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Bundesanstalt für
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Using Mechanistic-Empirical method to develope a catalouge design for cold recycled pavements in Germany

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2nd International Workshop on Asphalt Recycling Technologies - ART2025

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- Cold Recycling and Stabilization
- Bitumen Stabilized Material (BSM)
- The need for a catalogue
- ME design of pavements with BSM
- Proposed catalogue
- Validation
- Conclusion & Next steps

Cold Recycling & Stabilization

Cold Mixes	• Cold Process • Binding Agent • Aggregate mix
Cold Bituminous	• Cold • Bituminous • RA + VA
Bitumen Stabilized Mixes	• Cold • Low bitumen • RA + VA

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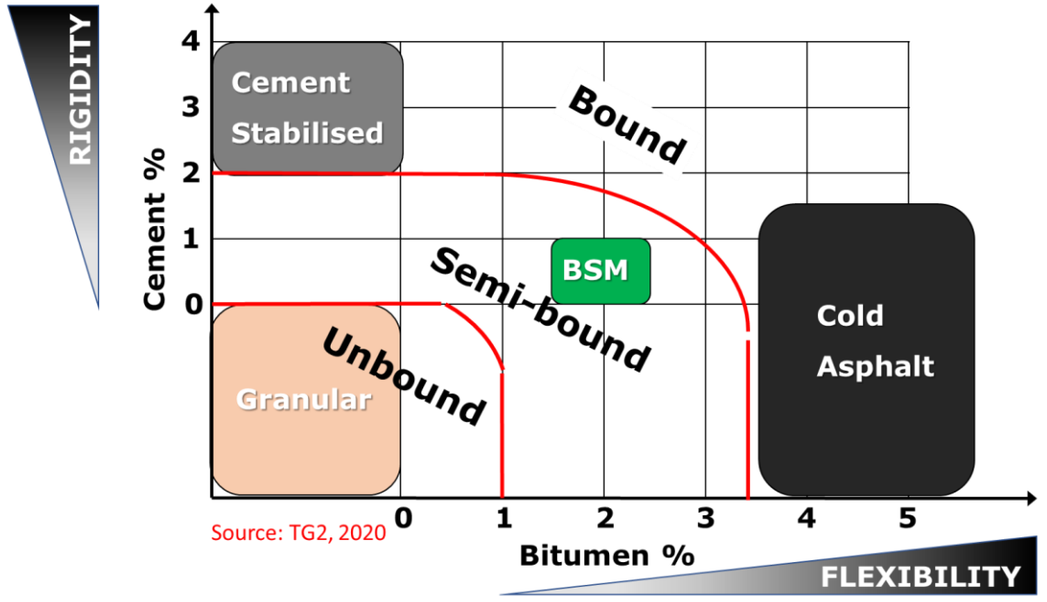
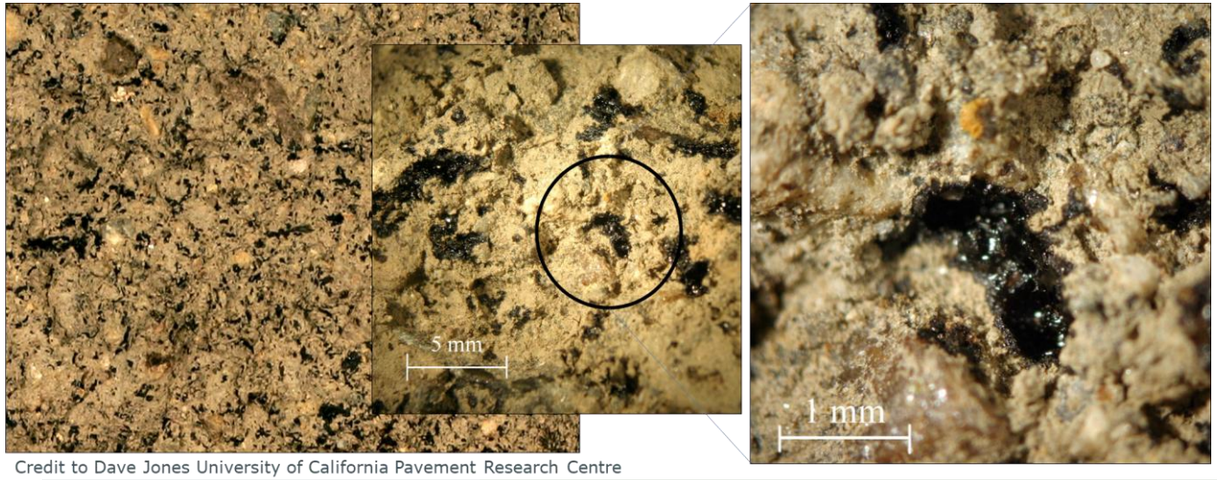
Bitumen Stabilized Material

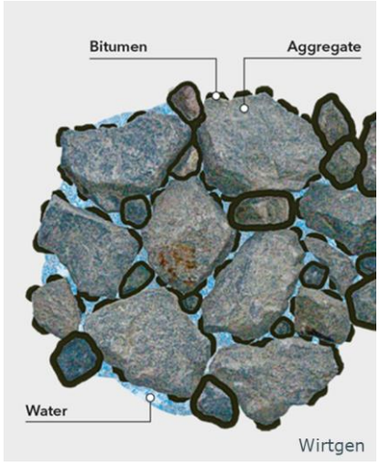
- Distribution of the bonds
  - Continuous
  - Non-continuous
- Failure
  - Crack
  - Permanent deformation



Source: TG2, 2020

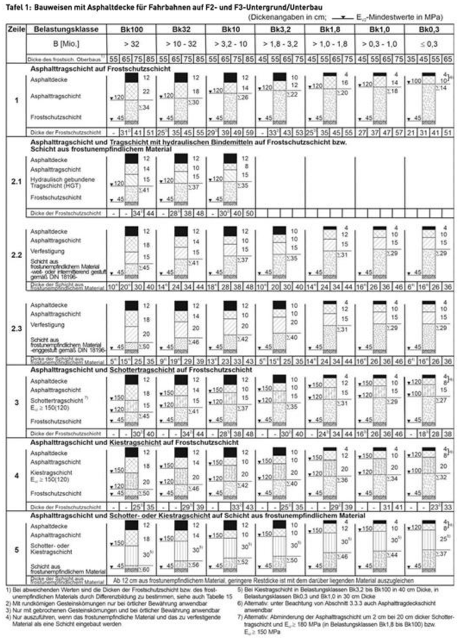


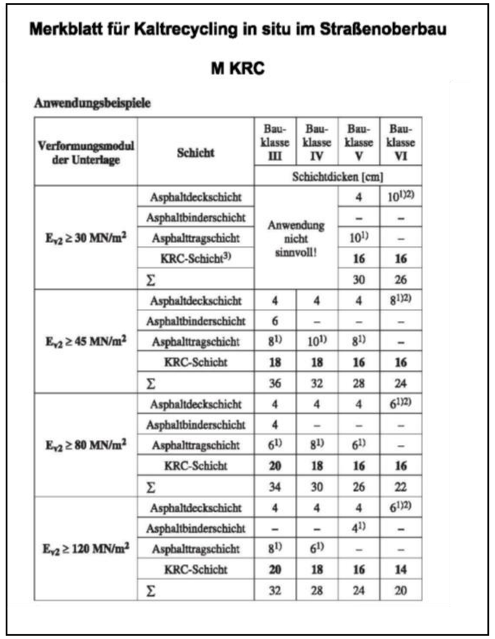
Credit to Dave Jones University of California Pavement Research Centre



The need for a catalogue in Germany

- Potentials + Positive international feedbacks on BSM -> increasing interest in Germany
- Besides the catalogue method, a well established ME method
- But, they don't include the BSM





Merkblatt für Kaltrecycling in situ im Straßenoberbau

M KRC

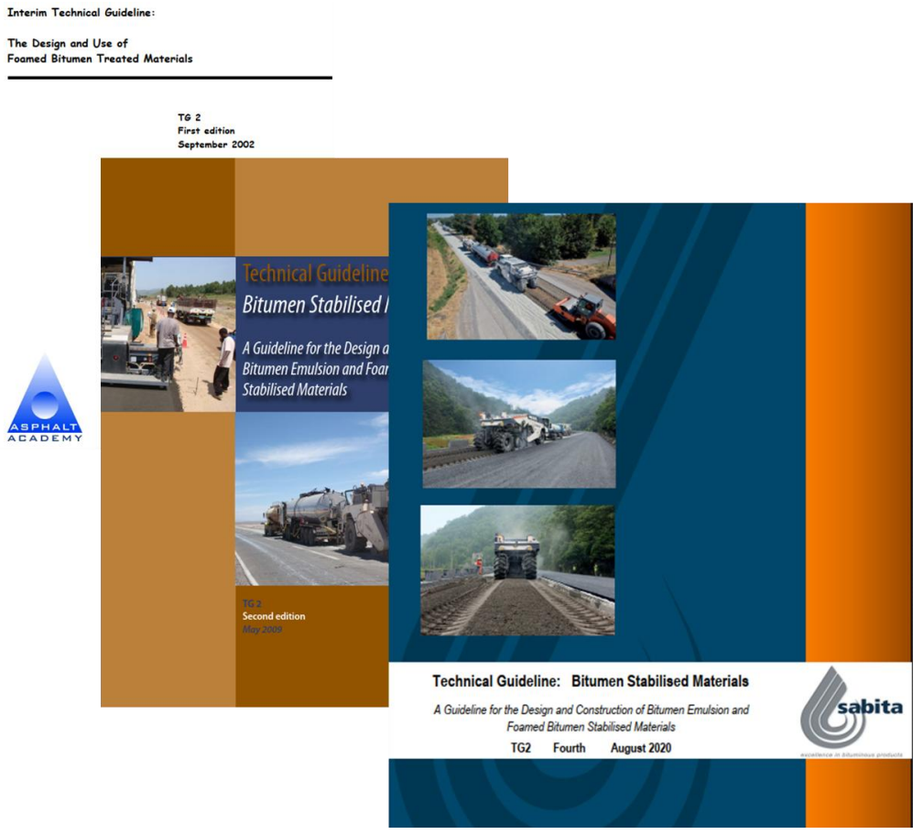
Anwendungsbeispiele

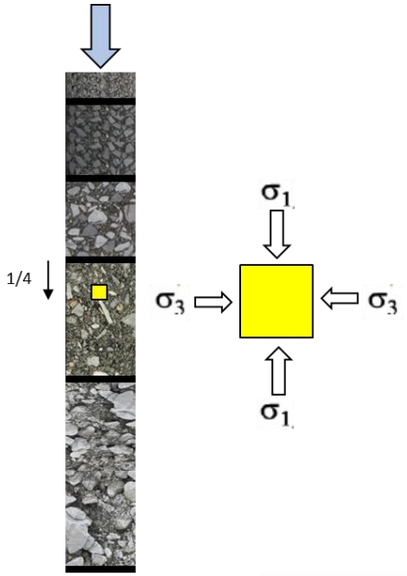
Verformungsmodul der Unterlage	Schicht	Bauklasse III	Bauklasse IV	Bauklasse V	Bauklasse VI
		Schichtdicken [cm]			
$E_{v2} \geq 30$ MN/m²	Asphaltdeckschicht	Anwendung nicht sinnvoll!		4	$10^{1)2)}$
	Asphaltbinderschicht			–	–
	Asphalttragschicht			$10^{1)}$	–
	KRC-Schicht$^{3)}$			**16**	**16**
	Σ			30	26
$E_{v2} \geq 45$ MN/m²	Asphaltdeckschicht	4	4	4	$8^{1)2)}$
	Asphaltbinderschicht	6	–	–	–
	Asphalttragschicht	$8^{1)}$	$10^{1)}$	$8^{1)}$	–
	KRC-Schicht	**18**	**18**	**16**	**16**
	Σ	36	32	28	24
$E_{v2} \geq 80$ MN/m²	Asphaltdeckschicht	4	4	4	$6^{1)2)}$
	Asphaltbinderschicht	4	–	–	–
	Asphalttragschicht	$6^{1)}$	$8^{1)}$	$6^{1)}$	–
	KRC-Schicht	**20**	**18**	**16**	**16**
	Σ	34	30	26	22
$E_{v2} \geq 120$ MN/m²	Asphaltdeckschicht	4	4	4	$6^{1)2)}$
	Asphaltbinderschicht	–	–	$4^{1)}$	–
	Asphalttragschicht	$8^{1)}$	$6^{1)}$	–	–
	KRC-Schicht	**20**	**18**	**16**	**14**
	Σ	32	28	24	20

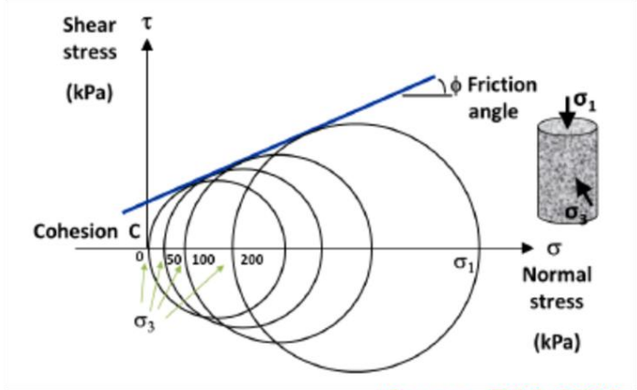
- A fast solution, producing a catalogue based on the existing international standard

ME design of pavements with BSM

- Like any other ME design concept
- TG2 guideline







Source: TG2, 2020

$$Deviator\ Stress\ Ratio\ (DSR) = \frac{\sigma_d}{\sigma_{d,f}} = \frac{\sigma_1 - \sigma_3}{\sigma_{1,f} - \sigma_3}$$

$$\sigma_{1,f} = \frac{(1 + sin\emptyset) \cdot \sigma_3 + 2 \cdot C \cdot cos\emptyset}{(1 - sin\emptyset)}$$

where

DSR	=	*Deviator Stress Ratio expressed as a fraction*
σ_1	=	*Major principle stress in the layer (kPa)*
σ_3	=	*Minor principle stress in the layer (kPa)*
$\sigma_{1,f}$	=	*Major principle stress at failure from a triaxial test (kPa)*
C	=	*Cohesion value of BSM from project mix design (kPa)*
Ø	=	*Friction Angle of BSM from project mix design*

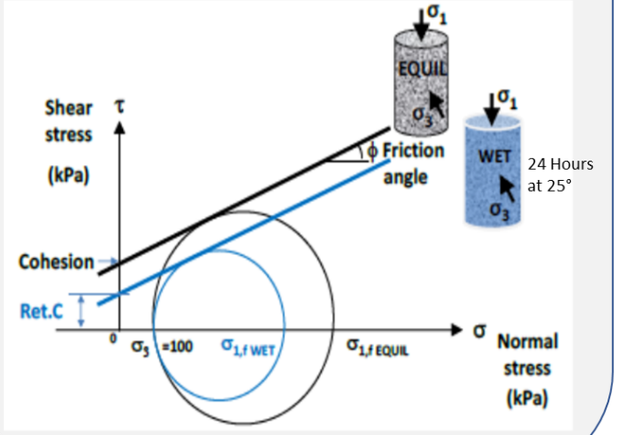
ME design of pavements with BSM

Mechanistic Part

Material & Pavement Model

$$\text{Deviator Stress Ratio (DSR)} = \frac{\sigma_d}{\sigma_{d,f}} = \frac{\sigma_1 - \sigma_3}{\sigma_{1,f} - \sigma_3}$$

$$\sigma_{1,f} = \frac{(1 + sin\emptyset) \cdot \sigma_3 + 2 \cdot C \cdot cos\emptyset}{(1 - sin\emptyset)}$$



Source: TG2, 2022

Empirical Part

Transfer Functions

Stellenbosch BSM Function (CAPSA,2019)

$$\log N = A - 57.286(DSR)^3 + 0.0009159(PMDD.RetC)$$

N = Number of axle repetitions to reach a set rut depth
P_{MDD} = BSM dry density expressed as a percentage of MDD (%)
DSR = Deviator Stress Ratio, as a fraction
RetC = Retained cohesion (%)
A = Reliability Coefficient linked to Road Category

Reliability	Road Category	A	Rut Limit (mm)
95%	A	1.71113	10
90%	B	1.79873	15
80%	C	1.88733	20
50%	D	2.00443	25

Source: TG2, 2022

Loudon's BSM Function

$$\log N = A + B(RD) + C(RetC) + D(PS) + E(DSR)$$

N = Number of axle repetitions to reach a set rut depth
RD = Relative Density (%)
DSR = Deviator Stress Ratio, as a fraction
RetC = Retained cohesion (%)
PS = Allowable Plastic Strain (% of the layer thickness)
A = 1.55 (constant for 90% reliability)
B = 0.10 (empirical constant)
C = 0.05 (empirical constant)
D = 0.10 (empirical constant)
E = -22.3333 (empirical constant)

Source: Loudon

Design parameters

- The same loading classes as RStO 12/24
- Input parameters for the design
  - HMA: all three layers 5000 MPa, 0.35
  - BSM: 900 MPa, 0.3
  - Anti-frost: 200 (130) MPa, 0.49
  - Subgrade: 45 MPa, 0.49
  - ❖ For Anti-frost layer, the modulus was calculated for a 30 cm layer over the subgrade of 45 MPa to reach the desired Ev2 value (60 to 150 MPa) on top of that
- Extra inputs for the BSM

Description	Parameter
Relative density	86%
Allowed deformation	5% of thickness
Retained cohesion	75%
Cohesion	250 kPa
Angleof friction	40°

Relevant design traffic and assigned load class (RStO 12/24, 2024)

Equivalent 10-t-standard axles (Million ESALs)	Load class
Above 32	Bk 100
From 10 to 32	Bk 32
From 3.2 to 10	Bk 10
From 1.8 to 3.2	Bk 3.2
From 1.0 to 1.8	Bk 1.8
From 0.3 to 1.0	Bk 1.0
to 0.3	Bk0.3

Design software

Rubicon® Toolbox

Name: BK100

Notes:

Description:

Material Class	Thickness (mm)	Stiffness (MPa)	Poisson's Ratio	Transfer Function	Other
German Asphalt Surface (User Defined)	100	5000	0.35	Shell Asphalt Fatigue SF = 5	Edit
German Asphalt Base (User Defined)	80	5000	0.35	Shell Asphalt Fatigue SF = 5	Edit
BSM1	200	900	0.3	BSM Loudon (unpublished)	Edit
RSA G5 Wet (German Equivalent) (User D	300	200	0.49	RSA Granular Shear Cat A	Edit
RSA G8 Subgrade (German Equivalent) (U	Semi-Inf	45	0.49	RSA Subgrade Rut, 10mm, Cat A	N/A

Bitumen Stabilised Materials - Loudon Criteria

Relative Density Proportion:	86	(%)
Allowed Deformation:	5	(% of thickness)
Retained Coh:	75	(%)
Cohesion:	250	(kPa)
Angle of Friction:	40	(Degrees)

Reset To Material Default | OK

Pavement Situation At Start of Phase 1 of 1
Layered Elastic Evaluation for Standard Axle

Design Name: BK100

Axle Details: Loudon Germany 50 KN single axle
Effective Structural Capacity for All Phases is > 99 million Standard Axles
Time to Exceed Capacity for All Phases: 79.25 Years
Effective Structural Capacity for this Phase Only is > 99 million Standard Axles
Time to Exceed Capacity for THIS Phase only: 79.25 Years

Thickness = 100 mm German Asphalt Surface (User Defined) Stiffness = 5000 MPa; Poisson = 0.35 Criterion: Shell Asphalt Fatigue SF = 5 Bitumen Content by Vol = 10.0%	Maximum Horizontal Tensile Strain = 19 Critical Position: Bottom of Layer/Load Centreline Basic Axle Capacity: > 100 million Effective Axle Capacity: > 100 million Damage in this Phase from 0.00 to 1.00
Thickness = 80 mm German Asphalt Base (User Defined) Stiffness = 5000 MPa; Poisson = 0.35 Criterion: Shell Asphalt Fatigue SF = 5 Bitumen Content by Vol = 10.0%	Maximum Horizontal Tensile Strain = 99 Critical Position: Bottom of Layer/Load Centreline Basic Axle Capacity: > 100 million Effective Axle Capacity: > 100 million Damage in this Phase from 0.00 to 1.00
Thickness = 200 mm BSM1 Stiffness = 900 MPa; Poisson = 0.3 Criterion: BSM Loudon (unpublished) RD = 86%; Plastic Strain = 5%; Ret-Coh = 75%; C = 250 kPa; Phi = 40	Shear Stress Ratio = 0.173 Critical Position: 25% Layer Depth/Load Centreline Basic Axle Capacity: > 100 million Effective Axle Capacity: > 100 million Damage in this Phase from 0.00 to 1.00
Thickness = 300 mm RSA G5 Wet (German Equivalent) (User Defined) Stiffness = 200 MPa; Poisson = 0.49 Criterion: RSA Granular Shear Cat A Cohesion = 30 kPa; Angle of Friction = 40.5	Shear Stress Safety Factor = 3.58 Critical Position: Middle of Layer/Load Centreline Basic Axle Capacity: > 100 million Effective Axle Capacity: > 100 million Damage in this Phase from 0.00 to 1.00
Thickness = Semi-Infinite; RSA G8 Subgrade (German Equivalent) (User Defined) Stiffness = 45 MPa; Poisson = 0.49 Criterion: RSA Subgrade Rut, 10mm, Cat A None	Vertical Compressive Strain = 212 Critical Position: Top of Layer/Load Centreline Basic Axle Capacity: > 100 million Effective Axle Capacity: > 100 million Damage in this Phase from 0.00 to 1.00

Load Details:
Setup: Loudon Germany 50 KN single axle; Daily Count = 500
Growth Rates: Yr 0 to 5 = 4% ; Yr 5 to 10 = 4% ; Yr 10 to End = 4%

Pavement Notes:

Rubicon Toolbox

Proposed catalogue

Load class (million ESALS of 10t)	**Bk 100 > 32**		**Bk 32 > 10 - 32**		**Bk 10 > 3.2 - 10**		**Bk 3.2 > 1.8 – 3.2**		**Bk 1.8 > 1.0 – 1.8**		**Bk 1.0 > 0.3 – 1.0**		**Bk 0.3 ≤ 0.3**	
	RStO 12	**BSM**	RStO 12	**BSM**	RStO 12	**BSM**	RStO 12	**BSM**	RStO 12	**BSM**	RStO 12	**BSM**	RStO 12	**BSM**
Asphalt Surface (cm)	12	10	12	10	12	10	10	10	4	4	4	4	4	4
Asphalt Base (cm)	22	8	18	8	14	-	12	-	16	-	14	-	10	-
BSM (cm)	-	20	-	15	-	20		15	-	25	-	20	-	20
E_{v2} under BSM (MPa)	≥ 120												≥ 100	
Anti-frost layer (cm)	The thickness of the Anti-frost layer should be determined according to the frost-depth, based on the RStO 12/24													
E_{v2} over subgrade (MPa)	≥ 45													

- For Bk3.2 to Bk100, Stellenbosch and for the lower 3 classes the Loudon
- Lower classes: 4 cm HMA wearing course
- Middle classes: + min. 6 cm HMA binder course
- Higher classes: + min. 8 cm HMA base course

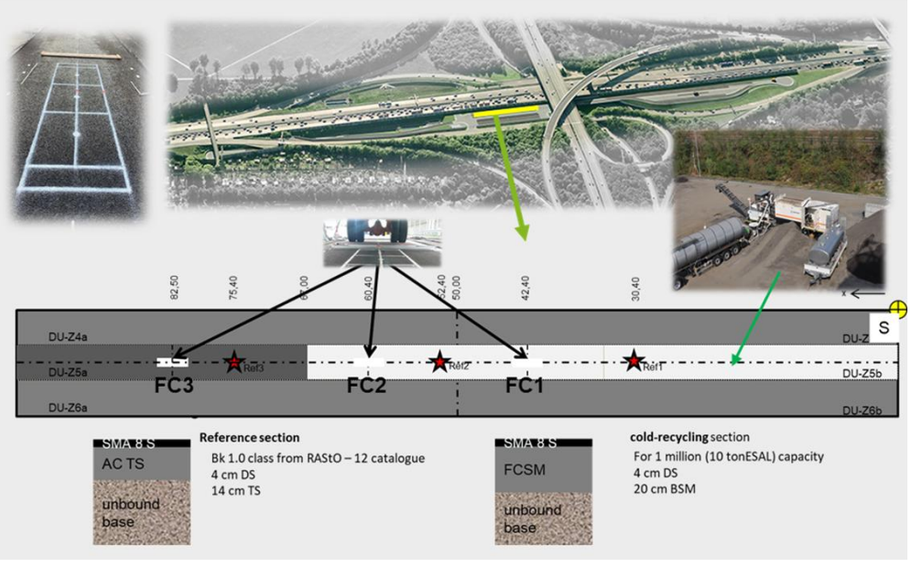
Proposed catalogue

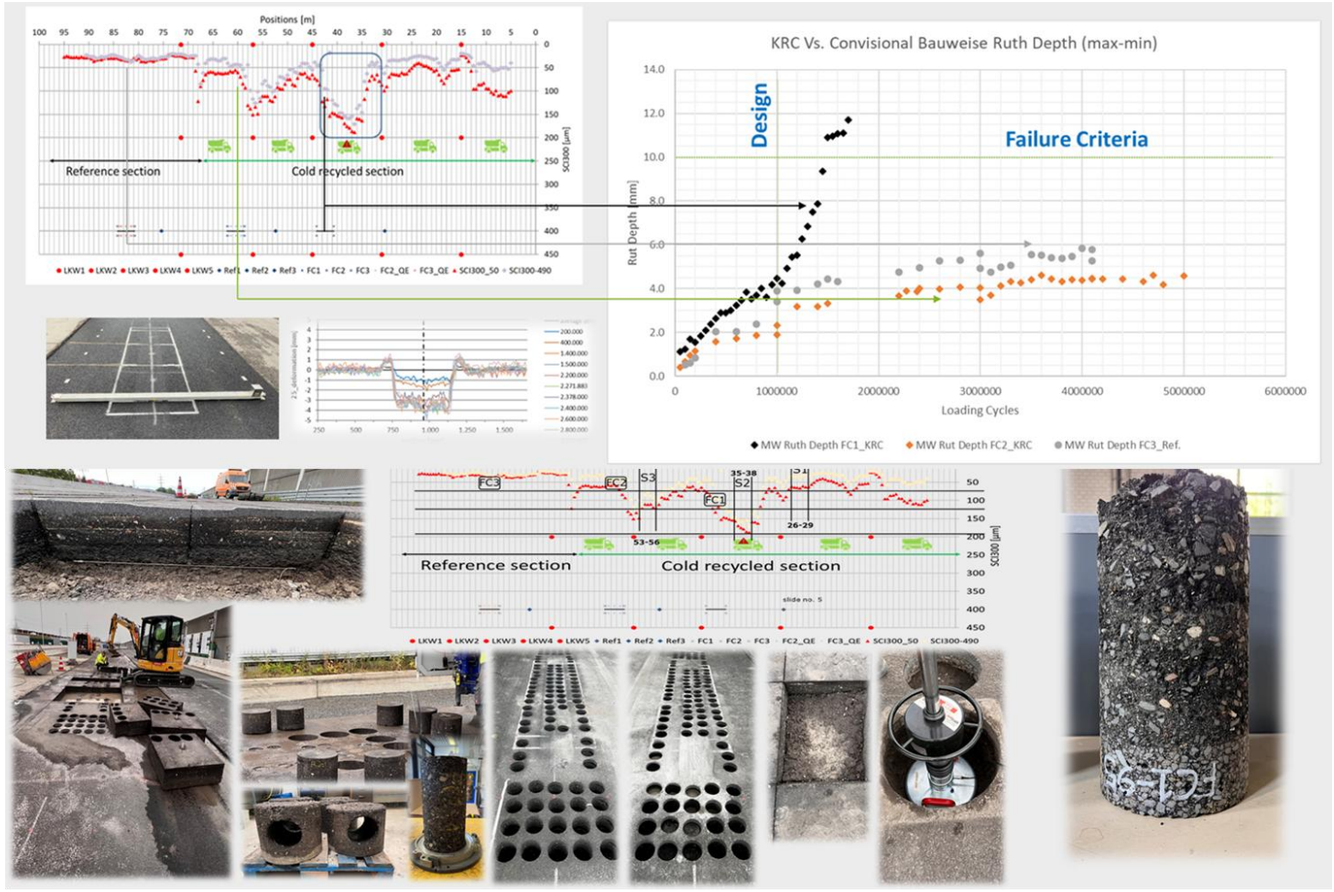
E_{v2} uK. BSM (MPa)	Schichten (cm)	Bk						
		0,3	1,0	1,8	3,2	10	32	100
150	Asphaltdecke		4	4	10	10	10	10
	Asphalttragschicht		-	-	-	-	8	8
	BSM		20	23	13	19	14	18
120	Asphaltdecke		4	4	10	10	10	10
	Asphalttragschicht		-	-	-	-	8	8
	BSM		20	25	15	20	15	20
100	Asphaltdecke	4	4	4	10	10	10	10
	Asphalttragschicht	-	-	-	-	-	8	8
	BSM	20	24	30	16	20	18	20
80	Asphaltdecke	4	4	4	10	10		
	Asphalttragschicht	-	-	-	-	-		
	BSM	20	26	32	17	21		
60	Asphaltdecke	4	4	4				
	Asphalttragschicht	-	-	-				
	BSM	22	28	32				
45	Asphaltdecke	4	4	4				
	Asphalttragschicht	-	-	-				
	BSM	24	30	33				

Validation

Validation trough APT projects in duraBASt (BASt's outdoor facility)

- Construction 2019, In-Plant production
- 75% RAP + 25% Sand (0-2mm)
- 2.2% bitumen, 1% cement (1-425N)
- Loading 2020 -22, total of 10.9 Million (10 ton axle)





Kalantari, M. 2023. ***Cold recycling with foamed bitumen, gained knowledge from a test track in Germany,*** **Roads and Bridges- Drogi I Mosty. 2023, 22(4), 463–480**

Conclusion & Next steps

- An ME approach was used to produce a catalogue design for BSM in Germany.
- The lower loading classes (Bk 1.8), were validated with APT in BASt's outdoor facility.
- The proposed catalogue seems to be conservative but justification will be possible after more national projects and validations.
- The catalogue can be used as a fast orientation for other countries too.
- Other criteria as the fatigue of HMA, can be controlled on the basis of the existing ME method in Germany (RDO guideline).
- The thicknesses need to be checked from construction point of view to be then finalized.

Acknowledgment

- My colleagues in Loudon International:
  - A.H. Greyling
  - C. Whitehead
  - A.J. Robertson

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Thank you for your attention!

I will be happy to answer your questions

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