UCID--19387

DE82 014867

WIRE-ROPE EMPLACEMENT OF DIAGNOSTICS SYSTEMS*

W. L. BURDEN

NUCLEAR TEST ENGINEERING DIVISION
LAWRENCE LIVERMORE NATIONAL LABORATORY

MAY 7, 1982

ABSTRACT

The study reported here was initiated to determine if, with the Cable Downhole System (CDS) currently under development, there is an advantage to using continuous wire rope to lower the emplacement package to the bottom of the hole. A baseline design using two wire ropes as well as several alternatives are discussed in this report. We have concluded that the advantages of the wire-rope emplacement system do not justify the cost of converting to such a system, especially for LLNL's maximum emplacement package weights.

INTRODUCTION

At the Nevada Test Site, the nuclear explosives package and the associated diagnostics canister are married together and lowered into a drilled hole in the ground to a depth as required to contain the effects of the detonation. These holes vary in depth from approximately 600 ft to as much as 4000 ft in some special cases, and with canister diameters that typically are from 48 in. to 96 in. The total gross weight of the emplaced system can approach 700,000 lb in some of the larger systems.

The emplacement method currently employed is to lower the diagnostics and explosives system into the hole on API-110 drill casing as used in oil field practice. These sections are available in 40 ft lengths and as these sections are joined and lowered into the hole, the signal cables are attached to and supported from the drill casing. Since the signal cables are attached to the drill casing, it is necessary to leave the drill casing in the hole during an event, and to expend the casing.

A new method of handling the signal cables is now under development that would allow the cables to be emplaced without being attached to the drill casing and with only support from the top of the hole. This would make it possible to retrieve the emplacement system, and since the present method of emplacement with the API-110 drill casing is rather time consuming and labor intensive, a proposal has been made to replace this system with a continuous-wire-rope system. The comparison of the present system with the proposed continuous-wire-rope system is made with the assumption that both systems will be retrieved and re-used after emplacement.

DISCUSSION

Two-Rope - Two-Drum System

A continuous-wire-rope system for downhole diagnostics package emplacement appears at first to have advantages over the existing API-110 casing system. Some of the advantages are:

1) Procurement, storage, quality assurance, pull-testing and transportation of the API casing would be eliminated.
2) A sub-base over the hole during emplacement would not be required.
3) Pipe handling and joint make-up with torquing during downhole operations would be eliminated.
4) Since API casing with tapered buttress threads can only be used four or five times before the threads must be recut, the expense for this operation, when the casing is to be reused, would be eliminated.
5) The wire-rope system could be slightly faster in going downhole. The time to make a joint on the casing is approximately 5 minutes. In a 2000-ft-long string with 50 joints, this amounts to 4 hours and 10 minutes apparent advantage for the wire-rope system. (Some of this time would not be realized, since on a twin-rope system, the two ropes must be tied together periodically with rigid links to prevent spinning of the canister.)
6) The wire-rope system will require less inspection time after retrieval than does the API casing, since all threads on the casing require gauging and perhaps recutting prior to any reuse.

Considering the apparent advantages, we began our analysis with the assumption that if a wire-rope downhole system is to be as useful as the present casing system, it should have at least the same load capacity. The ringer crane's load limit for emplacement is 833,000 lb, the maximum load that can be emplaced at NTS. However, realistically, the maximum load is determined by the casing capabilities. The 10.75-in. x 71.1-lb

API-110 casing has a load capability of 1,913,600 lb at yield. With the required safety factor (S.F.) of 3, the maximum load that can currently be emplaced at NTS is 637,000 lb. Therefore, this is the load we considered for a wire-rope system design.

Los Alamos National Laboratory (LANL) has some wire-rope downhole experience (Dick Reitmann, WX6) where a S.F. of 4 is used. For our design purposes, we assumed a S.F. of 4 on the breaking strength of the rope, and that two 4.25-in.-diam ropes would support the load. We then calculated the rope weights, hoisting drum requirements, torque to turn the hoisting drum, power requirements, gearing and sheave arrangement, to determine the type of machine needed to lower the canister on a wire-rope system. These calculations are presented in Appendix A, and are summarized in Tables I, II and III.

With these calculations, we established a scale for the proposed system. Although not intended to be the ultimate design for such a system, since many arrangements are possible, it does, in fact, establish that this system is large and cumbersome (see Figure 1). The special-purpose machine will weigh several hundred thousand pounds and require its own track system for mobility. Transporting the ropes alone would tax the capability of most of the trucks at the Nevada Test Site (NTS).

Our analysis further revealed several other disadvantages of the proposed system that lead us to recommend its rejection:

1) A crane or cranes would still be required to erect the diagnostics canister into a vertical position and to move it to the hole prior to the start of downhole operations and during prestemming. If the package weight exceeds the capability of the medium-range emplacement rig (400,000 lb), a ringer would be required.
2) The system is inflexible, and since the capability for emplacing with pipe would be eliminated, the breakdown of the one machine would effectively stop the testing program until the machine was repaired. The answer to this, of course, is more than one special-purpose machine at a cost of perhaps $3 million each.

3) There is apparently no real assurance based on LANL experience that fittings can really be made available that are suitable for downhole work for a 4.25-in.-diam wire rope.

4) All new procedures will be required if it becomes necessary to land the system when it is partially downhole to repair or replace equipment, for example. Landing on the ropes would be required.

5) Moving the machinery into place and set-up will be nearly as complicated as with the ringer crane.

6) Events requiring rooms will also require special landing supports in the casing.

7) Scheduling of downholes will have to be based on the availability of the downhole wire-rope system.

8) The stock hardware used at the top of the diagnostics canister would have to be modified to attach to the rope system.

9) There is no real gain in time on the downhole with the wire-rope system vs the pipe system.

10) Design and procurement of the rope system would probably take several years if done on a routine basis.

11) Emplacements would be limited to 2000 ft.

In addition to the two-wire-rope system analyzed, we also considered and rejected several alternative systems and arrangements:

a. Four ropes and drums.

b. Eight ropes and drums.

c, Multiple-part line systems.

d. Alternative materials for hoisting ropes.

Calculations for these systems, and the reasons for their rejections as practical options, are presented in Appendix B.

CONCLUSIONS

Both the present and proposed emplacement systems permit retrieval of the emplacement string after the diagnostics package is lowered using the Cable Downhole System. At first glance, a wire-rope downhole system appears to have a number of potential advantages over the existing API casing system, particularly when a casing is no longer required for supporting the signal cables. One of the initially perceived major advantages was time savings. However, our calculations and considerations of the proposed system, as well as several alternative systems studied, showed that the system would, at best, save less than one day in emplacement time. The cost of even a very basic new system would be in excess of $3 million. It would be large, heavy and would lack mobility and flexibility. Emplacements would be limited to 2000 ft. Furthermore, design and procurement of such a wire-rope system would probably take several years if done on a routine basis. The small savings in emplacement time through use of a continuous wire rope do not warrant expenditure of the time and money involved to develop a replacement to the API casing system presently used. It is therefore recommended that the continuous-wire-rope system not be pursued further.

APPENDIX A: Calculations for Continuous Wire Rope System

Two-Rope - Two-Drum System

Wire Rope Requirements

637,900 x 4 = 2,551,600 is the required breaking strength of the two wire ropes. 2,551,600/2 = 1,275,800 lb/each rope.

The largest stock 6 x 37 wire rope is listed as 3.5-in.-diam with a breaking strength of 898,000 lb in improved plow steel.[1]

$$\frac{D^2}{1,275,800} = \frac{3.5^2}{898,000} \qquad D = 4.17 \text{ in. required (say 4.25-in.-diam).}$$

Use Two 4.25-in.-diam Ropes

$\frac{4.25^2}{3.5^2} \times 898,000 = 1,324,092$ lb actual gross breaking capacity for 4.25-in.-diam rope. The listed weight for 3.5-in.-diam rope is 19 lb/ft. By proportions:

$$\frac{19}{3.5^2} = \frac{W}{4.25^2} \qquad W = 28 \text{ lb/ft/rope.}$$

The weight of the two ropes is 2 x 28 = 56 lb/ft.

If a downhole capability of 2000 ft is required, and assuming at least 10% of the rope length must remain on the hoisting drum, the total weight of each rope will be:

2200 x 28 = 61,600 lb.

[1] Machinery's Handbook, 20th Edition-Industrial Press, Inc., page 490, Table 3, 6 x 37 Wire Rope

Both ropes will weigh 2 x 61,600 = 123,200 lb, of which 2000 x 28 x 2 = 112,000 lb will be hanging from the drum. The diagnostics canister weight can then be 662,046 - 112,000 = 550,046 lb, which is a reasonable figure. Adjustment in this figure will have to be made for the tension due to bending around the hoisting drum, however. LANL presently uses two 2-1/2-in. wire ropes in sections 80 ft long to emplace their packages. Swaged on both ends of this rope with a 2000 ton press are 1035 steel fittings. The stated capacity of this combination is 300,000 lb. The cost of each 80-ft section is approximately $5000. LANL is now trying to increase the capability of this system to a stated 450,000 lb with two 3-in.-diam wire ropes. A 3-in.-diam wire rope with swaged fittings was fabricated by Armco and tested at LANL. This wire rope with swaged fittings did not achieve the design breaking strength, and a new wire rope has been designed. ZIA will swage the fittings on the new rope in the near future.

Hoisting Drums

The recommended minimum diameter for a hoisting drum with 6 x 37 wire rope is 27 times the rope diameter. 27 x 4.25 in. = 114.8 in. or 9.56 ft. The direct tension load is increased by bending a rope around a sheave per the following formula:

$$P_b = S_b A$$

where

$S_b = E\, d_w/D$ is the bending stress

$A = d^2 Q$ Q = A constant = 0.470 for wire core 6 x 37

dw = 0.045 d is the diameter of the individual strands of 6 x 37 wire rope

d is the wire-rope diameter = 4.25 in.

E is the modulus of elasticity = 12,000,000

D is the hoisting drum diameter (assumed to be 15 ft)

$dw = 0.045 \times 4.25 = 0.191$ in.

$A = 4.25^2 \times 0.470 = 8.49$ in.^{2}

$D = 15 \times 12 = 180$ in.

$S_b = 12{,}000{,}000 \times 0.191/180 = 12{,}733$ psi

$P_b = 12{,}733 \times 8.49 = 108{,}103$ lb.

This 108,103 lb must be subtracted from the breaking strength of the rope as calculated earlier. Therefore:
1,324,092 - 108,103 = 1,215,987 is the net breaking load of each rope.
1,215,989/4 = 303,997 is the working load for each rope with a S.F. of 4.
2 x 303,997 = 607,994 = total load capacity of both ropes at the top of the hole.
607,994 - 112,000 = 495,994 lb is the allowable weight of the diagnostics canister after subtracting the rope weight. This is slightly under the desired 500,000-lb capability, but is perhaps reasonable. These calculations are tabulated in Table II.

It is apparent since P_b is inversely proportional to the diameter of the hoisting drum and directly proportional to the square of the rope diameter that this factor is decreased with a smaller rope diameter and with a larger drum diameter. The 15-ft-diam drum appears to be a reasonable compromise. Structural considerations would indicate that a 36-in.-wide drum may be as wide as can be reasonably tolerated. Therefore, about eight turns of rope can be stored on the drum per layer. The length of each turn on the first layer is π (180 + 4.25) = 578.84 in. = 48.23 ft. The first layer can hold 385.9 ft of rope. It then requires about 5.5 layers of rope on the drum to hold the 2200 ft of rope. This increases the drum diameter to 180 + (2.0 x 6.0 x 4.25) = 231 in. = 19.25 ft to accommodate the rope layers.

Torque to Turn Hoisting Drum

The torque required to turn each hoisting drum at maximum load is:

$$T = F \times L = 303{,}997 \times 9.625 = 2{,}925{,}971 \text{ ft-lb}$$

If this torque is to be transmitted to the drum by a 20-in.-O.D. solid shaft, the shaft shearing stresses will be:

$$t_{max} = \frac{TC}{J}$$

$$J = \frac{\pi d^4}{32} = \frac{\pi \times 20^4}{32} = 15{,}708 \text{ in.}$$

$$t_{max} = \frac{2{,}925{,}972 \times 12 \times 10}{15{,}708} = 22{,}353 \text{ psi.}$$

This is a reasonable value, so a 20-in.-O.D. shaft is satisfactory in shear. No check will be made on bending stresses at this point.

Power Requirements

The Manitowoc ringer crane presently in use at NTS is powered by two GM-71 V-12 diesel engines--a 300 hp unit for the hoisting drum and a 200 hp unit for boom elevation, swings and track operation.

1 hp = 33,000 ft-lb/min.

300 x 33,000 = 9,900,000 ft-lb/min.

Without considering efficiencies in the system, this would allow the ringer to lower a 650,000-lb load at the following rate:

$$R = \frac{9{,}900{,}000 \text{ ft-lb/min.}}{650{,}000 \text{ lb}} = 15.23 \text{ ft/min.}$$

Obviously, since the system is not 100% efficient, the lowering rate will be something less than the above value. The power requirements for a wire-rope system will be at least as great as for the ringer crane, since the loads are the same.

Gearing

Gearing for the hoisting drum becomes a major problem as illustrated below. It is possible that some form of hydraulic motor drive system might be utilized, but, assuming the system is mechanical, the following requirements must be satisfied. A hydraulic system would be approximately 50% efficient, at best, and would require more power.

The lowering speed is approximately 15 ft/min. The drum circumference is approximately 60 ft.

$$\text{rpm}_{\text{Hoisting Drum}} = \frac{15}{60} = 0.25 \text{ rpm.}$$

The engine rpm is approximately 1200; therefore, it is necessary to have a reduction system which has a 4800:1 reduction ratio. This is not an insignificant undertaking, while still retaining some reasonable efficiency and within reasonable size constraints. A crane solves this problem admirably by having about a 20-part line, which allows the mechanical gearing system to become a more reasonable 240:1.

Table II summarizes the hoisting drum, power requirements, and gearing information.

Adjustable Sheaves

In order to allow movement of the package in the hole as the downhole operation proceeds, the hoisting ropes will have to feed off the hoisting drums and over sheaves that can be moved at least the diameter of the hole in all directions. These sheaves will be approximately 10 ft in diameter to satisfy the minimum bend radius requirements for the 4.25-in.-diam rope. Some mechanism will be required to feed the ropes onto the hoisting drum properly as these sheaves are moved relative to the hoisting drum.

All of the above is done basically to establish some scale for this proposed system and is not intended to be the design for such a system. Many arrangements are possible. It does, in fact, establish that at least this system is a rather large and cumbersome machine. It will obviously weigh several hundred thousand pounds and require its own track system for mobility. Transporting the ropes alone would tax the capability of most of the trucks at NTS.

APPENDIX B: Alternative Systems

We considered a number of alternative systems and arrangements for emplacing the diagnostics canister. The first and most obvious solution to the large rope and hoisting drum size is to increase the number of hoisting ropes, either by adding sheaves at the top of the diagnostics canister and having multiple-part lines, or by simply increasing the number of hoisting drums and ropes. Adding hoisting drums will be considered first.

a. Four Ropes and Drums

If the number of hoisting ropes is increased from the originally considered two-on-two drums to four ropes on four drums, the following occurs.

1) The rope size will be reduced from 4.25-in.-diam to 3-in.-diam if the same load capability is to be maintained. Each rope now requires a breaking strength of 637,900 lb. Each rope weighs 14 lb/ft so that the total rope weight remains constant. (Listed breaking strength of 3-in.-diam rope is 670,000 lb.)
2) If the hoisting drum is reduced in diameter to 12 ft, the stress in bending (S_b) in the wire rope is 11,250 psi and the reduction in each rope's capacity is 47,857 lb due to bending. Each wrap of rope in the first layer will be 36.75 ft long. Eight turns per layer requires a 24-in.-wide drum. Approximately seven layers will be required for 2200 ft of rope, increasing the outside diameter of the drum 42 in. The overall drum diameter is then approximately 15.5 ft.

3) The torque required to turn each drum is reduced to:

$$T = 155{,}536 \times 7.75 = 1{,}205{,}402 \text{ ft-lb}$$

and the shaft size for each drum can be reduced to 15 in. O.D. with a shearing stress of 21,828 psi.

4) The horsepower required remains essentially constant.

5) The same gearing problem exists for all practical purposes since the drum circumference is only reduced from 60 ft to 48 ft.

6) Adjustable sheaves at the top of the hole will still be required. The diameter of these sheaves can be reduced from 10 ft to approximately 7 ft; however, four sheaves will be required, or perhaps two dual sheaves could be used.

In summary, the addition of two additional ropes has reduced the size of the lifting components, but has doubled the number of these components. Control problems have been increased, especially the problem of maintaining equal tension on all ropes. Also, tying the ropes together to prevent spinning of the canister has become more complicated and would probably add to the downhole time. The only real advantage that this system might have, with the exception of the size of the components, is that it would be possible and perhaps realistic to split the machine into two machines, each with half the total capacity, and with the capability and control arrangement such that the two machines could be tied together straddling the hole to lower heavy systems. This would in effect make available two machines with a capacity at the top of the hole of 311,000 lb, or one combined machine with a capacity of 622,000 lb. This would increase the flexibility and usefulness of the system and would probably be the desired configuration. Unfortunately, this arrangement does not overcome the major disadvantages of the two-rope system to the extent necessary to justify the procurement of such a system.

b. Eight Ropes and Drums

The process of adding ropes and drums can be carried to almost any degree. However, only one more step in the process will be considered, and that is to increase the total number of drums and ropes to eight.

The effect of this change would be to reduce the wire rope's size to 2.125-in.-diam. The hoisting drums could be approximately 8.5 ft in diam and 18-in. wide. The total rope weight would essentially remain constant, as would the power requirements, and the gearing ratio would be reduced by a factor of 2.

In summary, the net effect of this change would be smaller hoisting components, but at the cost of an increase in control complexity. Splitting this machine into four dual-rope machines would not accomplish any useful purpose, since the capacity of each machine would only be 156,000 lb. This would be useful only on rare occasions, and would severely complicate the arrangement at the top of the hole for heavy emplacements. An eight-rope system does not appear to have any advantages over the four-rope system.

c. Multiple-Part Line Systems

The minimum sheave size at the top of the diagnostics canister should be less than the diameter of the canister in order to avoid having the sheave dictate the emplacement hole size. On an 86-in.-diam canister, then, the sheave could be 80-in.-diam and this would allow use of a 3-in.-diam wire rope. The breaking strength of the 3-in.-diam. rope is 670,000 lb. With a S.F. of 4, a four-part line would be required to emplace the desired load. This would require dual sheaves at the top of the canister, and we now introduce rotating sheaves as well as moving wire ropes at the top of the diagnostics canister. One leg of the rope would, of course, be moving at a velocity that is four times as great as the downhole canister velocity, or approximately 60 ft/min. The hoisting drum also must have a capacity for storing a length of rope that is four times the expected downhole depth of 2000 ft. The hoisting drum would have to have an 8200-ft capacity. The versatility of this system is limited since the minimum sheave size dictates the rope size and the sheaves for 3-in.-diam cable are so large as to preclude the use of this system on anything but an 86-in.-diam canister.

If the assumption is made that a 48-in.-diam canister must be emplaced with this system, a 40-in.-diam sheave at the top of the canister would be a reasonable choice. The maximum rope size for this sheave would be approximately 1.5-in.-diam. Wire rope of 1.5-in.-diam has a breaking strength of 176,000 lb. To obtain the desired capacity from this system, a 15-part line would be required. If a 16-part line is considered, this would be a standard ringer crane rigging setup. In effect, the traveling block of the ringer would be hooked directly to the top of the diagnostics canister and would go downhole during the emplacement. For a 2000-ft emplacement, this would require a minimum of 33,000 ft of wire rope. Storing that much rope on a single hoisting drum would not appear to be reasonably practical, so some alternative method would be required. One alternative method would be to use the hoisting drum only to develop the power for the system and with only sufficient wraps of rope to develop the friction necessary to lift the load, as on a yacht winch, and allow the tailing rope to be stored on an auxiliary reel. A tailing mechanism would have to be developed to insure that the proper friction load was always available at the hoisting drum, and to prevent inadvertent release of the load. This might be feasible with some difficulty. Another possibility would be to use a system similar to a Lucker wire-rope pulling system, which uses two gripping mechanisms in a hand-over-hand type of motion, obviously with one hand always engaged to pull the load. The units are presently available in the required capacity. However, the speed of the available system would be much too slow to be of any value. With a 16-part line at a lowering speed of 15 ft/min, the hoisting line would travel at 16 x 15 = 240 ft/min. The Lucker system's normal operating speed with 1.5-in.-diam rope is 15 ft/min, or a factor of 16 too slow. Assuming that a system could be obtained with the proper speed, the tailing rope would be stored on an auxiliary reel. If the assumption is made that this reel is 10 ft in diameter at the tread and 5-ft wide to allow transportation on a truck, each turn would accept 31.4 ft of rope, and the first layer would accept 1036 ft of rope. Approximately 30 layers would be required for the full 33,000 ft of rope, and this would add 90 in. to the tread diameter. The O.D. of this drum would be approximately 18 ft and the total rope weight would be 128,000 lb.

In summary, a system could probably be designed to use a 16-part line for a downhole emplacement system. This system would still suffer from all the disadvantages of the two-rope system with the exception of the gearing problem and the fitting problem since stock fittings are available for the 1.5-in.-diam line. In addition, the use of a traveling block downhole introduces moving wire ropes into the system, all of which are moving at different velocities up to a maximum of 240 ft/min. Contact of signal cables with these wire ropes would undoubtedly create damage in the signal cables. Also, the volume required for the 16 wire ropes would of necessity be significantly greater than that required for alternative systems, and in a small hole would be a significant percentage of the total hole volume. The length of the wire rope and the transportation and inspection of over 6 miles of this rope is a greater problem than the transportation and inspection of the API casing. All this leads to the conclusion that this course should not be pursued further.

d. Alternative Materials for Hoisting Ropes

There are materials available today from which lighter and perhaps stronger ropes might be fabricated, such as nylon, Kevlar, carbon fibers, etc. Until the basic disadvantages inherent in a rope system can be overcome, no great amount of effort should be expended in pursuing these alternatives.

TABLE I

Maximum Load Ratings for a Two-Rope System

	Max. Load (lb)	Safety Factor	Comments
Ringer crane	833,000	--	Max. load = 5/6 x rated load of crane (Manitowoc ringer crane is rated at 1,000,000 lb)
10.75 in. x 71.1 lb API 110 casing	637,900	3	Safety factor is based on yield strength
4.25-in.-diam wire rope	331,000	4	-Safety factor is based on breaking strength -The largest stock rope is 3.5-in.-diam
Max. emplacement package weight with two 4.25-in.-diam ropes	496,000 (2 ropes)	4	-Two ropes are used for emplacement -See Table II for calculation of load for one rope

TABLE II

Maximum Weight Of Emplacement Package For A 2000-Foot Depth Of Burial

	Force (lb)
Breaking load on each rope	1,324,100
Tension in rope due to bending 4.25-in.-diam rope over a 15-ft-diam drum	-108,100
	1,216,000
Working load on each rope with a safety factor of 4	304,000
Weight of 2200 ft of rope	-56,000
Working load at bottom of rope	248,000
Total allowable weight of emplacement package with two ropes	496,000

TABLE III

Sizing of the Equipment to Handle the 4.25-in.-diam Wire Rope

Hoisting drum diameter	20 ft
Shaft diameter for drum	20 in.
Power required to drive the drum	300 hp (taken to be the same as the ringer crane)
Gear reduction required to lower the emplacement package at 15 ft/min with a diesel engine (1200 rpm)	4800:1

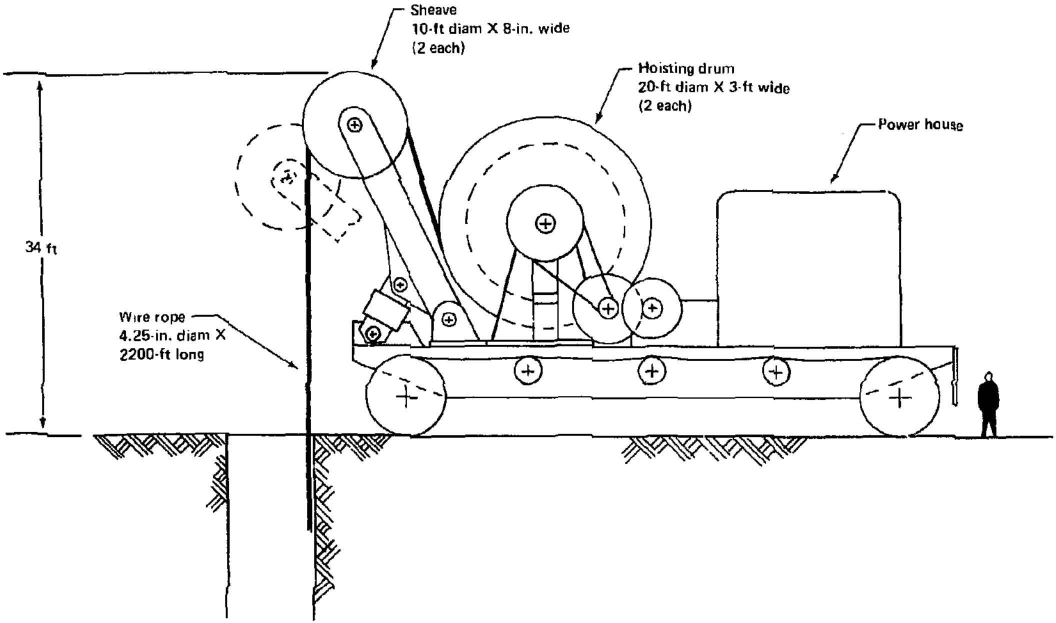

Figure 1. Conceptual Design of Two-Rope System