Bearing capacity and long-term performance of crushed concrete in highway structures

NVF Road Technology webinar

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RAMBOLL

Bright ideas.
Sustainable change.

About speaker

- A Lappish guy whos been lost at Southern part of Finland over a couple of decades, lives in Tampere.
- M.Sc. In Infrastructural engineering(2008) Tampere University of Technology
- Working at Ramboll as a specialist. The key competences are road and railway structures, especially materials/aggregates/pavements and bearing capacity and life cycle of structures.

- History:
  - 2008-2013 Tampere University of Technology, researcher
  - 2014-2018 Ramboll (Specialist) & Tampere University of Technology (researcher)
  - 2019→ Ramboll, Specialist

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Agenda

- Study in brief
- Test sites
- Examples of results
- ”New” types of structures for crushed concrete
- Conclusions

Study in brief

- A study Ramboll conducted for Finnish Transport and Infrastructure Agency (FTIA).
- The aim of this study was to determine how crushed concrete has performed in road structures over the long term.
- Crushed concrete has been used in road structures in Finland since the mid-1990s, and some of the test sites have been monitored with FWD-measurements.
- This study included two highway projects from the mid/late 1990s and one project completed about five years ago, which used crushed concrete in its structures.
- In previous studies, the long-term monitoring has focused on tracking the development of the overall stiffness of the structure.
- The main content of this study is related to more detailed analysis of measurements taken from test structures and the investigation of the load-bearing capacity of the crushed concrete structure.

Study in brief

- FWD measurements were carried out in the selected sites during the summer of 2024. The structural thickness data of the sites were considered sufficiently accurate based on previous studies and registry information.
- Using the measured deflections and determined structural layer thickness data, back-calculations were performed to determine the stiffness modulus of the structural layers for the test sections.
- The obtained data were used for calculations with tool based on multi-layer theory (ERAPAVE) and with a software based on the finite element method (PLAXIS 3D). A cross-comparison between the methods was carried out to assess the reliability of the results.
- Based on the obtained results, the most suitable location for crushed concrete in road structures was determined to be the base course. It was also possible to define the sufficient thickness to crushed concrete layer to ensure the long-term functionality of the crushed concrete layer.
- Sensitivity analyses were performed with the selected assumptions for structure types corresponding to load classes 10.0; 25.0; and 60.0 (referring to Millions of ESALs).

Process for the study

Selection of test sites
Existing studies
FTIA project database

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FWD-measurements

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Back calculation
Determination of moduli values for structural layers

↓ ↓

MLET analysis with ERAPAVE
Critical strains

FEM analysis with PLAXIS 3D
Effect of dynamic loading

↓ ↓

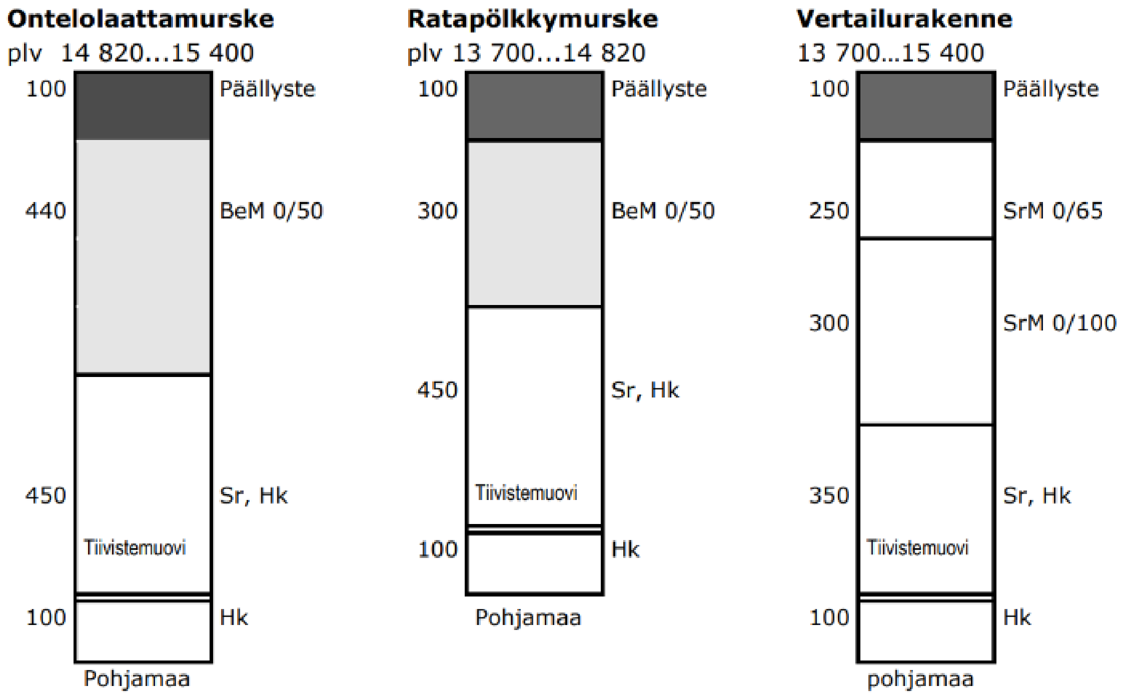
Sensitivity analysis
Calculations verified with two methods
Use of existing fatique models
New possible structure types for Crushed concrete

Test sites

Test site	E12 Metsäkylä-Sasi	E75 Järvenpää-Mäntsälä	E8 Nousiainen-Mynämäki
Road address	3/203/4900-3/203/6625	4/109/1250-4/109/3925	8/106/500-8/106/6110
Constructed in	1996	1998	2019
Average daily traffic	ca. 11 000	ca. 24 500	ca. 5 000
Average daily heavy traffic	ca. 870	ca. 2 030	ca. 900

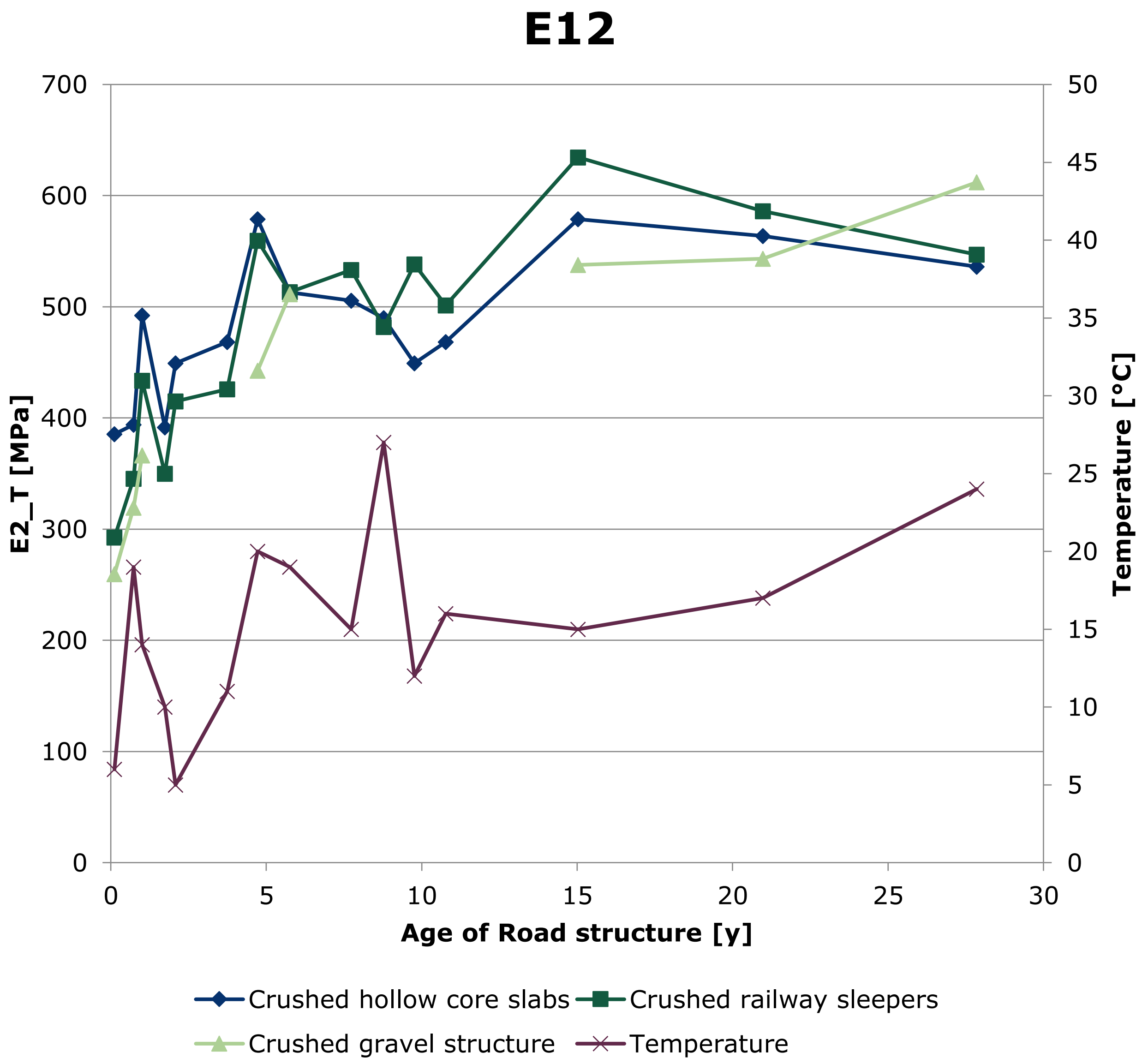
The sites E12 and E75 have been monitored more or less regularly since their construction. The site E8 has not been monitored before this study, but the crushed concrete sections built in the project were obtained from FTIA database Velho.

Test site E12

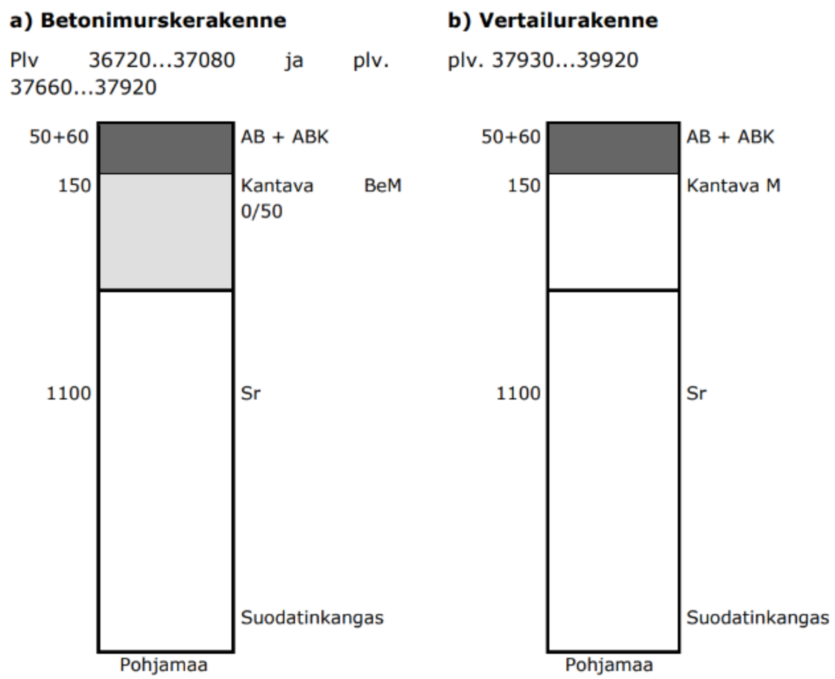


Kuva 5. Vt 3, välillä Metsäkylä-Sasi 1996. Suunnitellut betonimurskerakenteet ja vertailurakenne.

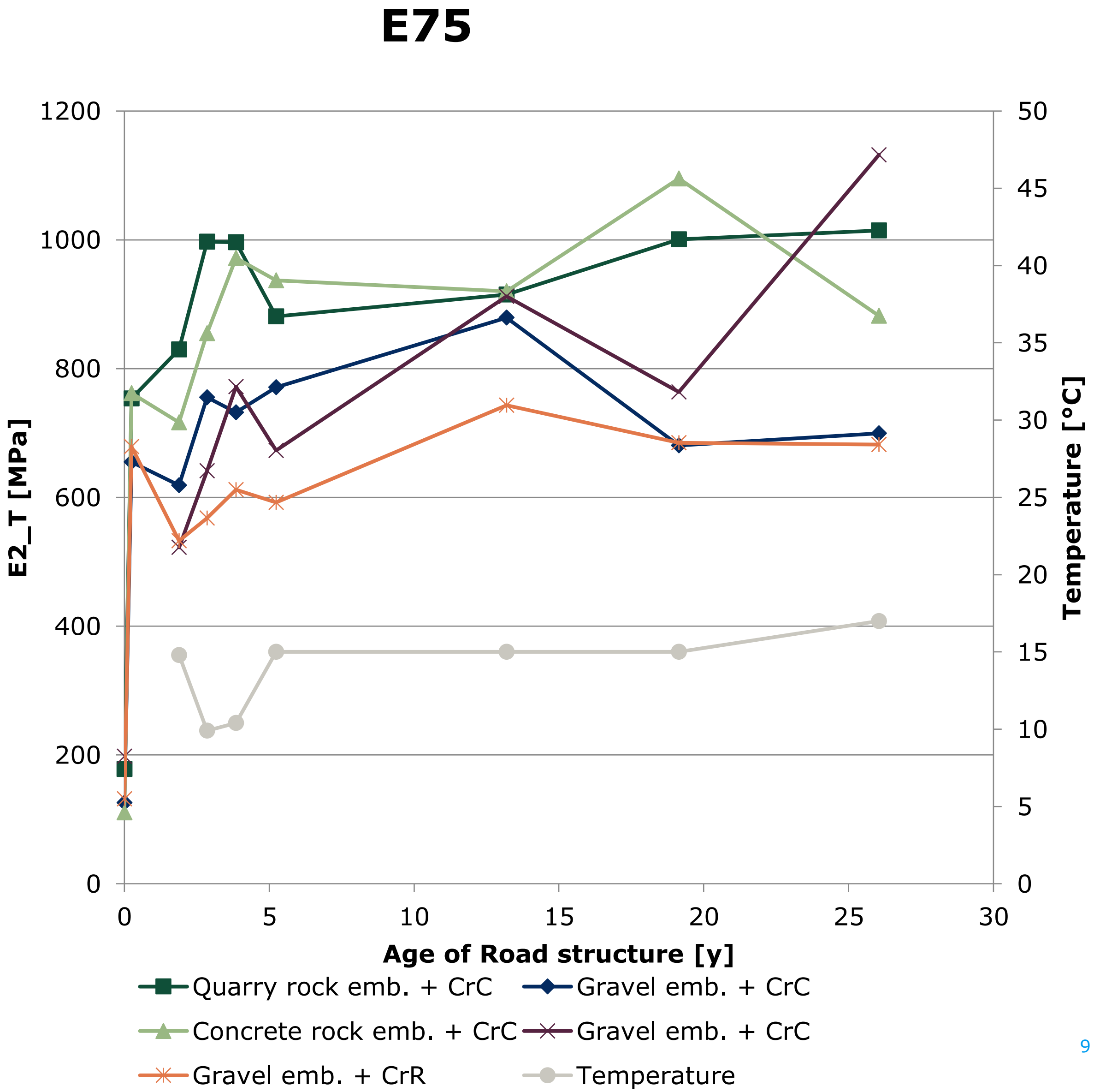
GPR in 2012, pavement thickness ca. 120…140 mm.
Pavement remixed in 2014 (in-situ rut-remix)
Overlay in 2017. Remix in early May 2024.
→ Total pavement thickness 160…180 mm.



Test site E75



Kuva 10. VT 4. Suunnitellut betonimurskerakenne ja vertailurakenne.



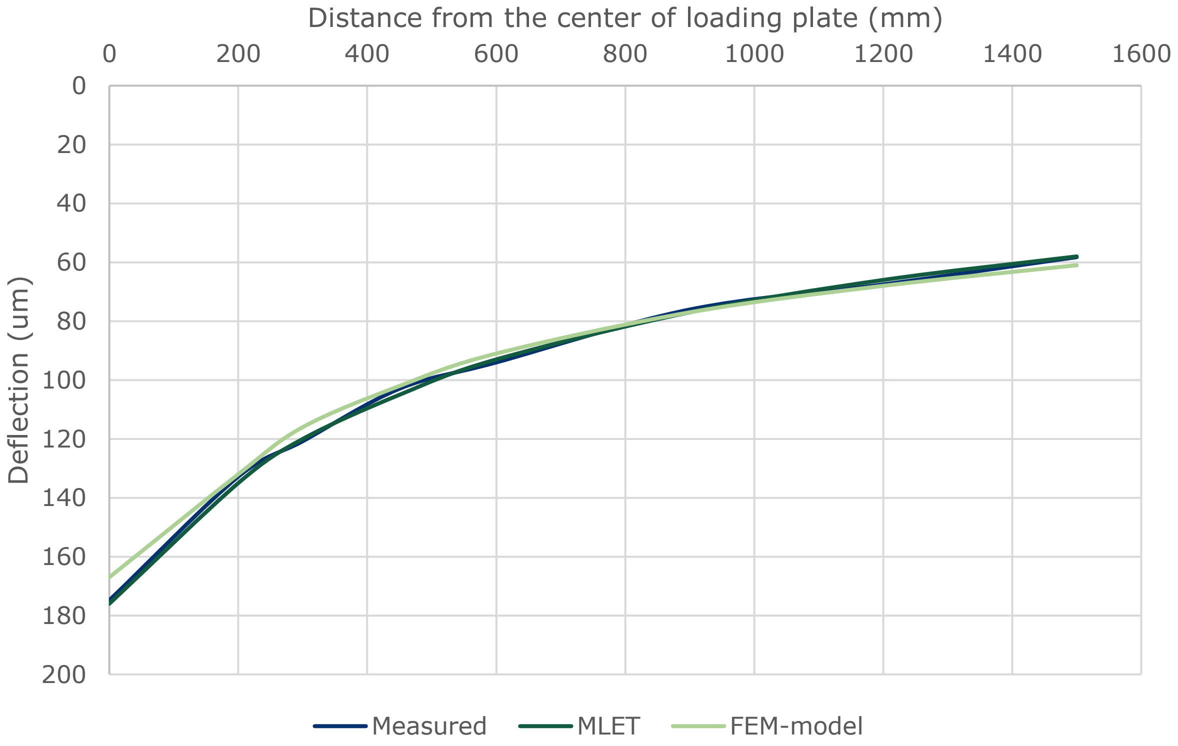
GPR in 2012, pavement thickness ca. 200 mm.
Pavement remixed in 2013
Milling + Overlay in 2017. Remix in 2023.
→ Total pavement thickness 220…240 mm.

Example of results

- Back calculated moduli values for structural layers at test site E75.

Structure					
Base course	Embankment	Pavement	Base course	Embankment/ Road structure	Subgrade
CrC	Gravel	4376	1031	515	139
CrC	Quarry rock	4672	875	400	117
CrC	Concrete rock	4560	887	562	189
CrR	Gravel	3769	582	222	127

- Deflection basins at test site E75, quarry rock embankment.



Example of results

- Critical strains at test site E75.

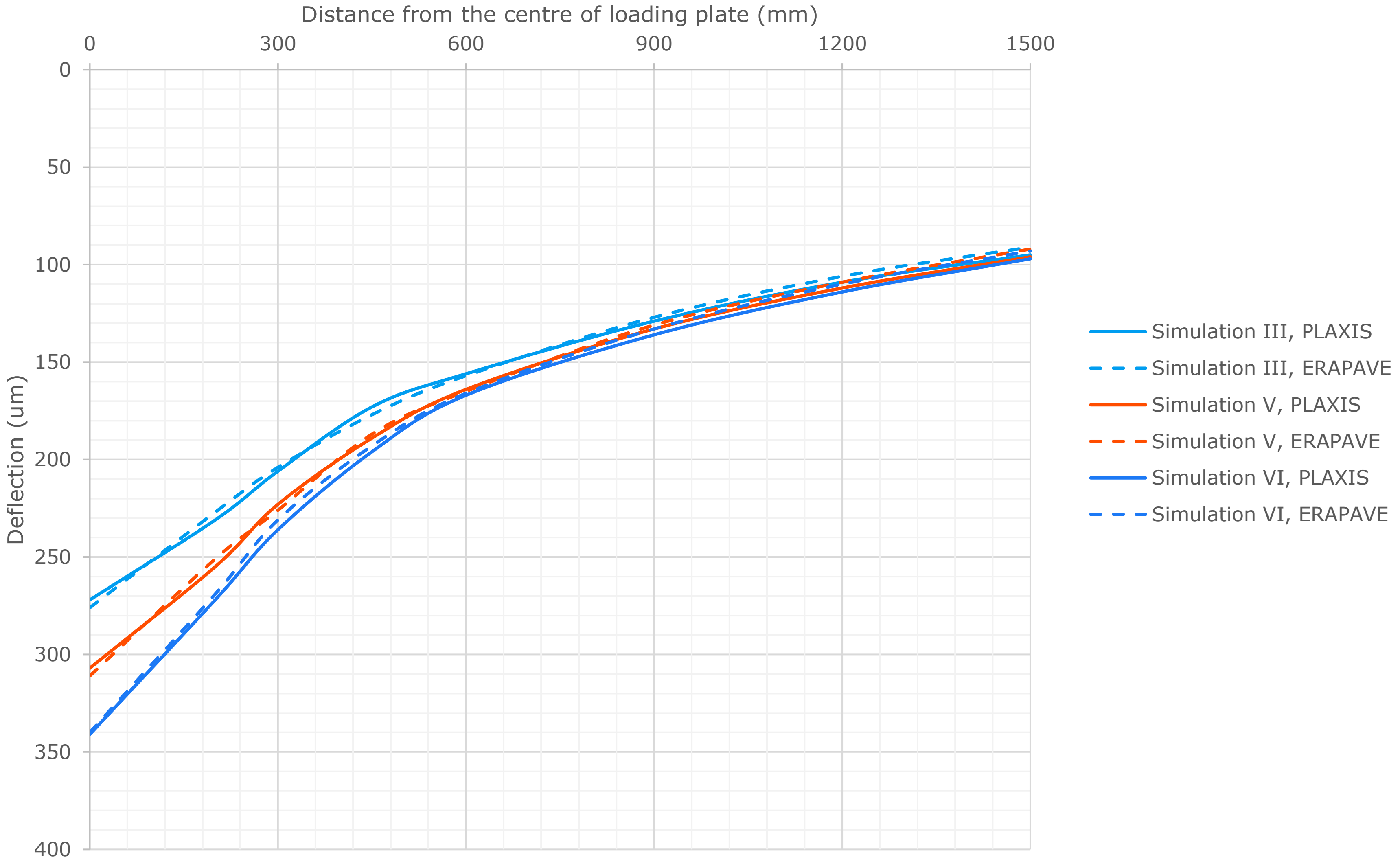
Gravel embankment + crushed concrete						
Method	Pavement strain (um/m)		Compressive strain on top of base course (um/m)	Compressive strain on top of the subgrade(um/m)	Strain at the bottom of crushed concrete (um/m)	
	ε_{xx}	ε_{yy}	ε_{zz}	ε_{zz}	ε_{xx}	ε_{yy}
ERAPAVE	79	79	202	37	61	61
PLAXIS	89	92	195	52	113	114
Quarry rock embankment + crushed concrete						
ERAPAVE	65	65	161	38	57	57
PLAXIS	71	72	140	40	52	50
Concrete rock embankment + crushed concrete						
ERAPAVE	78	78	225	149	60	60
PLAXIS	81	83	189	43	56	54
Gravel embankment + crushed rock aggregate						
ERAPAVE	80	80	198	46	82	82
PLAXIS	90	93	135	55	131	133

Defining new types of structures for crushed concrete

The assessed structure had an overall thickness of approximately 1.5…1.6 meters.
The modules for this assessment were selected based on the structural layer moduli back-calculated from the test sites. The selected modules are intentionally somewhat conservative to initially determine the minimum potential of crushed concrete structures in terms of load-bearing capacity.
(*Simulation VII is the comparison structure, which is entirely constructed of aggregates, and the moduli values for the unbound structural layers are based on the Finnish guidelines for road structure design.

Structural layer	**Pavement**		**Crushed concrete base course**		**Sub-base**		**Filtration/frost protection**		**Subgrade**	
Simulation	Thickness (mm)	Moduli value (MPa)	Thickness (mm)	Moduli value (MPa)	Thickness (mm)	Moduli value (MPa)	Thickness (mm)	Moduli value (MPa)	Thickness (mm)	Moduli value (MPa)
I	200	3500	300	400	300	200	800	100	-	100
II	200	3500	300	400	300	200	800	100	-	50
III	200	3500	400	400	300	200	700	100	-	100
IV	160	3500	300	400	300	200	800	100	-	100
V	160	3500	400	400	300	200	700	100	-	100
VI	130	3500	400	400	300	200	800	100	-	100
VII	240	3500	300 (*	280 (*	300	200	800	100	-	100

The effect of pavement thickness on the deflection basin of a crushed concrete structure



The life cycle of new types of structures for crushed concrete

	Pavement strain (um/m)		Allowed number of ESALs (Million)		Pavement strain defined from deflection basin (um/m)		Allowed number of ESALs (Million)	
Simulation	PLAXIS	ERAPAVE	PLAXIS	ERAPAVE	PLAXIS	ERAPAVE	PLAXIS	ERAPAVE
I	113	110	72,1	81,3	119	121	57,1	52,9
II	116	110	64,1	81,3	118	115	59,3	66,6
III	114	108	69,3	88,3	114	119	69,2	57,1
IV	146	143	22,8	24,9	139	143	28,3	24,9
V	141	140	26,6	27,4	135	137	32,3	30,3
VI	178	162	9,3	14,2	160	162	15,0	14,2
VII	117	115	61,6	66,6	111	117	78,1	61,6

Conclusions

- Based on the obtained results, it seems that a more compared to traditional load-bearing design, more advanced design methods can provide significantly more information about the load-bearing capacity of road structures.
- However, wider use of structural design would also require updating the fatigue models used to assess load-bearing capacity.
- By using high-quality, cohesive crushed concrete instead of unbound crushed rock aggregate in the base course, with a sufficiently thick layer (approximately 400 mm), it is possible to construct a road with comparable design life using a thinner overall pavement thickness. Even with the relatively conservative assumptions used in the study, the impact was equivalent to about one pavement layer/slab (40 mm).
- One notable observation was the E8 structure type BeM B, which utilized foam glass lightweight fill with the minimum cover depth as per guidelines (0.8 meters in Finland). In this case, the determined design life of the structure was significantly shorter (about 3.5 million ESALs) compared to otherwise consistent load class 10.0 structure (10 million ESALs).

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