PAVEMENT DENSITY

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EXECUTIVE SUMMARY

The 1997 Transit New Zealand Specification for Construction of Unbound Granular Pavement Layers (TNZ B/2 : 1997) includes end result criteria for compaction. The minimum level of compaction for the basecourse layer is specified as 95% of the maximum dry density (MDD) as determined by the vibrating hammer compaction test in NZS 4402.

This project has examined the level of compaction achieved on 5 newly constructed sites. Nuclear density tests before sealing and after an initial two months trafficking period have been evaluated to determine if the 95% MDD level is appropriate. It was found that low density measurements (<95% MDD) increase in density after trafficking and high density measurements (>95% MDD) tended to decrease. Generally measurements close to 95% MDD did not change after trafficking. There is no evidence from this research that the specification (TNZ B/2) should change. However, it is recommended that the sites be retested after one year to confirm the 95% MDD minimum compaction requirement.

ABSTRACT

The 1997 Transit New Zealand Specification for the Construction of Unbound Granular Pavement Layers (TNZ B/2: 1997) specifies the minimum degree of compaction required is 95% of the maximum dry density (MDD) obtained using the vibratory hammer compaction test in NZS 4402.

This report examines the 95% MDD requirement by testing five sites just before sealing and testing the sites again after two months of trafficking. Linear regression analysis of changes in density after trafficking as a function of initial percentage of MDD indicates that basecourse compacted to 95% MDD shows little change in density after trafficking.

1. INTRODUCTION

The 1997 Transit New Zealand Specification for Construction of Unbound Granular Pavement Layers (TNZ B/2 : 1997) specifies end result criteria for compaction. The end result criteria were derived from the performance of basecourse complying with the TNZ M/4 specification using the repeat load triaxial test. The results of the test showed that rapid shear failure under traffic could occur when a saturated basecourse was compacted to less than 90% of the maximum dry density (MDD) obtained using the vibratory hammer compaction test of NZS 4402. Basecourses compacted to 95% of MDD exhibited stable behaviour in the repeat load triaxial test. Hence the 1997 revision of TNZ B/2 introduced a requirement that the minimum degree of compaction of a granular basecourse must be 95% of the MDD.

The vibratory hammer compaction test was originally developed in Great Britain and is meant to model the degree of compaction that occurs in the field. If this also applies to New Zealand pavements, the current minimum of 95% MDD means that a further 5% compaction can occur under traffic. This 5% compaction is equivalent to a 15 mm rut in a 300 mm layer.

The introduction of the MDD test in the TNZ B/2 specification has resulted in contractors having to use more compactive effort than was used in the previous specification, but there is still the danger that, especially in thicker pavement layers, premature rutting could occur.

This project is designed to compare the level of compaction occurring in trafficked pavements with that obtained with the vibratory hammer laboratory compaction test to ensure that the minimum levels of compaction currently specified are cost effective and appropriate.

2. SITE SELECTION AND TESTING

Five sites where identified that were scheduled for overlays or constructions. Four of the sites were on state highways, two in South Canterbury and two in the Wellington region. The fifth site was an arterial road newly constructed in the Wellington region. All sites used M/4 basecourse material.

At each site MDD tests were performed on the basecourse as delivered to site. Before sealing, density tests using a nuclear density meter were taken in the wheeltracks and each site precisely located. The minimum target for basecourse density at each site was 95% MDD as per TNZ B/2 : 1997. The tests performed in this investigation were not used for compliance testing and therefore results below the specification minimum were obtained. All tests were conducted in accordance with NZS 4407 and NZS 4402.

After a minimum of two months of being open to the traffic the density tests were repeated at each site. The traffic volumes at each site are detailed in Table 1.

Table 1. Traffic volumes.

Site	Construction type	AADT	% HCV	Estimated HCV passes
1	Overlay	3800	12	25080
2	Shape correction	4405	12	23258
3	Overlay	4400	5	13860
4	Curve realignment	10400	3	61152
5	New construction	8000	5	34000

Sites 1 and 2 had the chipseal removed at the testing points before the "after" testing was conducted. Due to the difficulty of removing the seal, an analysis was made to determine if the single coat chipseal made a significant difference to the compacted density measured in backscatter mode. Initially there was a concern the additional hydrocarbons in the bitumen would alter the moisture content reading and thus distort the dry density readings. To check if the chipseal had a significant effect, a number of tests were conducted on the seal. The seal was removed and the tests were conducted again. These results are given in Table 2. It was concluded that density measurements were not significantly effected by the chipseal layer and the chipseal was not removed for sites 3, 4 and 5.

Table 2. The effect of chipseal removal.

Test no.	Dry density (kg/m^3)		Moisture content (%)	
	Seal on	Seal off	Seal on	Seal off
1	2026	2043	6.8	6.7
2	2028	2039	6.2	6.0
3	2006	1956	6.5	6.4
4	2033	1931	5.6	6.1
5	2074	2060	4.8	4.9
6	2155	2065	4.8	4.5
7	2058	2038	4.8	4.7
8	2108	2022	4.8	4.6
9	2042	2121	4.6	4.4
Average Std	2059 42	2031 51	5.4 0.8	5.4 0.8

3. RESULTS

The results of the before and after tests are listed in Tables 3.1 to 3.5.

Table 3.1. Site 1.

Maximum dry density 2.32 t/m^3
Optimum moisture content 5%

Test no.	Dry density before (t/m^3)	MC before (%)	Dry density after (t/m^3)	MC after (%)	Dry density		% OMC	
					Before (%) MDD	After (%) MDD	Before	After
1	2.39	4.0	2.32	3.5	103.0	100.0	80.0	70.0
2	2.31	4.0	2.29	3.0	99.6	98.7	80.0	60.0
3	2.25	4.0	2.24	3.5	97.0	96.6	80.0	70.0
4	2.26	4.5	2.33	3.5	97.4	100.4	90.0	70.0
5	2.27	4.5	2.36	4.0	97.8	101.7	90.0	80.0
6	2.25	4.5	2.29	4.0	97.0	98.7	90.0	80.0
7	2.27	4.0	2.30	3.0	97.8	99.1	80.0	60.0
8	2.24	4.5	2.28	3.5	96.6	98.3	90.0	70.0
9	2.20	4.5	2.32	3.5	94.8	100.0	90.0	70.0
10	2.24	4.5	2.33	3.5	96.6	100.4	90.0	70.0
11	2.28	4.0	2.27	3.5	98.3	97.8	80.0	70.0
12	2.27	4.5	2.28	3.5	97.8	98.3	90.0	70.0
13	2.29	4.0	2.27	3.5	98.7	97.8	80.0	70.0
14	2.26	4.0	2.26	3.0	97.4	97.4	80.0	60.0
15	2.25	4.0	2.29	3.5	97.0	98.7	80.0	70.0
Average Maximum Minimum	2.27 2.39 2.20	4.2 4.5 4.0	2.30 2.36 2.24	3.47 4.0 3.0	97.8 103.0 94.8	98.9 101.7 96.6	84.7 90.0 80.0	69.3 80.0 60.0

Table 3.2. Site 2.

Maximum dry density 2.32 t/m^3
Optimum moisture content 5.5%

Test no.	Dry density before (t/m^3)	MC before (%)	Dry density after (t/m^3)	MC after (%)	Dry density		% OMC	
					Before (%) MDD	After (%) MDD	Before	After
1	2.34	4.4	1.96	5.1	100.6	84.4	80.0	92.7
2	2.34	4.0	2.03	4.8	100.7	87.3	72.7	87.3
3	2.30	5.4	2.03	6.6	99.2	87.7	98.2	120.0
4	2.26	5.2	2.10	5.6	97.5	90.4	94.5	101.8
5	2.24	5.0	2.15	5.2	96.7	92.8	90.9	94.5
6	2.31	4.7	2.11	5.3	99.4	90.8	85.5	96.4
7	2.20	5.4	2.17	5.6	94.8	93.3	98.2	101.8
8	2.18	5.8	1.99	6.8	94.1	85.9	105.5	123.6
9	2.18	5.6	2.06	5.8	94.1	88.7	101.8	105.5
10	2.29	4.9	2.15	5.8	98.8	92.8	89.1	105.5
11	2.18	5.3	2.20	5.7	93.9	94.9	96.4	103.6
12	2.25	5.2	2.14	5.5	96.8	92.4	94.5	100.0
13	2.11	5.4	2.16	5.8	90.9	92.9	98.2	105.5
14	2.16	5.7	1.96	6.4	93.1	84.7	103.6	116.4
15	2.12	6.0	2.13	6.5	96.1	92.0	109.1	118.2
Average	2.23	5.2	2.09	5.8	96.1	90.1	94.5	104.8
Maximum	2.34	6.0	2.20	6.8	100.7	94.9	109.1	123.6
Minimum	2.11	4.0	1.96	4.8	90.9	84.4	72.7	87.3

Table 3.3. Site 3.

Maximum dry density 2.24 t/m³
Optimum moisture content 6%

Test no.	Dry density before (t/m³)	MC before (%)	Dry density after (t/m³)	MC after (%)	Dry density		% OMC	
					Before (%) MDD	After (%) MDD	Before	After
1	2.16	4.6	2.07	4.8	96.3	92.6	76.7	80.0
2	2.16	4.4	2.07	4.9	96.5	92.5	73.3	81.7
3	2.17	4.3	2.16	4.8	96.7	96.2	71.7	80.0
4	2.13	4.5	2.01	4.9	95.2	89.9	75.0	81.7
5	1.62	5.9	2.06	4.8	72.4	91.9	98.3	80.0
6	2.10	4.8	2.07	4.9	93.7	92.5	80.0	81.7
7	2.14	4.2	2.11	4.8	95.6	94.1	70.0	80.0
8	1.80	5.4	2.04	5.0	80.1	90.8	90.0	83.3
9	1.67	5.2	2.04	4.6	74.7	91.2	86.7	76.7
10	1.56	6.7	2.06	5.0	69.7	92.1	111.7	83.3
11	1.97	4.5	2.03	4.7	87.7	90.8	75.0	78.3
12	1.63	5.5	2.14	4.8	72.8	95.5	91.7	80.0
13	1.98	4.5	2.03	4.9	88.6	90.4	75.0	81.7
14	1.61	6.1	2.08	5.2	71.8	92.9	101.7	86.7
15	1.96	4.9	2.08	4.6	87.7	93.0	81.7	76.7
16	2.19	4.8	2.10	5.1	97.7	93.8	80.0	85.0
Average	1.93	5.0	2.07	4.9	86.1	92.5	83.6	81.0
Maximum	2.19	6.7	2.16	5.2	97.7	96.2	111.7	86.7
Minimum	1.56	4.2	2.01	4.6	69.7	89.9	70.0	76.7

Table 3.4. Site 4.

Maximum dry density 2.23 t/m³
Optimum moisture content 6.7%

Test no.	Dry density before (t/m³)	MC before (%)	Dry density after (t/m³)	MC after (%)	Dry density		% OMC	
					Before (%) MDD	After (%) MDD	Before	After
1	2.01	5.7	2.12	5.7	90.1	95.2	85.1	85.1
2	2.24	5.7	2.10	5.9	100.3	94.1	85.1	88.1
3	2.27	5.0	2.06	5.4	101.6	92.5	74.6	80.6
4	2.35	5.2	2.14	5.2	105.4	95.8	77.6	77.6
5	2.46	5.0	2.07	5.8	110.4	92.8	74.6	86.6
6	2.31	5.3	2.07	6.0	103.5	92.6	79.1	89.6
7	2.19	6.2	2.09	6.2	98.1	93.6	92.5	92.5
8	2.11	6.2	2.00	6.3	94.4	89.7	92.5	94.0
9	2.15	5.7	2.03	5.6	96.3	91.2	85.1	83.6
10	2.35	5.3	2.01	6.5	105.2	90.0	79.1	97.0
11	2.47	4.8	2.03	6.2	110.7	90.9	71.6	92.5
12	2.42	5.2	2.03	6.8	108.6	90.9	77.6	101.5
13	1.95	6.1	2.13	5.7	87.4	95.5	91.0	85.1
14	2.04	6.1	2.00	6.6	91.6	89.6	91.0	98.5
Average	2.24	5.5	2.06	6.0	100.3	92.5	82.6	89.4
Maximum	2.47	6.2	2.14	6.8	110.7	95.8	92.5	101.5
Minimum	1.95	4.8	2.00	5.2	87.4	89.6	71.6	77.6

Table 3.5. Site 5.

Maximum dry density 2.23 t/m^3
Optimum moisture content 6.5%

Test no.	Dry density before (t/m^3)	MC before (%)	Dry density after (t/m^3)	MC after (%)	Dry density		% OMC	
					Before (%) MDD	After (%) MDD	Before	After
1	2.11	4.4	2.10	4.8	94.5	94.0	67.7	73.8
2	2.15	3.4	2.05	4.9	96.3	91.9	52.3	75.4
3	2.21	3.5	2.08	5.5	99.1	93.3	53.8	84.6
4	2.20	4.1	2.11	4.8	98.7	94.8	63.1	73.8
5	2.25	3.7	2.05	4.3	100.9	92.1	56.9	66.2
6	2.15	3.6	2.04	4.7	96.3	91.7	55.4	72.3
7	2.17	3.9	2.10	4.7	97.1	94.0	60.0	72.3
8	2.11	4.0	2.14	4.8	94.5	95.9	61.5	73.8
9	2.11	3.5	2.10	4.4	94.8	93.9	53.8	67.7
10	2.12	3.2	2.08	4.1	94.9	93.2	49.2	63.1
11	2.11	3.7	2.21	3.9	94.4	98.9	56.9	60.0
12	2.11	3.8	2.01	4.8	94.5	90.3	58.5	73.8
13	2.20	3.6	2.01	4.5	98.5	90.3	55.4	69.2
14	2.19	3.4	2.10	5.2	98.3	94.1	52.3	80.0
15	2.07	3.5	2.13	4.5	93.0	95.4	53.8	69.2
16	2.04	3.4	2.14	4.8	91.7	96.0	52.3	73.8
17	2.02	3.6	2.15	4.4	90.5	96.4	55.4	67.7
18	2.11	3.1	2.12	4.3	94.7	95.1	47.7	66.2
Average	2.13	3.6	2.10	4.6	95.7	94.0	55.9	71.3
Maximum	2.25	4.4	22.1	5.5	100.9	98.9	67.7	84.6
Minimum	2.02	3.1	2.01	3.9	90.5	90.3	47.7	60.0

4. ANALYSIS

The basic plots of before and after % MDD and % optimum moisture content (OMC)) are shown in Figures 1 and 2.

Figure 1. Changes in percentage of maximum dry density.

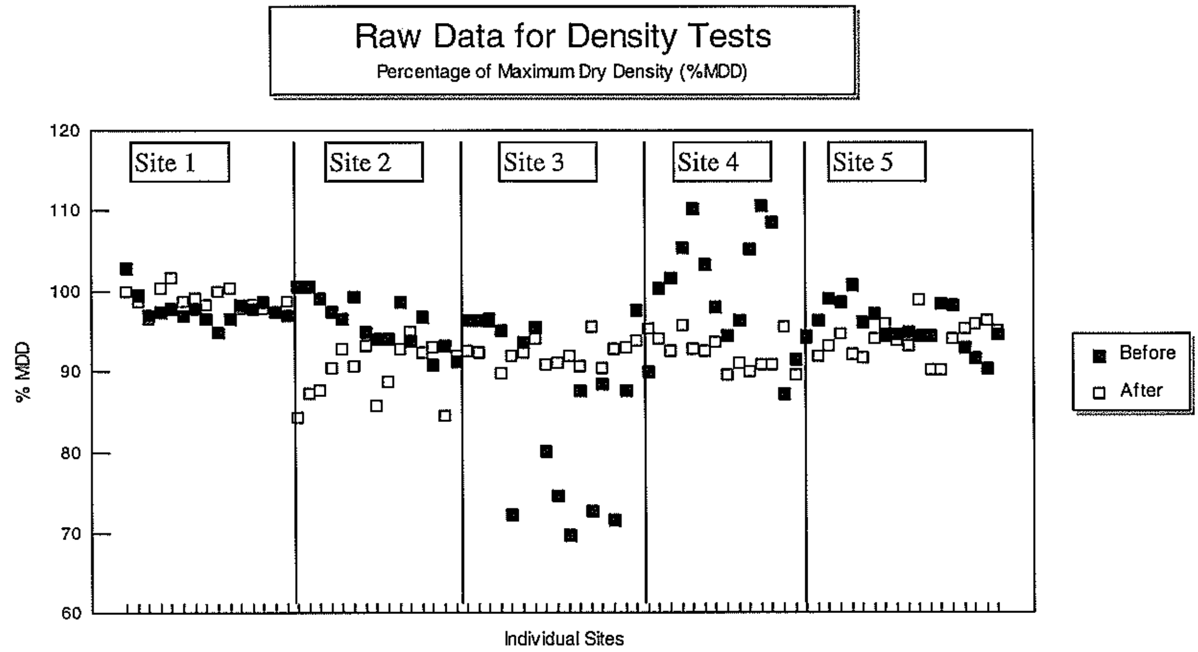


Figure 2. Changes in percentage of optimum moisture content.

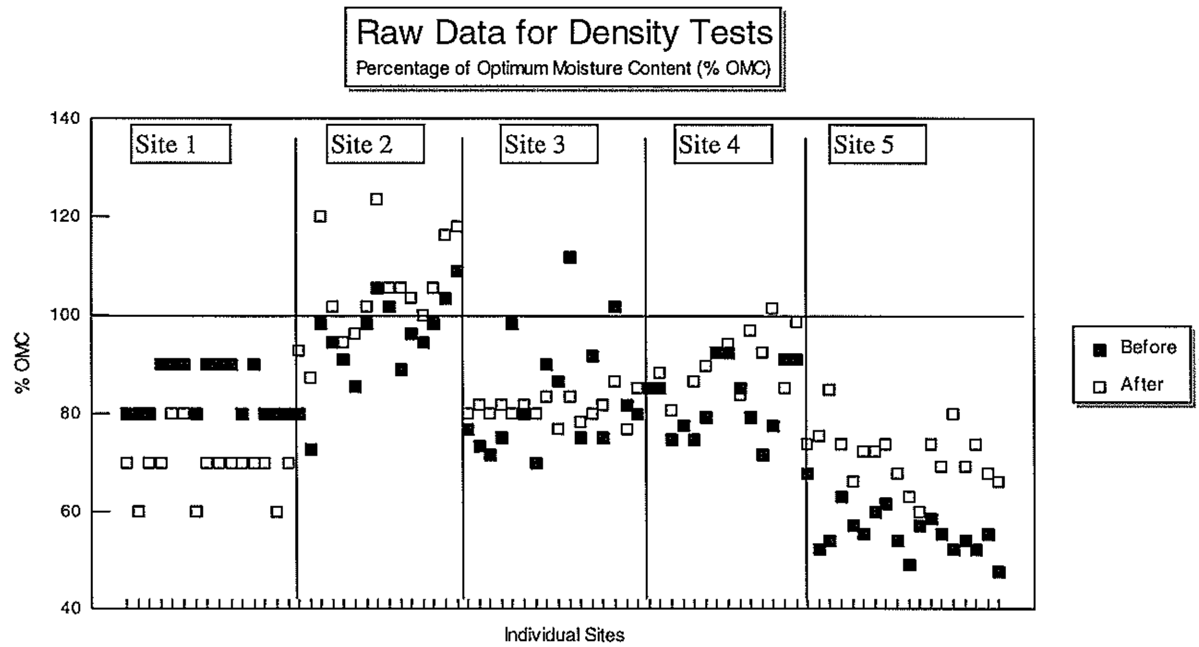


Table 4. Summary statistics for the percentage of maximum dry density.

Site	Before traffic				After traffic			
	Average	Std	+95%	-95%	Average	Std	+95%	-95%
1	97.79	1.75	101.21	94.37	98.94	1.32	101.52	96.36
2	96.14	3.11	102.22	90.05	90.07	3.28	96.49	83.64
3	86.06	10.31	106.27	65.85	92.51	1.71	95.85	89.16
4	100.26	7.28	114.52	86.00	92.45	2.08	96.53	88.37
5	95.70	2.62	100.83	90.57	93.96	2.15	98.17	89.74
Average	95.03	7.65	110.02	80.03	93.60	3.64	100.72	86.47

Table 5. Summary statistics for the percentage of optimum moisture content.

Site	Before traffic				After traffic			
	Average	Std	+95%	-95%	Average	Std	+95%	-95%
1	84.67	4.99	94.44	74.89	69.33	5.74	80.57	58.09
2	94.55	9.39	112.95	76.14	104.85	10.24	124.91	84.79
3	83.65	11.67	106.52	60.77	81.04	2.63	86.19	75.89
4	82.62	6.97	96.28	68.96	89.45	6.69	102.55	76.34
5	55.90	4.78	65.27	46.52	71.28	5.71	82.47	60.09
Average	79.35	15.69	110.10	48.60	82.62	14.52	111.09	54.16

The analysis was conducted in two parts. The first part used the students' T-test, a standard test to determine if there had been a statistically significant change in the average densities at each site. The second part was to conduct a linear regression analysis of trends in the data.

The results of the students' T-test are listed in Table 6. T-test values below 0.05 show that a statistically significant change has occurred, to a 95% confidence level, between the before and after averages. The table shows that statistically significant change in average densities has occurred at all sites except for site 1. However, when all the sites are combined and analysed as one set of data a statistically significant change can not be determined, this is not unexpected as increases and decreases in average % MDD were observed at different sites.

Table 6. T-test and F-test values.

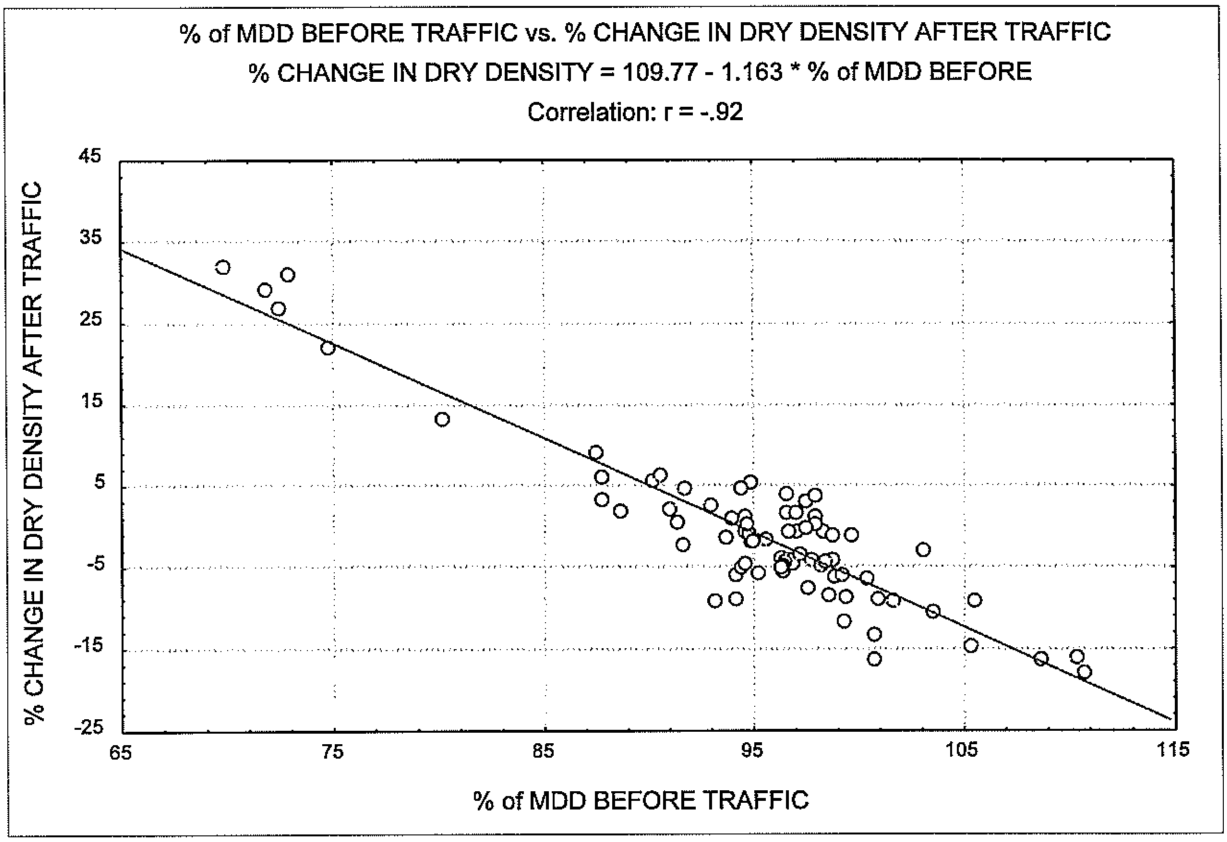
Site	Average % MDD before	Average % MDD after	T-test value	F-test value
1	97.79	98.94	0.060	0.303
2	96.14	90.07	0.000	0.841
3	86.06	92.51	0.030	0.000
4	99.81	92.45	0.002	0.000
5	95.70	93.96	0.041	0.425
All sites	95.03	93.60	0.142	0.000

The F-test determines whether two sets of data are from the same distribution. The F-test results in Table 6 show that the distribution of the data points has changed in sites 3 and 4, and over the entire project as a whole, to a confidence level well over 95%. Examining the before and after standard deviations suggests that the density is becoming less variable after trafficking.

A linear regression analysis was conducted to provide some additional insights into the data. It was found the that percentage of maximum dry density before trafficking and the percentage change in dry density gave a reasonable correlation coefficient of 0.92 (Figure 3). The analysis indicates that zero change in density under traffic is associated with a 94.5% MDD when considering all the sites together.

Changes in moisture content relative to the optimum moisture content did not provide good correlations with the observed changes in density. The analysis indicated that there was no relationship between the changes in moisture content, relative to the optimum moisture content, and changes in density under traffic.

Figure 3. Linear regression analysis.



5. DISCUSSION

It is interesting to note that material compacted to a level in excess of 95% MDD appears to decrease in compaction with trafficking. There is a possible explanation for this. During construction the surface is compacted by both vibrating and static rollers, with the vibrating compactors leaving layers nearest the surface less compact than those below, and the static rollers compacting the surface layers to a higher density. The explanation of the observed behaviour is that traffic loading is of a dynamic nature and the decrease in density could be due to this additional vibrating compaction loosening the surface layers. Material compacted to less than 95% MDD increased in density suggesting that the decrease in compaction has a limit.

The extreme changes in density observed in the data suggest that movement should be observed in the surface profile of the road at some test points. While specific measurements of the surface profile were not made, it can be said that movements of the magnitude indicated should have been clearly visible without specific measurement. One explanation for not seeing these movements is that the pavement is seeking an equilibrium in density, and isolated changes in density are unlikely to occur. That is, at a specific point the density will change as a result of the surrounding material changing in density as well as with vertical deformation. This equilibrium idea is reflected in the F-test data in Table 6 which shows the variation in the material is decreasing. The average change in density provides a better picture of the magnitude of vertical deformation likely to be observed on the surface of the pavement.

The accuracy of the surface moisture density gauge needs to be taken into consideration when considering the results. In backscatter mode, the Troxler manual gives the gauge's precision as ± 8.3 kg/m^3 at 2000 kg/m^3; this defines the repeatability of the measurement or the minimum change in density or moisture which is detectable by the instrument. In terms of % MDD this is approximately 0.4%. The expected total error on any material is listed as ± 54.4 kg/m^3 although ± 40.0 kg/m^3 is associated with not being sure of the type of material the test is being conducted on.

6. CONCLUSIONS

The analysis shows the average percentage of maximum dry density changes with time. When all sites are combined it appears that the average has decreased from 95% to 93.6% of the maximum dry density. The students T-test shows that definite changes are occurring at each site, however, when all the sites are combined the picture becomes less clear. The linear regression shows that the amount of change observed is dependent on the initial percentage of maximum dry density. It is very interesting to note in the regression analysis that the over-compacted sites (<95% MDD) appear to become less dense with time.

Considering all the sites together, the regression analysis suggests that material compacted to around 95% MDD will not significantly change in density after two months of trafficking, so the current requirement of a minimum compaction value of 95% MDD would seem appropriate. However, when comparing individual sites there is some suggestion that it may be better to assess the compaction level required on a case by case method depending on the source of the aggregate. Sites 2 and 4 have shown significant decreases in density when compacted above 95% MDD whereas site 1 shows an increase in density when compacted above 95% MDD.

7. RECOMMENDATIONS

Repeating the tests at one year and perhaps at additional times during the pavement's life would provide a better indication of the final density that the pavement reaches. This information could be used to confirm that 95% MDD is actually the likely final pavement density. At one year, conventional rutting models would suggest the pavement is fairly close to being as dense as it is likely to get.

The results of this investigation gives no basis for changing the current minimum level of compaction of 95% MDD.

8. REFERENCES

Troxler International Ltd 1979. *3400-B Series Manual : Surface Moisture Density Gauge.* Troxler International Ltd, USA.