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
• 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
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

So type of contract affects sustainability
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
<table>
<thead>
<tr>
<th></th>
<th>10% of sections has failed after [years]</th>
<th>50% of sections has failed after [years]</th>
<th>90% of sections has failed after [years]</th>
<th>Maintenance costs</th>
<th>Delay hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Currently</td>
<td>7</td>
<td>11</td>
<td>16</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>In case of reduced variability</td>
<td>9</td>
<td>13</td>
<td>16</td>
<td>0.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>

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

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

Roller passes for Thursday Lane 1

20 Roller passes; 18% voids

4 Roller passes → 28% voids

T = 145 °C

T = 100 °C

Distance in metres
Consequences on mixture stiffness (20 °C and 8 Hz) and tensile strength
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

<table>
<thead>
<tr>
<th>Phase</th>
<th>Day</th>
<th>Time frame</th>
<th>Repair</th>
<th>€</th>
<th>Repair</th>
<th>€</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>00.00-05.00</td>
<td></td>
<td></td>
<td>05.00-08.00</td>
<td></td>
</tr>
<tr>
<td>Repair</td>
<td>Mo-Fr</td>
<td>€ 12.500</td>
<td></td>
<td></td>
<td>€ 25.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sa-Sunday</td>
<td>€ 12.500</td>
<td></td>
<td></td>
<td>€ 25.000</td>
<td></td>
</tr>
</tbody>
</table>

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 collecting 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
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
• 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) \( € 4 / \text{kg} \)
- Damage to Ozone layer (CFK-11 eq) \( € 30 / \text{kg} \)
- Climate change (CO$_2$ eq) \( € 0.05 / \text{kg} \)
- Eco-toxicity (1.4-DCB eq dichlorobenzene) \( € 0.06 / \text{kg} \)
- Smog (C$_2$H$_2$ eq) \( € 2 / \text{kg} \)
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

- **Recycle BSM + HMA**
- **Recycle CTB & overlay GCS + HMA**
- **Mill, rework and replace HMA**
- **Patch & overlay**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Action</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR &gt;80</td>
<td>Patch</td>
<td>150mm (6&quot;)</td>
</tr>
<tr>
<td>CBR &gt;45</td>
<td>Patch</td>
<td>150mm (6&quot;)</td>
</tr>
<tr>
<td>CBR ±10</td>
<td>Rework</td>
<td>200mm (8&quot;)</td>
</tr>
<tr>
<td>CBR &gt;45</td>
<td>GCS</td>
<td></td>
</tr>
<tr>
<td>CBR &gt;80</td>
<td>CTB</td>
<td></td>
</tr>
<tr>
<td>CBR ±10</td>
<td>BSM</td>
<td></td>
</tr>
</tbody>
</table>

**30 million ESALs / 20 years**
<table>
<thead>
<tr>
<th>Material procurement / Construction activity</th>
<th>Unit</th>
<th>Energy consumed (Mj)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material procurement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graded crushed stone (GCS)</td>
<td>Mj / t</td>
<td>50</td>
</tr>
<tr>
<td>HMA manufacture</td>
<td>Mj / t</td>
<td>30</td>
</tr>
<tr>
<td>Cement</td>
<td>Mj / t</td>
<td>70</td>
</tr>
<tr>
<td>Bitumen</td>
<td>Mj / t</td>
<td>60</td>
</tr>
<tr>
<td>Material haulage</td>
<td>Mj / t km</td>
<td>1</td>
</tr>
<tr>
<td><strong>Construction activity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milling ¹</td>
<td>Mj / t</td>
<td>5</td>
</tr>
<tr>
<td>In situ recycling / stabilising</td>
<td>Mj / t</td>
<td>10</td>
</tr>
<tr>
<td>Processing aggregate layer</td>
<td>Mj / t</td>
<td>66</td>
</tr>
<tr>
<td>Ditto per m² for 150mm thick layer</td>
<td>Mj / m²</td>
<td>10</td>
</tr>
<tr>
<td>Compacting and finishing layer ²</td>
<td>Mj / m²</td>
<td>10</td>
</tr>
<tr>
<td>HMA paving and compaction</td>
<td>Mj / t</td>
<td>20</td>
</tr>
</tbody>
</table>
Whole of Life Cost & Energy Consumed

<table>
<thead>
<tr>
<th></th>
<th>$ / m²</th>
<th>MJ / m²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overlay</strong></td>
<td>88%</td>
<td>150</td>
</tr>
<tr>
<td><strong>Mill n Fill</strong></td>
<td>70%</td>
<td>100</td>
</tr>
<tr>
<td><strong>Recycle CTB</strong></td>
<td>69%</td>
<td>150</td>
</tr>
<tr>
<td><strong>Recycle BSM</strong></td>
<td>58%</td>
<td>50</td>
</tr>
</tbody>
</table>

88% of the cost and 133% of the energy consumption is for Overlay.
70% of the cost and 69% of the energy consumption is for Mill n Fill.
69% of the cost and 150% of the energy consumption is for Recycle CTB.
58% of the cost and 50% of the energy consumption is for Recycle BSM.
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!
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
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

G1 is top class base course material in South Africa
4% moisture
104% degree of compaction

CDW
Masonry : Concrete = 1 : 1 by volume

DOC=97%

DOC=105%
Cement treated Mixed Granulate

Masonry : Concrete

100 : 0  35 : 65  0 : 100
UCS 28 days

Unconfined compressive strength (MPa)

\[ f_c = 0.0747 \cdot \frac{C}{W} \cdot D^8 \cdot e^{0.0088 \cdot M} \]

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

\begin{align*}
    y &= 0.077x \\
    R^2 &= 0.96 \\
    y &= 0.100x \\
    R^2 &= 0.95 \\
    y &= 0.125x \\
    R^2 &= 0.95 \\
    y &= 0.191x \\
    R^2 &= 0.96
\end{align*}
## UCS Requirements

<table>
<thead>
<tr>
<th>Country</th>
<th>Curing</th>
<th>UCS (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C1</td>
</tr>
<tr>
<td>South Africa</td>
<td>7 days at 100% compaction</td>
<td>6~12</td>
</tr>
<tr>
<td></td>
<td>7 days at 97% compaction</td>
<td>&gt;4</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>7 days at 100% compaction</td>
<td>CBM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5~4.5</td>
</tr>
<tr>
<td>China</td>
<td>7 days at 100% compaction</td>
<td>Base of highway</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;4</td>
</tr>
</tbody>
</table>
Cement contents for CDW to fulfill Chinese and South African specifications

<table>
<thead>
<tr>
<th>Composition Masonry : Concrete</th>
<th>Cement content for base course in China or C1 in South Africa</th>
<th>Cement content for subbase layer in China or C2 in South Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 : 0</td>
<td>8.6 %</td>
<td>4.2 %</td>
</tr>
<tr>
<td>65 : 35</td>
<td>8 %</td>
<td>3.8 %</td>
</tr>
<tr>
<td>35 : 65</td>
<td>6.7 %</td>
<td>3.3 %</td>
</tr>
<tr>
<td>0 : 100</td>
<td>5.6 %</td>
<td>2.8 %</td>
</tr>
</tbody>
</table>
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 AND DURABILITY CAN GO “HAND IN HAND” AND SHOULD GO “HAND IN HAND”
THANK YOU FOR YOUR ATTENTION