Pavement Response to Heavy Truck Axle Loadings: The Canadian Vehicle Weights and Dimensions Study

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1.0 INTRODUCTION

In 1984 a major government/industry cooperative research project, the Vehicle Weights and Dimensions Study, was launched with an overall goal of achieving uniformity in the application of vehicle weight and dimension regulations across Canada. As part of this study, a research program was developed to assess the relative destructive effects of traffic load variables on pavements from insitu pavement response measurements. The program, referred to as the Pavement Impacts Investigation, involved the installation of instrumentation capable of recording strains and deflections under moving traffic loads in fourteen flexible pavement structures at various locations across Canada. During the summer of 1985, pavement surface deflections and asphalt concrete-base layer interfacial tensile strains under a wide range of controlled truck axle loads and configurations was carried out at each site. These field measurements, together with established pavement distress criteria, are being used to calculate load equivalency factors for each test configuration.

This paper contains a brief description of the instrumented structures. The installed instrumentation and data acquisition system used to record the pavement response variables are described and vehicle loading conditions and test procedures followed at each site are presented. Results of preliminary analyses carried out on surface deflections and interfacial tensile strains recorded at one of the fourteen sites are presented.

2.0 INSTRUMENTED PAVEMENT STRUCTURES

The location and description of each instrumented pavement structure included in the study is presented in Table 1. This information was extracted from more detailed structural data provided by the host provinces. The structures were selected as representing typical regional design and construction practices. The fourteen sites encompass pavements with asphalt concrete layer thicknesses ranging from 56 mm to 225 mm, total component layer thicknesses varying from approximately 300 mm to greater than 2000 mm, and a wide spectrum of base, subbase and subsoil materials.

In Alberta, site 9 is immediately adjacent to site 10. Similar paired sites are 3A and 3B, and sites 4 and 5, in Quebec. The multichannel capabilities of the acquisition system used to monitor the pavement responses enabled these paired sections to be tested concurrently.

3.0 INSTRUMENTATION AND DATA ACQUISITION SYSTEM

Instrumentation developed by the Alberta Research Council for measuring pavement deflections and strains under moving wheel loads was installed in each pavement structure. Details of the instrumentation and a description of the operations of the data acquisition system used to monitor the pavement response variables are presented in Reference 1.

3.1 INSTRUMENTATION

Instrumentation installed at each site consisted of:

i) subsurface referencing assemblies for housing surface-set differential transformers, positioned transversely across the outer wheelpath, to measure total pavement deflection,

ii) asphalt plate strain carriers with embedded gauges, positioned across the outer wheelpath at the asphalt concrete-base layer inter-

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face, to measure longitudinal interfacial tensile strains,

iii) an access port, located off the shoulder, for housing cabling leading from the roadway instrumentation, and

iv) a thermocouple string, located near the outer edge of the instrumented lane, for pavement temperature measurements.

The program design called for the installation of three pavement surface deflection and three strain transducers in the outer wheel path at each site. A schematic of a typical pavement transducer layout is shown in Figure 1. The triplicate transducer configuration, with deflection and strain transducers directly aligned, minimized the number of test runs required to record maximum strains and deflections under a given vehicle loading and provided backup in the event of a transducer malfunction.

Instrumentation consisting of three strain carriers, housing for three deflection transducers, an access port and a thermocouple string was fabricated for each site. These instrumentation packages, together with all necessary cabling and guidelines describing recommended installation procedures, were forwarded to the host agencies.

Table 1 – Pavement test sites

Site no.	Province	Location	A.C. thick. (mm)	Base thick. (mm) - material	Sub-base thick. (mm) -material	Subgrade material
1	New Brunwick	Hwy. 15 - 10 km E. of Moncton	225	76- Crushed rock	460- Crushed sandstone	Silty-sand
2	Nova Scotia	Hwy. 102 - 6 km S. of Truro	160	275- Granular	200- Granular	Gravelly-clay
3A	Quebec	Hwy. 40 - 55 km W. of Quebec City	135	200- Crushed limestone	625- Granite sand	Granitic-gravel
3B	Quebec	Hwy. 40 - 55 km W. of Quebec City	130	375- Crushed limestone	450- Granitic sand	Granitic-gravel
4	Quebec	Rte. 363 - 73 km W. of Quebec City	56	150- Granitic gneiss	450- Granitic sand	Clay
5	Quebec	Rte. 363 - 73 km W. of Quebec City	56	200- Granitic gneiss	550- Granitic sand	Clay
6	Ontario	Hwy. 7 - Peterborough Bypass	110	150- Granular A	350- Granular C	Silty-sand
7	Ontario	Hwy. 403 - 19 km W. of Brantford	170	200- Granular A	250- Granular B	Sand
8	Ontario	Hwy. 55 - 8 km. E. of St. Catharines	190	300- Granular A	90- Old road	Clay
9	Alberta	Hwy. 21 - 8 km N. of Three Hills	136	170- Cement stab. sand	- -	Clay
10	Alberta	Hwy. 21 - 8 km N. of Three Hills	136	250- Granular	- -	Clay
11	British Columbia	Hwy. 97 - 110 km W. of Chetwynd	75	145- Asphalt bnd. gran. 200-Granular	610- Granular 1000-Shot rock	Peat/silty sand
12	British Columbia	Hwy. 97 - 112 km W. of Chetwynd	85	155- Asphalt bnd. gran. 210- Granular	610- Granular 975- Silty gravel	Silty-sand
13	British Columbia	Hwy. 16 - 16 km N.W. of Tete Jaune Cache	100	545- Granular	50- Clay and sand 450- Pit run gravel	Clay

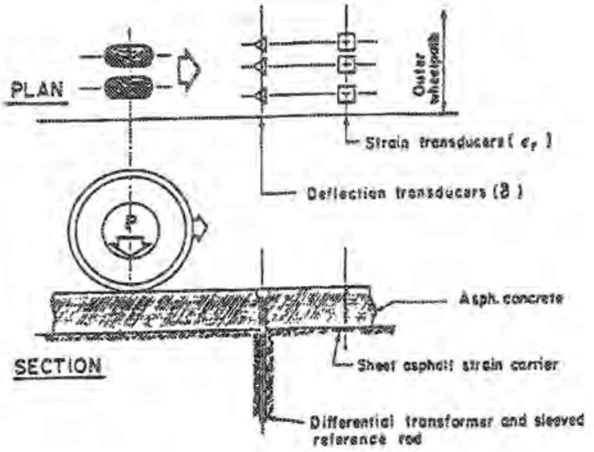
3.1.1 Installation of Instrumentation

The instrumentation was installed by Highway and Transportation personnel during the summer and fall of 1984, with regional on-site supervision and technical assistance by Alberta Research Council personnel. This was provided for the installation of all instrumentation at site 1 - New Brunswick, site 2 - Nova Scotia, site 3A and 3B - Quebec, sites 9 and 10 - Alberta, site 13 - British Columbia, and following paving operations for the installation of two deflection transducer casings at site 7 - Ontario.

3.2 DATA ACQUISITION SYSTEM

The data acquisition system used to record the pavement strains and deflection is developed around a mini-computer with various peripherals and, for field operations, is housed in a van with a self-contained power source. The peripherals include dual hard disks for mass storage of transducer signals and two real time clocks which permit variable signal sampling rates and enable the time of recorded pavement response variables to be identified and vehicle velocities calculated. A video and hardcopy terminal, together with developed software, enable the operator to obtain a visual display and hardcopy printout of maximum and minimum response values recorded under each axle by all designated transducers. The system is capable of monitoring 16 channels simultaneously.

Data collected for all vehicle loadings included in the study was stored on hard disk and subsequently retrieved for summary and analysis.



Schematic of field instrumentation

FIGURE 1

4.0 FIELD TESTING PROGRAM

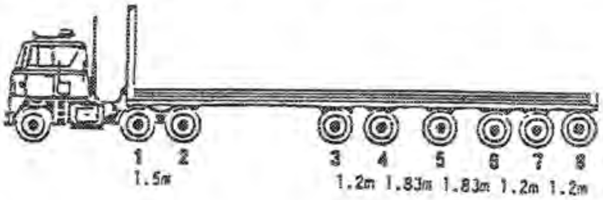
In designing the study, it was the consensus of the Pavements Advisory Committee that the program encompass pavement surface deflection and longitudinal interfacial tensile strain measurements under a series of loads and axle configurations at each site. To ensure that vehicle load variables were constant from site to site, and to facilitate field testing operations, a flatdeck trailer was specially modified to accommodate all desired loading conditions. The following contains a brief description of the pavement test vehicle. Load variables included in the study are presented, and field testing procedures are described.

4.1 PAVEMENT TEST VEHICLE

A schematic of the pavement test vehicle is shown in Figure 2.

The specially designed trailer, equipped with one fixed axle (axle 6) and five lift axles, together with the tractor steering and tandem drive axles, provided the following axle configurations to the study.

Configuration	Axle(s)
1) Single Axle-Single Tire	Steering
2) Single Axle-Dual Tire	6
3) Tandem Axle-Dual Tire (1.2 m)	6 & 7
4) Tandem Axle-Dual Tire (1.5 m)	Drives (1 & 2)



Tractor:	1985 MACK R688ST: - 5.1 m wheelbase - spread tandem drives on Neway ARD244 air suspension
Trailer:	1974 Fruehauf 13.7 m Flatdeck: - 1 fixed axle on Neway AR95 air suspension - 5 lift axles on Neway AR95 air suspension
Tires:	All axles fitted with Michelin 11R22.5 XZA LRH tires.

Pavement test vehicle

FIGURE 2

5) Tandem Axle-Dual Tire (1.8)	5 & 6
6) Triaxle-Dual Tire (2.4 m)	6 & 7 & 8
7) Triaxle-Dual Tire (3.7 m)	4 & 5 & 6
8)*Triaxle-Dual Tire (4.9)	3 & 5 & 6

* This configuration, with unequal spacings between axles, is commonly termed a belly axle assembly.

Twenty-seven concrete blocks, each weighing 1000 kg, were used for live load. Variations in gross axle weights for each configuration were obtained by loading, unloading and/or repositioning the blocks using a mobile crane on the trailer deck.

4.2 LOADING CONDITIONS

Calibration of the test vehicle was carried out by Canroad Transportation Research Corporation personnel at the Alfred, Ontario scale site during mid-May 1984. This task involved a) identifying both the number and the location of concrete blocks on the trailer which would yield gross weights for each configuration approximating guidelines established by the Pavements Advisory Committee and, concurrently, b) establishing a testing sequence which would minimize the number of block loading, unloading, and repositioning, operations. The developed testing sequence was comprised of 19 test iterations and is presented in Table 2.

Table 2 – Vehicle axle configurations and loadings by test series

Test series	Test configuration	Gross weight of test configuration (kilograms)*	Gross weight of tandem drives (kilograms)
1	Triaxle 2.4 m	31 645	10 645
2	Triaxle 2.4 m	26 145	10 345
3	Triaxle 3.7 m	31 664	5 445
4	Triaxle 4.9 m	31 955	6 682
5	Tandem 1.2 m	22 327	15 336
6	Triaxle 2.4 m	20 082	15 582
7	Triaxle 3.7 m	26 036	9 109
8a	Tandem 1.8 m	22 127	11 718
8b	Triaxle 4.9 m	25 836	8 209
9	Tandem 1.2 m	18 100	14 936
10a	Tandem 1.8 m	18 382	11 827
10b	Triaxle 3.7 m	20 510	9 555
11	Tandem 1.2 m	13 582	14 582
12	Tandem 1.2 m	14 064	12 500
13	Single axle	11 127	13 136
14a	Single axle	9 182	13 236
14b	Steering axle	3 790	13 236
15a	Tandem 1.5 m	19 280	19 280
15b	Steering axle	5 110	19 280

* 1 kg = 2.205 lb.

Test series identified by letters "a" and "b" involved a change in axle configuration with the number and arrangement of concrete blocks remaining constant. With the exception of test series 15b, steering axle gross weights were relatively constant and approximately equal to 3900 kg. To obtain the steering axle weight equal to 5110 kg, series 15b, the position of the fifth wheel was moved forward approximately 450 mm. In addition to the listed loadings, pavement responses under a 9570 kg single axle-dual tire load (axle 6) were monitored when conducting test series 15a. Inflation pressure of all tires was held constant and equal to 690 kPa throughout the study.

The loading condition matrix obtained from the calibration and used throughout the study is:

Configuration	Gross Weights, (kg)
Steering Axle	3790, 5110
Single Axle	9182, 9570, 11127
Tandem (1.2 m)	13582, 18100, 22327
Tandem (1.5 m)	5445 to 19280
Tandem (1.8 m)	14064, 18382, 22127
Triaxle (2.4 m)	20082, 26145, 31645
Triaxle (3.7 m)	20510, 26036, 31664
Triaxle (4.9 m)	25836, 31955

Prior to commencing field tests, individual axles of each configuration were weighed at the Leduc, Alberta scale station. Gross weights of each configuration were in very close agreement with those obtained during calibration, and with the exception of triaxle configurations tested under series 3, 4, 7 and 8b, the gross weight of each tandem and triaxle group was approximately equally distributed on axles comprising the group. Weight distributions for the four triaxle configurations were:

Test series	Axle 3	Axle 4	Axle 5	Axle 6	Gross wt. (kg)
3		9330	10520	11570	31420
4	9300		10860	11690	31850
7		7860	8770	9080	25710
8b	7610		8730	9130	25470

5.0 TESTING PROCEDURE AND ANALYSIS METHOD

Pavement responses for each configuration and loading were measured at approximately 6 km/hr., 13 km/hr. and 50 km/hr. In addition, when posted speed limit, traffic safety and local conditions allowed, one loading configuration was tested at approximately 80 km/hr. To ensure that maximum pavement responses were recorded under each loading condition, a minimum of three test runs were carried out at each velocity level. An engine governor on the test vehicle enabled very close replication of velocity.

Immediately following each test run pavement responses were recorded under an 8160 kg single axle-dual tire load of a Benkelman Beam vehicle with tires inflated to 550 kPa. Employing this testing procedure, comparisons between the magnitude of pavement responses caused by each loading condition to those caused by the standard load are made at similar vehicle velocities and pavement temperatures. These comparisons (in the form of interfacial tensile strain and surface deflection ratios), combined with asphaltic concrete fatigue life and limiting pavement surface deflection criteria, allow the relative potential damaging effect or load equivalency factors of each vehicle loading condition to be predicted.

Details of procedures used to derive equivalency factors from the measured responses are contained in Ref. 1. Briefly, equivalency factors, F, for single axle loads are predicted using these expressions:

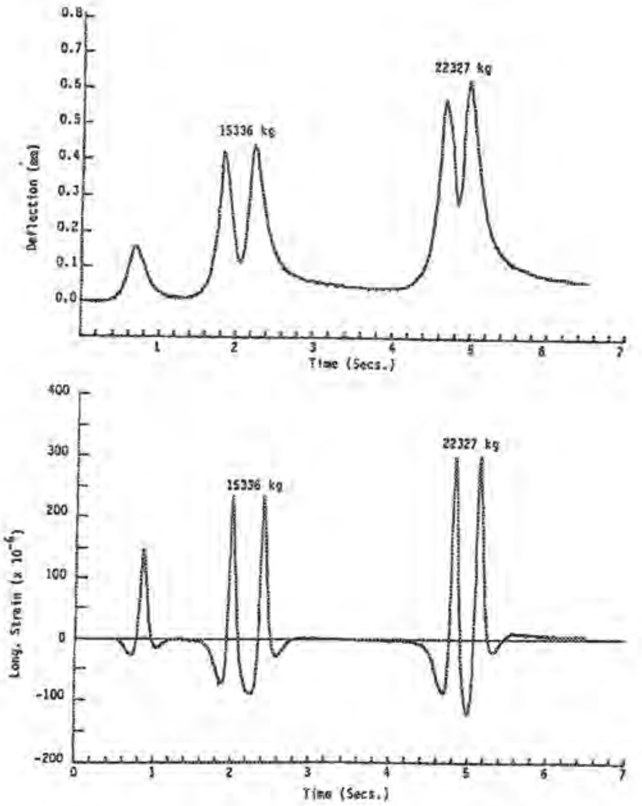
$F_\varepsilon = (\varepsilon/e_b)^{c_o}$ and $F_\delta = (\delta/\delta_b)^{c_1}$

where

ε/e_b = the ratio of maximum longitudinal interfacial tensile strains caused by a single axle load to those caused by the standard load,

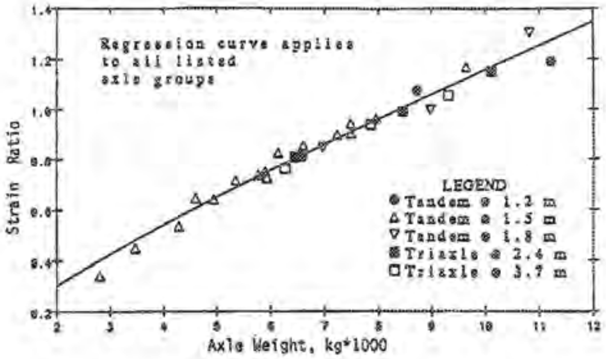
δ/δ_b = the ratio of maximum surface deflections caused by a single axle load to those caused by the standard load, and

c_o and c_1 = the slope of fatigue life-tensile strain and deflection anticipated traffic relationships, respectively.



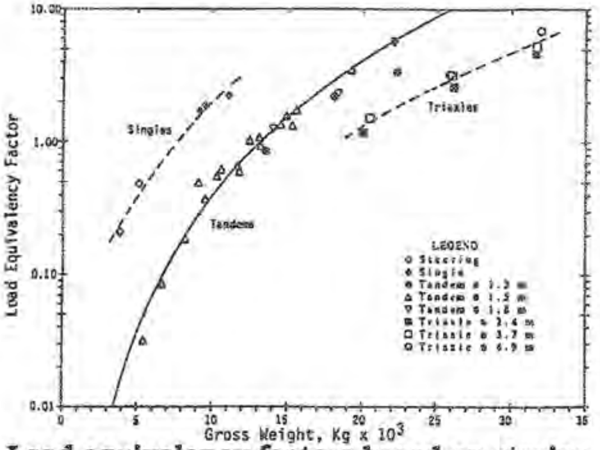
Typical deflection and strain profiles

FIGURE 3



Axle weight versus strain ratio

FIGURE 4



Load equivalency factors based on strains

FIGURE 5

Equivalency factor for axle groups are predicted from the sum of exponential response ratio values for all axles in the group. Following the recommendations of the Pavements Advisory Committee to the study, the exponents C were set equal to 3.8.

6.0 PRELIMINARY RESULTS

The field testing program commenced on May 29, 1985 in Alberta and was completed on August 19, 1985 in Quebec. The full program included approximately 2500 test runs with the pavement test vehicle and approximately an equal number with Benkelman Beam vehicles. At the present time, data analysis and report preparation tasks are underway. The following presents preliminary results from one of the 14 test sites.

Typical pavement surface deflection and longitudinal interfacial tensile strain profiles recorded under the test vehicle are shown in Figure 3. Loading conditions for these response profiles are described in Table 2 by test series 5. Comparisons between average maximum tensile strains caused by the lead axle groups, within this and other test series at the site, to those recorded under the standard 8160 kg load at the same velocities and pavement temperatures as the lead axles are shown in Figure 4. These comparisons or strain ratios suggest that interfacial tensile strains are primarily dependent on axle weights and are, for practical purposes, independent of axle spacing. Similarly, results of analysis carried out on surface deflections indicate that maximum deflections under the lead axle of axle groups are primarily axle weight dependent. Applying the exponent coefficient C equal to 3.8 to strain response ratios, gross axle weight versus load equivalent factor trends for single, tandem and triaxle configurations are presented in Figure 5.

The trends suggest that, based on asphaltic concrete fatigue life criteria,

(a) at gross weights equal to approximately 9500 kg, one application of a single-axle dual tire configuration is approximately equivalent in potential damaging effect to three applications of a tandem axle-dual tire configuration,

(b) at gross weights ranging from approximately 20000 to 23000 kg, one application of a tandem axle configuration is approximately equivalent in relative destructive effect as three applications of a triaxle configuration and,

(c) for a given tandem axle-dual tire gross weight, equivalent single and triaxle gross weights are approximately 60 and 140 percent, respectively, the tandem gross weight.

As previously noted, results presented herein are preliminary and from one of the 14 instrumented pavement test facilities. The results may not be indicative of those obtained from other sites or be representative of the overall findings of the study.

7.0 REFERENCES

1. Christison, J.T. "In Situ Measurement of Pavement Behaviour Under Load", Roads and Transportation Association of Canada, Transportation Forum, Vol. 1 - 4, March 1985.