Available Robotics Technology for Applications in Heavy Industry

James S. Albus, Nicholas G. Dagalakis, Ben-Li Wang
Joseph Unger, James D. Lee, Charles W. Yancey

National Bureau of Standards
Gaithersburg, MD 20899

ABSTRACT

The need for automation and the use of robots in the heavy construction industry and large scale assembly is examined. Some problems relating to the operation of cranes, like low load stiffness to rotation in all directions and translation in the horizontal plane, lateral translation load outfitting, etc., are discussed. The effect of these properties on the operation of robots suspended from cranes is considered.

A new crane payload suspension mechanism consisting of six wireropes properly oriented in three dimensional space is described. Several examples of the use of this mechanism for the suspension of robot manipulators from overhead, gantry, and boom cranes are presented.

An 1/10 and1/1 scale size models of a robot crane with lateral translation load outfitting capability, which utilize this suspension mechanism, were built and are described in this paper. The stiffness of the manipulator to side loads and moments was studied. Stiffness measurement tests were conducted using the small size laboratory model. The results of these tests for various external loads, heights, and payloads are given.

INTRODUCTION

The U.S. manufacturing industry has seen a tremendous growth in the use of robots with more than 20,000 units installed, most of them in the automotive or automotive-related industries [U.S. Dept. of Commerce, 1987]. Amidst this astounding technological development the application of robots in the heavy construction industry and large scale assembly, is virtually non-existent in the U.S. The reasons for that delay are probably due to the more complex and unconstrained environment of the construction site as compared to the relatively constrained environment of the factory. For example in the case of the shipbuilding construction industry the reasons for the lack of automation and the use of robotics can be attributed to the fact that this is an order made industry, requiring great precision in the construction of components and blocks as well as requiring an enormous number of structural members and machines most of which are heavy and bulky. Construction, being labor intensive, is becoming more expensive every year while robotic automation is becoming less expensive and more capable every year. Perhaps the time has come for the two technologies to intersect and to help each other enhance their cost competitiveness and productivity.

The need for improved automation and productivity of the construction industry was the subject of a workshop co-sponsored by the National Bureau of Standards [Evans, J.M., 1985], which reported on the needs and priorities for future research on this subject. The workshop concluded that the key for this improvement in automation and productivity is the application of computers to data management and process control both off-site for design and planning and on-site for inventory management, production control and creation of an as-built data base. The achievement of this new technology would require the integration of systems for measurement and automated control of on-site construction and assembly tasks. According to the consensus of the attendees the following problems need to be attacked. System integration and standardization for on-site use, standardization of labeling, real time measurement and better machine control technology for lifting and material handling machines. The design of more productive lifting and material handling machines is the subject of this work.

The development of robots specially designed for construction and heavy industry applications is advancing rapidly in Japan. In reference [Albus, J.S., 1986] the Japanese progress in robotics for construction is reported. This report was based on visits to six of Japan's largest construction companies, a university and a robotics research association and provides a unique glimpse of the Japanese research and development effort in that field. Perhaps the most important finding, mentioned in this report, is that all the major Japanese construction companies have large research budgets and impressive in-house research staff. These companies compete aggressively with each other, including the application of robotics in construction. As a result of that effort these Japanese companies and Waseda University have developed robots for concrete placement and finishing, for positioning steel reinforcing bars, for spraying fireproofing material, for automatically assembling tunnel linings, for automatic removing and placing nuclear reactors control and fuel rods, etc. It seems possible that within the next decade Japanese construction robots may begin to dominate world markets much the same as Japanese automobiles and machine tools do today.

In shipbuilding construction robotics the Japanese have taken the lead too. The Japanese Shipbuilding Society started a five-year research and development plan of "Modernization of

Production Technology in Japan" in 1982 [Kubo, M., 1987]. The program is sponsored by a consortium of seven major Japanese shipbuilders, and funded by the Japan Foundation for Shipbuilding Advancement. As a result of this effort prototypes of large size gantry type robots for welding, surface preparation and painting of ship structures have been built by Ishikawajima-Harima Heavy Industries Co. and are now being tested by Sumitomo Heavy Industries, Ltd.

One significant part of heavy construction activity involves handling, lifting, positioning and assembling of large and small components and machinery. These operations are not only labor intensive but dangerous and tiring too. For example, end load outfitting involves transfer of loads from a crane to hand rigging equipment. Lateral translation of the load usually involves additional transfers or trolleys running on rails temporarily attached to the structure. Installation and operation of hand rigging equipment is heavy labor intensive work and each load transfer is a potentially very dangerous evolution. Many construction system components must be landed on foundation or inserted with precise lateral position orientation and declivity. Additional rigging, tag lines and contact forces applied by rigging personnel are used to make these landings. Hands and feet in way of the lift are in danger of being crushed by slack loads suddenly seating. Often final alignment must be made with jack screws, wedges and gibs.

Currently, ordinary cranes used for handling, lifting, positioning and assembling of large and small components and machinery are stable only in the vertical direction. The load is free to rotate in all directions and sway in the horizontal plane under the slightest side pressure like a pendulum does. Under these conditions it would be very difficult for the crane to support any robotic operations due to the excessive compliance of its end effector. Automatic crane antisway control devices have been proposed and tested by several people [Kogure, H. et. al., 1978, Carbon, L., 1976, Gercke, U.S. Patent No. 2,916,162]. Although these devices tend to suppress the pendulum motions in the horizontal directions they fail to suppress any pitch,roll or yaw rotations of the load. Other systems have been developed which try to solve the sway problem by employing several wires and winches [Noly, U.S. Patent No. 4,350,254]. These systems add considerable complexity and cost to the load handling system and have not found practical application thusfar.

Conventional design type robots, could probably be used as heavy industry and construction cranes, but they would probably be impractical for handling heavy loads. Considering the low payload to manipulator arm weight ratio of these robots they would have to be constructed of gigantic dimensions, occupy a large area of the ground, and consume large amounts of power.

In this paper we propose a new crane design, which despite its simplicity, results in a very stiff load platform which can be used as a robot base or end effector for heavy loads. A small size and a large size model of the proposed crane was constructed and its load stiffness to external loads was measured.

THE PROPOSED CRANE SUSPENTION MECHANISM

Because of the requirements for a crane load platform which are to provide superior stiffness to load roll and sway, a large work volume but not to occupy any significant floor space and to have a reasonable size, the suspension mechanism concept shown in Figure 1 is proposed. It consists of an equilateral triangular platform which will be suspended by six wireropes, two at each vertex of the triangle, from an overhead carriage. The carriage can be attached to either an overhead or a boom crane (see Figures 2 and 3) depending on the application. The carriage includes a single winch onto which all six wireropes attach as shown in Figure 4, and rope guides which guide the six wireropes away from the winch in three pairs equidistantly spaced. If it is desired it is possible to adjust the length of the individual wireropes with actuators which are mounted between the carriage and the guides. Adjusting the length of the wireropes will result in a change of the position and orientation of the suspended platform and the rope tensions [Albus, J.S., 1987].

The six wireropes suspended platform behaves as if the six wireropes were an extensible single solid beam with a spring constant dependent on the weight of the load and the height of the crane for a given geometry and wireropes. This is a significant improvement in stiffness over a conventional crane and it enables the load to be accurately positioned and provides a stable platform which can be used to exert torques and side forces on objects being positioned. The suspended platform can be used as a stabilized base for the direct mounting of conventional manipulator arms or it can be used for the suspension of special substructures for specific crane applications. Figures 3 and 5 show examples of the possible use of the platform as a manipulator base. In the case of Figure 5 the combination of the crane and manipulator arm allow for the stable transport and positioning of difficult loads. To extend the reach inside closed spaces a subplatform load handling mechanism, like the one shown in Figure 6 for a gantry bridge robot crane, can be used which will make possible end load outfitting of modules and precision handling of system components with improved productivity and personnel safety. To balance the load a counter weight will have to be used. This counter-balance weight will have to be mobile in order to make possible the loading and unloading of various loads. Figure 7 shows a possible design of that mechanism. To pass through narrow openings and to reach inside closed spaces a folding

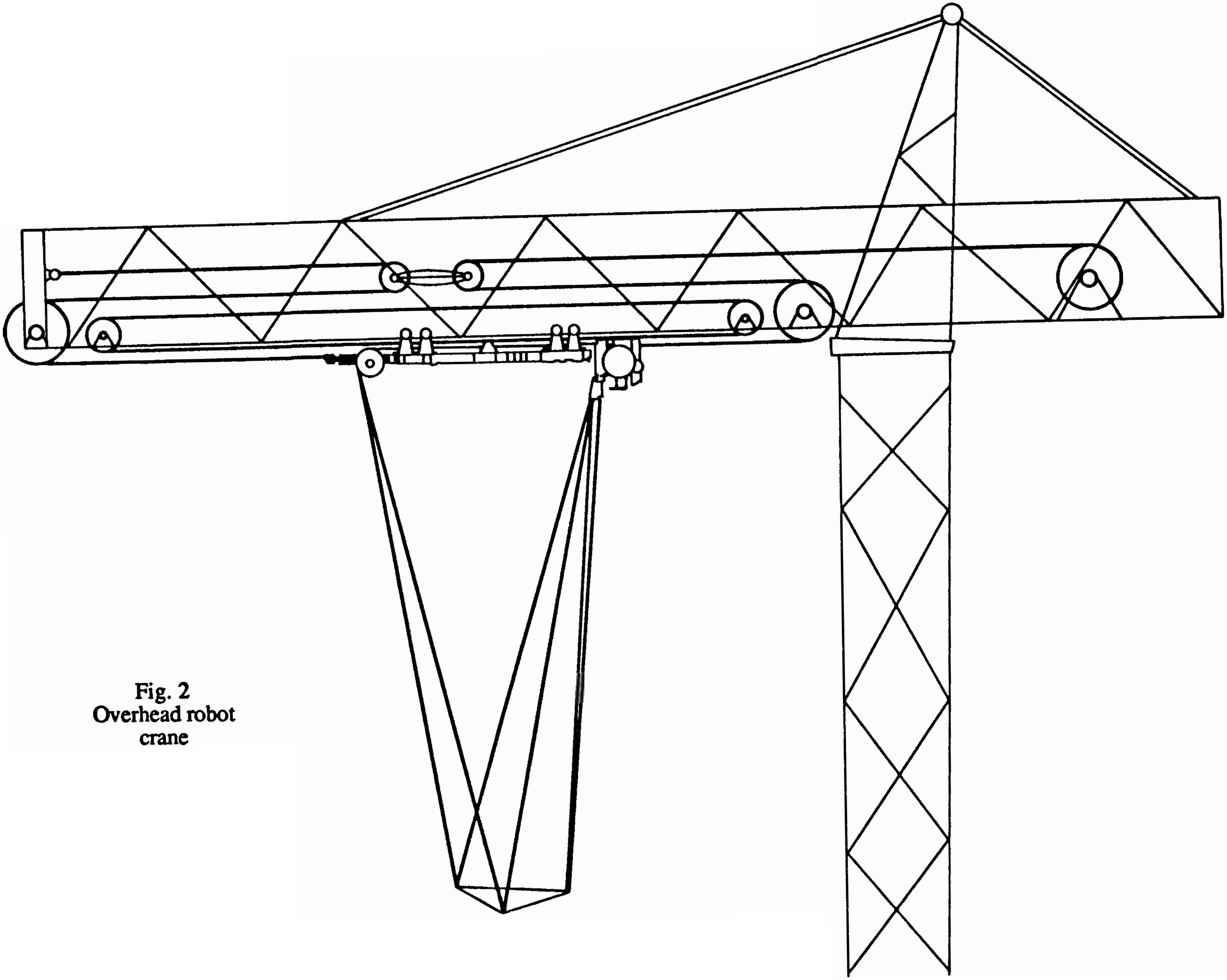


Fig. 2
Overhead robot
crane

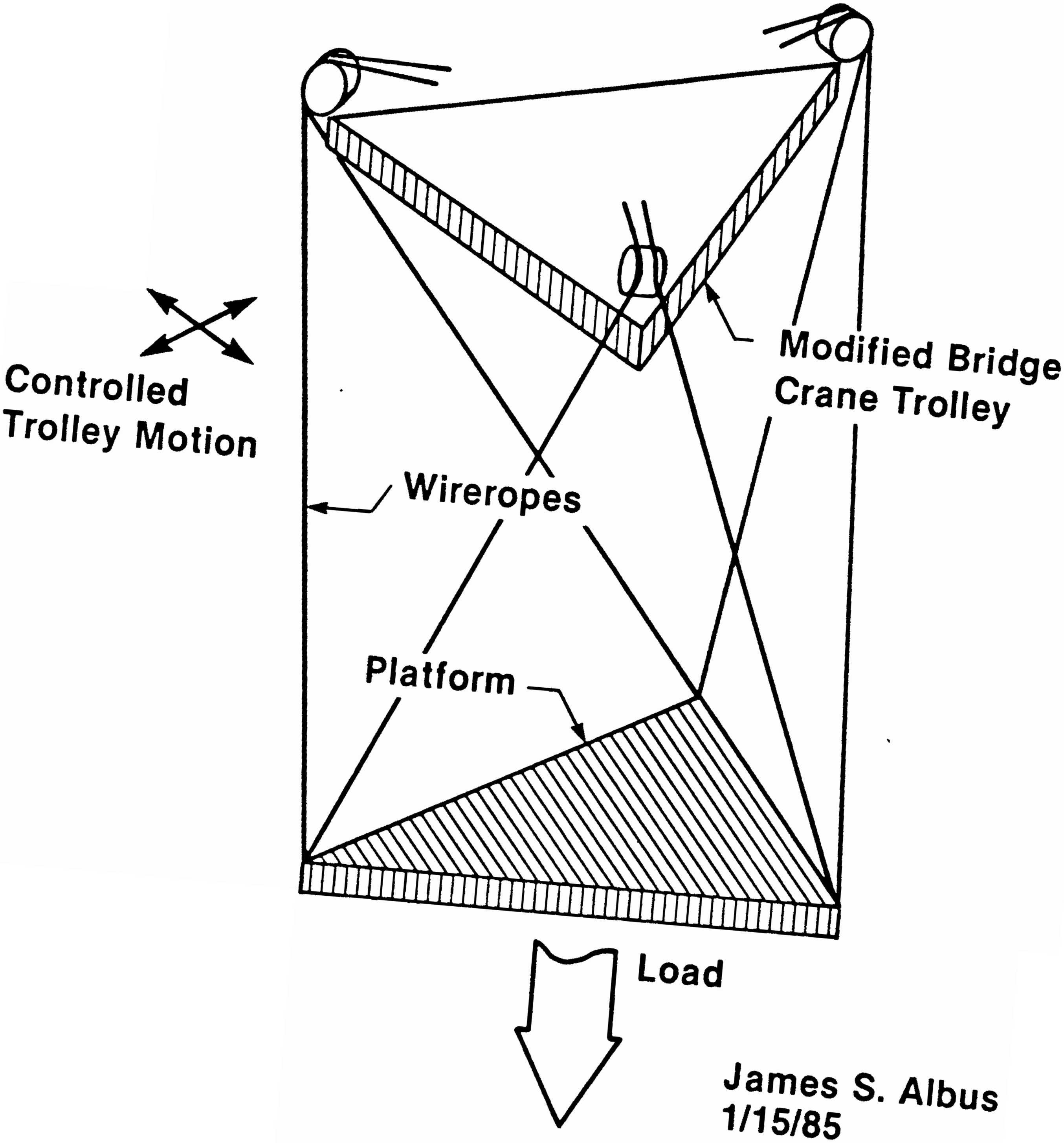
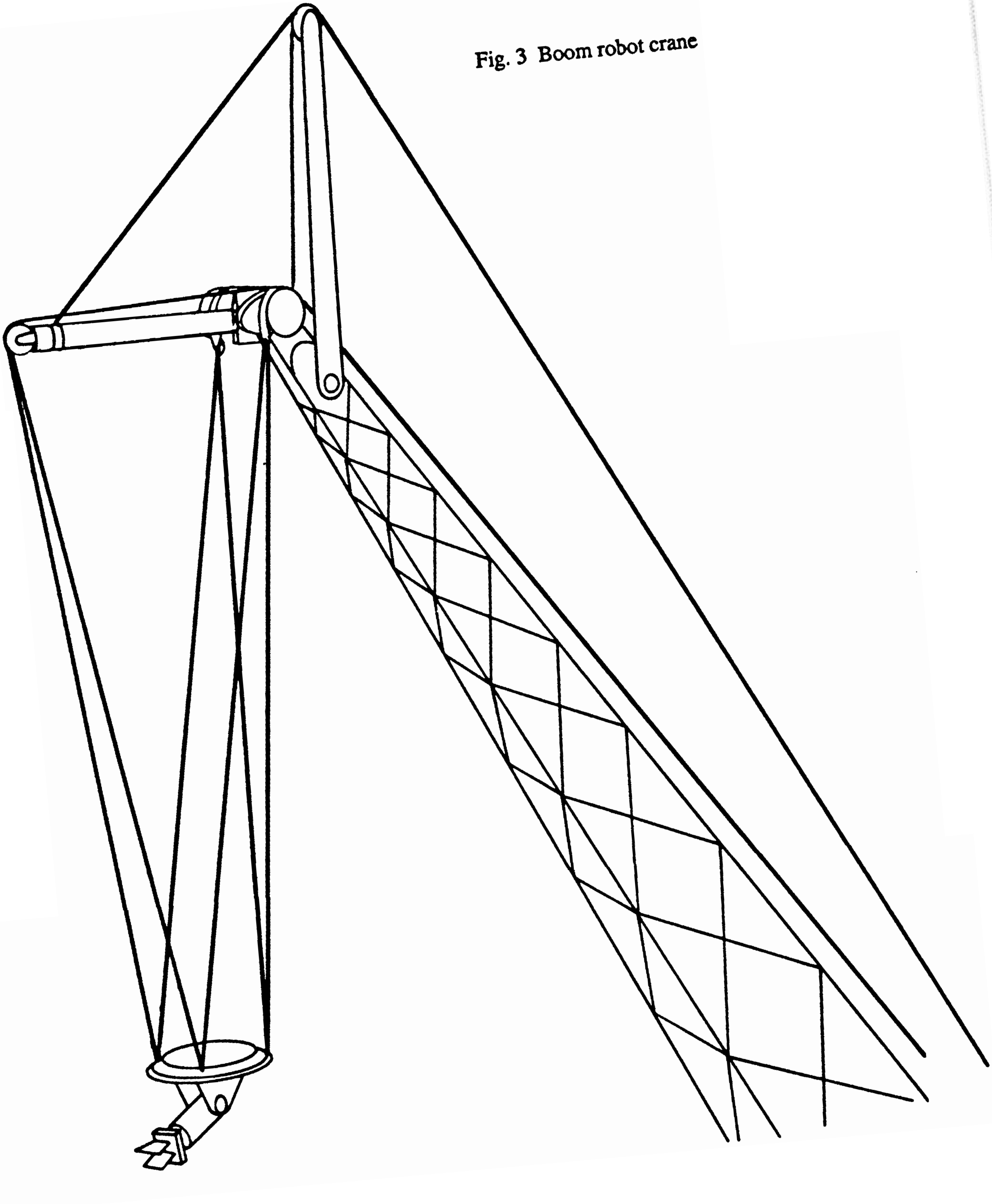


Fig. 1 Mechanism concept

Fig. 3 Boom robot crane



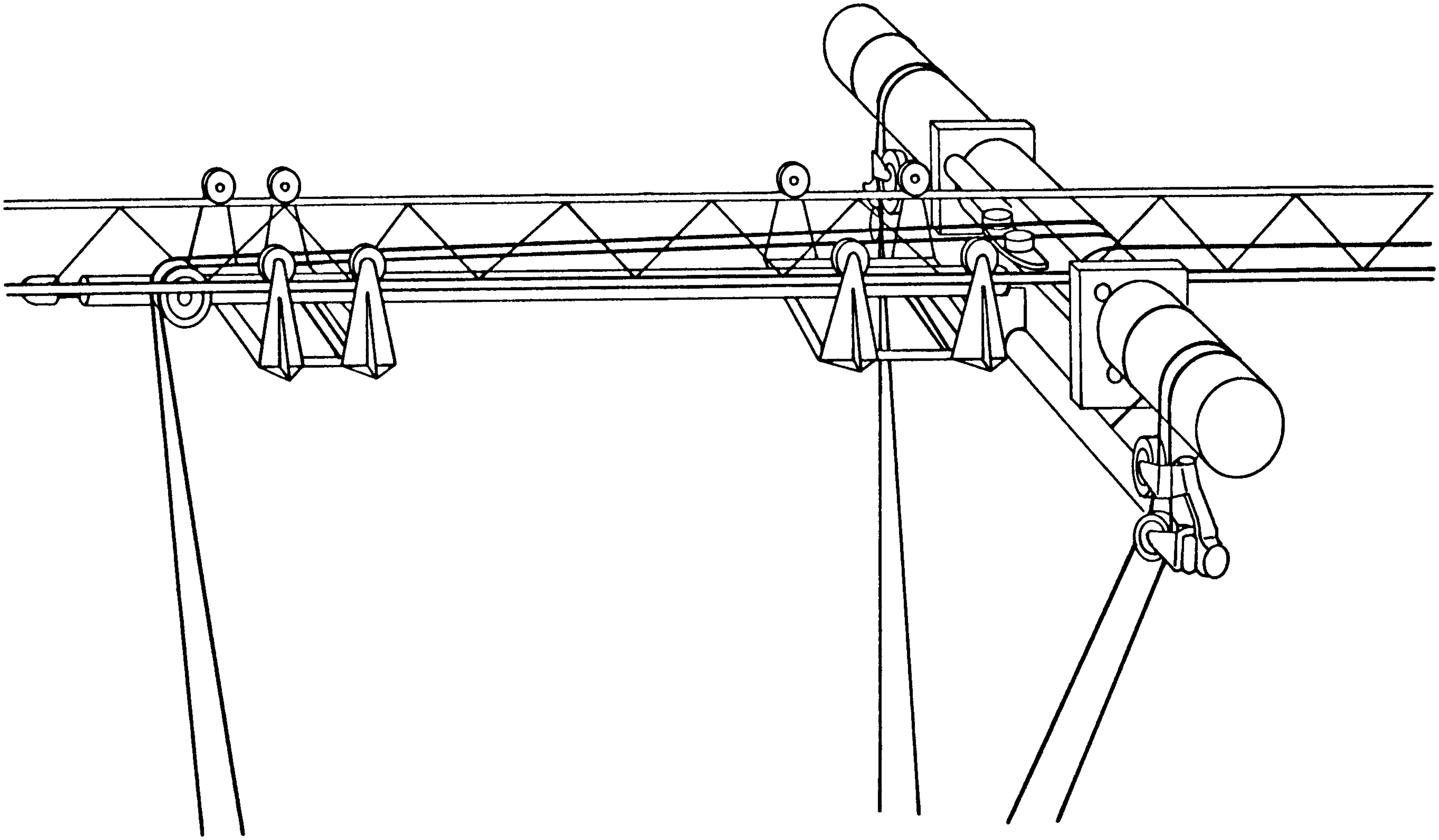


Fig.4 Cable suspension carriage with winch

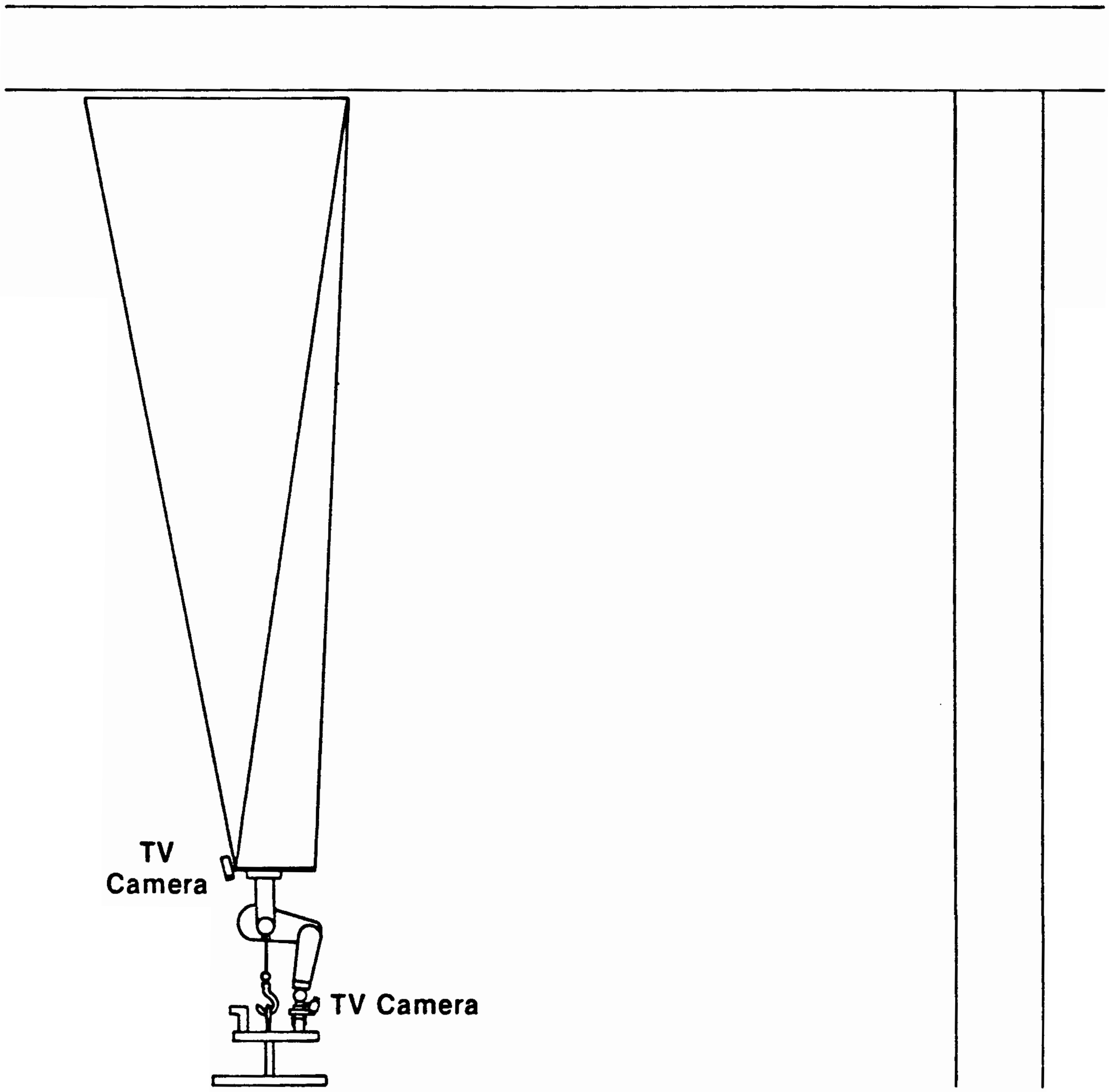


Fig. 5 Crane and robot manipulator combination

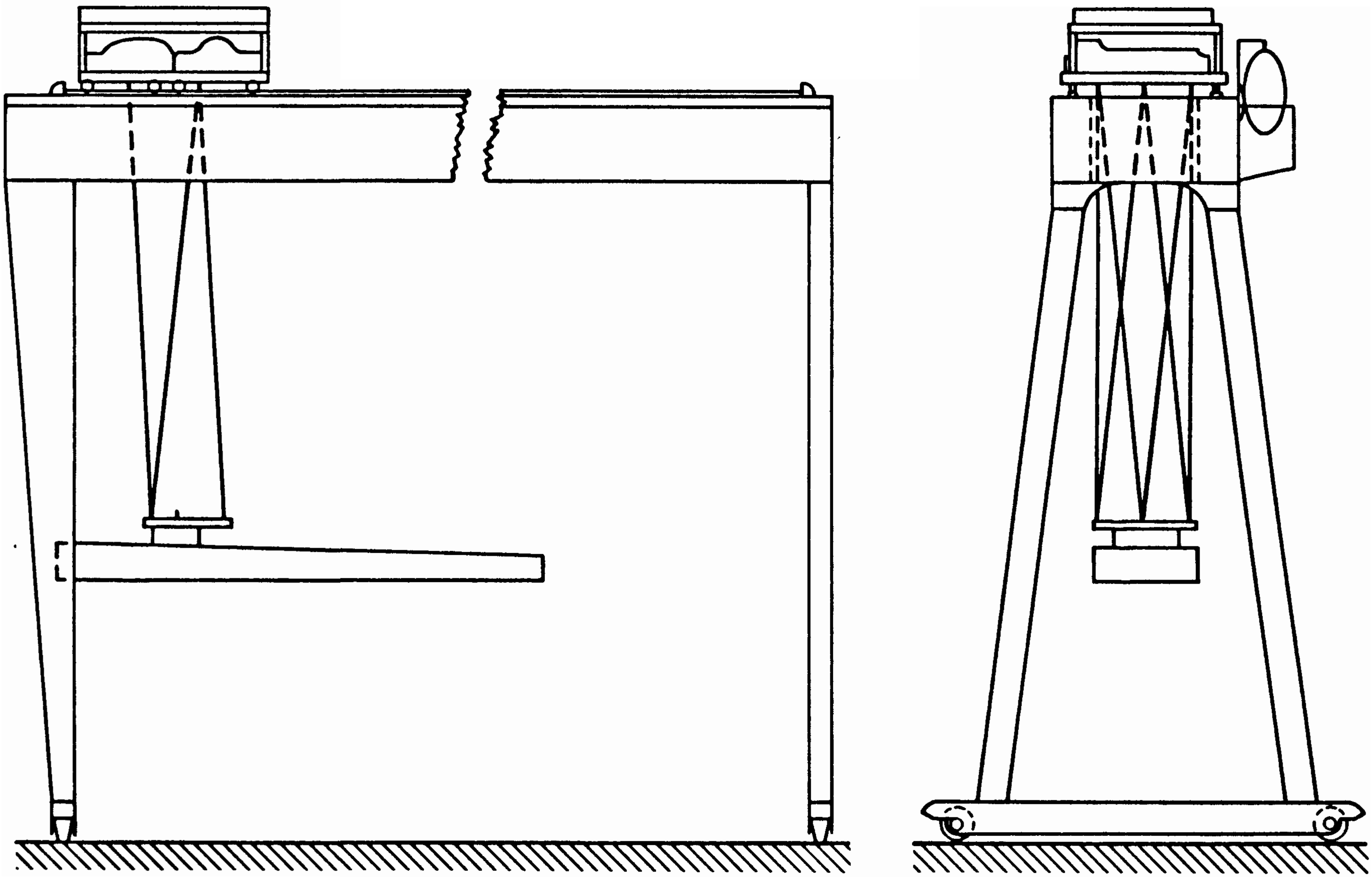


Fig. 6 Gantry bridge robot crane with extended reach

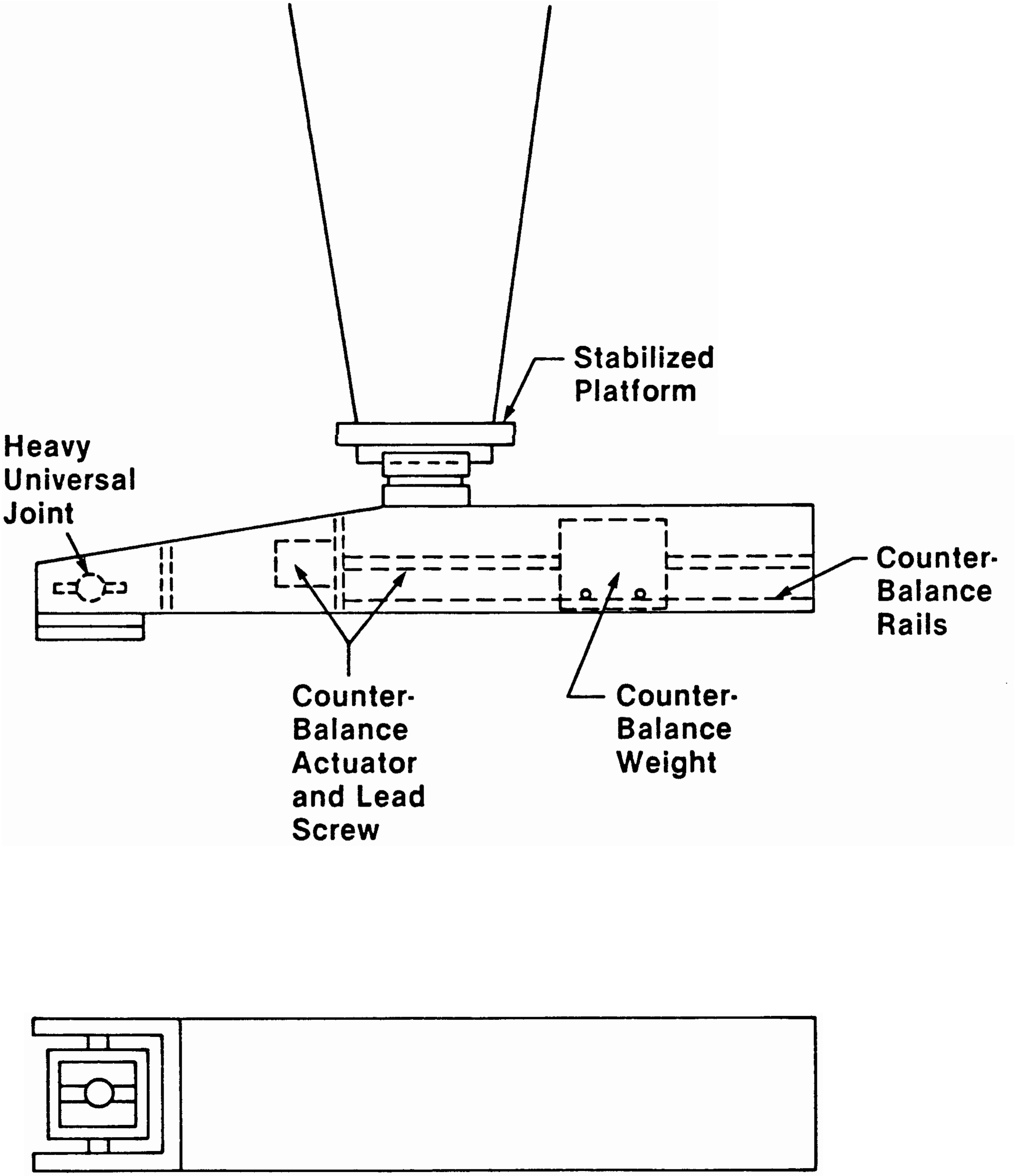


Fig. 7 Subplatform structure with counter-balance weight

subplatform mechanism like the one shown in Figure 8 can be used. Once inside the space it can unfold to cover the desired inner space volume.

The Figure 1 proposed robot crane platform suspension mechanism imitates the behavior of a parallel link manipulator arm. The arm mechanism is called that because the links are positioned side by side, "approximately" parallel to each other and each link serves a role "approximately" equal to that of its neighbor. This is different than the design of the more common serial link manipulators built of a chain of links connected end to end in a serial manner. Parallel link manipulators are in general known for the simplicity of their mechanical design, and their high strength and stiffness-to-weight ratios, because their actuators bear no moment loads but act in simple tension or compression. They are also known for their high force and moment capacity, since their actuators act all in parallel. Such manipulators with solid adjustable length beams in the place of the wireropes were first used for the design of tyre test machines [Gough, V.E. et.al., 1957, 1962], later they were used for the design of flight simulators [Stewart, D., 1965]. With the increasing interest in robotic arm manipulators, studies have been conducted for their use as mechanical wrists [Bennett, W.M., 1968], compliant devices [McCallion, H., at.al., 1979], force/moment or position sensors [Koliskor, A.S., 1982], robot arms [Fichter, E.F., et.al., 1980, 1984, 1987, Powell, I.L., 1982, Landsberger, S.E., et.al., 1985, Sheridan, T.B., 1986, Konstantinov, M.S., et.al., 1985], and industrial manipulators for assembly [Gadfly, 1983] and for grinding[Multicraft, 1987].

The design discussed in this paper is taking advantage of the suspended crane load to maintain the wireropes extended and thus form six flexible wires which, with their elastic deformation, oppose any displacement of the payload. The stiffness created by this elastic deformation is superimposed to the pendulum effect created stiffness of ordinary cranes. Although individual rope length control of the position and orientation of the platform is possible, it is probably difficult for the length of the wires considered here, it is probably energy consuming for the payloads considered, and it is probably not necessary if the responsibility for the manipulation control is placed on the end-effector device which will be suspended from the platform.

SUSPENSION MECHANISM MODELS

A small model of the proposed robot crane suspension mechanism was constructed. The model consisted of two Aluminum triangular plates, like the ones shown in Figure 1, of equal side length a = b = 114.3 mm (4.5"). The lower platform was suspended by six steel wires of 1.08 mm (0.042") diameter. The height h, which ranged from 3 to 4.5 feet, and the suspended weight W,

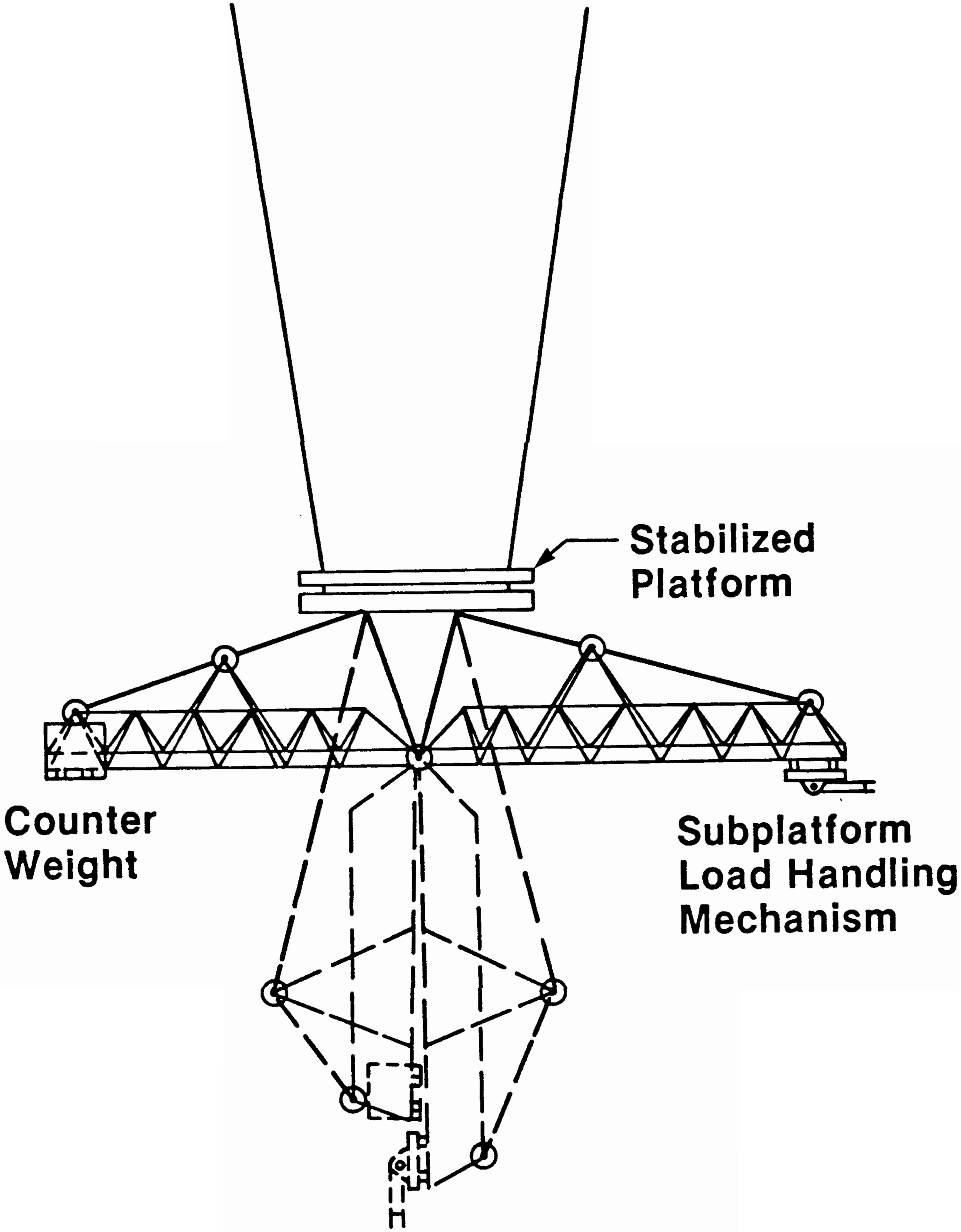


Fig.8 Schematic of a folding subplatform mechanism

which ranged from 100 to 350 lbs, varied depending on the test conditions. During testing external loads (force or moment) of various amplitudes and orientations were applied through a multiaxis load-cell. The resulting displacement in the direction of load application was measured with a Linear Voltage Differential Transducer (LVDT).

A prototype size model of the crane suspension mechanism with a lateral translation end load outfitting subplatform structure, similar to the one shown in Figure 6 was also built. Figure 9 shows a schematic drawing of that model. It consists of a support frame mounted on the concrete reaction wall of a seismic test facility and two I beams connected at a 90 degrees angle. These two beams are suspended by six wires from the support frame at approximately 30 feet height and form the model of the lower platform and the subplatform structure. Each wire is connected to these beams through a load-cell for monitoring its tension and a turn-buckle for adjusting its length. The load,which was taken to be approximately 5,000 lbs and the counter balance weight, which was taken to be 10,000 lbs, are simulated by lead bricks placed in two baskets which hang from the two ends of the long boom beam (not shown in Figure 9). This model is now being instrumented and will be used in the future for testing.

EXPERIMENTAL TEST RESULTS

The test results which are reported here involved the application of a single external force on the lower platform of the small model crane in the horizontal direction, passing through its center of gravity. The amplitude of the force, the length of the model crane wires l_0, and the total supported weight W were varied. Figure 10 shows the external force versus the resulting displacement plot from the experimental test data for a certain wire length l_0 and total suspended weight W combination. As can be seen from that Figure for the range of external forces used in this test the relationship between force and displacement is close to linear. The slope of that line corresponds to the stiffness of the crane suspension system to horizontal external forces.

For comparison purposes, the external force versus the resulting displacement of a single wire pendulum mathematical model with 1/6 the suspended weight W was also plotted, shown by the dashed line of Figure 10. It is obvious that a crane constructed that way would have a fraction of the stiffness of the proposed robot crane to horizontal external forces.

Figure 11 shows the results of a similar test for a lighter suspended weight W. As can be seen for lighter weights the stiffness of the crane to horizontal external forces decreases.

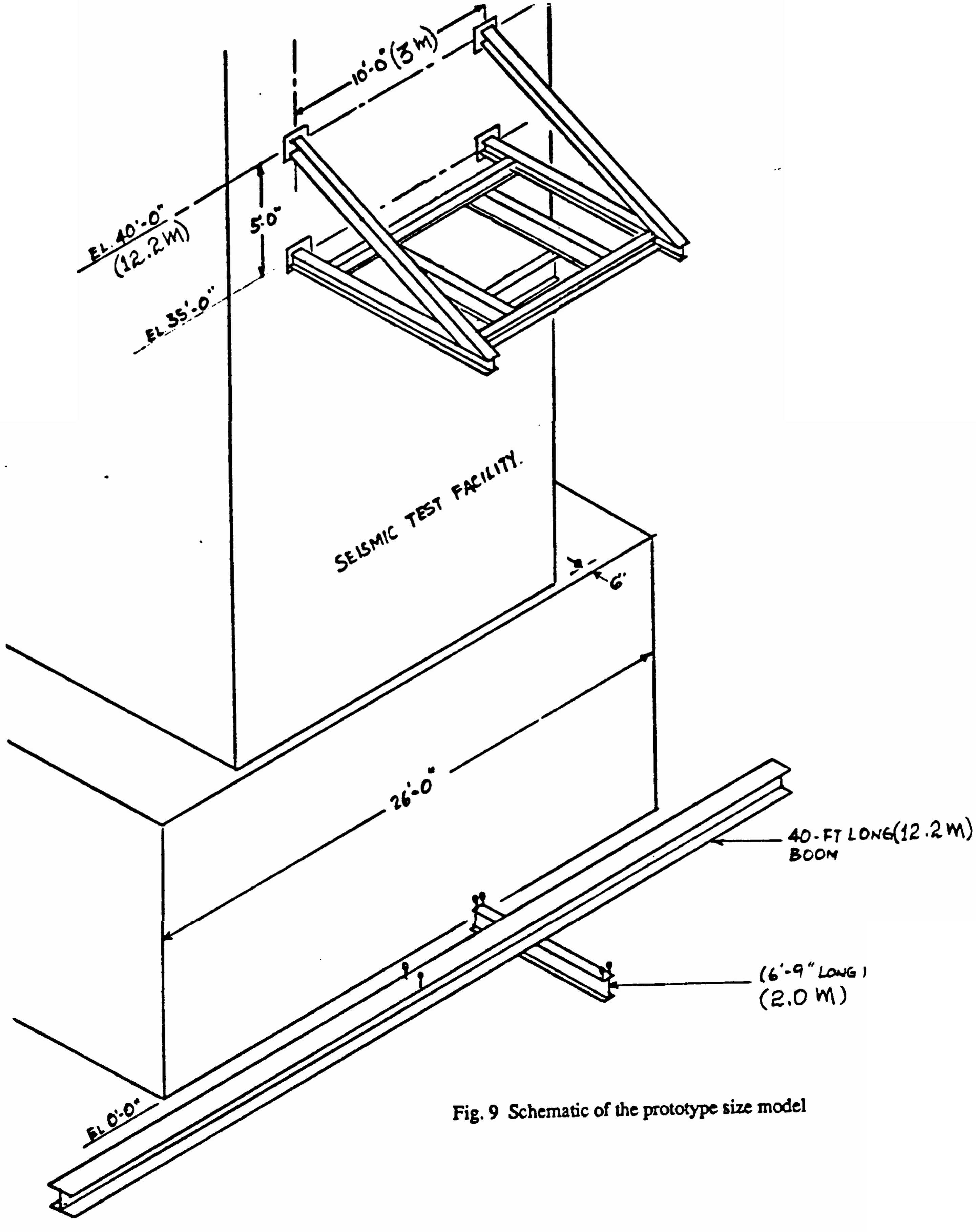
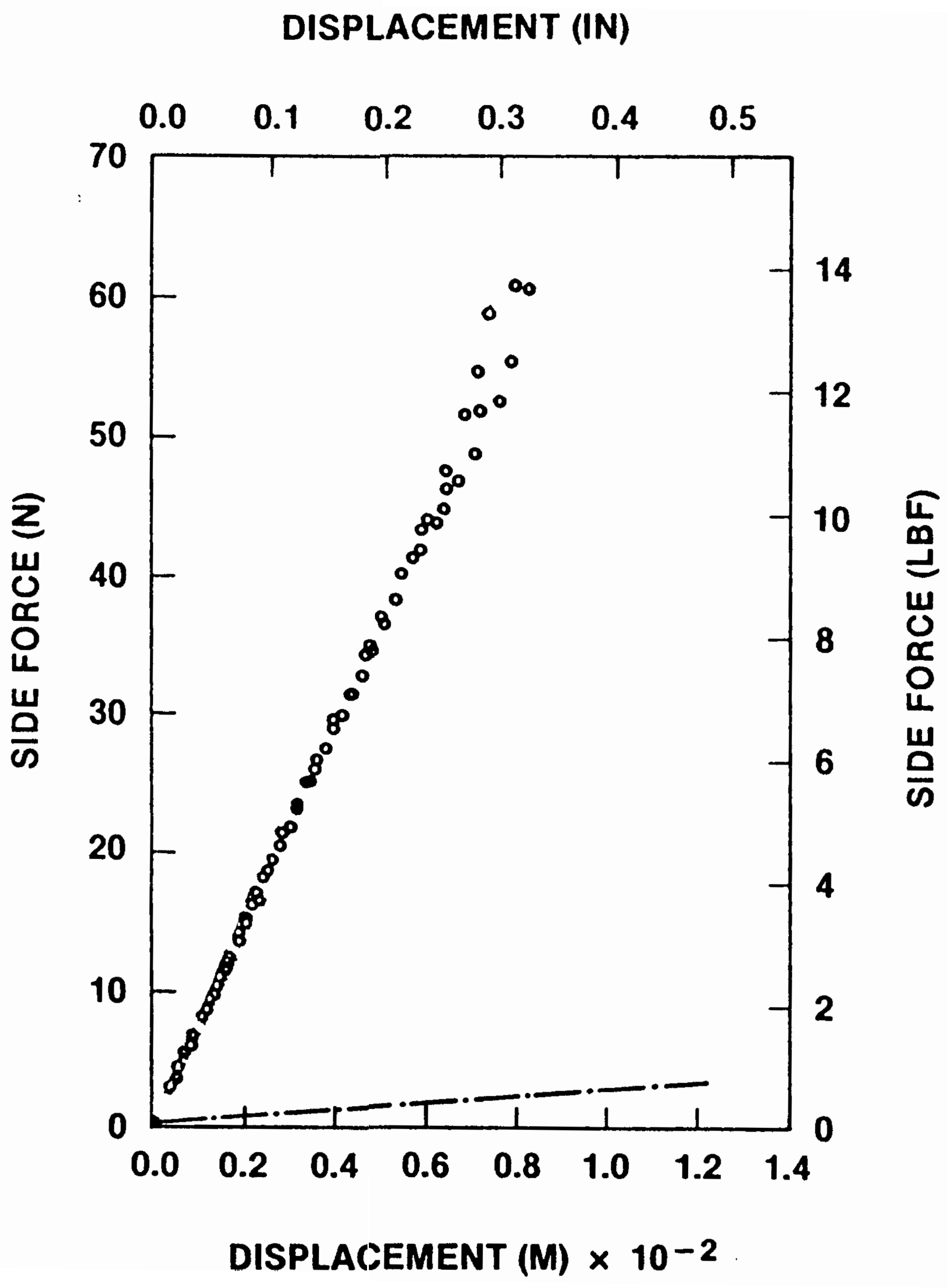
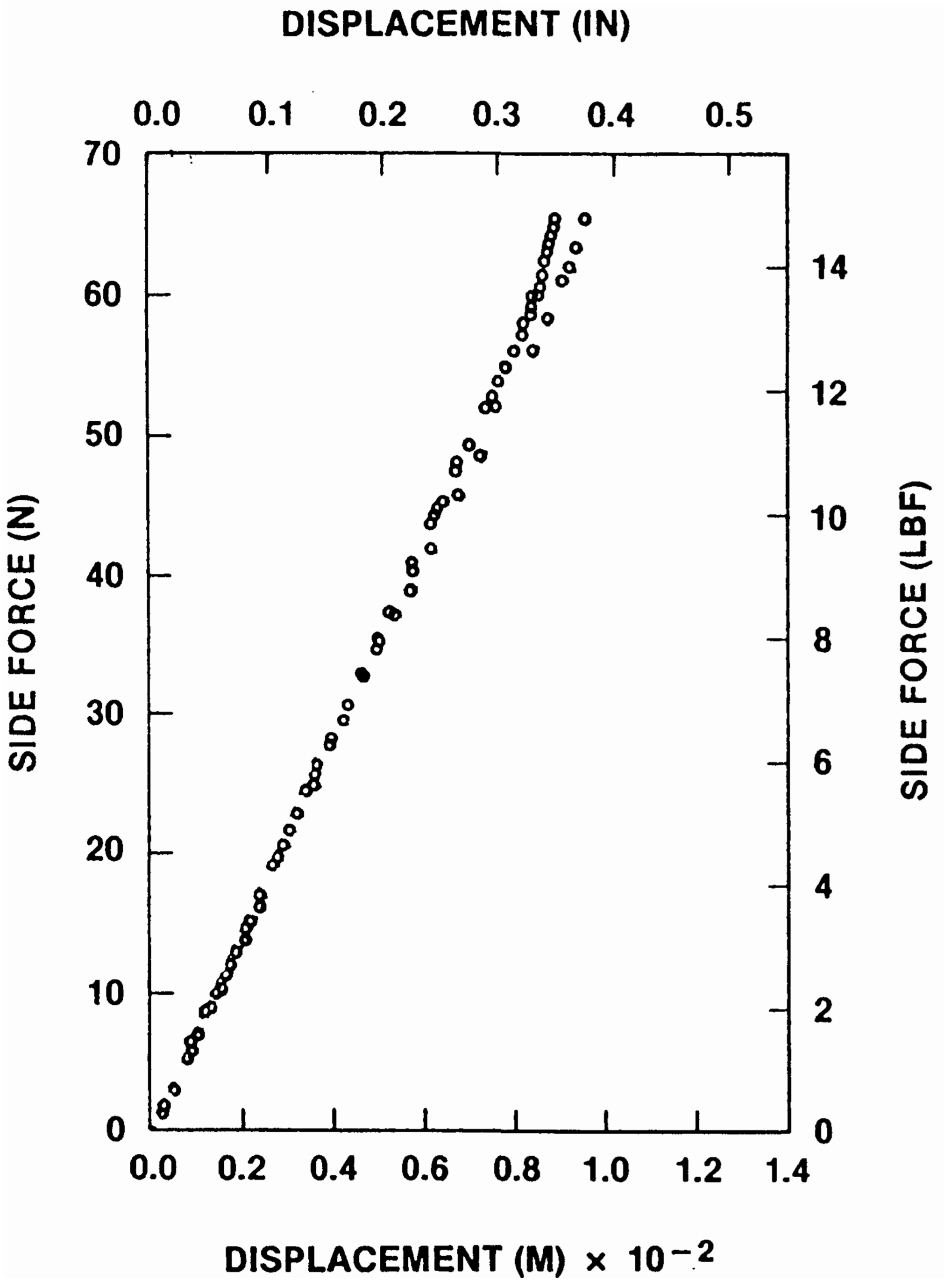


Fig. 9 Schematic of the prototype size model



Wire Length $\ell_o = 1.039$M (40.93 in)
Suspended Weight (Force) W = 1494N (336 LBF)

Fig.10 Experimental testing results



Wire Length $\ell_o = 1.039$M (40.93 In)
Suspended Weight (Force) W = 1027N (231 LBF)

Fig. 11 Experimental testing results

Figures 12 and 13 show the same external force versus the resulting displacement plots for the same suspended weights W but longer wire length l_0. Comparing these Figures with Figures 10 and 11 shows a significant decrease of crane stiffness to horizontal external forces as a result of the increase in the wire length.

A mathematical model of the proposed crane suspension system is now under development. Future publications will report on how well it can predict the experimental results.

CONCLUSIONS

A new crane platform suspension mechanism has been proposed and several examples of its use for the design of robot cranes were discussed.

A decrease in the suspended weight causes a decrease of the stiffness of the proposed crane mechanism design. An increase in the wire length causes a significant decrease in stiffness.

The stiffness of the proposed robot crane mechanism is significantly higher than the equivalent conventional single wire crane.

Of course these conclusions apply only for the selected crane design of the two equilateral triangles and six wireropes shown in Figure 1.

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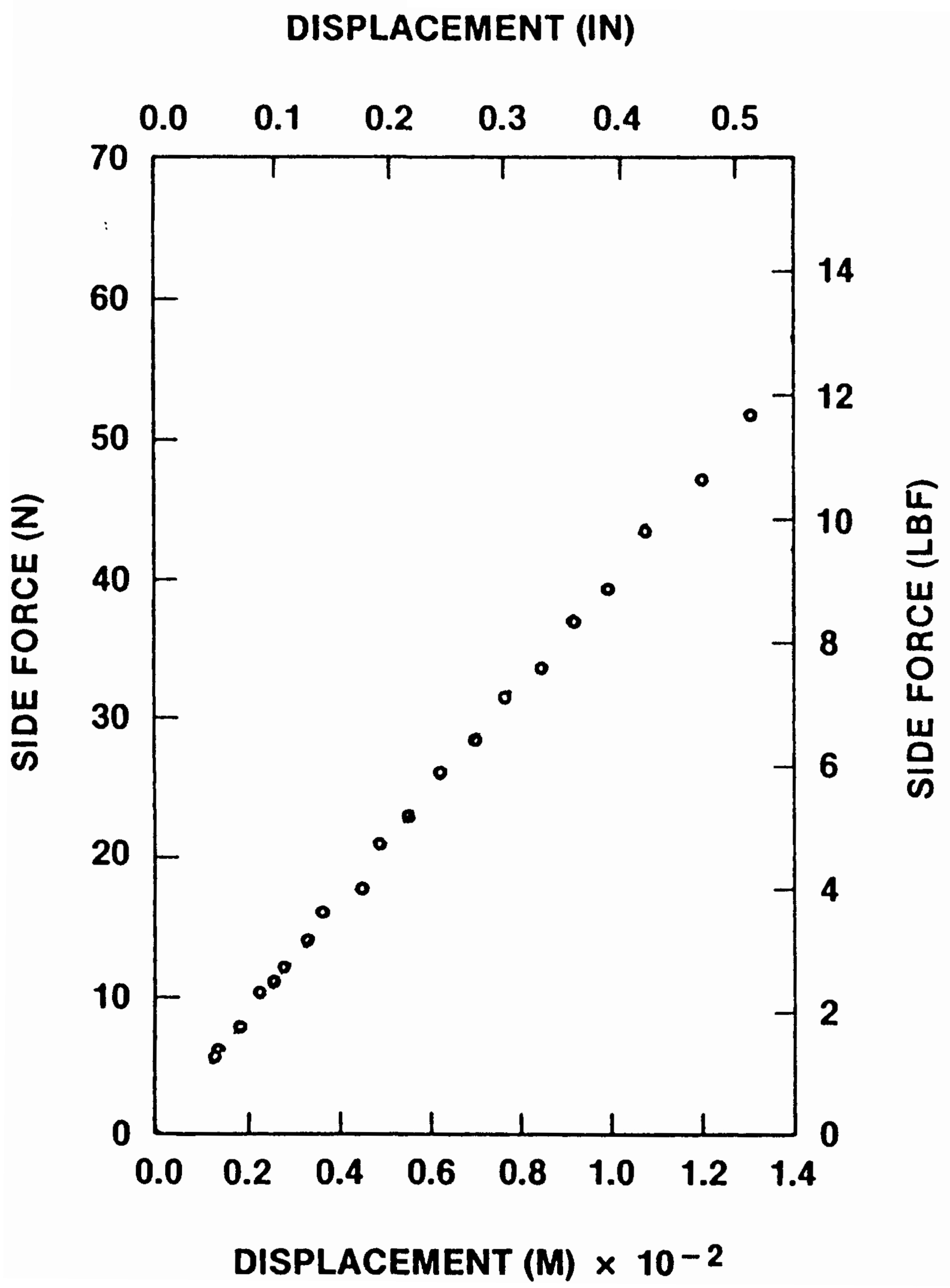
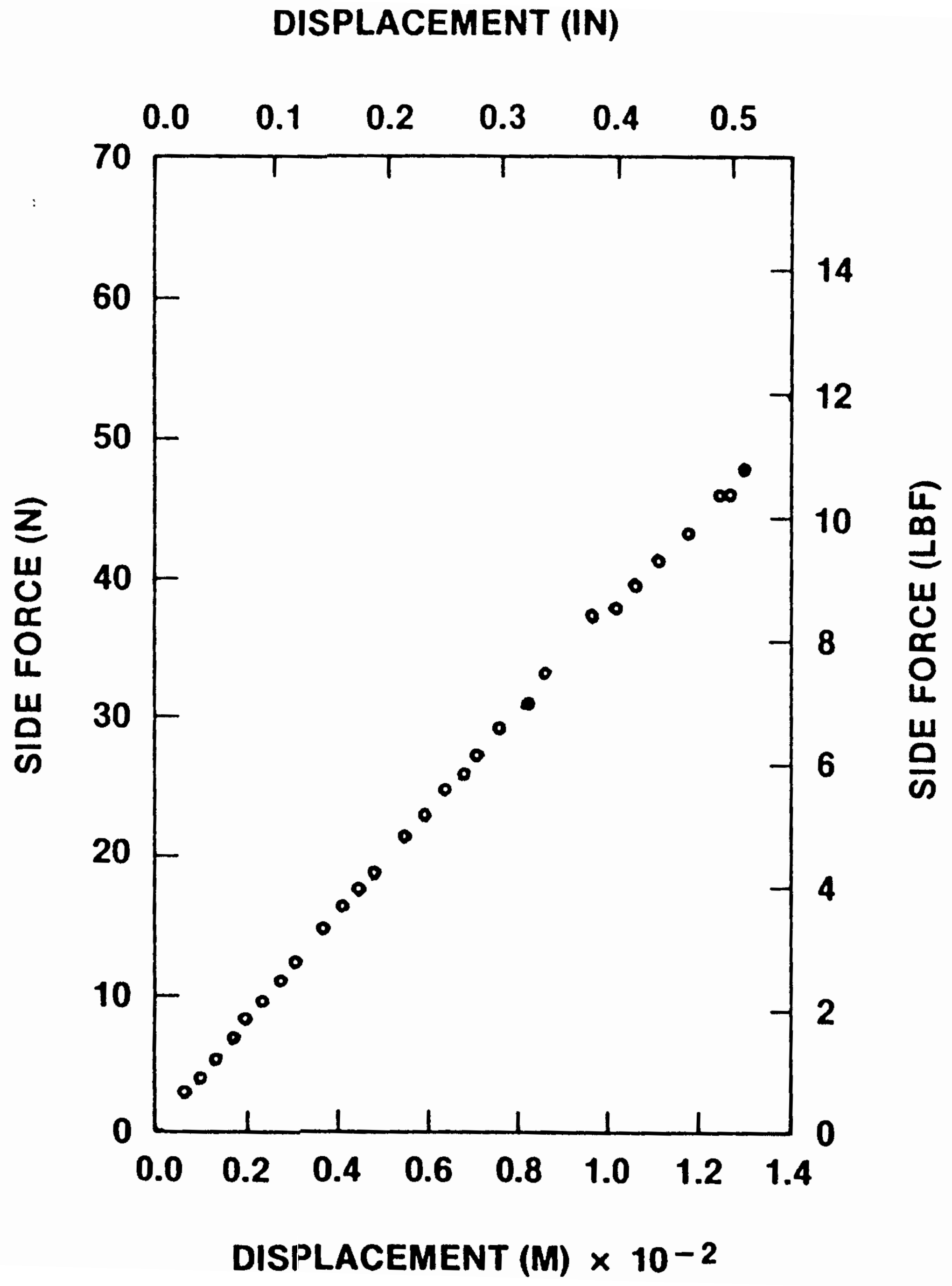


Wire Length $\ell_o = 1.350M$ (53.18 In)
Suspended Weight (Force) $W = 1494N$ (336 LBF)

Fig. 12 Experimental testing results



Wire Length $\ell_o = 1.350$M (53.18 in)
Suspended Weight (Force) W = 1027N (231 LBF)

Fig. 13 Experimental testing results

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