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Pavement Material Modelling and Design

Characterization of H M A mixture response



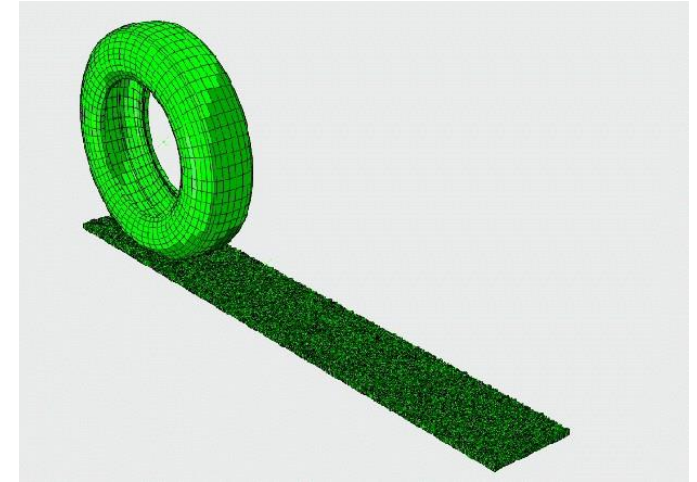
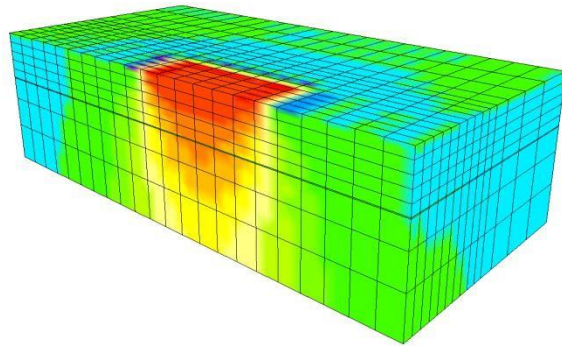
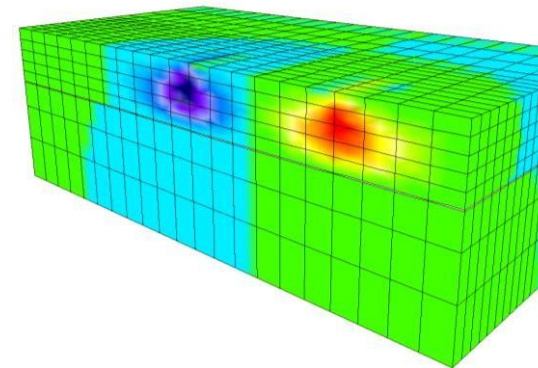
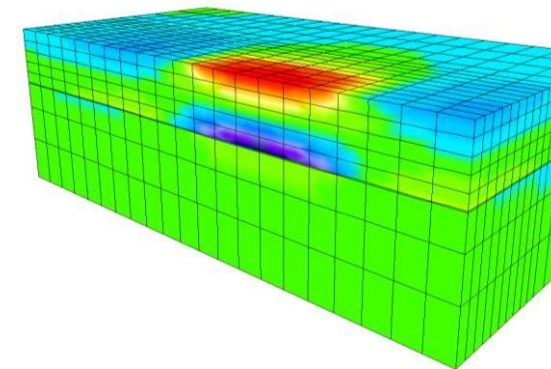
HMA characterization tests

- Mixture characterization tests
 - used to determine and describe fundamental HMA mixture
 - parameters :
 - bulk specific gravity
 - theoretical maximum specific gravity
 - binder content
- Performance tests
 - used to predict the performance of HMAs in terms of :
 - ✓ rutting resistance
 - ✓ fatigue cracking
 - ✓ thermal cracking
 - ✓ moisture sensitivity

- what tests ?
- at what conditions
- at what stress level?



- traffic loading is not stationary
- traffic loading causes a multitude of stresses in the pavement



- material properties are needed



structural analysis

performance evaluation



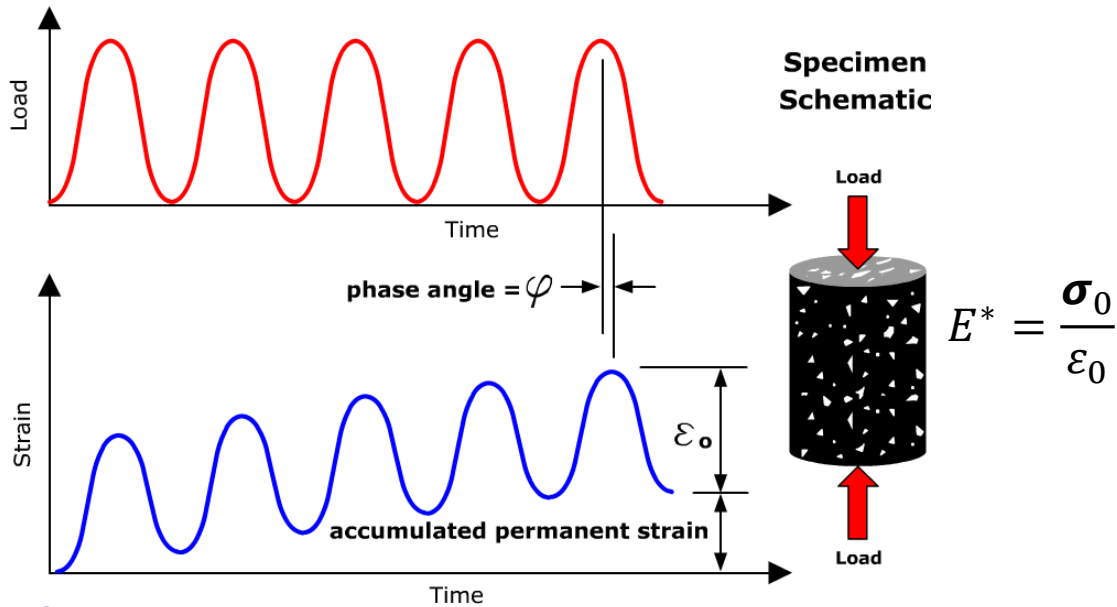
➤ H M A characterization tests

- dynamic modulus tests
- The dynamic modulus test is widely accepted by pavement agencies as the critical parameter for the mechanistic empirical design procedure and the candidate of the simple performance test to accompany the volumetric mix design process.
- This test method covers procedures for preparing and testing hot mix asphalt (HMA) to determine the dynamic modulus and phase angle over a range of temperatures and loading frequencies.
- There are many different ways to conduct dynamic modulus tests, including uniaxial compression, indirect tension, four-point bend and semi-circle bend etc.



H M A characterization tests

- dynamic modulus tests: uniaxial compression
- ✓ Measures the stress-strain relationship under a continuous sinusoidal loading as expressed by E^*



Sample dimensions: 100 mm diameter by 150 mm height

where: E^* = Dynamic modulus

σ_0 = peak stress amplitude (applied load / sample cross sectional area)

ε_0 = peak amplitude of recoverable axial strain = $\Delta L/L$. Either measured directly with strain gauges or calculated from displacements measured with linear variable displacement transducers (LVDTs).

L = gauge length over which the sample deformation is measured

ΔL = the recoverable portion of the change in sample length due to the applied load

Performed at a range of temperatures and frequencies depending on PG
NCHRP Reports 1-37A, 465, 513, 614

AASHTO TP 62





NCHRP stands for:

National Cooperative Highway Research Program

This work was sponsored in 1962 by the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration

1-37A: 2002 Guide for the Design of New and Rehabilitated Pavement Structures



- Dynamic modulus tests: uniaxial compression : NCHRP 614

Table 2. Recommended Testing Temperatures and Loading Frequencies.

PG 58-XX and softer		PG 64-XX & PG 70-XX		PG 76 –XX and stiffer	
Temperature °C	Loading Frequencies Hz	Temperature °C	Loading Frequencies Hz	Temperature °C	Loading Frequencies Hz
4	10, 1, 0.1	4	10, 1, 0.1	4	10, 1, 0.1
20	10, 1, 0.1	20	10, 1, 0.1	20	10, 1, 0.1
35	10, 1, 0.1, and 0.01	40	10, 1, 0.1, and 0.01	45	10, 1, 0.1, and 0.01

Example Dynamic Modulus Summary Sheet.

Conditions		Specimen 1		Specimen 2		Specimen 3		Average	Modulus	Average	Std Dev
Temperature	Frequency	Modulus	Phase Angle	Modulus	Phase Angle	Modulus	Phase Angle	Modulus	CV	Phase	Phase
C	Hz	Ksi	Degree	Ksi	Degree	Ksi	Degree	Ksi	%	Deg	Deg
4	0.1	1170.9	18.8	1214.8	19.6	1443.2	18.5	1276.3	11.5	19.0	0.5
4	1	1660.8	12.0	1743.5	12.5	2027.0	11.6	1810.5	10.6	12.0	0.4
4	10	2107.3	8.1	2245.6	8.4	2596.1	8.2	2316.3	10.9	8.2	0.2
20	0.1	259.1	33.9	289.9	33.5	315.2	34.6	288.1	9.8	34.0	0.6
20	1	604.1	27.4	657.3	26.8	711.2	27.0	657.5	8.1	27.1	0.3
20	10	1065.1	21.0	1181.5	18.8	1231.4	19.8	1159.3	7.4	19.9	1.1
40	0.01	17.2	18.6	16.5	18.8	18.8	19.2	17.5	6.7	18.9	0.3
40	0.1	26.5	24.8	26.4	26.1	30.6	26.0	27.8	8.6	25.6	0.7
40	1	62.9	31.5	63.9	32.1	74.5	32.7	67.1	9.6	32.1	0.6
40	10	180.1	35.2	197.6	35.1	220.6	35.2	199.4	10.2	35.2	0.1

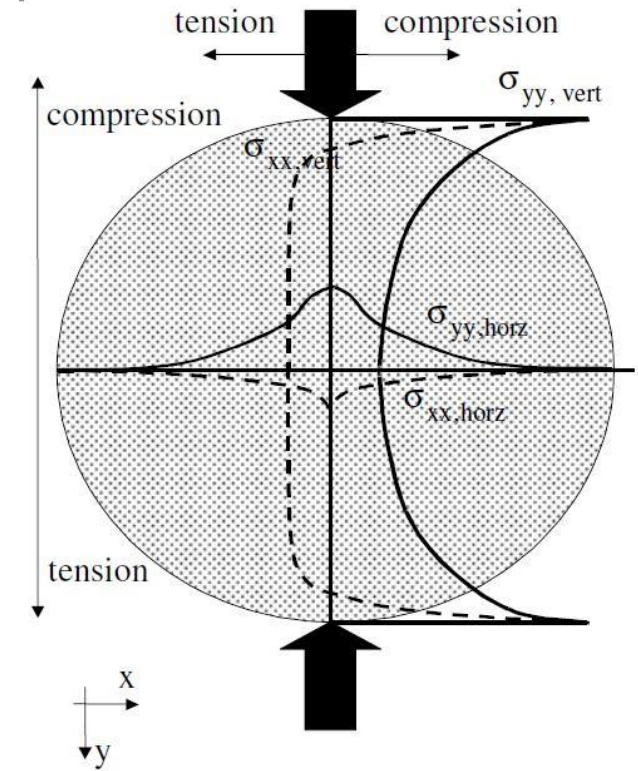


➤ H M A characterization tests

- dynamic modulus: cyclic indirect tensile test
 - EN 12697-26

Principle

- The method is applicable to **cylindrical specimens**, manufactured in the laboratory or cored from a road layer.
- During multistage tests **different temperatures** and loading **frequencies** are applied on the specimens in order to determine the master curve.





- H M A characterization tests
 - dynamic modulus: cyclic indirect tensile test
 - EN 12697-26

Sample preparation

- At each test temperature **4 specimens** shall be tested. An additional specimen may be needed for estimating the required loading condition.

Table F.1 — Specimen dimensions

Maximum grain size mm	Specimen diameter mm	Specimen height mm
≤ 16	100 ± 3	40 ± 2
> 16 to < 32	150 ± 3	60 ± 2
≥ 32	150 ± 3	90 ± 2



- Dynamic modulus: cyclic indirect tensile test : EN 12697-26

Testing condition

- In minimum, the following 4 test temperatures shall be chosen: **-10, 0, 10 and 20 °C.**

Table F.2 — Load cycles required for the multistage-tests

Load frequency	Number of load cycles	Analysis of load cycle
10 Hz	110	98 to 102
5 Hz	100	93 to 97
3 Hz	50	43 to 47
1 Hz	20	13 to 17
0,3 Hz	15	8 to 12
0,1 Hz	10	3 to 7

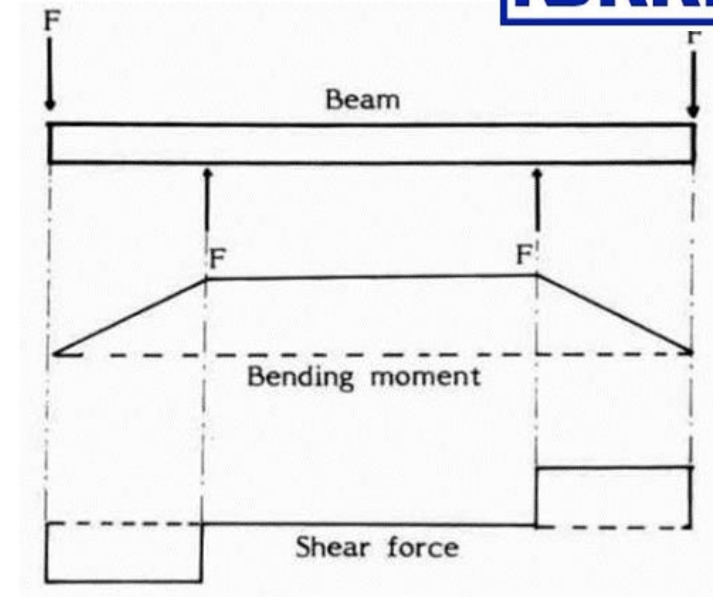
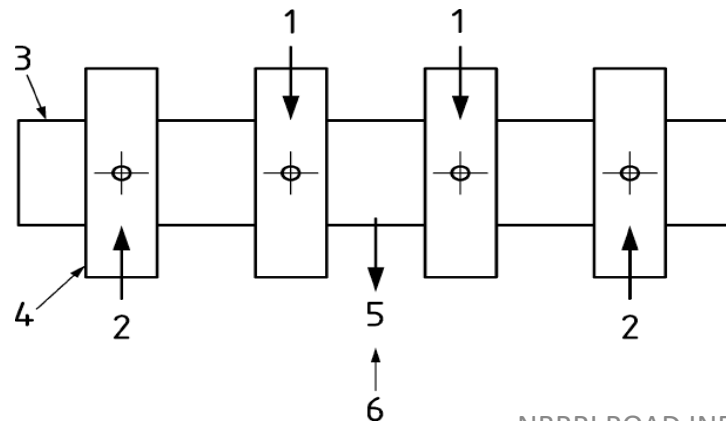


➤ H M A characterization tests

- dynamic modulus: Four point bending test (4PB)
- EN 12697-26

Principle

- During the test, the force needed for the deformation of the specimen is measured as a function of time as well as the phase lag between the **force** signal and the **displacement** signal. From this, the stiffness modulus of the tested material is calculated.

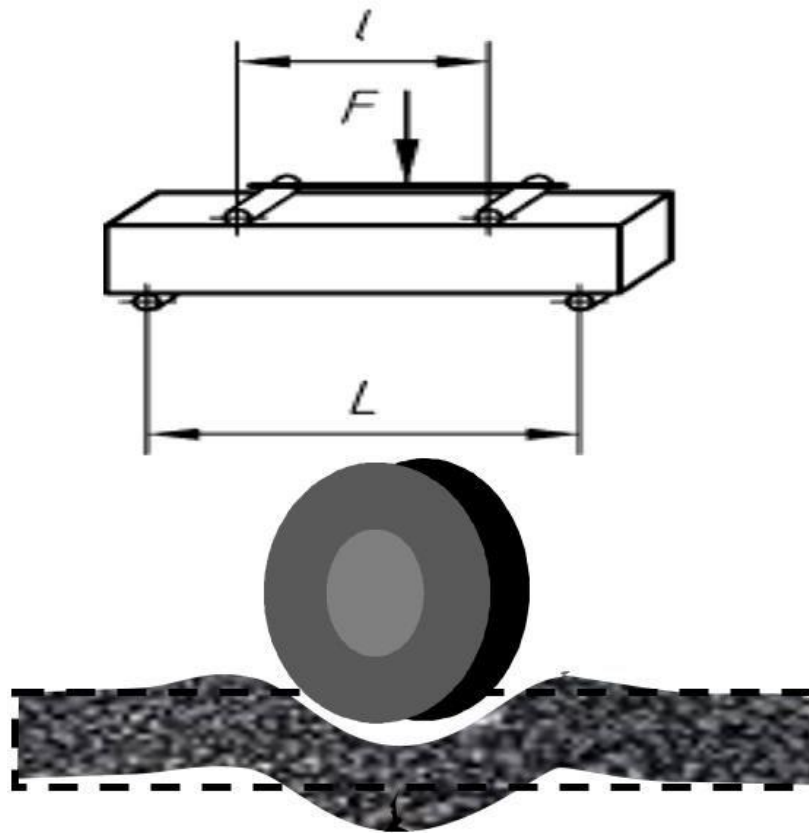
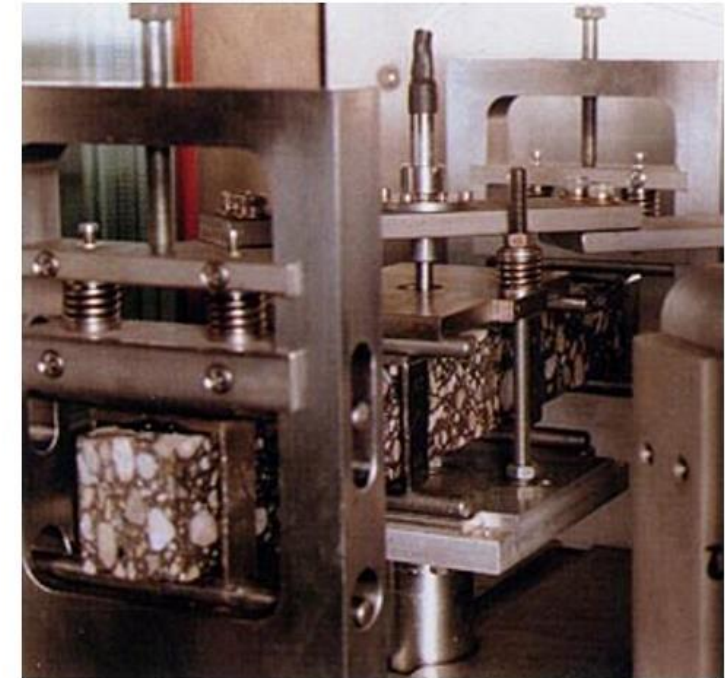


- 1 applied load
- 2 reaction
- 3 specimen
- 4 specimen clamp
- 5 deflection
- 6 return to original position



➤ H M A characterization tests

- dynamic modulus: Four point bending test (4PB)
 - EN 12697-26





- Dynamic modulus: Four point bending test (4PB): EN 12697-26

Sample preparation

- At each test temperature **3 specimens** shall be tested.
- Beam sample:
 - Length: 400 mm
 - Width: 50 mm
 - Height: 50 mm



Testing condition

- Temperature: **0, 10 and 20 and 30 °C**
- Frequency: **0.1, 0.2, 0.5, 1, 2, 5, 8, 10, 20, 30 Hz**

The **stiffness modulus** is typically determined at the 100th cycle because this is often defined as the initial stiffness modulus value and, more importantly, the required parameters (e.g. strain amplitude) should be constant by the cycle at which the stiffness modulus is determined





Procedure

- Specimen is taken from the slab.
- Specimen is stored on flat surface at temperature 5-15°C for 2-8 weeks.
- Start the test; force, displacement and phase lag are recorded after 100 cycle (those values will produce initial stiffness).
- Specimen is subjected to a sinusoidal displacement controlled load with maximum strain magnitude of 50 μm .

frequency sweep [Hz]	0.1	0.2	0.5	1	2	5	8	10	20	30	0.1
Number of cycles	26	26	56	106	106	106	106	106	106	106	26
Trigger cycle	21	21	51	101	101	101	101	101	101	101	21

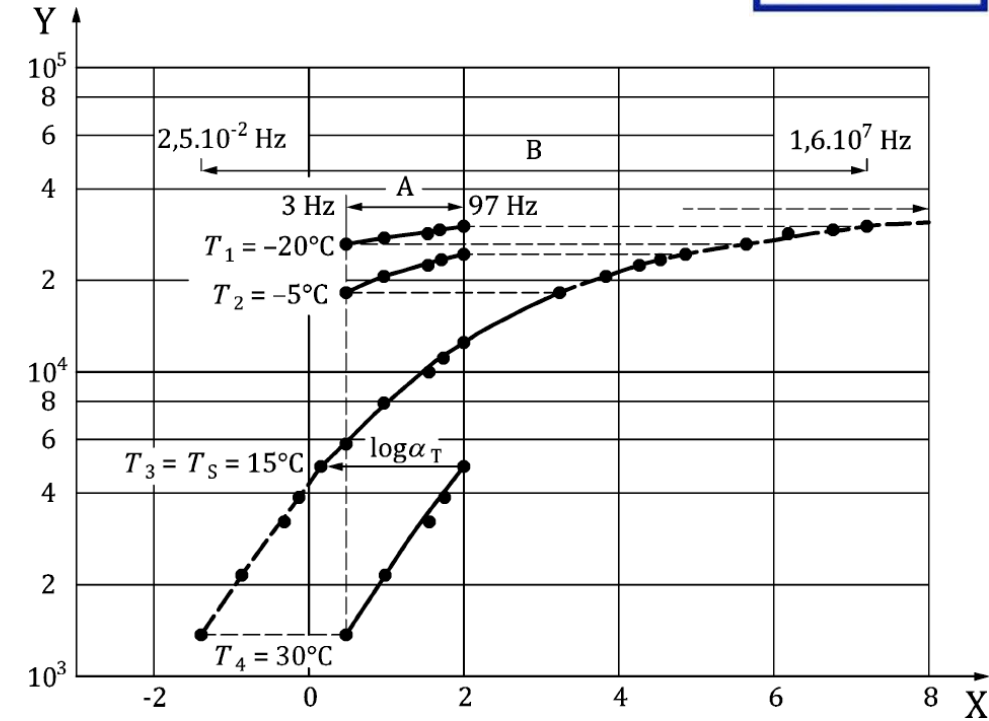
- In the Netherlands, the initial stiffness is determined at test temperature of 20°C and load frequency of 8Hz.

➤ H M A characterization tests

- dynamic modulus: EN 12697-26

Master curve of stiffness

- The stiffness modulus of bituminous mixes obey the **frequency-temperature superposition** principles.
- This means that a master curve of the complex modulus can be constructed for a **reference temperature** from experimental data over a limited range of frequencies and temperatures, provided that a shift factor is used to calculate the reduced frequency.



A experimental range

B range covered by the master curve

X $\lg(\alpha_T \cdot f) = f_s$

Y Stiffness, in MPa



➤ H M A characterization tests

- Typical dynamic modulus:

TABLE 7.7 Typical Values of Dynamic Modulus for HMA

Temperature (°F)	Load frequency (Hz)					
	1		4		16	
	Range	Mean	Range	Mean	Range	Mean
40	6.0–18.0	12.0	9.0–27.0	16.0	10.0–30.0	18.0
70	2.0–6.0	3.0	4.0–9.0	5.0	5.0–11.0	7.0
100	0.5–1.5	0.7	0.7–2.2	1.0	1.0–3.2	1.6

Note. Modulus in terms of 10^5 psi, 1 psi = 6.9 kPa.



➤ H M A characterization tests

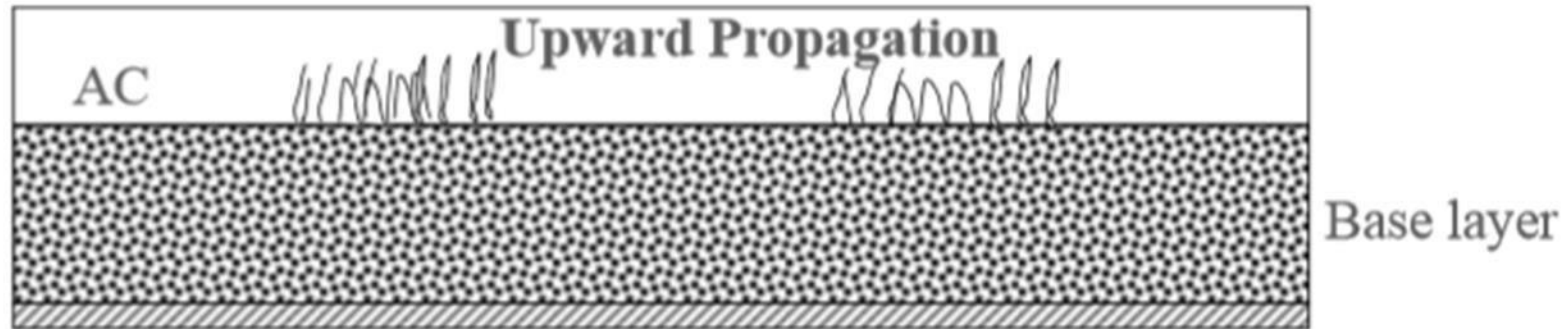
- Fatigue test
 - HMA fatigue properties are important because one of the principal modes of HMA pavement failure is fatigue-related cracking, called fatigue cracking. Therefore, an accurate prediction of HMA fatigue properties would be useful in predicting overall pavement life.
 - EN 12697-24:Resistance to fatigue and AASHTO TP 8: Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending



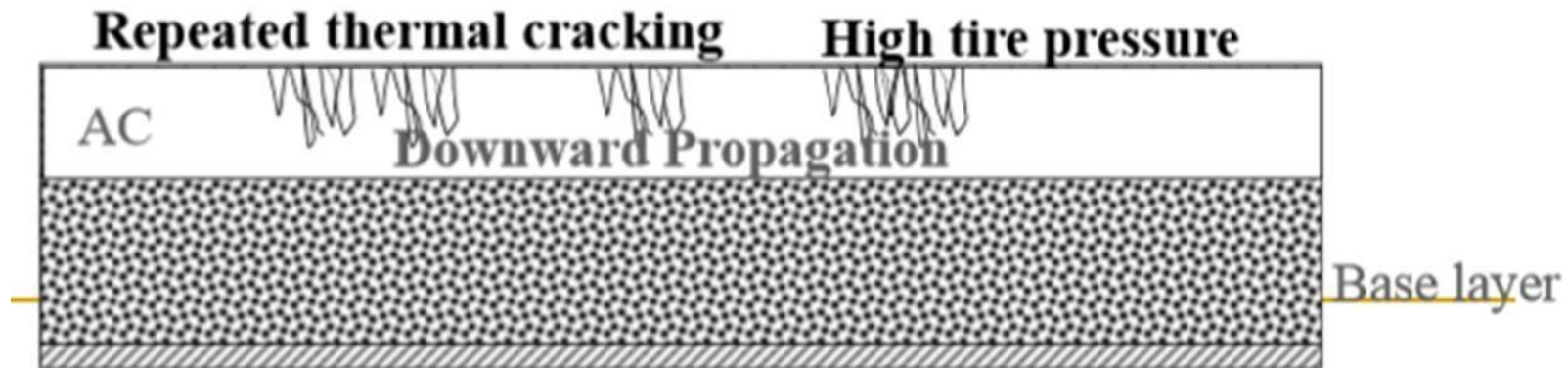


➤ Fatigue Mechanisms

■ Bottom-Up



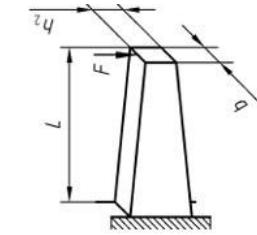
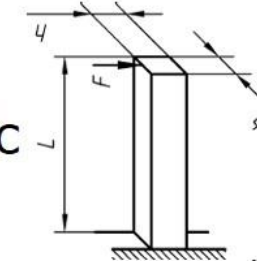
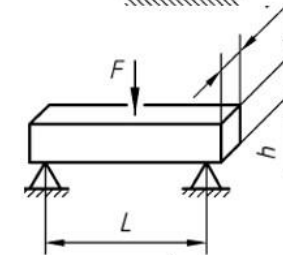
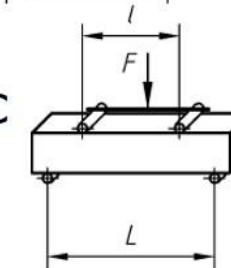
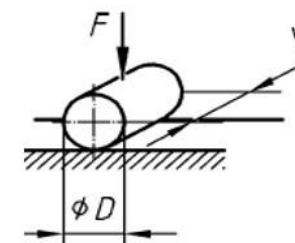
■ Top-Down





Fatigue testing: EN12697-24

- Annex A: Two point bending test on trapezoidal specimens
- Annex B: Two point bending test on prismatic specimens
- Annex C: Three point bending test on prismatic specimens
- Annex D: Four point bending test on prismatic specimens
- Annex E : Indirect tension test on cylindrical specimens (IT-CY)

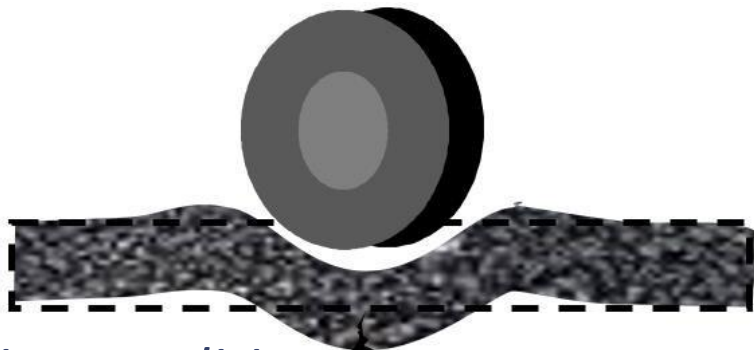




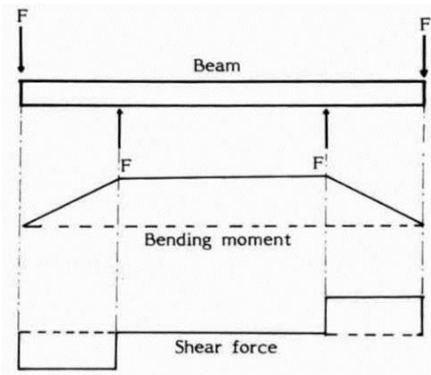
➤ H M A characterization tests

Fatigue Test: EN12697-24

- Four Point Bending Test : *Principle*
- During the test, the loading configuration create a **constant moment** in the form of a sine function. The **load** required to bend the specimen and the **deflection** are measured as a function of time. Using these measurements, the **fatigue characteristics** of the material tested shall be determined.

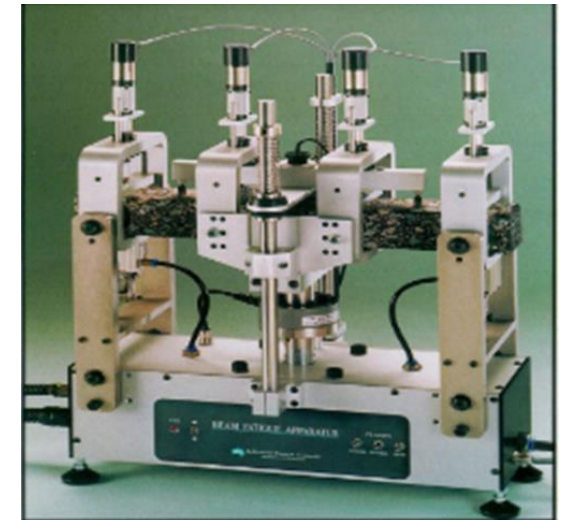


Testing condition



At each loading level, **2 specimens** shall be Tested

Temp: room temperature 20 °C , loading frequency 30Hz, 3 different strain Loading level(high,mid and low)





➤ H M A characterization tests: Fatigue Test: EN12697-24

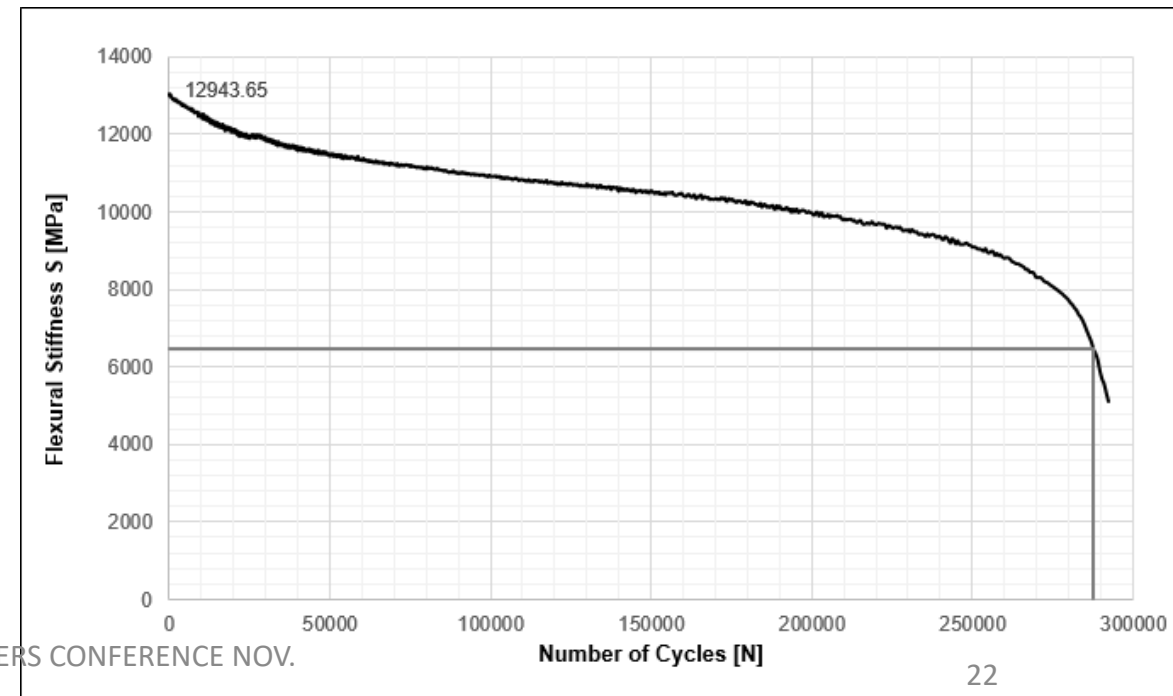
Four Point Bending Test

Result

The **failure point** is defined as the number of cycles where the **stiffness is half the initial value**. The number of failure cycles can be plotted as a function of applied tensile strain in a log-log scale. The fatigue parameters of asphalt can be derived as follows:

$$N_f = a \cdot \varepsilon^{-n}$$

- N_f = Indirect tensile strength
- ε = Applied tensile strain, [μm]
- a, n = Fatigue parameters



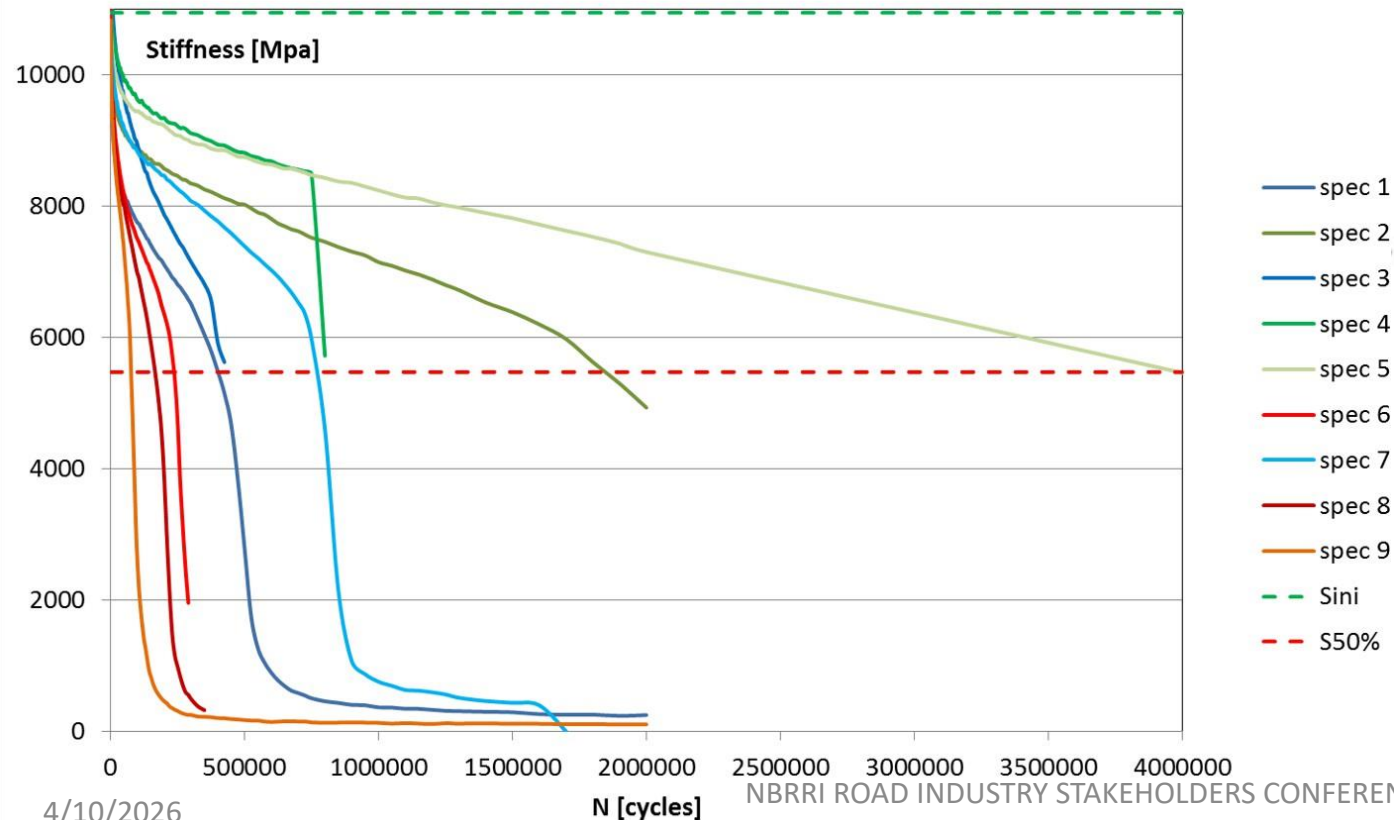
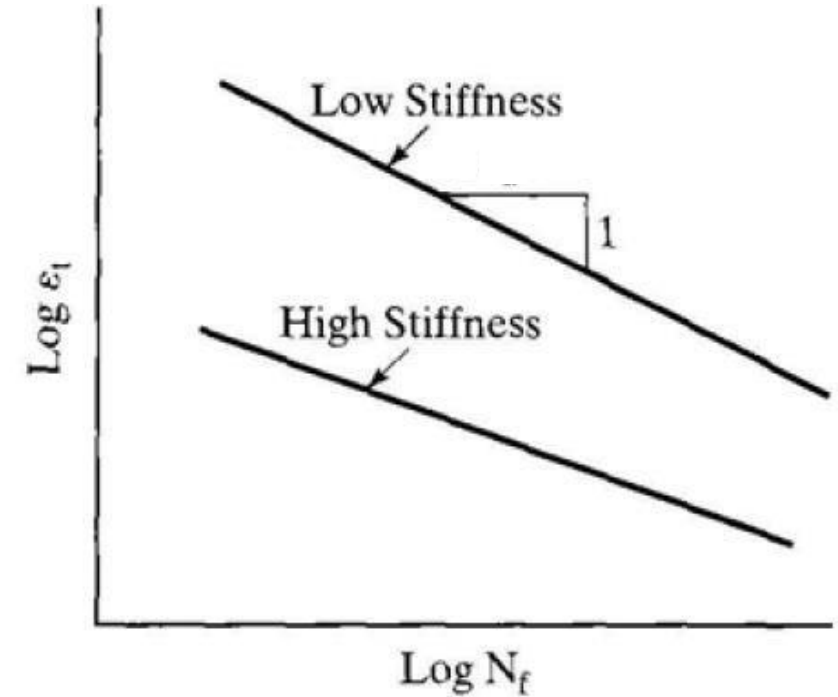


➤ H M A characterization tests

■ Fatigue Test: EN12697-24

Four Point Bending Test

Result $\log(N_f) = \log(a) - n \log(\epsilon)$





➤ H M A characterization tests

■ Other fatigue Models

Because f_2 is much greater than f_3 , the effect of ϵ_t on N_f is much greater than that of E_1 . Therefore, the E_1 term may be neglected:

$$N_f = f_1(\epsilon_t)^{-f_2}$$

Equation 11.8 has been used by several agencies:

Illinois Department of Transportation (Thompson, 1987)

$$N_f = 5 \times 10^{-6} (\epsilon_t)^{-3.0}$$

Transport and Road Research Laboratory (Powell *et al.*, 1984)

$$N_f = 1.66 \times 10^{-10} (\epsilon_t)^{-4.32}$$

Belgian Road Research Center (Verstraeten *et al.*, 1982)

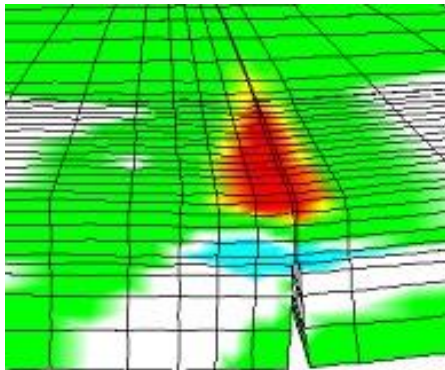
$$N_f = 4.92 \times 10^{-14} (\epsilon_t)^{-4.76}$$

Reference: Pavement Analysis and Design 2nd Edition. by Yang Huang



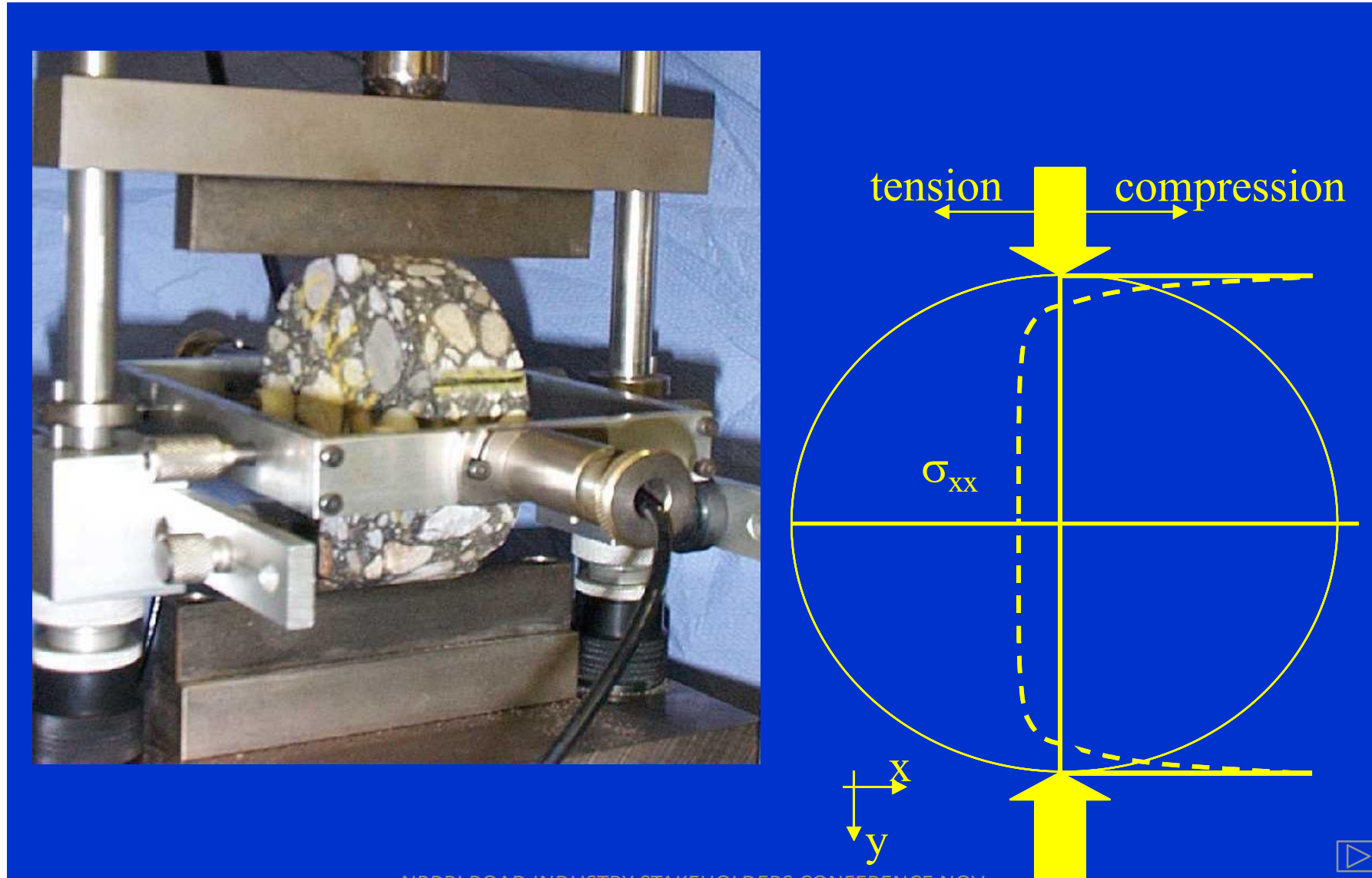
➤ Performance tests

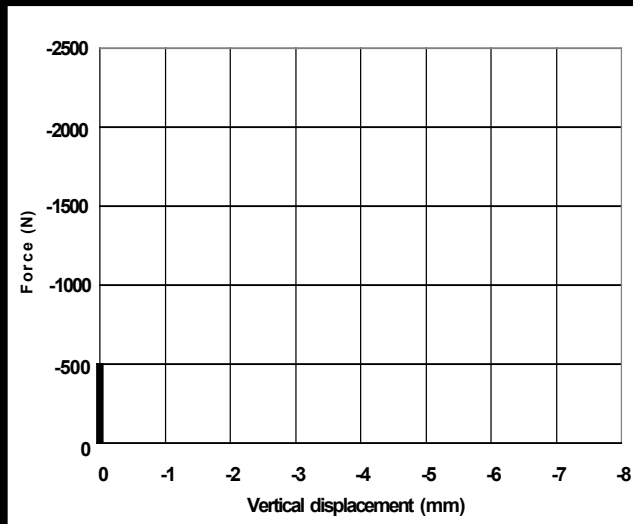
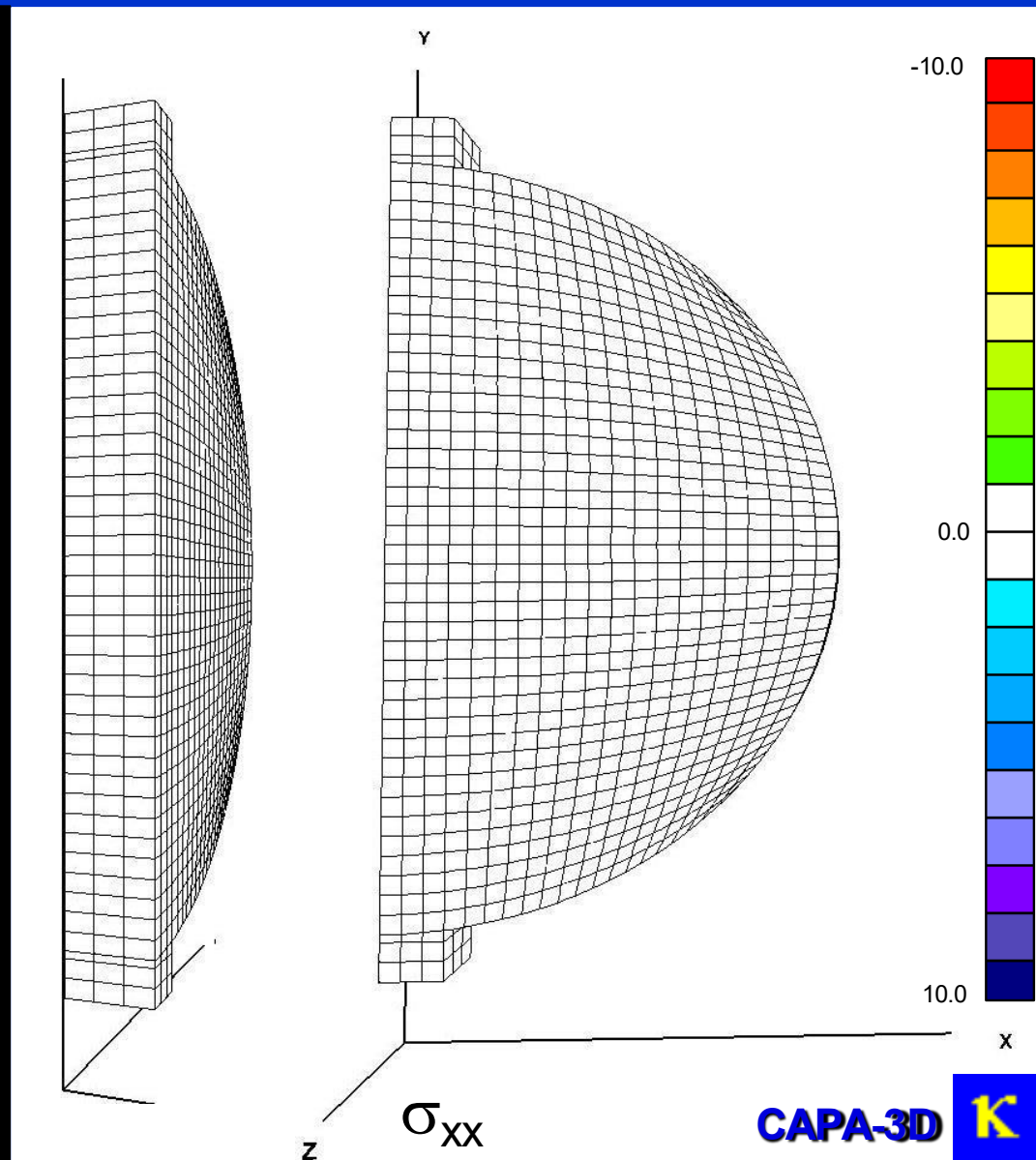
- Tensile strength
- The standard test method for the indirect tensile strength has proved to be a useful experimental method to evaluate the tensile strength of concrete and mortar. Because of its simplicity, the rapid rate of conducting the test, and the ease of assembling the apparatus, its use has been extended to other materials such as rocks, ceramics, and bituminous Materials
- EN12697-23, AASHTO T 322

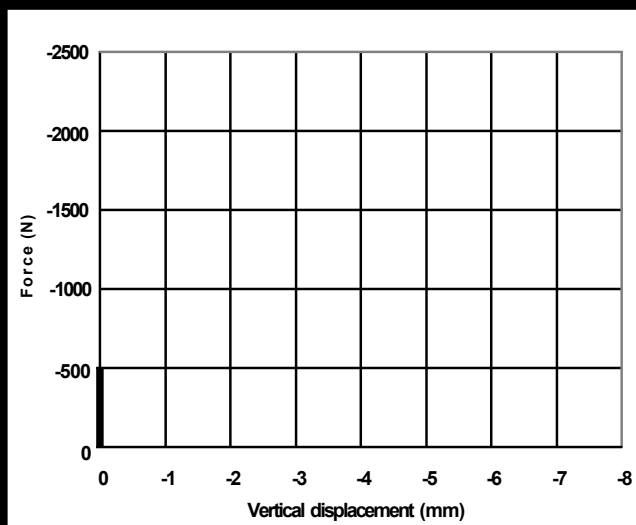
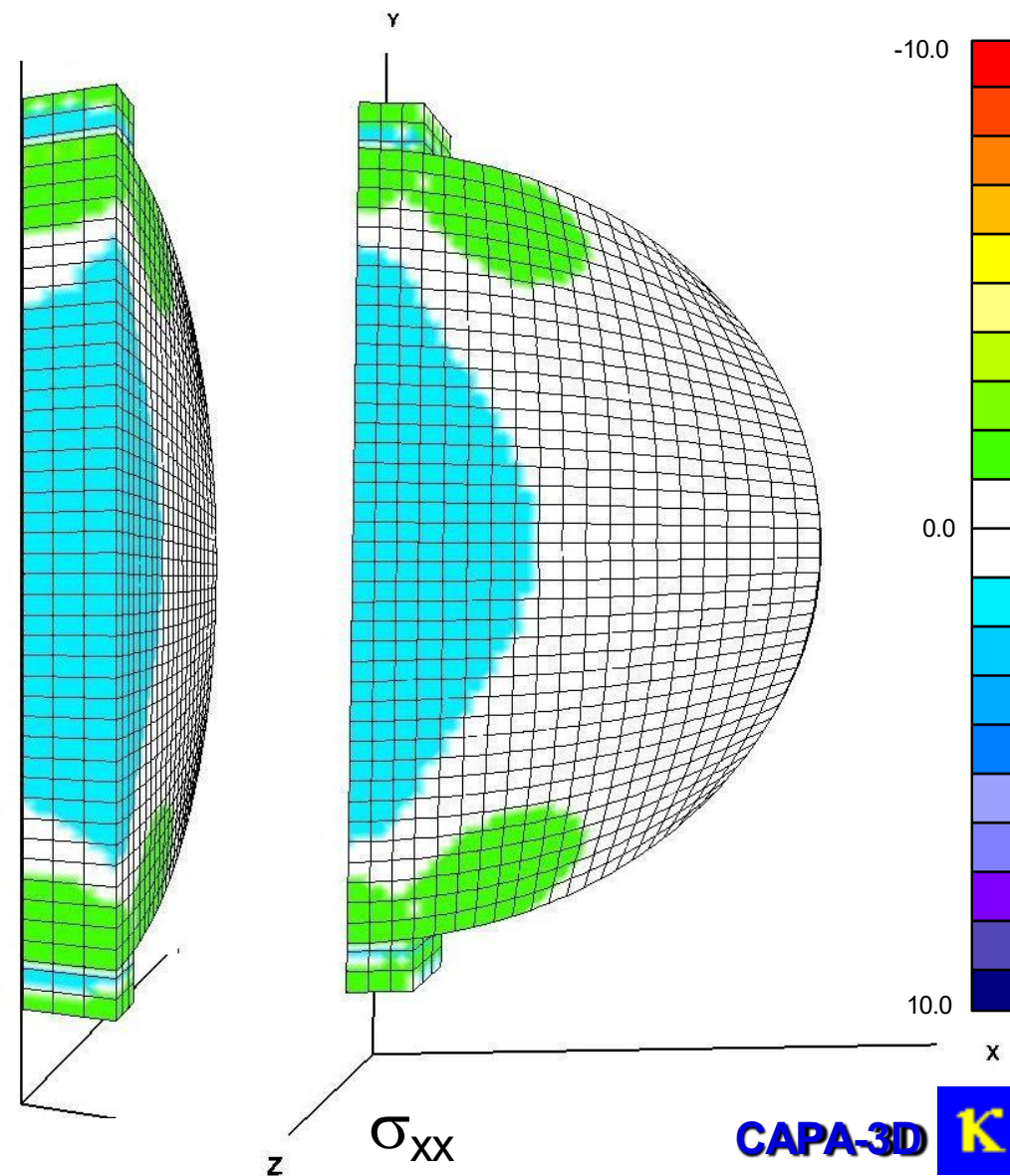


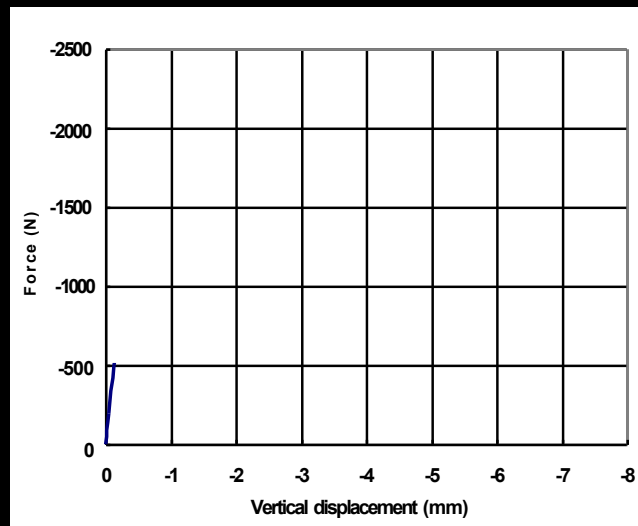
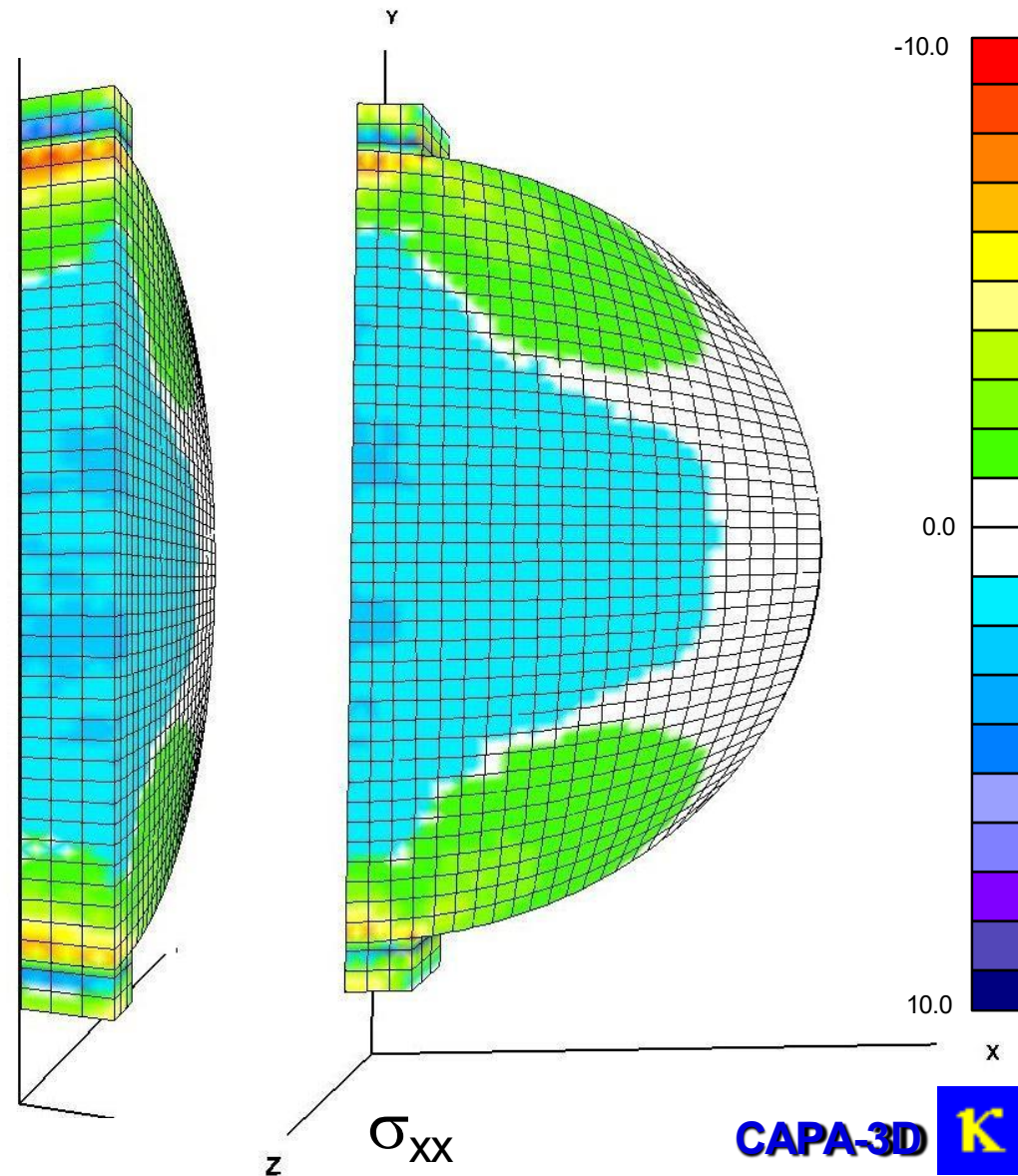


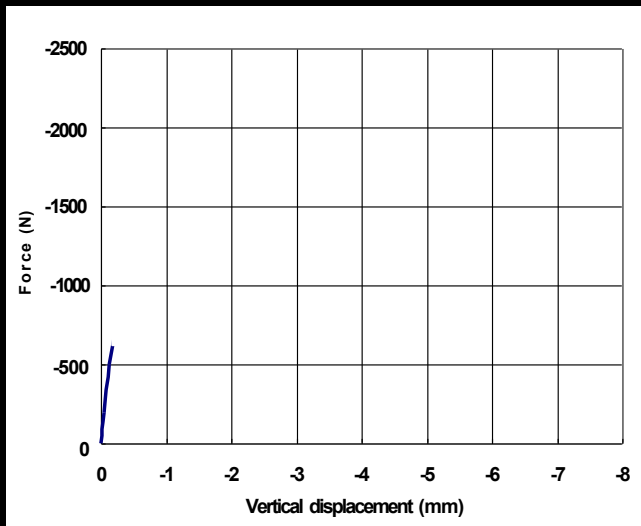
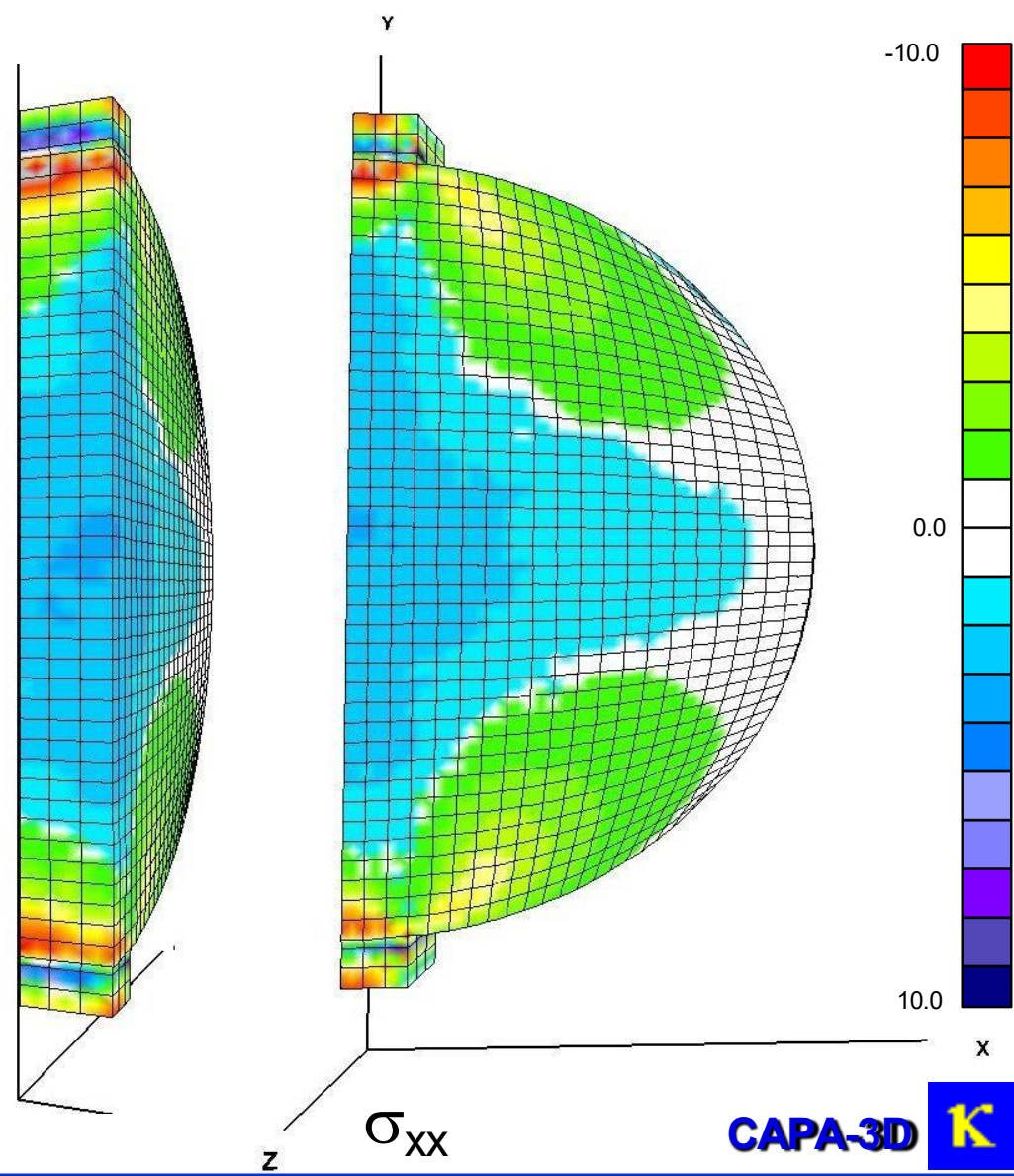
- material model verification

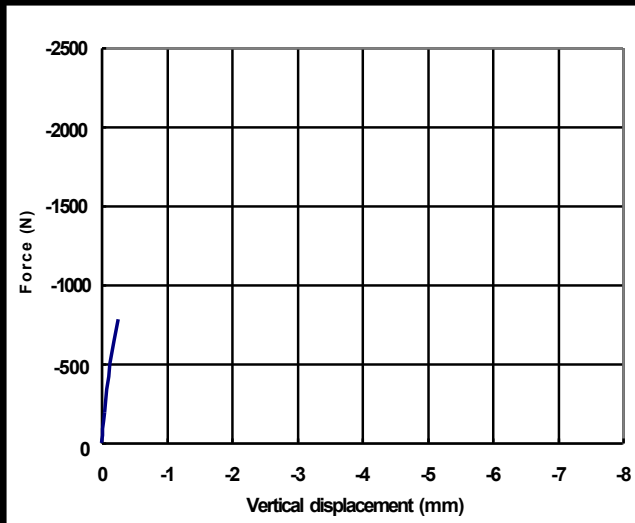
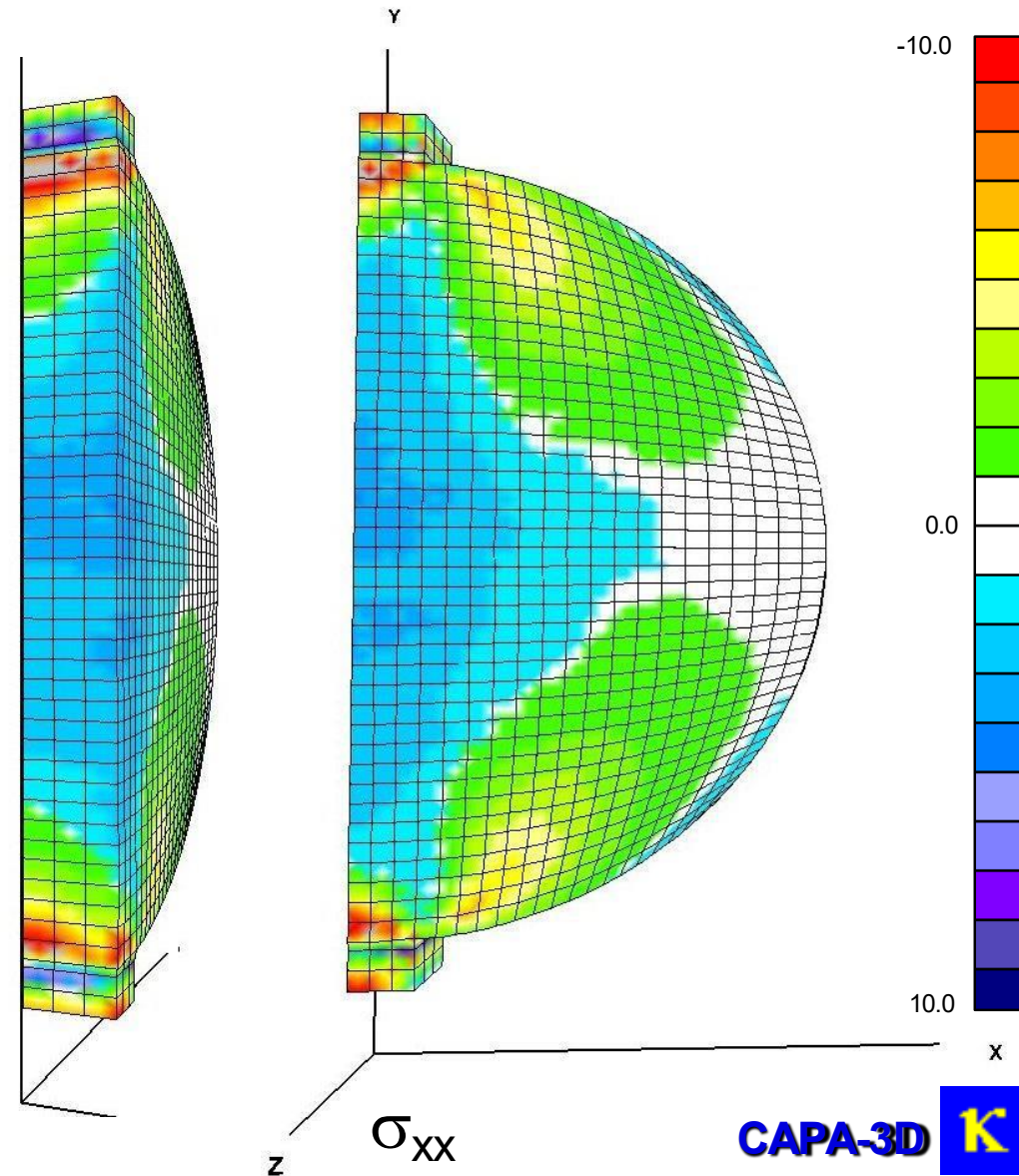


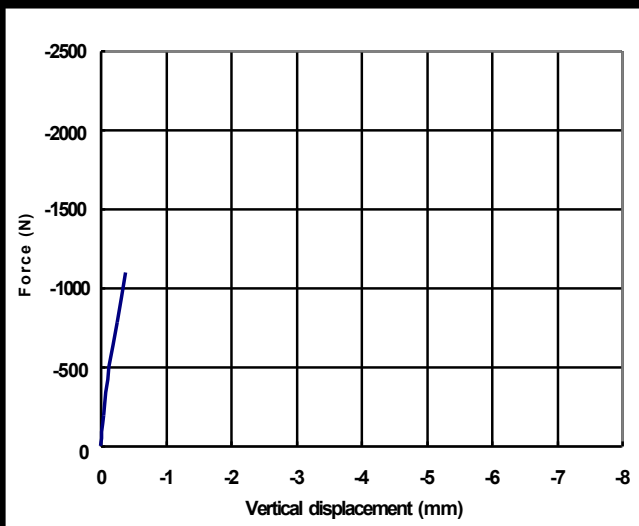
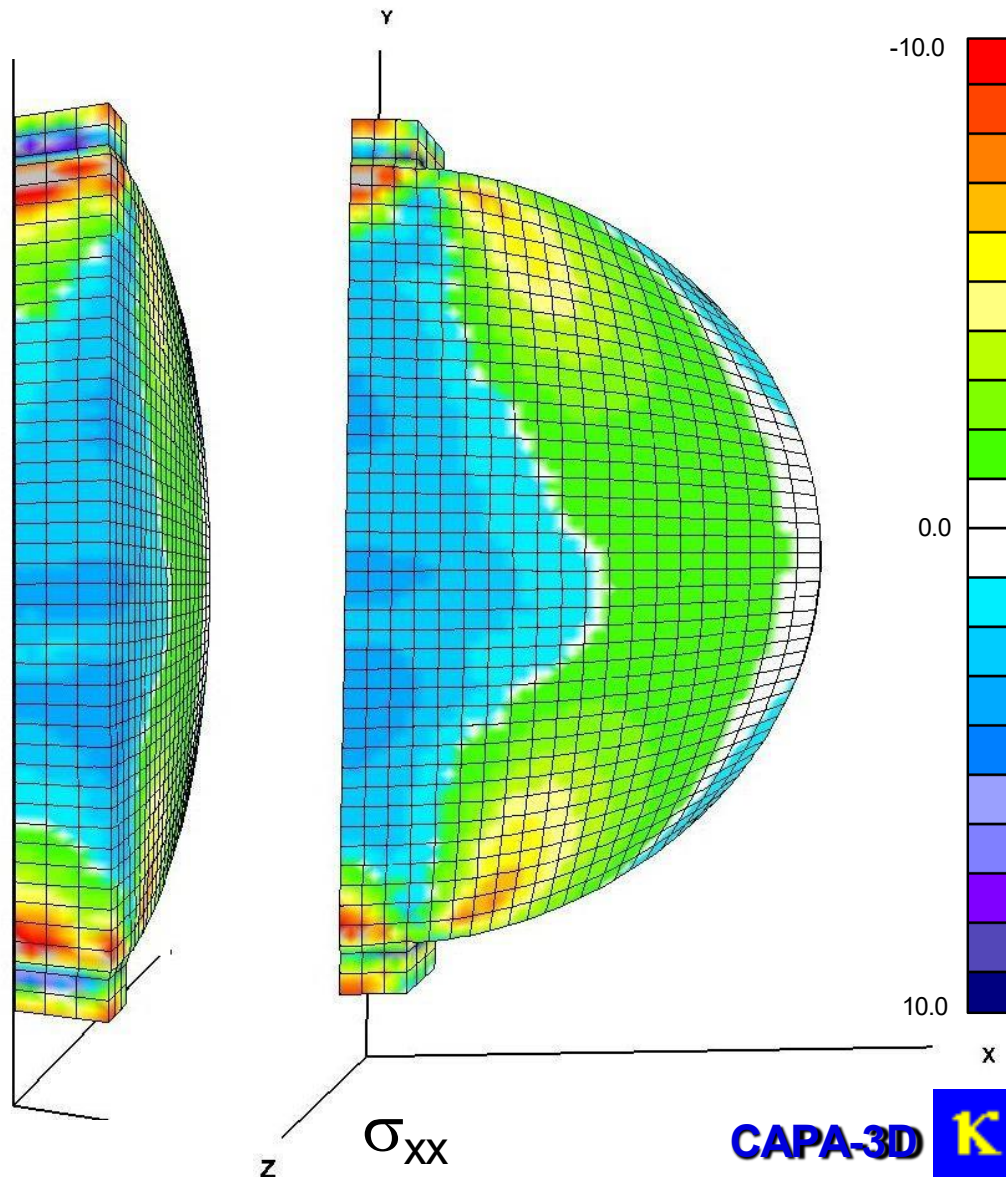


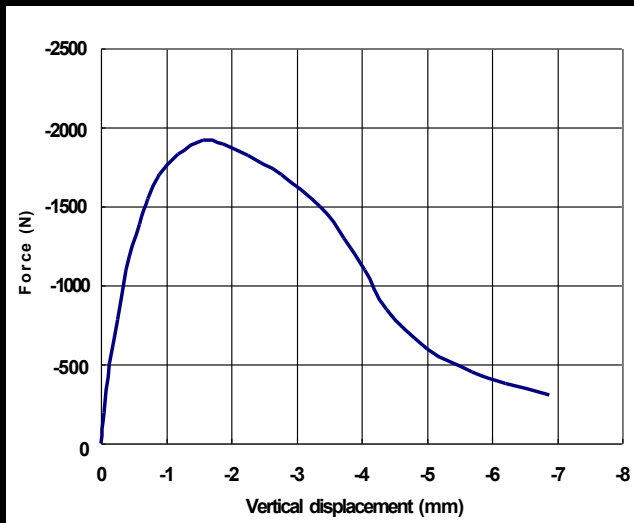
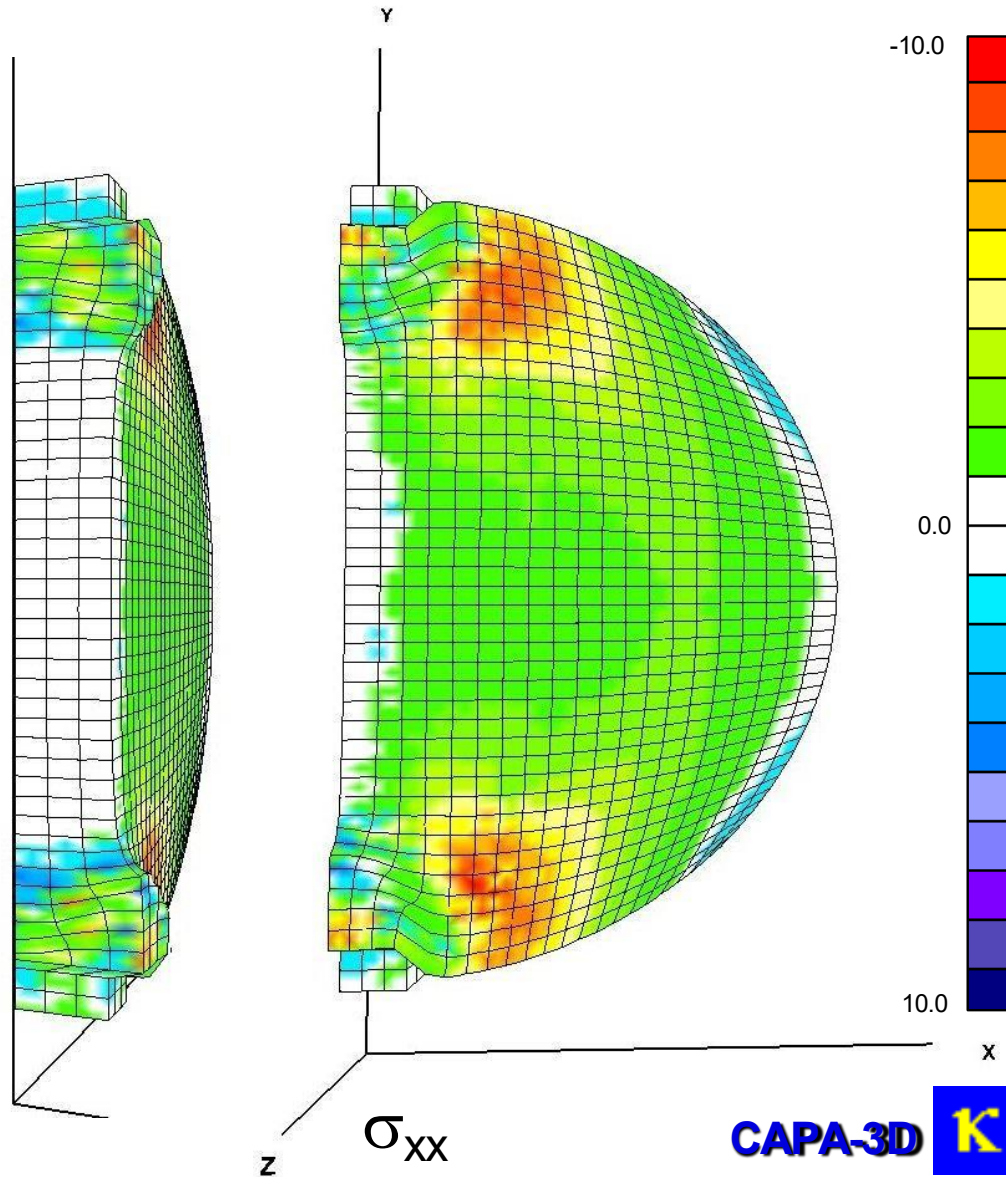






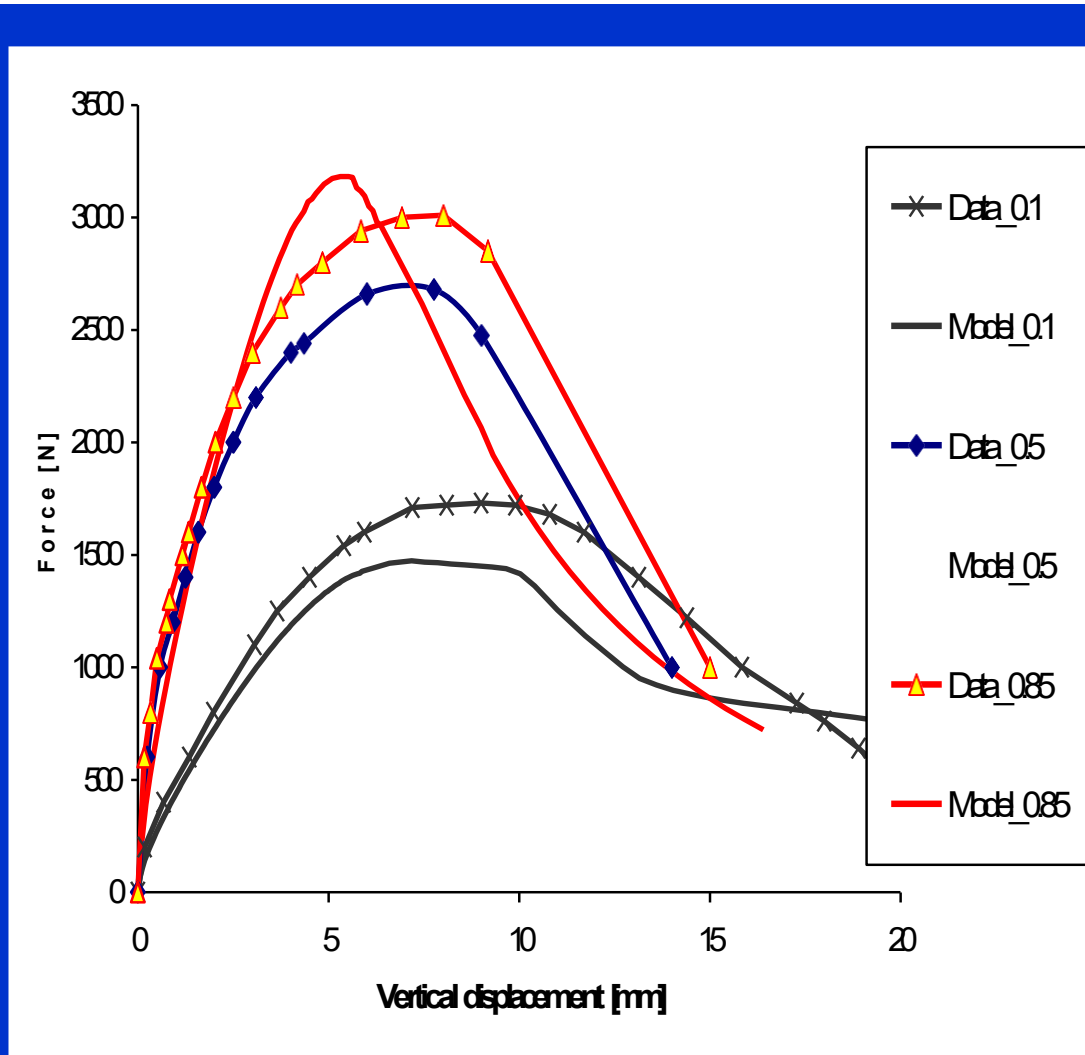
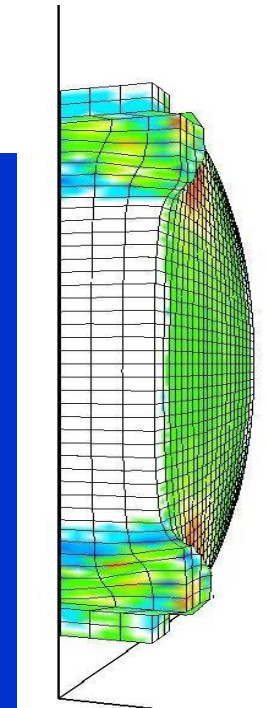
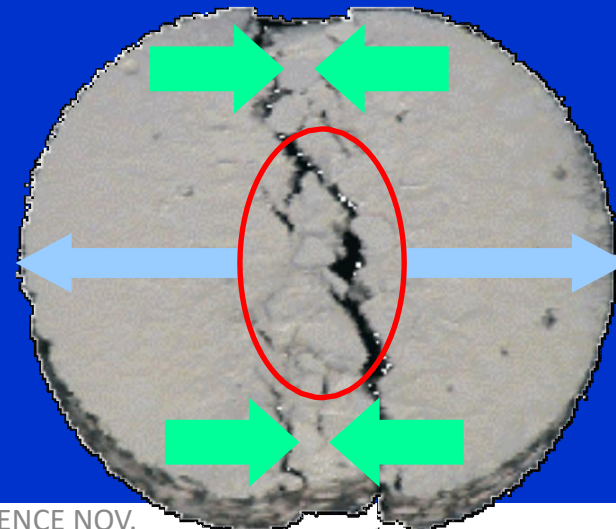








- ITT simulation



Types of failure

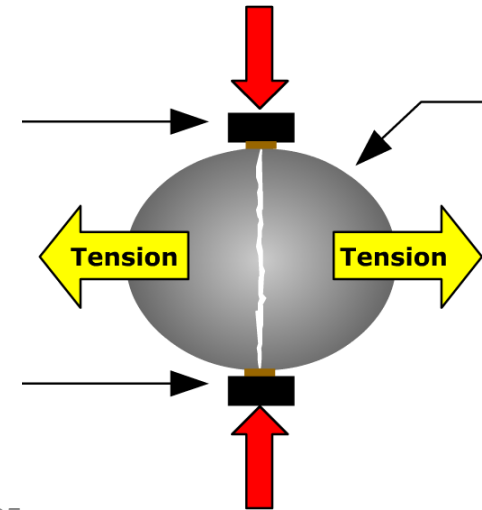
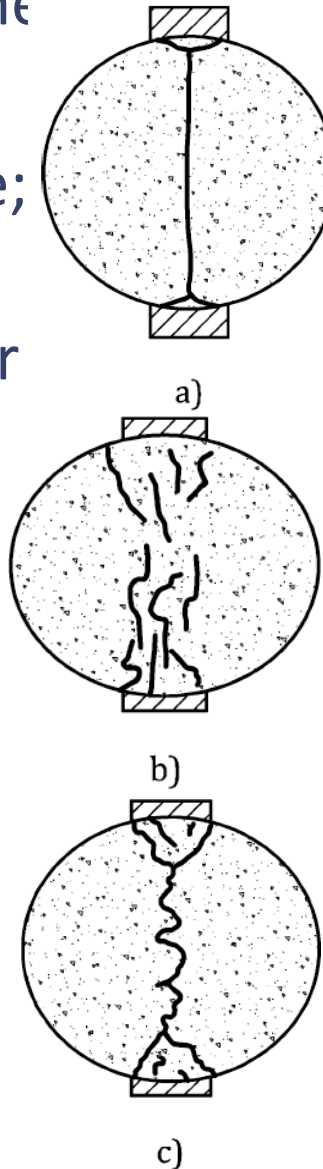
- a) “clear tensile break” – Specimen clearly broken along a diametrical line except perhaps for small triangular sections close to the loading strips;
- b) “deformation” – Specimens without a clearly visible tensile break line; or
- c) “combination” – Specimens with a limited tensile break line and larger deformed areas close to the loading strips

$$S_{t,n} = \frac{2 \times P_{f,n}}{\pi \times b_n \times D_n}$$

$P_{f,n}$ = maximum load observed for specimen, n ;
 $S_{t,n}$ = tensile strength of specimen, n .

b_n, D_n = thickness, diameter

✓ AASHTO T 322





➤ H M A characterization tests

- Water sensitive: EN 12697-12
- *Sample preparation*
 - At least **six cylindrical specimens** shall be prepared for each sample to be tested. All specimens shall be of the same age (prepared the same day).

Result

$$ITSR = \frac{ITS_w}{ITS_d} \times 100\%$$

- $ITSR$ = Indirect tensile strength ratio, [%]
- ITS_w = Average indirect tensile strength of wet group, [Kpa]
- ITS_d = Average indirect tensile strength of dry group, [Kpa]

Maximum grain size mm	Specimen diameter mm	Specimen height mm
<11	80 ± 2	35-75
<22	100 ± 3	
<31.5	120 ± 3	
<40	150 ± 3	



➤ H M A characterization tests

- Water sensitive: EN12697-12

Report

- Identification number and type of specimens;
- Average diameter and height of specimens;
- Test temperature;
- Average indirect tensile strength of each group (Dry and wet);
- indirect tensile strength ratio, ITSR in percent (%);
- Type of failure and observations of broken or crushed aggregate;
- Type of failure and observations of broken or crushed aggregate;

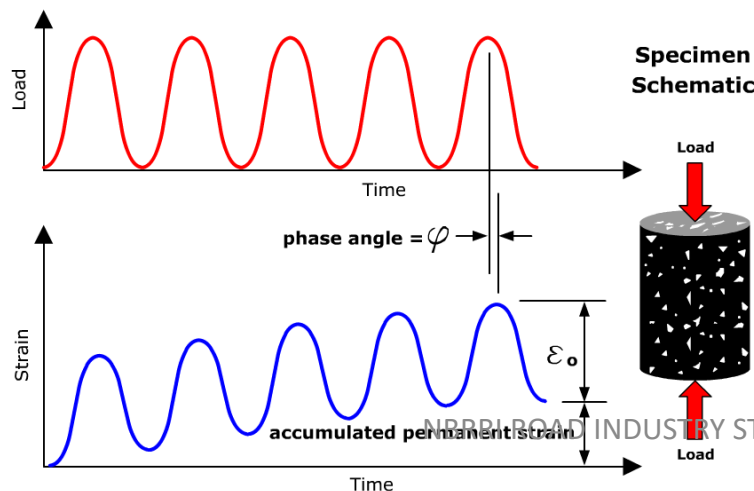


➤ H M A characterization tests

■ Permanent deformation test: EN12697-25

Principle

- This test method determines the **resistance to permanent deformation** of a **cylindrical test specimen** of bituminous **mixture by repeated load**.
- During the test, the **change in height** of the test specimen is measured at specified numbers of loading cycles. From this, the **cumulative axial strain** of the test specimen is determined as a function of the number of loading cycles.



$$\frac{\epsilon_p}{\epsilon_r} = a_1 T^{a_2} N^{a_3}$$





Wheel track testing

❑ Sample Preparation

- Sample is prepared after producing asphalt mixture of known maximum theoretical density
- The mixture is compacted using gyratory compactor and resize to a height of 60mm and 150mm diameter
- Place the samples in the sample mould for testing



Placing of resized sample in testing mould

The rut depth is typically measured after a set number of wheel tracking cycles. The rut depth represents the amount of permanent deformation or rutting that occurs in the asphalt mixture.

The rut depth (R) after a certain number of wheel passes can be calculated by:

$$R = \frac{\Delta h}{h_0}$$

R = Rut depth (mm)

Δh = Change in height of the specimen (mm), which is the difference in the initial height and the height after the desired number of cycles

h_0 = Initial height (before testing) of the specimen (mm)

