

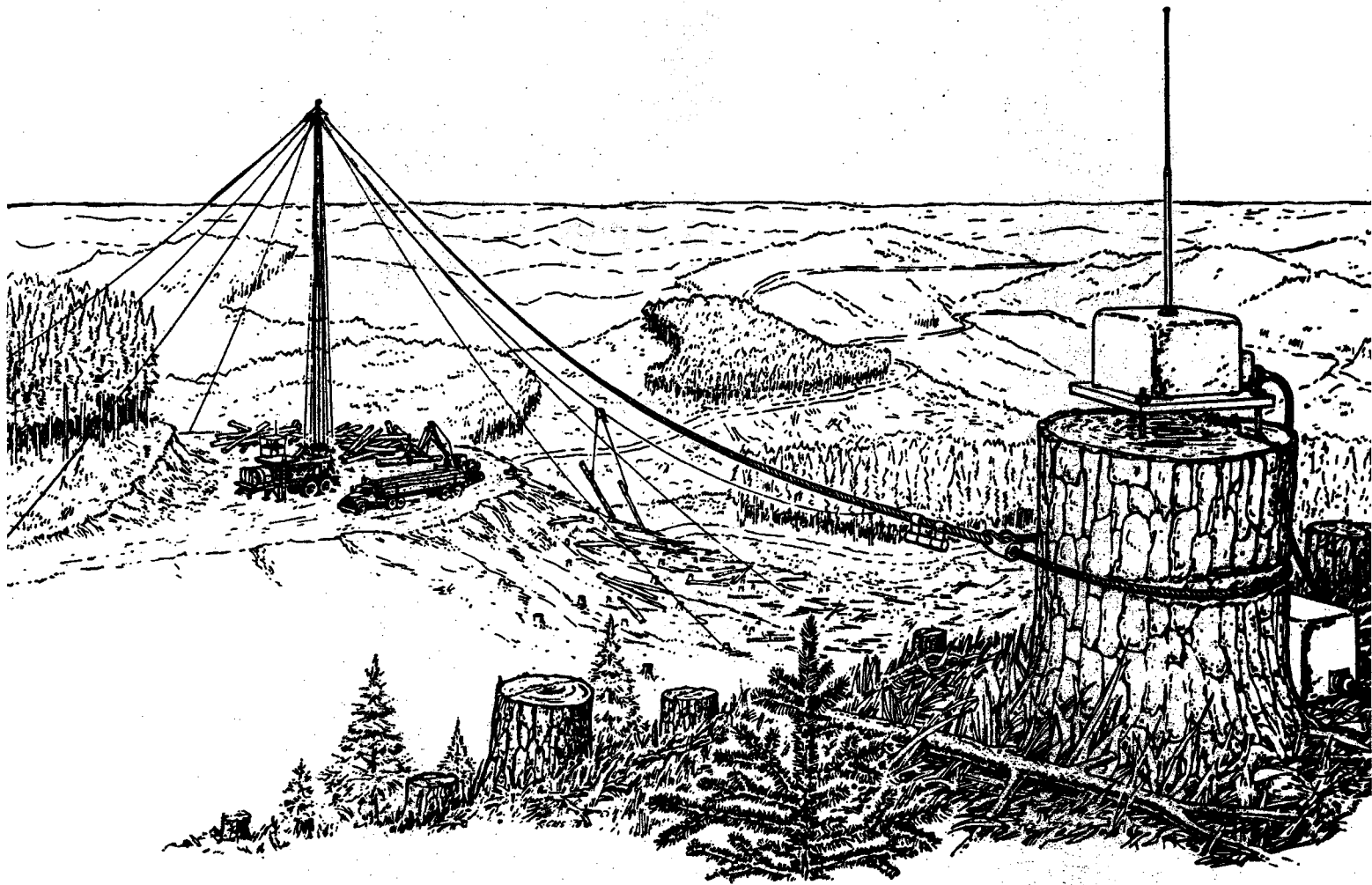


JULY 1978

project record

San Dimas Equipment Development Center

SKYLINE ANCHOR DYNAMICS TEST



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FOREST SERVICE

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SKYLINE ANCHOR DYNAMICS TEST

Submitted to—

**FOREST SERVICE—U. S. DEPARTMENT OF AGRICULTURE
EQUIPMENT DEVELOPMENT CENTER
SAN DIMAS, CALIFORNIA 91773**

for—

**ED&T Project No. 2640
Substitute Anchors for Aerial Cable Transport Systems**

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TECHNICAL REPORT FE-UW-7702

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PREFACE

Adequate anchorages for cable logging systems have always been a concern of logging operators. Further, the rapid depletion of old growth stumps and the advent of large skyline systems have become a major concern to logging engineers. This concern has caused a renewed interest in substitute anchors and the San Dimas Equipment Development Center (SDEDC) was assigned a project to:

- **Design and develop substitute anchors**
- **Develop methods for predicting the holding capacity of anchors**
- **Develop instrumented systems for early warning of impending anchor failures.**

These developmental objectives created a need to ascertain the magnitudes of static and dynamic loads occurring on current anchor cable systems. Researchers at the Pacific Northwest Forest and Range Experiment Station (PNW) were contacted and field tests were agreed upon to develop the necessary information.

Contracts were let to the University of Washington, College of Engineering, to develop a test plan as agreed to by SDEDC and PNW and to analyze the test data. This summary report contains the information on the skyline anchor dynamics test by the University of Washington.

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ABSTRACT

A test for both the static and dynamic behavior of a skyline logging guyline cable system was conducted during the week of January 10-15, 1977 at Snoqualmie, Washington. The primary objective of the test was to produce information needed to quantify the loading of system anchors during a typical logging operation. A secondary objective was to provide experimental information applicable to the validation of analytical models used to explore system behavior. Both objectives were accomplished.

The field data consist of careful survey of the yarding geometry, stump and tower motion during static loading, carriage and load location necessary to calculate skyline loading and the dynamic tension and acceleration data collected on selected guylines, stumps and the yarding tower.

Data were collected on six pre-planned tests simulating typical yarding conditions, and the data are reported here along with objective and purpose of each test. Some assessment of the success of experiment and a limited amount of data analysis are presented.

The static data collected compare favorably with analytical predictions. The dynamic tension in some of the tests produced peak tensions exceeding yield in the skyline, even though the static (mean) load was within safe limits. The tests clearly showed the importance of dynamics of the system and the necessity for dynamic modeling in skyline systems design.

ACKNOWLEDGEMENT

The results obtained in the tests reported here are the culmination of an extensive team effort. We, therefore, would like to recognize the efforts of the following individuals and groups:

Virgil Binkley, Joe Gorsh and Don Studier of the USDA Forest Service, members of the Steering Committee, that made this study possible and provided funds for its completion.

John Warner - Region 6, USDA Forest Services - for his excellent work in rounding up the survey team and providing our topographical data.

Jerry (G.C.) Gilles of the Weyerhaeuser Company in providing the vital liaison with their Snoqualmie Falls regional division in providing the yarder and a very patient and cooperative crew.

Bill Bramwell, Robert Ryan and Steve Reutebuch, University of Washington graduate assistants, for providing services at the test site and programming help in the data reduction.

Finally, the computer services (PDP-11) by the Mechanical Engineering Department and the release time from teaching and summer support by the College of Forest Resources for the Principal Investigator (Jorgensen) was appreciated.

The data reduction was completed as part of Contract 0292-43-77 with the USDA Forest Service Equipment Development Center, San Dimas, California.

I. INTRODUCTION

1.1 Background

This report presents the data collected during a Skyline Anchor Dynamics Test conducted the week of January 10-15, 1977.

The purpose of the test was to provide information about the loading spectrum experienced by the stumps used to anchor cable logging systems. It was recognized that these anchor loads will vary between cable system configurations, their particular anchoring geometry and the operating line tensions being experienced. Therefore, a second objective was to examine the particular system tested for general information which would be applicable to other systems. Although this experiment did yield data about specific loadings, each test was planned for a purpose suited to the second objective.

This report primarily presents the data collected and suitably reduced for display. No major attempts were made to include conclusions drawn from the data analysis other than general trends and what was considered prudent engineering analysis to validate the data.

1.2 Organization & Responsibilities

The information reported in this document was developed through the cooperative efforts of many organizations.

The need for the anchor load spectrum of cable yarding systems was identified by the Division of Timber Management of the USDA Forest Service. They arranged funding for the project through the San Dimas Equipment Development Center (SDEDC) who then became responsible for arranging the test. Early in the planning, a mutual interest in the test developed between the University of Washington and the Forest Service. The SDEDC then contracted with the University to create a

plan for the test and to develop a means of reducing the data which would be collected. This phase was completed under Purchase Order #834-43-76, in cooperation with the Forest Engineering Research Project in Seattle, Washington.

The Weyerhaeuser Company shared an interest in the anchor load information and offered to contribute their facilities at Snoqualmie Falls, Washington for the test. The test was conducted there during the week of January 10 of 1977. The test instrumentation was provided at the site by the Development Sciences Corporation, under contract to the SDEDC. The University of Washington provided the recording equipment and supervisory personnel.

The final data reduction to the form presented here was performed by the University of Washington on the PDP-11/40 computer equipment in their Mechanical Engineering Department under the supervision of Dr. Jens Jorgensen.

II. YARDING SYSTEM DESCRIPTION & DATA COLLECTION

2.1 Yarding System

The test was conducted on a live skyline, rigged as a flyer system as shown in Figure II-1. This system consisted of a 1-3/8" skyline, a 1" mainline, a 110' steel tower mounted on a Washington 208 yarder, a flyer carriage of known weight, and seven 1-3/8" guylines anchored to stumps. The yarder was situated on a conventional landing and a tailhold anchor was located to provide a span in excess of 1200 feet. The chord slope of the setting was steep enough to allow the carriage to cover 80% of the span under gravity control without the assistance of a haulback. The Washington 208 yarder had two live drums for control of the skyline and mainline during yarding at tensions in the range of one-third the breaking strength of these operating lines. The yarder is shown in Figure II-2.

2.2 System Loads

Three logs of known weight were used during testing. These had been weighed in the Weyerhaeuser Snoqualmie Falls mill yard and brought to the test site by truck. The logs were all 36' long with weights of 21,600 pounds, 9,700 pounds, and 4,600 pounds. The weights were accurate to within 100 pounds.

The carriage used for testing is shown in Figure II-3. Its weight was 2,840 pounds. Survey sights for load and carriage deflection measurements were made to the target shown on the side of the carriage.

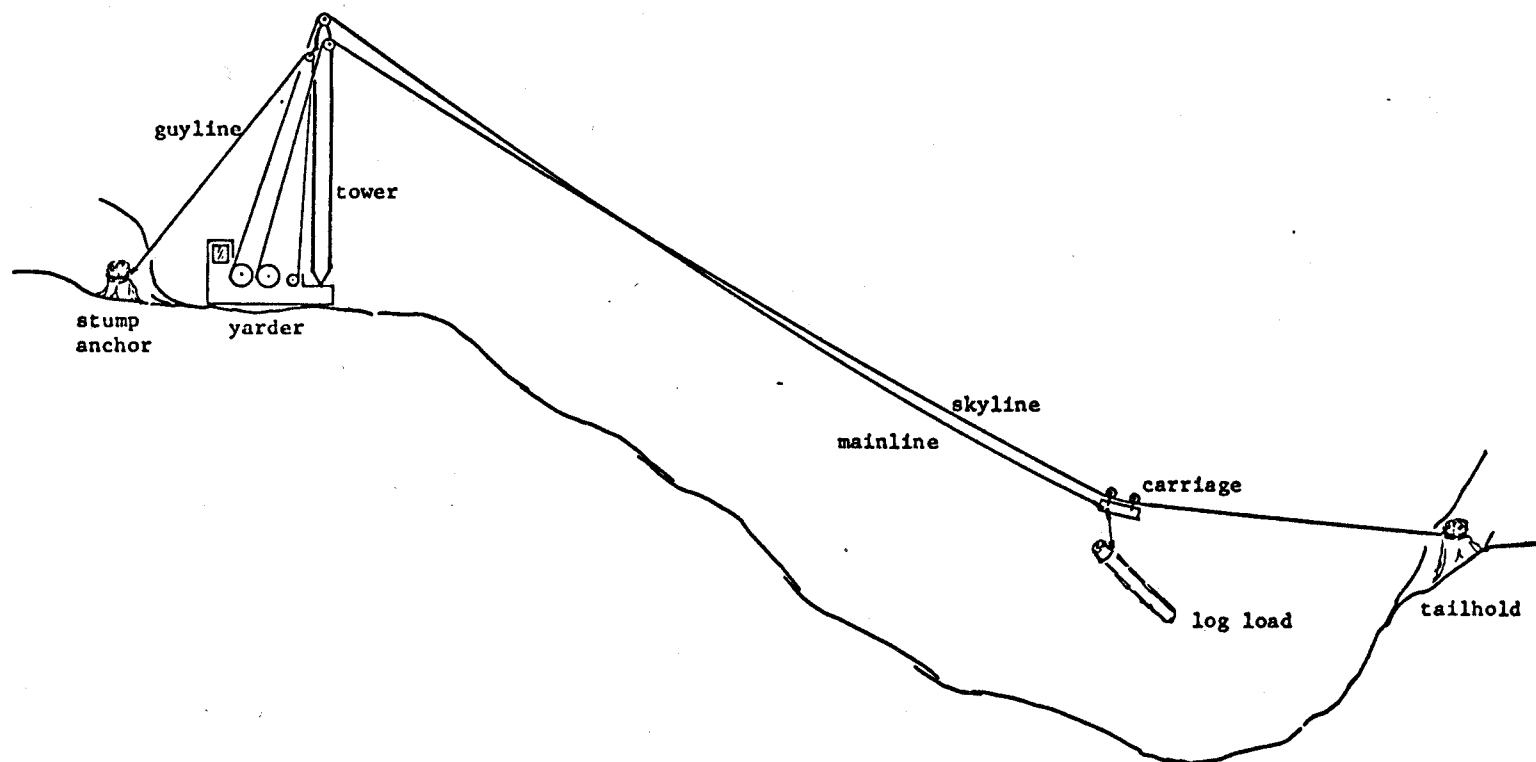


Figure II-1. Yarding System: Live Skyline Rigged as a Flyer

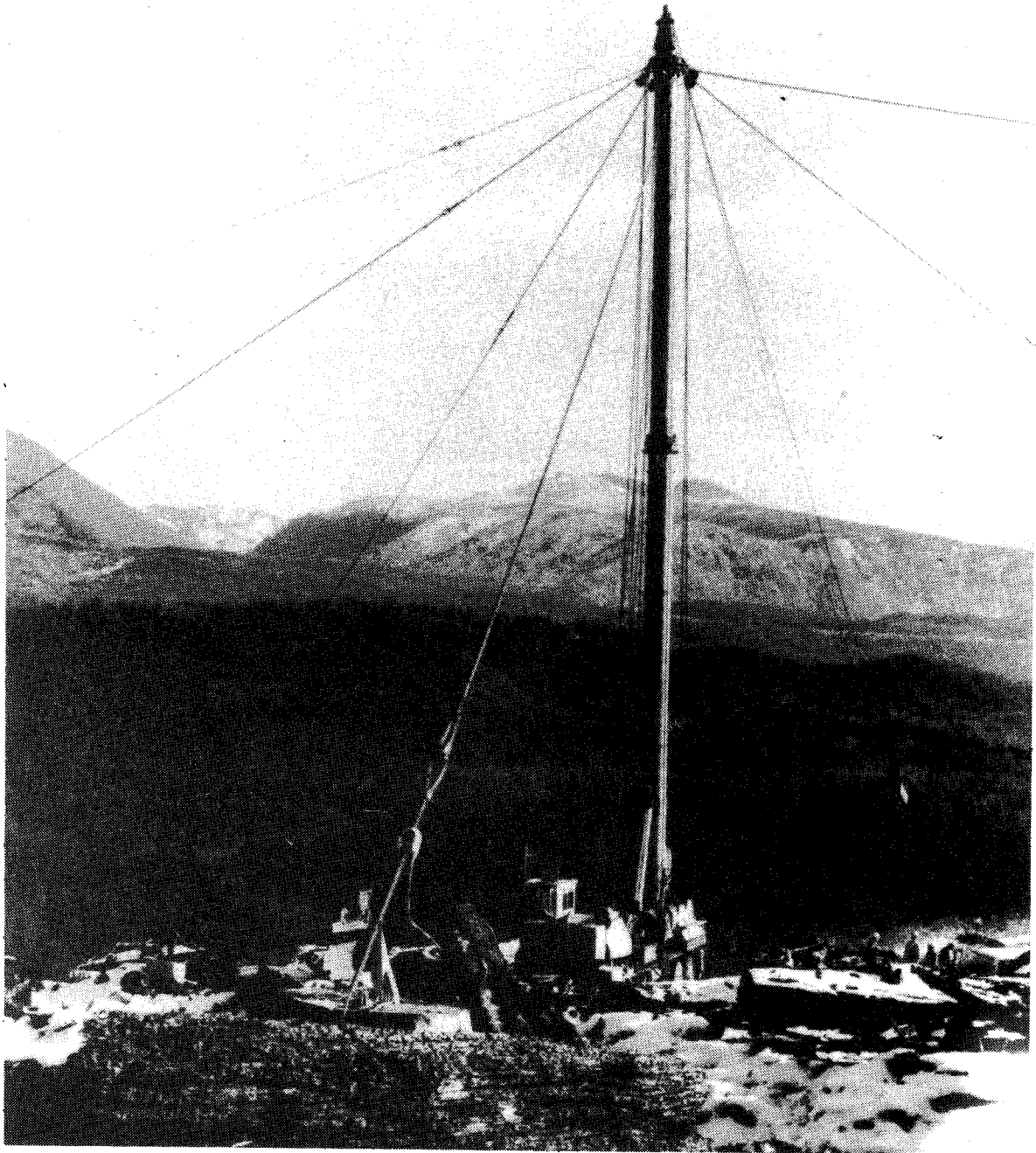


Figure II-2. The Washington 208 yarder and tower.

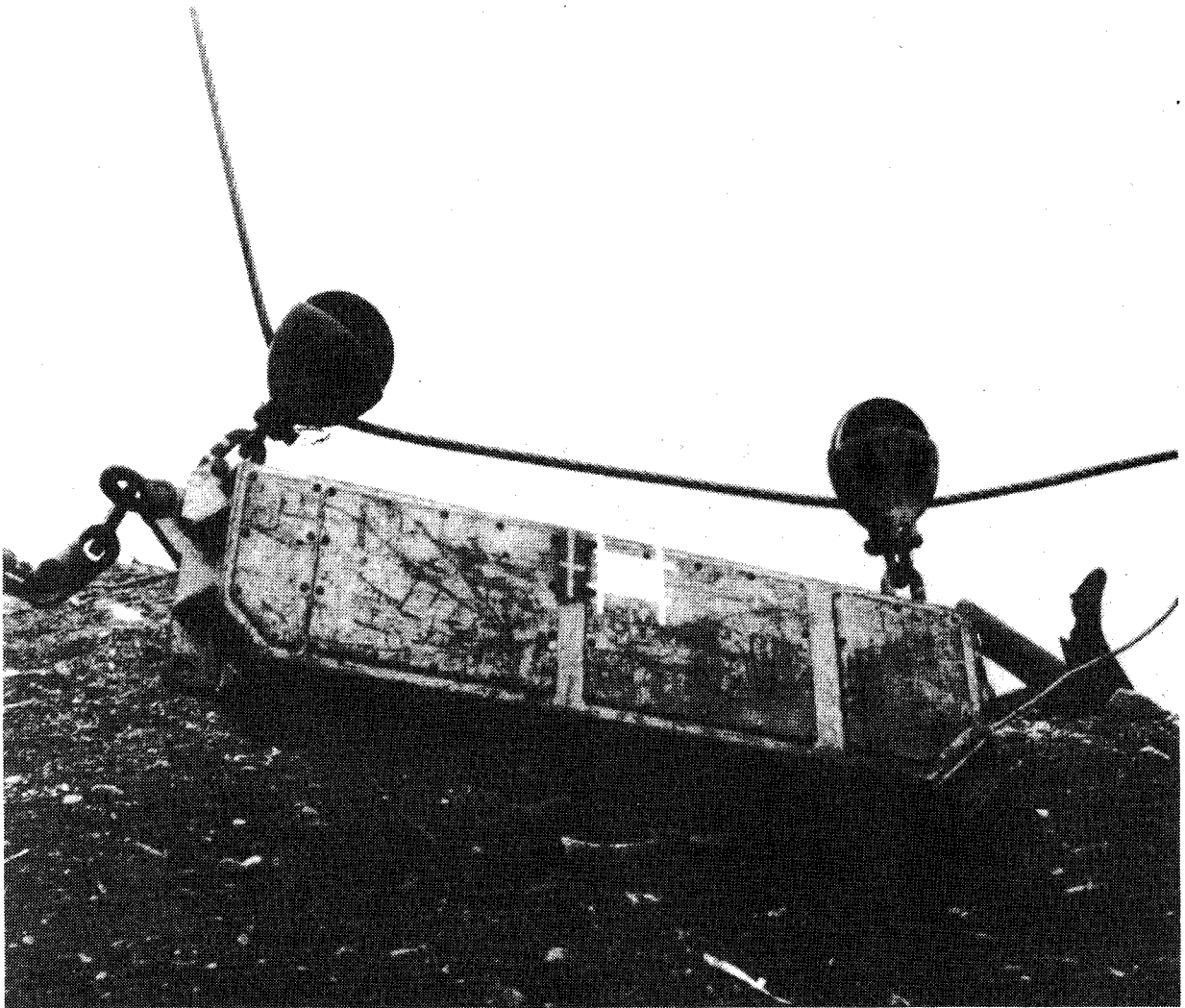


Figure II-3. The carriage employed in the yarding tests.

2.3 Anchor System

Seven guylines were used to anchor the 110' steel tower. All guylines were secured to stumps. The plan view of the anchor arrangement along with the coordinates and elevations at the guyline notch of each stump is shown on Figure II-4. Figure II-5 shows the arrangement of the stump marking, notching and the attachment of the instrumentation in the guylines.

2.4 Guyline & Tower System

A Washington 110' telescoping steel tower with seven 1-3/8" guylines was used in the system. The tower was free to pivot at its base. At the tower top, the mainline (identified as the haulback in conventional highlead rigging) left the tower through a fairlead above the skyline. This caused a crossover of the mainline and skyline near the tower.

2.5 Test Area Layout

Figure II-6 shows a plan view of the overall test area layout complete with the Trig points used for collection of survey information and the approximate location of the truck which housed the instrument recording equipment. Figure II-7, taken from Trig point 1, presents a perspective of the test site layout.

2.6 Survey Data Collection

An important data source in this test was the survey information collected from the three Trig Points - 1, 2A and 2B. The survey system was organized by John Warner, Logging Systems of Region 6; and conducted by John Shackleford, Doug Dow and Forrest Shoemaker of the Enumclaw Technical Center of Snoqualmie National Forest.

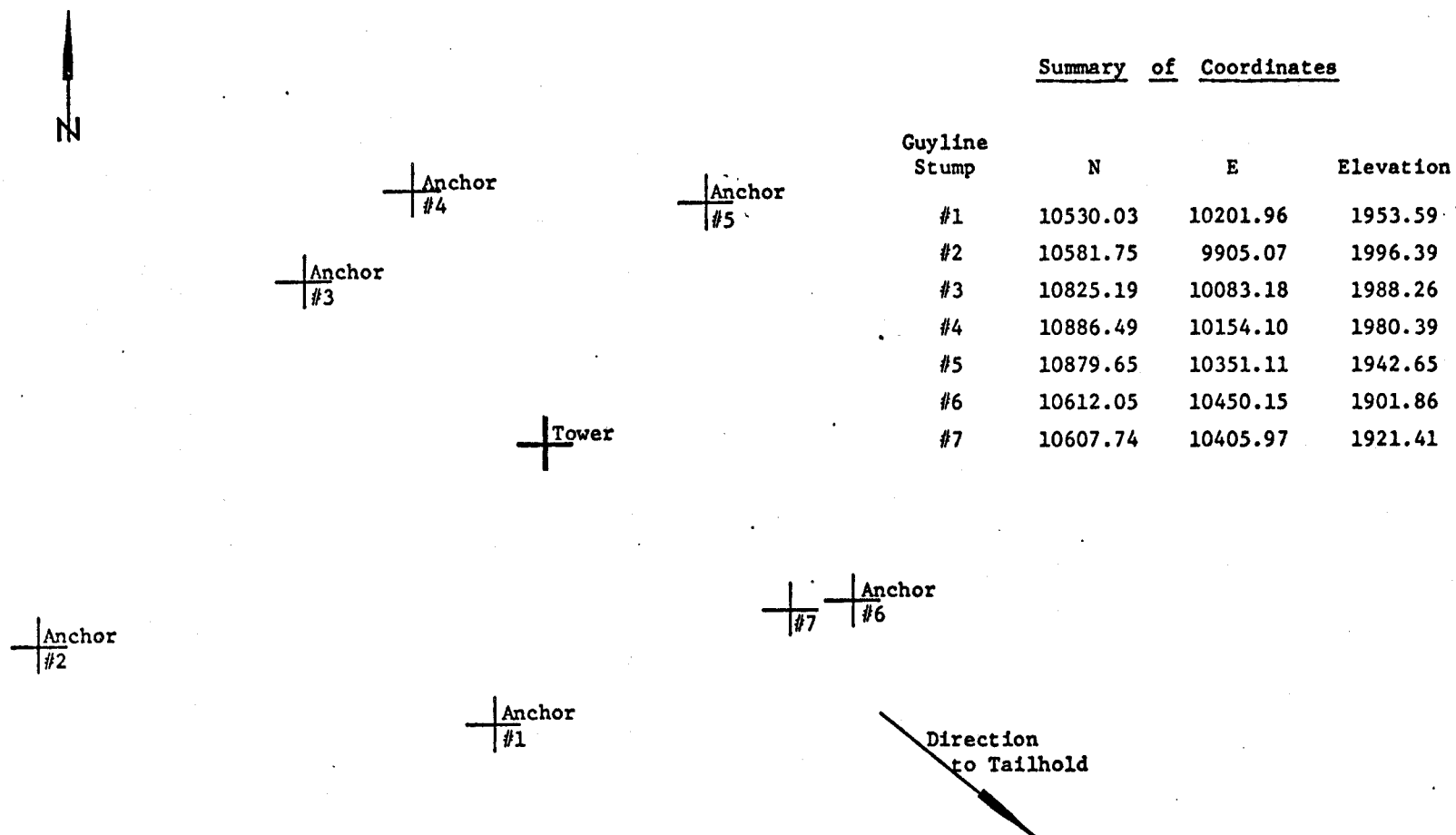


Figure II-4. Plan View of the Tower and Anchor Layout



(A) View of Stump No. 2 with the notch and the cable strap for insertion of the tension gauge.



(B) View of Stump No. 3 with preparation for a stump impact test. This stump was fitted with both tension and acceleration gauges.

Figure II-5. Basic instrumentation of the guyline anchor stumps.



Point
2B

Point
2
Point
2A
Van

Tower

Summary of Coordinates

Point	N	E	Elevation
#1	10000.00	10000.00	2000.00
#2	10678.14	10107.37	1983.54
#2A	10600.10	10145.69	1971.91
#2B	10861.64	10106.88	1983.65
#3	9614.62	11010.33	1878.94
Tower			
-top target	10718.09	10243.80	2070.61
-bottom	10718.09	10243.80	1975.26
Tailhold	9799.77	11055.83	1854.90

Point
1

Tailhold

Point
3

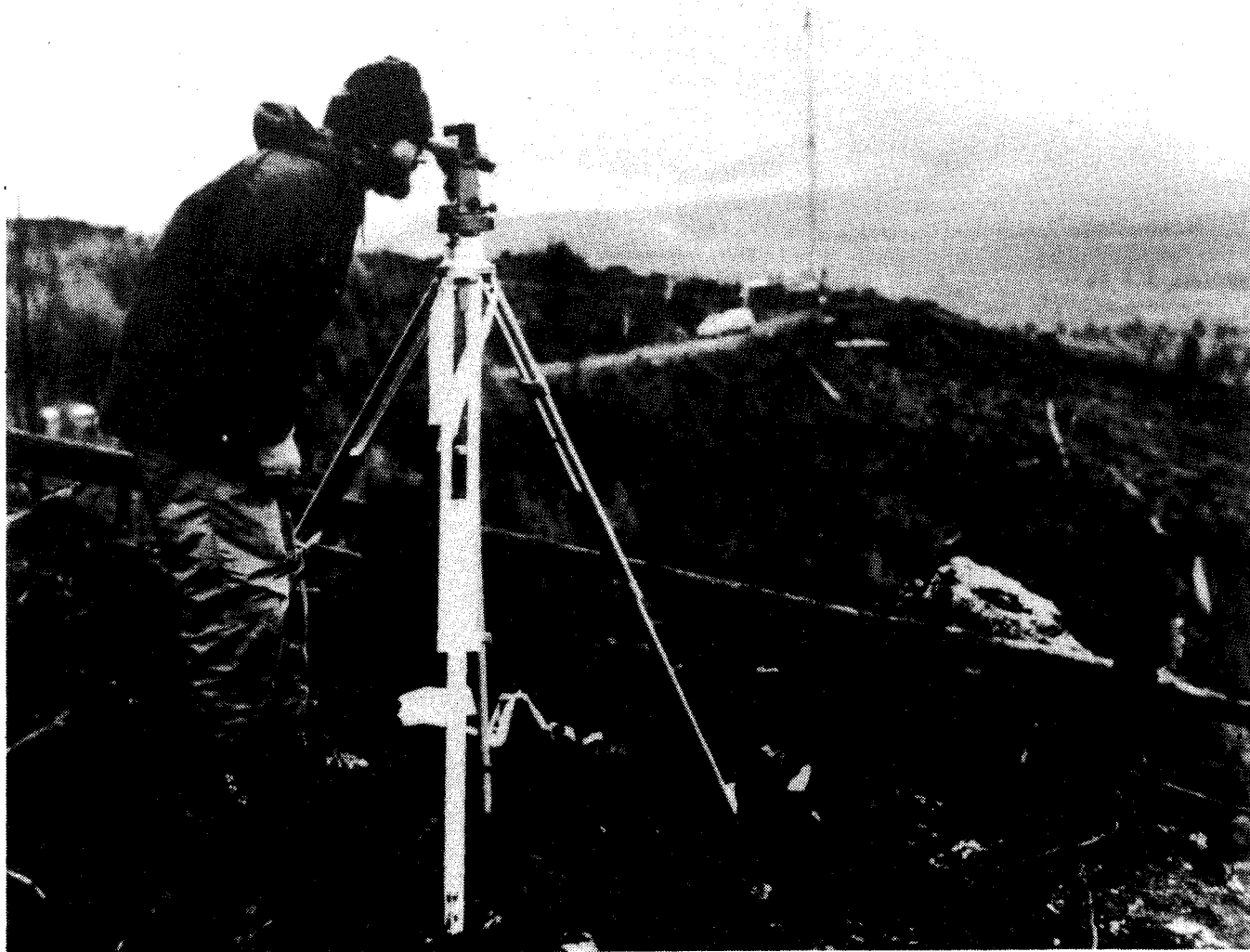


Figure II-7. View of the test area from Trig. Point 1.

One objective of the survey was to establish relative coordinates for the guyline anchor stumps and the tailhold anchor stump with respect to the location of the tower base. A profile of the terrain under the skyline corridor was established also. The coordinates and a profile view of the corridor are shown in Figure II-8.

The Trig points were occupied during testing. The objectives were to: 1) track the location of the carriage with respect to the yarder tower; 2) record the displacements of anchor stumps #3 and #4; and 3) record the displacements of the yarder tower. These were all accomplished.

2.7 Instrumentation & Calibration

Basic Instrumentation

The basic instrumentation package employed four tension gauges and two accelerometers of the type shown on Figure II-9. The installation of these in the guyline system at stump #3 was shown earlier in Figure II-5. The complete instrumentation system consisting of the tension gauges, accelerometers, cables and conditioning equipment was provided by Development Sciences Co. (DSI), 15747 East Valley Boulevard, City of Industry, California.

The tension gauge utilized a semi-conductor, two-arm active, strain gauge bridge built into a Young coupling Model 750S STD. Each gauge contained two separate bridges. The bridge output was fed to a signal conditioner containing the power supply, balance network and the calibration resistors. The gauge range was from 0-100,000 pounds.

Figure II-6. Plan View of the Overall Test Area Layout

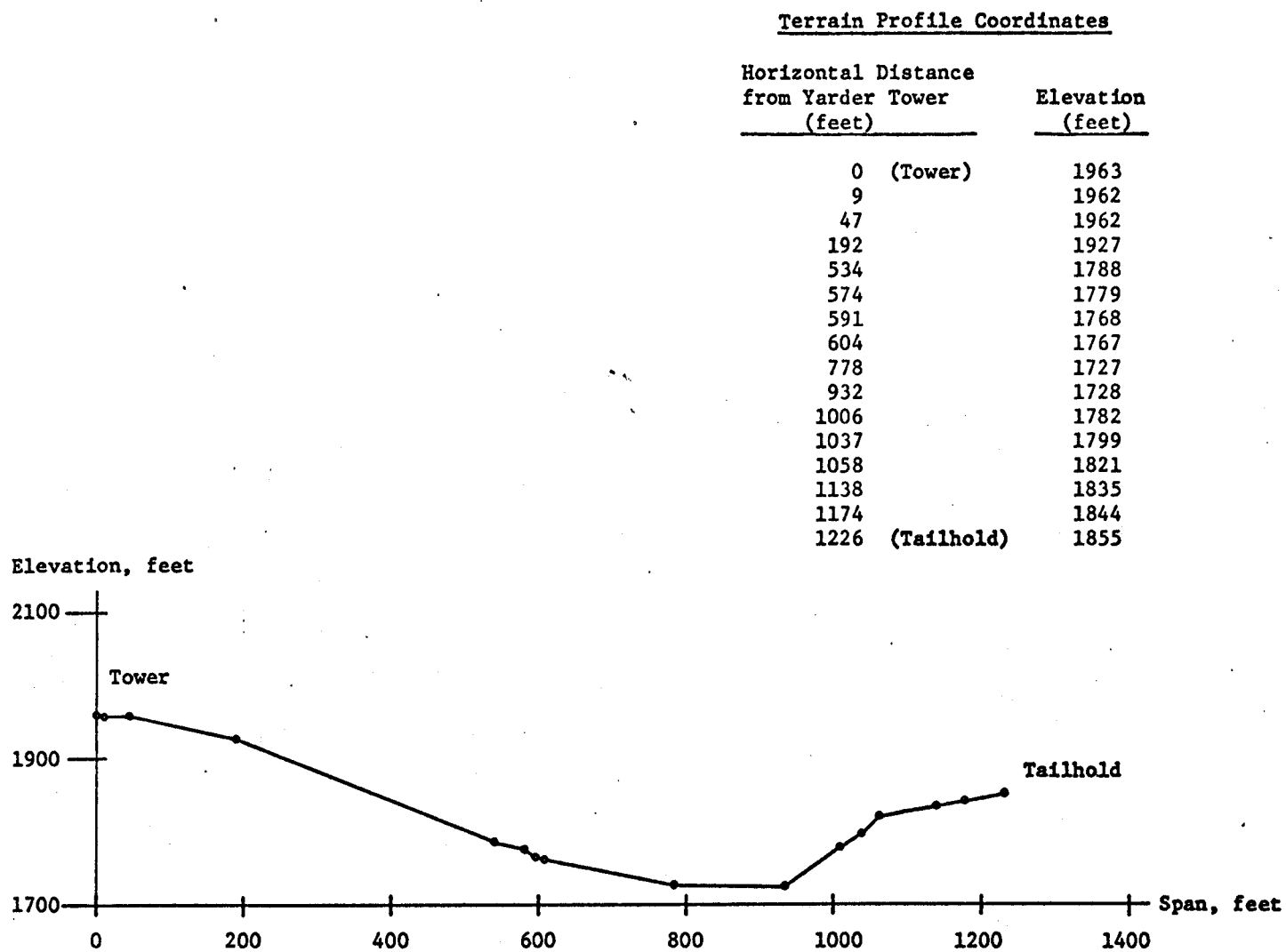
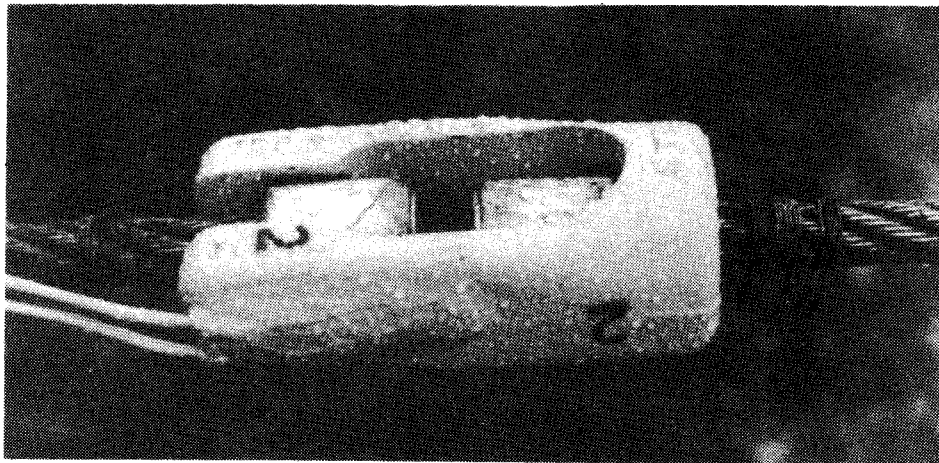
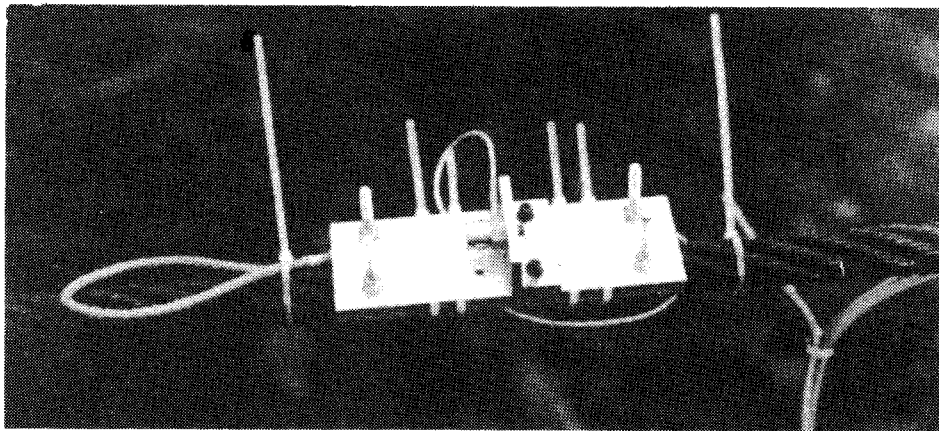


Figure II-8. Terrain Profile of the Yarding System Set-Up



(A) Tension gauge. A semi-conductor strain gauge bridge built into a Young 750S STD coupling.



(B) Accelerometer mounted bracket for attachment to cable strap.

Figure II-9. Basic instrumentation employed in the tests.

The accelerometers employed were commercial gauges of the piezo-resistance type with the following specifications:

Stump #3 Accelerometer

Make:	Entran Devices, Inc.
Model:	EGG-750-10
S/N:	3016J-M1-1
Range:	± 10 g
Freq. Range:	90 Hz (Nom)
Sensitivity:	19.9 mV/g (@ 15 VDC)
Excitation:	15 VDC

Tower Accelerometer

Make:	Endevco
Model:	2264AM4
S/N:	0077
Range:	1506
Excitation:	10 VDC
Sensitivity:	2.6 mV/g

The stump accelerometer was mounted in the #3 guyline on an aluminum plate clamped to the cable, with its sensitive axis along the guyline as indicated on Figure 9(B).

Calibration

The calibration of all the instruments was carried out by DSI and each data channel was provided with a calibration and zero signal for recording on magnetic tape at the start of each run.

Calibration of the accelerometers was a simple matter because of the response to DC and hence ± 1 G can be provided by a 180-degree rotation of the gauge perpendicular to its sensitive axis.

The tension gauges were tested in a standard tensile test machine out to 100,000 pounds employing a simulated ferrule and load strap. The original calibration factors were reported in the ranges out to 10,000, 50,000 and 100,000 with linearity and repeatability well within two percent of full scale value. However, during the reduction of the static data, it became apparent that there were difficulties with the original calibration factors.

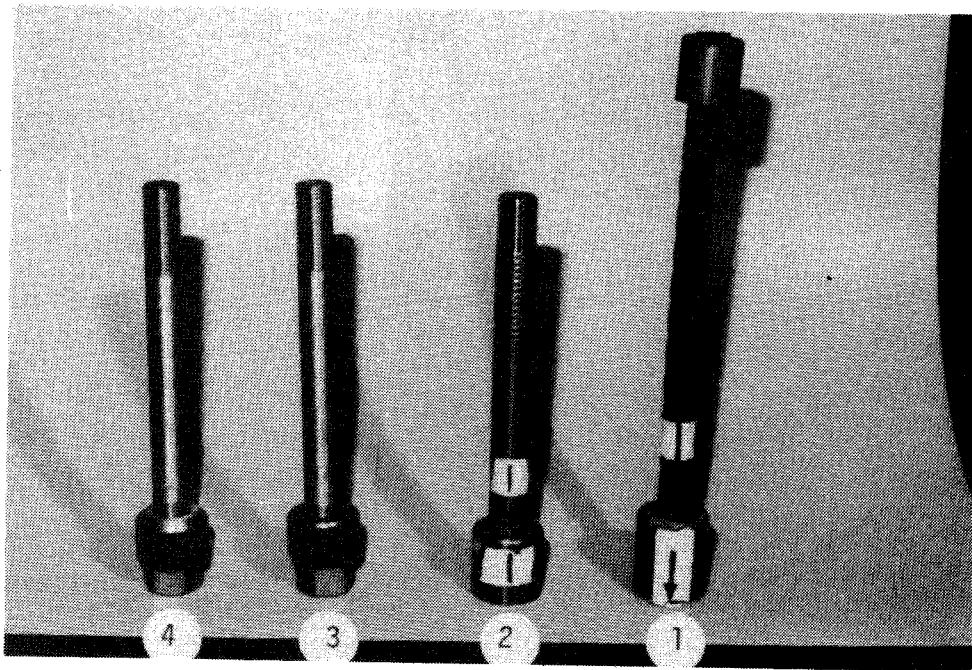
A series of test links were employed to recalibrate the tension gauges as shown on Figure 11-10. The most realistic test was provided by a cable strap^{(1)*} 20" long and 1-3/8" in diameter with poured ferrules on the end mating with the Young coupling (#7 in Figure 11-10 A). We carefully marked each ferrule and gauge, as shown in Figure II-10A, and found that the gauge calibrations depended on the orientation of the ferrule with respect to the gauge. Repeated testing of the gauges by rotating the ferrule 90 degrees with respect to the gauge gave an "average" sensitivity that we adopted in the range of 0-50,000#. The results of these tests are tabulated in Table 2.1

TABLE 2.1
CALIBRATION OF TENSION GAUGES WITH A
CABLE STRAP & POURED FERRULE

Stump Number	Gauge Number	Sensitivity S (#/mV)	Standard Deviation
2	3	1371.23	301.38
3	2	824.15	45.97
4	1	1090.86	90.06

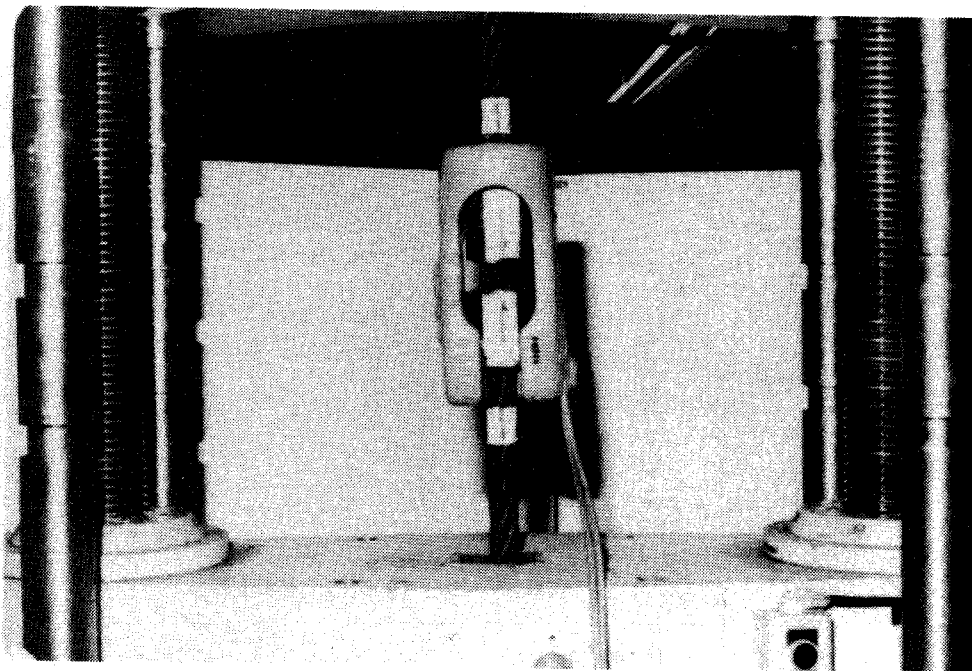
We feel that the final testing method provides the most realistic values for the gauge sensitivities. The values listed in Table 2.1, when applied to the experimental results, yield consistent tension readings and cross check with the transverse vibration test data in Section 4.3.

* Numbers in the brackets refer to the list of references on page 74.



(1) Cable calibration strap with poured ferrule; (2) Original simulated cable strap; (3) Simulated cable strap with rounded shoulder; (4) Simulated cable strap with large chamfered shoulders.

(A) Cable straps employed in the recalibration of the tension gauges.



(B) Tension gauge mounted in the Tinius Olson testing machine (120 kips).

Figure II-10. Calibration straps and mounting of tension gauge in the recalibration tests at the University of Washington.

Variance of Tension Gauge Sensitivity

The variance in the gauge readings are caused by two basic factors:

- Uneven mating of the ferrule and gauge body surfaces.
- Nonuniform stress field in gauge body.

The basic problem here is that the gauge body is too short compared to its width and, therefore, violates the basic premise in instrumentation that a uniform state of stress must exist over the measurement section. Because the loading conditions influence the state of stress, we must expect variance in the gauge sensitivity. Gauge #3 (in stump #2) had a standard deviation of 22% of the mean, whereas gauges 1 and 2 were 8% and 6% respectively. The latter two gauges were the most important and we, therefore, feel that with the new calibration we have obtained valid data.

A solution to the above dilemma is to adopt a design employing a solid bar between two Young couplings as the stress member. This approach can be designed to avoid the connection problem experienced in the present design.

2.8 Data Collection

All test activities were reported in the Master Test Log and the run numbers were assigned in sequential order starting with the number 100 for all runs on day #1. Static deflection data were handled by the survey team and reduced by Ward Carson.

2.8.1 Tension & Displacement Data Collection

The basic data collection system is shown in Figure II-11. Each measuring gauge output is brought to the DSI central conditioner and amplifier unit. The signals are then transmitted to the Tandberg tape recorder for a permanent record of all dynamic data. The recorded signals into the FM recorder were monitored with a four-channel Brush paper tape recorder.

MEASUREMENT

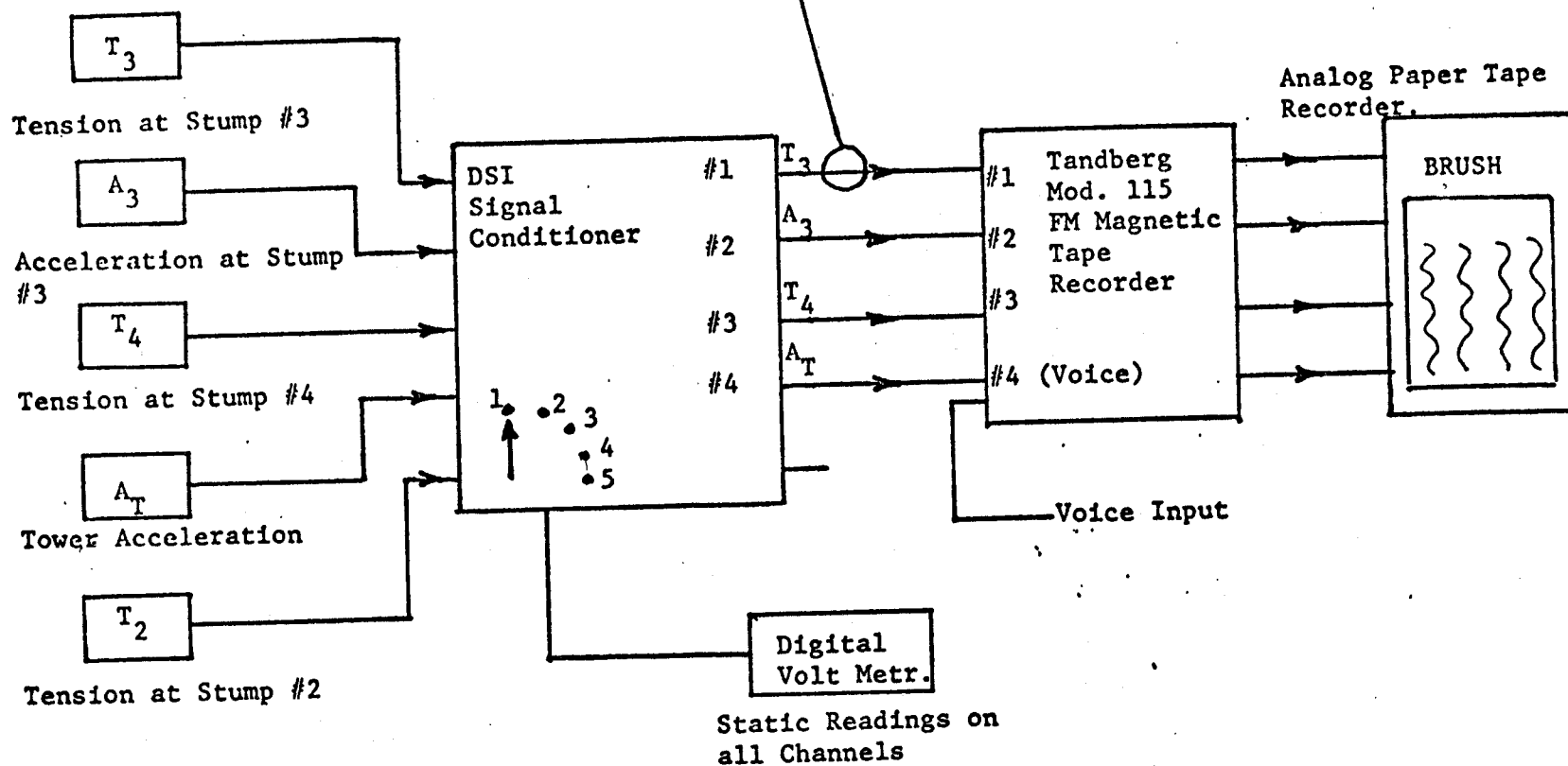


Figure II-11. Schematic of the Data Recording System for the Static & Dynamic Data

The DSI conditioning unit also provided calibration signals in (engineering units)/mv to each channel along with the zero level. Prior to each test, a calibration zero pulse was produced on each channel.

The static data were read by a digital voltmeter via a channel selector switch on the DSI conditioning unit. The data recording system in the field van is shown on Figure II-12. A separate log was kept with the data stored on magnetic tape and the static readings of the stump tensions.

2.9 Data Reduction

The dynamic data were reduced by computer processing. The information on each channel of the FM tape recorder (each variable) was digitized through the PDP-11/40 Laboratory Peripheral System (LPS). However, prior to digitizing the data, a certain amount of signal conditioning was found necessary.

Filtering

The acceleration data were found to contain a large amount of noise, which when analyzed turned out to be caused by transducer "ringing" due to its inherent low damping. The accelerometers had a natural frequency of 800 Hz that swamped the actual data. This is shown by examining the acceleration traces on channels 2 and 4 in Figure II-13. When the data are filtered, the DC offset removed and amplified by a gain of 100, we were able to recover the fundamental motion for the stump and tower acceleration for test run #227 (sudden load test) as shown on Figure II-14. This particular run required a 1.5 Hz low-pass filter.

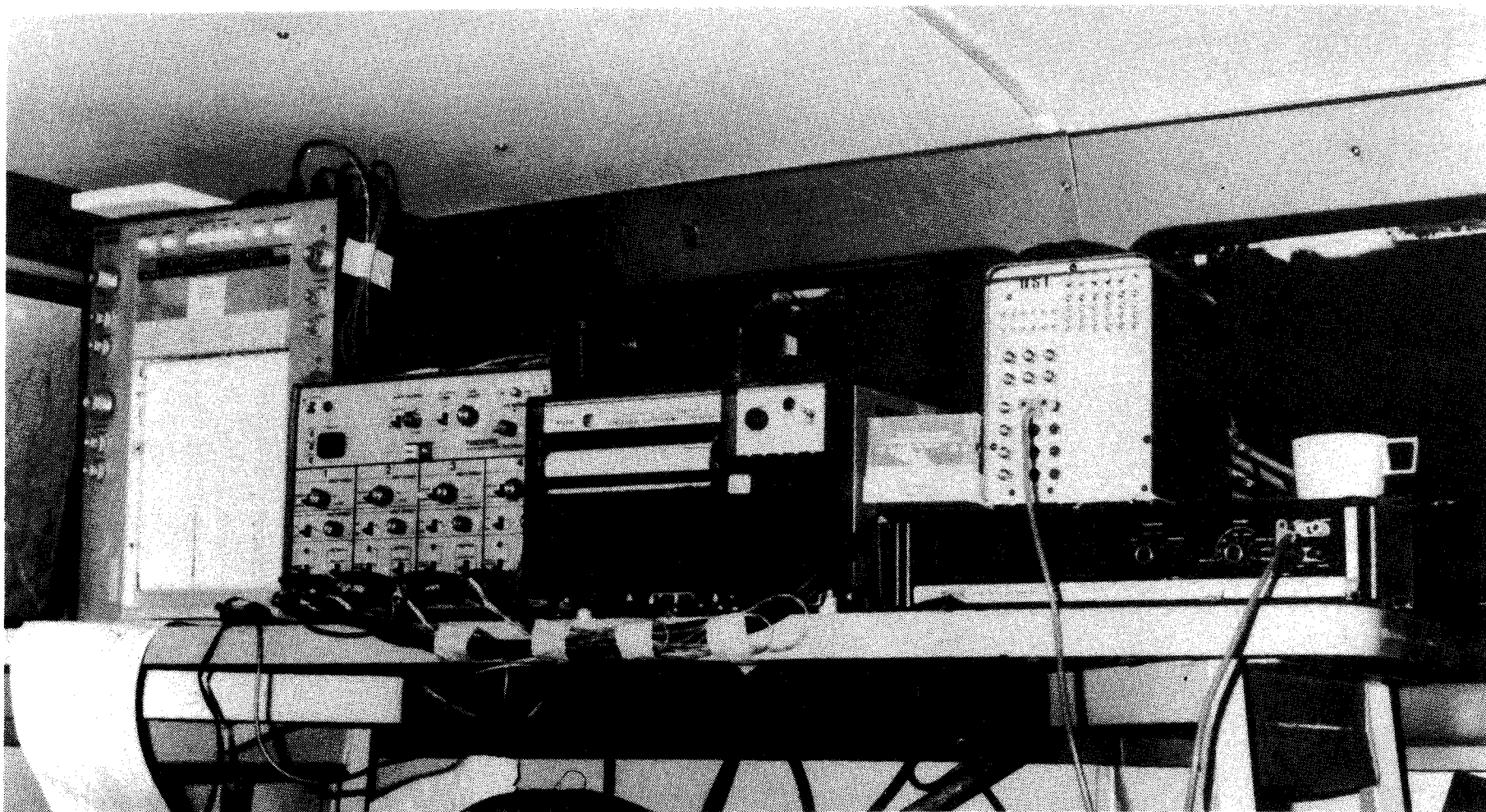


Figure II-12. Basic recording instrumentation and the instrument van.

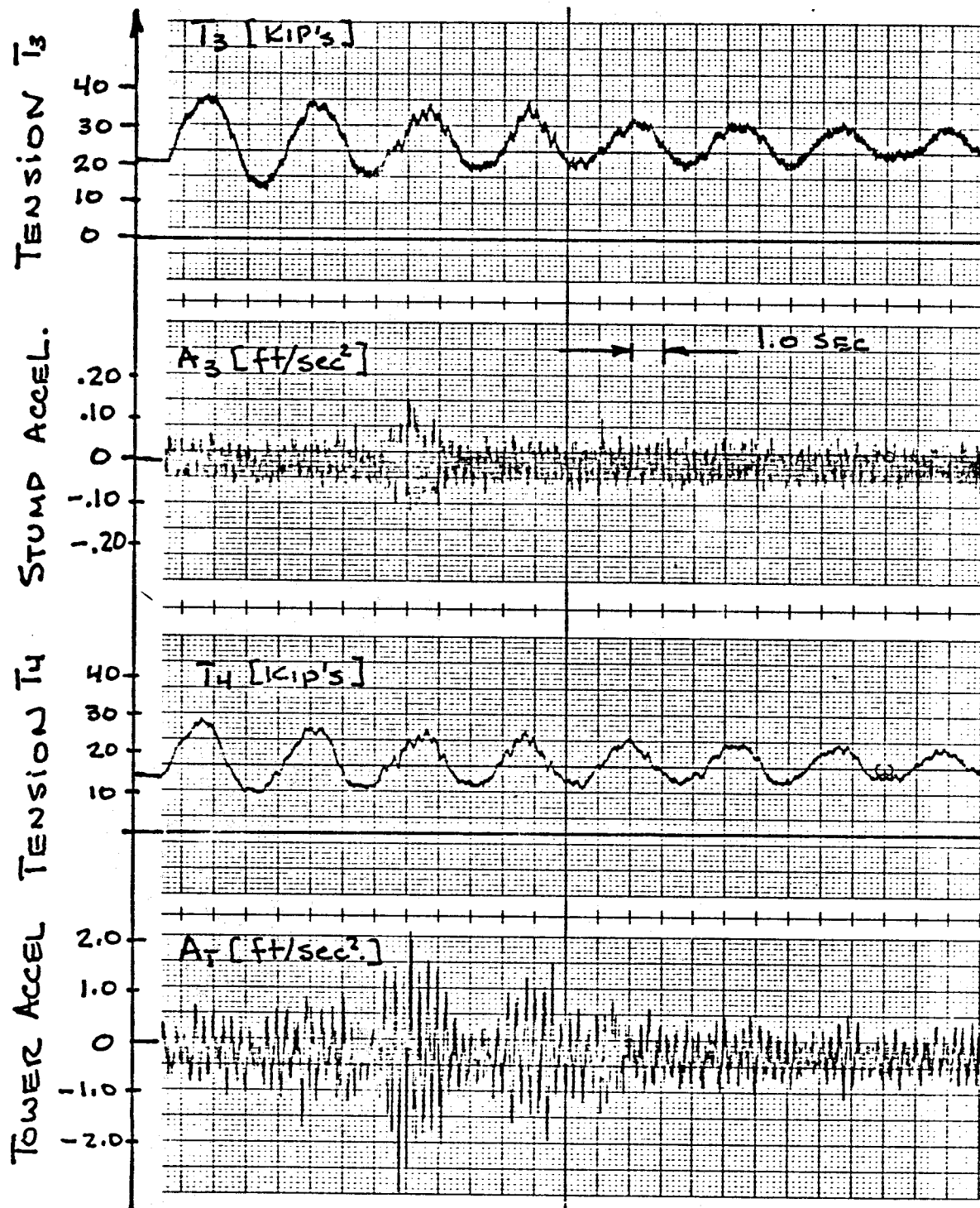


Figure II-13. Original Recording of the Sudden Load Event, Run #227

(The acceleration traces are obliterated by the "ringing" of the poorly damped transducer with a natural frequency at 800 Hz.)

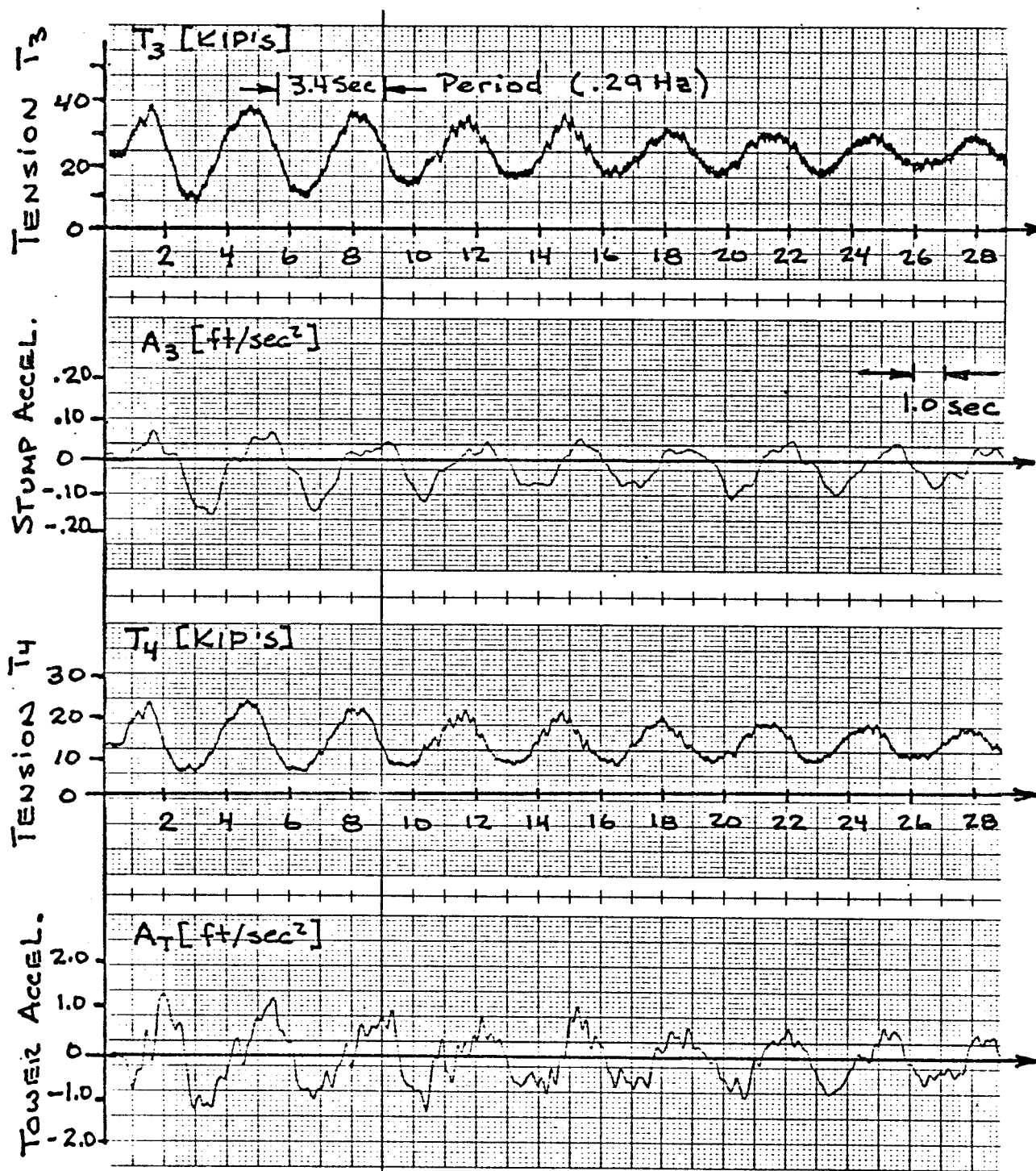


Figure II-14. The Filtered Response of the Sudden Load Test Event, Run #227

(The acceleration channels, #2 and #4, have both been filtered through a low-pass filter at 1.5 Hz and magnified with a gain of 100.)

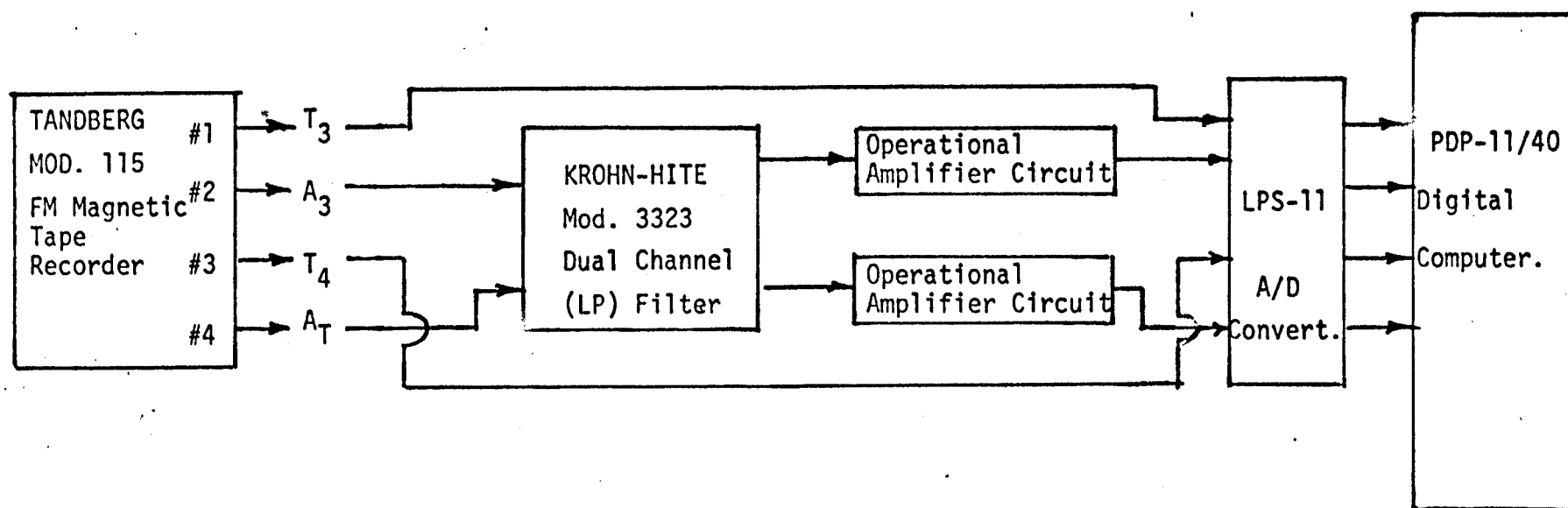
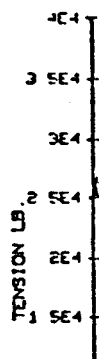


Figure II-15. Basic Signal Processing Circuit for Anchor Dynamics Data Reduction

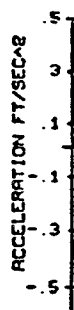
The basic signal processing circuit employed is shown on Figure II-15. The tension data are fed directly into the computer through the analog to digital (A/D) converter. The acceleration signals were filtered (Krohn-Hite) and had the bias removed and amplified with a gain of 100 before entering the A/D converter. The calibration signal on the tape recorder was processed separately to provide the proper calibration constant for each channel in engineering units/volt.

The data from each digitized run are stored on digital magnetic tape in five separate files under its proper run number. The first four files contain the actual data from each of the four data channels and the fifth contains the calibration data and the information regarding the organization of the test, recording and sampling rate of the data.

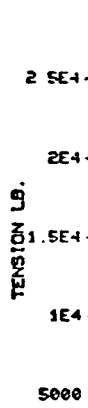
The stored files may be recalled by the run number program control for subsequent plotting, analysis, computation of parameters or comparison with a theoretical model. A composite record of run #227 is shown on Figure II-16. Here are shown the digitized data, as plotted from the disc files, as compared to the analog plot of the data as they were digitized. As we expect, if the digitizing is carried out properly, the agreement is excellent.



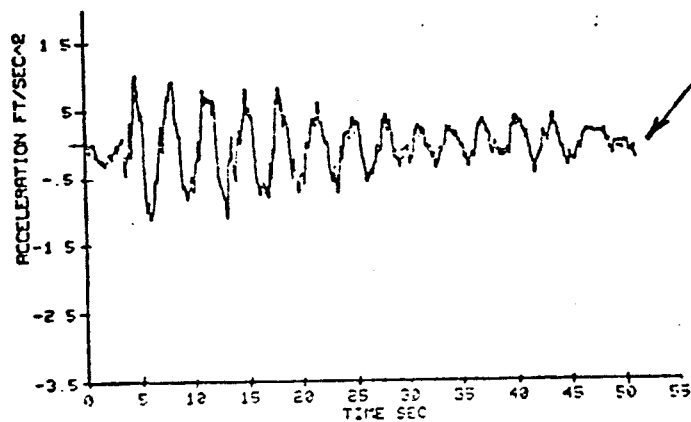
a) Tensions in Guyline #3.



b) Acceleration in Guyline (Stump) #3.

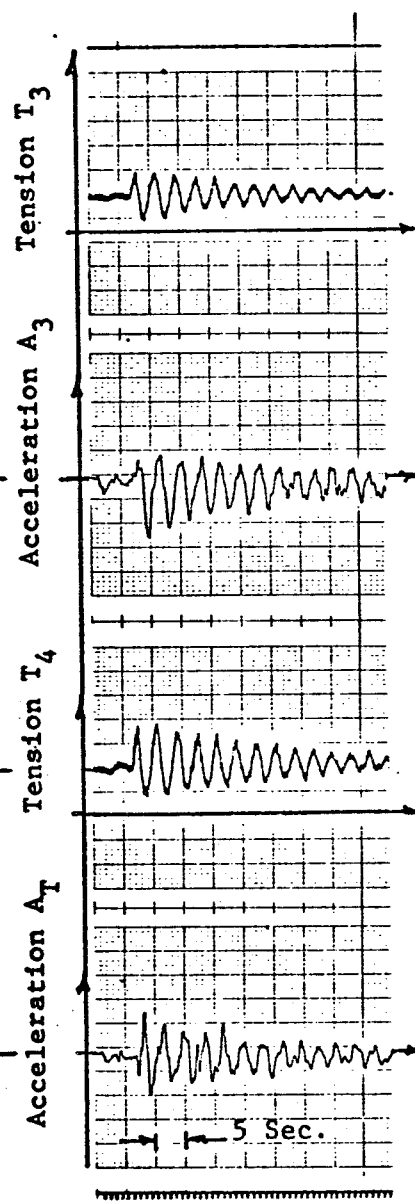


c) Tension in Guyline #4.



d) Tower top acceleration.

(A) Typical digitized data display.



B) Analog Data Display

III. TEST OBJECTIVES, DESCRIPTIONS & PROCEDURES⁽²⁾

The primary objective of this project was to establish a record of guyline anchor loads experienced by a skyline system during typical logging. The load cells in guylines #3 and #4 were inserted to meet this objective. Although this information is representative of skyline anchor loads, it is not general enough to be useful as a basis for predicting loads in other cable configurations or other geometries. Therefore, a secondary objective of providing information useful for analysis of the dynamic behavior which would lead to more understanding of these systems was established. For purposes of this secondary objective, and respecting constraints on time and funding, six tests were planned and conducted. The objective and purpose of each are identified in this section.

3.1 Static Guyline Tension & Stump Reaction (Test #1)

Objective:

Measure

- a. The tensions which develop in the test guylines as the skyline system is loaded with the operating lines,
- b. The displacement of the stumps to which the test guylines are anchored, and
- c. The displacement of the tower top.

Purpose:

- a. Test the hypothesis that static loads in the guylines can be computed by analysis based on principles of engineering mechanics, and

- b. Determine the spring rates for those stumps which will be monitored in subsequent tests.

Test Description:

Load cells were inserted in guylines #3 and #4. The tower was erected and guylines pretensioned in the usual manner. The system was loaded by tensioning the mainline and skyline through a range of tensions recorded during the first two days of testing.

Test Scenario:

- a. Loaded the skyline with logs of predetermined weight.
- b. Moved the carriage and load to a location in the span where their position could be surveyed from Trig Point #1. The system was loaded by adjusting the skyline and mainline lengths such that tensions in each line varied through a range of values. The number of points and their specific locations were dictated somewhat by the circumstance of the other tests.
- c. Recorded the developed guyline tensions, stump displacements, tower displacements and surveyed carriage positions.

3.2 Impact Response of Stumps (Test #2)

Objective:

Measure the response of a stump anchor to impact loads.

Purpose:

Determine the damping characteristics of these stump anchors so that the importance of anchor damping on total system dynamic response can be investigated.

Test Description:

A means of impacting the stumps was designed and provided at the test site. Levels of static loading were established and held with the operating lines while impact tests were conducted. Impact response was measured at five different static load configurations. These tests were distributed in with other tests in the series.

Test Scenario:

- a. Constructed and erected the impactor at the test stump.
- b. At five of the load situations developed in Test #1, impacted stump #3 while recording dynamic response on the accelerometer and load cell in guyline #3.

3.3 Guyline Transverse Vibration (Test #3)

Objective:

Measure the response of the test guylines' transverse perturbations.

Purpose:

To test the hypothesis that the transverse frequency is a simple function of guyline length, tension and mass.

Test Description:

A means of creating transverse vibrations in the guyline was designed and provided at the test site. Guyline #3 was tensioned to a specified level with the operating lines. The transverse perturbations were induced directly in the guylines while data were collected.

Test Scenario:

- a. Tensioned the system and recorded the information as specified in the scenario for Test #1.
- b. Prepared a means to develop transverse vibrations in Guyline #3.
- c. Created a sudden release of the transverse loading by cutting the load line with an axe.
- d. Measure dynamic response on instruments.

3.4 Sudden Load Response (Test #4)

Objective:

To measure the reaction of the guyline system to a sudden load created in the operating lines.

Purpose:

Determine the relationship between dynamic loads in the guyline system and the dynamic loads which would be predicted to exist in the operating line system.

Test Description:

The skyline system was loaded to a specific initial condition. This was created by suspending the 9,700-pound log free of the ground and adjusting its location with the mainline. At a given instant, the mainline brake was released to allow the log load and carriage to accelerate down the skyline. At the instant the carriage reached a second specified point identified by a mark on the mainline, the main drum brake was applied quickly to bring the load to a sudden stop. Data were recorded until the system came to rest.

Test Scenario:

- a. Established and surveyed two positions of the carriage with the log load fully suspended above the terrain. Marked clearly the position of mainline associated with these two positions.
- b. Returned the carriage and load to the position of highest elevation.
- c. Began a countdown, at the end of which the instruments were turned on and the mainline brake was released.
- d. The carriage and load accelerated under the gravity force towards the second position established on the skyline in Step A. The operator monitored this advance by watching the mainline being removed from its drum. At the moment the mark on the mainline associated with the second position, appeared, the operator engaged the mainline drum brake abruptly. Recordings were continued until the dynamic response of the system had damped to the static position.
- e. The final position of the carriage was surveyed.

3.5 Yarding Sequence Response* (Test #5)

Objective:

Measure the response to a yarding sequence consisting of the three specific phases:

- (1) Load fully suspended above the ground.

*This is a combination of the three separate tests listed as 3.5, 3.6 and 3.7 in the original test plan (2). In the field, they were carried out as one continuous test and will be so reported.

- (2) Load partially suspended where the front end of the log is clear of the ground and the trailing end of the log is supported.
- (3) Ground lead yarding where log is in full contact with the ground.

Purpose:

To determine the relationship between the dynamic response of the system and the static tension which would be computed.

Test Description:

Establishment of five points delineating the yarding regimes in the following manner:

- a. Establish point (1) in the yarding sequence as the starting point nearest the tailhold. Mark both skyline and mainline.
- b. Establish point (3) where the log first establishes contact with the ground. Delineates separation between fully suspended and partially suspended load tests.
- c. Establish a point (2) midway between (1) and (3).
- d. Establish point (4) where the log is in lead with one end on the ground and the choked end 10-15 feet off the ground.
- e. Establish point (5) where the log first comes into full contact with the ground. Consider this the start of ground lead.

3.6 Yarding Response to a Hang-Up (Test #6)

Objective:

Measure the response to the common operational occurrence of yarding into a hang-up which stops the log load abruptly.

Purpose:

Determine the dynamic overloads that are developed in the guyline system due to sudden loads in the operating system.

Test Description:

The carriage and the 4,600-pound test log were positioned in the skyline corridor, such that they could be fully suspended above a stump on the ground. The lower end of the test log was choked to the stump. Surveys were made from Trig Point #1 of a position with the chokers taut and the carriage uphill of the stump. The carriage was returned to the lower position; and at a specified instant, the carriage and log were accelerated forward with the mainline until the lower 5/8" choker broke. This test was conducted three times each at two positions in the skyline corridor.

Test Scenario:

- a. Choked free end of the log to stump on the ground.
- b. Established and surveyed carriage location at an uphill position and a downhill position. Choker was taut in both these positions.
- c. Returned to downhill position.
- d. Accelerated load uphill with mainline until lower 5/8" choker broke.
- e. Repeated steps a through d three times at each of two locations in the skyline corridor.

IV. TEST RESULTS

4.1 Static Guyline Tension & Stump Reaction (Test #1)

The major objectives of this series of tests were to collect information on guyline tension and the displacements of the anchors (stumps) and the tower. The complete set of the static data collected is given in Table 4.1

Guyline Tension

The guyline tension data were reduced with the revised calibration constants (Ref. Section 2.7) and we now feel these measurements are accurate within $\pm 10\%$. Particular emphasis is placed on the tension readings from day #1 (Runs #121-135). They are tabulated along with the computed skyline load on Table 4.2. Comparisons of these data were made with the University of Washington static anchor simulation program^(3,4) and the results are tabulated in Table 4.3. The actual initial tensions in guylines #2, #3 and #4 (Ref. Figure IV-1) were inputted to the simulation and the remaining guyline tensions were estimated. These initial values are not unique, as a large number of distributions in the remaining guylines will produce an equilibrium condition. It was very unfortunate that we were unable to record the tension readings from stump #5 (due to lack of signal cable length) as this tension influences strongly the remaining tension distribution. However, assuming the horizontal component of #5 was of the same magnitude as #2 (Ref. Figure IV-1), we computed the tensions as shown in Table 4.3 and displayed graphically in Figure IV-2. The results show reasonable agreement with the theory at the lower input skyline tensions. The discrepancy is primarily due to the model employing a linear (chord) spring model for the guyline shape rather than a catenary.

TABLE 4.1

ANCHOR STATICS DATA

RUN #	LOG WEIGHT	TENSION STUMP #2	TENSION STUMP #3	TENSION STUMP #4	CARRIAGE LOCATION		TOWER DISPLACEMENT	
					X	Y	DISTANCE	ANGLE
121		12683.9	13186.4	12163.1	0	0	0	0
123		15042.4	24889.3	22689.9	834.9	1755.1	.4304	9
124		15549.7	31647.4	29431.4	847.6	1795.1	.5134	4.9
128	21,600	15851.4	34095.1	31176.8	846.4	1804.1	.5843	2.4
129		15549.7	32240.7	28820.5	848.2	1795.2	.5629	3.1
130		15193.2	29405.7	26104.3	847.9	1780.6	.5346	4.1
131		14356.8	25491	22231.7	844.6	1754.9	.4578	7.5
135	4,600	12587.9	19623	18850.1	836.1	1830.2	.2689	1.1
204		10846.4	16730.2	10374.1	0	0	0	0
206		13876.8	39724	21926.3	850	1789.8	.5277	5.4
207		14164.8	39930.1	22362.6	475.9	1845	.542	5.5
208		14507.6	40919	23922.6	656.5	1810.8	0	0
209		0	0	0	0	0	.5543	7.2
210		14713.3	32133.6	15435.7	374.3	1874.3	.4312	10.3
211	21,600	14535	23933.3	11061.3	225	1923.8	.2532	8.3
212		0	0	0	962.2	1786.3	0	0
214		16537	48196.3	29529.6	145.6	1955.8	.797	3.4
217		0	0	0	102.2	1973.7	.5883	8.5
218		0	0	0	131	1960	.5475	10.4
220		0	0	0	88.2	1978.7	.6088	9.4
222		18895.5	26208	17693.7	475.8	1877.5	.438	9.9
223		18895.5	26059.6	17159.2	432.5	1887	0	0
225		19005.2	26743.7	17857.4	482.7	1876.1	0	0
226		18854.4	25969	16308.4	381.5	1901.8	0	0
228		18525.3	27246.4	17824.7	485.5	1877.8	0	0
229		18264.8	25062.4	15686.6	317.4	1918.8	0	0
231	9,700	18209.9	27526.6	17901	479.9	1879	0	0
232		18045.4	25276.7	15555.7	320.8	1917.9	0	0
234		18113.9	27543.1	17748.3	481.8	1878.5	.489	4.6
237		18141.4	28111.8	17911.9	728.1	1834.5	.5132	10.1
238		17976.8	26661.3	16330.2	400	1896.2	0	0
240		18018	28606.2	18490.1	744.7	1832.1	0	0
241		17757.4	26817.8	16166.5	393.7	1897.7	0	0
243		17812.3	28614.5	18031.9	744	1832	.5268	9.4
301		10585.9	9197.51	4483.43	0	0	0	0
303		9722.02	19210.9	7428.76	0	0	0	0
305		11559.5	31927.6	19122.8	293.8	1926.4	0	0
306		11285.2	27164	14366.6	274.7	1926.4	0	0
307		11504.6	27955.2	15206.6	300	1918	0	0
309		12231.4	24386.6	16101.1	298.8	1919	0	0
311		12382.2	23752	16406.5	301.9	1917.9	0	0
313		12286.2	21081.8	14093.9	234.4	1938.7	0	0
314	4,600	12821	21872.9	15282.9	443.4	1855.87	0	0
315		13026.7	22153.2	15664.7	4452.8	1835.9	0	0
317		13492.9	21658.7	15632	453.9	1853.7	0	0
319		13863.1	21246.6	16068.4	453.6	1853.5	0	0
321		13849.4	19425.2	14366.6	396.3	1867.3	0	0
322		13616.3	15831.9	11432.2	666.9	1808.7	0	0
323		14864.1	40020.7	32802.2	664.5	1929.3	0	0
324		14260.8	24798.7	17704.7	0	0	0	0
325		14096.2	21131.2	13777.6	0	0	0	0
326		13835.7	17785.2	11312.2	0	0	0	0

TABLE 4.2
SUMMARY OF SKYLINE & GUYLINE TENSIONS
AND TOWER DEFLECTION RESULTS

Run Number	Guyline Tensions			Skyline Tensions*		Tower Deflections (feet)	
	#2	#3	#4	(pounds)	(angle)	X-comp.	Y-comp.
121	12,684	13,186	12,163	0	0	0	0
123	15,042	24,889	22,690	45,259	22.75°	0.4251	-0.0673
124	15,550	31,647	29,431	57,633	19.85°	0.5115	-0.0439
128	15,851	34,095	31,177	61,658	19.27°	0.5838	-0.0245
129	15,550	32,241	28,820	57,675	19.83°	0.5621	-0.0304
130	15,193	29,406	26,104	52,264	20.89°	0.5332	-0.0382
131	14,357	25,491	22,232	45,208	22.75°	0.459	-0.0598
135	12,588	19,623	18,850	30,052	19.24°	0.2689	-0.0052

* Computed from observed carriage position and payload weight.

TABLE 4.3

STATIC LOAD TESTS: CALCULATED GUYLINE TENSIONS
 COMPARED TO EXPERIMENTAL TENSIONS FOR VARIOUS STATIC LOADINGS

Run Number	X-Comp. of Load Vector	Guyline Tension (pounds)			
		Experimental		Calculated	
		Guyline 3	Guyline 4	Guyline 3	Guyline 4
121	0	13,186	12,163	13,186	12,163
123	35,564	24,889	22,690	24,452	23,247
124	46,758	31,647	29,431	28,188	27,426
128	50,280	34,095	31,177	29,356	28,761
129	46,794	32,241	28,820	28,188	27,426
130	41,954	29,406	26,104	26,612	25,627
131	35,522	25,491	22,232	24,452	23,247
135	24,278	19,623	18,850	20,892	19,765

Initial Pretensions Used in Computations of Loaded Tensions*		
Guyline	Tension	
1	6,051	computed
2	12,684	experimental
3	13,186	experimental
4	12,163	experimental
5	10,171	computed
6	16,891	computed
7	16,891	computed

*There is an infinite number of sets of computed guyline pretensions for guylines #1, #5, #6 and #7 which will balance the initial unloaded system. The set of computed tensions used in this analysis represents tensions which correspond in magnitude with the observed tensions.

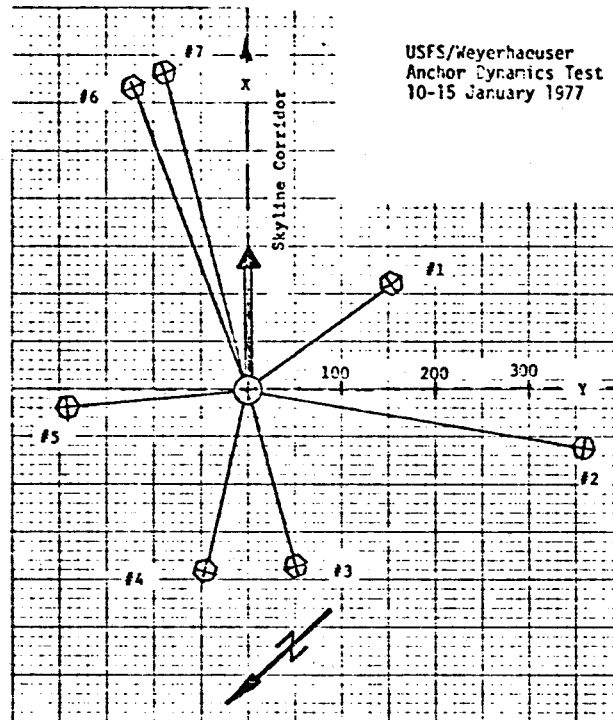


Figure IV-1. The Geometry of the Anchor System Layout

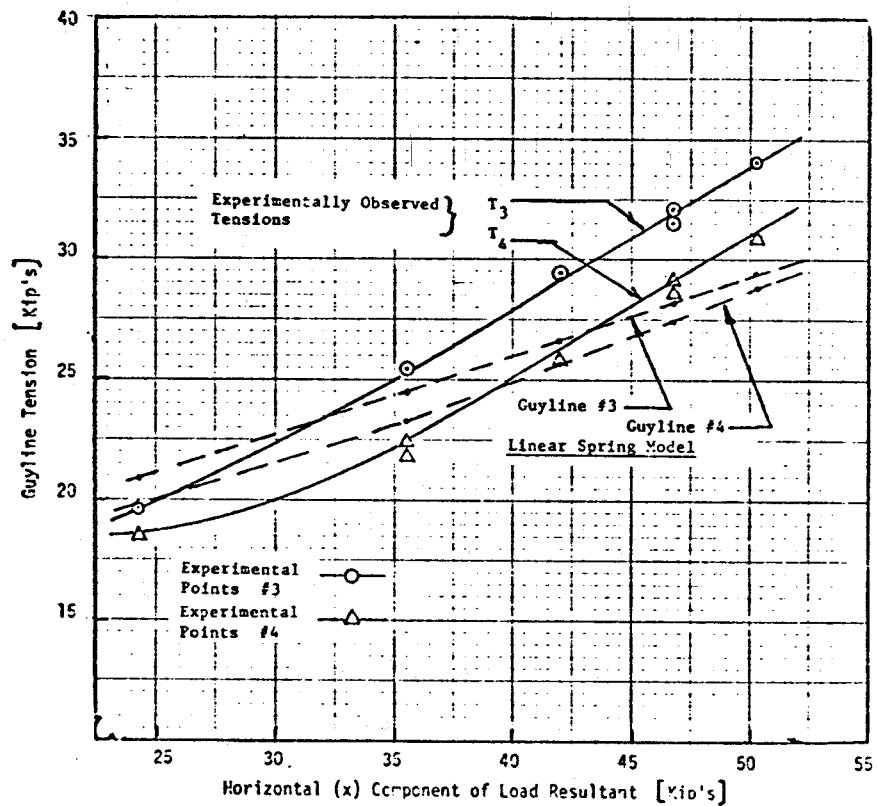


Figure IV-2. Comparison of the Field Measured Tensions with those of the Computer Simulation

We, therefore, feel confident that the static tension readings are realistic and that our modeling effort to predict the static tension distributions is valid. A catenary model should be implemented which, along with the tower deflection data, could provide us with the necessary means for checking our model.

Anchor & Tower Displacements

The anchor (stump) and tower displacements, as measured by the survey instruments, were suitably reduced. Unfortunately, the anchor (stump #3) displacement data are too scattered and small to be of significant value. In the static loading tests, we were only able to produce a tension change of 20,000 lbs. in the guylines (between runs #121 and #128) and this is estimated to have given us a stump displacement of one-fourth inch. This small of a distance is near the threshold of the reading accuracy of the survey instrument and hence unreliable. All we conclude is that the displacement during the static tests were insignificant and the stumps have a high static stiffness (in excess of $20,000 \text{ lbs./}.25" = 80,000 \text{ lbs./inch}$). If we could have produced tension changes of 30,000 to 50,000 we could possibly have obtained significant readings. A more sensitive instrument is required to measure stump motion.

The tower motion data collected appear to follow a reasonable trend and the values collected for the static runs (#121-135) are compared to the computed values from the guyline simulation program⁽³⁾ as shown on Figure IV-3. The tower displacement along the skyline corridor (x) is displayed against the horizontal (x-component, Ref. Figure IV-1) component of the skyline mainline tension. Agreement with the model is good, and this is very encouraging. We can now employ this tower deflection data to further cross-check our tension readings and obtain a better estimate of the initial tensions in the guylines where we could not read the tensions.

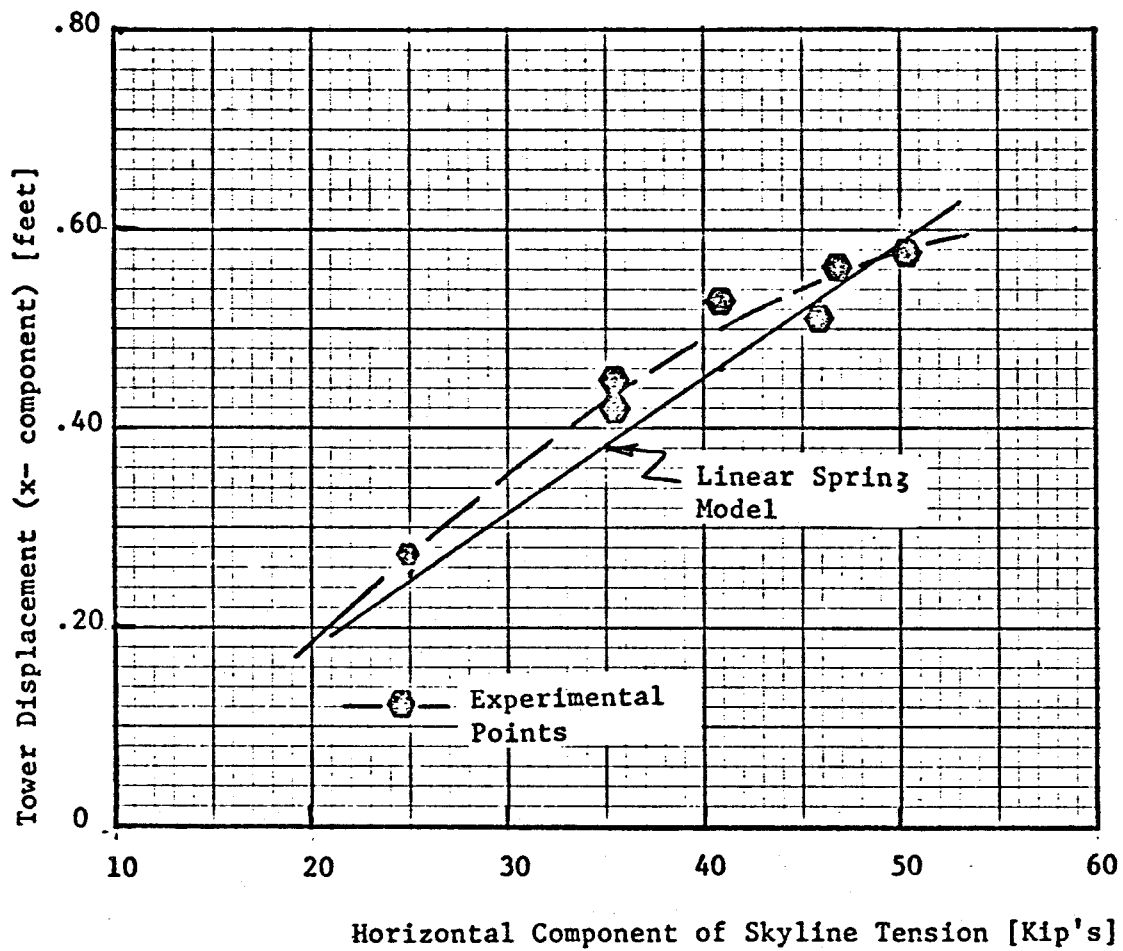


Figure IV-3. Tower Top Deflection (x) in the Direction of the Skyline Versus Horizontal Component of the Skyline Tension

Clearly, the value of the test runs where we have both tension readings and tower motion will be important in validating future computer modeling efforts. From static considerations, it also appears that the guylines are only moderately stressed. The maximum recorded guyline stress (run #128) was 34,095# when the skyline at that point was estimated to be at its safe working load (Ref. Table 4.2).

4.2 Impact Response of Stumps (Test #2)

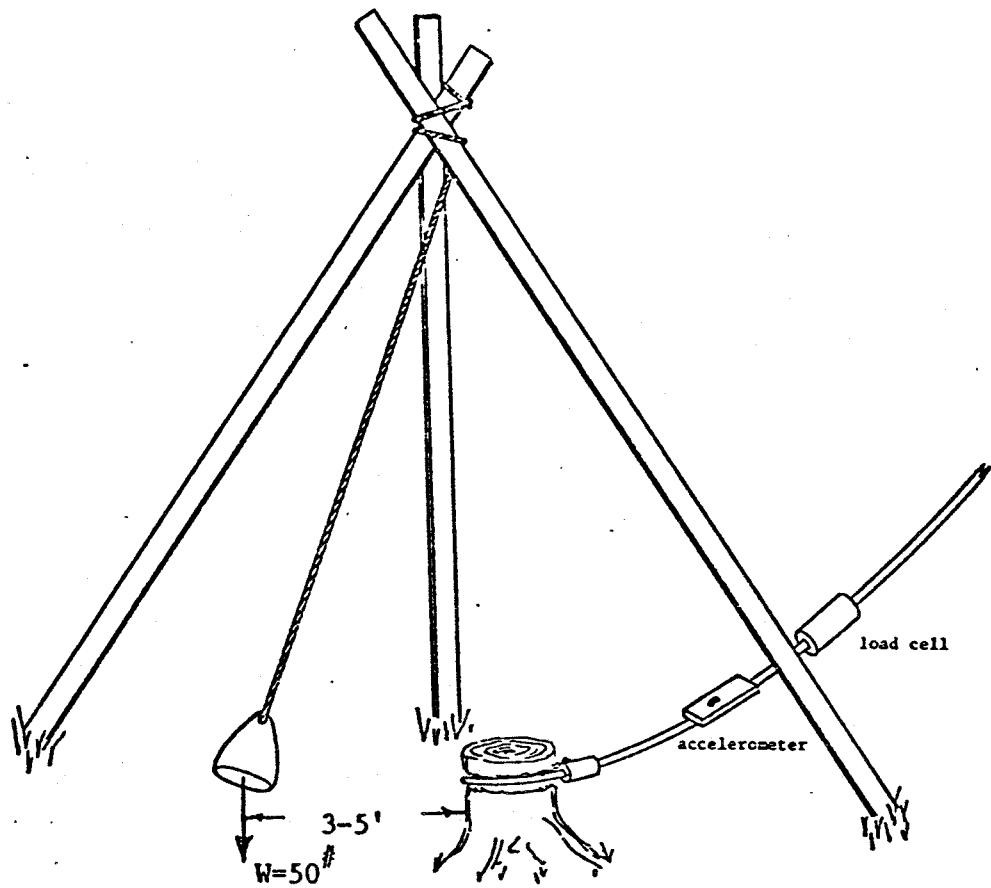
This test was designed to yield dynamic information on stump motion and energy absorption. The lack of stump motion and the fact that the accelerometer was mounted on the guyline rather than the stump prevented us from reporting on results related to the original objective. However, the test provided excellent information with which the elastic properties of the guylines could be checked.

Figure IV-4 (A) shows the basic set-up of the experiment where the pendulum load is moved back to provide an impact load to the stump. In Figure IV-4(B), the raw and filtered acceleration data are displayed. A 300 Hz low-pass filter setting was employed to provide the digitized data shown in Figure IV-5(A). The major "spikes" represent the longitudinal wave produced by the impact, and the period ($T = 34.90$ msec) is read from the record. This represents the elapsed time for the wave to travel from the stump to the tower and back.

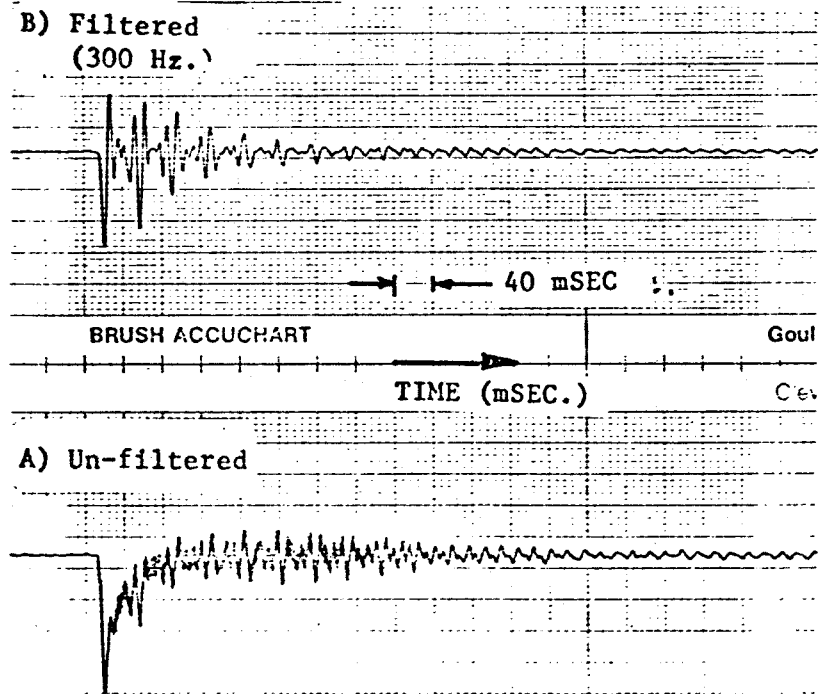
The wave speed v_L (in feet per second) is:

$$v_L = \sqrt{\frac{AE}{\mu}}$$

$$\mu = \frac{w}{g}$$

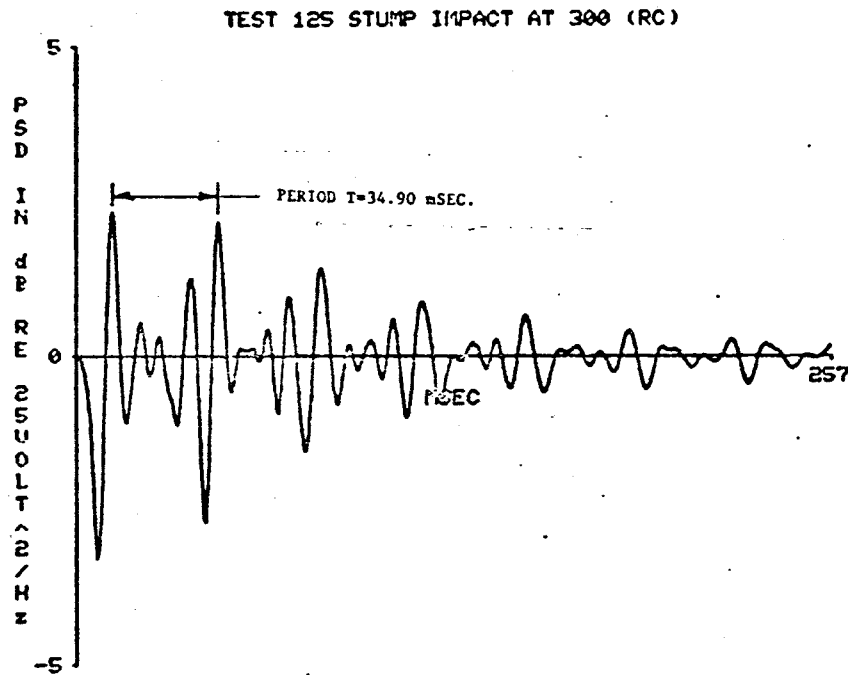


(A) Schematic Layout of the Stump Impact Test

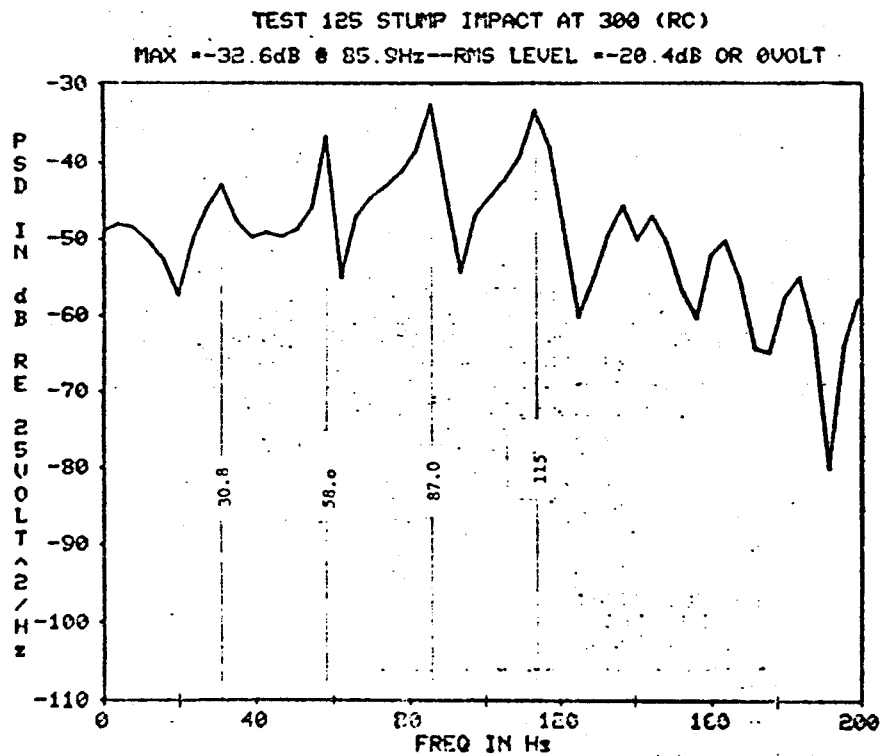


(B) Recorded Data from Accelerometer at Stump #3.

Figure IV-4. Stump Impact Test Set-Up & Results



(A) Stump acceleration data as digitized by the computer.



(B) Frequency spectrum analysis of the acceleration data.

Figure IV-5. Analysis of the Stump Acceleration Data for Special Components

where μ = wire density = .1087 (lbs.-sec.²/ft.²)
 A = wire cross-sectional area = .876 (in.²)
 E = Young's modulus = 14×10^6 lbs./in.²
 w = wire rope weight per foot = 3.5 lbs.

and the period T is then given by:

$$T = \frac{2S_c}{v_L}$$

where

$$S_c = \text{Guyline length} = 212 \text{ (ft.)}$$

Employing the standard values for the material constants and the values above, we calculated a value for the wave period $T = 39.92$ msec, which compares very favorably with the reported value of 34.90 msec (Figure IV-5 A). The frequency, f , corresponding to this period is:

$$f = \frac{1}{T} = 29 \text{ Hz}$$

and on the spectral plot of Figure IV-5(B), we identify this as the fundamental frequency. The higher modes (58, 87 and 115 Hz.) are also shown as multiples of the fundamental frequency. In calculations of the natural modes of a cable system, we can therefore employ standard tabulated values* and expect to come within ten percent of the experimental values.

To meet the original objective of measuring stump motion and its dynamic behavior the accelerometer must be placed on the stump. The impact level must also be raised considerably, preferably by an order of magnitude, to give us a response representative of the input levels we may experience during logging.

*United States Steel, "Tiger Brand Wire Rope Engineering Handbook," pp. 29-30.

4.3 Guyline Transverse Vibration (Test #3)

This test, planned originally for the incidental purpose of checking the simple vibrating string model of the guyline, provided some of the most important information obtained. The test pointed out an interesting characteristic of the tower-guyline system and the transfer of energy which can occur between guylines. It brought up important questions concerning the influence of tower motion on guyline dynamic tensions. And, it provided the data which supported most strongly the suspicions about the original calibrations of the load cells. Unfortunately, only one run was made under this test.

The transverse vibration of guyline #3 was induced as shown in Figure IV-6 and as discussed in Section 3.3.

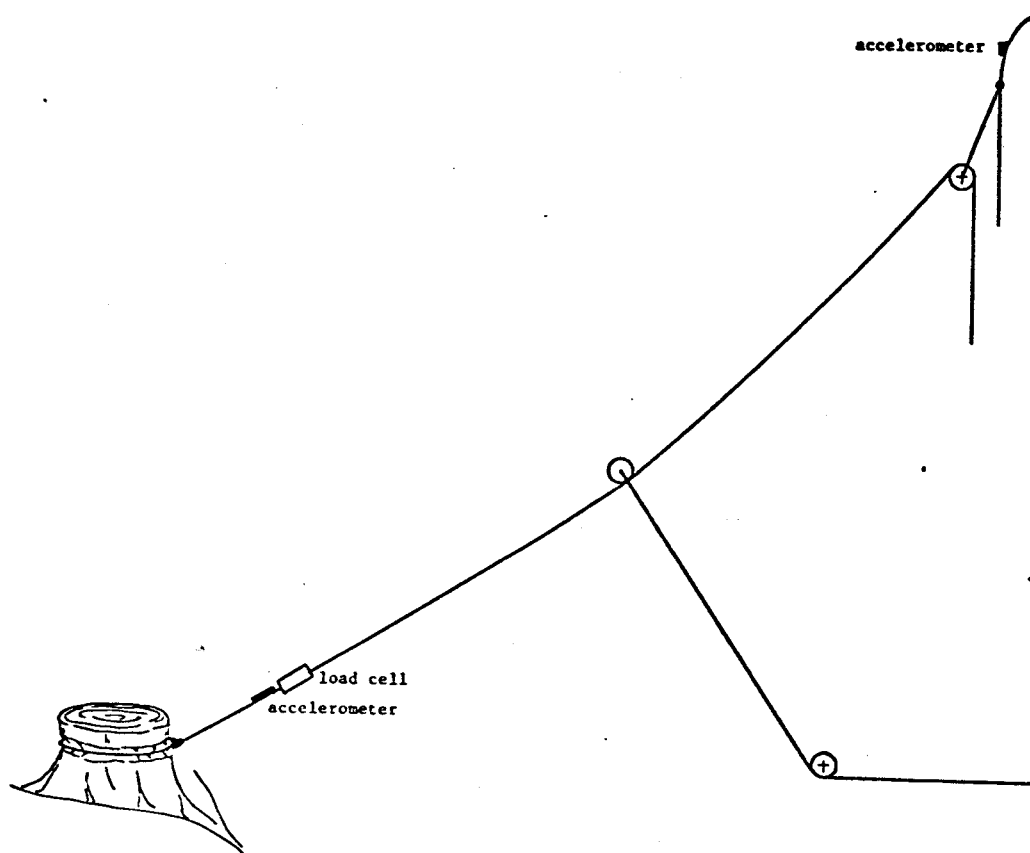


Figure IV-6: Loading for Transverse Vibration

We expected this light loading to produce first mode oscillation with a frequency near that predicted by the vibrating string model. The frequency expression for a vibrating string is:

$$\omega = \frac{\pi}{\ell} \sqrt{\frac{T}{\mu}}$$

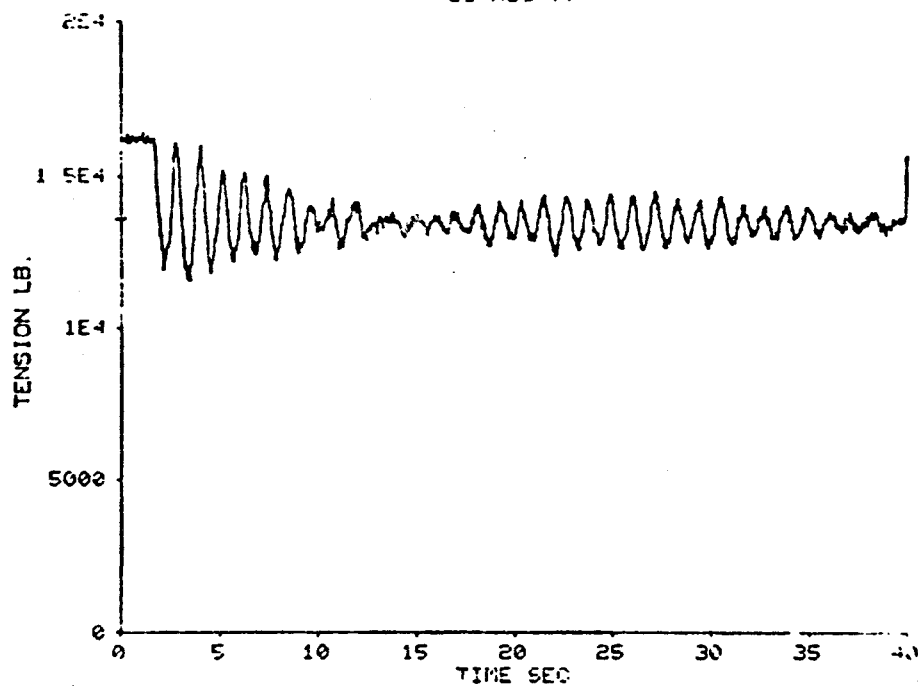
where T is the tension; μ is the mass per unit length; and ℓ is the string length.

With $\mu = .1083 \text{ lb. sec.}^2/\text{ft.}^2$ and $\ell = 212 \text{ feet}$, measurements of frequency off the tension history in Figure IV-7(A) ($\omega = 5.54 \text{ rad/sec}$) a tension of 15,150 pounds was predicted for guyline #3, and yet our original instrument calibration indicated a tension of 8,500 pounds.

There are nonlinear effects which one would expect to cause a discrepancy; however, this spread was considered too large and our suspicions were aroused. As reported in Section 2.7, our suspicions were confirmed and the final calibrations showed a mean tension in guyline #3 of near 13,500 pounds during this test. This reading agrees with the predicted value to within the range expected.

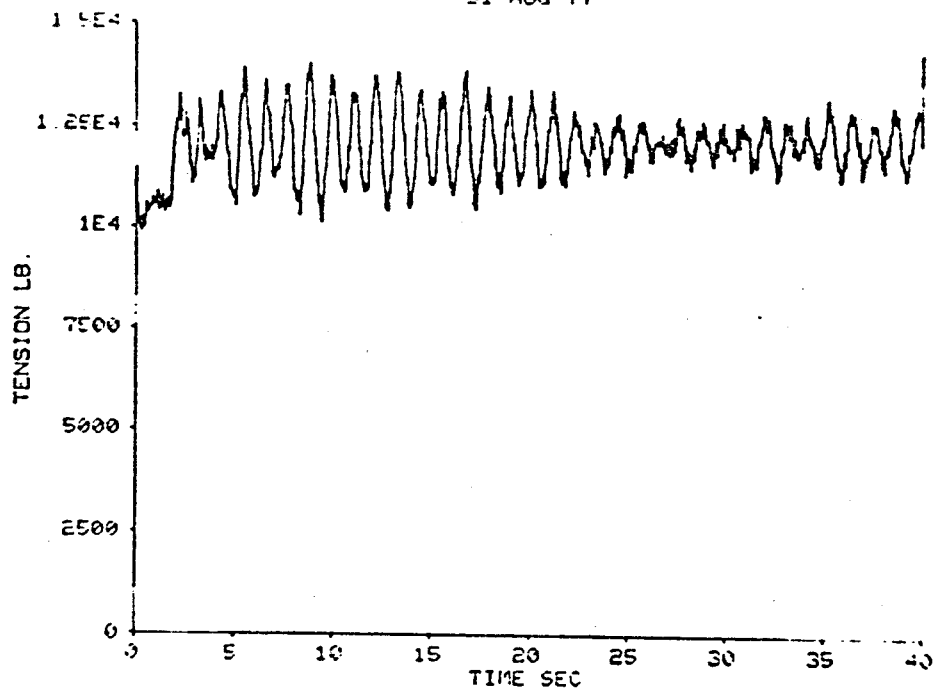
Another result of this test leads us to consider the classic two-degree-of-freedom problem of the motion induced in a pair of coupled pendulums.^{(5)*} When oscillation is initiated in one pendulum of a system of two pendulums coupled by a weak spring, there is a transfer of energy between the two which results in a motion where each will alternately pass through periods of simple harmonic oscillation and periods of no motion. The results of this test showed this type of behavior. This is apparent in the tensions of guylines #3 and #4 for run #122. These figures show the initial tension variations in guyline #3 rapidly damping to a steady mean, while the tension in guyline #4 builds up to its largest variation near 15 seconds. Following the theory, the tension in #3 then builds up again to a maximum between 25 and 30 seconds, while the #4 tension diminishes to a steady mean near these times. Beyond this point, the pattern appears to repeat itself out to the point where data collection ceased at 40 seconds.

RUN NUMBER 122 CHANNEL NUMBER 1
31-AUG-77



(A) Tension in Guyline #3.

RUN NUMBER 122 CHANNEL NUMBER 3
31-AUG-77



(B) Tension in Guyline #4.

Figure IV-7. Tension History of Transverse Vibration Test

We were able to reproduce this behavior analytically with the model shown here. The physical constants for this model were related to our system as follows:

1. A vibrating string and a spring-mass system have natural frequencies expressed as:

$$\omega = \frac{\pi}{\ell} \sqrt{\frac{T}{\mu}}$$

and

$$\omega = \sqrt{\frac{k}{m}}$$

respectively. A vibrating string can then be modeled with the spring-mass system by adopting a mass of:

$$m = \mu \ell$$

This requires the spring constant to be modeled as:

$$k = \frac{T\pi^2}{\ell}$$

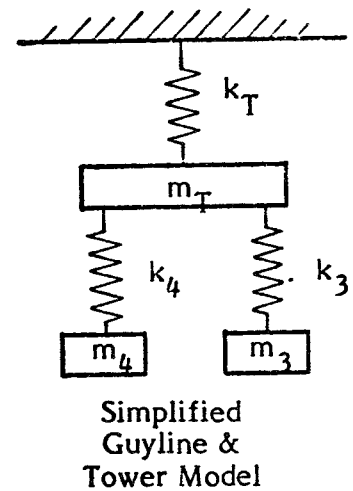
In our test model masses of

$$m_3 = 22.92 \frac{\text{lb sec}^2}{\text{ft.}^2} \quad \text{and}$$

$$m_4 = 23.06 \frac{\text{lb sec}^2}{\text{ft.}^2}$$

are required. Spring constants are determined by the tension as discussed below.

2. The moment of inertia of the tower, plus an effective mass due to contributions from other guylines, would determine m_T . Considering these values, we adopted a value of $560 \text{ lb. sec.}^2/\text{ft.}^2$ for m_T .



3. The effective spring constant, k_T , depends upon the guyline geometry as well as the operating line resistance. Considering the small deflections involved in this test, we adopted a value of 40,000 lbs./ft. for k_T .

Figure IV-8 shows the results of our analytical simulation of the test. It shows a composite of the #3 and #4 guyline tension variations which should be compared with the test results of Figure IV-7. Note that the mean tension values, namely 12,000 pounds for guyline #3 and 13,000 pounds for guyline #4 differ from the apparent experimental values of 13,500 pounds and 12,500 pounds. This was necessary to produce the behavior shown in the analytical results. The point at which tension variations in guyline #3 go to their minimum amplitude near 17 seconds, depends quite strongly on the relative magnitudes of #3 and #4 mean tensions. It depends also on the tower spring constant. The values we have used are the result of many runs of the type displayed in Figure IV-8. More analysis of these data should provide a better understanding of the system.

Although our simple spring-mass model has provided general agreement with the behavior experienced in this test, we know from other studies that the vibrating cable is nonlinear and the motion of its anchors, the stump and the tower in our case, has a strong influence on its behavior. Unfortunately, we did not get good data on these anchor motions; however, good data could be collected in future tests. Now that the results of this one run have been examined, we see an opportunity to learn much about a guyline system by performing tests of this type. Future tests coupled with more analytical work in this area could be quite fruitful.

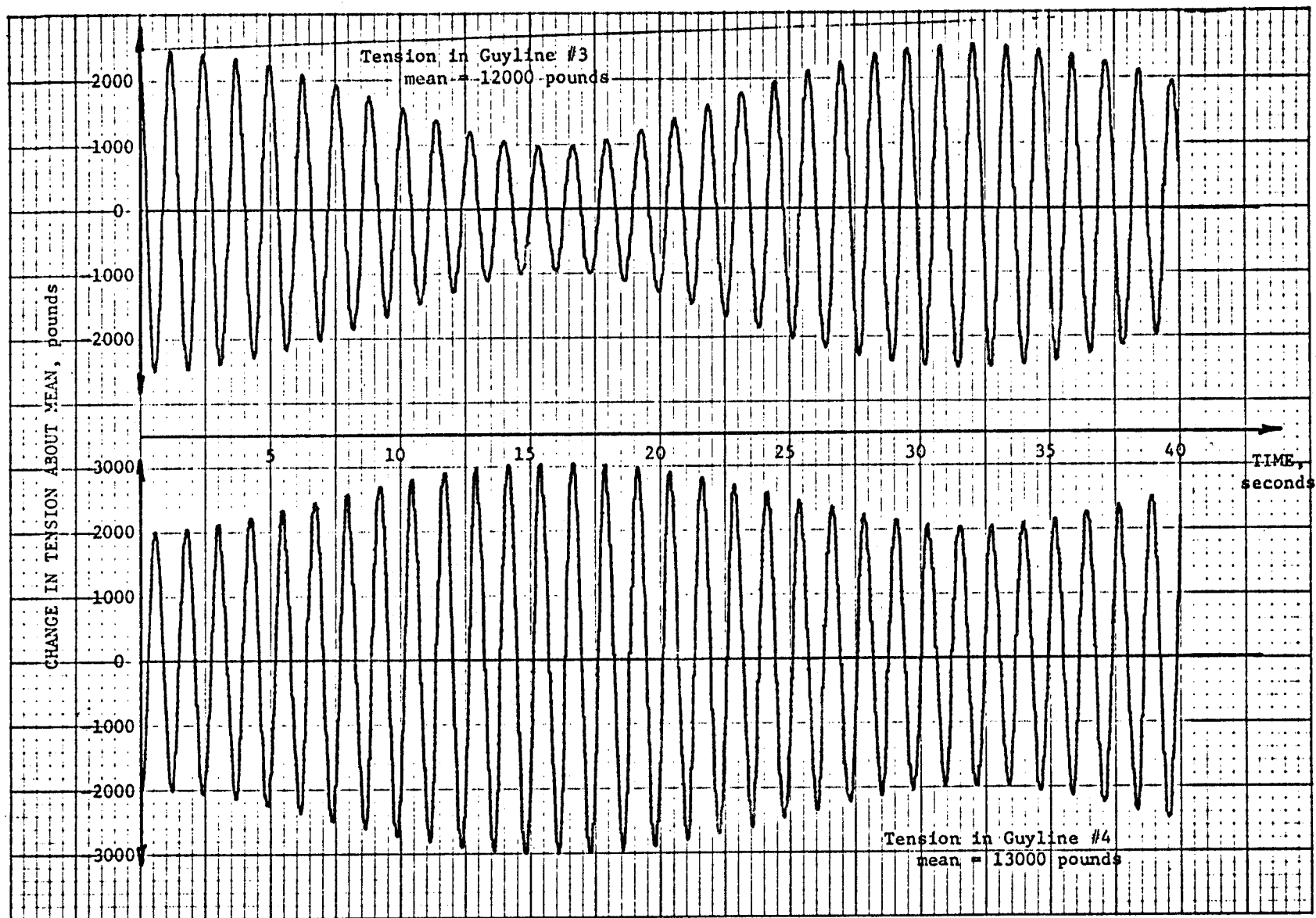


Figure IV-8. Tensions Predicted by the Spring-Mass Model

4.4 Sudden Load Response (Test #4)

The primary objective of this test was to measure the reaction of the guyline system to a sudden impulsive load in the operating lines, as may occur when a load suddenly drops.

In the test, the skyline system was loaded with the 9,700-pound log at a predetermined initial position (see Figure IV-9). At a given instant, the mainline brake was released and the load and carriage allowed to slide down the skyline to a predetermined final position (obtained by marking the mainline) where the mainline brake was suddenly applied. The typical data for this test are shown on Figure IV-10. The data for stump and tower accelerometers were filtered at 1.5 Hz.

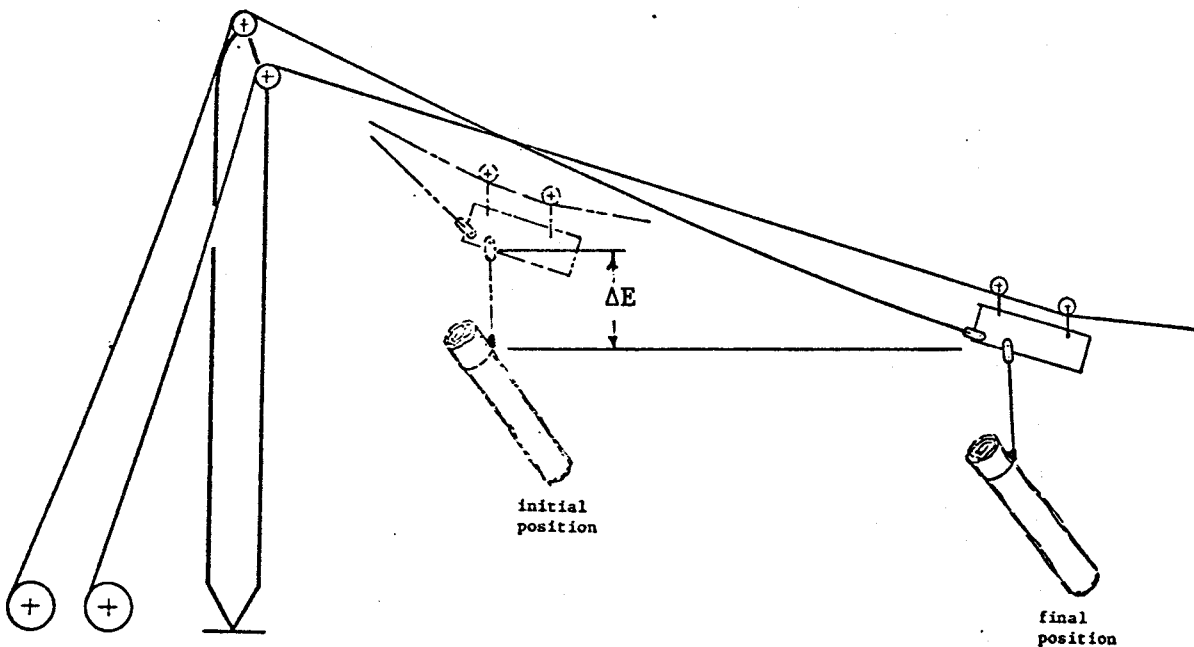
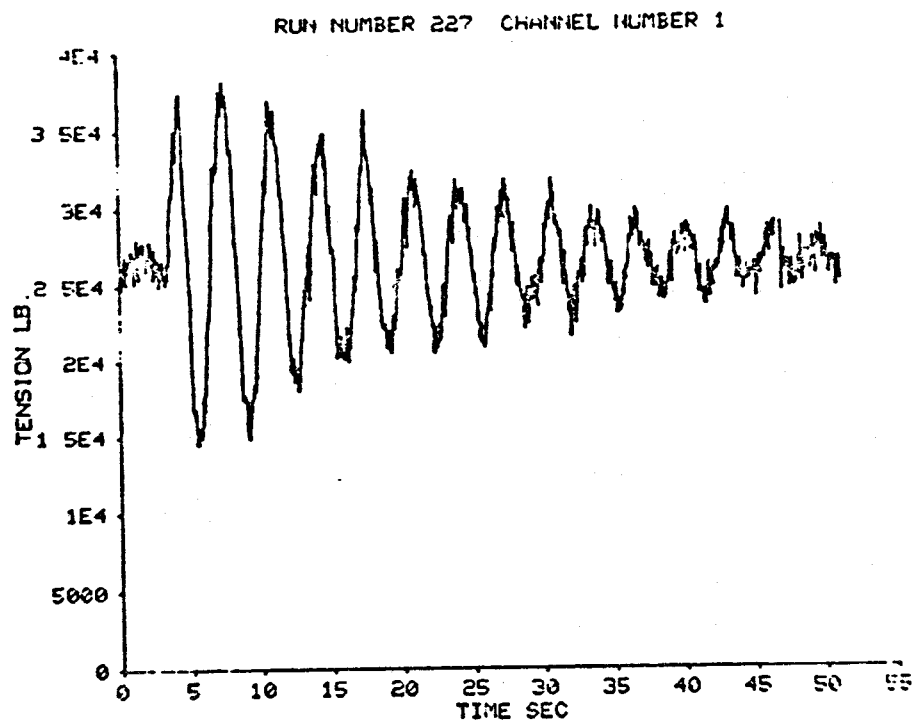
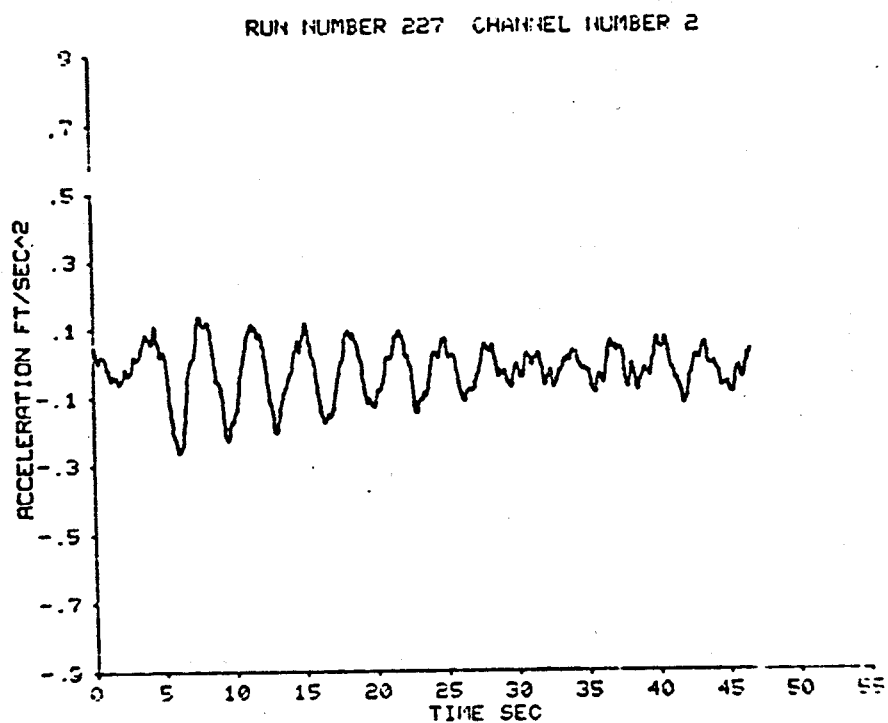


Figure IV-9: Schematic of the Sudden Load Response Test Set-Up

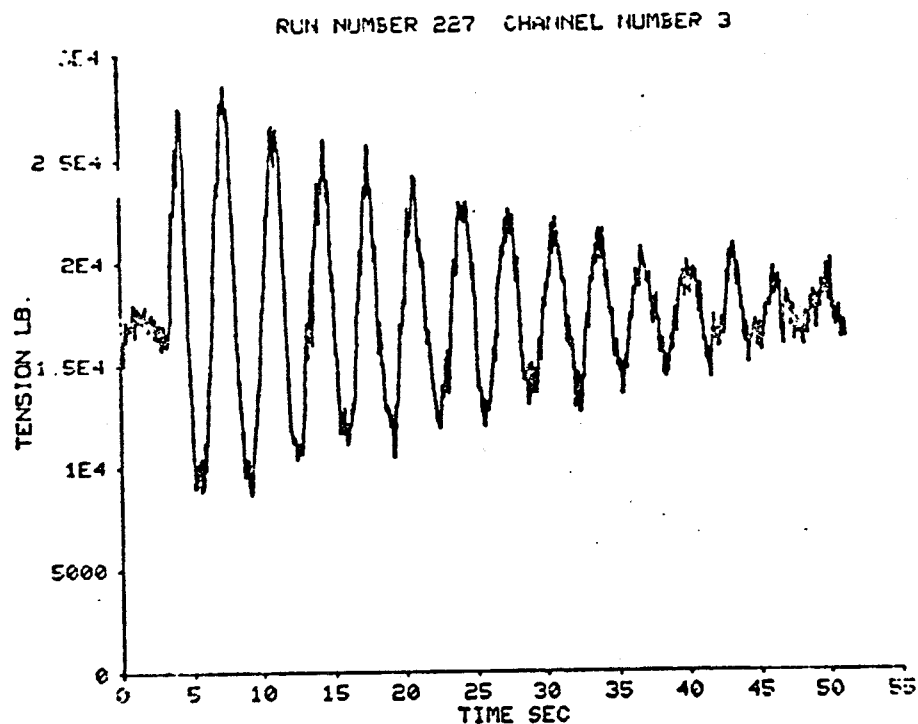


(A) Tension in Guyline (Stump) #3.

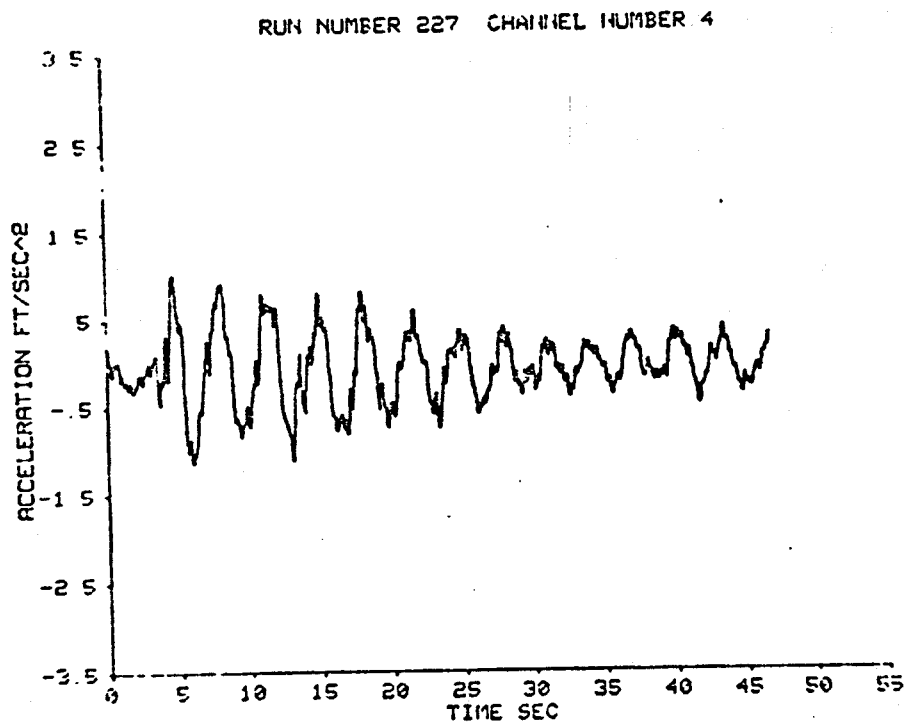


(B) Acceleration in Guyline (Stump) #3.

Figure IV-10. Display of the Dynamic Data for the Sudden Load Test (Run #227)



(C) Tension in Guyline (Stump) #4.



(D) Tower Acceleration

Figure IV-10. Display of the Dynamic Data for the Sudden Load Test (Run #227)

A summary of the tests in this series is given in Table 4.4, where we have concentrated on the important parameters; load elevation drop (ΔE), initial and maximum tensions (T_i , T_m), the relative change in tension, $\Delta T/T_i$ where $\Delta T = T_m - T_i$, the frequency of vibration and the motion of the stump and tower accelerometers.

The tension data are most appropriately discussed by considering Figure IV-11, where we plot the relative change in tension normalized with respect to the initial tension, as a function of the change in load elevation. In the range of load elevation change from 10 to 30 feet, we observe linear increase in the relative tension as expected, since we added more energy to the impact. At the larger load, elevation changes the frictional losses as the carriage moves down the skyline and the mainline dragging on the ground, reduces the energy input and hence the response.

The most notable conclusion here is that for the modest drops of the load (10-30 feet) the changes in guyline tension ranges from 30% to 110%. The peak tension is:

$$\frac{T_m}{T_i} = 1 + \frac{\Delta T}{T_i}$$

and would then range from 130% to 210% of the mean tension. Applied to the skyline, this could easily cause damage to the line over the sheaves even if the line is loaded to its safe operating load (one-third yield strength). This is because the outer wires are stressed above the mean tension, often by a factor of 100%, and the dynamic impact load easily causes the tension to exceed the yield strength, resulting in local damage to wires. The results for this specific test do not indicate the stresses exceeded the safe levels of operation. However, because the peak magnitude of the tensions may exceed twice the mean, static considerations alone will not suffice in anchor load analysis.

TABLE 4.4
SUDDEN LOAD TEST SUMMARY

Run #	Load Drop E [feet]	Tension - Stump #3			Tension - Stump #4			Frequency of Vibration [Hz]	Tower Displacement x_T [feet]	Stump #3 Displacement x_3 [feet]
		Initial T_i	Max T_m	Rel. Change T/T	Initial T_i	Max T_m	Rel. Change T/T			
224	11	26,059	34,381	.321	17,159	26,000	.51	.2	.436	.07
227	24.20	25,969	38,461	.48	16,308	28,846	.77	.28	.623	.108
230	39.8	25,062	43,269	.73	15,686	32,846	1.09	.25	1.09	.177
233	39.4	25,276	41,538	.64	15,555	30,000	.93	.28	.78	.169
239	64	26,661	50,000	.88	16,330	36,923	1.26	.28	1.09	.231
242	65	26,817	50,000	.88	16,166	35,384	1.19	.28	1.25	.277

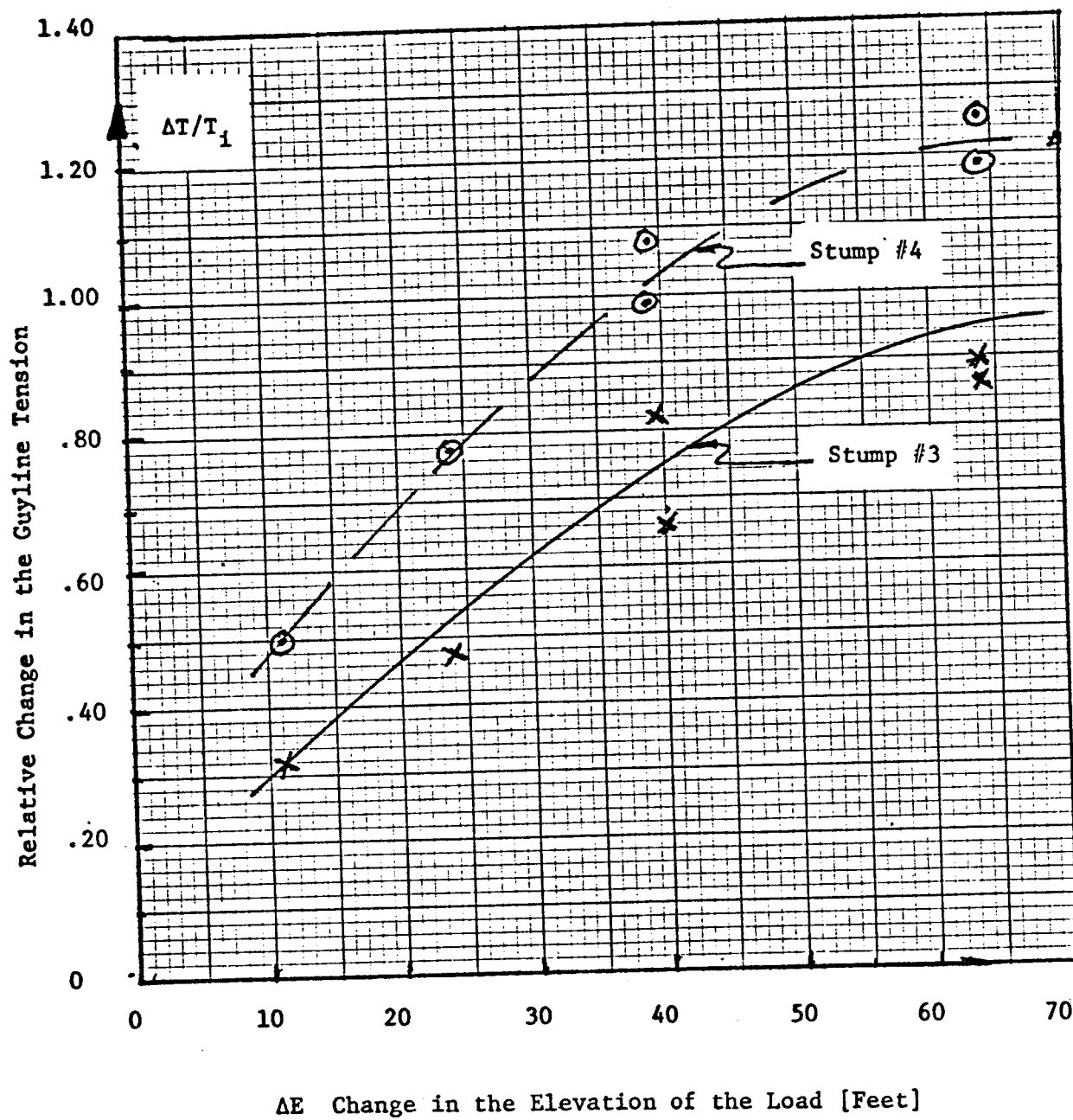


Figure IV-11. Change in the Relative Tension Vs. Elevation Difference of the Load for the Sudden Load Test (Runs #224-242)

The stump and tower motion displacement were "estimated" from the acceleration data by assuming the motion to be sinusoidal. Hence:

$$\ddot{x} = \omega^2 x_0 \sin \omega t$$

and the peak-to-peak displacement would be:

$$x_{pp} = \frac{\ddot{x}_{pp}}{\omega^2}$$

where $\ddot{x}$ = acceleration

x_0 = amplitude of vibration

ω = frequency of vibration

pp = denotes the maximum or peak-to-peak values.

Figure IV-12 displays the tower and stump accelerometer displacements. We observe tower motions in the order of one foot and this is consistent with static measurements (see Section 4.1), as the dynamic loadings were more than twice static.

The stump accelerometer displacements are considerably larger than the static measurements and might appear contradictory. However, motion of the accelerometer due to cable motion (catenary changes the shape) and cable stretch (may be negligible). Hence, further analysis is required on these data to extract the actual stump displacement.

The tension and accelerometer data are observed to change at the same frequency and for the test range, this is observed to be in the range of .2-.3 Hz, with a period from 3.3 to 5 seconds. These frequencies are predictable by considering the natural frequency of the skyline as:

$$\omega = \sqrt{\frac{K}{M}}$$

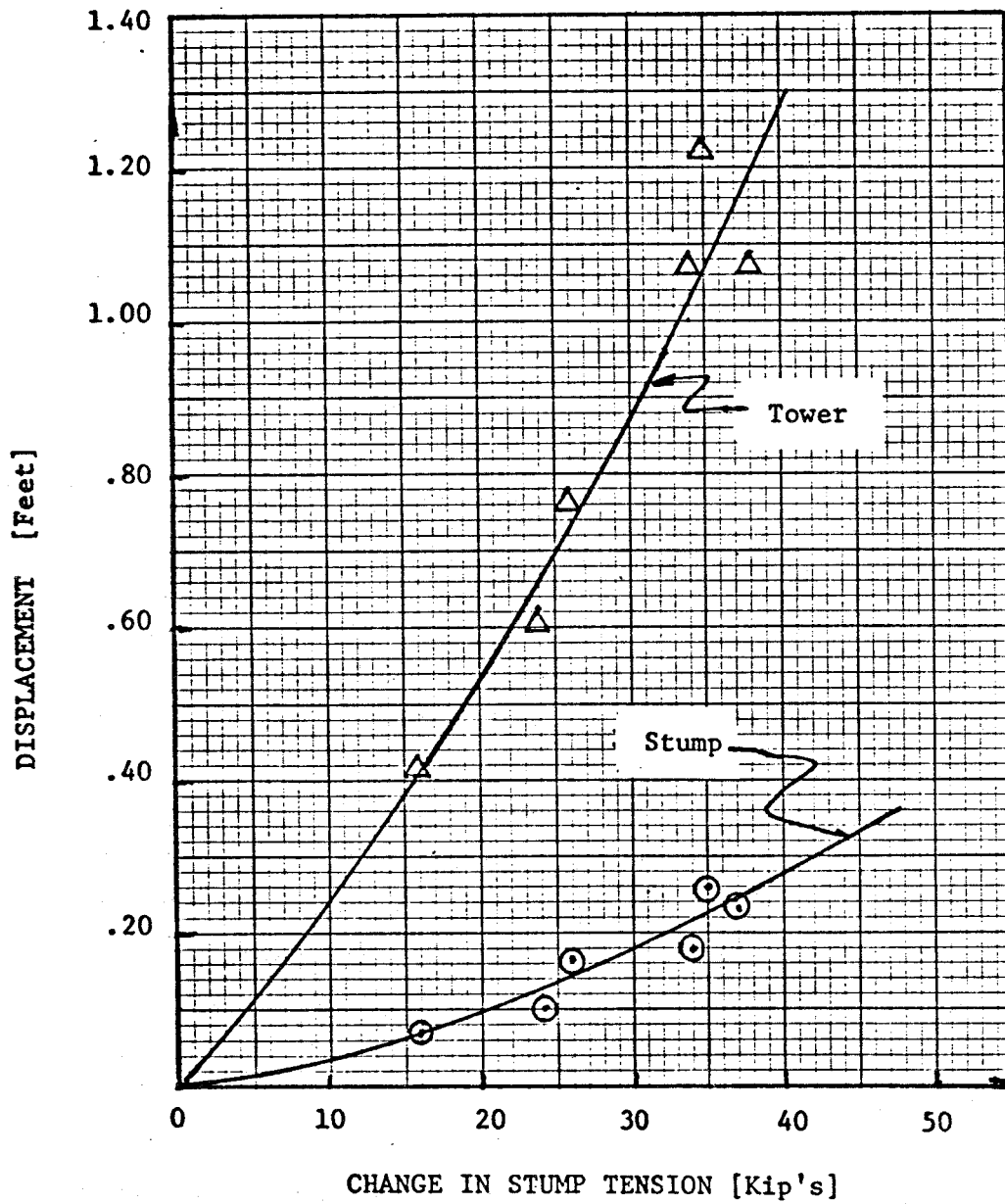


Figure IV-12. Tower & Stump #3 Accelerometer Displacement Readings Vs. Change in Stump Tension for Runs #224-242

where K is the effective spring rate of the skyline and M the mass of the log and carriage. For run #227, the predicted frequency was .27 Hz and the observed is .28 Hz. The harmonic content of the acceleration data was not analyzed.

The effective decay of vibration is obtained from considering the decrease in the tensions in Figure IV-10. Employing the log-decrement method^{(5)*} where the damping ratio ζ is related to log decrement δ :

$$\zeta = \frac{\delta}{2\pi}$$

where

$$\delta = \ln(T_1/T_2)$$

and T_1 , T_2 are the tension values at successive peaks. Averaged over a run, this produced a damping coefficient $\zeta = .025$. This indicates that the energy dissipation in cable systems of this nature is extremely small.

The major conclusions from this set of experiments are:

- Dynamic changes are important and even for moderate energy input can exceed twice the mean tension.
- Stump motion can best be detected by an accelerometer placed on the stump and the motion is appreciable (measurable) during dynamic loading.
- The basic vibrational frequencies are dictated by the skyline geometry and the load.
- The energy dissipation in a skyline system is very low and can be compared to a second order mass-spring-dashpot system with a damping coefficient much less than 1/10.

*Ref. 5, p. 40

4.5 Yarding Sequence Response (Test #5)

The series of runs under this test produced data of most immediate interest to the practitioner. By static analysis, the logging engineer can compute the expected static guyline tensions of a system whose geometry and load is known.⁽⁶⁾ Since there are obvious dynamic loadings, however, the question always exists about the quantitative relationship between the static and dynamic magnitudes of line tensions. The objective of this test was to establish these relationships for typical logging conditions, and the data show results which are quite enlightening.

The definition of the yarding zones are shown on Figure IV-13 and the corresponding profile view of the test set-up is shown on Figure IV-14. The time locations corresponding to the field points were marked on channel #4 (tower accel.) as "blips" with the voice button. When the load passed over the station, a command was given from Trig Point #1 to "blip" channel #4. In this manner, we can identify the yarding zones.

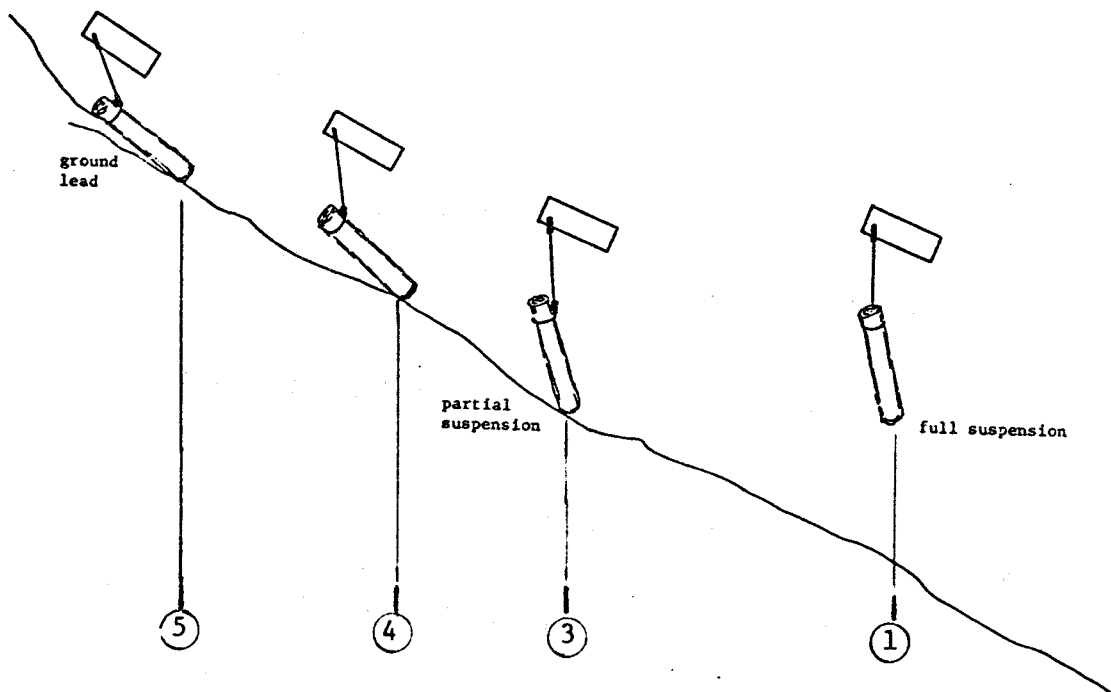


Figure IV-13: Definition of the Yarding Zones that Delineate the Yarding Sequence Tests

USFS/Weyerhaeuser
Anchor Dynamics Test
10-15 January 1977
Snoqualmie Falls, Wn.

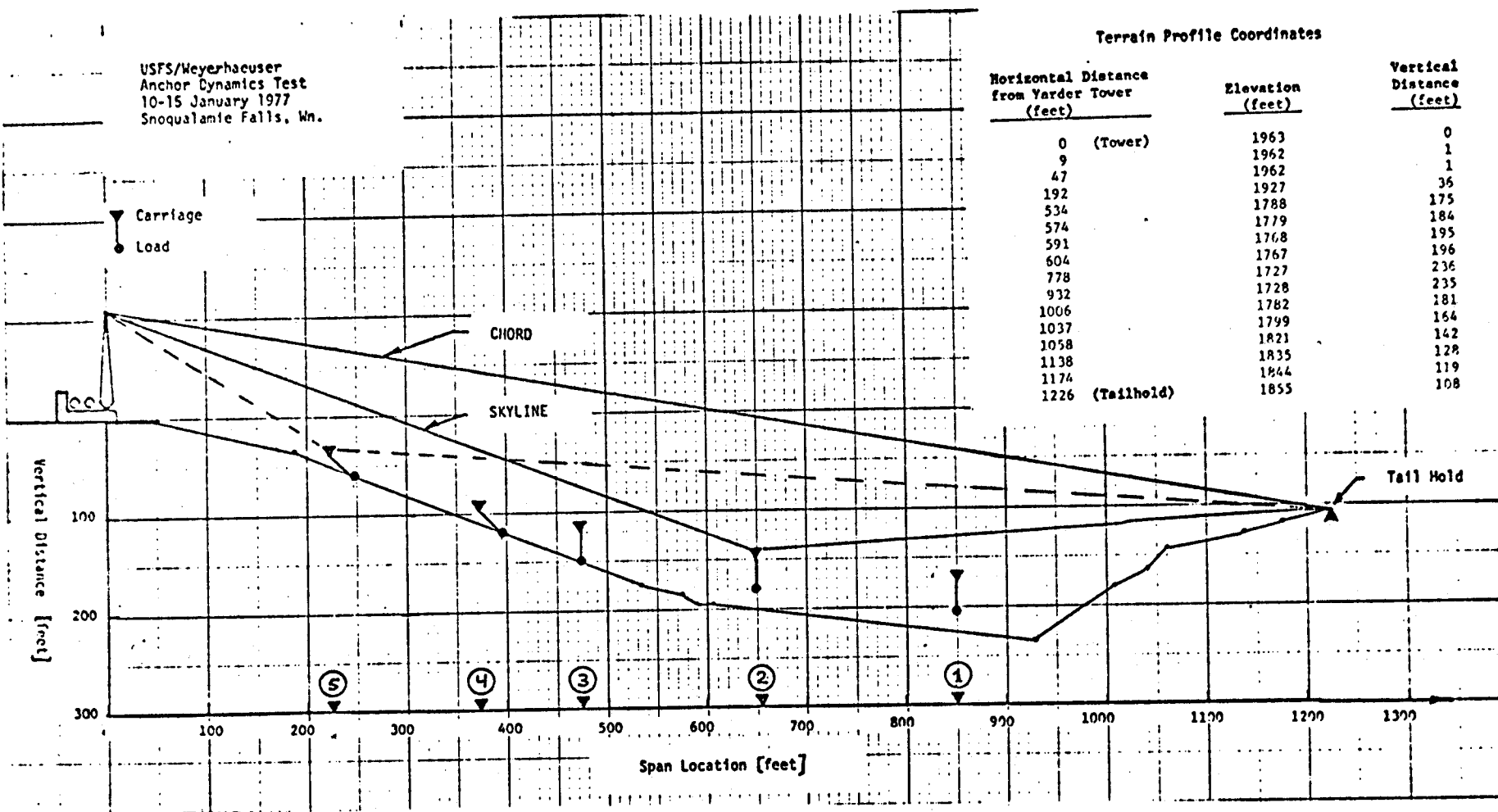


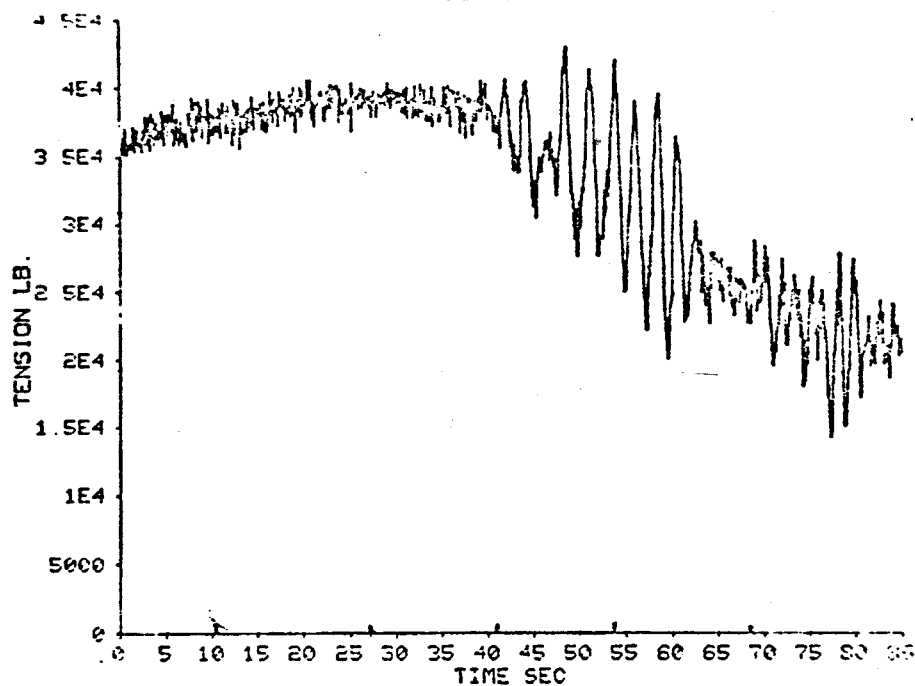
Figure IV-14. Description of the Yarding Sequence Test Set-Up:
The numbers define the yarding zones and corresponds to the "blips" on the
Acceleration Channel #4 of the data runs.

Consider the tension history of the yarding sequence shown in Figure IV-15 for run #212, channel #1. These data show the #3 guyline tensions for the three regimes of yarding shown in Figure IV-15(A): "load fully suspended" (points 1 through 2 to 3); "partially suspended" (points 3 through 4 to 5); and "ground lead" (point 5 and beyond). As expected, the fully suspended reaction was most predictable. Dynamic perturbations were mild, and variations about a predictable static mean were less than $\pm 5\%$. The dynamic excursions about the mean in the partially suspended regime were, by contrast, somewhat surprising. A peak-to-peak range of nearly 20,000 pounds about a mean tension of 30,000 pounds cannot be considered insignificant. It should be noted that the guyline tensions exceeded the magnitudes that would have been produced had the load been fully suspended at the same carriage deflection rather than dragged on the ground. Similar results, with less of a dynamic range, were obtained in the ground lead regime. It should be pointed out that consistent ground lead yarding was not possible; and some partial suspension, with the attendant behavior, happened beyond point 5.

Theory shows that for a mass spring system, dynamic loadings can induce tensions as large as twice the static mean. Although the tension in guyline #3 reached levels of 45,000 pounds, a bouncing log could have induced tensions nearer 70,000 pounds. Had the guyline geometry and loading put the static mean tension nearer the 60,000 pounds operating level that is allowed by design practice for a 1-3/8" wire rope, one can see that there is enough dynamic action to raise the rope tension beyond its yield point when yarding with a partially suspended load. Drastic failures would not occur at this tension, however, wear and wire weakening due to strand flattening where the rope passes over a sheave could be expected. This type of wire wear and reduction in ultimate (breaking) tension capability have lead to tower failure.

RUN NUMBER 212 CHANNEL NUMBER 1

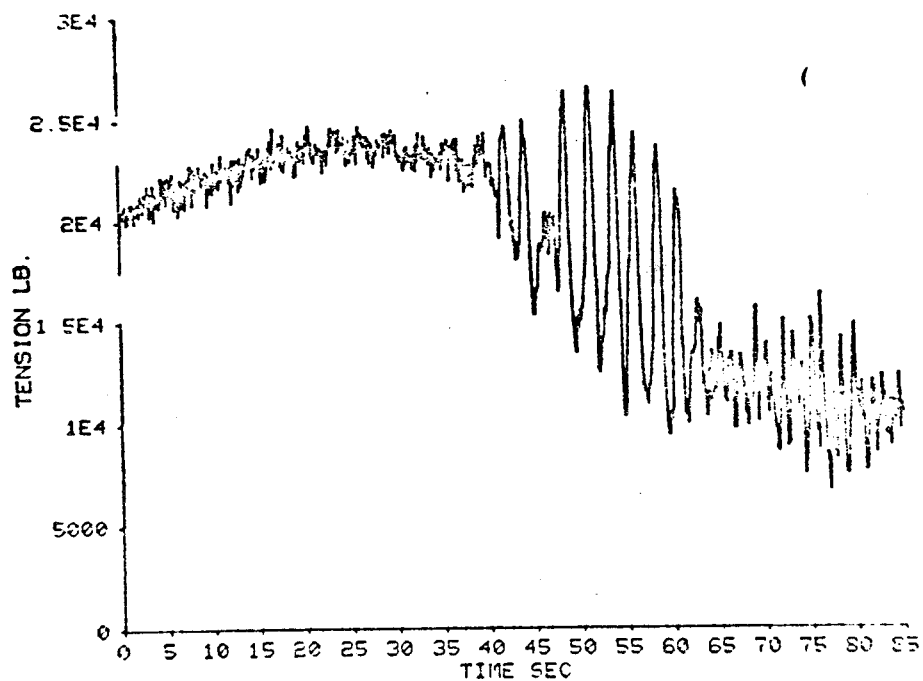
31-AUG-77



(A) Tension in Guyline #3.

RUN NUMBER 212 CHANNEL NUMBER 3

31-AUG-77

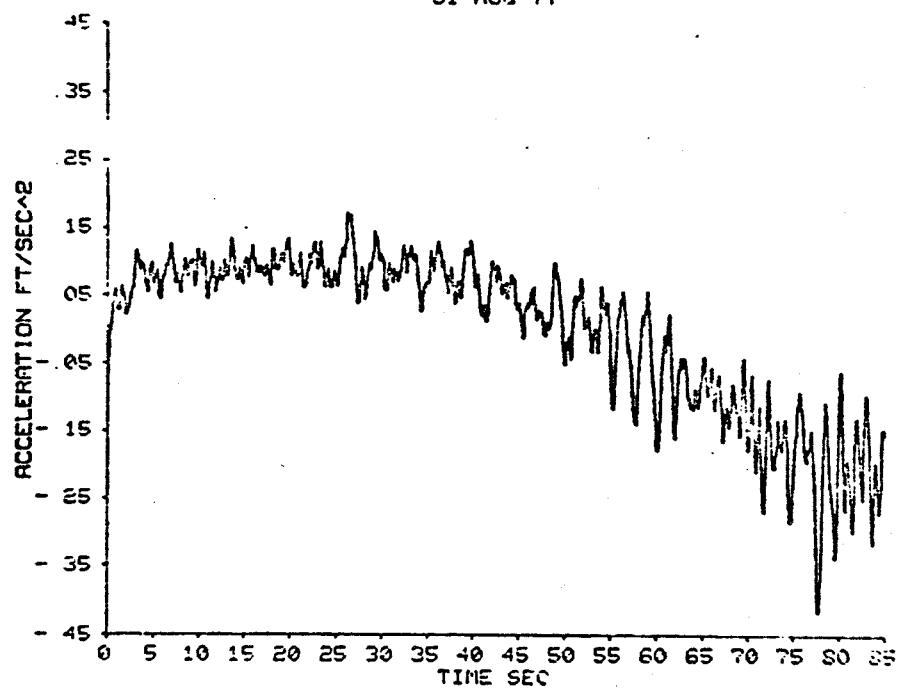


(B) Tension in Guyline #4.

Figure IV-15. Tension History During Yarding Sequence

RUN NUMBER 212 CHANNEL NUMBER 2

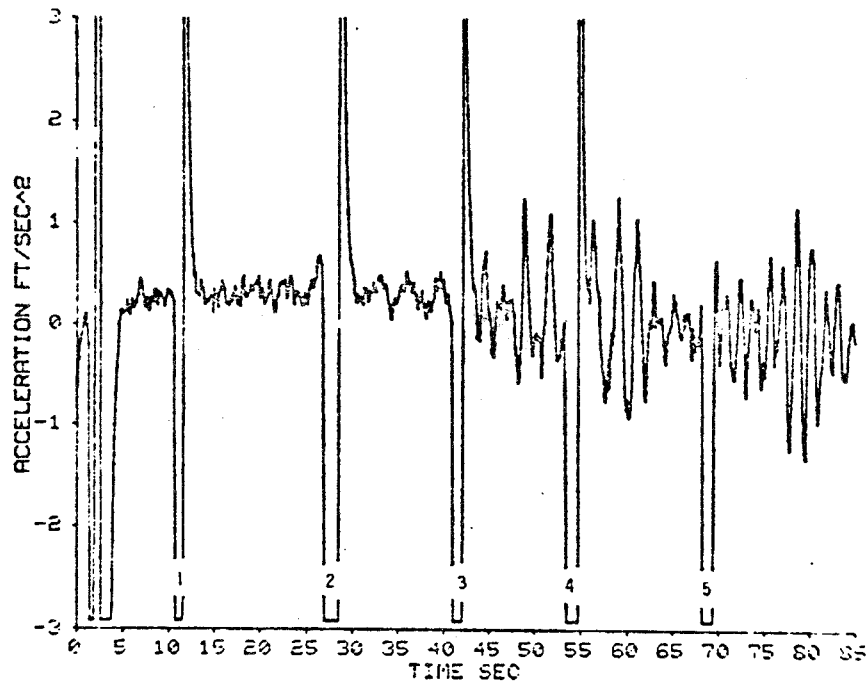
31-AUG-77



(A) Acceleration at stump.

RUN NUMBER 212 CHANNEL NUMBER 4

31-AUG-77



(B) Acceleration at tower.

Figure IV-16. Accelerations During Yarding Sequence

We must emphasize that the results of this test are most probably very specific to this geometry and loading. These should not be extended to other cases until an acceptable analytical model of this behavior can be validated. For example, it seems clear intuitively that the relationship between the load size, the speed of yarding and the dynamic and static friction coefficients between the logs and the ground can have a major influence on the oscillatory motion of the logs and carriage. If this motion occurs near the natural frequency of some system component such as the mainline or a guyline, which is quite probable, very large dynamic loads could be generated. Phenomena of this type must be understood more thoroughly before these results can be extended.

The tension history of guyline #4 was similar, but more dramatic in the partially suspended load regime. The mean tension in the guyline is most likely the major influence causing the quantitative difference between it and guyline #3.

The filtered stump acceleration data appear qualitatively correct. The dominant frequency agrees with the tension measurements and the relative magnitudes agree also. The tower acceleration data have the marks used to indicate the carriage position superimposed upon them and, therefore, the continuous behavior is obscured. The data that are apparent show the influence of dynamic tensions upon the motion that would be expected.

4.6 Yarding Response to a Hang-Up (Test #6)

The series of runs under this test yielded good data for tensions in guylines #3 and #4; however, in retrospect, we recognize that our objective was not met fully. As stated, our intention was to simulate the common situational occurrence of a "hang-up" during inhaul. We may well have accomplished this; however, the fact that the momentum of the 4600 pound log may have contributed measurably to breaking the 5/8" choker does introduce some uncertainty about our simulation.

The physical description of the test method employed is shown in Figure IV-17. Figure IV-18 shows the typical results for two separate runs.

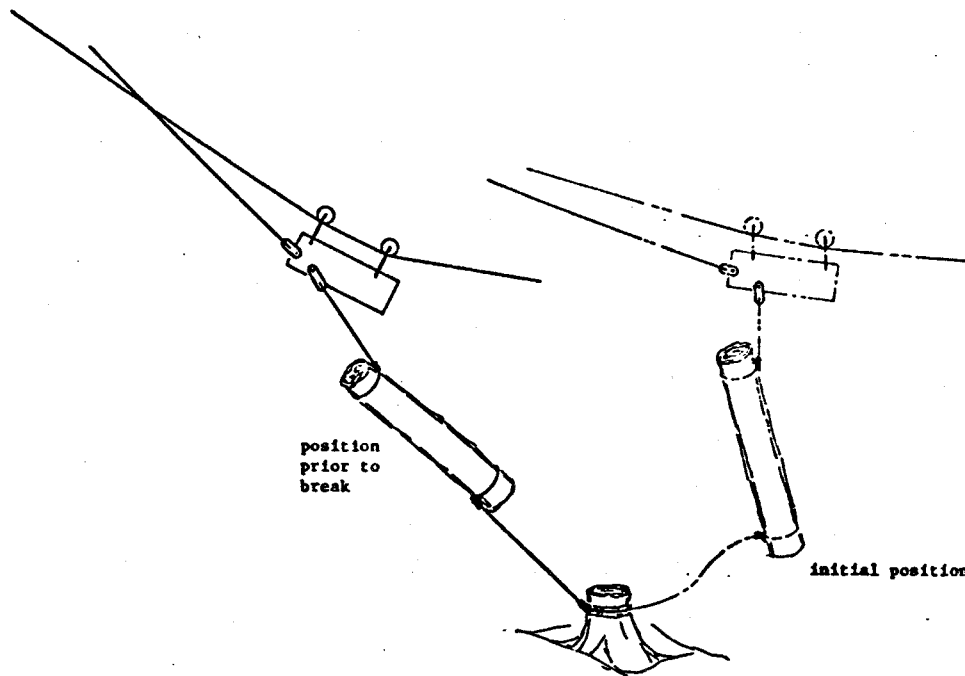
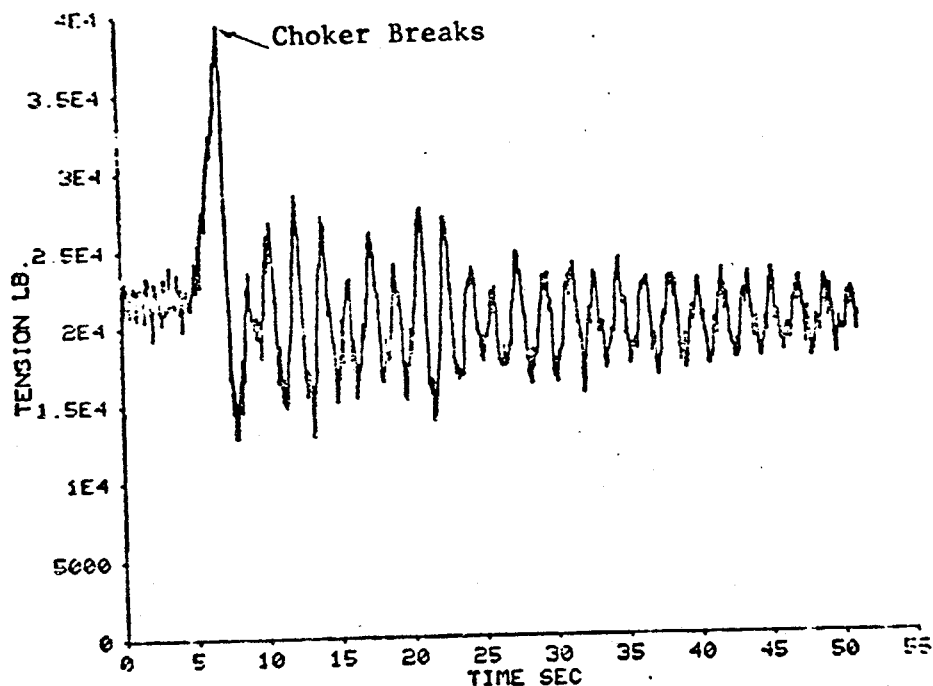


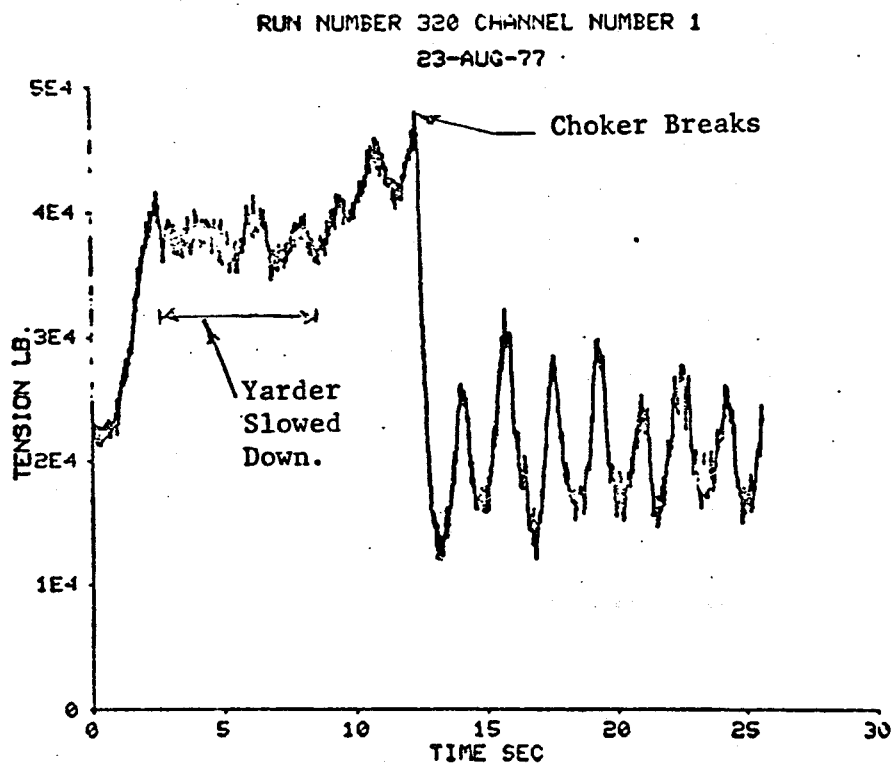
Figure IV-17: Description of the Method for Simulation of a Yarding Hang-Up

In run #316 (Figure IV-18(A)), the log had attained significant momentum at the time the choker broke. This resulted in a significantly lower maximum tension in guyline #3 (40,000 lbs.) as compared to run #320 (Figure IV-18(B)), (50,000 lbs.). The carriage was inadvertently slowed down in run #320 and the log, therefore, attained a much lower speed (momentum). The tension necessary to break the choker is, therefore, transmitted directly to the skyline which resulted in the higher tension recorded in guyline #3.

The dynamic response to the hang-up test is very similar to the sudden load test in that both represents the reaction to a fast (impulsive) tension loading. The peak loading of 50,000 pounds are nearly identical and the frequency of vibration of the system after the choker broke is also predicted by the same means. In future testing, the sudden load test could therefore be substituted for this test.



(A) Tension in Guyline #3 for a run where the log has significant momentum at the time the choker broke.



(B) Tension in Guyline #3 for a run where the log has negligible momentum at the time the choker broke.

Figure IV-18. Typical Tension Traces from the Hang-Up Test

V. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

The overall test plan was excellent and the data collected on most of the tests are very valuable. As in any test, no matter how well planned, some features of either a test or the data are bound to be poor, and this test was no exception to this rule.

The attempt to verify the accuracy of the data collected against theoretical models indicates that, except for the static test, all our data are of good quality.

We are prepared to draw the following major conclusions:

- . The static survey of the system geometry, including the carriage location, is a valuable data source.
- . Survey of the static tower motion appears to be an excellent data base for cross-checking the static tension data and to validate a theoretical anchor static model.
- . Static tracking of stump motion by optical survey methods is too crude. An electronic read-out is required.
- . Static and dynamic tension measurements in a skyline system are both feasible and can be carried out with sufficient accuracy provided proper gauges - calibration techniques and signal conditioning are employed.
- . The means of collecting dynamic displacement information via accelerometers is a viable experimental technique in skyline systems. Care in signal conditioning of the data is required.

- . The static data collected on anchor tension and tower motion appear to be an excellent data base for static modeling of anchor systems.
- . The dynamic data collected on both the transverse vibration (run #122) and on the sudden load tests were an excellent information source for further understanding of skyline dynamics. In particular, the transverse vibration test provides a means for field checking the static tension. The sudden load test indicates that even under normal operating conditions a sudden impact load may occur that will cause the skyline tension to temporarily exceed breaking strength values. This shortens line life and can have adverse effects on anchoring.
- . The yarding sequence test indicated that static tensions (average) are within values predicted by theory. However, the dynamic variations in tensions with the load partially suspended were 50% of the mean tension. Skyline tensions twice the safe load can, therefore, easily be produced. The maximum dynamic loads were observed when the load went from full to partial suspension and, therefore, are dependent on the yarding speed. By reducing the yarding (load) speed at impact with the ground, these tensions could be controlled. The effect of these dynamic tensions are to shorten line life and may lead to fatigue failure of the lines, particularly where they run over small sheaves.
- . The "hang-up" test was poorly planned; however, it still promises to be a good source of data. It was found to be very similar in response to the sudden load test and hence the latter could substitute for the former.
- . In general, dynamic models can be built to predict the behavior of the system. The critical parameters – such as natural frequencies and energy damping – can be estimated. The latter was found to be very low and hence the cause of the large

dynamic excursions. Control of energy absorption is desirable to protect the skyline and yarding system. This is important when considering man-made anchors, particularly rock anchors.

5.2 Recommendations

This test series only provided a "first-cut" at the problem of cable systems anchoring, and the treatment of the collected data was limited in scope to a mere display of the significant results for further evaluation and analysis. The detailed analysis of this data base, its comparison with and modeling of the cable system still remains.

Future testing and modeling should be carried out with the following objectives in mind:

- Improve our understanding of basic tension behavior in yarding tower guyline tower systems so that means can be provided to predict the loads on natural or man-made anchors.
- Improve our understanding and ability to quantify the holding power of natural and man-made anchoring systems when loaded by cable yarding systems.
- Provide improved guidelines and techniques for guy-lining and application of anchors to yarding towers, as well as the development of means to detect the overload; or imminent failure of the skyline, guyline or anchors.

To meet these objectives, we offer the following suggested approach:

Data Analysis & Modeling

- . The static data should be further analyzed and compared with a proper catenary model of the skyline system. A reasonable means for cross-checking the data exists in that the tower deflection information from most of the runs appears good. This would validate the static guyline modeling analysis and provide the basis for formulating basic "rules of thumb" on guylining yarding towers and the employment of anchors, natural or man-made.
- . Provide, from the static models, loading ranges on typical anchoring situations for use with man-made anchors to cover the most common skyline set-ups.
- . Analysis and modeling of the transverse vibration test data to achieve better understanding of the guyline/tower dynamics and as a means of providing guides for field measurements of cable tensions.
- . Frequency analysis of the dynamic guyline data for input to test procedures of man-made anchors.
- . The "energetics" in terms of energy decay of the sudden load tests should be explored.
- . A dynamic yarding model is possible and should be employed to study the effects on the yarding sequence, with particular emphasis on predicting maximum loads in the cable and anchor systems.
- . A rational dynamic model of a stump or man-made anchor system should be designed to study the energy absorption and the decay of tension waves in the skyline/guyline system.

It should also be recognized that the tension capability of an anchoring system can be increased by interconnecting several stumps or man-made anchors. No rational modeling procedure exists to predict the tensions in the interconnecting lines, the number of stumps or anchors needed, and their placements. This appears to be an area in need of analysis and experimentation.

Future Tests

Experiments

- Insight into and quantification of the static tension capability of stumps are required. A set of comprehensive tests should be conceived and executed that provides quantitative information on the relationship between the major parameters governing the holding capability of stumps as they are loaded progressively toward failure.
- The energy absorption capability of stumps and anchors are desired. A series of simple impact tests should be carried out on a variety of anchors (natural or man-made) under several soil and moisture conditions.
- Extended testing on the yarding system in terms of the transverse vibration, yarding sequence and the sudden load stop tests are needed to increase our data base on a variety of yarding systems.

Instrumentation

Execution of the suggested tests may be carried out with our current instrumentation capability and only requiring minor modifications to the instruments. These include:

- Redesign of the static tension gauges to provide more repeatable results and to incorporate a simple technique for field calibration.
- Stump displacements should be measured directly with a simple two-axis accelerometer system mounted directly on the stump.
- A sheave mounted tension meter or similar system should be incorporated into the skyline or operating lines of the yarding system to obtain the system load input in a more direct manner (field backup via survey instruments are necessary).

REFERENCES

1. Chalupnik, J.D. and Jorgensen, J.E. "Calibration of USFS Guyline Cable Load Cells," Technical Report FE-UW-7703, Mechanical Engineering, University of Washington, October 1977.
2. Carson, W.W., et al., "Test Plan for Skyline Anchor Dynamics Testing," Technical Report FE-UW-7601, Mechanical Engineering, University of Washington, September 1976.
3. Carson, W.W., Jorgensen, J.E., and Bramwell, W.J. "ANCHOR 1: A Computer Program for Determination of the Tensions in Skyline Guywire Anchor Systems," Technical Report FE-UW-7701, College of Forest Resources, University of Washington, June 1977.
4. Bramwell, W.J., "A Computer Model for Determination of Tension in Cable Logging Guylines," MS Thesis, College of Forest Resources, University of Washington, September 1977.
5. Den Hartog, J. P. Mechanical Vibrations, McGraw-Hill, 1956.
6. Carson, W. W. "Programs for Skyline Planning." USDA For. Serv. Gen. Technical Report PNW-31, 1975. Pacific Northwest Forest & Range Exp. Station, Portland, Oregon.