ROADEX
Implementing Accessibility

Northern Periphery Programme 2007–2013

Innovatively investing in Europe's Northern Periphery for a sustainable and prosperous future

European Union
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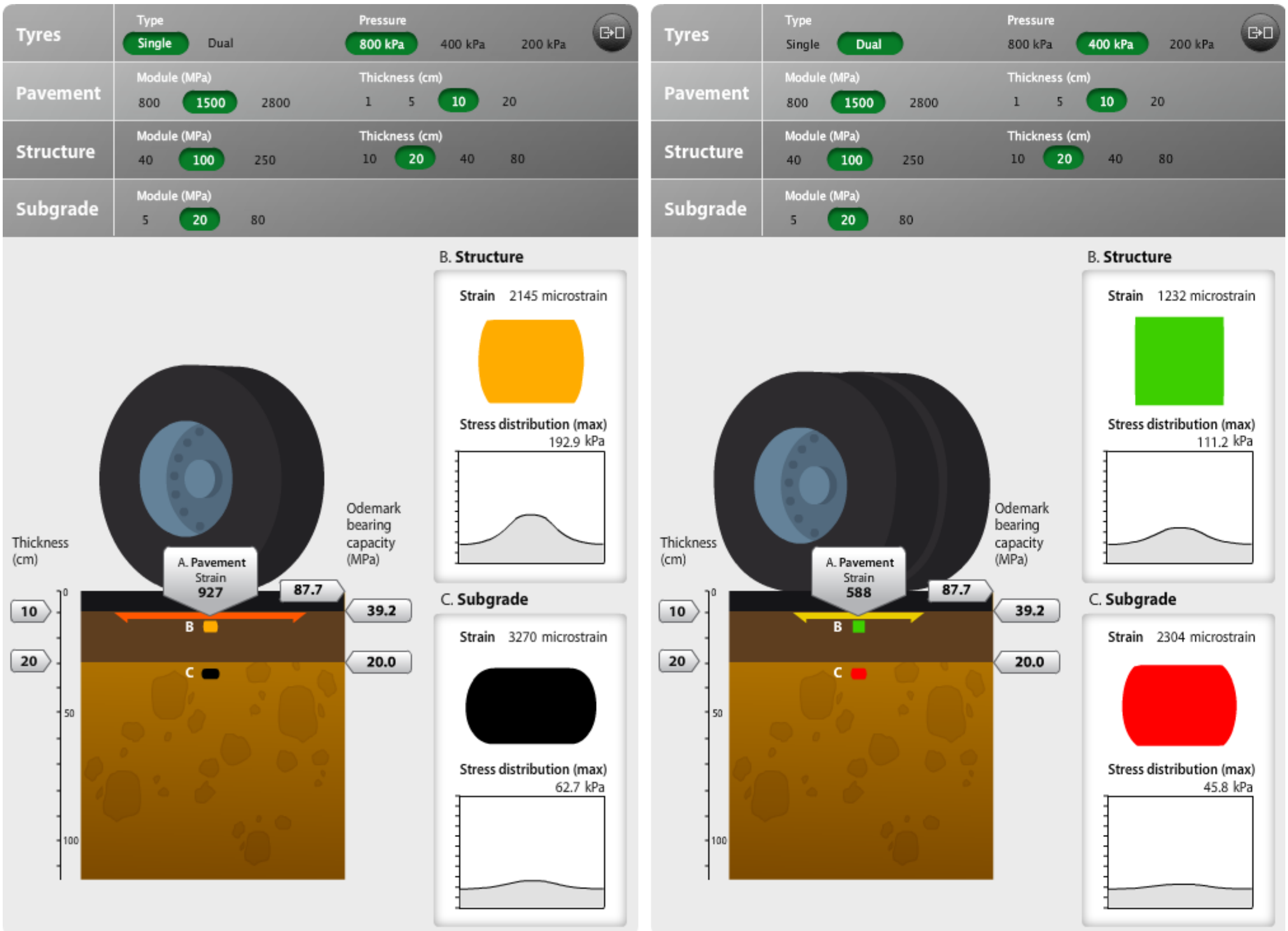

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THE ROADEX PAVEMENT STRESS AND STRAIN CALCULATION DEMO, V. 1.3 20.10.2010

INTRODUCTION AND THE INSTRUCTIONS FOR USE

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1. INTRODUCTION TO THE ROADEX PAVEMENT STRESS AND STRAIN CALCULATION DEMO

Road structures and materials in low volume roads in cold climate areas generally follow visco-elastic or visco-elastic-plastic behaviour rather than elastic behaviour. It is however important to understand the role of the elastic modulus in determining the bearing capacity and resistance to permanent deformation in the different parts of the road structure and subgrade soil. The overall structural quality of a road is defined by its “weakest link” and this can be located in different points of the road structure, or in the subgrade.

The elastic modulus, or modulus of elasticity, describes the stiffness of a material, i.e. its capacity to bear and spread load. In general, the greater the modulus the smaller will be the material’s elastic deformation (strain) caused by the particular stress increment applied.

In an ideal road structure the modulus of the materials in the pavement layers should decrease from top to bottom. This is because the closer the material is to the surface, the greater will be the stress caused by the wheel load. A stiffer material will spread the load better over the layer below. This will reduce the stresses and strains in the lower layer and permit weaker materials to be used. The ratio between the moduli values of the two layers should not be too high however; as horizontal tensile forces could be created in the base of the upper (stiffer) layer.

The layer thickness and the modulus of a layer will influence the bearing capacity of the layers on top of it rather than the bearing capacity of the layers below. Thus the bearing capacity at the top of the pavement structure will be determined by the properties of the subgrade and each of the individual structural layers in the road. So when designing a road structure, it has to be ensured that the stresses and strains in every structural layer, and on the subgrade, are well below their critical limits. The same rule applies when designing the strengthening of an old road.

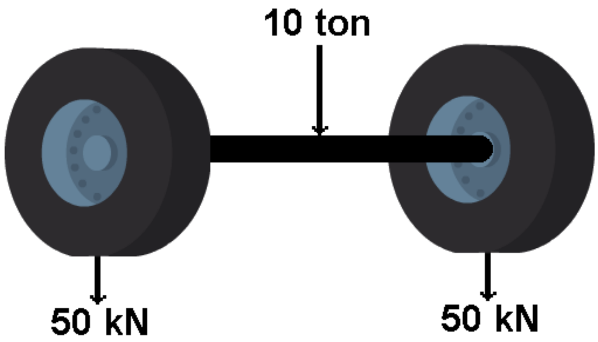
There are many different ways to achieve bearing capacity when designing a new road or rehabilitating an existing road, but the long term resistance to permanent deformation must also be considered. This can be done by analysing the points in the road structure where the stresses and strains are close to the critical limit. These critical points can be difficult to identify in a road structure and to help this ROADEX has designed the following “ROADEX Stress and Strain Demo”. This will help the reader to estimate the stresses and strains in the road structural layers and the top of the subgrade as well as showing the development of bearing capacity up through the structure. In addition, the demo is designed to provide information on the effect of different tyre types and tyre pressures on the critical stresses and strains in the road.

It is hoped that the ROADEX demo can be used as a simple design tool for low volume roads. It should be kept in mind however that there are other factors, such as road width, frost, drainage, etc. that can have a great effect on the bearing capacity and permanent deformation of a road and these should be considered also. The demo can also be used as a specialist tool to assess timber haulage routes; e.g. to determine if it would be more appropriate to use CTI on a route rather than strengthening the road.

Note: “The ROADEX Pavement Stress and Strain Calculation Demo” has been produced for educational purposes only. The ROADEX project does not take any responsibility for its use in real design projects.

2. INSTRUCTIONS FOR USE

The stresses and strains for the following demo were pre-calculated using Bisar© software based on linear elastic theory. The calculations were carried out using typical loading configurations, layer thicknesses and material moduli found in the Northern Periphery area. The parameters were chosen so that a wide range of road structures from very poor to very high quality could be covered. The wheel load used in the demo is always the same, a standard wheel load of 50 kN representing a 10 ton axle load. All other parameters can be changed.



2.1. LOADING CONFIGURATION AND STRUCTURAL OPTIONS

The road structure used in the demo contains three layers: A. the pavement (the bound layers), B. the structure (the unbound structural layers) and C. the subgrade.

Tyres

Select the loading configuration to be used. There are two options for **tyre types**:
Single: a “super-single” tyre
Dual: two standard single tyres in a dual configuration

Choose the **tyre pressure** from the following options:
800 kPa: high (normal) tyre pressure; the typical value for trucks without Central Tyre Inflation (CTI) equipment.
400 kPa: lowered tyre pressure, used in trucks equipped with CTI; typical value for driving on low volume roads.
200 kPa: very low tyre pressure, used in trucks equipped with CTI; only used occasionally in exceptional situations. These cases are calculated only for the weakest structures.

Pavement

Choose **the modulus for the bitumen bound layers**. The options are:
800 MPa: Poor quality pavement with fatigue cracking
1500 MPa: Old pavement with minor damages
2800 MPa: New and good quality pavement

After selecting the layer modulus you have four options to choose from for **the thickness of the bound layers**:
1 cm: The thinnest bound layer, equivalent to gravel road conditions without a bound layer.
5 cm: A thin bound layer
10 cm: The average bound layer thickness

20 cm: A thick bound layer

Structure

Choose **the modulus for the unbound structural layers**. The options are:
40 MPa: Poor quality material
100 MPa: Moderate quality material
250 MPa: Good quality material

After selecting the layer modulus you have four options to choose from for **the thickness of the unbound structural layers**:
10 cm
20 cm
40 cm
80 cm

Subgrade

Choose **the modulus for the subgrade**. The options are:
5 MPa: Weak subgrade; e.g. peat, soft clay or wet silt
20 MPa: Moderately load bearing subgrade; e.g. dry silt, wet silty sand or wet silty moraine
80 MPa: Strong subgrade; e.g. gravel, sand or coarse grained moraine

2.2. THE RESULTS

The results diagram summarises the stresses and strains in the road structure at the most critical positions for the development of permanent deformation. For single tyres the calculation positions are below the centre point of the tyre and for dual tyres below the centre point of one tyre.

The tensile strain in the pavement layers is shown as a two-headed arrow located at the bottom of the bound layers. The length of the arrow indicates the amount of strain. A long arrow indicates a high strain. Compressive strains in the structure and subgrade are shown as a compressible rectangle in each layer. The compressed height of the rectangle indicates the amount of strain. A very compressed rectangle indicates a high strain.

Arrows and rectangles are coloured to represent the risk of permanent deformation or failure in the layer.

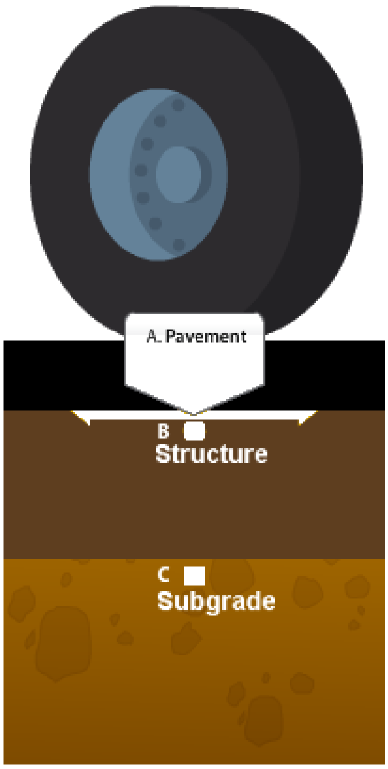
Green means a safe stress and strain level and a very low risk for failure / permanent deformation

Yellow means a moderate stress and strain level and a modest risk for failure / permanent deformation

Red means a high stress and strain level and a high risk for failure / permanent deformation

Black means that failure / rapid permanent deformation is likely to take place

The weakest layer in the arrangement defines the overall rating of the whole road structure. For example, if one or more of the three strains is rated black the whole road structure is considered as inadequate and will have failures under the designed loading.



A. The horizontal tensile strain at the bottom of the bound layers

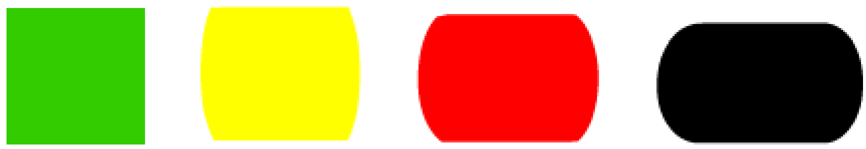
High values of strain indicate a risk of pavement fatigue. These results are displayed only for the pavement thicknesses of 10 cm and 20 cm. The calculation method used in the demo is not appropriate for thin pavements. With thin pavements, the most critical parameter is not the pavement strain but the quality of the base course.

B. The vertical compressive stress and strain at the upper part of the unbound layers

The stresses and strains in this position are the most critical for the development of Mode 1 rutting.

C. The vertical compressive stress and strain on the top of the subgrade

The stresses and strains in this position are the most critical for the development of Mode 2 rutting.



A diagram of the vertical compressive stress distribution for the structure and subgrade is supplied for the calculated positions in the structure. The value displayed is the maximum stress in the diagram for the calculation point. This distribution is designed to demonstrate schematically how wide area the load will be distributed in different structure and load distributions.

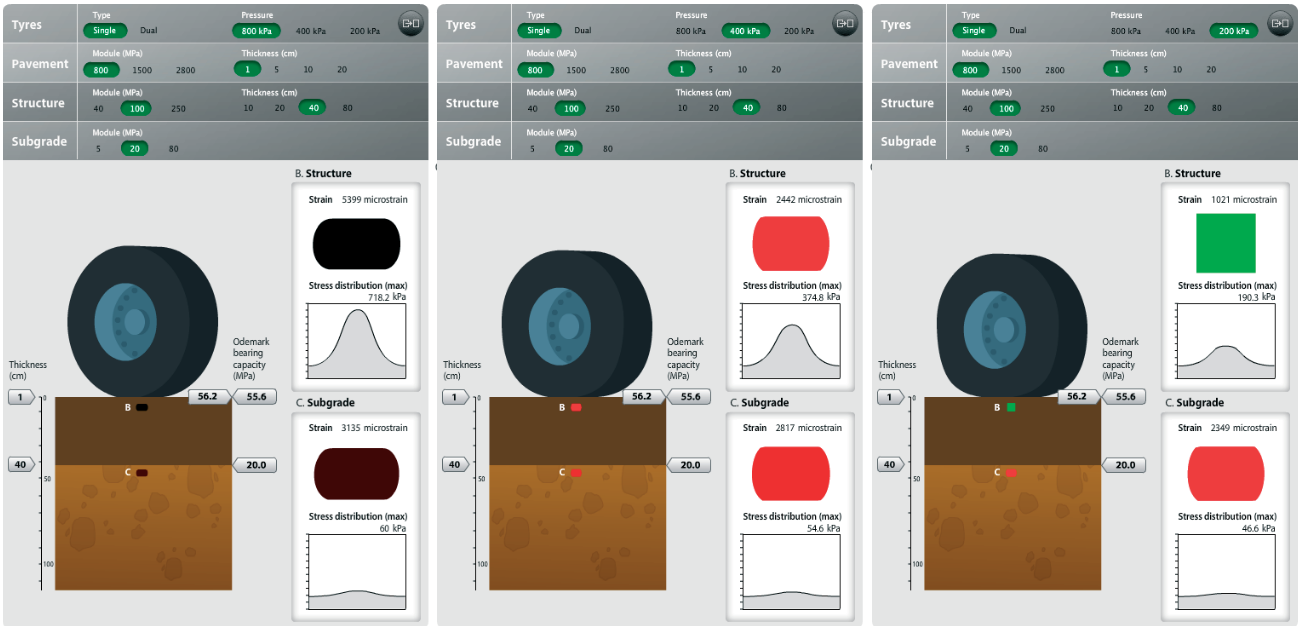
In addition to summarising the stresses and strains in the road layers, the demo also shows the bearing capacity calculated at the top of the subgrade and each structural layer using the Odemark method. As mentioned before, both the layer thickness and the modulus affect the increase of bearing capacity on the top of a structural layer compared to the bearing capacity beneath the layer. Thus the bearing capacity on the top of the pavement structure is determined by the properties of the subgrade and each individual layer above the subgrade. The Odemark formula is a simple method for determining the bearing capacity of a layered structure. It does not take loading into account. The bearing capacity is calculated only on the basis of the thickness and the modulus of the layer. Nevertheless, the formula provides the user an easy way to quickly evaluate if the structure stiffness is adequate for the loads on the road. The Odemark formula is well known and still very widely used in many countries for low-volume roads structural design. The formula is defined as follows:

$$E_P = \frac{E_A}{\left(1 - \frac{1}{\sqrt{1+0,81\times\left(\frac{h}{0,15}\right)^2}}\right)\frac{E_A}{E} + \frac{1}{\sqrt{1+0.81\times\left(\frac{h}{0,15}\right)^2\left(\frac{E}{E_A}\right)^{2/3}}}}$$

where
E_P = bearing capacity on the top of the layer being dimensioned [MPa]
E_A = bearing capacity beneath the layer being dimensioned [MPa]
E = the material elastic modulus of the layer being dimensioned [MPa]
h = thickness of the layer being dimensioned [m]

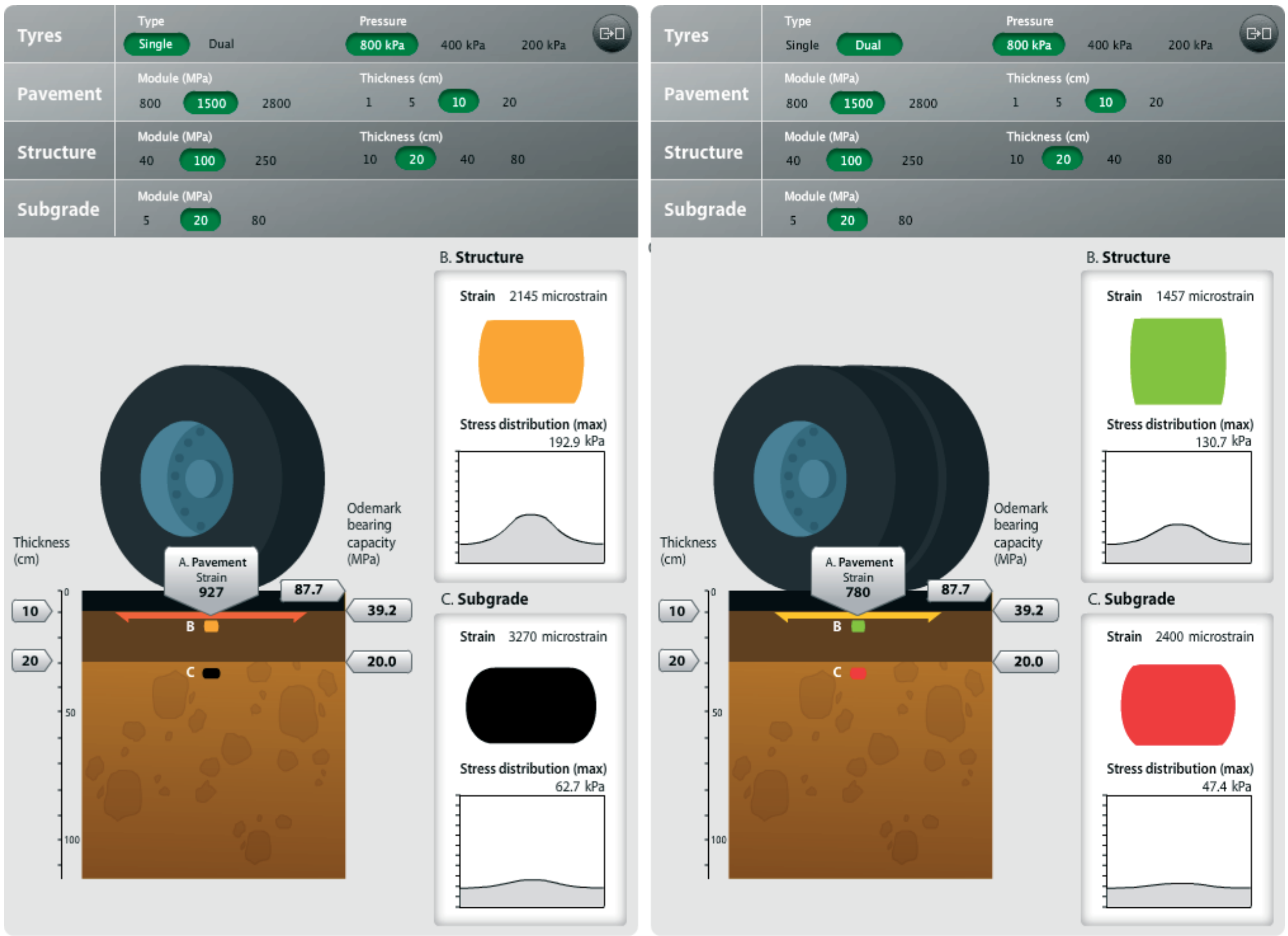
Pressing the "duplicate" button at the top right corner of the demo will move the current model to the right side of the screen and allow you to calculate and compare another structural option.

2.3. EXAMPLES



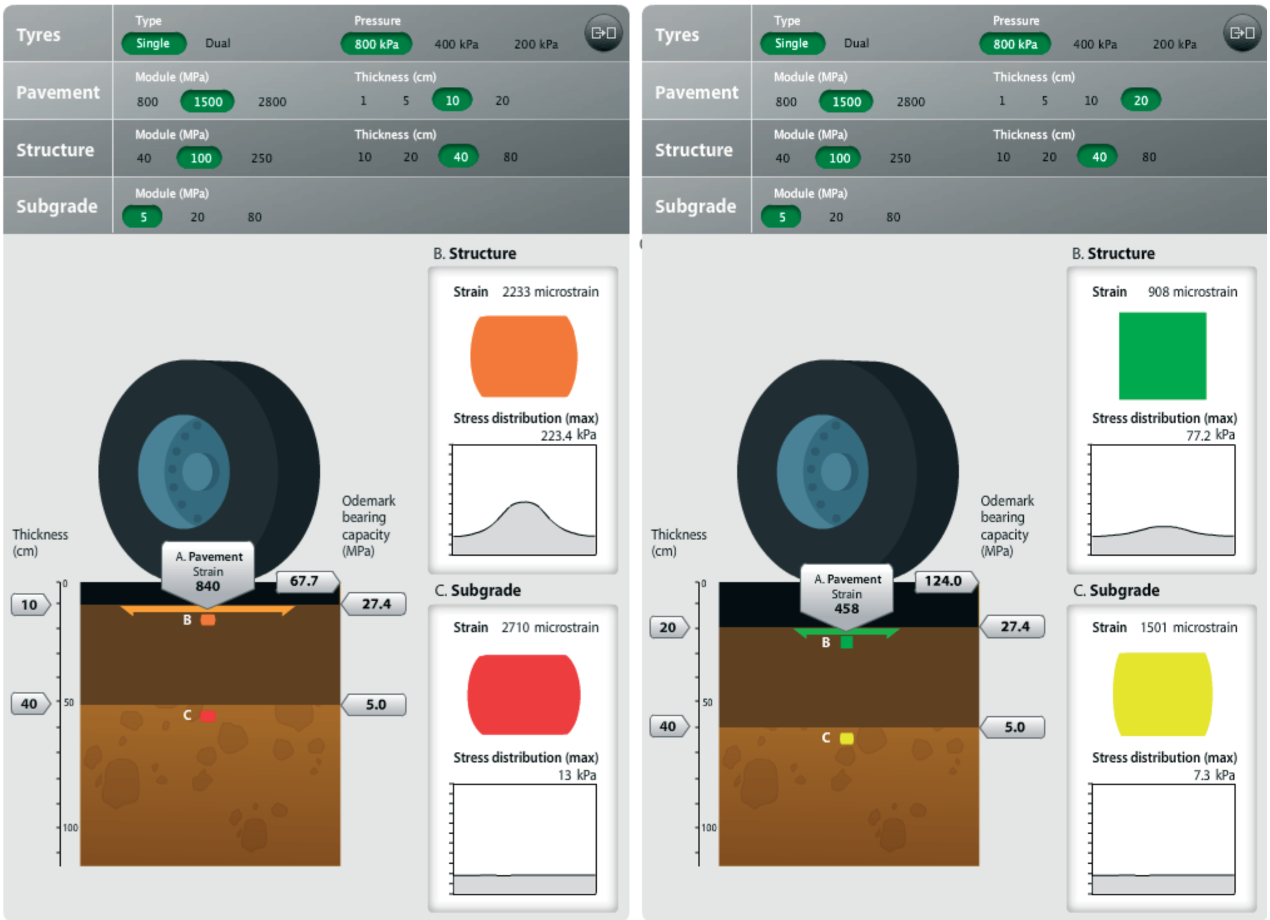
Example 1: The effect of Central Tyre Inflation (CTI).

An example to demonstrate the benefit of using CTI on a weak gravel road.
The use of lowered tyre pressure increases the contact area between the wheel and the road. Consequently, the stresses and strains induced in the road structure by the wheel load are reduced. In this example the road under a super single tyre would fail (both Mode 1 and Mode 2 rutting) while a truck using CTI would induce stresses and strains below the critical limit.



Example 2: Single tyre vs. dual tyre.

An example of the difference of super single tyres and dual tyres over a weak pavement structure. The use of a dual tyre configuration instead of a "super -single" tyre increases the contact area, and spreads the load wider. In this example the super single tyre will produce a critical strain on the subgrade and Mode 2 rutting problems, while the use of a dual tyre will reduce the strain to beneath the critical limit .



Example 3: The effect of thicker bound layer.

The effect of thicker bound layer.
The closer the material is to the surface, the greater is the stress caused by the wheel load. A thicker bound layer will spread the load better over the layers below. This will reduce the stresses and strains in the lower layers. This example demonstrates the substantial benefits that can be achieved by increasing the thickness of the bound layer.

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