

CONCRETE PAVEMENTS CONTRIBUTE TO DECARBONISING OF TRANSPORT



Photo : W. Kramer

***UP TO 6% FUEL SAVINGS FOR HEAVY TRUCKS RIDING ON
CONCRETE PAVEMENTS – THIS CAN ALREADY MAKE THE
DIFFERENCE TODAY!***

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



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.

This results correspond to the physical principle, that the rolling resistance between a wheel and a bearing surface decreases according to the rigidness 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 steely 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 show 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.

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.

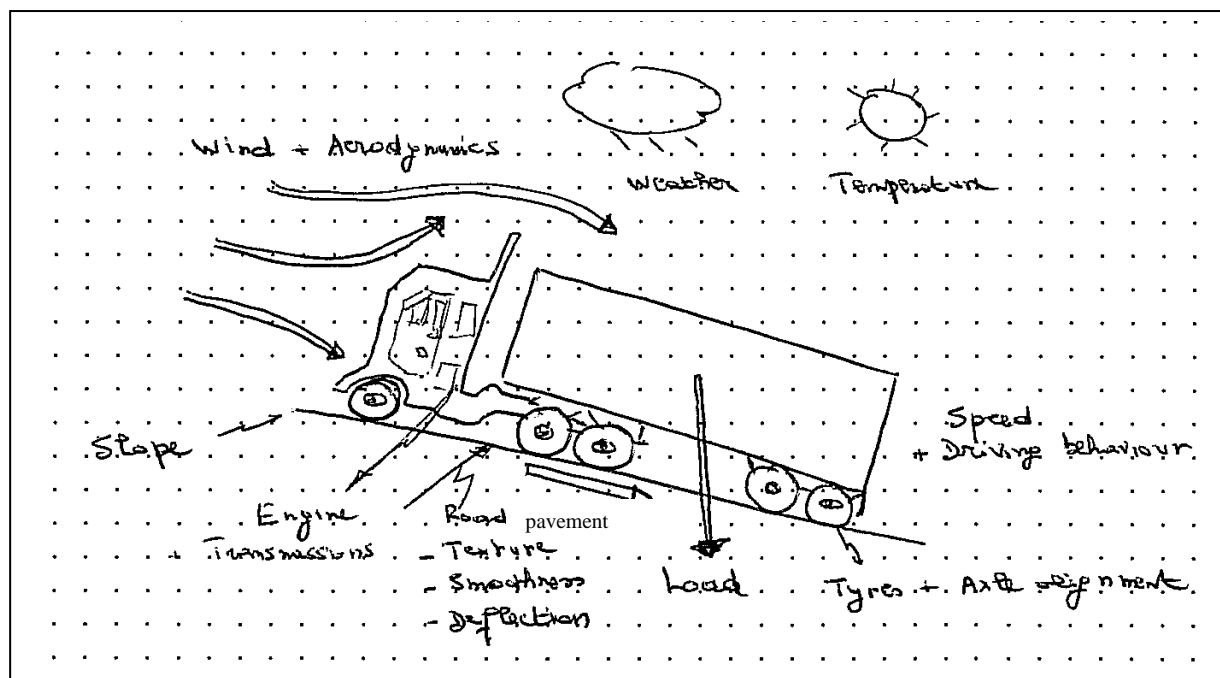


Figure 1 : factors influencing fuel consumption

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. 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 %. 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.

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 : [7]

Figure xx 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 yy shows a similar graph for a concrete motorway and the area is much smaller here because of the stiffness of the pavement. The energy lost in the asphalt pavement is about four times higher than in the concrete pavement. It shows that there is a lot of potential to save fuel by choosing the appropriate pavement for truck traffic.

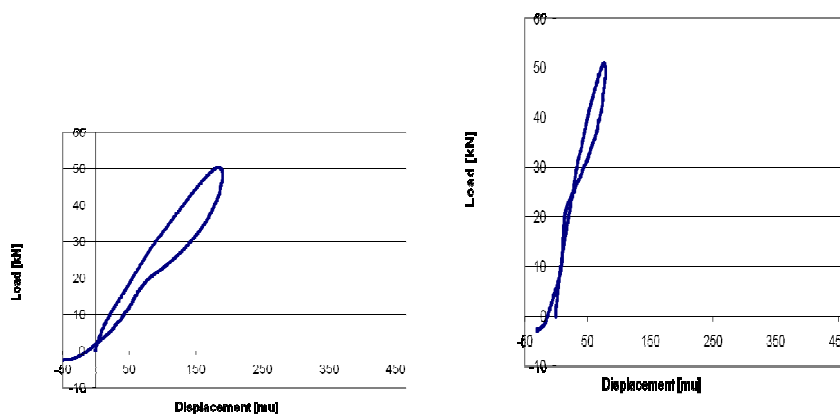


Figure 2 : hysteresis curves of Falling Weight Deflectometer tests, left for asphalt, right for concrete.

(figures to be redrawn with clear indication of shaded surface inside the loops)

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.

For a passenger car - Volvo 940 – the measurements showed 1.1 % less fuel consumption on the concrete pavement compared to the asphalt pavement. 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 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. The difference is attributed to less rolling resistance, partly because of the macro texture, partly because of the stiffness of the 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 relatively low speed the fuel consumption rate for the asphalt pavement

was 0.8 to 3.4 % higher than the concrete pavement. For the inter-city mode, at 80 km/h, the benefit varied from 1.4 to 4.8 %.

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.



Photo : [2]



Photo : [2]

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.

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)
 - o Nitrogen oxides NO_x 25 to 28 g/l
 - o Particulates PM 0.2 to 0.4 g/l
 - o Hydrocarbons HC 0.4 to 1 g/l
 - o Carbon monoxide CO 1 to 7 g/l
 - o Carbon dioxide CO₂ 2.7 kg/l
 - o 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.

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			fuel saving	price diesel	CO ₂
km road	number of heavy vehicles per day	directions	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 (€)	CO₂ (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 (€)	CO₂ (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 (€)	CO₂ (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!

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 owing 1 to 1 000 heavy goods vehicles.



Transport company			not on rigid	fuel saving	price diesel	CO ₂
nr HV	km/year/heavy vehicle	total km/year	pavement	l/100 km	€/l	kg/l
1	100 000	100 000	80%	0.45	1.5	2.7
10	100 000	1 000 000	80%	0.45	1.5	2.7
20	100 000	2 000 000	80%	0.45	1.5	2.7
50	100 000	5 000 000	80%	0.45	1.5	2.7
100	100 000	10 000 000	80%	0.45	1.5	2.7
200	100 000	20 000 000	80%	0.45	1.5	2.7
500	100 000	50 000 000	80%	0.45	1.5	2.7
1000	100 000	100 000 000	80%	0.45	1.5	2.7
Savings per year						
liter diesel	costs (€)	CO ₂ (kg)				
450	675	1 215				
4 500	6 750	12 150				
9 000	13 500	24 300				
22 500	33 750	60 750				
45 000	67 500	121 500				
90 000	135 000	243 000				
225 000	337 500	607 500				
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.

RING ROAD OF ANTWERP					
km road	number of heavy vehicles per day	directions	fuel saving l/100 km	price diesel €/l	CO ₂ kg/l
12	14000	2	0.45	1.5	2.7
Savings per day					
liter diesel	costs (€)	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 (€)	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				

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.



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 show 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.
- 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.
- 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.

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.

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