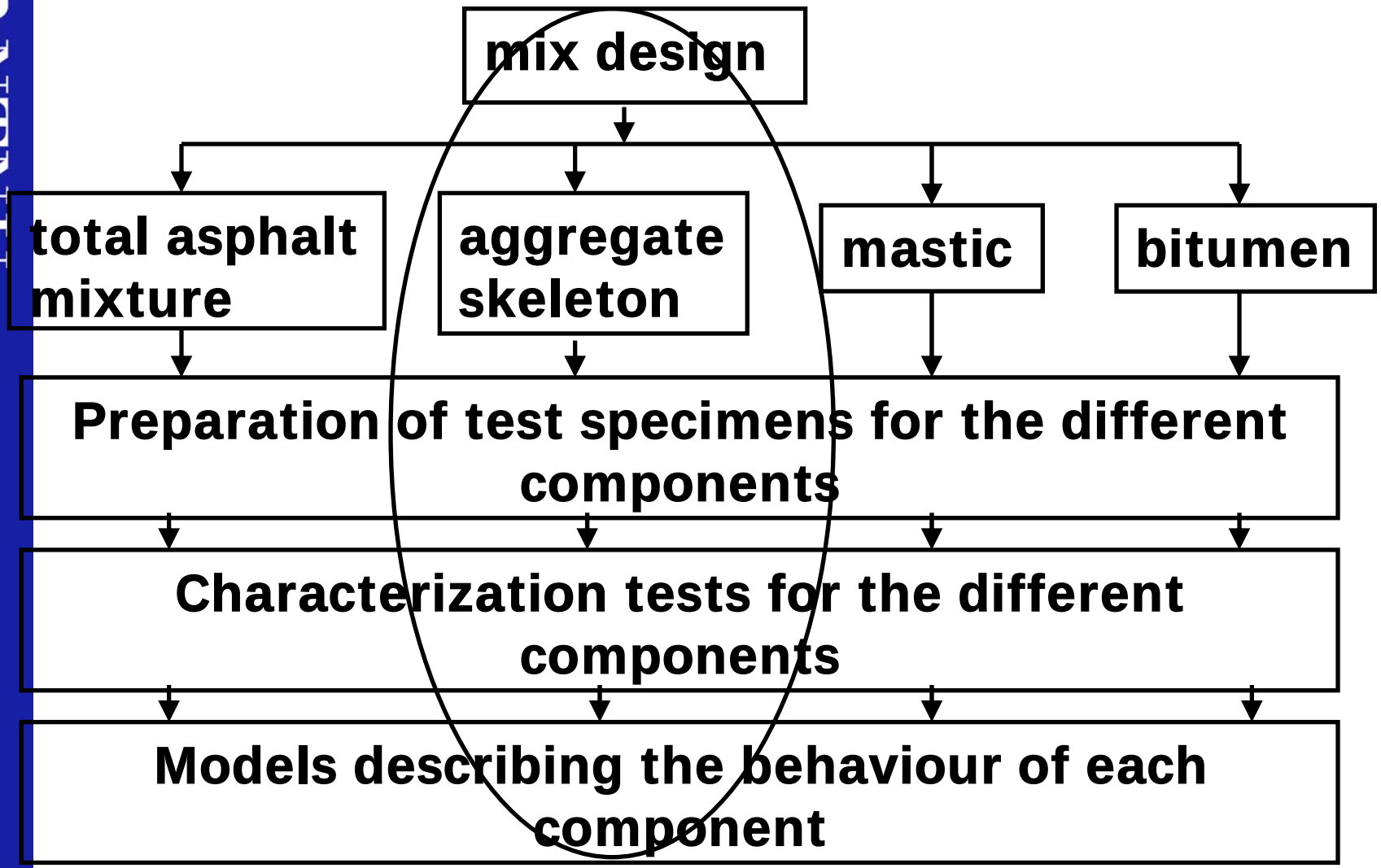
Permanent Deformation of Aggregate Skeleton in Asphalt Mixes

Contents

Aim

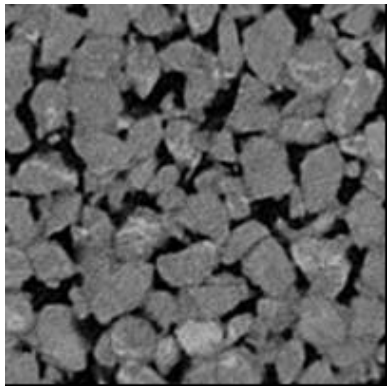
To characterize the aggregate component in asphalt mixtures

Overview

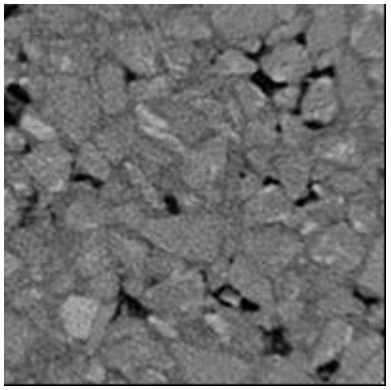

mix design
total asphalt mixture
aggregate skeleton
mastic
bitumen
Preparation of test specimens for the different components
Characterization tests for the different components
Models describing the behaviour of each component

Mix Design

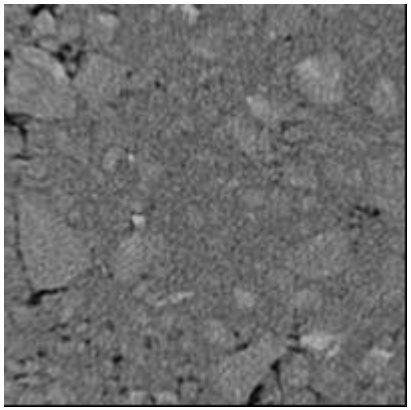
Selected mixes



PAC 0/16



SMA 0/11



DAC 0/16

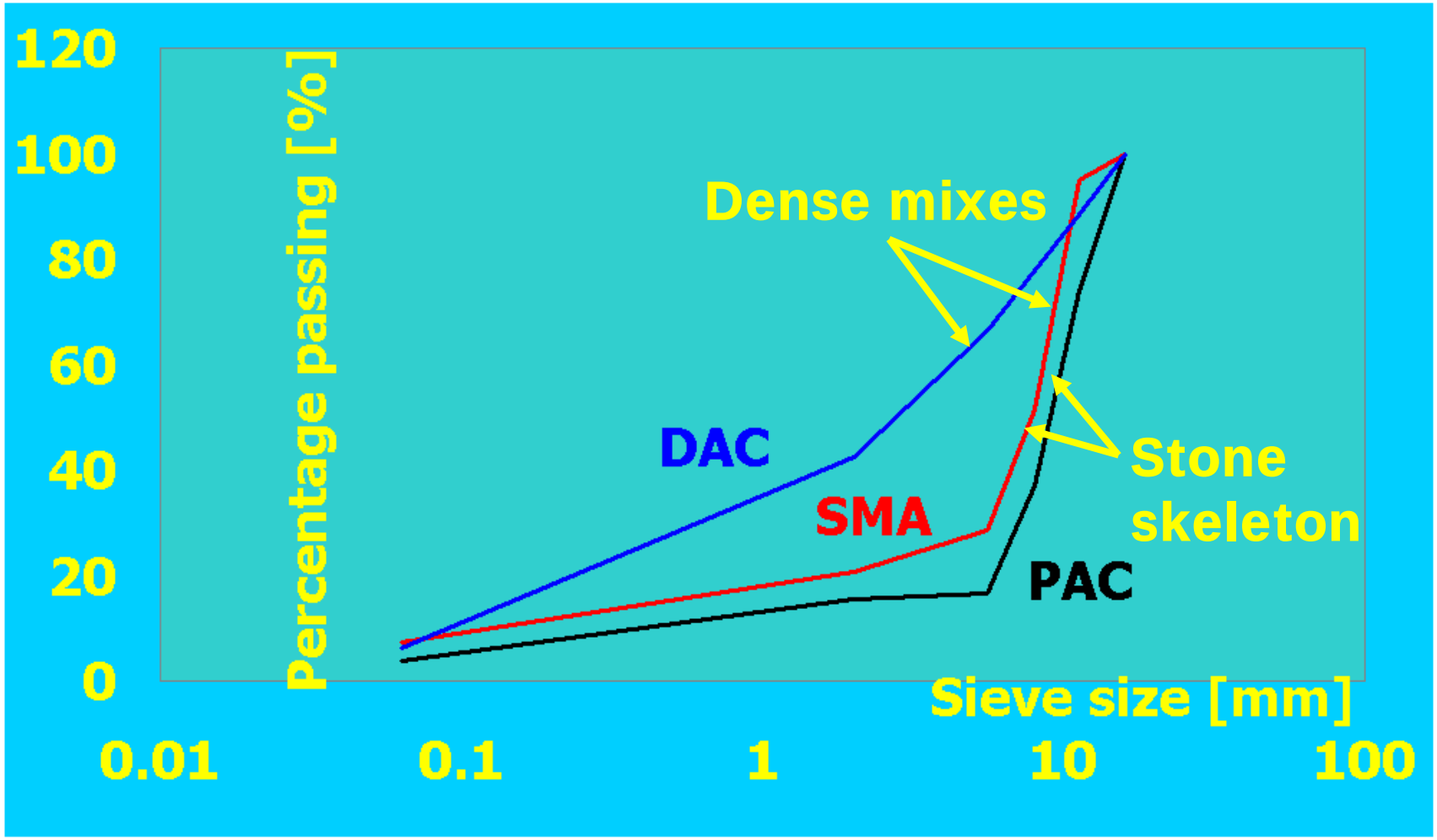
Marshall mix design

Complete Marshall mix design – DAC

Volumetric mix design – PAC, SMA

2 x 50 4.54 kg blows, falling height 0.457 m

Mix Gradation



Aggregate Skeleton Specimen Preparation

- Aggregate skeleton specimens composed of aggregate fractions only.
- Minimum aggregate fraction determined by means of visual observation during mixing and compaction.
- Density of aggregate skeleton determined based on the cumulative aggregate fraction content in the skeleton and mix design density.

$$\text{agg density} = \frac{\text{cum agg \% > min size}}{100} \text{ x mix design density}$$

Aggregate Skeleton Specimen Preparation

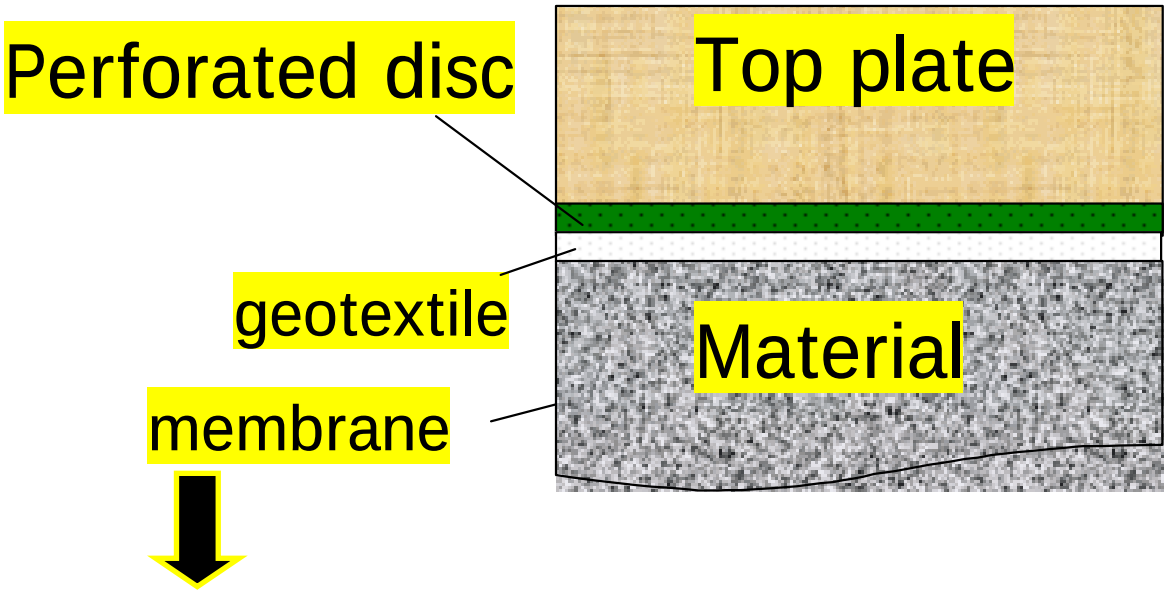
- Min size = 0.5 mm (PAC), 2 mm (SMA), 0.063 mm (DAC)
- 0.7 % water by weight added to PAC and DAC aggregate specimens to facilitate uniform mixing.
- No water added to SMA.
- Aggregates mixed by hand.

Aggregate Skeleton Specimen preparation

- Failure tests specimens compacted in 3 layers
- Permanent deformation tests specimens compacted in 5 layers

Compaction - Kango hammer and vacuum system

Aggregate Skeleton Specimen preparation



External membrane composed of 3 latex membranes and an optional geotextile at high confinement (150 & 250 kPa) permanent deformation tests

Aggregate Skeleton Specimen preparation

Instrumentation

- Specimen instrumented in the middle third
- Axial and radial deformation measured

Tests Performed During the Characterization of Aggregate Skeleton

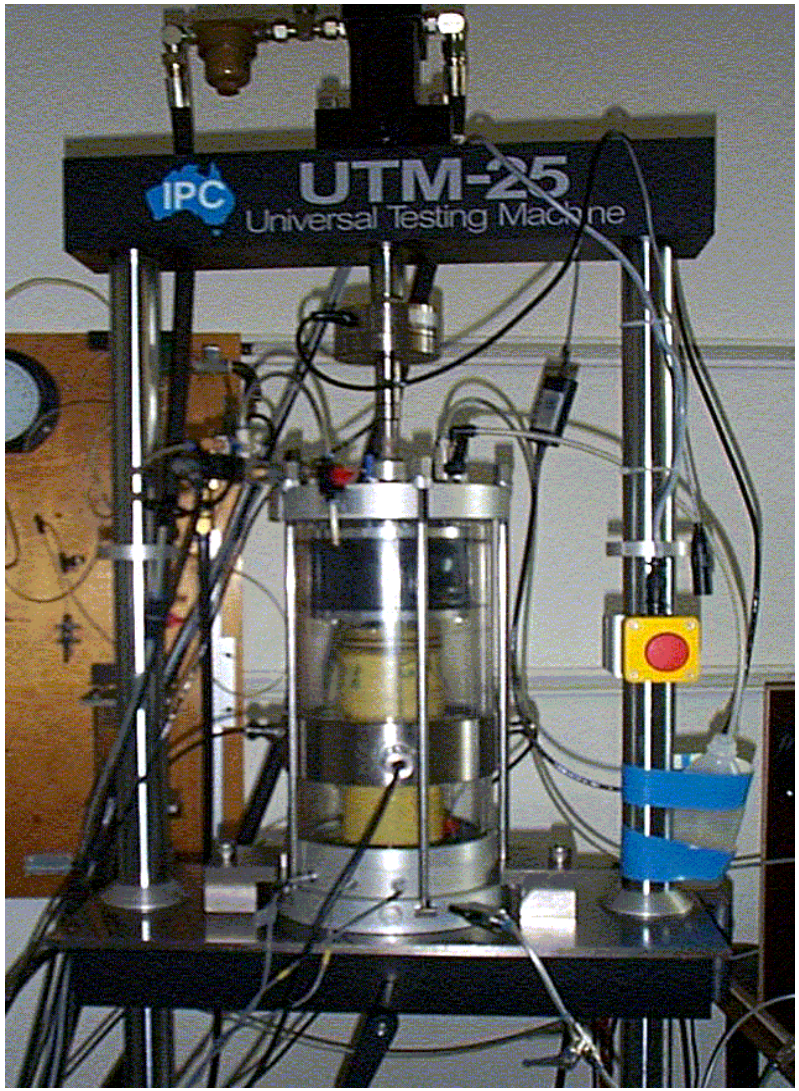
Failure Tests and Permanent Deformation Tests

- **Failure tests - strain controlled constant displacement tests performed under constant confinement**
- **Permanent deformation tests:**

1. **Cyclic vertical stress signal + cyclic confining stress**
2. **Cyclic vertical stress signal + constant confining stress**

Testing equipment

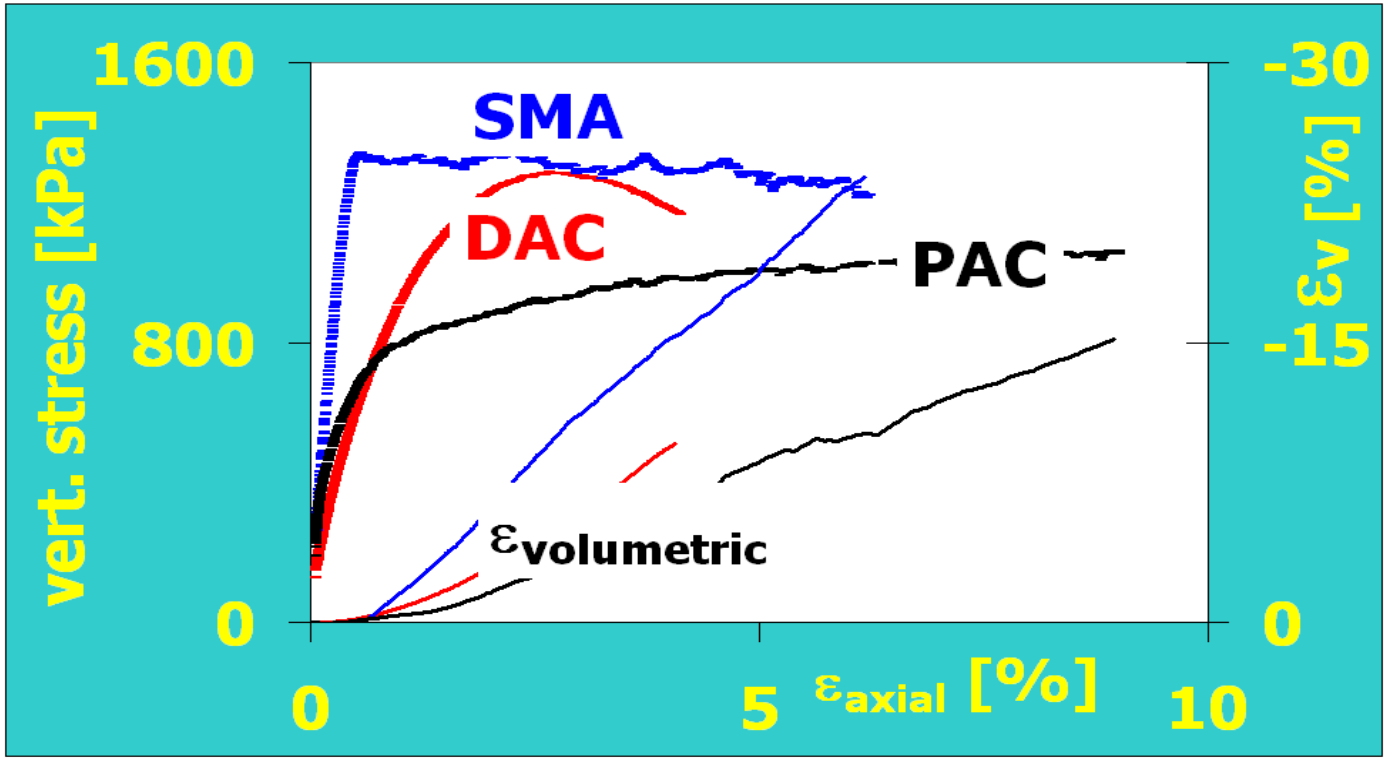
IPC UTM 25



Strain Controlled Monotonic Failure Test Conditions

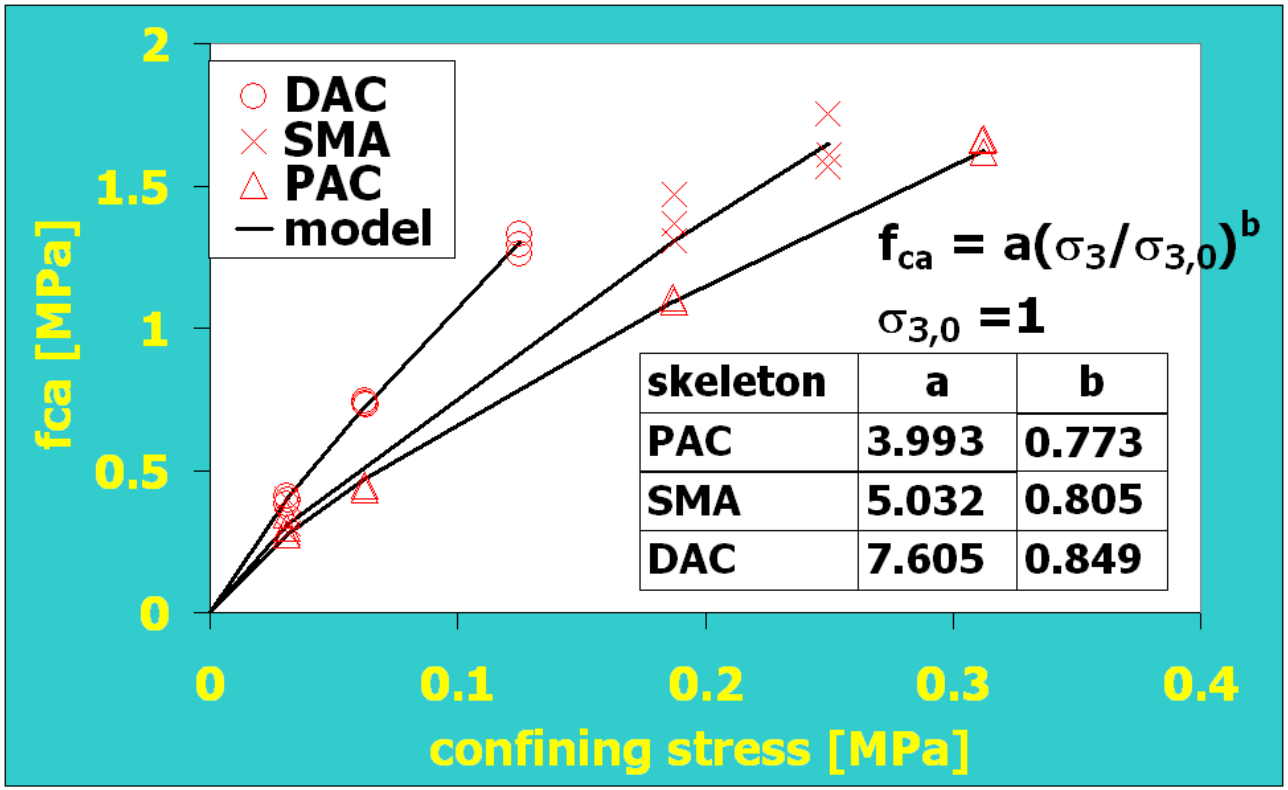
confinement [kPa]		31	63	125	188	250	313
strain rate [% /sec]	0.02	PAC, SMA & DAC	PAC & DAC	DAC	PAC & SMA	SMA	PAC
	0.2	PAC	PAC	-	-	-	-

Failure Test Results



- PAC and SMA aggregate skeletons retain considerable post-peak stability even at high strains
- Dilation is the main mode of deformation

Monotonic failure test results



skeleton	a	b
PAC	3.993	0.773
SMA	5.032	0.805
DAC	7.605	0.849

failure stress: DAC > SMA > PAC

Pavement Stresses Analysis

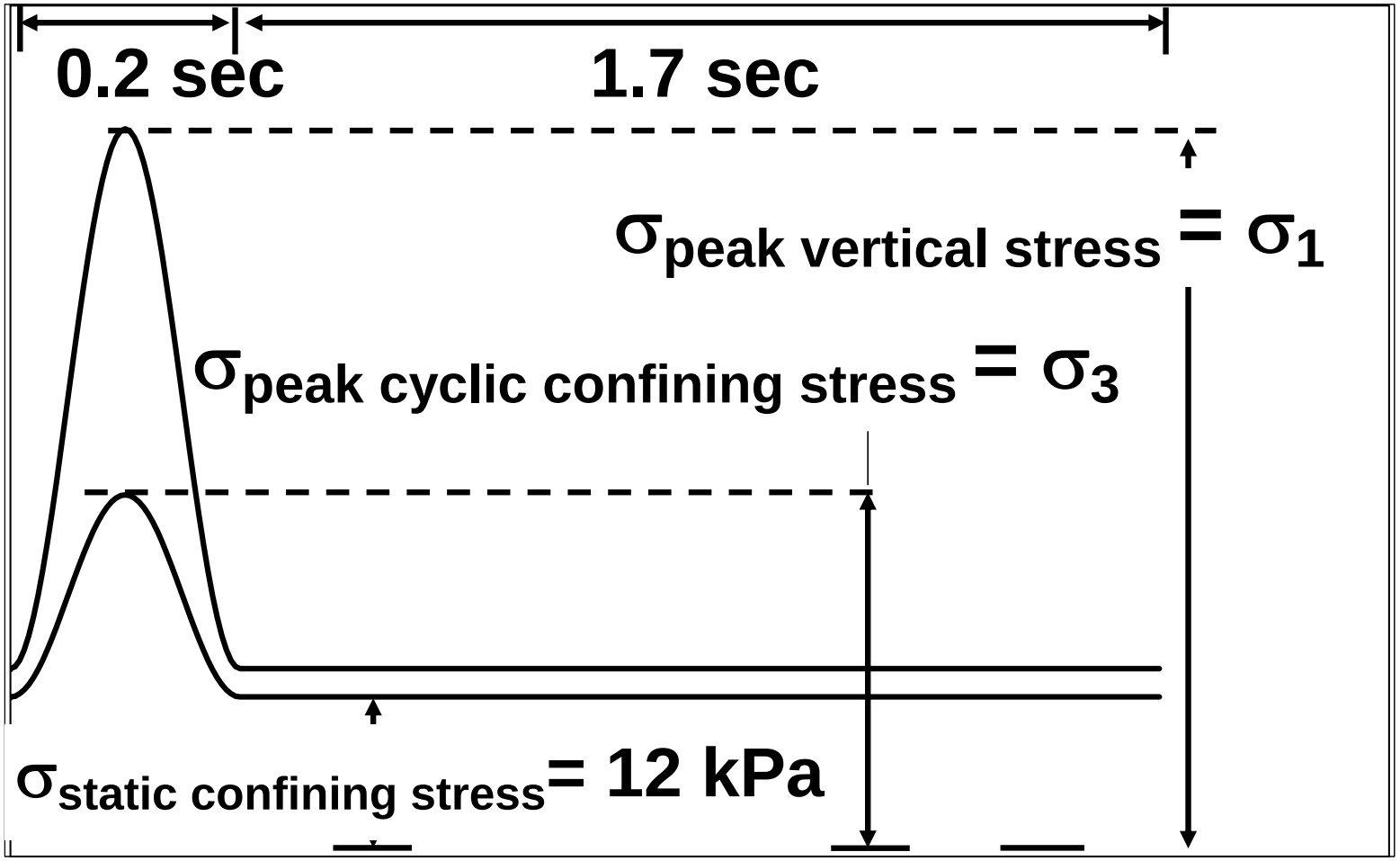
- **Triaxial vertical and triaxial confinement in the pavement are cyclic in nature**
- **cyclic vertical stress + cyclic confinement would provide a better simulation of the triaxial stresses in the pavement**

Consequently:

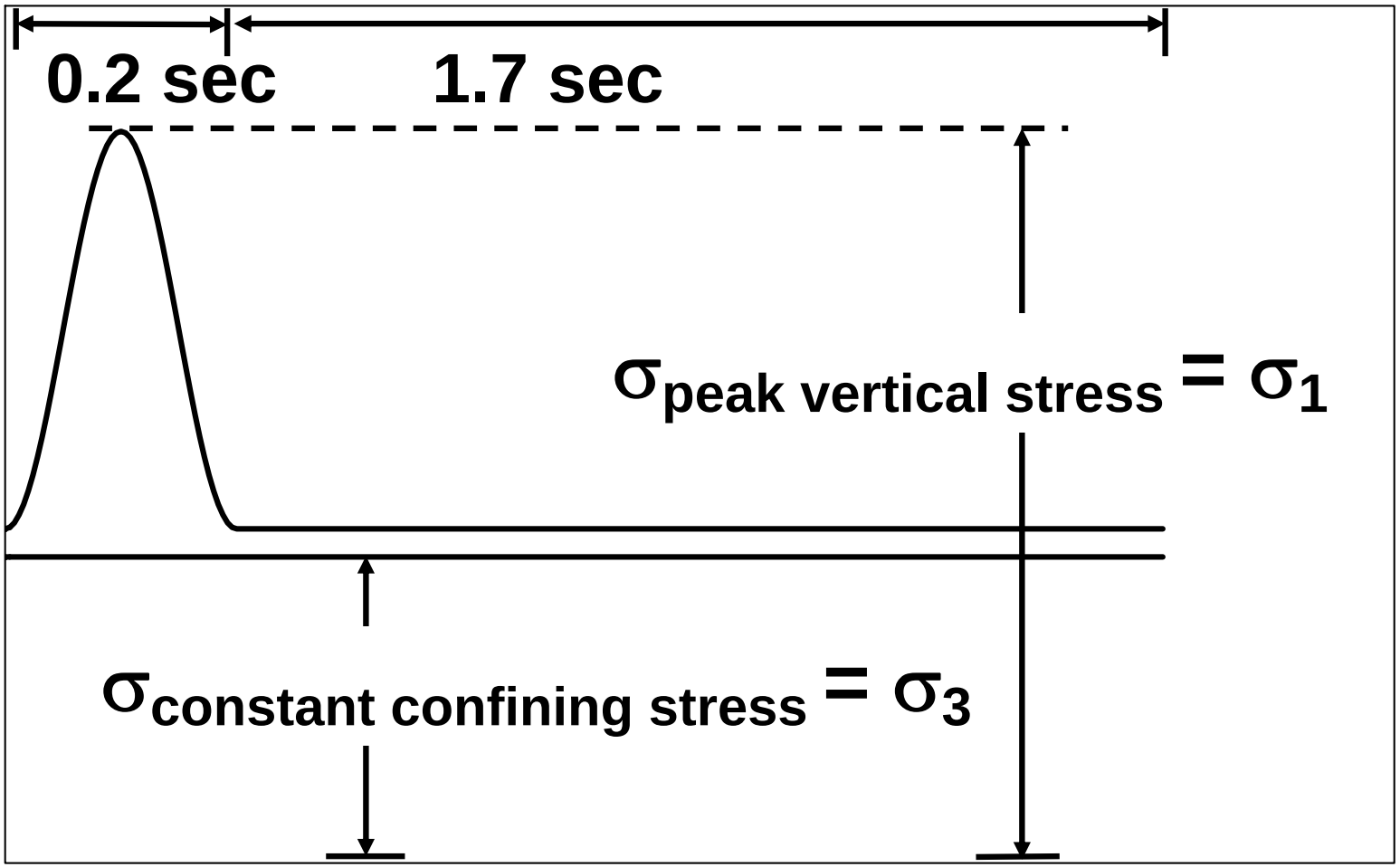
Pilot permanent deformation tests were performed on PAC and DAC to investigate the effect of cyclic confinement

1. **cyclic vertical stress + cyclic confinement**
2. **cyclic vertical stress + constant confinement**

Cyclic vertical stress + cyclic confinement



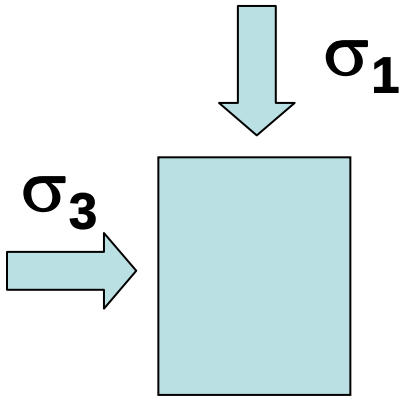
Cyclic vertical stress + constant confinement



Perm deform. test conditions – stress ratio

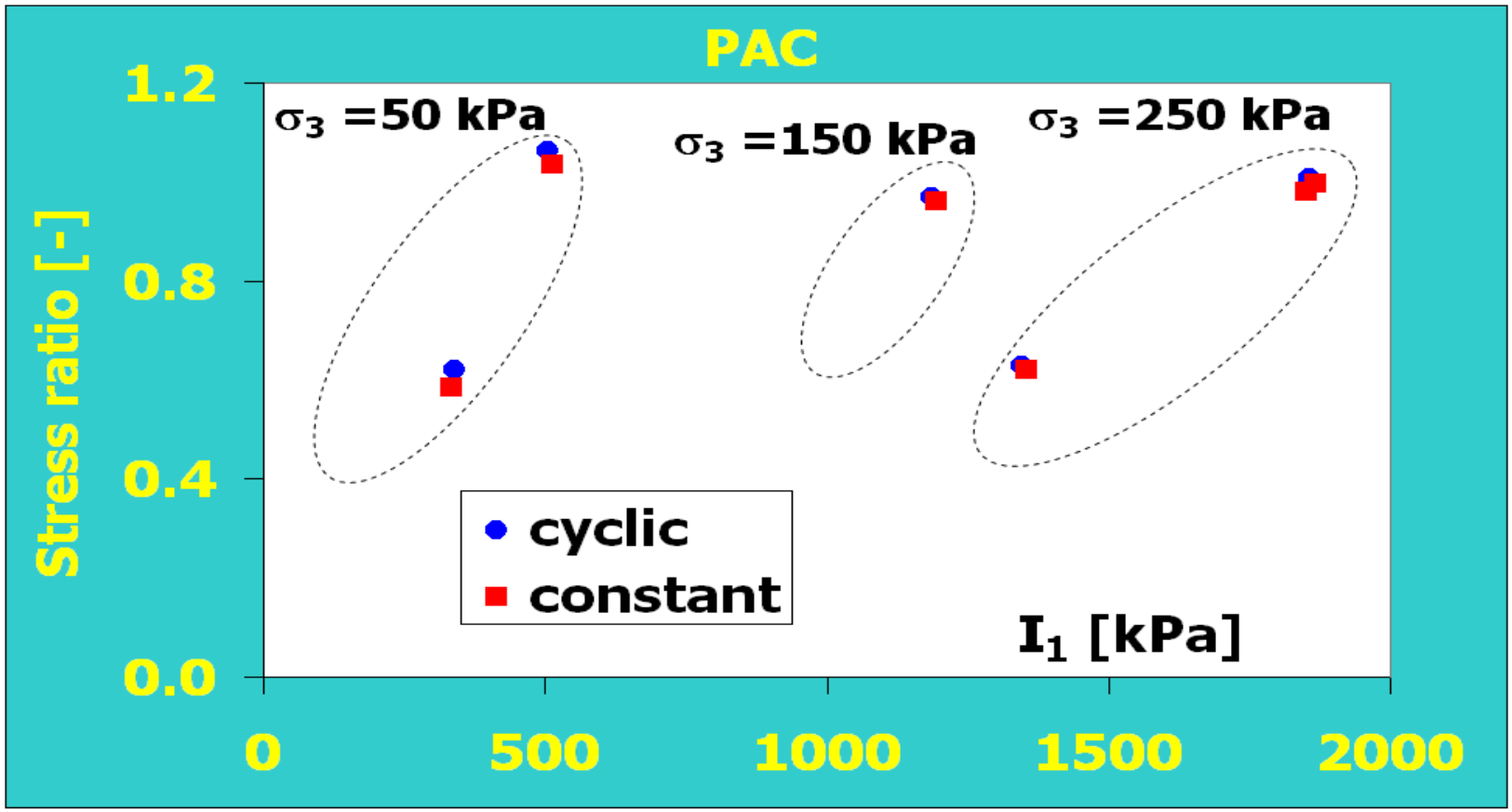
N_{max} = 20 000

$$\text{stress ratio} = \sigma_1 / f_{ca} = \frac{\sigma_1}{a\left(\frac{\sigma_3}{\sigma_{3,0}}\right)^b}$$

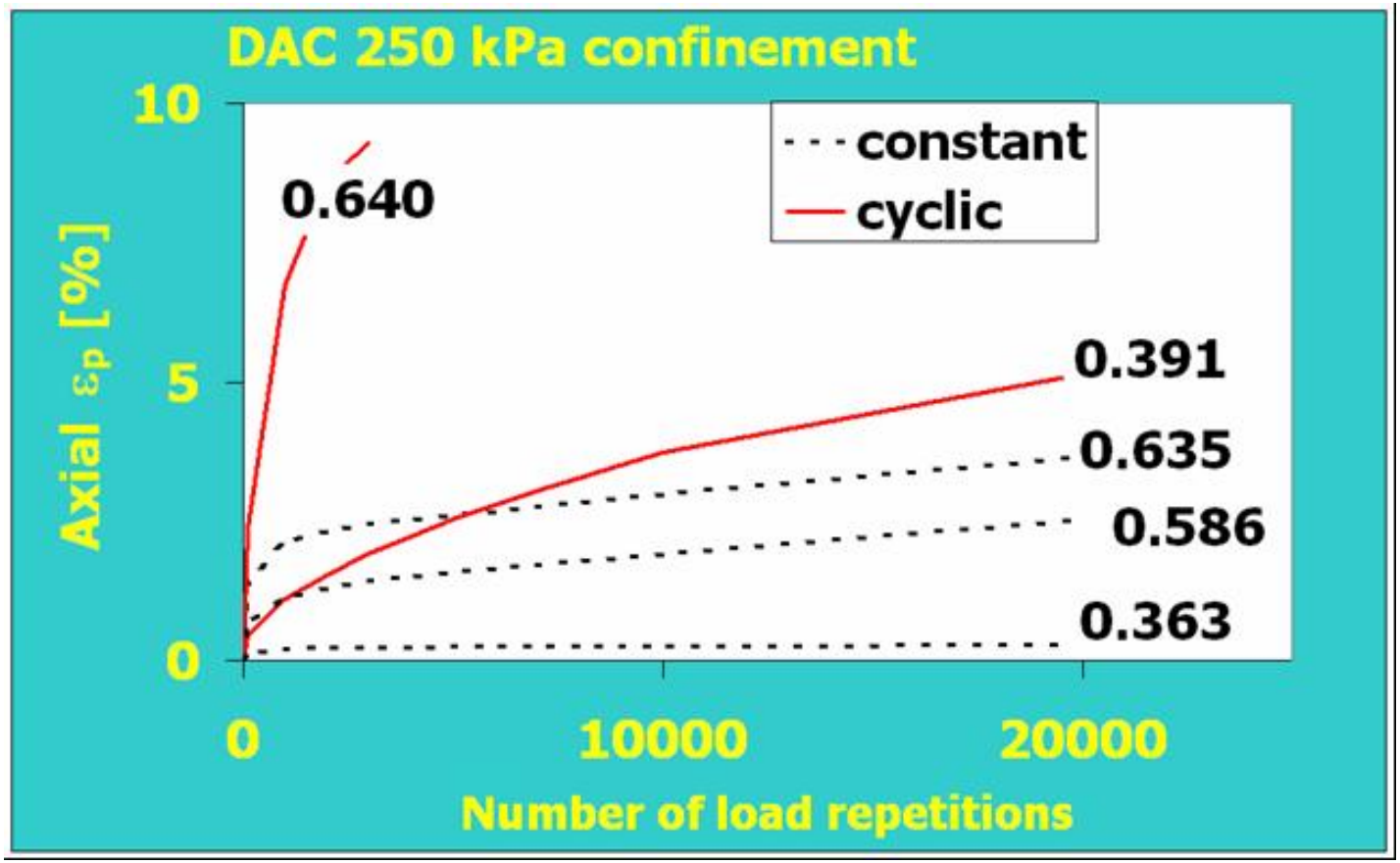


σ_1 = peak vertical stress for permanent deformation tests
f_{ca} = maximum stress determined from failure tests
a, b = coefficients determined from failure tests
σ_3 = peak confinement in cyclic tests or confinement in constant confinement tests

Perm deform. test conditions – Pilot Tests PAC

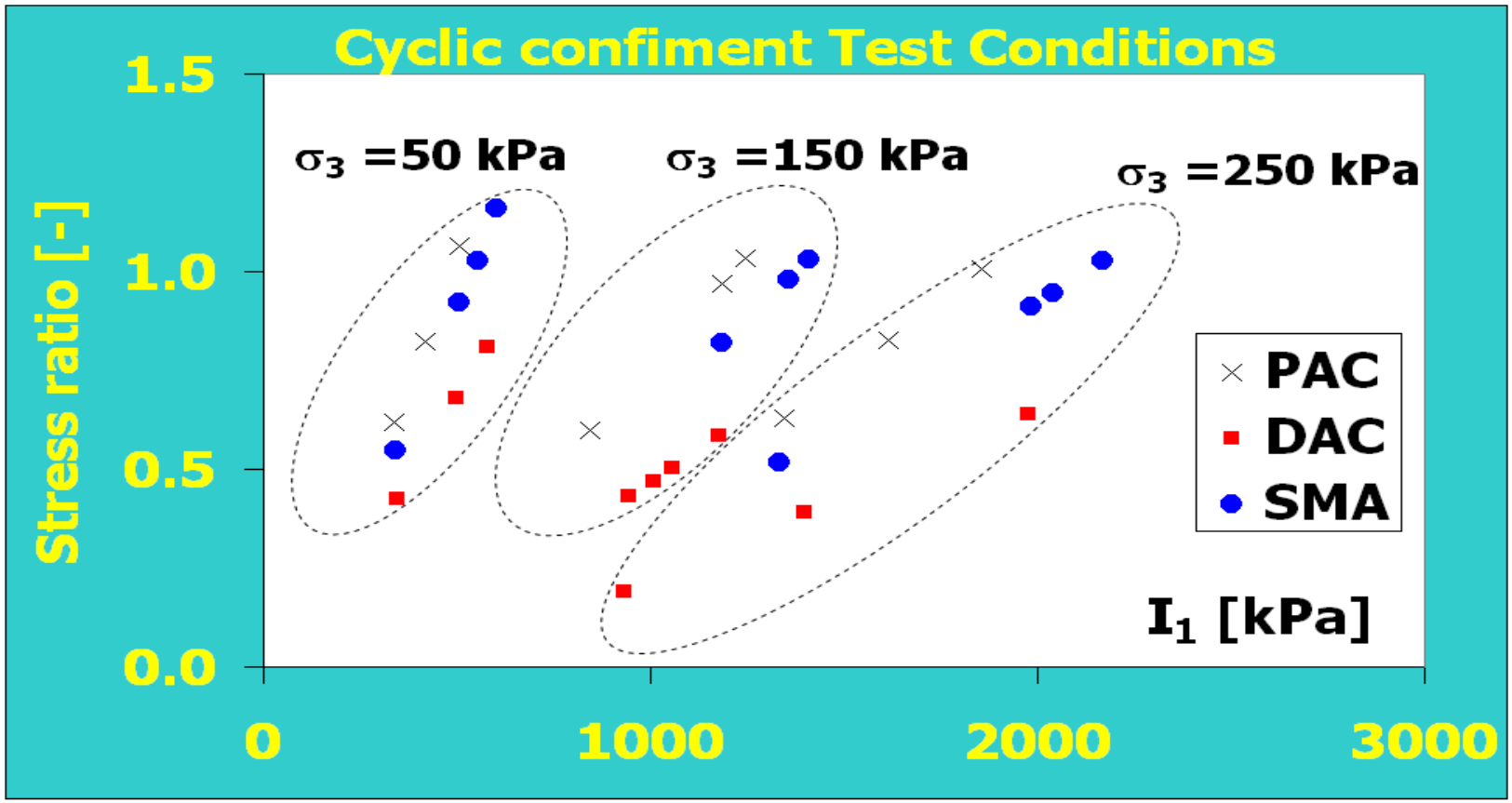


Pilot permanent deformation test results



ε_p cyclic confinement > ε_p constant confinement

Perm test conditions – All cyclic confinement tests



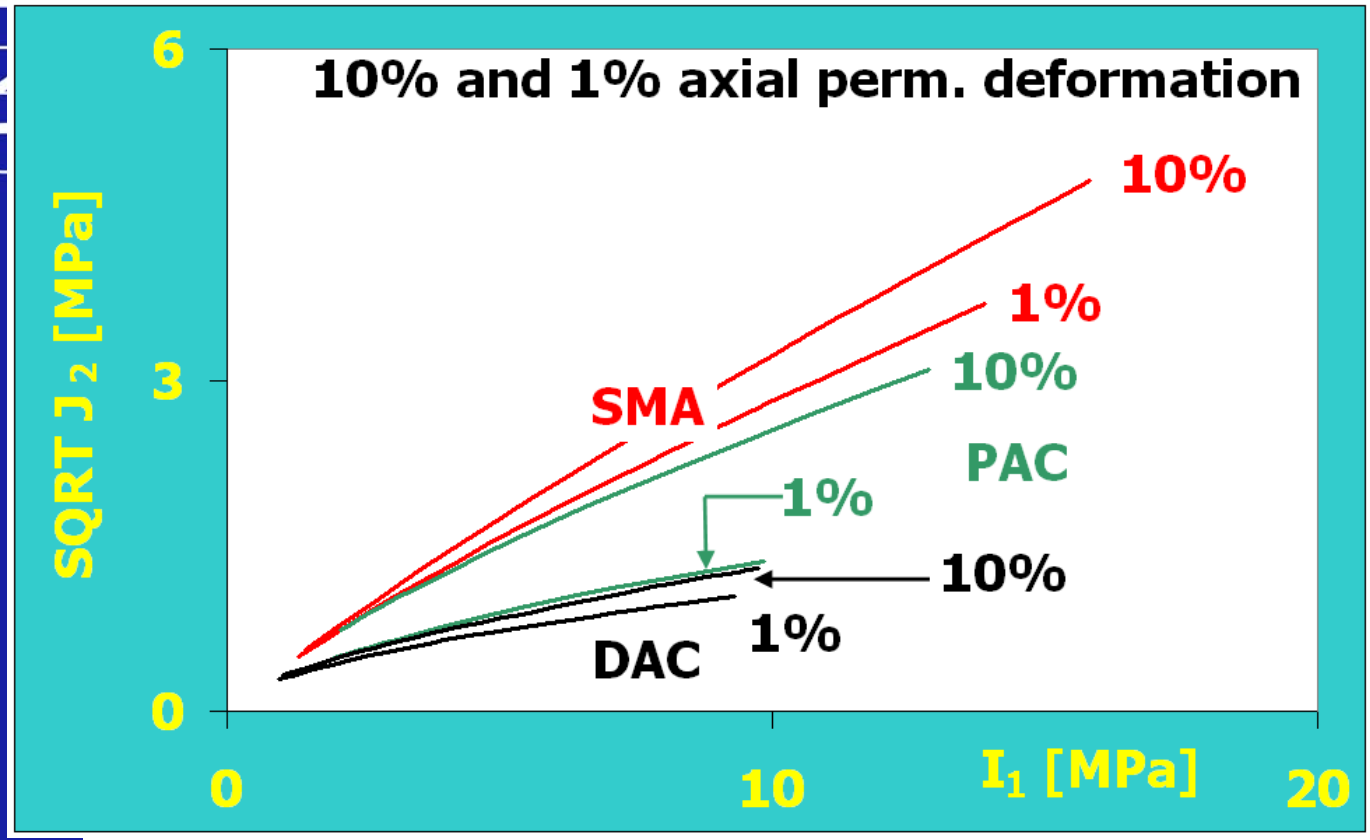
Permanent Deformation Results

$$\varepsilon_p = AN^B + C\left(e^{\frac{DN}{1000}} - 1\right)$$

Belgian model

$$I_1 = \sigma_1 + 2\sigma_3;\ \ J_2 = \frac{\left(\sigma_1 - \sigma_3\right)^2}{3}$$

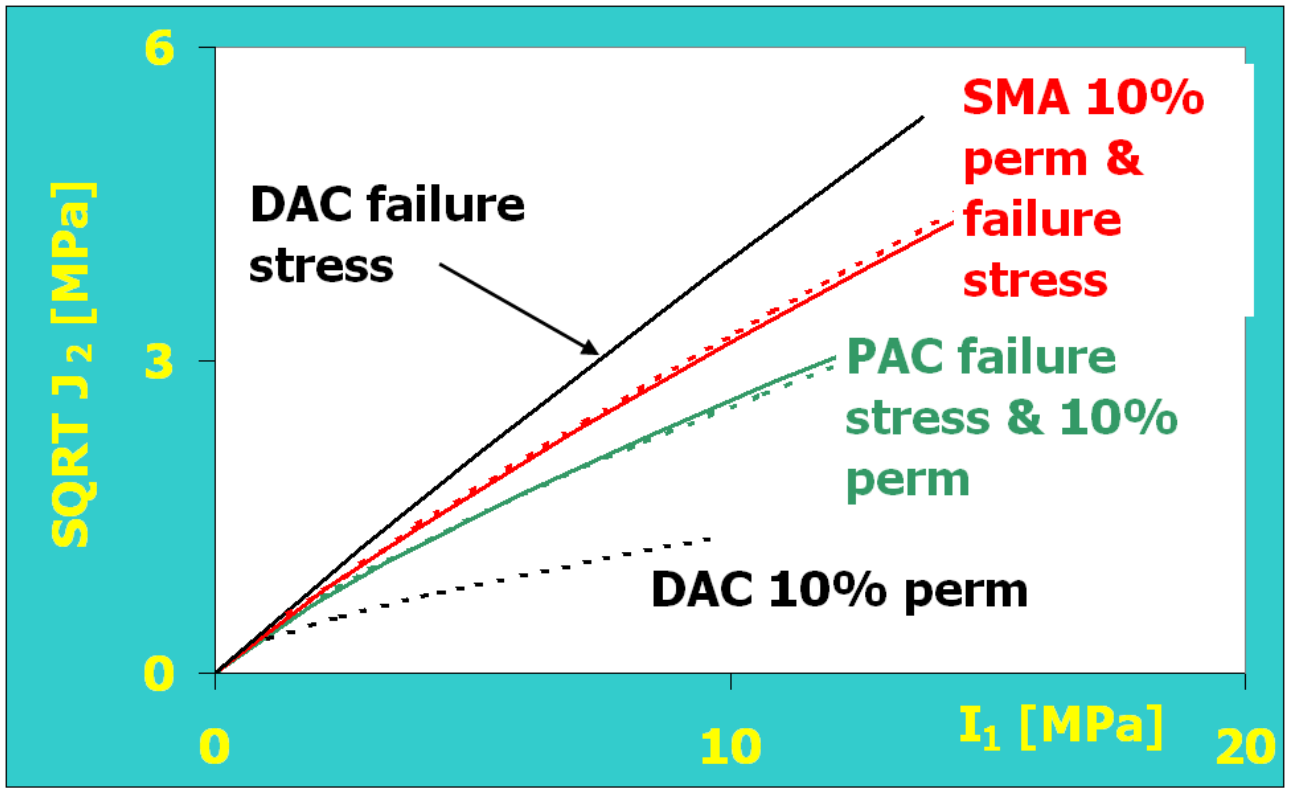
Permanent Deformation Results



perm rest.:
SMA>PAC>DAC

SMA & DAC more sensitive to stress conditions than PAC

Permanent deformation results



- Severe perm in SMA and PAC close to failure test stresses
- Severe perm in DAC much lower than failure stresses

Conclusions

- **The permanent deformation of aggregate skeletons under cyclic confinement is higher than the permanent deformation under constant confinement.**

- **The permanent deformation behaviour of SMA and DAC aggregate skeletons is much more sensitive to stress conditions in comparison to that of PAC aggregate skeleton.**

- **SMA and PAC stone aggregate skeletons are more resistant to permanent deformation in comparison to the skeleton in the DAC.**

Conclusions

- **Severe permanent deformation in the PAC and SMA stone skeletons takes place at stresses similar to the maximum stress in the failure tests.**

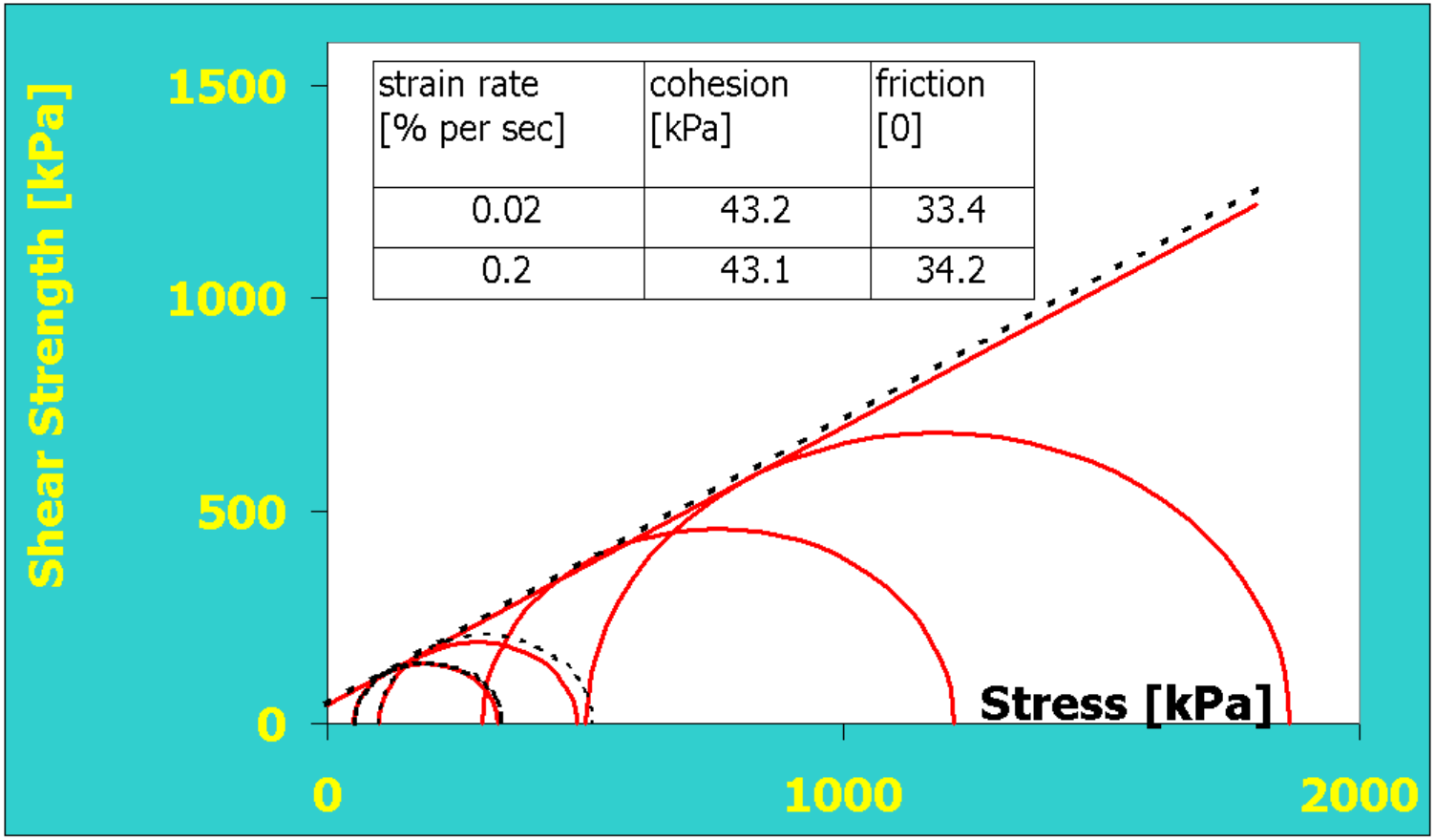
- **Severe permanent deformation in the fine DAC skeleton occurs at much lower stresses in comparison to the maximum stress in the failure tests.**

- **The maximum stress in the failure tests is a good indicator of stress conditions leading to severe permanent deformation for the stone skeletons but a poor indicator for fine skeletons such as DAC.**

NTNU

Thank you

PAC skeleton failure Test results



results linear and similar at both 0.2% and 0.02%

Aggregate Skeleton Specimen Preparation

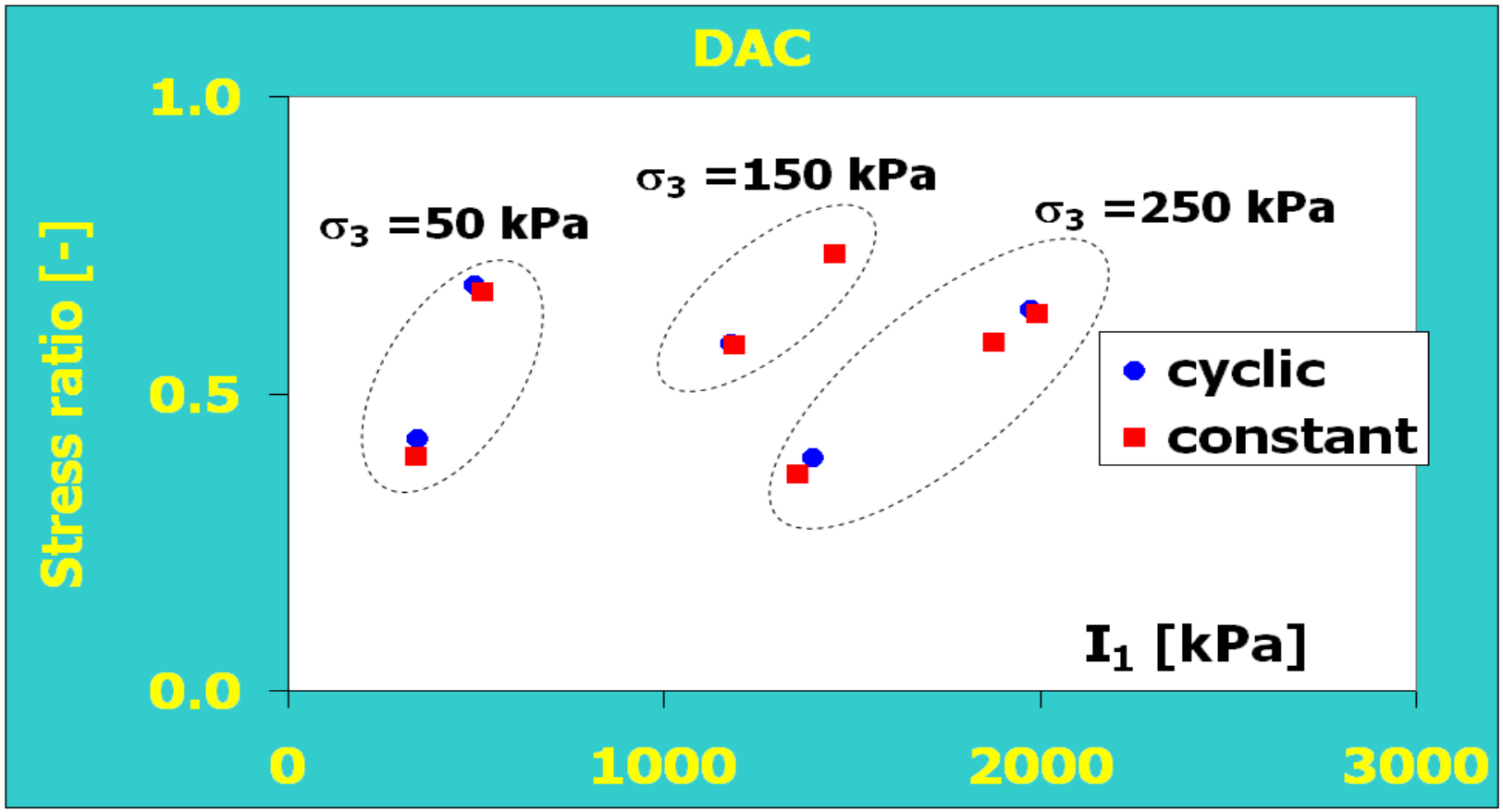
- PAC agg < 0.5 mm segregated during mixing.
- SMA agg < 2 mm segregated during compaction.
- DAC < 0.063 mm segregated during mixing and compaction.
- Min size = 0.5 mm (PAC), 2 mm (SMA), 0.063 mm (DAC)
- 0.7% water by weight added to PAC and DAC aggregate specimens to facilitate uniform mixing.
- No water added to SMA.
- Aggregates mixed by hand.

Aggregate Skeleton Specimen preparation

Instrumentation

- Specimen instrumented in the middle third
- LVDTs attached to holders glued on the membrane in monotonic failure tests
- LVDTs attached to studs embedded in the specimen in permanent deformation tests
- Axial and radial deformation measured

Perm deform. test conditions – Pilot Tests DAC

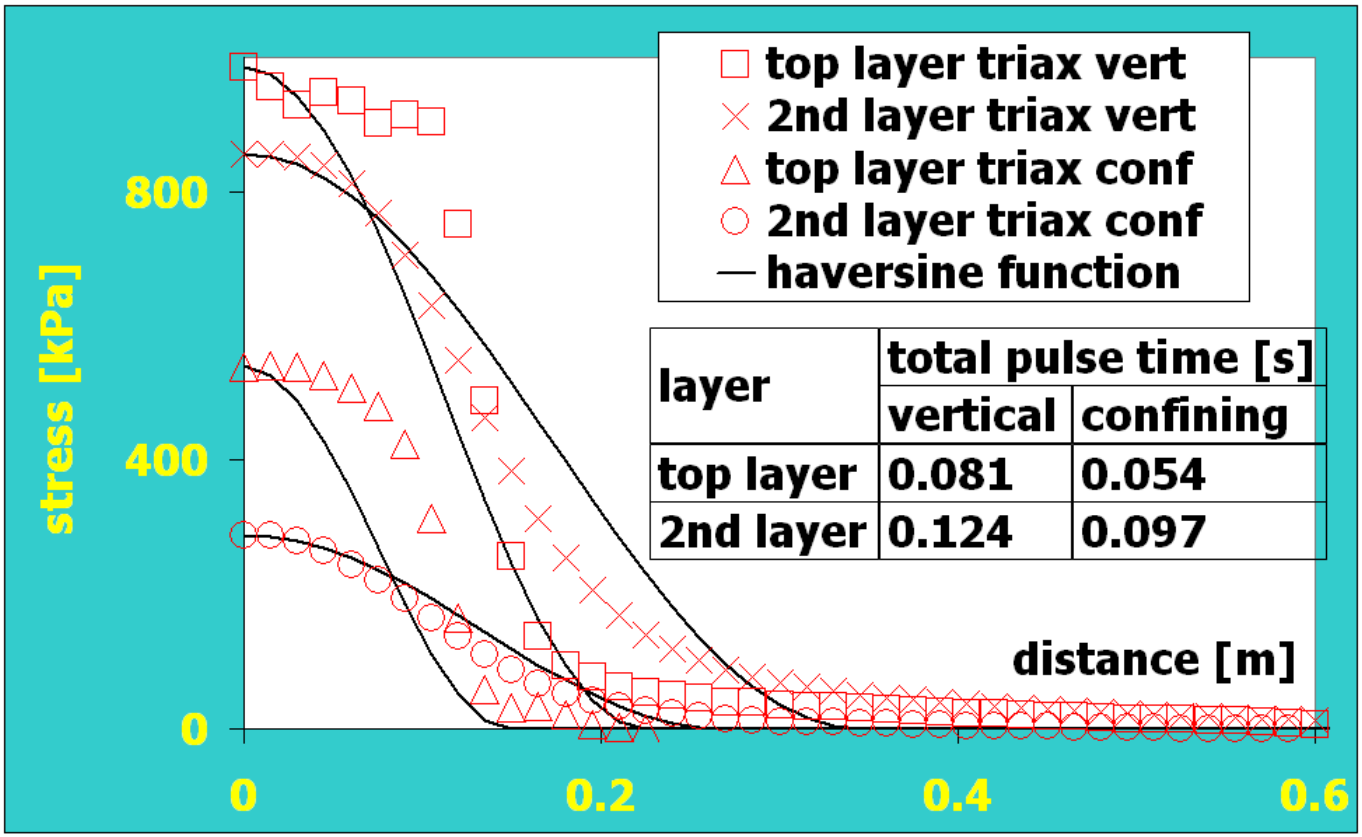


Nature of Stresses in the pavement

layer	description	η_1 [MPa.s]	η_2 [MPa.s]	E_1 [MPa]	E_2 [MPa]	Poissons ratio [-]
top layer 40 mm thick	Dense asphalt concrete	9557	38	868	384	0.35
Second layer 60 mm thick	Open asphalt concrete	1799	28	391	200	0.35
Third layer 80 mm thick	Stone asphalt concrete	1953	48	616	145	0.35
fourth layer 90 mm thick		1683	55	764	131	0.35
fith layer 250 mm thick	Cement bound asphalt aggregate base	-	-	2200	-	0.45
subgrade	over 5 m well compacted sand	-	-	150	-	0.5
wheel load characteristics	std. wide based tyre 45 kN load, 0.9 MPa tyre pressure, 0.123 m contact radius, 20 km/h speed					
temperature	between 38 - 40^{0}C at the top of the pavement and 32 - 34^{0}C at the top of the base					

$$\text{triaxial confinement} = \frac{1}{3}\left(I_1 - \sqrt{3J_2}\right), \quad \text{triaxial vertical} = \frac{1}{3}\left(I_1 + 2\sqrt{3J_2}\right)$$

Nature of Stresses in the pavement

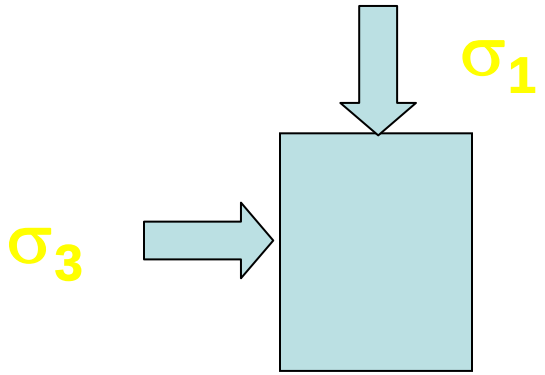


layer	total pulse time [s]	
	vertical	confining
top layer	0.081	0.054
2nd layer	0.124	0.097

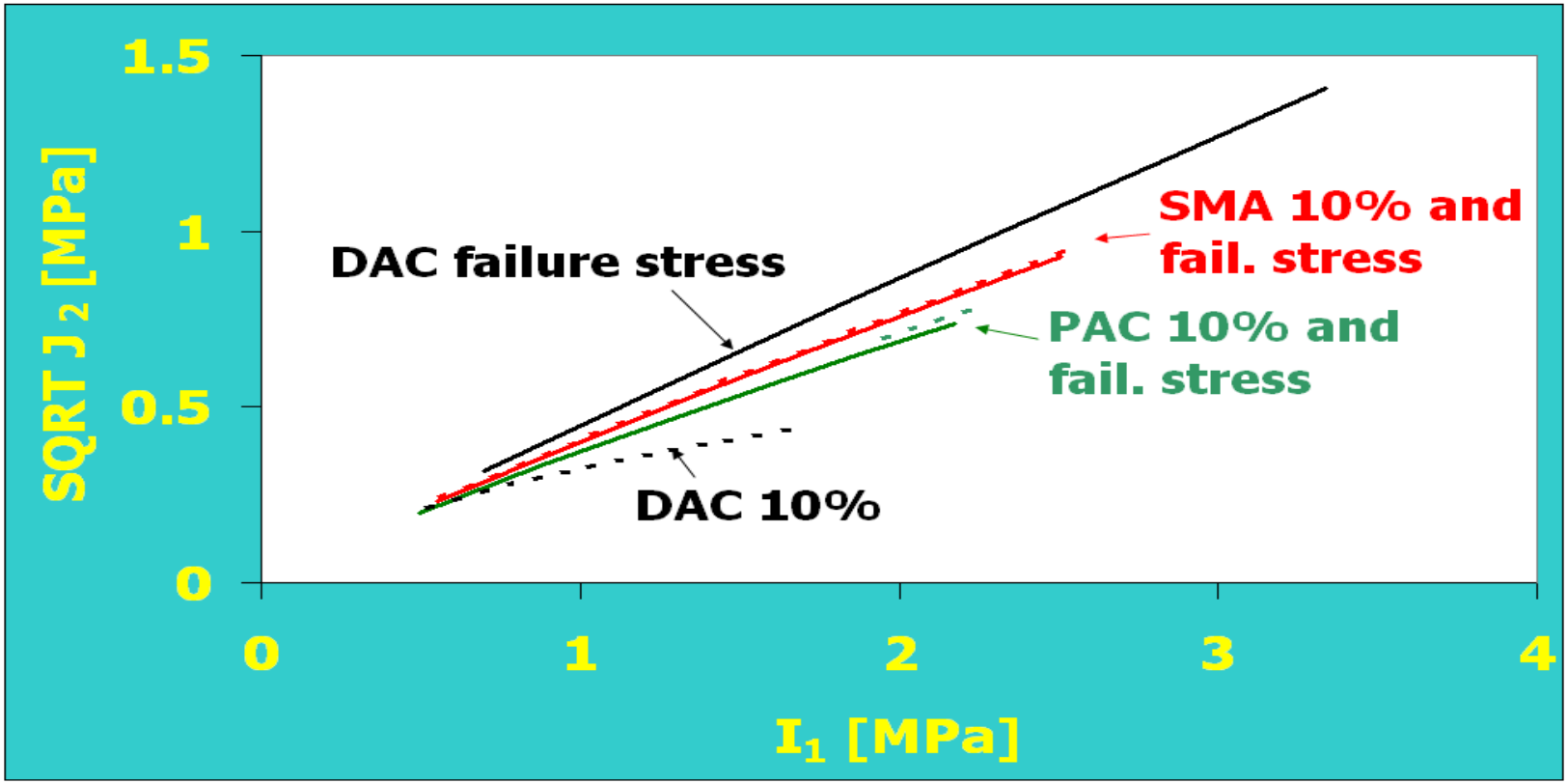
Perm stress conditions

Nature of confining	magnitude of confining stress [kPa]											
	skeleton	50				150				250			
cyclic conf	PAC	0.620	0.823	1.063		0.600	0.971	1.034		0.630	0.828	1.008	
	DAC	0.424	0.682	0.808		0.432	0.469	0.504	0.584	0.190	0.391	0.640	
	SMA	0.549	0.922	1.027	1.159	0.818	0.979	1.029		0.517	0.911	0.947	1.027
constant conf	PAC	0.586		1.034			0.960			0.622	0.981	0.996	
	DAC	0.392	0.670					0.581	0.734	0.363	0.586	0.635	
	pilot permanent deformation tests												

$$\text{stress ratio} = \sigma_1 / f_{ca} = \frac{\sigma_1}{a\left(\frac{\sigma_3}{\sigma_{3,0}}\right)^b}$$



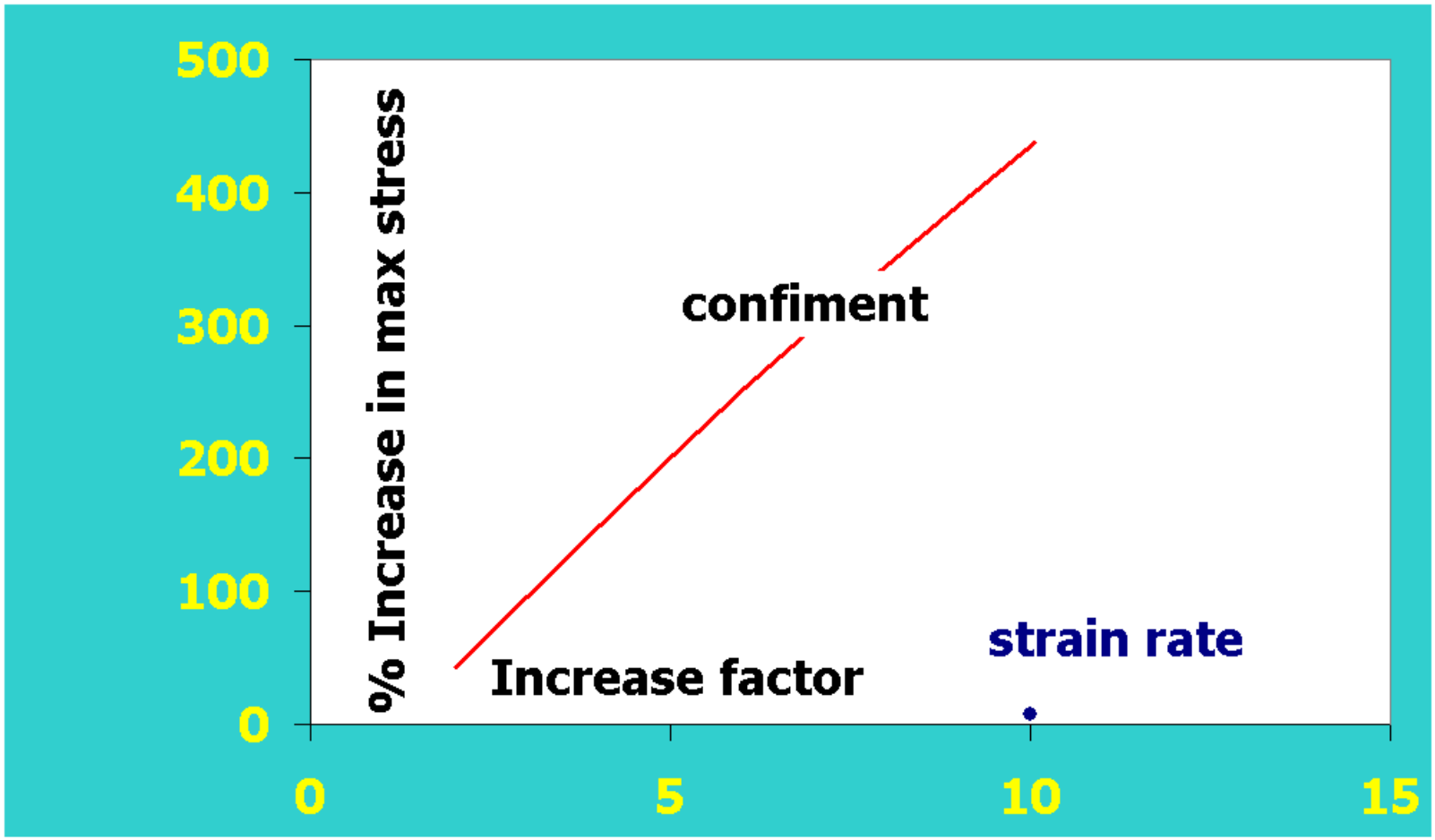
Permanent deformation results



severe perm in SMA and PAC close to failure stresses

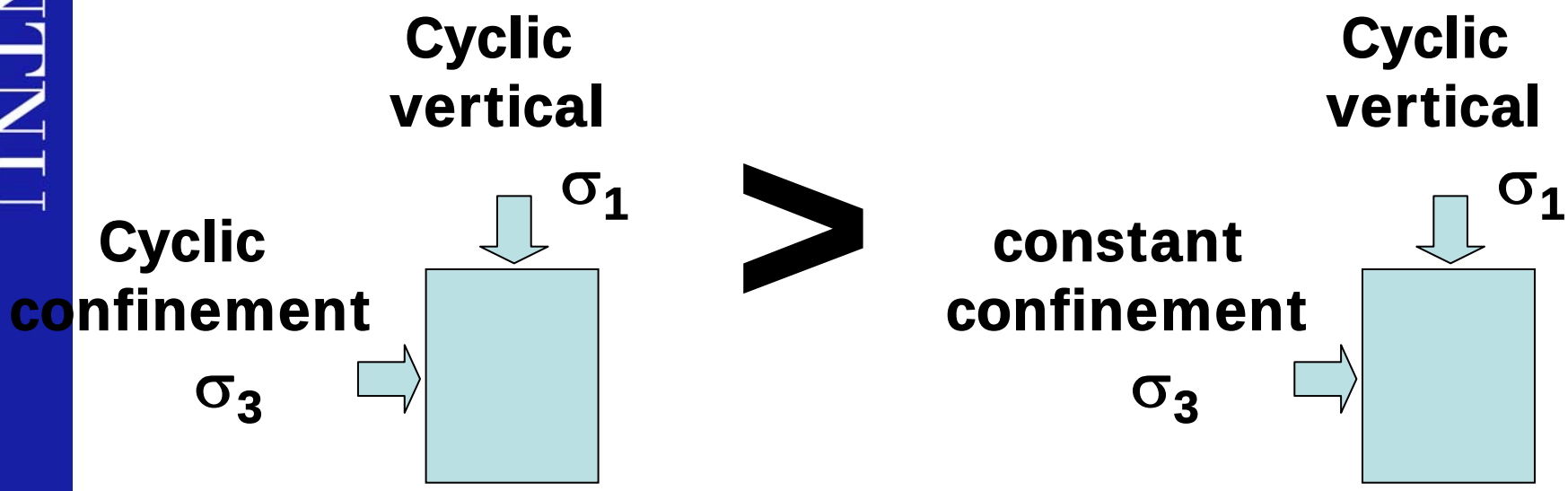
Severe perm in DAC much lower than failure stresses

PAC Skeleton – failure test results



Influence of confinement >> influence of strain rate

Permanent deformation test results



- 8 out of the 10 tests conducted at cyclic confinement resulted in higher permanent deformation in comparison to the tests conducted at constant confinement and at similar stress ratios.