

Concrete pavements contribute to decarbonising of transport



UP TO 6% FUEL SAVINGS
*for heavy trucks riding
on concrete pavements.
This can already make
the difference today !*

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Preface

Sustainable construction, congestion relief and fuel consumption are issues mentioned in the objectives of our association EUPAVE. Developing a more sustainable network of transport infrastructure across Europe and countering the climate change by CO₂ reduction is on the other hand one of the objectives of the EU. This brochure is about the common aspects of these two goals and shows how concrete pavements can contribute to this.

The longevity and durability of concrete structures is well-known. Just like the fact that concrete pavements hardly need any maintenance, which makes that traffic is less disturbed and congestion is avoided. But who knows that concrete roads can contribute to CO₂ reduction, even if the opposite often is told? There are several direct positive aspects of concrete which are present throughout the lifetime of the pavement : the uptake of CO₂ in the hardened concrete, the light reflectivity of a concrete surface which contributes to the cooling of our planet and last but not least : the reduced fuel consumption of heavy vehicles riding on a non-deformable pavement. This third aspect will be highlighted in this publication, based on a number of international studies and researches. We also encourage any additional research, preferably on European scale, to confirm the results which all show a benefit for concrete pavements.

We are convinced that this is useful information in a decision making process for sustainable road infrastructure and we hope that one day it can be part in evaluation procedures for green public procurement.

Aniceto Zaragoza
President of EUPAVE



Photo : Oficemen

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GENERAL

On the website of the Directorate-General for Climate Action (“DG CLIMA”) of the European Commission, we find the following statement:

“Road transport contributes about one-fifth of the EU’s total emissions of carbon dioxide (CO₂), the main greenhouse gas. While emissions from other sectors are generally falling, those from road transport have continued to increase since 1990. Eager to tackle climate change, the European Commission has a comprehensive strategy designed to help the EU reach its long-established objective of limiting average CO₂ emissions from new cars to 120 grams per km by 2012” [4]

Most of these actions undertaken by the European Commission deal with passenger cars, such as “green cars”, “electrification”...

Road haulage, however, produces around 40 % of the CO₂ from road transport in Europe. That is why also the issue of CO₂ from heavy duty vehicles (i.e. trucks, buses, etc.) needs to be addressed. Studies and researches are going on in the field of vehicle technologies including hybrid and electric vehicles, small engines, etc.

But while a lot of efforts are being put in these long-term potential solutions, the results of several worldwide studies proof an obvious potential of CO₂-reduction within the design and construction of pavements, what can make the difference today. All studies and researches on this subject show clearly, that stiff and rigid pavements, such as concrete roads, remarkably reduce the fuel consumption compared to flexible pavements. The findings of this studies and researches show substantial fuel savings – up to 6 % – for heavy trucks riding on concrete pavements. Abstracts of these studies are presented hereafter.

These results correspond to the physical principle, that the rolling resistance between a wheel and a bearing surface decreases according to the rigidity and the hardness of both, wheel and surface.



The lowest technical rolling resistance is known between the steel wheels of a train running on a steel rail.

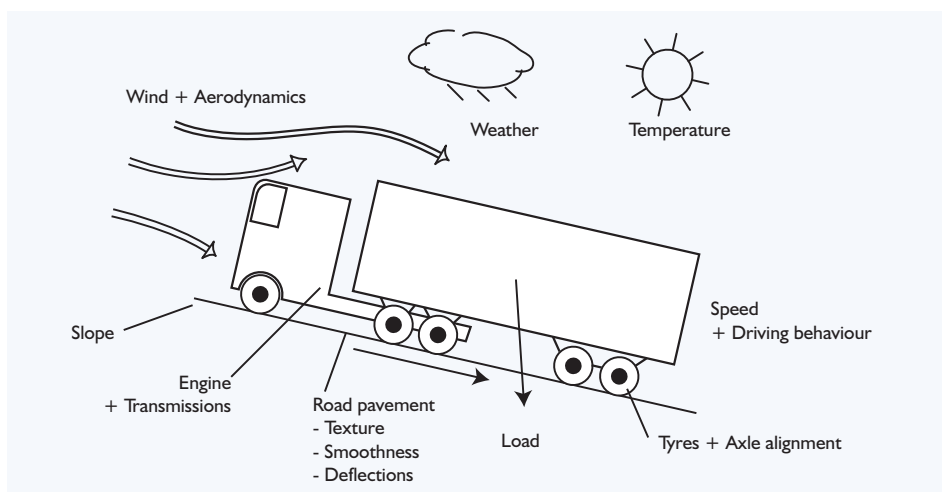
Even though the particular findings of the aforementioned studies and researches may presently seem fairly defined to give a final evaluation on average savings of fuel and CO₂, the summation of the findings shows the clear evidence of the saving-effect. This may be a strong motivation for all concerned authorities and governments in Europe to concentrate on further research in order to achieve a final perception.

LCA AND THE ROLE OF FUEL CONSUMPTION [8; 13]

A life cycle assessment (LCA) is the investigation and valuation of the environmental impacts of a given product, process or service. For a road, the life cycle can be split up in :

- extraction and production of materials;
- initial construction phase;
- maintenance and rehabilitation;
- usage phase;
- end-of-use phase.

In pavement projects, specifically, the focus has been often on estimating the ecological footprint of the production cycle of various pavement materials as well as the initial construction phase. However, a key finding of several studies is that any such sustainability assessment must also consider the maintenance activities as well as traffic emissions during the usage phase. When considering a 20 to 50 year design life that is typical for roads and the annual vehicle distances of travel, the impact of traffic will dwarf impact estimations from the material production or construction phases. Depending on the amount of traffic, its impact can easily be up to ten times greater than all the other phases of the lifetime of the road. Measures that could



reduce fuel consumption are therefore of very great importance. Not only fuel and automobile technology (motor, tyres,...) but also the type of pavement and the quality of the surface may have significant influence on the final result.

Figure 1 : factors influencing fuel consumption

FACTORS THAT INFLUENCE FUEL CONSUMPTION

There are many factors influencing the fuel consumption of a vehicle. Some of them are related to the vehicle and its engine or to the resistance of the vehicle due to aerodynamics or the slope of the pavement. The one where the pavement itself plays a role is the rolling resistance, in which the tyre-pavement interaction is of utmost importance.

Several studies have shown the impact of the “quality” of the road surface on rolling resistance and thus also on fuel consumption. The quality includes smoothness with no undulations, uneven patches, rutting, potholes or deteriorated joints. This parameter is often expressed by the International Roughness Index (IRI). [1]

Finally, there is also the type of pavement that plays a role and more specifically the rigidity of the pavement. The deflection of a flexible pavement – asphalt with visco-elastic properties – increases the rolling



resistance and consequently the fuel consumption of heavy goods vehicles riding upon it. This is not the case for rigid concrete pavements. The fuel efficiency of concrete versus asphalt pavements has been shown in several researches and studies.

CANADA - NATIONAL RESEARCH COUNCIL (NRC) [11]

The best known study is the one made in Canada by the National Research Council (NRC). This was in fact a series of four investigations, which were progressively extended with additional tests on various types of roads and vehicles in different seasons and using a variety of statistical models. Reduced fuel consumption by heavy goods vehicles was observed in all phases for concrete pavement compared to flexible bituminous pavement. The final phase, which was also the most complete and looked at a range of roads with various degrees of smoothness and with observations made in all seasons did admittedly reveal the least large differences, but came nonetheless to the conclusion that the **“fuel saving on concrete roads compared to asphalt roads, both for an empty and full tractor-trailer unit ranged from 0.8 to 3.9 % and that this was found with statistically significant results with a field of reliability of 95 %.”** An average fuel saving of 2.35 % is certainly not negligible and would over the lifetime of a busy motorway represent an immense difference in overall fuel consumption and emissions of polluting gases.

UK - TRANSPORT RESEARCH LABORATORY (TRL) [3]

Laboratory research by the TRL (Transport Research Laboratories) in Great Britain commissioned by the

Highways Agency was carried out to determine the effect of the rigidity of the pavement on fuel consumption.

This difference proved, however, to be statistically insignificant. On the other hand the difference

could have been greater because the concrete slab used in the tests was constructed in laboratory conditions.

The reduced deflection of concrete pavement was found to lead to a 5.7 % reduction in rolling resistance, which corresponds to a fuel saving of 1.14 %.

SWEDEN – LUND UNIVERSITY - FWD TESTS [7]

Swedish researchers used a pavement evaluation device, the falling weight deflectometer FWD, to evaluate the energy attenuation losses in the pavement and in the soil. In a FWD test, a dynamic load is applied to the pavement by dropping a large weight (50 kN) and pavement deflections are measured at fixed distances from the impact point. The test site was located on highway 4 about 40 km north of Uppsala, Sweden.



Photo : [11]



Photo : [7]

Figure 2a shows the load-deflection graph on a typical asphalt motorway. This diagram shows a hysteresis loop, which means that a part of the energy has dissipated in the structure due to the visco-elastic behaviour of the structure.

The amount of energy loss is represented by the size of the area within the loop. Figure 2b shows a similar graph for a concrete motorway and the area is much smaller here because of the stiffness of the pavement.

It shows that there is a lot of potential to save fuel by choosing the appropriate pavement for truck traffic.

The energy lost in the asphalt pavement is about four times higher than in the concrete pavement.

SWEDEN – SWEDISH NATIONAL ROAD AND TRANSPORT INSTITUTE (VTI) [6]

The Swedish National Road and Transport Institute VTI also investigated the impact of pavement type on fuel consumption by measurements on a motorway north of Uppsala, Sweden, where a motorway section included both asphalt and concrete pavements.

The results were found to be statistically significant. The difference is mainly **attributed to differences in surface texture** (stone mastic asphalt versus brushed concrete, both with an aggregate size of 16 mm). There was a good correlation with results from a calculation model called VETO.

The difference is attributed to less rolling resistance, partly because of the macro texture, partly **because of the stiffness of the concrete**.

For a passenger car – Volvo 940 – the measurements showed 1.1 % less fuel consumption on the concrete pavement compared to the asphalt pavement.

The measurements with a Heavy Goods Vehicle – a four axle Scania R500 + three axle trailer, total weight 60 tonnes at a speed of 80 km/h – showed an average of 6.7 % less fuel consumption on the concrete pavement compared to the asphalt pavement.

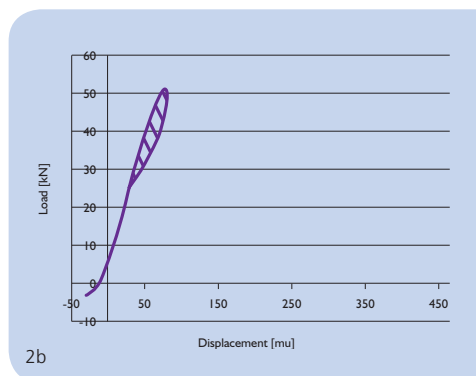
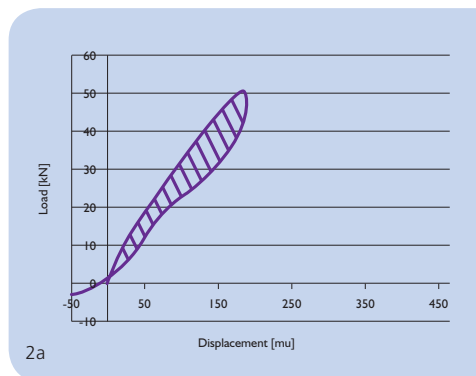


Figure 2 : hysteresis curves of Falling Weight Deflectometer tests, 2a for asphalt, 2b for concrete.

Photo: VTI, Sweden [6]



JAPAN – NIPPON EXPRESSWAY RESEARCH INSTITUTE [12]

In this study, the running resistance – the sum of aerodynamic drag and rolling resistance – was measured through coast-down tests according to the Japanese Industrial Standards (JIS) D1012. In these tests, a heavy vehicle is accelerated to a speed (e.g. 55 km/h), shift into the neutral gear and then allowed to freely decelerate to a speed of 5 km/h. From the speed-time relationship, the running resistance can be calculated. By repeating the test for different speeds, the rolling resistance can be determined. Test sites in asphalt and concrete were selected with particular attention to the length and the grade of the sections. From the differences in rolling resistance, the differences in fuel consumptions have been derived. **For the inner-city mode at**

For the inter-city mode, at 80 km/h, the benefit varied from 1.4 to 4.8 %

relatively low speed the fuel consumption rate for the asphalt pavement was 0.8 to 3.4 % higher than the concrete pavement.

TEXAS – UNIVERSITY OF TEXAS AT ARLINGTON – CITY DRIVING [2]

The main objective of this study was to investigate any differences that might exist in fuel consumption and CO₂-emissions when operating a motor vehicle on an asphalt road versus a cement concrete pavement under city driving conditions. Two pairs of streets (2 x asphalt – 2 x concrete) were selected in Arlington, Texas. Each pair asphalt/concrete had similar gradients and roughness indices. The streets were approximately parallel so as to minimize the effect of wind direction and velocity during measurement runs. Two different driving modes were used in the test runs: one at a constant cruise speed

of 30 mph and one acceleration mode from zero to 30 mph in 10 seconds. The test vehicle was a **Chevy Astro van of about 1 360 kg**. It was found that the fuel consumption rates per unit distance were consistently lower on the concrete sections regardless of the test section, driving mode and surface condition (dry vs. wet). In all cases, the differences were found to be statistically significant at 10 % level of significance. **The comparison between a road in continuously reinforced concrete and one in asphalt showed savings between 3 and 8.5 % in favour of concrete.** It should be mentioned that in a second case differences even much higher were recorded, but considering the limited mass of the test vehicle, they were most probably due to surface characteristics such as texture and transverse evenness.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY – CONCRETE SUSTAINABILITY HUB [10]

A recent study carried out by CSHub@MIT derived a quantitative mechanistic Pavement-Vehicle Interaction (PVI) model to relate fuel consumption to structural design parameters, such as pavement thickness, and material properties such as stiffness, viscosity, strength of top layer and subgrade. The model is calibrated and validated. A key finding of the model is that, with all the parameters equal, **asphalt pavements need to be 25 to 60 % thicker to display the same fuel consumption performance as concrete.** The derived functional relations between fuel consumption, structural design and material parameters are found to be useful to provide pavement engineers and decision makers with a design tool to optimize pavement inventory for high performance fuel and greenhouse gas emissions efficiency.



Photo : [2]



Photo : [2]

Many littles make a much !

The potential environmental impact due to traffic load can be up to 100 times more than due to construction and maintenance together. Thus, the largest and most effective reduction in environmental impact is possible in this phase. Even with small differences in fuel saving between pavement types, the overall difference is significant.

Some numerical examples and case-studies will make this clearer. The question is what do these relatively low percentages of fuel savings become in total quantities. How much fuel, money and emissions can be saved?

In order to make a comprehensive quantification, we make the following assumptions, based on currently available data :

- fuel price (diesel) of 1.5 euro/l;
- fuel emission conversion factors (emissions per liter diesel)

| | |
|-----------------------------------|----------------|
| • Nitrogen oxides NO _x | 25 to 28 g/l |
| • Particulates PM | 0.2 to 0.4 g/l |
| • Hydrocarbons HC | 0.4 to 1 g/l |
| • Carbon monoxide CO | 1 to 7 g/l |
| • Carbon dioxide CO ₂ | 2.7 kg/l |
| • Sulphur S | 0.1 g/l |

Fuel savings for heavy trucks (rigid vs. flexible pavements – loaded and unloaded – 60 to 100 km/h – different seasons) vary from 1 to 6 %. In terms of litres

fuel saved, the data of the study by the National Research Council of Canada, which is the most complete and best documented one, will be used. The average of the measured differences was a saving of **0.45 l per 100 km**, which, in consideration of all available findings, is a rather reasonable approach.

SAVINGS PER ROAD

Considering a road of 100 km long with a daily traffic of heavy goods vehicles per carriageway from 5 000 to 15 000, this brings us to the following results:



ROAD

| km road | number of heavy vehicles per day | directions | fuel saving | price diesel | CO ₂ |
|---------|----------------------------------|------------|-------------|--------------|-----------------|
| | | | l/100 km | €/l | kg/l |
| 100 | 5 000 | 2 | 0,45 | 1,5 | 2,7 |
| 100 | 10 000 | 2 | 0,45 | 1,5 | 2,7 |
| 100 | 15 000 | 2 | 0,45 | 1,5 | 2,7 |

| SAVINGS PER DAY | | |
|-----------------|-----------|----------------------|
| liter diesel | costs (€) | CO ₂ (kg) |
| 4 500 | 6 750 | 12 150 |
| 9 000 | 13 500 | 24 300 |
| 13 500 | 20 250 | 36 450 |

| SAVINGS PER YEAR | | |
|------------------|-----------|----------------------|
| liter diesel | costs (€) | CO ₂ (kg) |
| 1 642 500 | 2 463 750 | 4 434 750 |
| 3 285 000 | 4 927 500 | 8 869 500 |
| 4 927 500 | 7 391 250 | 13 304 250 |

| Savings over the 30year lifetime of the road | | |
|--|-------------|----------------------|
| liter diesel | costs (€) | CO ₂ (kg) |
| 49 275 000 | 73 912 500 | 133 042 500 |
| 98 550 000 | 147 825 000 | 266 085 000 |
| 147 825 000 | 221 737 500 | 399 127 500 |

In other words : every km of concrete road instead of a flexible pavement can reduce the CO₂ emission, due to fuel consumption, over its 30 year lifetime by 1 000 to 4 000 tonnes!



SAVINGS PER TRANSPORT COMPANY

One can also look at it from the viewpoint of a national or international transport company. Considering that trucks are driving for at least 80 % on flexible pavements, the following table shows the saving potential for companies operating 1 to 1 000 heavy goods vehicles.

TRANSPORT COMPANY

| nr HV | km/year/ heavy vehicle | total km/year | not on rigid | fuel saving | price diesel | CO ₂ | SAVINGS PER YEAR | | |
|-------|---------------------------|------------------|--------------|-------------|--------------|-----------------|------------------|-----------|----------------------|
| | | | pavement | l/100 km | €/l | kg/l | liter diesel | costs (€) | CO ₂ (kg) |
| 1 | 100 000 | 100 000 | 80% | 0,45 | 1,5 | 2,7 | 450 | 675 | 1 215 |
| 10 | 100 000 | 1 000 000 | 80% | 0,45 | 1,5 | 2,7 | 4 500 | 6 750 | 12 1250 |
| 20 | 100 000 | 2 000 000 | 80% | 0,45 | 1,5 | 2,7 | 9 000 | 13 500 | 24 300 |
| 50 | 100 000 | 5 000 000 | 80% | 0,45 | 1,5 | 2,7 | 22 500 | 33 750 | 60 750 |
| 100 | 100 000 | 10 000 000 | 80% | 0,45 | 1,5 | 2,7 | 45 000 | 67 500 | 121 500 |
| 200 | 100 000 | 20 000 000 | 80% | 0,45 | 1,5 | 2,7 | 90 000 | 135 000 | 243 000 |
| 500 | 100 000 | 50 000 000 | 80% | 0,45 | 1,5 | 2,7 | 225 000 | 337 500 | 607 500 |
| 1000 | 100 000 | 100 000 000 | 80% | 0,45 | 1,5 | 2,7 | 450 000 | 675 000 | 1 215 000 |

CASE STUDY – THE RING ROAD OF ANTWERP

The Ring Road around Antwerp (Belgium) was rehabilitated in 2004-2005. After a life-cycle cost comparison and a multi-criterion analysis, it was decided to build the largest part in concrete, which comprises 4 to 7 lanes per carriageway over about 12 km. The Road Authorities were looking for a long-life pavement with minimum maintenance required but did not know, at that moment, that this choice would save fuel, money and emissions to society.

The average daily heavy traffic amounts 14 000 HV/day per carriageway. This is an average from 32 traffic counting posts and includes weekends and holiday periods (data from 2010). Only the heavy vehicles with a length greater than 6.9 m are considered in order to exclude passenger cars, light trucks and vans. These heavy vehicles are indeed the scene in which deflection of the pavement makes the most significant difference in fuel consumption.

Even over the small length of 12 km, taking into account the very intense heavy traffic flow, the savings become sizeable. Not only the CO₂ but also other harmful emissions such as nitrogen oxide and fine solid particles undergo substantial reductions.

RING ROAD OF ANTWERP

| km road | number of heavy vehicles per day | directions | fuel saving | price diesel | CO ₂ |
|---------|--|------------|-------------|--------------|-----------------|
| | | | l/100 km | 7,5 pt/l | kg/l |
| 12 | 14000 | 2 | 0,45 | 1,5 | 2,7 |

SAVINGS PER DAY

| liter diesel | costs (7,5 pt) | CO ₂ (kg) | NOx (kg) | PM (kg) | HC (kg) |
|--------------|----------------------|----------------------|----------|---------|---------|
| 1 512 | 2 268 | 4 082 | 40 | 0 | 1 |
| CO (kg) | SO ₂ (kg) | | | | |
| 6 | 0 | | | | |

SAVINGS PER YEAR

| liter diesel | costs (7,5 pt) | CO ₂ (kg) | NOx (kg) | PM (kg) | HC (kg) |
|--------------|----------------------|----------------------|----------|---------|---------|
| 551 880 | 827 820 | 1 490 076 | 14 625 | 166 | 386 |
| CO (kg) | SO ₂ (kg) | | | | |
| 2 208 | 55 | | | | |

SAVINGS OVER THE 30YEAR LIFETIME OF THE ROAD

| liter diesel | costs (€) | CO ₂ (kg) | NOx (kg) | PM (kg) | HC (kg) |
|--------------|----------------------|----------------------|----------|---------|---------|
| 16 556 400 | 24 834 600 | 44 702 280 | 438 745 | 4 967 | 11 589 |
| CO (kg) | SO ₂ (kg) | | | | |
| 66 226 | 1 656 | | | | |



CASE STUDY – ROAD FREIGHT TRANSPORT IN EUROPE

National and international road freight transport all over Europe accounted for about 1 878 billion tonne-kilometres (2006). [9] Assuming an average freight load of 10 tonnes, the distance covered by heavy goods vehicles is 188 billion kilometres.

According to the findings of the aforementioned Canadian research the saving of 0.45 litres/100km of diesel leads to the following savings:

- 636 millions of litres diesel per year
- € 1 269 million per year
- 2.25 million tonnes CO₂ per year

Even the smallest differences in fuel consumption of 0.2 litres/100 km result in huge savings as follows :

- 376 millions of litres diesel per year
- € 564 million per year
- 1 million tonnes CO₂ per year



General Conclusions

The fuel consumption of both passenger cars and heavy duty vehicles has been investigated from the perspective of several parameters. Out of those parameters affecting fuel consumption, the type of pavement, more specifically the rigidity of the pavement, has been examined throughout research projects:

- The Canadian National Research Council study shows that fuel saving on concrete roads compared to asphalt roads ranges from 0.8 to 3.9%.
- Transport Research Laboratories found out that the reduced deflection of concrete pavement led to a fuel saving of 1.1%.
- Swedish researchers showed that there is a substantial potential

to save fuel by choosing the appropriate pavement type for truck traffic where the energy lost in concrete pavement is four times less than in asphalt pavement due to visco-elastic behavior of the structure.

- The Swedish National Road and Transport Institute research showed 1.1 to 6.7% less fuel consumption on concrete pavement compared to asphalt pavement, to be attributed to the stiffness of the concrete.



Photo : P. De Winne



Photo : A. Jasienski

- Japanese researchers showed that fuel consumption rate for the asphalt pavement is 0.8 to 4.8% higher than the concrete pavement, for different modes stated.

All studies and researches, related to heavy traffic loadings, lead to the conclusion that fuel consumption is lower on concrete pavements compared to asphalt pavements in a range from about 1 to 6 %. Smooth concrete pavements are not only the most favourable option in terms of life-cycle cost. They also constitute an easy and effective solution in the decarbonising of freight road transport.

- A research in U.S. showed that fuel consumption rates per unit distance were consistently lower (3 to 17%) on the concrete sections regardless of the test section, driving mode and surface condition (dry vs. wet)
- The Massachusetts Institute of Technology developed a pavement-vehicle interaction model showing that asphalt pavements need to be 25 to 60% thicker to display the same fuel consumption performance as concrete.

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