Installing weight monitoring devices in flexible pavements: the New Zealand experience

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Over the last five years New Zealand has followed the worldwide trend of roading authorities by embarking on an ambitious programme to install weight monitoring devices throughout its strategic highway network. To date ten sites have been completed, using a range of equipment developed in Europe and Australia. Our success rate has been variable, and a number of lessons have been learnt about the six different systems which we have purchased. Problems which have been encountered include site selection, temperature variation, pavement flexibility, and reporting format. Our future programme has been modified to concentrate on fewer key locations using more accurate, robust equipment.

1. BACKGROUND

The New Zealand National Roads Board's plan for weight monitoring in 1987 included building 10 weigh-in-motion (WIM) devices annually at strategic locations over a five year period. These were intended to augment the programme for traffic classifiers — devices which record numbers, speeds and axle spacings, but not weight. At that time Roading Division of Ministry of Works and Development, as servicing agent for the Board, had already installed the first bending plate system at Pukerua Bay, north of Wellington.

The policy then developed into the installation of a wide range of devices manufactured in Europe and Australia, with the intention of later assessing their relative success rate in New Zealand's flexible pavements. To date six different systems have been trialled at ten sites. These include:

(a) Bending plates containing strain gauges internally wired as a bridge;

(b) Piezo-electric cables set in epoxy. Three different brands have been trialled;

(c) Capacitance strips set in epoxy; and

(d) Strain gauge transducers fixed to culverts.

The locations of the weight monitoring devices installed as at 1 December 1991 are shown in Fig 1.

2. NEW ZEALAND'S FLEXIBLE PAVEMENTS

New Zealand is a small country (266,917 sq km in area or approximately 10% larger than the United Kingdom), has a low population density (3.45 million) and has a total roading network of 92,600 km of which the state highway length is 10,677 km. It is also a geologically varied country with a wide range of soil and rock conditions. In places its topography is mountainous, and its climatic conditions severe.

Many of the roads in New Zealand developed from cart tracks by gradual improvement and eventually being surfaced. The typical road has been constructed of unbound aggregates on a compacted subgrade with a chip-sealed bituminous surfacing. On state highways the pavement depth is of the order of 250-350 mm, whilst on more minor roads it is typically only 100 mm.

Approximately 96 percent of New Zealand roads have very flexible, low strength and low cost pavements compared to nearly all other developed countries. The reason for this has been both the shortage of original capital to construct higher quality pavements and the use of technology which has tended to increase serviceability for the least possible capital outlay.

Only in the urban areas and on heavily trafficked pavements has use been made of both thin and structural layers of asphaltic concrete. A few concrete roads were built in the late twenties while in the late fifties to early sixties a number of pavement layers were cement stabilised. More recently there has been a trend towards lime stabilisation.

3. SITE SELECTION AND INVESTIGATIONS

Locations for weight monitoring devices have been largely dictated by information requirements. The sites selected have all been on routes which carry significant numbers of heavy vehicles. Proximity to permanent weight enforcement facilities (eg weighbridges and scales) has also been a consideration.

Once the need for a device in a general location has been established, detailed investigations have been undertaken to confirm the practicality of a site and select a specific location. With increasing experience of the performance of the various devices, the degree of investigation has also increased.

At all potential sites where devices are to be installed within the road surface, a full picture of the pavement is obtained from visual inspection, records, and excavation. Testing by benkelman beam survey is carried out to establish uniformity and indicate pavement flexibility. A detailed survey in each wheel path is made to establish the road profile in advance of the site. A check is made of crossfall to ensure that this is not excessive. In several cases a dynamic load simulation has been obtained using a program developed by the Australian Road Research Board, which drives a typical six axle truck/trailer unit over the road profile and records the variation in dynamic weight of the axle groups (refer to Figs 2-3 for an example).

A report of investigations at a proposed piezo-electric cable site is shown as Appendix 1.

4. GENERAL RESULTS

4.1 Bending plates

Three sites were completed late in 1989 and have been operating for two years now, using the DAW 200 weighpad system from Pietzsch Automatisierungstechnik GmbH (PAT), Germany. This system uses strain gauges bonded to low profile pads supported in a concrete foundation. We have found this system to be robust and highly accurate. Capital costs to install the equipment were high, and we also experienced some adverse reaction from the transport industry because of the obvious presence of the devices within the road surface.

4.2 Piezo-electric cables

In an effort to reduce capital costs and follow developments in overseas technology, sites were selected for installation of three brands of piezo-electric sensors.

A single-lane AWACS 6000 from GK Instruments Ltd, United Kingdom (now renamed Peek Traffic Ltd) was installed in an existing granular pavement. This equipment initially performed satisfactorily, but it proved impossible to set reliable calibration levels because of apparent seasonal variation in the pavement stiffness. The site has recently been abandoned and equipment retrieved.

For a two-lane piezo-electric model from ECM (Electronique Controle Mesure), France a 200mm thick reinforced concrete slab was specially constructed to locally strengthen the area of installation. Benkelman beam testing before and after strengthening confirmed a tenfold reduction in pavement flexibility. To date this site has had commissioning problems, relating to the software and sensor installation. The equipment is of the earlier single sensor design, and the processing unit is to be upgraded. We anticipate a moderate accuracy level from this site once the alterations are completed.

The third system which has been tried is the PAT DAW 200 piezo-electric cable model, which uses identical software and computing equipment as the PAT weighpads. The piezo system used was an early design involving a trapezoidal loop installed in each lane, which incorporated three half-lane sensors. This equipment was installed at three sites in Auckland city in 1989 within motorway pavements having 100mm thick asphaltic concrete (semi-flexible) construction. One four-lane site has operated satisfactorily since commissioning. A second site has recently been abandoned because of problems with vehicles lane changing and ghosting of results due to pavement flexibility. The third site at Auckland, whilst operating successfully, has recently been decommissioned because few heavy vehicles were passing.

4.3 Capacitance strips

The most recent installation has used the Marksman 600 capacitance strip system from Golden River Ltd, United Kingdom. This has been located in a semi-flexible pavement as an initiative by the manufacturer's local agent. It is currently operating as a traffic classifier, but it is hoped that it will be calibrated for weight monitoring shortly. Five other sites are operating as urban classifiers where weight information is not required.

4.4 Strain gauges on structures

A single lane CULWAY system developed and marketed by the Australian Road Research Board was installed on a short span bridge about four years ago. It has been producing reliable data in a summary format which has yet to be analysed for accuracy of weight measurement.

5. REPORTS FROM BENDING PLATE WIMs

5.1 Data collection

These three systems have produced over two years' data each. Data is collected in two forms:

(a) Hourly statistics of cars and light commercial vehicles with and without trailers, and heavy vehicles in two categories based on length. Speed statistics are given for all types of vehicles and gross load and axle group load statistics are given for heavy commercial vehicles.

(b) Individual vehicle records for heavy vehicles consisting of:
- date and time vehicle passed over site
- site and lane numbers
- vehicle type code
- gross weight and individual axle weights
- total length and inter-axle distances
- speed

An example of individual records (ie real time format) is shown in Table 1.

Heavy vehicles in 1991 data are currently defined according to the New Zealand Transport Amendment Act 1989 as "a motor vehicle . . . the gross laden weight of which exceeds 3,500 kilograms". Previously the minimum gross weight of 2,000 kilograms as defined by the Heavy Motor Vehicle Regulations was used, but this was distorting statistics as 70 percent and more of the vehicles being recorded were car/light commercial vehicles with or without trailers which were just exceeding the limit.

Heavy vehicles are given a code based on axle configuration and in some cases, eg 2 axle vehicles, wheelbase. An attempt has been made to distinguish between rigid trucks and articulated vehicles based on the distance between the front steer axle and the second axle in single steer vehicles. The code has been developed from the standard PAT classification system of approximately 50 vehicle types.

5.2 Data processing

Data is retrieved from the sites using a personal computer and modem. The data is then transferred to the mainframe computer where it is stored in keyed VSAM (Virtual sequential access method) databases. Statistics are stored in one database for all sites for each year. Individual vehicle records are stored in individual site databases for each year. These individual databases can be easily combined at any time if required.

Statistics data are loaded unedited into the database. Vehicle records are systematically screened prior to loading into the databases to edit any outliers.

Samples from the database can be selected based on site, lane, vehicle code, hour of day, day of week and/or date.

Using software specifically developed for Transit New Zealand reports in table or graph format can be produced on weight, length, speed, Equivalent Design Axle (EDA) and compliance with Heavy Motor Vehicle Regulations for the selected sample.

5.3 Reports

An example of a monthly report format prepared for the national heavy vehicle enforcement agency (Ministry of Transport) is included as Appendix 2. It should be emphasised that these reports are prepared in order to highlight trends in heavy vehicle transportation, since the devices are not intended to act as real-time screens for the enforcement authorities.

6. INTERIM CONCLUSIONS FROM THE INSTALLATION PROGRAMME

Weight monitoring technology never stands still. There has been an enormous amount of interest in the subject from roading agencies and enforcement organisations, and this has led to rapid product development. We now have a very wide range of equipment available, ranging from the high capital cost, robust, bending plate systems capable of achieving at least ± 8 percent gross weight accuracy, through to a multitude of piezo-electric componentry which is cheaper to install, around 15-20 percent accurate, and may last three years if good fortune is with you.

Problems encountered by Transit New Zealand have included:

- poor site selection, insufficient investigation of pavement
- pavement flexibility
- incompatible modems
- epoxy failures
- temperature variations
- reporting format
- classification systems
- equipment obsolescence

We have found that piezo-electric systems prefer stiffer pavements (eg benkelman beam deflections below 0.5mm at all times), and that results generally fall well short of the purchaser's expectations. It is likely that in future we will focus on fewer key sites using high accuracy weighing equipment located on good foundations, and rely on traffic classifiers, possible fitted with low accuracy weighing capability, to provide overall patterns and trends.

We have found that the data capture and analysis is time consuming and requires a dedicated staff resource. We also quickly built up a plethora of SAS-derived reporting formats produced for various different purposes. We have now been able to standardise reports more, while the enforcement agency has better defined its information requirements.

REFERENCES

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2. BURT EJ. Enforcement Weighing Facilities. National Roads Board Submission 87/6/9041, June 1987.
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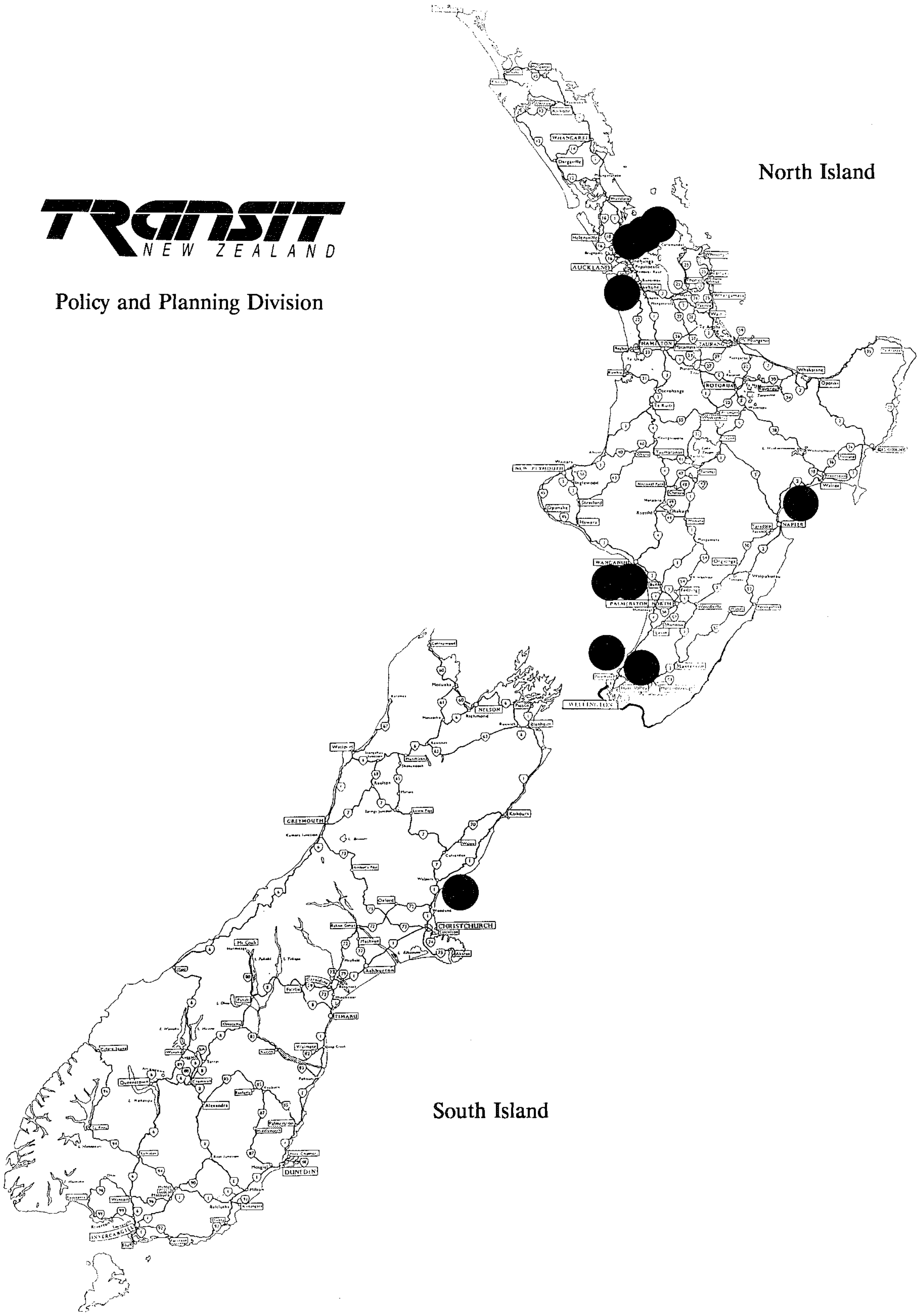


Fig 1 Weight monitoring sites in New Zealand (as at 1 December 1991)

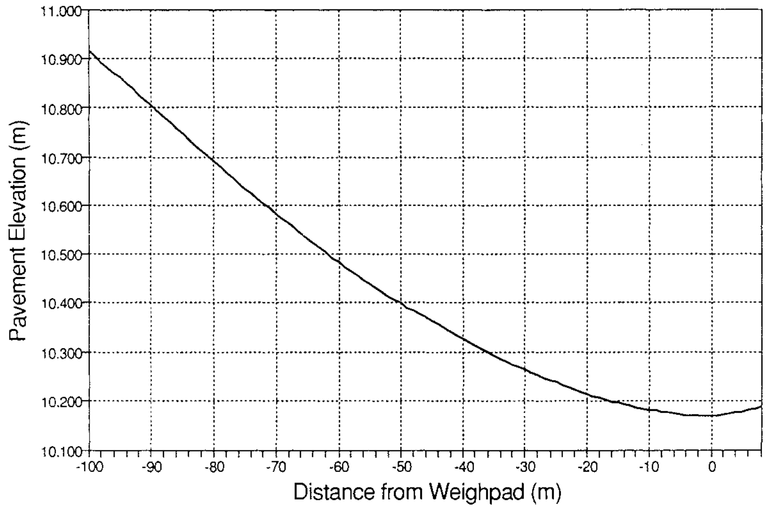


Fig 2 Road profile of a weight monitoring site

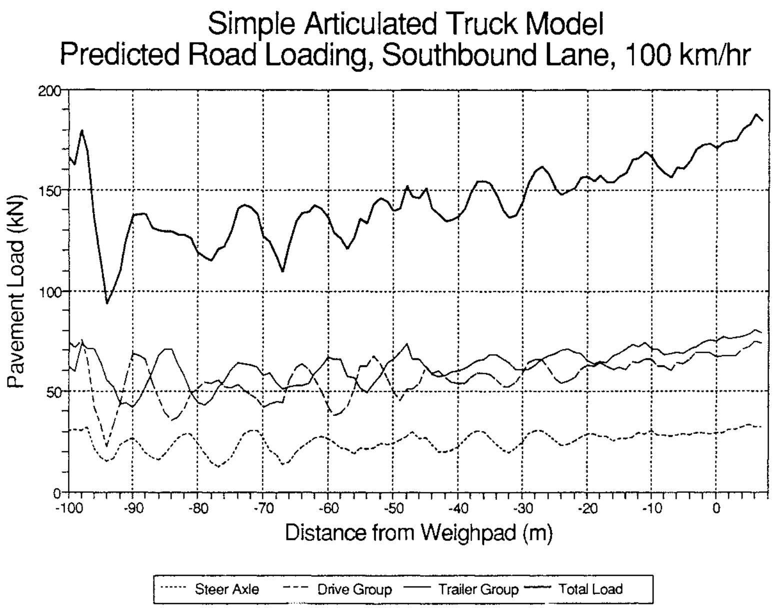


Fig 3 Predicted road loading from dynamic simulation
Reproduced with thanks to Australian Road Research Board, Victoria, Australia

Table 1
Individual vehicle records for heavy vehicles at a PAW DAW 200 weighpad site

Site number : 1
Lane number : 2
Date : 18/2/92 Time : 3:11:52

Vehicle type :	62
Total weight :	37930 (kgs)
Total length :	1927 (cms)
Speed :	73 (km/h)

Axle No	Axle Weight (kgs)	Inter axle distance (cms)
1	3620	
		327
2	6020	
		390
3	6140	
		132
4	6390	
		364
5	8480	
		434
6	7280	

Site number : 1
Lane number : 2
Date : 18/2/92 Time : 3:11:53

Vehicle type :	69
Total weight :	30490 (kgs)
Total length :	1422 (cms)
Speed :	71 (km/h)

Axle No	Axle Weight (kgs)	Inter axle distance (cms)
1	4330	
		355
2	5780	
		134
3	4870	
		484
4	5250	
		128
5	5210	
		128
6	5050	

APPENDIX 1

Report of investigations at a weight monitoring site.
Reproduced with thanks to Works Consultancy Services, Napier, New Zealand.

WORKS Consultancy Services
Shakespeare Road, Private Bag, Napier, New Zealand
Phone (070) 358-196, Fax (070) 350-881

Materials Test Lab,
NAPIER.

Lab File F.I 90
20-7-90

LAB TEST REPORT No. F.I 90/34.

PIEZO WEIGH STATION - WEIGH IN MOTION SITE.
STATE HIGHWAY 2 : R.P 638/5.11 - BAY VIEW , NAPIER.
PAVEMENT INVESTIGATIONS.

JOB No: X336R1L.

CLIENT: Transit New Zealand,
Head Office, WELLINGTON.

CLIENT REQUEST: Carry out pavement investigations at the above site consisting of :
1. Trial test pit to record materials & depths , on departure side of the site.
2. Benkelman Beam Survey.

WORK PERFORMED: The test pit was carried out in the South Lane, on the departure side, 1.7 metres from Survey mark 00.
Benkelman Beam readings were taken at 15 metre intervals for a distance of 60 metres each side of the site.

Tests were performed in accordance with the following standard test methods:
Benkelman Beam Deflection Measurements N.R.B T/1 : 1977.
Determination of Soil strength using a Dynamic Cone(Scala) Penetrometer NZS 4402 Test 6.5.2 : 1988.
Soil Description for Engineering Geological Mapping - IAEG Bulletin No.24:1981.
Determination of Water Content NZS4402:1986 Test 2.1.

RESULTS: Benkelman Beam deflections have been tabulated on Page 2 of this report.
A Bore Log of the test pit has also been presented in graphic form.

A. Ching,
Laboratory Manager.

Benkelman Beam Test results;

Route Position.	Distance from Centreline (m).	Lane.	Deflection Xt (mm).
638/5.050	2.6 = Left	South	0.84
"	0.8 = Right	"	0.84
"	2.6 = Left	North	1.18
"	0.8 = Right	"	1.10
638/5.065	2.6 = Left	South	0.52
"	0.8 = Right	"	0.84
"	2.6 = Left	North	1.06
"	0.8 = Right	"	1.16
638/5.080	2.6 = Left	South	0.84
"	0.8 = Right	"	0.90
"	2.6 = Left	North	0.84
"	0.8 = Right	"	0.78
638/5.095	2.6 = Left	South	0.92
"	0.8 = Right	"	0.98
"	2.6 = Left	North	1.02
"	0.8 = Right	"	1.00
638/5.11	2.6 = Left	South	1.00
"	0.8 = Right	"	0.94
"	2.6 = Left	North	0.98
"	0.8 = Right	"	1.26
638/5.125	2.6 = Left	South	1.20
"	0.8 = Right	"	0.99
"	2.6 = Left	North	1.24
"	0.8 = Right	"	1.04
638/5.140	2.6 = Left	South	0.64
"	0.8 = Right	"	0.90
"	2.6 = Left	North	0.90
"	0.8 = Right	"	0.82
638/5.155	2.6 = Left	South	0.64
"	0.8 = Right	"	0.78
"	2.6 = Left	North	1.14
"	0.8 = Right	"	1.02
638/5.170	2.6 = Left	South	0.64
"	0.8 = Right	"	0.86
"	2.6 = Left	North	0.92
"	0.8 = Right	"	0.92

BOREHOLE LOG | SHEET 3 OF 3 | BOREHOLE NO. 1.

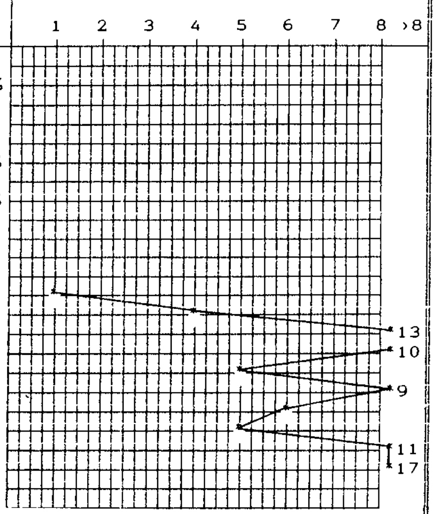
PROJECT: Piezo Weigh Station
SH 2 RP. 638/5.11
PROJECT NO. X336R1L LAB No.FI 90/34

DISTANCE AT START:
DISTANCE: 01.7 m **OFFSET:** South Lane
DESCRIPTION

DRILLING METHOD: Hand Excavated Test Pit.
LOGGED BY: M. McHattie
DATE: 20-7-90
CHECKED BY: A. Ching

PENETRATION RESISTANCE TESTS.
NZS 4402 Test 6.5.2:1988
HAND METHOD USING A DYNAMIC CONE (SCALA) PENETROMETER.
* Number of Blows / 50mm.

DEPTH (M)	DESCRIPTION OF STRATA	GRAPHIC	WATER CONTENT
–	CHIPSEAL 60mm		
–.1	GRAVEL - Silty;Greyish Brown;S.Moist.		3.5%
–.2	220mm		
–	CHIPSEAL(Old Seal)–260mm		
–.3	GRAVEL - Silty		5.4%
–.4	SILT - Clayey;Yellowish Brown;Firm;S.Moist		24.0%
0.5			
–.6	Test Pit Terminated at 0.6 metres depth.		
–.7			
–.8			
–.9			
1.0			



APPENDIX 2
PAT DAW 200 Bending Plate Monthly Report for November 1991

1. Introduction

To present the weigh-in-motion data from the PAT DAW 200 sites in a more user friendly manner a complete reappraisal of reporting procedures has been undertaken over the past few months.

The current format presents a summary of the data giving basically the same information as before but limiting it to three pages per month.

One full week's data from each month is reported. The November reports in the format sent to the Regional Offices for the PAT DAW 200 plate site on State Highway 1 at Pukerua Bay are contained herewith, as Tables 3-4.

2. Vehicle types

The vehicle types used are based on a classification system which groups vehicles according to wheel base and the number of axles. This system was devised by Dave Wanty of the Transit New Zealand Traffic Monitoring Group. Table 2 tabulates the classification system.

Abbreviations used to describe vehicle types are explained below Table 2.

Table 2
Transit New Zealand Vehicle Classification System

Category	Class	Description	Axles	Wheelbase	AS1	AS2
Short	1	light vehicles	2	≤3.1		
Medium	2	light veh + trailer	3	≤8.5	>2,0 ≤4.0	>2.0 ≤5.0
		light veh + trailer	4, 5	≤8.5	>2.2 ≤4.0	>2.0 ≤5.0
	3	van	2	≤4.0		
	4	truck	2	>4.0 ≤5.4		
	5	truck/tractor	3	≤6.7		
		artic	3	≤8.5	>2.0	>5.0
	6	truck/artic	4,5	≤8.5		
	7	bus	2	>5.4 ≤8.5		
		bus/coach	3	>6.7 ≤8.5		
Long	8	artic	3,4	>8.5 ≤15.5		
	9	or	5	>8.5 ≤15.5		
	10	truck + trailer	6,7	>8.5 ≤15.5		
V long	11	T&T	4-6	>15.5 ≤21		
		A&T, T&T	7	>15.5 ≤34		
		B-train				
	12	A&T, T&T	8,9	>15.5 ≤34		
		B-train				
		transporter				
Other	13	unknown	1+			

Notes:
1. No axle spacing can be <0.9m or >10.0m.
2. A vehicle is checked for a fit to the above starting at class 1. As soon as a fit is made no further checking is done.

Abbreviations:

A&T	articulated vehicle and trailer	t	tonnes
artic	articulated vehicle	EDA	Equivalent Design Axle (8.2 tonne dual tyred reference axle)
LV&T	light vehicle and trailer		
T&T	truck and trailer	Std	Standard Deviation

Table 3
EDA Statistics, Gross Vehicle Weight, and Compliance with legal load limits
S H 1 Pukerua Bay 18-24 November 1991

Vehicle class	Vehicle type	Freq	EDA/vehicle		Gross Weight (t)		Compliance with Legal Load Limit			
							Within Limit	0-10% Over	10-20% Over	>20% Over
			Mean	Std	Mean	Std	Percent	Percent	Percent	Percent
Vehicle — Medium wheel base (3.1m-8.5m)										
2	3 axle LV&T	14	0.058	0.057	7.774	1.010	100	0	0	0
	4 axle LV&T	4	0.055	0.058	8.315	1.372	100	0	0	0
3	2 axle van	117	0.574	2.760	8.108	2.766	94	5	0	1
4	2 axle truck	520	0.305	0.543	8.248	1.637	97	2	1	0
5	3 axle truck	192	0.614	0.868	11.425	4.807	94	5	1	1
6	4 axle truck	20	1.429	1.620	20.185	9.137	60	15	5	20
7	2 axle bus	161	0.375	0.455	8.997	1.718	97	2	1	0
	3 axle bus	83	0.594	0.604	12.040	3.659	93	4	4	0
Total		1111	0.435	1.097	9.383	3.616	95	3	1	1
Vehicle — Long wheel base (8.5m-15.5m)										
8	3 axle artic	32	0.114	0.160	8.756	1.629	97	3	0	0
	4 axle artic	20	0.526	0.710	17.013	9.216	55	0	0	45
	4 axle T&T	8	0.769	1.263	11.606	5.403	100	0	0	0
9	5 axle artic	42	2.715	1.517	32.622	10.307	38	12	7	43
	5 axle T&T	23	2.187	0.899	31.913	6.541	22	13	39	26
10	6 axle artic	184	1.815	0.834	34.134	6.695	66	16	7	12
	6 axle T&T	41	2.331	0.867	37.227	6.757	41	17	7	34
	7 axle	5	1.214	0.551	35.434	5.673	60	0	20	20
Total		355	1.747	1.158	30.427	11.100	60	13	8	20
Vehicle — Very long wheel base (15.5m-34.0m)										
11	4 axle T&T	4	1.936	2.578	16.332	5.894	100	0	0	0
	5 axle T&T	6	1.887	1.144	30.473	7.801	33	0	0	67
	6 axle T&T	77	2.452	1.039	39.192	7.135	16	6	6	71
12	7 axle A&T	9	2.137	0.618	39.911	3.670	78	11	0	11
	7 axle T&T	109	2.812	1.026	42.516	7.170	27	23	11	39
	7 axle B-train	72	2.467	2.538	38.971	7.558	82	15	1	1
	8 axle T&T	24	2.423	0.671	44.673	5.231	33	46	17	4
	8 axle B-train	40	1.809	0.987	40.742	8.611	55	32	7	5
Total		341	2.468	1.500	40.373	7.973	42	19	7	31
Vehicle — Other										
13	unknown	2	3.617	2.769	35.200	16.886	50	0	0	50

Table 4
Axles, Axle Group and Compliance with legal load limits
S H 1 Pukerua Bay 18-24 November 1991

Axle group type	Freq	Group Weight (t)		Compliance with legal load limit			
				Within Limit	0-10% Over	10-20% Over	>20% Over
		Mean	Std	Percent	Percent	Percent	Percent
Single steer	1751	4.172	1.343	92	6	1	1
Twin steer	99	9.345	1.769	82	14	3	1
Single non-steer	1194	5.456	1.940	88	5	3	4
Tandem	1377	10.918	4.124	82	13	4	2
Tri	207	16.411	4.820	44	29	17	10