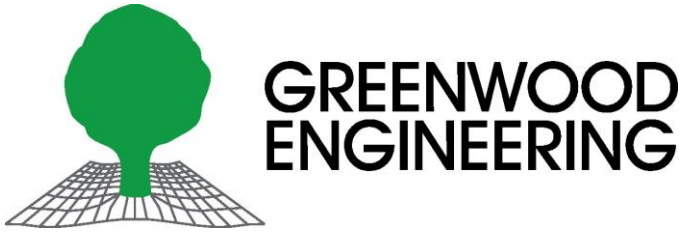
Combining Deflection Measurements with High Quality Surface Images

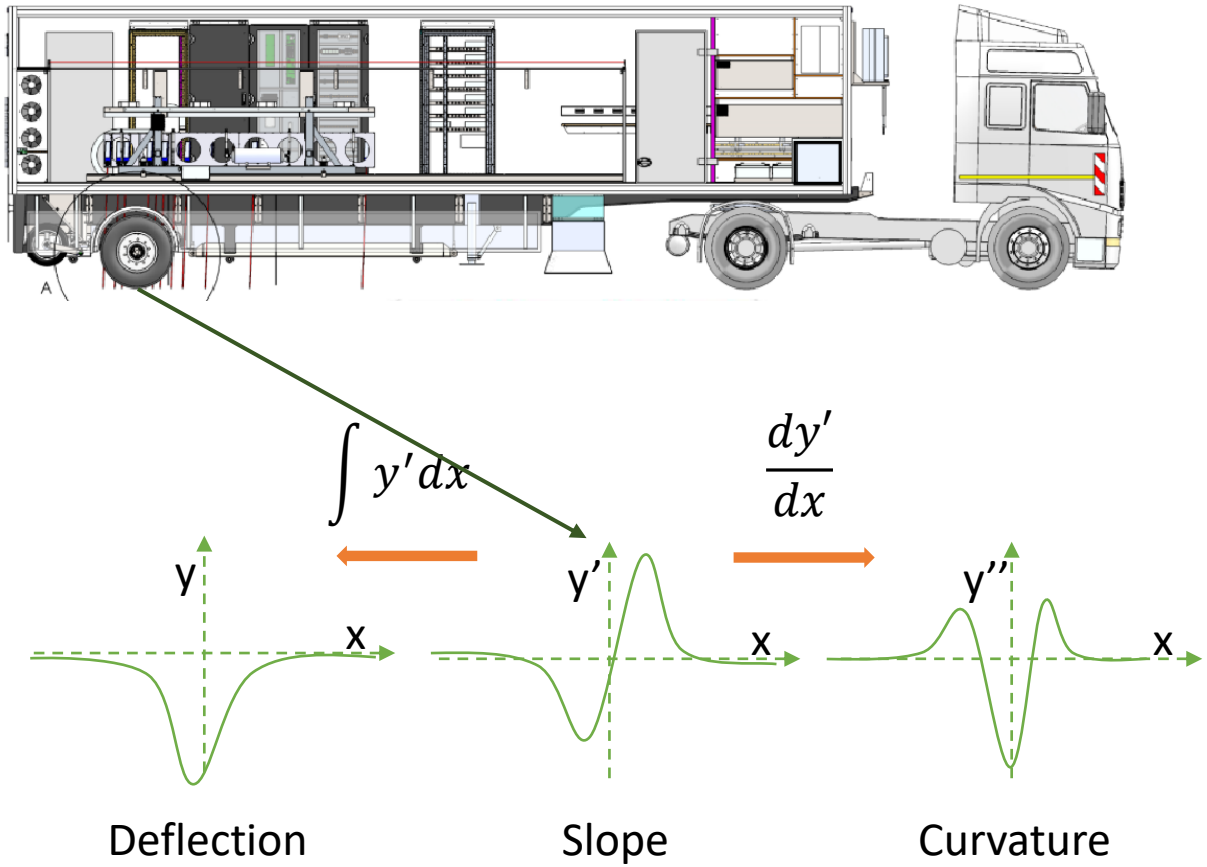
David Malmgren-Hansen,
Greenwood Engineering A/S



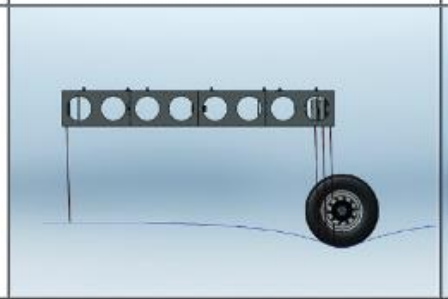
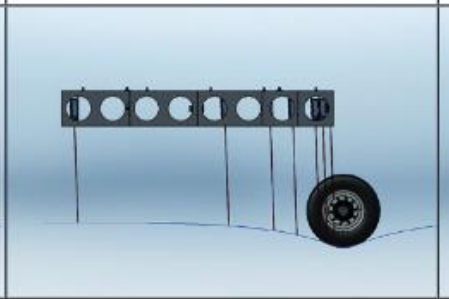
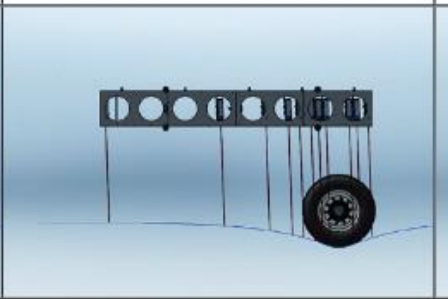
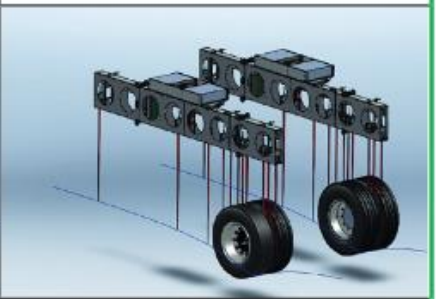
TSD - Intro

GE Traffic Speed Deflectometer

- Measures dynamic pavement response under axle load with Doppler laser technology @ traffic speed.
- Response is measured by the slope curve of the deflection.
- Integration of the slope curve gives deflection.
- Differentiation of slope give curvature.
- Next year SIS is an add-on option for GE TSD's



TSD - Intro

	Generation 1 (2004-2008)	Generation 2 (2009-2017)	Generation 3 (2018-2019)	Generation 4 (2020-now)
Vehicle number	TSD 1 + TSD 2	TSD 3 - TSD 12	TSD 4 + TSD 14 + TSD 15	TSD 7 + TSD 16 and newer
				
Number of sensors in front of rear axle	4 sensors	7 sensors	8 sensors	8 sensors with options for more lasers
Number of sensors behind rear axle	-	-	3 sensors	3 sensors
Laser type	1 kHz Doppler laser	1 kHz Doppler laser	1 kHz Doppler laser	250 kHz Doppler laser

...

TSD – New Index

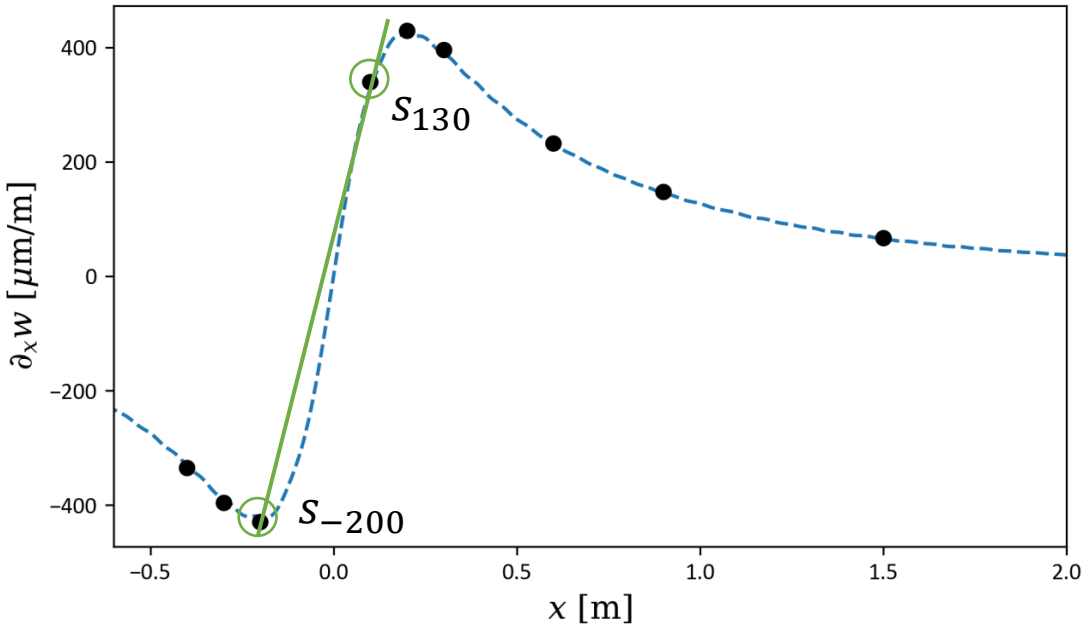
- Maximum curvature can be represented with an index.
- The new index is called SCI_{TSD}:

$$SCI_{TSD} = \frac{s_{130} - s_{-200}}{2} * 0.33m$$

- This is proportional to maximum strain in the bottom of the top layer.

$$\varepsilon = \frac{H}{2}\frac{\partial^2 w}{\partial x^2} \Rightarrow \frac{H}{(330mm)^2} \cdot SCI_{TSD}$$

	SCI 300	SCI_TSD
Calculated from	Deflection	Slopes
Dependency	Model (Integration)	None
Highest Resolution	1 m	5 cm



TSD - Strain

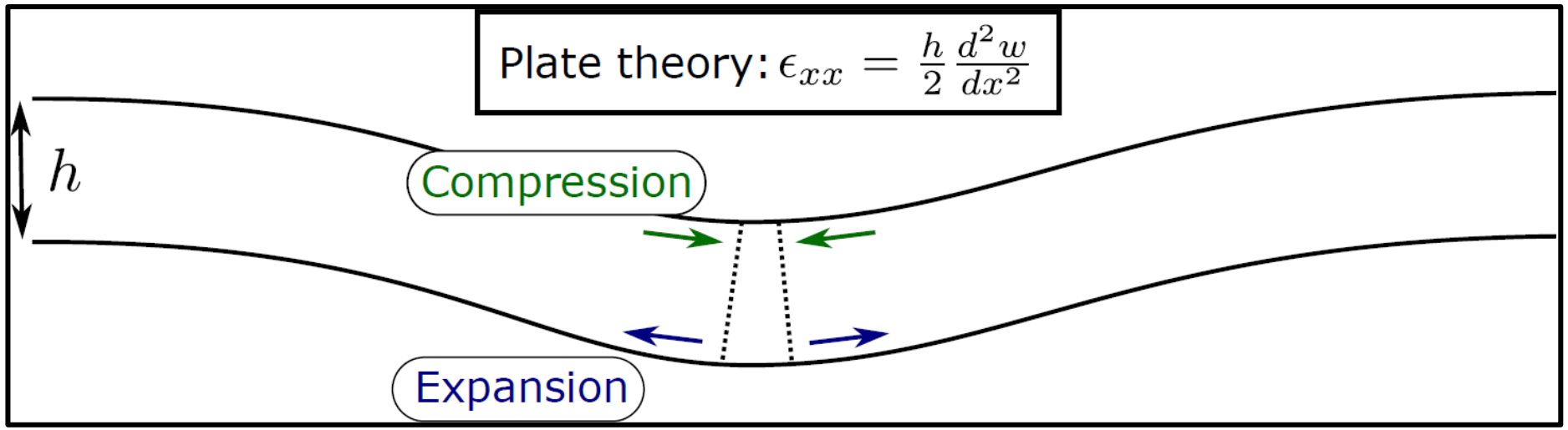
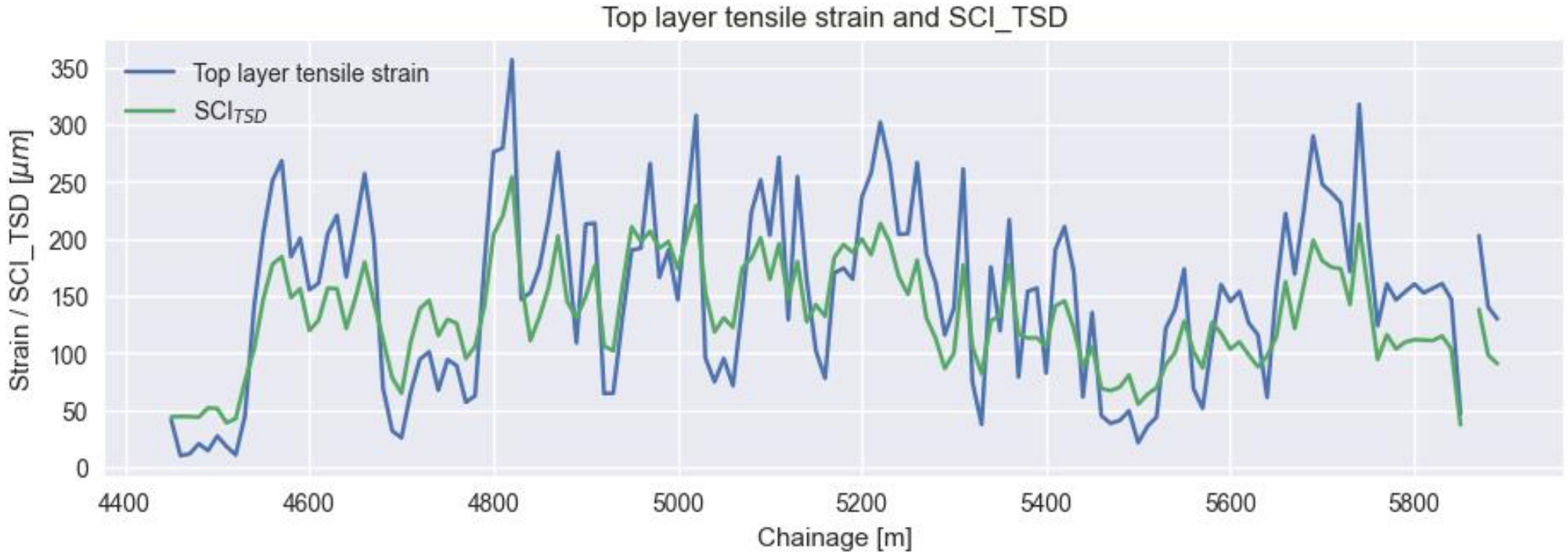


Plate theory: $\epsilon_{xx} = \frac{h}{2}\frac{d^2w}{dx^2}$
h
Compression
Expansion

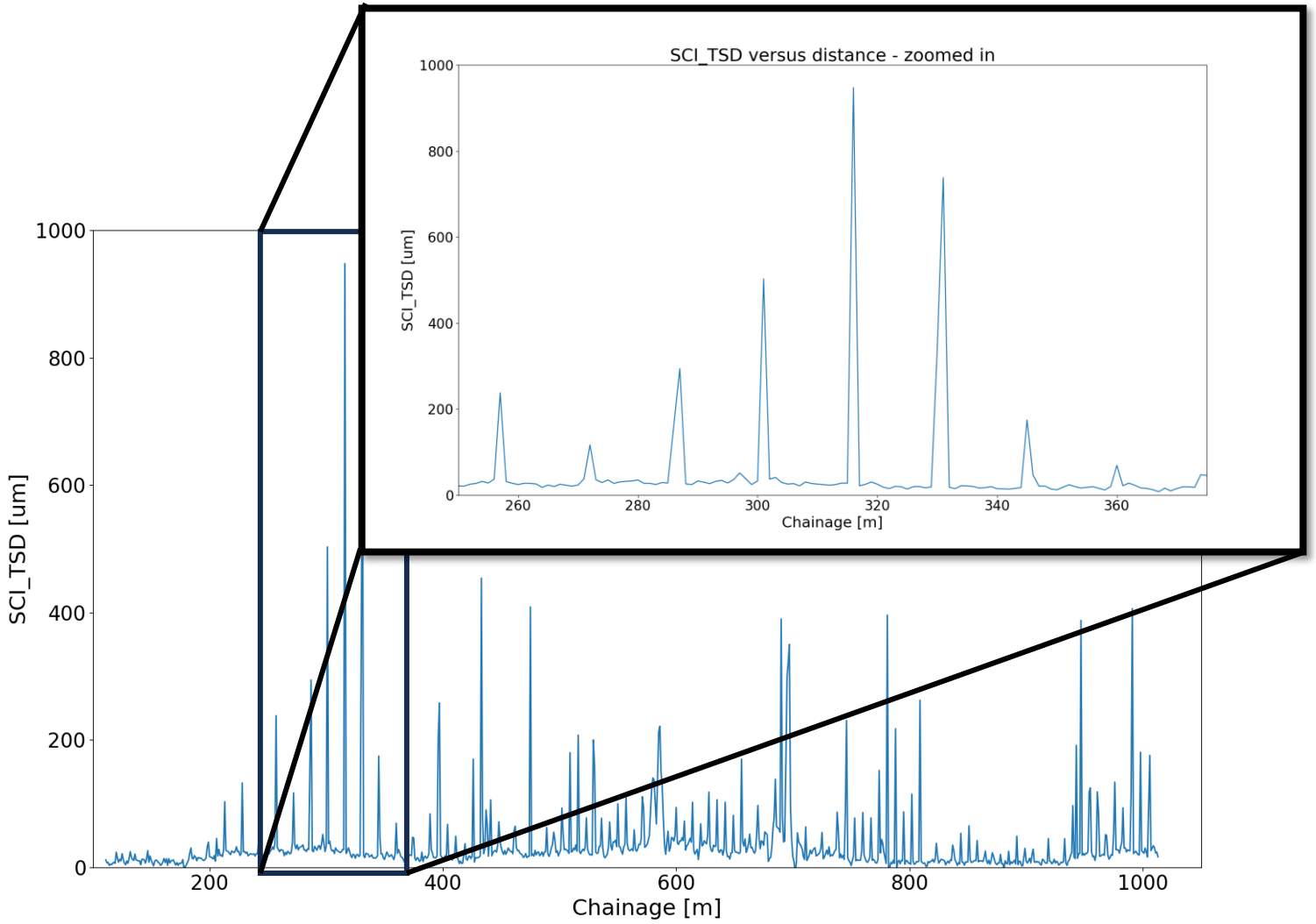
TSD - Strain vs SCI_{TSD}

- TLT Strain from Greenwood's Visco-Elastic back-calculation model[1] plotted against SCI_{TSD}.



Nielsen, C. P. (2019). Visco-Elastic Back-Calculation of Traffic Speed Deflectometer Measurements. Transportation Research Record, 2673(12), 439-448. https://doi.org/10.1177/0361198118823500

TSD – Surface/Sub-surface features

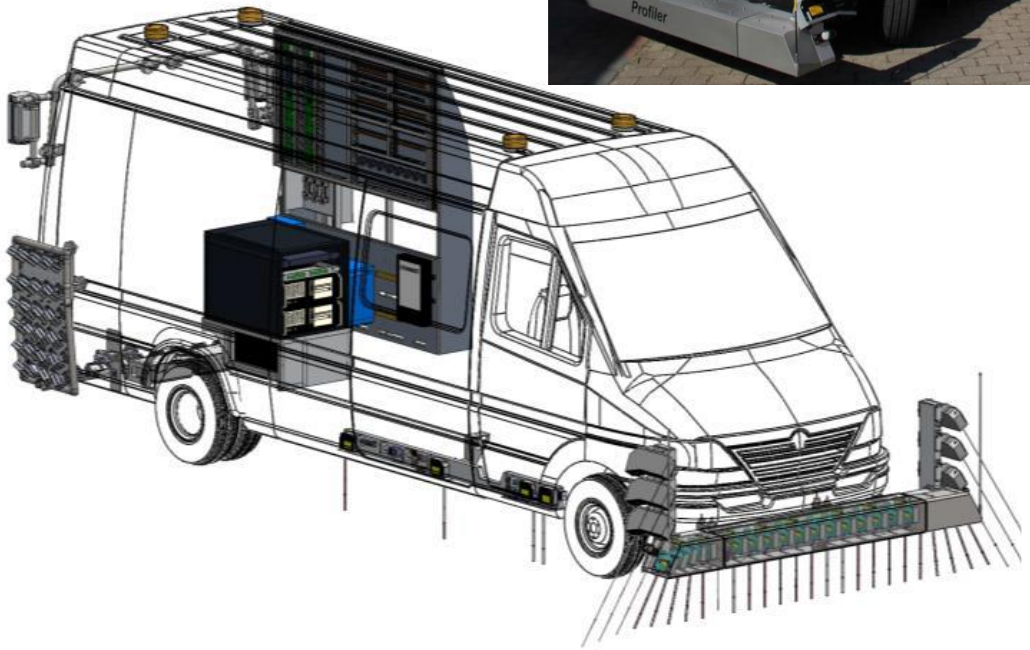


SIS - Surface Imaging System

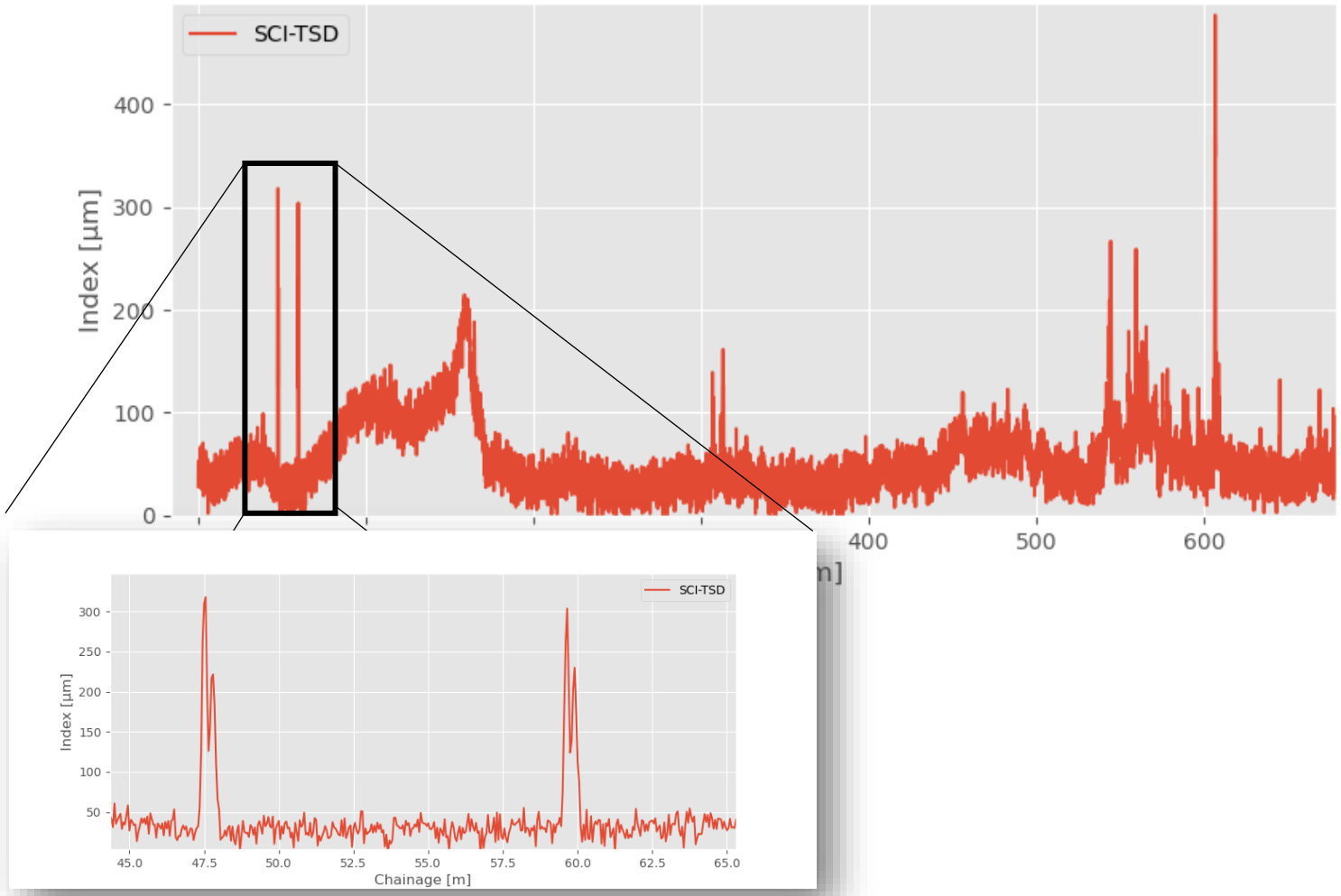
System specifications example

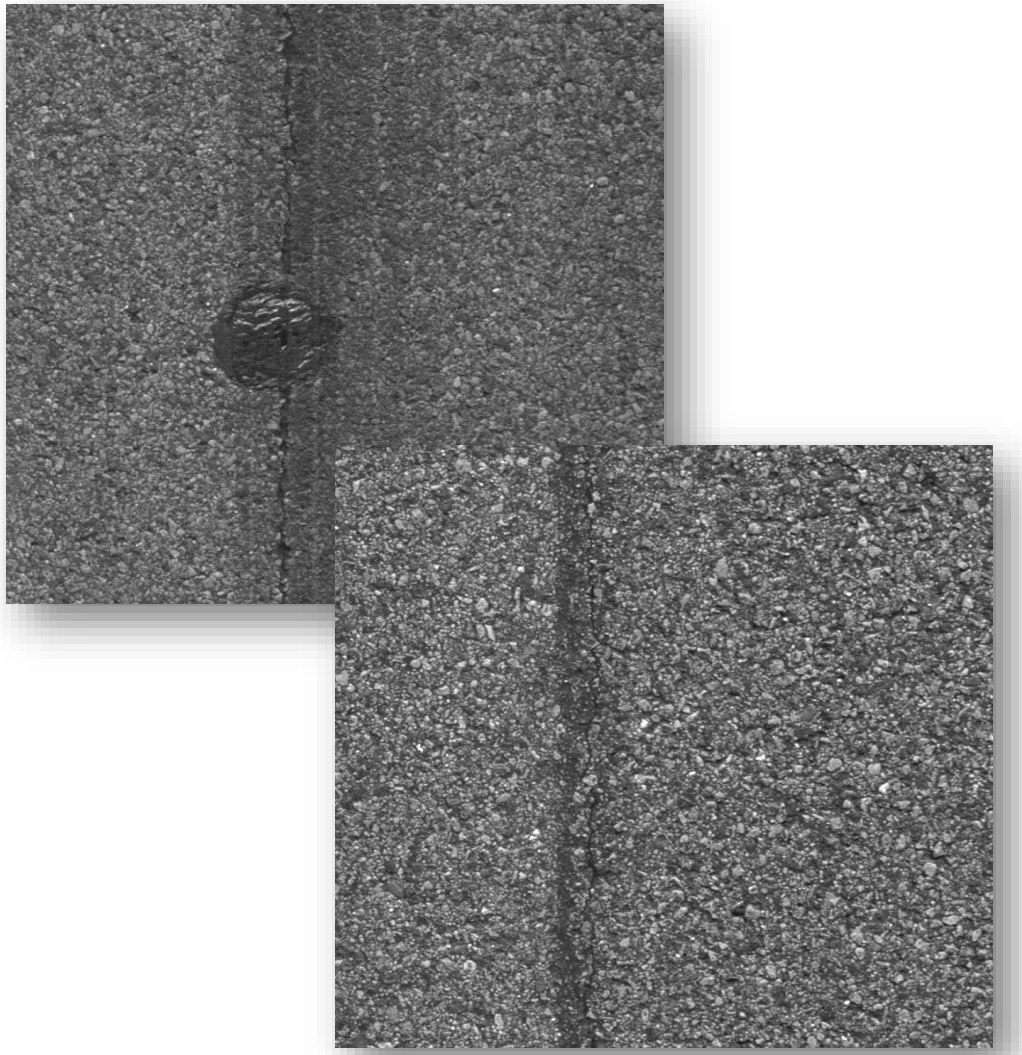
- 2 Linescan cameras + 64 LED lamps
- 4m measuring width
- 1mm x 1mm per pix.
- Pulsed light system, 1 pulse/mm, <30kHz
- One continuous image of the surface
- Driving speed <130 km/h
- Red light source

  -> To be independent of sunlight
- Homogenous light profile

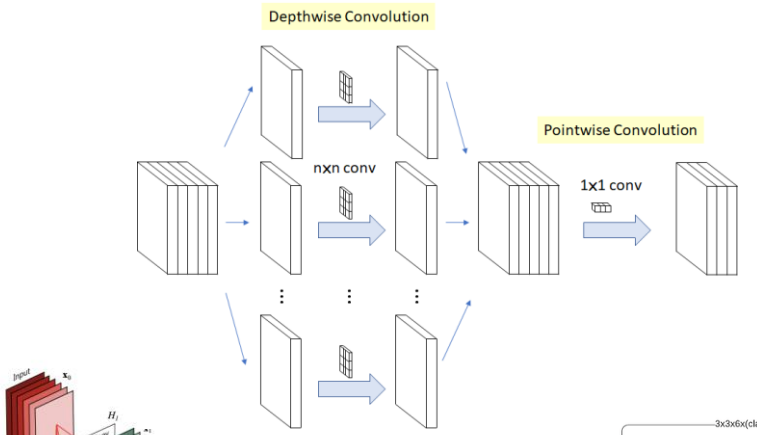


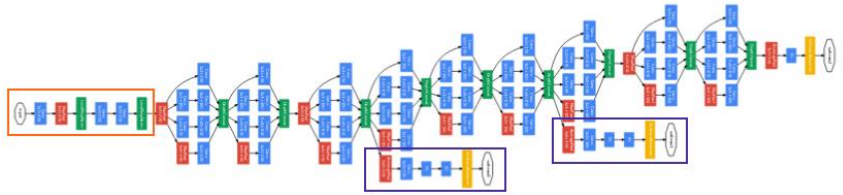
TSD+SIS - Measurements

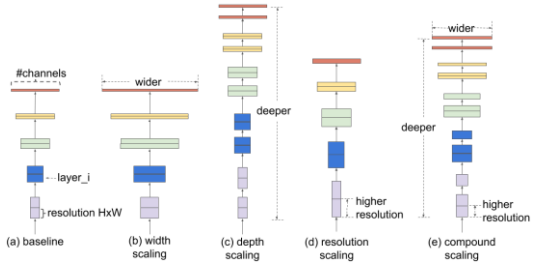


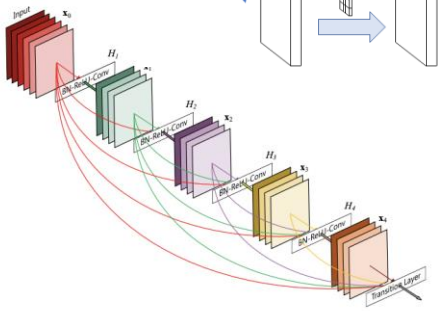


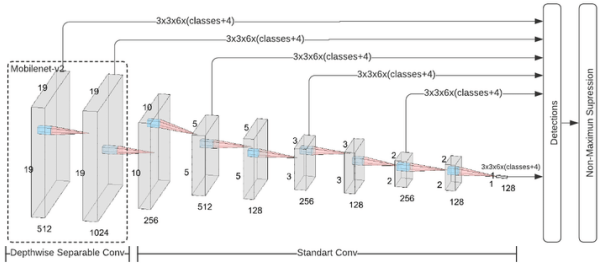
Crack Detection - CNN

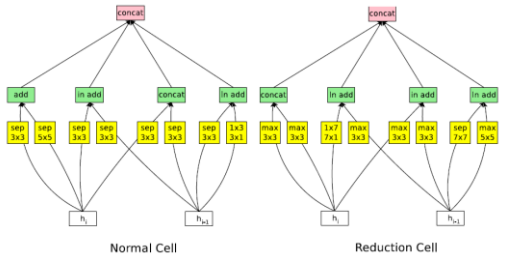








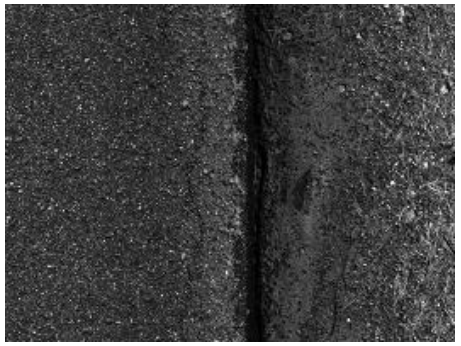




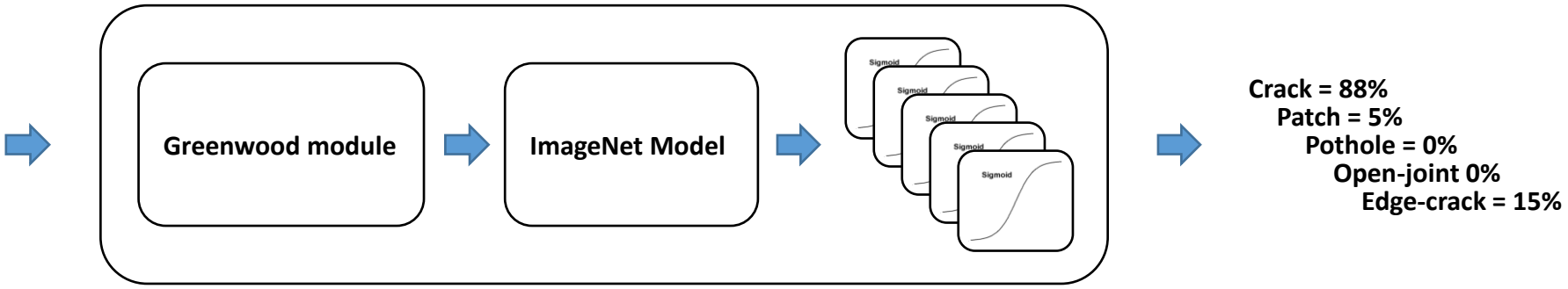
ImageNet models:
DenseNet, Xception, MobileNet, InceptionResNet, NasNet, **EfficientNet**

ImageNet:
1M+ photos of everyday objects and animals – 1000 Classes

Crack Detection - Model



1358x991 pixels



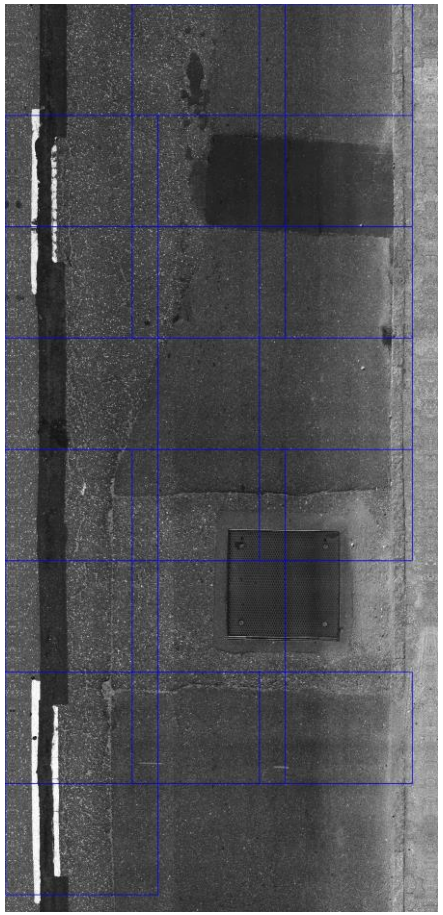
- The Greenwood Module consist of a convolutional layer and a subsampling layer.
- This is to reduce the large amount of computations needed in the ImageNet model which normally takes images of 300x300 pixels.
- Typical ImageNet models takes weeks to train on a non-cluster setup on ~1M images.

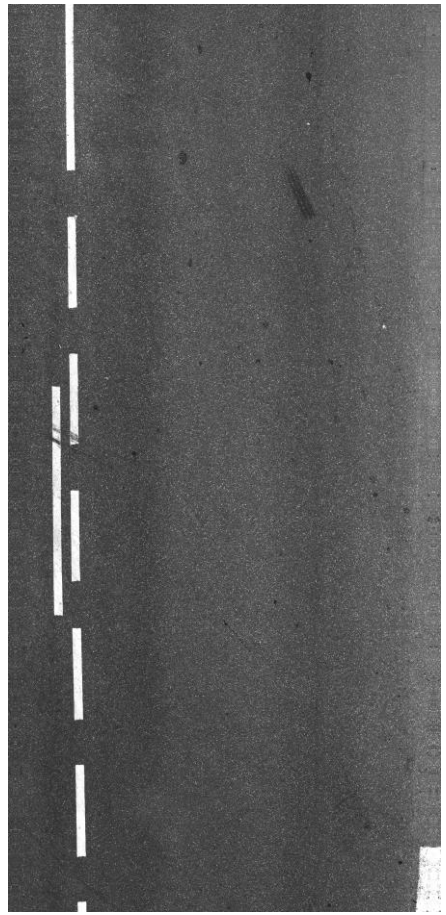
Crack Detection - Model

GDM-BC-1v0:

- Classifications in blocks of app. 1m x 1.3m
- Developed on a dataset of 1.5M Images
- Classes: ["crack", "patch", "pothole", "open joint", "edge crack"]
- >94% accuracy, tested on more than 150 000 out-of-sample images
- Image 1: correctly marked blocks with surface damages
  Image 2: the algorithm correctly ignores oil stains and tire marks on the surface

- Next step: Crack segmentation -> measuring crack area on millimeter scale.





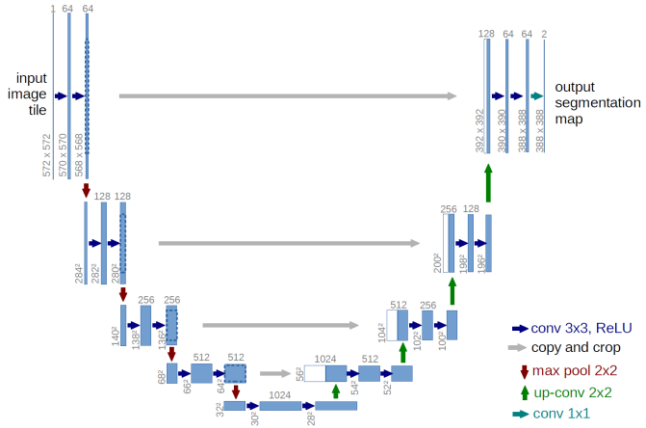
Crack Segmentation - Model

Master Thesis collaboration with Technical University of Denmark, candidate: Yunchong Ma.

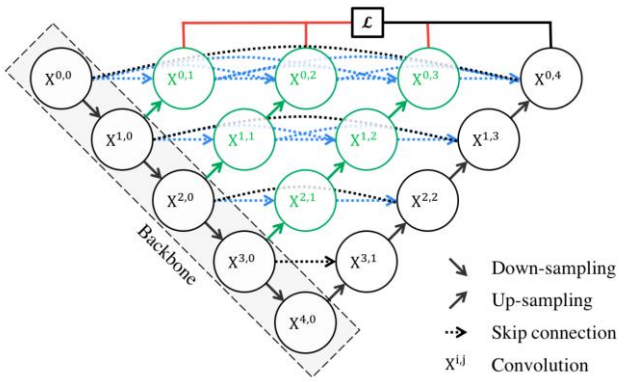
- Convolutional Neural Network for Segmentation
- Based on pricinples:
  - Inspired by the UNet++ Architecture
  - Atrous Spatial Pyramid Pooling (ASPP) Module
  - Residual Modules
  - Multiple Encoder/Decoder paths
  - Attention Gate or SE (Squeeze and Excitation)

    Blocks for Skip-connections in decoders

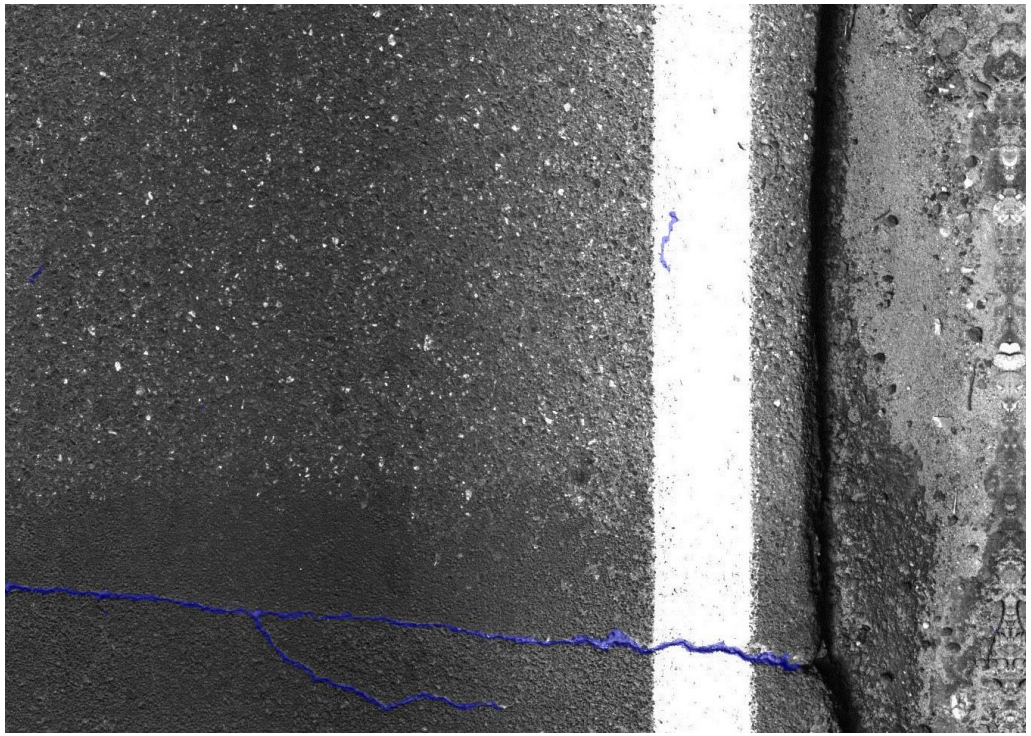
UNet

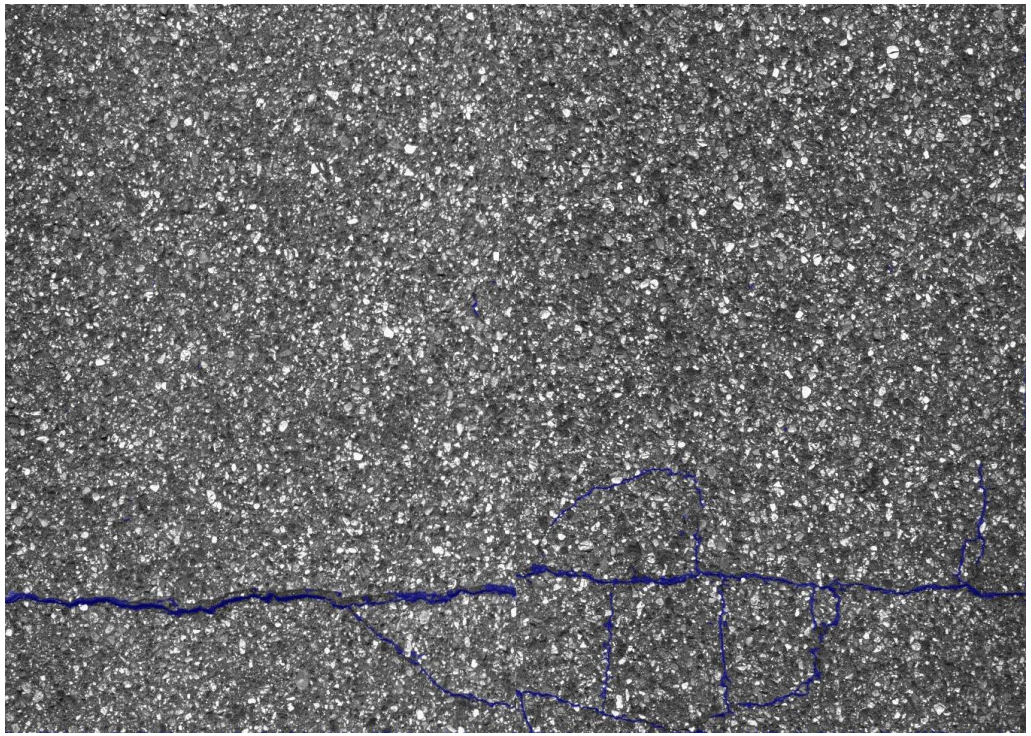


Unet ++

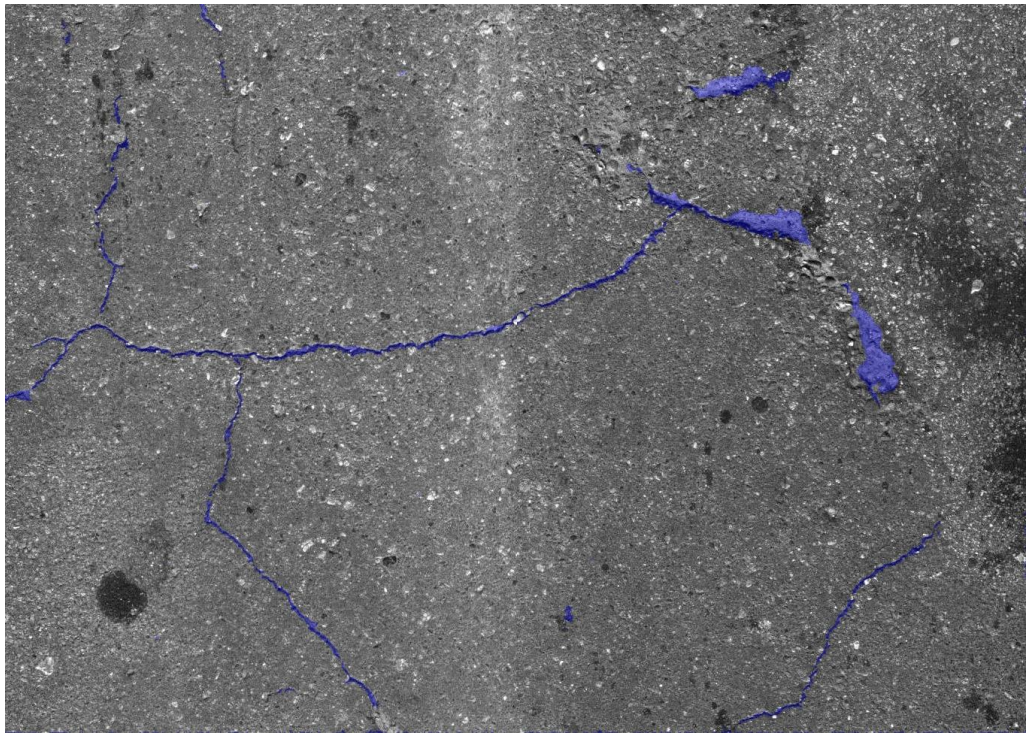


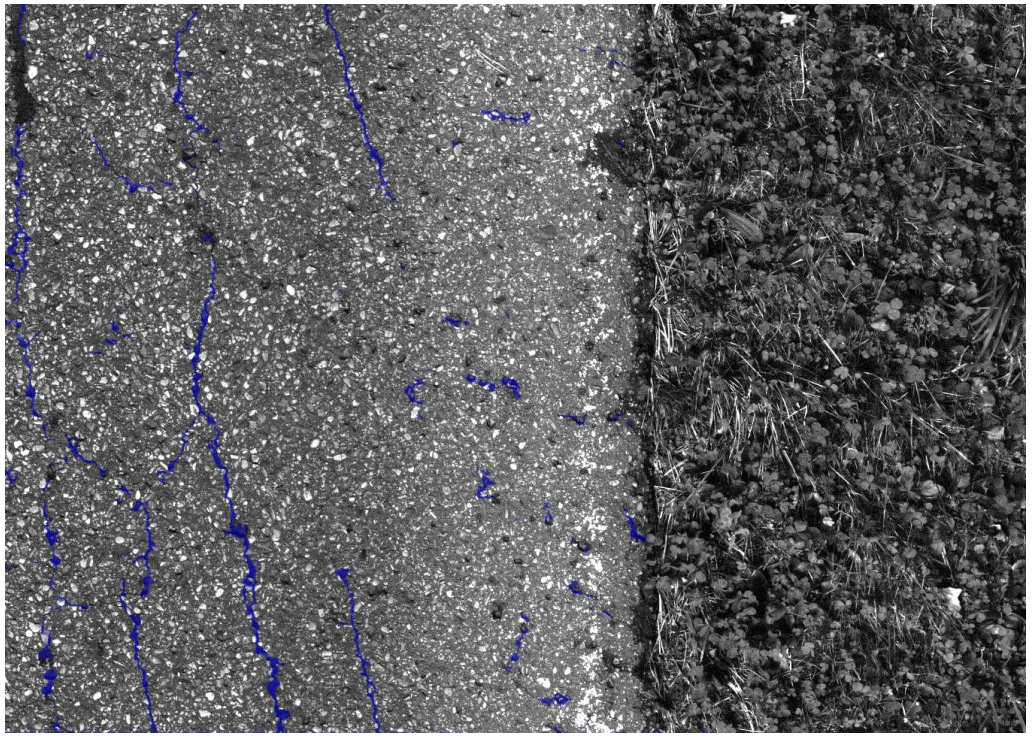
Crack Segmentation - Predictions





Crack Segmentation - Predictions





Crack Segmentation - Performance

Model performance

- High Precision and Recall
- High IOU shows it captures crack pattern very well.
- Fairly balanced between TP and TN.

```
IOU:  0.915533226921139
Precision:  0.955550709375013
Recall:  0.9562581580855692
F1 Score: 0.9559043028375835
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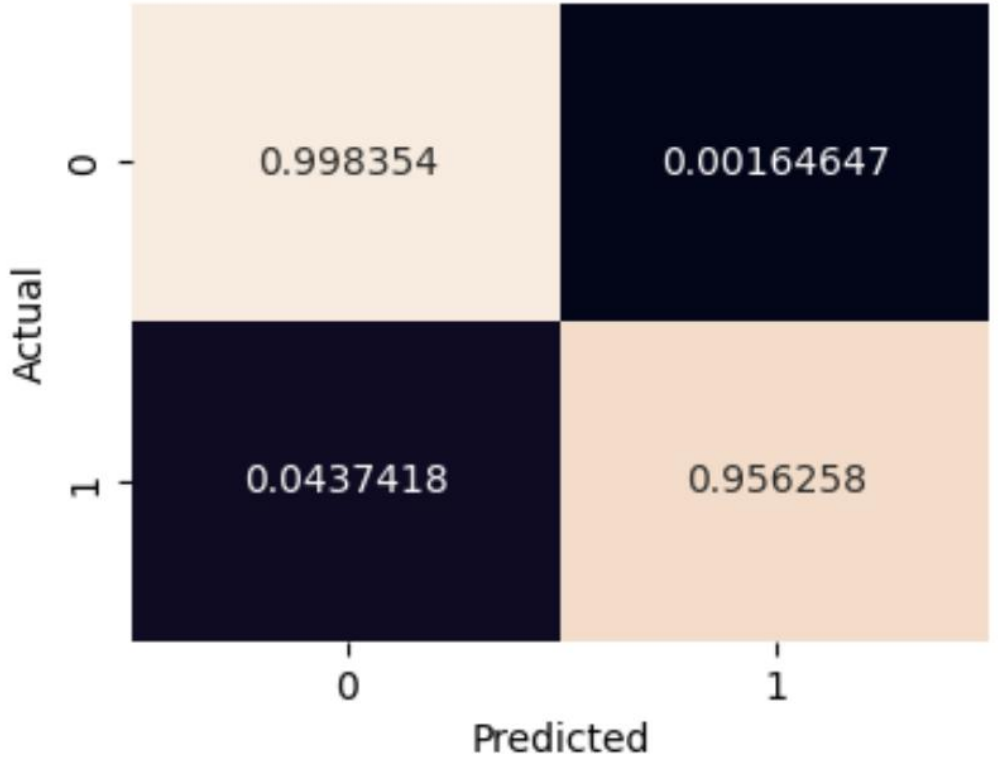

Summary

- TSD data can represent weak/strained layers – New Index
- To study which weakness shows on the surface we need Surface Images
- GE-SIS is an option for quality data to do surface inspection
- High quality images + AI algorithms can provide detailed surface crack information, >90% Accuracy
- Combining Crack –Detection with –Segmentation can process large amount of data fast and at the same time give detailed information

The End ☺

Questions, Comments or Request: David Malmgren-Hansen, dmh@greenwood.dk