The Effect of Ontario's Weight Regulations on Commercial Vehicle Design

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ABSTRACT

The Ontario weight regulations have permitted legal gross weights up to 63 500 kg (140 000 lb) on an 8-axle combination since 1971. These regulations were based upon a bridge formula developed from a consideration of the force effects of trucks of various configurations on bridges. They recognize that trucks of different configuration are useful in different applications and should be treated equally if they have the same force effect on bridges. Industry has made innovative use of the regulations to evolve a rich mixture of truck configurations, with each adapted to its own mission. Some of these configurations may not have been entirely desirable from the point of view of stability and handling, but with time and experience many of these vehicles have been weeded out.

This paper briefly describes the background and theoretical development of the Ontario bridge formula, which gives significantly higher weights than the bridge formula used in the US. It describes the program of bridge testing that has been conducted over the last 15 years, which has demonstrated over and over that bridges have considerable reserves of strength relative to conventional methods of analysis. It shows how this research led to the development of the "Ontario Highway Bridge Design Code," the only code having a load model representative of today's trucks.

The paper summarizes a survey of provincial weight regulations and shows that, in terms of their effect on bridges, they all follow the trend of the Ontario bridge formula, despite the diversity of principles and considerations that may have gone into their development.

Finally, the paper makes some observations on the development of truck configurations, as a consequence of the Ontario regulations, as industry has striven to improve the productivity of its equipment.

1. INTRODUCTION

The Province of Ontario is the industrial centre of Canada. It relied originally on waterways, then later railroads, for transportation of raw materials and distribution of manufactured goods. These modes are still used for certain bulk commodities, but the truck is now the dominant mode of goods transportation because of its flexibility and the availability of a network of good highways. Ontario is a spacious province, and transportation costs are a significant factor in the price of both raw materials and finished products. Solid civil engineering research and the need to encourage competitiveness by industry permitted Ontario to raise its maximum legal gross weight to 63 500 kg (140 000 lb) as long ago as 1971. Only the state of Michigan permits higher legal gross weights, and they are far above nearly all other states in the US. In 1970 the other provinces of Canada had gross weights around 33 500 kg (73 900 lb). In the intervening years, these have also increased but are still 6000 to 11 000 kg (13 200 to 24 200 lb) less than Ontario's, except for the Yukon, which adopted the Ontario regulations, and B.C., which permits 63 500 kg (140 00 lb) gross weight for a special vehicle configuration.

The basis for the Ontario weight regulations is the Ontario bridge formula (OBF). This permits axle group loads to be transformed to a uniformly distributed load, which is convenient for both analysis and design. It also means that if trucks of different configuration are the same by the

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formula, they are treated equally because they have the same force effect on bridges. Industry has made innovative use of the form of the regulations to evolve a wide variety of truck configurations, with each adapted to its own mission. Some of these configurations may not have been entirely desirable from the point of view of stability and handling, but industry has learned, and with experience, many of these vehicles have been weeded out.

2. ONTARIO WEIGHT REGULATIONS

Permissible loads in Ontario have been raised at intervals since restrictions were introduced in 1916 (1), when single-axle loads were limited to 4082 kg (9000 lb). Figure 1 is a historical account of the growth of permissible weights in Ontario.

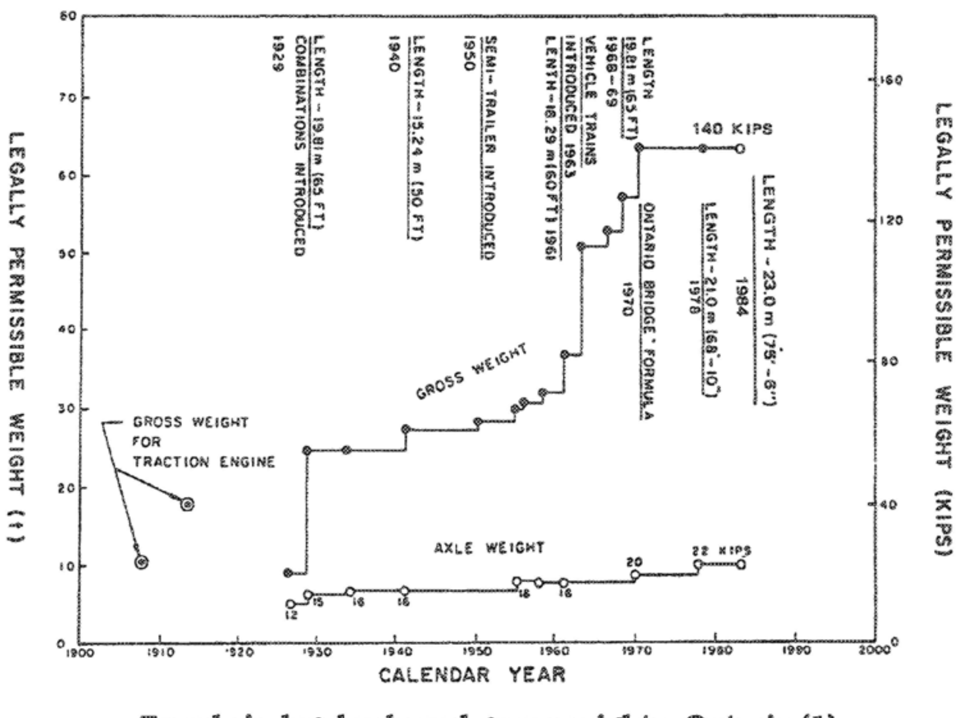
Prior to 1970, truck weight regulations were primarily based on gross vehicle weight control (2). Maximum allowable load limits were the following:

Single axle	8 165 kg	(18 000 lb)
Dual axle tandem	14 515 kg	(32 000 lb)
Tractor or single truck		
2 axle	12 700 kg	(28 000 lb)
3 axle	19 050 kg	(42 000 lb)
Trailer or semitrailer		
2 axle	14 515 kg	(32 000 lb)
3 axle	19 050 kg	(42 000 lb)
Combinations		
5 axle	33 565 kg	(74 000 lb)
6 axle	38 100 kg	(84 000 lb)
8 axle	52 615 kg	(116 000 lb)
9 axle or more	57 150 kg	(126 000 lb)

Although single- and dual-axle weight limits were specified, they were rarely enforced (3). Axle spacing was not considered, and the typical truck was short with closely spaced dual axles.

2.1 ONTARIO BRIDGE FORMULA

The Trans-Canada Highway and Highway 401 (from Windsor to the Quebec border) were completed in the mid-60s. With improvements and new construction on other highways, the modern truck with high-speed cruising capability that had evolved with the US interstate highway system became attractive in Ontario. This led to demand by the industry for increased weights. The Department of Highways carried out a theoretical assessment of the operational level of the load-carrying capacities of existing bridges designed in accordance with the AASHTO specifications for HS20 loading. These capacities are shown in Figure 2. As a result of this study, the OBF was developed (4):



Trends in legal axle and gross weights, Ontario (1)

FIGURE 1

$$W_m = 2.0 + 2.07\,B_m - 0.0071B_m^2 \qquad (1)$$

where

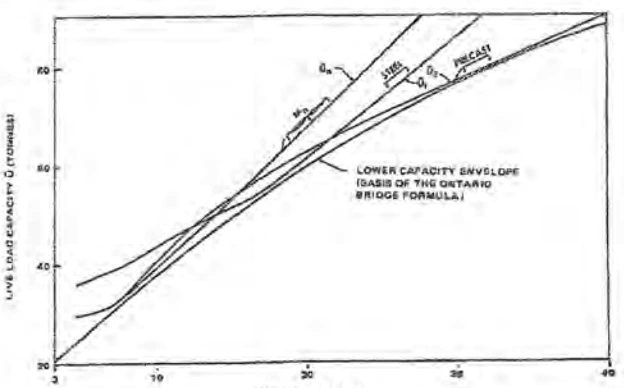
W_m = permissible weight on a group of consecutive axles, in kips

B_m = equivalent base length of the group of axles, in feet

The equivalent base length, B_m, illustrated in Figure 3, is the length over which the total weight on a group of axles must be distributed uniformly to cause force effects in a bridge structure similar to those caused by the group of axles.

Under normal operating conditions only the basic axle weight is an important factor for pavements. The bridge formula suggested, however, that axle weights, axle spacing, and gross vehicle weight were all important for bridges. A truck survey in 1967 had revealed a startlingly high frequency of overloaded axles (4). Based on these observations and OBF development, it was decided that higher weights could be allowed, provided axle weight control based on axle spacing was introduced, with strict enforcement so that observed axle loads in the 1967 survey were not exceeded and overall force effects on bridges generally remained at the 1967 level.

In 1970, the Ontario bridge formula became part of the Highway Traffic Act. It increased the single axle weight limit to 9071 kg (20 000 lb) and permitted a dual-axle weight limit of 15 875 kg (35 000 lb) to 18 143 kg (40 000 lb), depending on the axle spacing. In 1971, a set of regulation tables were developed for various vehicle combinations (5), which allowed an increased gross vehicle weight up to 63 500 kg (140 000 lb).



Live load capacities $\overline{U}$ of critical bridge types for normal operation (4)

FIGURE 2

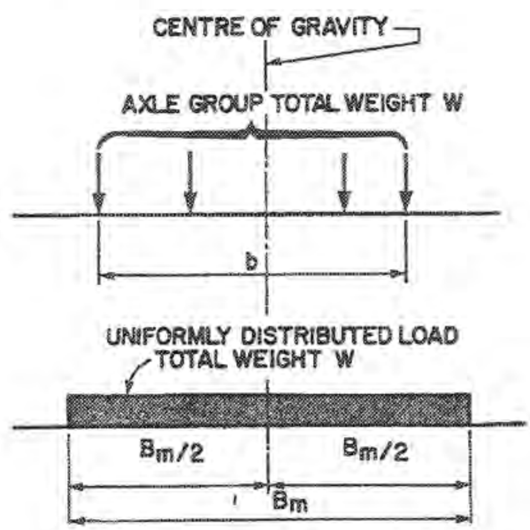
2.2 SIMPLIFIED VEHICLE WEIGHT TABLES

The bridge formula law required all possible sub-configurations of a vehicle to be checked for violation of the formula limits. This was a complex and time-consuming operation and was considered impractical at the truck inspection stations, where the highway carrier inspectors had only a few minutes to check a vehicle for weight violation. The 1971 regulation tables (5) initially contained all existing vehicle configurations and axle spacings. They rapidly became outdated as the bridge formula opened doors for innovation and flexibility in the design of truck configurations. By 1973, there were many truck configurations the inspectors could not find in the regulation tables, so the weight regulations were not fully enforceable.

To correct the situation, in 1978 a series of simplified vehicle weight tables was developed (6) and introduced into the regulations (7). To avoid the check on every axle sub-configuration, new definitions of axle groups and the inter-vehicle unit distance were introduced, as shown in Figure 4. The tables give limits on axle units, axle groups, and the gross vehicle weight. These tables were based on a revised and metricated OBF, which allowed a higher single axle weight of 10 000 kg (22 046 lb). The revised bridge formula was

$$W_m = 10.0 + 3.0\,B_m - 0.0325\,B_m^2 \qquad (2)$$

with W_m expressed now in thousand kilograms (tonnes) and B_m expressed in metres.



Equivalent base length concept

FIGURE 3

However, 63 500 kg (140 000 lb) was maintained as the maximum gross vehicle weight limit.

Truckers, highway carrier inspectors, and the courts found these tables easy to understand. Enforcement also improved because they were simple to use.

3. BRIDGE TESTING

Many of the existing highway bridges in Canada, if evaluated by conventional theoretical standards, would not be capable of carrying modern heavy vehicles. However, they have been carrying these vehicles routinely for many years without signs of distress. This indicates that there are large differences between the actual load-carrying capacities of bridges and those predicted by conventional theory. This difference will depend upon the bridge structure type, material, and geometry. Bridges, however, have finite capacities, and the difference between their actual and assumed capacities, however large, cannot be indiscriminately relied upon.

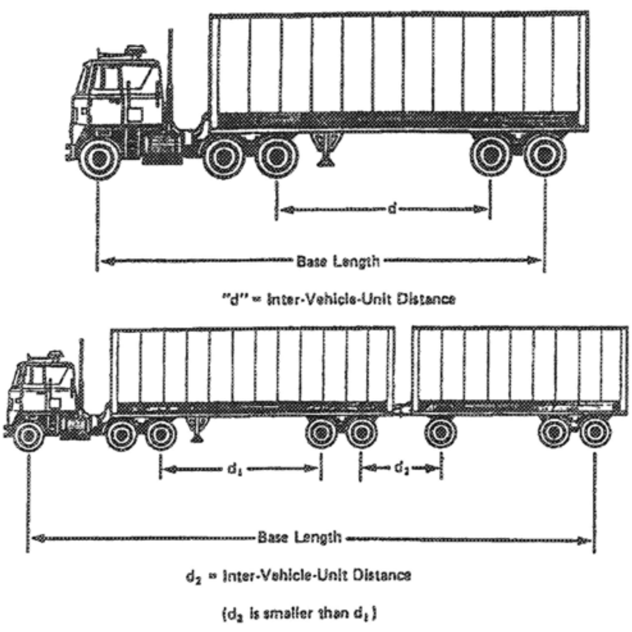
To get the maximum use out of a bridge, its assessed capacity should be safely close to its actual capacity. Bridge testing provides a reliable means to assess correctly the true capacity of a bridge.

The Ontario Ministry of Transportation and Communications has tested more than 150 bridges in a program of bridge testing over the past 15 years (8). The tests may be divided into the following four categories.

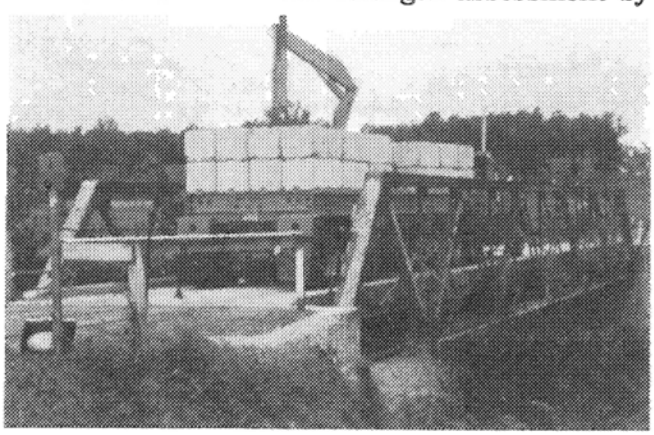
Behaviour Tests
These are carried out to verify the results of a method or methods of analysis which, if validated, could be used in evaluation of the load-carrying capacity of similar bridges. The loads applied during such a test are kept well below the safe loads of the structure. The test, therefore, provides information only on the load distribution in the structure and furnishes little data on its strength. Testing to determine bridge dynamic characteristics is also included in this category.

Proof Tests
These tests are conducted to establish the safe load-carrying capacity of a specific bridge. During these tests, the structure is subjected to exceptionally high static loads. The loads are such that responses caused by them are higher than those caused by the maximum allowable loads on the bridge, including the appropriate values of the load factors and dynamic load allowance (the impact factor). However, subjecting a bridge to a high enough load alone is not always a confirmation of its load-carrying capacity. Supporting analysis must be carried out to ensure that the observed bridge strength is not due to a temporary feature of the structure, such as, frozen bearings in a steel truss bridge. Loads for proof test are applied by one or two test trucks loaded with concrete blocks, as shown in Figure 5.

Ultimate Load Tests
These tests are carried out to determine the ultimate load-carrying capacity of bridges, usually to confirm the ultimate strength assessment by



Inter-vehicle-unit distance
FIGURE 4



Proof testing a bridge
(note the 8 T [8 t] posted load)
FIGURE 5

some methods of strength analysis. After validation by an ultimate load test on an existing bridge, the methods can be used with some confidence on other similar structures. These tests result in failure of some member of the bridge, so are only conducted on bridges that are scheduled for demolition.

Diagnostic Tests
When the cause of the failure of a component on a bridge is not easily established by calculations, load tests on the bridge can be used to find the reason for the damage. Such tests usually involve the monitoring of a component similar to the one which has failed.

Nearly one-third of the bridges were proof tested, and invariably, it was concluded that the load-carrying capacities of the tested bridge was substantially higher than the capacity predicted by analytical methods, as seen in Figure 5. In a specific test, a timber bridge, with a posting sign of 5 T (5.08 t), was loaded by two test vehicles, each carrying about 100 T (101.6 t) (9). It is not suggested that bridge testing will always demonstrate such dramatically higher capacities. Indeed, in a few cases, the posted load has had to be reduced. Between 1975 and 1983, 17 bridges that were considered structurally suspect were declared safe after proof testing, resulting in savings of millions of dollars (9). For many other bridges, the existing posting limit was increased or removed after testing.

4. ONTARIO HIGHWAY BRIDGE DESIGN TRUCK

With weight regulations rationalized and properly in place, as described in Section 2, it was decided to revise the bridge design loadings to reflect the modern heavy truck population (10). Through a number of weight surveys in Ontario from 1967 to 1975 (4,10,11) it was established that trucks do exceed the legal limits in everyday operation. The amount of overload was found to be up to 10 000 kg (22 000 lb) for the entire range of equivalent base length. The live load truck model for the "Ontario Highway Bridge Design (OHBD) Code" was, therefore, developed at this maximum observed load (MOL) level (12) given by the equation

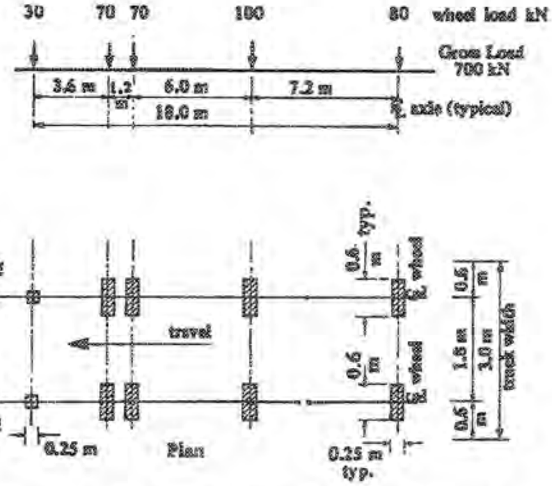
$$W_{MOL} = 20.0 + 3.0\, B_m - 0.325\, B_m^2 \qquad (3)$$

This is simply the OBF plus 10 T (10.2 t) where WMOL is expressed in thousand kilograms (tonnes) and Bm is expressed in metres. This truck model is shown in Figure 6 (13,14). It consists of a heavy single axle of 200 kN, a heavy dual axle of 280 kN, and a gross vehicle weight of 700 kN. The various sub-configurations of relevance of the OHBD truck are plotted on the W-B_m chart in Figure 7 to display their closeness to the MOL level.

Sub-configurations of the OHBD truck were adopted for the purpose of evaluation of posting loads for substandard bridges for various categories of trucks under a new triple-level posting system developed in Ontario (12).

The Ontario bridge formula and the MOL level thus provided a direct relationship between the bridge design standards and the weight regulations. The MOL level was subsequently adopted as the basis for special overweight permit policy in Ontario.

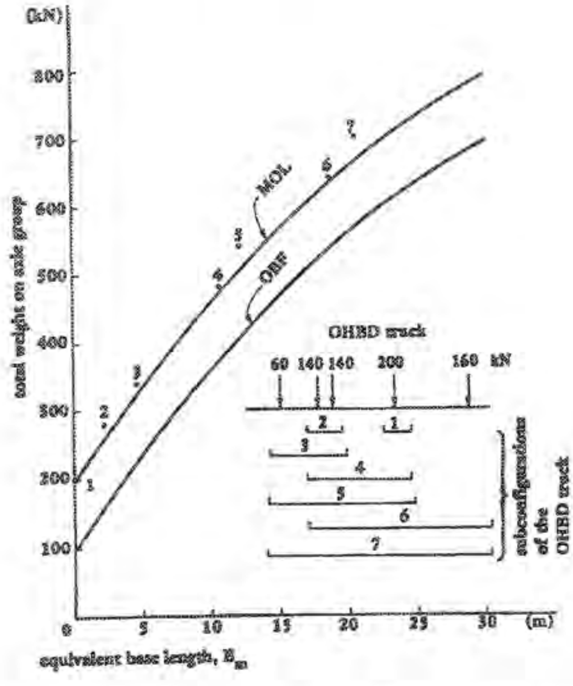
The OHBD truck was used as a part of the load model for the "Ontario Highway Bridge Design Code" (14), first introduced in 1979. This code is the first based on the limit states philosophy. Not only does the code include loads truly representative of the truck population, but it also uses load factors derived from those loads by a calibration which gives a rather uniform level of safety for all types of bridge (15). While other jurisdictions can use the concepts embodied in the code, it cannot be adapted without choice of repre-



Ontario highway bridge design truck (OHBD truck) (14)

FIGURE 6

sentative loads and a calibration. The code is now being very favorably reviewed by a number of other jurisdictions.



Plot of OHBD truck on the W-B_m chart (14)

FIGURE 7

5. SURVEY OF PROVINCIAL WEIGHT REGULATIONS

In 1978, a study was carried out for the Roads and Transportation Association of Canada (RTAC) Project Committee for Vehicle Weight and Dimensions to compare the weight regulations of the provinces of Canada (16). For this study, W-Bm charts were considered to be a convenient and constant tool on which sub-configurations of the legally allowable trucks for each province were plotted. Although, on the surface, the various regulations had significant differences, as shown in Table 1, critical for interprovincial trucking operation, it was found from the study that the difference in effect on the highway infrastructure was not very large. The Maritime provinces, Quebec, Ontario, and Manitoba had force effects on the bridges of similar magnitude, whereas Alberta, British Columbia, and Saskatchewan had force effects up to 15% less. Figures 8 and 9 present an example from each group. This study served an important function in displaying that the practical differences in regulations were not large and should be easily resolvable for interprovincial trucking.

To confirm further that the bridge capacities across the country are also similar, the RTAC Project Committee for Vehicle Weight and

Table 1 – Length and weight regulations for commercial vehicles, 1978 (16)

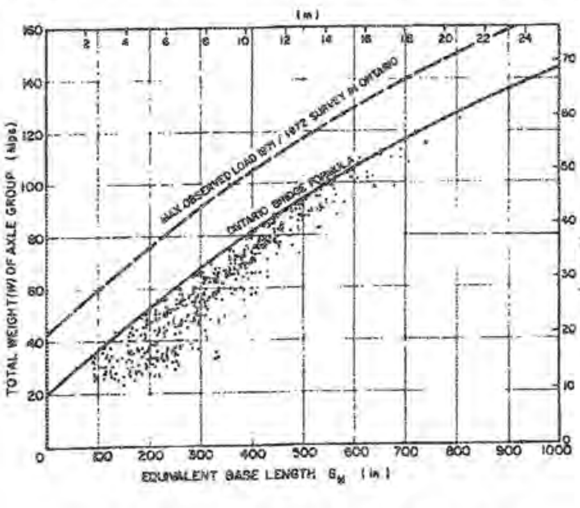
Province	Maximum axle weight (kips) Single	 Tandem	Maximum gross weight (kips)	Maximum length of combination (ft.)
Newfoundland	18.0 (8 165 kg)	32.0 (14 515 kg)	112.0 (50 802 kg)	65 (19.8 m)
Nova Scotia	20.0 (9 072 kg)	35.0 (15 876 kg)	80.0 (36 287 kg)	65 (19.8 m)
New Brunswick	20.0 (9 072 kg)	40.0 (18 144 kg)	125.0 (56 699 kg)	65 (19.8 m)
Prince Edward Island	20.0 (9 072 kg)	35.0 (15 876 kg)	110.0 (49 895 kg)	65 (19.8 m)
Quebec	22.0 (9 979 kg)	38.0 (17 237 kg)	126.0 (57 153 kg)	65 (19.8 m)
Ontario	20.0 (9 072 kg)	40.0 (18 144 kg)	140.0 (63 503 kg)	65 (19.8 m)
Manitoba	20.0 (9 072 kg)	35.0 (15 876 kg)	110.0 (49 895 kg)	65 (19.8 m)
Saskatchewan	20.0 (9 072 kg)	35.0 (15 876 kg)	110.0 (49 894 kg)	70 (21.3 m)
Alberta	20.0 (9 072 kg)	35.0 (15 876 kg)	110.0 (49 895 kg)	70 (21.3 m)
British Columbia	20.0 (9 072 kg)	35.0 (15 876 kg)	110.0 (49 895 kg)	72 (21.9 m)
Yukon Territory	20.0 (9 072 kg)	40.0 (18 144 kg)	132.0 (59 874 kg)	70 (21.3 m)

Dimensions also undertook to evaluate about 50 steel girder/concrete deck-type bridges across Canada. This type of bridge was selected because it was considered to be the weakest link on the highway system. The results (17) suggested that the steel girder bridge often has a theoretical capacity significantly higher than legal load limits across Canada, as shown in Figure 10. The legal limits could therefore be brought up to a uniform level without a real concern for highway bridges, particularly on the Trans-Canada Highway. Thus, problems of regulatory differences for interprovincial transportation could be removed. Since the completion of these studies, some provinces have amended their weight regulations to reduce differences in the weight limits.

6. DESCRIPTION OF ONTARIO'S WEIGHT REGULATIONS

This section paraphrases definitions and omits certain details and infrequent cases for clarity and brevity. Reference should be made to the current regulations (7) to determine whether a particular vehicle can operate legally in Ontario. The weight permitted for a vehicle is determined by three steps.

The first step simply checks tire load, which the regulations restrict to 11 kg/mm of tire width. In theory, this restricts axle loads, but since the load corresponds reasonably well with typical manufacturers' ratings for tires, this is not generally a problem for vehicles operating legally.



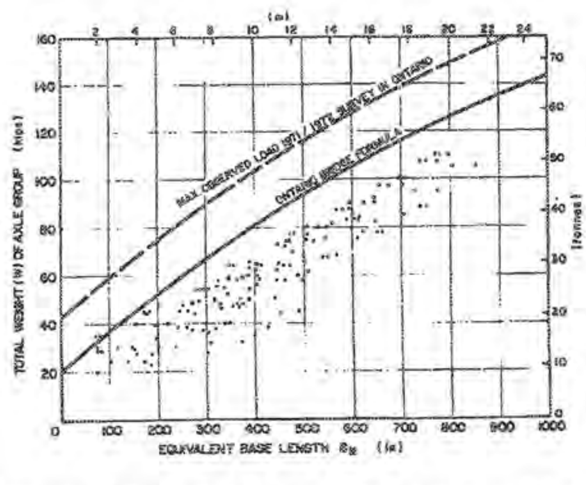
New Brunswick axle weight control regualtions (16)

FIGURE 8

It is, however, often governing in overload permit cases.

The second step checks axle and axle group loads. A single axle must be separated at least 2.5 m (98.4 in) from another axle; otherwise, it may be considered as part of an axle group, if it is not the front axle. A single axle is permitted 9000 kg (19 842 lb) with single tires and 10 000 kg (22 046 lb) with dual tires. A dual axle consists of two axles spaced more than 1 m (39.4 in) apart, articulated from a common attachment to the vehicle, which is designed to equalize the load between the axles. A triple axle consists of three equally spaced axles subject to the same conditions as the dual axle. Loads on the dual and triple axles are obtained from Tables 2 and 3, respectively, as a function of axle spacing. Two-, three-, and four-axle groups are defined where the dual- or triple-axle definitions do not apply and axles are separated by less than 2.5 m (98.4 in). Loads on these axle groups are also defined by tables as a function of axle group spread. The loads are slightly less than those permitted on the dual or triple axles of the same spacing because load equalization is not presumed. The final limitation is that dual and triple axles equipped with single tires may not exceed loads of 18 000 and 27 000 kg (39 683 and 59 400 lb), respectively.

The third step checks gross weight. This requires three definitions. Base length (not to be confused with equivalent base length) is the distance between the centres of the first axle of the front axle and the last axle of a vehicle or combination, as shown in Figure 4. The inter-vehicle unit distance is the least distance between the centres



Alberta axle weight control regulations (16)

FIGURE 9

of the last axle of a towing vehicle unit and the first axle of the towed vehicle unit for a combination vehicle, also shown in Figure 4. Front axle weight is the load on a single front or dual steering axle or half the weight on a steering 2-axle group. Gross vehicle weight is then the lesser of:

1. the sum of the front axle weight and the maximum allowable weights for all axle units;

2. the sum of the front axle weight and the maximum allowable weights for all axle groups and all remaining axle units not included in the axle groups; or

Table 2 – Maximum allowable weight for dual axle

Axle spacing (metres)	Maximum allowable weight (kilograms)
1.0 to less than 1.2	15 400
1.2 to less than 1.3	16 800
1.3 to less than 1.4	17 200
1.4 to less than 1.5	17 500
1.5 to less than 1.6	17 900
1.6 to less than 1.7	18 300
1.7 to less than 1.8	18 700
1.8 or more	19 100

Table 3 – Maximum allowable weight for triple axle

Axle spacing (metres)	Maximum allowable weight (kilograms)
2.0 to less than 2.4	19 500
2.4 to less than 2.8	21 300
2.8 to less than 2.9	21 700
2.9 to less than 3.0	22 000
3.0 to less than 3.1	22 400
3.1 to less than 3.2	22 700
3.2 to less than 3.3	23 100
3.3 to less than 3.4	23 400
3.4 to less than 3.5	23 800
3.5 to less than 3.6	24 100
3.6 to less than 3.7	24 400
3.7 to less than 3.8	24 800
3.8 to less than 3.9	25 100
3.9 to less than 4.0	25 500
4.0 to less than 4.1	25 800
4.1 to less than 4.2	26 200
4.2 to less than 4.3	26 500
4.3 to less than 4.4	26 900
4.4 to less than 4.5	27 200
4.5 to less than 4.6	27 600
4.6 to less than 4.7	27 900
4.7 to less than 4.8	28 300
4.8 or more	28 600

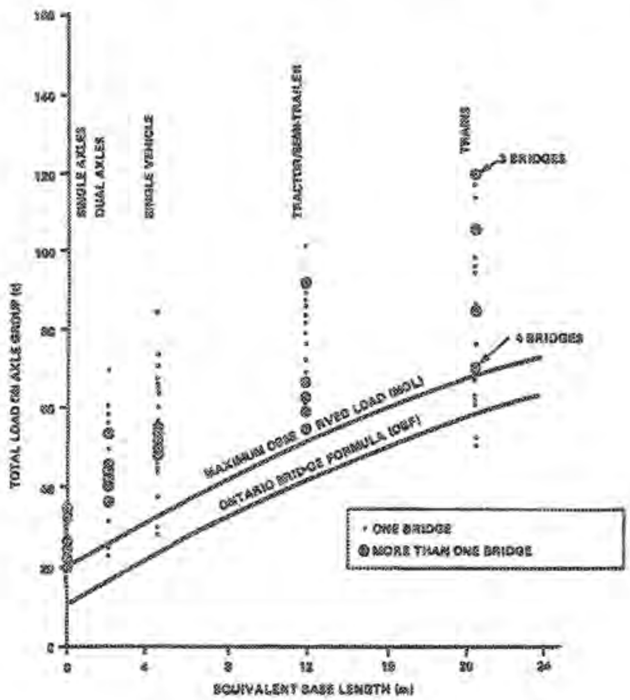
3. the gross weight determined from a table based on the number of axles, front axle weight, base length, and inter-vehicle-unit distance.

Sub-configurations within the vehicle must also be checked, although this is only restrictive for unusual configurations.

Table 4 is a typical table, with annotations. Given a 7-axle vehicle of known inter-vehicle-unit distance, base length, and front axle weight, the gross weight is simply obtained from the table entry.

7. EFFECT OF ONTARIO'S WEIGHT REGULATIONS ON TRUCK CONFIGURATIONS

It is important to realize that a single entry in an Ontario gross weight table represents an infinity of vehicles. For instance, the particular entry highlighted in Table 4 could be a 3-axle tractor with a 4-axle semitrailer of various axle configurations, a 7-axle A-train with a long drawbar dolly, a 7-axle B-train, or some



Theoretical capacities of HS20 bridge compared with Ontario bridge formula and maximum observed load (17)

FIGURE 10

Table 4 – Typical vehicle weight table

VEHICLE WEIGHT TABLE 27

ALLOWABLE GROSS WEIGHT ON A VEHICLE WITH SEVEN AXLES (KILOGRAMS)

INTER-VEHICLE-UNIT DISTANCE, 3.6 METRES OR MORE

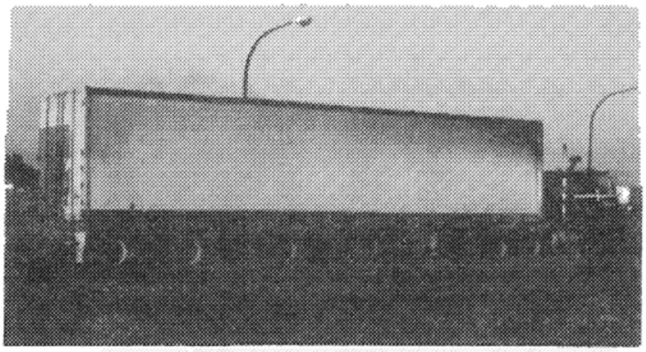
FRONT AXLE WEIGHT, (KILOGRAMS)

BASE LENGTH, (METRES)	5 000 OR LESS	5 001 TO LESS THAN 5 500	5 000 TO LESS THAN 6 000	6 000 TO LESS THAN 6 500	6 500 TO LESS THAN 7 000	7 000 TO LESS THAN 7 500	7 500 TO LESS THAN 8 000	8 000 TO LESS THAN 8 500	8 500 TO LESS THAN 9 000	9 000 TO LESS THAN 9 500	9 500 TO AND INCL 10 000
LESS THAN 15.00	52,300	52,700	53,100	53,500	54,000	54,400	54,900	55,300	55,800	56,200	56,700
15.00 TO LESS THAN 15.25	52,800	53,100	53,500	54,000	54,400	54,800	55,300	55,700	56,200	56,600	57,100
15.25 TO LESS THAN 15.50	53,200	53,600	53,900	54,400	54,800	55,300	55,700	56,100	56,600	57,000	57,500
15.50 TO LESS THAN 15.75	53,700	54,000	54,400	54,800	55,200	55,700	56,100	56,500	57,000	57,400	57,900
15.75 TO LESS THAN 16.00	54,100	54,400	54,800	55,200	55,700	56,100	56,500	56,900	57,400	57,800	58,300
16.00 TO LESS THAN 16.25	54,500	54,900	55,200	55,600	56,100	56,500	56,900	57,300	57,800	58,200	58,600
16.25 TO LESS THAN 16.50	55,000	55,300	55,600	56,100	56,500	56,900	57,300	57,800	58,200	58,600	59,000
16.50 TO LESS THAN 16.75	5,400	55,700	56,100	56,500	56,900	57,300	57,700	58,200	58,600	59,000	59,400
16.75 TO LESS THAN 17.00	55,900	56,200	56,500	56,900	57,300	57,700	58,200	58,600	59,000	59,400	59,800
17.00 TO LESS THAN 17.25	56,300	56,600	56,900	57,300	57,700	58,100	58,500	59,000	59,400	59,800	60,300
17.25 TO LESS THAN 17.50	56,700	57,000	57,300	57,700	58,100	48,500	58,900	59,300	59,800	60,200	60,700
17.50 TO LESS THAN 17.75	57,100	57,400	57,700	58,100	58,500	58,900	59,300	59,700	60,100	60,600	61,000
17.75 TO LESS THAN 18.00	57,500	57,800	58,000	58,500	58,900	59,300	59,700	60,100	60,500	60,900	61,300
18.00 TO LESS THAN 18.25	57,900	58,200	58,400	58,800	59,300	59,700	60,100	60,500	60,900	61,300	61,700
18.25 TO LESS THAN 18.50	58,400	58,600	58,800	59,200	59,600	60,100	60,500	60,900	61,300	61,700	62,100
18.50 TO LESS THAN 18.75	58,800	59,000	59,200	59,600	60,000	60,400	60,900	61,300	61,700	62,100	62,500
18.75 TO LESS THAN 19.00	59,300	59,500	59,700	60,000	60,400	60,900	61,300	61,700	62,100	62,550	62,900
19.00 TO LESS THAN 19.25	59,700	59,900	60,200	69,500	69,900	61,300	61,700	62,100	62,500	62,900	63,300
19.25 AND OVER	60,100	60,300	60,600	60,900	61,300	61,700	62,100	62,500	62,900	63,300	63,500

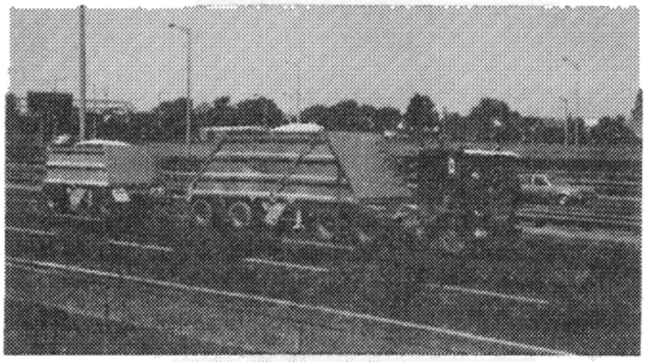
truck-trailer combination. Some possible configurations are shown in Figure 11. Since all these vehicles have approximately the same effect on bridges, it is entirely reasonable that they should be permitted the same gross weight. The tables, therefore, are a performance specification, and this gives vehicle designers freedom to configure for a particular mission. This freedom has allowed innovation in vehicle configuration to flourish in Ontario. While some may question the wisdom or economics of some of the results, vehicle designers seem to learn very quickly. The result of the regulations has been a wide variety of vehicle configurations on the highway. Since many configurations considered unusual by other jurisdictions are around in some numbers, it appears that whatever their design rationale, they are making sufficient money for somebody to prevent their disappearance.

The evolution of truck configurations since 1971 has also been spurred by two changes in the dimension regulations. In 1978 the overall length was increased from 65 ft to 21 m (68.9 ft) when the regulations were converted to metric. In 1984 the maximum semitrailer length was changed from 14 m (46 ft) to 14.65 m (48 ft) to adopt the new US standard. At the same time, the overall length was increased further to 23 m (75.5 ft) subject to the restriction that if the distance from the back of the drivers compartment on the tractor to the back of the vehicle exceeds 19 m (62.3 ft), the distance from the kingpin of the lead trailer to the back of the vehicle must be less than 16.75 m (55 ft). The purpose of this change was to encourage longer wheelbase tractors.

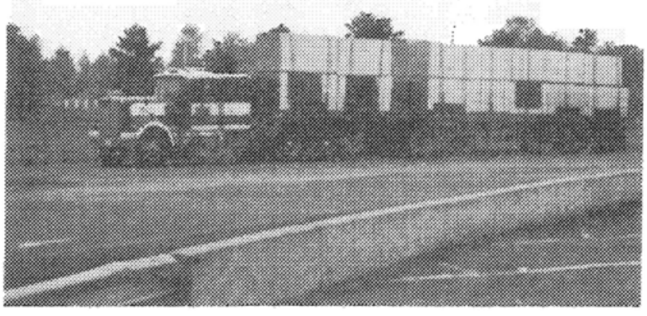
Prior to 1971 the gross weight limit in Ontario was 52 615 kg (116 000 lb). The standard vehicle used for heavy haul consisted of a 3-axle tractor with a semitrailer with a triple axle. This vehicle



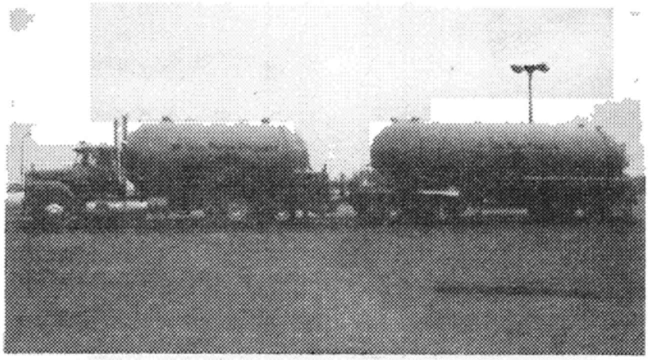
7-axle semi
FIGURE 11a



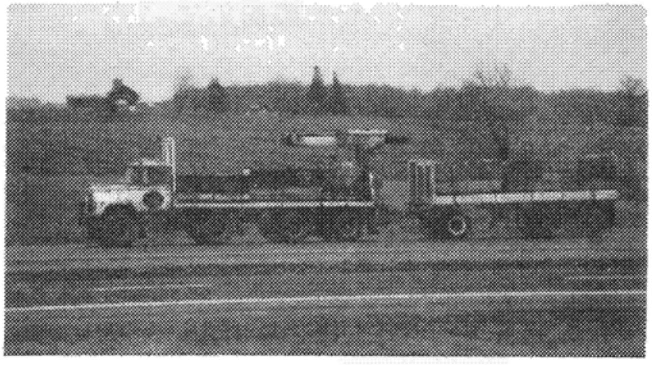
7-axle A-train
FIGURE 11b



7-axle B-train
FIGURE 11c



7-axle configuration with 3-axle truck
FIGURE 11d



7-axle configuration with 4-axle truck
FIGURE 11e

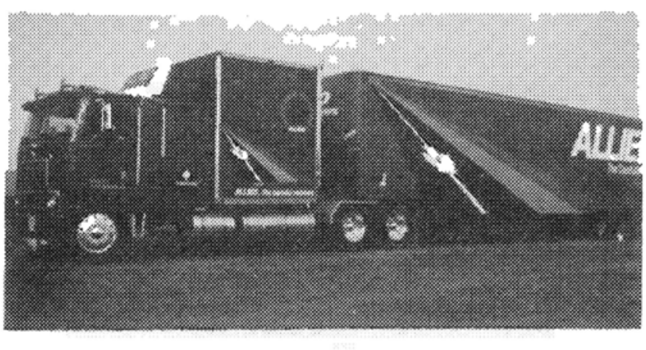
remained legal when the Highway Traffic Act was amended to include the OBF for determination of gross weight. However, the big change was that doubles of seven and eight axles suddenly became attractive to bulk and heavy haulers as the gross weight limit was increased to 63 500 kg (140 000 lb). Doubles had previously been legal in Ontario, but the gross weight limit made them attractive only for mixed freight, much as the doubles are presently used in the US.

The less-than-truckload operators benefit in little if any significant way from Ontario's regulations relative to most other jurisdictions, as the dimension regulations differ little. Double 28s are just possible, provided the trailer kingpin is set back 1.2 m (4 ft) or so. Household movers and a few other specialized shippers use a long wheelbase tractor with a load-carrying compartment behind the cab, for some reason called a "dromedary", with a semitrailer, as shown in Figure 12. This configuration can provide a total loaded length up to about 20 m (65 ft) within the 23 m (75.5 ft) overall length. Otherwise, trailer lengths and overall dimensions are similar to those of other jurisdictions.

The real beneficiaries of the Ontario regulations are the truck-load operators. who can make use of the high gross weight allowed.

One of the most evident vehicle configurations seen in Ontario is the 13.72 m (45 ft) or 14.65 m (48 ft) semi with a widespread trailer tandem axle, typically 1.83 or 2.48 m (6 or 8 ft), and an airlift belly axle 3.0 m (10 ft) forward of the tandem axle. A typical example is shown in Figure 13. This vehicle, with six axles, can carry a full 10 000 kg (22 046 lb) additional gross weight over the corresponding 5-axle semi without the airlift axle. The gross weights of 5- and 6-axle semitrailers is limited by the sum of allowable axle loads, not by the bridge formula. It gets difficult for operators to keep axle loads below the limits as the vehicle approaches its allowable gross weight, so it is reasonable to say these are troublesome vehicles from a compliance standpoint -- there are many unwitting offenders. However, the airlift axle control is usually in the cab, and many drivers lift this axle to make low-speed turns, which overloads the tractor drive and trailer tandems. The air pressure may also be incorrectly set for cruising, which can result in an improper distribution of axle loads. The 6-axle semi is a popular and productive configuration in Ontario and, also, Quebec. It is important because the extra axle confers additional weight, which weigh-scale data indicate is used by carriers -- their average gross weight is very close to their legal limit. The alternative configuration if belly axles were not permitted presumably would be a 6-axle A-train double, with single-axle trailers, which can gross within about 1000 kg (2205 lb) of the 6-axle semi. This configuration has a much lower threshold for trailer swing and rollover in dynamic manoeuvres than the 6-axle semi and, in these conditions, would be a less desirable vehicle.

Clearly, if one airlift axle is productive, two are more productive. A range of 4-axle semitrailers has been developed, which gives rise to 7-axle combinations that are now limited by the gross weight tables. Perhaps the most numerous configuration simply adds another airlift axle 2.48 to 3.05 m (8 to 10 ft) ahead of the position used for the 3-axle trailer just described. However, since axle loads need no longer reach their limits, there is more freedom to space axles. A second configuration uses a tri-axle unit at the rear of the trailer, with a single airlift axle 2.48 to 3.05 m (8 to 10 ft) ahead of it, and tandem-tandem, single-tandem-single, and four single axle arrangements are also seen. Typical



Household mover dromedary semi

FIGURE 12

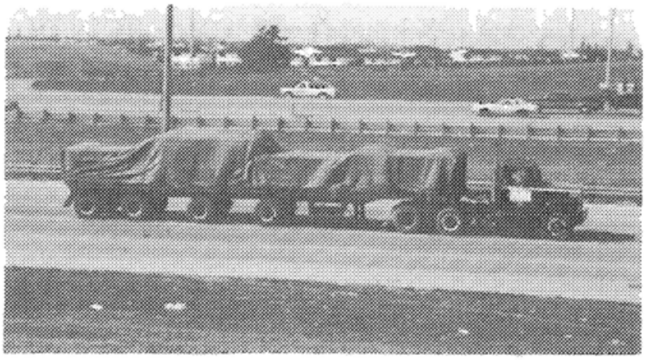
6-axle semi with airlift belly axle

FIGURE 13

configurations are shown in Figure 14. None of the airlift axles in these configurations use self-steering. There is no evident reason why one of these configurations should be preferred to another. A particular design is presumably determined by operational and other considerations that are important to the owner.

The 7-axle semi, just discussed, is a versatile vehicle for heavy loads. However, for some loads that do not exceed the gross weight it is difficult to place the load so that axles or axle groups are not overloaded, particularly if the airlift axle pressures are incorrectly set. A 5-axle semitrailer has recently been developed that results in an 8-axle combination, as shown in Figure 15. While this configuration gains little extra payload, because the additional axle almost exactly equals the weight of the added axle, that axle reduces the likelihood of axle or axle group overload.

Combinations of five and six axles with long trailers, 13.7 or 14.6 m (45 or 48 ft), essentially have their gross weights limited by the sum of their front axle and other axle or axle group loads. Combinations with typical short trailers of 8 to 8.5 m (26 to 28 ft) may be limited by the bridge formula. However, vehicle combinations of more than six axles are generally limited by the bridge formula, and some of the axle groups may be under-loaded. For example, an 8-axle vehicle with a gross weight for 63 500 kg (140 000 lb) and a front axle load of 7500 kg (16 500 lb) has an average load of only 8000 kg (17 600 lb) on each of the other seven axles. While the vehicle might be configured with these axles in groups that provide the average loading, typically several of the

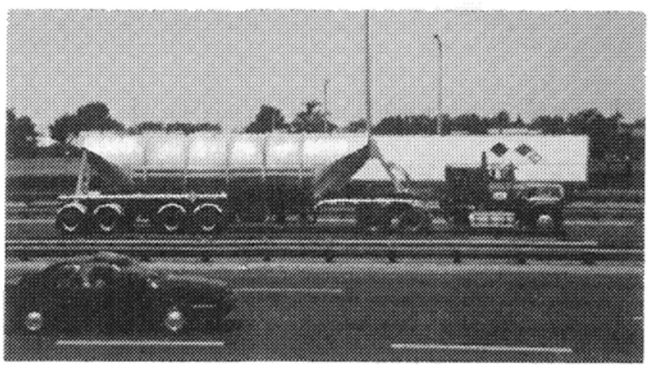


7-axle semi with tandem and two airlift singles

FIGURE 14a

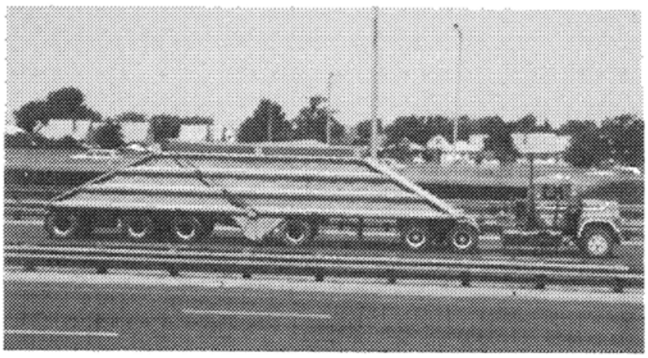
7-axle semi with tri-axle and airlift single

FIGURE 14b



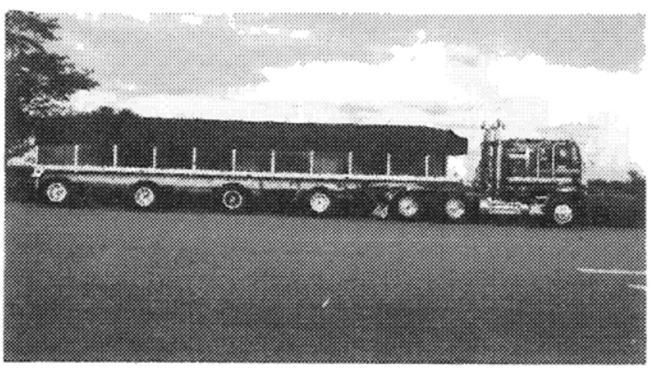
7-axle semi with tandem and tandem airlift

FIGURE 14c



7-axle semi with single airlift, tandem and single airlift

FIGURE 14d



7-axle semi with four singles

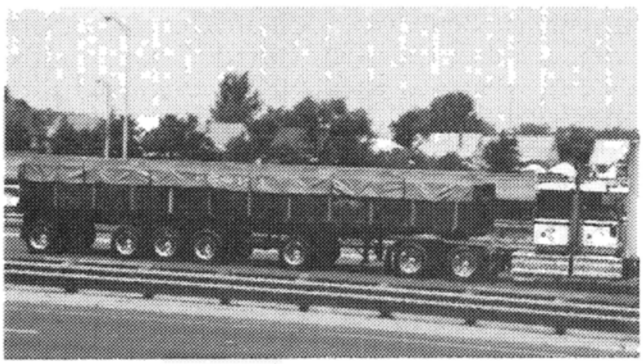
FIGURE 14e

axles are loaded less than they could be. For commodities such as steel, when the gross weight is known, it might be difficult to place the load so that particular axles were not overloaded if maximum axle and gross weights occurred simultaneously. In practice, then, the trucker has some freedom to place such loads to avoid overloading axles or axle groups.

The Ontario weight regulations provide a gross weight incentive to the B-train over the A-train, through the definition of the inter-vehicle-unit distance. An A-train consists of tractor-semitrailer-full-trailer, as shown in the lower diagram of Figure 4, for an 8-axle combination. The governing inter-vehicle-unit distance is typically 2.1 to 3.0 m (6.9 to 9.8 ft). However, for an 8-axle B-train, which consists of tractor-semitrailer-semitrailer, the inter- vehicle-unit distance is always in excess of 3.6 m (12 ft). This requires use of a different table, which, typically, would allow the B-train 2000 to 3000 kg (4400 to 6600 lb) more than the A-train. Most other provinces currently tend to allow, at best, no advantage to the B-train over the comparable A-train, though B.C. only permits a particular B-train configuration to reach its maximum gross weight of 63 500 kg (140 000 lb) (18).

A de facto standard heavy-haul vehicle emerged in Ontario after 1978, exemplified by the B-train double tanker originated by the petroleum industry, shown in Figure 16. This 8-axle vehicle is 21.0 m (69 ft) long. The short wheelbase cab-over-engine tractor has a heavy-duty front axle carrying at least 7000 kg (15 400 lb), with a fifth wheel about 0.76 m (30 in) ahead of the centre of the drive tandem to transfer load to the front axle. The centre tri-axle has an overall spread of 3.05 m (10 ft), and the two tandem axles each have spreads of 1.83 m (6 ft). This vehicle can gross 63 500 kg (140 000 lb). Notice, however, that with a 7000 kg (15 400 lb) steer axle load and a maximum load of 22 400 kg (49 400 lb) on the centre tri-axle, the two tandem axles, at an average of 17 050 kg (37 600 lb), are loaded less than the maximum permitted. This provides the operator some flexibility in loading the vehicle.

Prior to 1978 A-trains with short pup trailers, such as shown in Figure 17, were widely used as



8-axle semi

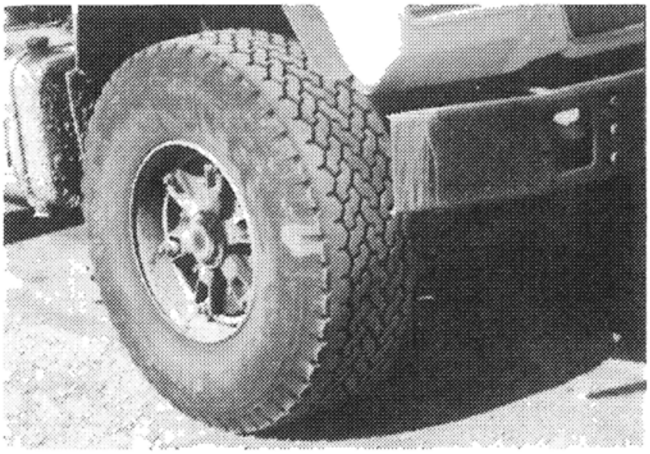
FIGURE 15

8-axle A-train with short pup trailer

FIGURE 17

8-axle B-train

FIGURE 16



Typical gravel truck front axle

FIGURE 18

tankers because this was an easy configuration with which to achieve maximum gross weight. Unfortunately, this configuration has relatively low stability, and it was easy to roll the pup trailer in an accident avoidance manoeuvre. The pup trailer also tended to sway in normal driving. The change in 1978 effectively eliminated these vehicles in favour of the B-train.

It is of interest to note that the various sectors of the trucking industry have evolved their own de facto standards for truck design. Moreover, they do not always make full use of the allowances permitted by the regulations. For instance, concrete mixers and straight trucks used for earth or gravel haul, either alone or in a truck-trailer combination, uniformly use the full allowable front axle load of 9000 kg (19 800 lb), as shown in Figure 18. The petroleum industry requires only 7000 kg (15 400 lb) front axle load to reach a gross weight of 63 500 kg (140 000 lb) and uniformly uses that, though the front axle typically has a higher rating than that. Other heavy-haul sectors, such as steel, lumber, and gravel in tractor-trailers or doubles, generally restrict their front axle loads to 5000 to 6000 kg (11 000 to 13 200 lb), even though there may be a modest payload advantage by using the higher front axle load. Other operators use the A-train, either for particular operational reasons or because it provides the highest gross weight between Ontario and one or more other jurisdictions.

The range of vehicle configurations in Ontario is very large. The diversity is principally in vehicles of six or more axles, which are designed for a particular mission that is usually weight limited. Such vehicles make up, perhaps, 30% of the total heavy trucks on the highway, with the 6-axle combinations being the bulk of these. The number of a particular configuration, or the number making use of a particular feature of the regulations, is unknown. Moreover, these numbers are always changing as designers find new ways to increase productivity. Indeed, it is not considered particularly useful to identify and track vehicle configurations within the fleet. As new configurations are created, they flourish if they are productive and handle well, or disappear if their economics are not good enough or they have operational or safety problems.

8. CONCLUSIONS

The Ontario weight regulations are among the most liberal in North America. They are based mainly upon considerations of bridge and pavement loading. They are solidly founded on many years of research, testing, and analysis. The bridge design loads embodied in an innovative bridge design code are modelled upon the actual traffic on Ontario's highways.

The Ontario weight regulations are organized as a set of tables, with a myriad of vehicles possible for each entry. Each such vehicle has an approximately equal effect on bridges. The regulations do not address vehicle configuration directly, so they are similar to a performance specification, and vehicle designers have considerable freedom to configure vehicles to a particular mission. This freedom has been extensively used, as can be seen in the rich mixture of vehicles on the highway, which demonstrates the ingenuity of industry to squeeze additional productivity from their fleets.

Some vehicle configurations that arose in the early days were less than ideal in terms of stability, handling, and other operational factors. Most disappeared rather quickly, as designers learned new ways to use the regulations to their advantage. Some less desirable configurations remain, but by the safety records it appears that their drivers must simply be able to adapt their style of driving to the vehicle.

REFERENCES

1. Agarwal, A.C., "Legal Axle and Gross Vehicle Weight Trends in Canada," Appendix A, Vehicle Weights and Dimensions - Bridge Capacity Study, Roads and Transportation Association of Canada, Ottawa, Ontario, 1980.

2. "The Highway Traffic Act," Revised Statues of Ontario, 1970, Vol. 2, Chapter 202, Government of Ontario, 1970.

3. Armstrong, M.D., Jung, F.W., and Phang, W.A., "A Proposed Method of Regulating Vehicle Weights in Ontario," RR 166, Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1970.

4. Jung, F.W., and Witecki, A.A., "Determining the Maximum Permissible Weights of Vehicles on Bridges," RR175, Research and Development Division, Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1971.

5. "Axle Weight Legislation made under the Highway Traffic Act and Regulations," Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1971.

6. Agarwal, A.C., "The Proposed Vehicle Weight Tables and their Operating Procedure," Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1977.

7. "Vehicle Dimensions and Weight Limits in Ontario," Ministry of Transportation and Communications of Ontario, Downsview, Ontario, Compliance Branch booklet, July 1984.

8. Bakht, B., and Csagoly, P.F., "Bridge Testing," Ontario Ministry of Transportation and Communications, Research and Development Branch Report 79-SSR-10, August 1979.

9. Bakht, B., "Protection of the Road and Structure Investment through Weight Control - Bridge Testing," ONT-020, Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1985.

10. Csagoly, P.F., and Dorton, R.A., "Proposed Ontario Bridge Design Load," RR 186, Research and Development Division, Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1973.

11. Agarwal, A.C., and Wolkowicz, M., "Ontario Commercial Vehicle Survey 1975," Interim Report, Research and Development Division, Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1976.

12. Agarwal, A.C. and Csagoly, P.F., "Evaluation and Posting of Bridges in Ontario," Bridge Engineering, Volume 1, Transportation Research Record 664, Transportation Research Board, National Academy of Sciences, Washington, D.C. 1978.

13. Csagoly, P.F. and Dorton, R.A., "Truck Weights and Bridge Design Loads in Canada," SRR-79-2, Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1978.

14. "1983 Ontario Highway Bridge Design Code and Commentary," Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1983.

15. Nowak, A.S., and Agarwal, A.C., "Calibration of the Ontario Highway Bridge Design Code," SRR-81-01, Research and Development Branch, Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1981.

16. Agarwal, A.C., "Vehicle Weight Regulations Across Canada: A Technical Review with Respect to the capacity of Highway System," RR214, Research and Development Division, Ministry of Transportation and Communications of Ontario, Downsview, Ontario, 1978.

17. Agarwal, A.C., and Davis, B.R., "Bridge Evaluation for Vehicle Weight Regulations Across Canada," Bridge Maintenance and Rehabilitation Conference, ASCE/TRB/IABSE/WVDOH, Morgantown, West Virginia, 1980.

18. Nix, F.P., Clayton, A.M., and Bisson, B.G., "A Study of Vehicle Weight and Dimension Regulations and Canada's Trucking Industry, Background Paper #1, Analysis of Canada's Vehicle Weight and Dimension Regulations," University of Toronto/York University Joint Program in Transportation, draft report, October 1985.