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U. S. NAVAL AIR TEST FACILITY (SI)

LAKEHURST, NEW JERSEY

Report NATF-E-1078

DYNAMIC PERFORMANCE OF A MARK 7 MOD 1 ARRESTING SYSTEM USING 24-INCH AND 28-INCH PD FAIRLEAD SHEAVES

Final Report
12 May 1966

by

W. B. Siller
Recovery Division

Prepared under Bureau of Naval Weapons
Problem Assignment Number RSSH-0[illegible]

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U. S. NAVAL AIR TEST FACILITY
(SHIP INSTALLATIONS)
U. S. NAVAL AIR STATION
LAKEHURST, NEW JERSEY

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Prepared under Bureau of Naval Weapons
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ABSTRACT

This report compares Mark 7 Mod 1 arresting-gear dynamic performance with standard 24-inch and prototype 28-inch pitch-diameter (PD) fairlead sheaves: performance with the 28-inch PD fairlead sheaves was satisfactory.

The report also presents data of a Lang-lay purchase cable which failed in a destructive test after 653 arrestments: excessive wear and corrosion contributed to the failure.

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I INTRODUCTION

This report presents performance results obtained with a Mark 7 Mod 1 arresting-engine system using 24- and 28-inch pitch diameter (PD) fairlead sheaves. These tests had been originated to determine both performance and purchase-cable-life using 24- and 28-inch PD fairlead sheaves; however, the purchase-cable-life test was performed with 24-inch PD fairlead sheaves only. The results of the purchase-cable-life test are included in this report. The tests were authorized by BUWEPS under Problem Assignment RSSH-03-119, and were conducted by the U. S. Naval Air Test Facility (Ship Installations) (NATF(SI)), U. S. Naval Air Station, Lakehurst. New Jersey, at the Recovery Systems Track Site (RSTS) No. 2.

II SUMMARY OF RESULTS

The test program consisted of 716 ON-CENTER arrestments using a deck span of 95 feet, as outlined below:

TABLE I
Summary of Test Program and Conditions

Test Phase	Number of Arrestments Performed	Nominal Deadload Weight (Pounds)	Nominal Engaging-Speed Range (Knots)	CRO Valve Ratio Setting	Fairlead Sheave PD (Inches)
I	8	10,000	90 - 120	1.1:1	24
	12	25,000	80 - 120	1.95:1	"
	12	50,000	70 - 115	3.15:1	"
II	653	50,000	115 ± 2	3.15:1	24
III	8	10,000	90 - 120	1.1:1	28
	10	25,000	80 - 120	1.95:1	"
	13	50,000	70 - 115	3.15:1	"
Total	716				

Phase I established arresting-gear dynamic performance with 24-inch PD fairlead sheaves.

Phase II was a destructive test of a Lang-lay purchase cable reeved over 24-inch PD fairlead sheaves. Data pertaining to the history, physical condition, dynamic loading, and failure of the purchase cables was obtained and is included under Test Results and Analysis.

Phase III established arresting-gear dynamic performance with 28-inch PD fairlead sheaves.

III CONCLUSIONS

1. Arresting-gear dynamic performance with 28-inch PD fairlead sheaves is comparable with that of the same system incorporating 24-inch PD fairlead sheaves (page 8).

2. Interstrand corrosion and excessive wear contributed to the failure of the port purchase cable used during the Phase II tests (pages 4 and 5).

IV RECOMMENDATION

1. The incorporation of 28-inch PD fairlead sheaves as a service change of the Mark 7 Mod 1 arresting gear is recommended for the following reasons:

a. Arresting-gear performance with 28-inch PD fairlead sheaves is at least comparable with 24-inch PD fairlead sheaves performance.

b. Tests conducted by reference (a), indicate that an increase in purchase cable fatigue life is attained with 28-inch PD fairlead sheaves.

c. Current industry practice favors the use of larger sheave diameters to improve sheave and cable service life, reference (b).

V TEST EQUIPMENT AND PROCEDURE

A. The arresting-engine system employed the following:

1. Mark 7 Mod 1 arresting engine, Serial No. 16

2. Cam: K-5 (PN 502715-1P)

3. Cam Torque: 90 ±20 foot-pounds

4. Cam-Chain-Drive Pre-tension: 400 ±10 pounds

5. Arresting-Engine Ratio Dial: NAEL(SI) PN 316152-1

6. Purchase Cables:

a. Phase I - NAEL PN A92791-8, 1-3/8-inch-diameter regular-lay 6 x 25, fiber core, anchored externally.

b. Phases II and III - NAEL PN A92791-27, 1-3/8-inch-diameter Lang-lay 6 x 24, fiber core, planetary formed, anchored externally.

7. Sheave-damper buffer-accumulator pre-pressure: 750 ±25 psi

8. Sheave-damper accelerator-accumulator pre-pressure: 300 ±25 psi

9. Orifice-ring in operating-end-accumualtor piping: 2-1/2-inch-diameter.

10. Return-flow orifice in buffer-accumulator flapper valve: 3/8-inch diameter.

11. Return-flow orifice in accelerator-accumulator flapper valve: 1/2-inch diameter.

B. Test Phases I and III were conducted by arresting deadloads of various weights at increasing engaging speeds. Test Phase II was conducted by repeatedly arresting a 50,000-pound deadload at 115 knots until the purchase cable failed. Purchase cables were inspected periodically during Phase II. The following arresting-system parameters were recorded during all three test phases:

1. Arresting-gear cable tension versus time (four locations)

2. Arresting-engine cylinder pressure versus time and versus ram stroke

3. Arresting-engine ram stroke versus time

4. Arresting-engine accumulator pressure versus time

5. Arresting-hook axial load versus time

6. Deadload deceleration versus time

7. Sheave-damper port and starboard cylinder pressure, piston stroke, and piston velocity versus time.

VI TEST RESULTS AND ANALYSIS OF PHASE II DATA

A. Purchase-Cable History: The port and starboard purchase cables were installed on 17 July 1964. The port purchase cable failed on 15 April 1965: total time in service was eight months. During this period, 653 arrestments were conducted as outlined in Table I. Particulars of the port purchase-cable failure which occurred during the last arrestment of Phase II are given in Table II.

TABLE II
Particulars of Port Purchase-Cable Failure

Deadload Weight (Lb)	Engaging Speed (Kn)	Type and Location of Failure	At Failure: Cable Tension (Lb)	At Failure: Elapsed Time (Sec)	At Failure: Ram Stroke (In.)
50,251	113.4	6 strands parted 68-1/2 feet from port deck terminal	100,000	0.55	45.7

1. Pendant Failures: One pendant failure occurred during the test program, but no damage was imposed on the purchase cable.

2. Purchase-Cable/Arresting-Engine Damage Caused by Development of Cable Slack in the Engine: Purchase-cable damage usually evidenced by peening and broken wires, and engine-ram damage caused by cable impacts, were not experienced during this test program.

B. Purchase-Cable Physical Condition

1. Broken Wires: Bi-weekly purchase-cable inspections revealed no broken wires during the entire test period.

2. Birdcaging (Opening of the strands of the cable): Birdcaging did not occur; however, the starboard cable was damaged by kinking when the port cable failed, and this damage has the appearance of birdcaging.

3. Strand Distortion: None was discovered.

4. Extrusion of the Core: Observation revealed no core extrusion.

5. Wire Distortion (Unlaying of wires from the normal lay): Wire distortion occurred at the poured sockets only, and resulted from poured socket/cable preparation and interaction.

6. Interstrand Notching: Internal inspection could not be performed because the cable was to remain intact for magnetic-particle tests.

7. Core Condition: Not examined for same reason as above.

8. Interstrand Corrosion: Both the port and the starboard purchase cables exhibited interstrand corrosion as pictorially recorded in Figure 1A. This figure is a photograph of the starboard cable, but the condition is also typical of the port cable. Such corrosion as in

Figure 1A extends for a distance away from the deck terminals to points approximately 300 feet along both cables. The 300 feet of cable is that length which is or can be in contact with the fairlead system. Figure 2 depicts the RSTS No. 2 fairlead system. The elevation view shows that the port cable is led beneath the track via a conduit and four vertical fairlead sheaves located in pits alongside the track. The pits and the conduit frequently have water in them from drain-off and seepage, and it is assumed that this condition would accelerate corrosion of the cable. It is believed that the port cable will exhibit a greater extent of interstrand corrosion in a region 100 to 200 feet from the deck socket than the starboard cable. Internal inspection could not be performed because the cable was to remain intact for magnetic-particle tests. Figures 1B and 1C are photographs of the broken ends of the port cable: Figure 1B is the end of the short section (68 feet) of purchase cable connected to the pendant: and Figure 1C is the end of the long section (905 feet) of purchase cable. Corrosion of the strands can be detected in both figures. Corrosion can be seen particularly in Figure 1B because the strands have unlayed.

9. Excessive Wear: "Q" measurements in accordance with NAVWEPS 51-5BAA-1 were taken twice. The first set of readings was obtained after approximately 600 arrestments, and the second set after cable failure at 653 arrestments. Results of the first measurements indicated that wear replacement criteria had not been attained on either cable and that the most severe wear on either cable was found on the port cable at approximately 150 feet from the deck socket where a "Q" value for one strand was 0.950 inch. Results of the second set of measurements appear in Table III and are indicated in Figure 3. At this inspection it was discovered that the wear of the port cable at station number 2, 48 feet from the deck socket, had exceeded replacement criteria (that is, the sum of "Q" values for six strands was 8.75 inches). This area of wear is located 20 feet from the rupture.

10. Elongation: Figure 4 is a graph of purchase-cable elongation versus number of arrestments. Maximum percent permanent elongations are calculated as 1.6 percent port and 1.7 percent starboard respectively. These elongations are based upon purchase cable lengths of 1,000 feet port and 850 feet starboard: actual lengths of the cables at removal were 973 feet port, and 836 feet starboard. These actual lengths are shorter than 1,000 feet and 850 feet respectively because the differences represent cable removed in cropping poured sockets and in adjusting the battery position of the crosshead. Figure 4 indicates that the cables continued to elongate up until the time of failure. The purchase-cable diameters measured at the time of removal indicate, by the results of Table III, that the port cable diameter was diminished by 0.092 inch and the starboard by 0.127 inch.

TABLE III
Q Values and Purchase-Cable Diameters

Strand	Port Purchase-Cable Station No. 1	2	3	4	5	6
1	1-9/16	1-5/16	2-1/4	Readings Not Recorded--slight wear		
2	1-19/32	1-1/2	2-1/32			
3	1-21/32	1-17/32	2-1/8			
4	"	1-13/32	1-25/32			
5	1-17/32	1-9/16	"			
6	1-13/32	1-7/16	2-1/16			
Q Sum of 6 Strands	9.32	8.75*	12.03	-	-	-
No. of Strands With Q < 1.25	0	0	0	0	0	0
Diameter	1.333	1.307	1.367	1.370	1.383	1.412

Strand	Starboard Purchase-Cable Station No. 1	2	3	4	5	6
1	1-7/16	1-5/8	1-5/8	2.0	Readings Not Recorded--Slight wear	
2	1-17/32	1-21/32	1-5/8	1-13/16		
3	1-15/32	"	1-9/16	2-1/16		
4	1-5/8	"	"	2-3/32		
5	1-23/32	1-15/32	"	2-1/16		
6	1-17/32	1-18/32	"	1-7/8		
Q Sum of 6 Strands	9.32	9.53	9.50	11.91	-	-
No. of Strands With Q < 1.25	0	0	0	0	0	0
Diameter	1.283	1.345	1.285	1.336	1.349	1.358

NOTES:

1. Readings taken 3 May 1965, after failure occurring during arrestment of event 653 of Phase II
2. Diameter of unused cable = 1.454; Nominal = 1-3/8 inches.
3. Average purchase-cable diameter: Port = 1.362 inches; Starboard = 1.327 inches.
4. Length of cable at removal: Port = 973 feet; Starboard = 836 feet.

* This Q dimension indicates excessive wear of the purchase cable because it is less than 9 inches.

VII TEST RESULTS AND ANALYSIS OF PHASES I AND III DATA

A. Dynamic performance with 24- and 28-inch PD fairlead sheaves installed in the arresting-engine system is presented by the data plotted in Figures 5 through 10. The parameters in each of these figures are discussed separately.

1. Maximum Deck-Cable Tension: Figure 5 indicates lower cable tensions (the dark symbols) were recorded with 28-inch PD sheaves for the 50,000-pound deadload arrestments. A separate envelope (the dashed curves) has been drawn to indicate the range of tensions with 28-inch PD sheaves. The 28-inch PD sheave data overlaps into the 24-inch PD sheave data (the light symbols); the disparity between the two becomes more evident at higher engaging speeds. Maximum cable tensions recorded for the 25,000-pound deadload with 28- and 24-inch PD fairlead sheaves are nearly identical and a single envelope is drawn about them. The 10,000-pound deadload results are similar with respect to 24- and 28-inch PD fairlead sheaves except that starboard tensions with 28-inch PD sheaves are slightly lower (5,000 pounds).

2. Maximum Arresting-Hook Axial Load and Deadload Longitudinal Deceleration: Differences exist between 24- and 28-inch PD sheave data. Figure 6 indicates maximum arresting-hook axial loads are lower with 28-inch PD sheaves for the 50,000- and the 10,000-pound deadloads; the axial loads are lower for the 25,000-pound deadload at engaging speeds below 110 knots, and higher at engaging speeds above 110 knots. Figure 7 presents the curves of maximum deadload longitudinal deceleration versus engaging speed; these curves attest to the validity of the hook load curves because of their similarities. Maximum decelerations are lower with 28-inch PD sheaves for the 50,000- and 10,000-pound deadloads; the decelerations are lower for the 25,000-pound deadload at engaging speeds below approximately 110 knots and higher at engaging speeds above approximately 110 knots. The differences in maximum decelerations are small for the 25,000- and 50,000-pound deadloads and data scatter from additional arrestments may be expected to eliminate differences. The above should also apply to maximum hook loads particularly for the 25,000-pound deadload.

3. Maximum Engine-Cylinder Pressure: The data points of Figure 8 indicate slightly higher maximum cylinder pressures were recorded with 28-inch PD fairlead sheaves. This was noticed only with the 50,000- and 25,000-pound deadloads. The 10,000-pound deadload data exhibits no difference between 24- and 28-inch PD fairlead sheaves. Although the increases found with 28-inch PD sheaves range from 4 to 10 percent, in no case does a difference exceed 400 psi. The differences are not considered significant and individual curves have not been drawn for the 28-inch PD fairlead sheave data.

4. Maximum Engine-Ram Strokes: Figure 9 indicates greater maximum engine ram strokes were obtained with 28-inch PD fairlead sheaves for the 10,000- and 50,000-pound deadloads. It is significant that higher ram strokes were recorded with these deadload weights because these deadloads generally exhibited lower maximum deck-cable tensions,

maximum arresting-hook axial loads and longitudinal decelerations. It is assumed that the increased runout realized with greater ram strokes tended to lower the parameters mentioned.

5. Maximum Anchor-Cable Tensions: No significant differences in the values of this parameter are found comparing 24- and 28-inch PD fairlead sheave data. Figure 10 is a plot of maximum anchor-cable tension versus engaging speed for the three deadload weights of 10,000-, 25,000-, and 50,000-pounds. The data points are distributed into three envelopes, one for each deadload weight.

B. Summary of Performance; The use of 28-inch PD fairlead sheaves provided lower values of maximum deck-cable tension, maximum arresting-hook axial load, and maximum deadload longitudinal deceleration than the 24-inch PD fairlead sheaves. All loads are generally within the range of accepted test scatter. The following variables exist which affect the magnitude of arresting loads:

Item No.	Variable
1	Increased weight and moment of inertia of the 28-inch PD fairlead sheaves
2	Increased angle-of-wrap about the 28-inch PD fairlead vertical pit sheaves
3	Increased length of purchase cable with 28-inch PD fairlead sheaves
4	Increased maximum engine-ram strokes recorded with 28-inch PD fairlead sheaves
5	Increased angle-of-wrap about the movable damper sheave with 28-inch PD fairlead sheaves

1. Item 1 would tend to increase rather than decrease dynamic loads, but other properties of the 28-inch PD sheaves may lower loads. The larger sheave diameter (28 inches versus 24 inches) increases the rotational torque applied by the purchase cable. (The calculated torque increase is 16 percent.) The larger sheave circumference requires less severe bending of the purchase cable, and allows the sheave to rotate slower than the 24-inch sheave. These three factors could lower cable tensions and may account for the larger ram strokes recorded with the 28-inch sheaves. More of the initial engaging energy would be absorbed in the arresting engine if less engaging energy was dissipated by bending cable and rotating fairlead sheaves. Adverse inertial effects are not apparent with the 28-inch PD sheaves.

2. The effects of Items 2 and 3 are considered negligible because the increases were small (approximately 6 degrees and 10 feet respectively).

3. Item 4 was considered as contributing to lowering of loads.

4. Because Item 5 could produce a force increase upon the movable damper sheaves, the effects are discussed below:

a. Sheave-Damper Cable Geometry: Figure 11 is a sketch of the sheave-damper cable system indicating the increase in cable wrap with 28-inch PD fairlead sheaves. Figure 12 is a graph of cosine α versus movable-sheave stroke. The force upon the movable sheave is 2T cosine α where T equals purchase-cable tension. For a given stroke, the force upon the movable sheave is greater with 28-inch PD sheaves because the angle α is less. Figure 12 indicates force on the movable sheave may be increased up to 5 percent at a given stroke with 28-inch PD fairlead sheaves.

b. Sheave-Damper Performance: Port and starboard sheave-damper maximum piston stroke, piston velocity, and cylinder pressure are plotted on Figure 13 for 10,000-pound deadload arrestments using 24- and 28-inch PD fairlead sheaves. Slight differences are detected in comparing 24- and 28-inch PD sheave data. At engaging speeds of 90 and 110 knots, maximum piston strokes with 28-inch PD fairlead sheaves are greater than those of 24-inch PD fairlead sheaves; however, maximum piston velocities and cylinder pressures are lower than those with 24-inch PD fairlead sheaves. These differences are attributed to varying sheave cylinder prepressures. Figure 14 is a graph of sheave-damper cylinder prepressure versus maximum sheave-damper piston stroke for the 10,000-pound-deadload arrestments of Figure 13. The maximum sheave-damper piston stroke varies inversely with the cylinder prepressure and directly with the engaging speed. A variance of maximum piston stroke as great as 11 inches is produced by varying the prepressure by 200 psi. The zone between the dashed lines of Figure 14 represents a tolerable prepressure range of 750 $\pm$ 25 psi. Maximum piston-stroke data within this tolerable range of prepressure may vary by approximately 5 inches or 8 percent. Such variance is greater than the 5-percent stroke increases predictable from changing the sheave-damper cable geometry.

c. Sheave-Damper Energy Absorption: No significant difference in the quantity of energy absorbed by the sheave dampers could be detected when comparing 24- and 28-inch PD fairlead-sheave data. Figure 15 is a graph of sheave-damper-energy absorbed versus deadload engaging speed for a 10,000-pound deadload with 24- and 28-inch PD fairlead sheaves.

d. Time Histories: Figures 16 through 18 contain time histories of sheave-damper parameters for 10,000-pound-deadload arrestments with 24- and 28-inch PD fairlead sheaves. The sheave-damper cylinder prepressures for these events were approximately 750 psi. The similarity of the 24- and 28-inch PD sheave curves indicates that sheave-damper performance was unaffected by the 28-inch PD fairlead sheave cable geometry.

VIII REFERENCES

(a) Report NAEL(SI)-ENG-7279 of 13 Apr 1965, Comparative Wire Rope Performance and Effect of Sheave Diameter on Fatigue Life as Determined with the NAEL(SI) Cycle Tester

(b) Wire Rope Engineering Handbook, American Steel and Wire Company

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NATF-E-1078

A - STARBOARD PURCHASE-CABLE INTERSTRAND CORROSION

B - PORT PURCHASE-CABLE (DECK SECTION) BROKEN END, UNLAYED STRANDS, AND CORROSION

C - PORT PURCHASE-CABLE (ENGINE SECTION) BROKEN END AND CORROSION

Figure 1 - Purchase-Cable Corrosion

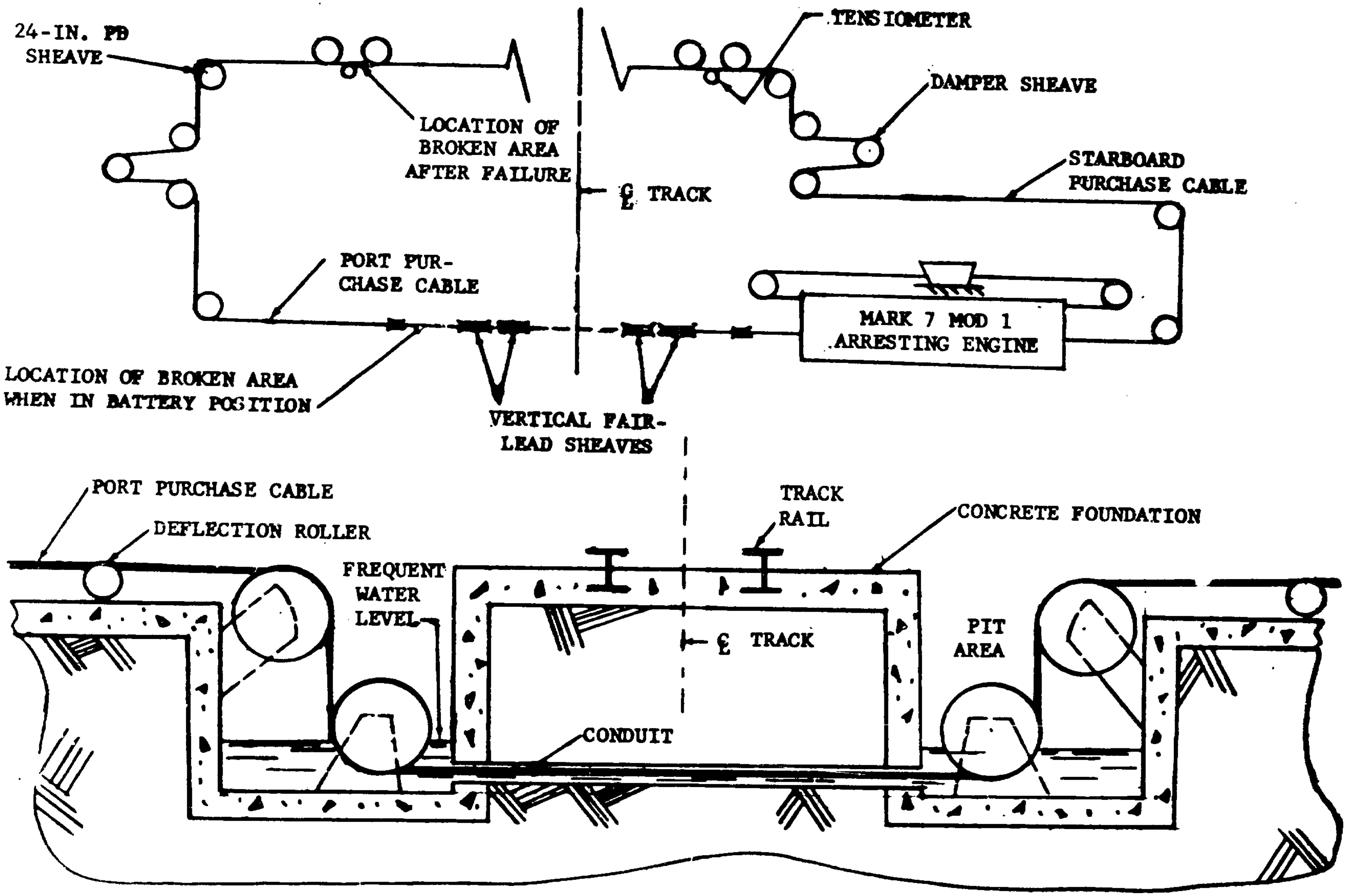

Figure 2 - Schematic Diagrams: Fairlead System (Upper), and Sectional View of Pits (Lower)

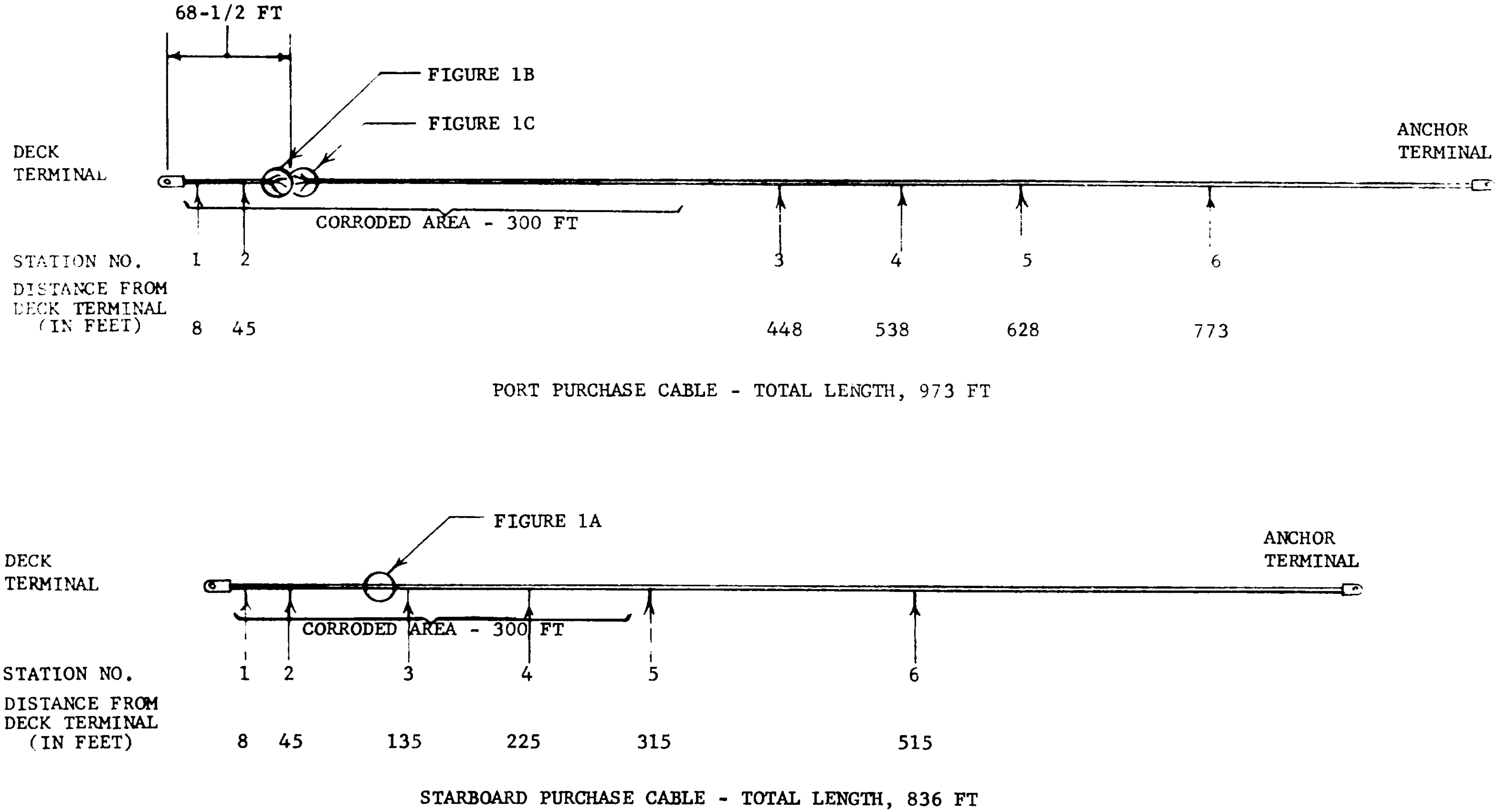

Figure 3 - "Q" Measurement Stations for Purchase Cables

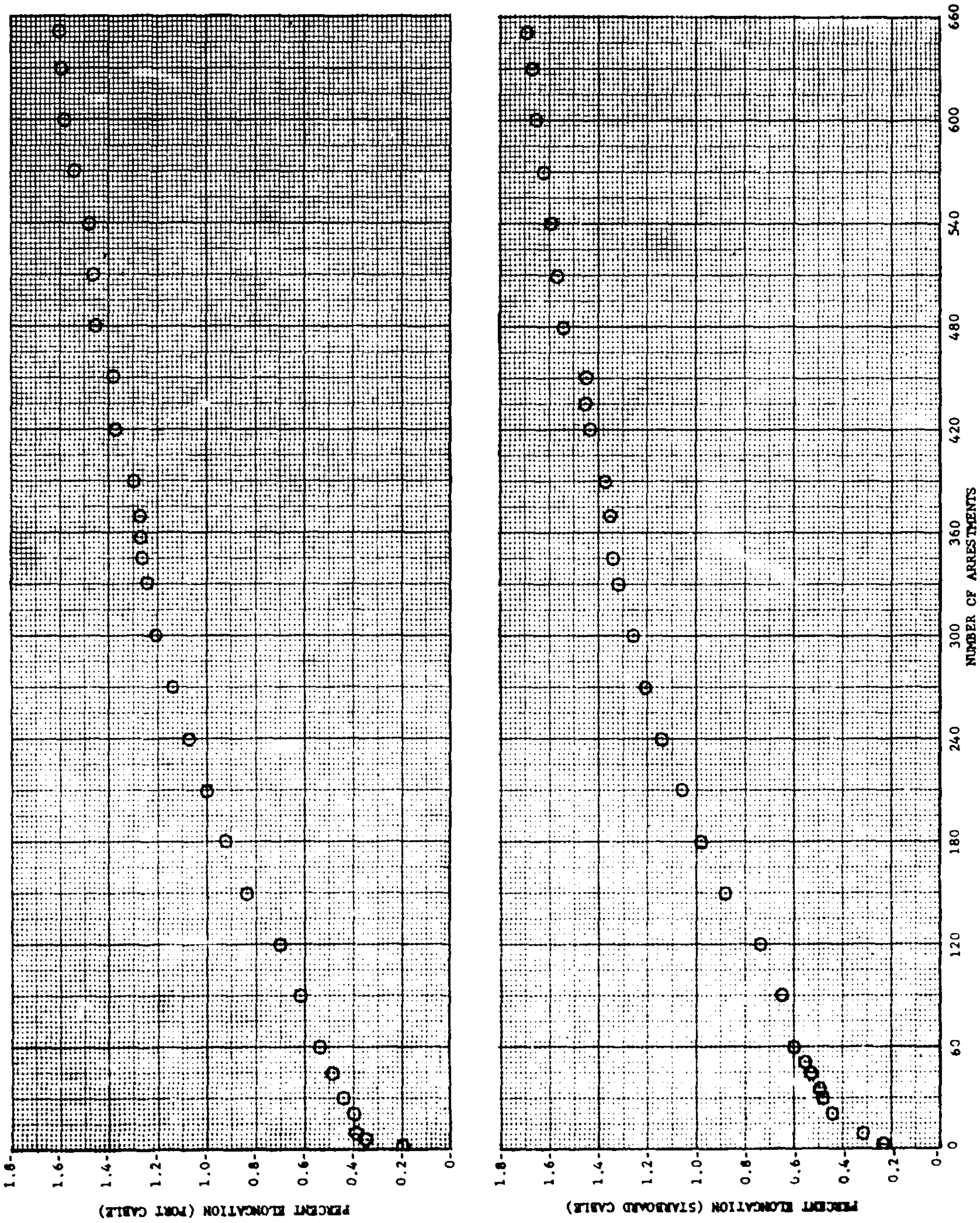

Figure 4 - Percent Elongation versus Number of Arrestments - Port and Starboard Purchase Cables

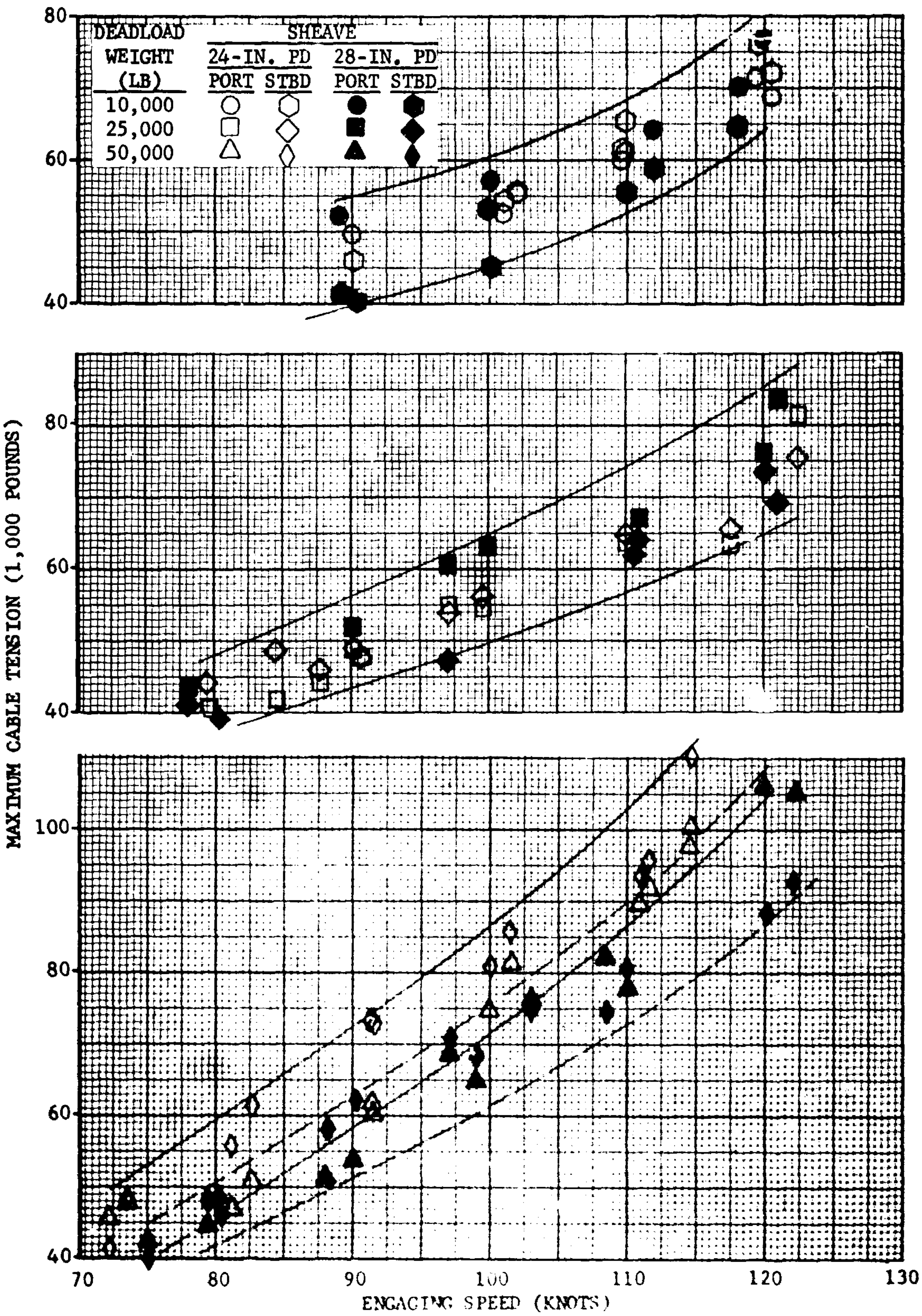

Figure 5 - Maximum Deck-Cable Tension versus Engaging Speed

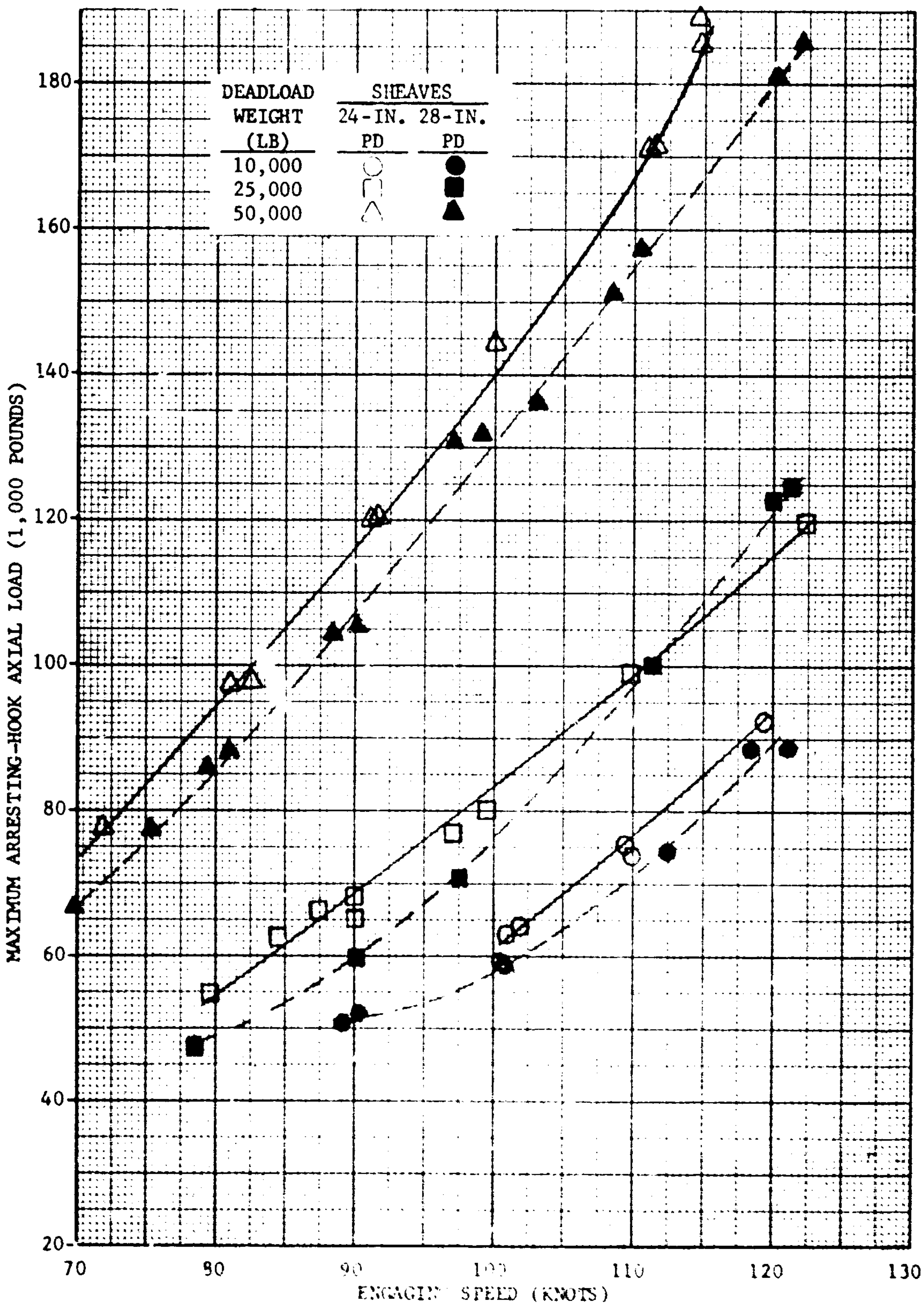

Figure 6 - Maximum Arresting-Hook Axial Load versus Engaging Speed

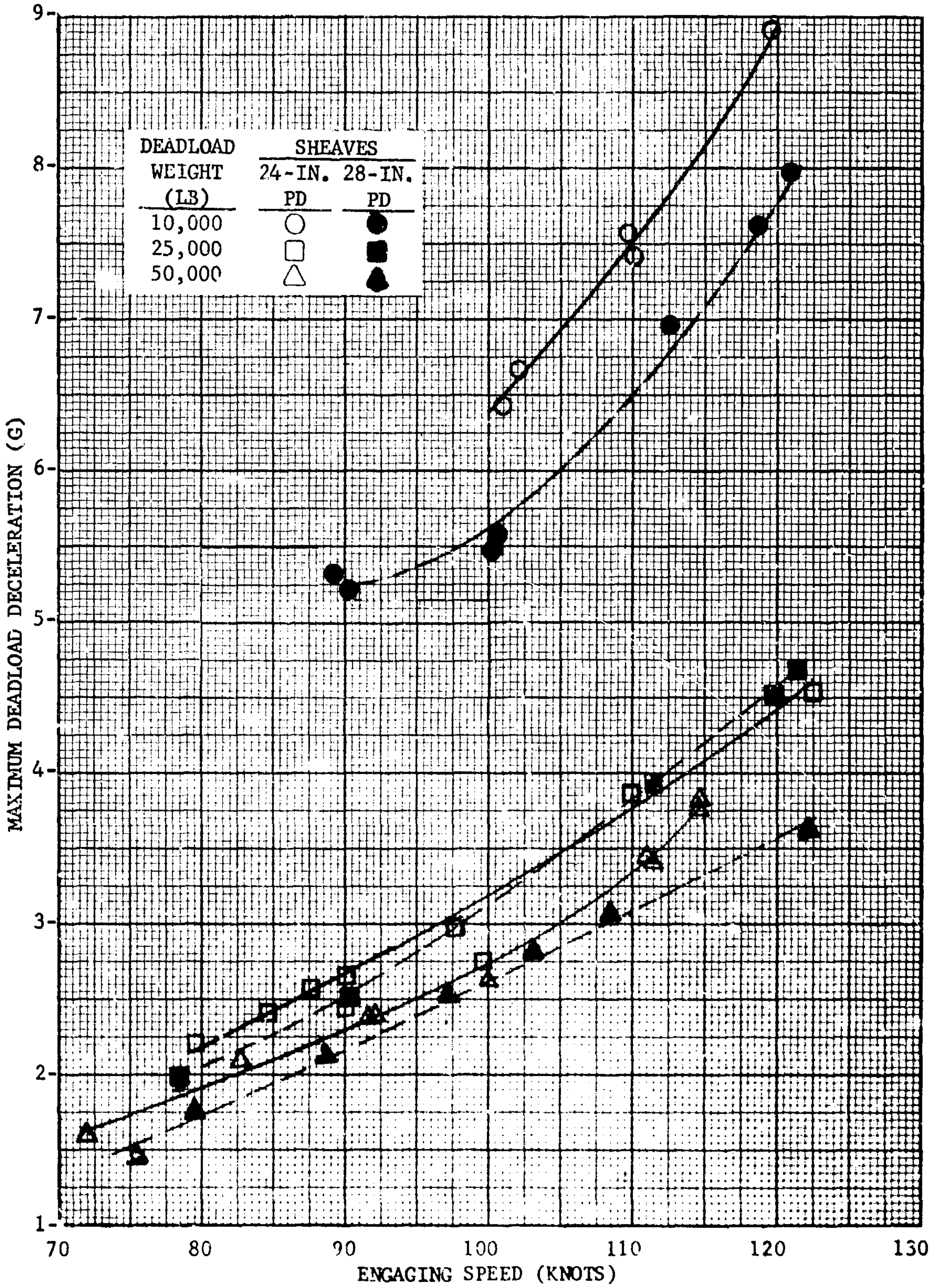

Figure 7 - Maximum Deadload Deceleration versus Engaging Speed

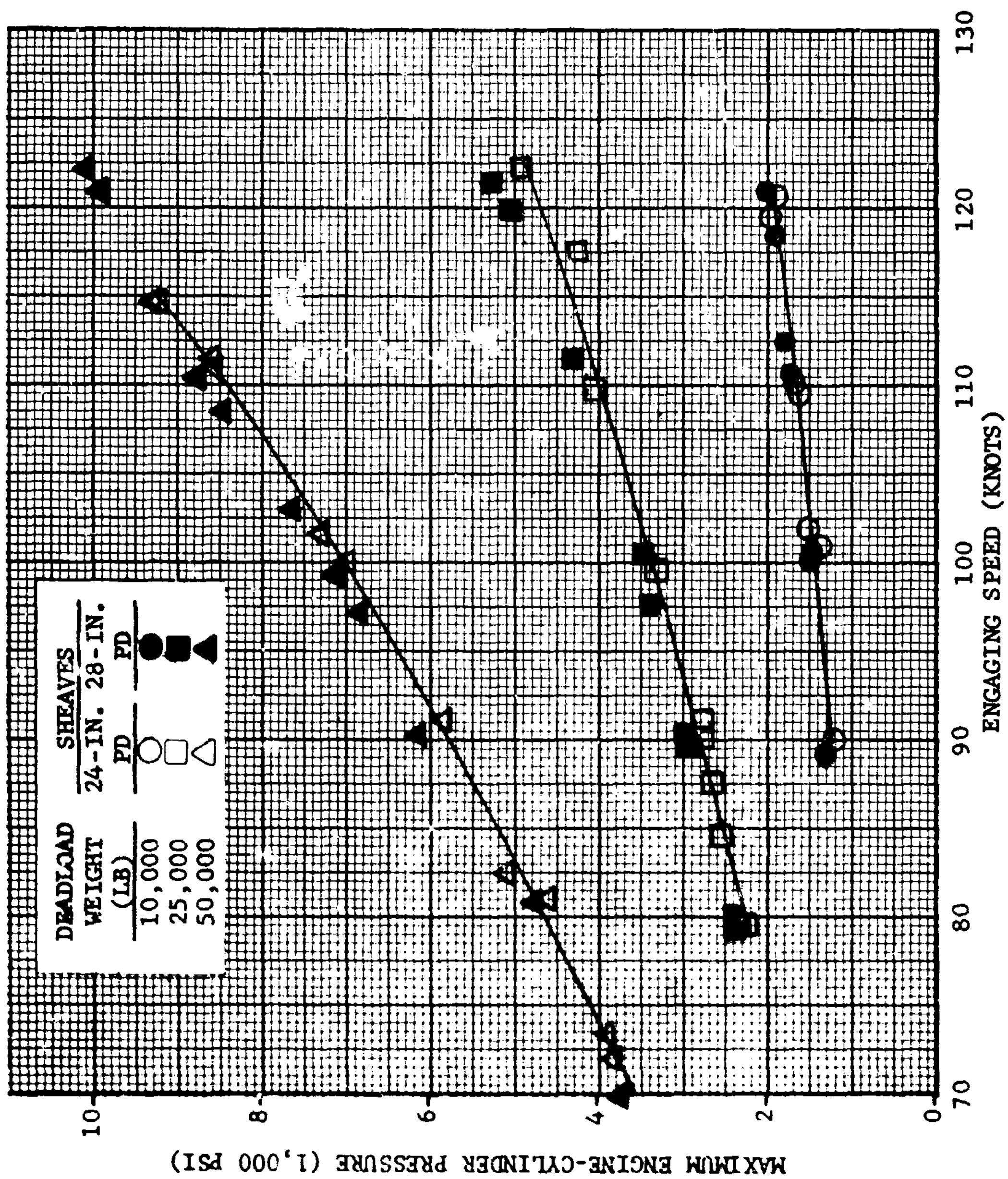

Figure 8 - Maximum Engine-Cylinder Pressure versus Engaging Speed

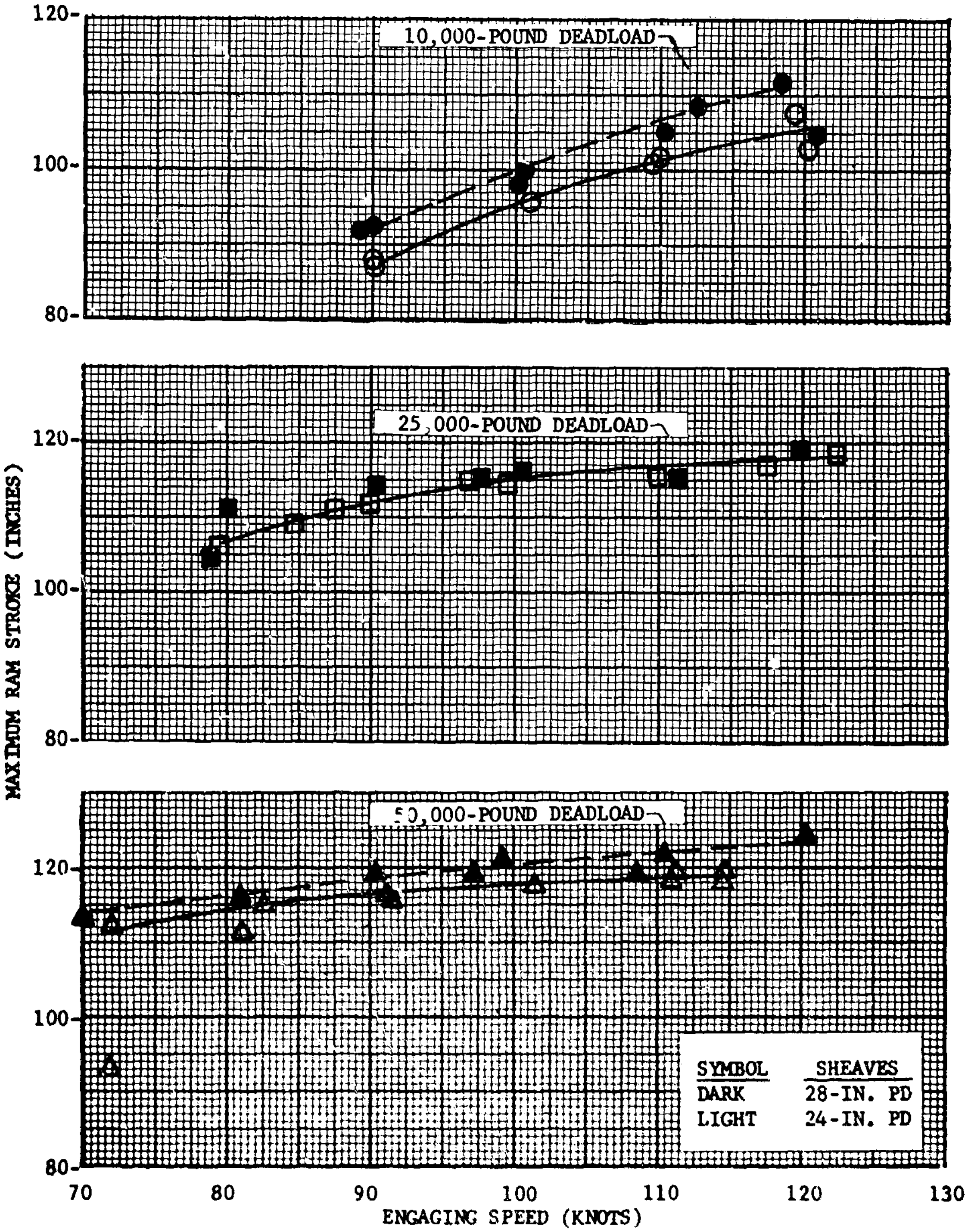

Figure 9 - Maximum Engine Ram Stroke versus Engaging Speed

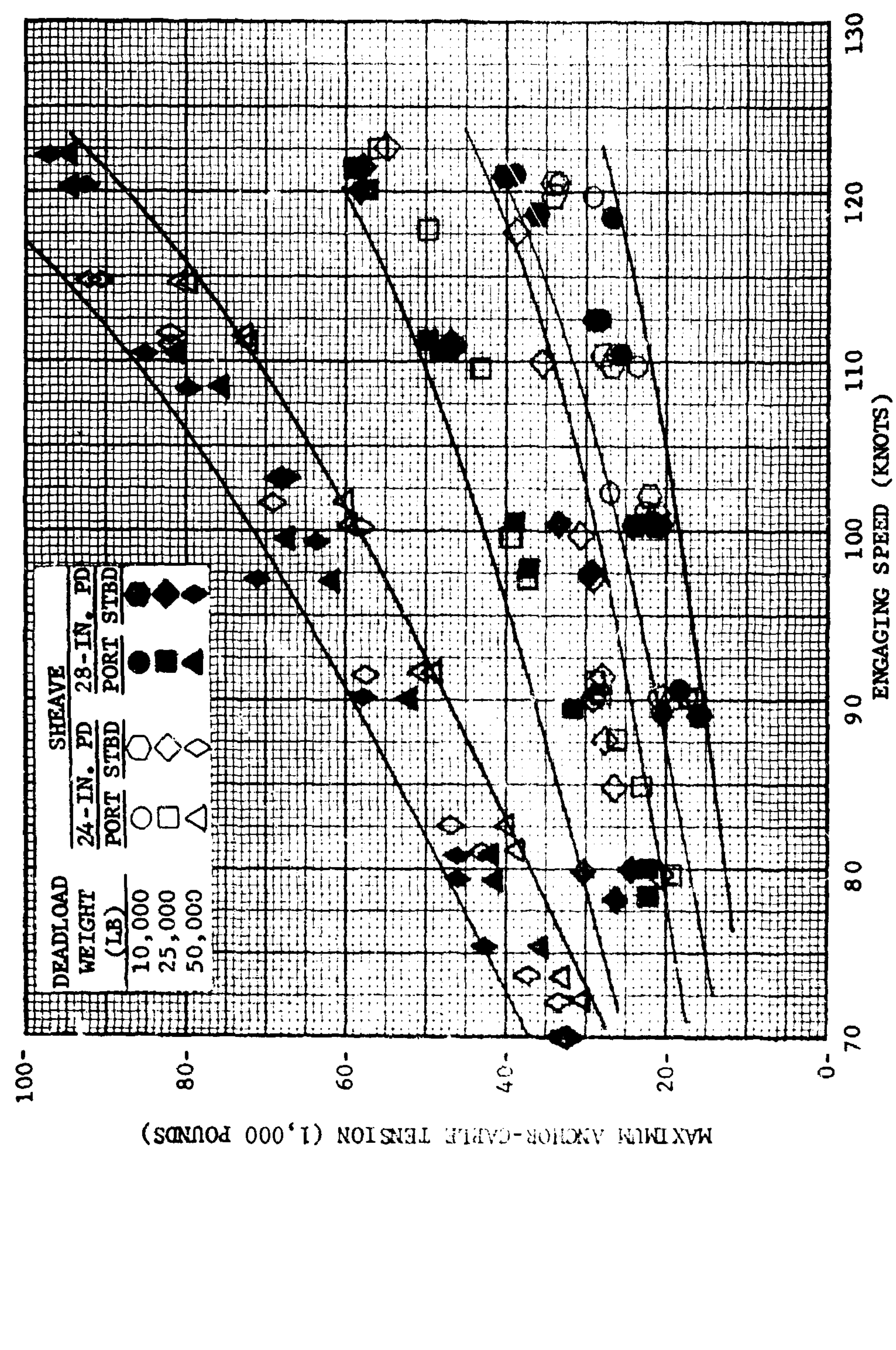

Figure 10 - Maximum Anchor-Cable Tension versus Engaging Speed

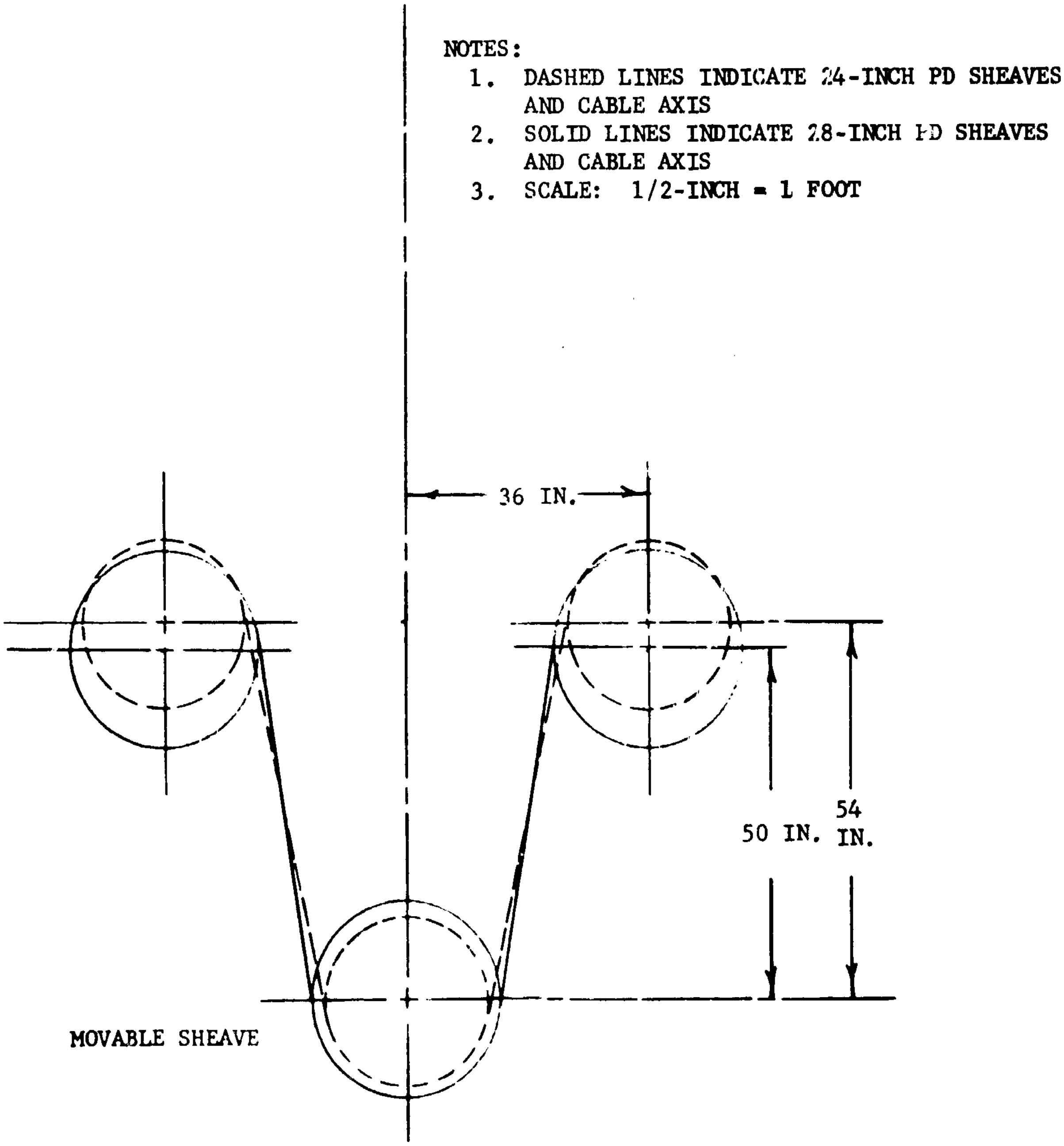

Figure 11 - Schematic Diagram of Sheave-Damper Cable Systems

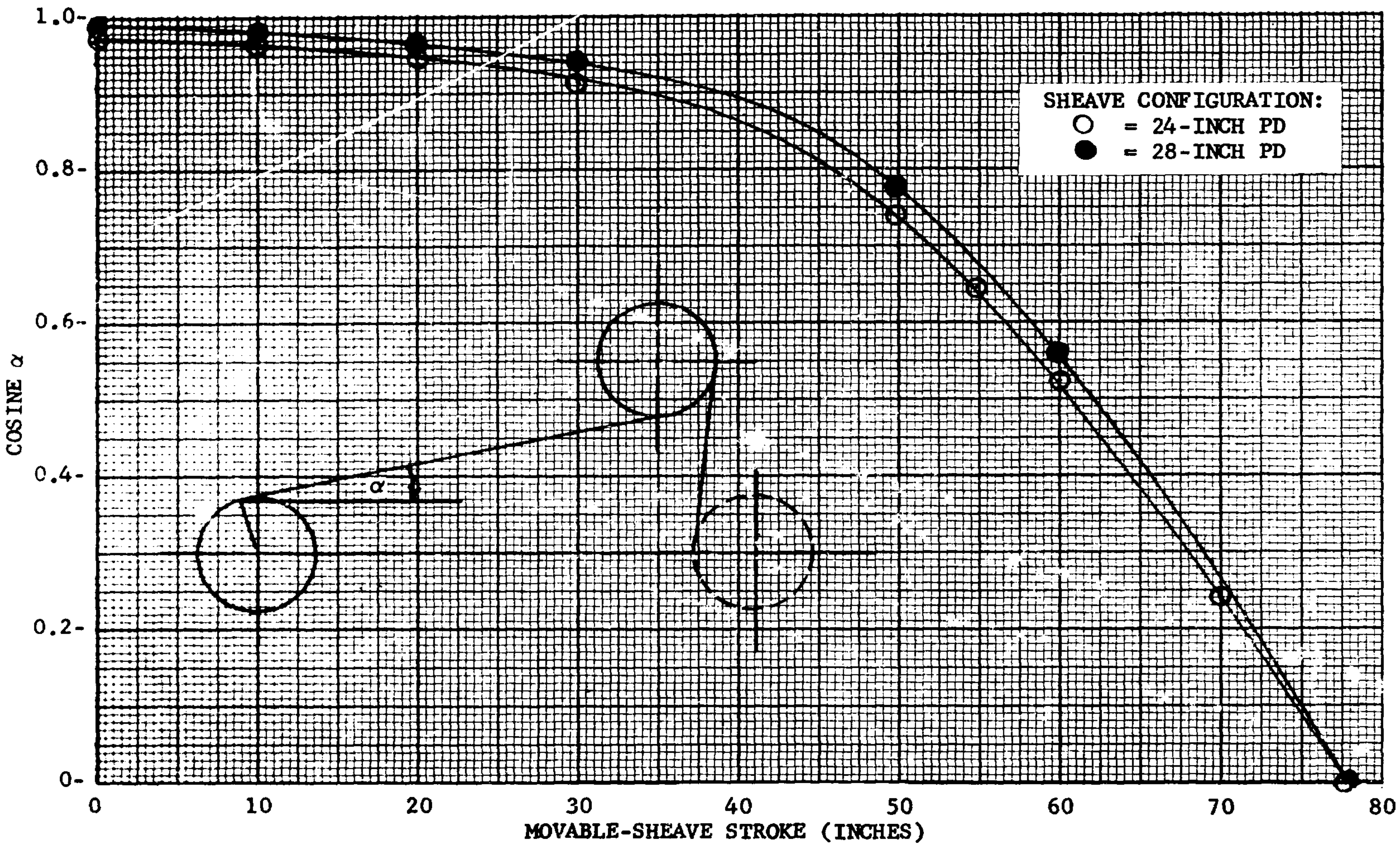

Figure 12 - Cosine α versus Movable-Sheave Stroke

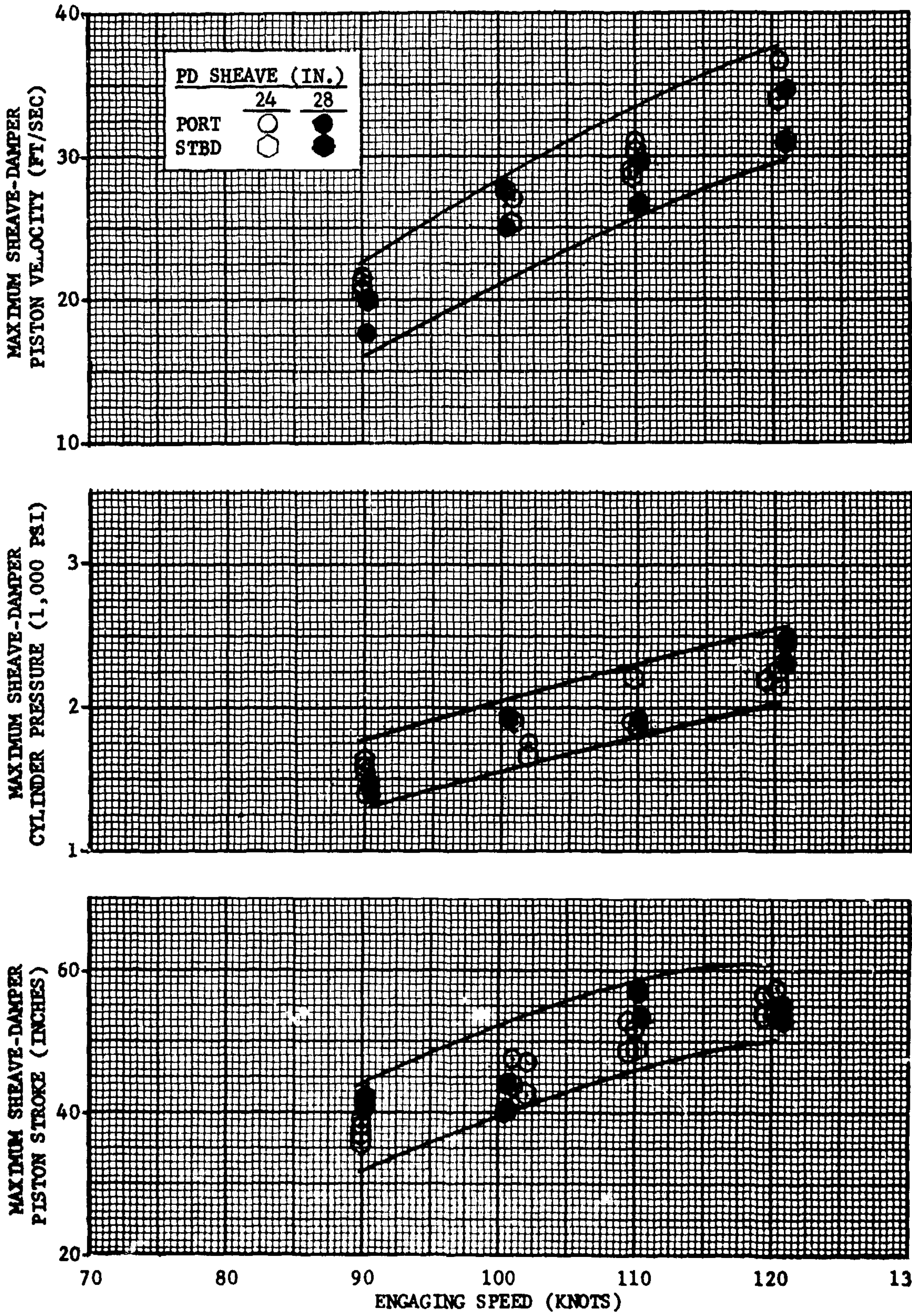

Figure 13 - Maximum Sheave-Damper Piston Stroke, Cylinder Pressure, and Piston Velocity versus Engaging Speed

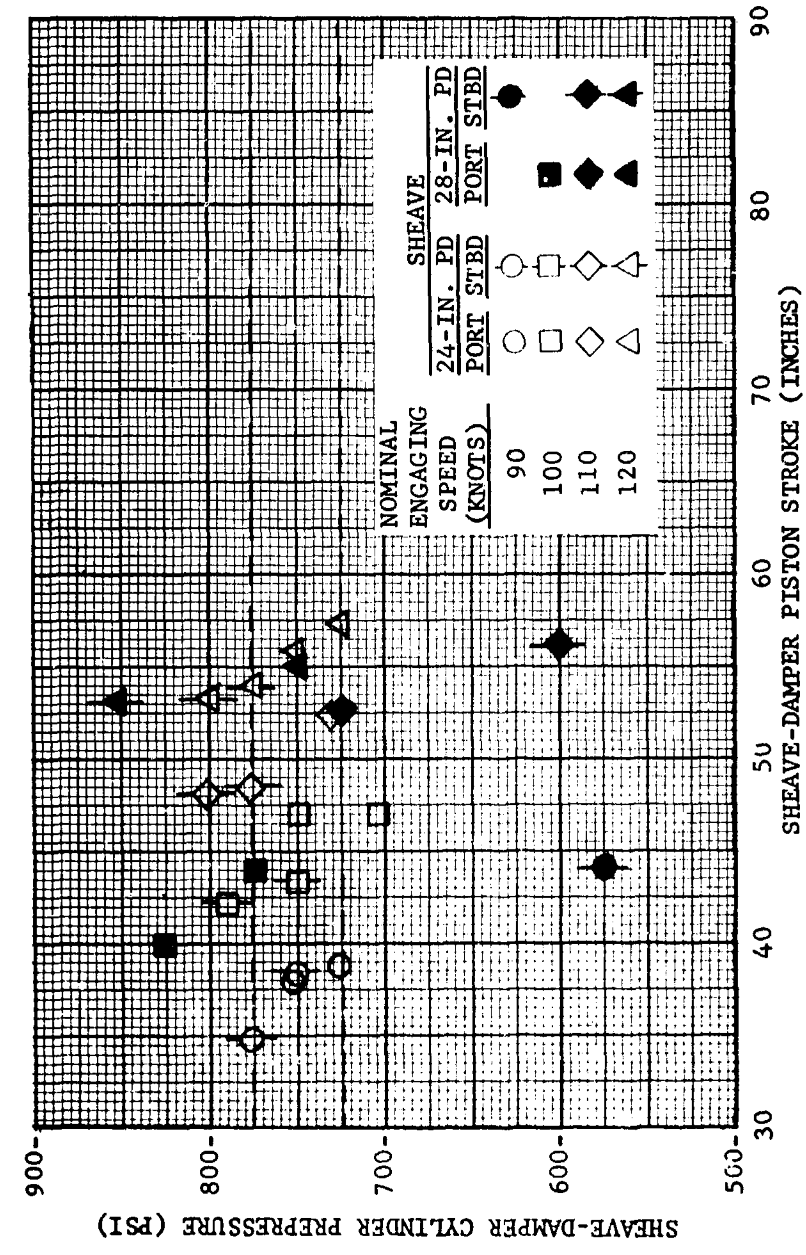

Figure 14 - Sheave-Damper Cylinder Prepressure versus Sheave-Damper Piston Stroke

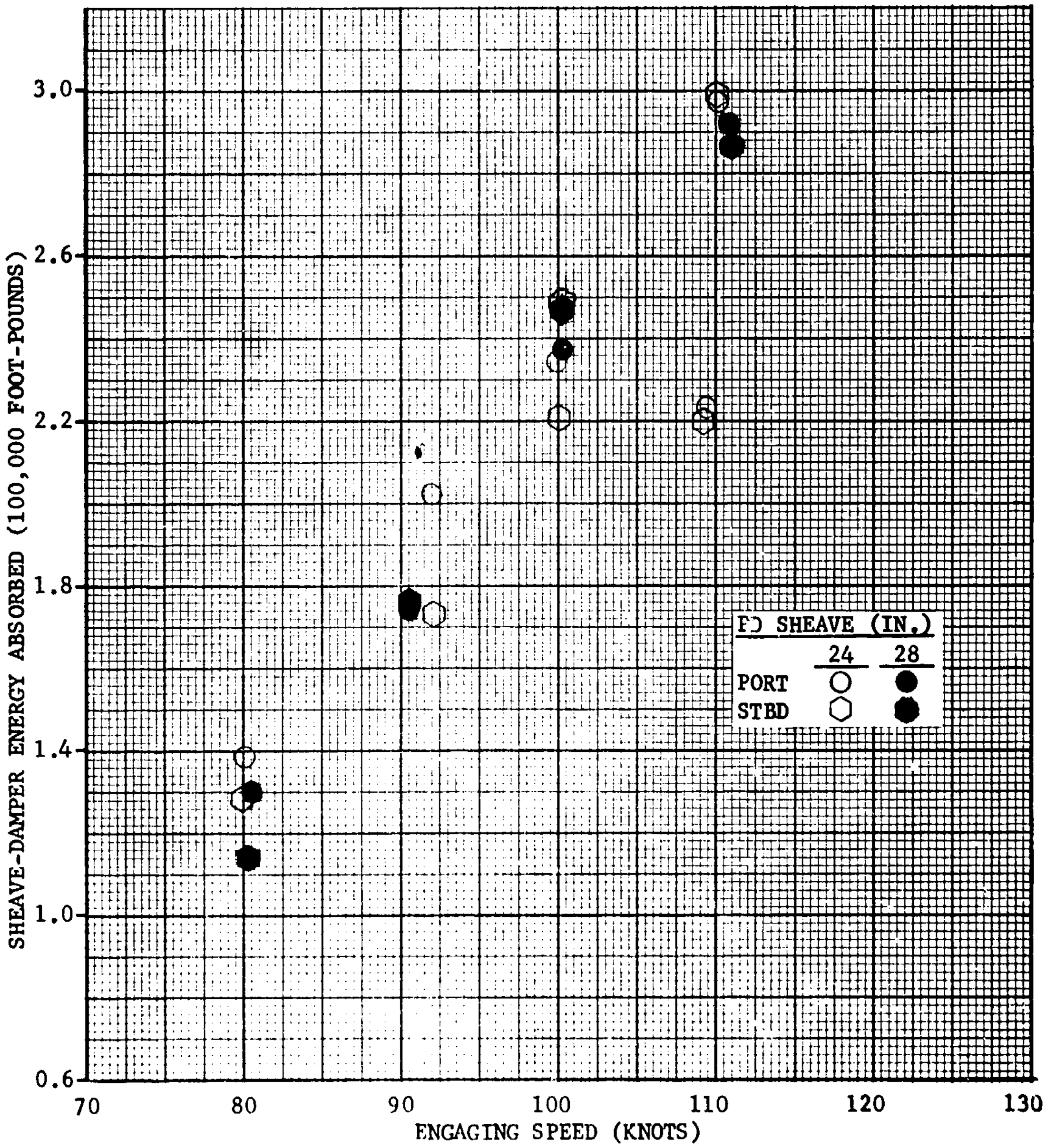

Figure 15 - Sheave-Damper Energy Absorbed versus Engaging Speed

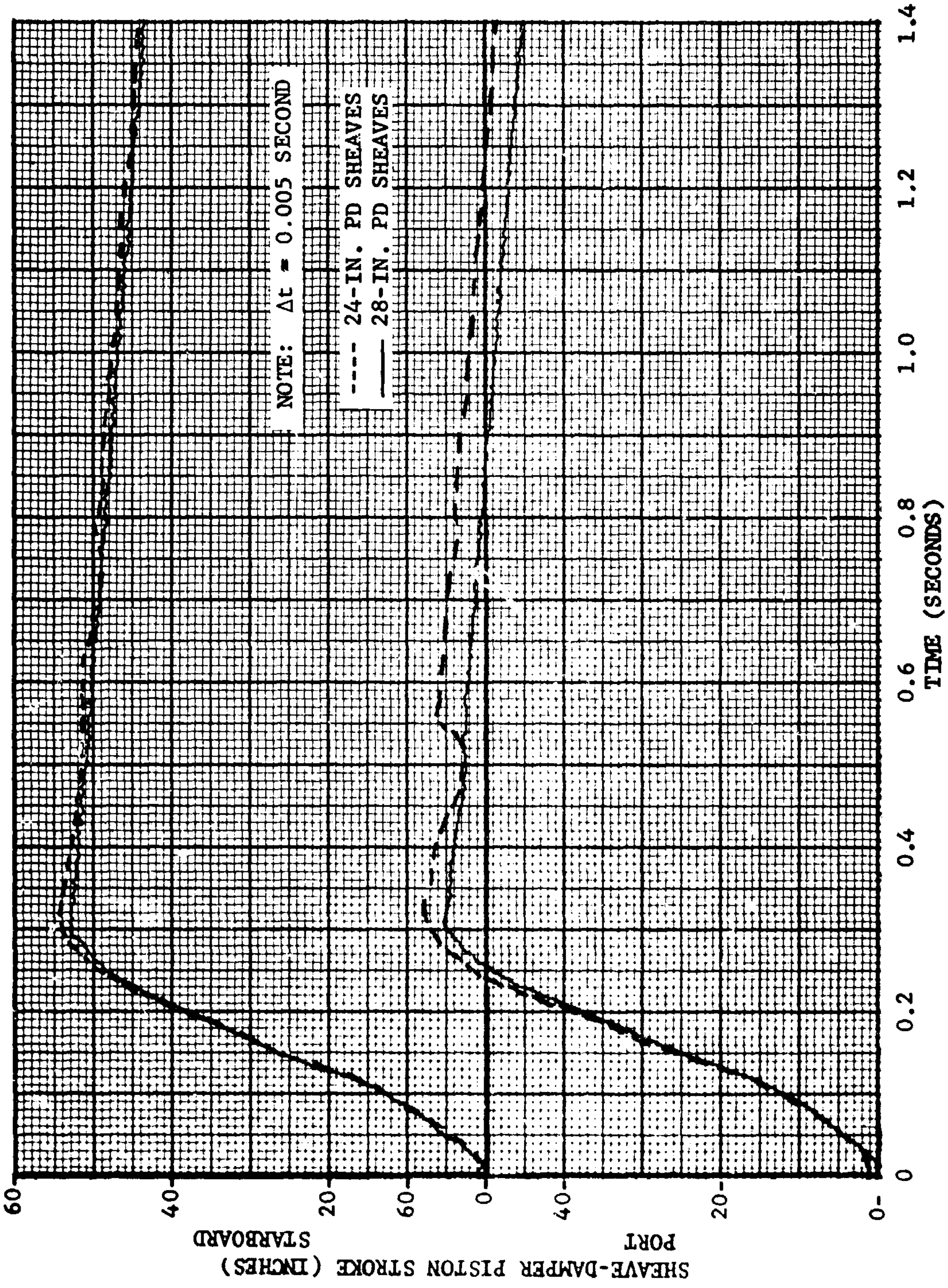

Figure 16 - Typical Time History of Sheave-Damper Piston Stroke (Port and Starboard) versus Time

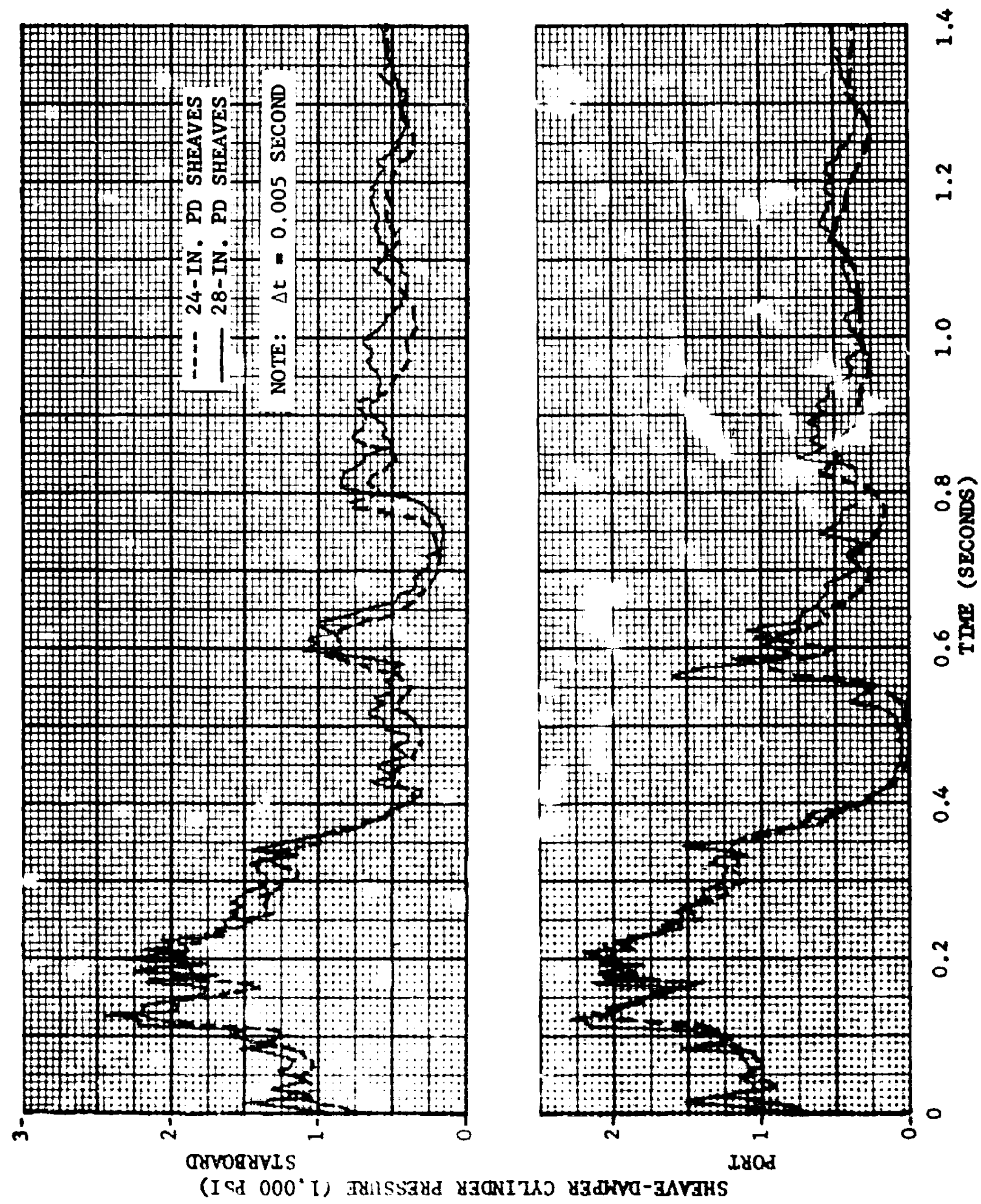

Figure 17 - Typical Time History of Sheave-Damper Cylinder Pressure (Port and Starboard) versus Time

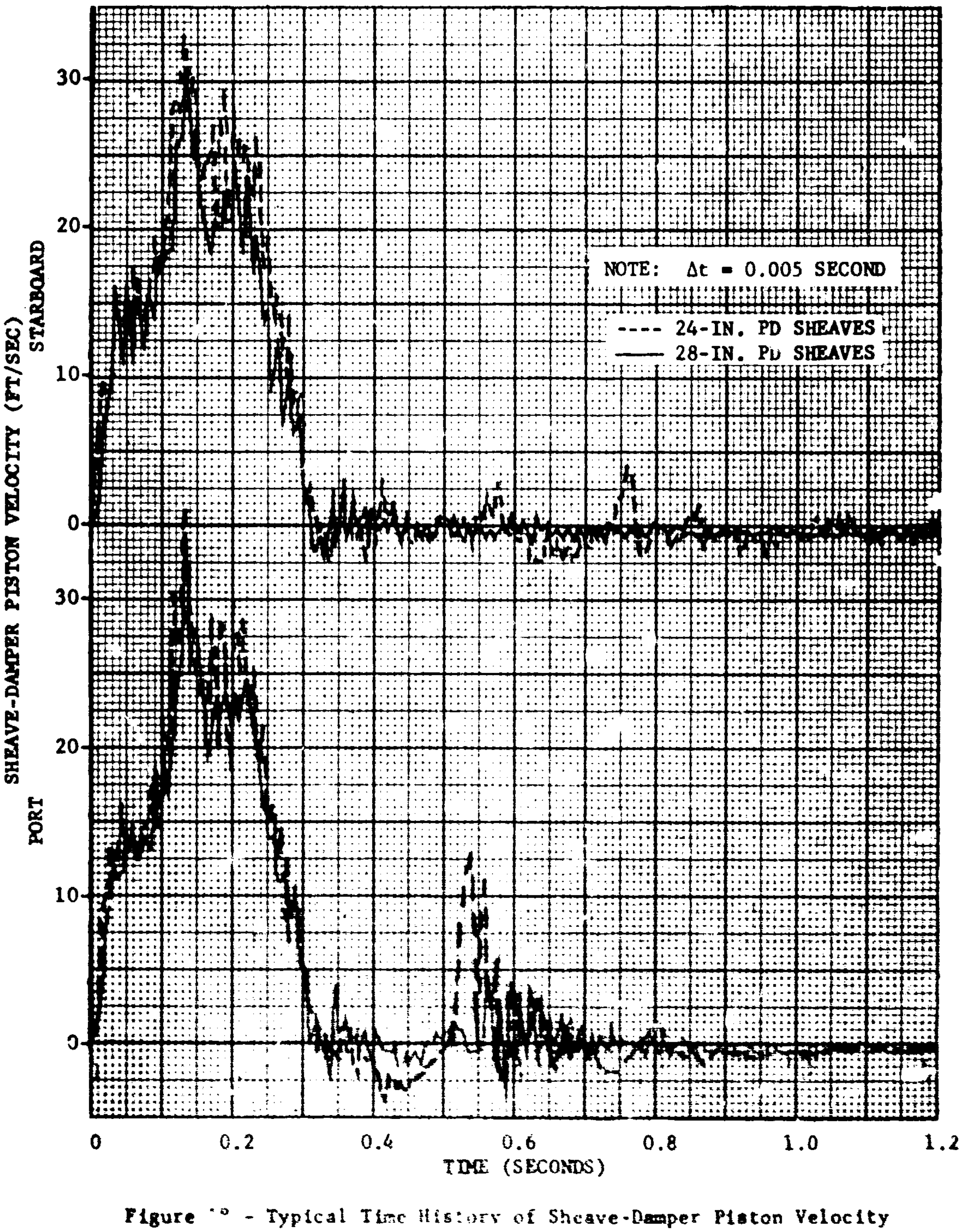

Figure 10 - Typical Time History of Sheave-Damper Piston Velocity (Port and Starboard) versus Time

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13. ABSTRACT

This report compares Mark 7 Mod 1 arresting-gear performance with standard 24-inch and prototype 28-inch PD fairlead sheaves. Performance with the 28-inch PD fairlead sheaves was satisfactory. The report also presents data of a Lang-lay purchase cable which failed in a destructive test after 653 arrestments: excessive wear and corrosion contributed to the failure.

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(Report No. NATF-E-1078)
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UNCLASSIFIED

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1. Arresting Gear
2. Aircraft Recovery
3. Dynamic Performance

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