COMMENTARY TO AG:PT/T233 - FATIGUE LIFE OF COMPACTED BITUMINOUS MIXES SUBJECT TO REPEATED FLEXURAL BENDING

PREFACE

This asphalt test method was prepared by the Asphalt Research Review Group on behalf of Austroads. Representatives of Austroads, ARRB Group and the Australian Asphalt Pavement Association have been involved in the development and review of this test method.

FOREWORD

This test method was based on the Strategic Highway Research Program (SHRP) Designation M-009, “Standard Method of Test for Determining the Fatigue Life of Compacted Bituminous Mixtures Subjected to Repeated Flexural Bending”, developed by the University of California, Berkeley for the Strategic Highway Research Program - Contract A-003A but modified to suit Australian developed test equipment and data acquisition systems.

SCOPE

This test method details the requirements for determining the flexural stiffness, phase angle, dissipated energy per cycle, cycles to failure and cumulative dissipated energy at failure of asphalt subjected to repeated flexure by cyclical four-point controlled displacement loading.

This test method is applicable to asphalt with a maximum aggregate particle size of 20 mm.

Further Development

Revision of the accuracy and number of replicates. Derivation of an uncertainty of measurement statement.

SAMPLE PREPARATION – FATIGUE LIFE OF COMPACTED BITUMINOUS MIXES SUBJECT TO REPEATED FLEXURAL BENDING

1 REFERENCED DOCUMENTS

The following documents are referred to in this method:

AUSTROADS

AG:PT/T220 Preparation of asphalt slabs suitable for laboratory characterisation

Selection & Design of Asphalt Mixes: Australian Provisional Guide, Revision No. 2, APRG Report No. 18, Austroads, Sydney, Australia, December 2002.

AS /NZS

1545 Methods for the calibration and grading of extensiometers

2193 Methods for calibration and grading of force-measuring systems of testing machines

2891 Methods of sampling and testing asphalt

2891.1 Method 1: Sampling of asphalt

2891.2.1 Method 2.1: Mixing, quartering and conditioning of asphalt in the laboratory

2891.7.1 Method 7.1: Determination of maximum density of asphalt - Water displacement method

2891.8 Method 8: Voids and density relationships for compacted asphalt mixes

2891.9.2 Method 9.2: Determination of bulk density of compacted asphalt - Presaturation method

Miscellaneous

Beam Fatigue Apparatus Manufacturers' Operation and Reference manuals (See Note 1).

2 DEFINITIONS

For the purpose of this test method, the definitions below apply:

a. Four-point loading (also known as third-point loading): Loading applied to a beam which is simply supported at two points, such that equal loading is applied at those points which trisect the distance between the support points.

b. Haversine function: A cyclical function whose value ranges from zero to a maximum in a sinusoidal manner. The haversine of x – denoted as (hav x) - is defined mathematically as: hav (x) = ½ (1 - cos x).

c. Haversine loading: Cyclical loading such that the displacement of the beam at its mid-length is a haversine function of time.

d. Sine loading: Cyclical loading such that the displacement of the beam at its mid-length is a sine function of time.

e. Peak displacement: The maximum displacement of the beam during a loading cycle determined at its mid-length from its initial (pre-test) position.

f. Controlled displacement loading: Loading which is controlled to achieve a fixed level of peak displacement for all loading cycles applied during the test.

g. Peak force excursion: The algebraic (vector) difference between the maximum force applied to the beam and the force applied to the beam when it is returned to its initial (pre-test) position.

h. Peak tensile stress: That tensile stress in the extended (stretched) face of the beam at its mid-length which is associated with the peak force excursion assuming elastic behaviour.

i. Peak tensile strain: That tensile strain in the extended (stretched) face of the beam at its mid-length which is associated with the peak displacement - calculated on the assumption of simple beam behaviour.

j. Flexural stiffness: The ratio of peak tensile stress to peak tensile strain for the loading cycle under consideration.

k. Initial: The fiftieth (50th) loading cycle.

l. Failure condition: The condition of the specimen when it is deemed to have failed in fatigue. Defined to be when the flexural stiffness has decreased to fifty percent (50%) of its initial value.

m. Cycles to failure (Fatigue life): The number of cycles to reach the failure condition (see Note 10).

n. Reduction in flexural stiffness: The flexural stiffness at termination (when testing to the standard reference test conditions this will be a maximum of one million cycles) divided by the initial flexural stiffness and multiplied by 100.

3 APPARATUS

3.1 Testing Machine

a. A closed-loop pneumatic or hydraulic testing machine capable of applying both continuous (and pulsed) haversine displacement loading and continuous (and pulsed) sine displacement loading at frequencies up to 10 Hz (See Note 2). As a minimum, the testing machine shall meet the following requirements:

b. Load Measurement and Control in the range ± 4.5 kN with a resolution of 2.2 N or better and an accuracy of ± 20 N.

c. Displacement Measurement and Control in the range ± 0.5 mm with a resolution of 0.25 μm or better and an accuracy of ± 1 μm.

d. Temperature Measurement in the range 10°C to 30°C with a resolution of 0.1°C and an accuracy of ± 0.5°C.

e. The specimen shall be subjected to four-point loading, with free rotation at all four points and free longitudinal translation at the two reaction (support) points, which shall be separated by a distance typically 356 mm. With haversine loading, the specimen shall be returned to its pre-test position (i.e. zero displacement) at the end of each loading cycle.

f. The test system shall be computer-controlled such that, during each loading cycle:

   I. it measures the peak displacement of the beam,

   II. computes the peak tensile strain in the beam, and

   III. adjusts the applied force so that a constant level of peak displacement - consistent with the required level of peak tensile strain is achieved during each cycle.

g. The machine shall be capable of maintaining the required level of peak tensile strain within the tolerance specified in Table 6.1 throughout the duration of the test (See Note 3).

h. Data for a specific loading cycle shall be recorded for every tenth loading cycle up to one thousand cycles and, thereafter, for those loading cycles such that the ratio of successive cycle numbers remains approximately constant for the duration of the test. The ratio between successive cycle numbers shall be less than 1.10 (ratio expressed as the greater cycle divided by the smaller cycle number see examples provided in Appendix B).

i. For each load cycle for which data are recorded, the system shall record:

   I. the cycle number,

   II. the beam temperature through a dummy specimen or specimens placed in the temperature cabinet (See Note 4),

   III. the time traces of applied load, and

   IV. the time traces of beam displacement at its mid length.

It shall also calculate (in accordance with Appendix A) and record those properties of the asphalt beam specimen specified in Section 8.

3.2 Controlled Temperature Cabinet

The temperature cabinet shall be capable of maintaining the test temperature within ± 0.5°C. The cabinet shall have sufficient internal space to accommodate the loading frame, at least two test specimens in addition to the specimen to be tested, a dummy temperature specimen (see Note 4), permit adjustment of the loading frame and the displacement measuring devices and the placing of specimens into, and removal from, the loading frame.

3.3 Specimen Dimension Measurement Devices

A vernier calliper and/or other suitable devices capable of measuring the depth and width of the beam specimen to an accuracy of 0.1 mm.

4 TEST SPECIMENS

4.1 Number of Replicate Specimens

A minimum of three (3) replicate specimens is required to be tested under the same test conditions (See Note 5).

4.2 Specimen Preparation

Specimens shall be prepared either from slabs of asphalt, which have been mixed either in the plant or in the laboratory, conditioned, and compacted in the laboratory in accordance with AST05 or which have been obtained from a pavement. Slabs shall be cut to produce beam specimens of rectangular cross section, transverse to the direction of compaction, with dimensions 390 ± 5 mm in length, 50 ± 5 mm in depth and 63.5 ± 5 mm in width.

The specimens shall have all cut faces and shall not have imperfections likely to adversely affect the performance of the test or the quality of the data captured during the test. If any such imperfections are apparent prior to testing or become apparent during the test or upon examination of the data captured, the test result shall be rejected.

Care is to be exercised at all times to ensure that the specimens remain flat prior to testing as described in Section 5.3 (See Note 6).

4.3 Specimen Storage Prior to Test

Specimens and the slabs from which they are to be prepared shall be stored in an environment where the temperature will does not exceed 30°C. Wherever practicable, tests should be performed within 30 days of the date of compaction for laboratory-prepared slabs or the date of removing slabs from field pavements. During this storage period the specimens should be placed on a flat stiff surface (See Note 6).

5.4 Measurement of Specimen Dimensions

Measure the beam specimen width and depth at five locations along the beam;

- at points within 20 mm of each end,
- within 10 mm of the centre of the beam, and
- within 10 mm of points located 90 mm in either direction from the centre of the beam.

The mean of the five measurements for each dimension shall be reported to the nearest 0.1 mm. Reject the beam if any one of the five measurements, for either width or depth, differs by more than 1.5 mm from the respective mean value.

4.5 Measurement of Density and Air Voids

Because asphalt properties are heavily dependent on its level of compaction (specifically, Percent Air Voids), testing shall be carried out on each replicate specimen to determine Percent Air Voids.

Air voids shall be determined as follows:

a. Determine the maximum density of the asphalt mix in accordance with AS 2891.7.1 for each mix type. Determine the bulk density of each beam specimen in accordance with AS 2891.9.2. Calculate the air voids in the beams in accordance with AS 2891.8.

b. The bulk density shall be determined either before or after the fatigue test. However, if the bulk density is determined before testing, then the specimens shall be dried to constant mass at ambient temperature prior to placing in the loading frame.

c. The maximum density of the asphalt from field pavements, if determined using the beam specimens, shall be determined upon completion of the fatigue test.

5 STANDARD REFERENCE TEST CONDITIONS

For the purpose of ranking asphalt on the basis of its flexural and fatigue properties, the standard reference test conditions in Table 1 are specified.

Table 1 Standard reference test conditions (see Notes 7 and 8)

Test Parameter	Standard reference test conditions
Test temperature (°C)	20 ± 0. 5
Loading frequency (Hz)	10 ± 0.1
Mode of loading	Continuous haversine (i.e. no rest period between successive loading cycles) in controlled displacement
Peak tensile strain for the 50th and subsequent cycles ($\mu\varepsilon$)	400 ± 10 (i.e. ± 2.5%)
Failure condition	When the flexural stiffness is reduced to 50% of the initial flexural stiffness or one million loading cycles have been applied, whichever occurs first
Air void content (%)	5 ± 0.5
Number of replicates	3

For test conditions applicable for more complete characterisation of an asphalt mixture see Note 7.

6 PROCEDURE

The following steps apply for each of the replicate specimens:

a. Measure the beam specimen width, and depth at locations described in Section 5.4. Calculate and record the mean depth and width of the beam specimen.

b. The test specimen, or a dummy specimen (see Note 4) shall be maintained at the target temperature ± 0.5°C throughout the testing process. .

c. Select the mode of loading to be used (haversine or sine).

d. Input the following test parameters on the test parameter set-up screen:

   I. specimen identification and dimensions,

   II. peak tensile strain,

   III. loading frequency, and

   IV. termination criteria, a maximum allowable number of cycles and termination stiffness (see Note 10).

e. Position the loading frame cradle in the centre of its stroke.

f. Insert location draw-bars.

g. Position the beam specimen in the loading frame cradle. Close the end plastic clamps to hold the specimen ends in place.

h. Lower the outer and then inner clamps at the four points to hold the specimen in place.

i. Remove the location draw-bars.

j. Adjust on-specimen displacement transducer to centre stroke.

k. Allow a minimum of 30 minutes to enable the specimen clamping stresses to be relieved before the commencement of test, and again check that the on-specimen transducer level is close to zero and adjust level, if necessary.

l. Secure the on-specimen transducer lock nut.

m. Check that the dummy specimen core temperature is at the target temperature within the tolerance specified in Table 6.1 prior to commencement of the test.

n. Start (RUN) the test.

o. Initial Flexural Stiffness: The initial flexural stiffness is the flexural stiffness calculated by the data acquisition software at the 50th load cycles. Check to confirm that the selected peak tensile strain level (± 2.5%, see Table 6.1) is achieved at the 50th cycle.

p. After the completion of the first 50 loading cycles, enter the required termination stiffness (see Note 10).

q. On completion of the test remove the beam specimen.

r. Save the binary file.

s. Repeat steps (a) to (r) for remaining replicate specimens.

7 CALCULATIONS

For each valid replicate specimen (See Note 5), and for all loading cycle data captured, calculate the following variables in accordance with Appendix A:

a. Peak tensile stress (kPa)

b. Peak tensile strain (micro-strain)

c. Flexural stiffness (MPa)

The resultant values shall be recorded in an ASCII file under the following column headings together with row entries for each captured loading cycle:

Loading Cycle	Peak Force Excursion (kN)	Peak Displacement (mm)	Peak Tensile Stress (kPa)	Peak Tensile Strain ($\mu\varepsilon$)	Flexural Stiffness (MPa)	Temperature (°C)

The test will terminate either due to reaching a predetermined number of cycles or when the flexural stiffness decreases to approximately 40% the initial flexural stiffness (as determined by the operator, see section 7.2 (p)).

8 TEST REPORT

9.1 General

The test report shall contain the following information:

a. Asphalt description: Specimen identification and source (i.e. laboratory prepared or from insitu pavement)

b. For laboratory prepared specimens the following shall be recorded:

c. date of manufacture of the asphalt slab from which the specimen was prepared.

d. For field specimens, in addition to the mix component information as available, the following information shall be recorded, if known

e. date of placement in the field (if known),

f. location of slab relative to wheel path location,

g. past traffic loading (if known), and

h. date of removal from the pavement of the slab from which the specimen was prepared.

i. Description of test conditions used as ‘standard reference test conditions’(see Table 6.1) or ‘non-standard test conditions’. Where non-standard conditions are used, the variation from standard reference conditions shall be reported (e.g. target peak tensile strain, temperature, frequency, mode of loading, failure condition, etc. (see Notes 7, 8 and 10).

j. Date and time of test.

k. Other variations to standard practice during manufacture, placement or compaction of the asphalt slab, (e.g. reheating) or preparation of beam specimen (e.g. orientation relative to the direction of compaction).

l. The number of this test method, i.e. AG:PT/T223.

9.2 Test Results (See Note 5)

For each replicate beam report the following:

a. Mean depth of beam to the nearest 0.1 mm.

b. Mean width of beam to the nearest 0.1 mm.

c. Bulk density of beam to the nearest 0.05 t/m^3.

d. Air void content to the nearest 0.1%.

e. Initial temperature and the temperature at termination, to the nearest 0.1°C.

f. Initial peak tensile strain to three significant figures in microstrain (e.g. 400 $\mu\varepsilon$)

g. Initial flexural stiffness to the nearest 10 MPa.

h. Cycles to failure and/or reduction in flexural stiffness.

For all replicate beams tested under the same test conditions, report the following:

a. Number of replicates.

b. Mean air void content (if determined) to the nearest 0.1%.

c. Mean initial peak tensile strain to three significant figures in microstrain (e.g. 400 $\mu\varepsilon$).

d. Mean initial flexural stiffness to the nearest 10 MPa.

e. Mean cycles to failure and/or reduction in flexural stiffness.

f. Coefficient of Variation (CoV, %) for properties b) to e).

9 PRECISION

Not determined.

10 OCCUPATIONAL HEALTH AND SAFETY

This test method may involve hazardous materials, operations and equipment (see Note 9) and, it does not purport to address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate health and safety practices and determine the applicability of regulatory limitations prior to use.

NOTES ON THE TEST

1. Apparatus: At the time that this test method was prepared the only available apparatus in Australia was manufactured by Industrial Process Control (IPC) and hence the method has been based on that apparatus. Any alternative apparatus should be assessed to ensure that its results are compatible with those produced by the IPC apparatus.

2. Mode of Loading: The test method allows two alternative modes of loading (haversine and sine) because, internationally, both modes are in use (haversine predominating in North America and sine predominating in Europe). While haversine is the preferred option within Australasia because it provides a direct link to U S developmental work, the use of sine loading is appropriate when direct comparison with European practice is sought.

3. Adjusting Strain Level: In order to achieve the required level of peak tensile strain under the Standard Reference Test Conditions or higher strain levels when testing stiffer asphalt beams in the IPC apparatus it may be necessary to adjust the Auxiliary Control Proportional Gain to a greater value than the default value shown on the control limits. The default value is appropriate for specimens prepared from laboratory compacted slabs but not for slabs of aged asphalt extracted from field pavements. Operators should refer to the Manufacturers Operation and Reference Manuals for further information.

4. The test specimen can be prepared to accommodate the temperature measuring devices. This ensures that the temperature recorded during the test is the temperature of the test specimen. However, it is also permitted to use a dummy specimen which has been prepared to accommodate the temperature measuring devices. Where a dummy specimen is used to monitor the test temperature (which is the more common practice) then the relationship between the temperature of the dummy specimen and the temperature of the test specimen needs to be established.

   The dummy specimen should have a mass of at least 25% of that of the test specimen and be composed of a material similar to that of the test specimen. The mass and composition requirement ensures that the dummy specimen has similar temperature sensitivity as the test specimen.

   The temperature measuring devices shall be placed so as to provide a measure of core and surface temperature. The core temperature device should be placed at about mid depth and displaced from the sample edge by at least half the sample thickness. The core temperature can be attached to the surface of the sample or placed in a shallow groove. In both cases the surface temperature measuring devices shall be shielded from contact with the air. A common practice is to cover the surface temperature measurement device with a thin strip of polystyrene. When the test sample is used to record test temperature, the temperature measurement devices shall not be placed so as to interfere with the test outcome.

   Allow sufficient time for the test specimen and/or dummy specimen to reach temperature equilibrium. It is advisable for the temperature to stabilise rather than allow testing to commence immediately the temperature falls within the tolerance range.

5. Replicate Specimens: The method requires 3 replicate specimens to be tested but more may be tested provided that all specimens are representative of the asphalt

mixture both in composition and age. The method allows asphalt slabs and/or specimens to be stored for up to 30 days from the date of compaction or extraction of the slabs to the date of testing and requires the rejection of specimens, which have imperfections or do not conform dimensionally. Therefore, sufficient asphalt slabs have to be stored to ensure that, if any of the initial replicates are rejected, additional specimens which are representative of the asphalt mixture, can be prepared.

Regardless of the number of replicate specimens tested, the results of the testing of all replicates must be reported unless a specimen is rejected for imperfections or dimensional non-conformance.

6. Specimen Handling and Storage: It is imperative that no cracks or stresses are induced in test specimens prior to testing as this will adversely affect the fatigue life. The specimens shall be placed on a flat, stiff surface such that it is fully supported on the face to be loaded (i.e. one of the pair of largest faces), throughout the period between the time of preparation and the time of placing in the loading frame for testing.

7. Test Conditions: For more complete characterisation of the fatigue and flexural properties of asphalt, it may be appropriate that tests be conducted over a range of temperatures, peak strain values, and loading frequencies. The set of test conditions to be adopted for a specific asphalt should be formulated with regard to the likely field conditions (field temperature, pavement configuration, traffic speed, rest period) in which the asphalt pavement will operate. For full characterisation of the asphalt, testing at three strain levels is recommended as a minimum. This will require a minimum of nine beams (3 strain levels × 3 or more replicates at each strain level - see also section 3.7, Selection & Design of Asphalt Mixes: Australian Provisional Guide, Revision no. 2, APRG Report No.18, December 2002).

8. Non-conventional Asphalt Characterisation: For asphalt with non-conventional binders such as polymer modified or multigrade binders, the test conditions may need to be varied from those shown in Table 6.1, by adopting a lower temperature or a higher target peak tensile strain to achieve failure within a practical test duration.

9. Safety: It is the responsibility of the users to ensure that manufacturers instructions regarding operation of the apparatus are understood, and complied with, before proceeding with testing, to avoid serious injury to users or damage to equipment.

10. Termination Criteria and Cycles to Failure: For the IPC apparatus, a test is terminated on the first occasion that either of the following criteria is satisfied:

- The flexural stiffness falls below the operator-specified value of termination stiffness;
- The number of loading cycles applied reaches the operator-specified maximum allowable number.

Values of both termination stiffness and the maximum allowable number of cycles are specified by the operator prior to the commencement of the test at Step (d) of Section 7.2. During the course of the test, the value for Initial Flexural Stiffness is displayed (subsequent to its calculation) and, in response to this information, the operator is invited to alter either or both of the values for termination stiffness and maximum allowable number of cycles (Step (p) of Section 7.2).

To ensure the accurate assessment of “Cycles to Failure” for the specimen, it is necessary to prolong the test slightly beyond the number of cycles where the specimen has reached its failure condition. This is achieved by firstly setting the initial value of terminal stiffness at an artificially low value and the initial value of the maximum allowable number of cycles at an artificially high value. Subsequently, when the operator is invited to alter either or both of these values, the value of terminal stiffness determined in accordance with Step (p) of Section 7.2 is entered and the artificially high value for maximum allowable number of cycles is retained.

The value adopted for termination stiffness is intentionally set lower than the stiffness value at failure in order to minimise the risk of premature termination of the test caused by spurious electrical signals producing spuriously low values for flexural stiffness.

After the completion of the test, the “Cycles to Failure” is determined by reviewing the ASCII file to locate the two records, which straddle the value of failure stiffness. The “Cycles to Failure” is obtained by linear interpolation between the numbers of cycles to which each of these records relates.

APPENDIX A
Data Calculations

A 1 Peak Tensile Stress (kPa)

$$\sigma_t = \frac{LP}{wh^2} \times 10^6$$

where: σ_t = peak tensile stress (kPa)

L = beam span (mm), typically 356 mm

P = peak force excursion (kN)

w = beam width (mm)

h = beam height (mm)

A 2 Peak Tensile Strain (mm/mm)

$$\varepsilon_t = \frac{108\delta h}{23L^2} \times 10^6$$

where: εt = peak tensile strain (microstrain)

δ = peak displacement (mm)

A 3 Flexural Stiffness (MPa)

$$S_{mix} = \frac{1000 \times \sigma_t}{\varepsilon_t}$$

where: S_{mix} = flexural stiffness (MPa)

Appendix B

An example of an appropriate sequence of loading cycles for which the beam temperature and the time traces of peak force and peak displacement are to be recorded when the test is set to terminate at or prior to 1 million (106) loading cycles .

Load Cycle

10	20	30	40	50	60	70	80	90
100	110	120	130	140	150	160	170	180
190	200	210	220	230	240	250	260	270
280	290	300	310	320	330	340	350	360
370	380	390	400	410	420	430	440	450
460	470	480	490	500	510	520	530	540
550	560	570	580	590	600	610	620	630
640	650	660	670	680	690	700	710	720
730	740	750	760	770	780	790	800	810
820	830	840	850	860	870	880	890	900
910	920	930	940	950	960	970	980	990
1000	1010	1020	1030	1040	1050	1060	1070	1080
1090	1100	1120	1130	1140	1150	1160	1170	1180
1190	1200	1220	1230	1240	1250	1260	1280	1290
1300	1310	1320	1340	1350	1360	1380	1390	1400
1420	1430	1440	1460	1470	1490	1500	1510	1530
1540	1560	1570	1590	1600	1620	1640	1650	1670
1680	1700	1720	1730	1750	1770	1780	1800	1820
1830	1850	1870	1890	1910	1920	1940	1960	1980
2000	2020	2040	2060	2080	2100	2120	2140	2160
2180	2200	2220	2240	2260	2290	2310	2330	2350
2380	2400	2420	2440	2470	2490	2520	2540	2560
2590	2610	2640	2660	2690	2720	2740	2770	2800
2820	2850	2880	2900	2930	2960	2990	3020	3050
3080	3110	3140	3170	3200	3230	3260	3290	3320
3350	3390	3420	3450	3480	3520	3550	3590	3620
3660	3690	3730	3760	3800	3840	3870	3910	3950
3990	4020	4060	4100	4140	4180	4220	4260	4300
4340	4390	4430	4470	4510	4560	4600	4650	4690
4740	4780	4830	4870	4920	4970	5020	5060	5110
5160	5210	5260	5310	5360	5420	5470	5520	5570
5630	5680	5740	5790	5850	5900	5960	6020	6080
6130	6190	6250	6310	6370	6440	6500	6560	6620
6690	6750	6820	6880	6950	7020	7080	7150	7220
7290	7360	7430	7500	7580	7650	7720	7800	7870
7950	8020	8100	8180	8260	8340	8420	8500	8580
8660	8750	8830	8920	9000	9090	9180	9270	9350
9440	9540	9630	9720	9810	9910	10000	10100	10200
10300	10400	10500	10600	10700	10800	10910	11010	11120
11220	11330	11440	11550	11660	11780	11890	12000	12120
12240	12350	12470	12590	12710	12840	12960	13090	13210
13340	13470	13600	13730	13860	13990	14130	14270	14400
14540	14680	14820	14970	15110	15260	15400	15550	15700
15850	16010	16160	16320	16470	16630	16790	16950	17120

17280	17450	17620	17790	17960	18130	18310	18480	18660
18840	19020	19210	19390	19580	19770	19960	20150	20340
20540	20740	20940	21140	21340	21550	21760	21970	22180
22390	22610	22820	23040	23270	23490	23720	23950	24180
24410	24650	24880	25120	25370	25610	25860	26110	26360
26610	26870	27130	27390	27650	27920	28190	28460	28730
29010	29290	29570	29860	30150	30440	30730	31030	31320
31630	31930	32240	32550	32860	33180	33500	33820	34150
34480	34810	35150	35490	35830	36170	36520	36870	37230
37590	37950	38320	38690	39060	39430	39810	40200	40590
40980	41370	41770	42170	42580	42990	43410	43820	44250
44670	45100	45540	45980	46420	46870	47320	47780	48240
48700	49170	49640	50120	50610	51090	51590	52080	52590
53090	53600	54120	54640	55170	55700	56240	56780	57330
57880	58440	59000	59570	60140	60720	61310	61900	62500
63100	63710	64320	64940	65570	66200	66840	67480	68130
68790	69450	70120	70800	71480	72170	72870	73570	74280
74990	75720	76450	77180	77930	78680	79440	80200	80980
81760	82540	83340	84140	84950	85770	86600	87440	88280
89130	89990	90860	91730	92620	93510	94410	95320	96240
97170	98100	99050	100000	100970	101940	102920	103920	104920
105930	106950	107980	109020	110070	111130	112210	113290	114380
115480	116600	117720	118850	120000	121160	122320	123500	124690
125900	127110	128340	129570	130820	132080	133360	134640	135940
137250	138570	139910	141260	142620	143990	145380	146780	148200
149630	151070	152530	154000	155480	156980	158490	160020	161560
163120	164690	166280	167880	169500	171140	172790	174450	176130
177830	179550	181280	183020	184790	186570	188370	190180	192020
193870	195740	197630	199530	201450	203400	205360	207340	209330
211350	213390	215450	217520	219620	221740	223880	226030	228210
230410	232630	234880	237140	239430	241740	244070	246420	248790
251190	253610	256060	258530	261020	263540	266080	268640	271230
273850	276490	279150	281840	284560	287300	290070	292870	295690
298540	301420	304330	307260	310220	313210	316230	319280	322360
325470	328600	331770	334970	338200	341460	344750	348070	351430
354820	358240	361690	365180	368700	372250	375840	379460	383120
386820	390550	394310	398110	401950	405820	409740	413690	417670
421700	425770	429870	434010	438200	442420	446690	450990	455340
459730	464160	468640	473160	477720	482320	486970	491670	496410
501190	506020	510900	515830	520800	525820	530890	536010	541170
546390	551660	556980	562350	567770	573240	578770	584350	589980
595670	601410	607210	613060	618970	624940	630960	637040	643190
649390	655650	661970	668350	674790	681300	687860	694500	701190
707950	714770	721670	728620	735650	742740	749900	757130	764430
771800	779240	786750	794330	801990	809720	817530	825410	833370
841400	849510	857700	865970	874320	882750	891250	899850	908520
917280	926120	935050	944060	953170	962350	971630	981000	990460
1000000								

Appendix C

Informative

The following optional parameters can be calculated from the data derived during the test.

Phase angle: The time elapsed between the occurrence of the mid-point force and the occurrence of the mid-point displacement - relative to the duration (period) of the loading cycle. It is expressed as an angle (measured in degrees), with the duration of the loading cycle assigned a value of 360 degrees.

$\phi = 360\,ft$

where: ϕ = phase angle (degree)

f = load frequency (Hz)

t = time lag between P and δ (s) (see equations A1 and A2, Appendix A)

Dissipated energy per cycle: The maximum energy per unit volume dissipated within the beam over the course of a loading cycle. It is represented by the area within the hysteresis loop formed from the plot of peak tensile stress versus peak tensile strain.

The dissipated energy per cycle (kPa) is calculated by determining the area within the hysteresis loop formed from the plot of peak tensile stress versus peak tensile strain.

Cumulative dissipated energy: Cumulative dissipated energy (MPa) is the sum of the dissipated energies per cycle for all cycles up to and including the reported cycle.

Cumulative dissipated energy at failure: The cumulative dissipated energy at the loading cycle wherein the failure condition is reached.

For each replicate beam the following may be reported:

a. Initial dissipated energy per cycle.

b. Initial phase angle to the nearest degree.

c. Cumulative dissipated energy at failure.

For all replicate beams tested under the same test conditions, the following may be reported:

a. Mean initial dissipated energy per cycle.

b. Mean cumulative dissipated energy at failure.

c. Coefficient of Variation (CoV, %) for the mean initial dissipated energy per cycle and the mean cumulative dissipated energy at failure.

AMENDMENT RECORD

Amendment No.	Clauses amended	Action	Date
1	Changed test number	Substitution	25th Oct 2004
	Amendment record	New	
	Clause 3 (m)	Substitution	
	Clause 3 (n)	New	
	Clause 4.1	New	
	Clause 4.2	Removal	
	Clause 7 (b)	Substitution	
	Clause 7 (r)	Substitution	
	Clause 8	Removal	
	Clause 9.1 (c)	Removal	
	Note 4	Removal	
	Note 10	Removal	
	Appendix C point 6	Substitution	
2	Commentary Page	New	June 2005
	Footer and header	Format	
	Applied revised test method number	Format	
	Applied new styles	Format	
3	Page 2 title	Substitution	Dec 2005
4	Further development	New	Jan 2006
	6 (b) Temperature monitoring	Substitution	
	Note 4 Temperature monitoring	Substitution	

Key

Format	Change in format
Substitution	Old clause removed and replaced with new clause
New	Insertion of new clause
Removed	Old clauses removed