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Sustainable and Durable Design of Pavement Assets

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- **This talk is not about pms**

- **It is about how design and construction issues affect durability, sustainability and future maintenance**

Why do we need:

- **ARAN type condition monitoring vehicles**
- **Falling weight deflectometers**
- **Traffic speed deflectometers**

Reason

- **We cannot apply *usage dependent* maintenance like we do with our cars**
- **We need to apply *condition dependent* maintenance**

Why no usage dependent maintenance?

- **Variability in materials and structures is high**
- **Loading conditions (e.g. climate) unpredictable**
- **We often have no idea how many loads have been applied**
- **Construction and maintenance data often poorly recorded**
- **Poor construction!**

Poor construction?

- **YES!**
- **Many pavements show unexpected short lifetime**
- **What are the reasons?**
- **What can we improve?**

Some provocative statements

- **Warrantee period is often only 1 year, this is ridiculously short**
- **It should be AT LEAST 7 years**
- **In the contracts we specify the MINIMUM required quality and that is what we get**

Some provocative statements

- **Contractors should be made much more responsible if pavements do not perform as expected**
- **Contractors should be given a bonus when pavements perform better than expected**

Something to think about

TYPE OF CONTRACT HAS LARGE INFLUENCE ON DURABILITY OF PAVEMENT STRUCTURE
AND SO ON
OPTIMAL USE OF SCARCE RESOURCES
AND FUTURE MAINTENANCE COSTS

Something to think about

SUSTAINABILITY IMPLIES OPTIMAL USE OF SCARCE RESOURCES

<u>So type of contract affects sustainability</u>

Some reasons for LACK of DURABILITY

- Too low average lifetime
- Too high variability in material properties and layer thicknesses
- Not paying attention to important details
- Not collecting important information
- Ignoring important information

Example 1

Porous Asphalt Wearing Courses in the Netherlands

too short lifetime, too high variability

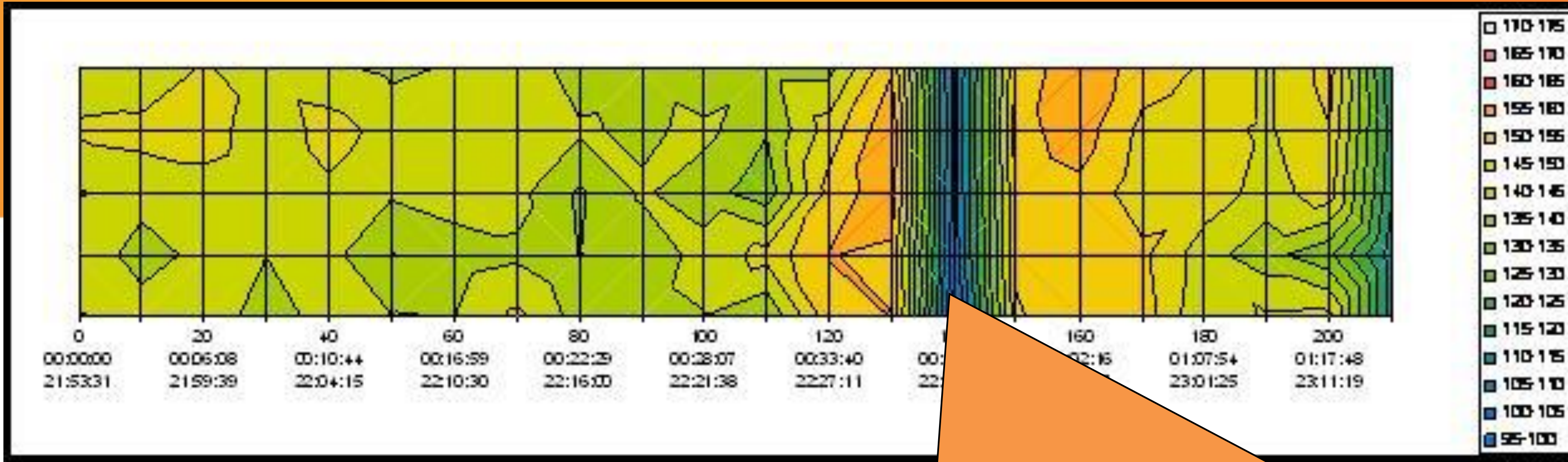
Porous Asphalt Concrete (PAC)

- **Reduction of traffic noise with 3 – 5 dB(A)**
- **20% voids for noise absorption**
- **Reduction of splash and spray**

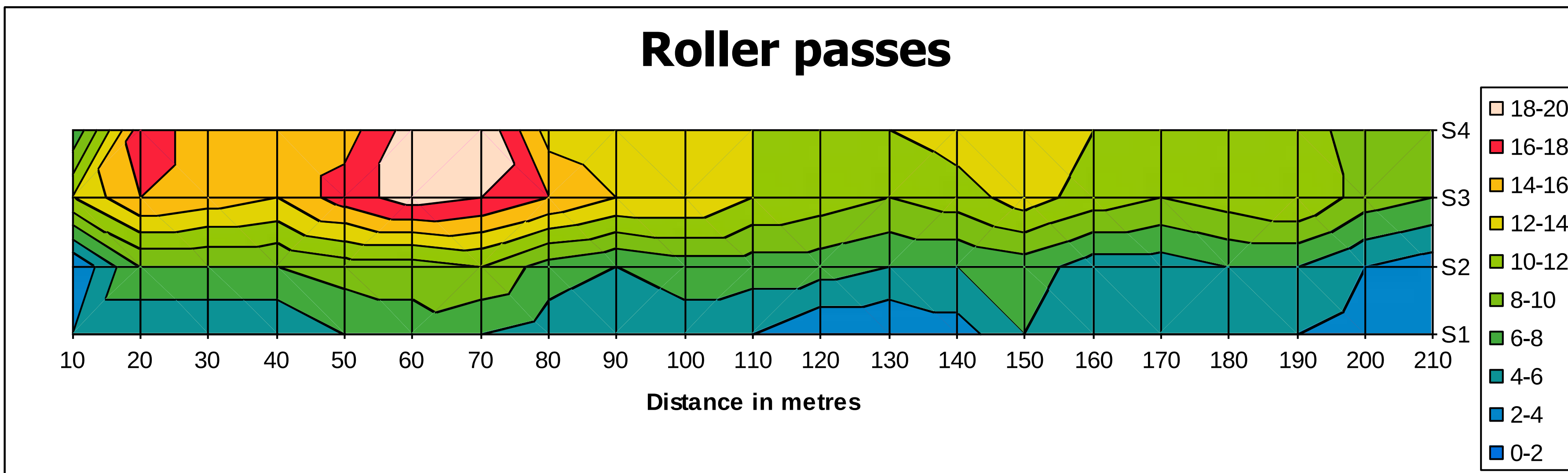
Effect of reduced Variability of Porous Asphalt Concrete on Costs and Delay Hours

	10% of sections has failed after [years]	50% of sections has failed after [years]	90% of sections has failed after [years]	Mainte-nance costs	Delay hours
Currently	7	11	16	1	1
In case of reduced variability	9	13	16	0.8	0.9

Less delay hours, less use of fuel, less fumes, more environmentally friendly



cooling of the asphalt when the paver did stop



Obviously there were problems during construction

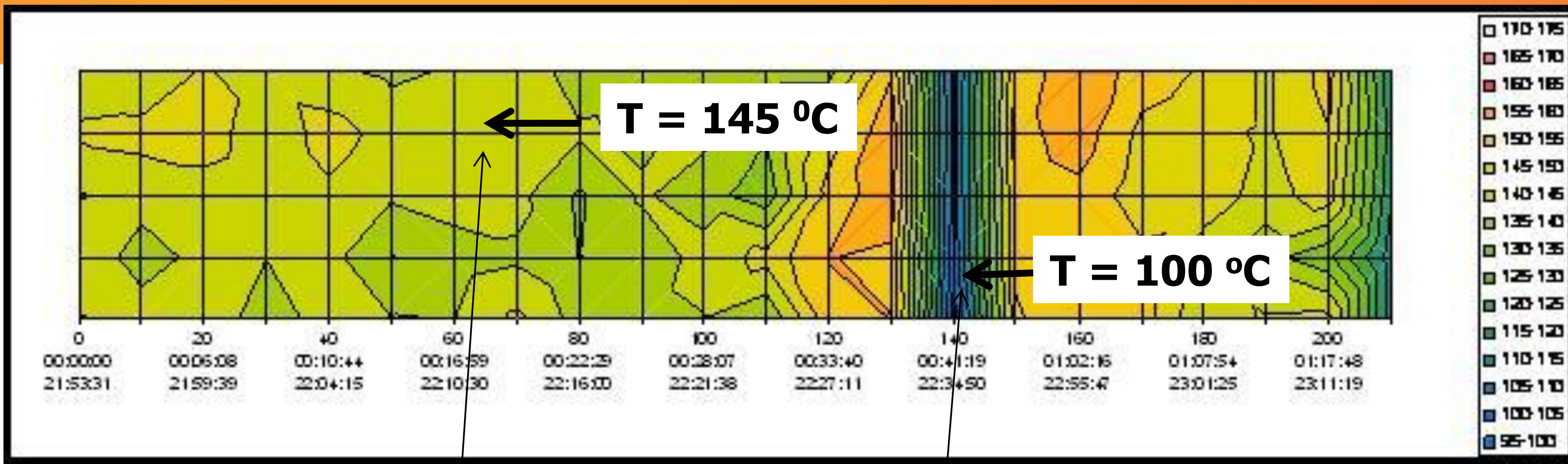
and/or

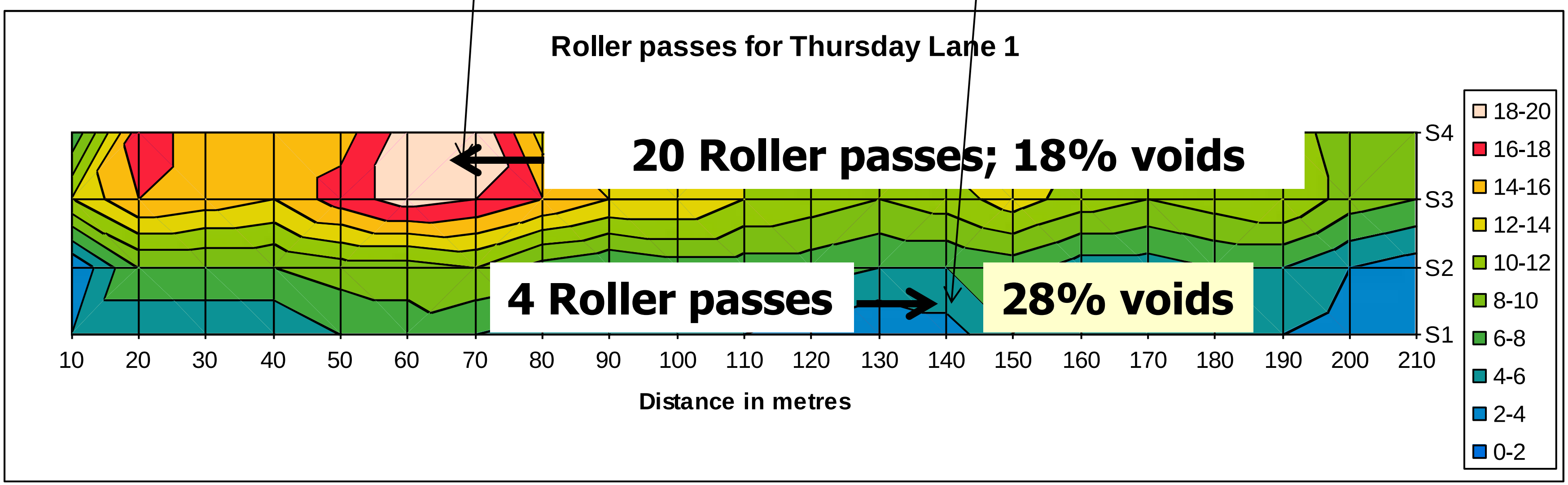
contractor did not pay enough attention to details

e.g. supply of material

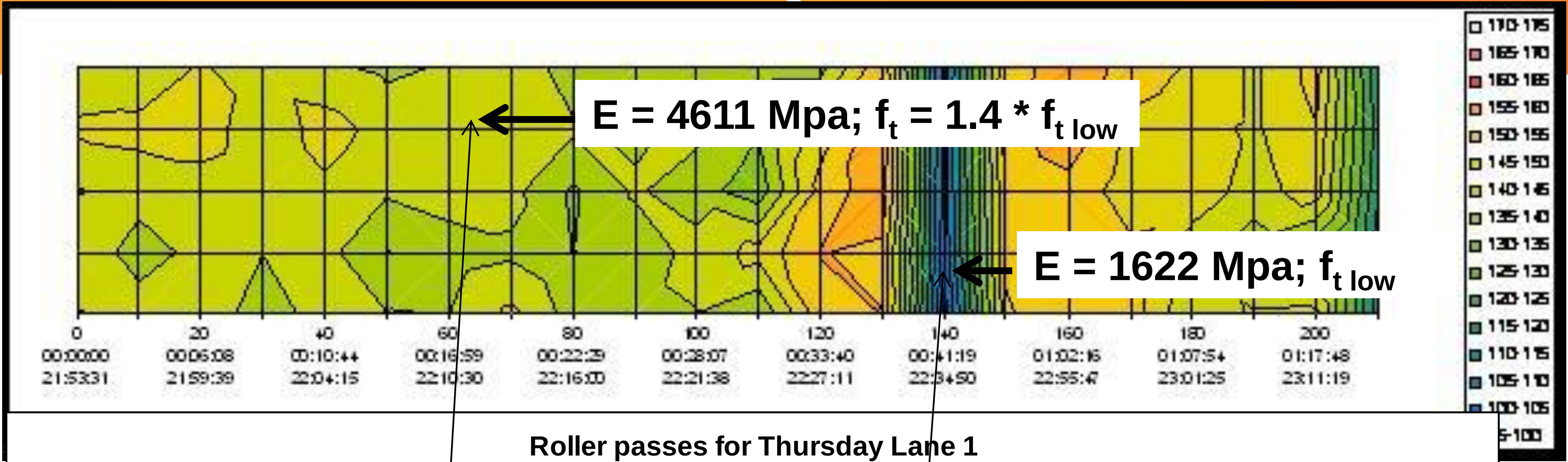
BUT WHAT ARE THE CONSEQUENCES ?!

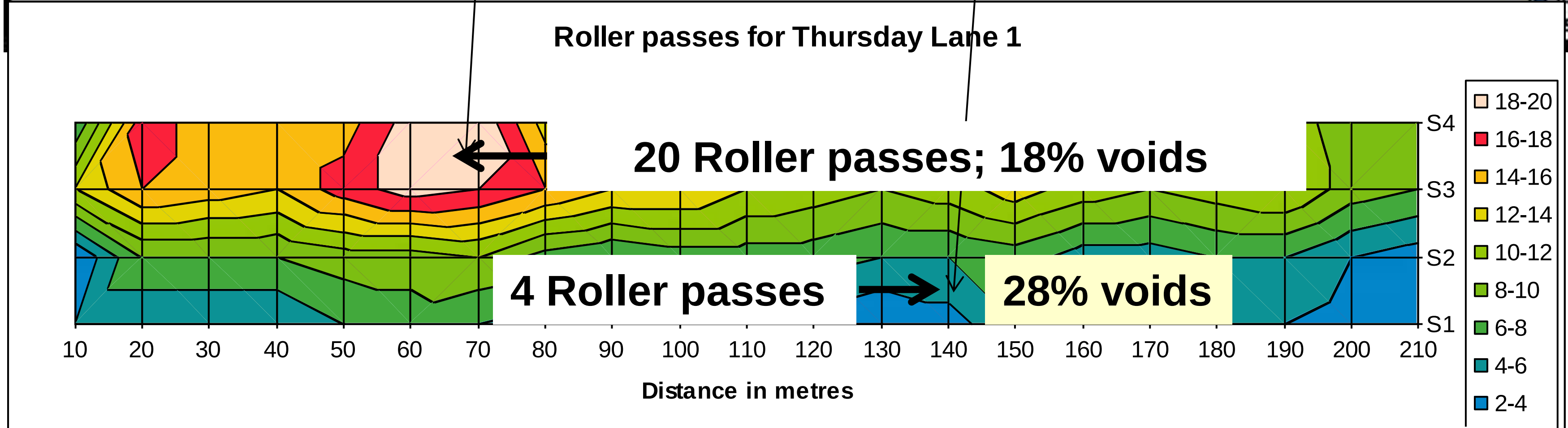
Consequences





Consequences





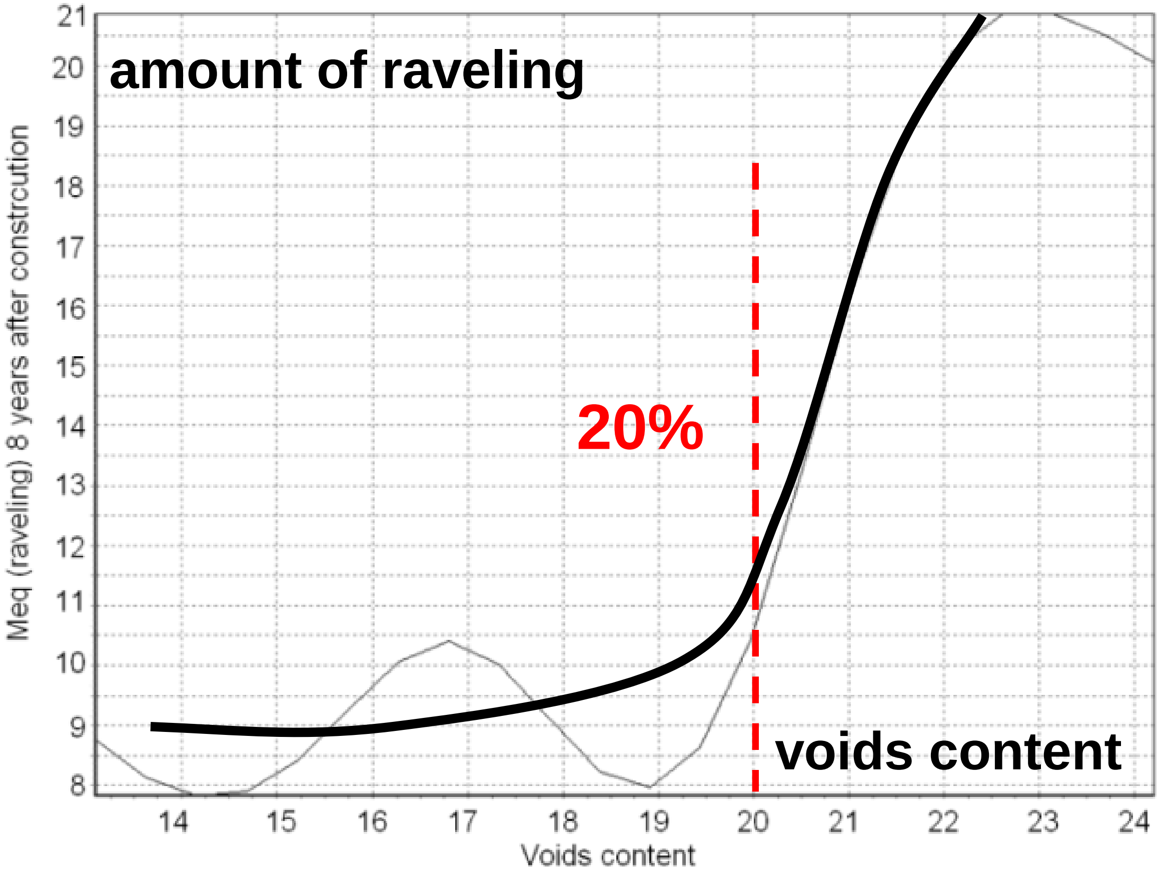
Consequences on mixture stiffness (20 ºC and 8 Hz) and tensile strength

Result

Premature damage at poorly compacted areas

The result is raveling which increases noise levels and gives rise to safety issues

Influence of void content on amount of raveling 8 years after construction



Graph shows that spot with 28% voids will show serious damage after 8 years. The spot with 18% damage will still be in fine condition.

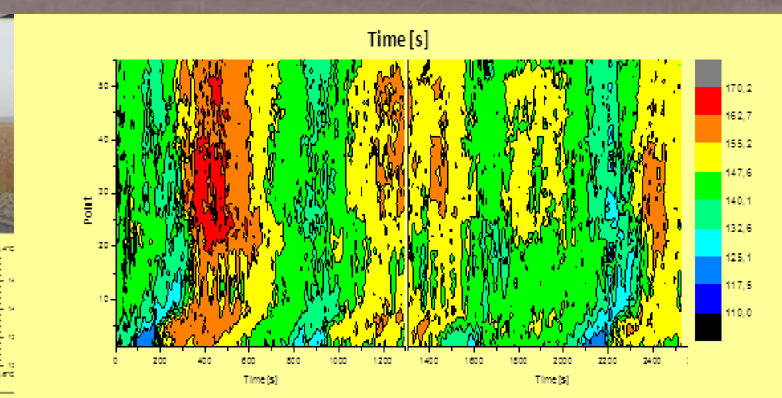
Conclusions

- Variations occurring during construction caused significant variation in material quality
- Premature, unnecessary, damage will occur because of lack of control during construction
- Unnecessary maintenance = not optimal use of materials = not sustainable structure

Recommendation

- **Measure pavement condition during construction!**
- **It gives a lot of info on potential future maintenance needs**
- **Contractors should provide initial quality report!**

GPS
GPR
Infrared



Contractual aspects

- 10% of porous asphalt sections failed within 7 years
- Client increased warrantee period from 3 to 7 years
- For large projects, client decided to go for DBFM contracts covering 30 year period
- Number and duration of maintenance moments are specified in contract
- Heavy penalty when maintenance is needed outside those periods

Penalties for not scheduled Lane Closures

Phase	Day	Time frame			
		00.00-05.00	05.00-08.00	08.00-22.00	22.00-00.00
Repair	Mo-Fr	€ 12.500	€ 25.000		€ 12.500
Repair	Sa-Sunday	€ 12.500		€ 25.000	

Penalty per closed lane per 15 minutes

1 Euro is at the moment around 1.08 USD

Other reasons unsatisfactory, not sustainable performance

- **Wrong designs!**
- **Not paying attention to important details**
- **Not collecting important information**
- **Ignoring important information**

- **You cannot fool around with hostile conditions like poor soils and heavy rainfall.**
- **Built in failures will show up immediately!**

EXAMPLE 2

NOT DURABLE, NOT SUSTAINABLE STRUCTURE IN AFRICA

Extensive longitudinal cracking in shoulder

Example of not paying attention to and not collecting information

- **Borrow pit material was classified as A-2-4; A-2-6**

- **Material contained significant amount of MICA; this was overlooked when colleting material data although geological info pointed at it!**

- **WHAT WERE THE CONSEQUENCES ?!**

Excessive required compaction

- When soil contains MICA it is very difficult to compact
- Excessive compaction effort was required to achieve specified % compaction
- Soil started to break down after a certain number of roller passes
- Test pits in completed pavements showed that material was A-4; A-6 with a significant swell potential
- Swell and shrinkage of soil under shoulder was cause of cracking

There was an even bigger problem!

Drainage system how it should look like

Concrete lining where long. gradient > 4%

This is how it looked like

Drainage problems

- Problem soils with little to no resistance to erosion
- Design back slopes with acute gradient 1:1.5 not suitable given the climatic conditions
- Only 30% of project side drainage is concrete lined
- Concrete lining only covers 53% of slope distance leaving the upper re-worked pavement layers exposed
- Extremely intense rainfall resulting in flash floods and excessive surface runoff
- Eroded materials are being transported and deposited resulting in culverts being silted up. Continuous maintenance issue

Conclusions

The specifications and design were not suitable. Public did not get a road which would last for the required duration.

IT IS NOT FIT FOR PURPOSE!

The specification and design will lead to excessive maintenance costs

Conclusions

This is neither a durable pavement nor a sustainable pavement

Improper design resulted in waste of scarce resources

OK, this was all about a structure not being sustainable because of design and construction problems.

But can we evaluate the sustainability of a structure if all is well?

Systems have been developed to assess the "environmental loading" due to pavement construction. Example: Dutch System DUBOCALC

DuboCalc

- Software tool to determine environmental effects of using materials and energy for building structures
- 10 environmentally important aspects are evaluated by means of one single indicator being the Environment Cost Indicator (ECI)

Aspects considered a.o.

• Acidification (SO_2 equivalent)	€ 4 / kg
• Damage to Ozone layer (CFK-11 eq)	€ 30 / kg
• Climate change (CO_2 eq)	€ 0.05 / kg
• Eco-toxicity (1.4-DCB eq dichlorobenzene)	€ 0.06 / kg
• Smog (C_2H_2 eq)	€ 2 / kg

How Calculated

- Data base of products and materials for which environmental load is determined
- Based on type and quantities of materials used ECI (environment cost indicator) is calculated
- ECI of the total project is calculated and this fictitious amount is added to the real bid
- So you may have a very good technical solution for a low price but you still might loose the project because your price + ECI is higher than that of competitor

State of the Art

- System is used for big DBFM contracts
- Further developments are underway

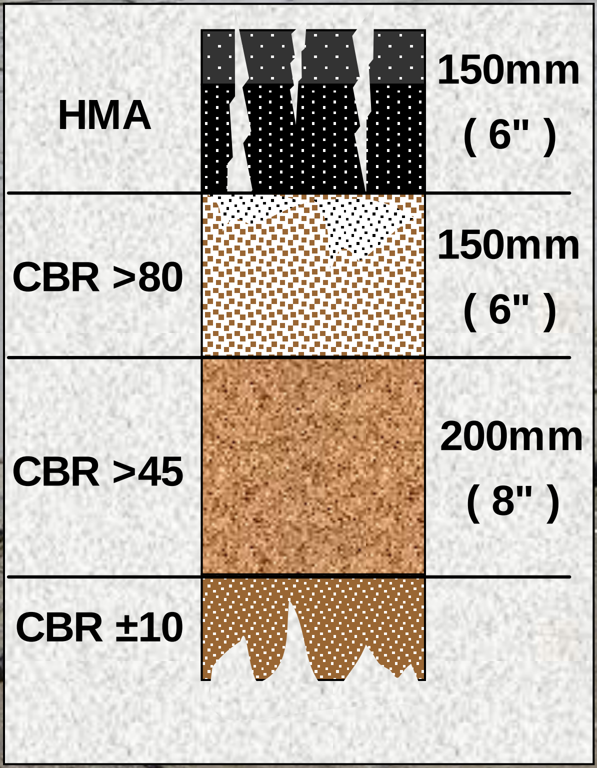
You might say:

“your example works in the Netherlands but what about the rest of the world?”

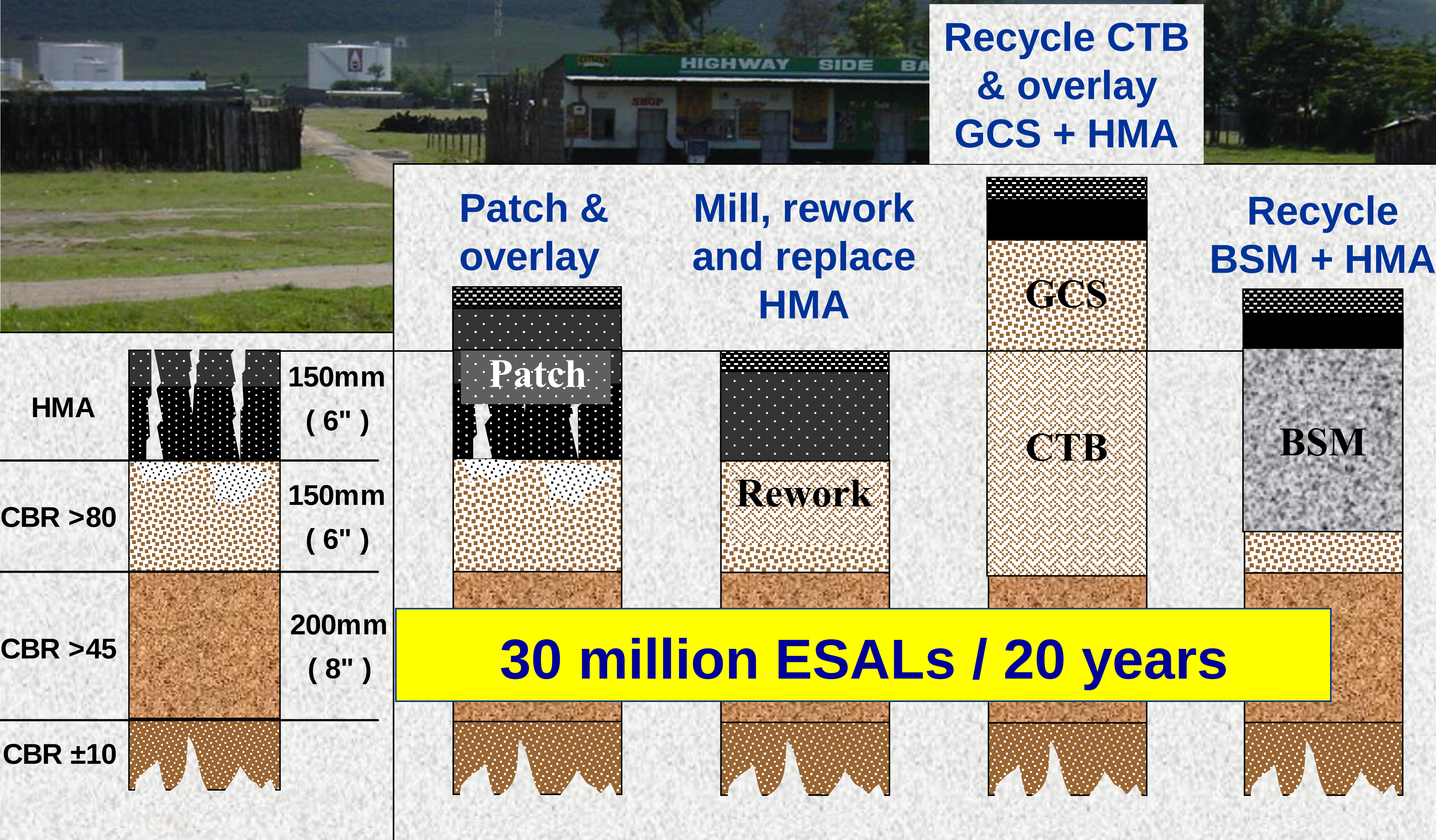
Pavement rehabilitation example in Africa

Rehabilitation Options ?

30 million ESALs
20 year service life

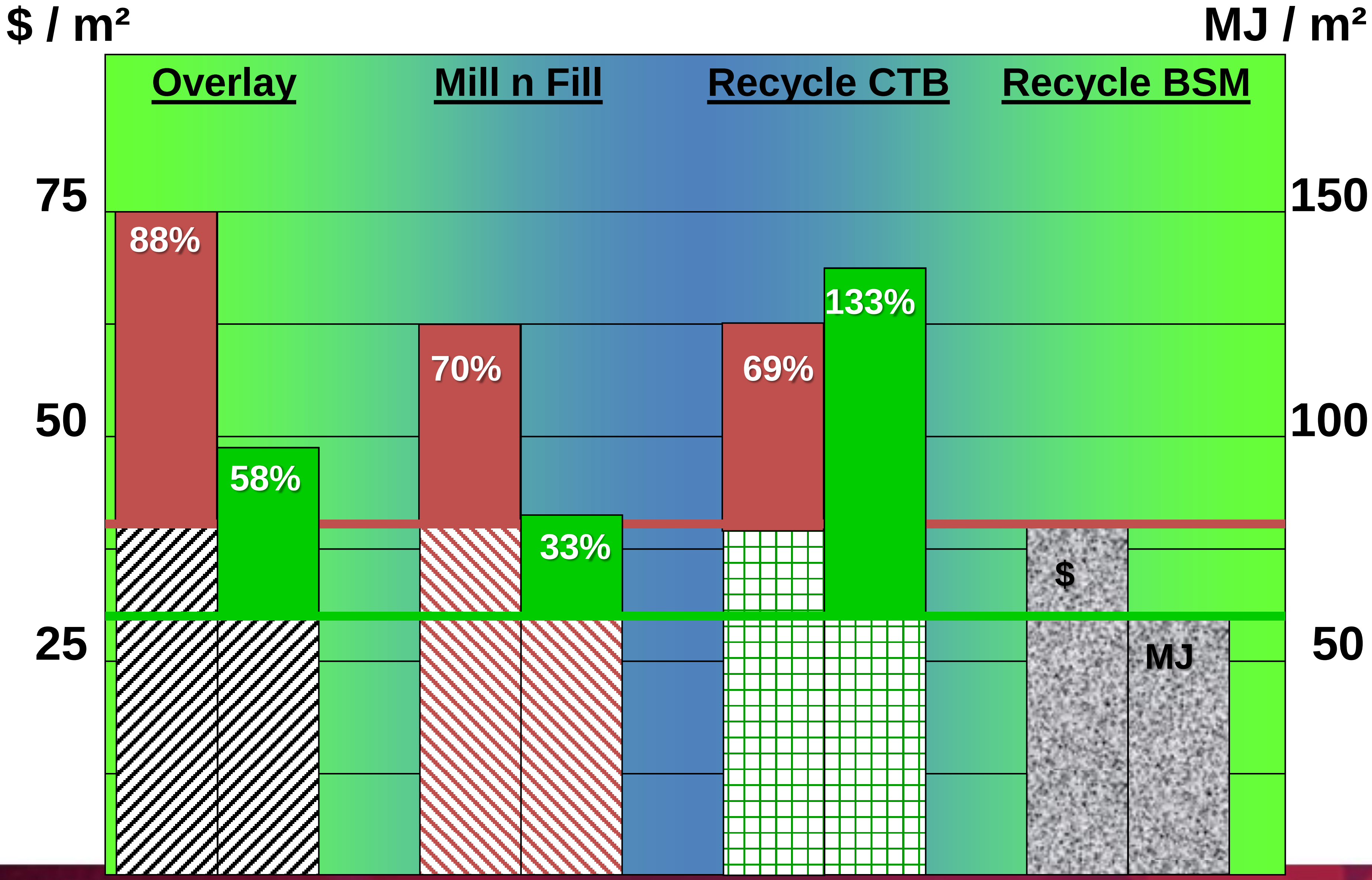


Summary of rehabilitation options



Material procurement / Construction activity	Unit	Energy consumed (Mj)
Material procurement		
Graded crushed stone (GCS)	Mj / t	50
HMA manufacture	Mj / t	30
Cement	Mj / t	70
Bitumen	Mj / t	60
Material haulage	Mj / t km	1
Construction activity		
Milling [1]	Mj / t	5
In situ recycling / stabilising	Mj / t	10
Processing aggregate layer	Mj / t	66
Ditto per m² for 150mm thick layer	Mj / m²	10
Compacting and finishing layer [2]	Mj / m²	10
HMA paving and compaction	Mj / t	20

Whole of Life Cost & Energy Consumed



So calculation of the environmental load and amount of scarce resources used is not only applicable in a rich country like the Netherlands !

It is applicable everywhere !

Recycling

Most effective way for building sustainable structures is using recycled materials.
So called waste is very often very valuable !

Example: recycling of Construction and Demolition "Waste" (CDW)

Concrete (left) and Masonry (right) Rubble

Specifications for properties of the concrete and masonry rubble are mainly related to "purity"

Recycling of Construction Demolition Waste

- **Overall in Europe: 5%**
- **In the Netherlands: 90%**

- **Reasons for high recycling level in the Netherlands:**
  - environmental issues
  - no space for dumping
  - no natural materials

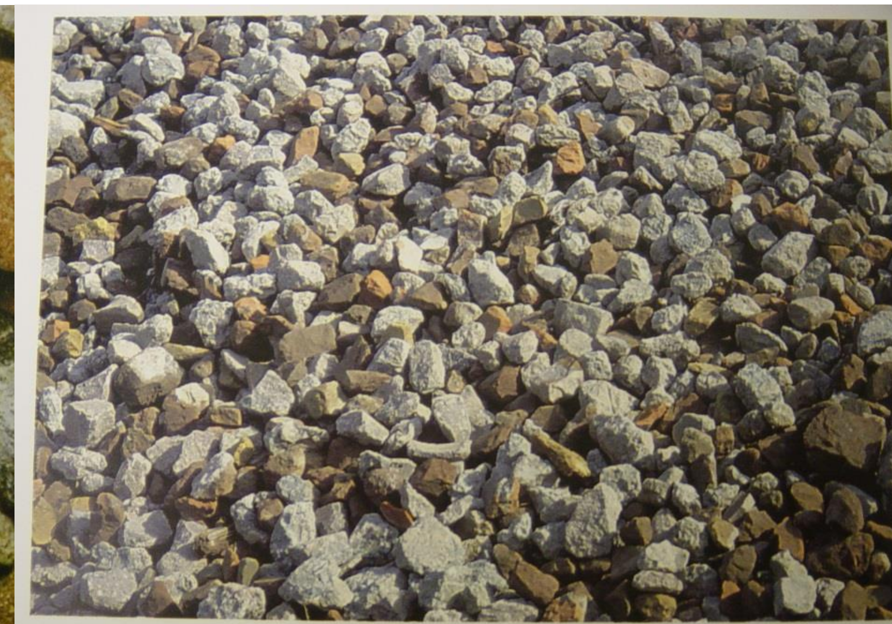
Construction Demolition Waste

- In the Netherlands 5 * more CDW is produced compared to RAP
- CDW is NOT waste but a valuable material when properly treated
- Selective demolition is essential
- Mixtures of crushed masonry and crushed concrete 50/50 by volume can be used very well in subbase and base courses
- Cement treatment enhances application

Governmental Support absolutely needed to enhance Recycling

- Government pushed the market with legislation on waste deposits
- Active policy in development of techniques, specifications, test methods etc
- Because of that, contractors understood there was a market and invested in equipment etc

Final Product



Figuur 1. Menggranulaat

Concerns

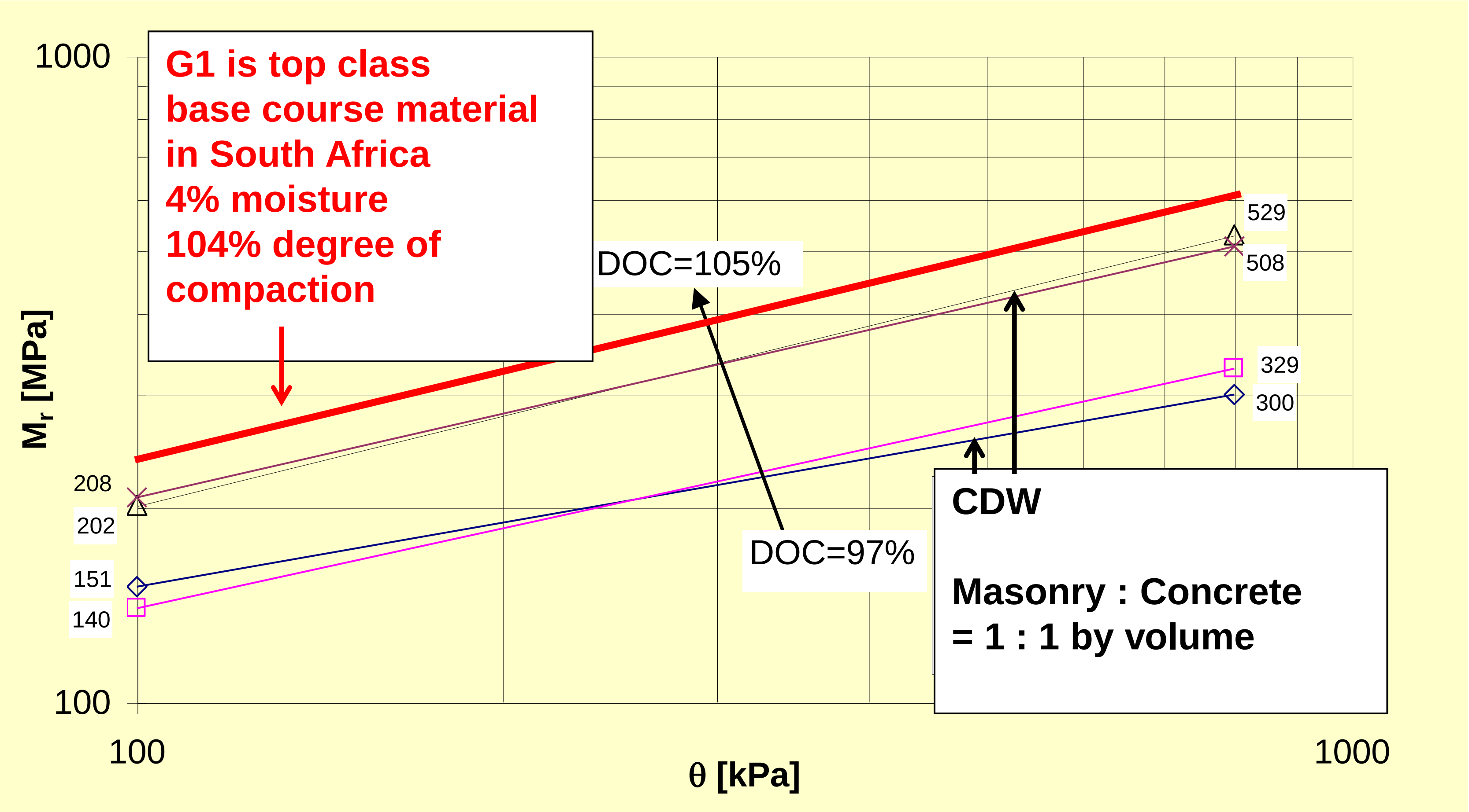
How good is this “stuff” ?

Can we really use it as a base course material ?

Aren’t we compromising pavement quality ?

Aren’t we compromising durability for the sake of sustainability ?

At same compaction level CDW stone base is (almost) as good as G1 stone base

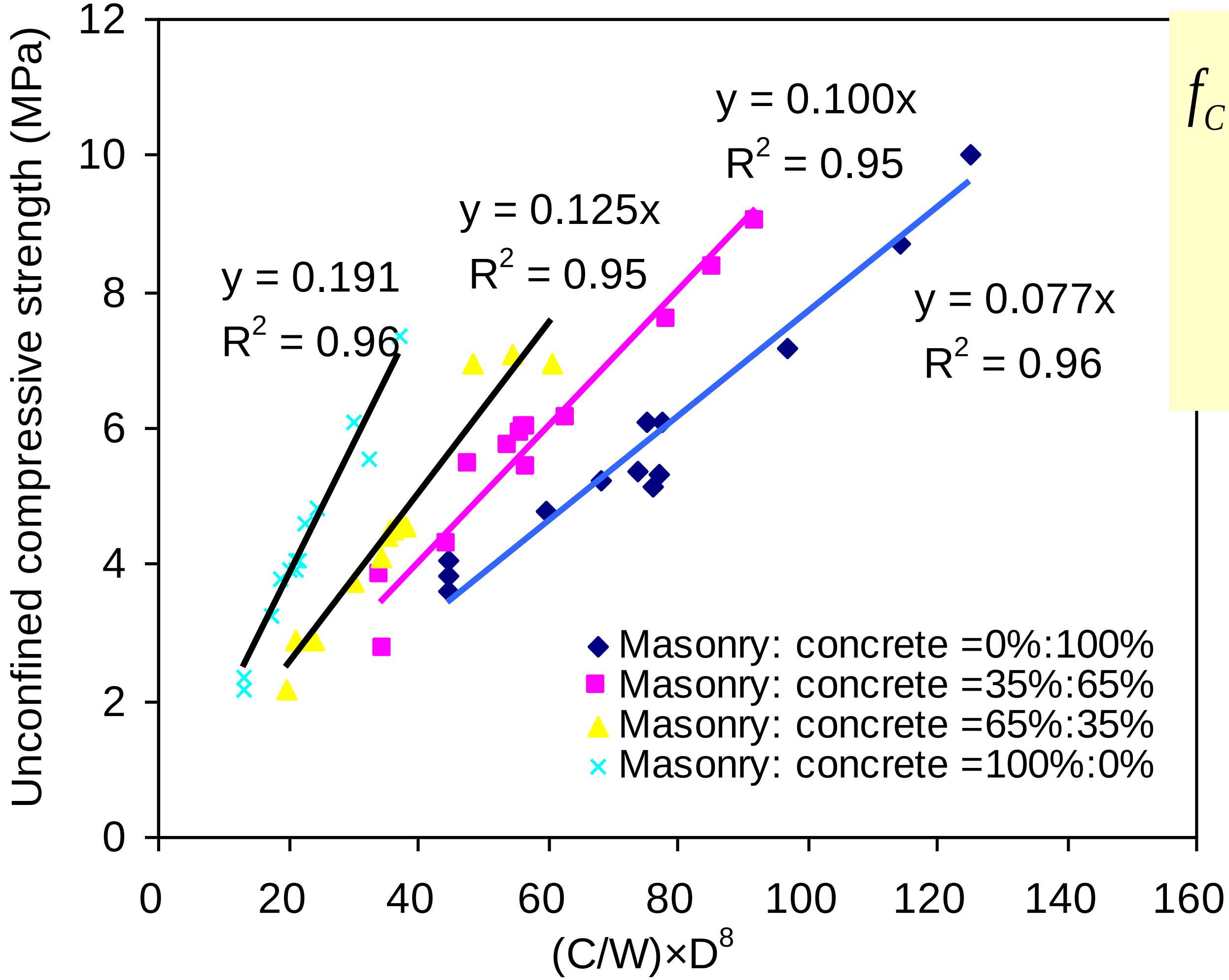


Cement treated Mixed Granulate

Masonry : Concrete

100 : 0 **35 : 65** **0 : 100**

UCS 28 days



$$f_C = 0.0747 \cdot \frac{C}{W} \cdot D^8 \cdot e^{0.0088 \cdot M}$$

C = **cement content**
W = **water content**
D = **dry density**
M = **masonry content**

UCS Requirements

Unconfined Compressive Strength Required as a Road Base

Country	Curing	UCS (MPa)	
		C1	C2
South Africa	7 days at 100% compaction	6~12	3~6
	7 days at 97% compaction	>4	>2
United Kingdom	7 days at 100% compaction	CBM1	CBM2
		2.5~4.5	4.5~7.5
China	7 days at 100% compaction	Base of highway	Subbase
		>4	>2

Cement contents for CDW to fulfill Chinese and South African specifications

Composition Masonry : Concrete	Cement content for base course in China or C1 in South Africa	Cement content for subbase layer in China or C2 in South Africa
100 : 0	8.6 %	4.2 %
65 : 35	8 %	3.8 %
35 : 65	6.7 %	3.3 %
0 : 100	5.6 %	2.8 %

Conclusion

- **Cement Treated Demolition Waste can be successfully used as base/subbase material**
- **It is a DURABLE and SUSTAINABLE material**

Final comments

- **Sustainable structures are durable structures made of materials having the lowest "environmental loading"**
- **Improper designs affect durability and sustainability**
- **Improper construction affects durability and sustainability**

Final comments

- Recycling is a MUST but don't rely on the market for being applied. It should be driven by the authorities
- Contracts should not specify the minimum allowable quality but should give an incentive to contractors to produce the best possible quality

Sustainability ⇄ Durability

SUSTAINABILITY AND DURABILITY
CAN GO “HAND IN HAND”
AND
SHOULD GO “HAND IN HAND”


THANK YOU FOR YOUR ATTENTION