SWECO

Road Construction and Maintenance:

-Road Profiles, Friction and Safety

Photo: Daniel Sjöholm

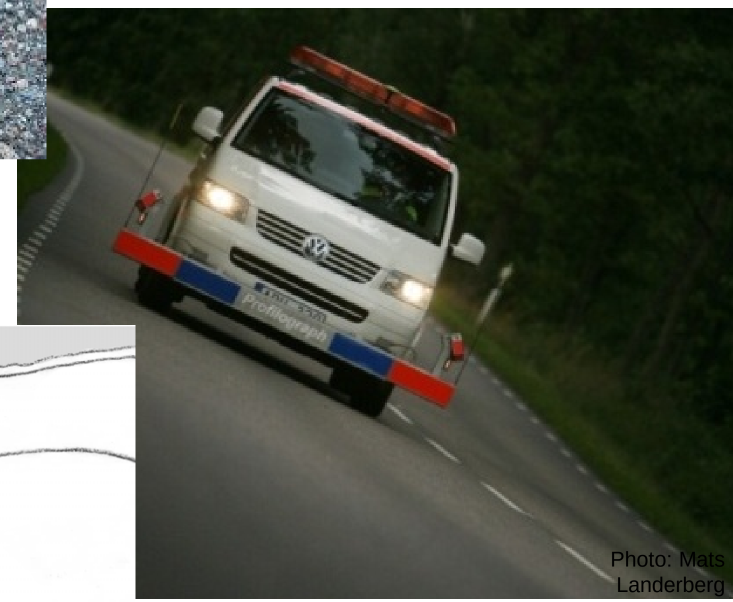
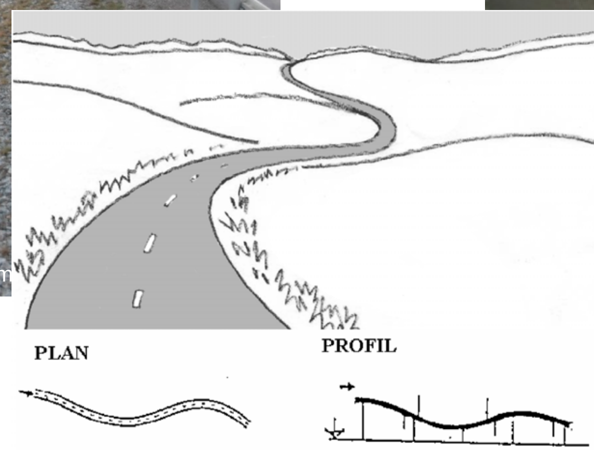


Photo: Mats Landerberg



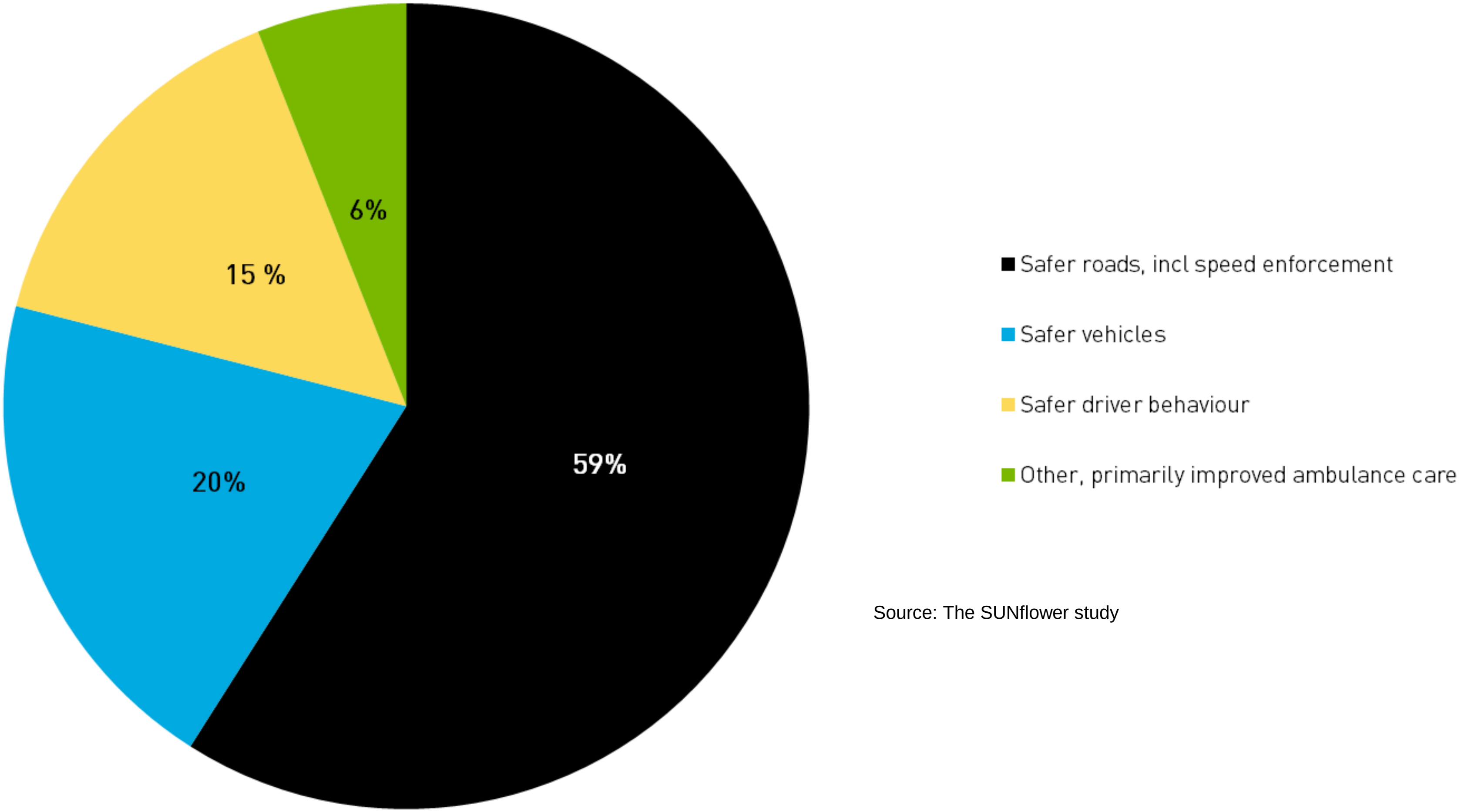
johan.granlund@sweco.se, Senior Consultant

LinkedIn   Nokian Tyres   Svensk Åkeri tidning

KTH 2014-05-06

Expected crash reduction

Divided between policy areas



Source: The SUNflower study

In broad terms

Road alignment and surface condition are laserscanned with high accuracy at normal traffic speed.
Road alignment determines lateral forces.
Road roughness and texture; properties or damages?
Also surface condition affects the crash risk:

- Road friction and split friction due to asphalt spot repair
- Road roughness reduce grip and increase crash risk.

Some texture absorbs traffic noise, the other creates noise.
Vehicle suspension systems insulate all vibration. Or?
CAD design of geometric pavement repair.
Quality control of airfield runways and highways.

Road condition surveying

with laser/inertial Profilographs

Photos in full High-Definition of road environment and road surface (optional).

Alignment, roughness and condition.

Laser/inertial technology.

Roots of GM's research in the 1960´s.

Accuracy: Fractions of mm.

Traceable per Swedish Transport Administration approved methods VVMB 121 & VVMB 122.

Results positioned with satellite support (GNSS, GPS & GLONASS), for presentation on maps, etc.

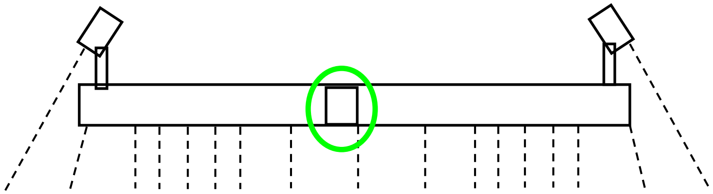
Profilometers in commercial operation since 25 years on roads and airfields.

An accurate & robust Profilograph costs about 500 000 €.

Road condition surveying (Cont.)

Measurement at normal traffic speed:

- Travelled distance of the left non-powered wheel.
- Distance to road surface is measured in 17 lateral positions, 16 000 times per second, about 1 sample/mm.

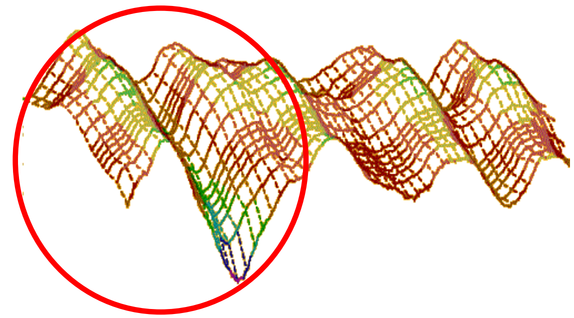


- Movements of the rut bar.

Road condition surveying (Cont.)

By combining data from lasers, inertial unit, etc., an accurate model of the lane "topographical shape" is created.

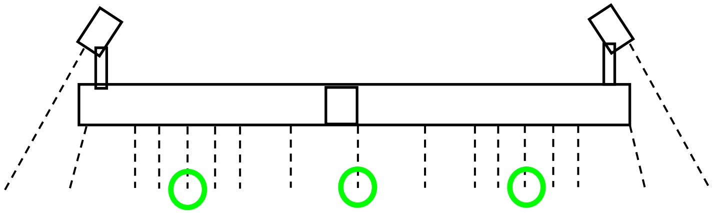
Photo: Mats Landerberg



At 72 km/h, the system measures 3.2 m width x 20 m lane length every second.

400 000 samples/sec => 8 000 filtered values stored.

Road condition surveying (Cont.)



Road surface texture affects friction, rolling resistance, noise, road serviceable life etc.

For friction reasons, texture can´t be too low - "fattening up".

Split friction can occur if the macrotexture is inhomogeneous across the road, i e repair in one wheel track only.

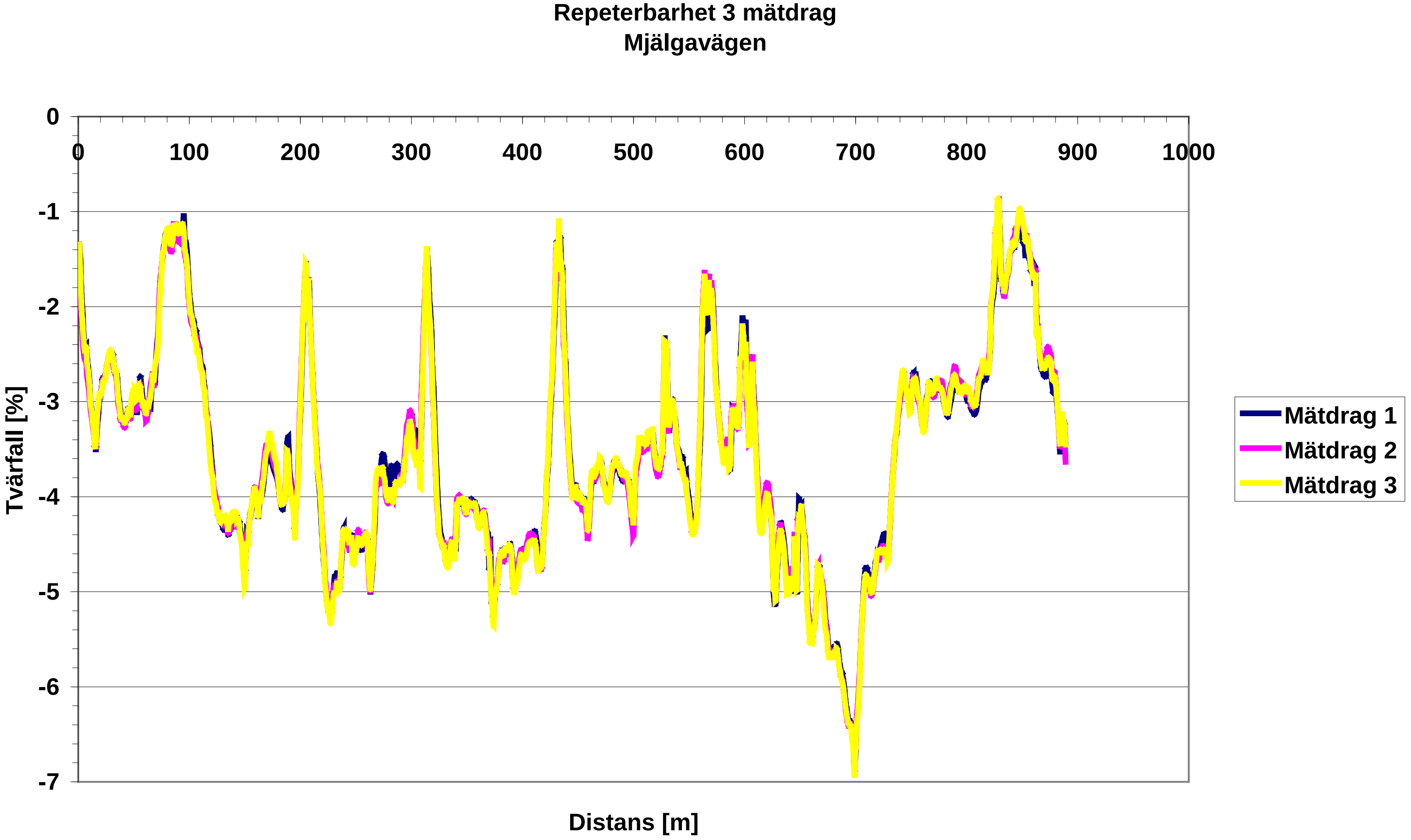
Texture is sampled in **both wheeltracks**, and **between tracks**.

Texture lasers take 64 000 samples / sec; 3 samples / mm.

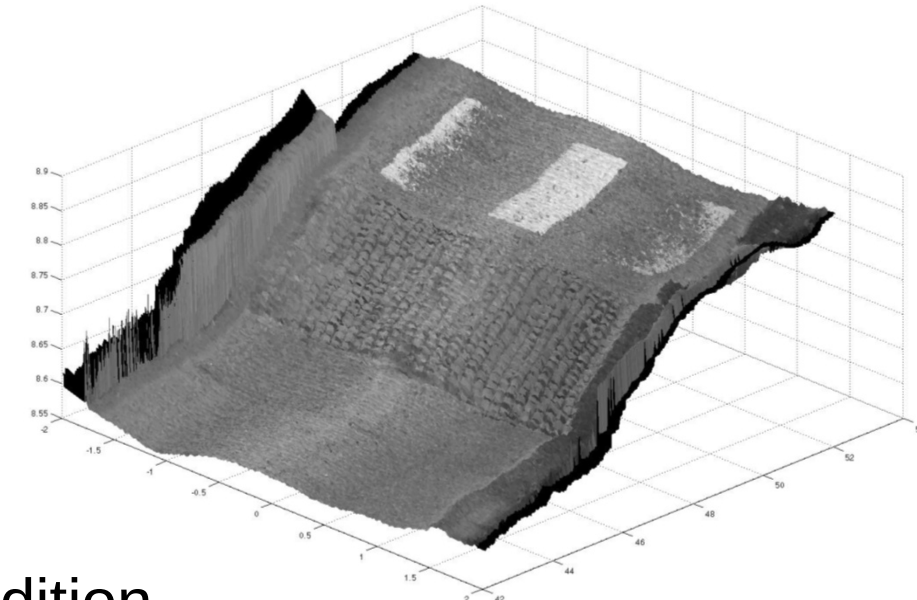
On highways, macrotexture MPD should be around 1 mm.

A lower benchmark is MPD > 0.4 á 0.6 mm.

Excellent repeatability



Road profiling with sweeping laser



Alignment, roughness and condition.

Laser/inertial technology.

Photos in full HD.

Retroreflection.

Height & Width Clearance.

Pavement and roadside depicted in **full 3D**.

5 times as many fatal single-vehicle crashes in outer-curves

than in inner-curves

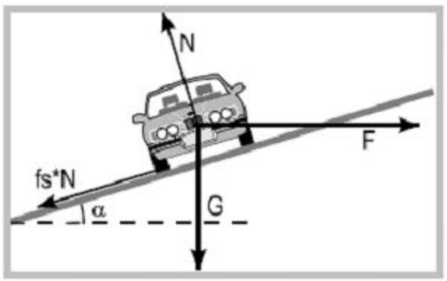
Two key factors are:

- Insufficient banking => high lateral (side) forces.
- Often poor drainage at entrance/exit of banked curves.

Cornering stability

depends on radius, crossfall and friction

Forces on the vehicle and the driver's percepted ride differ, depending on vehicle inertia and other properties.



Road design codes stipulate superelevation, based on this formula:

$$\tan(\alpha) \approx \frac{v^2}{R*g} - f_s$$

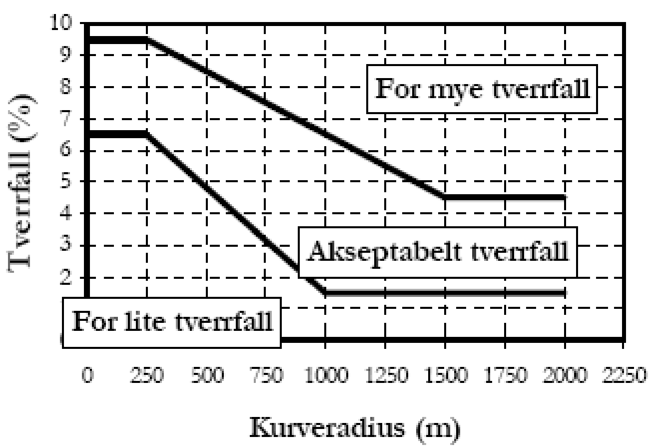
where tan(α) = superelevation (crossfall in curve),

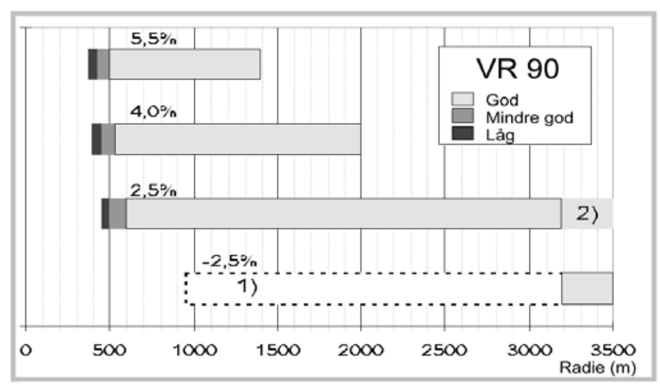
v = reference speed [m/s], R = curve radius [m], g = 9.82 m/s²

and f_s = side friction between car tyre and road

For slippery roads, side friction is about 0.1 (f_s is much lower than brake friction).

Superelevation distributions used in Norway and in Sweden:





Heavy vehicles are

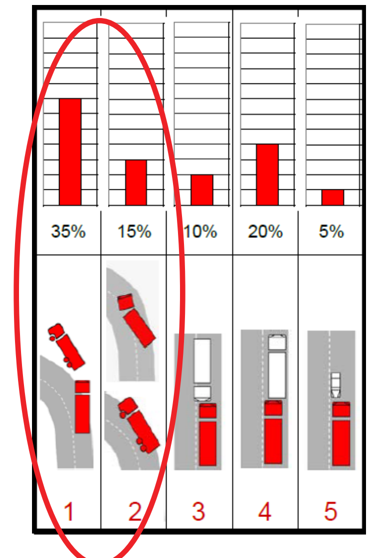
very sensitive to side forces

Photo: Volvo Trucks

The crash type were most truck drivers are injured is the **rollover**.

Higher C.o.G. makes the vehicle prone to improperly banked outercurves

Crashes with severly injured truckies



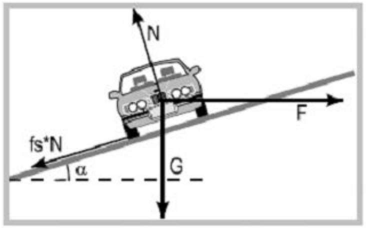
Source: Volvo Trucks

Typical number of truck rollovers:

- Norway: 200 per year
- Finland: 200 per year
- Sweden: 650 per year

Evaluation of risk for
loss-of-control crases
in existing curves

We use the formula for balanced side forces “rearwards” to calculate the demand for side friction.



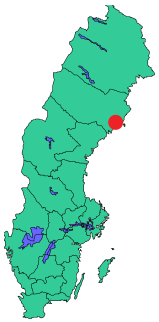
Side friction demand: $f_s \approx \frac{v^2}{R*g} - \tan(\alpha)$

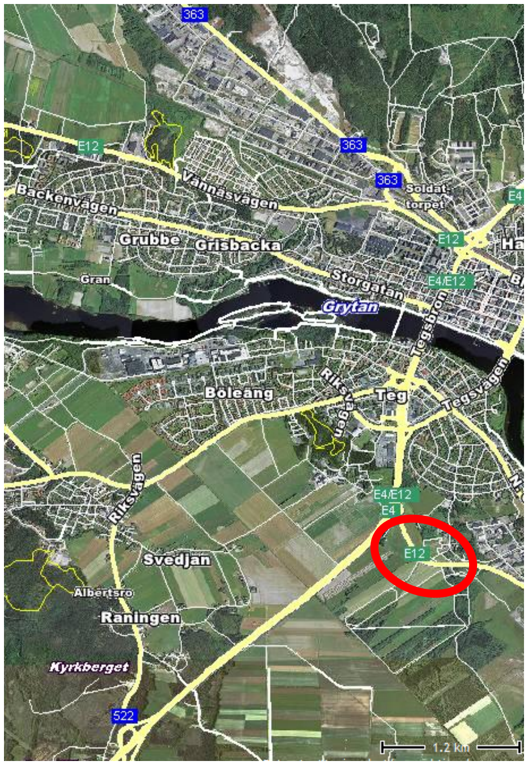
Measured data for the radius of curvature R and superelevation tan(α) are taken from our laser/inertial Profilograph.

Reference speed converted into SI-unit [m/s].

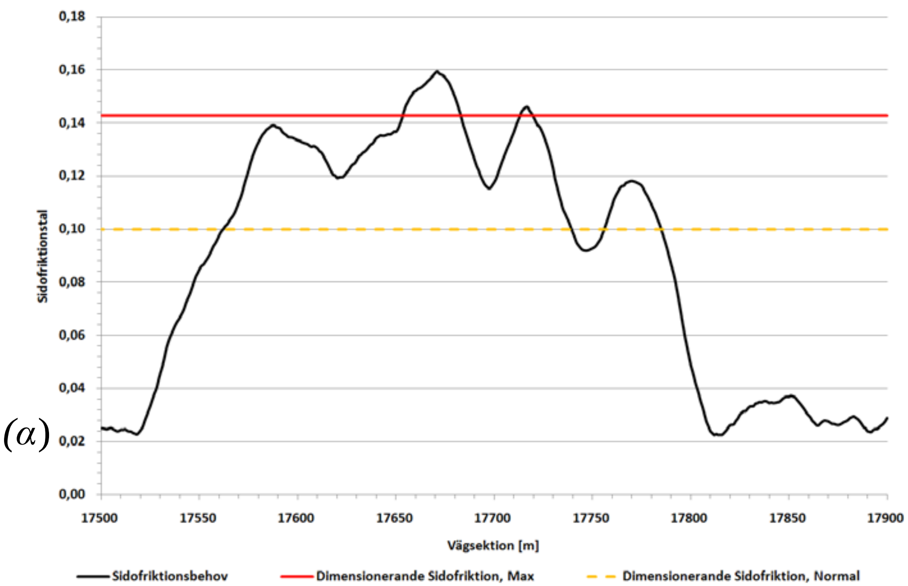
Ex. 80 km/h = 80 / 3.6 = 22 m/s

Analysis of the improperly banked
"Curve of Death"





$$f_s \approx \frac{v^2}{R*g} - \tan(\alpha)$$

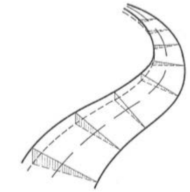


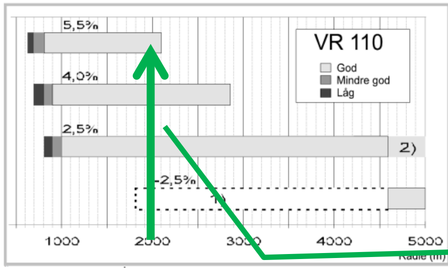
The improperly banked curve on road E12 have 5 crashes in 45 meter.

The need for side friction in the "Curve of Death" exceeds the friction supply value in the road design code VGU.

80 % lower friction demand

in banked outer-curve on E4



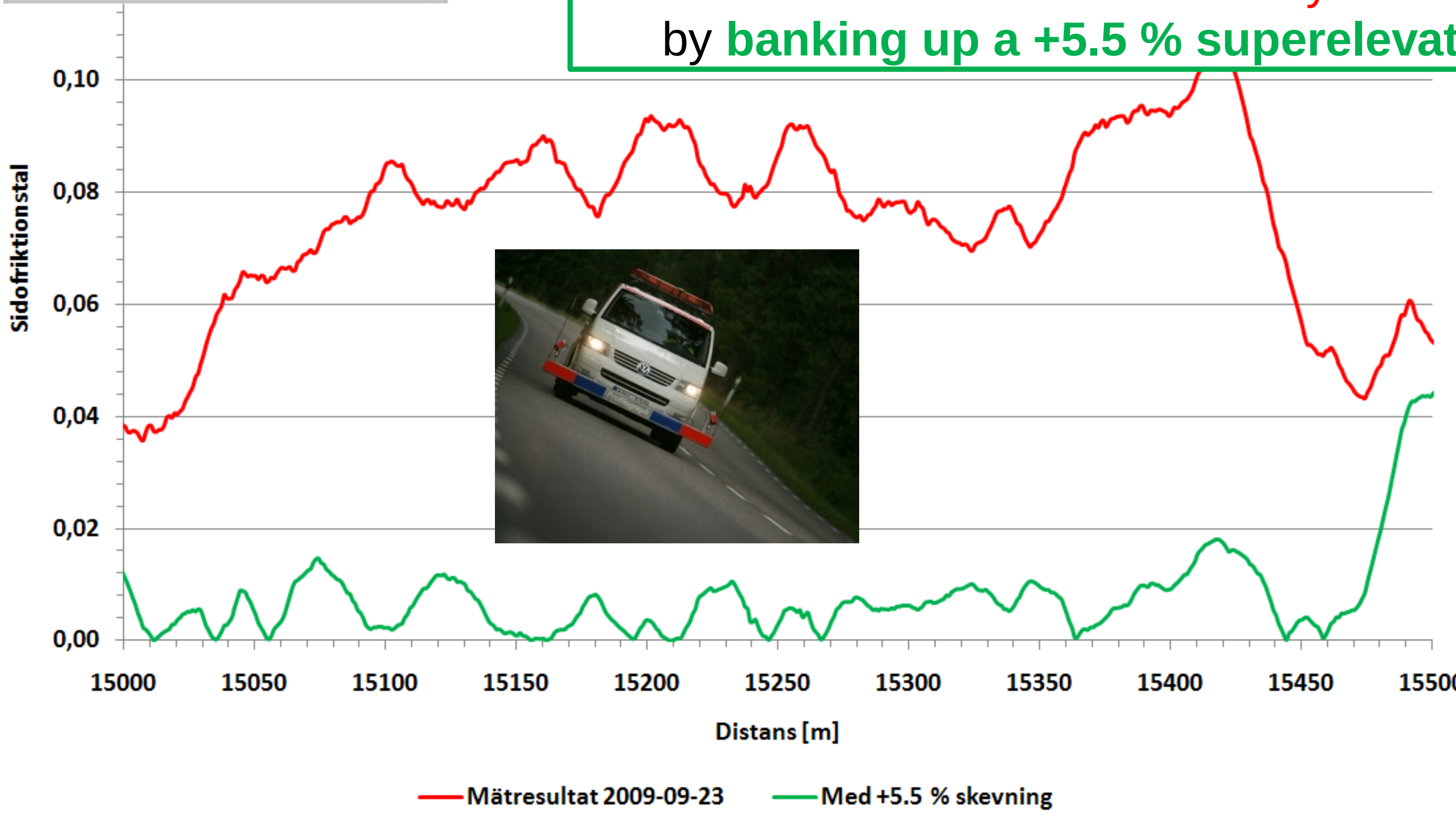


Case: Outer-curve with radie 2000 m

Negative crossfall -3.5 %.

The friction demand is reduced by some **80 %**,

by **banking up a +5.5 % superelevation.**



Hydroplaning at banked outer curve

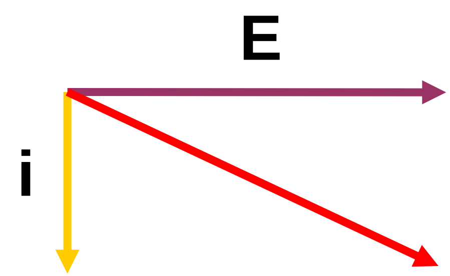
Oncoming Heavy Goods Vehicle brakes at curve entrance.

The waterfilm is very thick just there, due to improperly designed Drainage Gradient (DG).

Video source: Prof B Psarianos, NTUA

Unacceptably low Drainage Gradient (DG)

Drainage Gradient (**DG**) is resultant to crossfall (**E**) and longitudinal grade (**i**).



$$DG = \sqrt{(i^2 + E^2)}$$

Risk for low DG only where **E** change direction, pass 0 % (zero) and changes sign +/-.

This occur at entrance and exit of banked outercurves*.

**In the UK & OZ: Left hand curves, due to left hand traffic.*

Too low Drainage Gradient at
the Canyon of Death

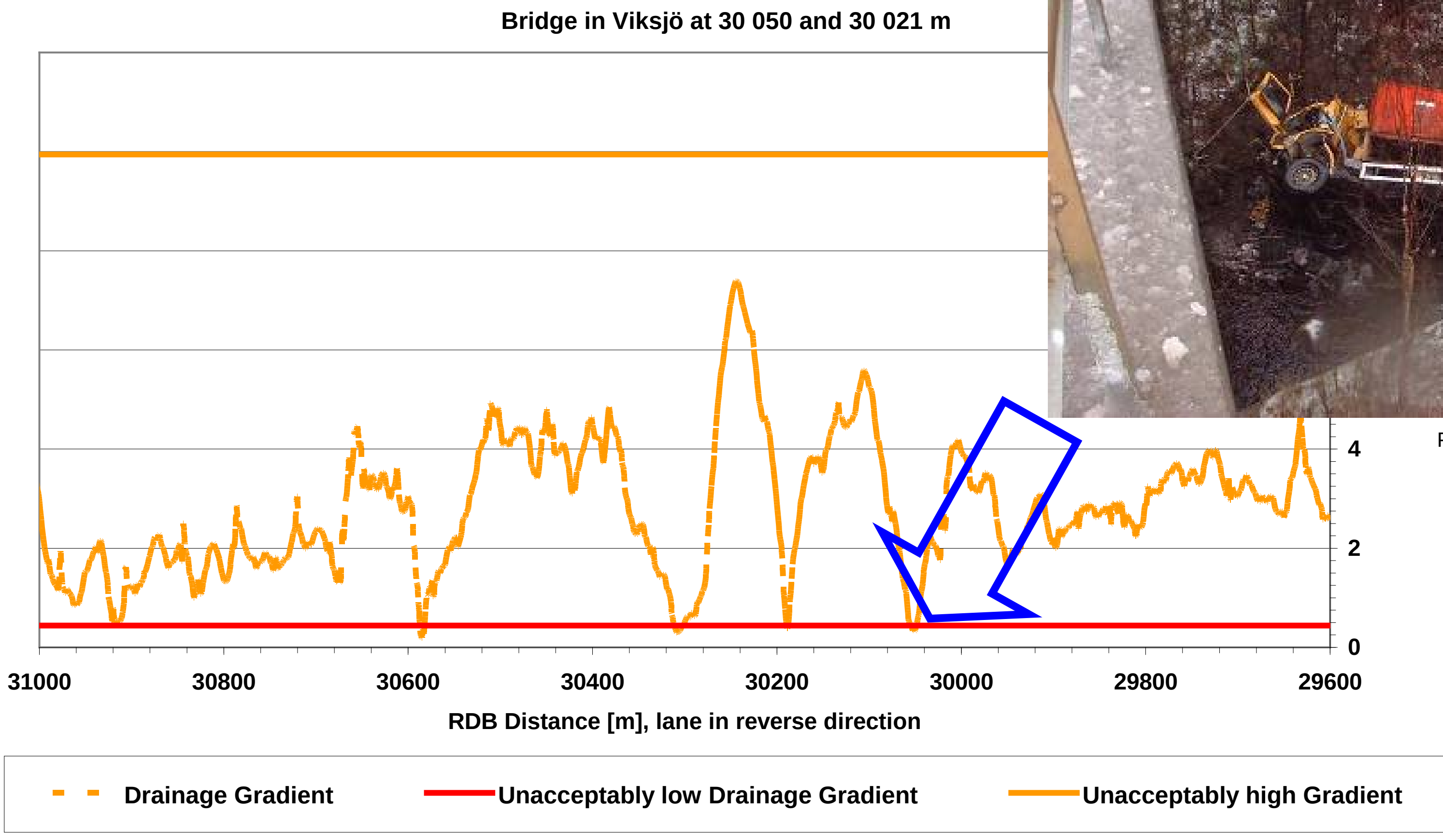
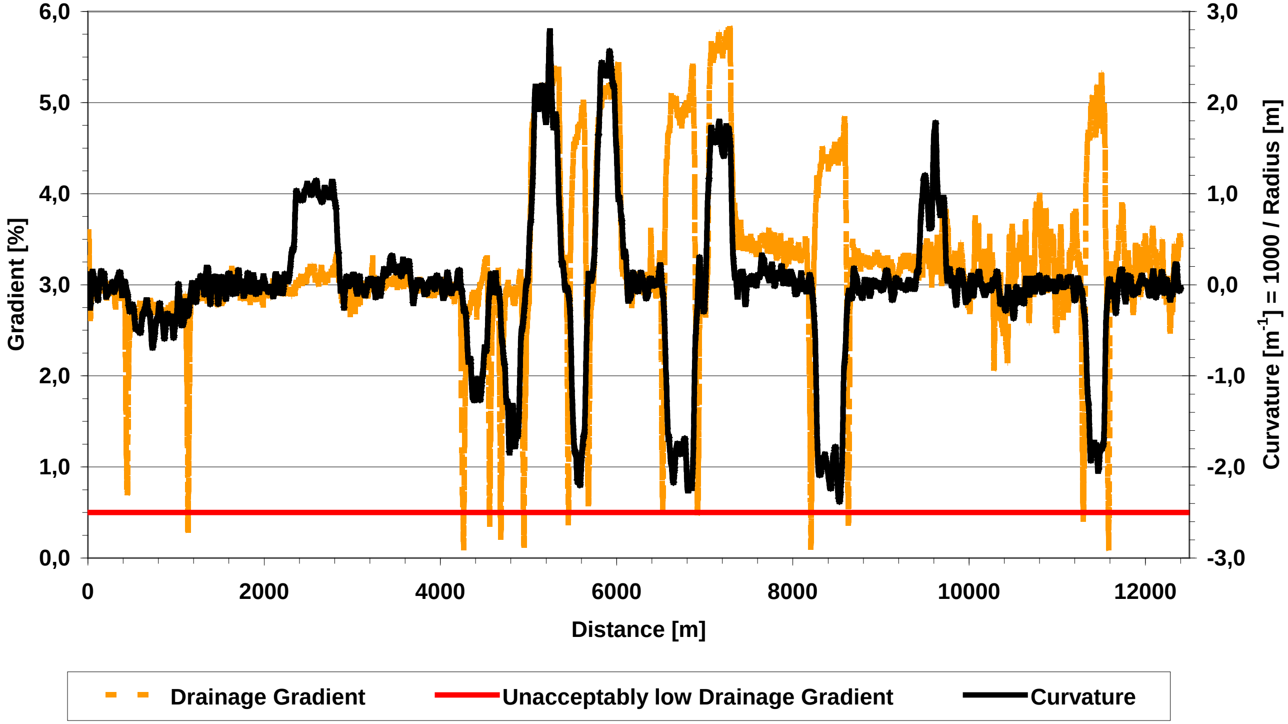


Photo: High Coast Rescue Dept

Exit from
outer-curve.

Insufficient DG also at new roads!



New Hw 90: 12 hazardous sites within 12.3 km.

All sites at entrance or exit of outer-curves.

The road condition affects the crash risk

Vägegenskap	Kriterie										
								Slitage och skador			
	Väghållbarhet	Vinterdrift	Buller	Smuts	Framkomlighet	Säkerhet	Komfort	Fordon	Däck	Gods	Drivmedel
Bärighet	3				3						
Ytans styvhet			1								2
Ojämnhet i längdled	3	2	2	1	3	3	3	3	2	3	3
Megatextur	2	2	3	1	2	2	3	3	2	3	3
Makrotextur	2	2	3	1		2	1	1	3		3
Tvärfall	2			1	1	2	1	1	1		1
Kantdeformation	3	2	1		3	3	3	2	1	2	1
Spårdjup	3	2	1	2	2	2	2	1	1	1	1
Pölbildning	1	1	1	3	2	3	2				1
Friktion		3	1		3	3	2		3		3
Retroreflektion					2	2	2				

[Efter VTI Notat 21, 1993.]

	Betydelse
Stor	3
	2
	1
Liten	0

Most important factors:

- Roughness
- Edge deformation
- Water pooling
- Friction

Surface property or road damage?

Material property

Controlled by f x choice of roller compactor

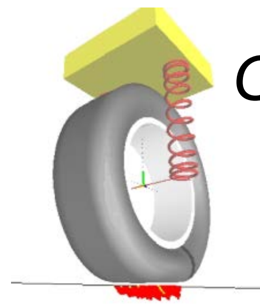
Roughness/Unevenness

Mega-texture

Macrotexture

Micro-texture

Road damages



Can also be created in construction works

0.5 mm | 5 mm | 50 mm | 0.5 m | 5 m | 50 m

Wavelength

Negative MaTx with ca. 5 mm wavelength forms up ”acoustic pores”, absorbing noise.

Road Surface Macrotexture (MaTx)

"Deviations longer than 0.5 mm from a true planar surface, affecting the road / tyre interaction."

Low macrotexture < 0.5 mm (polished, bleeding/"fattening up"):

- poor wet friction – especially when braking hard at high speed,
- insufficient water runoff – increased splash and spray,
- glare from light reflection.

High texture >> 1 mm (separations, raveling, weathering):

- loss of surface aggregate; reduced pavement service life,
- vibration and noise (if longer than ca. 8 mm waves),
- increased rolling resistance and tyre wear.

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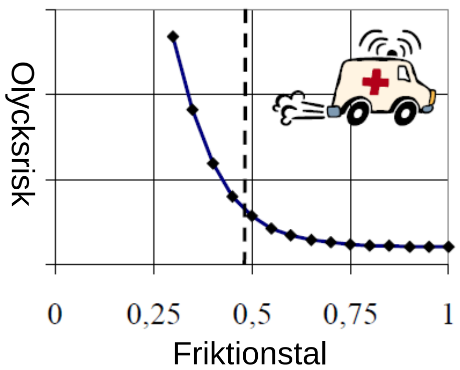
Grip between tyre and road:

Road friction management



[From VTI Message 911A:2001]

Crash risk booms at low friction.

Increased braking distance, decreased steering response and lateral stability.

Poor friction on bare asphalt

Poor friction on winter road conditions

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Factors increasing the skid risk

Road damages

Abrasion ruts from studded tyras

Change Crown/Superelevation

"Fat" bitumen spots

High speed

Fast change of lane

Loose gravel

Snow, ice and slush

Adverse camber

Foto: www.larm-soderhamn.se

High air humidity

Wind bursts

Pollen

Wet road

Temperature close to 0° C

Oil leakage

"Split friction" between tracks

Road roughness

Ruts by deformation

Slippery road marking

Tyre or road friction?

Friction describes the grip between tyre and road.
Friction is created by both vehicle/tyre and road properties.


Bildkälla: Wikimedia


Bildkälla: SMC

Foto: M Gabrielsson

Road surface friktion can be measured as an isolated property. This is possible by using standardized measurement methods; reference tyres, drift angle, slip percentage, speed, dry, 0.5 mm water film, 1 mm water film, et c.

5 crashes within 2 weeks

after improper repair of edge deformation

Photo: Bengt Andersson, Svt.se

Photo: Stefan Hedlöf

Patched crash curve (cont.)

Entrance to sharp bend.

The edge was patched with a ”fat” asphalt mix.

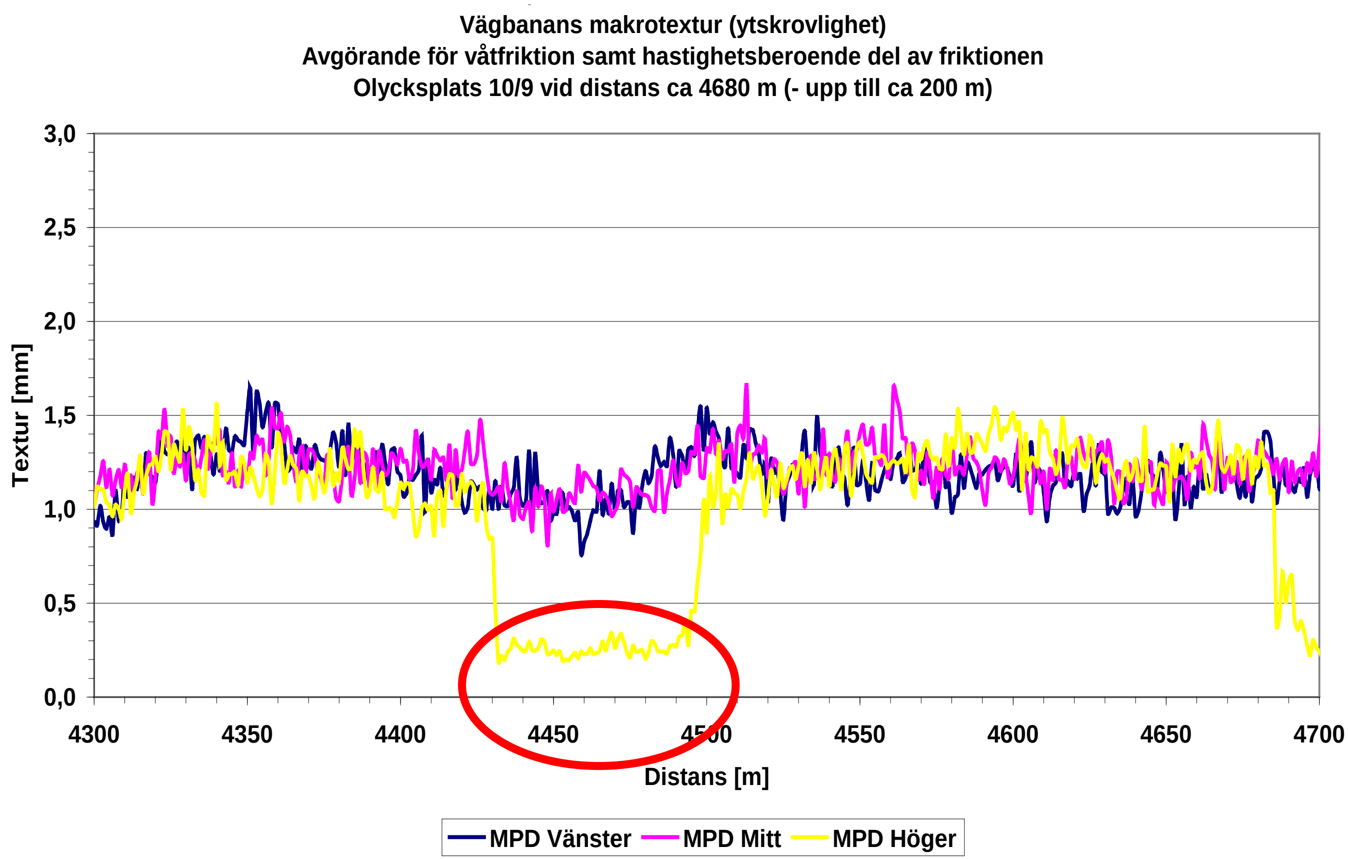
NOTE: Sealed longitudinal joint.

Hazardous lack of Macrotexture

at the crash curve

66 m long ”fat” (bitumen-rich) patch in the right hand wheelpath.

Macrotexture far below threshold value ”Minimum 0.6 mm.”



International Friction Index


Photo: Transportstyrelsen


Photo: Dirk James Insurance

International Friction Index (IFI) clearly shows how much friction decrease with increased speed.
IFI is defined in standard ASTM E1960 (SRI in EN 13036-2).
IFI & SRI are calculated from data on friction at any speed, together with data on texture from laser scanning.


Picture: Halliday Tech

International Friction Index (2)

Friction at any speed, FS, is determined from IFI parameters.

FS = F60 x EXP ((60–S)/Sp), where

F60 = Friction at 60 km/h

Picture: Halliday Tech

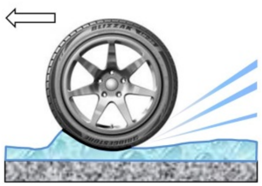
Sp = Speed index = 14.2 + 89.7 x MPD

Typical road friction at 70 km/h

Surface type	Wet friction	Dry friction
Polished wet ice	<0.1	
Glare ice		0.1 – 0.2
Packed snow		0.25 – 0.5
Dry asphalt/PCC		0.55 – 1.0
Wet asphalt/PCC, 1 mm texture	0.35 – 0.9	
Pollinized wet asphalt	0.35	
Wet ”fat spot”, 0.2 mm texture	<0.2	

Sources: VTI, Statens Vegvesen

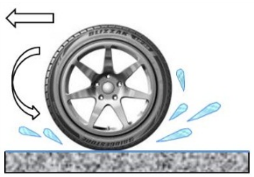
Hydroplaning



Dynamic hydroplaning:

A thick waterfilm can give the tyre a lift already at low speed.

Photo: Dirk James Insurance



Viscous hydroplaning:

May occur already at 0.5 mm waterfilm (barely moisted surface).

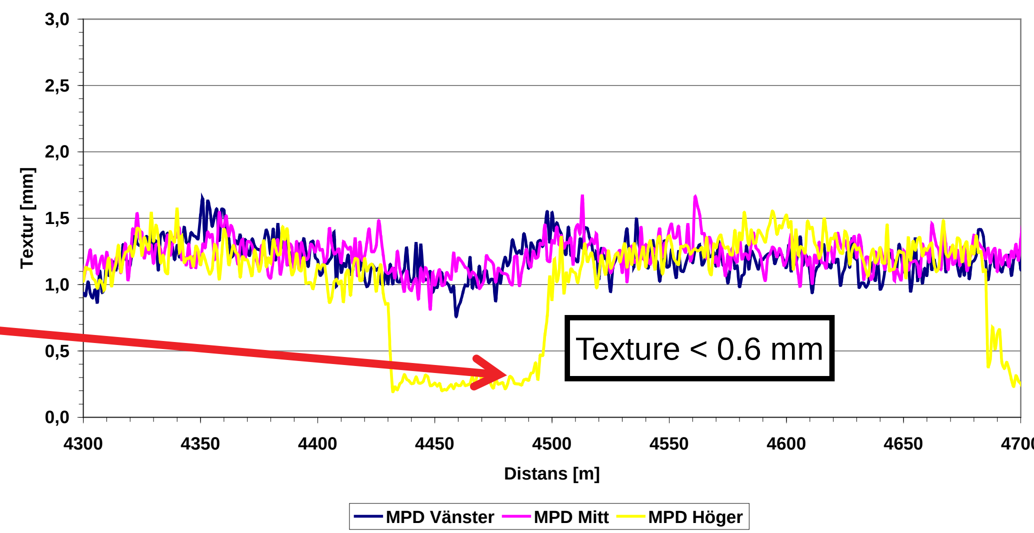
Wheel locks easily, without transfering significant braking forces.

Critical road properties:

- Unusually slick road surface; texture < 0.6 mm.
- Insufficient drainage gradient; safety limit 0.5 %. *Common at entrance/exit of banked outercurves!*

Viscous hydroplaning

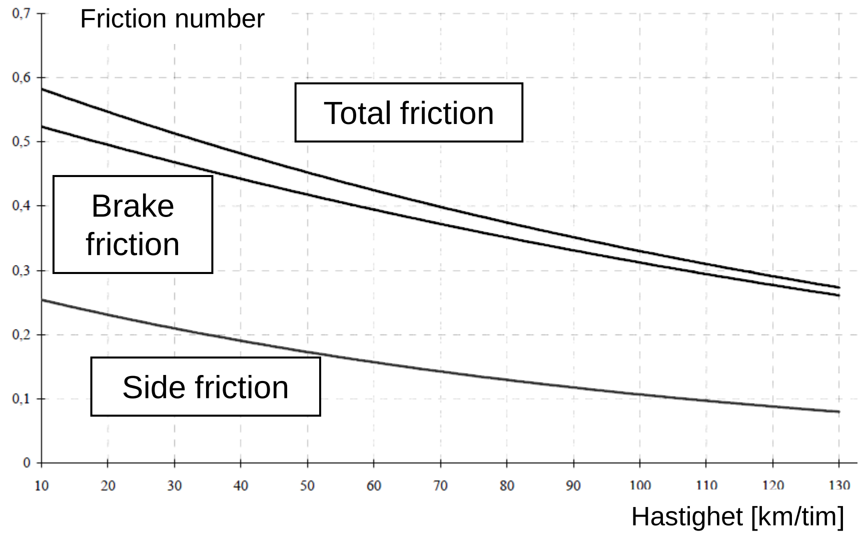
Example at Hw 61:
5 crashes within 2 rainy weeks after ”fat” patchwork.



Low friction also cause reduced lateral stability

In-depth studies of fatal crashes show that the most frequent characteristic is that the vehicle has lost stability and skidded.

Dimensioning friction in the road design code VGU



The friction between road and tyre limits forces in both longitudinal and lateral direction.

Forces acting to stabilize the vehicle in lateral direction, drops when braking. This may get critical in horizontal curves!

Safety limits on friction at bare roads (non-winter)

Sweden: STA´s friction requirements applies to any paved surface open for traffic.

The road surface friction must be measured to assure that the safety demands are met.

The friction number must, for roadways, pedestrian paths and bicycle lanes with bound wearing course, exceed 0,50 (averaged per 20 m).

[STA technical requirement in the national standard ”TBT”]

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Safety limits on
friction at winter road surfaces

Photo: T Elverheim, ST

10 procent fler olyckor i halkan

Publicerad: 20 oktober 2010, 15.45. Senast ändrad: 20 oktober 2010, 16.49

När halkan slår till ökar antalet olyckor.
– Det är i skiftningen mellan torrt väglag och halka som flest olyckor sker, säger Johan Strandroth, trafiksäkerhetsanalytiker vid Trafikverket.

10 % more crashes on slippery roads

Lowest acceptable friction as per the Swedish Winter standard:

Krav vid uppehållsväder och när åtgärdstid efter nederbörd löpt ut.

Sektions-element	Vägytetemperatur			Ojämnhet cm
	varmare än -6°C friktionstal	-6°C till -12°C friktionstal	kallare än-12°C friktionstal	
Körfält	snö/isfritt	0,35	0,25	1,5
Vägren	0,25	0,25	0,25	1,5
Sidoanläggning	0,25	0,25	0,25	1,5

Example for highways in standard levels 1-3

Accurate measurement of friction

Sweco use several types of friction meters:

- **RT3** measures with normal car tyres and 1.5° drift angle. *Measures surfaces ranging from dry asphalt to polished wet ice.*


Photo: LTU

Photo: M Gabrielsson

- **TWO** measures with industrial forklift tyres, made of very hard rubber, rotating with 20 % longitudinal slip. *Delivers minimal variance between repeated measurements.*

- **ViaFriction** has a water spraying system and measures at variable slip and at any speed. *Measured data are normalized to 18 % slip at 60 km/h; perfect for accurate calculation of International Friction Index (IFI) and other friction indices.*

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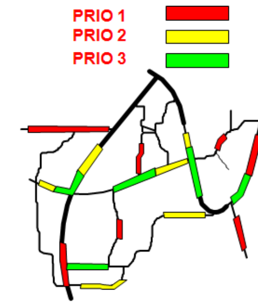
Skid Prevention Management



Analysis of data over crashes and traffic

Identifying sites where low friction is extra hazardous

Analysis of Curvature, Crossfall, Longitudinal grade and Drainage Gradient measured with laser/inertial high speed Profilograph

Identifying bare surfaces with risk for low wet friction

Analysis of Macrotexture from Profilograph

Control of bare ground friction indices, preferably IFI

Measurement with ViaFriction

Control of winter-friction

Measurement with ViaFriction, RT3 or TWO

Risk analysis and proposals for countermeasures

Comparison before/after countermeasures

At bare ground (asphalt paving works) as well as on winter surfaces

What is road roughness?

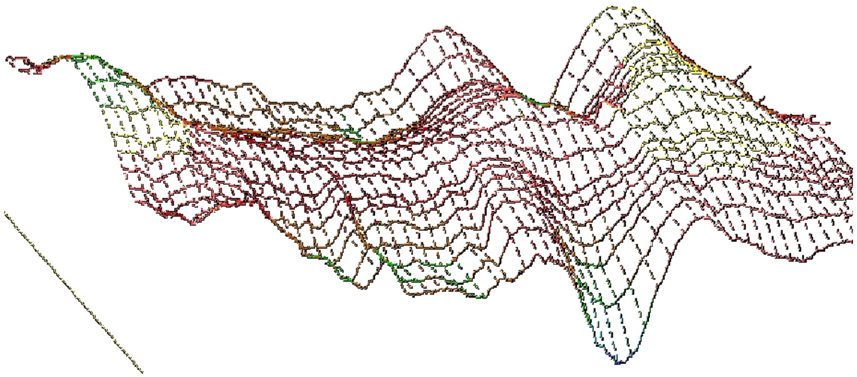
Deviations from a true planar surface, affecting:

- winter road maintenance *(straightedge),*
- water runoff *(slope meter, rut bar),*
- dynamic effects *(speed, suspension properties…).*

Road roughness are longer than 0.5 m.

(Shorter waves = Megatexture)

Road roughness cause undesired vibration



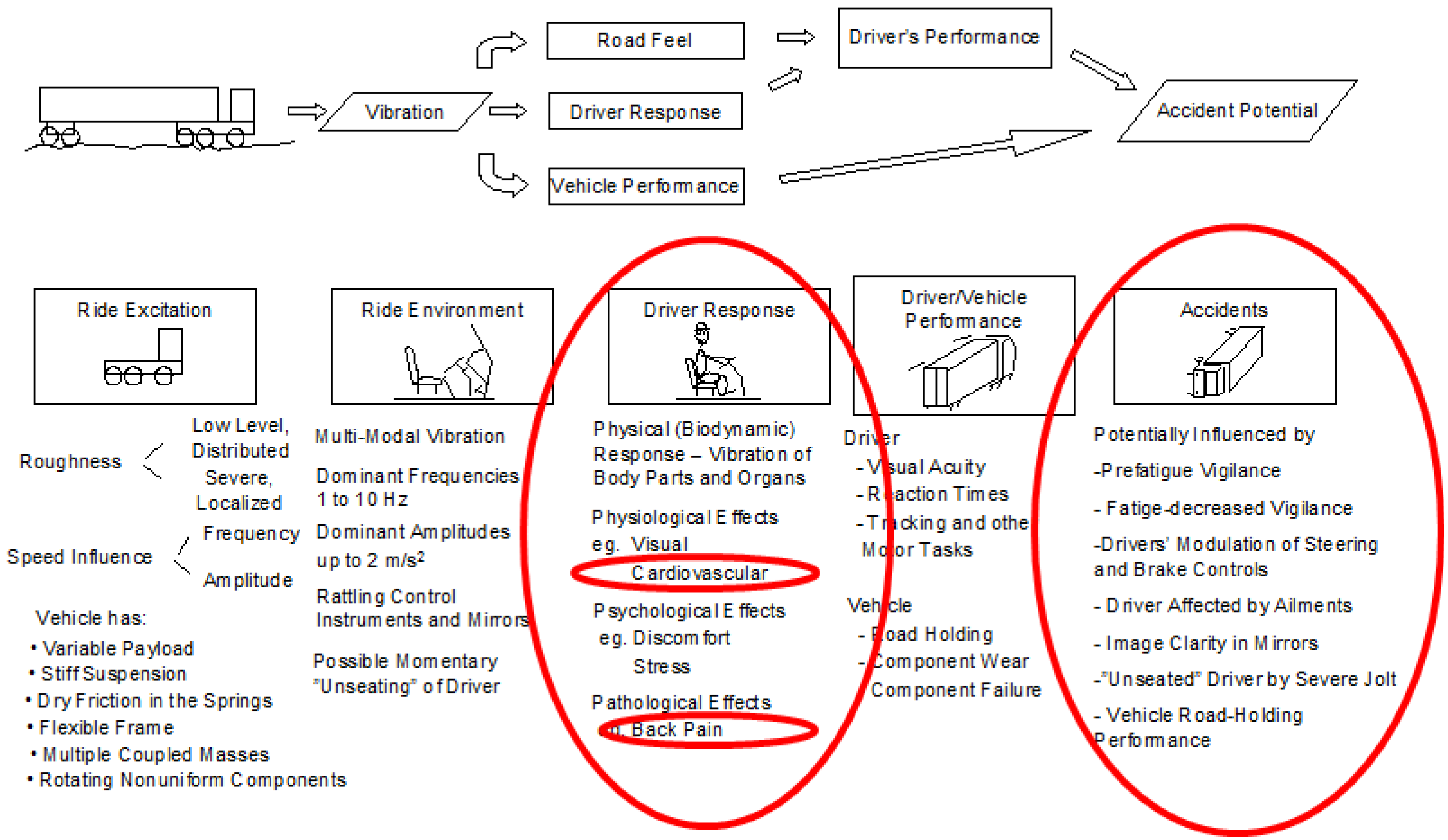
Roughness shape

Vertical motion in vehicle at speed

Elevation, depth, height	[mm]	⇔	Displacement, level	[mm]
Slope	[mm/m]	⇔	Vibration velocity, IRI	[mm/s]
Slope variance	[mm/m²]	⇔	Vibration acceleration	[mm/s²]

[Photo: Wiman Ambulance]

Health and safety aspects on ride vibration



[Highway Safety Research Institute]

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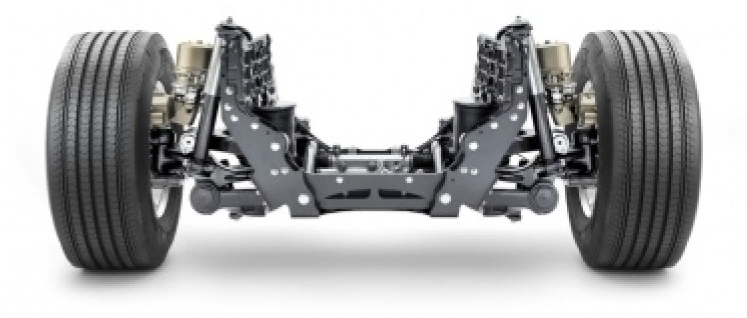
Road roughness cause
hazardous steering effects



__Bump-Steer:__

Suspension yield changes in camber and caster angles.

This changes forces acting on the tyre / the vehicle.

Non-symmetric suspension (only one wheel bouncing) cause a steering effect.

Uncomfortable Bump-Steer is common in heavy vehicles.

[Photo: Volvo Trucks]

Road unevenness cause poor road grip

[Photo: AlfaMotorHomes]

Weight transfer:

Road roughness (as well as wind bursts, acceleration, braking and cornering) cause weight transfer from side to side.

Weight transfer reduce the vehicle´s total road grip and may cause skidding.

Worst are sudden spatial change in crossfall as well as longwave unevenness.

Road damages increase the crash risk


AFTONBLADET

TIPSA OSS

ettan@aftonbladet.se

TISDAG 26 OKTOBER 2004

HÄR DOG TVÅ Polisen misstänker att ett gupp i vägbanan kan ligga bakom olyckan som tog två ungdomars liv. "Guppet är farligt", säger Anders Hammarberg, som ofta färdas på sträckan.

Foto: ANDERS ANDERSSON

Guppet blev deras död

elitserien

Frölunda tillbaka i serieledning

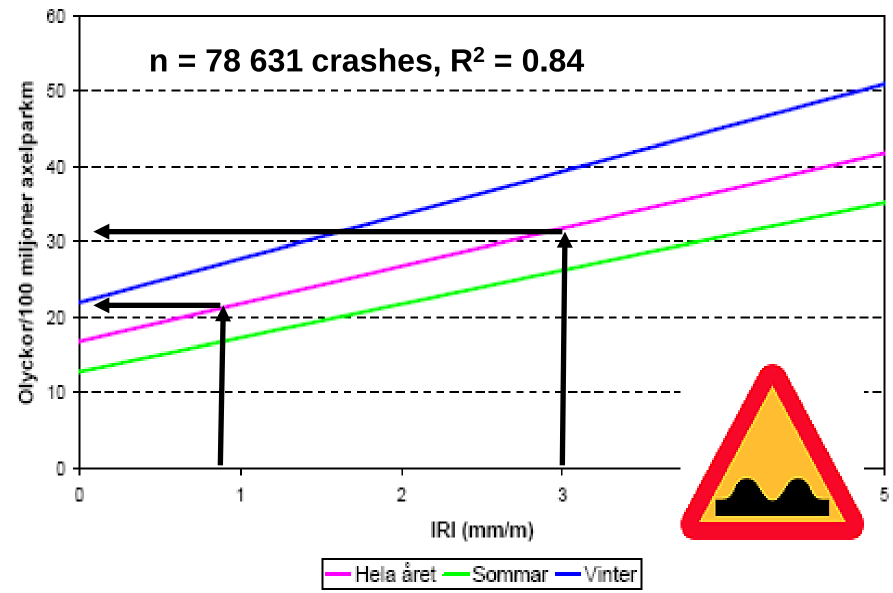
webb-tv

webb-tv Glassen som är gjord av guld - världens dyraste sundae

du+jag

PLUS Fixa första året ihop Så undviker ni de vanliga problemen

PLUS Hitta



Bumpy roads with roughness IRI 3 mm/m have 50 % more crashes than smooth roads with IRI 0.9 mm/m.

[Source: VTI Message 909-2002]

Short wave road roughness

I.e. potholes, corrugations and some frost boils.

Makes winter road maintenance more difficult.

Exposes the tyres to very high impact forces.

Efficiently isolated (> 75 %) from the vehicle body.

Remaining < 25 % vibration may cause much discomfort.

Stressing / alarming effect on vehicle drivers.

May cause fatigue if present for long time.

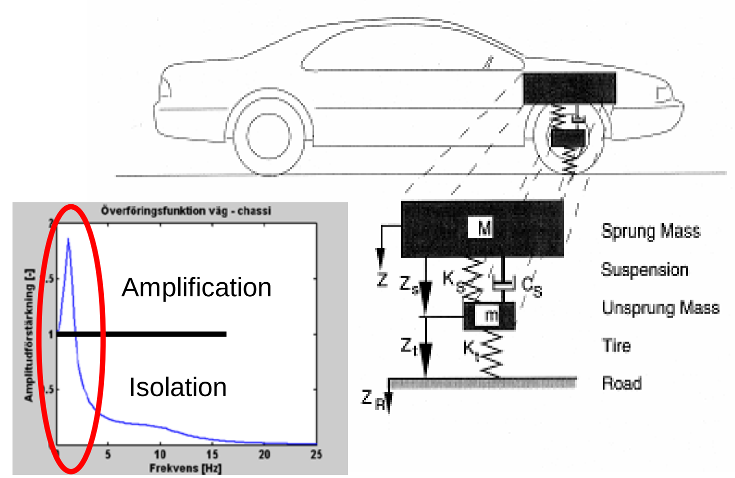
Longwave road roughness

Settlements, certain frost boils, sudden spatial variance in crossfall.

Causes vehicle body bounce, pitch and roll vibration.

The suspension system amplifies vehicle body bounce by up to 80 %.

The slow motions may cause drowsiness to vehicle occupants.



Bouncing heavy vehicles cause large dynamic loads with long duration (seconds / several tenfold meters) into the pavement. This cause severe road damage.

Illustration: UMTRI

SWECO

Roughness scale IRI – suspension velocity

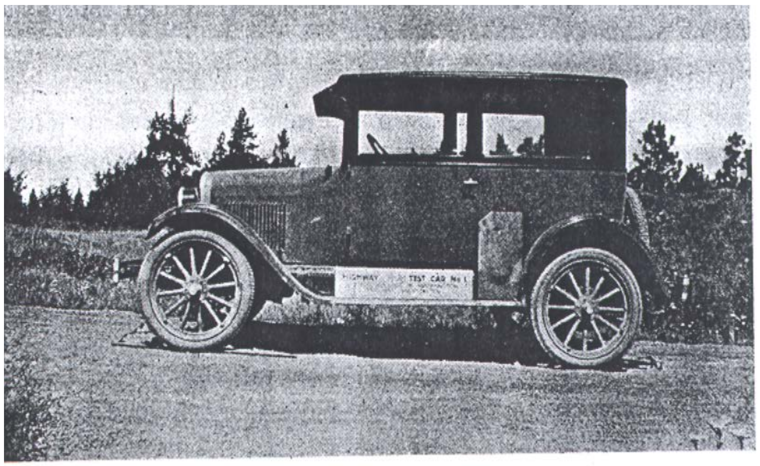
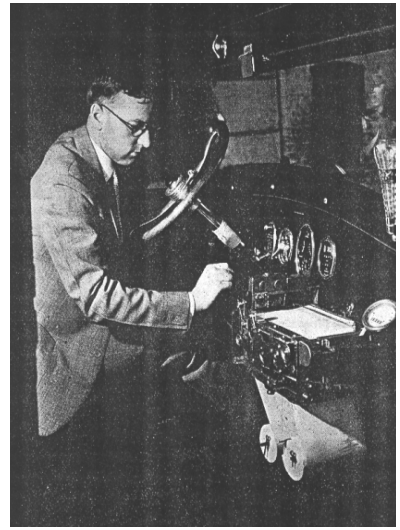


Figure 11. View of Highway Washboard Test Car of the Engineering Experiment Station; Car Is Shown with High Pressure Tires.



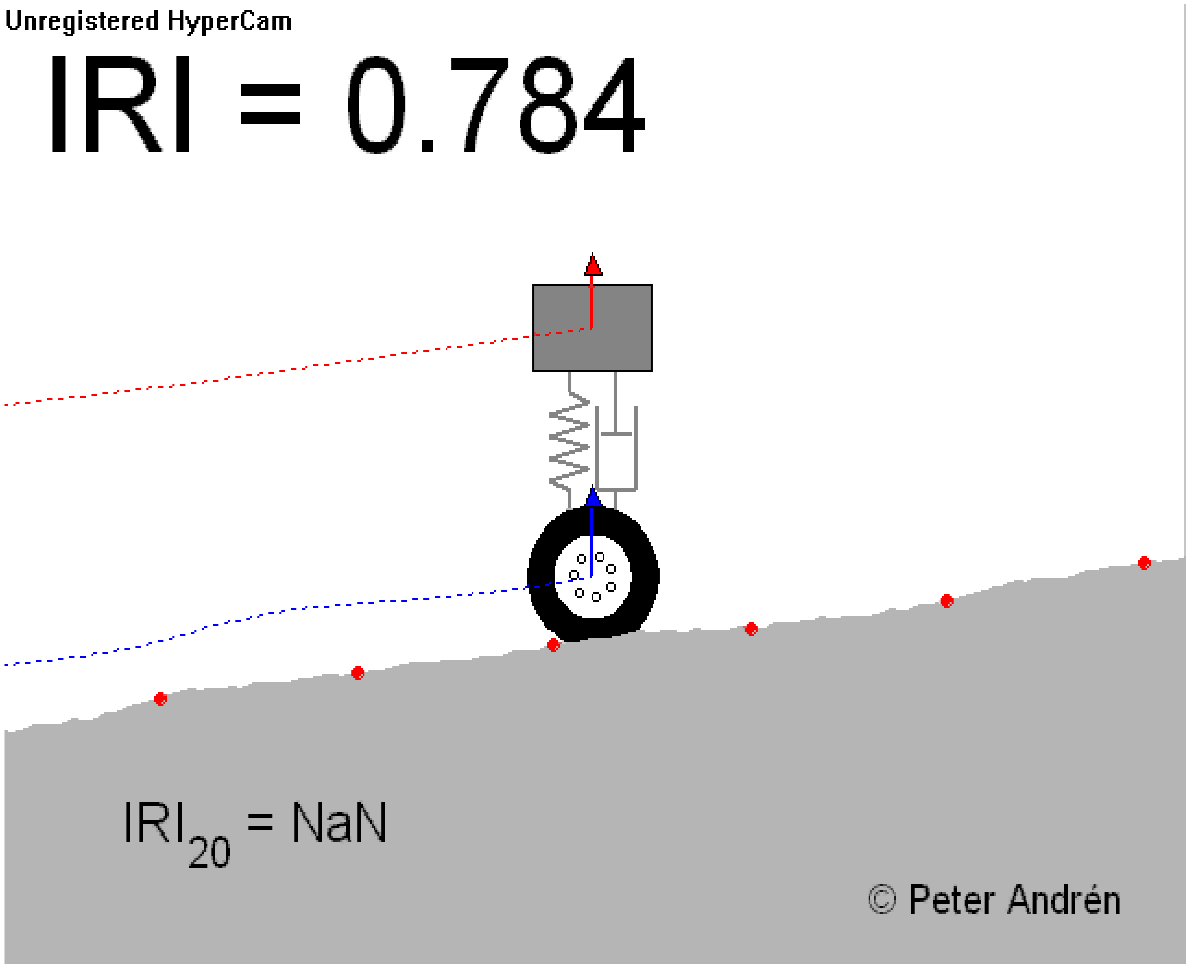
1927: Bump slope [mm/m] recorded by suspension stroke [mm/m].

1986: International Roughness Index (IRI) standardized by the World Bank.

IRI is computed as suspension velocity [mm/s] in a reference quarter car model, divided by the model´s ”driving speed” **80 km/tim** (22 m/s).

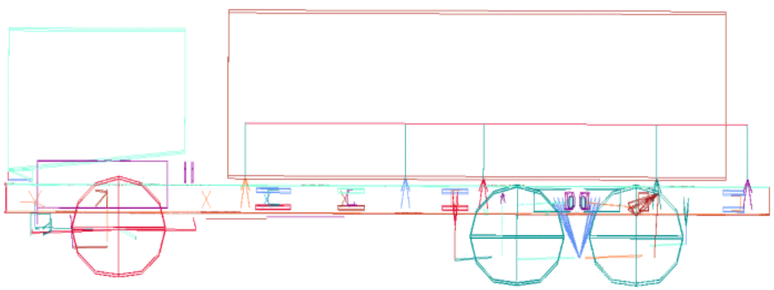
[Pictures: H J Dana, Transportation Research Record & U Nilsson]

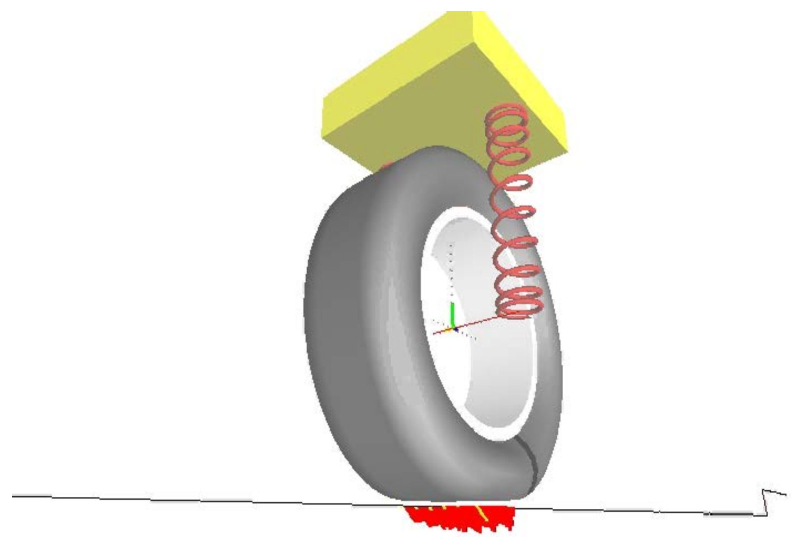
International Roughness Index



[Animation: P Andrén]

Beyond IRI: More accurate simulations

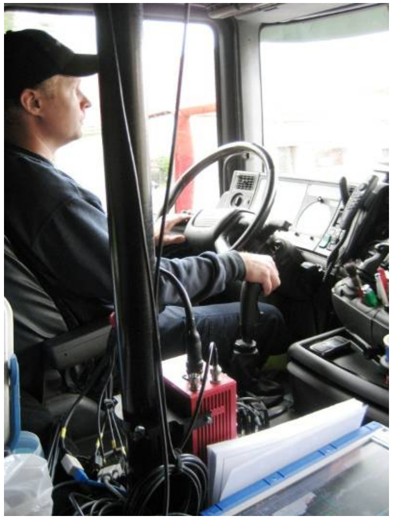




[Animations: Volvo 3P & Ftire]

Mapping ride vibration from road profile to driver seat

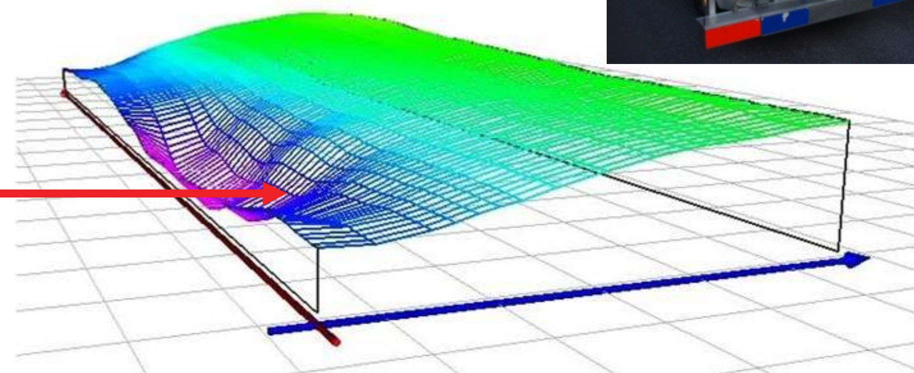
Road properties are more decesive to drivers daily vibration exposure than vehicle suspension, speed and driving hours.



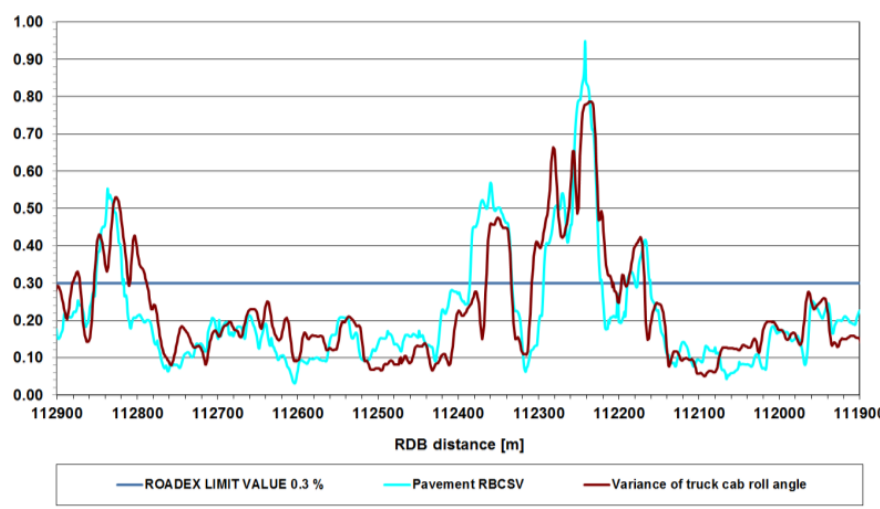
Hazardous edge slump

Deformed road edges cause roll vibration and roll-related lateral buffeting = skid risk on icy roads.

Photo: M Risberg



Edge slump is measured with the Rut Bottom Cross Slope Variance (RBCSV) parameter.



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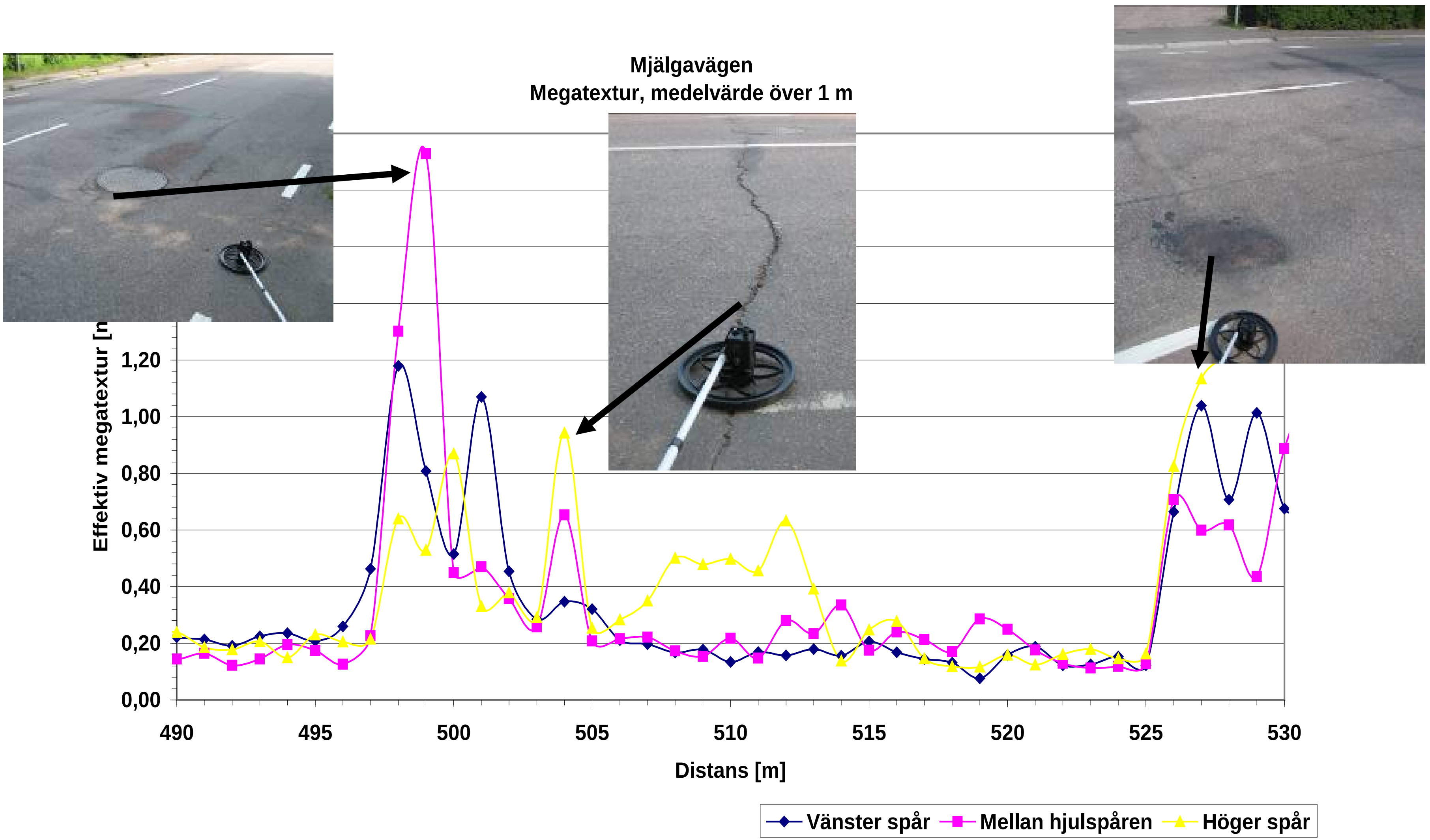
Megatexture are short wave road damages

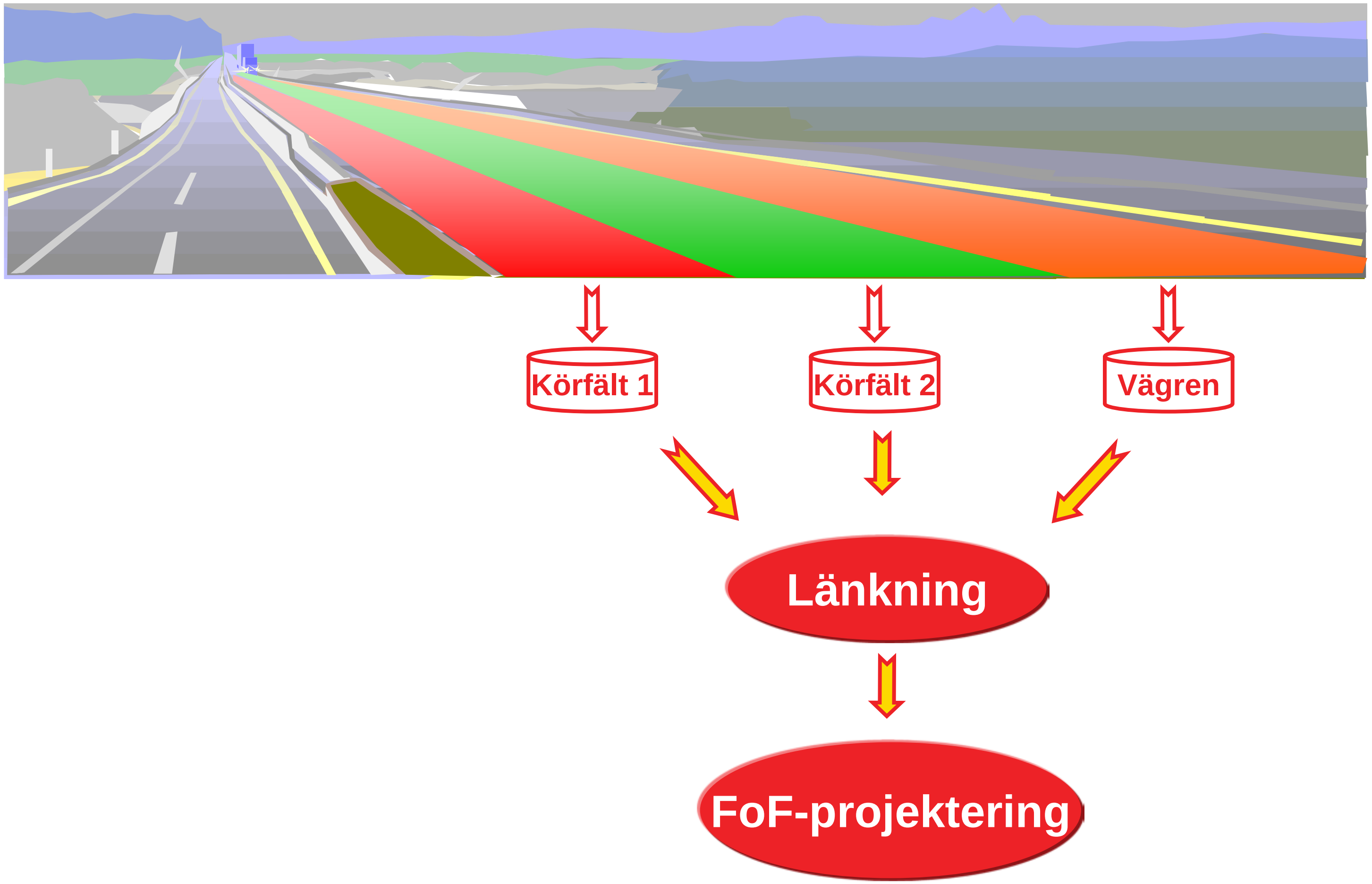


Noisy cobble stones

has much Megatexture

Comprehensive surface measurement for

CAD of resurfacings

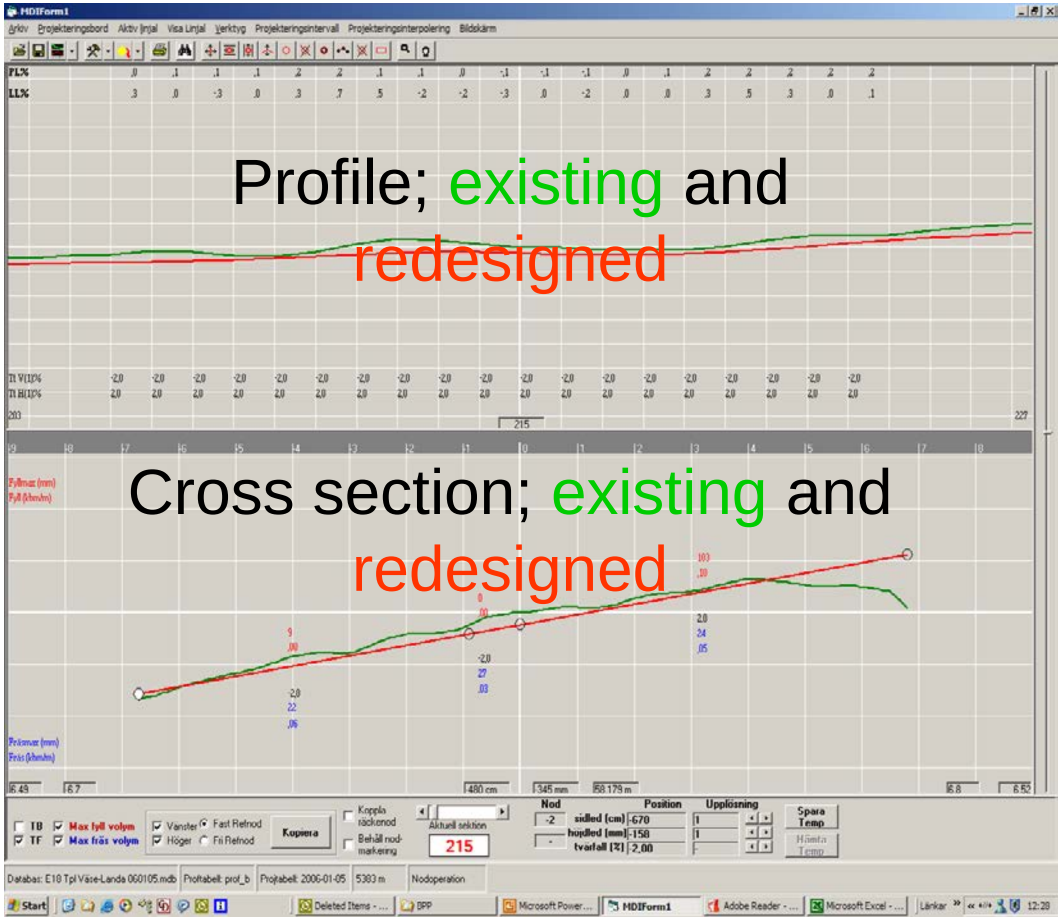


pavement geometry

E18 Väse – Landa: Computer Aided Design (CAD) of **unevenness repair**.

Spot levelling and milling, followed by reinforcement by 60 mm bound base.

On top: A thin wearing course with high resistance to wear from studded tyres.



Results from CAD of geometric road repair

Digital drawings with accurate volumes of asphalt works.

Contourmap in bird perspecive:

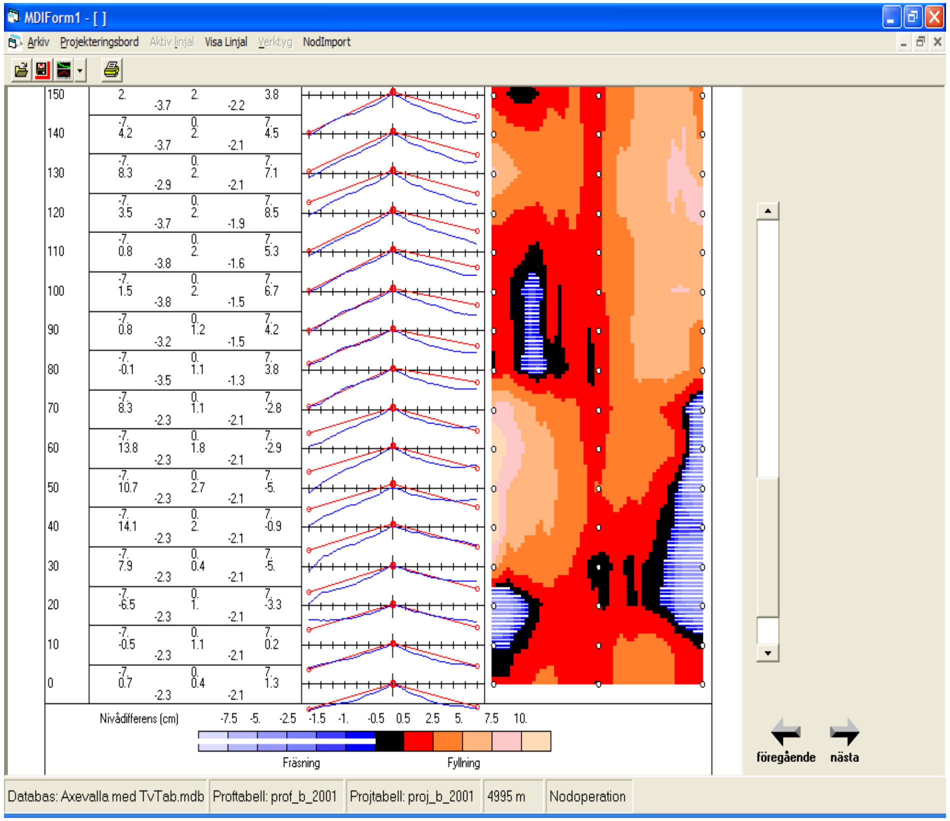
• Spot levelling (lighter colour = thicker adjustment)

• Milling (blue/white lines)

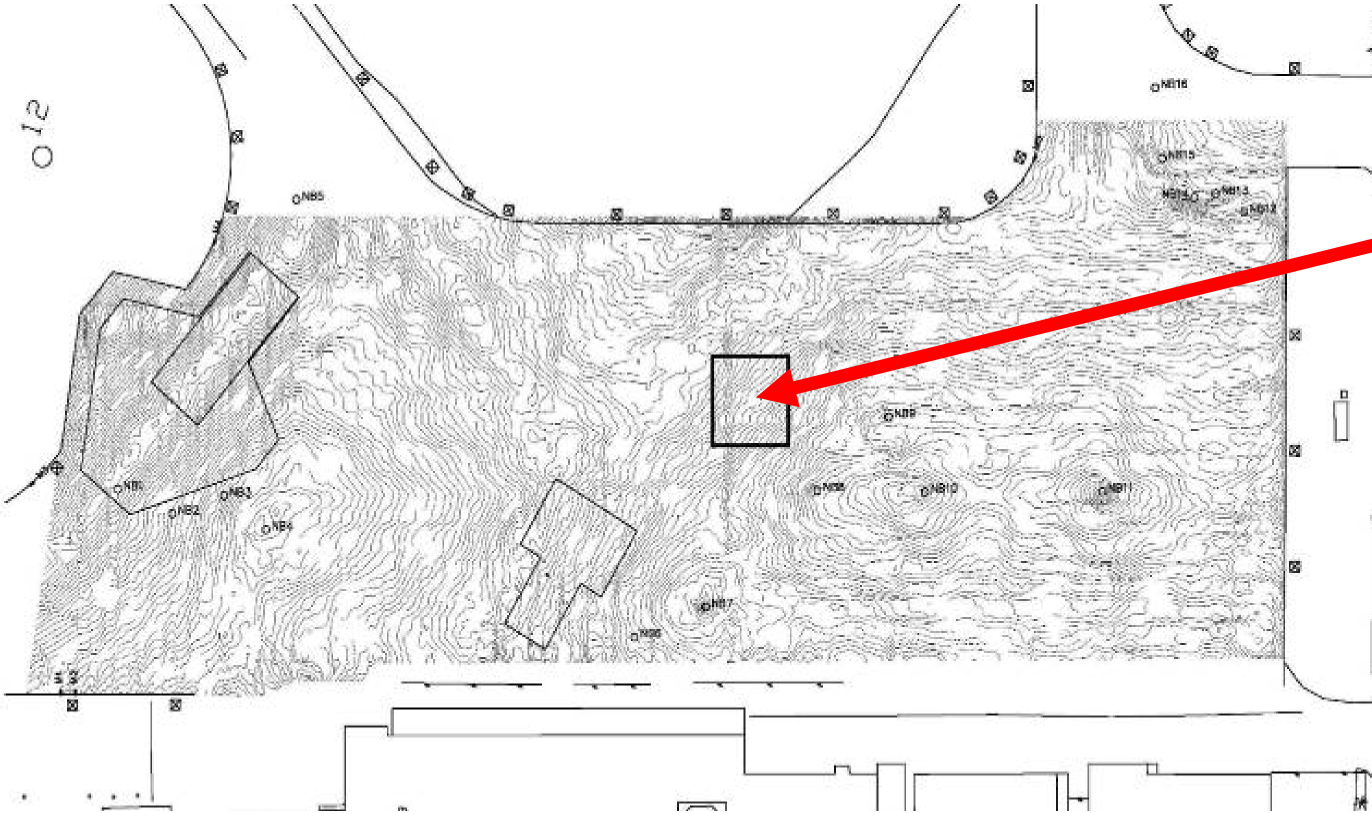
• Do nothing areas (black)

Cross sections.

Data for manual stake-out as well as computer aided manufacturing (CAM).

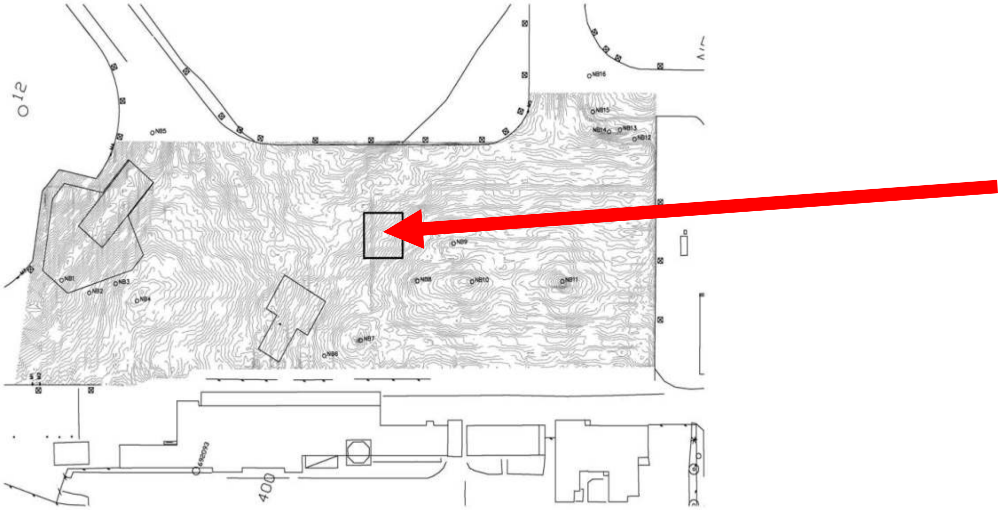


Rough apron

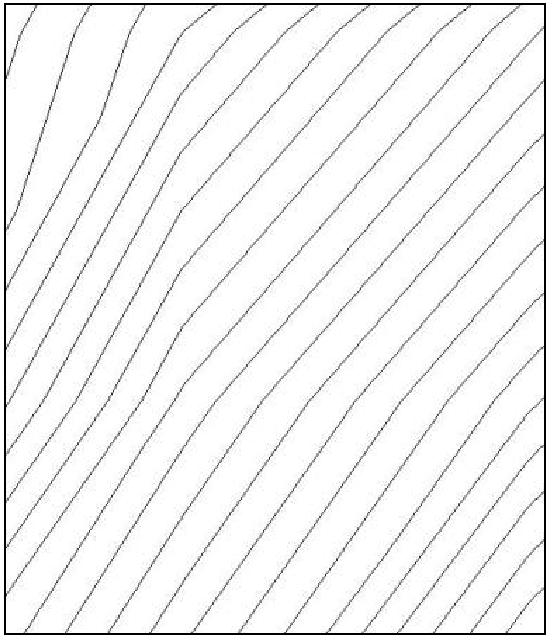


Square with 20 m edge length

Cont., rough apron



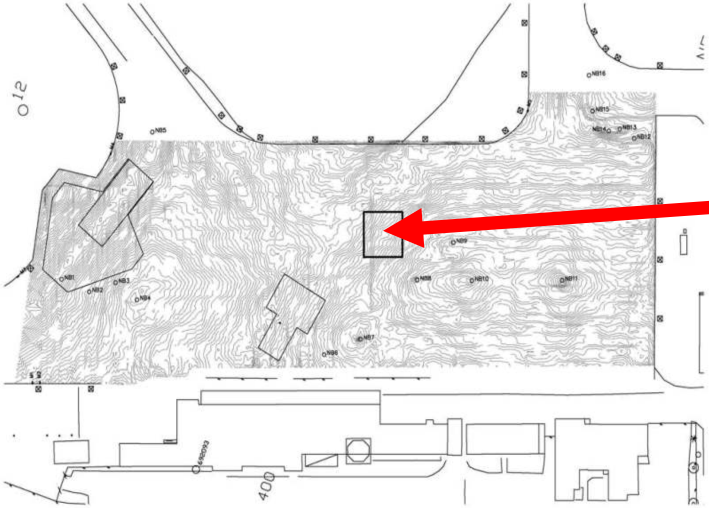
Traditional 10 m grid:

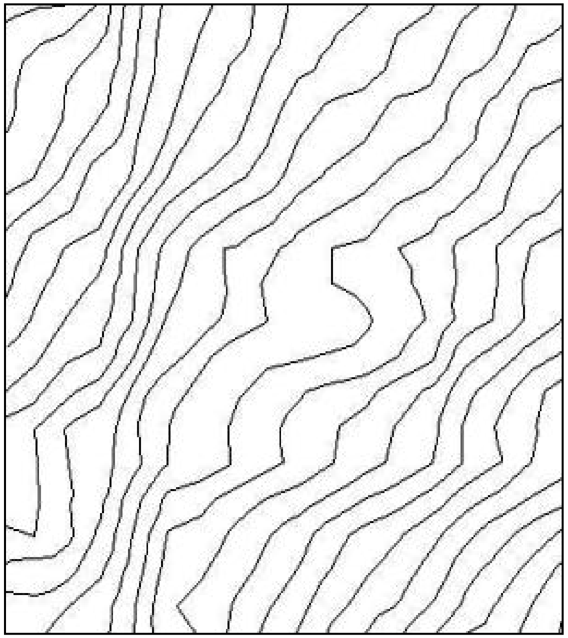


Equidistance 10 mm

Cont., rough apron

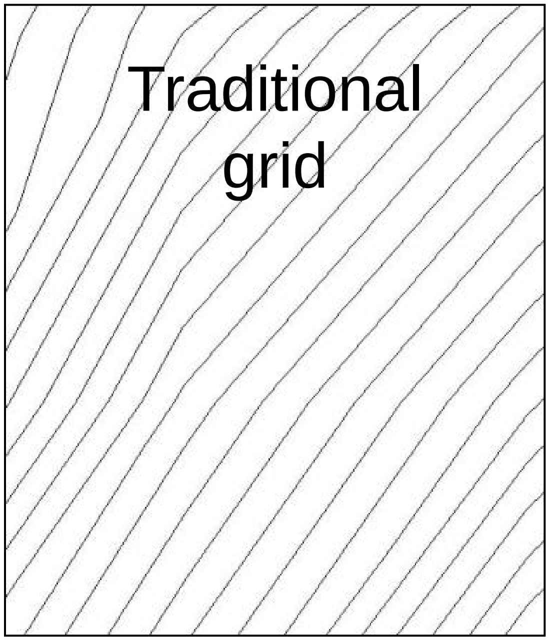
With *Comprehensive surface measurement*^{TM}:

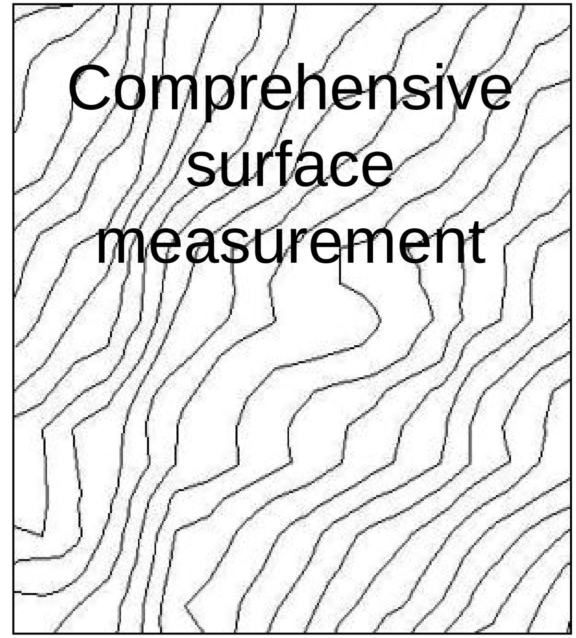




Equidistance 10 mm

Experiences from the rough apron





Traditional measurement showed nice slope.
Comprehensive surface measurement revealed 5 m waves with 2 cm height/depth amplitudes.

Correct information is a prerequisite to optimal action!

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Control measurements at airfields

Swedavia demands at finished wearing course:

Roughness, shortwave	< 3 mm / 3 m straightedge
Rourhness, 0.5 - 30 m	IRI_{100} < 1.3 mm/m (1.4 taxiway)
Elevation	z within +/- 6 mm
Cross slope	1.5 % +/- 0.3 %
Macrotexture	0.75 < MTD < 0.9 mm
Wet friction	*> 0.5 @ 130 km/tim, osv*

Control measurements at highways

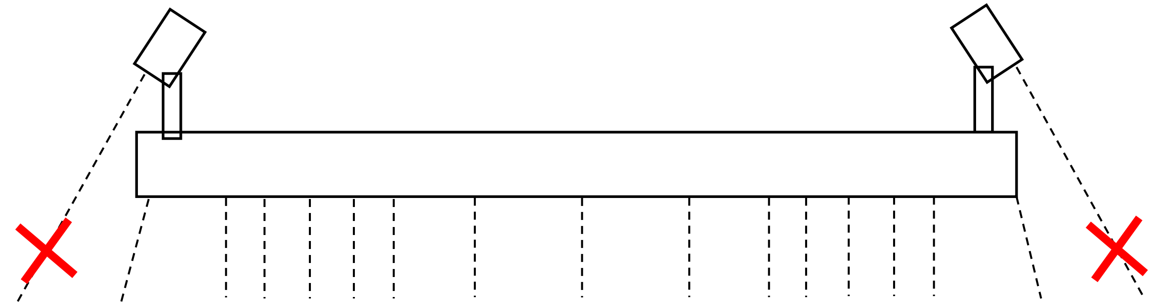
Control made by approved mobile high speed laser/inertial profilometer as per Trafikverket method 122.

Each lane measured in 3 (4) runs.

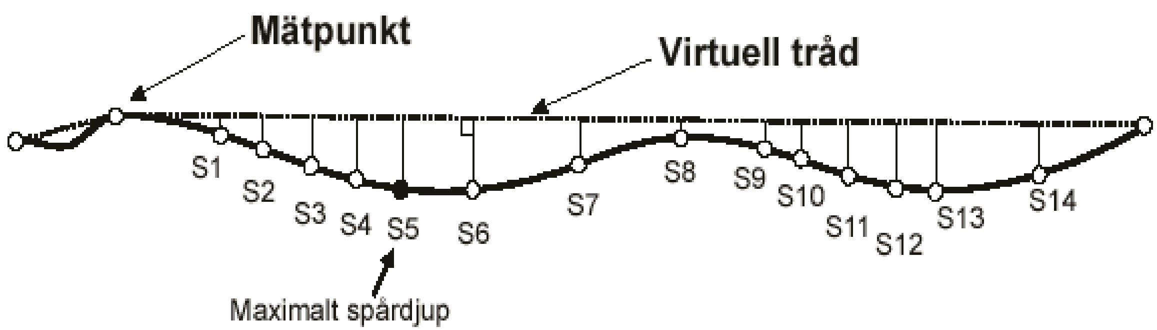
20 meter average values.

Cross slope:	Within MIN- and MAX-limits. Max deviation from designed value.
Bumps, $IRI_{höger}$:	Values below limit.
Road profile:	New measurements and demands are under investigation.
Macrotexture:	Min-/maxvalues, sideway homogenity.

Control measurements at highways (2)



Measuered width reduced by narrow lanes (< 3,5 m)



”Rut depth”: Not exceeding the limit, f x 3.0 mm.

Comfort, comfort my people, says your God

A voice of one calling in the desert;
-Prepare the way for the Lord, make straight paths for him. Every valley shall be filled in, every mountain and hill made low. The crooked roads shall become straight, the rough ways smooth.

The path of the righteous is level;
O upright One, you make the way of the righteous smooth.
And all mankind will see God's salvation.

Isaiah 26:7 Isaiah 40:1,3-5 Luke 3:5, Matthew 3:3, John 1:23

Vectura