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ISSUES RELATED TO THE USAGE OF A TILT TABLE FOR MEASURING THE ROLL STABILITY CHARACTERISTICS OF HEAVY-DUTY TRUCK COMBINATIONS

Final Report

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16. Abstract
Issues related to the technical suitability and practicality of using a tilt table device for measuring the roll stability of heavy duty commercial vehicles are discussed. The technical literature citing the use of tilt tables in research elsewhere in the world is referenced in examining the attractiveness of tilt table applications in the U.S. The conceptual design of a tilt table constructed to meet domestic needs is presented.

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CONTENTS

1.0 INTRODUCTION

This document reports on issues related to the use of a tilt-table device for measuring the roll stability of heavy-duty trucks. The project was sponsored by the Motor Vehicle Manufacturer's Association (MVMA) as a means to explore the advisability of constructing such a device in the U.S. to serve the needs of the domestic trucking industry. The work involved a search of the literature as well as direct contact with practitioners in truck safety research to obtain answers to four basic questions concerning tilt tables and to develop a concept design for an in-place tilt-table facility at The University of Michigan Transportation Research Institute (UMTRI). The four specific questions are addressed in Section 2.0 and the concept design is presented in Section 3.0.

2.0 QUESTIONS CONCERNING AN APPLICATION OF TILT TABLES IN THE U.S.

1) What is the relationship between the static stability measure obtained using a tilt table and the dynamic rollover thresholds which may pertain to realistic highway rollover conditions?

This question can be answered in two stages. First, it is important to establish the extent to which the value for rollover threshold determined by the tilt table is accurate for defining the rollover threshold which would actually accrue in a steady turn. The results presented in Figure 1 (Kemp, et al., from TRRL [1]) show that the tilt table served to predict steady-turn results within 0.02 g's for eight different tractor-semitrailers, with an average error of 0.01 g's. In general, it would appear difficult to do the steady-turn experiments any more repeatably than these comparisons indicate--thus the differences are probably more due to the accuracy of the field test than to the conceptual adequacy of the tilt table experiment.

Second, one can ask whether the "realistic on-highway rollover conditions" will be simply of the steady-turn rollover variety or will involve complex dynamics. One issue of this type was addressed in a study in 1973 by Miller and Barter [2] in which concern for the confounding influence of trailer articulation angle prompted tilt table tests incorporating a range of articulation angles. The results showed that articulation angle had little effect on the rollover threshold. Additionally, there is proper concern for the resistance of vehicles to rolling over in response to "run-off-road" conditions. Although such scenarios will involve complex dynamics, it is apparent that the typically low static rollover threshold of loaded commercial vehicles will have a major role to play in determining whether rollover occurs. Thus, the dominant aspect of truck roll stability which calls for the attention of the engineering community appears to be the static characteristic--even though there may exist certain purely dynamic phenomena which also

VEHICLE / TEST METHOD	GUY/ SCAMMELL 45 Tonne	ATKINSON/ CRANE FRUEHAUF 32 Tonne	ATKINSON/ CRANE FRUEHAUF 38 Tonne	ERF/ TASKER (NORMAL) SPRING BASE) 32 Tonne	ERF (WIDE SPRING BASE) 32 Tonne	GUY/ BODEN 32 Tonne	GUY/ CRANE/ FRUEHAUF 38 Tonne	AEC 2-AXLE TRACTOR+ TANKER 32 Tonne	AEC 3-AXLE TRACTOR+ TANKER 32 Tonne
DYNAMIC TRACK TEST (AVERAGE)*	0.21g	0.30g	0.28g	0.28g	0.30g	0.25g	0.27g	0.31g	0.32g
TILT TEST	0.21g	0.32g	0.30g	0.29g	0.30g	0.27g		0.31g	0.33g

Figure 1. Comparison of static rollover thresholds measured by a steady-turning test on a skid pad and by a tilt-table device (from Ref. [1]).

influence the outcome in response to complex dynamic excitations. Such observations seem to have prompted researchers in different parts of the world to recommend tilt table methodologies for obtaining a suitable measure of truck roll stability. Strandberg, for example [3], advocated such a methodology in 1975, as did Ervin [4] in 1980 and Sweatman [5] in 1984. In fact, Sweatman declared that "the tilt test is widely recognized as a suitable standard of stability."

2) How can a tilt table device be applied in support of the design and development of commercial vehicles?

The tilt table is basically a mechanism for supplying a precise lateral acceleration condition to a standing vehicle. While the device has been proposed to MVMA and others for use in determining rollover thresholds, it is also useful as a means of studying the rollover process and quantifying certain roll response properties of suspensions. In the recent report by Sweatman concerning research uses of the Australian tilt table [5], load cells were installed beneath the wheels to measure instantaneous vertical loads, and motion transducers were employed to monitor suspension deflections and the roll motions of the sprung and unsprung masses. Accordingly, it is clear that the tilt table can be applied as a ready means for evaluating overall roll stability and for quantifying certain key parameters of the vehicle which influence the net stability level. To the extent that vehicle designers are concerned with (a) roll stability per se, or (b) the properties of suspensions influencing roll stability, the tilt table can be gainfully employed.

It may also be that a manufacturer is concerned with exercising the vehicle through a precisely controlled roll condition for purposes other than that of assessing stability. For example, the tilt table provides a convenient setup for directly measuring the location of the kinematic roll center of a suspension. Also, one may simply investigate clearance problems encountered by, say, steering or suspension elements over the range of roll motions. In developing a cab suspension, it is also conceivable that one would wish to characterize the induced motions or loads deriving from a precisely defined lateral acceleration/roll condition. A corollary to this last application would involve any specialized, suspended load (for example, a crane) whose static lateral or roll deflections under the influence of lateral acceleration may be difficult to quantify without a tilt table experiment. Note that, in conducting such experiments, the relationship between the lateral acceleration condition and the roll response can be conveniently varied simply by employing different loading weights at different heights on the sprung mass.

Moreover, the tilt table should be seen not only as a device for measuring rollover thresholds, but also as a means for providing a precise roll and lateral acceleration condition to a whole vehicle. The ability to provide such precise experimental conditions offers the opportunity to make unusual engineering measurements which may be attractive in various development activities.

3) What applications are made of existing tilt tables in other countries?

There are basically three settings in which tilt tables currently exist, namely, research, manufacturing, and regulatory enforcement organizations. Each of these will be discussed in turn.

In the first area, the primary facility on which research work is currently in progress is in Australia. The facility was built by the Australian Road Research Board, outside of Melbourne, and research was funded through a group of sponsors which included the Department of Transport, the trucking industry, and various manufacturers of motor trucks, trailers, suspensions, and hitch mechanisms. The research project described in Reference [5] addressed the development of the facility and various tasks involving measurement of vehicles, development of an analytical model, and validation of calculated results. Tilt table experiments produced measures of vertical compliance of the tires, suspension compliance, roll center location, and fifth-wheel compliance. The research was stimulated primarily by the interests of the petroleum industry, which was concerned with the rollover hazards imposed upon tankers carrying flammable liquids. The Australian device is shown in Figure 2. The tilt platform is an integral structure which is tilted by the action of four hydraulic cylinders.

Another device, upon which the pioneering research by Isermann [6] was based, is currently in Munich, West Germany and is used by the M.A.N. Corporation. The device was originally built in Wolfsburg in cooperation with the University of Hanover, under original sponsorship which included at least M.A.N. The device is no longer used in public domain research, but is used by this vehicle manufacturer. An illustration of this machine is shown in Figure 3. The tilt table is a portable facility employing jack screws to elevate small crossmembers which are placed under the respective tractor and trailer axle assemblies.

A third tilt table used in a research context is at the National Road and Traffic Research Institute of Sweden [7]. Shown in Figure 4, this device employs one hydraulic actuator at each axle position. The device is portable and requires adjustment of the actuator locations to match axle positions of each vehicle which is measured. This device was used in research which led to a proposal for a Swedish standard requiring a 4 m/sec^2 rollover threshold for heavy commercial vehicles.

The two vehicle manufacturers known to operate their own tilt table facilities are M.A.N., in Munich, and Volvo, in Gothenburg, Sweden. M.A.N. is understood to use its facility only infrequently, in conjunction with the development of buses which are to be sold in the United Kingdom (where roll stability of such vehicles is regulated using a tilt-table requirement).

The Volvo facility is quite new and is understood to be used primarily in the development of trucks which are to be sold with

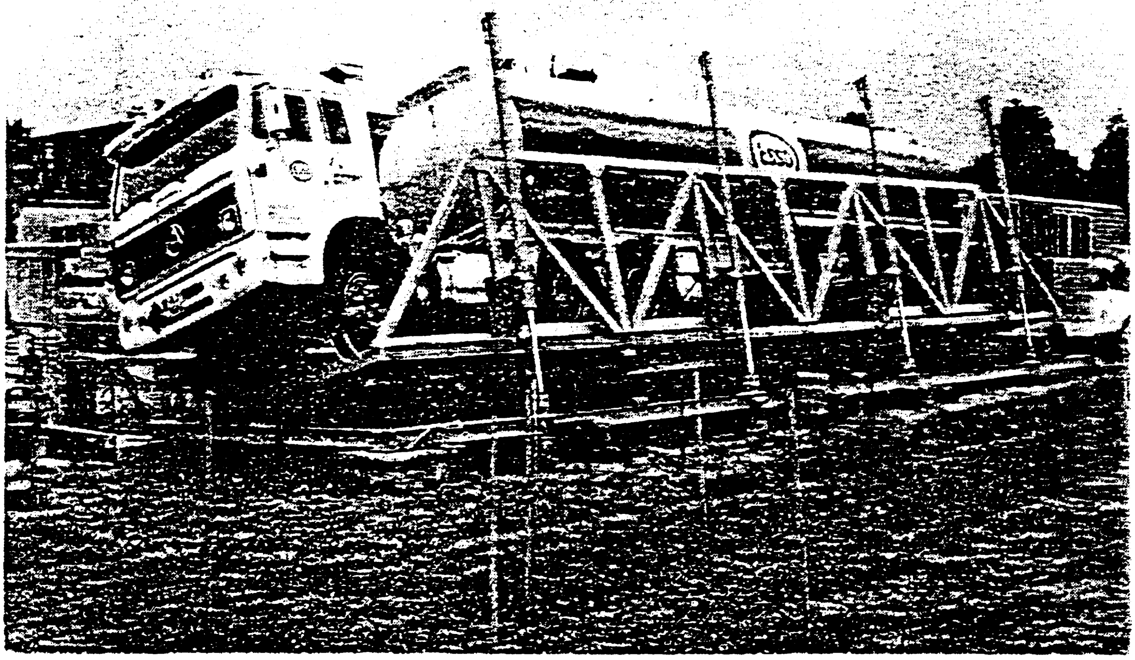


Figure 2. Tilt-table at the Australian Road Research Board (from Ref. [5]).

Bild 17. Tanksattelkraftfahrzeug auf der Kippbrücke

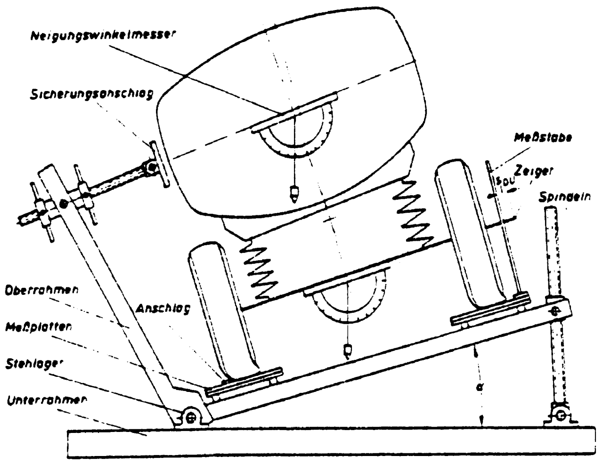


Bild 18. Fahrzeug auf der Kippbrücke

Figure 3. Tilt-table employed by Isermann [6] in West Germany.

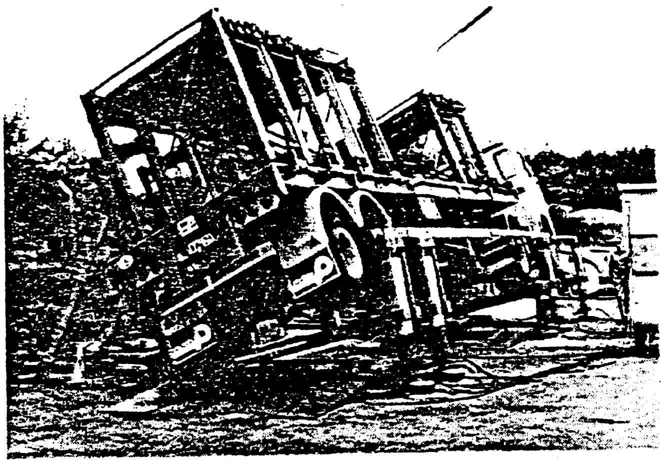


Figure 4. Tilt-table at the Swedish National Road and Traffic Research Institute (from Ref. [7]).

Volvo-manufactured vocational bodies. Photos of the Volvo tilt table are shown in Figures 5 and 6. Individual platforms are actuated at each axle position using motor-driven screw jacks. Since the actuators are fixed to an in-floor bed plate arrangement, there is no need for a specially made foundation structure.

There are a number of tilt platforms in the United Kingdom for evaluating the compliance of "public service vehicles" (motor coaches) against the roll stability standard for such vehicles. There are only two facilities, however, capable of tilting vehicles which are longer than 26 feet or heavier than 35,000 lbs. These devices constitute permanent installations of the Military Vehicle Experimental Establishment (MVEE) located at Chobham and Christchurch. Photos of each facility are shown in Figures 7 and 8, respectively. Both devices incorporate solid tables which are actuated from below. The table at the facility in Chobham appears to pivot about an axis which is at the nominal mid-track position of the vehicle. In Miller's use of this facility for studying roll response properties [2], he saw fit to measure table tilt angles at front and rear so as to account for twist deflections in the structure. The tilt table at MVEE, Christchurch, was employed by Kemp in the research study cited in Reference [1]. Kemp also pointed out that both of the MVEE tilt tables had been used by operators of trucking fleets to check the stability of their vehicles.

4) To what extent will the planned tilt table facility for Transport Canada be useful for meeting the measurement needs of the U.S. trucking industry? Can this facility be enhanced to better meet U.S. needs, if found deficient in any way, or might it be more advisable to build a facility at UMTRI for meeting U.S. needs?

The Canadian facility is being funded as part of the study on weights and dimensions which is organized and administered through the Roads and Transportation Association of Canada (RTAC). The tilt table is to be designed by the Quebec Industrial Research Center, in Quebec City. The device will be originally installed at the

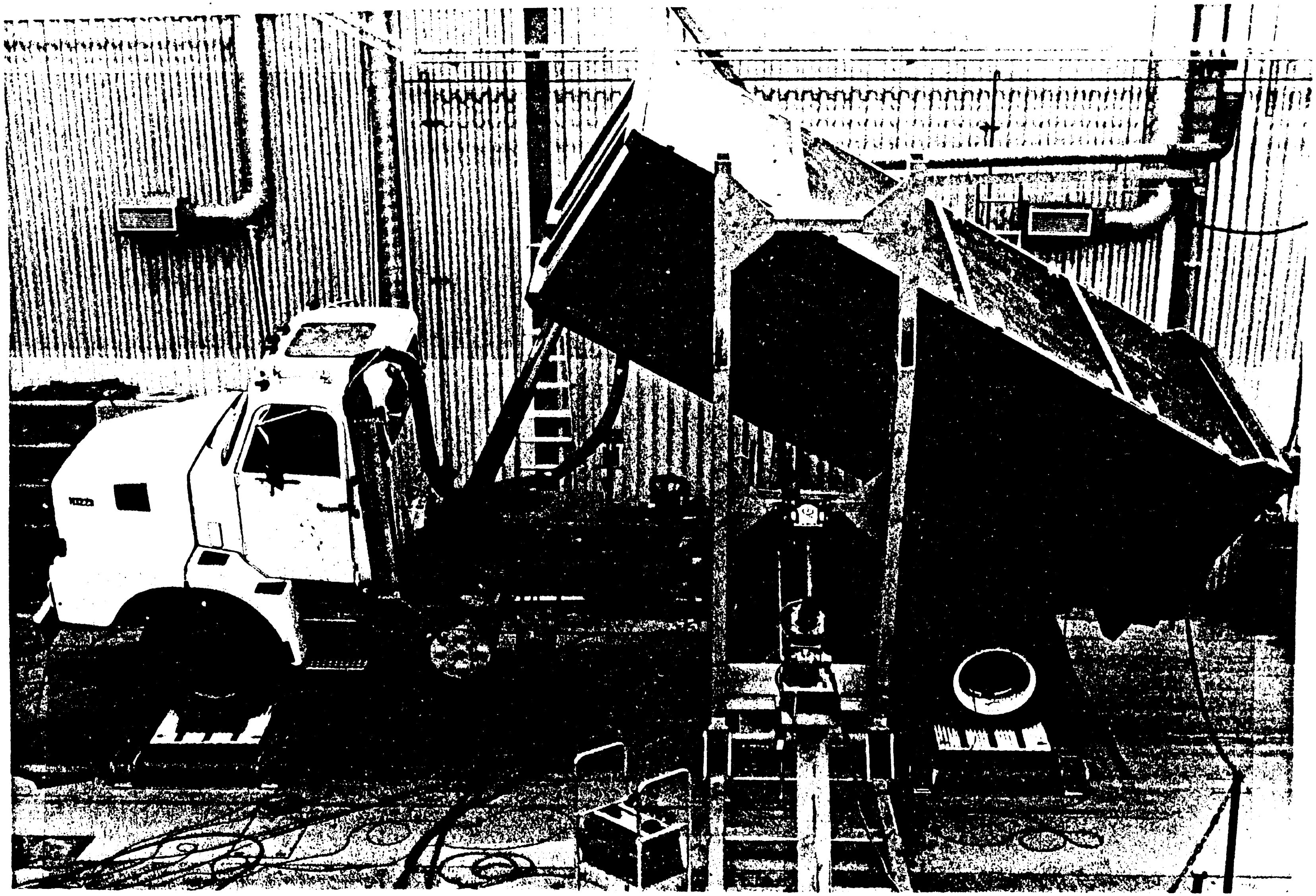


Figure 5. Tilt-table at the Volvo Truck Corporation, Gothenburg, Sweden

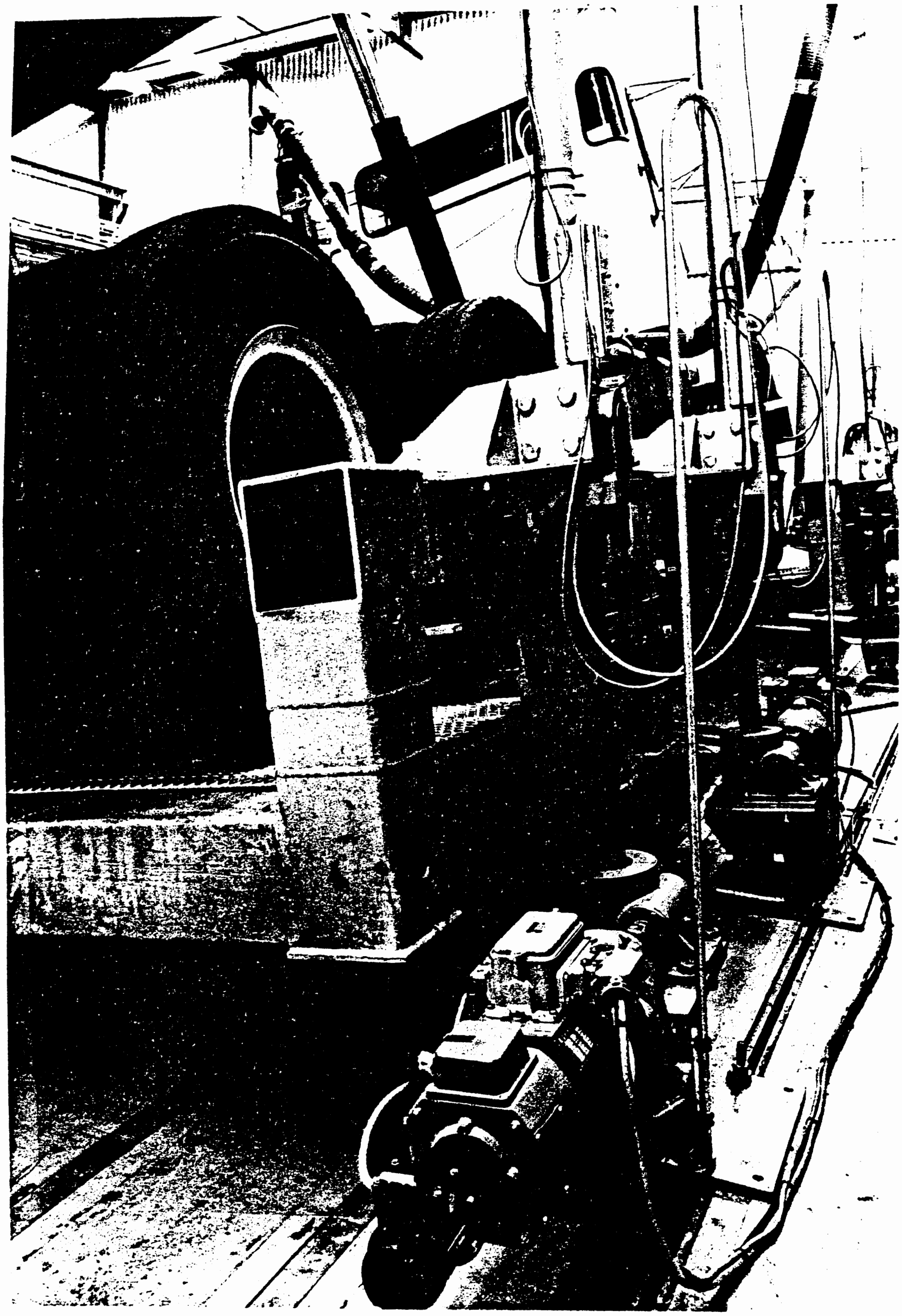


Figure 6. Screw-jack actuators on Volvo tilt-table.

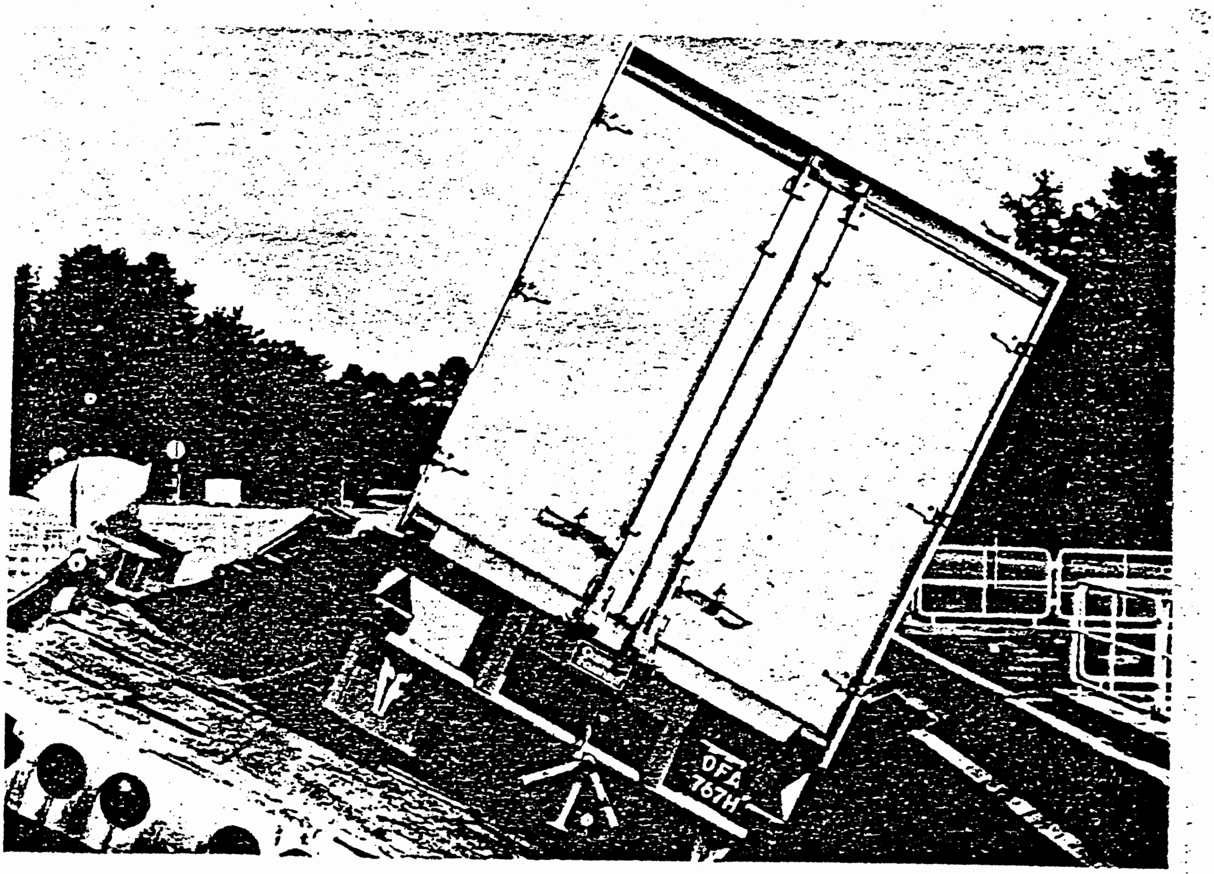
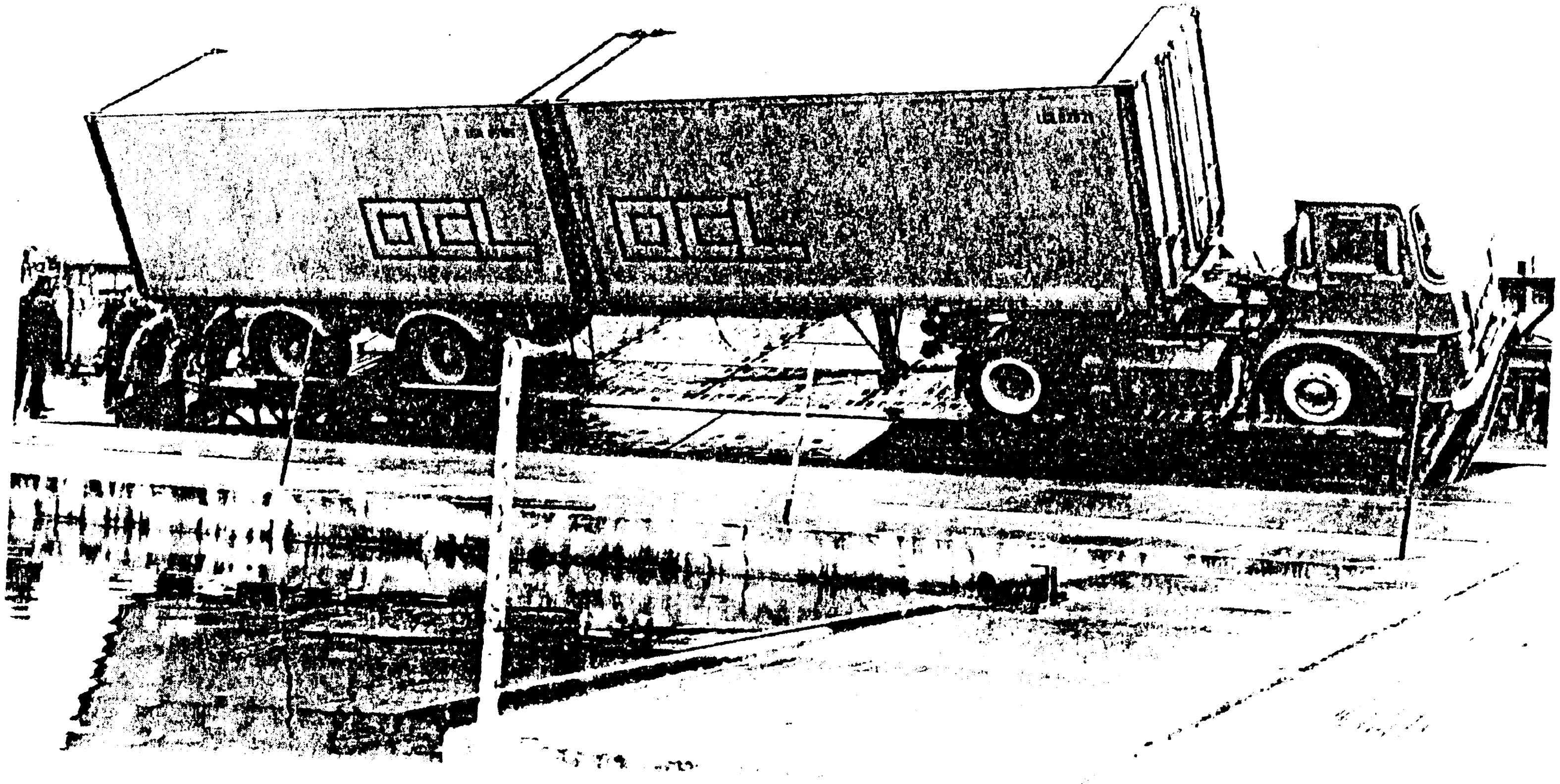


Figure 7. Tilt-table at the Military Vehicle Experimental Establishment, Chobham, England (from Ref. [2]).



Neg. M V E E Christchurch

Figure 8. Tilt-table at the Military Vehicle Experimental Establishment, Christchurch, England (from Ref. [1]).

Transport Canada test centre at Blainville, Quebec about 20 miles north of Montreal. The following constitute the preliminary specifications for this device:

- Overall length (to accommodate a long conventional tractor coupled to two 48-foot semitrailers), approximately 120 feet.
- Maximum vehicle weight , 200,000 lbs.
- Maximum width across vehicle tires , 112 in
- Maximum tilt angle , 35 degrees
- Instrumentation , Load cells provided for measuring loads beneath each axle of a 9-axle combination. Also, roll angle is to be transduced and a micro-processor is to be provided for determining the composite vehicle c.g. height, given the roll angle and load transfer data.

The scheduled completion date for the facility is April, 1985. The device is to be a portable assembly, constituting three sections which can be transported over the road to other test sites. It is planned that the device would be transported to the Railway Laboratory of the National Research Council of Canada during the RTAC-sponsored research study on size and weight for a battery of tests and then, later, be moved back to the Blainville site. Following the re-installation at Blainville, the device would be available for use by any parties, through arrangement with Transport Canada.

Clearly, the Canadian plans are to provide the world's largest facility of this kind. The provision of the capability for measuring wheel loads further enhances the utility of the device for research purposes.

3.0 CONCEPT DESIGN FOR A TILT TABLE AT UMTRI

Shown in Figure 9 is the end-view of a tilt table which could be built at the UMTRI site. This device would consist of a hydraulically actuated, permanently installed, structure which pivots about a hinge line located within the nominal wheel tracks of the vehicle. This layout reduces the demands for structural materials in the table by reducing the stressing of beam elements. The pivot itself is to be established by a string of bearing supports, one every four feet. The actuation cylinders would be servo-controlled to assure smooth roll angle development and to maintain a planar shape in the table despite nonuniform loading along its length. With the cylinders acting only four feet from the hinge, the cylinder length is kept short. The specifications for this design are as follows:

SPECIFICATIONS

Total Length of Table	70 feet
Total Width of Table	10 feet
Maximum Tilt Angle	30 degrees
Maximum Gross Vehicle Weight	200,000 lbs
Maximum Axle Group Load	75,000 lbs over a 20-ft span
Table Weight	38,000 lbs
No. of Actuating Cylinders	4
Cylinder Size	6" Bore X 24" Stroke
Hydraulic Supply	2 GPM at 2000 psi
Type of Actuation Control	Electrohydraulic Servos
No. of Bearings Comprising the Pivot	18
Deck Material	1/2 inch steel plate
Longitudinal Beam Members	8" Wide Flange Beams,

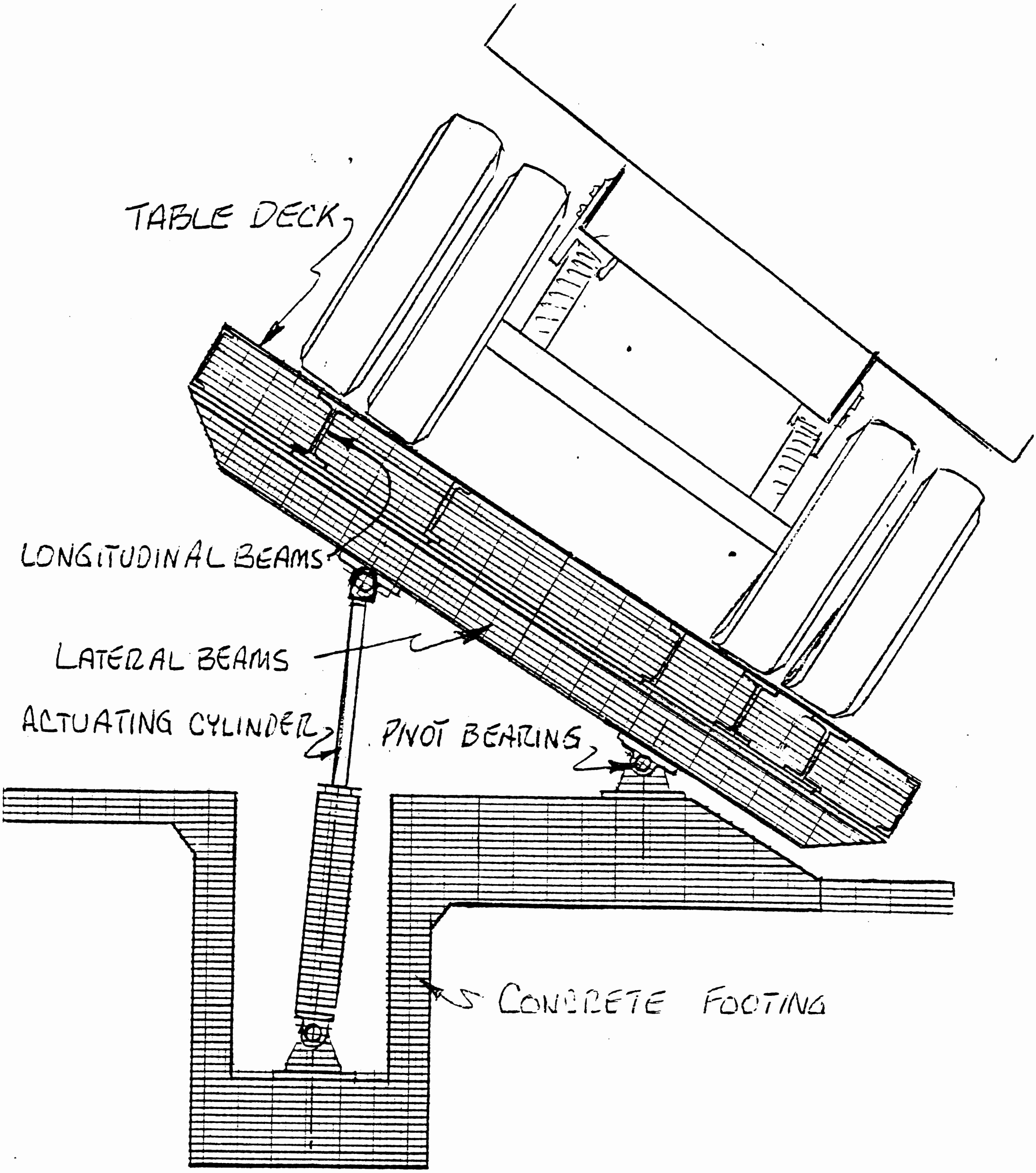


Figure 9. End view of concept tilt-table installation

35 lb/ft

Lateral Beam Members--------------------8" Wide Flange Beams, 35 lb/ft

Ground Structure------------------------Reinforced Concrete

Means of Vehicle Constraint-------------Chains preventing rollover and bolted angle restraining tires

Figure 10 shows the location of the pivot bearings and actuating cylinders and a cross-section of the simple deck construction. The deck is made to be a very stiff beam by the welding of 1/2-inch plate onto both the top and bottom of the longitudinal wide-flange beams. On the bottom of the deck, the plate is attached in two strips, approximately 30 inches wide. An additional wide-flange longitudinal beam is placed in the deck structure above the pivot bearings to further stiffen the table under the heavily loaded, "outside" tires. Also, the lateral beams are run full-width every four feet along the table to assure a flat deck surface.

It is estimated that this device could be constructed and installed at UMTRI for a total cost of $95,000, assuming funding by means of a gift to the University. The estimate assumes construction in FY 1985/86. The time to complete the work would be approximately eight months. The device would be installed just east of the UMTRI highbay building.

Any party could have measurements made on the installed tilt table at UMTRI, under the same conditions which govern the use of other Institute laboratory facilities. The measurement of rollover threshold on a typical combination vehicle is expected to cost approximately $800, with UMTRI staff conducting the test.

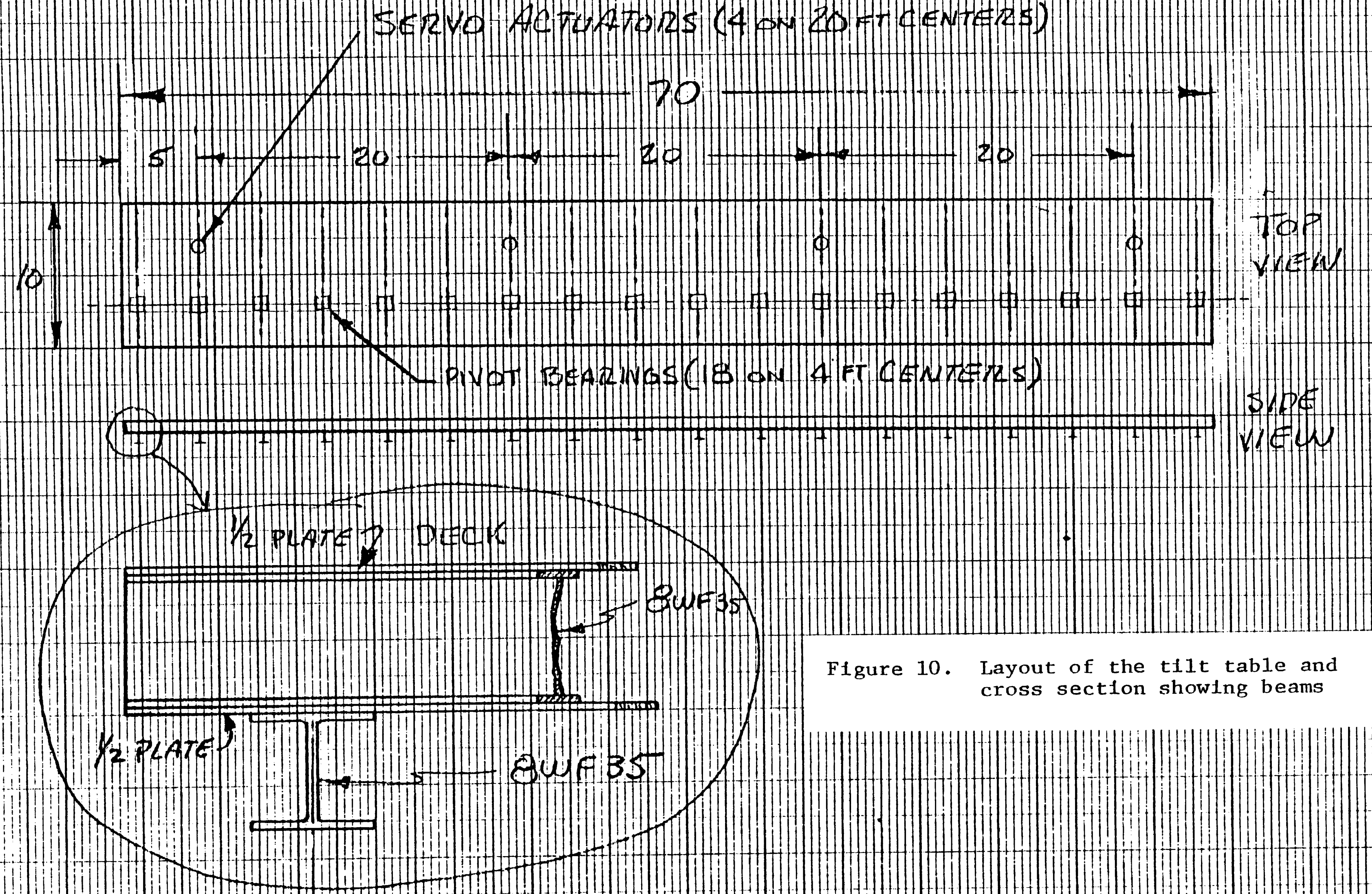


Figure 10. Layout of the tilt table and cross section showing beams

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