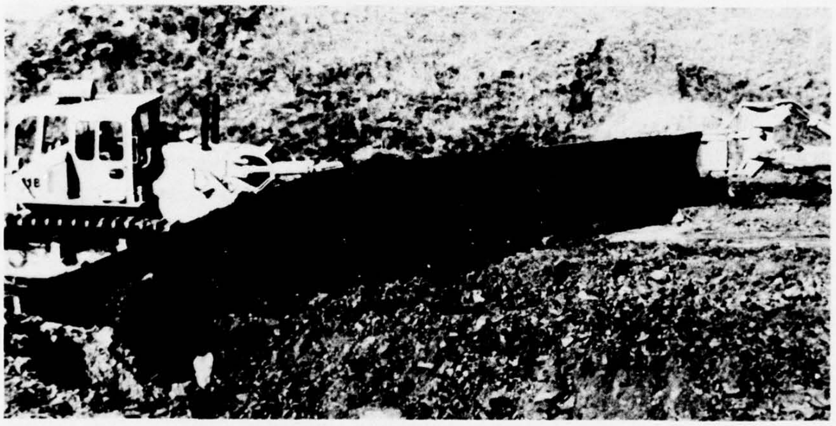
* Rush and Willoughby, op. cit., p 12.

** "The Orange Disc," the magazine of the Gulf Companies, November-December 1975.

a. Lead tractor



b. A blade

c. Rear tractor

Figure 6. Two 41B/A blade

Figure 7. Location of test areas 1-5

Figure 8. Location of test areas 6-14

Data Collected

Soil data

Table 2 presents the basic soil data collected to relate to earthmoving performance rates and to describe test conditions. Figure 9 shows the soil classification data. Both are discussed in the following paragraphs. Measurements of cone index, moisture content, and density were made at three spoil bank locations: on the spoil bank ridge before the first dozing cut, on the spoil bank after the last dozing cut, and on the outslope before dozing. The outslope spoil material resulting from the dozing operations was not measured. The outslopes were measured before dozing began but were not used in the analysis.

Soil classification. Samples were collected for laboratory analysis from each test area. Because of the similarity of characteristics in some test areas, they were combined and represented by the same gradation curve. Consequently, five sets of classifications describe all 23 test areas. The classification shown is based on the Unified Soil Classification System, a system of identification of soils according to their textural and plasticity qualities that indicates how they will behave as an engineering construction material. The classification does not reflect the isolated rocks that were present throughout the material. They ranged from numerous gravel size rocks to a few rocks that were approximately 6 ft in diameter.

Cone index. Cone index is an index of the shearing resistance of soil and is measured with a cone penetrometer. The resistance to penetration by a 30-deg cone with a 0.5-sq-in. circular base is expressed in pounds of force on the handle per square inch of the base area. In the WES soil model, the cone index values are considered as indexes only and no direct meaning is assigned to its dimensions. The index range is usually from 0 to 750 with the highest readings reflecting the strength of the firmest soils. Cone index readings were made at the surface and at 1-in. vertical increments to 12-in. but for convenience were averaged to obtain values for the 0- to 6- and 6- to 12-in. layers. Measurements were made before the first dozing cut and after

Table 2

Basic Soil Data

Test Area	Location	Average Cone Index of Layers			Moisture Content, Percent Dry Weight, of Layers			Dry and Wet Density, lb/cu yd, of layers							
								Dry			Wet			Loose Wet	Swell Factor*
		0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-12 in.	0-12 in.
					D8H/S Blade										
1	Ridge, before dozing	539	750	645	21.6	30.8	26.2	2622	2365	2494	3189	3094	3142	2160	1.45
	Ridge, after dozing	326	662	496	16.2	--	--	2714	--	--	3154	--	--	2684	--
	Slope, before dozing	140	497	319	14.9	20.2	17.6	2538	2665	2601	2916	3186	3051	1922	1.59
2	Ridge, before dozing	263	321	292	21.6	24.0	22.8	2581	2700	2641	3137	3348	3243	2238	1.45
	Ridge, after dozing	408	621	515	21.9	19.3	20.6	2516	2438	2477	3067	2908	2988	2554	1.17
	Slope, before dozing	112	129	121	19.6	28.1	23.8	2155	2500	2328	2579	3202	2891	2211	1.31
3	Ridge, before dozing	309	478	394	22.8	22.4	22.6	2608	2730	2669	3202	3340	3271	2238	1.46
	Ridge, after dozing	185	523	354	20.8	24.0	22.4	2813	2930	2872	3399	3634	3517	2554	1.38
	Slope, before dozing	179	176	178	21.1	26.2	23.6	2403	2392	2398	2911	3019	2965	2211	1.34
10A	Ridge, before dozing	184	273	228	17.8	18.8	18.3	2176	2036	2106	2568	2419	2494	1777	1.40
	Ridge, after dozing	227	379	303	19.5	18.1	18.8	2314	2365	2340	2754	2792	2773	2219	1.25
	Slope, before dozing	163	239	201	--	--	--	--	--	--	--	--	--	--	--
	Slope, after dozing	25	64	45	--	--	--	--	--	--	--	--	--	--	--
12A	Ridge, before dozing	263	495	379	19.8	12.4	16.1	2165	2276	2471	2597	3127	2862	1844	1.55
	Slope, before dozing	148	247	198	--	--	--	--	--	--	--	--	--	--	--
					D9H/Rec-U Blade										
1	Ridge, before dozing	366	555	461	21.0	25.4	23.2	2705	2627	2666	3272	3294	3283	--	--
	Ridge, after dozing	294	700	497	15.6	--	--	2673	--	--	3089	--	--	2527	--
	Slope, before dozing	150	334	242	16.5	17.6	17.0	2090	2797	2444	2435	3289	2862	--	--

(Continued)

* Swell factor is determined by dividing the 0- to 12-in. layer of wet density by the 0- to 12-in. layer of loose wet density.

(Sheet 1 of 5)

Table 2 (Continued)

Test Area	Location	Average Cone Index of Layers			Moisture Content, Percent Dry Weight, of Layers			Dry and Wet Density, lb/cu yd, of layers							
								Dry			Wet			Loose Wet	Swell Factor
		0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-12 in.	0-12 in.
					D9H/Rec-U Blade (Continued)										
2	Ridge, before dozing	219	333	276	20.0	23.0	21.5	2654	2657	2656	3186	3267	3227	2371	1.36
	Ridge, after dozing	313	481	397	18.6	18.8	18.7	2938	2886	2912	3483	3429	3456	2606	1.33
	Slope, before dozing	114	112	113	17.6	26.6	22.1	2249	2265	2257	2646	3210	2928	2184	1.34
3	Ridge, before dozing	235	538	387	21.1	22.4	21.7	2576	2730	2653	3116	3340	3228	2211	1.46
	Ridge, after dozing	447	750	599	24.4	18.2	21.3	2673	2676	2675	3326	3162	3244	2684	1.21
	Slope, before dozing	103	138	121	20.7	24.8	22.8	2284	2314	2299	2757	2889	2823	2052	1.38
4	Ridge, before dozing	239	525	382	21.5	34.6	28.0	2236	2203	2220	2716	2967	2842	2371	1.20
	Ridge, after dozing	288	572	430	15.4	13.5	14.4	2892	2878	2885	3391	3267	3329	2660	1.25
	Slope, before dozing	109	359	234	13.5	16.4	15.0	2195	2452	2324	2495	2854	2675	2263	1.18
14	Ridge, before dozing	433	676	555	16.7	18.8	17.8	2473	2562	2518	2889	3046	2968	1817	1.63
	Ridge, after dozing	310	655	483	--	--	--	--	--	--	--	--	--	--	--
	Slope, before dozing	264	595	430	--	--	--	--	--	--	--	--	--	--	--
					41B/U Blade										
4	Ridge, before dozing	485	750	618	15.1	16.2	15.6	2435	2570	2503	2803	2986	2895	2633	1.10
	Ridge, after dozing	197	419	308	17.5	17.9	17.7	2803	2932	2868	2932	3456	3375	2527	1.34
	Slope, before dozing	87	274	181	12.0	16.6	14.3	2381	2460	2421	2684	2867	2776	2238	1.24
5	Ridge, before dozing	423	750	587	18.0	17.2	17.6	2468	2681	2575	2911	3302	3107	2290	1.36
	Ridge, after dozing	188	500	344	20.2	22.6	21.4	2471	2597	2534	2970	3186	3078	2371	1.30
	Slope, before dozing	130	265	198	15.8	23.9	19.8	2284	2560	2422	2646	3170	2908	2106	1.38

(Continued)

(Sheet 2 of 5)

Table 2 (Continued)

		Average Cone Index of Layers			Moisture Content, Percent Dry Weight, of Layers			Dry and Wet Density, lb/cu yd, of layers							
								Dry			Wet			Loose Wet	Swell Factor
Test Area	Location	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-12 in.	0-12 in.
						SxS D9H/U Blade									
1B	Ridge, before dozing	265	589	427	14.4	17.5	16.0	2978	2816	2897	3407	3310	3359	2500	1.34
	Ridge, after dozing	287	561	424	32.6	33.5	33.0	2255	2233	2244	2989	2981	2985	2371	1.26
3B	Ridge, before dozing	209	402	306	23.1	28.2	25.6	2649	2511	2580	3259	3221	3240	2500	1.30
	Ridge, after dozing	119	214	167	21.0	21.2	21.2	2722	2770	2746	3294	3359	3327	2473	1.35
4B	Ridge, before dozing	273	601	437	18.0	18.5	18.2	2624	2827	2726	3097	3351	3224	2184	1.48
	Ridge, after dozing	537	750	644	23.9	22.8	23.4	2697	--	--	3343	--	--	2184	--
						SxS D9H/A Blade									
1A	Ridge, before dozing	499	701	600	13.4	17.2	15.3	2630	2819	2725	2981	3302	3142	2317	1.36
	Ridge, after dozing	265	589	427	14.4	17.5	16.0	2978	2816	2897	3407	3310	3359	2500	1.34
	Slope, before dozing	150	169	160	25.5	25.8	25.6	2430	2411	2421	3048	3032	3040	2263	1.34
2A	Ridge, before dozing	224	414	319	18.4	24.8	21.6	2514	2643	2579	2975	3299	3137	2263	1.39
	Ridge, after dozing	258	453	356	22.7	24.7	23.7	2660	2576	2618	3262	3213	3238	2568	1.26
	Slope, before dozing	131	122	127	21.0	27.7	24.4	2476	2530	2503	2997	3232	3115	2001	1.56
3A	Ridge, before dozing	210	319	265	18.8	24.6	21.7	2673	2670	2672	3175	3326	3251	2290	1.42
	Ridge, after dozing	209	402	306	23.1	28.2	25.6	2649	2511	2580	3243	3221	3232	2500	1.29
	Slope, before dozing	121	157	139	22.7	26.4	24.6	2130	2279	2205	2614	2881	2748	2238	1.23
4A	Ridge, before dozing	261	529	395	19.8	21.1	20.4	2462	2468	2465	2957	2989	2970	2473	1.20
	Ridge, after dozing	273	601	437	18.0	18.5	18.2	2624	2827	2726	3097	3371	3234	2184	1.48

(Continued)

(Sheet 3 of 5)

Table 2 (Continued)

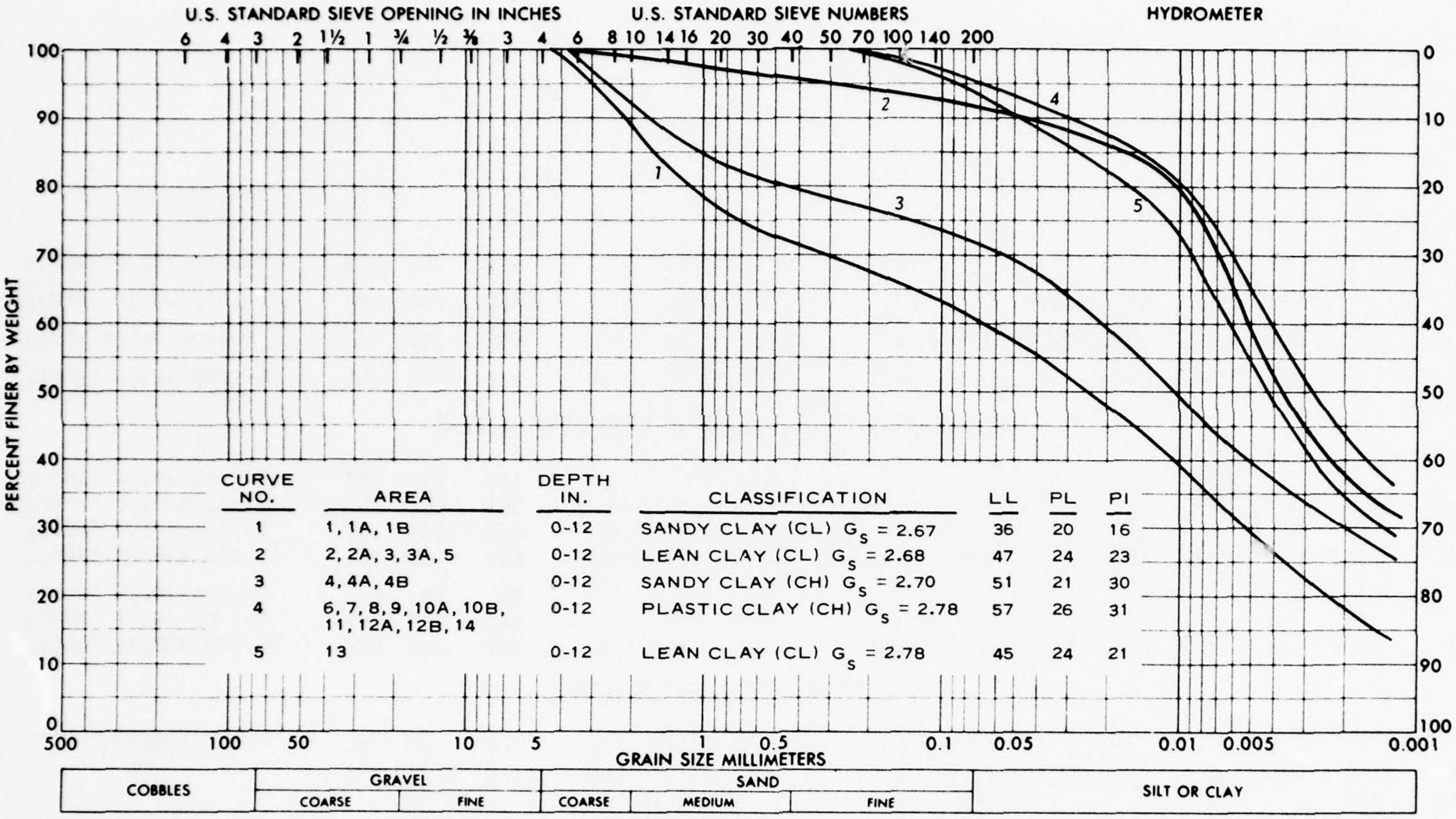
Test Area	Location	Average Cone Index of Layers			Moisture Content, Percent Dry Weight, of Layers			Dry and Wet Density, lb/cu yd, of layers							
								Dry			Wet			Loose Wet	Swell Factor
		0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-12 in.	0-12 in.
						Two 41B/A Blade									
6	Ridge, before dozing	234	369	302	21.1	20.4	20.8	2638	--	--	3216	--	--	2149	--
	Ridge, after dozing	311	429	370	--	--	--	--	--	--	--	--	--	--	--
	Slope, before dozing	32	69	51	--	--	--	--	--	--	--	--	--	--	--
7	Ridge, before dozing	333	443	383	20.0	23.0	21.5	2624	2484	2554	3148	3056	3102	2363	1.31
	Ridge, after dozing	433	592	513	--	--	--	--	--	--	--	--	--	--	--
	Slope, before dozing	69	85	77	--	--	--	--	--	--	--	--	--	--	--
	Slope, after dozing	44	167	106	--	--	--	--	--	--	--	--	--	--	--
8	Ridge, before dozing	246	567	407	19.6	17.3	18.4	2573	--	--	3078	2705	2892	2203	1.31
	Ridge, after dozing	440	702	571	--	--	--	--	--	--	--	--	--	--	--
	Slope, before dozing	154	274	214	--	--	--	--	--	--	--	--	--	--	--
	Slope, after dozing	189	362	276	--	--	--	--	--	--	--	--	--	--	--
9	Ridge, before dozing	210	308	259	19.8	18.4	19.1	2565	2506	2535	3078	2965	3021	2179	1.39
	Ridge, after dozing	447	706	577	--	--	--	--	--	--	--	--	--	--	--
	Slope, before dozing	175	360	268	--	--	--	--	--	--	--	--	--	--	--
	Slope, after dozing	95	281	188	--	--	--	--	--	--	--	--	--	--	--
10B	Ridge, before dozing	227	379	303	19.5	18.1	18.8	2314	2365	2338	2754	2792	2772	2219	1.25
	Ridge, after dozing	400	521	461	--	--	--	--	--	--	--	--	--	--	--
	Slope, before dozing	163	239	201	--	--	--	--	--	--	--	--	--	--	--
	Slope, after dozing	25	64	45	--	--	--	--	--	--	--	--	--	--	--
11	Ridge, before dozing	124	200	162	18.6	21.6	20.1	2435	2425	2430	2889	2986	2938	2098	1.40
	Ridge, after dozing	445	644	545	--	--	--	--	--	--	--	--	--	--	--

(Continued)

Table 2 (Concluded)

Test Area	Location	Average Cone Index of Layers			Moisture Content, Percent Dry Weight, of Layers			Dry and Wet Density, lb/cu yd, of layers							
								Dry			Wet			Loose Wet	Swell Factor
		0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-6 in.	6-12 in.	0-12 in.	0-12 in.	0-12 in.
Two 41B/A Blade (Continued)															
12B	Ridge, before dozing	285	588	437	12.2	12.1	12.2	2743	2527	2635	2919	2835	2877	2265	1.27
	Ridge, after dozing	468	640	554	--	--	--	--	--	--	--	--	--	--	--
	Slope, after dozing	23	48	36	--	--	--	--	--	--	--	--	--	--	--
13	Ridge, before dozing	397	601	499	24.1	23.7	23.9	2660	2419	2540	3299	2989	3144	2427	1.30
	Ridge, after dozing	501	738	620	--	--	--	--	--	--	--	--	--	--	--
	Slope, before dozing	189	195	192	--	--	--	--	--	--	--	--	--	--	--
	Slope, after dozing	215	487	351	--	--	--	--	--	--	--	--	--	--	--
Drawbar Pull-Slip and Motion Resistance Tests															
1A	Ridge, after dozing	287	561	424	32.6	33.0	32.8	2255	2233	2244	2990	2965	3978	--	--
2A	Ridge after dozing	258	453	356	22.7	24.7	23.7	2660	2576	2618	3264	3212	3238	--	--
3A	Ridge, after dozing	229	447	338	21.0	21.2	21.1	2722	2770	2746	3294	3357	3325	--	--
4A	Ridge, after dozing	537	750	644	23.9	22.8	23.4	2697	--	2697	3342	--	3342	--	--

(Sheet 5 of 5)



CURVE NO.	AREA	DEPTH IN.	CLASSIFICATION	LL	PL	PI
1	1, 1A, 1B	0-12	SANDY CLAY (CL) G_s = 2.67	36	20	16
2	2, 2A, 3, 3A, 5	0-12	LEAN CLAY (CL) G_s = 2.68	47	24	23
3	4, 4A, 4B	0-12	SANDY CLAY (CH) G_s = 2.70	51	21	30
4	6, 7, 8, 9, 10A, 10B, 11, 12A, 12B, 14	0-12	PLASTIC CLAY (CH) G_s = 2.78	57	26	31
5	13	0-12	LEAN CLAY (CL) G_s = 2.78	45	24	21

Figure 9. Soil classification data

the last one and are assumed to be representative of the soil strength under the tractor tracks supporting the tractor and providing traction.

Moisture content. Soil moisture content for the 0- to 6- and 6- to 12-in. layers was determined both before and after the earthmoving tests. Soil moisture content is expressed as a percentage of the weight of water driven off at 105°C to the weight of the remaining dry soil.

Density. Dry and wet density measurements were determined from samples taken with a standard soil trafficability sampler of constant volume for the above soil layers. Dry density was determined from the weight with the moisture removed, while wet density was computed from the wet sample weight and known volume. Loose wet density, representing the material being dozed, was measured by shoveling soil from the ridge before the first cut and after the last cut into a 1-cu-ft box, filling it, vibrating it gently, and then weighing.

Surface slope data

Slopes of the test area surfaces that might affect traction and dozing performance were difficult to determine since they could change within a given test or even during a given pass of the tractor. For the U-blade dozers, the tractor dozing was usually downslope; and for the A-blade dozers, the tractor dozing was usually on level surfaces. For both blade types, the soil was usually dropped over the outslope; although this procedure was a factor in dozing performance, it was not considered in the analysis.

Earthmoving data

Earthmoving data collected are summarized in Table 3 and are discussed below.

Test area length. This is the longitudinal distance along the spoil bank to be leveled. The value can be used in estimating earthmoving rates on an areal basis.

Volume of soil moved. Rod and level profiles, before the spoil bank was moved and after it was leveled, were measured in what was considered sufficient quantity along the length of the test area to compute the volume of soil moved during the specified operating time.

Table 3

Basic Earthmoving Performance Data

Tractor Dozer	Blade Angle deg	Test Area	Test Area Length ft	Volume Soil Moved, LCY: Total Volume	Volume Soil Moved, LCY: Per hr of Dozing Time	Volume Soil Moved, LCY: Per hr of Operating Time	Soil Movement Distance, ft: Along Dozer Blade Path	Soil Movement Distance, ft: Centroid Hori-zontal	Soil Movement Distance, ft: Centroid Verti-cal	Operating Times, hr: Dozing	Operating Times, hr: Loading and Backup	Operating Times, hr: Dozing, Loading, Backup	Operating Times, hr: Turn Around	Operating Times, hr: Total	Soil Move-ment Speed mph	No. of Passes	Average Tractor Dozer Track Slip, %
D8H/S Blade	0	1	222	2548	910	591	42	34.9	7.2	2.80	1.51	4.31	--	4.31	1.90	2	0.05
		2	200	2016	1326	741	41	33.9	7.1	1.52	1.20	2.72	--	2.72	↓	2	↓
		3	175	2196	1356	868	45	37.3	10.8	1.62	0.91	2.53	--	2.53	↓	2	↓
		10A	400	635	1628	1008	28	23.2	7.5	0.39	0.24	0.63	--	0.63	↓	1	↓
		12A	400	686	1673	1039	25	20.5	4.9	0.41	0.25	0.66		0.66	↓	1	↓
D9H/Rec-U Blade	0	1	178	4036	1703	1106	63	51.5	12.3	2.37	1.28	3.65	--	3.65	1.50	2	0.08
		2	200	2848	1573	989	46	37.7	8.4	1.81	1.07	2.88	--	2.88	↓	↓	↓
		3	200	2410	1339	870	41	34.3	8.5	1.80	0.97	2.77	--	2.77	↓	↓	↓
		4	200	3211	1559	1046	51	41.6	12.1	2.06	1.01	3.07	--	3.07	↓	↓	↓
		14	250	1253	1843	1217	31	25.6	5.0	0.68	0.35	1.03	--	1.03	↓	↓	↓
41B/U Blade	0	4	200	3619	2496	1748	51	41.5	9.5	1.45	0.62	2.07	--	2.07	1.40	3	12.00
		5	300	3506	2262	1511	45	32.4	10.3	1.55	0.77	2.32	--	2.32	1.40	3	12.00
SxS D9H/U Blade	0	1B	600	6460	3549	2132	54	45.2	7.7	1.82	1.21	3.03	--	3.03	1.70	2	14.00
		3B	600	6416	3041	1767	65	54.2	4.7	2.11	1.52	3.63	--	3.63	1.70	2	14.00
		4B	400	3750	2907	1803	55	46.0	4.1	1.29	0.79	2.08	--	2.08	1.70	1	14.00
SxS D9H/A Blade	46	1A	600	7845	3754	1134	51	37.4	11.3	2.09	0.09	2.18	1.13	3.31	1.30	22	18.00
		2A	800	7702	3056	2000	44	31.7	6.5	2.52	0.33	2.85	1.00	3.85	1.20	19	18.00
		3A	600	9794	3320	2152	58	41.9	10.6	2.95	0.04	2.99	1.56	4.55	1.40	34	18.00
		4A	950	8340	3897	2752	44	32.0	8.1	2.14	0.28	2.32	0.71	3.03	1.40	14	18.00
Two 41B/A Blade	40	6	325	1118	5590	2867	44	27.9	6.9	0.20	--	0.20	0.19	0.39	1.20	4	0.03
		13	385	1337	5348	3183	39	25.2	6.3	0.25	--	0.25	0.17	0.42	1.20	↓	0.08
	45	7	410	1620	6231	3306	34	24.0	5.8	0.26	--	0.26	0.23	0.48	1.20	↓	0.04
		10B	400	1808	6696	4305	34	23.8	6.5	0.27	--	0.27	0.15	0.42	1.10	↓	10.00
	50	8	280	1061	6241	2653	29	21.5	5.3	0.17	--	0.17	0.23	0.40	1.30	↓	0.08
		12B	400	1810	6962	4310	33	24.9	7.2	0.26	--	0.26	0.16	0.42	1.20	↓	0.08
	55	9	280	1131	7540	2693	31	24.7	6.0	0.15	--	0.15	0.27	0.42	1.40	↓	0.06
		11	500	2099	7496	4199	29	24.1	6.8	0.28	--	0.28	0.22	0.50	1.40	↓	0.07

Volume of soil (loose cubic yards) moved per hour of dozing time. The total volume of soil moved was divided by the measured actual time each tractor was dozing soil. This value is considered to be earthmoving production rate at 100 percent efficiency.

Volume of soil (loose cubic yards) moved per hour of operating time. The total volume of soil moved was divided by the total operating time. This value, when compared to volume of soil moved during dozing only, yields a percent efficiency that is an indicator of operating efficiency for actual application of dozing operations.

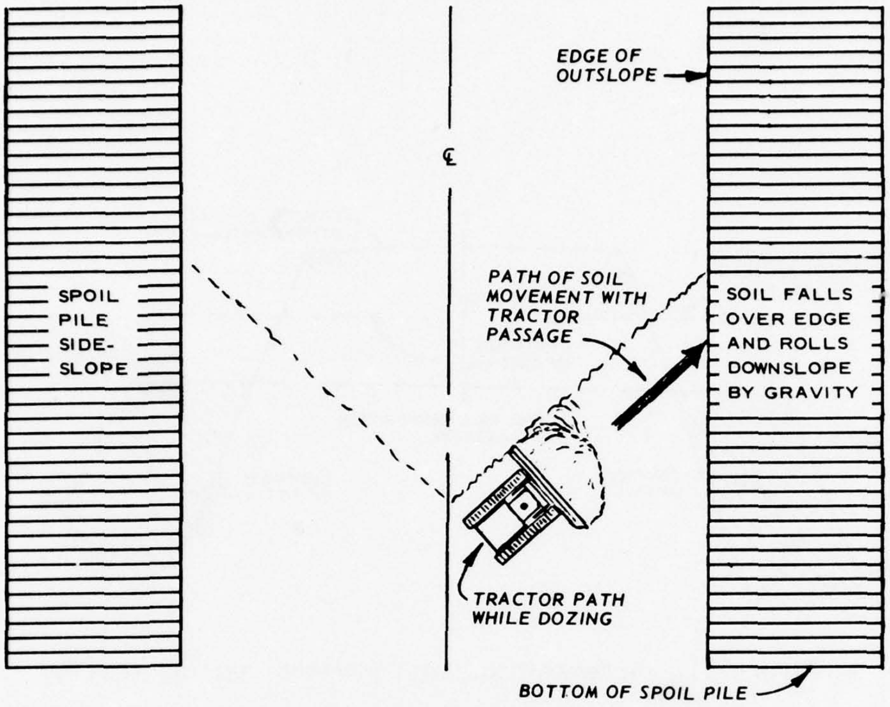
Soil movement distances relating to dozer blade path. This value is used for the analysis of optimized production. In the feasibility study that considered S and U blades only, the dozing distances along the path of the dozer began at the point of blade full and ended with the discharge of soil over the outslope. For the S and U blades in the study herein, the dozing distances for optimization of production were determined in the same way.

For the A blades, the determination of soil movement distances was somewhat more difficult than for the S and U blades. For studies of optimization of earthmoving rates for the A blades, the soil movement distances are assumed to be one-half the width of the blade face, and a full blade is maintained by continuous cutting along the blade face and continuous discharge at the blade trailing edge over the outslope. The optimum blade angle for conditions of parallel spoil banks is assumed to be that angle formed when the leading edge of the blade coincides with the center line of a given spoil bank and the trailing edge just overhangs the outslope. Any blade angle on the same spoil bank less than the one wherein the blade just spans the distance between center line and outslope would cause the trailing edge to overhang the outslope and production would be less than optimum. Any blade angle greater than the one that just spans the center line to outslope distance will yield less than optimum production because the trailing edge of the blade will not reach the outslope when the leading edge is on the center line of the spoil bank; thus the spoil will have to be moved a second time. The determination of optimum blade angle for optimum production then is a function of spoil bank size and blade length, assuming adequate tractor horsepower and tractive force.

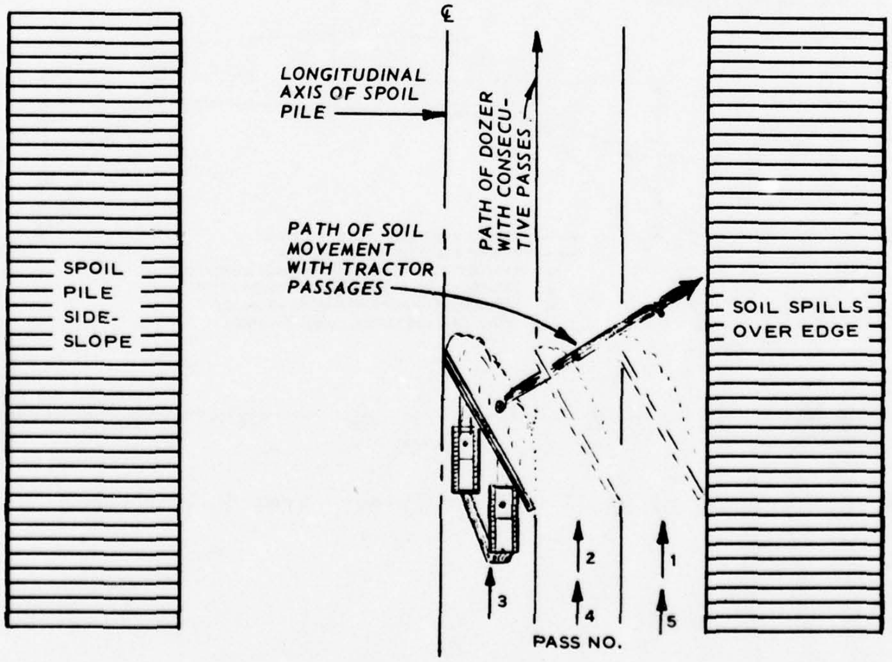
In the A-blade tests herein, the tractor dozers moved along a path parallel to the longitudinal axis of the spoil bank, while the soil moved across the blade face and was discharged at an angle away from its origin but toward outslope disposal. A variable number of passes, depending on spoil bank size, were required to move the soil completely across the spoil bank to disposal at the outslope. The average angles between the longitudinal spoil bank axis and the average horizontal distance that the soil was moved across the spoil bank to disposal at the outslope were used to determine equivalent dozing distances for the A blades relative to the S and U blades. Figure 10 illustrates the determination of soil movement distance relative to dozer blade path.

Soil movement distances with respect to soil mass centroids. Soil movement distances with respect to soil mass centroid are used in practical applications and were therefore measured along with other earthmoving data. Soil movement distances with respect to soil mass centroid are determined as the horizontal and vertical distances from the mass centroid before dozing to the mass centroid after dozing. Figure 11 presents a schematic of soil movement showing these horizontal and vertical distances. Longitudinal displacement of the centroid after dozing was not measured, because it was considered negligible. Figure 12 is an example of a spoil bank profile showing realistic shapes before and after dozing.

Operating times. Four operating times are listed in Table 3. Dozing time was measured as the time the blade was full, or when the operator ceased cutting new soil, until the mass was disposed over the outslope. Loading and backup time was measured as the time of completing disposal of one load over the outslope until the blade was again loaded. Dozing, loading, and backup time constitute the total time required to move the entire soil mass and, for S and U blades, is the same as total operating time. Turnaround time was measured for the A blades at the end of each test area. For the two 41B/A blade, only two measurements, dozing time and turnaround time, were made. For the SxS D9H/A blade,



a. S AND U BLADES



b. ANGLE BLADES

Figure 10. Direction of soil movement with respect to tractor dozer direction

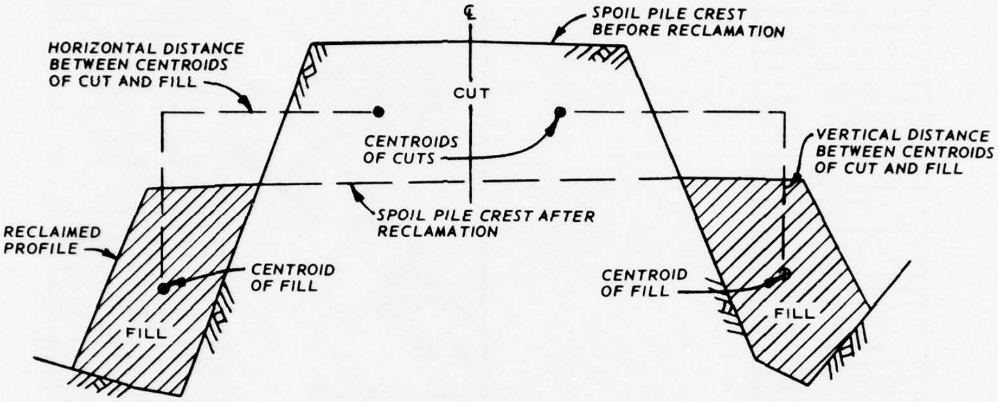


Figure 11. Schematic of soil movement during testing

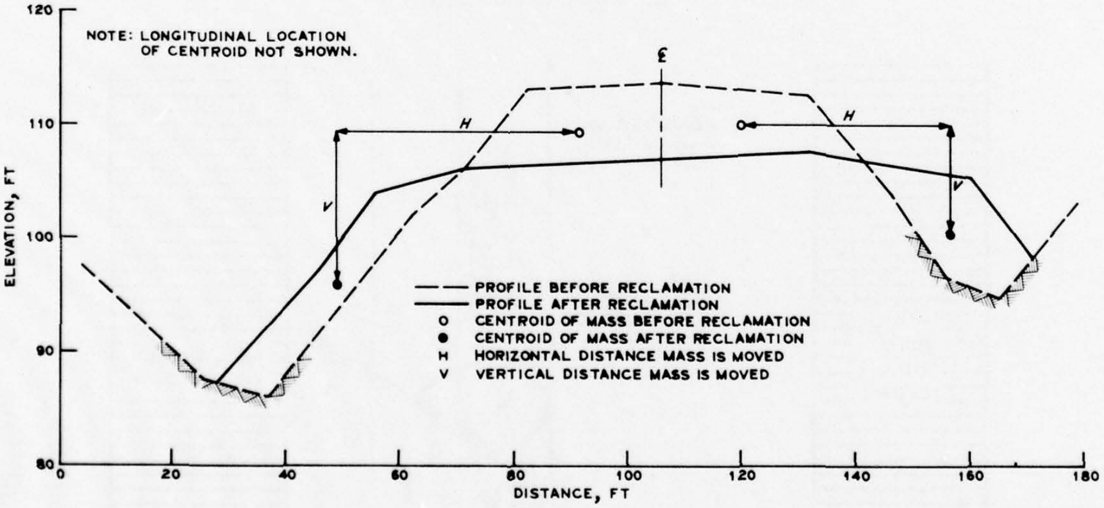


Figure 12. Example of spoil bank profiles: area 5, profile 2, sta 1+50

in addition to dozing and turnaround times, a time was noted in the dozing, loading, and backup column of Table 3 to account for removal of boulders that hindered operation.

Soil movement speed. Soil movement speed is the same as tractor dozer speed. For S and U blades, it is the speed of movement in front of the blade. For the A blades, it is the speed of discharge of soil from the trailing edge of the blade which, once the system has reached equilibrium, is also equal to the speed at which the dozer is traveling.

Number of passes. This is the number of passes along the spoil bank that was required to reduce the bank to the desired reclamation level. See the discussion on "Description of Tests Conducted" for clarity of this item.

Tractor dozer track slip. Slip is defined as the percentage of track movement ineffective in advancing a vehicle forward. Maximum tractive force in fine-grained soils, similar to those in this study, has been determined to occur at about 20 percent slip. Track slip less than about 20 percent denotes that additional traction was available but not used, while track slip greater than about 20 percent means that the tracks had exceeded the capability of the soil to withstand shear.

Traction data

Drawbar pull, track slip, and motion resistance (force required to tow with transmission disengaged) were determined using the D8H and D9H tractor on level spoil banks. Soil and dozer performance data are given in Tables 2 and 4, respectively.

Description of Tests Conducted

The type of tractor blade (S, U, or A) generally dictates the operating technique used in reclaiming area surface mines. In this study, the tests conducted with the six blades described previously were designed according to the techniques normally used in surface mine reclamation.

S- and U-blade tests

The S- and U-blade tests were conducted in the same manner. After

Table 4

Drawbar Pull-Slip and Motion Resistance Tests

Tractor Dozer	Gear	Drawbar Pull lb	Drawbar Pull Coefficient	Track Slip, %
		Area 1A		
D8H (67,800 lb)	1	25,042	0.37	0
		29,255	0.43	1.2
		37,914	0.56	1.6
		41,893	0.62	1.6
		48,446	0.72	2.3
		53,829	0.79	5.1
		58,510	0.86	9.1
		56,638	0.84	37.5
		52,191	0.77	91.3
		55,233	0.82	100.0
		47,276	0.70	62.3
		55,702	0.82	100.0
	2	28,750	0.42	0
		32,404	0.48	0.4
		37,276	0.55	0.6
		41,906	0.62	1.0
		45,317	0.67	1.5
		46,535	0.69	4.0
		47,753	0.70	5.8
		50,190	0.74	Stall
	3	19,890	0.29	0
		23,340	0.34	0.4
		24,762	0.37	0.9
		24,964	0.37	1.4
		27,197	0.40	1.4
		40,592	0.60	Stall
		Motion Resistance		
		7,102	0.10	
		Area 2A		
D8H	1	21,256	0.31	0
		24,563	0.36	0
		26,925	0.40	0.5
		33,065	0.49	1.6

(Continued) (Sheet 1 of 4)

Table 4 (Continued)

		Drawbar Pull		
Tractor Dozer	Gear	lb	Coefficient	Track Slip, %
		Area 2A (Continued)		
D8H	1	41,332	0.61	2.0
		40,859	0.60	2.2
		44,638	0.66	2.3
		45,819	0.68	2.4
		48,181	0.71	2.9
		52,432	0.77	3.0
		53,377	0.78	3.7
		60,460	0.89	18.5
		59,990	0.88	18.7
		59,900	0.80	40.7
		57,156	0.84	100.0
		58,573	0.86	100.0
	2	25,560	0.38	0
		28,874	0.43	0.4
		33,290	0.49	0.7
		37,864	0.56	2.5
		43,074	0.64	2.9
		57,967	0.85	Stall
	3	20,574	0.30	0
		26,447	0.39	0
		24,034	0.35	0.4
		24,734	0.36	0.5
		27,260	0.40	0.6
		29,295	0.43	1.0
		24,967	0.37	1.0
		26,660	0.39	1.6
		32,143	0.47	1.8
		31,500	0.46	2.4
		37,100	0.55	Stall
		38,246	0.56	Stall
		Motion Resistance		
		5,944	0.09	
		Area 3A		
D8H (67,800 lb)	1	21,656	0.36	0
		26,228	0.39	1.8
		29,837	0.44	2.2

(Continued) (Sheet 2 of 4)

Table 4 (Continued)

Tractor Dozer	Gear	Drawbar Pull lb	Drawbar Pull Coefficient	Track Slip, %
		Area 3A (Continued)		
D8H	1	32,965	0.49	2.5
		38,018	0.56	3.3
		38,740	0.57	4.3
		43,792	0.65	5.1
		47,402	0.70	5.2
		51,012	0.75	6.6
		59,193	0.87	18.3
		57,268	0.84	45.9
		58,230	0.86	100.0
	2	24,160	0.36	0
		26,818	0.40	0.2
		27,542	0.41	1.2
		33,582	0.50	2.7
		38,656	0.57	3.6
		44,213	0.65	5.2
		48,318	0.71	10.0
		54,118	0.80	Stall
	3	17,284	0.25	0
		21,802	0.32	0
		22,940	0.34	0
		25,338	0.37	1.6
		26,710	0.39	2.5
		38,496	0.57	Stall
		Motion Resistance		
		7,616	0.11	
		Area 4A		
D8H	1	27,288	0.40	1.2
		36,582	0.54	4.0
		39,350	0.58	5.9
		42,712	0.63	6.2
		49,040	0.72	6.6
		56,554	0.83	11.2
		57,740	0.85	39.5
		58,531	0.86	100.0

(Continued)

(Sheet 3 of 4)

Table 4 (Concluded)

Tractor Dozer	Gear	Drawbar Pull lb	Drawbar Pull Coefficient	Track Slip, %
		Area 4A (Continued)		
D8H	2	28,130	0.41	1.0
		30,111	0.44	1.0
		32,687	0.48	2.1
		36,846	0.54	3.1
		40,611	0.60	4.4
		43,582	0.64	6.1
		46,355	0.68	9.5
		53,883	0.79	Stall
	3	14,098	0.21	0
		17,454	0.26	0
		22,152	0.33	0
		23,160	0.34	0
		26,516	0.39	2.0
		28,193	0.42	2.0
		35,244	0.52	Stall
		Motion Resistance		
		5,302	0.09	
		Area 1A		
D9H (92,900 lb)	1	54,326	0.58	1.8
		64,232	0.69	3.9
		57,340	0.62	4.5
		65,818	0.71	5.0
		69,454	0.75	5.2
		75,107	0.81	9.9
		76,722	0.83	10.0
		81,166	0.87	20.0
		79,548	0.86	23.8
		76,396	0.86	28.7
		80,760	0.87	33.0
		76,962	0.83	41.3
		78,337	0.84	46.1
		75,914	0.82	59.6
		77,530	0.83	100.0
		Motion Resistance		
		7,938	0.08	

(Sheet 4 of 4)

a spoil bank had been selected, a test section on the spoil that was relatively uniform in size and shape through its length, usually 200 to 400 ft long, was marked off. Cross-section profiles and soil data were collected in the test section. Then on signal, the dozer operator would start at one end of the test section by moving spoil until a vertical cut approximately equal to the height of the dozer blade was exposed across the test section. The dozer would then work along the face of the vertical cut pushing the right half of the spoil over the edge of the right bank and the left half of the spoil over the edge of the left bank. To move soil on the right of the center line, the dozer operator placed the left edge of the dozer blade at the longitudinal center line of the spoil bank and worked toward the right edge of the spoil bank along a path whose average angle was 56 deg with the spoil bank center line. As the dozer moved along this path, soil accumulated quickly (in a distance of a few feet) in front of the blade until a bladefull developed; then the dozer continued forward until the soil was pushed over the bank's edge. In this operation most of the soil in front of the blade was cut by the vertical edge of the dozer blade against the vertical wall rather than the horizontal cutting edge of the dozer blade against the ground surface. When the dozer backed to the spoil bank center line, the dozing technique was repeated. Usually after three or four pushes on the right side, the dozer was turned and worked on the left side of the center line.

Working in this manner, the dozer moved along the test section until a layer of spoil approximately the height of the dozer blade had been cut and pushed over the edge of the spoil bank. The dozer would continue to remove the spoil layers in this manner until the spoil bank was reduced in height to the required reclamation level. The time used to remove each spoil layer, as well as to push and back up, was recorded. After reclamation was completed, soil and cross-section profile data were taken in the same locations as were the "before reclamation" test data.

A-blade tests

After a spoil bank had been selected and a test section marked off, a standard dozer was used to build an area at each end of the test section for the A-blade dozers to turn around. In addition, the standard dozer was used to cut the bank down to a level where the top of the bank was wide enough to allow the two A-blade dozers to begin work on the test section. Cross-section profiles and soil data were collected; and then on signal, the dozers began working in a forward direction along the longitudinal axis of the spoil bank. As these dozers moved along the top of the test section, soil accumulated and moved to the right along the face of the A blade until it was cast over the edge of the spoil bank. The dozers would continue to operate in a forward direction until they reached the turnaround area at the end of the test section. Then, the dozer operators would turn and work back along the test section in a similar manner, casting soil over the opposite edge of the spoil bank until they reached the turnaround at the beginning of the test section. Repeating this technique, the dozers operated back and forth along the test section until the soil bank was reduced in height to the desired reclamation level. The time used to make each pass, as well as each turnaround, was recorded. On a few occasions, these A-blade dozers had to stop continuous forward operation during a pass and work back and forth within a short distance on the test section, usually to push an isolated large rock over the bank's edge. When this occurred, the time required to do the work was recorded separately from the time required to make the complete pass. After reclamation was completed, soil and cross-section profile data were taken in the same locations as were the "before reclamation" test data.

Determining maximum blade capacities

Dozer blade capacities for the S and U blades were determined by having the dozer operator begin the normal dozing functions of "filling" the blades to maximum capacity by shearing soil along the bottom and sides with the blades and, once filled, "drifting" the blades with no additional shearing action but stopping just prior to discharge over the outslope. The volumes of soil in front of the blades then were measured. This sequence was repeated several times to obtain an average value.

Dozer blade capacities for the A blades were determined in a similar manner; however, with A blades, to maintain maximum blade capacities (maximum discharge at the trailing edge) soil shearing along the bottom of the blades is continuous. For the A-blade measurements, once the blades were discharging at a maximum capacity, the tractors were stopped, and the volume of soil in front of the blade was measured. This sequence was repeated several times to obtain an average value. These values are presented and discussed later in Chapter 4.

Drawbar pull-slip and motion resistance tests

Drawbar pull-slip tests were conducted with the D8H and the D9H tractor dozers (Table 4). Drawbar pull was measured with a load cell connected between the test tractor and a load tractor. Necessary electronic-electrical measuring and recording devices were monitored on the test tractor to determine the distances that the tractor and a point on the track traveled in a given period of time. These two distances were used to compute track slip, the percentage of track movement ineffective in moving the tractor forward. The load vehicle applied various loads to the test vehicle while both were moving forward, and these different loads produced slip values ranging from 0 to 100 percent for first gear only. Power stalls occurred in other gears before significant slip occurred. Measurements were made in this manner until a sufficient number of load and slip combinations were recorded to develop a drawbar pull-slip curve.

Motion resistance tests were conducted in conjunction with the drawbar pull-slip tests. With its engine idling and transmission disengaged, the test vehicle was towed at approximately 1.0 mph, while a continuous record of motion resistance was made with the same measuring and recording equipment used in drawbar-pull tests.

Observations of dozer handling and maneuverability

Generally, all operators were able to handle and maneuver the dozers efficiently. The standard D8H and D9H were naturally the easiest to operate. The SxS D9H dozers operated almost equally as easy because the two tractors had just one driver, and the controls of the tractors were very well synchonized. The two 41B/A blade configuration was more difficult to operate than the others because it required continuous coordination between its two operators. However, it was considered that this problem did not reduce the performance to any measurable extent.

CHAPTER 4: ANALYSIS OF DATA

The data analyzed herein includes: (a) the measured earthmoving production rates and the effect, or lack of effect, of soil characteristics on those rates; (b) the measured maximum blade capacities versus the operating blade capacities; (c) the optimized earthmoving production rates as determined by the model presented in Appendix A; (d) the comparisons of measured and estimated production rates; (e) the operating efficiencies in practical application; and (f) the results of limited drawbar pull-slip tests conducted with crawler tractors.

Effects of Soil Characteristics on Measured Earthmoving Rates

Basic soil data and soil classification data are presented in Table 2 and Figure 9, respectively. For a given tractor dozer, the basic soil data were examined two ways in an attempt to determine any effects on measured performance: first, on an individual test data basis; and second, by combining test data according to the grouping of test areas in the classification analysis, Figure 9. The soil values examined were the average of the 0- to 6-in. cone index values before and after dozing, average of the 0- to 6-in. moisture content before and after dozing, and average loose wet density approximating the density of the material being dozed. Cone index and moisture content, pertinent characteristics of the soil on which the tractor dozer traction elements were riding, could affect traction forces, and the loose wet density of the dozed material could influence dozing capabilities of the blade. The measured performance value of each tractor dozer was the volume of soil moved in LCY/hr based on actual dozing time (100 percent efficiency). On a 100 percent efficiency basis, the volume of soil moved is affected by dozing distance; the shorter the dozing distance, the greater the volume moved. Results of this analysis are discussed by tractor dozers in the following paragraphs.

D8H/S blade

The following tabulation summarizes the performance of the D8H/S blade and the soil characteristics of the five areas in which the blade was tested:

Test Area	Volume of Soil Moved LCY/hr	Dozing Distance ft	Average Cone Index of 0- to 6-in. Layer	Average Moisture Content of 0- to 6-in. Layer % Dry Weight	Loose Wet Density of 0- to 12-in. Layer lb/cu yd
1	910	42	433	18.9	2422
2	1326	41	336	21.8	2396
3	1355	45	247	21.8	2396
10A	1628	28	206	18.7	1998
12A	1673	25	263	19.8	1844

Examination of the tabulation indicates a general trend of increased earthmoving rates with decreased dozing distances and loose wet density. The cone index and moisture content differences between areas were apparently not enough to affect the earthmoving rates significantly.

D9H/Rec-U blade

The following tabulation summarizes the performance of D9H/Rec-U blade and the soil characteristics of the five areas in which the blade was tested:

Test Area	Volume of Soil Moved LCY/hr	Dozing Distance ft	Average Cone Index of 0- to 6-in. Layer	Average Moisture Content of 0- to 6-in. Layer % Dry Weight	Loose Wet Density of 0- to 12-in. Layer lb/cu yd
1	1703	63	330	18.3	2527
2	1573	46	266	18.8	2489
3	1339	41	341	22.9	2448
4	1559	51	263	18.5	2516
14	1843	31	372	16.7	1817

Examination of the tabulation shows slight changes in earthmoving rates for areas 1 through 4 with changes in dozing distances and soil characteristics; however, area 14, when compared to the other areas, presents the expected trend of higher volume of soil moved for a shorter dozing distance and lower loose wet density.

41B/U blade

The following tabulation summarizes the performance of 41B/U blade and the soil characteristics of the two areas in which the blade was tested:

Test Area	Volume of Soil Moved LCY/hr	Dozing Distance ft	Average Cone Index of 0- to 6-in. Layer	Average Moisture Content of 0- to 6-in. Layer % Dry Weight	Loose Wet Density of 0- to 12-in. Layer lb/cu yd
4	2496	51	341	16.3	2580
5	2262	45	306	19.1	2331

Examination of the tabulation does not indicate the expected trend of increased volume of soil moved either with shorter dozing distances or with lower density of soil.

SxS D9H/U blade

The following tabulation summarizes the performance of SxS D9H/U blade and the soil characteristics of the three areas in which the blade was tested:

Test Area	Volume of Soil Moved LCY/hr	Dozing Distance ft	Average Cone Index of 0- to 6-in. Layer	Average Moisture Content of 0- to 6-in. Layer % Dry Weight	Loose Wet Density of 0- to 12-in. Layer lb/cu yd
1B	3549	54	276	23.5	2436
3B	3041	65	164	22.1	2487
4B	2907	55	405	21.0	2184

Examination of the tabulation does not reveal any trend of increased volume of soil moved with shorter dozing distances or with lower densities of soil. Test area 3B had one of the lowest cone indexes encountered; however, the volume of soil moved was not affected to any significant extent by the low strength.

SxS D9H/A blade

The following tabulation summarizes the performance of the SxS D9H/A blade at a 46-deg angle and the soil characteristics of the four areas in which the blade was tested:

Test Area	Volume of Soil Moved LCY/hr	Dozing Distance ft	Average Cone Index of 0- to 6-in. Layer	Average Moisture Content of 0- to 6-in. Layer % Dry Weight	Loose Wet Density of 0- to 12-in. Layer lb/cu yd
1A	3754	51	382	13.9	2409
2A	3056	44	241	20.6	2416
3A	3320	58	210	21.0	2395
4A	3897	44	267	18.9	2328

Examination of the tabulation indicates that there were no trends in performance resulting from changes in soil characteristics or dozing distances.

Two 41B/A blade

The following tabulation summarizes the performance of two 41B/A blade at angles of 40, 45, 50, and 55 deg and the soil characteristics of the eight areas in which the blade was tested:

Test Area	Volume of Soil Moved LCY/hr	Dozing Distance ft	Average Cone Index of 0- to 6-in. Layer	Average Moisture Content of 0- to 6-in. Layer % Dry Weight	Loose Wet Density of 0- to 12-in. Layer lb/cu yd
			40-deg Angle		
6	5590	44	272	21.1	2149
13	5348	39	449	24.1	2427
			45-deg Angle		
7	6231	34	383	20.0	2363
10B	6696	34	314	19.5	2219
			50-deg Angle		
8	6241	29	343	19.6	2203
12B	6962	33	377	12.2	2265
			55-deg Angle		
9	7540	31	329	19.8	2179
11	7496	29	285	18.6	2098

Examination of the tabulation shows that the data are insufficient to draw any conclusive analysis for a specific blade angle; however, there is a general trend of increased earthmoving rates with increased blade angle.

Summary discussion of effects of soil characteristics on measured earthmoving rates

The cone index and moisture content values listed in the preceding paragraphs were values of the soil on which the tractors obtain traction when cutting soil and floating the full blade to the discharge point. Cone index and moisture content probably have more influence on the cutting operation (not a part of this study) than the dozing operation since greater traction is required, in most cases, to cut and fill the blade than to move the soil to a discharge point. Hence, lack of correlations between these soil characteristics and earthmoving rates was not unexpected.

The loose wet density values represent the mass of soil being moved at a given time by the dozer. The lower the density the greater the volume of soil that can be moved in a given period of time, up to maximum traction capacity or maximum blade capacity. Since dozing distance, along with wet density, is one of the most influential factors affecting earthmoving production rates, it does contribute to the problem of correlations when examining one or two soil factors at the time.

The data in Figure 9 indicate that if sufficient testing had been accomplished with a given dozer in all areas, then correlations of performance versus soil parameters may have been realized. On the basis of the gradation curves only, the areas tend to group with one group comprising test areas 1, 1A, 1B, 4, 4A, and 4B (curves 1 and 3) and the other group comprising the remaining test areas (curves 2, 4, and 5).

Comparisons of Maximum Blade Capacities and Operating Blade Capacities

The maximum blade capacities were measured during the field test program, as shown in Table 1, and the procedures for determining these capacities were explained previously on page 41. With the D8H/S blade operating in area 1 as an example of the computation of operating blade capacity, values representing the volume of soil moved on each dozing trip for each dozer were calculated as follows:

a. Average dozing (soil movement) speed = 1.90 mph (2.79 fps).
b. Average dozing (soil movement) distance = 42 ft.
c. Volume of soil moved (100 percent efficiency) = 910 cu yd/hr of dozing time.
d. 42 ÷ 2.79 = 15.05 sec/dozing trip.
e. 3600 ÷ 15.05 = 239 trips/hr.
f. 910 ÷ 239 = 3.81 cu yd/dozing trip.

Thus, on each dozing trip, the dozer was computed to be pushing 3.81 cu yd of soil. When compared to the measured blade capacity of 9.0 cu yd, this value indicates that the dozer was operating at only 42.3 percent of its probable capacity. Table 5 presents a summary of the operating blade capacities computed by this procedure for each dozer at each test area.

Table 5 indicates that all blades were operating at less than 67 percent of maximum blade capacity with the A blades showing the lowest efficiencies. These operating efficiencies would most likely vary somewhat for other spoil bank configurations. The low efficiencies could further mean, particularily for the A blades, that the techniques used to measure maximum blade capacity may not have been entirely adequate. This problem will surface again later in the analysis.

Optimized Earthmoving Production Rates

In the feasibility study, the analytical models developed by WES to relate performance capabilities of ground vehicles to the terrain conditions on which they are required to perform were extended to convert tractive force and speed into estimates of optimum earthmoving rates. Appendix A discusses the extended model. Briefly, to determine optimum earthmoving rates and speed, the theoretical tractive force-speed curves (available from manufacturers for all ground vehicles) are adjusted to account for motion resistances due to soil-track interactions and thereby to develop effective drawbar pull-speed curves. Following the conversion of the theoretical tractive force-speed curves to

Table 5

Blade Capacities and Efficiencies

			Operating Blade Capacity		
Tractor Dozer	Blade Angle deg	Maximum Blade Capacity cu yd	Area	cu yd/ Dozing Trip	Average Percent Efficiency
D8H/S Blade	0	9.0	1	3.81	
			2	5.41	
			3	6.08	
			10A	4.53	
			12A	4.16	
			Average	4.80	53.3
D9H/Rec-U Blade	0	14.0	1	13.51	
			2	9.15	
			3	6.94	
			4	10.06	
			14	7.20	
			Average	9.37	66.9
41B/U Blade	0	30.0	4	17.21	
			5	13.79	
			Average	15.50	51.7
SxS D9H/U Blade	0	35.6	1B	21.39	
			3B	22.04	
			4B	17.83	
			Average	20.42	57.4
SxS D9H/A Blade	46	48.0	1A	19.25	
			2A	14.98	
			3A	18.24	
			4A	16.24	
			Average	17.18	35.8
Two 41B/A Blade	40	84.0	6	24.20	
			13	21.55	
			Average	22.87	27.2
	45		7	23.69	
			10B	27.23	
			Average	25.46	30.3

(Continued)

Table 5 (Concluded)

Tractor Dozer	Blade Angle deg	Maximum Blade Capacity cu yd	Operating Blade Capacity Area		Operating Blade Capacity cu yd/ Dozing Trip	Average Percent Efficiency
Two 41B/A Blade (Continued)	50	84.0	8		20.81	
			12B		28.07	
				Average	24.44	29.1
	55		9		25.31	
			11		25.24	
				Average	25.28	30.1

effective drawbar pull-speed curves, the latter curves are converted to earthmoving production-speed curves by accounting for dozing distance, dozing speed, and the density of the dozed material.

Again, using the procedures in Appendix A, the average cone index in Table 2 for before and after dozing as the soil strength for traction, and the loose wet density in Table 2 as the density of the dozed material, optimum production-speed curves were computed for each tractor tested (Figures 13 through 39). These figures also are used for further analysis in the following paragraphs.

Comparisons of Measured and Estimated Earthmoving Production Rates

This part of the analysis compares measured earthmoving production rates at 100 percent efficiency (dozing time only) with estimated production rates (dozing time only) determined by maximum blade capacity, optimum at measured speed, and optimum at optimum speed. For convenience, Table 6 presents a summary of production rate values used in the analysis.

Estimated production rates based on maximum blade capacities

For the analysis, the maximum blade capacities were used to estimate earthmoving production rates. To calculate the estimates, the maximum blade capacity value given in Table 5 was multiplied by the number of dozing trips per hour (100 percent efficiency) for each dozer test. For example, the D8H/S blade operating in area 1 made 239 dozing trips/hr, and the maximum blade capacity was 9.0 LCY; therefore, the estimated production rate was 2151 LCY/hr, assuming maximum blade capacity on each trip.

Figure 40 compares measured earthmoving production rates with estimated production rates based on maximum blade capacity. Figures 13 through 39 also present both measured and estimated rates. Figure 40 further shows that only in one test area, with the D9H/Rec-U blade, did the tractor dozers operate near maximum blade capacity. The overall efficiency for all tractor dozers and all tests was 53.9 percent, with the

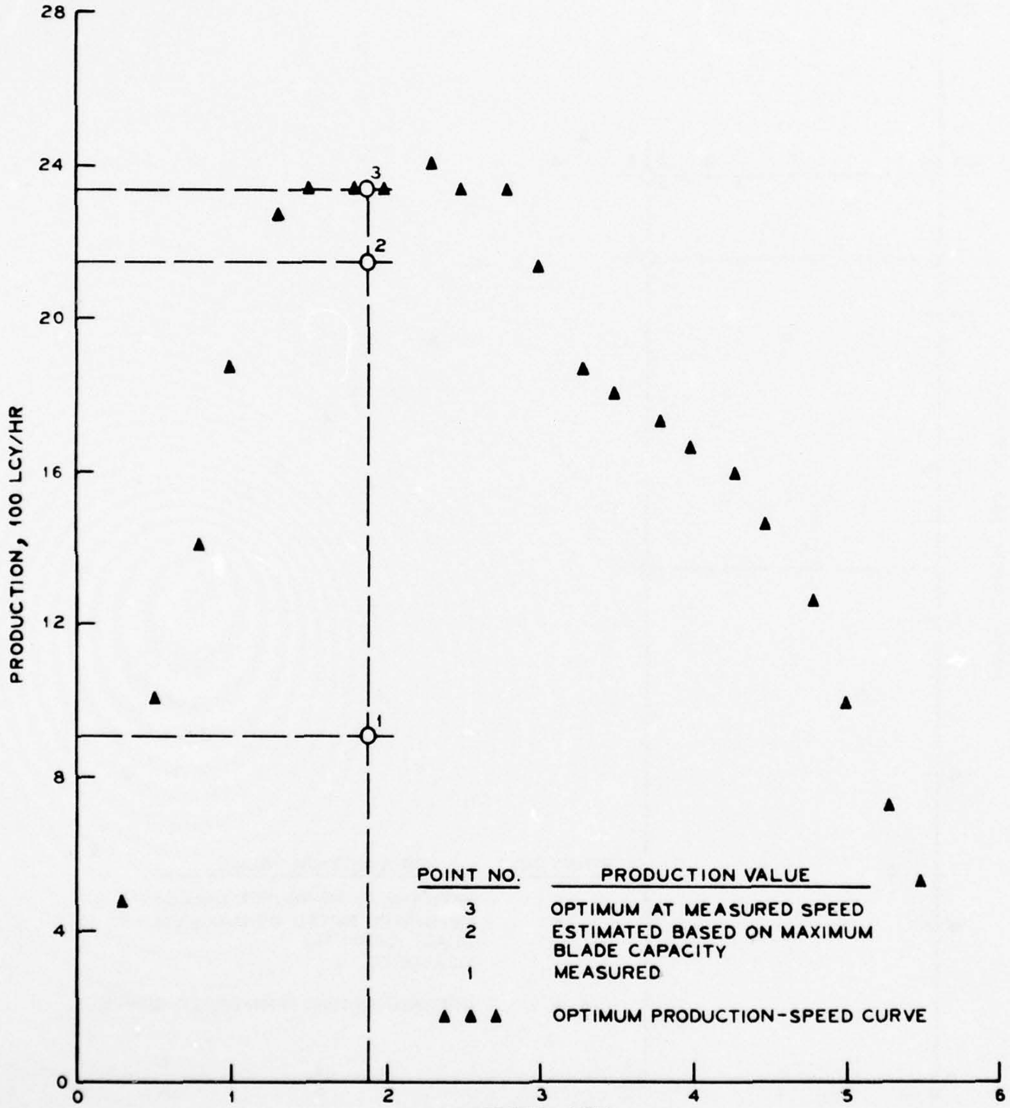


Figure 13. Earthmoving production rates versus speed; D8H/S blade, area 1

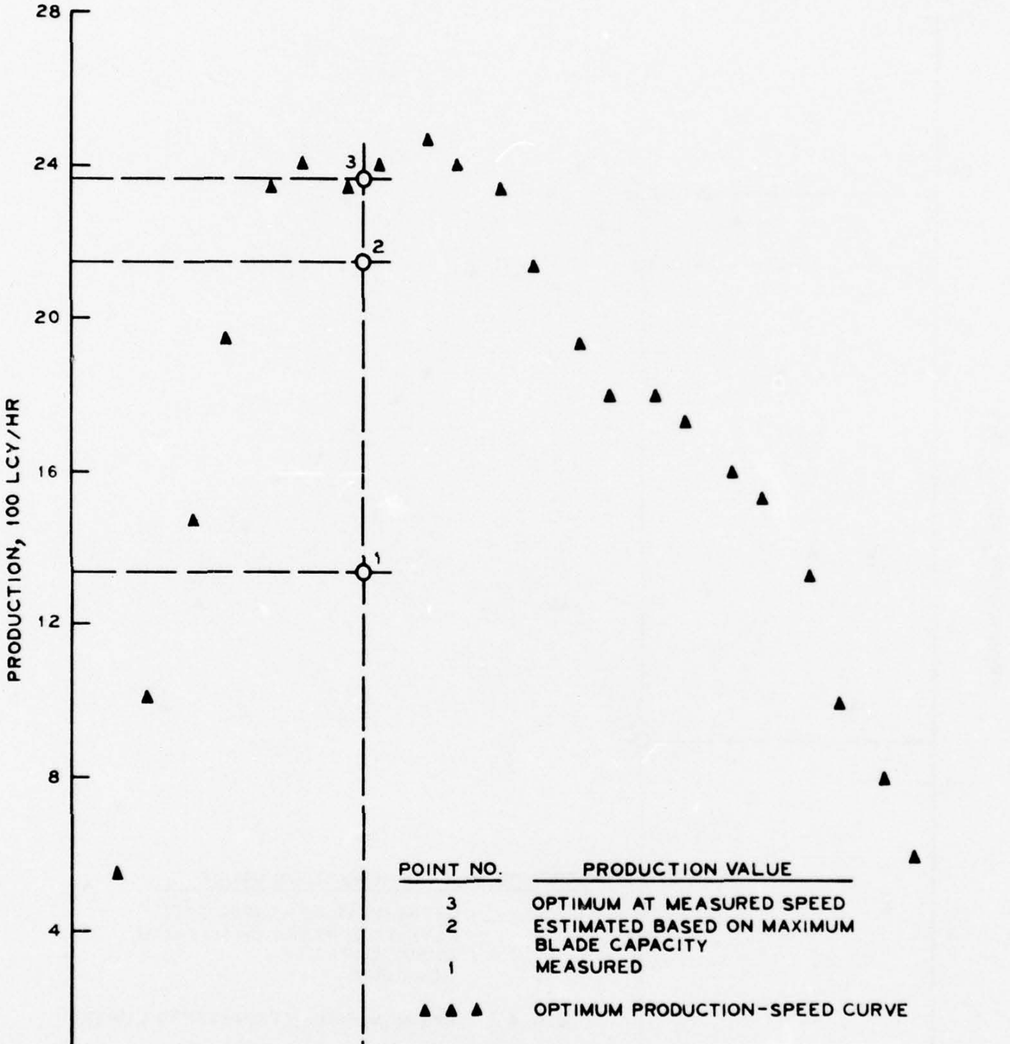


Figure 14. Earthmoving production rates versus speed; D8H/S blade, area 2

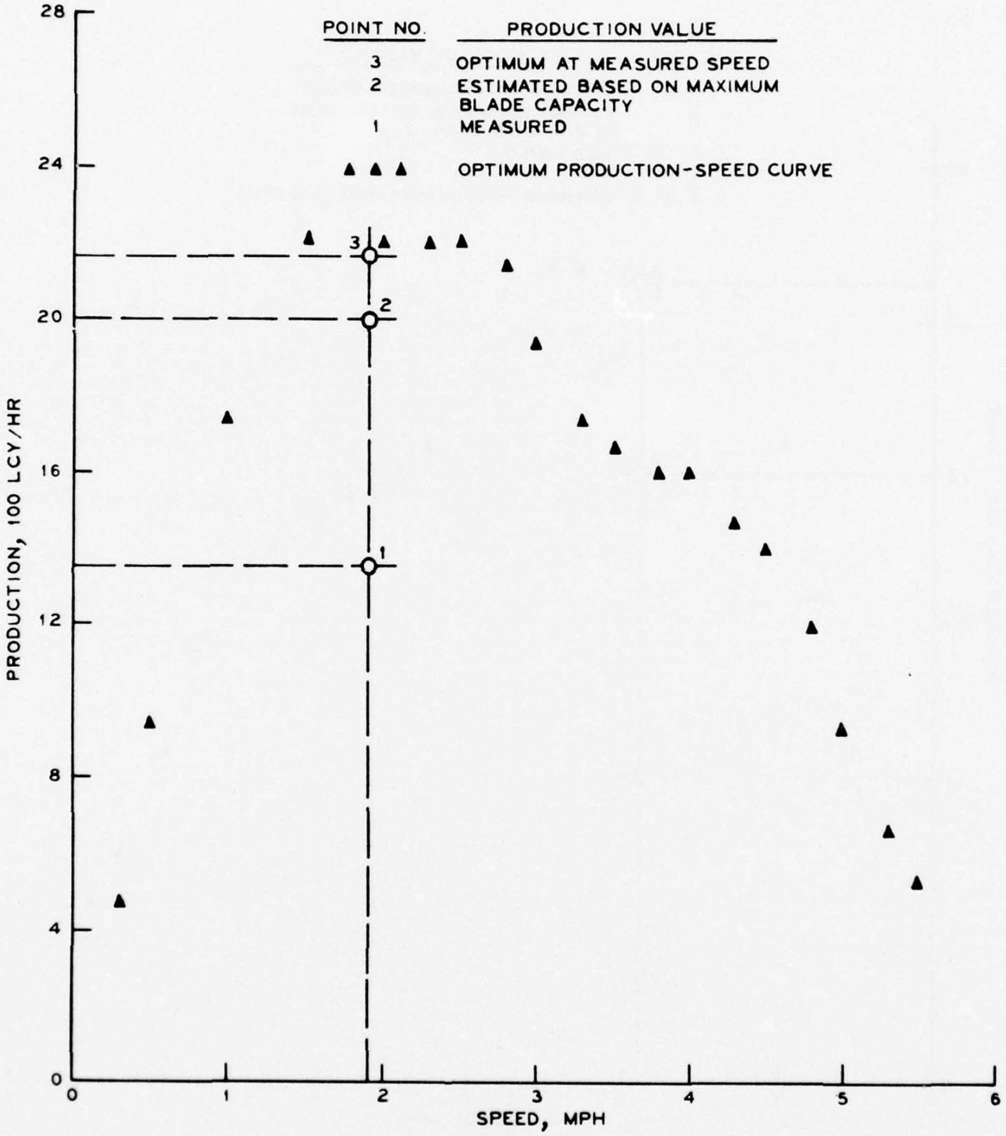


Figure 15. Earthmoving production rates versus speed; D8H/S blade, area 3

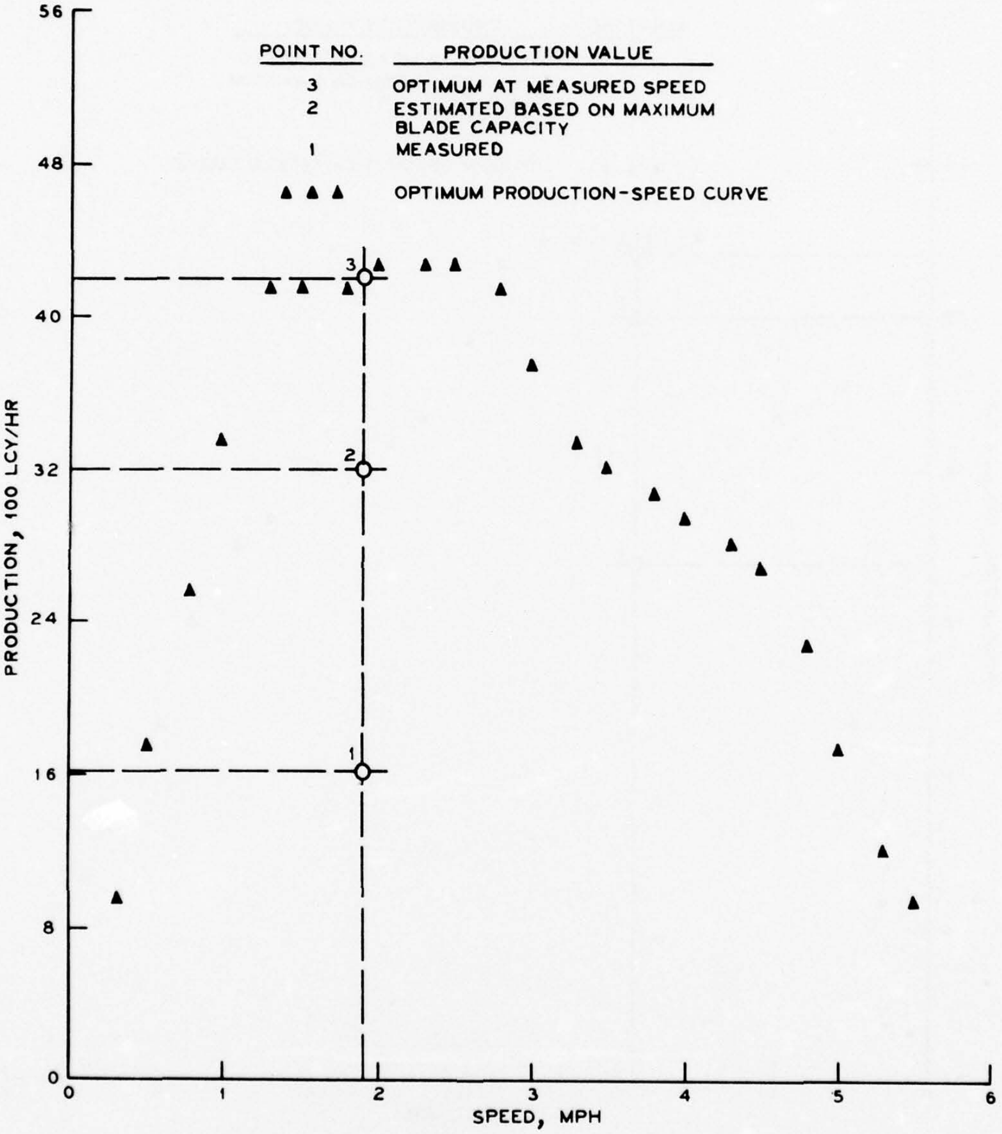


Figure 16. Earthmoving production rates versus speed; D8H/S blade, area 10A

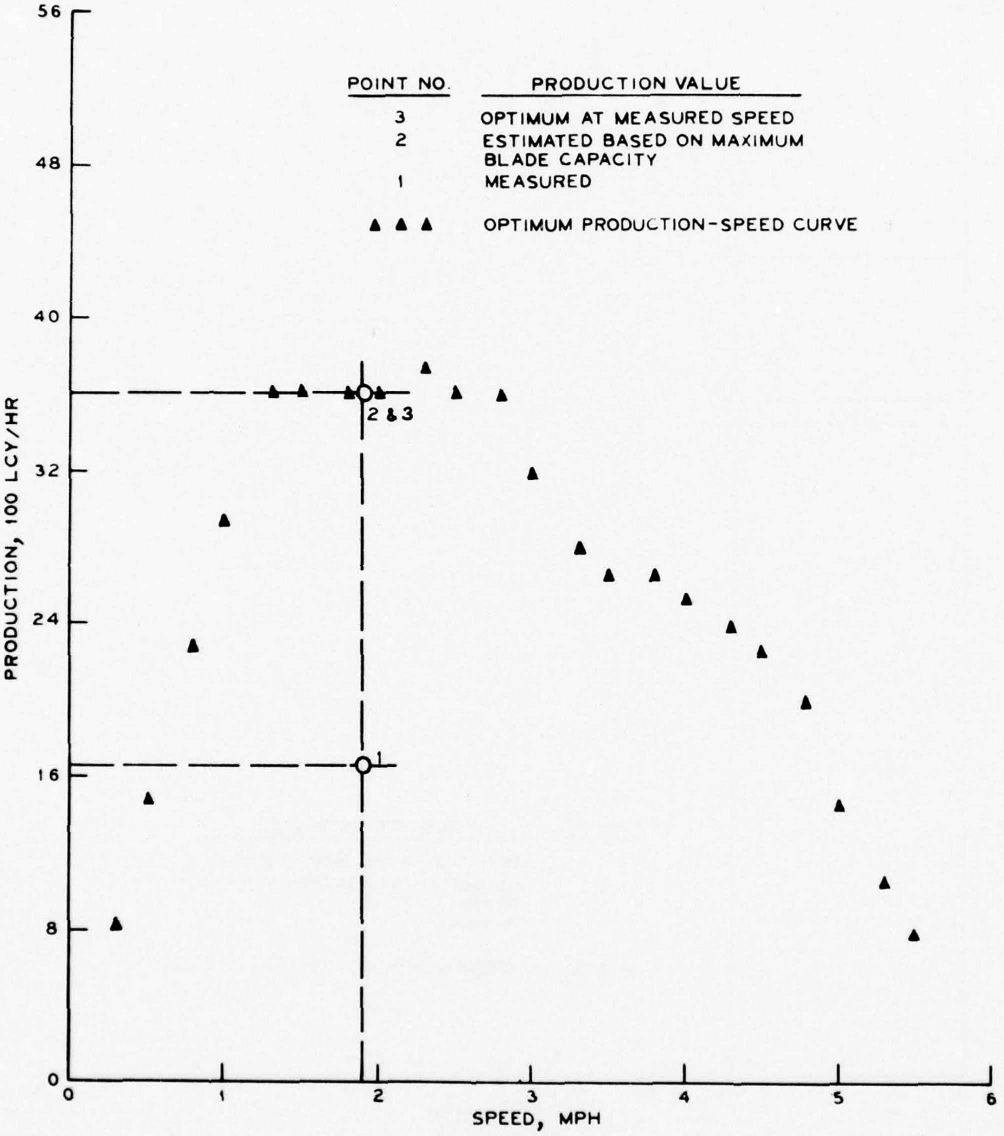


Figure 17. Earthmoving production rates versus speed; D8H/S blade, area 12A

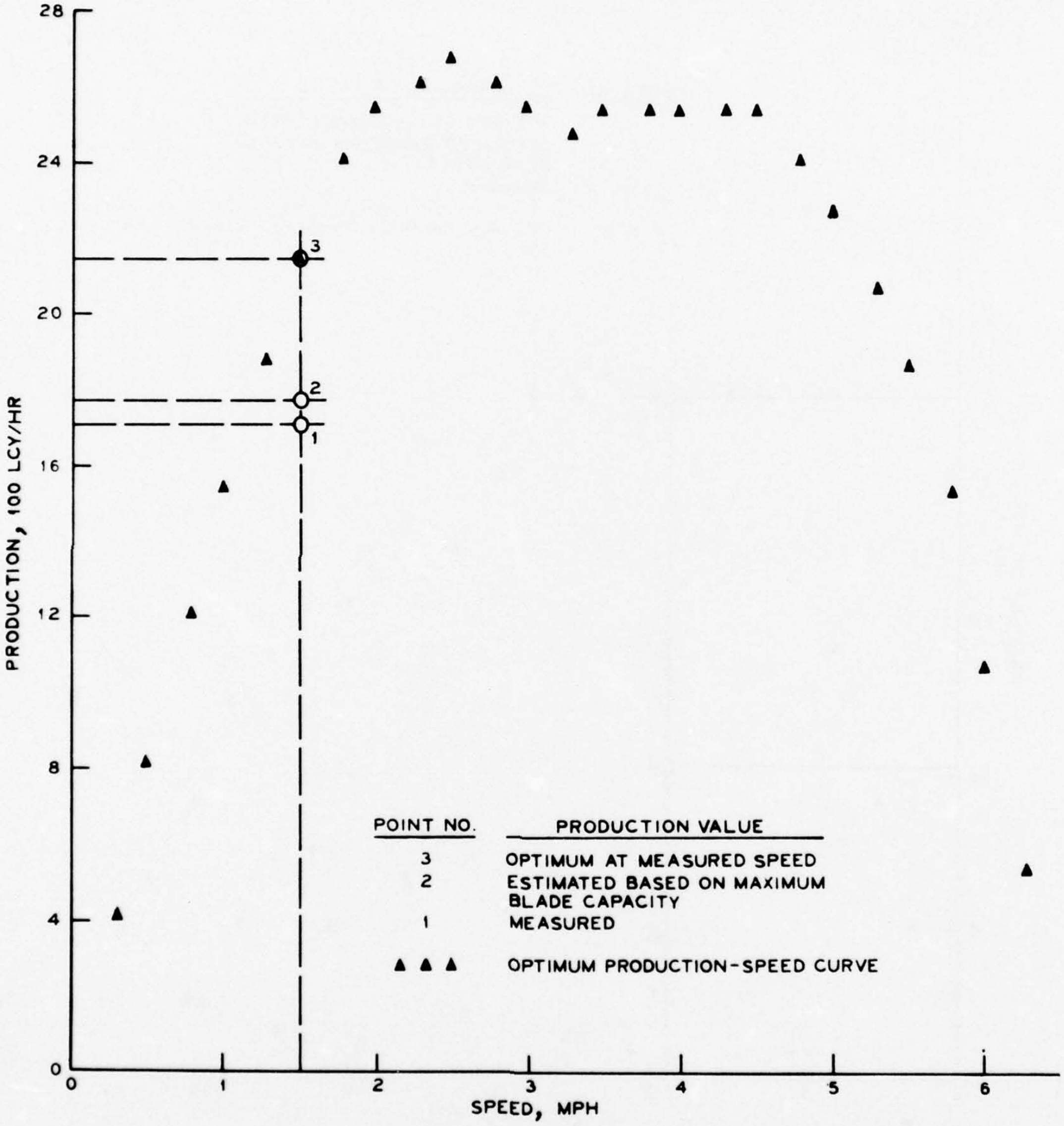


Figure 18. Earthmoving production rates versus speed; D9H/Rec-U blade, area 1

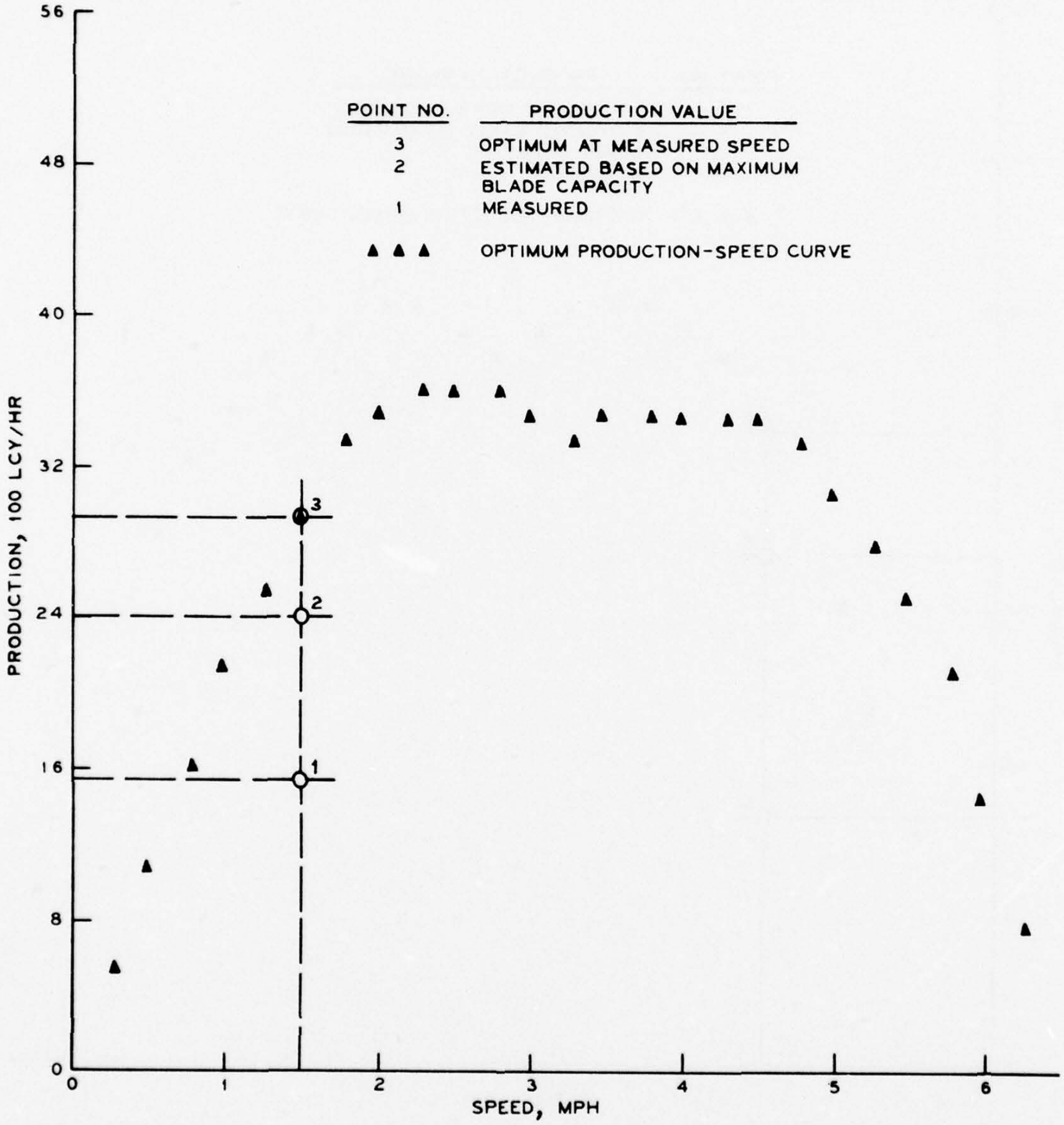


Figure 19. Earthmoving production rates versus speed; D9H/Rec-U blade, area 2

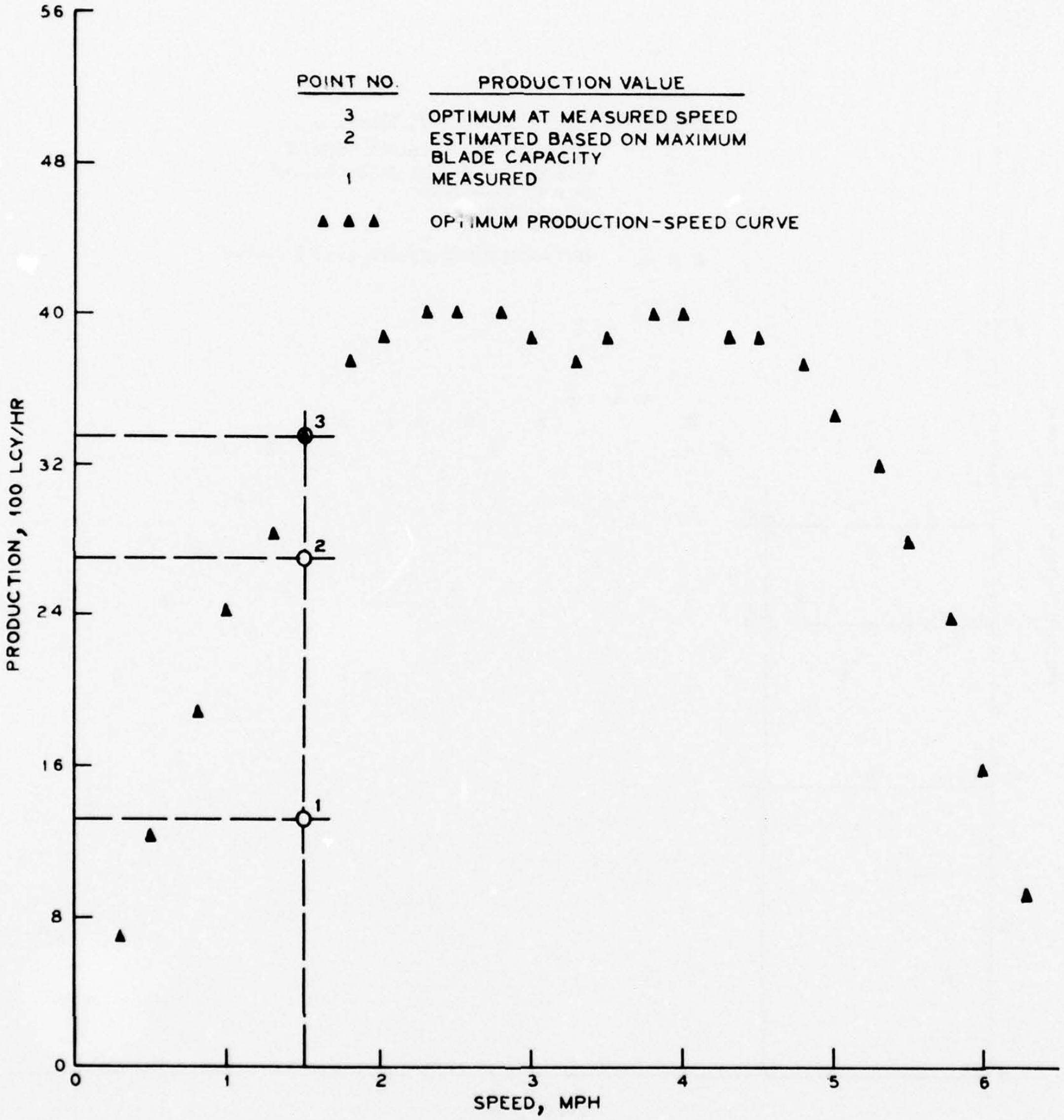


Figure 20. Earthmoving production rates versus speed; D9H/Rec-U blade, area 3

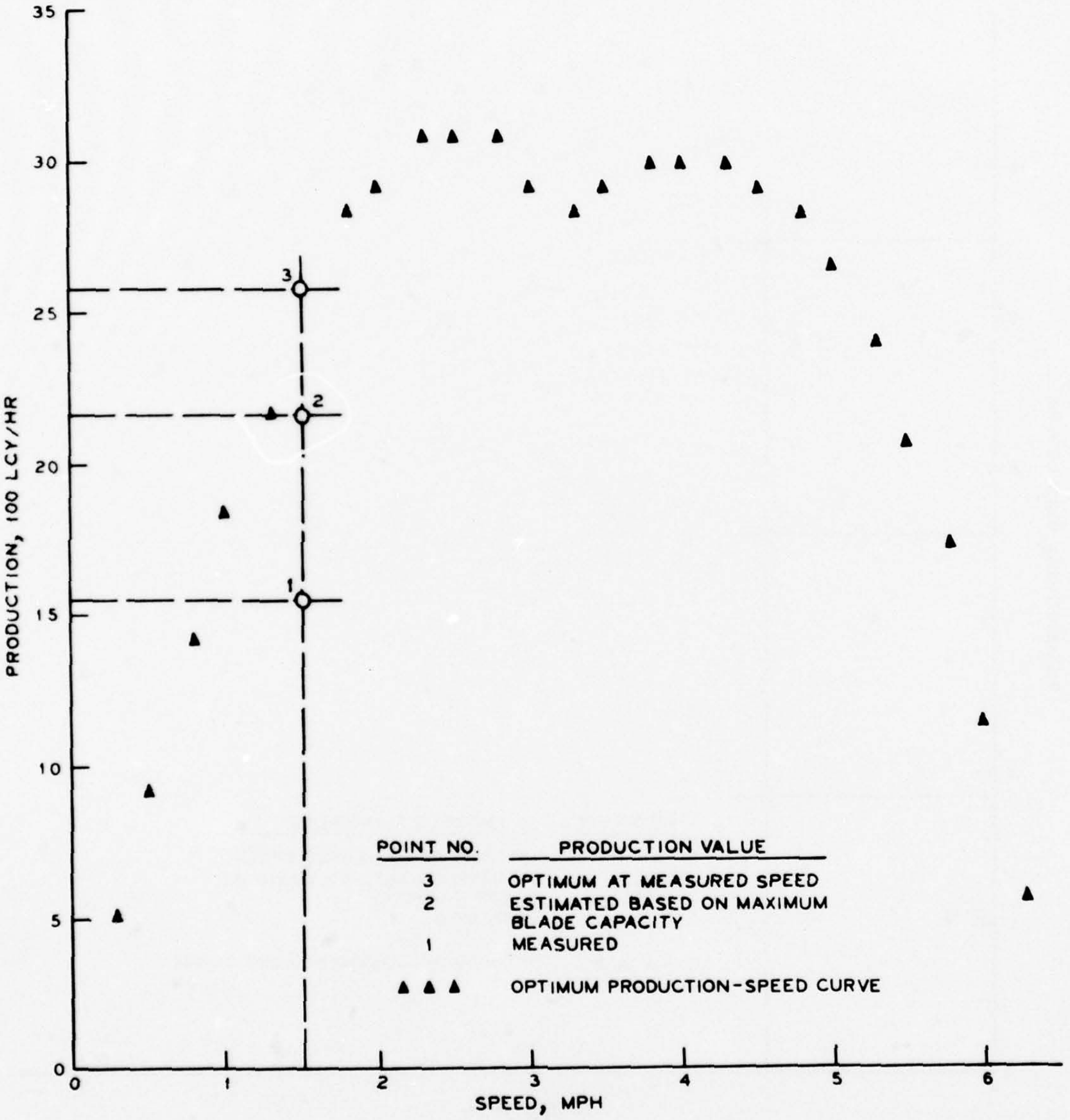


Figure 21. Earthmoving production rates versus speed; D9H/Rec-U blade, area 4

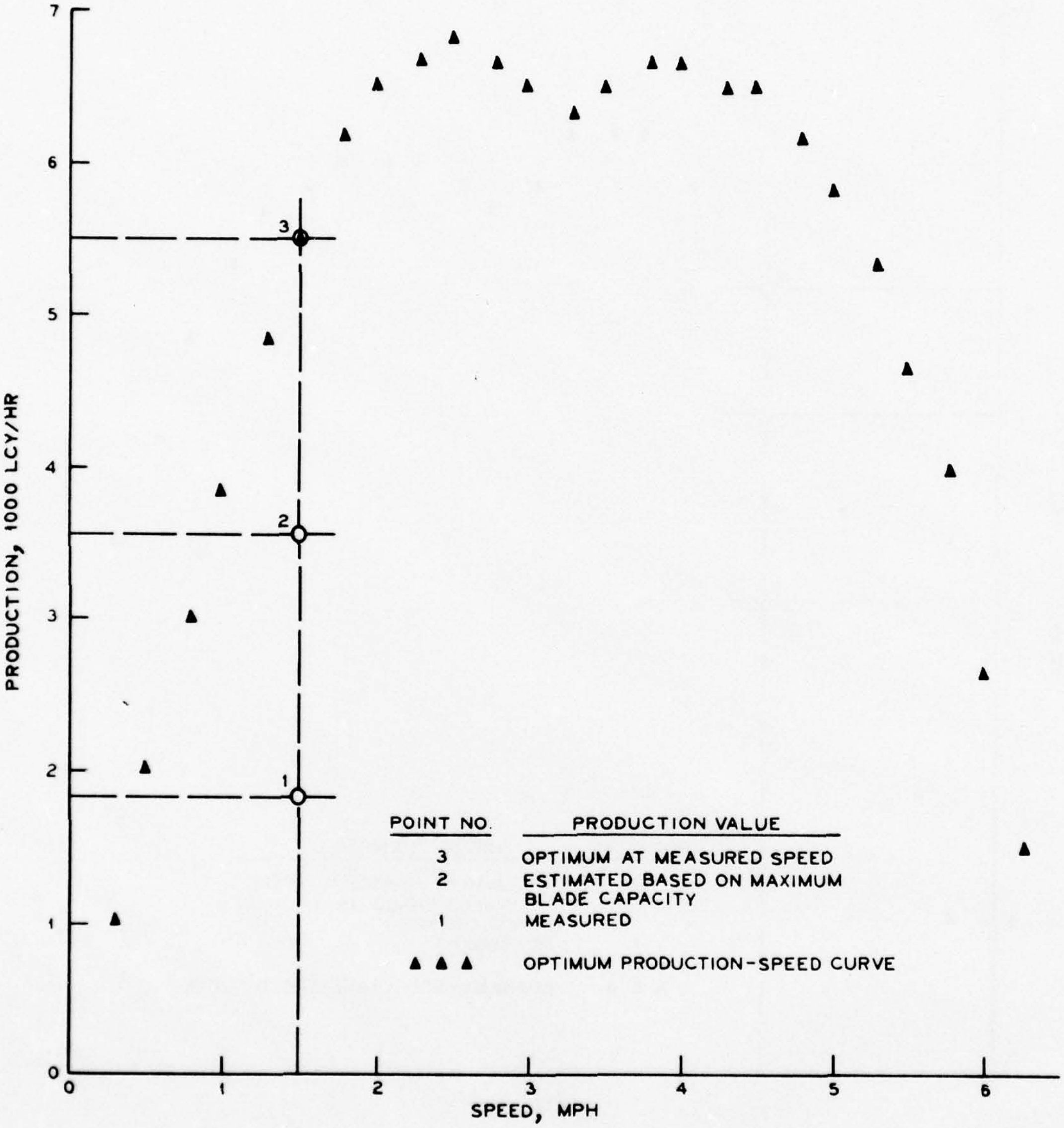


Figure 22. Earthmoving production rates versus speed; D9H/Rec-U blade, area 14

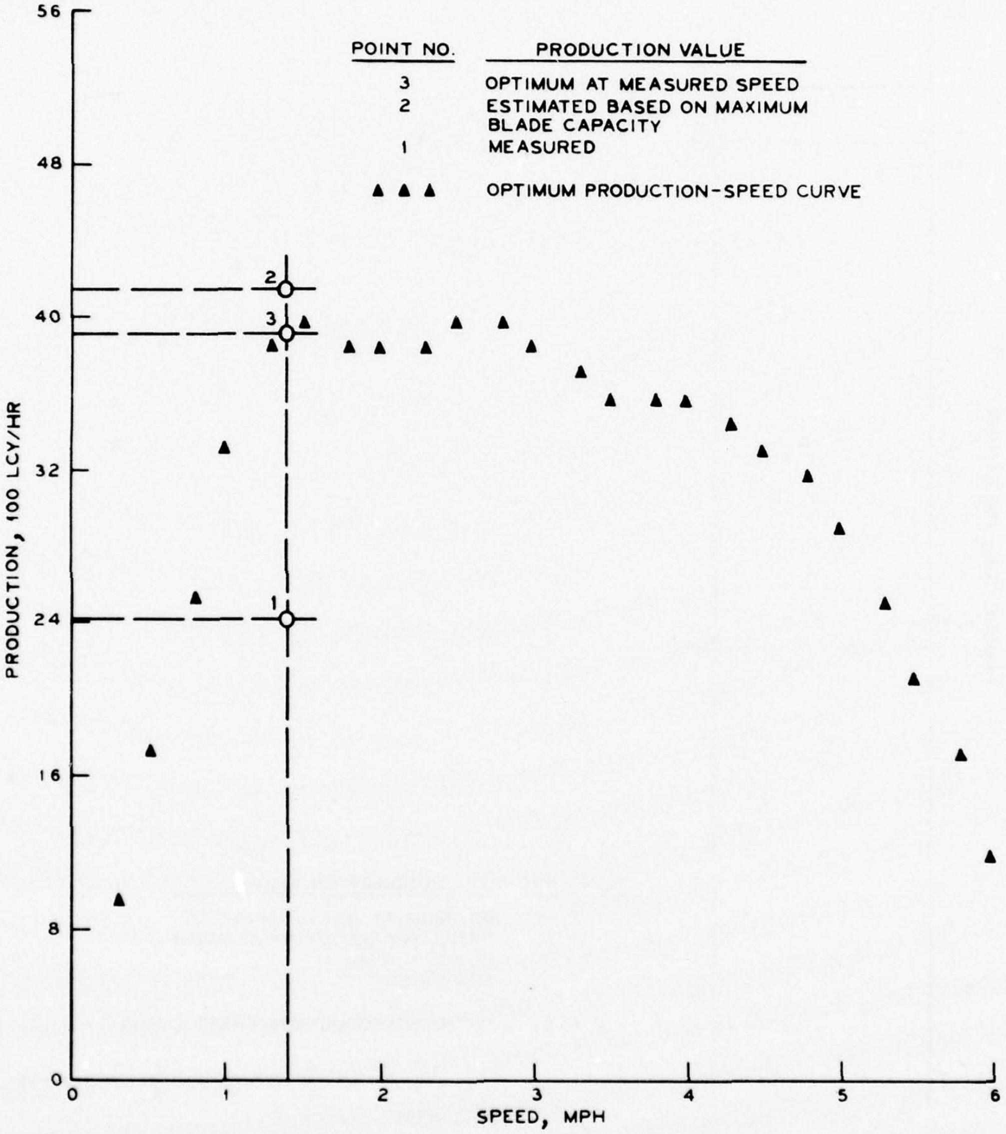


Figure 23. Earthmoving production rates versus speed; 41B/U blade, area 4

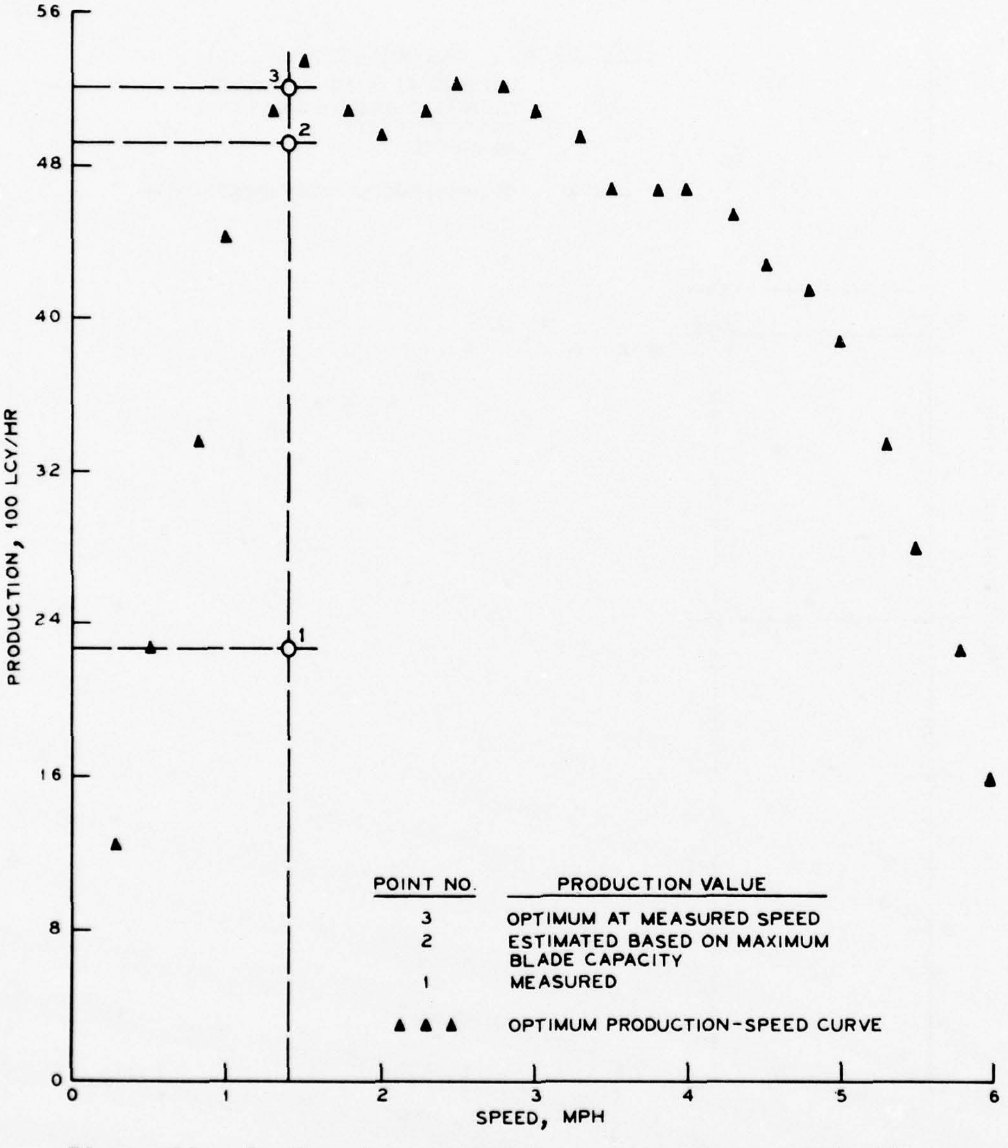


Figure 24. Earthmoving production rates versus speed; 41B/U blade, area 5

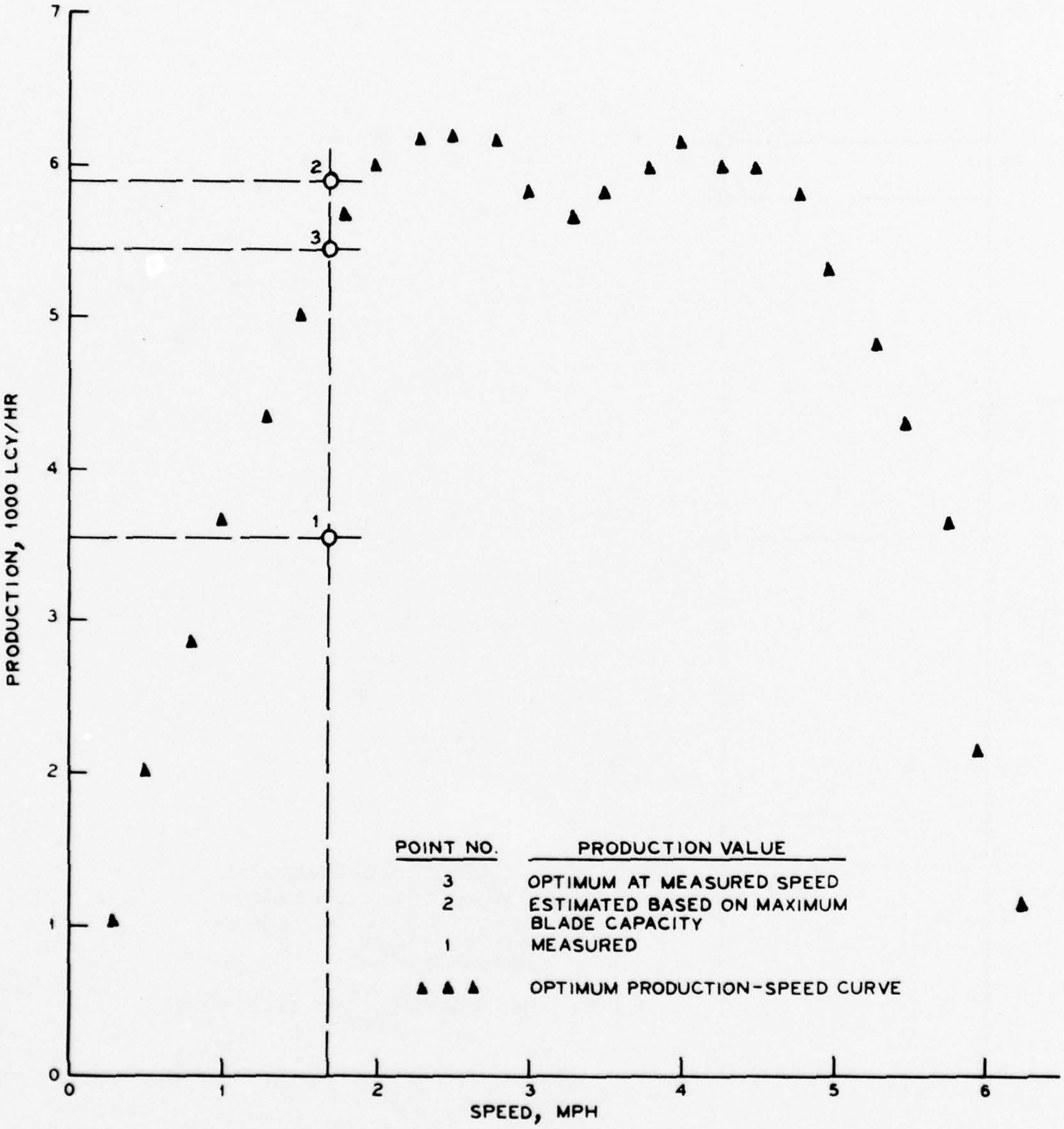


Figure 25. Earthmoving production rates versus speed; SxS D9H/U blade, area 1B

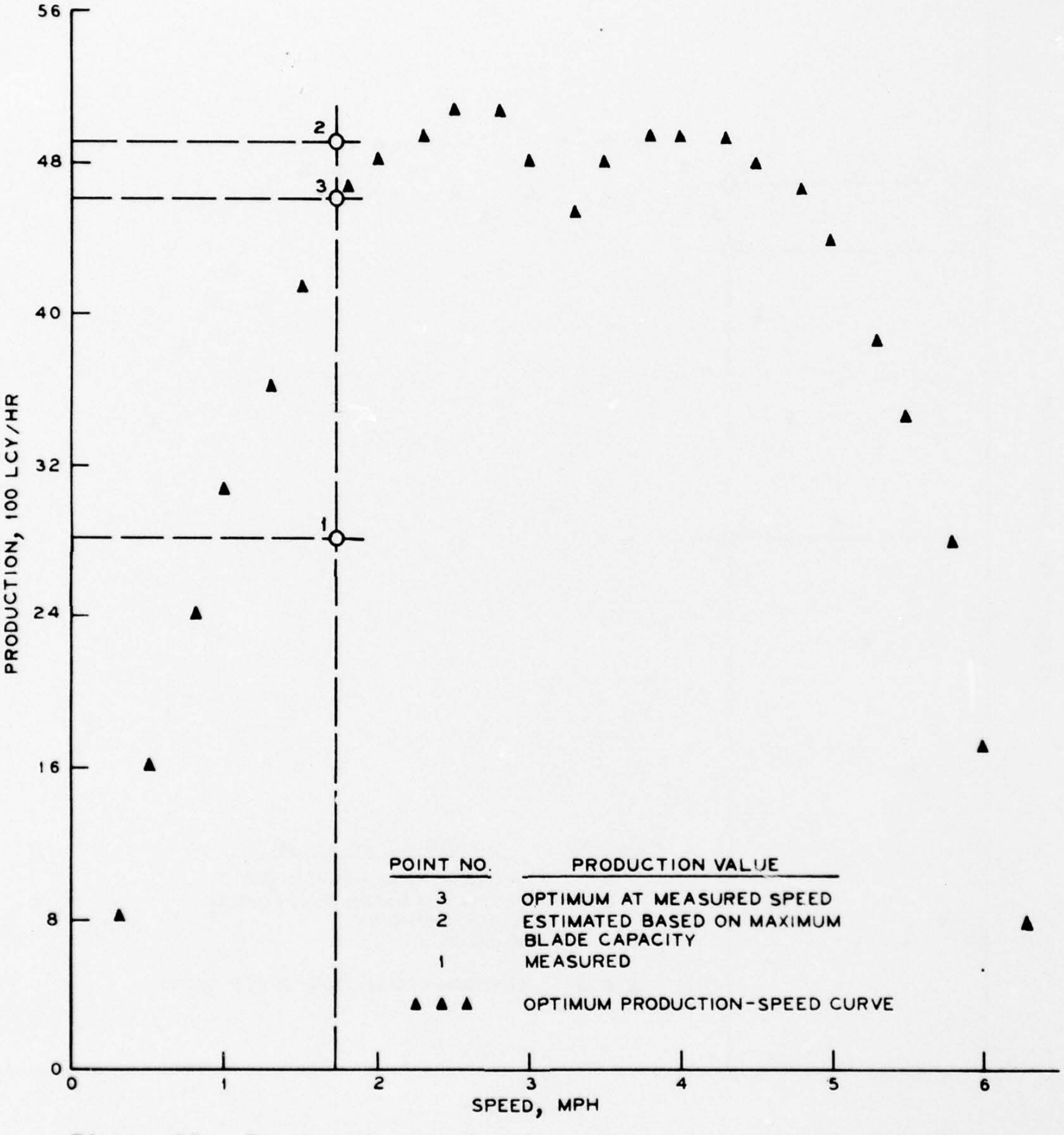


Figure 26. Earthmoving production rates versus speed; SxS D9H/U blade, area 3B

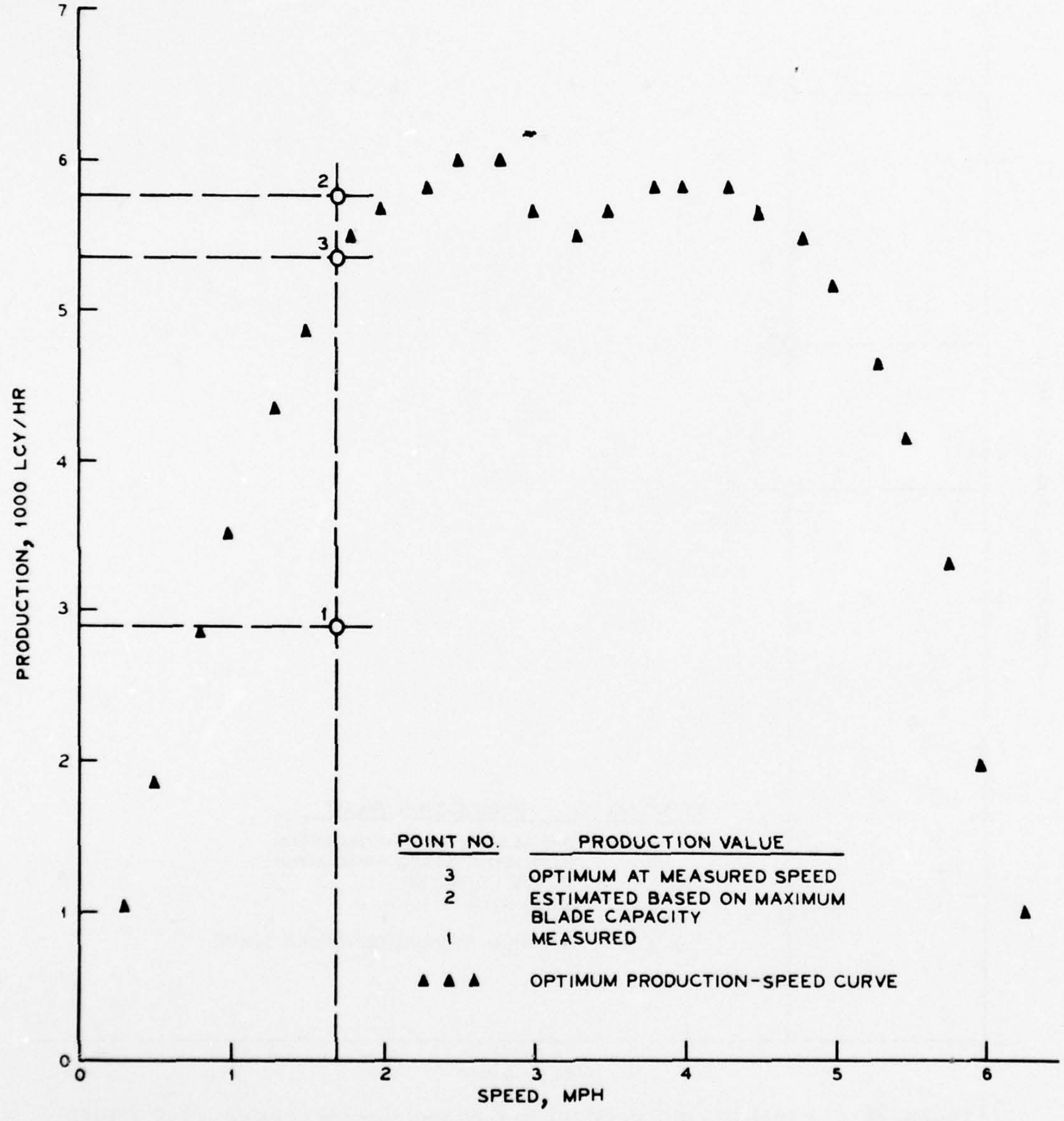


Figure 27. Earthmoving production rates versus speed; SxS D9H/U blade, area 4B

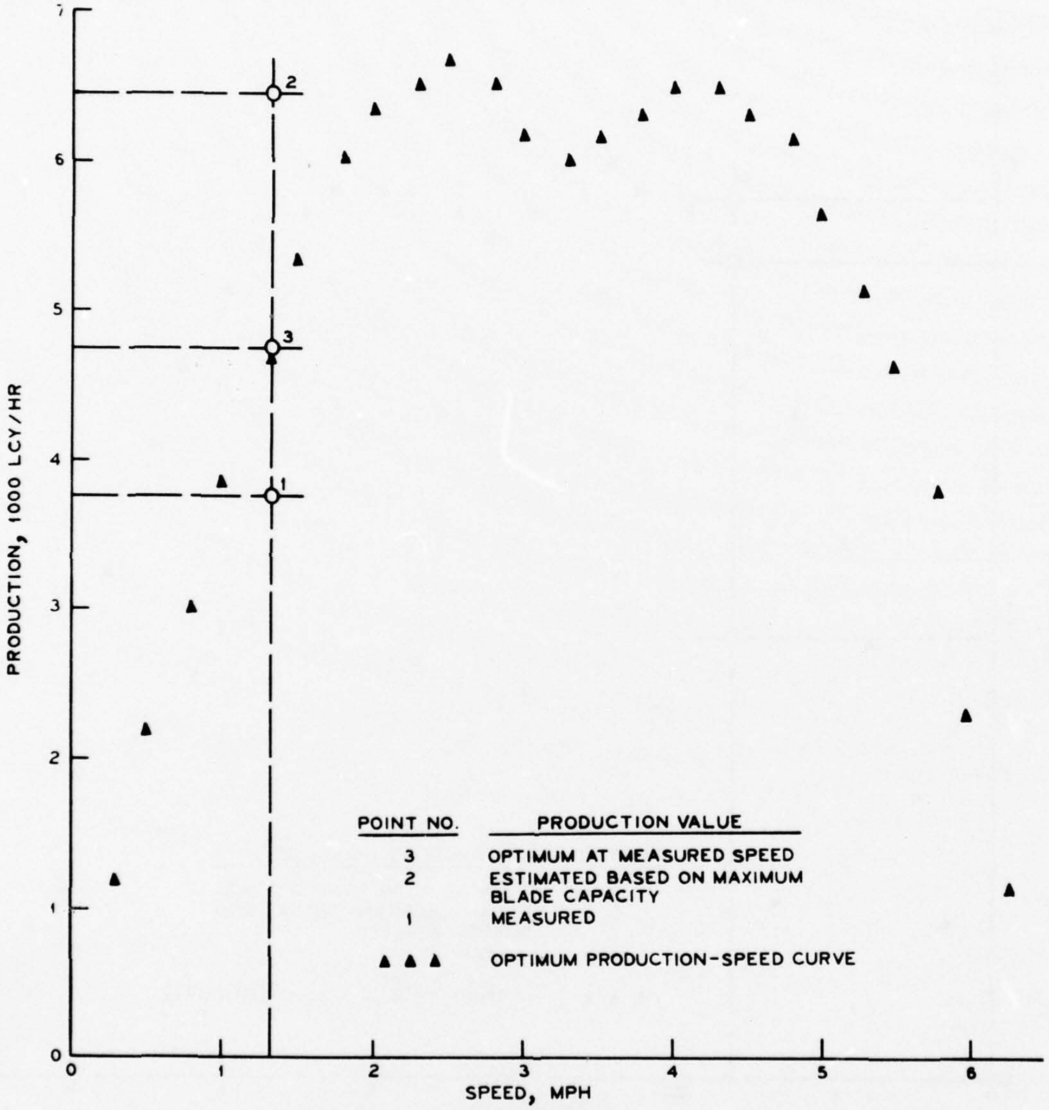


Figure 28. Earthmoving production rates versus speed; SxS D9H/A blade, area 1A

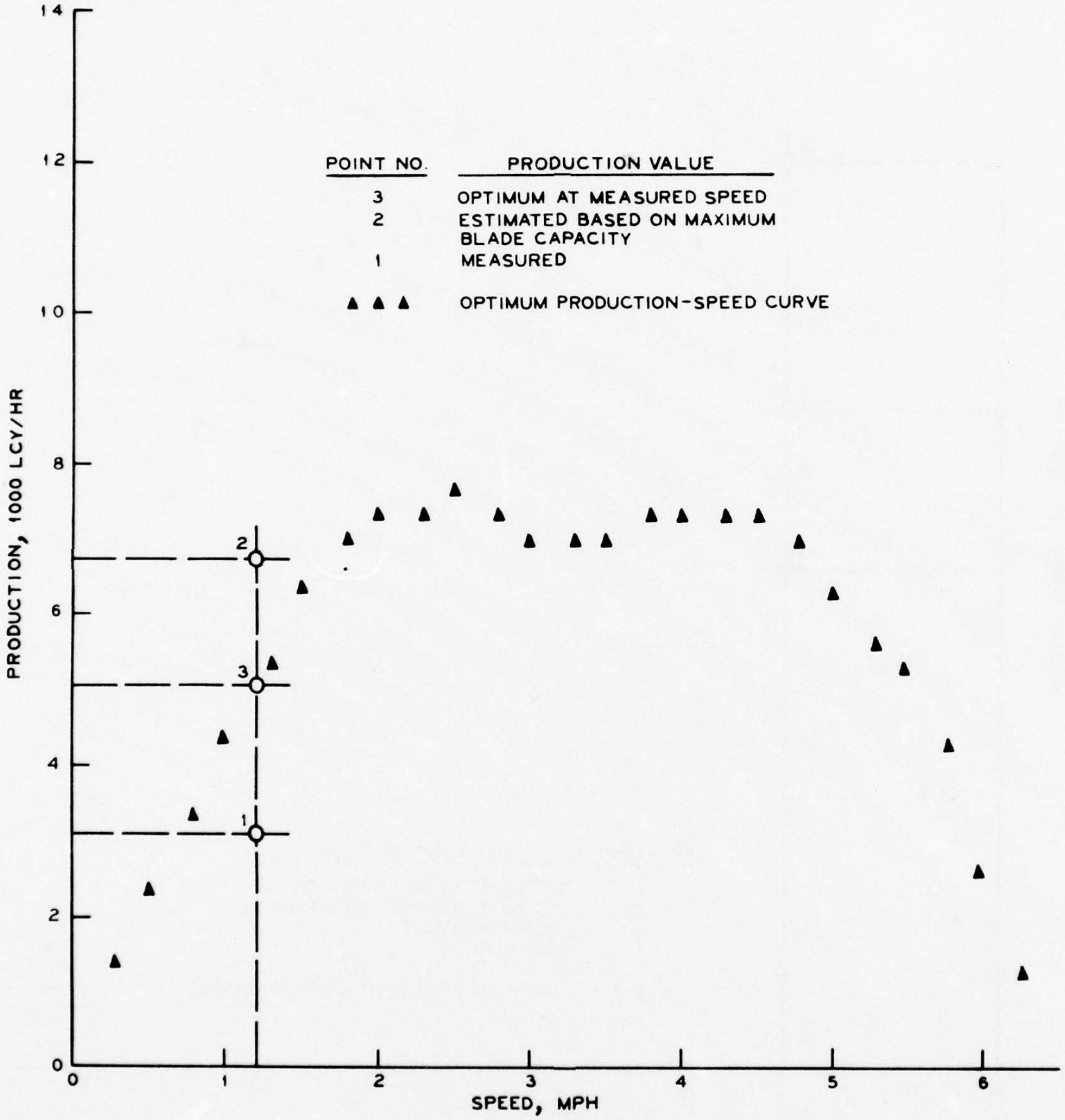


Figure 29. Earthmoving production rates versus speed; SxS D9H/A blade, area 2A

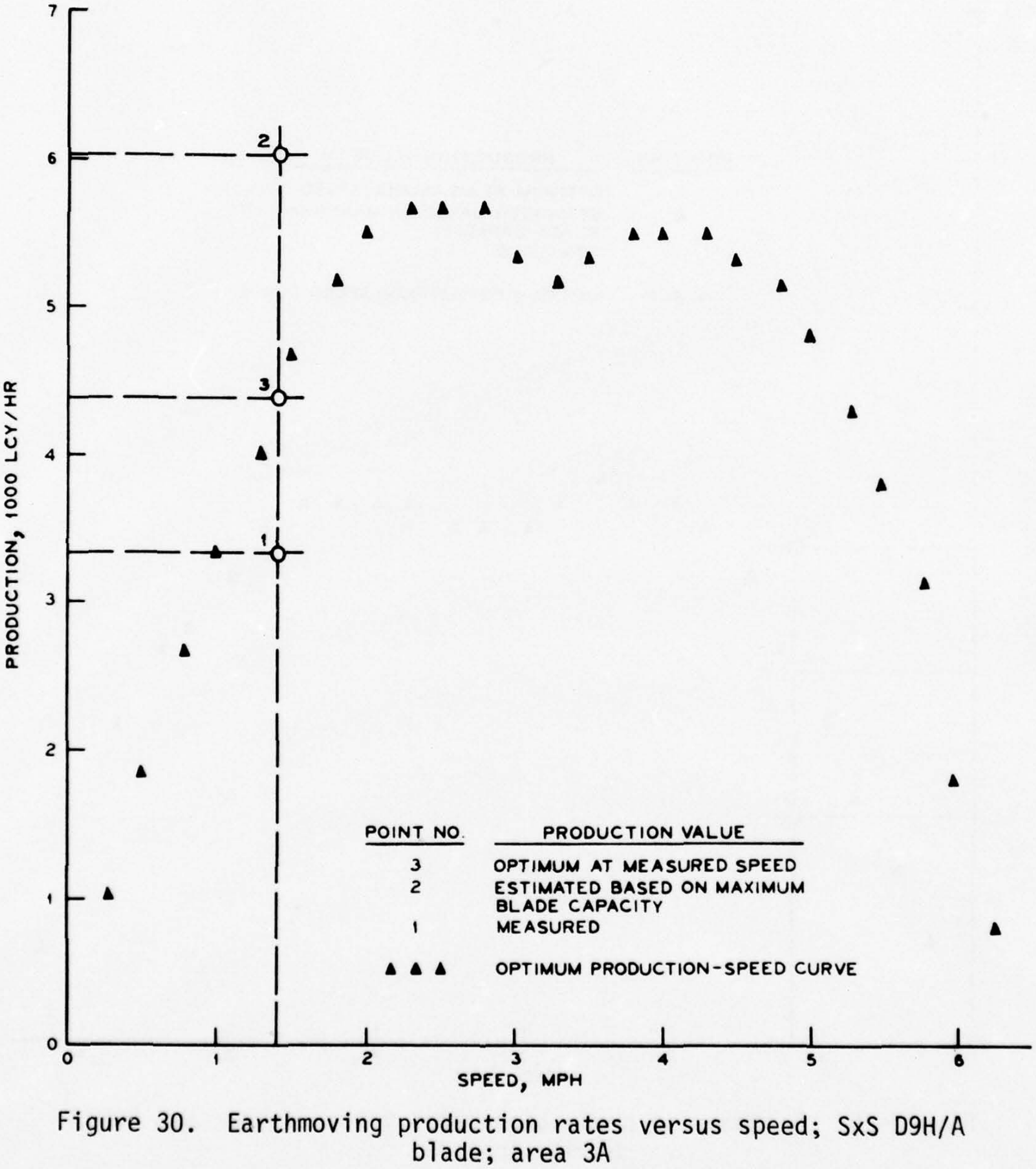


Figure 30. Earthmoving production rates versus speed; SxS D9H/A blade; area 3A

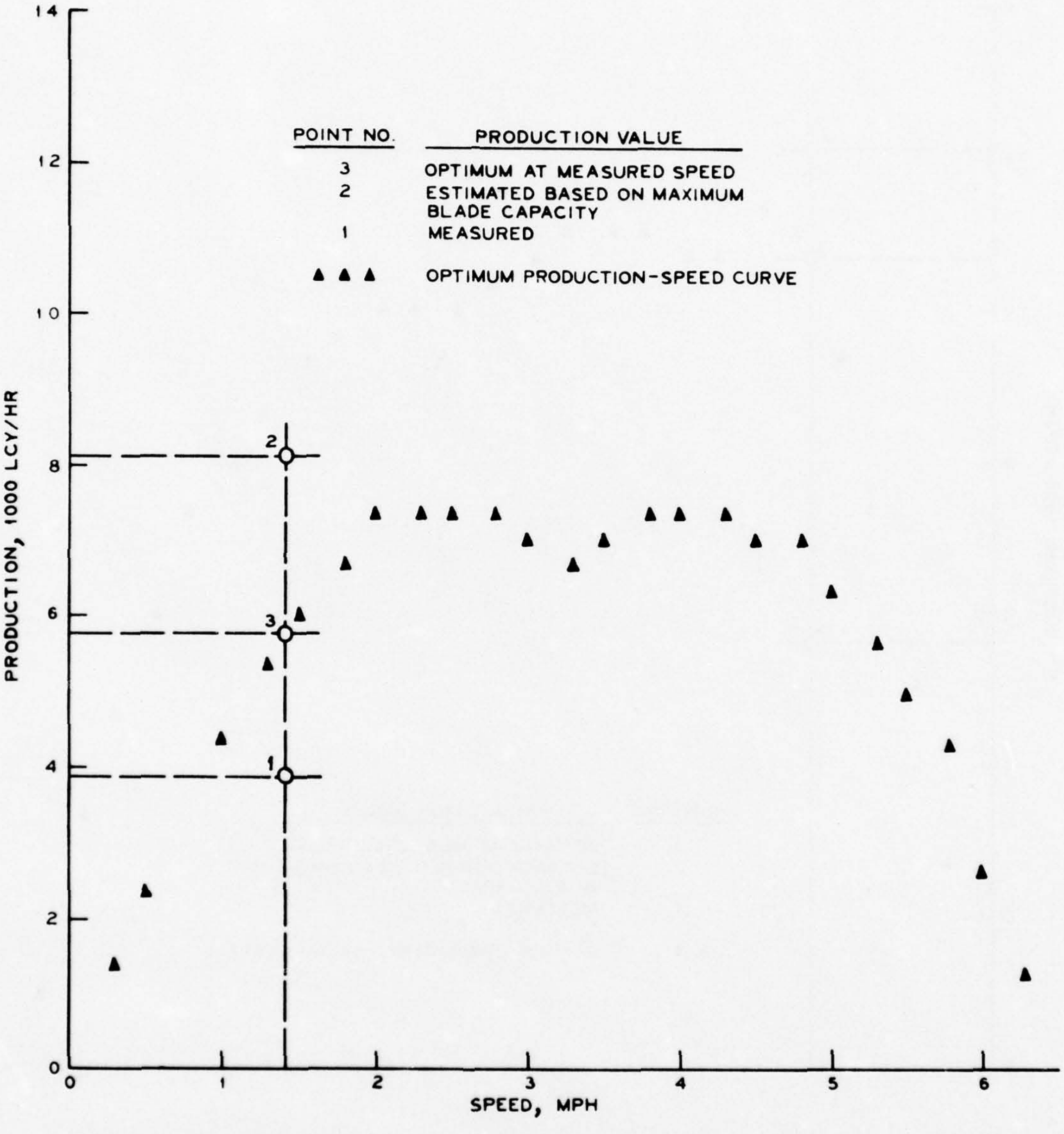


Figure 31. Earthmoving production rates versus speed; SxS D9H/A blade, area 4A

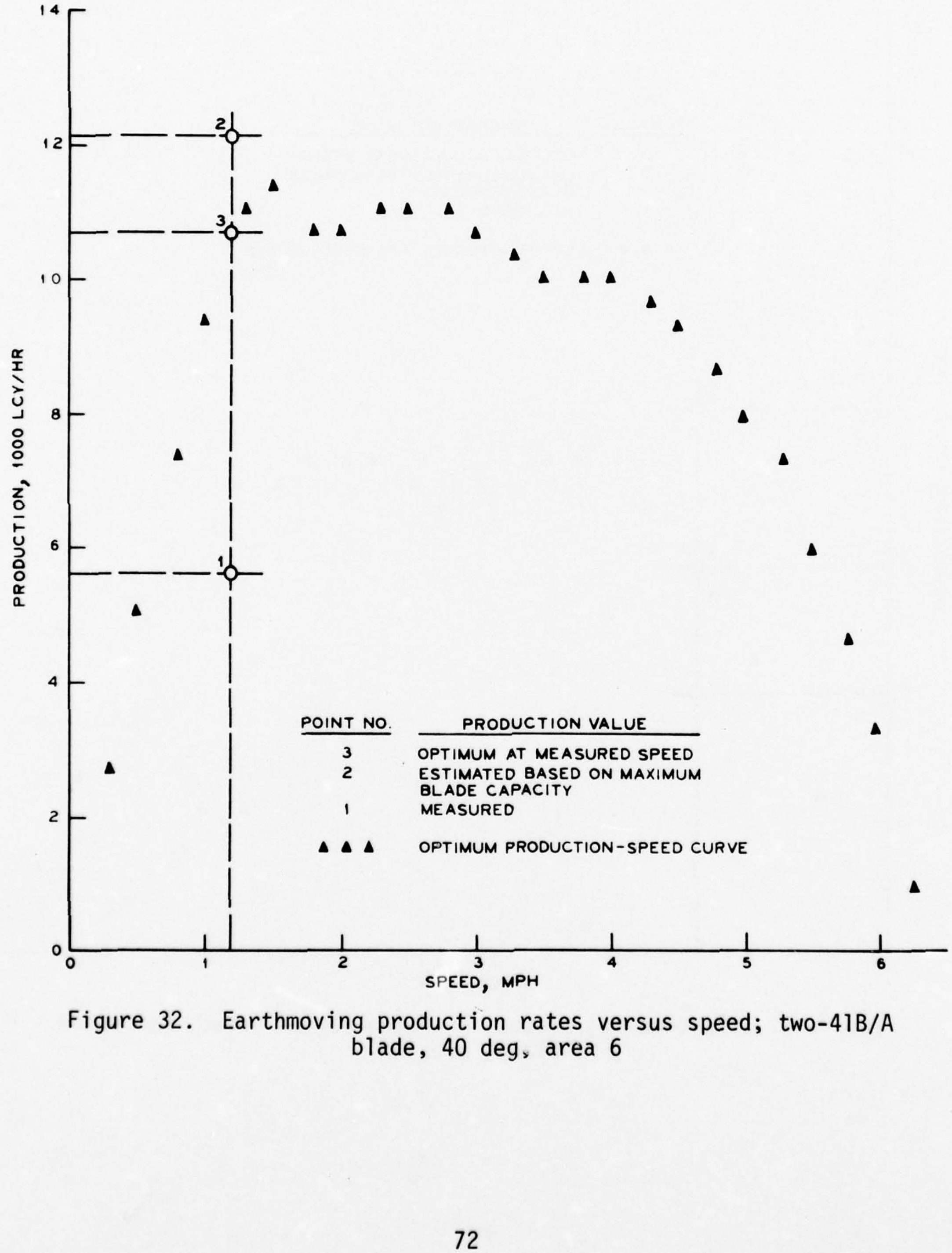


Figure 32. Earthmoving production rates versus speed; two-41B/A blade, 40 deg, area 6

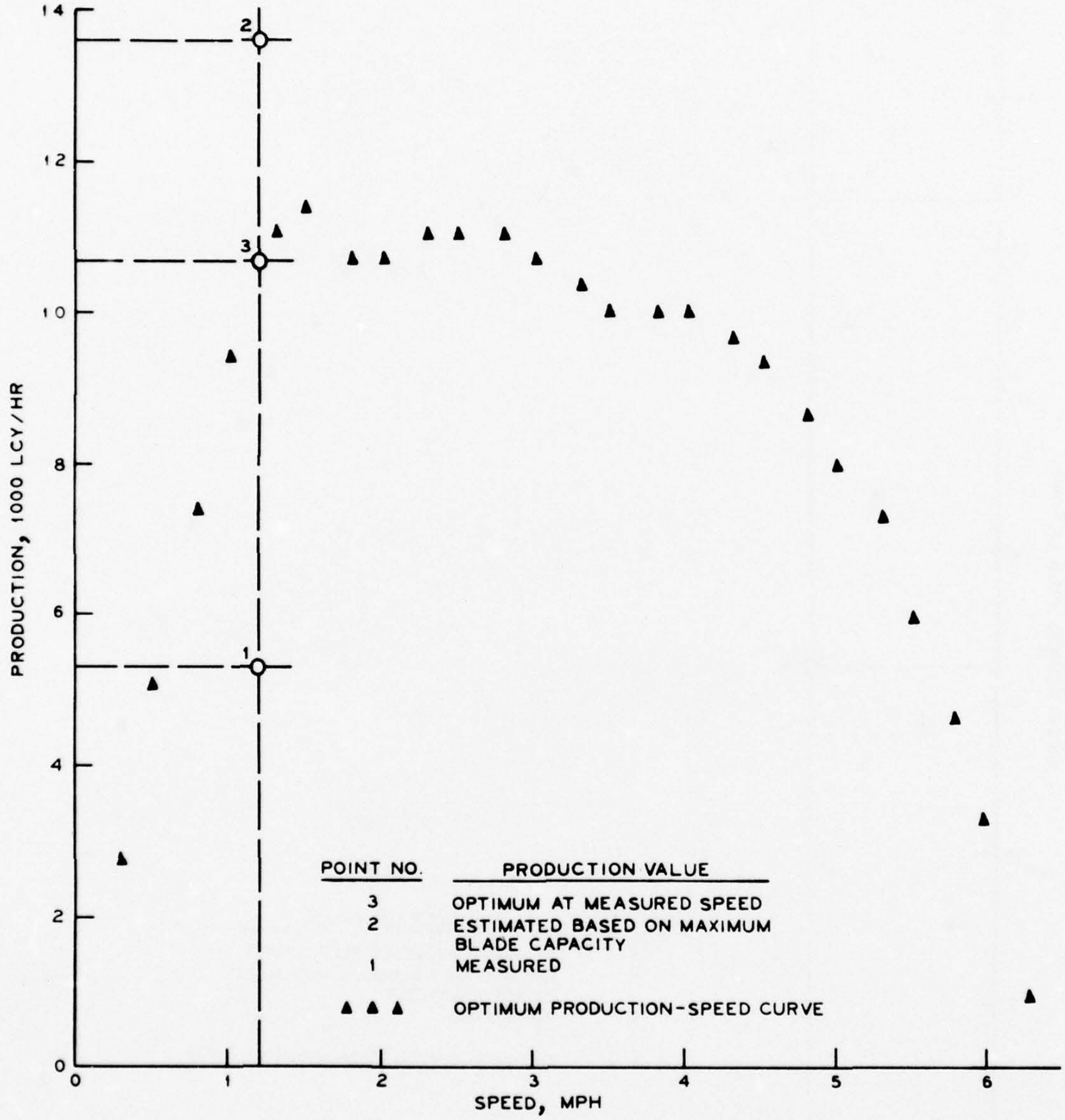


Figure 33. Earthmoving production rates versus speed; two-41B/A blade, 40 deg, area 13

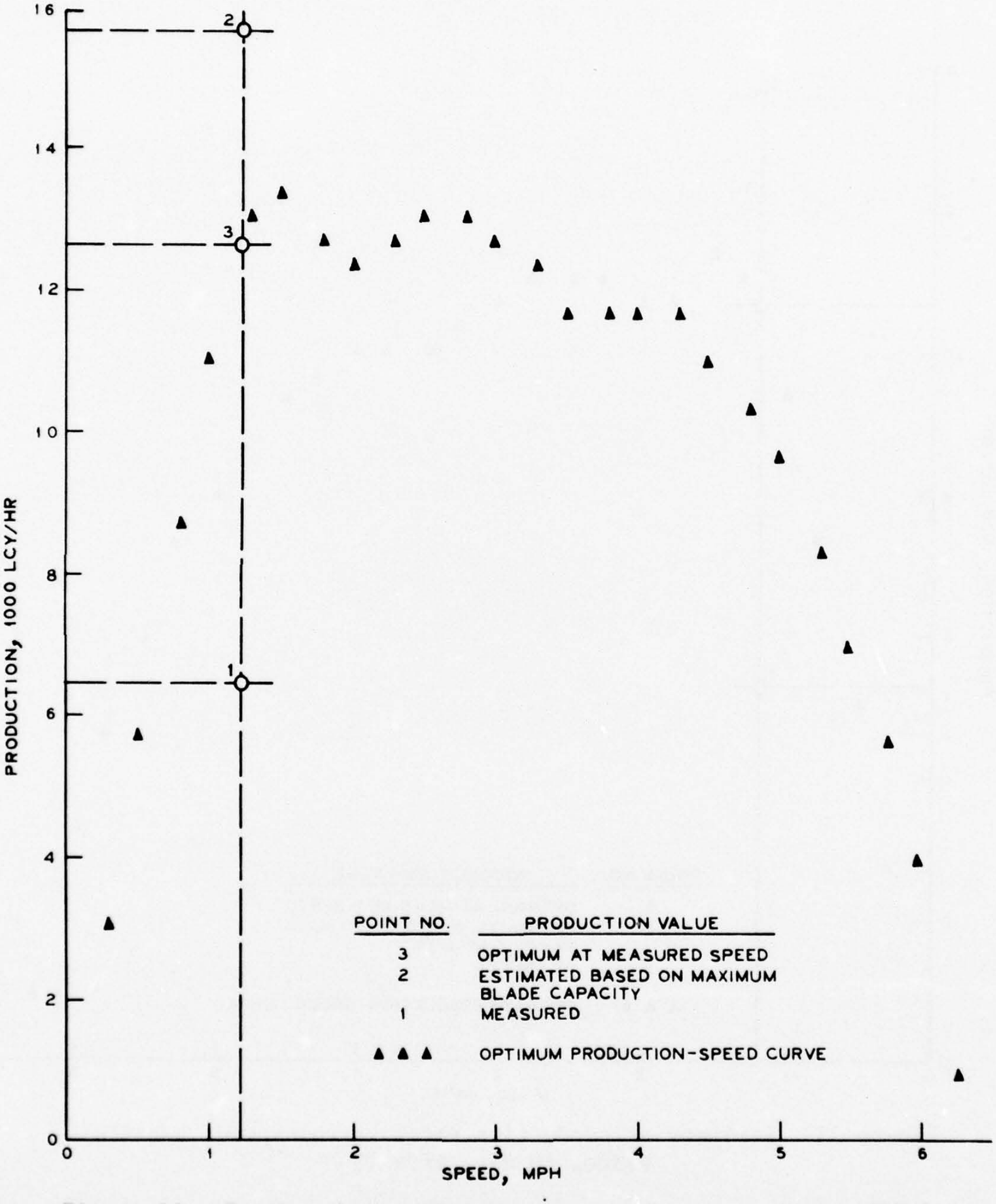


Figure 34. Earthmoving production rates versus speed; two-41B/A blade, 45 deg, area 7

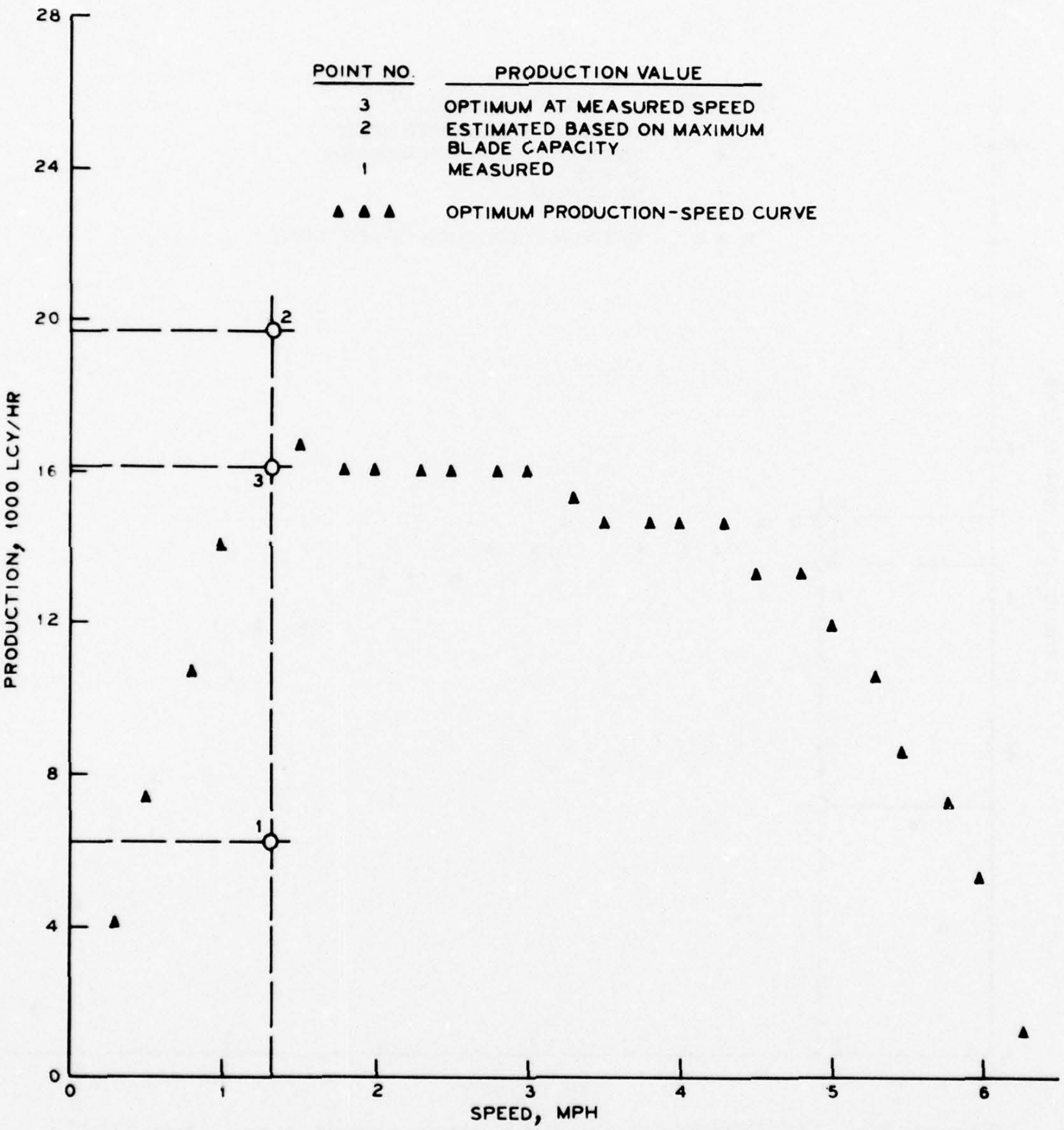


Figure 35. Earthmoving production rates versus speed; two-41B/A blade, 45 deg, area 10B

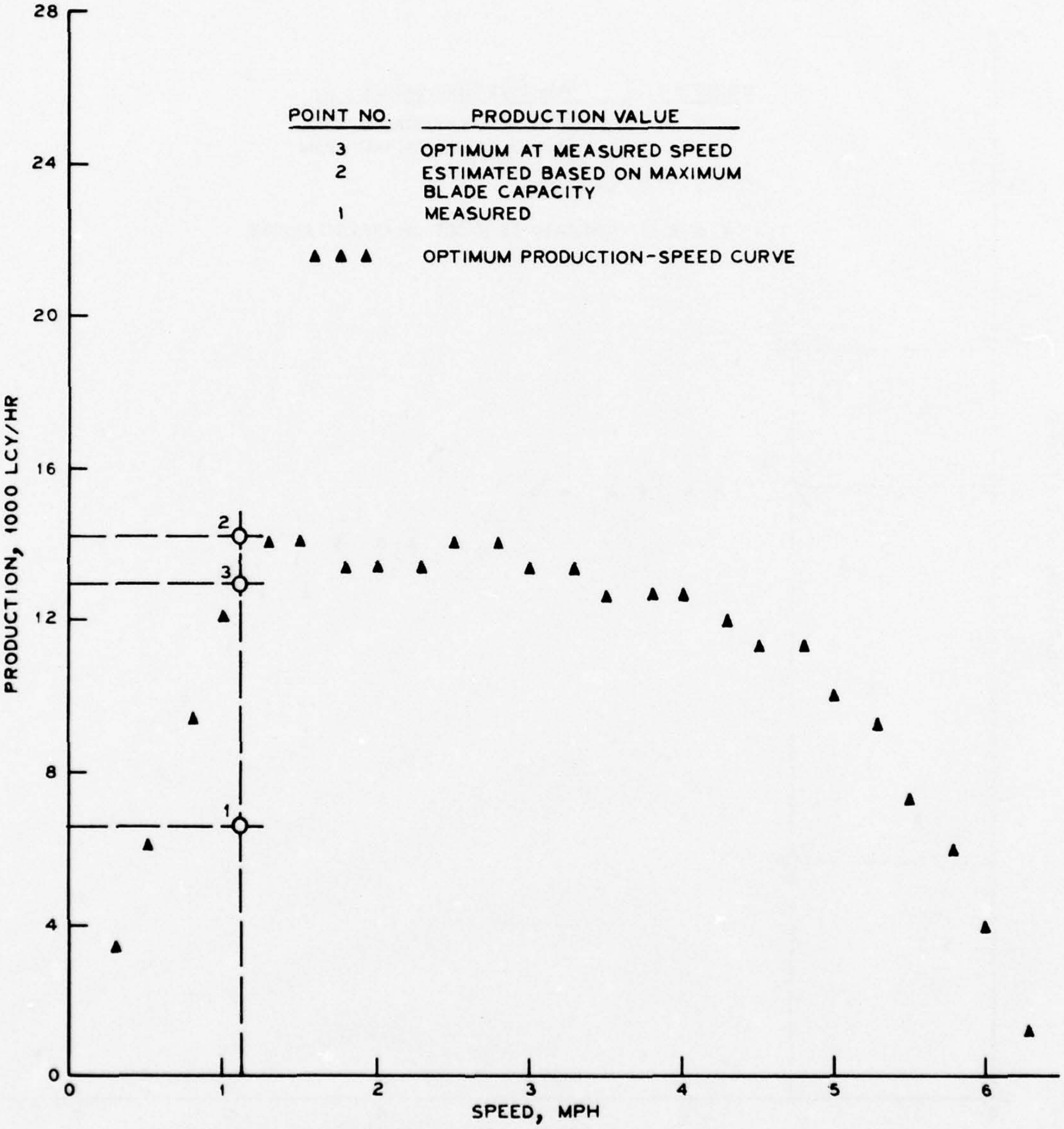


Figure 36. Earthmoving production rates versus speed; two-41B/A blade, 50 deg, area 8

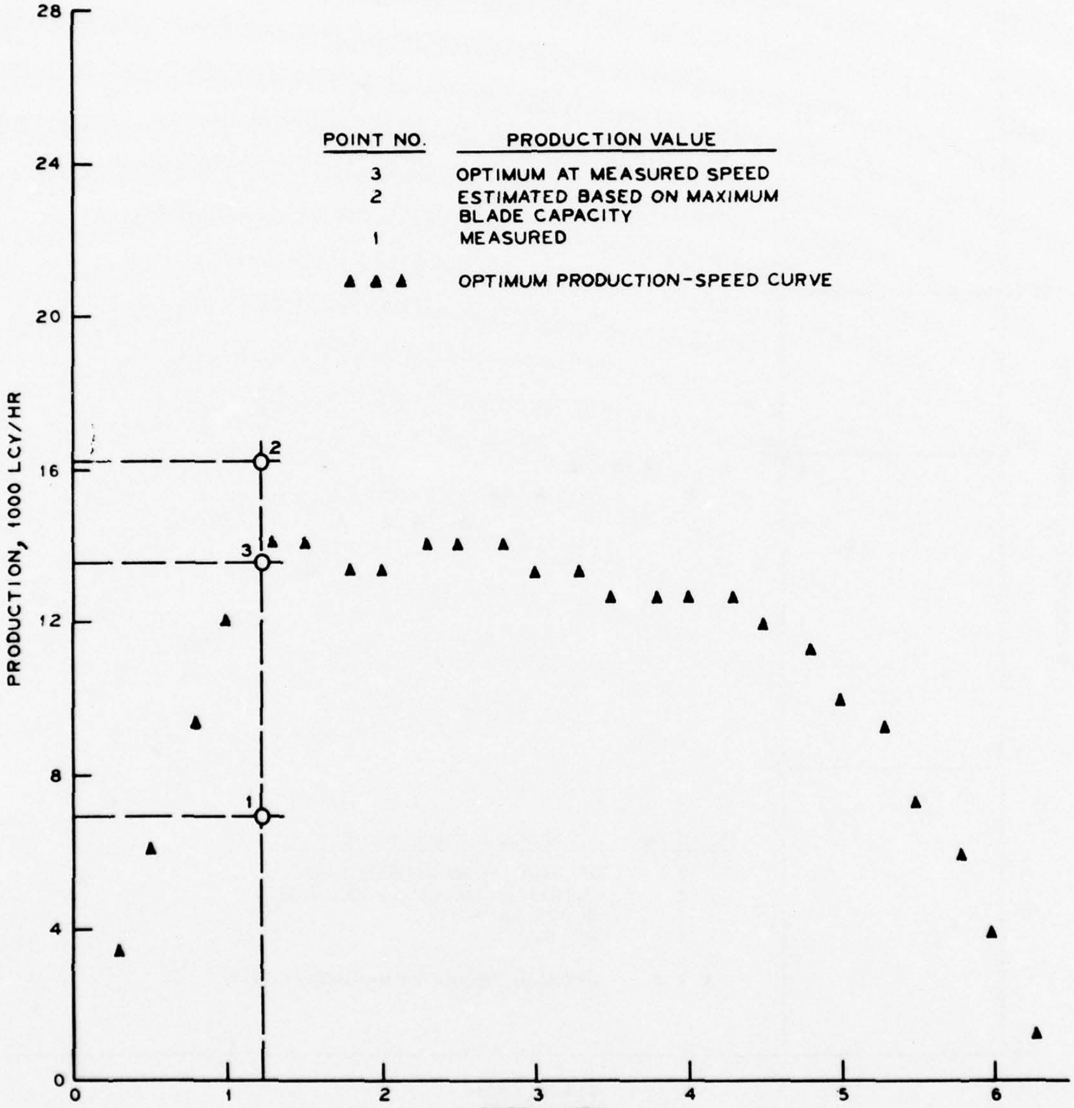


Figure 37. Earthmoving production rates versus speed; two-41B/A blade, 50 deg, area 12B

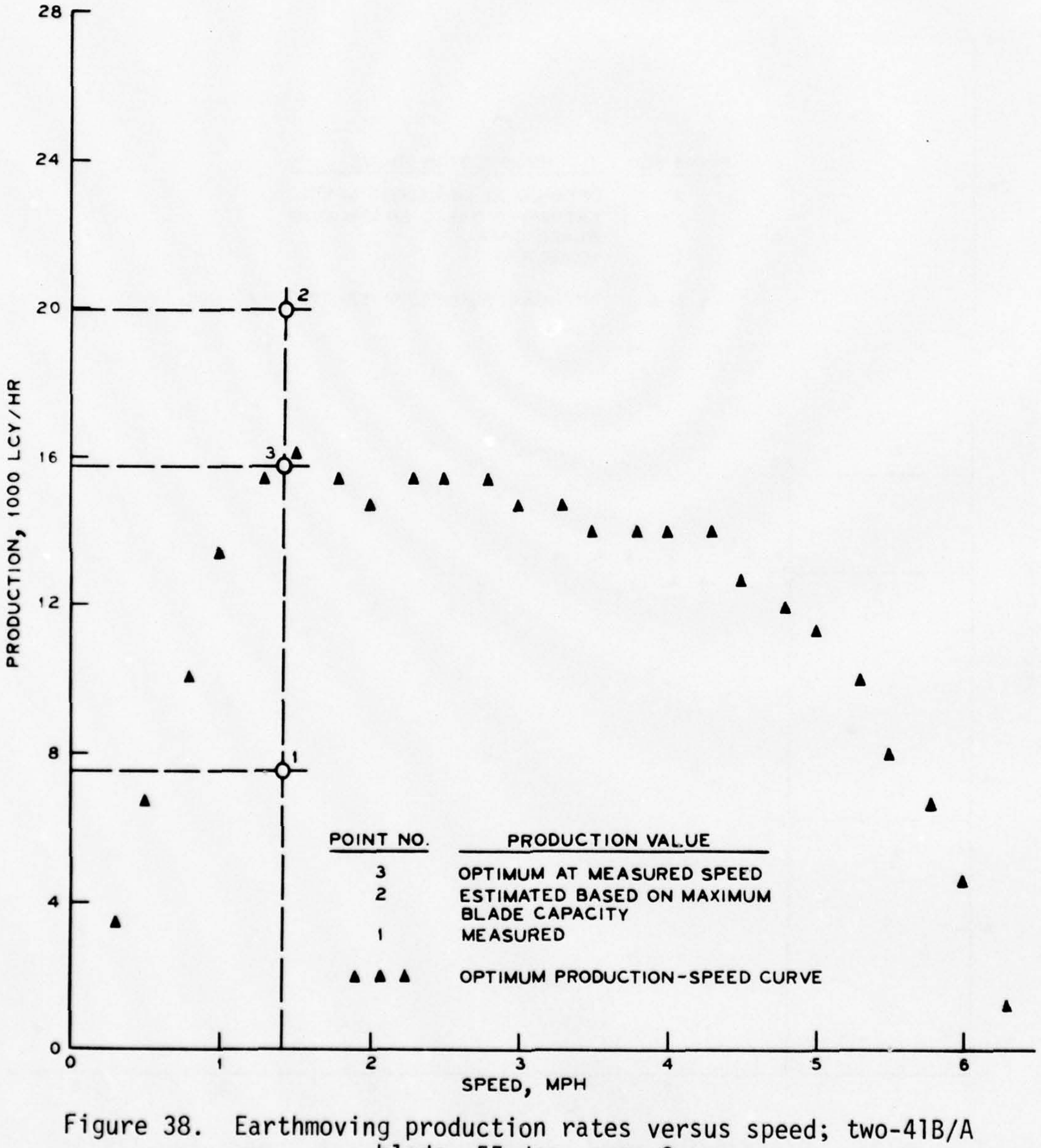


Figure 38. Earthmoving production rates versus speed; two-41B/A blade, 55 deg, area 9

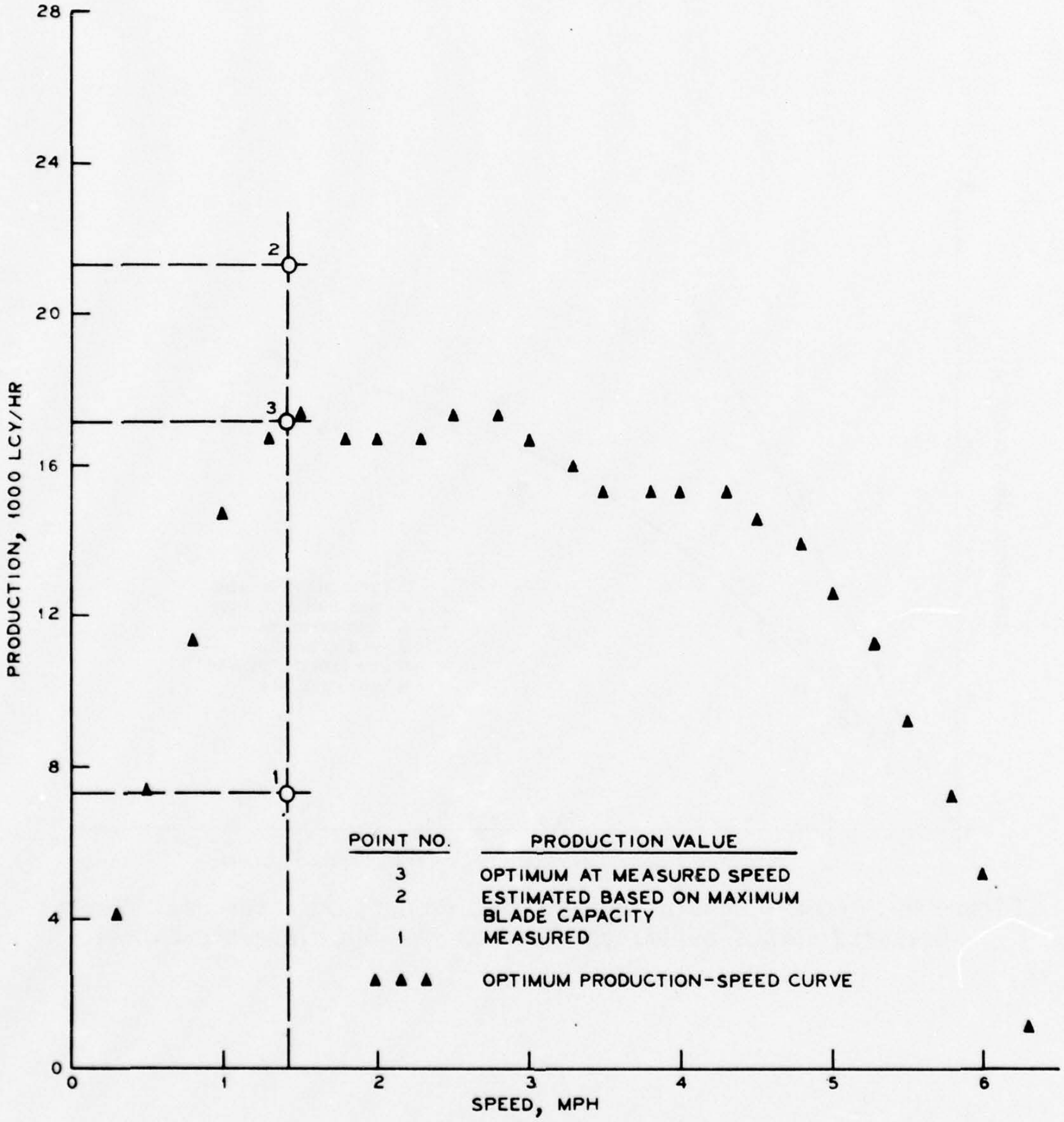


Figure 39. Earthmoving production rates versus speed; two-41B/A blade, 55 deg, area 11

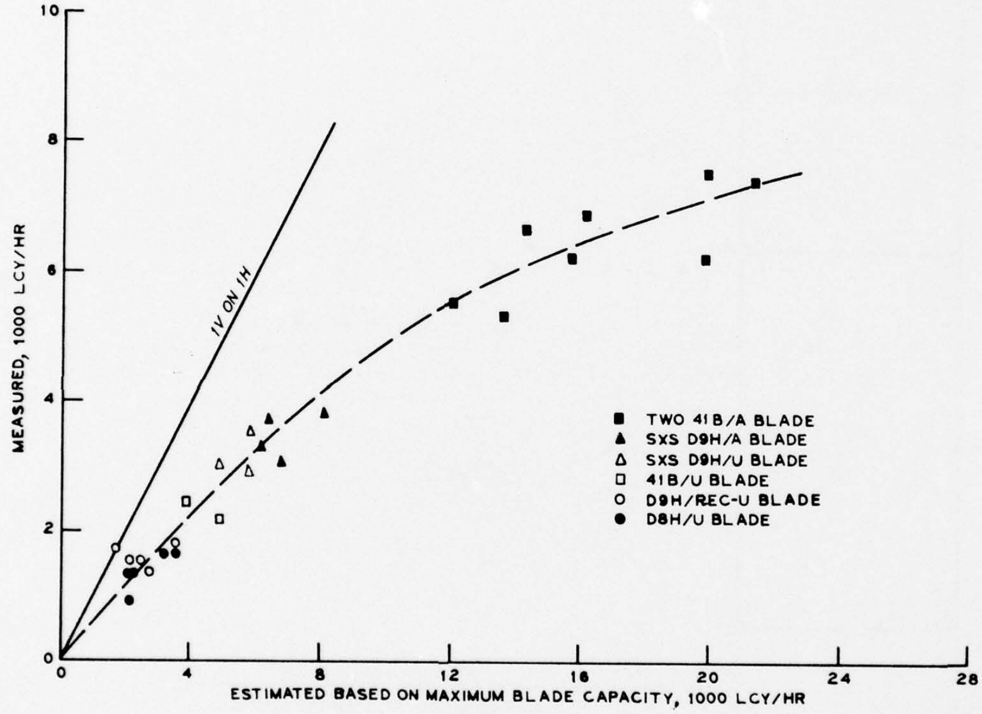


Figure 40. Comparisons of earthmoving production rates, all dozers; measured versus estimated based on maximum blade capacities

Table 6

Summary of Earthmoving Production Rates

	Earthmoving Production Values, LCY/hr			
Area	Measured	Estimated Based on Maximum Blade Capacity	Optimum at Measured Speed	Optimum at Optimum Speed
		D8H/S Blade		
1	910	2,151	2,348	2,386
2	1326	2,205	2,360	2,443
3	1355	2,007	2,168	2,226
10A	1628	3,200	4,200	4,286
12A	1573	3,618	3,618	3,693
		D9H Rec-U Blade		
1	1702	1,764	2,156	2,635
2	1573	2,408	2,951	3,607
3	1339	2,702	3,311	4,047
4	1559	2,170	2,544	3,100
14	1842	3,584	5,533	6,762
		41B/U Blade		
4	2495	3,960	4,350	4,038
5	2262	4,920	5,200	5,277
		SxS D9H/U Blade		
1B	3550	5,910	5,460	6,229
3B	3041	4,913	4,624	5,075
4B	2907	5,803	5,380	5,998
		SxS D9H/A Blade		
1A	3753	6,480	4,750	6,595
2A	3056	6,912	5,040	7,571
3A	3320	6,096	4,390	5,687
4A	3897	8,064	5,800	7,497
		Two 41B/A Blade (40 deg)		
6	5590	12,096	10,586	11,242
13	5344	13,608	10,777	11,231

(Continued)

Table 6 (Concluded)

	Earthmoving Production Values, LCY/hr			
Area	Measured	Estimated Based on Maximum Blade Capacity	Optimum at Measured Speed	Optimum at Optimum Speed
		Two 41B/A Blade (45 deg)		
7	6231	15,624	12,640	13,231
10B	6698	14,280	13,000	14,090
		Two 41B/A Blade (50 deg)		
8	6242	19,908	16,160	16,639
12B	6961	16,128	13,640	14,222
		Two 41B/A Blade (55 deg)		
9	7543	19,992	15,600	15,737
11	7497	21,336	17,200	17,472

D9H/U blade having the best efficiency (66.9 percent) and the two 41B/A blade having the worst efficiency (40 percent). Two observations were made: (a) the A blades seldom dozed with the blade near maximum capacity, and (b) some spoil banks were not of the configuration desired for maximum performance of the A blades. Specifically, they were too narrow on at least the first two passes to take advantage of the 60-ft blade width.

Estimated production based on maximum blade capacity does not take into account dozing speed, which is an important factor when computing loose cubic yard/hr of soil moved. For the comparison herein, it was assumed that measured speeds were the same for both measured and estimated production rates.

Optimum production rates at measured speeds

The optimum earthmoving production rates at measured speeds are determined from Figures 13 through 39 at the points of intersection of the measured speed values and the optimum production-speed curve, e.g., in Figure 13, point 3 with a production value of 2348 LCY/hr. All point 3 values were computed during the computer printing of Figures 13 through 39. Table 6 summarizes these values of optimum production at measured speeds for all tests. Figure 41 shows the measured production values versus optimum production at measured speed values for each test. This figure also indicates that all tractor dozers were operating considerably under optimum capabilities at measured dozing speeds. The overall efficiency was 55.6 percent for this analysis; the best efficiency was 70.6 percent for the SxS D9H/A blade; and the worst efficiency was 49.0 percent for the two 41B/A blade.

Optimum production rates at optimum speed

The optimum earthmoving production rates at optimum speeds were computed during the computer printing of Figures 13 through 39. Table 6 summarizes the values of optimum production at optimum speeds for all tests. Figure 42 shows the measured production values versus optimum production at optimum speed values for each test. The overall

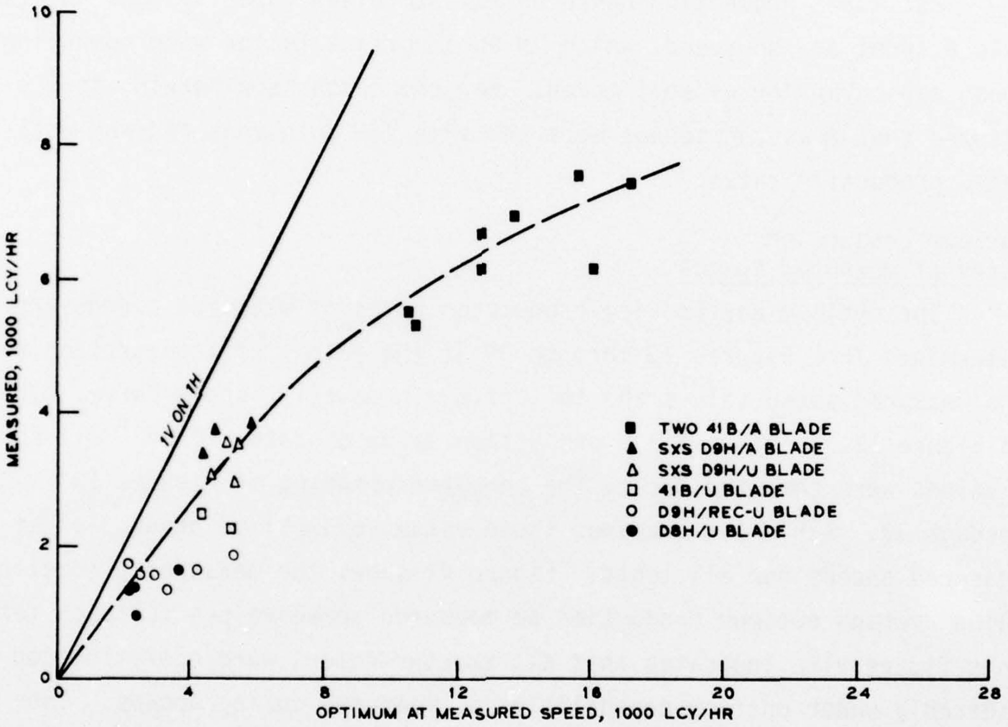


Figure 41. Comparisons of earthmoving production rates, all dozers; measured versus optimum at measured speed

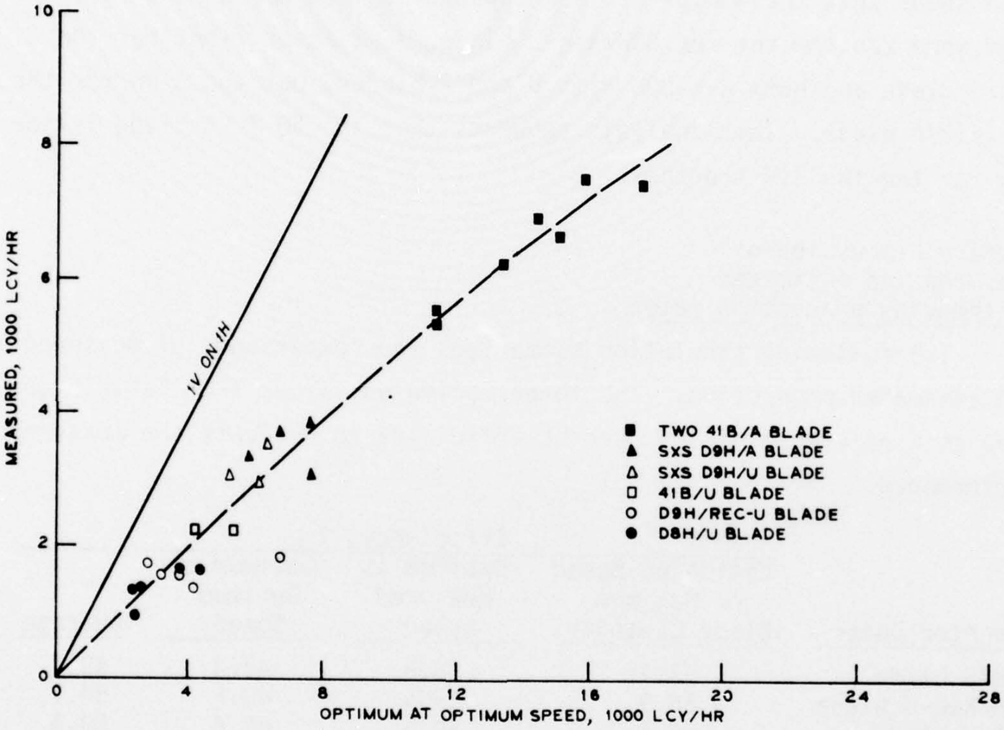


Figure 42. Comparisons of earthmoving production rates, all dozers; measured versus optimum at optimum speed

efficiency, using optimum production at optimum speed as a base, was 49.4 percent; the best efficiency was 55.1 percent with the SxS D9H/U blade; and the worst efficiency was 43.8 percent with the D9H/Rec-U blade.

Figure 43 presents comparisons of estimated production rates based on the measured maximum blade capacities and the optimum production at optimum speed that depends on maximum traction capacities. The figure also shows that the measured blade capacities made during the field program were too low for the D9H/Rec-U blade, just about right for the D8H/S blade and both SxS D9H with U and A blades, but too high for the two 41B/A blade. This analysis suggests that the 60-ft A blade is too big for the two 41B tractors.

Summary discussion of measured and estimated earthmoving production rates

The following tabulation summarizes the comparisons of measured and estimated production. The three estimated values from Table 6 are used as a reference of 100 percent efficiency to evaluate the measured performance.

	Efficiency, %			
Tractor Dozer	Estimated Based on Maximum Blade Capacity	Optimum at Measured Speed	Optimum at Optimum Speed	Average
D8H/S blade	53.4	48.5	47.3	49.7
D9H/Rec-U blade	66.9	53.4	43.8	54.7
41B/U blade	54.5	50.5	52.4	52.5
SxS D9H/U blade	57.4	61.6	55.1	58.0
SxS D9H/A blade	51.2	70.6	51.9	57.9
Two 41B/A blade	40.0	49.0	46.1	45.0

Using this tabulation as a basis for comparing performance of the dozers, the two SxS D9H with U and A blades performed about the same (58.0 and 57.9 percent), and both were better than the others. The two 41B/A blade had the worst performance in terms of efficiency. Even though its efficiency when comparing measured production with estimated production was lower, the fact remains that the two 41B/A blade moved, on the average for all blade angles, 6513 LCY/hr of material, which was

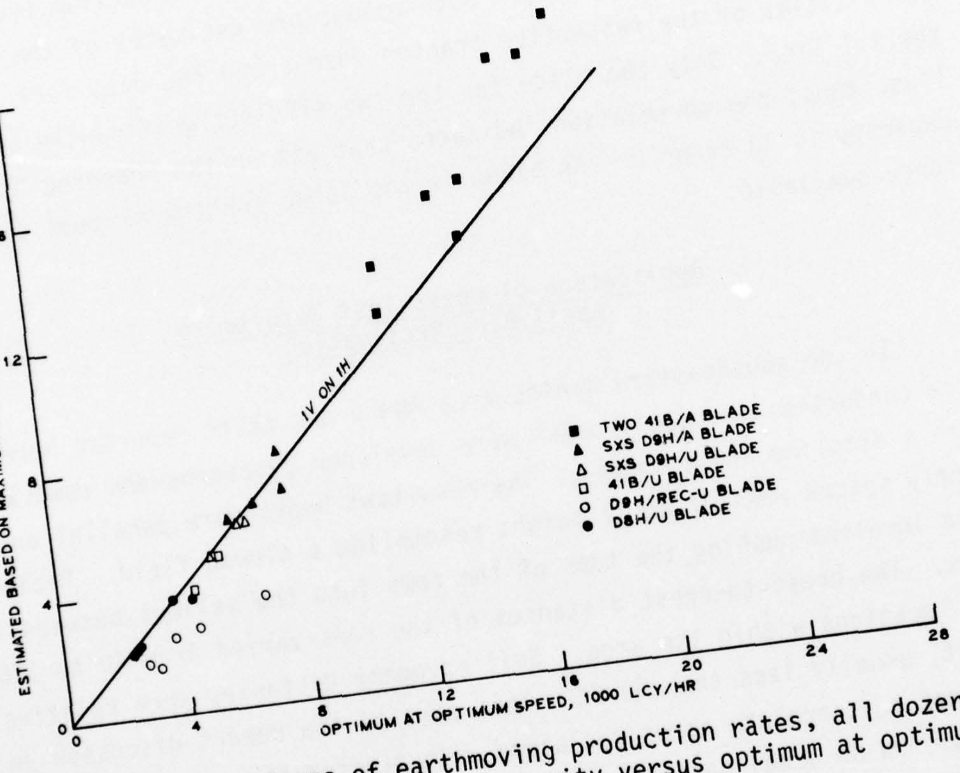


Figure 43. Comparisons of earthmoving production rates, all dozers; estimated based on maximum blade capacity versus optimum at optimum speed

an 86 percent increase over the average of 3506 LCY/hr moved by the SxS D9H/A blade.

The fact that all measured production values fall below the optimum production-speed curves in Figures 13 through 39 gives some validity to the earthmoving production model based on traction capabilities. Also lending validity to the model are the results of the correlation of production based on maximum blade capacity versus optimum production at optimum speed (Figure 43). Both values are estimates of the maximum capabilities of the respective tractor dozers and the data fall close to the 1:1 line. Only the blade for the two 41B is significantly above the line; thus, the correlation indicates that either the measured blade capacity is in error or the blade is too large for the maximum tractive force available.

Application of Dozer Test Results to Spoil Bank Reclamation

In the southeastern Kansas area where the tests reported herein were conducted, the spoil banks were developed by overburden removal with a dragline and a shovel. The resultant banks were parallel and uniformly spaced rows of equal height resembling a plowed field. Reclamation involves pushing the tops of the rows into the valleys between the rows. The crest-to-crest distances of the rows varied from 40 to 120 ft for locations within the area. Soil movement distances were relatively short, usually less than 50 ft. This part of the report discusses an attempt to correlate acres reclaimed with tractor horsepower requirements. On an areal basis the test areas were small; consequently, a value of acres per hour of dozing time was used to correlate with horsepower. The area occupied by each test was determined by multiplying the length shown in Table 3 by the width after the test was completed. The largest area leveled was 2.33 acres with the SxS D9H/A blade on 120-ft crest-to-crest center lines, and the smallest area leveled was 0.29 acre with the two 41B/A blade. Dozing time was used instead of total operating time because the experimental A-blade dozers were designed for continuous movement along the entire length of the spoil bank and, with relatively short test areas including turnaround times, would be penalized unjustly.

Figure 44 shows the average acres per hour of dozing time versus tractor horsepower. Average acres per hour were used instead of acres per hour for each test because of the scatter that occurred with individual tests. Test areas 10A and 12A were not included in the average for the D8H/S blade since these tests were the only ones wherein the spoil bank crest had not been leveled prior to the test. Average acres per hour for the SxS D9H/A blade were low because of additional soil rehandling as indicated by the large number of passes required to lower the spoil bank to the desired level. The following tabulation summarizes the results of the analysis of application tests:

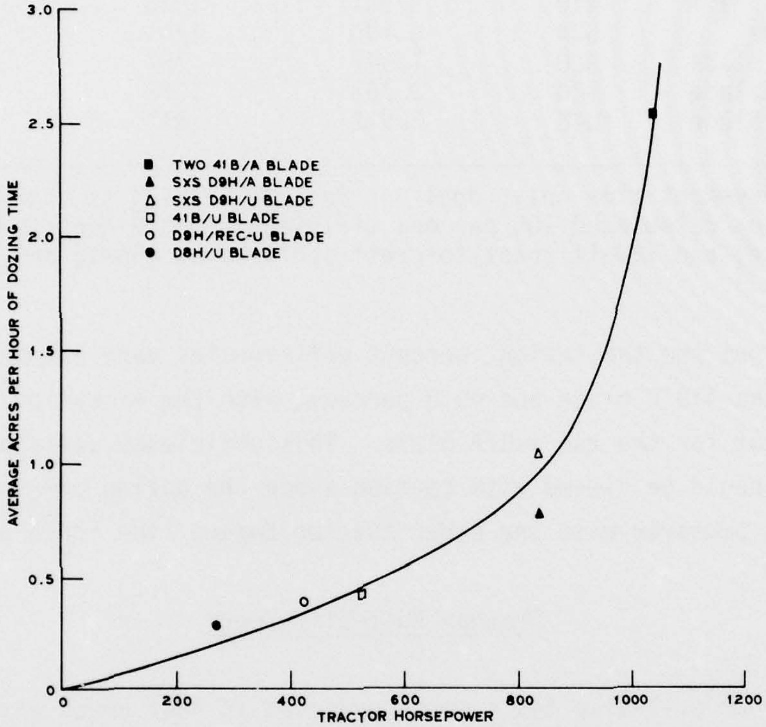


Figure 44. Average acres per hour of dozing time versus tractor horsepower

Tractor Dozer	Horse-power	Average acres/hr of Dozing Time*	Horsepower Hr/acre	Percent Efficiency**
D8H/S blade	270	0.282	957	39.5
D9H/Rec-U blade	410	0.381	1076	35.1
41B/U blade	524	0.409	1281	29.5
SxS D9H/U blade	820	1.042	787	48.0
SxS D9H/A blade	820	0.761	1078	35.1
Two 41B/A blade	1048	2.512	417	90.6

* Soil movement time only; does not include backing up time, etc.
** Based on calculated 100 percent efficiency at 378 horsepower (hr/acre) and 120-ft crest-to-crest spoil banks (Goris and Howland, op. cit.).

As noted from the tabulation, percent efficiencies vary between 29.5 percent for the 41B/U blade and 48.0 percent, with the exception of 90.6 percent for the two 41B/A blade. This efficiency seems high and probably should be viewed with caution since the dozing times were very short when compared with the other tractor dozers (see Table 3).

Drawbar Pull-Slip Tests

Drawbar pull-slip tests were conducted in four areas with the D8H dozer and in one area with the D9H dozer. The data are tabulated in Table 4 and are shown graphically (for first gear only) in Figures 45 and 46. Maximum drawbar pull occurred around 20 percent slip, and the drawbar pull coefficients were 0.88 and 0.86 for the D8H and D9H dozers, respectively. Test data for second and third gears were not plotted since track slips were very low prior to power stall and a curve could not be developed. The necessary support equipment was not available to conduct drawbar pull-slip tests with the larger tractors.

The soil strengths of the test areas were all above a cone index of 200, where changes in soil strength have little effect on changes in drawbar pull. The maximum drawbar pulls that were developed were considerably higher than maximum drawbar pulls used in the tractive force-soil submodel for making estimates of optimum production rates. Data from other field test programs were examined to determine if tests with

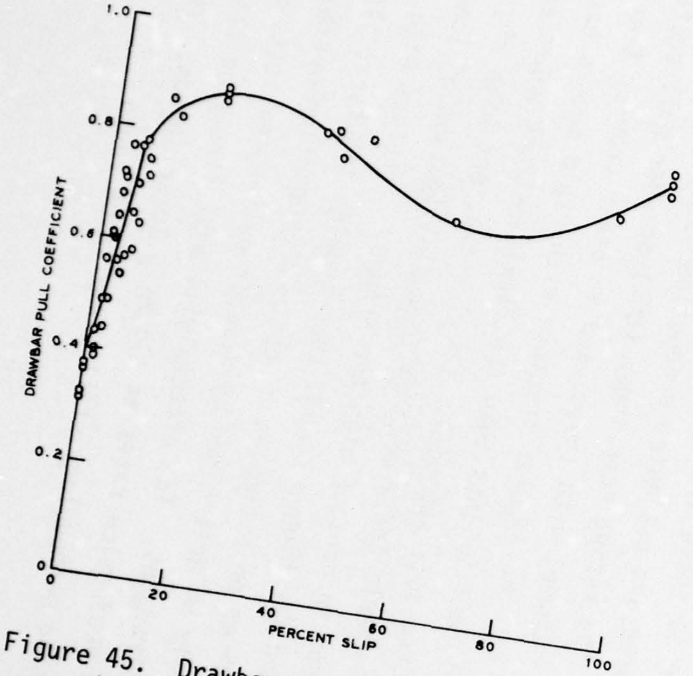


Figure 45. Drawbar pull-slip test; D8H dozer, first gear only

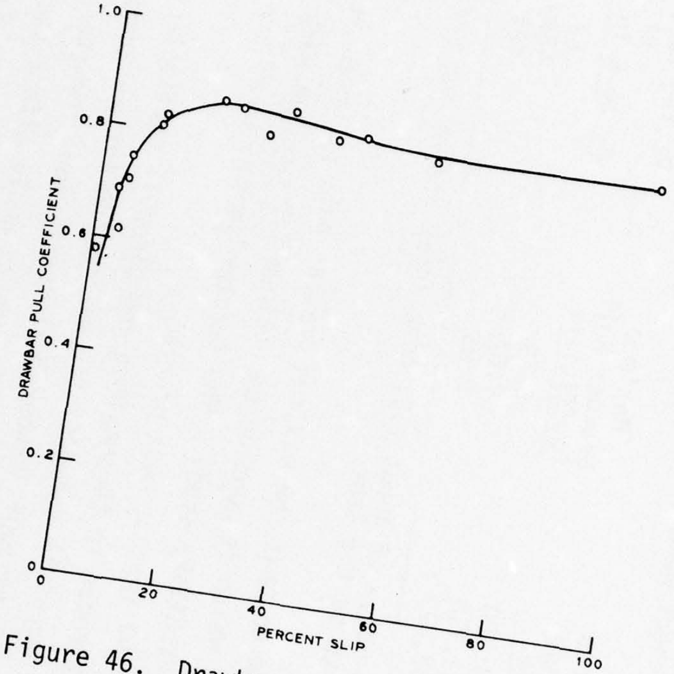


Figure 46. Drawbar pull-slip test; D9H dozer, first gear only

other crawler tractors (rigid tracks) also produced high drawbar pulls. Results of the data check were as follows:

Tractor	Tractor Weight lb	Maximum Drawbar Pull Coefficient	Rating Cone Index* of 0- to 6-in. layer
IH500E	11,500	0.79	69
Cat D6C	33,130	0.87	488
Cat D7F	52,025	0.85	404

* Above an index value of about 150, cone index and rating cone index are considered to be the same.

These tests revealed that the maximum drawbar pull occurred at about 20 percent slip, which is considered optimum for maximum work output as shown in the feasibility study. The tractor performances are similar to the ones tested in this test program.

The differences in the maximum drawbar pull coefficient used in the tractive force-soil submodel for making the optimum production rates estimates and the maximum drawbar pull coefficient reported here were examined to determine if these differences would affect the results of comparisons of measured and estimated production rates. Figure 47 presents comparison of the rating cone index (RCI)-drawbar pull coefficient curves used in the submodel with those used in other crawler tractors. As noted in Figure 46, the crawler tractors with rigid tracks have higher drawbar pull coefficients than the flexible-track vehicles used in the tractive force-soil submodel. Crawler tractors with rigid tracks have smaller road wheels and a more uniform distribution of loading over the track area in contact with the ground. Tractors with flexible track are designed for higher speeds than crawler tractors. The effects of these differences on estimates of optimum production-optimum speed relations can only be determined by drawbar pull-speed tests over a range of soil strengths. The effects will most likely be slightly higher optimum production rates at slightly lower speeds. The earthmoving production methodology still seems to be sound.

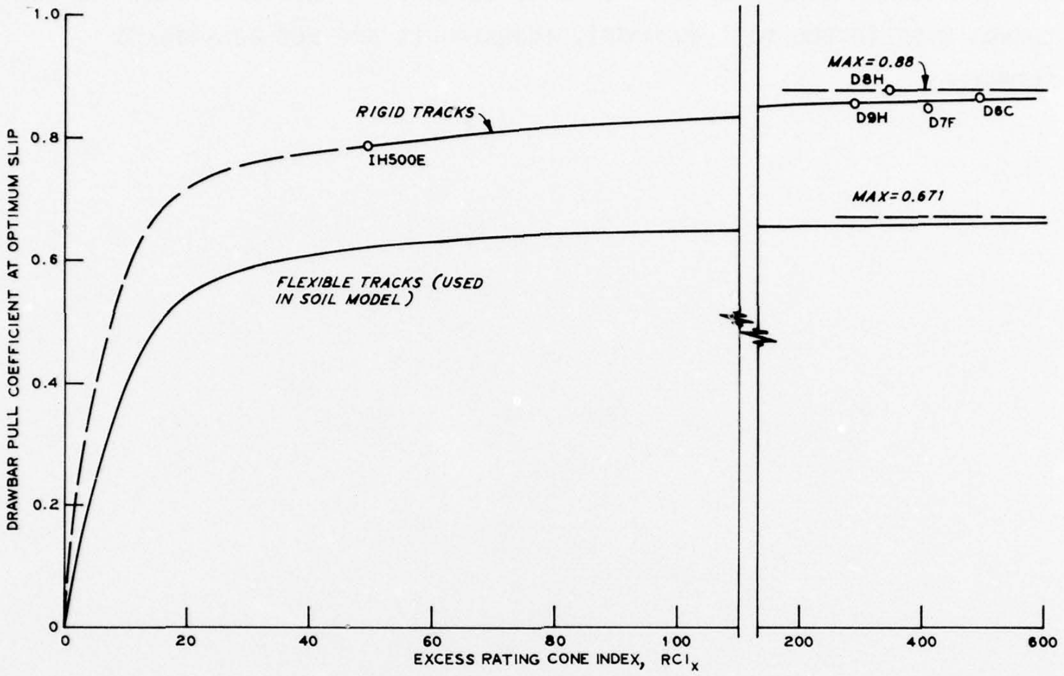


Figure 47. Comparison of the RCI$_X$-drawbar pull coefficients in rigid- and flexible-track vehicles

Motion Resistance Tests

Motion resistance tests were conducted along with the drawbar pull-slip tests. The following tabulation summarizes the results of the D8H and D9H tests during this test program and the results of tests from other programs with crawler tractors:

Tractor	Tractor Weight, lb	Motion Resistance Coefficient	Rating Cone Index of 0- to 6-in. layer
IH500E	11,500	0.085	69
Cat D6C	33,130	0.050	488
Cat D7F	52,025	0.080	404
D8H	67,800	0.098	327
D9H	92,900	0.080	287

Since motion resistances of these five tractors are in line with motion resistances of other vehicles used to develop the motion resistance-RCI_x curves used in the soil submodel, adjustments are not considered necessary.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the analysis, the following conclusions are drawn:

a. Soil and test area characteristics (spoil bank configuration) did not vary enough to determine their influence on tractor dozing performance in terms of merely moving material. They would propably have more influence on soil cutting performance, which was not a part of this study.

b. Comparisons of measured blade capacities and operating blade capacities show that all blades were operating at less than 67 percent of maximum capacity, and the U blades were operating at higher blade capacities than the A blades.

c. The earthmoving production model based on traction capabilities has validity based on the fact that all measured earthmoving production values were below the computed optimum value. Using optimum production at measured speed as 100 percent efficiency, the tractor dozers efficiencies were as follows:

Tractor Dozer		Percent Efficiency
D8H/S blade		48.5
D9H/Rec-U blade		53.4
41B/U blade		50.5
SxS D9H/U blade		61.6
SxS D9H/A blade		70.6
Two 41B/A blade		49.0
	Average	55.9

d. The above efficiencies show that although the largest blade, the two 41B/A blade, has the next lowest efficiency, it moved by far the greatest amount of material, 6513 LCY/hr. This was an 86 percent increase over the next largest blade, the SxS D9H/A blade.

e. Production based on maximum blade capacity shows good correlation when compared with computed production at optimum speed except for the two 41B/A blade. The correlation indicates that either the measured blade capacity is in error or the blade is too large for the maximum tractive force available.

f. Good correlations were affected between horsepower and average acres of spoil reclaimed per hour of dozing time.

g. Based on the drawbar pull-slip test, the maximum tractive force used in the earthmoving production model is too low for crawler tractors. The effects of the lower values are not considered significant; however, if the new maximum drawbar pull values were used in the model, the optimum production rates will be slightly higher and occur at slightly lower speeds.

Recommendations

Based on the results of this limited evaluation, the recommendations are as follows:

a. Additional reclamation tests be conducted but on different spoil banks from those tested during this program to obtain earthmoving production data on a variety of spoil materials and sizes and shapes of spoil banks. Such a data base is needed to develope a user's manual for reclamation purposes.

b. Carefully controlled tests be conducted to determine optimum production rates and the optimum tractor dozer speeds to validate the earthmoving production model.

c. A study be conducted on the effects of spoil material on the cutting capabilities of dozer blades, and the tractive forces required to cut soil with dozer blades.

d. Additional drawbar pull-slip and pull-speed tests be conducted on a range of tractors to develop soil-vehicle relations for tractor dozers.

e. Earthmoving performances be determined for wheeled dozers when operating in reclaiming efforts.

f. A study be undertaken to standardize a method for determining maximum blade capacity.

APPENDIX A: WES METHODOLOGY FOR OPTIMIZATION OF DOZER PRODUCTION

The procedures developed by WES to optimize dozer production in the reclamation of coal-mined areas are presented in this appendix. These procedures initially take the theoretical tractive force-speed curves furnished by dozer manufacturers, modify these curves to correct for soil resistances, and then use the remaining drawbar pull available to compute the productivity of the dozer in terms of loose cubic yards per hour relative to the soil weight and the average distance the mateial is displaced along the dozing path. The dozer is assumed to be equipped with a blade capable of at least moving the volume of soil that can be pushed with available traction and to be able to move the material in about the same manner each time, i. e. a repetitive dozing operation in which the material is loaded in front of the blade to bladefull and pushed about the same dozing distance each time to disposal over the side of the spoil pile. A blade-full condition is maintained throughout the dozing distance. Although the techniques are applicable to many types of dozing operations, those described herein were used in this analysis for reclamation of parallel triangular-shaped spoil piles with crest-to-crest distances in the range of 90-120 ft.

Theoretical Tractive Force-Speed Curves

In the design of almost every self-propelled vehicle, the initial step in determining the expected performance of the vehicle is to use the power train characteristics selected for the vehicle to calculate, theoretically, the maximum tractive force the vehicle can develop without any assumed inefficiencies or traction losses. The maximum tractive force can be expressed as a function of vehicle speed, such as the curve for a D8H tractor in Figure A1. This curve will usually not be obtainable in normal operations because of mechanical inefficiencies or traction losses resulting from slippage of the vehicle running gear at the

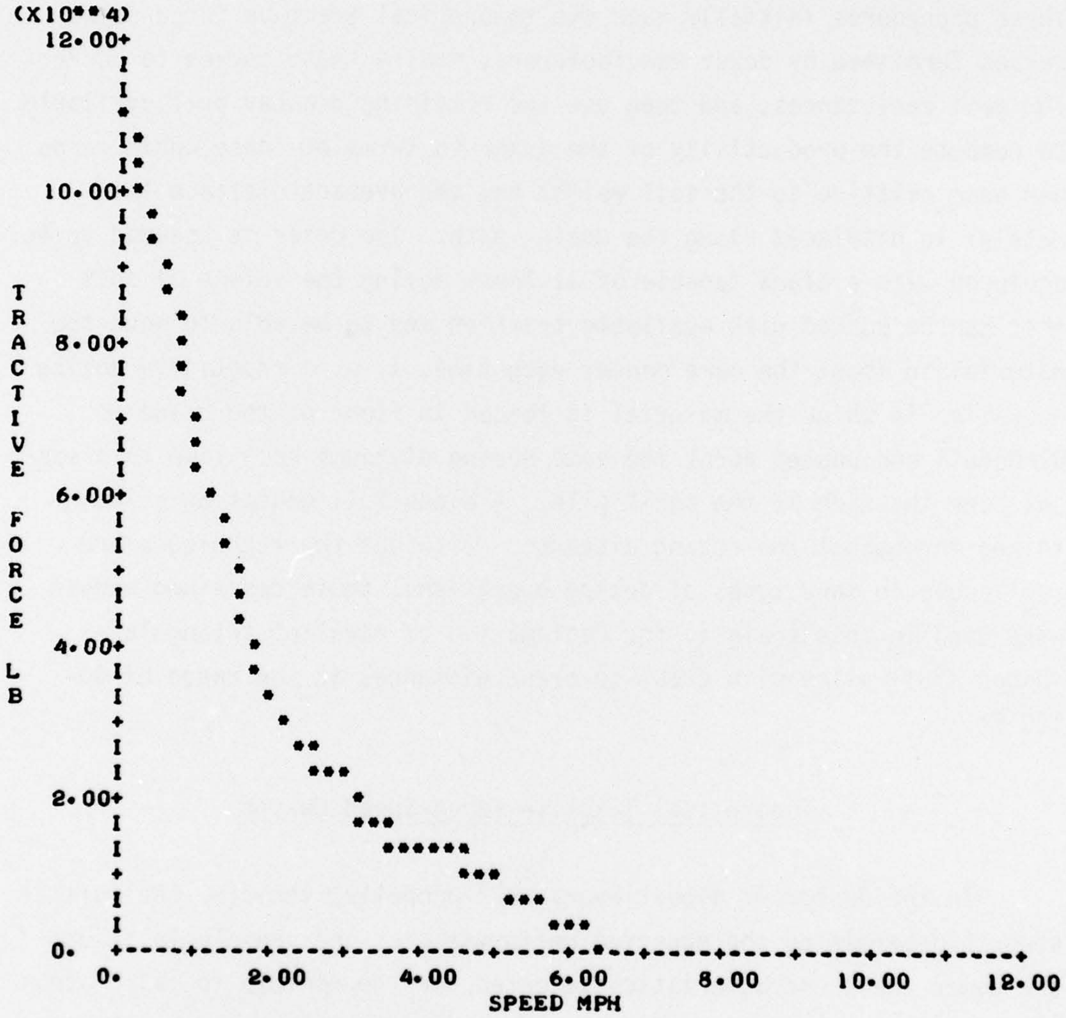


Figure A1. Theoretical tractive force-speed curve for a D8H tractor soil interface. Futhermore, this curve is strictly theoretical and must be adjusted downward to compensate for the inefficiencies in order to determine the expected performance of the vehicle in a field environment.

Effective Drawbar Pull-Speed Curves

Empirical relations of vehicle towed motion resistance versus speed have been developed by WES from approximately 20 years of field testing in a variety of field conditions with a multitude of vehicles of various sizes, shapes, and propulsion systems. The curve in Figure A2 was developed for use in determining the effective drawbar pull of a vehicle in a field situation, for the theoretical tractive force of a vehicle in each gear, less the motion resistance, determines the effective drawbar pull of that vehicle. The effective drawbar pull is then used to calculate the total weight of soil the vehicle can move while operating, or the production of the vehicle (Figure A3).

Production-Speed Curves

The effective drawbar pull of a vehicle at a particular speed, divided by the weight of soil or material reclaimed (along with soil friction forces as soil is pushed over soil), determines the number of loose cubic yards the tractor can move during each dozing pass. The distance the material must be pushed during each dozing pass, or the dozing distance, is divided by the speed of the tractor in feet per second to calculate the number of seconds required to push the material the dozing distance for each pass. The volume of material per pass is then multiplied by the number of passes of the vehicle per hour of dozing time to get the total production in loose cubic yards per hour. Usually no efficiencies are considered in this determination in order to get the dozer production in loose cubic yards per hour at 100 percent efficiency (Figure A3). This value can then be easily adjusted downward to compensate for inefficiencies of traction, operation, operator skill, soft soil, angle blades, etc. to estimate the production of the vehicle

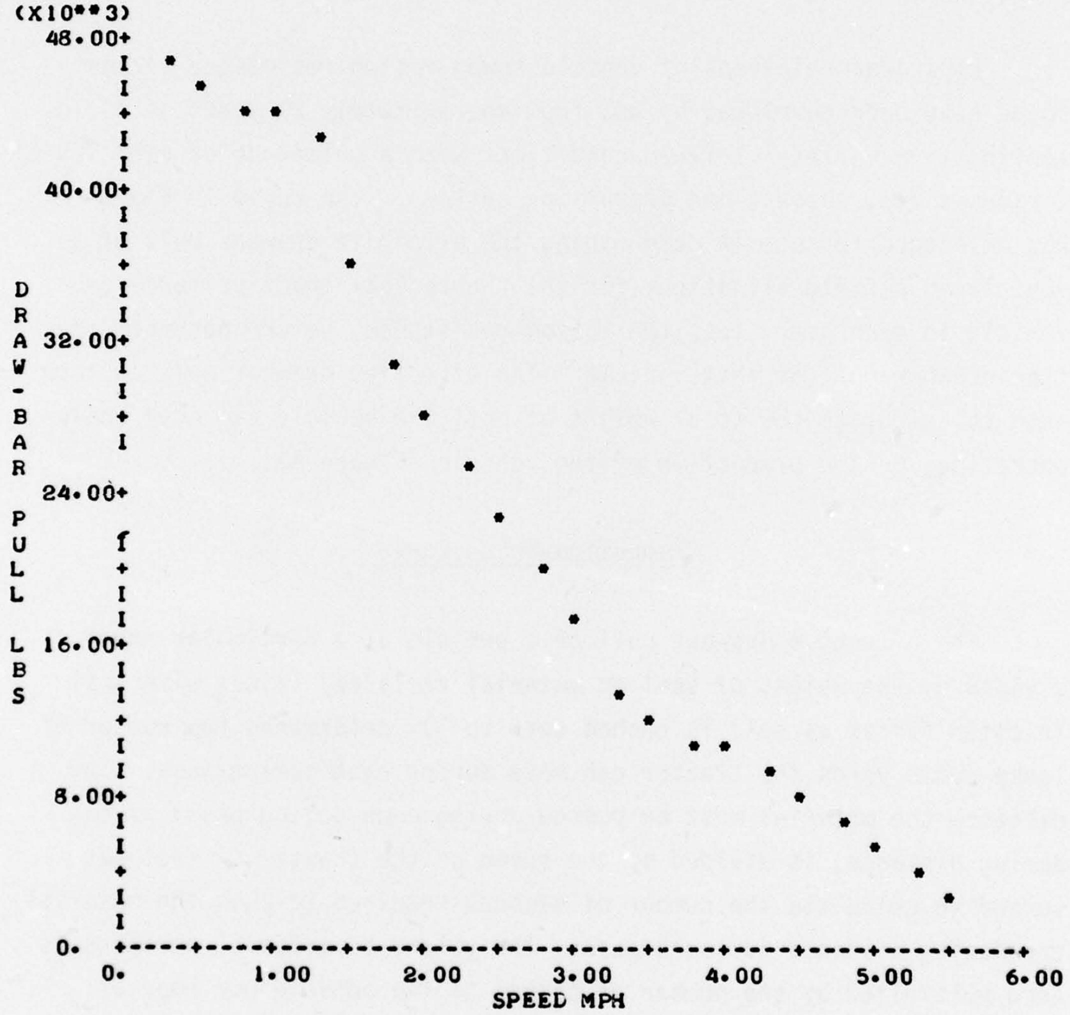


Figure A2. Effective drawbar pull-speed curve for a D8H tractor

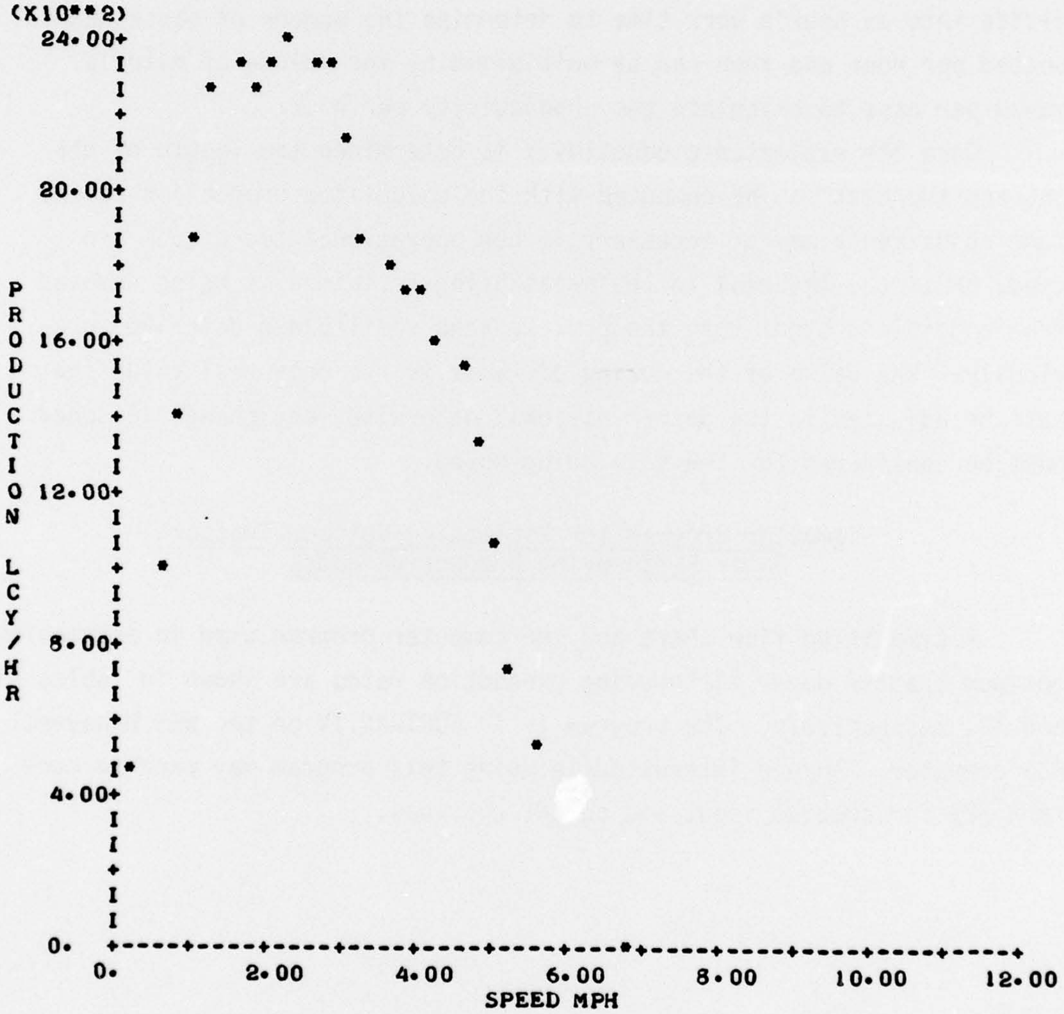


Figure A3. Earthmoving production versus speed for a D8H tractor with S blade in a field environment. These efficiencies have been shown in field tests to vary from about 30 to 50 percent with, of course, some variation due to the aforementioned factors. If true values of time lost by backing up, turning around, fueling, maintenance, etc., are known, the time of each complete pass (dozing time + nondozing time) can be used to divide into an hour's work time to determine the number of passes expected per hour and then can be multiplied by the volume of material moved per pass to calculate the productivity per hour.

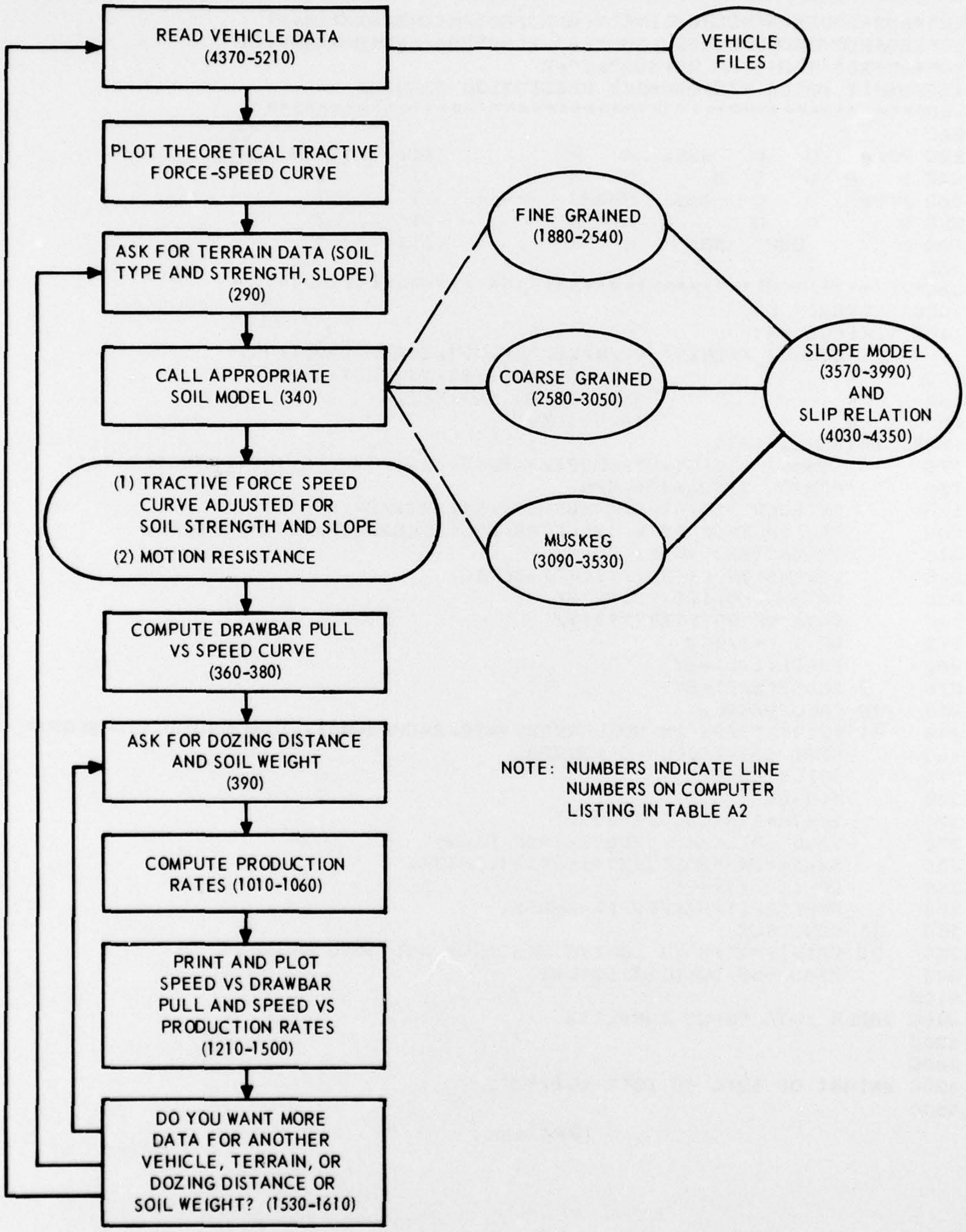
Once the estimated productivity is determined the length of the job and the cost can be computed with the calculated production rates. Some adjustments may be necessary if new operational techniques are used, or if the material in the areas being reclaimed is being removed from conditions other than the peak-to-peak spoil banks described previously. The value of the dozing distance is the only real value that must be adjusted in the determinations; otherwise, any change in speed must be considered for the soil being moved.

Computer Program for Estimating Optimum Tractor Dozer Earthmoving Production Rates

A simplified flow chart and the computer program used in estimating optimum tractor dozer earthmoving production rates are shown in Tables A1 and A2, respectively. The program is in FORTRAN IV on the WES Honeywell 635 computer. Anyone interested in using this program may want to contact WES for special input and output routines.

TABLE A1

SIMPLIFIED FLOW CHART OF "PUSH IT" MODEL



NOTE: NUMBERS INDICATE LINE NUMBERS ON COMPUTER LISTING IN TABLE A2

Table A2

Computer Program for Estimating Optimum Earthmoving Production Rates for Tractor Dozers

---

```
10*#RUN*;ROFRO6/MEDHB/LINEIN,R;ROFRO6/MEDHB/ARAYIN,R;
12*#ROFRO6/MEDHB/CURVEL.SUB"SS",R;ROFRO6/MEDHB/OPENF,R;
14*#ROFRO6/MEDHB/PPLOT.SUB"XX",R
16CPUSHIT DOZER PERFORMANCE PREDICTION PROGRAM
18C****************************************************
20C
22C PPPP   U   U   SSSS  H   H          III    TTTTT
24C P   P  U   U  S      H   H           I       T
26C PPPP   U   U   SSS   HHHHH  -----    I       T
28C P      U   U      S  H   H           I       T
30C P       UUU   SSSS   H   H          III      T
32C
34C****************************************************
100C  TERRAIN DATA
110C VEHICLE DATA
120       COMMON /VEHIN/ VD,W,WP,GHP,HPT,TVAR,TIRPSI,TL,
130     &                XTL,GCX,XTW,XWD,V1,XRDT,TPR,
140     &                GH,XNTE,BN,XNA,XCF,
150     &                NP,VD1,XNT
160C  INTERNAL DATA
170       COMMON ISOILT,CI,SLOPE,FARY(2,180),SARY(2,180),FORCE(2,180)
180       COMMON TFMUL,NPS,NPL
190       INTEGER ISOILT,VD1,XCF,XGF,V1,XNTE,BN
200       EQUIVALENCE (XTW,TW),(TPR,ATS),(XCF,XGF),(XTP,TIRPSI)
210       CHARACTER IANS*1
220       DIMENSION XX(80),YY(80),ZZ(80)
230       DATA LF/0012012012012/
240       DATA BK/0377777777777/
250       DO 1 I=1,180
260       FORCE(1,I)=BK
270     1 FORCE(2,I)=BK
280    90 CALL VEHPLT
290    91 PRINT,"TYPE IN SOIL TYPE(1=FG,2=CG,3=MK),CONE INDEX AND SLOPE"
300       READ 555,ISOILT,CI,SLOPE
310       SOILSTRN=CI
320       XIN=CI
330       THETA=ATAN(SLOPE/100.)
340       CALL SOIL(SMR,TFORCE,TACX,RTOW)
350       SMRSS=SMR*COS(THETA)+W*SIN(THETA)
360       DO 11 I=1,NPS
370       FARY(2,I)=FARY(2,I)-SMRSS
380    11 CONTINUE
390    92 PRINT,"TYPE IN DOZING DISTANCE AND SOIL WEIGHT"
400       READ 555,DOZDIST,SOILWT
410C
420C TABLE DATA INPUT COMPLETE
430C
440C
450C WEIGHT OF SOIL TO DOZE (LB/YD^3)
460C
```

(Continued)

(Sheet 1 of 11)

Table A2 (Continued)

```
470C LENGTH OF WORK "HOUR" (MIN)
480       WORKMINS=60.
490C
500C OVERALL DOZING EFFICIENCY (%)
510       EFF=100.
520C
530C DRAW-BAR INCREASE TO PUSH SOIL MASS (%)
540       DBPINCR=22.
550C
560C HARDEST SOIL STRENGTH (CI;RCI)
570C
580C DOZING DISTANCE (FT)
590C
600       SOILLOAD=SOILWT+DBPINCR/100.*SOILWT
610C
620       WRITE(42,300) LF
630       WRITE(42,301)
640       WRITE(42,300) LF
650  300 FORMAT(A4)
660  301 FORMAT(70(1H-))
670       WRITE(42,103)
680  103 FORMAT(
690      & /' THEORETICAL TRACTIVE FORCE',18X,'COMPUTED SPEED, DRAW-',
700      & /'       VS. SPEED CURVE       ',17X,'BAR PULL, AND PRODUCTION',
710      &//' SPEED-MPH           FORCE-LBS',14X,'  SPEED         DBP   PRODUC
711      &TION',
720      & /' ---------           ---------',14X,'  -----         ---   ------
721      &----')
730       SPEEDSAV=0.
740       PRODMAX=0.
750       KSW=1
760       DO 50 I=1,NP
770       IF(SARY(2,I).LE.0.) GO TO 50
780       IF(KSW-2) ,51,50
790       KSW=KSW+1
800       MIN=I-1
810       GO TO 50
820   51 IF(FARY(2,I).LE.0.) GO TO 50
830       MAX=I
840   50 CONTINUE
850       DO 30 IS=1,80
860       SPEEDMPH=FLOAT(IS)/4.
870       DO 13 I=MIN,MAX-1
880       IF(SPEEDMPH.GT.SARY(2,I+1)) GO TO 13
890       IF(SPEEDMPH-SARY(2,I))13,15,14
900   13 CONTINUE
910   14 X=SPEEDMPH
920       X1=SARY(2,I)
930       X2=SARY(2,I+1)
940       Y1=FARY(2,I)
```

(Continued)

(Sheet 2 of 11)

Table A2 (Continued)

```
      Y2=FARY(2,I+1)
      Y=((Y2-Y1)/(X2-X1))*(X-X1)+Y1
      DBP=Y
      GO TO 16
   15 DBP=FARY(2,I)
   16 IF(DBP.LT.FARY(2,MAX)) GO TO 40
      SPEEDFPS=SPEEDMPH*1.46667
      VOLUME=DBP/SOILLOAD
      TIMESECS=DOZDIST/SPEEDFPS
      WORKSECS=WORKMINS*60.
      TRIPS=WORKSECS/TIMESECS
      PRODUCT=TRIPS*VOLUME
      XX(IS)=SPEEDMPH
      YY(IS)=PRODUCT
      ZZ(IS)=DBP
      NIS=IS
      NPTS=NPTS+1
      WRITE(42,101) FORCE(2,IS),IFIX(FORCE(1,IS)),
     &                    SPEEDMPH,IFIX(DBP+0.5),IFIX(PRODUCT+0.5)
  101 FORMAT(1H ,F7.2,I17,16X,F7.2,I11,I9)
      IF(PRODUCT.LT.PRODMAX)GO TO 30
      PRODMAX=PRODUCT
      SPEEDSAV=SPEEDMPH
   30 CONTINUE
   40 IF(IS.GT.NP) GO TO 41
      DO 42 NL=IS,NP
   42 WRITE(42,101) FORCE(2,NL),IFIX(FORCE(1,NL)+0.5)
   41 WRITE(42,200) LF
  200 FORMAT(A4)
      WRITE(42,102) PRODMAX,SPEEDSAV,SOILSTRN
      NLF=MAX0(IS,NP)
      NLF=54-(NLF+16)
      IF(NLF) 44,44,
      NLF=NLF/4
      WRITE(42,201) (LF,L=1,NLF)
  201 FORMAT(/(A4))
   44 WRITE(42,300) LF
      WRITE(42,301)
      WRITE(42,201) LF,LF
      CALL PPLOT(XX,ZZ,NPTS,"*"," ","SPEED MPH",9,
     &               "DRAW-BAR PULL LBS",17,6,6)
      WRITE(42,201) LF,LF
      WRITE(42,301)
      WRITE(42,201) LF,LF
      NPTSM=NIS+1
      XX(NPTSM)=6.9
      YY(NPTSM)=0.
      NPTS=NPTSM
      CALL PPLOT(XX,YY,NPTS,"*"," ","SPEED MPH",
     &     9,"PRODUCTION LCY/HR",17,6,6)
```

(Continued)

(Sheet 3 of 11)

Table A2 (Continued)

```
1480        WRITE(42,201) LF,LF
1490        WRITE(42,301)
1500        WRITE(42,300) LF
1510    102 FORMAT(1H ,"MAXIMUM PRODUCTION OF ",F8.1," OCCURS AT",F5.1,
1520      &        " MPH ",/," ON A SOIL STRENGTH OF",F5.0)
1530        PRINT,"DO YOU WANT TO RUN ANOTHER DOZING DISTANCE OR SOIL WEIG
1540       &HT"
1550     70 FORMAT(A1)
1560        READ 70,IANS
1570        IF(IANS.EQ."Y")GO TO 92
1580        PRINT,"DO YOU WANT TO RUN ANOTHER SOIL GROUP"
1590        READ 70,IANS
1600        IF(IANS.EQ."Y")GO TO 91
1610        PRINT,"DO YOU WANT TO RUN ANOTHER VEHICLE"
1620        READ 70,IANS
1630        IF(IANS.EQ."Y")GO TO 90
1640        STOP"END OF JOB"
1650    555 FORMAT(V)
1660        END
1670        SUBROUTINE SOIL(SMR,TFORCE,TACX,RTOW)
1680        COMMON /VEHIN/ VD,W,WP,GHP,HPT,TVAR,TIRPSI,TL,
1690      &                XTL,GCX,XTW,XWD,V1,XRDT,TPR,
1700      &                GH,XNTE,BN,XNA,XCF,
1710      &                NP,VD1,XNT
1720        COMMON ISOILT,CI,SLOPE,FARY(2,180),SARY(2,180),FORCE(2,180)
1730        COMMON TFMUL,NPS,NPL
1740        INTEGER ISOILT,VD1,V1,XCF,XNTE,BN,XGF
1750        EQUIVALENCE (XTW,TW),(TPR,ATS),(XCF,XGF),(XTP,TIRPSI)
1760        IFLAG=1
1770        GOTO(10,20,30),ISOILT
1780     10 CALL FGSOIL(SMR,TFORCE,TACX,RTOW)
1790        RETURN
1800     20 CALL CGSOIL(SMR,TFORCE,TACX,RTOW)
1810        RETURN
1820     30 CALL MKSOIL(SMR,TFORCE,TACX,RTOW)
1830        RETURN
1840        END
1850C
1860C
1870C
1880        SUBROUTINEFGSOIL(SMR,TFORCE,TACX,RTOW)
1890        COMMON /VEHIN/ VD,W,WP,GHP,HPT,TVAR,TIRPSI,TL,
1900      &                XTL,GCX,XTW,XWD,V1,XRDT,TPR,
1910      &                GH,XNTE,BN,XNA,XCF,
1920      &                NP,VD1,XNT
1930        COMMON ISOILT,CI,SLOPE,FARY(2,180),SARY(2,180),FORCE(2,180)
1940        COMMON TFMUL,NPS,NPL
1950        INTEGER ISOILT,VD1,V1,XCF,XNTE,BN,XGF
1960        EQUIVALENCE (XTW,TW),(TPR,ATS),(XCF,XGF),(XTP,TIRPSI)
1970        DIMENSION WK(3),WRK(3),WFK(4),WFK2(4),X1(5,4)
```

(Continued)

(Sheet 4 of 11)

Table A2 (Continued)

```
1980         DATA WK/50000.,70000.,100000./,WRK/2000.,13500.,20000./
1990         DATA WFK/.533,.033,.142,.278/,WFK2/0.,1.05,-.42,-3.115/
2000         DATA X1/.544,.0463,.0702,.758,.82,.4554,.0392,.0526,.671,
2010       &      .71,.3885,.0265,.0358,.674,.76,.379,.0219,.0257,.585,.655
2011       &/
2020         RCI=CI
2030         IF(VD.GT..5)GO TO 2
2040         CPF=W/(2.*XTL*TW)
2050         WF=1.
2060         DO 11 I=1,3
2070         IF(W-WK(I))12,11,11
2080      11 WF=WF+.2
2090         WF=WF+.2
2100      12 TF=TW/100.
2110         GF=1.1
2120         IF(GH.LT.1.5)GF=1.
2130         WLORBF=W/(10.*BN*ATS)
2140         GOTO10
2150       2 CPF=(W*2.)/(XTW*XWD*XNTE)
2160         WR=W/XNA
2170         WX=WR/1000.
2180         DO 13 I=1,3
2190         IF(WR-WRK(I))14,13,13
2200      13 CONTINUE
2210      14 WF=WFK(I)*WX+WFK2(I)
2220         TF=(10.+XTW)/100.
2230         GF=1.+XCF*.05
2240         WLORBF=WX/XNT
2250      10 CLF=GCX/10.
2260         EF=1.05
2270         IF(HPT.GT.10.)EF=1.
2280         TXF=1.+TVAR*.05
2290         VMI=((CPF*WF)/(TF*GF)+WLORBF-CLF)*EF*TXF
2300         N=1
2310         IF(CPF.GE.4)N=2
2320         IF(IFIX(VD).EQ.1)N=N+2
2330         GOTO(20,20,30,30),N
2340      20 VCI1=7.+.2*VMI-39.2/(VMI+5.6)
2350         GOTO35
2360      30 VCI1=11.48+.2*VMI-39.2/(VMI+3.74)
2370      35 RCIX=RCI-VCI1
2380         REAVAL=RCIX
2390         IF(RCIX.GT.0.)GOTO36
2400         REASON=1
2410         RETURN
2420      36 XX=X1(1,N)+X1(2,N)*RCIX
2430         DOW=FDOW(XX,X1(3,N),RCIX)
2440         CX=X1(4,N)
2450         CXP=X1(5,N)
2460         RTOW=.045+2.3075/(RCIX+6.5)
```

(Continued)

(Sheet 5 of 11)

Table A2 (Continued)

```
2470       IF(N.EQ.3)RTOW=.035+.861/(RCIX+3.249)
2480       CF=RTOW+DOW-CX
2490       TACX=(CF+CXP-RTOW)*WP/W
2500       SMR=RTOW*W
2510       TFORCE=TACX*W+SMR
2520       CALLARYMAK(TFORCE,CF,N)
2530       RETURN
2540       END
2550C

2570C
2580       SUBROUTINECGSOIL(SMR,TFORCE,TACX,RTOW)
2590       COMMON /VEHIN/  VD,W,WP,GHP,HPT,TVAR,TIRPSI,TL,
2600      &                XTL,GCX,XTW,XWD,V1,XRDT,TPR,
2610      &                GH,XNTE,BN,XNA,XCF,
2620      &                NP,VD1,XNT
2630       COMMON ISOILT,CI,SLOPE,FARY(2,180),SARY(2,180),FORCE(2,180)
2640       COMMON TFMUL,NPS,NPL
2650       INTEGER ISOILT,VD1,V1,XCF,XNTE,BN,XGF
2660       EQUIVALENCE (XTW,TW),(TPR,ATS),(XCF,XGF),(XTP,TIRPSI)
2670       N=1
2680       IF(XGF.GE.1.)N=2
2690       IF(IFIX(VD).EQ.1)N=3
2700       GO TO (20,30;50),N
2710    20 DOW=.695
2720       RTOW=.1
2730       GOTO40
2740    30 DOW=.568
2750       RTOW=.074
2760    40 TFORCE=(RTOW+DOW)*W
2770       TACX=DOW
2780       GOTO70
2790    50 TRFA=5.
2800       IF(XTW/XRDT.GE.2.4)TRFA=2.
2810       WDF=TRFA*XTW+XRDT
2820       CPF=.607*XTP+1.35*(117.*TPR/WDF)-4.93
2830       CAF=ALOG10(W/CPF)
2840       SF=-.35*CAF+.0526*XNTE+.0211*XTP+1.587
2850       VCI1=10.**SF
2860       XCI=CI-VCI1
2870       REAVAL=XCI
2880       IF(XCI.GT.0.)GOTO60
2890       REASON=1
2900       RETURN
2910    60 SFF=ALOG10(CI)
2920       DOW=(28.87*SFF+10.1*CAF-1.52*XNTE-.61*XTP-43.82)/100.
2930       CX=.56
2940       CXP=.57475
2950       RTOW=(22.2+.92*XTP+((ALOG10(CI))*(-8.-.37*XTP)))/100.
2960       IF(RTOW.LT..035)RTOW=.035
```

(Continued)

(Sheet 6 of 11)

Table A2 (Continued)

```
2970       CF=RTOW+DOW-CX
2980       TACX=(CF+CXP-RTOW)*WP/W
2990    70 SMR=RTOW*W
3000       TFORCE=TACX*W+SMR
3010       X=RTOW
3020       IF(N.EQ.3)X=CF
3030       CALLARYMAK(TFORCE,X,N)
3040       RETURN
3050       END
3060C
3070C
3080C
3090       SUBROUTINE MKSOIL(SMR,TFORCE,TACX,RTOW)
3100       COMMON /VEHIN/ VD,W,WP,GHP,HPT,TVAR,TIRPSI,TL,
3110      &               XTL,GCX,XTW,XWD,V1,XRDT,TPR,
3120      &               GH,XNTE,BN,XNA,XCF,
3130      &               NP,VD1,XNT
3140       COMMON ISOILT,CI,SLOPE,FARY(2,180),SARY(2,180),FORCE(2,180)
3150       COMMON TFMUL,NPS,NPL
3160       INTEGER ISOILT,VD1,V1,XCF,XNTE,BN,XGF
3170       EQUIVALENCE (XTW,TW),(TPR,ATS),(XCF,XGF),(XTP,TIRPSI)
3180       N=1
3190       IF(IFIX(VD).EQ.1)N=2
3200       GOTO(20,30),N
3210    20 VCI1=13.+.25*W/(2.*TW+2.*XTL*XNTE)
3220       GO TO 40
3230    30 VCI1=13.+1.07*W/(2.*XTW+2.*XWD*XNT)
3240    40 XCI=CI-VCI1
3250       REAVAL=XCI
3260       IF(XCI.GT.0.)GO TO 50
3270       REASON=1
3280       RETURN
3290    50 GO TO(60,70),N
3300    60 XX=.1091*XCI+.5464
3310       DOW=FDOW(XX,.192,XCI)
3320       CX=.88
3330       CXP=.95
3340       GO TO 80
3350    70 XX=.02258*XCI+.3537
3360       DOW=FDOW(XX,.0307,XCI)
3370       CX=.68
3380       CXP=.745
3390    80 RTOW=.045+2.3075/(XCI+6.5)
3400       CF=RTOW+DOW-CX
3410       TFORCE=(CF+CXP)*W
3420       TACX=CF+CXP-RTOW
3430       SMR=RTOW*W
3440       CALL ARYMAK(TFORCE,CF,N)
3450       RETURN
3460       END
```

(Continued)

(Sheet 7 of 11)

Table A2 (Continued)

```
C
C
C
      FUNCTION FDOW(X1,X2,X3)
      FDOW=X1-SQRT(X1*X1-X2*X3)
      RETURN
      END
C
C
C
      SUBROUTINE ARYMAK(TFORCE,X,N)
      COMMON /VEHIN/ VD,W,WP,GHP,HPT,TVAR,TIRPSI,TL,
     &                XTL,GCX,XTW,XWD,V1,XRDT,TPR,
     &                GH,XNTE,BN,XNA,XCF,
     &                NP,VD1,XNT
      COMMON ISOILT,CI,SLOPE,FARY(2,180),SARY(2,180),FORCE(2,180)
      COMMON TFMUL,NPS,NPL
      INTEGER ISOILT,VD1,V1,XCF,XNTE,BN,XGF
      EQUIVALENCE (XTW,TW),(TPR,ATS),(XCF,XGF),(XTP,TIRPSI)
      NPP=NP
      J=1
      THETA=0.
      TNTS=TFORCE
      GO TO 325
    5 NPL=NPP
      THETA=ATAN(SLOPE/100.)
      J=2
      TFORCS=TFORCE*COS(THETA)
      TNTS=TFORCS
  325 IF(FORCE(1,1).GT.TNTS)GO TO 326
      II=1
      GO TO 419
  326 DO 418 II=1,NP
      IF(FORCE(1,II).LE.TNTS)GO TO 417
      FARY(J,II)=FORCE(1,II)
  418 SARY(J,II)=0.
      STOP"SOIL"
  417 FARY(J,II)=TNTS
      SARY(J,II)=0.
      NPP=NP+1
  419 DO 420 I=II,NP
      III=I
      IF(II.NE.1)III=I+1
      Y=FORCE(1,I)/W-X
      CALL CPSLIP(N,THETA,Y,SLIP)
      FARY(J,III)=FORCE(1,I)*COS(THETA)
      TEMP=-SLIP+1.
      SARY(J,III)=FORCE(2,I)*TEMP
  420 CONTINUE
      IF(J.EQ.1) GO TO 5
```

(Continued)

(Sheet 8 of 11)

Table A2 (Continued)

```
3970       NPS=NPP
3980       RETURN
3990       END
4000C
4010C
4020C
4030       SUBROUTINE CPSLIP(N,THETA,Y,SLIP)
4040       COMMON /VEHIN/ VD,W,WP,GHP,HPT,TVAR,TIRPSI,TL,
4050      &               XTL,GCX,XTW,XWD,V1,XRDT,TPR,
4060      &               GH,XNTE,BN,XNA,XCF,
4070      &               NP,VD1,XNT
4080       COMMON ISOILT,CI,SLOPE,FARY(2,180),SARY(2,180),FORCE(2,180)
4090       COMMON TFMUL,NPS,NPL
4100       INTEGER ISOILT,VD1,V1,XCF,XNTE,BN,XGF
4110       EQUIVALENCE (XTW,TW),(TPR,ATS),(XCF,XGF),(XTP,TIRPSI)
4120       DIMENSION SLIPFG(4,4),SLIPCG(4,1),SLIPMK(4,2)
4130       DATA SLIPFG/.0257,.0161,.01519,.8353,.0733,.0063,.00734,.7177,
4140      &     .0621,.021,.01888,.7794,.084,.016,.01414,.6697/
4150       DATA SLIPCG/.0074,.0061,.00374,.5785/
4160       DATA SLIPMK/.0585,.0106,.01336,.964,.1024,.00864,.01062,.7564/
4170       GO TO (10,20,30),ISOILT
4180    10 SLIP=FSLIP(SLIPFG,N,Y)
4190       RETURN
4200    20 GO TO (50,60,40),N
4210    50 SLIP=1.704*Y-.72+SQRT((1.704*Y-.72)**2+.09*Y+.009)
4220       RETURN
4230    40 SLIP=FSLIP(SLIPCG,1,Y)
4240       RETURN
4250    60 SLIP=(.005312/(.573-Y))-.0083
4260       RETURN
4270    30 SLIP=FSLIP(SLIPMK,N,Y)
4280       RETURN
4290       END
4300C
4310       FUNCTION FSLIP(X,N,Y)
4320       DIMENSION X(4,1)
4330       FSLIP=X(1,N)*Y-X(2,N)+X(3,N)/(X(4,N)-Y)
4340       RETURN
4350       END
4360C
4370       SUBROUTINE VEHPLT
4380       COMMON /VEHIN/ VD,W,WP,GHP,HPT,TVAR,TIRPSI,TL,
4390      &               XTL,GCX,XTW,XWD,V1,XRDT,TPR,
4400      &               GH,XNTE,BN,XNA,XCF,
4410      &               NP,VD1,XNT
4420       COMMON ISOILT,CI,SLOPE,FARY(2,180),SARY(2,180),FORCE(2,180)
4430       COMMON TFMUL,NPS,NPL
4440       INTEGER ISOILT,VD1,XCF,XGF,V1,XNTE,BN
4450       DIMENSION BUFFER(380)
4460       EQUIVALENCE (IVD,VD),(XTW,TW),(IV1,V1),
```

(Continued)

(Sheet 9 of 11)

Table A2 (Continued)

```
     &                 (TPR,ATS),(ITRBG,BN),(INOTR,XNTE),
     &                 (ICDTT,XCF),(XCF,XGF),(XTP,TIRPSI)
      CHARACTER VID*60,FILE*70,FILN*71
      DATA LF/0012012012012/
   16 WRITE(42,105)
      READ(41,106) FILE
      ENCODE(FILN,107) FILE,1H;
      CALL ATTACH(2,FILN,1,0,ISTAT,BUFFER)
      VD1=1
      TFMUL=1.
      READ(2,120) VID
      READ(2,110) IDUM,IVD
      READ(2,110) IDUM,W
      WP=W
      READ(2,110) IDUM,GHP
      HPT=GHP*2000./W
      READ(2,110) IDUM,TVAR
      READ(2,110) IDUM,TL
      XTL=TL+3.
      READ(2,110) IDUM,GCX
      READ(2,110) IDUM,XTW
      KSW=1
      IF(IVD.EQ.1) KSW=2
      IF(KSW-1) ,,20
      READ(2,110) IDUM,IV1
      GO TO 22
   20 READ(2,110) IDUM,XWD
   22 IF(KSW-1) 24,24,
      READ(2,110) IDUM,XRDT
   24 READ(2,110) IDUM,TPR
      IF(KSW.EQ.2) READ(2,110) IDUM,TIRPSI
      IF(KSW-1) ,,26
      READ(2,110) IDUM,GH
   26 READ(2,110) IDUM,ITRBG
      IF(KSW.EQ.2) XNTE=BN
      IF(KSW-1) 27,27,
      READ(2,110) IDUM,XNA
      XNT=XNA*2.
      GO TO 28
   27 READ(2,110) IDUM,INOTR
   28 READ(2,110) IDUM,ICDTT
      NP=360
      CALL ARAYIN(2,BUFFER,NP)
      DO 30 I=1,NP,2
      J=(I-1)/2+1
      FORCE(1,J)=BUFFER(I)
   30 FORCE(2,J)=BUFFER(I+1)
      WRITE(42,104) LF
      WRITE(42,200)
  200 FORMAT(70(1H-))
```

(Continued)

(Sheet 10 of 11)

Table A2 (Concluded)

```
4970        WRITE(42,102) LF,VID,LF,LF
4980        N=NP/2
4990        NP=N
5000        CALL PPLOT(FORCE,0.,-N,'*','*','SPEED MPH',9,
5010       &              'TRACTIVE FORCE LB',17,6,6)
5020        WRITE(42    1) LF,LF
5030    201 FORMAT(2A4)
5           WRITE(42,200)
5050        DO 32 M=1,NP
5060        TEMP=FORCE(1,M)
5070        FORCE(1,M)=FORCE(2,M)
5080     32 FORCE(2,M)=TEMP
5090        WRITE(42,104) LF
5100        CALL DETACH(2,ISTAT,BUFFER)
5110    101 FORMAT(A1)
5120    102 FORMAT(A4,'VEHICLE: ',A60,2A4)
5130    104 FORMAT(A4)
5140    105 FORMAT(' ENTER VEHICLE NAME')
5150    106 FORMAT(A70)
5160    107 FORMAT(A70,A1)
5170    108 FORMAT(' FILE-',A70,/,' ATTACH STATUS-',O12)
5180    110 FORMAT(V)
5190    120 FORMAT(T5,A60)
5200        RETURN
5210        END
```

(Sheet 11 of 11)

APPENDIX B: CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) AND METRIC (SI) TO U. S. CUSTOMARY UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
	U. S. Customary to Metric (SI)	
inches	25.4	millimetres
feet	0.3048	metres
square inches	0.000645	square metres
acres	4046.856	square metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
cubic yards per hour	0.7645549	cubic metres per hour
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic yard	0.5933	kilograms per cubic metre
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
feet per second	0.3048	metres per second
miles (U. S. statute) per hour	1.609344	kilometres per hour
horsepower (550 foot-pounds per second)	745.6999	watts
degrees (angular)	0.01745329	radians
	Metric (SI) to U. S. Customary	
Celsius degrees or Kelvins	1.8	Fahrenheit degrees*

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* To obtain Fahrenheit (F) temperature readings from Celsius (C) readings, use the following formula: F = 1.8(C) + 32. To obtain Fahrenheit readings from Kelvins (K), use: F = 1.8 (K - 273.15) + 32.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Rush, Edgar S
Limited evaluation of experimental and standard tractor dozer blades / by Edgar S. Rush, Barton G. Schreiner, William E. Willoughby. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
115 p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; M-78-5)
Prepared for Office of the Assistant Director-Mining, Bureau of Mines, Department of the Interior, Washington, D. C., under Contract No. H0252009, Modification 1 and 2.

1. Bulldozers. 2. Cutting blades. 3. Earth handling equipment. 4. Field tests. 5. Tractors. I. Schreiner, Barton G., joint author. II. Willoughby, William E., joint author. III. United States. Bureau of Mines. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; M-78-5.
TA7.W34m no.M-78-5