Flexural modulus of typical New Zealand structural asphalt mixes

March 2008

Land Transport New Zealand
Research Report 334

Flexural modulus of typical New Zealand structural asphalt mixes

R. J. Peploe
Bartley Consultants Ltd, New Zealand

Land Transport New Zealand Research Report 334

ISBN 978–0–478–28747–9
ISSN 1177–0600

© 2008, Land Transport New Zealand
PO Box 2840, Waterloo Quay, Wellington, New Zealand
Telephone 64-4 931 8700; Facsimile 64-4 9318701
Email: *research@landtransport.govt.nz*
Website: *www.landtransport.govt.nz*

Peploe, R. J. 2008. Flexural modulus of typical New Zealand structural asphalt mixes. *Land Transport NZ Research Report 334*. 58pp.

Bartley Consultants Ltd, PO Box 26454, Auckland

Keywords: contamination, environmental impact, leaching, recycling, road construction, secondary aggregates

An important note for the reader

Land Transport New Zealand is a Crown entity established under the Land Transport Amendment Act 2004. The objective of Land Transport New Zealand is to allocate resources in a way that contributes to an integrated, safe, responsive and sustainable land transport system. Each year, Land Transport New Zealand invests a portion of its funds on research that contributes to this objective.

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

While this report is believed to be correct at the time of its preparation, Land Transport New Zealand, and its employees and agents involved in its preparation and publication, cannot accept any liability for its contents or for any consequences arising from its use. People using the contents of the document, whether directly or indirectly, should apply and rely on their own skill and judgement. They should not rely on its contents in isolation from other sources of advice and information. If necessary, they should seek appropriate legal or other expert advice in relation to their own circumstances, and 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 Land Transport New Zealand but may be used in the formation of future policy.

Acknowledgements

The author wishes to acknowledge Mr Michael Haydon, Dr Greg Arnold and Mr Robert Patience for their input into this research.

Abbreviations and acronyms

AASHTO	American Association of State Highway and Transportation Officials
CBR	California bearing ratio
ESA	Equivalent standard axle
HMA	Hot mix asphalt
ITT	Indirect tensile tests
NAS	National asphalt specification
RTA	Road Transport Authority (New South Wales)

Contents

Executive summary

The primary objective of this project was to examine the elastic modulus parameter for hot mix asphalt (HMA) materials typically used in New Zealand. Elastic modulus parameters obtained from flexure and indirect tensile tests (ITT) were compared with published presumptive values and the results of analyses using the Shell Bands software. The influence of a number of material and test variables was also examined.

The main conclusions drawn from the testing carried out in this research were as follows:

- Elastic modulus values obtained for the various asphalt mixes ranged from 1600 to 3552 MPa and 2981 to 6150 MPa for the ITT and flexure test procedures respectively. When the flexure test results were corrected to reflect temperature and loading rates that were consistent with the ITT, the range of results was 1893 to 3905 MPa.
- The testing carried out in this project indicated that the elastic modulus values applicable to typical HMA mixes used in New Zealand were lower than, or at the low end of, the Austroads (2004b) presumptive value ranges.
- The Shell Bands software did not predict the elastic modulus values very well when simulating the flexure test configuration, especially for the specimens comprising 80/100 binder. A slightly better correlation between the measured and predicted modulus values was obtained using realistic temperature and loading rate parameters; however, the Bands prediction was generally significantly higher than the corresponding ITT-derived value.
- The elastic modulus values obtained from the flexure and ITT procedures were reasonably consistent for specimens comprising 40/50 and 60/70 binders when the flexure test results were corrected to allow for temperature and loading rate effects. The difference between the flexure and ITT modulus parameters for 80 to 100 specimens was somewhat greater.
- Mean ITT elastic modulus values for the mixes used in this investigation were established and are presented in the report. These results should not be used directly as pavement design inputs but they do show trends and indicative values.
- The aggregate type used in the various mixes had an influence on both the elastic modulus and the fatigue resistance parameters. HMA specimens comprised of basalt aggregate yielded higher elastic modulus parameters while greywacke mixes showed superior fatigue resistance.
- TNZ Mix 20 provided excellent performance properties in terms of both elastic modulus and fatigue resistance. In particular, the basalt Mix 20 specimens provided favourable elastic modulus properties and, therefore, this mix would be suitable as an intermediate structural HMA layer, providing superior load spreading capability and rut resistance. The greywacke Mix 20 specimens provided favourable fatigue resistance and, therefore, this mix would be suitable as a high fatigue base layer in a structural HMA pavement.

Abstract

Structural hot mix asphalt (HMA) pavements have become popular in New Zealand in recent times as heavy traffic volumes have increased and early failures of granular pavements have become more common, especially in urban areas where road maintenance causes major traffic disruption.

Elastic modulus values are important inputs for the structural HMA pavement design process; however, there is generally a lack of data in New Zealand regarding appropriate elastic modulus values for typical HMA mixes. The primary objective of this project was to address the issue of characterising the elastic modulus parameter for HMA materials.

The project involved performing flexural modulus and indirect tensile tests on specimens of HMA typically used in New Zealand. The results were compared with published presumptive values and the results of analyses using the Shell Bands software. The report interprets the elastic modulus results with respect to a number of material and test variables. The fatigue properties of the test specimens were also examined.

1. Introduction

1.1 General

The majority of road pavements constructed in New Zealand comprise flexible structures with compacted unbound aggregate layers overlain by a bituminous chip seal or a thin hot mix asphalt (HMA) surfacing. This type of pavement has performed extremely well due to the relatively low level of traffic loading and the plentiful supply of high quality aggregates.

However, in recent times, structural asphalt pavements have become increasingly more popular as heavy traffic volumes increase and the ability to mine aggregates becomes more difficult, especially in urban areas where the majority of the infrastructure upgrades occur. The use of structural asphalt pavements has also reduced the risk of early failure issues that have been relatively common with granular pavements, particularly in locations where road maintenance can cause severe traffic disruption.

There are a number of other benefits that structural asphalt pavements offer, eg:

- reduced maintenance requirements
- construction expediency
- reduced susceptibility to adverse weather conditions
- reduced road user costs
- reduced risk of poor performance, especially on greenfield sites.

The benefits described above can be summarised by saying that, in relatively high traffic volume applications, structural asphalt pavements generally present a low-risk solution in terms of design and construction, and they benefit the travelling public by reducing delays that would otherwise be generated by time-consuming construction and maintenance requirements.

There is a good understanding of the production and construction aspects of HMA in New Zealand. The major contractors have a high level of expertise and experience and the production plant, at least in the main centres, is generally of a high standard. In the main, this high level of capability has been established by the need to produce quality HMA surfacings that are often constructed on very flexible pavement layers. However, there is not the same level of experience in the characterisation of HMA materials for the design of structural asphalt pavements.

The principal objective of this project was to help address the issue of HMA characterisation by carrying out a number of flexural modulus and indirect tensile tests on samples of structural asphalt mixes typically used in New Zealand.

2. Literature review

2.1 General

A review of the technical literature was carried out to provide background information on the design of structural asphalt pavements in New Zealand, the significance of the elastic modulus parameter for HMA and procedures that could be used to establish the elastic modulus parameter. The results of the literature review are presented in the following paragraphs.

2.2 Structural asphalt pavement configuration

Structural asphalt pavements are typically used in New Zealand when the design traffic loading is very high, eg greater than about 10^7 ESA, or where construction expediency is paramount. This is often the case in central city locations where disruption to traffic can result in substantial road user delay costs.

Structural asphalt pavements can comprise two, three or four layers depending on the application and the objectives of the designer. Multiple layers may also be required to ensure that the materials receive adequate compaction during construction. A two-layer structure would typically comprise a thin surfacing layer over a relatively thick layer of rut resistance HMA. The surfacing mix would be specifically designed to provide appropriate texture, shear resistance and drainage properties.

A three-layer structure incorporates similar materials as those described above for a two-layer structure except that a high fatigue HMA layer is constructed beneath the rut resistant (intermediate) layer. The high fatigue layer has an elevated bitumen content and consequently is better able to resist the repeated tensile strains that occur at the underside of the pavement structure. However, the high fatigue layer has a low level of stability and hence it must be kept relatively thin with an adequate thickness of HMA cover to ensure that it does not become overstressed, either during construction of the overlying layers or during its service life. In addition, a high fatigue layer can cause a permeability reversal resulting in high water pressures in the overlying asphalt layers. This mechanism has been identified as the cause of a number of premature pavement failures in Australia and consequently the use of high fatigue layers is not permitted by the Road Transport Authority (RTA) in New South Wales.

A four-layer structure is similar to the three-layer structure described above except that an additional layer is provided between the intermediate layer and the surfacing layer. The objective of the additional layer is to provide an improved running surface for the placement of the surface layer. This results in the best possible ride quality on the pavement surface.

In New Zealand, three-layered HMA structures are preferred as they are considered to provide the most cost-effective solution. Each layer has a specific role to play in the pavement structure and the respective HMA mixes can be designed to best achieve the required characteristics.

Research carried out in the United Kingdom by Nunn (1977) introduced the concept of perpetual pavements. Nunn reported that HMA pavements with a thickness greater than approximately 160 mm had virtually an indefinite structural life as long as the layers were kept waterproof and the axle loading did not increase. In this context the surface layer is considered to be a sacrificial layer that is replaced when it no longer achieves its required surfacing properties eg, texture, skid resistance and water spray abatement.

The perpetual pavement concept was also reported by Gallagher (1999) as a result of the bitumen in the HMA increasing in stiffness as it oxidised with age. This effectively means that the overall structural quality of HMA layers improves with time and, therefore, a very long service life can be achieved. Nunn et al. (1997) reported that the modulus of a macadam roadbase material can increase by a factor of four over a period of 20 years.

2.3 Design of structural asphalt pavements

The Austroads pavement design procedure, which is the design standard used in New Zealand, adopts the so-called 'mechanistic–empirical' approach. This involves modelling a proposed pavement structure as a sequence of linear elastic layers with a standard axle load located at the top surface of the upper layer (see Figure 2.1).

The computer program Circly (Wardle 2005) is used to calculate the response of the model to the superimposed loading. The magnitude of the strain occurring at critical locations is then used to determine the theoretical design life of the pavement. The analysis used to determine the critical strain values is the mechanistic component of the process, while the relationship between the magnitude of the strain and the expected pavement life is the empirical component.

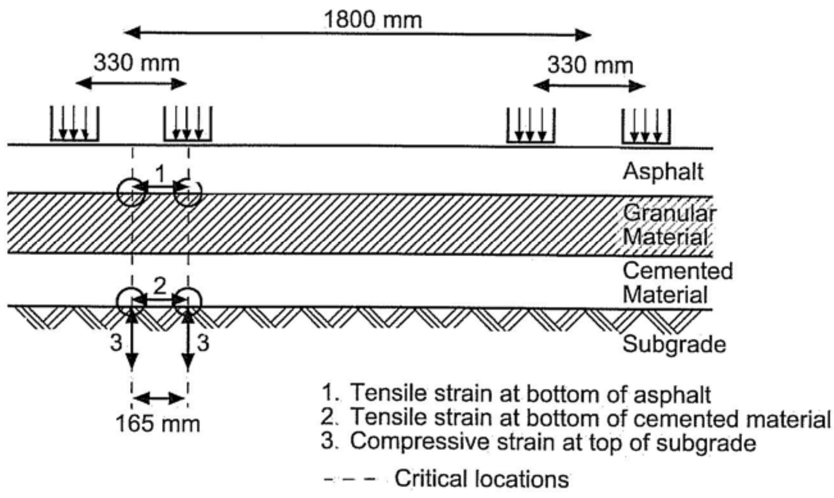

Figure 2.1 Mechanistic pavement model (from Austroads 2004b).

The input data required for each layer in the Circly model comprises:

- elastic modulus
- Poisson's ratio
- layer thickness.

The details of the axle loading are input to the Circly model in terms of:

- tyre contact pressure
- tyre locations
- tyre radius.

In road pavements, the axle loading comprises a standard configuration known as the equivalent standard axle (ESA). The details of the ESA are presented in the design manual (Austroads 2004b) and can be stored in the Circly database for re-use.

The layer thickness is the main variable for a given pavement configuration so the user simply adjusts the thickness value until a suitable solution is obtained. Circly has the ability to optimise the layer thickness automatically if necessary. The Poisson's ratio has a relatively small influence on the response of the pavement model and, therefore, presumptive values for various material types are generally considered to be adequate. The elastic modulus parameter is the one that is most elusive.

There are a number of reasons why the elastic modulus parameter is difficult to establish, particularly for HMA materials. The factors that affect the elastic modulus of HMA include (Austroads 2004b):

- mix composition

  - aggregate mineralogy
  - aggregate grading
  - aggregate angularity
  - binder penetration and softening point
  - binder content and volume
  - air voids
- temperature
- rate of loading
- age.

The complexity of establishing elastic modulus values for input into the mechanistic analysis is not confined only to HMA layers. For example, subgrade and unbound aggregate materials show non-linear stress/strain responses, and the test results are significantly influenced by factors such as moisture conditions, sample preparation techniques, and soil structure and mineralogy. In addition, the test results that are used to establish the elastic modulus generally involve correlations with other test parameters. For example, subgrade elastic modulus values (E_{SG}) are often related to the California bearing ratio (CBR) of the soil using the relationship E_{SG} = 10 (CBR) where the CBR parameter itself has been correlated from some other test parameter. There is also considerable scatter in the E_{SG} versus CBR relationship.

Designers should avoid the temptation to rely on high levels of precision in the characterisation and pavement modelling processes of the materials considering the number of assumptions and simplifications that are inherent in the testing and analysis methodologies.

2.4 Elastic modulus of HMA materials

2.4.1 General

There are a number of definitions for stiffness or modulus parameters for pavement layers that generally involve minor variations on the same theme. In addition, there are a number of test procedures and correlations that can be used to establish the various elastic modulus parameters. It should be noted that there can be large variations in test results both from one test procedure to another and within the same test procedure.

In basic terms the elastic modulus (E) of a material is defined as follows:

E = applied stress/recovered strain

For the purposes of this study, the terms 'elastic modulus' and 'resilient modulus' are considered to be similar.

It is important to make the distinction regarding the state of stress under which the particular modulus parameter is measured, ie the modulus could be established under compressive, tensile, shear or flexural states of stress. Each of these stress conditions is likely to result in a different response from the same sample of HMA.

Austroads (2004b) reports that there are three methods that are currently used to establish elastic modulus parameters for HMA materials, ie:

- laboratory testing using the indirect tension test (ITT)
- consideration of bitumen properties and mix volumetrics using the Shell nomographs
- presumptive values derived from published data.

There are a number of other test procedures in addition to the ITT that can be used including:

- flexure tests
- triaxial tests.

2.4.2 Indirect tensile test (ITT)

The ITT is sometimes known as the Brazilan test. It was developed simultaneously, but independently, in Brazil and Japan in 1953 (Peploe 1987). At the time, the Brazilian Institute of Technology was investigating the bearing capacity of cast iron casks filled with concrete that were being used as rollers to shift an ancient structure. It was noticed that overloaded rollers consistently failed by splitting in tension rather than crushing in compression. This experience was adapted to develop a tensile testing procedure.

Application of elastic theory indicates that when a cylindrical specimen is loaded diametrically there is a very uniform distribution of tensile stress perpendicular to the direction of the applied load. This tensile stress distribution is used to simulate the tensile stresses that occur at the underside of an HMA layer when a pavement is subjected to axle loads.

The ITT equipment comprises a testing frame and platens with 13 mm wide loading strips that are contoured to the radius of the specimen. The load is applied across the vertical diameter and the specimen deflections are measured across both the vertical and horizontal diameters (see Figure 2.2).

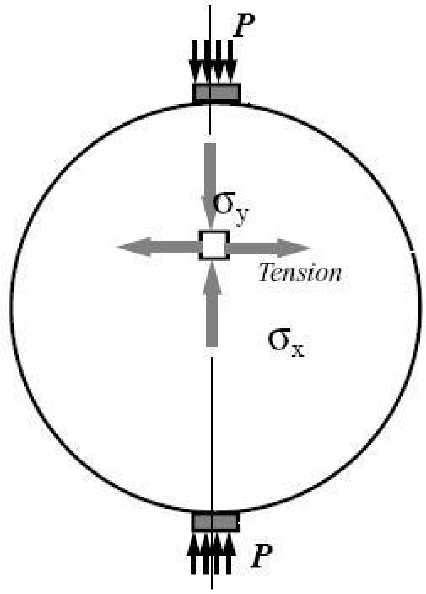

Figure 2.2 Indirect tension test configuration.

The test equipment and procedure used in New Zealand are specified in Standards Australia (1995). In summary, the test specification requires that the testing machine apply a repeated load pulse with a rise time of 0.04 s and a pulse repetition period of 3.0 s. The test is carried out under stain controlled conditions with a specified recovered horizontal strain of 50 με ± 20 με.

A specimen diameter of 100 to 150 mm is used, depending on the maximum particle size of the HMA. The specimen length is half the diameter. The test is carried out at a constant temperature of 25ºC.

The resilient modulus parameter is determined by first carrying out a preconditioning loading sequence, then applying a sequence of five load pulses. The resilient modulus (E) is defined as:

$$E = P(\upsilon + 0.27) / Hhc$$

where E : elastic modulus (MPa)
P : applied load (kN)
υ : Poisson's Ratio (assumed to be 0.4)
H : recovered horizontal deformation (mm)
hc : specimen height (mm).

Alba et al (1997) report that the advantages of the ITT over other test methods are:

- the test is relatively simple and expedient to conduct
- the type of specimen and the equipment can be used for other testing
- failure is not seriously affected by surface conditions

- failure is initiated in a region of relatively uniform tensile stress
- the variation of test results is low compared with other test methods
- a specimen can be tested over a range of orientations and the results can be used to determine whether the sample is homogeneous and undisturbed
- the test can provide information on the tensile strength, Poisson's ratio, fatigue characteristics and permanent deformation characteristics of HMA.

Alba et al (1997) also report that the main disadvantage of the test is that the stress conditions do not simulate the in-service stress conditions accurately, although it is argued that the test provides a reasonable approximation.

Alba et al (1997) refer to literature stating that the ITT generally overstates the strength and stiffness parameters of materials as the failure plane is forced into a single location, ie tensile failure across the diameter perpendicular to the direction of loading. Other test methods generally allow the specimen to fail in the mode or orientation of least resistance.

2.4.3 Shell nomographs

The *Austroads Pavement Design Guide* (Austroads 2004b) reports that the nomographs presented by Shell (1978) are appropriate for estimating the elastic modulus of HMA materials with conventional binders.

The Shell process comprises two parts. The first part involves input of three parameters, ie loading frequency, operating temperature and penetration of the binder, to establish the stiffness modulus of the binder component of the mix. This part of the process was originally developed by van der Poel (1954).

The second part of the process involves input of the stiffness modulus of the binder and the volumetric proportions of the HMA to establish the stiffness modulus of the mix. This part of the process was originally developed by Heukelom and Klomp (1964). In recent times the Shell nomographs have been incorporated into the Shell Bands software package.

2.4.4 Published data

The main source of published data for use in New Zealand is that presented in Austroads (2004b), see Table 2.1. The Austroads data is based on standard ITT test conditions and specimens compacted to 5% air voids.

Many designers consider that presumptive values are reasonable for design, especially considering the complexity of HMA performance and the number of factors that can have an influence on the elastic modulus parameter. While the typical values reported in Austroads (2004b) may be useful, it should be noted that the reported ranges of data are very wide. There would be a significant variation in layer thickness requirements depending whether the presumptive modulus values were taken from the low end or the high end of the range.

Table 2.1 shows that there is only a slight increase in presumptive modulus values with increasing mix size; however, there is a significant increase in presumptive modulus with increasing binder stiffness, ie Class 170 to Class 600.

Table 2.1 Presumptive elastic modulus values for typical Australian HMA materials (after Austroads 2004b).

Binder	Mix size (mm)					
	10		14		20	
	Range	Typical	Range	Typical	Range	Typical
Class 170	2000–6000	3500	2500–4000	3700	2000–4500	4000
Class 320	3000–6000	4500	2000–7000	5000	3000–7500	5500
Class 600	3000–6000	6000	4000–9000	6500	4000–9500	7000
Multigrade	3300–5000	4500	3000–7000	5000	4000–7000	5500
A10E	1500–4000	2200	2000–4500	2500	3000–7000	3000

2.4.5 Flexure test

In the flexure test, a beam specimen is subjected to third-point controlled displacement loading. The third-point loading involves loading at points at one-third distances from the beam ends which results in uniform bending stresses in the middle third of the specimen (Flintsch et al 2005). The test is generally used to evaluate the fatigue properties of HMA materials; however, it uses the modulus of the specimen as the basis for the evaluation of the fatigue performance.

The test conditions are specified in Austroads (2001). The main features of the test conditions are:

- the specimen must be 390 mm long by 50 mm deep by 63.5 mm wide
- the test is carried out at a constant temperature of 20ºC
- the loading frequency is 10 Hz
- the loading configuration is a continuous haversine with a target peak tensile strain of 400 με.

The test setup is shown in Figure 2.3.

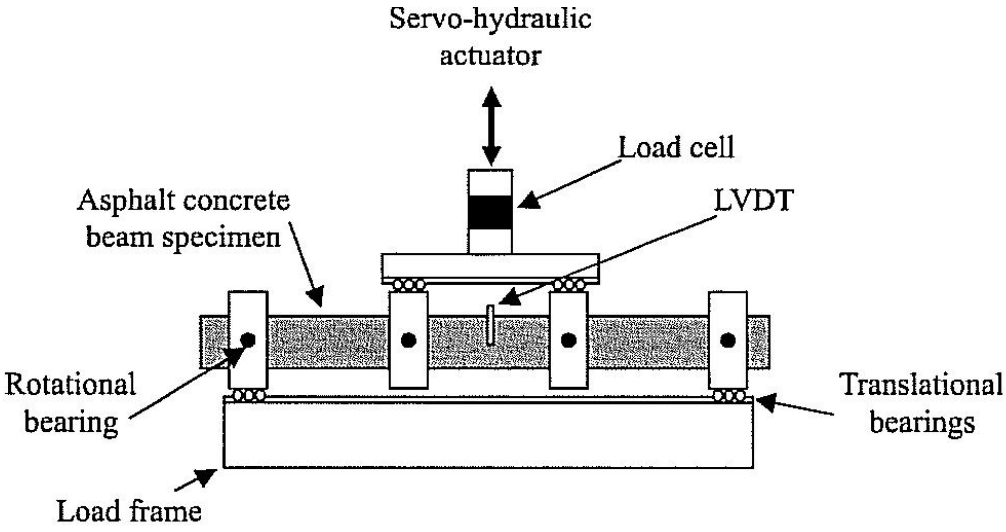

Figure 2.3 Flexure test configuration (from Flintsch et al 2005).

As described above, the flexure test is usually carried out to evaluate the fatigue properties of an HMA specimen. This is achieved by first subjecting the specimen to a preconditioning loading sequence of 50 load cycles. At that point the initial flexural stiffness of the specimen is calculated. The loading sequence is then continued until the flexural stiffness reduces to 50% of the initial value, at which point the specimen is deemed to have reached the end of its fatigue life and the test is discontinued. The test is generally discontinued after 10^6 load cycles irrespective of the flexural stiffness decay of the specimen.

The flexural stiffness (S_{mix}) is calculated using the following relationships:

$$S_{mix} = 1000\sigma_t / \varepsilon_t$$

and

$$\sigma_t = LP/wh^2$$

$$\varepsilon_t = 108\delta h / 23L^2$$

where

σ_t : peak tensile stress (kPa)
L : beam span
P : peak force (N)
w : beam width (m
h : beam height (mm)
ε_t : peak tensile strain (microstrain)
δ : peak displacement (mm).

Rowe and Bouldin (2000) report that HMA specimens in flexure tests experience four separate conditions as the repeated loading test progresses. These are:

- internal heating
- micro-crack formation

- crack formation
- sample breakdown.

Internal heating of the specimen occurs as a result of the work done during the repeated deflection of the viscous HMA material. This increase in temperature tends to reduce the stiffness of the specimen and the test results can be distorted accordingly. Rowe and Bouldin (2000) recommend that a temperature correction be applied to the test results, especially where a relatively large strain excursion is applied or where modified binders are being used.

Alba et al (1997) report that the advantages of the flexure test are:

- it is well known, in widespread use and well understood
- the test procedure measures a fundamental property that can be related to the pavement application
- the test can be carried out successfully in controlled stress or controlled strain mode.

Alba et al (1997) report that the main disadvantages of the flexure test are:

- it is time consuming
- it is costly
- it suffers from a lack of repeatability
- the stress conditions in the test are uniaxial whereas the stresses in a pavement layer are triaxial
- it requires specialised equipment.

The test is often criticised regarding the configuration of the beam specimens, in particular that the specimens are relatively small in cross section. Consequently, the test results can be significantly influenced by edge effects and discontinuities in the specimen material, especially at the underside of the specimen where the tensile stresses are greatest.

2.4.6 Triaxial test

The dynamic modulus (triaxial) test was developed for use with the American pavement design procedures (NCHRP 2004). The test was originally developed at Ohio State University and it became the Asphalt Institute’s standard modulus test for HMA (Harman 2001).

The test involves applying sinusoidal vertical loads to a 100 mm diameter cylindrical HMA specimen (see Figure 2.4) and measuring the corresponding vertical deformation. The test is carried out over a range of specimen temperatures, ie 14, 40, 70, 100 and 130ºF as well as a range of load frequencies, ie 25, 10, 5, 1.0, 0.5 and 0.1 Hz. The result of the testing is a master curve that is used in the American Association of State Highway and Transportation Officials (AASHTO) pavement design procedure.

The dynamic modulus test is sometimes known as the 'complex modulus test' as the analysis includes real and imaginary parts corresponding to the elastic and viscous responses of the HMA respectively.

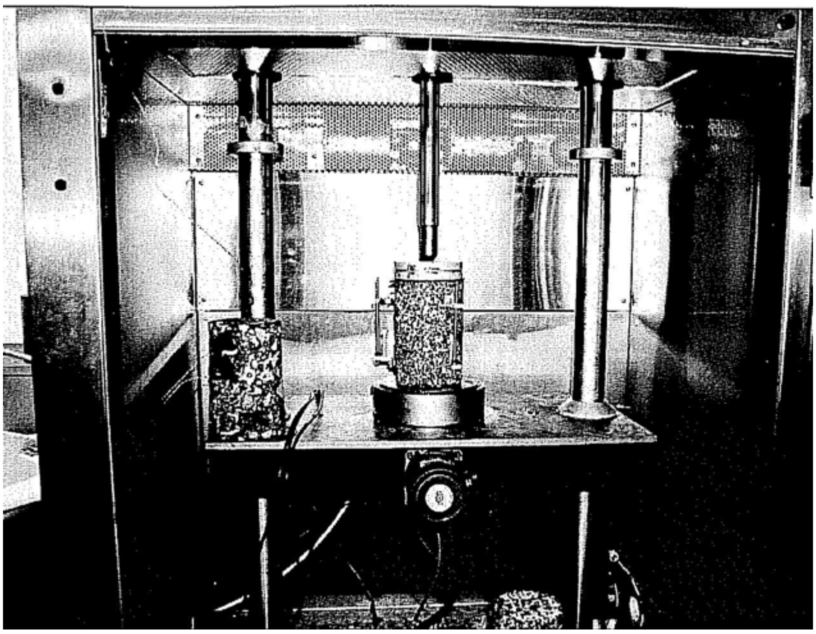

Figure 2.4 Dynamic modulus test setup (from Bhasin et al. 2005).

3. Testing programme

3.1 Testing laboratory

All sample preparation and testing were carried out at the Works Infrastructure Laboratory located at Mt Wellington, Auckland

3.2 HMA mix selection

The project proposal stated that resilient modulus parameters would be determined for two typical HMA materials using both flexure and indirect tension tests. In addition, each mix would be tested using basalt and greywacke aggregates.

The actual testing costs proved to be lower than the estimated costs which allowed a greater number of mixes to be included. After conferring with the Project Steering Committee a new list of candidate mixes was established. The objective was to include mixes that were commonly used, at least in the Auckland region where structural asphalt pavements were most prevalent. The candidate mixes included surfacing, intermediate and high fatigue materials.

In all, 10 HMA materials were tested, as shown in Table 3.1.

Table 3.1 HMA mixes used in the testing programme (B – basalt, G – greywacke).

Mix designation	Application	Binder penetration grade		
		40/50	60/70	80/100
NAS(1) AC14	Surface	–	B & G	–
NAS(1) AC20	Intermediate	B	B & G	B
Transit NZ(2) Mix 20	Intermediate	–	B & G	–
NAS AC20HB(3)	High fatigue	–	B	B

Notes:

(1) NAS mixes comply with the National Asphalt Specification (AAPA 2004).

(2) Transit NZ mix complies with the Transit NZ M/10 Asphaltic Concrete Specification (Transit New Zealand 2005).

(3) AC20HB designation corresponds with a high bitumen mix.

The NAS AC20 mix was considered to be of most interest as Transit New Zealand is in the process of adopting the Australian Asphalt Pavements Association (AAPA) NAS specification for use in New Zealand. In addition, the AC20 mix was considered to be a versatile, rut resistant mix for use in intermediate layers of structural asphalt pavements. The 60/70 penetration grade binder was also considered to be important as that binder is most commonly used in the Auckland region. Other binders were included given that softer

bitumens are sometimes used in high fatigue mixes and softer or harder binders are sometimes used in intermediate layer mixes depending on the location of the site.
The basalt and greywacke aggregates were sourced from Holcim Quarry at Bombay and Brookby Quarry respectively.

3.3 Specimen preparation

The HMA mixes described in Table 3.1 were prepared to the NAS (AAPA 2004) and TNZ M/10 (Transit New Zealand 2005) specifications as applicable. Aggregate sampling was carried out in accordance with the procedure detailed in Austroads (2004a).

The pre-batched aggregates were heated and the appropriate quantity of binder was added to achieve standard mix designs. The HMA was then mixed and conditioned in an oven for 60 minutes. A roller compactor was used to produce the samples under conditions that simulated field compaction. The target air voids were 5.0% +/- 0.5% and these were achieved for all except one sample, ie the greywacke TNZ Mix 20 which achieved 4.3% air voids. It was decided to continue with the test specimen preparation for the non-complying sample rather than rejecting it.

The specimens were compacted into moulds measuring 400 x 305 x 75 mm for the flexural tests and 305 x 305 x 75 mm for the indirect tension tests. Once the HMA samples had cooled they were removed from the moulds.

The flexural test specimens were prepared by cutting to size using a diamond saw. The test specimen size criteria were:

- width : 63.5 mm +/- 5.0 mm
- depth : 50.0 mm +/- 5.0 mm
- length : 390 mm +/- 5 mm

The ITT specimens were prepared using a 100 mm diameter core cutter and the cores were then trimmed to achieve a length of 60 mm +/- 5 mm.

Relevant details of the HMA samples are presented in Table 3.2.

Table 3.2 Specimen details.

Mix	Binder	Aggregate	Air voids (%)	Binder content (%)	Bulk density (t/m3)
NAS AC14	60/70	Greywacke	5.3	5.4	2.353
		Basalt	4.6	5.0	2.465
NAS AC20	40/50	Basalt	4.7	4.5	2.492
	60/70	Greywacke	5.3	4.7	2.375
		Basalt	5.0	4.5	2.484
	80/100	Basalt	4.8	4.5	2.479

NAS AC20HF	60/70	Basalt	4.8	5.0	2.479
	80/100	Basalt	4.7	5.0	2.480
TNZ Mix20	60/70	Greywacke	4.3	6.0	2.370
	60/70	Basalt	4.8	6.0	2.479

3.4 Testing procedures

3.4.1 Indirect tensile tests

The indirect tensile tests were carried out in accordance with the procedure described in 'Determination of the resilient modulus of asphalt indirect tensile method' (Standards Australia 1995).

The basic features of the test are described in Section 2.4.2. As for the flexure tests, the indirect tensile tests were carried out under controlled strain conditions. The test temperature was 25ºC and each HMA sample was tested using triplicate specimens.

3.4.2 Flexure testing

The flexure tests were carried out in accordance with the procedure described in 'Fatigue life of compacted bituminous mixes subject to repeat flexural bending' (Austroads 2001). This test method is an Australian version of the SHRP M-009 test, 'Standard method of test for determining the fatigue life of compacted bituminous mixtures subjected to repeated flexural bending' (Tayebali et al. 1992).

The basic features of the test are described in Section 2.4.5. The test specification calls for the use of displacement (or strain) control which means that each excursion of repeated load is applied to achieve a constant level of strain. This condition corresponds with pavement layers that do not provide the main structural contribution to a pavement structure, ie surface and high fatigue layers. Structural (intermediate) HMA layers are better modelled using controlled stress test conditions; however, the test procedure does not accommodate this condition.

The test temperature was 20ºC and a target tensile strain of 400 με was used. The repeated loading was continued until the flexural modulus reduced to 50% of the initial flexural modulus, or 106 load cycles had been applied, whichever occurred first. The number of load cycles required to achieve the 50% was taken as the fatigue life of the specimen.

The flexure tests were carried out in triplicate.

3.5 Test results

Results from the ITT and flexure tests are summarised in Table 3.3 and test result sheets are presented in Appendix A and B respectively.

Table 3.3 Summary of ITT and flexure test results.

Mix type	Binder	Aggregate	Air voids (%)	Binder content (%)	Elastic modulus (MPa)[1]			Cycles to failure (x106)[1]
					ITT	Flexure		
						Raw result[2]	Corrected[3]	
NAS AC14	60/70	Greywacke	5.3	5.4	1600	2981	1893	0.93
		Basalt	4.6	5.0	2756	3927	2493	0.73
NAS AC20	40/50	Basalt	4.7	4.5	3447	6143	3900	0.34
	60/70	Greywacke	5.3	4.7	1781	3206	2036	0.57
		Basalt	5.0	4.5	2616	3999	2539	0.42
	80/100	Basalt	4.8	4.5	2301	4974	3158	0.24
NAS AC20HF	60/70	Basalt	4.8	5.0	2333	4097	2601	0.65
	80/100	Basalt	4.7	5.0	1870	5447	3458	0.33
TNZ Mix 20	60/70	Greywacke	4.3	6.0	2542	4365	2771	1.00
		Basalt	4.8	6.0	3552	6150	3905	0.71

Notes:

(1) Elastic modulus and cycles to failure results are presented as the mean of triplicate test results – see appendices for detailed test results.

(2) The raw flexural modulus results refer to the modulus measured at the start of the repeated loading sequence.

(3) The raw flexural modulus results have been corrected to approximate the test conditions used in the ITT tests. A factor of 0.67 has been used to account for the temperature difference, ie 25ºC in the ITT versus 20ºC in the flexure test. In addition, a factor of 0.95 has been used to account for the slightly different loading rise time used in the two tests, ie 40 ms for the ITT and (approximately) 50 ms for the flexure test.

3.6 Interpretation of the test data

3.6.1 General

The main points of interest in examining the test data are to:

- compare the measured elastic modulus test results with the presumptive modulus values provided in Austroads (2004b)
- compare the measured elastic modulus test results with the modulus values obtained from the Shell nomographs
- investigate the influence on elastic modulus of a number of test and specimen variables, including:
  - the test procedure
  - the mix type
  - the binder stiffness
  - the binder content
  - the aggregate type
- compare the relative fatigue resistance properties of the various HMA mixes.

These matters are discussed in the following sections.

3.6.2 Comparison with published data

Austroads (2004b) presents a table of presumptive modulus values for typical Australian HMA mixes (see Table 2.1). A direct comparison of the presumptive modulus values and the values obtained from the current testing cannot be achieved due to differences between the binders used in Australia and New Zealand. However a reasonable approximation can be used as shown in Table 3.4. The results are also presented graphically in Figure 3.1.

Table 3.4 Comparison between test and presumptive modulus values.

<table>
<tr><th rowspan="2">Mix</th><th rowspan="2">Binder</th><th rowspan="2">Aust equiv binder</th><th rowspan="2">Agg</th><th colspan="3">Modulus (MPa)</th></tr>
<tr><th>ITT</th><th>Flexure test (corrected)</th><th>Austroads presumptive</th></tr>
<tr><td rowspan="2">NAS AC14</td><td rowspan="2">60/70</td><td rowspan="2">Class 320</td><td>G</td><td>1600</td><td>1893</td><td>2000–7000</td></tr>
<tr><td>B</td><td>2756</td><td>2493</td><td>2000–7000</td></tr>
<tr><td rowspan="4">NAS AC20</td><td>40/50</td><td>Class 600</td><td>B</td><td>3447</td><td>3900</td><td>4000–9500</td></tr>
<tr><td rowspan="2">60/70</td><td rowspan="2">Class 320</td><td>G</td><td>1781</td><td>2036</td><td>3000–7500</td></tr>
<tr><td>B</td><td>2616</td><td>2539</td><td>3000–7500</td></tr>
<tr><td>80/100</td><td>Class 170</td><td>B</td><td>2301</td><td>3158</td><td>2000–4500</td></tr>
</table>

NAS AC20HF	60/70	Class 320	B	2333	2601	n/a
	80/100	Class 170	B	1870	3458	n/a
TNZ Mix 20[1]	60/70	Class 320	G	2542	2771	3000–7500
			B	3552	3905	3000–7500

Note:

([1]) The TNZ Mix 20 cannot be compared directly with the Australian NAS mixes due to different mix design criteria.

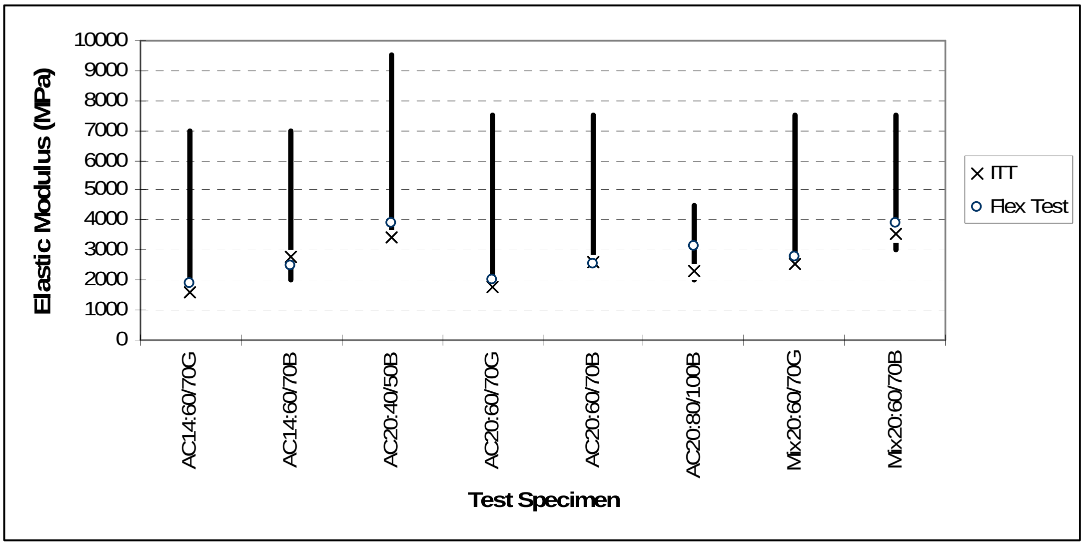

Figure 3.1 Plot showing elastic modulus results from ITT and flexure testing relative to the presumptive Austroads modulus ranges.

Table 3.3 and Figure 3.1 show that the ITT and (corrected) flexural modulus values obtained in the laboratory testing programme are generally below, or in the lower bracket, of the Austroads (2004b) presumptive modulus ranges.

3.6.3 Comparison with Shell nomograph data

A comparison between the flexural modulus test results and the corresponding elastic modulus values predicted using the Shell nomographs has been undertaken. A summary of the flexure test and Shell nomograph data is presented in Table 3.5.

Relevant parameters used in the Shell (Bands) process are as follows:

- temperature : 20ºC
- loading time : 0.1 s
- PI 40/50 : -0.03
- T_{800} 40/50 : 60.5ºC
- PI 60/70 : -0.05
- T_{800} 60/70 : 56.0ºC

- PI 80/100 : -0.06
- T_{800} 80/100 : 52.0ºC

Note that the parameters presented above correspond to binders one penetration grade stiffer than the actual binders used in the test specimens to account for the binder oxidation that occurs during mix production and laying.

Table 3.5 Elastic modulus values predicted using the Shell Bands software compared with flexural modulus test results.

Mix	Binder	Agg	Bulk den (t/m³)	Air voids (%)	Vol binder (%)	Vol agg (%)	Resilient modulus (MPa)	
							Shell Bands	Flexure test
NAS AC14	60/70	G	2.353	5.3	12.4	82.3	2050	2981
		B	2.465	4.6	12.1	83.3	2280	3927
NAS AC20	60/70	G	2.375	4.7	10.9	83.8	2520	6143
		B	2.484	5.3	10.9	84.1	2600	3206
	40/50	B	2.492	5.0	11.0	84.3	4080	3999
	80/100	B	2.479	4.8	10.9	84.3	1690	4974
NAS AC20HF	60/70	B	2.479	4.8	12.1	83.1	2240	4097
	80/100	B	2.480	4.7	12.1	83.2	1420	5447
TNZ mix 20	60/70	G	2.370	4.3	13.9	81.8	1850	4365
		B	2.479	4.8	14.5	80.7	1630	6150

There was not a strong relationship between the flexure test results and the corresponding values predicted using the Shell Bands procedure. While a good match was obtained for the NAS AC20 specimen with 40/50 binder, the remainder of the comparisons were very poor with Bands understating the modulus by a significant margin.

The understated modulus values obtained using Bands are somewhat surprising given that the author's experience with the Bands approach is that the predicted modulus values are generally higher than expected. The reason for this appears to be the relatively low rate of loading used in the flexure test procedure. In simulating the ITT procedure a loading time of 0.10 s has been used as input into Bands.

Austroads (2004b) states that, for the purposes of design, the elastic modulus of asphalt materials should be determined using either the ITT or the Shell nomographs. If the ITT is used the result must be adjusted to take into account temperature, material air voids and loading rate effects.

Table 3.6 presents a comparison of the measured ITT modulus values and corresponding Shell nomograph data for a hypothetical pavement design application. The following parameters have been adopted:

- design speed : 50 km/h
- design pavement temperature : 23ºC

Table 3.6 shows that the Shell Bands procedure predicts modulus results that are generally higher than the corresponding ITT results. The exception is the result obtained for the Mix 20 basalt sample which showed a higher ITT modulus than the Bands procedure predicted. The mean ratio of the Bands : ITT results is 1.68.

Table 3.6 Elastic modulus values predicted using the Shell Bands software compared with ITT modulus test results for 50 km/h/23°C application.

Mix	Binder	Agg	Vol binder (%)	Vol agg (%)	Resilient modulus (MPa)		Ratio Bands/ITT
					Shell Bands	Adjusted ITT	
NAS AC14	60/70	G	12.4	82.3	2850	1248	2.28
		B	12.1	83.3	3160	2150	1.47
NAS AC20	60/70	G	10.9	83.8	3450	2689	1.28
		B	10.9	84.1	3550	1389	2.56
	40/50	B	11.0	84.3	5250	2040	2.57
	80/100	B	10.9	84.3	2390	1795	1.33
NAS AC20HF	60/70	B	12.1	83.1	3100	1820	1.70
	80/100	B	12.1	83.2	2030	1459	1.39
TNZ Mix 20	60/70	G	13.9	81.8	2600	1983	1.31
		B	14.5	80.7	2310	2771	0.83

3.6.4 Influence of the resilient modulus test procedure

The ITT and flexure test procedures provide different results for the same HMA samples. This is as expected given that the two test procedures have very different loading configurations and are carried out at different temperatures.

3.6.4.1 Temperature

The ITT test is carried out at a standard temperature of 25ºC whereas the flexure test is carried out at 20ºC. Austroads (2004b) provides a correlation between modulus and temperature indicating that a factor of 0.67 should be applied to the flexure results for them to be comparable with the ITT results.

3.6.4.2 Loading rise time

The standard ITT loading rise time is 40 ms whereas the flexure loading rise time is 50 ms. Austroads (2004b) provides a correlation between modulus and loading rise time indicating that a factor of 0.95 should be applied to the flexure results for them to be comparable with the ITT results.

Combining the temperature and loading rise time factors results in an overall correction factor of 0.635. This factor has been applied to the raw flexure test results to obtain the corrected modulus values shown in Table 3.7.

The results obtained from the two test procedures show a reasonably consistent correlation, at least for the HMA samples containing 40/50 and 60/70 penetration grade binders. The mean ratio ITT modulus : (corrected) flexure modulus was 1.08 for the 40/50 and 60/70 specimens while the mean ratio for the two 80/100 specimens was 1.61.

Table 3.7 Summary of ITT and (corrected) flexure modulus results.

Mix	Binder	Aggregate	Modulus (MPa)		Ratio ITT/ corrected flexure
			ITT	Flexure (corrected)	
NAS AC14	60/70	Greywacke	1600	1893	1.18
		Basalt	2756	2493	0.90
NAS AC20	40/50	Basalt	3447	3900	1.13
	60/70	Greywacke	1781	2036	1.14
		Basalt	2616	2539	0.97
	80/100	Basalt	2301	3158	1.37
NAS AC20HF	60/70	Basalt	2333	2601	1.11
	80/100	Basalt	1870	3458	1.85
TNZ Mix 20	60/70	Greywacke	2542	2771	1.09
	60/70	Basalt	3552	3904	1.10

3.6.5 Influence of the mix type

Four mix types were used in the testing programme:

- NAS AC14
- NAS AC20
- NAS AC20HF
- TNZ Mix 20.

It is not possible to compare the respective mixes directly as the aggregate grading, air voids, and binder content and stiffness all vary from specimen to specimen. However, the test results have raised a few points of interest.

Considering only the specimens comprising 60/70 binder, it is evident that the NAS mixes all achieved approximately the same ITT modulus, ie:

- AC14 : mean modulus (greywacke and basalt) = 2178 MPa
- AC20 : mean modulus (greywacke and basalt) = 2199 MPa
- AC20HF : modulus of basalt specimen = 2333 MPa

These results indicate that the additional 0.5% binder added to the AC20HF mix did not have a significant influence on the modulus.

In addition, the mean modulus obtained from the TNZ Mix 20 was 3047, ie significantly higher than for the NAS mixes. This is most likely attributable to the additional binder contained in the Mix 20; however, there was not an excessive quantity of binder that would otherwise result in a reduction in modulus.

3.6.6 Influence of binder stiffness

The AC20 (basalt) specimens were prepared using 40/50, 60/70 and 80/100 binders. The mean ITT elastic modulus results were as follows:

- 40/50 : E = 3447 MPa
- 60/70 : E = 2616 MPa
- 80/100 : E = 2301 MPa.

The test results were as expected, ie the stiffer the binder, the higher the elastic modulus. This is also consistent with the trends given in the Austroads (2004b) presumptive modulus tables and the Shell nomographs.

The consequence of this result is an indication that stiffer binders can be used in asphalt mixes to obtain increased protection of underlying subbase and subgrade layers by achieving better load spreading. However, increases in modulus can be accompanied by an increased risk of fatigue cracking, although this has not necessarily been borne out in the fatigue testing results, ie:

- AC20 40/50 binder : 0.34 x 10^6 load cycles to 'failure'
- AC20 60/70 binder : 0.42 x 10^6 load cycles to 'failure'
- AC20 80/100 binder : 0.24 x 10^6 load cycles to 'failure'.

The fatigue testing results indicate that the number of load cycles to 'failure' were independent of the binder stiffness. While there was an increase in fatigue life between the 40/50 and 60/70 binder mixes, the 80/100 binder mix showed a decreased fatigue life. This is a somewhat surprising result given that the fatigue tests were carried out under controlled strain conditions. Austroads (2004b) states that, under controlled strain loading conditions, an increase in asphalt modulus results in a decrease in fatigue life. It is unclear why this behaviour was not observed in the test results.

3.6.7 Influence of aggregate type and binder content

Basalt and greywacke specimens were used in the test programme. The relevant test results are presented in Table 3.8.

Table 3.8 Elastic modulus data with respect to aggregate type and binder content.

Mix	Aggregate	Binder	Binder content (%)	Flexure modulus (corrected)
AC14	Greywacke	60/70	5.4	1893
	Basalt	60/70	5.0	2493
AC20	Greywacke	60/70	4.7	2036
	Basalt	60/70	4.5	2539
Mix20	Greywacke	60/70	6.0	2771
	Basalt	60/70	6.0	3905

Figure 3.2 shows a plot of elastic modulus obtained from the flexural testing versus binder content for the basalt and greywacke specimens.

Figure 3.2 Plot of (flexural) elastic modulus versus binder content for the greywacke and basalt specimens respectively.

Figure 3.2 shows that the basalt specimens exhibited a 20 to 30% increase in elastic modulus over the equivalent greywacke specimens. The reason for the observed difference in elastic modulus is unclear; however, it is most likely attributable to the basalt specimens having a greater degree of interparticle friction. This is a feasible explanation given that the Auckland basalt aggregates generally have a coarser surface texture than greywacke aggregates.

Electrochemical or mineralogical factors may have contributed to this observation; however, it is noted that both basalt and greywacke are considered to be 'basic' rocks and generally basic rocks show a greater affinity for bitumen than acidic rocks. Other factors such as particle shape and absorption properties may also be significant.

Figure 3.2 also shows that both the basalt and greywacke specimens showed an increase in elastic modulus at the highest binder content. This result is as expected; however, the elastic modulus would not continue to increase with increasing binder content as there is an optimum binder content, above which the voids would be saturated with binder and the elastic modulus would drop off.

3.6.8 Fatigue resistance tests

The fatigue resistance of an asphalt mix is dependent on a number of factors, the most significant of which are the binder content and the binder stiffness.

Figure 3.3 shows a plot of cycles to failure versus specimen binder content. The plot includes data for the three binder stiffnesses used. As expected, the fatigue resistance of the various mixes increases with increasing binder content. This reflects the ability of the thicker binder films to resist breakdown of the mix stiffness under increasing numbers of strain repetitions.

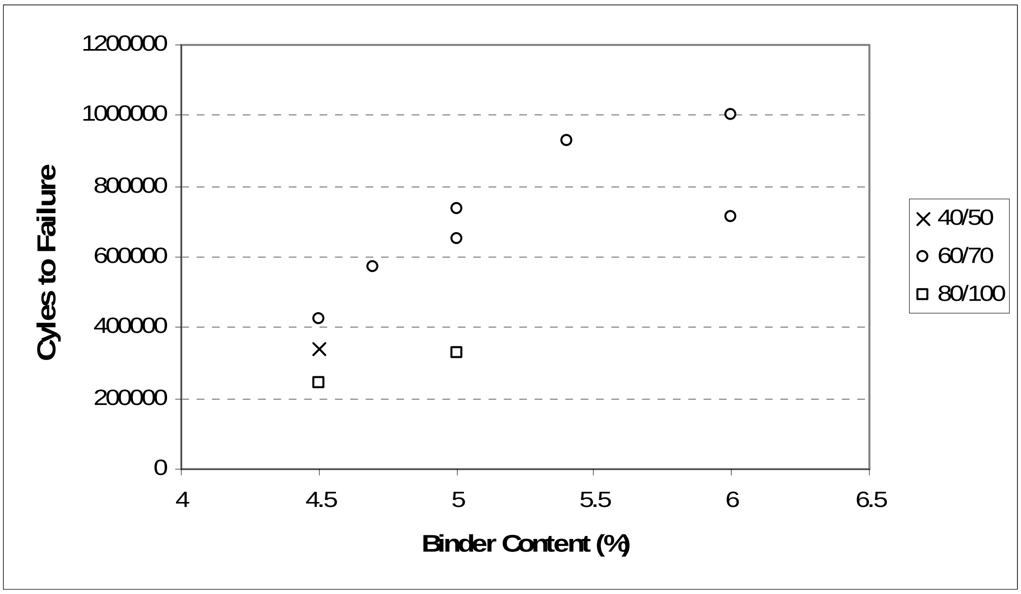

Figure 3.3 Plot of number of cycles to failure versus binder content for the three levels of specimen binder penetration grade.

Table 3.2 shows that aggregate type had a reasonably significant influence on fatigue resistance, ie the greywacke specimens showed increased fatigue resistance in comparison with the basalt specimens. This is most likely attributable to the greywacke aggregate having slightly finer texture than the basalt aggregate, therefore allowing the greywacke mixes to be slightly more compliant than the basalt mixes.

Table 3.2 also shows interesting trends in terms of the fatigue resistance of the various mix types. The highest fatigue resistance, in relative terms, was achieved by the NAS AC14 and TNZ Mix 20 specimens whereas the NAS AC20 mix achieved moderate fatigue resistance and the NAS AC20HF mixes achieved low to moderate fatigue resistance. This suggests that, for the specimens prepared in this study, the mixes that showed the greatest fatigue resistance were those whose primary role is not necessarily to resist fatigue cracking, eg AC14 and TNZ Mix 20. These mixes are designed to provide high stiffness and rutting resistance. Conversely, the mix with the primary function of fatigue resistance, ie AC20HF, performed relatively poorly in that role. The reasons for this behaviour are not clear although the relatively small number of test specimens and the vagaries of the various test procedures could be significant factors.

4. Summary

This report presents the results of an investigation into the elastic modulus properties of a range of asphalt mixes typically used in New Zealand. The main points of interest to emerge from the investigation are as follows:

- The elastic modulus test results obtained from the laboratory testing were typically below, or in the lower part of the range of presumptive modulus values reported in Austroads (2004b).
- An accurate match between modulus values measured in the flexure test and corresponding modulus values predicted using the Shell Bands approach was not achieved with the exception of the single test specimen prepared using 40/50 binder. In general the predicted modulus values decreased in accuracy with decreasing binder viscosity.
- When realistic temperature and loading rate parameters were applied to the ITT and corresponding Shell Bands data (speed = 50 km/h, temperature = 23ºC) the results showed that the Bands procedure predicted higher elastic modulus values for all expect one ITT specimen.
- The elastic modulus parameters determined using the indirect tension and flexure test showed a reasonable correlation after the flexure test results were corrected to simulate the ITT test temperature and loading rate conditions. Average ratios of $E_{(ITT)}$: $E_{(Flexure)}$ were 1.08 for the 40/50 and 60/70 binder specimens and 1.61 for the 80/100 binder specimens.
- The Australian NAS mixes used in the investigation, ie AC14, AC20 and AC20HF all achieved comparable level of elastic modulus. The only Transit New Zealand mix, ie Mix 20, achieved a higher elastic modulus, most likely attributable to its higher binder content.
- As expected, the elastic modulus of the various specimens was dependent on the stiffness of the binder. Keeping other parameters constant (as far as possible), changing the binder from 80/100 to 60/70 resulted in approximately a 14% increase in elastic modulus. Changing the binder from 80/100 to 40/50 resulted in approximately a 50% increase in elastic modulus.
- Increasing the binder content resulted in increased elastic modulus values. However, this trend would not be expected to continue past the optimum binder content for the various mixes.
- The aggregate type had an influence on the elastic modulus and fatigue resistance tests. The basalt specimens showed superior elastic modulus properties while the greywacke specimens showed superior fatigue resistance properties. These observations are considered to be attributable to the basalt's coarser surface texture compared with the greywacke.

- The fatigue resistance tests showed increasing fatigue resistance with increasing binder content as the thicker binder films allowed for relative movement between adjacent aggregate particles without causing a significant deterioration of the specimen stiffness.
- Reducing the binder stiffness from 40/50 to 60/70 resulted in an increase in fatigue resistance, as expected. However reducing the binder stiffness from 60/70 to 80/100 resulted in a reduction in fatigue resistance; the reason for this is unclear.
- The fatigue tests showed results that were not consistent with the typical functions attributed to the various mixes. For example, the AC14 material showed relatively high fatigue resistance properties even though its main application is as a surface course. Conversely, the AC20HF mix showed only moderate fatigue resistance even though it is used specifically as a high fatigue component.

5. Conclusions

The main conclusions that have been drawn from the testing carried out in this research programme are as follows:

- The ranges of presumptive elastic modulus values reported in Austroads (2004b) are relatively wide. The testing carried out in this project indicates that the elastic modulus values applicable to typical asphalt mixes used in New Zealand are lower than, or at the low end of, the Austroads presumptive value ranges.
- The Shell Bands software did not predict the elastic modulus values very well when simulating the flexure test configuration, especially for the specimens comprising 80/100 binder. A slightly better correlation between the measured and predicted modulus values was obtained using realistic temperature and loading rate parameters; however, the Bands prediction was generally significantly higher than the corresponding ITT derived value.
- The elastic modulus values obtained from the flexure and ITT procedures were reasonably consistent for specimens comprising 40/50 and 60/70 binders when the flexure test results were corrected to allow for temperature and loading rate effects. However, the difference between the flexure and ITT modulus parameters for 80/100 specimens was somewhat greater.
- The mean ITT elastic modulus values for the mixes used in this investigation have been established and are presented in Table 3.2. These results should not be used directly as pavement design inputs but they do show trends and indicative values.
- The aggregate type used in the various mixes had an influence on both the elastic modulus and the fatigue resistance parameters. Basalt mixes were found to be superior for elastic modulus parameters while greywacke mixes were found to be superior for fatigue resistance.
- The results of the testing indicate that TNZ Mix 20 provided excellent performance properties. In particular, a basalt Mix 20 provides favourable elastic modulus properties and, therefore, would be suitable as an intermediate structural asphalt layer. The high elastic modulus provides superior load spreading capability and rut resistance. Conversely, a greywacke Mix 20 provides favourable fatigue resistance, and, therefore, would be suitable as a high fatigue base layer in a structural asphalt pavement.

6. References

AAPA. 2004. *National asphalt specification*. 2nd edition. Australia: Australian Asphalt Pavement Association.

Alba, J., Barksdale, R. D., Khosla, N. P., Lambe, P. C. and Rahman, M. S. 1997. *Laboratory determination of resilient modulus for flexible pavement design*. National Cooperative Highway Research Program, Transportation Research Board. Washington: The National Academies Press. 464 pp.

Austroads. 2001. Fatigue life of compacted bituminous mixes subject to repeated flexural bending. AST 03. Sydney: Austroads.

Austroads. 2004a. Sample preparation – compaction of asphalt slabs suitable for characterisation. AST 05. Sydney: Austroads.

Austroads. 2004b. Pavement design. A guide to the structural design of road pavements. AP-G17/04. Sydney: Austroads.

Bhasin, A., Button, J. W., and Chowdhury, A. 2005. Evaluation of selected laboratory procedures and development of databases for HMA. *Report FHWA/TX-05/0-4203-3*. Texas: Texas Transportation Institute, Texas A&M University.

Flintsch, G. W., Al-Qadi, I. L., Loulizi, A., and Mokarem, D. 2005. *Laboratory tests for hot-mix asphalt characterization in Virginia.* Virginia: Virginia Transport Research Council.

Gallagher, P. 1999. *The future of asphalt pavements.* Paper presented at the Options for Post Millennium Pavements Symposium, New Zealand Institute of Highway Technology and Transit New Zealand, 17–19 October, Taupo, 1999.

Harman, T. 2001. Using the dynamic modulus test to assess the mix strength of HMA. *Public Roads 64* (6). McLean, Virginia: Turner-Fairbank Highway Research Centre, US Department of Transportation – Federal Highway Administration.

Heukelom, W., and Klomp, A. J. G. 1964. Road design and dynamic loading. In *Proceedings of the Association of Asphalt Paving Technologists 33.* USA.

NCHRP. 2004. *Guide for the mechanistic-empirical design of new and rehabilitated pavement structures.* Washington DC: National Cooperative Highway Research Program, Transportation Research Board.

Nunn, M., Brown, A., Weston, D., and Nicholls, J. C. 1997. Design of long-life pavements for heavy traffic. *Transport Research Laboratory Report 250*. United Kingdom: Department of Transport.

Nunn, M. 1998. Design of long-life roads for heavy traffic. In *Proceedings of the 1998 Australian Asphalt Pavement Association Industry Conference*, Surfers Paradise. Australia.

Peploe, R. J. 1987. The Brazilian test for lime stabilised clay. Master of Engineering Thesis, University of Auckland, New Zealand.

Rowe, G. M., and Bouldin, M. G. 2000. Improved techniques to evaluate the fatigue resistance of asphaltic mixtures. In *Proceedings of the Eurasphalt and Eurobitumen Congress*, Barcelona, September 2000, Book 1, pp. 754–763.

Shell. 1978. *Shell pavement design manual – asphalt pavements and overlays for road traffic.* London: Shell International Petroleum Company Ltd.

Standards Australia. 1995. Methods of sampling and testing asphalt, method 13.1: Determination of the resilient modulus of asphalt – indirect tensile method. AS 2891.13.1. Australia.

Tayebali, A. A., Deacon, J. A., Coplantz, J. S., Harvey, J.T., and Monismith, C. L. 1992. *Fatigue response of asphalt-aggregate mixes: Part 1. Test method selection*. SHRP Project A-003A. Washington DC: Strategic Highway Research Program, National Research Council.

Transit New Zealand. 2005. TNZ M/10 Specification for asphaltic concrete. Wellington: Transit New Zealand.

Van der Poel, C. 1954. A general system describing the viscoelastic properties of bitumens and its relation to routine test data. *Journal of Applied Chemistry 4* (3): 1–17.

Wardle, L. 2005. *CIRCLY V5 user manual*. Melbourne: Mincad Systems Pty.

Appendix A: ITT result sheets

AUCKLAND LABORATORY

72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5 Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. A06/605
REPORT DATE: 2/03/2007
PAGE 1 OF 1

Determination of the Resilient Modulus of Asphalt
Indirect Tensile Method - AS 2891.13.1 - 1995

CLIENT: Bartley Cosultants

CLIENT REF: A06/605

JOB LOCATION: Auckland Laboratory

MATERIAL: NAS AC14 (60/70) Greywacke Aggregate

MATERIAL SOURCE Laboratory Produced

SAMPLE DATE: 24/03/2006

SAMPLED BY: D Aubrey (Works)

DATE/TIME OF SAMPLE MANUFACTURE: 24/03/2006
MARSHALL COMPACTION BLOWS N/A
ASPHALT MIXING TEMPERATURE: 165°
CONDITIONING TEMPERATURE/TIME: 150°
INITIAL COMPACTION TEMPERATURE: 150°

DATE OF CORING: N/A
LOCATION: N/A
DIRECTION OF TRAFFIC FLOW: N/A

TEST CONDITIONS: Standard reference test conditions used
DATE/TIME OF TEST 29/03/2006 - 3.47pm

RESULTS:

Block #	Diameter (mm)	Height (mm)	Resilient Modulus Mean (Mpa)	Core temp (°C)	Rise Time (s)	Coeffecient of Variation (%)
1	99.8	60.3	1692	24.9	0.040	1.5
2	99.7	57.6	1560	24.9	0.039	1.4
3	99.8	58.2	1548	24.8	0.039	0.9

Mean Modulus(Mpa): **1600** **Tolerance: Mean (+/-) 15% = 240 Mpa**

Notes: 1. Standard reference test conditions used

Remarks:

D.Aubrey
Section Head

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works
INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. A06/
REPORT DATE: 2/03/20
PAGE 1 OF 1

Determination of the Resilient Modulus of Asphalt Indirect Tensile Method - AS 2891.13.1 - 1995

CLIENT: Bartley Cosultants

CLIENT REF: A06/677

JOB LOCATION: Auckland Laboratory

MATERIAL: NAS AC14 (60/70) Basalt Aggregate

MATERIAL SOURCE Laboratory Produced

SAMPLE DATE: 10/04/2006

SAMPLED BY: D Aubrey (Works)

DATE/TIME OF SAMPLE MANUFACTURE: 10/04/2006
MARSHALL COMPACTION BLOWS N/A
ASPHALT MIXING TEMPERATURE: 165°
CONDITIONING TEMPERATURE/TIME: 150°
INITIAL COMPACTION TEMPERATURE: 150°

DATE OF CORING: N/A
LOCATION: N/A
DIRECTION OF TRAFFIC FLOW: N/A

TEST CONDITIONS: Standard reference test conditions used
DATE/TIME OF TEST 13/04/2006 - 2.46 pm

RESULTS:

Block #	Diameter (mm)	Height (mm)	Resilient Modulus Mean (Mpa)	Core temp (°C)	Rise Time (s)	Coeffecient of Variation (%)
1	99.7	61.0	2928	24.9	0.039	1.8
2	99.9	56.5	2680	24.9	0.039	1.3
3	99.8	59.6	2660	24.9	0.039	3.1

Mean Modulus(Mpa): **2756** **Tolerance: Mean (+/-) 15% = 413 Mpa**

Notes: 1. Standard reference test conditions used

Remarks:

D.Aubrey
Section Head

AUCKLAND LABORATORY
72 Luna Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. A06/6
REPORT DATE: 2/03/20
PAGE 1 OF 1

Determination of the Resilient Modulus of Asphalt Indirect Tensile Method - AS 2891.13.1 - 1995

CLIENT: Bartley Cosultants

CLIENT REF: A06/606

JOB LOCATION: Auckland Laboratory

MATERIAL: NAS AC20 (60/70) Greywacke Aggregate

MATERIAL SOURCE Laboratory Produced

SAMPLE DATE: 24/03/2006

SAMPLED BY: D Aubrey (Works)

DATE/TIME OF SAMPLE MANUFACTURE: 24/03/2006
MARSHALL COMPACTION BLOWS N/A
ASPHALT MIXING TEMPERATURE: 165°
CONDITIONING TEMPERATURE/TIME: 150°
INITIAL COMPACTION TEMPERATURE: 150°

DATE OF CORING: N/A
LOCATION: N/A
DIRECTION OF TRAFFIC FLOW: N/A

TEST CONDITIONS: Standard reference test conditions used
DATE/TIME OF TEST 29/03/2006 - 4.06pm

RESULTS:

Block #	Diameter (mm)	Height (mm)	Resilient Modulus Mean (Mpa)	Core temp (°C)	Rise Time (s)	Coeffecient of Variation (%)
1	99.6	60.2	1789	24.8	0.039	2.2
2	99.7	59.4	1593	24.8	0.039	2.2
3	99.6	61.3	1962	24.8	0.039	1.7

Mean Modulus(Mpa): **1781** **Tolerance: Mean (+/-) 15% = 267 Mpa**

Notes: 1. Standard reference test conditions used

Remarks:

D.Aubrey
Section Head

AUCKLAND LABORATORY

72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. A06/6
REPORT DATE: 2/03/20
PAGE 1 OF 1

Determination of the Resilient Modulus of Asphalt Indirect Tensile Method - AS 2891.13.1 - 1995

CLIENT: Bartley Cosultants

CLIENT REF: A06/676

JOB LOCATION: Auckland Laboratory

MATERIAL: NAS AC20 (60/70) Basalt Aggregate

MATERIAL SOURCE Laboratory Produced

SAMPLE DATE: 6/04/2006

SAMPLED BY: D Aubrey (Works)

DATE/TIME OF SAMPLE MANUFACTURE: 6/04/2006
MARSHALL COMPACTION BLOWS **N/A**
ASPHALT MIXING TEMPERATURE: **165°**
CONDITIONING TEMPERATURE/TIME: **150°**
INITIAL COMPACTION TEMPERATURE: **150°**

DATE OF CORING: N/A
LOCATION: N/A
DIRECTION OF TRAFFIC FLOW: N/A

TEST CONDITIONS: Standard reference test conditions used
DATE/TIME OF TEST 13/04/2006 - 1.57pm

RESULTS:

Block #	Diameter (mm)	Height (mm)	Resilient Modulus Mean (Mpa)	Core temp (°C)	Rise Time (s)	Coeffecient of Variation (%)
1	99.8	65.0	2941	24.8	0.039	2.3
3	99.8	58.4	2441	24.8	0.039	1.5
4	99.8	60.1	2465	24.9	0.039	3.1

Mean Modulus(Mpa): **2616** **Tolerance: Mean (+/-) 15% = 392 Mpa**

Notes: 1. Standard reference test conditions used

Remarks:

D.Aubrey
Section Head

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. A06/1
REPORT DATE: 2/03/2
PAGE 1 OF 1

Determination of the Resilient Modulus of Asphalt Indirect Tensile Method - AS 2891.13.1 - 1995

CLIENT: Bartley Cosultants

CLIENT REF: A06/1189

JOB LOCATION: Auckland Laboratory

MATERIAL: NAS20 (80/100) Basalt Aggregate

MATERIAL SOURCE Laboratory Produced

SAMPLE DATE: 16/06/2006

SAMPLED BY: D Aubrey (Works)

DATE/TIME OF SAMPLE MANUFACTURE: 16/06/2006
MARSHALL COMPACTION BLOWS **N/A**
ASPHALT MIXING TEMPERATURE: **155°**
CONDITIONING TEMPERATURE/TIME: **140°**
INITIAL COMPACTION TEMPERATURE: **140°**

DATE OF CORING: N/A
LOCATION: N/A
DIRECTION OF TRAFFIC FLOW: N/A

TEST CONDITIONS: Standard reference test conditions used
DATE/TIME OF TEST 29/06/2006 - 11.32 am

RESULTS:

Block #	Diameter (mm)	Height (mm)	Resilient Modulus Mean (Mpa)	Core temp (°C)	Rise Time (s)	Coeffecient of Variation (%)
1	100.1	61.6	2218	24.5	0.038	2.1
2	100.1	62.3	2364	24.5	0.037	1.5
3	100.3	62.4	2322	24.7	0.038	1.4

Mean Modulus(Mpa): **2301** **Tolerance: Mean (+/-) 15% = 345 Mpa**

Notes: 1. Standard reference test conditions used

Remarks:

D.Aubrey
Section Head

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5, Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. A06/1:
REPORT DATE: 03/08/2(
PAGE 1 OF 1

Determination of the Resilient Modulus of Asphalt Indirect Tensile Method - AS 2891.13.1 - 1995

CLIENT: Bartley Cosultants

CLIENT REF: A06/1337

JOB LOCATION: Auckland Laboratory

MATERIAL: NAS AC20 (40/50) Basalt Aggregate

MATERIAL SOURCE Laboratory Produced

SAMPLE DATE: 06/07/2006

SAMPLED BY: D Aubrey (Works)

DATE/TIME OF SAMPLE MANUFACTURE: 06/07/2006
MARSHALL COMPACTION BLOWS N/A
ASPHALT MIXING TEMPERATURE: 165°
CONDITIONING TEMPERATURE/TIME: 150°
INITIAL COMPACTION TEMPERATURE: 150°

DATE OF CORING: N/A
LOCATION: N/A
DIRECTION OF TRAFFIC FLOW: N/A

TEST CONDITIONS: Standard reference test conditions used
DATE/TIME OF TEST 03/08/2006 - 2.11 pm

RESULTS:

Block #	Diameter (mm)	Height (mm)	Resilient Modulus Mean (MPa)	Core temp (°C)	Rise Time (s)	Coeffecient of Variation (%)
1	99.9	55.8	3765	24.6	0.038	1.5
2	99.9	56.7	3251	24.6	0.039	2.4
4	100.0	56.6	3326	24.6	0.039	2.1

Mean Modulus(MPa): 3447 **Tolerance: Mean (+/-) 15% = 517 Mpa**

Notes:
1. Standard reference test conditions used
2. Samples taken from slab manufactured using a slab compactor.

Remarks:

D.Aubrey
Section Head

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. A06/7
REPORT DATE: 2/03/2(
PAGE 1 OF 1

Determination of the Resilient Modulus of Asphalt Indirect Tensile Method - AS 2891.13.1 - 1995

CLIENT: Bartley Cosultants

CLIENT REF: A06/772

JOB LOCATION: Auckland Laboratory

MATERIAL: NAS 20HF (60/70) Basalt Aggregate

MATERIAL SOURCE Laboratory Produced

SAMPLE DATE: 21/04/2006

SAMPLED BY: D Aubrey (Works)

DATE/TIME OF SAMPLE MANUFACTURE: 6/04/2006
MARSHALL COMPACTION BLOWS **N/A**
ASPHALT MIXING TEMPERATURE: **165°**
CONDITIONING TEMPERATURE/TIME: **150°**
INITIAL COMPACTION TEMPERATURE: **150°**

DATE OF CORING: N/A
LOCATION: N/A
DIRECTION OF TRAFFIC FLOW: N/A

TEST CONDITIONS: Standard reference test conditions used
DATE/TIME OF TEST 25/05/2006 - 10.21 am

RESULTS:

Block #	Diameter (mm)	Height (mm)	Resilient Modulus Mean (Mpa)	Core temp (°C)	Rise Time (s)	Coeffecient of Variation (%)
1	100.2	63.2	2420	24.7	0.040	1.0
2	100.1	60.9	2387	24.7	0.039	0.8
3	100.2	64.0	2191	24.7	0.040	2.6

Mean Modulus(Mpa): **2333** **Tolerance: Mean (+/-) 15% = 350 Mpa**

Notes: 1. Standard reference test conditions used

Remarks:

D.Aubrey
Section Head

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5 Ph(09) 570-6607 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. A06/1507
REPORT DATE: 14/08/2006
PAGE 1 OF 1

Determination of the Resilient Modulus of Asphalt
Indirect Tensile Method - AS 2891.13.1 - 1995

CLIENT: Bartley Cosultants

CLIENT REF: A06/1507

JOB LOCATION: Auckland Laboratory

MATERIAL: NAS AC20HF (80/100) Basalt Aggregate

MATERIAL SOURCE Laboratory Produced

SAMPLE DATE: 08/08/2006

SAMPLED BY: D Aubrey (Works)

DATE/TIME OF SAMPLE MANUFACTURE: 08/08/2006
MARSHALL COMPACTION BLOWS N/A
ASPHALT MIXING TEMPERATURE: 165°
CONDITIONING TEMPERATURE/TIME: 150°
INITIAL COMPACTION TEMPERATURE: 150°

DATE OF CORING: N/A
LOCATION: N/A
DIRECTION OF TRAFFIC FLOW: N/A

TEST CONDITIONS: Standard reference test conditions used
DATE/TIME OF TES1 14/08/2006 - 3.31pm

RESULTS:

Block #	Diameter (mm)	Height (mm)	Resilient Modulus Mean (MPa)	Core temp (°C)	Rise Time (s)	Coeffecient of Variation (%)
1	100.2	58.7	1762	24.6	0.039	0.8
2	100.1	58.3	2079	24.5	0.040	1.7
4	100.2	57.3	1770	24.5	0.039	1.2

Mean Modulus(MPa): **1870** **Tolerance: Mean (+/-) 15% = 281 Mpa**

Notes: 1. Standard reference test conditions used
2. Samples taken from slab manufactured using a slab compactor.

Remarks:

D.Aubrey
Section Head

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. A06/6
REPORT DATE: 2/03/20
PAGE 1 OF 1

Determination of the Resilient Modulus of Asphalt
Indirect Tensile Method - AS 2891.13.1 - 1995

CLIENT: Bartley Cosultants

CLIENT REF: A06/643

JOB LOCATION: Auckland Laboratory

MATERIAL: TNZ20 (60/70) Greywacke Aggregate

MATERIAL SOURCE Laboratory Produced

SAMPLE DATE: 25/05/2006

SAMPLED BY: D Aubrey (Works)

DATE/TIME OF SAMPLE MANUFACTURE: 25/05/2006
MARSHALL COMPACTION BLOWS **N/A**
ASPHALT MIXING TEMPERATURE: **165°**
CONDITIONING TEMPERATURE/TIME: **150°**
INITIAL COMPACTION TEMPERATURE: **150°**

DATE OF CORING: N/A
LOCATION: N/A
DIRECTION OF TRAFFIC FLOW: N/A

TEST CONDITIONS: Standard reference test conditions used
DATE/TIME OF TEST 29/05/2006 - 4.06 pm

RESULTS:

Block #	Diameter (mm)	Height (mm)	Resilient Modulus Mean (Mpa)	Core temp (°C)	Rise Time (s)	Coeffecient of Variation (%)
1	99.9	56.5	2653	24.7	0.037	1.8
2	99.9	56.2	2625	24.7	0.037	1.2
3	99.9	58.3	2349	24.7	0.037	2.3

Mean Modulus(Mpa): **2542** **Tolerance: Mean (+/-) 15% = 381 Mpa**

Notes: 1. Standard reference test conditions used

Remarks:

D.Aubrey
Section Head

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5, Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. A06/9
REPORT DATE: 2/03/20
PAGE 1 OF 1

Determination of the Resilient Modulus of Asphalt
Indirect Tensile Method - AS 2891.13.1 - 1995

CLIENT: Bartley Cosultants

CLIENT REF: A06/978

JOB LOCATION: Auckland Laboratory

MATERIAL: TNZ20 (60/70) Basalt Aggregate

MATERIAL SOURCE Laboratory Produced

SAMPLE DATE: 24/05/2006

SAMPLED BY: D Aubrey (Works)

DATE/TIME OF SAMPLE MANUFACTURE: 24/05/2006
MARSHALL COMPACTION BLOWS N/A
ASPHALT MIXING TEMPERATURE: 165°
CONDITIONING TEMPERATURE/TIME: 150°
INITIAL COMPACTION TEMPERATURE: 150°

DATE OF CORING: N/A
LOCATION: N/A
DIRECTION OF TRAFFIC FLOW: N/A

TEST CONDITIONS: Standard reference test conditions used
DATE/TIME OF TEST 29/05/2006 - 3.27 pm

RESULTS:

Block #	Diameter (mm)	Height (mm)	Resilient Modulus Mean (Mpa)	Core temp (°C)	Rise Time (s)	Coeffecient of Variation (%)
1	99.9	59.6	3452	24.7	0.038	2.8
2	99.8	55.8	3588	24.7	0.038	2.6
4	99.9	55.3	3617	24.8	0.038	1.9

Mean Modulus(Mpa): **3552** **Tolerance: Mean (+/-) 15% = 533 Mpa**

Notes: 1. Standard reference test conditions used

Remarks:

D.Aubrey
Section Head

Appendix B: Flexure test result sheets

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. AMDA06/605/1
REPORT DATE: 25/07/2007
PAGE 1 OF 1

Fatigue Life of Compacted Bituminous Mixes Subject to Repeat Flexural Bending AST 03:2001

CLIENT: Bartley Consultants Ltd

CLIENT REF: NAS AC14 Greywacke (60/70 Bitumen)

JOB LOCATION: N/A

MATERIAL: NAS AC 14

MATERIAL SOURCE: Laboratory Produced

SAMPLE DATE: 24/03/2006

SAMPLED BY: D.Aubrey

TEST CONDITIONS: Standard Reference Test Conditions
DATE PREPARED: 28/03/2006
DATE AND TIME OF TEST See Table Below

RESULTS:

SAMPLE NO: DATE TESTED:	2 30/03/2006	3 31/03/2006	4 03/04/2006	MEAN VALUES	COV%
TIME TESTED:	12.19 pm	5.16 pm	9.12am		
MEAN DEPTH:	51.1	52.9	50.8		
MEAN WIDTH:	60.9	62.8	63.6		
BULK DENSITY t/m3	2.352	2.352	2.355	2.353	
AIR VOIDS %	5.3	5.3	5.2	5.3	1
TEST TEMPERATURE:INITIAL	20.5	20.3	20.3		
TEST TEMPERATURE:FINAL	20.4	20.4	20.3		
INITIAL FLEXURAL STIFFNESS: (MPa)	3193	2383	3368	2981	18
INITIAL PEAK TENSILE STRAIN:	399	399	398	399	0.14
CYCLES TO FAILURE:	1000100	1000100	780000	926733	13.7

Notes:

~~K.Embleton (Section Head)~~
D.Aubrey (Section Head)

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. AMD A06/677/1
REPORT DATE: 25/07/2007
PAGE 1 OF 1

Fatigue Life of Compacted Bituminous Mixes Subject to Repeat Flexural Bending AST 03:2001

CLIENT: Bartley Consultants Ltd

CLIENT REF: NAS AC14 Basalt (60/70 Bitumen)

JOB LOCATION: N/A

MATERIAL: NAS AC 14

MATERIAL SOURCE: Laboratory Produced

SAMPLE DATE: 10/04/2006

SAMPLED BY: D.Aubrey

TEST CONDITIONS: Standard Reference Test Conditions
DATE PREPARED: 12/04/2006
DATE AND TIME OF TEST See Table Below

RESULTS:

SAMPLE NO: / DATE TESTED:	1 18/04/2006	2 19/04/2006	4 21/04/2006	MEAN VALUES	COV%
TIME TESTED:	4.17 pm	11.22 am	10.11am		
MEAN DEPTH:	50.9	49.6	50.3		
MEAN WIDTH:	63.3	64.1	65.1		
BULK DENSITY t/m3	2.464	2.462	2.470	2.465	
AIR VOIDS %	4.6	4.7	4.6	4.6	1.2
TEST TEMPERATURE:INITIAL	20.2	19.9	20.2		
TEST TEMPERATURE:FINAL	20.0	20	20.2		
INITIAL FLEXURAL STIFFNESS: (MPa)	3874	3890	4016	3927	2
INITIAL PEAK TENSILE STRAIN:	400	401	400	400	0.14
CYCLES TO FAILURE:	647640	743670	809470	733593	11

Notes:

~~K.Embleton (Section Head)~~
D.Aubrey (Section Head)

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2302

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. AMD A06/1337/1
REPORT DATE: 25/07/2007
PAGE 1 OF 1

Fatigue Life of Compacted Bituminous Mixes Subject to Repeat Flexural Bending AST 03:2001

CLIENT: Bartley Consultants Ltd

CLIENT REF: NAS AC 20 Basalt (40/50 Bitumen)

JOB LOCATION: N/A

MATERIAL: NAS AC 20

MATERIAL SOURCE: Laboratory Produced

SAMPLE DATE: 06/07/2006

SAMPLED BY: D.Aubrey

TEST CONDITIONS: Standard Reference Test Conditions
DATE PREPARED: 06/07/2006
DATE AND TIME OF TEST: See Table Below

RESULTS:

SAMPLE NO:	1	2	4	MEAN	COV%
DATE TESTED:	19/07/2006	20/07/2006	24/07/2006	VALUES	
TIME TESTED:	9.45 pm	12.30 pm	10.40 am		
MEAN DEPTH:	49.6	49.2	49.8		
MEAN WIDTH:	62.2	62.5	63.2		
BULK DENSITY t/m3	2.497	2.488	2.491	2.492	
AIR VOIDS %	4.5	4.9	4.7	4.7	4.3
TEST TEMPERATURE:INITIAL	19.9	20.0	20.0		
TEST TEMPERATURE:FINAL	20.1	20.0	20.1		
INITIAL FLEXURAL STIFFNESS: (MPa)	5735	6130	6564	6143	6.8
INITIAL PEAK TENSILE STRAIN:	401	404	400	402	0.52
CYCLES TO FAILURE:	507670	228770	279530	338657	43.9

Notes:

~~K.Embleton (Section Head)~~
D.Aubrey (Section Head)

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. AMD A06/606/1
REPORT DATE: 25/07/2007
PAGE 1 OF 1

Fatigue Life of Compacted Bituminous Mixes Subject to Repeat Flexural Bending AST 03:2001

CLIENT: Bartley Consultants Ltd

CLIENT REF: NAS AC20 Greywacke (60/70 Bitumen)

JOB LOCATION: N/A

MATERIAL: NAS AC 20

MATERIAL SOURCE: Laboratory Produced

SAMPLE DATE: 24/03/2006

SAMPLED BY: D.Aubrey

TEST CONDITIONS: Standard Reference Test Conditions
DATE PREPARED: 28/03/2006
DATE AND TIME OF TEST See Table Below

RESULTS:

SAMPLE NO:	2	3	4	MEAN VALUES	COV%
DATE TESTED:	06/04/2006	07/04/2006	10/04/2006		
TIME TESTED:	10.32 am	10.04 am	11.02 am		
MEAN DEPTH:	52.1	50.6	51.8		
MEAN WIDTH:	62.7	62.0	62.0		
BULK DENSITY t/m3	2.371	2.377	2.378	2.375	
AIR VOIDS %	5.4	5.2	5.2	5.3	2.2
TEST TEMPERATURE:INITIAL	20.1	19.8	20.2		
TEST TEMPERATURE:FINAL	20	20.3	20.1		
INITIAL FLEXURAL STIFFNESS: (MPa)	3449	3161	3009	3206	7
INITIAL PEAK TENSILE STRAIN:	401	402	398	400	0.52
CYCLES TO FAILURE:	465990	762150	491190	573110	28.7

Notes:

~~K.Embleton (Section Head)~~
D.Aubrey (Section Head)

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 6. Ph(09) 570-5807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. AMD A06/676/1
REPORT DATE: 25/07/2007
PAGE 1 OF 1

Fatigue Life of Compacted Bituminous Mixes Subject to Repeat Flexural Bending AST 03:2001

CLIENT: Bartley Consultants Ltd

CLIENT REF: NAS AC20 Basalt (60/70 Bitumen)

JOB LOCATION: N/A

MATERIAL: NAS AC 20

MATERIAL SOURCE: Laboratory Produced

SAMPLE DATE: 01/08/2006

SAMPLED BY: D.Aubrey

TEST CONDITIONS: Standard Reference Test Conditions
DATE PREPARED: 03/08/2006
DATE AND TIME OF TEST See Table Below

RESULTS:

SAMPLE NO:	1	2	4	MEAN VALUES	COV%
DATE TESTED:	04/08/2006	07/08/2006	08/08/2006		
TIME TESTED:	4.13 pm	12.24 pm	4.18 pm		
MEAN DEPTH:	53.6	53.2	52.7		
MEAN WIDTH:	64.5	64.2	63.1		
BULK DENSITY t/m3	2.479	2.489	2.477	2.482	
AIR VOIDS %	5.4	4.8	5.3	5.2	6.2
TEST TEMPERATURE:INITIAL	20.1	19.9	19.9		
TEST TEMPERATURE:FINAL	20.1	20.1	20.1		
INITIAL FLEXURAL STIFFNESS: (MPa)	7028	6697	6936	6887	2.50
INITIAL PEAK TENSILE STRAIN:	399	401	400	400	0.25
CYCLES TO FAILURE:	238940	320970	423700	327870	28.2

Notes:

~~K.Embleton (Section Head)~~
D.Aubrey (Section Head)

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. AMD A06/1189/1
REPORT DATE: 25/07/2007
PAGE 1 OF 1

Fatigue Life of Compacted Bituminous Mixes Subject to Repeat Flexural Bending AST 03:2001

CLIENT: Bartley Consultants Ltd

CLIENT REF: NAS AC 20 Basalt (80/100 Bitumen)

JOB LOCATION: N/A

MATERIAL: NAS AC 20

MATERIAL SOURCE: Laboratory Produced

SAMPLE DATE: 21/04/2006

SAMPLED BY: D.Aubrey

TEST CONDITIONS: Standard Reference Test Conditions
DATE PREPARED: 26/04/2006
DATE AND TIME OF TEST: See Table Below

RESULTS:

SAMPLE NO: / DATE TESTED:	1 23/06/2006	3 26/06/2006	4 27/06/2006	MEAN VALUES	COV%
TIME TESTED:	2.52 pm	11.01 am	11.07 am		
MEAN DEPTH:	48.1	50	50.1		
MEAN WIDTH:	61.1	64.7	62.4		
BULK DENSITY t/m3	2.471	2.493	2.496	**2.487**	
AIR VOIDS %	5.5	4.7	4.6	**4.9**	**9.9**
TEST TEMPERATURE:INITIAL	19.9	20.0	19.9		
TEST TEMPERATURE:FINAL	19.8	20.0	20		
INITIAL FLEXURAL STIFFNESS: (MPa)	**5386**	**4645**	**4892**	**4974**	**7.6**
INITIAL PEAK TENSILE STRAIN:	402	401	400	**401**	**0.25**
CYCLES TO FAILURE:	178560	260980	293900	**244480**	**24.3**

Notes:

~~K.Embleton (Section Head)~~
D.Aubrey (Section Head)

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5 Ph(09) 570-6607 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. AMD A06/772/1
REPORT DATE: 25/07/2007
PAGE 1 OF 1

Fatigue Life of Compacted Bituminous Mixes Subject to Repeat Flexural Bending AST 03:2001

CLIENT: Bartley Consultants Ltd

CLIENT REF: NAS AC 20HF Basalt (60/70 Bitumen)

JOB LOCATION: N/A

MATERIAL: NAS AC 20HF

MATERIAL SOURCE: Laboratory Produced

SAMPLE DATE: 21/04/2006

SAMPLED BY: D.Aubrey

TEST CONDITIONS: Standard Reference Test Conditions
DATE PREPARED: 26/04/2006
DATE AND TIME OF TEST: See Table Below

RESULTS:

SAMPLE NO: / DATE TESTED:	1 04/05/2006	2 05/05/2006	4 08/05/2006	MEAN VALUES	COV%
TIME TESTED:	9.50 pm	10.33 am	10.21 am		
MEAN DEPTH:	50.3	50.4	50.9		
MEAN WIDTH:	64.1	63.9	63.5		
BULK DENSITY t/m3	2.483	2.468	2.480	2.477	
AIR VOIDS %	4.6	5.2	4.8	4.9	6.3
TEST TEMPERATURE:INITIAL	19.9	20.0	20.1		
TEST TEMPERATURE:FINAL	20.0	20.0	20.2		
INITIAL FLEXURAL STIFFNESS: (MPa)	4460	4000	3832	4097	7.9
INITIAL PEAK TENSILE STRAIN:	398	397	399	398	0.25
CYCLES TO FAILURE:	386370	564100	1000100	650190	48.6

Notes:

~~K.Embleton (Section Head)~~
D.Aubrey (Section Head)

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. AMD A06/1507/1
REPORT DATE: 25/07/2007
PAGE 1 OF 1

Fatigue Life of Compacted Bituminous Mixes Subject to Repeat Flexural Bending AST 03:2001

CLIENT: Bartley Consultants Ltd

CLIENT REF: NAS AC 20 Basalt (80/100 Bitumen)

JOB LOCATION: N/A

MATERIAL: NAS ACHF 20

MATERIAL SOURCE: Laboratory Produced

SAMPLE DATE: 08/08/2006

SAMPLED BY: D.Aubrey

TEST CONDITIONS: Standard Reference Test Conditions
DATE PREPARED: 11/08/2006
DATE AND TIME OF TEST See Table Below

RESULTS:

SAMPLE NO: DATE TESTED:	1 15/08/2006	2 20/07/2006	4 23/08/2006	MEAN VALUES	COV%
TIME TESTED:	5.42 pm	12.30 pm	5.26 pm		
MEAN DEPTH:	51.1	51.0	51.6		
MEAN WIDTH:	63.5	62.6	59.3		
BULK DENSITY t/m3	2.486	2.478	2.476	2.480	
AIR VOIDS %	4.5	4.8	4.9	4.7	4.4
TEST TEMPERATURE:INITIAL	19.6	19.9	19.9		
TEST TEMPERATURE:FINAL	20.1	19.8	20.0		
INITIAL FLEXURAL STIFFNESS: (MPa)	5434	5383	5523	5447	1.3
INITIAL PEAK TENSILE STRAIN:	401	400	400	400	0.14
CYCLES TO FAILURE:	445590	335780	209740	330370	35.7

Notes:

~~K.Embleton (Section Head)~~
D.Aubrey (Section Head)

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. AMD A06/643/1
REPORT DATE: 25/07/2007
PAGE 1 OF 1

Fatigue Life of Compacted Bituminous Mixes Subject to Repeat Flexural Bending AST 03:2001

CLIENT: Bartley Consultants Ltd

CLIENT REF: TNZ 20 Greywacke (60/70 Bitumen)

JOB LOCATION: N/A

MATERIAL: TNZ 20 60/70

MATERIAL SOURCE: Laboratory Produced

SAMPLE DATE: 25/05/2006

SAMPLED BY: D.Aubrey

TEST CONDITIONS: Standard Reference Test Conditions
DATE PREPARED: 25/05/2006
DATE AND TIME OF TEST See Table Below

RESULTS:

SAMPLE NO: / DATE TESTED:	1 06/06/2006	2 07/06/2006	4 10/06/2006	MEAN VALUES	COV%
TIME TESTED:	9.36 am	3.09 pm	10.23 am		
MEAN DEPTH:	51.4	52.1	48.1		
MEAN WIDTH:	63.6	62.7	65.2		
BULK DENSITY t/m3	2.370	2.371	2.369	2.370	
AIR VOIDS %	4.3	4.3	4.4	4.3	1.3
TEST TEMPERATURE:INITIAL TEST TEMPERATURE:FINAL	20.0 20.1	20.1 20.2	20 20.1		
INITIAL FLEXURAL STIFFNESS: (MPa)	4297	4274	4523	4365	3.2
INITIAL PEAK TENSILE STRAIN:	397	401	401	400	0.58
CYCLES TO FAILURE:	1000100	1000100	1000100	1000100	0

Notes:

~~K.Embleton (Section Head)~~
D.Aubrey (Section Head)

AUCKLAND LABORATORY
72 Lunn Ave, Mt Wellington, Private Bag 14925, Panmure, Auckland 5. Ph(09) 570-6807 Fax(09) 527-2362

Works INFRASTRUCTURE
A DIVISION OF DOWNER GROUP LIMITED

TEST REPORT

LAB No. AMD A06/978/1
REPORT DATE: 25/07/2007
PAGE 1 OF 1

Fatigue Life of Compacted Bituminous Mixes Subject to Repeat Flexural Bending AST 03:2001

CLIENT: Bartley Consultants Ltd

CLIENT REF: TNZ 20 Basalt (60/70 Bitumen)

JOB LOCATION: N/A

MATERIAL: TNZ 20 60/70

MATERIAL SOURCE: Laboratory Produced

SAMPLE DATE: 21/04/2006

SAMPLED BY: D.Aubrey

TEST CONDITIONS: Standard Reference Test Conditions
DATE PREPARED: 24/05/2006
DATE AND TIME OF TEST See Table Below

RESULTS:

SAMPLE NO: DATE TESTED:	1 30/05/2006	2 31/05/2006	3 01/06/2006	MEAN VALUES	COV%
TIME TESTED:	9.15 am	08.14 am	10.13 am		
MEAN DEPTH:	50.1	49.3	49.4		
MEAN WIDTH:	59.1	60.1	60.3		
BULK DENSITY t/m3	2.437	2.435	2.437	2.436	
AIR VOIDS %	4.6	4.5	4.6	4.6	1.3
TEST TEMPERATURE:INITIAL	20.0	20.1	20		
TEST TEMPERATURE:FINAL	20.1	20.1	19.9		
INITIAL FLEXURAL STIFFNESS: (MPa)	6834	5854	5761	6150	9.7
INITIAL PEAK TENSILE STRAIN:	400	399	398	399	0.25
CYCLES TO FAILURE:	502160	634000	1000100	712087	36.2

Notes:

~~K.Embleton (Section Head)~~
D.Aubrey (Section Head)