Investigating Articulated Vehicle Roll Stability Using a Tilt Table Device

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ABSTRACT

The Vehicle Weights and Dimensions Study was launched in Canada in 1984 under the cooperative sponsorship of government and the trucking industry. The research program included examinations of those factors which affect the stability of heavy commercial vehicles used in interprovincial carriage in Canada.

The Centre de Recherche Industrielle du Quebec was responsible for the design, construction and testing of a tilt table device capable of assessing the roll stability of long and heavy combination vehicles. The paper describes the design process used in constructing the 80 ft long, 200,000 lb. capacity table, the method of construction and the designed instrumentation and data acquisition capabilities.

The program of testing on the table is then reviewed, including the procedures used in preparing vehicles for testing, calibration of the instrumentation, data acquisition techniques and method of data analysis. The tentative findings of the program are then reviewed with respect to the influence of various parameter and equipment changes on the roll threshold of tractor semitrailers, including:

a. Tractor and Semitrailer suspension type

b. Track Width (96" vs 102")

c. Tire Selection (Bias, Radial, Low Profile, Super Single)

d. Fifth Wheel vertical slack

INTRODUCTION

The Centre de Recherche Industrielle du Quebec (CRIQ) was responsible for the design, construction and testing of a tilt table device capable of assessing the roll stability of long and heavy combination vehicles.

Consequently, this paper deals with the tilt table design and construction and also with the test procedures used in the tilt test program.

The tilt table itself is discussed first with:

- the General Design and Construction Considerations
- the Operation
- and the Instrumentation

Later, the following test procedures will be discussed such as:

- the Vehicle Preparation and Setup
- the Instrumentation and Data Acquisition
- and the Description of the Tests Done

TILT TABLE

DESIGN AND CONSTRUCTION CONSIDERATIONS

A tilt table is a device used to determine the rollover threshold of heavy vehicles. It is essentially a laterally tilting platform on which vehicles are installed and tilted until one or more high side tires are off the platform.

The table is made of two similar sections, each having a modular base and a tilt platform. The modular base is equipped with twelve adjustable supports so it can be leveled to compensate for the uneven pavement.

The structure on the swivel side has been reinforced by adding a longitudinal I-beam. The reac-

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tion of the hydraulic cylinders is exerted at two points which are compensated by adjustable supports located on each side of the hydraulic cylinders' resting point.

The tilt platform itself is also made of modules which are simply pivoted with respect to the base by a series of synchronized hydraulic cylinders. The structure of each platform is made of two sets of components which give it longitudinal and transversal stiffness.

The table is designed to be disassembled, transported and re-installed at a new site where the ground is appropriate. For transportation, each section width is reduced to about 4.3 m (14 ft) and the height is less than 3.05 m (10 ft).

The total length of the tilt table is 24.4 m (80 ft); however, the maximum distance between the front and the rear-most axle is limited to 23.75 m (78 ft). Its width is 2.9 m (114 in.); so, it takes axle widths ranging from 2.44 to 2.84 m (96 to 112 in.).

The tilt table strength allowed tilting a truck with a gross vehicle weight of 130 000 kg (297 000 lb). However, the load on one particular section must not exceed 67 500 kg (148 500 lb) and the maximum load per axle is limited to 12 000 kg (26 400 lb); there are also some restrictions on load concentration.

There is a set of ramps at each end of the table provided for boarding and disembarking; the maximum slope of these ramps is 10%.

The tilt table also incorporates an efficient vehicle restraint system; this system is made of a series of chains which are attached to the platform and to the trailer frame with sufficient slack to enable suspension extensions.

THE OPERATION

The maximum tilt angle is 35° and the operating temperature range is from -18° to 60° C (0° to 140° F). However, the data acquisition equipment must be maintained between 10° and 50° C (50° to 120° F).

The table tilt rate is fully adjustable from approximately 15 to 30 degrees per minute. The lowering speed is independently adjustable and varies of 15 degrees or less per minute.

The table is operated from a 60 HP-diesel engine.

The synchronization of hydraulic cylinders is done by using two complementary systems. The main system is a positive displacement flow divider consisting of a series of gear pumps having a common shaft. The divider's exit pressures are normally equal; however, when they differ, the efficiency of the gear pump is quite different and produces uneven flow ranging from 10 to 15%. In such a case, a complementary system has to be used. This second system is based on the direction of longer cylinders which are automatically drained until their lengths become approximately the same as the others.

At each cycle, at the end of the down stroke, a series of equalizing valves are electrically opened to compensate for any leakage which might have happened during the previous lifting. The controls also include a series of switches to make sure that each section of the table remains leveled and synchronized with the other.

An alarm is triggered by the switches telling the operator that the correction system cannot keep the two platforms at sufficient required leveling. However, when the load is well distributed over the two platforms, then, the pressure in all hydraulic cylinders is the same and the leveling correction is then seldom made. That condition corresponds to the ideal and desired operating conditions.

THE INSTRUMENTATION

The tilt table has five weight-measuring pads which can be moved to accomodate the various axle distributions. Each weighing pad contains four load cells which are temperature compensated and located at each corner of the pad.

The pad is 3.35 m (11 ft) long and 107 cm (42 in.) wide. The total capacity of each weighing pad is 45 455 kg (100 000 lb) i.e. 11 364 kg (25 000 lb) for each load cell. However, the maximum perpendicular load that one vehicle axle may exert on a weighing pad is limited to 22 727 kg (50 000 lb).

The pads can be positioned on either side of the tilt table. The spaces between the weighing pads are filled with a series of wood blocks which form a solid surface. The tilt angle is measured in two different ways:

- a pendulum-type tilt angle indicator is mounted on a tilting platform and it gives the operator a quick estimate of the angle the table has reached;

and there is also

- a precision tilt sensor installed on one platform and supplies the data acquisition system with a signal proportional to the tilt angle.

The precision of all the measurements coming from the load cells and the tilt sensor is ± 1% of full scale.

THE INSTRUMENTATION AND DATA ACQUISITION

The instrumentation used for the test program included the following:

- For the tilt table instrumentation, there was:

  axle load measuring pad

  a tilt table angle sensor

  and 2 inclinometers

- For vehicle instrumentation, there was:

  5 inclinometers

- The data acquisition system consisted of:

  a Hewlett Packard 9816 Computer

  an HP 3497A Data Logger including Input Voltage Card and Input Strain Card

  and a HP 82906A Printer

The zero balance of each pad was made including the pad weight.

Data was recorded every four seconds during each tilt test. It was handled, computerized and printed on graphs and tables.

VEHICLE PREPARATION AND SETUP

The basic vehicle configuration determined the way of positioning each vehicle and each weighing pad on the platform; however, the last trailer axle was always located at the same place.

Tires on the low side were blocked with 2 x 4 in. lumber placed flat along the pad sides to make sure that no side slipping would take place during tilting.

For loaded test, concrete blocks of 2 x 3 x 4 feet weighing between 1364 and 1455 kg (3000 to 3200 lb) were placed at the position corresponding to the double drive axle and the double trailer axle centre within ± 1 inch.

The total load including the axle load was 16 000 kg (35 200 lb) on each position. The load was secured by straps and chains.

Tire pressure was checked and set at 100 psi before each test.

Inclinometers were installed at the following positions:

- front of tractor (bumper)
- back of trailer frame
- front of trailer (deck)
- back of trailer (deck)
- longitudinal axis of trailer (for deck angle)

An inclinometer was also installed on each section of the table to monitor the tilt angle of each section and to supplement the permanently installed inclinometer on the table.

Specifications of each vehicle such as:

- tractor and trailer type
- tractor and trailer length
- tractor and trailer tire type
- tractor and trailer suspension type
- tractor and trailer axle spread
- tractor and trailer track width
- tire pressure
- fifth wheel height

were measured and catalogued.

The ambient air temperature during the test was also noted.

Each vehicle was also secured to the table with its restraint system. The tractor engine was started to get the normal operating pressure in air system and all brake systems were released for the tilt test.

Each test vehicle combination was tilt tested only once, from left to right when facing forward.

DESCRIPTION OF THE TEST

The tilt test program was designed to examine the influence of specific variations in loading, parameters and equipment on the static rollover threshold of combination vehicles.

The criterion established to define the rollover threshold was the following: rollover could be assumed to occur when one or more sets of tires on the high side of the trailer reach zero loading or come off the platform.

Efforts were made to obtain tractors and trailers with the same physical dimensions and components.

New tires were installed on all tractor and trailer axles and inflated to the same pressure.

For each tilt test conducted, time histories of the following data elements were collected:

a. the inclination angle of the tilt table, measured at three locations along its length;

b. the inclination angle of the tractor chassis (front and rear);

c. the inclination angle of the trailer deck (front and rear);

d. the loads on the high and low sides of the trailer axle group;

e. the loads on the high and low sides of the tractor drive axle group;

f. the load on the high side of the tractor steering axle;

g. the horizontal inclination (pitch) of the trailer deck.

In total, 51 tilt tests were conducted and are summarized.

The tests conducted in this study were divided as follows:

Test Series One:	Influence of Centre of Gravity Height
Test Series Two:	Influence of Tractor Suspension Selection
Test Series Three:	Influence of Track Width
Test Series Four:	Influence of Tire Choice
Test Series Five:	Influence of Fifth Wheel Vertical Slack

For *test series one*, two similarly equipped five axle tractor semi-trailers were prepared for the tilt test to illustrate the influence of centre of gravity height on the static roll threshold. In one case, the vehicle was loaded to obtain a centre of gravity of 60 inches, in the second case, the loading resulted in a centre of gravity height of 84 inches.

The objective of *test series two* was to examine the effect of different tractor and trailer suspension types on the static roll threshold of the five axle tractor semi-trailer combination.

A selection of four tractor and three trailer suspension types was made on the basis of those identified as being in most common usage in the Canadian interprovincial trucking fleet or which constituted genericallly different design concepts.

Four new, dimensionally similar tractors were obtained from International Harvester (Navistar) with the following tandem drive axle suspensions:

a. Hendrickson - Walking beam RTE 440 (44 000 lb rating)

b. Air - Neway ARD 244 (44 000 lb rating)

c. IH Air (38 000 lb rating)

d. IH 4 Spring (38 000 rating)

Three new, 48-foot tandem axle flatbed trailers were provided by Manac Trailers, equipped with the following tandem axle suspensions:

a. Walking Beam - Chalmers 700

b. Air - Neway AR95 - 17

c. Spring - Reyco 21B

Trailer axles have been available in Canada for several years in two lengths to provide nominal widths across the tires of either 96 inches or 102 inches. The objective of *test series three* was then to examine the influence of axle width, at these two points, on the static roll threshold of the tractor semi-trailer configuration.

Two new 48-foot flatbed semi-trailers were provided by Manac trailers for testing, which were both equipped with Reyco 21B 4 Spring suspensions.

Both trailer were prepared and loaded in a similar manner coupled in turn to a tractor fitted with a IH 4 Spring suspension on 96 inch nominal track width, and tilt tested in the standard manner.

The objective of *test series four* was to examine the influence of tire type and construction on the static roll threshold of the tractor trailer combination.

The tire types used for this test series were:

- Bias Ply - GoodYear Hi-Miler
- Radial - Michelin XZA
- Low Profile - Michelin Pilote XA
- Super Single - Michelin XM+S4

The two trailers equipped with axles providing nominal track widths of 96 inches and 102 inches were both used in this sequence, coupled to the tractor fitted with the IH 4 Spring suspension.

The loading condition of the trailers was maintained as in previous tests, with a centre of gravity height at an estimated 84 inches. The tires on the tractor were not varied.

The objective of test series five was to examine the influence of the vertical slack on the overall roll threshold of the tractor semi-trailer combination.

A tractor fitted with an IH 4 Spring suspension was coupled to a 48-foot flatbed semi-trailer loaded in the standard manner.

The combination was tilt tested without modification to the fifth wheel. Shims were then placed between the fifth wheel and the trailer mounting plate to remove one half of the slack present, and the test was repeated. Finally, shims were installed to remove all remaining slack and the test repeated again.

CONCLUSION

It would have been too exhaustive to discuss in this paper all the data and findings that were found from the study. However, there is a technical report which is available from RTAC.