GREENWOOD ENGINEERING

Your way to outstanding condition surveys
in the global road and airport industry







GREENWOOD ENGINEERING

CONTACTS

Greenwood Engineering A/S
H. J. Holst Vej 3-5C
DK-2605 Brøndby
Denmark

Phone: +45 3636 0200
Web: www.greenwood.dk
E-mail: greenwood@greenwood.dk

Sales Road department:
E-mail: **sales@greenwood.dk**

Sales Railway department:
E-mail: **miniprof@greenwood.dk**

Beijing Rep. Office, China
Room 1503, Huateng Building
No.302, Jinsong 3 district
Chaoyang District
100021 Beijing
China

Phone: +86 10 6581 6006
E-mail:
General: zhangyue@greenwood.dk
Business and technical inquiries: liangyinan@greenwood.dk

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OUR HISTORY

Greenwood Engineering was founded in Denmark in 1992 by CEO Leif Grønskov. The first project was a road profiler with 17 lasers and inertial system, developed by Leif Grønskov in corporation with his father Niels Grønskov. At the end of the 90s the High Speed Deflectometer/Traffic Speed Deflectometer was introduced and the first one was sold in 2001. Since then, a numerous of new products have been added, including the LaserProf, Road Marking Vehicles and Inventory Detection System.

In addition to the road equipment, Leif Grønskov in collaboration with Niels Grønskov has invented the MiniProf system, an advanced measuring system for the railway industry. The MiniProf systems are high-precision, full-contact profile measuring tools for monitoring and analyzing the cross-sectional profiles of rail tracks, wheels, brakes, switches and crossings.

Today, Greenwood has more than 40 employees, our headoffice is located near Copenhagen in Denmark, and we have local offices in New York and Beijing. We invest massively in development and new ideas to the benefit of our users. Through 30 years of great development in technology and engineering, we can be happy that the good story about our products is being told in the industry. This has resulted in thousands of users, a strong global agent network and local offices in Copenhagen, New York and Beijing.

We are characterized by a dedicated and innovative company spirit, in close collaboration with our customers. We keep a very high level of technical in-house knowledge and talent. The majority of the Greenwood employees are highly skilled engineers and technicians. Some key employees have seniority up to +25 years, some have joined us along the way and some are fresh out of university.

With the combination of a strong sales department and back office, Greenwood Engineering have built up a solid ground and continues to offer outstanding products and new developments for road, airport and railway industri.

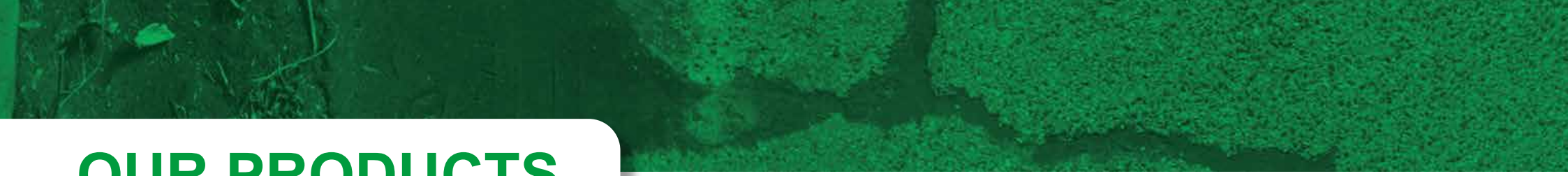
More than 30 years on the market, and still at the forefront of technology



One of the first road profilers with 17 laser and inertial system.



CEO Leif Grønskov and Sales Director Karsten Jensen.



OUR PRODUCTS

HIGHLY SPECIALISED MEASURING EQUIPMENT

Greenwood Engineering develops and manufactures advanced equipment for:

- Structural and functional pavement condition measurements in the global road and airport sector. All systems are designed to suit research level as well as routine survey operations. Mechanic and electronic designs as well as software are made in-house allowing for customised modules to be created to assure data continuity for the road administrations.

- High- precision full contact profile measurements and basic to advanced post analysis of railway wheels, rails and brakes.

Greenwoods wide product range spreads from the small, handheld and lightweight MiniProf units for monitoring and analysing the cross-sectional profile of train wheels, rails and brakes, to the truck semi-trailer based Traffic Speed Deflectometer (TSD) for both network level and project level bearing capacity measurement on roads while driving at normal traffic speed.

Identify, understand and react to the underlying problem – Don't just deal with the symptoms!

AT THE FOREFRONT OF TECHNOLOGY

Our products are operated with minimum disturbance to environment and traffic and with the highest user safety and comfort in focus. The solutions provide outstanding measuring results and constitute an extremely reliable foundation for making critical and economic decisions in maintenance, quality and safety departments all over the world.

Much has happened since the first projects were launched in 1992, but one thing remains unchanged: the basic premise for all marketed products is to be at the leading edge of frontier technology. Greenwood has an innovative company spirit and a close relation to our customers.

GREENWOOD PROVIDES

- ✔ Highly reliable measurement data for cost-effective maintenance planning
- ✔ State of the art products based on in-house research and development
- ✔ Excellent service and support, provided by a wide range of skilled staff (Ph.D´s, mechanical and electrical engineers, software developers, craftsmen, technicians etc.)



Advanced measurement equipment for cost-effective maintenance planning

OUR CUSTOMERS

OUR CUSTOMERS

Research institutes and universities

Concessionaires

Road and highway agencies

Airport operators

Service providers/contractors





































WE SUPPORT YOU ALL THE WAY

At Greenwood Engineering, we understand that road maintenance is a critical aspect of keeping your infrastructure in optimal condition. We take immense pride in being your dedicated partner every step of the way, providing you with a complete solution that covers equipment procurement, support, and service.

Customised equipment: We know choosing the right equipment for predictive road maintenance can be a complex task. That`s why our team of experts is here to assist you in finding the perfect equipment, which matches your specific needs.
All our products for road and airport measurements are based on well-proven components allowing for flexible modules to suit your needs, local requirements etc.

Dedicated support: Our commitment to your success doesn't end with the purchase. Our customer support team is readily available to address any questions, concerns, or issues you may have. Whether it's technical guidance, maintenance tips, or troubleshooting, we are there for you.

Service you can rely on: A well-maintained fleet of road maintenance equipment is essential for efficient operations. Our service technicians are highly trained to ensure your equipment stays in top condition. We offer maintenance and repair services that minimise downtime, so you can focus on maintaining your roads without interruption.

To maintain the high-precision equipment properly and ensure that your measurements are always reliable and within the high standards and tolerances set by Greenwood Engineering A/S, we recommend service approximately once a year depending on use.

Upgrade your equipment: and unlock the full potential for both mechanical and digital measuring equipment. Our upgrades are designed to seamlessly integrate with your existing systems, minimizing downtime and maximizing productivity. Strengthen the longevity of your instruments, reducing maintenance costs and ensuring consistent performance over time.

We tailor the upgrade to meet your specific needs, ensuring that your equipment aligns perfectly with your applications. Your digital measuring equipment, can be connected to other devices, creating a unified and efficient workflow.

For the older TSD generations, more lasers can be installed, the beam can be updated to move automatically and an air tunnel can be installed to improve air-conditioning. Also other equipment such as GPR, texture laser, Surface Imaging Systems (SIS) etc. can be retrofitted to a previously delivered TSD. You can get a completely new Doppler system with 10× lower noise and 250 kHz sampling, enabling 5 cm reporting of repeatable and reliable data.

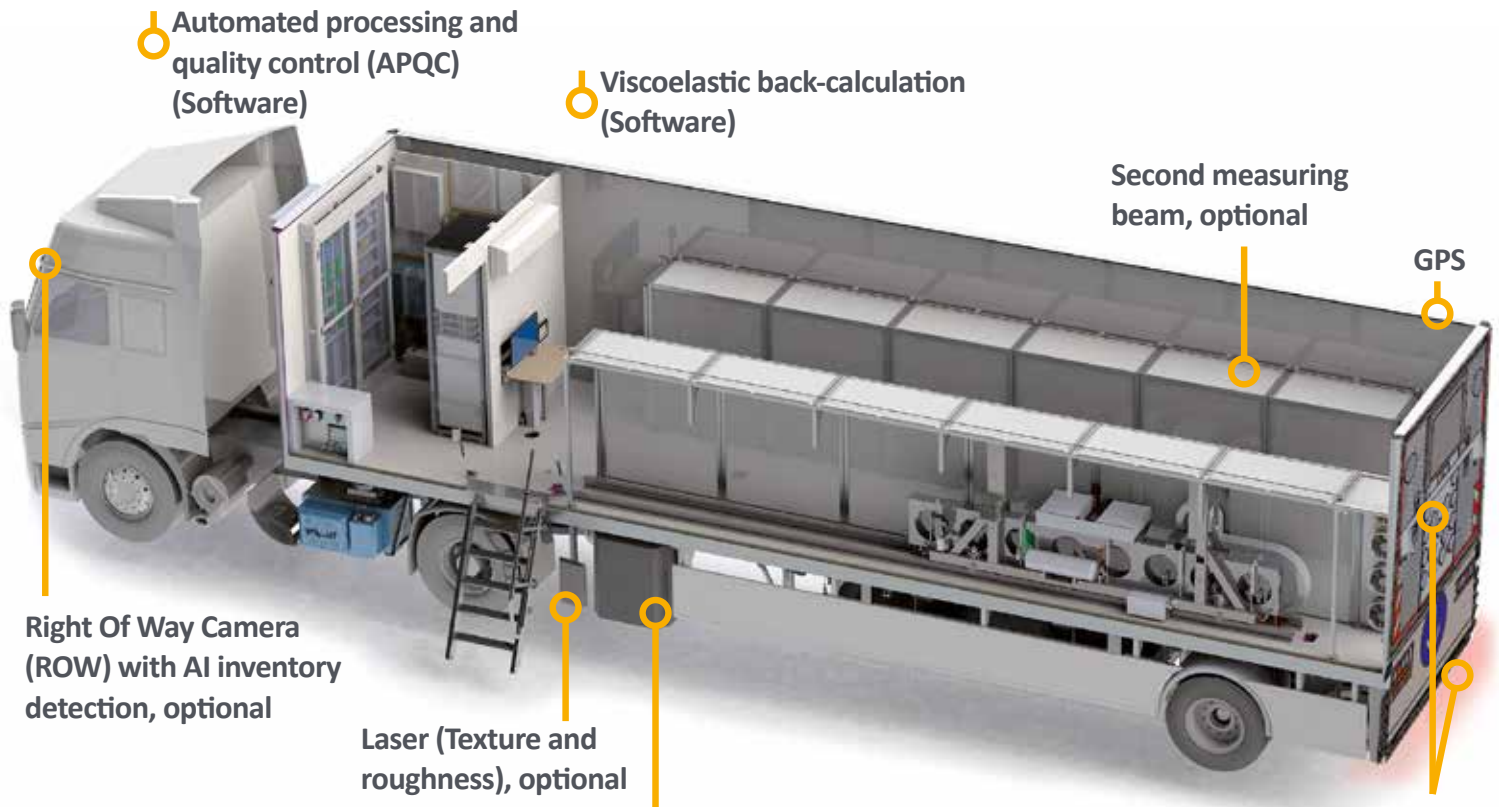
CUSTOMISED PRODUCTS

Our products are based on more than 30 years of development and user experience from customers in more than 50 countries.

Greenwood products are well-proven technology combined with a flexibility to suit local requirements and customers specifications. For the TSD, this may include optional equipment as Ground Penetrating Radar (GPR), Surface Imaging System (SIS), Right Of Way Camera (ROW) etc. for collection of a full set of synchronised road data in one drive.

More than 24 TSDs delivered all over the world:

- Doppler laser system for continously deflection measurements in the longitudinal centreline between the rear twin wheels
- Special designed trailer and wheel hubs for measuring behind as well as in front of the load axle
- Servo system and inertial units continuously monitor and control the position of the Doppler sensors
- Automated processing and quality control software (APQC) is standard in the newest TSD generation



ON THE ROAD WITH TSD



TRAFFIC SPEED DEFLECTOMETER (TSD)

The TSD is a well proven Rolling Wheel Deflectometer measuring pavement response to an applied load. The unique TSD technology is developed by Greenwood Engineering and has initiated a shift of paradigm in global pavement engineering.

With no lane closures, the TSD provides continuous bearing capacity results at project and network level while following the flow of traffic. This makes it possible to measure hundreds of kilometers per day and makes the TSD highly cost effective.

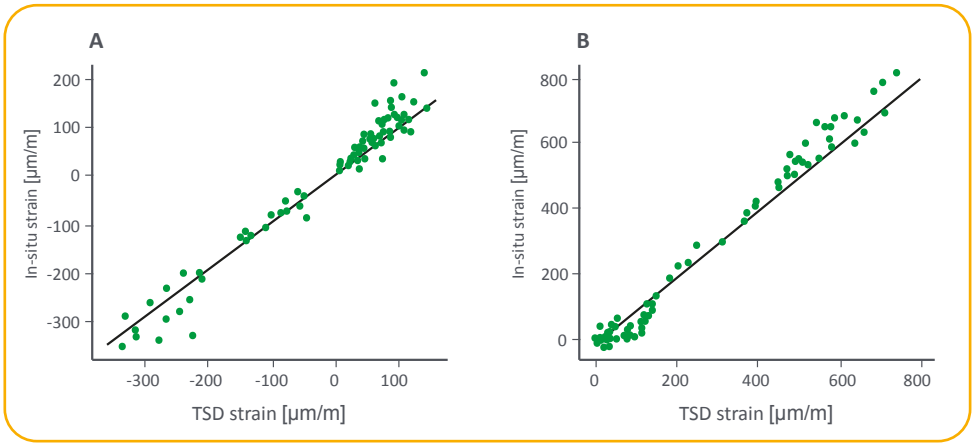
Why use the Traffic Speed Deflectometer (TSD)

- Allows for remaining life time calculation of roads and runways etc. based on continous measurement and visco-elastic back calculation of e-moduli and strains
- Uses Doppler lasers to measure pavement response
- Measures at traffic speed 1 – 80 km/h
- Continuous measurements in the wheel path center line
- One driver and one operator
- Highly repeatable measurements

TSD-MEASUREMENTS VALIDATED ON AN INSTRUMENTED ROAD

Results from a comprehensive set of validation measurements illustrate the ability of the Traffic Speed Deflectometer's (TSD) to accurately measure the actual pavement deflection when comparing with in-situ measurements.
Applying a linear viscoelastic back-calculation algorithm to the TSD, measurements produce estimates of E-moduli, stresses and strains inside the pavement structure.

Excellent agreement between the strains obtained by the TSD and the strains measured by in-situ transducers. Below plot from a research study made on Aurora test track in Munio Finland.



A.: In-situ peak transversal strains plotted versus TSD peak transversal strains.

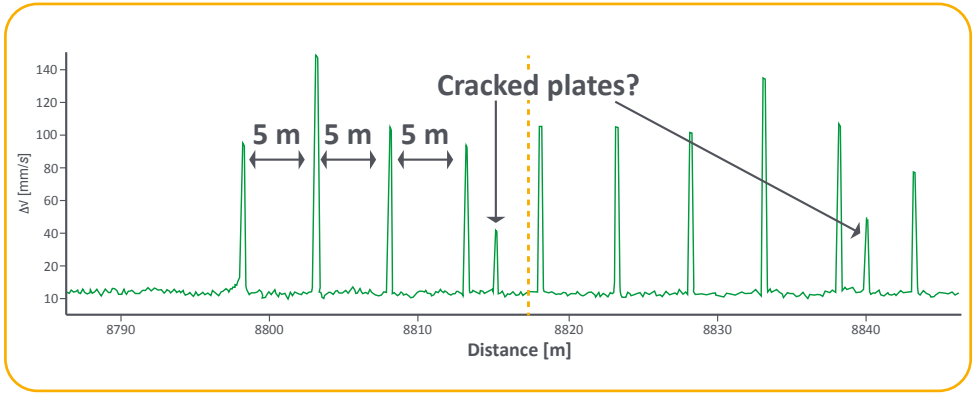
B.: In-situ peak vertical base course strains plotted versus TSD peak vertical base course strains.

ON THE ROAD WITH TSD

TSD MEASUREMENTS ON CONCRETE PAVEMENT

- Locates varying load transfere between concrete slaps
- Finds cracks on slaps
- Works on open concrete and concrete under asphalt
- Effective spring constant [MPa] can be calculated from raw measurements





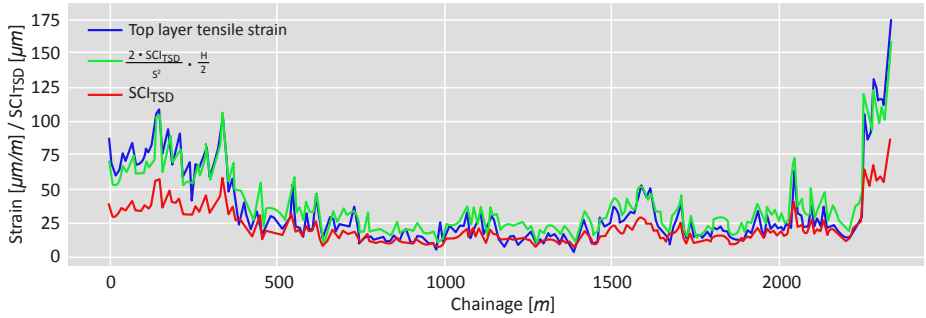
DISCOVER UNDERLYING WEAKNESSES AND MAKE RELIABLE LIFE-TIME ANALYSES WITH SCI_{TSD}

SCI_{TSD} is the **NEW** structural curvature index tailored for TSDs. As curvature relates to strain it is well suited for assessing large road networks and airfields to find problematic areas that will be prone to faulting/cracking.

The **SCI_{TSD}** index is mathematically derived from same principles as classical Surface Curvature indices but using the information about the actual response the road provide when loaded with real truck tires.

As curvature is proportional to strain with half the layer thickness, **SCI_{TSD}** can capture effects like viscoelasticity, debonding and very weak upper layers. Further, when discontinuities occur the movement of the road on each side is amplified making it suitable for characterizing joints, cracks and more, even when covered by layers of asphalt.

Top layer tensile strain and SCI_{TSD}



SCI_{TSD} vs. tensile strain at the bottom of the top layer. SCI_{TSD} is proportional to the strain, since they are both derived from the curvature of the deflection bowl, this means that the tensile strain can be calculated directly from SCI_{TSD} shown as the green curve.

TSD SOFTWARE

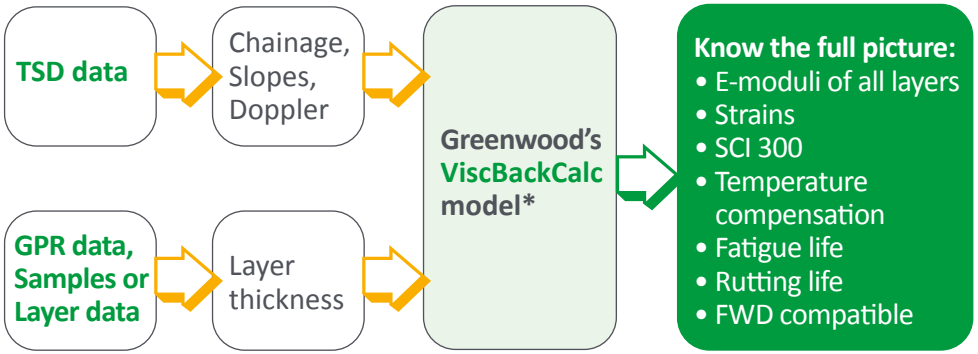
EFFECTIVE CALCULATION OF STRAINS AND E-MODULI FROM TSD MEASUREMENTS WITH VISCO-ELASTIC BACK CALCULATION

Greenwood Engineering has developed **ViscBackCalc**, the world's first online service capable of running visco-elastic back calculation on TSD measurements for precise prediction of pavement distress at network level. It´s a very fast and easy way to calculate the structural properties of the road network.

ViscBackCalc allows users to upload TSD-measurements and run visco-elastic back calculation and download calculated fatique- and rutting strains, and e-moduli.
It also generates plots for deflections, slopes and strains and allows for temperature compensation and dynamic layer information e.g. from a ground penetrating radar.

ViscBackCalc effectively calculates strains everywhere in the pavement structure from TSD measurements. These strains are induced into the pavement by a driving truck, and they are therefore exactly what is needed to assess the pavement damage caused by ordinary truck traffic.

Visco-elastic Back calculation workflow



OPTIMIZE YOUR TSD MEASUREMENTS WITH AUTOMATED PROCESSING AND QUALITY CONTROL (APQC)

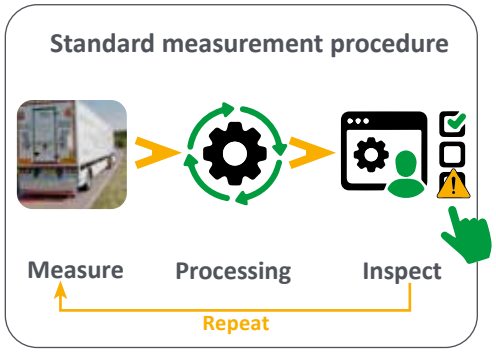
Greenwoods Automated Processing and Quality Control (**APQC**) tool improves operational efficiency by automated in-vehicle processing, quality checking and early detection of quality issues.

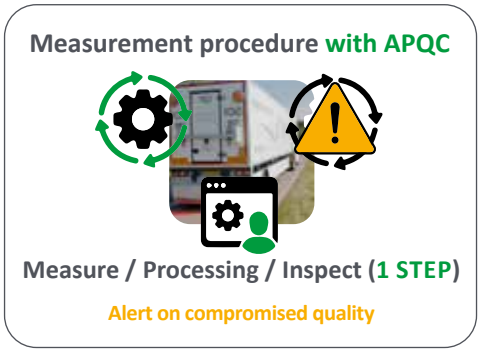
Why use APQC?

- Saves time through automation
- Ensures high data quality with expert checks
- Reduces errors with early issue detection
- Customizable and scalable for different missions
- Enables automated synchronization of processed measurements



With **APQC**, a configuration of the desired report can be created and saved to trigger the processing automatically, saving time and effort.
The processing can be configured to export a wide range of reports, removing the need for a manual export process after measurements are performed.





*Greenwoods Back Calculation Model - Christoffer Peder Nielsen.

GREENWOOD ENGINEERING

Optimal airport maintenance by continuous bearing capacity measurements with the Traffic Speed Deflectometer



MOTIVATION FOR RUNWAY MEASUREMENTS

- **Avoid unforeseen shut down due to**
  - Longitudinal unevenness
  - Rutting
  - Fatigue cracks
  - Potholes

BENEFITS OF USING A TSD

- **Speed**
  - Higher productivity
  - Can measure during normal operation
- **High 3D spatial resolution**
  - Continuous measurements
  - High repeatability
  - Measures on asphalt and also on concrete
  - Find small weak areas
  - Full overview of bearing capacity in all layers
- **Measures response to moving load**
  - Realistic effect of inertia
  - Realistic effect of viscoelasticity

WHY MEASURE AIRFIELD WITH A TSD

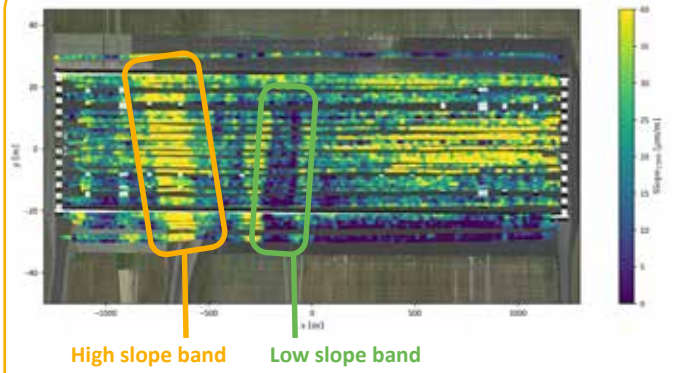
Runways suffer a great deal of wear and tear, simply as a result of normal operations. Maintaining those surfaces with minimal disruption to flights is part of any airport's responsibility to its users and a major challenge. Any defects or damage to the runway can lead to accidents, injuries, or even fatalities.

Environmental and climate-related factors such as changes in temperature or harsh winter weather can affect airport pavements, as can the natural deterioration of the materials used in their construction.

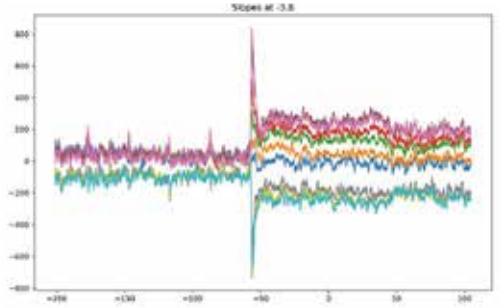
The main impact of aircraft on runways is caused by their weight and braking, which causes reflective cracking over time. Besides cracking, other types of damage that can occur include joint seal damage, distortion, disintegration and loss of skid resistance.

Effective runway maintenance is not only essential for safety and operational efficiency but also for cost-effectiveness. Timely detection and remediation of pavement defects through TSD surveys help prevent costly runway repairs and premature replacements. By implementing predictive maintenance strategies based on TSD data, airports can extend the lifespan of their runways and areas in the entire airport, optimize maintenance budgets, and minimize long-term operational costs associated with runway downtime and emergency repairs.

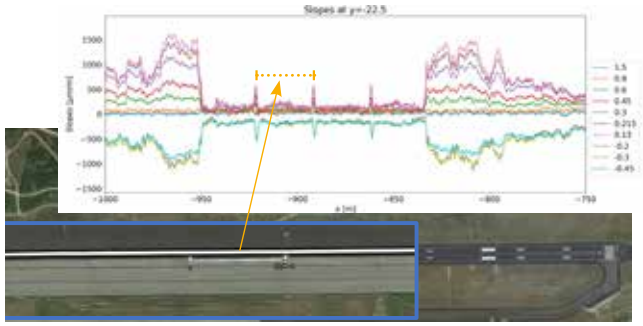
ACTUAL TSD AIRPORT MEASUREMENTS



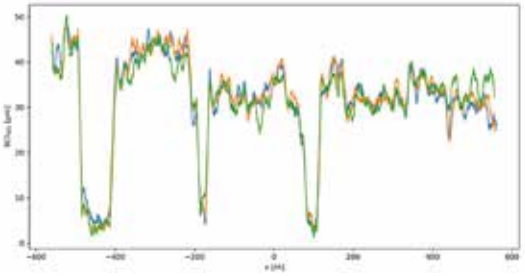
Slope in 1.5 m
Finds weaknesses in the lower subgrade layers, related to the subgrade geological features.



Measurements examples from parking lot
- Finds good and poor load transfer between slaps.
- Transition between original and reinforced pavement is clearly seen.
- Measured on concrete under asphalt.



Slope spikes on runway
Finds small weaknesses in the upper asphalt layer.



Around terminal building with repeated SCI_{300}.
3 measurement loops around terminal building shows a **very high repeatability.**

GREENWOOD ENGINEERING

EVERY CRACK COUNTS

DISCOVER AND MONITOR CRACKS FROM THE EARLY STAGE TO REPAIR

- Alligator cracking
- Longitudinal and transversal cracking
- Not visible bottom-up cracking (Possible with TSD)
- Concrete slap cracking

SIS can be configured for user needs with up to 4.5m measuring width and pixel resolutions down to 1mm. Images are tagged with travelled distance from a DMI and GPS coordinates if available on the vehicle, for precise co-location with data from other measurement systems.

The LED lamp light used in SIS is eye-safe.



SIS system can be mounted on any vehicle.

SURFACE IMAGING SYSTEM (SIS)

HIGH-RESOLUTION SURFACE IMAGES FOR CRACK DETECTION

The Surface Imaging System (SIS) is a high-resolution pavement imaging system based on linescan camera technology. SIS records the road pavement as one continuous uninterrupted image that can be exported in image blocks with a user selected length.

While recording at traffic speeds the road is illuminated by a high-power efficient LED based light system. The light is in the red wavelengths and is many times stronger than sunlight, which eliminates unwanted image disturbances such as shadow casts from road side objects and bridges. The light is adjusted to give a completely homogeneous illumination profile for the absolute best quality images possible.

Features

- Continuous undistorted image of the road surface, exported to user defined image sizes
- Eye safe light system
- Homogeneous illumination with less than +-5 DN variation over entire image width, i.e. no lines/areas with brighter or darker illumination
- Independent of sunlight illumination, hence, no shadow casts from road signs, bridges, etc.
- Include Greenwood Engineering's own LED based lamps for strong image illumination, several times stronger than sunlight
- Driving speed as high as undisturbed traffic

Crack Detection

The high quality of SIS images serve as the best possible foundation for analysis of surface defects, for example with Greenwood's new AI based crack detection algorithm.



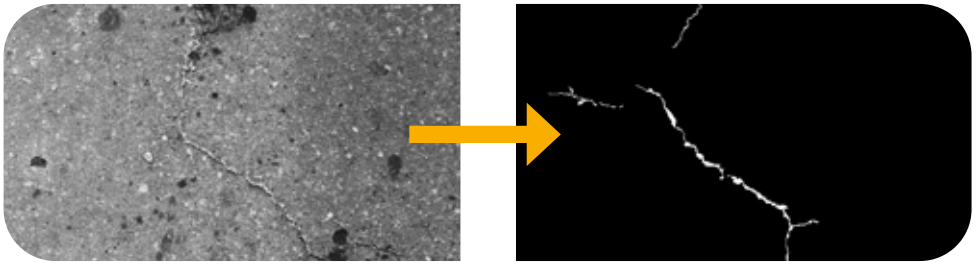
AI Crack Detection and Mapping

The AI pipeline concists of a fast screening stage where tiles with surface defects are found. They are then drawn up to pixel level crack maps by the Crackmapper software and then analysis of the cracks are performed to deduct various information, such as: types, width, orientation and more

CRACK DETECTION WORKFLOW

BlockClassifier	CrackMapper	CrackMap Analyzer
Fast screening of 1m x 1m tiles for cracks, joints, potholes. Processing speeds > 700kmh for full width images.	Detailed mapping of cracks on pixel level accuracy for geometric measurements.	Advanced analysis of cracks, geometry, types, orientation and more.

CRACK DETECTION AND MAPPING



LASERPROF



LASERPROF

LaserProf is a compact and portable profiler for reading texture (MPD) and roughness (IRI), and can be mounted on a standard tow hitch. It can have one or two laser sensors, measuring in the wheel paths, and is designed to be a tool for the pavement supervision engineer making quality control.

The LaserProf can also be mounted on a bike lane trailer for measuring bicycle lanes.



LaserProf comes in a suitcase, and can be installed in a normal vehicle on site without using special tools.



Technical Description

- Measures the longitudinal profile of any pavement at high speed, high reliability and high accuracy.
- Post processing software, allowing the simulations of other types of profiling instruments.
- Powerful software suite, which allows real-time calculation of IRI, displayed on the on-board laptop.
- The main sensor of a LaserProf is a LMI laser, which measures the distance to the roadfor reading texture (MPD) and roughness (IRI). This data is synchronised with input from a highly precise odometer sensor and an accelerometer.

Results

The longitudinal profile and IRI values can be viewed in real-time while measuring the roads and in post-processing specialized reports and calculations can be produced for either single measurements or on batches of data.

Typical reports include:

- Raw longitudinal profile
- International Roughness Index (IRI in mm/m or inch/mile)
- Simulated California type / Viagraph type
- Proscan (without the need to printout and scan the Profilograms)
- Macro texture (MPD)

In addition, custom designed filters can easily be built into the software. The output can be shown as both 2D and 3D graphs. It is also possible to arrange the results into intervals chosen by the user, typically 10m-100m.

GPS and Right-of-Way camera (ROW) can be added to the LaserProf

PROFILER AND ROAD MARKING VEHICLES





PROFILER

The Greenwood Profiler provides both transverse and longitudinal profile, and allows them to be combined in one 3D profile. It optimises management of pavement maintenance, and is used by road authorities and national road research institutes for pavement condition surveys. Profiler uses high precision sensors and digital data acquisition for highest possible measurement quality and can be operated as a standalone system or part of a multifunction vehicle. It is configurable to meet many different multifarious requirements and can be synchronised with GPS and other measurement systems like Surface Imaging System and Right-of-Way Imaging.

A unique possibility for measurements in city regions with many stops and low speed restrictions is to combine a Greenwood Profiler (inertial profiler) with a Greenwood HRM (Highway Road Monitor geometrical profiler). The Greenwood HRM can provide one longitudinal profile even at very low driving speed.

ROAD MARKING VEHICLES (RMV)

The Road Marking Vehicle (RMV) is an advanced integrated vehicle for measurements of road lane marking parameters. Our high-tech sensors and cameras precisely measure and evaluate road lane markings, to ensure that our roads remain safe and well-maintained.

The Road Marking Vehicle integrates Delta's LTL-M sensor for mobile retro-reflection measurements with Greenwood's own developed systems for laser surface measurements, high quality Surface Imaging System (SIS), front looking Right of Way imaging, all started from one single software application. Accompanying the RMV is a software stack of post processing applications which use intelligent Computer Vision algorithms to automatically extract coverage, length, width and more, from the SIS images. Further, linear regression models can be included in data exports to, e.g. deliver, wet retro-reflection, friction, daylight brightness (Qd) and more.

ROW AND AI - INVENTORY DETECTION





RIGHT-OF-WAY CAMERA (ROW)

ROW Imaging is a system designed for collection of digital images from a vehicle. The images are taken at fixed distance intervals, regardless of the speed of the recording vehicle. By pointing the cameras forward, the roadside inventory can be documented. By pointing the camera down to the road, the system obtains pictures of features found with other road measuring systems.

ROW Imaging supports multiple cameras. An additional camera pointing to the rear allows all signs to be read without travelling the road twice. The cameras are user selectable, giving both flexibility and the ability to read small signs at great distances.

The images from ROW Imaging can easily be synchronised with other measurements. This includes other data from other instruments as well as coordinates from a GPS.

AI - INVENTORY DETECTION

AI - Inventory Detection system detects traffic signs, reflective poles, traffic lights and crash barriers via front facing cameras and gives each asset a GPS coordinate. This automatically generates a map of the location of each asset as well an image.

The software utilises state-of-the-art machine learning algorithms and large quantities of image data. These algorithms look at the data and create a mathematical understanding of what an object looks like. Later it can use this knowledge to automatically detect the assets in new footage.

AI - Inventory Detection system can be customised to suit your requirements and can be retrofitted to a Traffic Speed Deflectometer (TSD), Profiler or other vehicles.

ON TRACK WITH MINIPROF

MINIPROF – MUCH MORE THAN A MEASUREMENT!

The small, handheld MiniProf profile measuring systems for railway tracks, wheels, brakes, switches and crossings are used by thousands of users in over 50 countries in the global railway industry. The various tools are used for planning and evaluation of maintenance activities such as rail grinding, rail milling and wheel machining as well as for quality control, research, safety regulation, vehicle dynamic performance studies and much more.

With an impressive profile accuracy from ±9-11 µm and a repeatability of ±2,5 µm, the MiniProf systems provide outstanding measuring results. The measurements are processed in the powerful, accompanying Envision software where numerous calculations and tools enable the user to easily monitor and analyze the wear. The high accuracy and reliability of the MiniProf measurements constitutes a solid and reliable foundation for critical decisions in railway operations all over the world.



Further information available at **www.greenwood.dk/railway/**
or by contacting the MiniProf team at **miniprof@greenwood.dk**



MiniProf Rail



MiniProf Wheel



MiniProf Switch

THE WORLD OF GREENWOOD

Greenwood Engineering is a Danish company with a large international profile. With products distributed and used successfully all over the world by thousands of users, a vast agent network.

Greenwood Engineering are proud to be a strong and contributing factor to the global optimisation of road, airport and railway conditions.

CONTACT US FOR MORE INFORMATION

E-mail:
Road department: **sales@greenwood.dk**
Railway department: **miniprof@greenwood.dk**



OUR CUSTOMERS AROUND THE WORLD

GREENWOOD ENGINEERING

Greenwood Engineering A/S • H.J. Holst Vej 3-5C • DK-2605 Brondby • Phone:+45 36 36 02 00 • www.greenwood.dk

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