LOADMAN PORTABLE FALLING WEIGHT DEFLECTOMETER: DETERMINATION OF ELASTIC MODULI OF PAVEMENT MATERIALS

Transfund New Zealand Research Report No. 124

LOADMAN PORTABLE FALLING WEIGHT DEFLECTOMETER: DETERMINATION OF ELASTIC MODULI OF PAVEMENT MATERIALS

BARTLEY CONSULTANTS LIMITED
Takapuna, Auckland, New Zealand

Transfund New Zealand Research Report No. 124

ISBN 0-478-11082-0
ISSN 1174-0574

© 1998, Transfund New Zealand
PO Box 2331, Lambton Quay, Wellington, New Zealand
Telephone (04) 473-0220; Facsimile (04) 499-0733

Bartley Consultants Ltd. 1998. Loadman falling weight deflectometer: determination of elastic moduli of pavement materials. *Transfund New Zealand Research Report No. 124.* 41 pp.

Keywords: elastic modulus, falling weight deflectometer, FWD, New Zealand, pavement, pavement design, road, testing

AN IMPORTANT NOTE FOR THE READER

The research detailed in this report was commissioned by Transfund New Zealand.

Transfund New Zealand is a Crown entity established under the Transit New Zealand Act 1989. Its principal objective is to allocate resources to achieve a safe and efficient roading system. Each year, Transfund New Zealand invests a portion of its funds on research that contributes to this objective.

While this report is believed to be correct at the time of publication, Transfund New Zealand, and its employees and agents involved in the preparation and publication, cannot accept any contractual, tortious or other liability for its content or for any consequences arising from its use and make no warranties or representations of any kind whatsoever in relation to any of its contents.

The report is only made available on the basis that all users of it, whether direct or indirect, must take appropriate legal or other expert advice in relation to their own circumstances and must rely solely on their own judgement and seek their own legal or other expert advice in relation to the use of this report.

The material contained in this report is the output of research and should not be construed in any way as policy adopted by Transfund New Zealand but may form the basis of future policy.

CONTENTS

LIST OF TABLES AND FIGURES

TABLES

FIGURES

EXECUTIVE SUMMARY

1. Introduction

The Loadman Portable Falling Weight Deflectometer (FWD) is a device for measuring the elastic modulus of pavement materials. The Loadman applies an impact force to the surface of the pavement layer being tested. The device measures the resulting deflection and calculates the corresponding elastic modulus using Boussinesq theory.

The AUSTROADS pavement design procedures were adopted by Transit New Zealand in 1995. These procedures use a mechanistic approach similar to the previous Transit New Zealand pavement design method but now the designer has greater control over the parameters used in the analysis. A significant requirement of the AUSTROADS procedure is to incorporate elastic modulus parameters of the different layers of a road pavement. This requirement has created a demand for cost-effective methods of establishing the elastic parameters for pavement materials.

The Loadman Portable FWD which has been introduced to the New Zealand market relatively recently (1996), shows significant potential as a very useful tool for the pavement engineering practitioner to obtain these parameters. As well, when compared with other test procedures, the Loadman is relatively inexpensive and is quick and simple to operate.

One of the drawbacks of the Loadman is that it is programmed to calculate elastic modulus values using the Boussinesq theoretical model. The Boussinesq model assumes a single layer of isotropic material, and this is somewhat contrary to most pavement conditions.

As the AUSTROADS design procedure promotes sub-layering a pavement to allow for differences in bulk stress and associated apparent elastic modulus of the material, the appropriate stress conditions must be used. The Loadman enables measurement /testing of elastic parameters in stress-sensitive materials, and allows for adjustments of test results.

2. Objectives

The objectives of this study, carried out in 1997 to investigate the use of the Loadman FWD, were:

- Determine the accuracy and repeatability of the Loadman , for measuring elastic moduli for both subgrade and compacted aggregate materials;
- Determine its zone of influence, both vertically and laterally;
- Determine limitations of its use.

3. Literature Review

A review of available literature on the Loadman was made to evaluate experience of users in Finland, United Kingdom, Canada and the Netherlands, and with similar types of equipment.

4. Experimental Investigation

Depth of Influence of Loadman LWD

Both the vertical and lateral zones of influence of the Loadman portable LWD were established. The extent of these zones dictates the depths at which tests should be carried out so that a continuous profile of data over a depth range can be obtained, and their placement relative to a boundary of the area being tested to minimise side effects.

Correlation between Loadman and Laboratory Tests

Four materials, rubber, pumice subgrade soil, compacted clay soil, and foamed concrete, spanning a range of elastic modulus values were tested with the Loadman.

Repeatability of the Loadman LWD

Repeatability is important in the evaluation of any test procedure, and results should be repeatable by a single operator and between different operators.

Two approaches were used: deflection results from Loadman tests on rubber blocks were analysed statistically; and Loadman tests on stabilised aggregate material were carried out over a period of time.

Requirements when using the Loadman FWD

Complete and uniform transfer of stress from the base plate of the Loadman to the pavement layer being tested must be obtained because erroneous values for elastic moduli will be recorded if the top surface of the pavement layer is not smooth.

The layer being tested must have a horizontal surface because the Loadman will give erroneous results if it is inclined.

5. Conclusions

The following conclusions have been drawn from the literature review and practical investigation into the performance of the Loadman portable FWD:

- The technical literature is quite sparse as the Loadman has been developed only relatively recently. The literature generally suggests that the Loadman results correlate reasonably well with the Benkelman Beam, FWD and the plate-bearing test.

- The Loadman was convenient and simple to use and the results were available with little or no post-testing analysis.

- The zone of influence of the Loadman was established by performing a number of Loadman tests on rubber blocks. The results showed that the vertical zone of influence of the device was approximately 150 mm and the lateral zone of influence was up to approximately 120 mm from the edge of the Loadman's base plate.

- A reasonable correlation of Loadman elastic modulus results with laboratory resilient modulus tests was obtained if the Loadman results were factored up by a coefficient in the range 1 to 3.

- Further testing is required to obtain a better understanding of the relationship between the elastic modulus data obtained from the Loadman and the resilient modulus data obtained from dynamic triaxial testing.

- When using the Loadman to establish elastic moduli for design, the designer should carry out correlation tests in the laboratory for each soil type encountered. As the Loadman imparts a relatively high level of stress that may be inappropriate for materials deep in the pavement, use of the large Loadman base plate will minimise this effect for subgrade soils.

- The repeatability of the Loadman test results was very good. In general 95% of the results lay within approximately 4% of the mean value.

  A consistent set of results was also obtained from Loadman tests carried out on a stabilised aggregate material over a period of time.

- The repeatability of the Loadman test makes it a valuable tool for construction quality control. It can give an indication of in situ elastic modulus data to provide feedback to the pavement designer, as well as showing up any variability in material or construction quality.

- The main practical limitation of the Loadman is the need to have a smooth upper surface on the layer being tested. This smooth surface allows the load applied during a test to be completely and uniformly transferred to the layer. Both the magnitude and the variability of the test results were also influenced by the roughness of the layer surface.

ABSTRACT

The Loadman Portable Falling Weight Deflectometer (FWD) is a device for measuring the elastic modulus of pavement materials. The Loadman applies an impact force to the surface of the pavement layer being tested. The device measures the resulting deflection and calculates the corresponding elastic modulus using Boussinesq theory.

The Loadman shows significant potential as a very useful tool for the pavement engineering practitioner, particularly since the AUSTROADS pavement design procedures were adopted by Transit New Zealand in 1995.

The objectives of this study, carried out in 1997 to investigate the use of the Loadman FWD, were:

- Determine the accuracy and repeatability of the Loadman , for measuring elastic moduli for both subgrade and compacted aggregate materials;
- Determine its zone of influence, both vertically and laterally; and
- Determine limitations of its use.

1. INTRODUCTION

1.1 General

In July 1995, Transit New Zealand adopted the AUSTROADS[1] pavement design procedures for the structural design of new and rehabilitated state highways in New Zealand (Transit New Zealand 1997). The AUSTROADS procedures, described in the document *Pavement Design - A Guide to the Structural Design of Road Pavements* (AUSTROADS 1992), use a similar mechanistic approach to the previous Transit New Zealand design method (Transit New Zealand 1989). However, the material performance criteria are different and the designer now has greater control over the material parameters used in the analysis.

The requirement in the AUSTROADS design procedure to incorporate the elastic modulus of the various pavement layers in trial pavement models has posed a difficulty for the New Zealand designer. In the past the elastic modulus parameter has been somewhat inconspicuous in the design process. This is because the procedure involved the use of a design chart that used the California Bearing Ratio (CBR) of the subgrade as the parameter that determined the elastic modulus properties of the pavement layers. An empirical relationship between the CBR and the elastic modulus was inherent in the development of that design chart. This empirical relationship is questionable and is frequently criticised in the technical literature. However, directly determining the elastic modulus of materials used in flexible pavements is a very complex task and it generally requires the use of complicated testing equipment and highly skilled technical staff.

Recently (1996), a simple and relatively inexpensive device called the Loadman was introduced in New Zealand. It is a lightweight, portable, falling weight deflectometer (FWD) apparatus that provides in situ elastic modulus data for pavement design. The Loadman can be used by one relatively unskilled operator and the results are displayed instantaneously by a liquid crystal display on the top of the device. Its portability allows the device to be used in locations where other more cumbersome devices may encounter access problems, e.g. in test pits and service trenches.

The Loadman apparatus has significant potential for use in New Zealand, especially now that the AUSTROADS pavement design procedures have been adopted. The Loadman should be suitable for both substantiating assumptions made during design and controlling the quality of construction.

The objectives of this study carried out in 1997 are to:

- Determine the accuracy and repeatability of the Loadman for measuring elastic moduli for both subgrade and compacted aggregate materials;

---

[1] Association of State, Territory and Federal road and traffic authorities in Australia and New Zealand.

- Determine its zone of influence; and
- Determine limitations of its use.

1.2 Elastic Parameters

In the AUSTROADS mechanistic design procedure the pavement layers are characterised by the elastic parameters E and ν, i.e. elastic modulus and Poisson's Ratio. In addition, all materials are assumed to conform to a *linear* elastic response for the sake of simplicity. However, it is widely recognised that most roading materials do not behave in a linear elastic fashion. As the Poisson's Ratio is generally accepted as not being overly influential on design solutions, presumptive values of ν are generally used.

The elastic modulus of a roading material is significantly influenced by the prevailing state of stress. For unbound materials the elastic modulus is a function of the sum of the principal stresses, or *bulk stress*. Conversely, for cohesive materials the elastic modulus is a function of the *deviator stress*, i.e. the difference between the total vertical stress and the confining stress.

The AUSTROADS design procedure promotes sub-layering of aggregate layers. This is done for two reasons. One is to achieve a progression of the material moduli with increasing elevation in the pavement to reflect the improving compaction conditions. The other reason is to allow for non-linear material response. Clearly, the material in the lower portion of an aggregate layer is subjected to a lower bulk stress than the material higher up in the pavement which is closer to the applied wheel loads. Sub-layering allows for this difference in bulk stress and the associated difference in the apparent elastic modulus of the material, even though the material at the two locations is essentially the same.

When measuring elastic parameters in stress-sensitive materials for design purposes, it is important that the appropriate stress conditions are used. Although some measuring systems allow the stress conditions to be controlled by the operator, most in situ testing procedures apply a constant stress regime. In this situation the pavement designer may consider adjusting the test results to allow for the stress sensitivity of the material.

2. THE LOADMAN PORTABLE FWD

2.1 Description of the Loadman Apparatus

The Loadman is a self-contained portable FWD, of Finnish design (AL-Engineering Oy 1996), comprising an aluminium tube that accommodates a sliding 10 kg steel weight. When the device is activated a powerful electromagnet at the top of the tube releases the weight which falls vertically down the tube for a distance of 800 mm and impacts against a circular steel base plate resting on the pavement layer to be tested. A rubber buffer attached to the bottom of the weight cushions the impact and spreads the loading over an appropriate time period. An accelerometer mounted on the top of the Loadman tube records the acceleration experienced by the device during the impact. The deflection of the pavement layer is determined by integrating the acceleration record twice. Boussinesq elastic theory is then used to calculate the elastic modulus of the pavement material.

The Loadman is supplied with two circular base plates, one is 132 mm in diameter (i.e. the diameter of the tube) and the other 200 mm in diameter. The smaller diameter plate is generally used unless the elastic modulus of the material being tested is so low that the deflection measurement is greater than 10 mm. The impact loading of the falling weight corresponds to approximately 22 kN of force. This equates to applied pressures of 1.6 MPa and 0.7 MPa for the 132-mm and 200-mm base plates respectively.

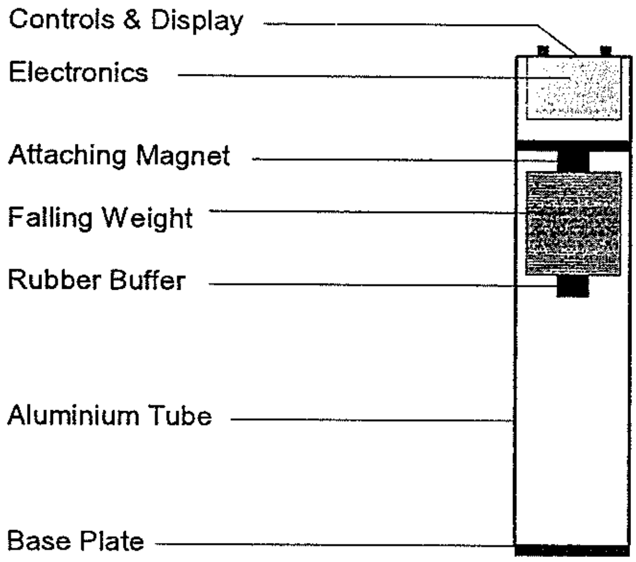

Figure 2.1 Diagram of the Loadman and its components.

2.2 Testing Procedure

Testing is carried out by one person and each test takes about 10 to 30 seconds to complete. No additional equipment, personnel or post-test processing is required to obtain the basic test results. The device is reported to be appropriate for materials ranging from soft subgrade soils to compacted high quality crushed rock basecourse. The Loadman should not be used on structural asphaltic concrete or cemented layers.

The surface of the material being tested must be level and smooth so that stresses are transferred uniformly from the Loadman's base plate onto the surface of the pavement layer. The suppliers suggest that fine sand can be used to smooth off rough or chipsealed surfaces.

Four or five tests are usually carried out at each test location. The first test is treated as a conditioning test and is generally ignored. The mean value from subsequent tests is taken as the recorded test result.

At the completion of the initial Loadman test a number of parameters are shown on the Loadman's output display. These are as follows:

- elastic modulus (MPa);
- measured deflection (mm);
- time to reach peak deflection (ms); and
- percentage of rebound deflection to total deflection.

Subsequent tests carried out without resetting the electronics have a slightly different set of test parameters shown on the display. The time to reach peak deflection and the percentage of rebound deflection to total deflection are replaced with the ratio of the current elastic modulus result to the initial elastic modulus result.

To initiate a new test the sliding mass is reset by carefully inverting the Loadman until the weight slides to the top end of the tube and is retained by the electromagnet. The device's electronic system is powered by three 9V batteries that are housed in the top part of the device.

2.3 Loadman Theory

The Loadman uses Boussinesq theory to convert the deflection measured during a test to an elastic modulus value. As Boussinesq theory is limited to a single material layer, the Loadman result will be effectively a single layer elastic modulus. The device can not provide a detailed analysis of multiple material layers.

The Boussinesq calculation for elastic modulus is as follows:

$$E = \frac{1.5pa}{\delta}$$

where: E = elastic modulus (vertical);
p = applied pressure;
a = radius of loaded area; and
δ = deflection.

The Loadman automatically calculates E by measuring δ while p is a constant. The parameter a is dependent on the size of the base plate in use and the appropriate constant is set into the device before testing is commenced.

3. LITERATURE REVIEW

3.1 New Zealand

The Loadman is a relatively recent development and only two samples were available in New Zealand at the time of conducting this review (1997). Therefore, local experience and documentation of results using the Loadman are scarce.

3.1.1 Pidwerbesky (1995)

A New Zealand research project (Pidwerbesky 1995) evaluated and compared five non-destructive methods of testing pavement structural integrity including the Loadman. The other test methods evaluated in the project were:

- falling weight deflectometer;
- Benkelman Beam;
- nuclear density meter; and
- Clegg hammer.

The tests reported by Pidwerbesky (1995) were carried out on two relatively high strength pavements. One pavement was constructed at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) while the other was the Christchurch Northern Expressway, which was under construction at the time. The pavement at CAPTIF consisted of 90 mm of asphalt overlying 200 mm of crushed rock basecourse and a silty clay subgrade with a CBR of 12%. The basecourse aggregate used in the pavement complied with Transit New Zealand Specification M/4 (TNZ 1995).

During construction of the CAPTIF pavement, extensive quality control tests were undertaken. After each lift of the clay subgrade the density of the material was measured using a nuclear density meter (NDM). Similarly the NDM was used to measure the aggregate layer density during the basecourse construction. FWD tests were carried out on the basecourse at various locations using various loading configurations. Triaxial tests were also performed to determine the elastic modulus of the basecourse aggregate. These tests indicated an elastic modulus value for the basecourse of approximately 280 MPa using a confining pressure of 103 kPa and a deviator stress of 207 kPa. This compared well with the mean in situ Loadman elastic modulus result of 250 MPa.

When the loading process at CAPTIF was completed the pavement was excavated at selected points so that layer profiles could be assessed and material samples tested in the laboratory. Small holes were cut in the seal at points of maximum, minimum and average pavement surface deformation, and the basecourse density was measured using the NDM. The Loadman was then used to measure the elastic modulus of the unbound basecourse and subgrade layers.

The results obtained from the FWD and Loadman tests are presented in Figure 3.1. The elastic modulus values obtained using the FWD were higher than the corresponding values obtained using the Loadman for 86% of the tests. This could be related to the non-linear stress/strain response of unbound materials causing higher elastic moduli at the higher states of stress produced by the FWD. The uniformity of the sub-base resulted in the tight grouping of the results (between 110 MPa and 200 MPa for both devices), with few extreme values, which gave a low coefficient of correlation. However, if the extreme values are used without the influence of the grouped results, the correlation coefficient is greatly improved.

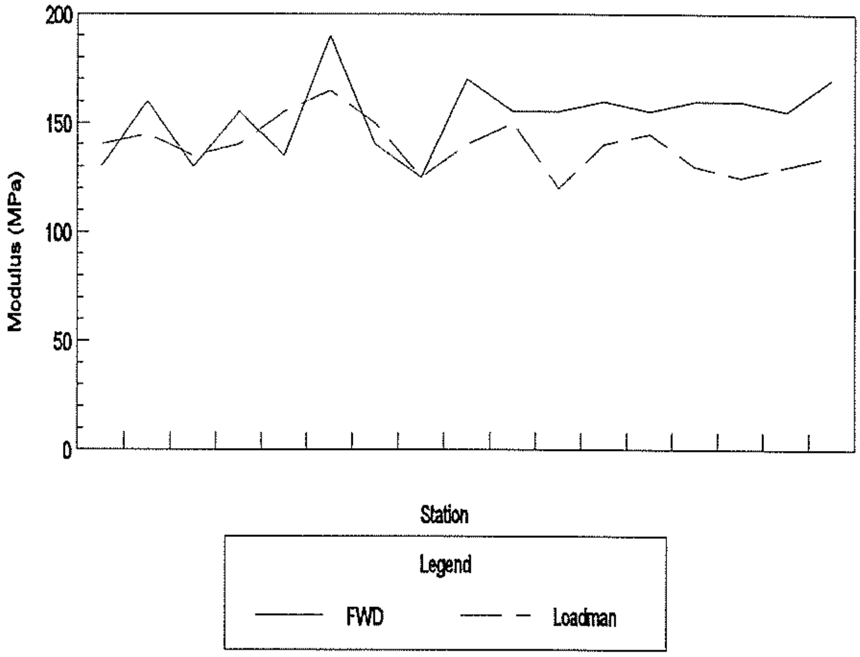

Figure 3.1 **Plot of Loadman and FWD results from CAPTIF basecourse layer for elastic modulus (MPa) (after Pidwerbesky 1995).**

The Benkelman Beam and the Loadman deflections were compared using measurements taken from the Christchurch Northern Expressway before it was sealed. The basecourse material used in the pavement complied with TNZ M/4 specification.

Deflection measurements from the Benkelman Beam compared very favourably with those measured using the Loadman. The correlation factor was 0.66, the highest of the test methods. A plot of deflection versus test station is presented in Figure 3.2.

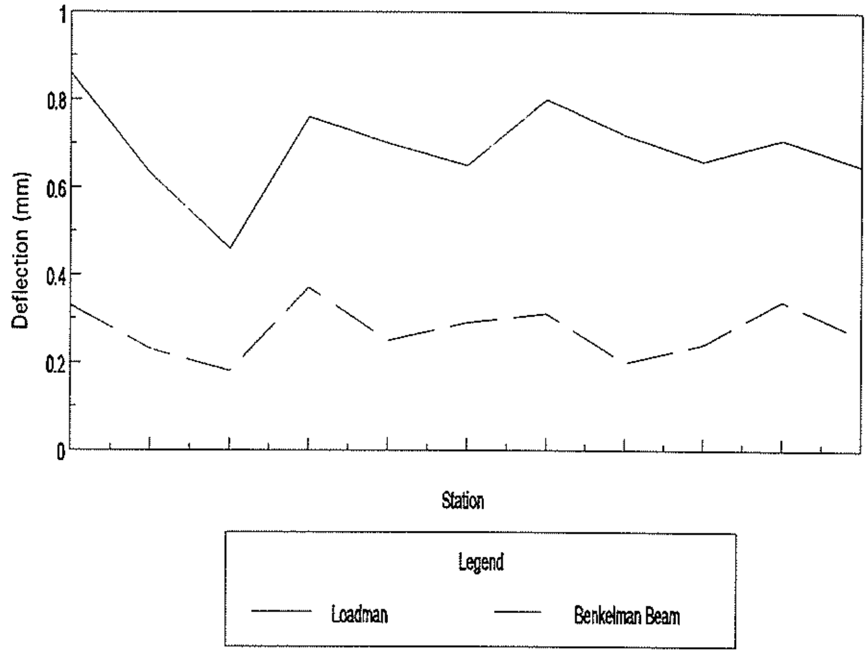

Figure 3.2 Plot of Loadman and Benkelman Beam deflection results from CAPTIF basecourse layer (after Pidwerbesky 1995).

The field trials of the Benkelman Beam and the Loadman resulted in a fair correlation between them. Both devices accurately identified areas of extreme strength and compaction.

Pidwerbesky (1995) presented the following conclusions:

- Correlations between the Loadman, FWD and Benkelman Beam were of a very high standard. Therefore converting quality control parameters from the FWD and the Benkelman Beam to the Loadman would be simple.

- The Loadman compared well with the NDM in compaction control. The Loadman was quicker to use and did not require a highly skilled technician to operate it. Also the Loadman does not contain a restricted substance as does the NDM, hence it can be used practically anywhere.

- The Loadman was rated as the second most effective instrument after the FWD for the evaluation of the properties and predicting the performance of a compacted unbound aggregate pavement.

3.2 Finland

3.2.1 Gros (1993)

Gros (1993) investigated the reliability of the Loadman, FWD and plate-bearing tests for the assessment of pavement strength. Gros used the Loadman and the FWD to measure the elastic modulus of bound structures (flexible pavements incorporating asphaltic concrete) and unbound structures (road building sites and house building sites). He also investigated the compaction and bearing capacity properties of unbound pavement layers using the Loadman and the plate-bearing test.

For flexible pavements comprising a thin asphaltic concrete (AC) surface layer overlying a layer of crushed gravel and subgrade, the results showed a poor correlation between the Loadman- and the FWD-derived elastic modulus results. The correlation coefficient ranged from 0.03 to 0.44. The Loadman also returned higher, and more erratic elastic modulus values than the FWD. However the correlation between the devices improved when the elastic moduli were in the range 150 MPa to 200 MPa. Gros suggested that the erratic results were related to the Loadman's sensitivity to aggregate particles located directly beneath the device or within the underlying layer.

The correlation between the Loadman, FWD and plate-bearing test results was found to be better on the unbound pavements. However, the elastic modulus values obtained using the Loadman were less than those obtained using the FWD. This is consistent with the results reported by Pidwerbesky (1995). Correlation coefficients between 0.31 and 0.99 were achieved. At relatively low elastic modulus values (80 MPa to 140 MPa) the correlation between the devices was significantly improved except for one case where the layer tested comprised 100 mm of sand over a much stiffer base. Gros reasoned that the Loadman's depth of influence is less than that of the FWD and therefore the test result was not influenced by the underlying stiffer layer.

Gros carried out tests at a road construction site and a house site to compare the Loadman and the plate-bearing test in the measurement of the degree of compaction of an unbound layer. In this study Gros evaluated a parameter termed the *compaction ratio*, i.e. the ratio of the elastic modulus values from the initial test (E_1) and the final test (E_2). The plate-bearing test returns an elastic modulus value for each level of loading so the compaction ratio (E_1/E_2) was simple to determine. On examining the elastic modulus values measured by multiple Loadman tests at an individual point it was observed that after 4 or 5 tests the result began to stabilise. Therefore the average of the elastic modulus values measured by the Loadman after the 4th or 5th measurement was used as E_2 and the initial elastic modulus value as E_1. A comparison of the compaction ratios showed that the correlation between the Loadman and the plate-bearing test was excellent for two sites but poor for a third site. Gros concluded that three points were insufficient for an accurate comparison.

The rebound deflection (elasticity index) was also evaluated as a potential parameter to characterise a material. The rebound deflection is defined as follows:

$$\delta_R = \frac{\delta_t - \delta_p}{\delta_t}$$

where δ_R = rebound deflection;
t = total deflection; and
δ_p = permanent component of deflection.

Some consistency with the corresponding elastic modulus values was expected because the rebound deflection is related to the elastic properties of the material. However no such consistency was found and Gros concluded that the rebound deflection was not accurate enough to be representative of the material's characteristics. The significance of the *deflection time*, as measured by the Loadman (i.e. the time to peak deflection) was also questioned by Gros, since in the majority of tests it was recorded as being the same value, i.e. 6 or 7 ms.

Gros concluded that the correlation between the Loadman and plate-bearing results for tests carried out on unbound layers was better than that for tests carried out on bound layers. Less than 5% of the measurements taken using the Loadman were considered to be erroneous. The errors that did occur were attributed to the user rather than the device and included non-verticality of the Loadman and testing on an uneven pavement layer surface.

3.2.2 Honkanen (1991)

The Finnish National Road Administration have conducted tests on the Loadman (Honkanen 1991). Honkanen compared results obtained from the Loadman with results obtained from the FWD and the plate-bearing test. The aim of the study was to assess the Loadman's effectiveness as an instrument for quality control during the construction of unbound pavement layers.

Three test pavements, 200 mm, 300 mm and 400 mm thick, were constructed using crushed rock aggregate with a maximum particle size of 45 mm. An additional pavement layer comprising 200 mm of crushed rock with a maximum particle size of 16 mm was also constructed.

A total of 400 tests were carried out using the Loadman, 40 using the FWD and 40 using the plate-bearing test. Measurements were taken at 10 locations, with 10 measurements taken at each location. Some additional measurements were taken on an existing oiled gravel road.

The results obtained using the Loadman showed that, for each pavement constructed using the 45 mm top size aggregate, the initial deflection ranged from 2 mm to 3 mm but then reduced to about 1 mm after two tests. For the 16 mm top size pavement the initial deflections ranged from 3 mm to 4 mm but they reduced to just over 1 mm after two tests. Honkanen therefore concluded that, to achieve reliable results, multiple readings should be taken at each test location.

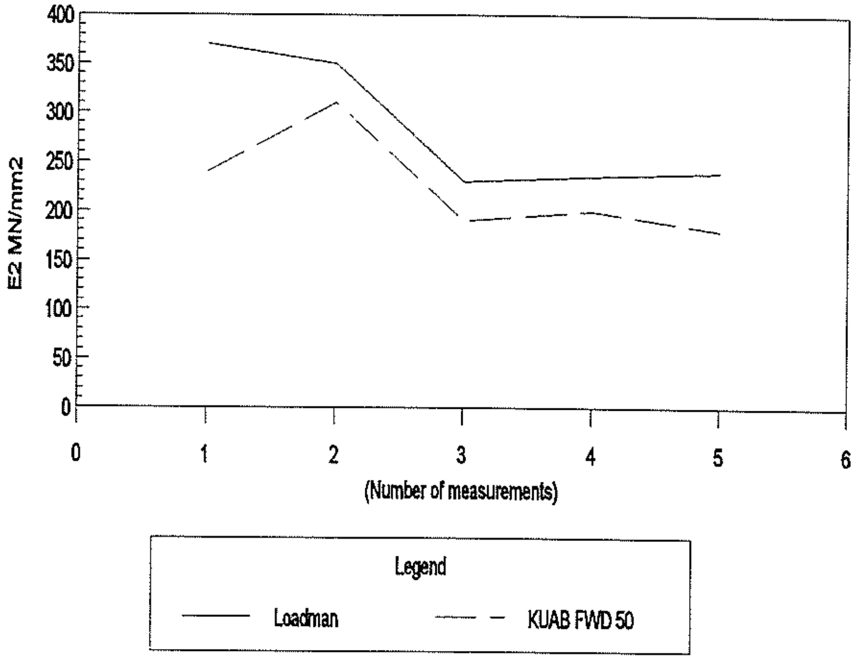

Figure 3.3 **Comparison of Loadman elastic modulus measurements at one point on a gravel road (after Honkanen 1991).**

Honkanen found that the elastic modulus values obtained on the oiled gravel pavement using the Loadman and the FWD were reasonably consistent except for the first measurement. The elastic modulus results ranged from about 300 MPa for the first two tests to about 200 MPa for the last three (Figure 3.3).

Honkanen suggested that a fine layer of sand should be spread between the base plate of the Loadman and the rough surface of an unbound aggregate layer. The sand acts as a levelling course and promotes repeatability of test results.

3.3 United Kingdom

3.3.1 Fleming & Rogers (1995)

Fleming & Rogers (1995) suggested that a major problem with the Loadman was that it had to be inverted to re-set the falling mass. This meant that relocating the base on the exact same spot was difficult. Also, maintaining the instrument in a vertical position was hampered by imperfections on the surface beneath the plate. The conclusions of the small amount of work carried out in the study suggest that the Loadman results are inconsistent. However the repeatability was good in ideal conditions.

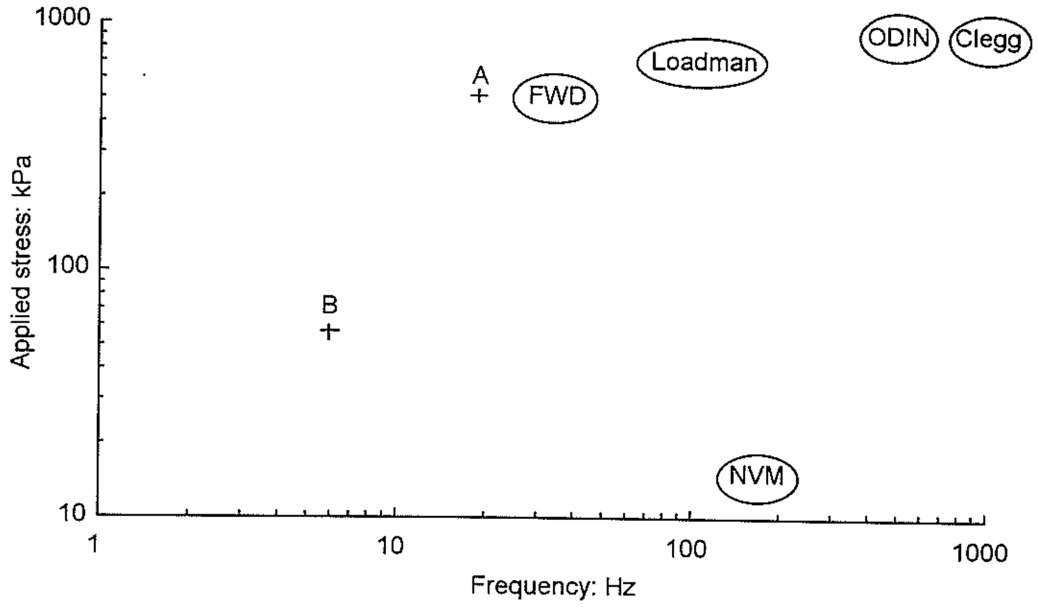

Figure 3.4 Stress/frequency graph (after Fleming & Rogers 1995).
Points A and B denote the stress applied by construction traffic at the top of the sub-base and subgrade, respectively, when trafficking at the top of the whole foundation.

Fleming compared the Loadman's testing stress and frequency of loading with other testing devices. Figure 3.4 shows that the stress conditions imposed by the Loadman are similar to those imposed by the FWD. These stress conditions are reasonably representative of the stress states associated with construction traffic on the sub-base (Point A) and the subgrade (Point B).

3.4 Canada

3.4.1 Davies (pers.comm. 1996)

At the time of writing this review (1997) an investigation into the Loadman was being undertaken at Saskatchewan Highways and Transportation. The objective of that study is to ascertain how effective the Loadman is for measuring the recovery of structural strength of thin membrane surface (TMS) pavements during the spring thaw in Saskatchewan. The ultimate goal is to develop a simple and effective procedure for managing pavement loading restrictions.

During field trials of the Loadman some issues regarding accuracy, repeatability and limitations were brought to the attention of the authors (T.Davies pers.comm. 1996). Davies suggests that the accuracy of the Loadman is comparable to that of the FWD. However the pavement must be sufficiently flexible so that the Loadman can register a reasonable deflection. Deflections of 0.1 mm to 0.2 mm are considered to be the minimum practical values while deflections of about 0.5 mm are preferred.

Deflection was the only parameter of interest in the Saskatchewan study. A reasonable correlation was established between the Loadman deflection and the FWD deflection (Figure 3.5).

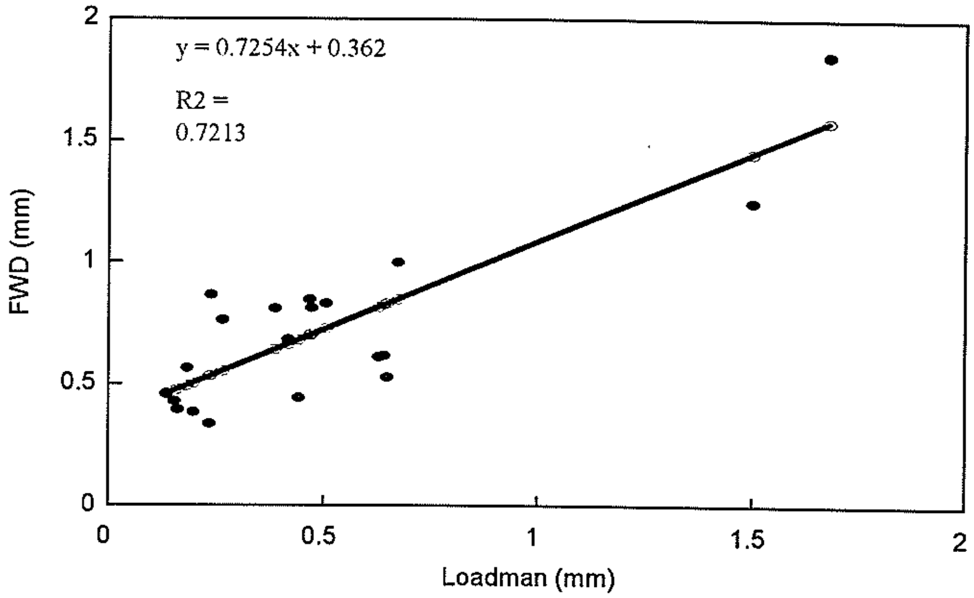

Figure 3.5 Correlation between deflection measurements using Loadman and FWD (after T.Davies, pers.comm. 1996).

Davies found that the result of the first drop at a given location is often different from the results obtained from subsequent drops. Therefore building a data file on single drops is not recommended. Initially ten drops per location were used in the study but this was later refined so that the average of the last 4 results of a 5-drop sequence were recorded.

Davies suggests that the operator of the Loadman can have a significant affect on the measurement obtained on a hard surface (asphalt, cold mix, seal). The experience of the operator and the ability to sense a "good drop" are valuable assets. Care and attention must be exercised when selecting a measuring point and aligning the Loadman, otherwise a significant degree of scatter in the results will be obtained. Selection of the test point is very important as two or three stones between the base plate and the surface will produce significantly different results to those measured on a relatively smooth surface.

3.5 The Netherlands

3.5.1 Henneveld (1994)

Henneveld (1994) assessed the Loadman, the Clegg Impact Tester, and a German device called the Dynamisches Plattendruckgerat, as quality control tests for the construction of unbound granular basecourse layers. Of the devices investigated, the Loadman was considered to be the best for on-site quality control testing. This conclusion is based on the good correlation between the Loadman results and the dynamic plate-bearing test (Figure 3.6), where the latter is used as an acceptance control test. However, Henneveld suggests that the elastic modulus values derived using the Loadman are purely empirical as the device does not measure the actual stress imposed on the layer surface. Therefore the Loadman elastic modulus should be considered as being indicative only.

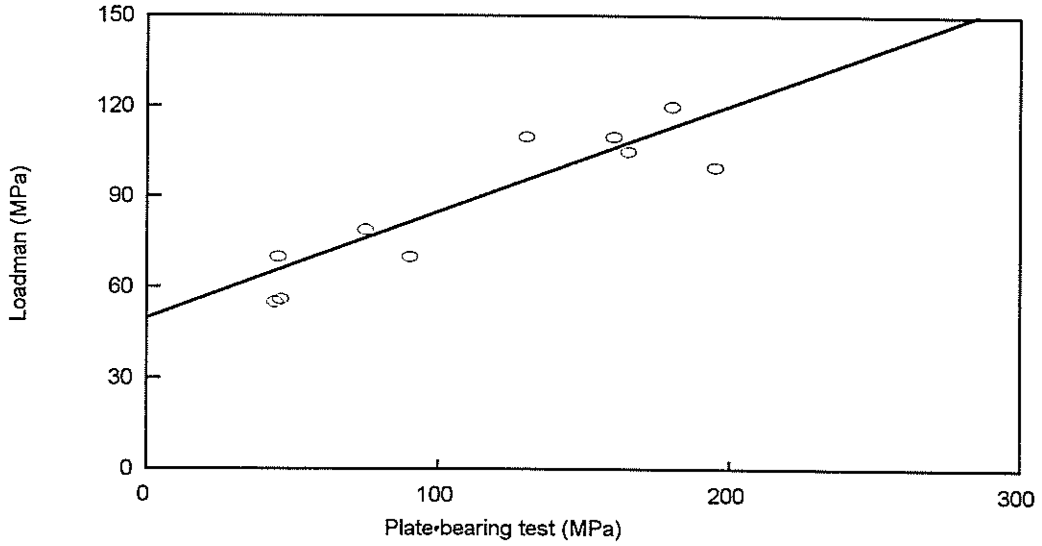

Figure 3.6 Average Loadman elastic moduli versus average plate-bearing test elastic moduli (after Henneveld 1995).

3.6 Summary

The following points summarise the results of the literature research carried out for this project on the use of the Loadman portable FWD:

- Loadman test results for unbound materials correlate well with those obtained using the Falling Weight Deflectometer, Benkelman Beam and Plate-Bearing test. The correlations are not as good for bound materials.

- Multiple measurements are required at each test location as a small amount of compaction takes place during the first two or three tests.
- The Loadman must be vertical during testing to allow free-fall of the sliding weight.
- The surface being tested must be smooth to ensure that a uniform contact is achieved between the surface of the layer and the Loadman base plate. A thin layer of sand may be used to achieve this.
- Large aggregate particles close to the surface of the layer being tested can have a significant influence on the Loadman test results because of the relatively small size of the Loadman base plate.
- Care has to be exercised when relocating the Loadman after it has been re-set to ensure that it is placed on the same area on which the previous measurements were made.
- The relatively light weight used by the Loadman and small size of the device's base plate means that the depth over which it is effective is not as great for some other test equipment, e.g. FWD and plate-bearing test.

4. EXPERIMENTAL INVESTIGATION

4.1 Vertical Zone of Influence

4.1.1 Objective of Investigation

The objective of this part of the research was to establish the effective zone of influence of the Loadman portable FWD. In particular, the depth of influence is important because the engineer must know which materials are contributing to the results obtained in each test. Also, the depth of influence dictates where tests should be carried out to achieve a continuous profile of data over a given depth range.

4.1.2 Investigation Procedure

To establish the Loadman's depth of influence, test drops were carried out on six rubber blocks of different thicknesses. The blocks were made up by laminating 19 mm-thick sheets of natural rubber with a Shore Hardness[2] Rating of 60. The nominal thickness of the blocks ranged from 57 mm to 285 mm (Table 4.1) and the plan dimensions were 400 mm by 400 mm.

Table 4.1 Test block details.

Block Number	Nominal Thickness (mm)
1	57
2	95
3	114
4	152
5	190
6	285

The rubber test blocks were placed on a concrete slab and the Loadman was used to measure the elastic modulus and maximum deflection at the centre of each block. Each block was subjected to an initial test followed by 5 subsequent tests using both the 132 mm- and the 200 mm-diameter Loadman base plates.

The investigation was then repeated with the rubber test blocks resting on a clay soil. Note that the maximum block thickness for the tests using the soil foundation was 190 mm while the maximum block thickness for the tests using the concrete foundation was 285 mm.

---

[2] Shore Hardness is a rating used in the rubber industry

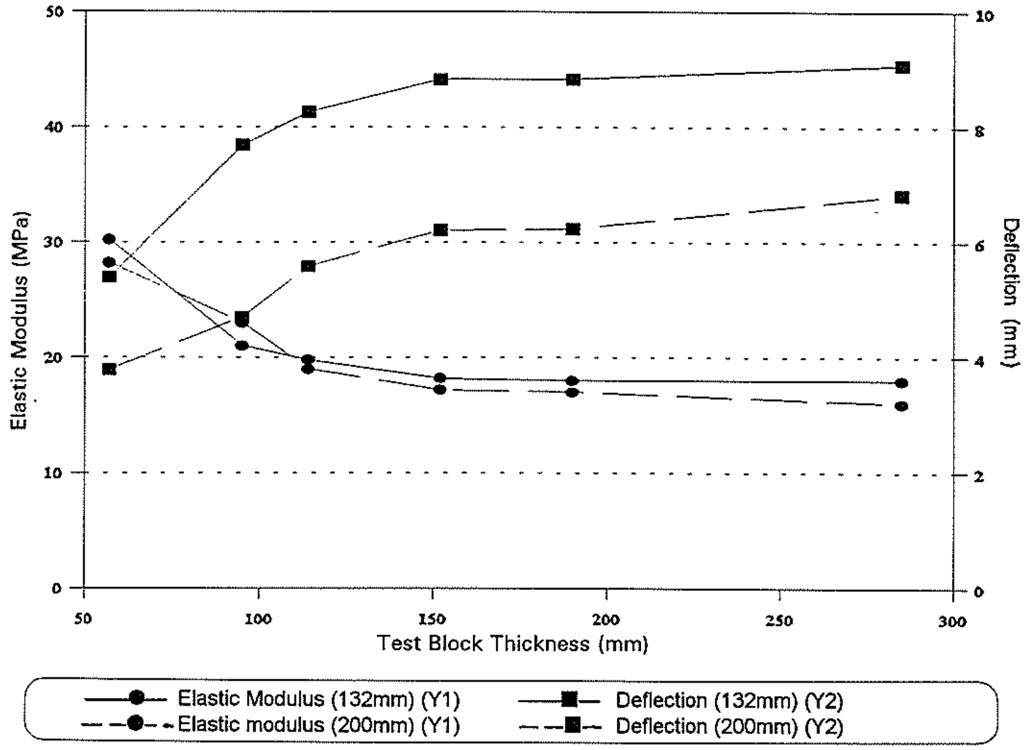

Figure 4.1 Elastic modulus (MPa) and deflection (mm) obtained by Loadman versus test block thickness (mm) for concrete foundation.

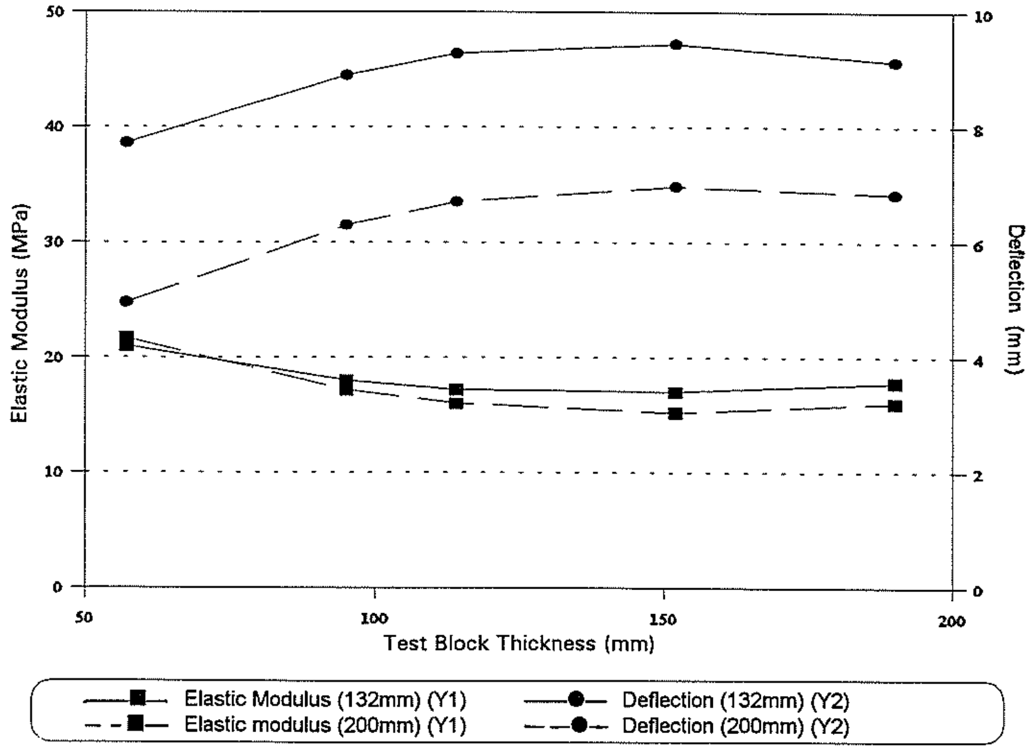

Figure 4.2 Elastic modulus (MPa) and deflection (mm) obtained by Loadman versus test block thickness (mm) for soil foundation.

4.1.3 Results

The Loadman elastic modulus and deflection data for each test block was recorded and the results are presented in Figures 4.1 and 4.2. Figure 4.1 corresponds to the tests carried out on the concrete foundation and Figure 4.2 corresponds to the tests carried out on the soil foundation. Trials were carried both with and without a thin sand layer beneath the rubber blocks. It was found that the sand layer had no influence on the results.

4.1.4 Discussion

Figures 4.1 and 4.2 show that at a block thickness of about 150 mm both the Loadman elastic moduli and the maximum deflections reach approximately consistent values. This suggests that the vertical zone of influence of the Loadman under the conditions emulated in this investigation is approximately 150 mm.

Figures 4.1 and 4.2 also shows that the elastic modulus measured using the 132 mm Loadman base plate is higher than the corresponding value using the 200 mm base plate for all test blocks thicker than approximately 100 mm. This is most likely related to a slight strain hardening tendency of the rubber.

The thickest block tested on the soil foundation shows a small decrease in deflection compared to the preceding block, while the thickest block tested on the concrete foundation shows a small increase in deflection compared to the preceding block. It is unclear why this may have happened although it may have been due to variations in the prevailing temperature on the days that the testing was carried out and/or inconsistencies in the preparation of the rubber test blocks.

4.2 Lateral Zone of Influence

4.2.1 Objective of Investigation

The lateral zone of influence dictates where the apparatus should be relative to a boundary of the area being tested. For example this lateral zone would establish what the minimum pit width should be, so that tests carried out at the base of the pit are not influenced by the pit walls or other structures horizontally offset from the test location.

4.2.2 Investigation Procedure

The 285 mm-thick rubber test block was used to determine how close the Loadman could be located from the edge of the block before it suffered from edge effects. Eleven points were tested starting at a distance of 50 mm between the edge of the block and the edge of the base plate, and increasing in 10 mm increments to 150 mm which was approximately at the centre of the block. At each point 5 drops were made and the average elastic modulus and maximum deflection results were recorded.

4.2.3 Results

The results of the investigation into the Loadman's lateral zone of influence are presented in Figure 4.3.

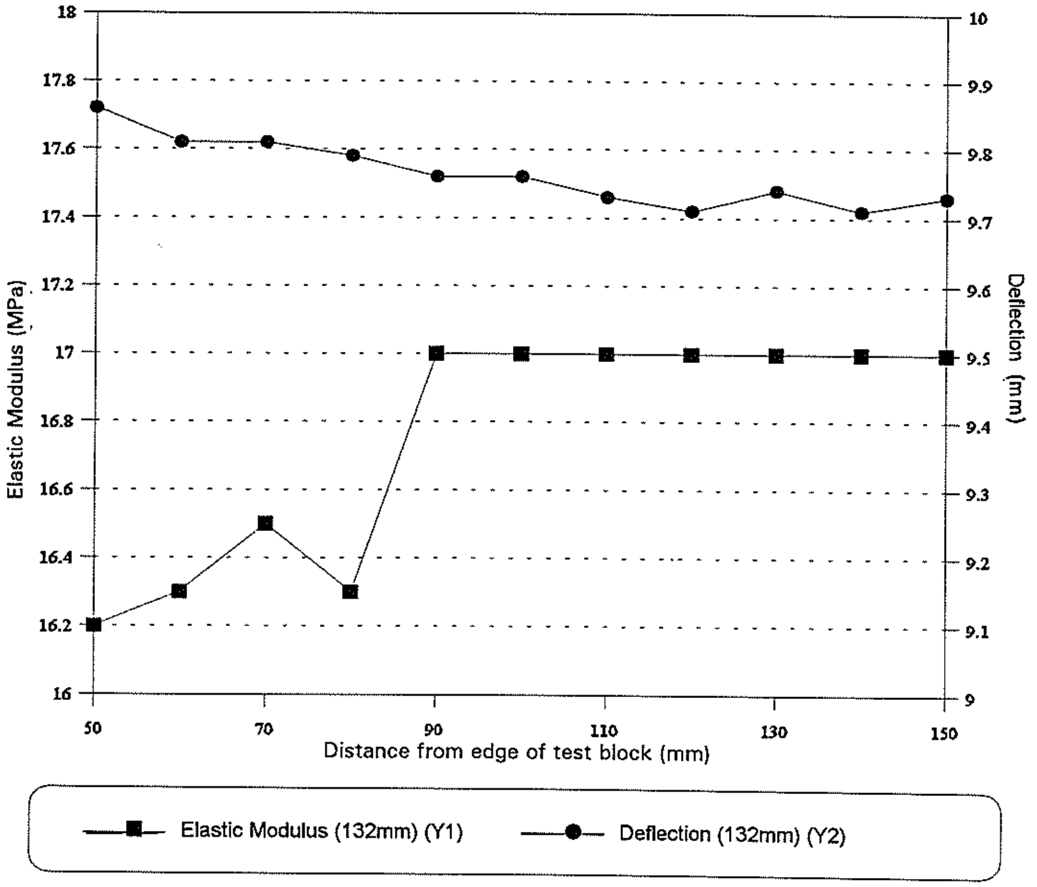

Figure 4.3 Elastic modulus (MPa) and deflection (mm) obtained by Loadman versus distance (mm) from edge of test block.

4.2.4 Discussion

The results presented in Figure 4.3 appear to be somewhat variable, but this may be related to the sensitivity of the ordinate scales on the plot. The results indicate that the Loadman is not significantly influenced by edge effects, especially when the lateral clearance from the edge of the base plate is greater than about 120 mm.

4.3 Correlation Between Loadman and Laboratory Elastic Modulus Tests

4.3.1 Objective of Investigation

When developing the concept of this project it was envisaged that the accuracy of the Loadman could be investigated by performing tests on rubber blocks with different elastic modulus values. The Loadman results would then be compared against the properties of the rubber established by laboratory tests. A target range of elastic moduli of approximately 30 MPa to 300 MPa was considered to be appropriate to emulate the properties of typical materials used in the construction of flexible pavements. However, rubber with an elastic modulus greater than about 18 MPa, as measured by the Loadman, was difficult to find so other materials had to be considered.

A complication that emerged in this part of the research was that the elastic modulus of most materials is not a unique property. This may be due to a number of reasons, but one of the most significant factors is that many materials have a non-linear stress/strain response. As the elastic modulus is the ratio of stress to strain, i.e. the slope of the stress/strain plot, the result of any elastic modulus test will be highly dependent on the stress conditions prevailing during the testing.

Other factors that may affect the result of elastic modulus tests are as follows:

- loading configuration, i.e. static or dynamic;
- frequency of loading;
- shape and duration of loading pulse;
- specimen size and shape;
- temperature; and
- platen configuration.

Considering these factors listed above, the decision was made to compare Loadman-derived elastic modulus values with elastic modulus values obtained using laboratory procedures that are applicable to pavement materials. In particular, the dynamic triaxial testing procedure was used. Two test configurations were adopted, viz. the Australian standard procedure AS 1289 (SAA 1995) and the SHRP Protocol P46 (AASHTO 1992).

4.3.2 Investigation Procedure

Four specimen materials were chosen for this part of the Loadman investigation. They were chosen on the basis that they would span the range of elastic modulus values required. The materials used were as follows:

- rubber;
- pumice subgrade soil;
- compacted clay soil; and
- lightweight foamed concrete.

The Loadman tests were carried out on samples 400 mm square by approximately 200 mm thick for all materials except for the pumice soil. These dimensions were chosen so that the influence of underlying materials and edge effects were minimised (see Sections 3.1 and 3.2 of this report). The pumice soil was tested in situ with the Loadman. A nuclear density meter was used to determine the density and water content so that a representative specimen could be prepared in the laboratory.

Rubber specimen

The rubber was the same natural rubber with a Shore Hardness Value of 60 that was used in the testing described in Section 3.1 of this report.

Pumice soil

The pumice soil had a dry density of 1.2 t/m^3 and a water content of 20%. The laboratory resilient modulus tests carried out on the pumice soil were performed at Canterbury University Engineering School and the test procedure conformed to SHRP Protocol P46.

Clay soil

The clay specimen was compacted into a wooden box in 50 mm layers and achieved a mean dry density of 1.8 t/m^3 at a mean water content of 12.8%. The cylindrical sample used in the triaxial apparatus was cut from the block of soil extracted from the wooded box mould. The dimensions of the sample were 97.5 mm diameter by 184 mm long.

Foamed concrete

The lightweight foamed concrete had a specified density of 0.9 t/m^3 but was delivered at a density of just over 0.8 t/m^3. Both the Loadman and the dynamic triaxial tests for the concrete specimen were carried out on the same day so that the curing period was consistent for both test specimens. A second lightweight concrete sample with a specified density of 0.6 t/m^3 was obtained but it disintegrated during testing.

The laboratory resilient modulus tests carried out on the rubber, compacted clay and foamed concrete were performed at Auckland University School of Engineering. The test procedure conformed to AS 1289 (SAA 1995).

4.3.3 Results

Rubber specimen

Numerous tests carried on the rubber specimens indicated that the Loadman-derived elastic modulus was 18 MPa using the 132 mm-diameter Loadman base plate. When the 200 mm-diameter base plate was used the elastic modulus result was 17 MPa.

In the laboratory tests four levels of deviator stress were applied to the specimen and the resilient modulus results ranged from 8.6 MPa for the lowest deviator stress to 9.4 MPa for the highest deviator stress. These results indicate that the rubber had a slight tendency to strain harden and the material response was not significantly influenced by the cell pressure.

Pumice soil

The Loadman elastic modulus for the pumice soil was found to be 55 MPa.

The laboratory resilient modulus test results for the pumice specimen are summarised in Figure 4.4. Figure 4.4 shows that the resilient modulus was not greatly influenced by the confining pressure. The resilient modulus values initially decreased with increasing deviator stress, but then increased when the deviator stress exceeded about 40 kPa. However, the resilient modulus results all fell in the range of 45 MPa to approximately 60 MPa.

Compacted clay soil

The Loadman elastic modulus result for the compacted clay specimen was taken as the mean value of the last four tests in a six test sequence, i.e. the first two tests were treated as conditioning the specimen and were ignored in the analysis. The Loadman elastic modulus results were 56 MPa for the 132 mm diameter base plate and 51 MPa for the 200-mm base plate.

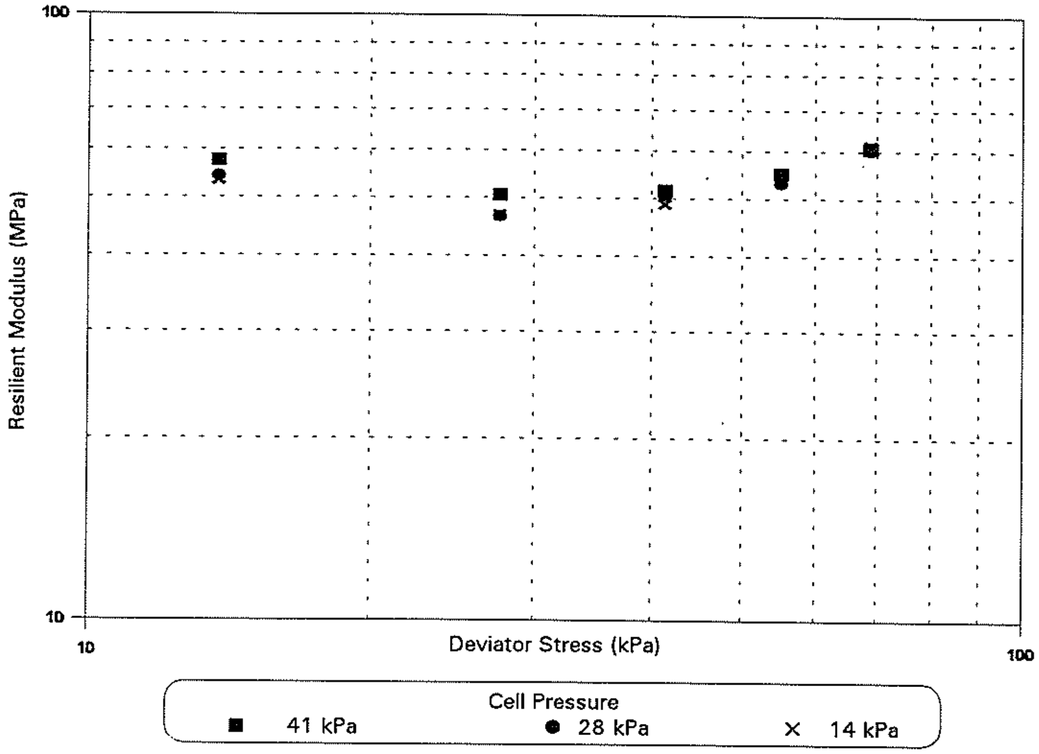

Figure 4.4 **Resilient modulus versus deviator stress for pumice soil specimen.**

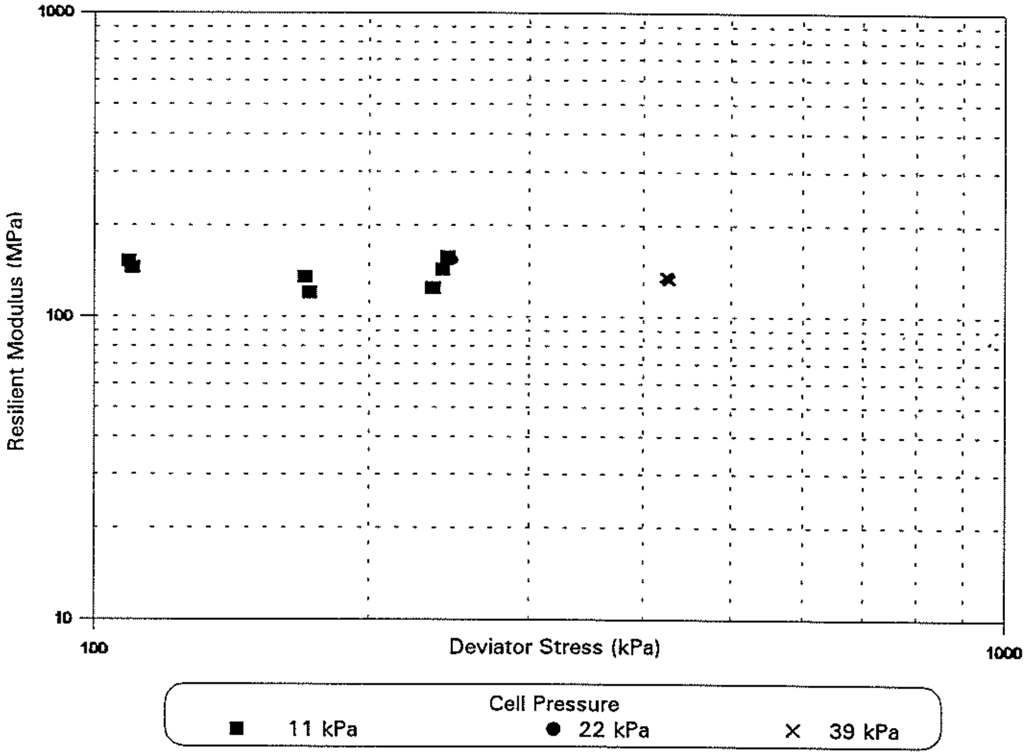

Figure 4.5 **Resilient modulus versus deviator stress for compacted clay specimen.**

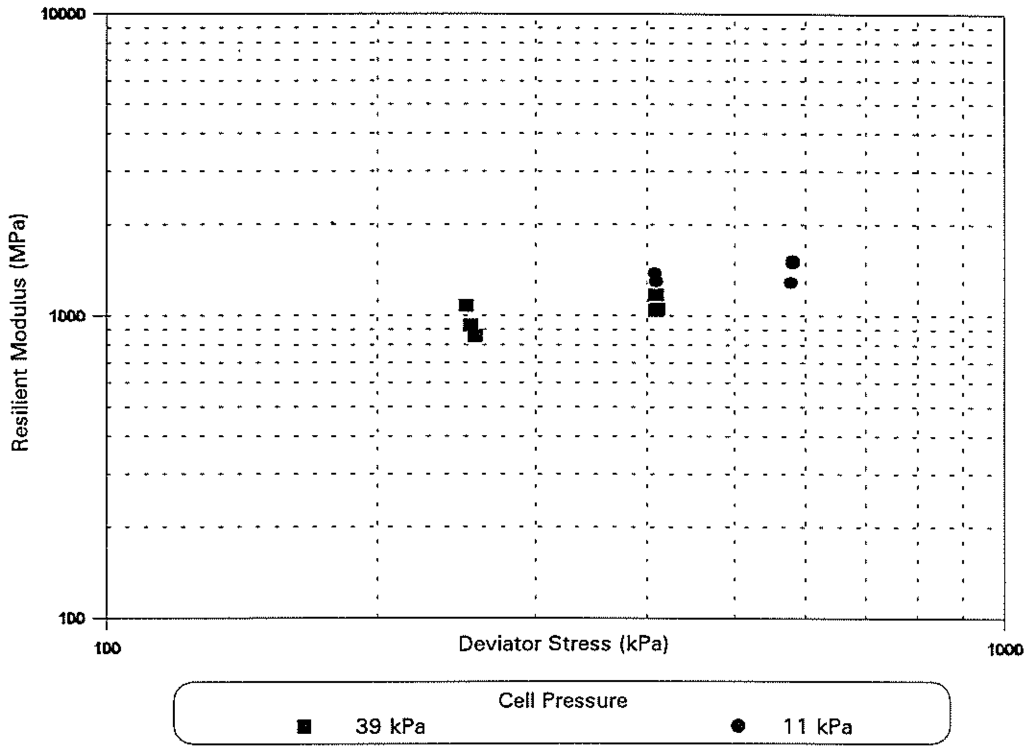

Figure 4.6 Resilient modulus versus deviator stress for foamed concrete specimen.

The laboratory resilient modulus test results for the compacted clay specimens are summarised in Figure 4.5. Figure 4.5 shows that the laboratory resilient modulus test results are reasonably consistent at about 150 MPa and they are not greatly influenced by the deviator stress. The laboratory elastic modulus result is significantly greater than the corresponding Loadman elastic modulus result.

Lightweight foamed concrete

Twelve Loadman tests were carried out on the lightweight foamed concrete. The first test resulted in a very low elastic modulus as the impact of the Loadman collapsed the air bubbles in the concrete directly beneath the base plate. The following six tests showed some inconsistency as further collapsing of air bubbles occurred. The final five tests provided a relatively uniform response. The mean elastic modulus from these tests was 446 MPa.

The laboratory resilient modulus test results for the foamed concrete specimens are presented in Figure 4.6. Figure 4.6 shows that the resilient modulus results are in the range 850 MPa to approximately 1500 MPa depending on the deviator stress and the cell pressure.

4.3.4 Discussion

Comparison of the Loadman elastic modulus results with the laboratory resilient modulus results obtained using the dynamic triaxial apparatus has been somewhat inconclusive. The laboratory tests carried out in accordance with the AS 1289 procedure did not match the corresponding Loadman results but the one laboratory test carried out in accordance with the SHRP Protocol P46 procedure matched the corresponding Loadman test very well.

A plot of Loadman elastic modulus versus laboratory resilient modulus is presented in Figure 4.7. Note that where a range of results were obtained in the laboratory tests the midpoint has been used in the data in Figure 4.7. The plot indicates that there may be a reasonable correlation between the Loadman and the laboratory results if the Loadman results are factored by a coefficient in the range 1 to 3, depending on the testing conditions. The plot also shows that there is a large gap in the current data and further testing is recommended to gain a better appreciation of the relationship between the Loadman and the laboratory resilient modulus test.

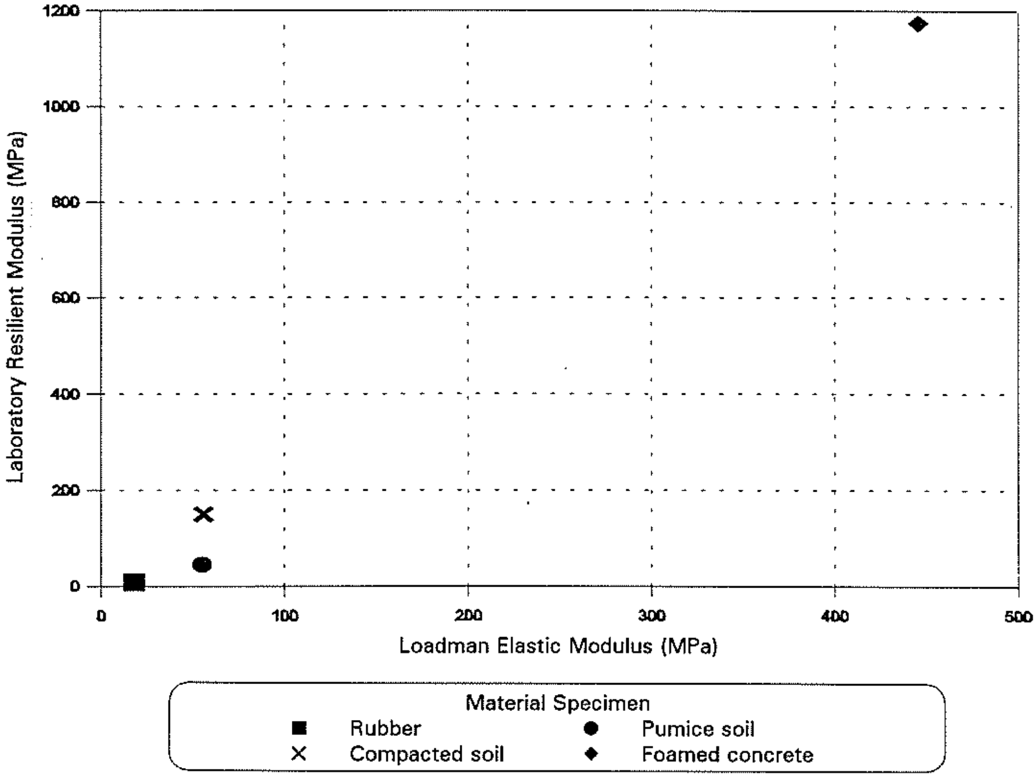

Figure 4.7 Plot of Loadman elastic modulus data versus laboratory resilient modulus data.

Considering the tests carried out using the AS 1289 procedure, the rubber specimen produced a laboratory resilient modulus lower than the corresponding Loadman result while the compacted clay and foamed concrete specimens produced higher laboratory resilient modulus values than the corresponding Loadman result.

The differences in the results obtained in this investigation are difficult to resolve, however it is considered that differences in the testing configuration may have had a major influence. In the laboratory testing the specimen strain was measured internally, i.e. directly from the specimen, for the pumice, clay and foamed concrete specimens whereas the strain was measured externally for the rubber specimen. External strain measurement generally results in lower elastic moduli than an equivalent test performed using internal strain measurement. Testing carried out at the University of Auckland has shown that internal strain measurement can produce elastic modulus results up to three times greater than corresponding results using external strain measurement. This is because the external measurement includes any compliance that is inherent in the components of the testing apparatus. If internal strain measurement had been used on the rubber specimens the Loadman and the laboratory results are likely to have been much closer.

A number of inconsistencies exist between the Loadman test and the laboratory resilient modulus test, and these are mainly with respect to the application of load. The Loadman imparts an impulse type load with a maximum stress of approximately 1.6 MPa for the 132 mm-diameter base plate and 0.7 MPa for the 200 mm-diameter base plate. The duration of the loading is dependent on the response of the material but is generally of the order of a few milliseconds. Conversely, the dynamic triaxial laboratory tests apply deviator stresses over a range of values which are generally much lower than 1.6 MPa or 0.7 MPa.

The duration of loading is also different for the two laboratory test procedures used. While the laboratory test is a dynamic test in that repeated load applications are used, the AS 1289 procedure adopts a 2 second loading period which can hardly be classed as "dynamic". SHRP P46 adopts a load duration of 0.1 seconds with a 1.9 second period of quiescence. The shorter load duration may be considered to be more appropriate for pavement material testing applications. It is certainly much closer to the loading conditions prevailing in the Loadman test and this may explain why the results for the Loadman and laboratory test results for the pumice soil (i.e. using the SHRP P46 method) correlated very well.

The configuration of the test specimens is another difference that could have contributed to inconsistencies between the Loadman and the resilient modulus laboratory tests. The Loadman specimens were block specimens that were simply resting on a concrete slab. Any movement of the slab during testing could have a detrimental influence on the result. Also, the compacted clay specimen used in the Loadman testing was accommodated in a timber mould which may have had a degree of compliance that influenced the results. Conversely, the laboratory specimens were cylindrical and it is a well established fact that these specimens are susceptible to friction and edge effects where they make contact with the platens of the loading device. The Loadman tests conducted on the pumice were in situ tests and hence they were not susceptible to detrimental influences from a mould or the supporting material.

The results of this investigation indicate that, when using the Loadman for obtaining elastic modulus design parameters, the pavement designer should carry out at least one laboratory resilient modulus test for each soil type encountered at a site. This allows a correlation between the Loadman and the laboratory results to be established.

The designer should also take into consideration the stress conditions that are appropriate for the pavement layer in question. The stress conditions imposed by the Loadman appear to be reasonable for materials located in the upper levels of a pavement. However the stresses are somewhat large for subgrade soils. In theory the Loadman would tend to produce an under-estimation of the elastic modulus for cohesive subgrades and an over-estimation of the elastic modulus for non-cohesive subgrades. By using the larger, 200 mm-diameter, Loadman base plate for subgrade tests this effect may be reduced.

The designer may apply a modification factor to allow for different states of stress between the testing and in-service situations. The AUSTROADS procedure for determining the appropriate elastic modulus for stress sensitive materials is as follows:

Granular sub-layers: $E_{\text{IN-SERVICE}} = E_{\text{MEASURED}} \times (\sigma_{PI} / \sigma_{PM})^K$

where:

σ_{PI} = In-service mean principal stress, i.e. $(\sigma_{xx} + \sigma_{YY} + \sigma_{ZZ}) / 3$

σ_{PM} = Measurement mean principal stress, i.e. $(\sigma_{xx} + \sigma_{YY} + \sigma_{ZZ}) / 3$

σ_{xx}, σ_{YY}, σ_{ZZ} = Principal stresses in the centre of the sublayer for the particular configuration in service or measurement under consideration

K = Range from 0.3 for low quality sub-base to 0.5 for high quality basecourse material

Subgrade sub-layers: $E_{\text{IN-SERVICE}} = E_{\text{MEASURED}} \times [(300 - \sigma_{PI}) / (300 - \sigma_{PM})]^P$

where:

σ_{PI} = In-service mean principal stress, i.e. $\sigma_{ZZ} - (\sigma_{XX} + \sigma_{YY}) / 2$

σ_{PM} = Measurement mean principal stress, i.e. $\sigma_{ZZ} - (\sigma_{XX} + \sigma_{YY}) / 2$

σ_{xx}, σ_{YY}, σ_{ZZ} = Principal stresses in the centre of the sublayer for the particular configuration in service or measurement under consideration

P = Subgrade stress dependency factor (0 to 8 depending on subgrade strength)

4.4 Repeatability of Loadman FWD

4.4.1 Objective of Investigation

Repeatability is an important factor in the evaluation of any test procedure. Not only should the results be repeatable by a single operator but they should be repeatable from one operator to another.

4.4.2 Investigation Procedure

The repeatability of the Loadman has been investigated using two approaches. In the first approach the deflection results from a number of Loadman tests carried out on rubber blocks have been analysed statistically. The consistency of the rubber samples means that any variation in the test results is a function of the Loadman's measuring system rather than variations in the structure of the sample. Deflection has been the focus of the analysis because it is the parameter that is reported to the highest degree of precision.

In the second approach Loadman tests were carried out on stabilised aggregate material over a period of time. The minimum, maximum and mean Loadman elastic modulus values were recorded to obtain an indication of the consistency of the data.

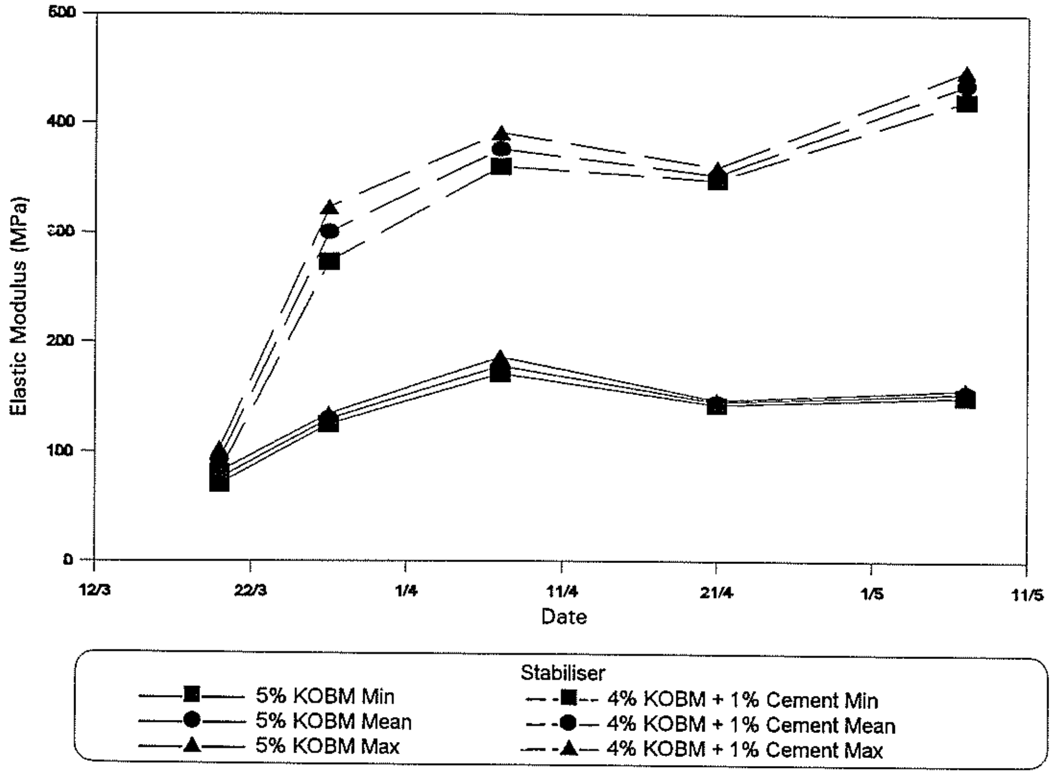

Figure 4.8 Loadman elastic modulus data for stabilised aggregate over time.

4.4.3 Results

Rubber Specimens

Thirty Loadman tests were carried out on rubber specimens. The mean deflection was 6.79 mm and the standard deviation was 0.15 mm. An alternative way of expressing these results is to say that 95% of the data lay within approximately 4% of the mean.

Stabilised Aggregate

The results of the Loadman tests are presented in Table 4.2 and Figure 4.8. The data represent minimum, maximum and mean elastic modulus values for granular materials treated with 5% KOBM and 4% KOBM with 1% cement.

4.4.4 Discussion

Both facets of this investigation have shown that the repeatability of the Loadman test is extremely good. The error that can be attributed to a lack of repeatability is far less than that associated with variability of the pavement materials in both the vertical and horizontal planes.

Table 4.2 Summary of field study of Loadman elastic modulus data from stabilised aggregate.

Date	Loadman Elastic Modulus (MPa)					
	5% KOBM			4% KOBM + 1% Cement		
	Min.	Max.	Mean	Min.	Max.	Mean
20.3.97	70.8	82.0	76.5	82.0	103.0	93.5
27.3.97	125.3	134.5	130.2	273.5	323.0	300.5
7.4.97	171.0	186.3	178.3	360.0	390.8	375.9
21.4.97	142.8	147.0	145.1	347.5	359.3	352.4
7.5.97	150.5	157.0	154.3	421.3	448.8	435.8

4.5 Requirements when using the Loadman FWD

4.5.1 Objective of Investigation

Stress Transfer

One of the most important aspects of operating the Loadman is that there must be a complete and uniform transfer of stress from the base plate of the Loadman to the pavement layer being tested. This was quickly identified as a basic requirement in the practical component of this research and was also borne out in the technical literature that was reviewed.

If there is not a complete and uniform transfer of stress the Loadman will report an elastic modulus value that is erroneous. It will also produce a relatively large scatter of data for multiple tests at a single location. This is because the stress applied by the device is being concentrated on a small number of point contacts rather than being spread over the entire area of the Loadman's base plate.

To achieve a complete and uniform transfer of stress, the top surface of the pavement layer must be as smooth as possible. As most pavement layers, in particular those comprising unbound materials, are not absolutely smooth the Loadman manufacturer suggests that a thin layer of sand should be applied to the layer surface. The sand layer, often referred to as a blinding layer, should be as thin as possible, i.e. zero thickness over the high spots, so that the test result is not overly influenced by the sand itself.

With experience it is possible to differentiate a "good test" from a "bad test" by the sound of the Loadman impact and the response of the device. A good test generally produces a solid "thump" sound and the Loadman remains steady on the test spot throughout the impact. Conversely, a bad test generally produces a "hollow" sound and the Loadman tends to vibrate or lurch to one side immediately after the impact.

Loadman Inclination

A second requirement when using the Loadman is to ensure vertical inclination of the device during testing. This can take two forms:

- where the pavement layer surface is not horizontal; and
- inadvertent inclination of the device caused by inaccurate operation.

When the layer being tested does not have a horizontal surface the Loadman test will be subject to errors. The inclination of the Loadman causes increased friction between the sliding mass and the walls of the device, and hence the applied impact load will be lower than usual. The inclination will also cause a reduced vertical sliding distance. Both these influences result in the Loadman overstating the elastic modulus of the layer being tested.

If the Loadman test is carried out on a horizontal surface but with the device inadvertently tilted, the result will not only be subject to the errors described above but there will also be a non-uniform transfer of stress from the Loadman to the test layer. This is analogous to the situation where the test is carried out on a layer with a rough surface.

In extreme cases of inclination of the Loadman, the device tends to topple over in the process of completing a test. This may occur on pavements with a cross fall of approximately 6% or more.

4.5.2 Investigation Procedure

In this part of the Loadman investigation, the influence of pavement layer roughness has been studied in detail. The effect of inclination of the Loadman has not been studied further as it is considered to be analogous to the surface roughness problem.

The influence of a rough pavement surface on the Loadman results has been investigated by carrying out a number of Loadman tests on pavements with different surface roughness. The surface roughness has been quantified using the sand circle test. This test is commonly used to evaluate surface texture for the calculation of binder application rates for pavement reseals.

Loadman tests have been carried out with and without the sand blinding layer at four pavements, and the magnitude and variation of the results have been correlated with the corresponding sand circle diameter.

4.5.3 Results

Four pavements were selected for testing. The surface properties of the pavements are described in Table 4.3. The Loadman results from each test pavement are presented in Tables 4.4 and 4.5.

Table 4.3 Details of the four test pavements.

Location	Surface Construction	Surface Description	Sand Circle Diameter (mm)
Kyle Road	Grade 4 Chip	Very Rough	195
Dene Court Road	Grade 4 Chip	Rough	200
Orwell Crescent	Grade 4 Chip	Intermediate	270
Bush Road	AC	Very Smooth	460

Table 4.4 Loadman deflection results for tests with and without a sand blinding layer.

Location	Deflection With Sand Blinding (mm)		Deflection Without Blinding (mm)	
	Mean	SD	Mean	SD
Kyle Rd	1.41	0.037	1.39	0.093
Dene Court Rd	1.03	0.032	0.96	0.030
Orwell Cres.	1.92	0.042	1.88	0.043
Bush Rd	0.63	0.053	0.57	0.041

Table 4.5 Loadman elastic modulus results for tests with and without a sand blinding layer.

Location	Elastic Modulus With Sand Blinding (mm)		Elastic Modulus Without Blinding (mm)	
	Mean	SD	Mean	SD
Kyle Rd	115	2.9	117	8.0
Dene Court Rd	158	4.9	170	5.3
Orwell Cres.	84	1.8	86	2.2
Bush Rd	259	21.5	285	20.3

4.5.4 Discussion

The Loadman results presented in Tables 4.4 and 4.5 show that the sand blinding layer resulted in a slightly higher deflection than the corresponding results without the blinding layer. Consequently the elastic modulus results showed an inverse trend, i.e. lower elastic modulus values when the blinding layer was used.

The results indicate that the data was quite consistent regardless of whether the sand blinding layer was used or not except for the roughest pavement, i.e. Kyle Road. Bush Road, which had a smooth AC surface, showed that the sand was in fact more of a hindrance than a help. Figure 4.9 shows a plot of elastic modulus variation versus sand circle diameter.

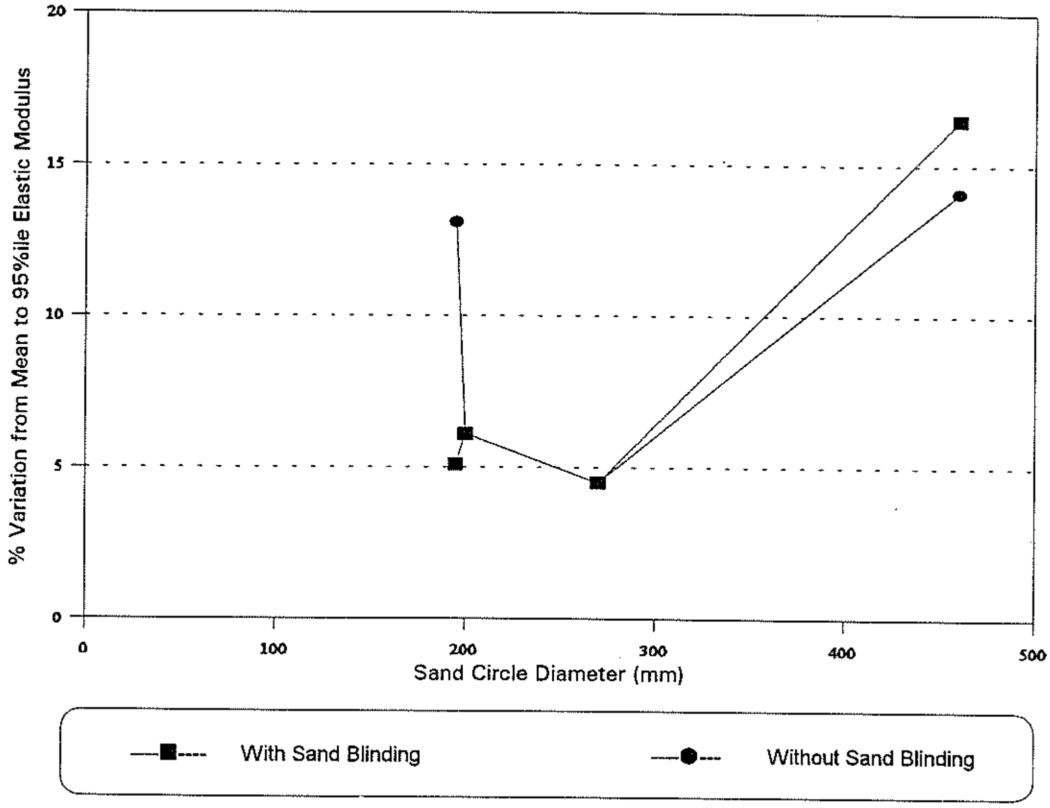

Figure 4.9 **Plot showing % variation from mean to 95%ile Loadman elastic modulus versus sand circle diameter.**

In summary, the roughness investigation was not as conclusive as expected. The feedback obtained from the Loadman while performing tests on an inconcsistent surface is more of an indication of a "bad" test than the data tend to suggest.

5. CONCLUSIONS

The following conclusions have been drawn from the literature review and practical investigation into the performance of the Loadman portable FWD:

- The technical literature on the Loadman is quite sparse as it has been developed relatively recently. The literature generally suggests that the Loadman results correlate reasonably well with the Benkelman Beam, FWD and the plate-bearing test. Most researchers agree that it is important to have a smooth surface on the layer being tested and that multiple tests should be taken at each location. The first two or three tests are considered to precondition the test material and these results should be ignored in the analysis.

- The Loadman was found to be convenient and simple to use and the results were available with little or no post-testing analysis.

- The results showed that the vertical zone of influence of the device was approximately 150 mm and the lateral zone of influence was up to approximately 120 mm from the edge of the Loadman's base plate.

- A reasonable correlation of Loadman elastic modulus results with laboratory resilient modulus tests was obtained if the Loadman results were factored up by a coefficient in the range 1 to 3.

  The Loadman gave higher elastic modulus results than the laboratory tests for the rubber specimens but lower results for the compacted clay and foamed concrete specimens. The reason for the variation in the results is thought to be due to inconsistencies in the testing conditions, in particular the configuration of the load application used in the AS 1289 testing procedure.

  The tests on the pumice soil gave a good match between the Loadman and the laboratory results. This may have been related to the use of the SHRP Protocol P46 laboratory testing procedure which has a loading configuration that more closely resembles that of the Loadman and of a pavement in service.

- Further testing is required to obtain a better understanding of the relationship between the elastic modulus data obtained from the Loadman and the resilient modulus data obtained from dynamic triaxial testing.

- When using the Loadman to establish elastic moduli for design, the designer should carry out correlation tests in the laboratory for each soil type encountered. As the Loadman imparts a relatively high level of stress that may be inappropriate for materials deep in the pavement, use of the large Loadman base plate will minimise this effect for subgrade soils.

- The repeatability of the Loadman test results was very good. In general 95% of the results lay within approximately 4% of the mean value. A consistent set of results was also obtained from Loadman tests carried out on a stabilised aggregate material over a period of time.

- The repeatability of the Loadman test makes it a valuable tool for construction quality control. It can give an indication of in situ elastic modulus data to provide feedback to the pavement designer, as well as showing up any variability in material or construction quality.

- The main practical limitation of the Loadman is the need to have a smooth upper surface on the layer being tested. This smooth surface allows the load applied during a test to be completely and uniformly transferred to the layer. Also both the magnitude and the variability of the test results were influenced by the roughness of the layer surface.

6. REFERENCES

AASHTO. 1992. Interim method of test for resilient modulus of unbound granular base/sub-base materials and subgrade soils. *SHRP Protocol P46.* American Association of State Highway and Transportation Officials.

AL-Engineering Oy. 1996. *Loadman Portable Falling Weight Deflectometer - Instructions for Use.* AL-Engineering Oy, Finland.

AUSTROADS. 1992. Pavement Design: a guide to the structural design of road pavements. *AUSTROADS Publication No. AP-17/92,* Sydney, Australia.

Fleming, P.R., Rogers, C.D.F. 1995. Assessment of pavement foundations during construction. *Proceedings of the Institution of Civil Engineers Transportation, U.K.*

Gros, C. 1993. *Use of a portable falling weight deflectometer; "Loadman".* University of Oulu, Publications of Road and Transport Laboratory, Finland.

Henneveld, R.J.P. 1995. In situ measurements of the bearing capacity of granular base courses. *Unbound Aggregates in Roads, Proceedings UNBAR.* Dawson, A.R. & Jones, R.H. (Eds), Department of Civil Engineering, University of Nottingham, U.K.

Honkanen, P. 1991. *Loadman.* Tielaitos, Finnish National Road Administration, Finland.

Pidwerbesky, B. 1995. *Evaluation of Loadman, FWD, Benkelman Beam, Nuclear Density Meter and Clegg Hammer for testing unbound granular pavements.* Department of Civil Engineering, University of Canterbury, New Zealand.

Standards Association of Australia (SAA). 1995. Soil strength and consolidation tests: - Determination of the resilient modulus and permanent deformation of granular unbound pavements. *AS 1289:1995.*

Transit New Zealand. 1989. *State Highway Pavement Design and Rehabilitation Manual.* Transit New Zealand, Wellington, New Zealand.

Transit New Zealand. 1997. *Pavement Design: A Guide to the Structural Design of Road Pavements. New Zealand Supplement.* Transit New Zealand, Wellington, New Zealand.

Transit New Zealand. 1995. Specification for crushed basecourse aggregate. *TNZ M/4: 1995.*