SUSTAINABLE DEVELOPMENT

THE ENVIRONMENTAL ROAD OF THE FUTURE

ENERGY CONSUMPTION & GREENHOUSE GAS EMISSIONS

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Abstract

The United Nations conference on the environment and sustainable development that was held in Rio in 1992 marked the beginning of universal awareness of the risks of damage facing the planet. The destruction of natural resources and climate change are the main causes of damage and disruption of ecosystems. Industry, agriculture and transport are blamed for being the main contributors.

This awareness was formalized by the Kyoto agreements in 1997, which featured, in particular, a commitment made by signatory states to bring GHG emission rates down to 1990 levels.

In the framework of its policy of sustainable development, the Organisation for Economic Co-operation and Development (OECD) has set a priority for the first ten years of the 21st century on two actions: limiting the impact of industry on climate change and optimizing the management of natural resources. The European Union has made sustainable development one of its major commitments. France is committed to specifying and implementing a National Sustainable Development Strategy and has recently adopted an Environmental Charter (25 June 2003). This is intended to be incorporated into the French Constitution.

All sectors of activity, but also consumers, are affected: we have in all areas of activity, to carry out an analysis and reduce our environmental impacts.

Road construction companies are aware of the strategic and universal issues associated with sustainable development and wish to make their own contribution to this collective effort, although the last decade has already seen a considerable number of environmental protection measures.

This report describes the contribution made by road construction as for energy consumption and greenhouse gas emissions. The latter is the main issue for sustainable development.

The principal road construction techniques are analyzed (hot mixes, bitumen emulsion technologies, concrete cement, in situ or plant recycling, etc.). The different types of road pavement structure are examined and compared to the total traffic these structures must withstand over a thirty year service life.

The entire production and construction process is taken into consideration, from the extraction of raw materials to the end of the pavement’s service life, including the phases of materials manufacture, laying for the construction of a new pavement, and maintenance works.

The results of this study are extremely interesting. The following construction and maintenance techniques are considered:

- Asphalt concrete, bitumen-bound gravel, high modulus asphalt concrete,
- Warm asphalt mixes, bitumen emulsion mixes, grave-emulsion,
- Cement-bound gravel, gravel and special road binder mix (80 % of the clinker being replaced with crushed slag), active joint,
- Concrete cement free slab or continuously reinforced pavements,
- Treated soil,
- In-situ hot recycling or in-situ cold recycling with bitumen emulsion,
- Hot recycled asphalt mixes.

Environmental data, such as the energy consumption and greenhouse gas emissions that result from the manufacture of materials (both constituents and final products) are taken from publications which are a subject of consensus. The references and data are given in the annexes.

The various technical solutions for the construction and placement of the products described in the documents issued by the French Highways Administration are compared.
Abstract

SUSTAINABLE DEVELOPMENT

September 2003

The environmental road of the future, life cycle analysis

Energy consumption

Results 1: per unit of material

With regard to the manufacture and placement of the considered products, four groups emerge:

- Concrete cement: between 700 and 1,100, with an average value of 900 MJ/t, i.e. a level of 6
- Hot or warm mixes, whether recycled or not: between 500 and 700, with an average value of 600 MJ/t, i.e. a level of 4
- Cold mixes (white or black other than concrete): between 300 and 400, with an average value of 350 MJ/t, i.e. a level of 2.3
- In situ treated soils (cold), “as dug” gravel, active joint and gravel bound with special hydraulic road binder, with an average value of 150 MJ/t, i.e. a level of 1

And therefore, the following levels:

1 2.3 4 6

Results 2: by pavement structure

When looking at the results after 30 years for an equivalent level of service, only three groups can be observed:

- Cement concrete structures maintained with bituminous mixtures: between 800 and 1200 MJ/m², i.e. a level of 1.7
- Hot mixes and composite pavements: between 550 and 850 MJ/m², i.e. a level of 1.2
- Emulsion cold mixes and composite pavements with special hydraulic road binders or active joints: between 450 and 700 MJ/m², i.e. a level of 1

And therefore, the following levels:

1 1.2 1.7

Results 3: by global structure

If we consider pavements of a width that is suited to the level of traffic, on the basis of our analyses we can conclude that, over a 30 year period, traffic consumes between 10 and 345 times more energy than road construction over the same period, depending on whether the traffic is light or heavy.

Greenhouse gas (GHG) emissions

Results 1: per unit of material

While four groups were identified in the analysis of energy consumption, only three are apparent for greenhouse gas emissions

- Cement concrete: 140 to 200 kg/t, i.e. a level of 10
- Hot or cold mixes whether recycled or not: 30 to 60 kg/t, i.e. a level of 3
- Cold retread (bitumen emulsion or cement), “as dug” gravel, gravel with special hydraulic road binder, and active joint: 10 to 20 kg/t, i.e. a level of 1

And therefore, the following levels:

1 3 10
Results 2: by pavement structure

If we consider the life of a pavement over a 30 year period, three groups can still be identified:

- Concrete cement: 100 to 160 kg/m², i.e. a level of 2.6
- Composite pavements with cement: 65 to 90 kg/m², i.e. a level of 1.5
- Hot or cold mix bituminous pavements, composite pavements with special hydraulic road binder or active joints: 40 to 65 kg/m², i.e. a level of 1

And therefore, the following levels:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>1.5</th>
<th>2.6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this case also, a clear difference can be seen between concrete and cement on the one hand and bituminous and composite pavements on the other. The first ones are responsible for 50 to 160 times more emissions than the second ones, for all traffic levels.

The specific advantages with regard to greenhouse gas emissions of pavements using bitumen emulsion and active joints should be mentioned.

Results 3: by global structure

Traffic is responsible from 10 to 400 times more GHG emissions (the ratio rising with the amount of traffic) than construction and maintenance of the road that carries it.

Overall effect on the environment
(Energy consumption and GHG emissions)

If we continue to consider levels of harmfulness, road techniques can be divided into four groups: pavements constructed using bitumen emulsion, composite pavements using active joint, composite pavements using special hydraulic road binder (level 1) and concrete cement pavements (level 2).

It should be noted that traffic, over a thirty year period, is between 10 and 400 times more “harmful” than the road, depending on whether traffic levels are low (10 million vehicles in each direction) or very high (2 billion vehicles in each direction).

Table 1: overview of materials and techniques

<table>
<thead>
<tr>
<th></th>
<th>Energy consumption</th>
<th>GHG emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement concrete</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Hot or warm bituminous mixes, recycled or not</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Cold mixes (white or black other than concrete)</td>
<td>2.3</td>
<td>3</td>
</tr>
<tr>
<td>Cold in-situ soil treatment, cold in-situ retread process, “as dug” gravel, active joint, gravel with special hydraulic road binder</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 2: overview of techniques over a 30 year period

<table>
<thead>
<tr>
<th>Level</th>
<th>Energy consumption</th>
<th>GHG emissions</th>
<th>Overall level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement concrete pavements</td>
<td>1.7</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Cement composite pavements</td>
<td>1.2</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Hot bituminous mix pavements</td>
<td>1.2</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>Cold bituminous mix pavements,</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>composite pavements using special hydraulic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>road binder or active joints</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusion

The main purpose of this study is to make an inventory of energy consumption and GHG emissions associated with road construction.

On the basis of a 30 year service life (which is in general more favourable to cement concrete structures), whatever the traffic or the type of roadbed, and irrespective of whether construction alone or construction with maintenance is considered, the results obtained in the study lead to the following conclusions:

- Energy consumption and GHG emissions linked to pavement construction are very much lower than those caused by total cumulative traffic. A very small reduction in vehicle consumption would cancel out the cost of the road (in terms of energy and GHG emissions).

- For hot mix bituminous pavements, the main process responsible for GHG emissions is mix manufacture. However in the case of reinforced cement pavements, the main processes that are responsible are cement manufacture and mainly steel manufacture.

- For new pavements, the most polluting structures are concrete cement, and the least polluting are those using bitumen emulsion, special hydraulic road binder or active joints.

- For rehabilitation, in situ bitumen emulsion recycling is by far the technique that consumes the least energy and which contributes least to the greenhouse effect.

This life cycle analysis of pavement structures shows the benefits of using bitumen emulsion and high modulus mixes. These techniques make it possible to manage and optimize energy consumption and reduce impacts on the greenhouse effect. Recycling saves materials and reduces transport.
References

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- Catalogue of standard structures for new pavements - Lcpc-Setra 1998
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- Web sites:
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  - www.x-environnement.org
  - www.usirf.com
  - www.equipement.gouv.fr
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I. INTRODUCTION

The United Nations conference on the environment and sustainable development that was held in Rio in 1992 marked the beginning of universal awareness of the risks of damage facing the planet. The destruction of natural resources and climate change are the main causes of damage and disruption of ecosystems. Industry, agriculture and transport are blamed for being the main contributors. This awareness was formalized by the Kyoto agreements in 1997, which featured, in particular, a commitment made by signatory states to bring GHG emission rates down to 1990 levels.

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This report describes the contribution made by road construction as for energy consumption and greenhouse gas emissions. The latter is the main issue for sustainable development.

The principal road construction techniques are analyzed (hot asphalt mixes, bitumen emulsion technologies, concrete cement, in situ or plant recycling, etc.). The different types of road pavement structure are examined and compared to the total traffic these structures must withstand over a thirty year service life.

The entire production and construction process is taken into consideration, from the extraction of raw materials to the end of the pavement’s service life, including the phases of materials manufacture, laying for the construction of a new pavement, and maintenance works.

The results are an efficient tool that assists in the selection of environmentally-friendly pavements. It can be used to research and development of tomorrow’s structures. Cold mix technologies and in situ pavement recycling are promising.
II. HYPOTHESES AND STUDY COMPONENTS

The analyses involve the construction of a new pavement and its maintenance over a service life of 30 years. Such a long service life is more in line with the spirit of sustainable development.

The pavement structures and the associated maintenance scenarios have been determined on the basis of French administration LCPC-SETRA design method:

French road network
Catalogue of standard structures for new pavements
LCPC-SETRA - 1998 edition

Road base

The structures have been analyzed for a roadbed with an average bearing capacity that places it in class PF2, with an elasticity modulus of 50 MPa (see definition in Annex 1 page 29).

Traffic

Traffic has a key role in pavement design and the analysis of environmental impacts. For the design of the pavement structure, total cumulative heavy lorry traffic over the foreseeable service life of the structure is considered. For the impact analysis, both cumulative total traffic (vehicles) and the relative proportion of heavy lorries (HL) and light vehicles (LV) are taken into account.

The following table shows the details of traffic flows for the classes that are the most representative of the situation in France (SETRA data, see Annex 1 page 29):

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>Traffic class</th>
<th>Traffic class</th>
<th>Traffic class</th>
<th>Traffic class</th>
<th>Traffic class</th>
<th>Traffic class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily heavy lorries traffic (per direction)</td>
<td>TC2&lt;sub&gt;30&lt;/sub&gt;</td>
<td>TC3&lt;sub&gt;30&lt;/sub&gt;</td>
<td>TC4&lt;sub&gt;30&lt;/sub&gt;</td>
<td>TC5&lt;sub&gt;30&lt;/sub&gt;</td>
<td>TC6&lt;sub&gt;30&lt;/sub&gt;</td>
<td>TC7&lt;sub&gt;30&lt;/sub&gt;</td>
</tr>
<tr>
<td>Daily vehicles traffic (per direction)</td>
<td>35</td>
<td>85</td>
<td>200</td>
<td>500</td>
<td>1200</td>
<td>3000</td>
</tr>
<tr>
<td>Daily vehicles traffic (per direction)</td>
<td>538</td>
<td>1,308</td>
<td>3,077</td>
<td>7,692</td>
<td>18,462</td>
<td>46,154</td>
</tr>
<tr>
<td>Cumulated vehicles traffic (in million per direction)</td>
<td>10</td>
<td>25</td>
<td>58</td>
<td>145</td>
<td>350</td>
<td>870</td>
</tr>
<tr>
<td>Cumulative heavy lorries traffic (in million per direction)</td>
<td>0.66</td>
<td>1.6</td>
<td>3.8</td>
<td>9.4</td>
<td>23</td>
<td>57</td>
</tr>
</tbody>
</table>

Table 1: Traffic and traffic classes according to the LCPC-SETRA classification over 30 years

Definition:
- Traffic class: According to the daily heavy traffic the pavement has to support, 8 classes are noticed from the TC1 (for the traffic < 35 HL/day/direction) to the higher TC8 (class for a traffic of 4000HL/day/direction).
  For example: TC7<sub>30</sub> means class traffic 7 and service life of 30 years.
- The definition of heavy lorries(HL) is : vehicles with a payload of 35 kN
- The initial daily traffic is the estimated two-way traffic at the opening date of the road expressed in average annual daily traffic (AADT).
- The cumulative traffic is the total two-way cumulative traffic over the foreseeable service life of the structure, expressed in each direction.
**Environmental data**

The data for the environmental analysis are provided by the relevant bodies or specialized agencies, Eurobitume for bitumen and Athena for cement and steel in the report for the Canadian Portland Cement Association, IVL, etc. (See Annex II page 30).

Pavement construction companies are mainly involved in the manufacture and laying of road construction materials, as shown in the diagram below (Figure 1).

![Diagram of pavement construction process](image-url)

**Figure 1: Construction of a road pavement**
Life Cycle Analysis (LCA)

As LCA deals with the ecosystem on a planetary level, the extraction and production of raw materials (oil, ore, etc.) and the pavement constituents materials (cement, bitumen, water, etc.) must be considered in the analysis.

All the phases and stages of production, extraction, manufacture, transport, laying, etc. that are required to obtain a pavement with an acceptable level of service over the selected service life are therefore considered. Figure 2 sets out the stages and transport distances are taken into account for a road pavement built in France.

To manufacture one ton of mix, the average distances considered are:

- 300 km between the refinery for bitumen production and the mixing plant,
- 150 km between the cement works and the plant where the concrete or the treated gravel is manufactured,
- 500 km between the steel factory and the site where the concrete or steel safety barriers are installed,
- 75 km between the aggregate quarry and the manufacturing site.

And finally, an average 20 km is estimated for the distance between the manufacturing site and the construction site.

Annex II and Annex III (page 30 & 31) contain the basic data concerning the energy required to manufacture components, greenhouse gas emissions, and the physical characteristics of the mixes and constituents.

The major well known products for which data exist are selected.

The data (energy and GHG emission) for these products can be obtained from the references.

Extreme values are removed, in order to select the ones which seem to be the subject of consensus.
Figure 2: Stages and elements in the life cycle analysis for a pavement structure
In a report for the United Nations in 1987, Mrs. Harlem Brundtland described sustainable development as: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

We have defined the sustainable pavement as follows: “A safe efficient and environmentally-friendly pavement which meets the needs of present-day users without compromising those of future generations”.

The principal criteria for a sustainable pavement are as follows:
- Optimizing the use of natural resources and reducing energy consumption,
- Reducing impacts on the greenhouse effect (GHG emissions),
- Limiting pollution (air, water, ground, noise, etc.),
- Improving health, safety and risk prevention,
- Ensuring a high level of user comfort and safety

Considerable progress has been made with regard to controlling large-scale pollution and improving working conditions in recent years. A great deal of attention has been given to limiting the consumption of natural resources, but efforts have been concentrated on the increase of the greenhouse effect, which is the most worrying problem in the field of sustainable development.

The Kyoto protocol specified a list of gases which contribute to the greenhouse effect. The main gases are carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4). These are followed by hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfurhexafluoride (SF6).

For example in France, in 2001 (see Figure 3), industrial GHG emissions, although constantly falling, accounted for approximately 33% of total GHG emissions. But the consumption of the transport sector (both passenger and freight) is particularly difficult to limit.

![Figure 3: Distribution of GHG emissions in 2001 in France according to sector of activity](Source CITEPA/ UNFCCC Inventory December 2002)
Transport accounts for 26% of GHG emissions, and 85% of these are generated by road transport. The contribution of this sector increased considerably between 1990 and 2000.

This study will concentrate on energy consumption, materials consumption and greenhouse gas emissions during road construction and maintenance operations.

We shall deal with the different types of available techniques separately.

We shall also make a comparison between the environmental influence of the road (as defined above) and its use, i.e. the traffic it carries.
IV. ENERGY CONSUMPTION

Energy consumption for the manufacture and laying is studied per ton of manufactured and laid material, per m² of pavement structure built and total cumulative traffic.

IV.1- Energy consumption per ton of material laid

Figure 4 shows the total amount of energy required to manufacture and lay one ton of material from extraction of the raw materials to placement at the worksite. Please refer to Annex III page 31 for the composition of the materials and Annex V page 33 for the energy consumption calculation.

Energy is expressed in MJ per ton of laid material.

Figure 4: Energy consumption for the manufacture and laying of main road technologies
Comments:

• “Binders” are counted the energy consumed in order to extract and transport raw materials and manufacture binders (bitumen, cement, modified binder, etc.).
• “Aggregates” are counted the energy consumed in order to extract and manufacture aggregates at the quarry.
• “Manufacture” is counted the energy consumed in order to manufacture mixes in a plant or production unit.
• “Transport” are counted the energy consumed in order to transport the constituents and mixes from the plants where the constituents are manufactured to the worksite.
• “Laying” is counted the energy consumed in order to lay the material and perform the works.
• The hydraulic road binder is a mix consisting in 80% of crushed blast furnace slag which is considered as a waste product and which therefore does not consume energy or emit GHG emissions.
• Cement concrete corresponds to undowelled concrete slab pavements. The binder in the case of continuously reinforced concrete pavements also includes the reinforcement bars.
• Active joint: pre-cracking is counted by the active joint process (See technical notice in Annex VII page 37). Although very small, the amount of energy required to manufacture the active joint has been taken into account.
• As road materials, in particular bituminous mixtures, can be recycled, the energy contained in the binder used in the pavement is not considered as being lost.
• RAP refers to reclaimed asphalt pavement.

Part conclusion

We can see that these technologies fall into four groups:

• Concrete cement: between 700 and 1,100, with an average value of 900 MJ/t, i.e. a level of 6
• Hot or warm mixes, whether recycled or not: between 500 and 700, with an average value of 600 MJ/t, i.e. a level of 4
• Cold mixes (white or black other than concrete): between 300 and 400, with an average value of 350 MJ/t, i.e. a level of 2.3
• In situ treated soils (cold), “as dug” gravel, active joint and gravel bound with special hydraulic road binder, with an average value of 15 MJ/t, i.e. a level of 1

And therefore, the following levels:

1 2.3 4 6

IV.2- Energy consumption for each type of structure (construction only)

In order to make an objective comparison, it seems necessary to take into account the real quantities of materials used for the construction of pavement structures with reference to traffic and the bearing capacity of the subgrade.

Figure 5 shows the total energy consumption for each type of pavement as a function of traffic class, for a bearing capacity of 50 MPa (class PF2).

Energy is expressed in MJ per m² of pavement structure.
**Figure 5: Energy consumption for pavement construction**

**N.B.**
According to the LCPC-SETRA guides, in order to obtain a class PF2 roadbed from a class AR1 (or PF1) formation, a thickness of 0.50 m of “as dug” gravel is required, or alternatively an in situ treatment with cement to a depth of 0.35 m.

<table>
<thead>
<tr>
<th>Material</th>
<th>Untreated granular material</th>
<th>Soil treated in-situ with lime + cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (m)</td>
<td>0.50</td>
<td>0.35</td>
</tr>
<tr>
<td>Energy (MJ/m²)</td>
<td>124</td>
<td>188</td>
</tr>
</tbody>
</table>

Table 2 : provides the energy consumption to obtain a PF2 class from an AR1 class

*Soil improvement by treatment with cement consumes more energy than adding “as dug” gravel.*
IV.3- Energy consumption for each type of structure taking account of maintenance

Figure 6 gives total energy consumption for each type of pavement as a function of traffic class, taking into account maintenance operations over a thirty year period.

Energy is expressed in MJ per m² of pavement structure.

The energy consumption classification remains basically the same as for the construction of a new pavement, with a considerable increase for concrete cement slab pavements which require a greater thickness of overlay, in particular for high levels of traffic above class TC6 (1200 heavy lorries per day).

Part conclusion

When looking at the results after 30 years for an equivalent level of service, only three groups can be observed:

- Cement concrete: structures maintained with bituminous mixtures: between 800 and 1200 MJ/m², i.e. a level of 1.7
- Hot mixes and composite pavements: between 550 and 850 MJ/m², i.e. a level of 1.2
- Cold mixes and composite pavements with special hydraulic road binders or active joints: between 450 and 700 MJ/m², i.e. a level of 1
And therefore, the following levels:

<table>
<thead>
<tr>
<th>1</th>
<th>1.2</th>
<th>1.7</th>
</tr>
</thead>
</table>

The benefits of structures that use cold materials (emulsion or special hydraulic road binders) are clearly apparent, and particular mention should be given to the active joint technique (See Technical Notice in Annex VII page 37). We have already made special mention of in situ cold treatment which can reduce overall energy consumption by at least 20 to 40%.

**IV.4- Energy consumption for the construction of safety barriers**

The following hypotheses are made on the basis of the Study “LCA in road industry”:

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>TC2</th>
<th>TC3</th>
<th>TC4</th>
<th>TC5</th>
<th>TC6</th>
<th>TC7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pavement width for both direction (in m)</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Central safety barrier</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>1 in concrete</td>
<td>1 in concrete</td>
<td>1 in concrete</td>
</tr>
<tr>
<td>Edge safety barrier</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>2 in steel</td>
<td>2 in steel</td>
</tr>
</tbody>
</table>

Table 3

Energy consumption for the construction of one km of barrier (see: *LCA in road industry*, Usirf 2002):

- 0.55.10⁶ MJ/km for a concrete safety barrier
- 1.55.10⁶ MJ/km for a steel safety barrier

Figure 7 shows the total energy consumption for the construction of safety barriers.

Consumption is expressed in MJ/km of road.
The energy consumption for steel and concrete safety barriers is around 250 MJ/m², i.e. depending on the technique approximately 50 to 100 % that of the pavement calculated over a 30 year period.

It is obvious that from the sole energy point of view, it is better to avoid steel safety barriers.

**IV.5- Energy consumption of total cumulative traffic expected to travel on the pavement over a 30 year period.**

Figure 8 shows the total energy consumption by traffic during the foreseeable service life of the pavement, as a function of traffic class.

The traffic considered is that of vehicles per section of pavement, and is therefore bidirectional. (See Annex IV page 32).

Consumption is expressed in MJ/km of pavement.
Figure 8: Energy consumption by total cumulative traffic during the service life of 30 years

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>TC230</th>
<th>TC330</th>
<th>TC430</th>
<th>TC530</th>
<th>TC630</th>
<th>TC730</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily heavy lorries traffic (per direction)</td>
<td>35</td>
<td>85</td>
<td>200</td>
<td>500</td>
<td>1200</td>
<td>3000</td>
</tr>
<tr>
<td>Daily vehicles traffic (per direction)</td>
<td>538</td>
<td>1308</td>
<td>3077</td>
<td>7692</td>
<td>18462</td>
<td>46154</td>
</tr>
<tr>
<td>Cumulated vehicles traffic (in million for the both directions)</td>
<td>20</td>
<td>50</td>
<td>116</td>
<td>290</td>
<td>700</td>
<td>1740</td>
</tr>
</tbody>
</table>

**IV.6- Energy consumption for pavement construction and maintenance and total cumulative traffic expected to use the carriageway**

Figure 9 gives a comparison between the total energy consumption of the cumulative traffic during the foreseeable service life of the pavement and the total energy consumption for pavement construction and maintenance over a 30 years period as a function of traffic class.

The traffic considered is that of vehicles per section of pavement, and is therefore bidirectional. (See Annex IV page 32)

Consumption is expressed in MJ/m².
**Figure 9:** Energy consumption for each type of pavement structure (construction + maintenance of the pavement and safety barriers), compared with the consumption of total cumulative traffic

**Part conclusion**

It can be observed that, over a 30 year period, traffic consumes between 10 and 345 times more than road construction and maintenance, depending on whether the traffic is light or heavy.

Table 4 shows the ratio between the consumption of total cumulative traffic over the 30 year service life and the energy consumption for road construction and maintenance (including safety barriers) over the same period of time.
<table>
<thead>
<tr>
<th>Traffic class</th>
<th>TC2</th>
<th>TC3</th>
<th>TC4</th>
<th>TC5</th>
<th>TC6</th>
<th>TC7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily heavy lorries traffic (per direction)</td>
<td>35</td>
<td>85</td>
<td>200</td>
<td>500</td>
<td>1200</td>
<td>3000</td>
</tr>
<tr>
<td>Cement concrete pavement</td>
<td>10</td>
<td>23</td>
<td>50</td>
<td>70</td>
<td>87</td>
<td>140</td>
</tr>
<tr>
<td>Bituminous pavement and pavement with base layers treated with cement</td>
<td>15</td>
<td>35</td>
<td>75</td>
<td>95</td>
<td>105</td>
<td>170</td>
</tr>
<tr>
<td>Pavement with cold mix materials (emulsion or special hydraulic road binder)</td>
<td>18</td>
<td>40</td>
<td>90</td>
<td>110</td>
<td>120</td>
<td>200</td>
</tr>
<tr>
<td>Pavement with base layers treated with special hydraulic road binder and active joint</td>
<td>17</td>
<td>40</td>
<td>95</td>
<td>140</td>
<td>220</td>
<td>345</td>
</tr>
</tbody>
</table>

Table 4

Thus for traffic class TC6 (1200 heavy lorries/day), the energy consumption of total cumulative traffic is 105 times higher than that of bituminous pavements.
V. GREENHOUSE GAS EMISSIONS

The increase in the greenhouse effect is considered to be the main cause of climatic change. The main greenhouse gases in the field of road construction are carbon dioxide (CO₂), nitrous oxide (N₂O) and methane (CH₄). As the contribution of these gases is not the same, their GWP (Greenhouse Warming Potential) must be expressed as a CO₂ equivalent. It is accepted that the GWP of N₂O is 310 and that of CH₄ is 21. That is to say that one kg of N₂O has as much effect as 310 kg of CO₂.

GHG emissions are studied for a ton of material manufactured and laid, and per m² of pavement structure. A comparison is made with the total GHG emissions of the cumulative traffic expected to use the pavement over the selected service life of 30 years.

In this study, GHG emissions are expressed in (CO₂) equivalence.

V.1- GHG emissions per ton of laid material

Figure 10 shows the GHG emissions for the manufacture of one ton of material from extraction of the raw materials to laying on the worksite. Please refer to Annex III page 31 for the composition of the materials and Annex V page 33 for the GHG emissions results for each type of product.

GHG emissions are expressed in kg per ton of material.
Figure 10: GHG emissions during manufacture and construction for the main road technologies

Comments:
- “Binders” are counted the energy consumed in order to extract and transport raw materials and manufacture binders (bitumen, cement, modified binder, etc.).
- “Aggregates” are counted the energy consumed in order to extract and manufacture aggregates at the quarry.
- “Manufacture” is counted the energy consumed in order to manufacture mixes in a plant or production unit.
- “Transport” are counted the energy consumed in order to transport the constituents and mixes from the plants where the constituents are manufactured to the worksite.
- “Laying” is counted the energy consumed in order to lay the material and perform the works.
- The hydraulic road binder is a mix consisting in 80% of crushed blast furnace slag which is considered as a waste product and which therefore does not consume energy or emit GHG emissions.
- Cement concrete corresponds to undowelled concrete slab pavements. The binder in the case of continuously reinforced concrete pavements also includes the reinforcement bars.
- Active joint: pre-cracking is counted by the active joint process (see technical notice in Annex VII page 37). Although very small, the amount of energy required to manufacture the active joint has been taken into account.
- As road materials, in particular bituminous mixtures, can be recycled, the energy contained in the binder used in the pavement is not considered as being lost.
- RAP refers to reclaimed asphalt pavement.
Part conclusion

While four groups were identified in the analysis of energy consumption, only three are apparent for GHG emissions:

- Cement concrete: 140 to 200 kg/t, i.e. a level of 10
- Hot or cold mixes whether recycled or not: 30 to 60 kg/t, i.e. a level of 3
- Cold retread (bitumen emulsion or cement), “as dug” gravel, gravel with special hydraulic road binder, and active joint: 10 to 20 kg/t, i.e. a level of 1

And therefore, the following levels:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>3</th>
<th>10</th>
</tr>
</thead>
</table>

V.2- GHG emissions for each type of structure without taking account of maintenance

The pavement structures and traffic levels are those described in Section III.2 of this document.

Figure 11 gives the GHG emissions for one m² of new pavement in the case of a type PF2 roadbed, without taking into account maintenance operations.

GHG emissions are expressed in kg per m² of pavement structure.
Figure 11: GHG emissions for the construction of pavement structures as a function of the traffic the pavement is expected to carry during its service life

Comments

According to the LCPC-Setra guides, in order to obtain a PF2 roadbed from a class AR1 (or PF1) formation, a thickness of 0.50 m of “as dug” gravel is required, or alternatively an in situ treatment with cement to a depth of 0.35 m.

Table 5 gives the GHG emissions for a transition from PF1 to PF2

Soil improvement by treatment with cement has a higher impact on the greenhouse than adding “as dug” gravel.

---

<table>
<thead>
<tr>
<th>Material</th>
<th>Untreated granular material</th>
<th>Soil treated in-situ with lime + cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (m)</td>
<td>0.50</td>
<td>0.35</td>
</tr>
<tr>
<td>GHG emissions (kg/m²)</td>
<td>16</td>
<td>35</td>
</tr>
</tbody>
</table>
V.3- GHG emissions for each type of structure taking maintenance into account

Figure 12 shows the GHG emissions for one m² of new constructed and finished pavement, taking into account maintenance operations over a 30 year period.

The GHG emissions are expressed in kg per m² of pavement built and maintained over a 30 year period.

Figure 12: GHG emissions for the construction and maintenance of pavement structures as a function of the traffic the pavement is expected to carry during its service life

The energy consumption classification remains basically the same as for the construction of a new pavement, with a considerable increase for concrete cement slab pavements which require a greater thickness of overlay, in particular for heavy traffic above class TC6 (1200 heavy lorries per day).
Part conclusion

If we consider the life of a pavement over a 30 year period, three groups can still be identified:

- Concrete cement: between 110 to 160 kg/m², i.e. a level of 2.6
- Composite pavements with cement: between 65 to 90 kg/m², i.e. a level of 1.5
- Hot or cold mix bituminous pavements, composite pavements with special hydraulic road binder or active joints: 40 to 65 kg/m², i.e. a level of 1

And therefore, the following levels:

| 1 | 1.5 | 2.6 |

In this case also, a clear difference can be seen between concrete and cement on the one hand and bituminous and composite pavements on the other. The first ones are responsible for 50 to 160 times more emissions than the second ones, for all traffic levels.

The specific advantages with regard to greenhouse gas emissions of pavements using bitumen emulsion and active joints should be mentioned.
V.4- GHG emissions resulting from the construction of safety barriers

Figure 13 shows the GHG emissions for the construction of safety barriers (See the hypotheses in Section VI.4). The following hypotheses for GHG emissions are made per km of safety barrier (based on the study LCA in the road industry – Usirf 2002):

- 87 500 kg/km for a concrete safety barrier
- 85 500 kg/km for a steel safety barrier

GHG emissions are expressed in kg per km of road.

![Figure 13: GHG emissions for the construction of safety barriers](image)

**Part conclusion**

In this case too, over a 30 year period, the impact of concrete and steel safety barriers on greenhouse gas emissions is approximately the same as for pavement construction and maintenance (0.3 to 1 times depending on the technique). Here too, if only GHG emissions are considered, metal safety barriers should be avoided.
V.5- GHG emissions by the total cumulative traffic expected to use the pavement over a 30 year period

Figure 14 shows the amount of GHG emissions emitted by the cumulative traffic during the foreseeable service life of the road, as a function of traffic class. The traffic considered is that of vehicles per section of pavement, and is therefore bidirectional.

GHG emissions are expressed in kg per km of pavement.

Figure 14: GHG emissions by total cumulative traffic during the service life (30 years)

LV : Light vehicles
LCV : Light Commercial Vehicles
HL : Heavy lorries

Traffic class:

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>TC2_{30}</th>
<th>TC3_{30}</th>
<th>TC4_{30}</th>
<th>TC5_{30}</th>
<th>TC6_{30}</th>
<th>TC7_{30}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily heavy lorries traffic (per direction)</td>
<td>35</td>
<td>85</td>
<td>200</td>
<td>500</td>
<td>1200</td>
<td>3000</td>
</tr>
<tr>
<td>Daily vehicles traffic (per direction)</td>
<td>538</td>
<td>1308</td>
<td>3077</td>
<td>7692</td>
<td>18462</td>
<td>46154</td>
</tr>
<tr>
<td>Cumulated vehicles traffic (in million for the both directions)</td>
<td>20</td>
<td>50</td>
<td>116</td>
<td>290</td>
<td>700</td>
<td>1740</td>
</tr>
</tbody>
</table>
V.6- GHG emissions for pavement construction and maintenance and total cumulative traffic expected to use the carriageway over a 30 year period

Figure 15 shows a comparison between the GHG emissions of the cumulative traffic during the foreseeable service life of the pavement and the total GHG emissions for pavement construction and maintenance over a 30 year period as a function of traffic class.

The traffic considered is that of vehicles per section of pavement, and is therefore bidirectional. (See Annex IV page 32)

GHG emissions are expressed in MJ/km of carriageway.

Figure 15: GHG emissions for each type of pavement structure (construction + maintenance of the pavement and safety barriers), compared to total cumulative traffic

Partial conclusion

With regard to GHG emissions, the impact of traffic is between 10 and 400 times more important (rising the heavier the traffic is) than construction and maintenance of the road that carries it (including safety barriers). See Table 6.
<table>
<thead>
<tr>
<th>Traffic class</th>
<th>TC2</th>
<th>TC3</th>
<th>TC4</th>
<th>TC5</th>
<th>TC6</th>
<th>TC7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily heavy lorries traffic (per direction)</td>
<td>35</td>
<td>85</td>
<td>200</td>
<td>500</td>
<td>1 200</td>
<td>3 000</td>
</tr>
<tr>
<td>Cement concrete pavement</td>
<td>8</td>
<td>18</td>
<td>41</td>
<td>57</td>
<td>85</td>
<td>135</td>
</tr>
<tr>
<td>Pavement with base layers treated with cement</td>
<td>14</td>
<td>33</td>
<td>68</td>
<td>89</td>
<td>128</td>
<td>205</td>
</tr>
<tr>
<td>Bituminous pavement</td>
<td>21</td>
<td>46</td>
<td>98</td>
<td>114</td>
<td>153</td>
<td>239</td>
</tr>
<tr>
<td>High modulus asphalt pavement and pavement with base layers treated with special hydraulic road binder</td>
<td>22</td>
<td>50</td>
<td>110</td>
<td>130</td>
<td>165</td>
<td>265</td>
</tr>
<tr>
<td>Pavement with cold mix asphalt</td>
<td>25</td>
<td>56</td>
<td>119</td>
<td>172</td>
<td>278</td>
<td>432</td>
</tr>
</tbody>
</table>

Table 6

Thus, for traffic class TC6 (1200 heavy lorries/day), the GHG emissions from the total cumulative traffic are approximately 165 times higher than those of a high modulus mix pavement.
VI. CONCLUSIONS AND OUTLOOK

The principal purpose of this study is to make an inventory of energy consumption and GHG emissions associated with road construction.

On the basis of a 30 year service life (which is in general more favourable to cement concrete structures), whatever the traffic or the type of roadbed, and irrespective of whether construction alone or construction with maintenance is considered, the results obtained in the study lead to the following conclusions:

- Energy consumption and GHG emissions linked to pavement construction are very much lower than those caused by total cumulative traffic (less than 1% in the case of bituminous and semi-rigid pavements carrying moderate and high levels of traffic).

- For hot mix bituminous pavements, the two main processes responsible for GHG emissions are binder manufacture and mix manufacture. However in the case of cement pavements, the main processes that are responsible are cement manufacture and steel manufacture in the case of reinforced concrete.

- For new pavements, the most polluting structures are concrete cement, and the least polluting are those using bitumen emulsion technologies.

- For rehabilitation, in situ bitumen emulsion recycling is by far the technique that consumes the least energy and which contributes least to the greenhouse effect.

This life cycle analysis of pavement structures shows the benefits of using bitumen emulsion and high modulus mixes. Composite pavements with special hydraulic road binder and active joints deserve special mention. These techniques make it possible to manage and optimize energy consumption and reduce impacts on the greenhouse effect. Recycling saves materials and reduces transport.
VII. BIBLIOGRAPHY AND REFERENCES

- Sustainable development : French standard NF FD X 30-021
- Life Cycle Inventory of Asphalt Pavements - Swedish Environmental Research Institute - IVL Report 2002
- Athena Report (for Canadian Portland Cement Association) - Athena Sustainable Materials Institute 1999
- LCA in road industry - Usirf 2002
- Catalogue of standard structures for new pavements - Lcpc-Setra 1998
- France inventory of GHG emissions - In the framework of the United Nations general agreement on climate change. CITEPA report. December 2002

- Web sites :
  www.x-environnement.org  www.usirf.com
  www.piarc.org  www.citepa.org

VIII. LIST OF ANNEXES

I. Roadbed and traffic classes
II. Environmental hypotheses
III. Composition of pavement construction materials
IV. Analysis of cumulative traffic – Consumption – GHG emissions
V. Energy consumption and GHG emissions for each type of product
VI. Standard structures as defined in the 1998 LCPC-SETRA catalogue
VII. Some technical notes about special Colas Group products
ANNEX I

Roadbed and traffic classes

Roadbed:

<table>
<thead>
<tr>
<th>Pavement formation class (PF)</th>
<th>PF1</th>
<th>PF2</th>
<th>PF3</th>
<th>PF4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic modulus (MPa)</td>
<td>20</td>
<td>50</td>
<td>120</td>
<td>200</td>
</tr>
</tbody>
</table>

Traffic class:

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>TC2</th>
<th>TC3</th>
<th>TC4</th>
<th>TC5</th>
<th>TC6</th>
<th>TC7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily heavy lorries traffic (per direction)</td>
<td>35</td>
<td>85</td>
<td>200</td>
<td>500</td>
<td>1200</td>
<td>3000</td>
</tr>
<tr>
<td>Daily vehicles traffic (per direction)</td>
<td>538</td>
<td>1308</td>
<td>3077</td>
<td>7692</td>
<td>18462</td>
<td>46154</td>
</tr>
</tbody>
</table>

Definition:

- Traffic class: According to the daily heavy traffic the pavement has to support, 8 classes are noticed from the TC1 (for the traffic < 35 HL/day/direction) to the higher TC8 (class for a traffic of 4000HL/day/direction).
  For example: TC7_{30} means class traffic 7 and service life of 30 years.
- The definition of heavy lorries(HL) is : vehicles with a payload of 35 kN
- The initial daily traffic is the estimated two-way traffic at the opening date of the road expressed in average annual daily traffic (AADT).
- The cumulative traffic is the total two-way cumulative traffic over the foreseeable service life of the structure, expressed in each direction.
ANNEX II
Environmental hypotheses

The table below gives the energy consumed and greenhouse gases emitted during the manufacture of one ton of finished product from extraction (quarry, oil deposit, etc.) until the sale at the production unit (refinery, cement plant, etc.):

<table>
<thead>
<tr>
<th>Product</th>
<th>Energy (MJ/t)</th>
<th>CO₂eq (kg/t)</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen</td>
<td>4,900</td>
<td>285</td>
<td>Eurobitume</td>
</tr>
<tr>
<td>Emulsion 60%</td>
<td>3,490</td>
<td>221</td>
<td>Eurobitume</td>
</tr>
<tr>
<td>Cement</td>
<td>4,976</td>
<td>980</td>
<td>Athena &amp; IVL</td>
</tr>
<tr>
<td>Hydraulic road binder</td>
<td>1,244</td>
<td>245</td>
<td>CED</td>
</tr>
<tr>
<td>Crushed aggregates</td>
<td>40</td>
<td>10</td>
<td>Athena &amp; IVL</td>
</tr>
<tr>
<td>Pit-run aggregates</td>
<td>30</td>
<td>2.5</td>
<td>Athena &amp; IVL</td>
</tr>
<tr>
<td>Steel</td>
<td>25,100</td>
<td>3,540</td>
<td>Athena &amp; IVL</td>
</tr>
<tr>
<td>Quicklime</td>
<td>9,240</td>
<td>2,500</td>
<td>IVL</td>
</tr>
<tr>
<td>Water</td>
<td>10</td>
<td>0.3</td>
<td>IVL</td>
</tr>
<tr>
<td>Plastic</td>
<td>7,890</td>
<td>1,100</td>
<td>IVL</td>
</tr>
<tr>
<td>Fuel</td>
<td>35</td>
<td>4.0</td>
<td>IVL</td>
</tr>
<tr>
<td>Production of hot mix asphalt</td>
<td>275</td>
<td>22</td>
<td>IVL</td>
</tr>
<tr>
<td>Production of warm mix asphalt</td>
<td>234</td>
<td>20</td>
<td>IVL</td>
</tr>
<tr>
<td>Production of high modulus asphalt</td>
<td>289</td>
<td>23</td>
<td>IVL</td>
</tr>
<tr>
<td>Production of cold mix plant</td>
<td>14</td>
<td>1.0</td>
<td>IVL</td>
</tr>
<tr>
<td>Surface milling of asphalt for RAP</td>
<td>12</td>
<td>0.8</td>
<td>IVL</td>
</tr>
<tr>
<td>In-situ thermo-recycling</td>
<td>456</td>
<td>34</td>
<td>Colas MM</td>
</tr>
<tr>
<td>In-situ cold recycling</td>
<td>15</td>
<td>1.13</td>
<td>IVL</td>
</tr>
<tr>
<td>In-situ soil cement stabilisation</td>
<td>12</td>
<td>0.80</td>
<td>IVL</td>
</tr>
<tr>
<td>Laying of hot mix asphalt</td>
<td>9</td>
<td>0.6</td>
<td>IVL</td>
</tr>
<tr>
<td>Laying of cold mix materials</td>
<td>6</td>
<td>0.4</td>
<td>IVL</td>
</tr>
<tr>
<td>Cement concrete road paving</td>
<td>2.2</td>
<td>0.2</td>
<td>IVL</td>
</tr>
<tr>
<td>Lorry transport (km/t)</td>
<td>0.9</td>
<td>0.06</td>
<td>IVL</td>
</tr>
</tbody>
</table>

Energy: this is the amount of energy (in MJ) required to obtain one ton of finished product.

CO₂eq; is the amount of greenhouse gas emitted, expressed in CO₂ equivalent. The main greenhouse gases are CO₂, N₂O and CH₄. Their GWP (Greenhouse Warming Potential) in CO₂ equivalent are: 310 for N₂O and 21 for CH₄.

The unit is kg or CO₂eq per ton of finished product available at the production unit.

Source: these are the references which provided the data for this report:
I. Eurobitume: "Partial Life Cycle Inventory for Paving Grade Bitumen" – May 1999
III. IVL Swedish Environmental Research Institute: Life Cycle Assessment of Road – March 2001. Study conducted for the Swedish National Road Administration
### ANNEX III

**Composition of pavement construction materials**

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density (kg/m³)</th>
<th>Crushed aggregates (kg/t)</th>
<th>Rolled aggregates (kg/t)</th>
<th>RAP (kg/t)</th>
<th>Bitumen (kg/t)</th>
<th>Emulsion (kg/t)</th>
<th>Cement (kg/t)</th>
<th>Water (kg/t)</th>
<th>Steel (kg/t)</th>
<th>PVC (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous concrete</td>
<td>2250</td>
<td>943</td>
<td>57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road base asphalt concrete</td>
<td>2250</td>
<td>700</td>
<td>258</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High modulus asphalt concrete</td>
<td>2250</td>
<td>940</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm mix asphalt concrete</td>
<td>2250</td>
<td>940</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emulsion bound aggregate</td>
<td>2200</td>
<td>935</td>
<td>65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold mix asphalt</td>
<td>2250</td>
<td>910</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement-bound aggregate</td>
<td>2200</td>
<td>455</td>
<td>455</td>
<td>40</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement-bound aggregate &amp; &quot;AJ&quot;**</td>
<td>2200</td>
<td>455</td>
<td>455</td>
<td>40</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Aggregate with hydraulic road binders</td>
<td>2200</td>
<td>455</td>
<td>455</td>
<td>40</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate with hydraulic road binders &amp; &quot;AJ&quot;**</td>
<td>2200</td>
<td>455</td>
<td>455</td>
<td>40</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Cement concrete slabs without dowels</td>
<td>2450</td>
<td>410</td>
<td>410</td>
<td>120</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous reinforced concrete**</td>
<td>2450</td>
<td>410</td>
<td>410</td>
<td>120</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Untreated granular material</td>
<td>2200</td>
<td>950</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil treated in-situ with lime + cement</td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermorecycling</td>
<td>2250</td>
<td>100</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Concrete bituminous with 10% RAP</td>
<td>2250</td>
<td>849</td>
<td>100</td>
<td>51</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Road base asphalt concrete with 20% RAP</td>
<td>2250</td>
<td>768</td>
<td>200</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road base asphalt concrete with 30% RAP</td>
<td>2250</td>
<td>672</td>
<td>300</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road base asphalt concrete with 50% RAP</td>
<td>2250</td>
<td>480</td>
<td>500</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emulsion in-situ recycling</td>
<td>2200</td>
<td>100</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Precracking with 2.30 m long active joint every 2 m and a lane width of 3.5 m.

** Percentage of reinforcement in continuously reinforced concrete: this is obtained on the basis of the cross-section of reinforcement stated in the LCPC-SETRA guide, i.e. 0.67% of the cross-section of the concrete or approximately 50 kg/m³ of concrete.

N.B.: The values adopted are those which are generally accepted in France.
ANNEX IV

Analysis of cumulative traffic – Consumption – GHG emissions

Traffic data from URF 2001
30 year service life – Annual increase in traffic: 5%

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>TC2</th>
<th>TC3</th>
<th>TC4</th>
<th>TC5</th>
<th>TC6</th>
<th>TC7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily heavy lorries traffic (per direction)</td>
<td>35</td>
<td>85</td>
<td>200</td>
<td>500</td>
<td>1200</td>
<td>3000</td>
</tr>
<tr>
<td>Daily vehicles traffic (per direction)</td>
<td>538</td>
<td>1308</td>
<td>3077</td>
<td>7692</td>
<td>18462</td>
<td>46154</td>
</tr>
<tr>
<td>Cumulative vehicles traffic (per direction)</td>
<td>1.02E+07, 2.47E+07</td>
<td>5.81E+07, 1.45E+08</td>
<td>3.49E+08, 8.72E+08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative heavy lorries (per direction)</td>
<td>6.61E+05, 1.61E+06</td>
<td>3.78E+06, 9.44E+06</td>
<td>2.27E+07, 5.67E+07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative total LV traffic (per direction)</td>
<td>7.93E+06, 1.93E+07</td>
<td>4.53E+07, 1.13E+08</td>
<td>2.72E+08, 6.80E+08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cumulative LCV traffic (per direction)</td>
<td>1.58E+06, 3.83E+06</td>
<td>9.01E+06, 2.25E+07</td>
<td>5.41E+07, 1.35E+08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy consumption HL (MJ/km) *</td>
<td>1.43E+07, 3.47E+07</td>
<td>8.16E+07, 2.04E+08</td>
<td>4.90E+08, 1.22E+09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy consumption LV+LCV (J/km) *</td>
<td>4.93E+07, 1.20E+08</td>
<td>2.82E+08, 7.04E+08</td>
<td>1.69E+09, 4.22E+09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy consumption for total cumulative traffic (MJ/km) *</td>
<td>6.36E+07, 1.54E+08</td>
<td>3.63E+08, 9.08E+08</td>
<td>2.18E+09, 5.45E+09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHG emission HL (kg/km) **</td>
<td>1.59E+06, 3.85E+06</td>
<td>9.07E+06, 2.27E+07</td>
<td>5.44E+07, 1.36E+08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHG emission LV+LCV (kg/km) **</td>
<td>5.48E+06, 1.33E+07</td>
<td>3.13E+07, 7.82E+07</td>
<td>1.88E+08, 4.69E+08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHG emission total cumulative traffic (kg/km) **</td>
<td>7.06E+06, 1.72E+07</td>
<td>4.04E+07, 1.01E+08</td>
<td>2.42E+08, 6.05E+08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total width pavement (m)</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Energy consumption (MJ/m²)</td>
<td>7 945</td>
<td>19 295</td>
<td>45 400</td>
<td>75 667</td>
<td>136 200</td>
<td>227 001</td>
</tr>
<tr>
<td>GHG emission (kg/m²)</td>
<td>883</td>
<td>2 144</td>
<td>5 044</td>
<td>8 407</td>
<td>15 133</td>
<td>25 222</td>
</tr>
</tbody>
</table>

Definition:
- Traffic class: According to the daily heavy traffic the pavement has to support, 8 classes are noticed from the TC1 (for the traffic < 35 HL/day/direction) to the higher TC8 (class for a traffic of 4000HL/day/direction).
- For example: TC7 30 means class traffic 7 and service life of 30 years.
- The definition of heavy lorries(HL) is: vehicles with a payload of 35 kN.
- The initial daily traffic is the estimated two-way traffic at the opening date of the road expressed in average annual daily traffic (AADT).
- The cumulative traffic is the total two-way cumulative traffic over the foreseeable service life of the structure, expressed in each direction.

LV : Light Vehicles  LCV: Light Commercial Vehicles
HL : Heavy Lorries

* Energy consumption for bidirectional traffic per km of road.

** GHG emissions for bidirectional traffic per km of road.
**ANNEX V**

**Energy consumption and GHG emissions for each type of product**

### Energy consumption (MJ/t)

<table>
<thead>
<tr>
<th>Product</th>
<th>Binders</th>
<th>Aggregates</th>
<th>Manufacture</th>
<th>Transport</th>
<th>Laying</th>
<th>Total (MJ/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous concrete</td>
<td>279</td>
<td>38</td>
<td>275</td>
<td>79</td>
<td>9</td>
<td>680</td>
</tr>
<tr>
<td>Road base asphalt concrete</td>
<td>196</td>
<td>36</td>
<td>275</td>
<td>75</td>
<td>9</td>
<td>591</td>
</tr>
<tr>
<td>High modulus asphalt concrete</td>
<td>284</td>
<td>38</td>
<td>289</td>
<td>79</td>
<td>9</td>
<td>699</td>
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<tr>
<td>Warm mix asphalt concrete</td>
<td>294</td>
<td>38</td>
<td>234</td>
<td>80</td>
<td>9</td>
<td>654</td>
</tr>
<tr>
<td>Emulsion bound aggregate</td>
<td>227</td>
<td>37</td>
<td>14</td>
<td>81</td>
<td>6</td>
<td>365</td>
</tr>
<tr>
<td>Cold mix asphalt</td>
<td>314</td>
<td>36</td>
<td>14</td>
<td>86</td>
<td>6</td>
<td>457</td>
</tr>
<tr>
<td>Cement-bound materials &amp; &quot;AJ&quot;</td>
<td>200</td>
<td>32</td>
<td>14</td>
<td>67</td>
<td>6</td>
<td>319</td>
</tr>
<tr>
<td>Aggregate with hydraulic road binders</td>
<td>203</td>
<td>32</td>
<td>14</td>
<td>67</td>
<td>6</td>
<td>323</td>
</tr>
<tr>
<td>Aggregate with hydraulic road binders &amp; &quot;AJ&quot;</td>
<td>50</td>
<td>29</td>
<td>14</td>
<td>61</td>
<td>6</td>
<td>160</td>
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<tr>
<td>Cement concrete slabs without dowels</td>
<td>598</td>
<td>40</td>
<td>14</td>
<td>84</td>
<td>2.2</td>
<td>738</td>
</tr>
<tr>
<td>Continuous reinforced concrete</td>
<td>1100</td>
<td>29</td>
<td>14</td>
<td>81</td>
<td>2.2</td>
<td>1226</td>
</tr>
<tr>
<td>Untreated granular material</td>
<td>0</td>
<td>40</td>
<td>-</td>
<td>68</td>
<td>6</td>
<td>113</td>
</tr>
<tr>
<td>Emulsion bound aggregate</td>
<td>63</td>
<td>0</td>
<td>-</td>
<td>7</td>
<td>12</td>
<td>81</td>
</tr>
<tr>
<td>Thermorecycling</td>
<td>98</td>
<td>4</td>
<td>-</td>
<td>12</td>
<td>456</td>
<td>570</td>
</tr>
<tr>
<td>Concrete bituminous with 10% RAP</td>
<td>250</td>
<td>35</td>
<td>275</td>
<td>73</td>
<td>9</td>
<td>642</td>
</tr>
<tr>
<td>Road base asphalt concrete with 20% RAP</td>
<td>157</td>
<td>33</td>
<td>275</td>
<td>64</td>
<td>9</td>
<td>538</td>
</tr>
<tr>
<td>Road base asphalt concrete with 30% RAP</td>
<td>137</td>
<td>30</td>
<td>275</td>
<td>58</td>
<td>9</td>
<td>510</td>
</tr>
<tr>
<td>Road base asphalt concrete with 50% RAP</td>
<td>98</td>
<td>25</td>
<td>275</td>
<td>47</td>
<td>9</td>
<td>454</td>
</tr>
<tr>
<td>Emulsion in-situ recycling</td>
<td>105</td>
<td>4</td>
<td>-</td>
<td>15</td>
<td>15</td>
<td>139</td>
</tr>
</tbody>
</table>

### GHG emission (kg/t)

<table>
<thead>
<tr>
<th>Product</th>
<th>Binders</th>
<th>Aggregates</th>
<th>Manufacture</th>
<th>Transport</th>
<th>Laying</th>
<th>Total (kg/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous concrete</td>
<td>16</td>
<td>9.4</td>
<td>22.0</td>
<td>5.3</td>
<td>0.6</td>
<td>54</td>
</tr>
<tr>
<td>Road base asphalt concrete</td>
<td>11</td>
<td>7.6</td>
<td>22.0</td>
<td>5.3</td>
<td>0.6</td>
<td>47</td>
</tr>
<tr>
<td>High modulus asphalt concrete</td>
<td>17</td>
<td>9.4</td>
<td>23.1</td>
<td>5.0</td>
<td>0.6</td>
<td>55</td>
</tr>
<tr>
<td>Warm mix asphalt concrete</td>
<td>17</td>
<td>9.4</td>
<td>20.5</td>
<td>5.3</td>
<td>0.6</td>
<td>53</td>
</tr>
<tr>
<td>Emulsion bound aggregate</td>
<td>14</td>
<td>9.4</td>
<td>1.0</td>
<td>5.4</td>
<td>0.4</td>
<td>30</td>
</tr>
<tr>
<td>Cold mix asphalt</td>
<td>20</td>
<td>9.1</td>
<td>1.0</td>
<td>5.7</td>
<td>0.4</td>
<td>36</td>
</tr>
<tr>
<td>Cement-bound materials</td>
<td>39</td>
<td>5.7</td>
<td>1.0</td>
<td>4.5</td>
<td>0.4</td>
<td>51</td>
</tr>
<tr>
<td>Cement-bound material &amp; &quot;AJ&quot;</td>
<td>40</td>
<td>5.7</td>
<td>1.0</td>
<td>4.5</td>
<td>0.4</td>
<td>51</td>
</tr>
<tr>
<td>Aggregate with hydraulic road binders</td>
<td>10</td>
<td>5.1</td>
<td>1.0</td>
<td>4.1</td>
<td>0.4</td>
<td>20</td>
</tr>
<tr>
<td>Aggregate with hydraulic road binders &amp; &quot;AJ&quot;</td>
<td>10</td>
<td>5.7</td>
<td>1.0</td>
<td>4.5</td>
<td>0.4</td>
<td>22</td>
</tr>
<tr>
<td>Cement concrete slabs without dowels</td>
<td>118</td>
<td>9.6</td>
<td>1.0</td>
<td>5.6</td>
<td>0.2</td>
<td>134</td>
</tr>
<tr>
<td>Continuous reinforced concrete</td>
<td>188</td>
<td>5.1</td>
<td>1.0</td>
<td>5.4</td>
<td>0.2</td>
<td>200</td>
</tr>
<tr>
<td>Untreated granular material</td>
<td>0</td>
<td>9.6</td>
<td>-</td>
<td>4.5</td>
<td>0.4</td>
<td>15</td>
</tr>
<tr>
<td>Soil treated in-situ with lime + cement</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td>1.1</td>
<td>14</td>
</tr>
<tr>
<td>Thermorecycling</td>
<td>6</td>
<td>1.0</td>
<td>-</td>
<td>0.8</td>
<td>34.2</td>
<td>42</td>
</tr>
<tr>
<td>Concrete bituminous with 10% RAP</td>
<td>15</td>
<td>8.6</td>
<td>22.0</td>
<td>4.9</td>
<td>0.6</td>
<td>51</td>
</tr>
<tr>
<td>Road base asphalt concrete with 20% RAP</td>
<td>9</td>
<td>7.8</td>
<td>22.0</td>
<td>4.3</td>
<td>0.6</td>
<td>44</td>
</tr>
<tr>
<td>Road base asphalt concrete with 30% RAP</td>
<td>8</td>
<td>7.0</td>
<td>22.0</td>
<td>3.9</td>
<td>0.6</td>
<td>41</td>
</tr>
<tr>
<td>Road base asphalt concrete with 50% RAP</td>
<td>6</td>
<td>5.2</td>
<td>22.0</td>
<td>3.1</td>
<td>0.6</td>
<td>37</td>
</tr>
<tr>
<td>Emulsion in-situ recycling</td>
<td>7</td>
<td>1.0</td>
<td>1.1</td>
<td>1.0</td>
<td>0.4</td>
<td>10</td>
</tr>
</tbody>
</table>
### ANNEX VI

Standard structures as defined in the 1998 LCPC-SETRA catalogue

**Initial pavement structures design for:**

**Design life: 30 years**

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>TC2</th>
<th>TC3</th>
<th>TC4</th>
<th>TC5</th>
<th>TC6</th>
<th>TC7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Lorries Traffic (HL/Day)</td>
<td>35</td>
<td>85</td>
<td>200</td>
<td>500</td>
<td>1200</td>
<td>3000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thickness of layers (m)</th>
<th>Pavement foundation: PF2 (E=50 MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grave emulsion BBF</td>
<td>0.06 0.06 0.06 0.08 0.08 0.08</td>
</tr>
<tr>
<td>GE</td>
<td>0.16 0.21 0.27 0.30 0.35 0.41</td>
</tr>
<tr>
<td>BB/GB3</td>
<td>0.060 0.06 0.065 0.08 0.08 0.08</td>
</tr>
<tr>
<td>BB3</td>
<td>0.15 0.19 0.23 0.26 0.30 0.36</td>
</tr>
<tr>
<td>EME2</td>
<td>0.025 0.025 0.025 0.025 0.08 0.08</td>
</tr>
<tr>
<td>EME2</td>
<td>0.14 0.17 0.20 0.23 0.23 0.28</td>
</tr>
<tr>
<td>GC ou GLR G3 BB</td>
<td>0.06 0.06 0.065 0.08 0.10 0.145</td>
</tr>
<tr>
<td>GC3</td>
<td>0.33 0.34 0.41 0.42 0.43 0.43</td>
</tr>
<tr>
<td>GC ou GLR G3+JA BB</td>
<td>0.06 0.06 0.065 0.08 0.10 0.12</td>
</tr>
<tr>
<td>GC3 + JA</td>
<td>0.29 0.30 0.33 0.34 0.35 0.41</td>
</tr>
<tr>
<td>BC5 (without dowels) BC5</td>
<td>0.20 0.22 0.22 0.24 0.26 0.28</td>
</tr>
<tr>
<td>BC5</td>
<td>0.15 0.15 0.20 0.20 0.20 0.20</td>
</tr>
<tr>
<td>BC2</td>
<td>0.15 0.15 0.18 0.18 0.18 0.18</td>
</tr>
<tr>
<td>BC2</td>
<td>0.14 0.15 0.16 0.17 0.19 0.22</td>
</tr>
<tr>
<td>BAC</td>
<td>0.15 0.15 0.18 0.18 0.18 0.18</td>
</tr>
</tbody>
</table>

BBF: Cold mix asphalt

BB: Bituminous concrete

EME2: High modulus asphalt concrete

GC G3: Cement-bound materials of G3 class

JA: Pre-cracking with 2,30 m long active joint

(See technical notice in annex VII page 37)

BC5: Cement concrete slabs without dowels

BC2: Base lean concrete

GE: Emulsion bound aggregate

GB3: Road base asphalt concrete

GLR G3: Aggregate with hydraulic road binders of G3 class

BAC: Continuous reinforced concrete
COLD IN-SITU RETREAD PROCESS

ANNEX VII
Technical notices

NOVACOL®

PRESENTATION

NOVACOL is a cold in-situ retread process for pavement layers to a depth of 5 to 20 cm.

The process consists of milling the material in place, proportioning and incorporating the additional materials, then mixing and laying the resulting material in order to obtain a new homogeneous and effective road base layer or base course. This course will subsequently be surfaced with a surface dressing, cold micro asphalt, or a hot or cold bituminous mix.

The process can be adapted to each situation by varying the depth of treatment and the nature and proportion of binders and additional materials.

NOVACOL is a valuable addition to the range of maintenance techniques available today.

VERSION OF COMMENT

FEBRUARY 2000 Novacol is covered by French patent FR 2 606 801 and European patent EP 274 920 NOVACOL is a registered trademark
For fast, economical and clean worksites

- Between 5,000 and 10,000 m² can be laid each day.

- Limited disruption to road users:
  - linear, compact laying plant
  - single operation,
  - rapid re-opening to traffic,
  - possibility of treating one lane only.

- Savings:
  - in materials, as all the material in place is reused,
  - in transport, because the process is conducted in-situ,
  - in energy, because the process is cold,
  - Novacol avoids the need to raise the level of road equipment (safety barriers, shoulders, kerbs, etc.)

- Effective:
  - longitudinal evenness and cross-section are improved,
  - restructuring of distressed pavement layers,
  - possibility of regenerating the binder in treated layers.

- Environmentally friendly:
  - the process generates
  - no gases or dust
A patented pre-cracking process which results in considerable improvements to pavements treated with hydraulic binders by applying the concept of a thick single layer subbase.

Pavement subbases manufactured with aggregate treated with hydraulic binders inevitably suffer from shrinkage cracking. Under the effect of temperature variations and truck traffic, these cracks spread through the surface layers and result in distress, initially at the surface and then throughout the pavement structure. This deterioration is made worse by the ingress of runoff water.

Pre-cracking provides a response to this problem and makes it possible to create short slabs which are separated by narrow straight cracks.

The French catalogue of standard new pavement structures (1998 edition) very clearly states the obligation for pre-cracking of semi-rigid pavement subbases for traffic levels in excess of TC6 (1,200 trucks per day) and recommends it in other cases.

The patented Active Joint (JOINT ACTIF®) process is nowadays recognized as the most effective pre-cracking procedure.

Furthermore, the use of an innovative sinusoidal extruded profile makes it possible to recreate the continuity of the subbase, ensuring the transfer of stresses from one slab to the next when a rolling load passes over the joint.

This fundamental advantage means it can be used in a single layer structure and also that the sub-base can be thinner than is the case with a two layer structure made using aggregate treated with a hydraulic binder.

A road or industrial pavement structure of this type, produced either as a new construction or as a result of strengthening works, can result in significant investment savings and is also more economical to maintain than a conventional structure.
The principle

The Active Joint procedure involves the creation of a break in the treated pavement layer by inserting a sinusoidal extruded PVC joint. The joint is placed transversally within the pavement, in a vertical position. One joint is placed in each traffic lane, every 2 or 3 metres depending on the mineralogical characteristics of the aggregate in the bound material.

During shrinkage, cracks are formed naturally at the joints and in their lateral prolongations. However, the cracks are so thin that they do not reflect through surface layers. The sinusoidal shape of the joints ensures effective separation between the slabs that are formed. The continuity of the subbase is re-established by the transfer of mechanical stresses from slab to the next.

The pavement concept

The Active Joint procedure means that a single layer subbase can be used and makes it possible to optimize the design of semi-rigid structures by reducing their thickness. This characteristic, combined with the lack of reflection cracking, leads to considerable savings in investment and maintenance.

A process recognized

Invented in 1983, The Active Joint procedure is the subject of several patents and was awarded a TECHNICAL ADVICE (n°102) by the French Committee for Road building Techniques (CFTR). In the framework of monitoring conducted for the Innovation Charter, it received a SETRA certificate in 1997. In March 2002, on the occasion of the "Global Road Achievement Awards", the General Assembly of the IRF (International Road Federation) awarded Active Joint the first prize for innovation.

Quality

The factory where the profiles are manufactured has ISO 9002 certification. The company has drawn up a specific quality assurance plan for laying the cement-bound aggregate subbase with Active Joints. All the agencies that place Active Joint have ISO 9002 certification.

Manufacture and placement

As laying progresses, and before the cement-bound material is compacted, a specially designed vibratory driving machine cuts slots for the joints. A tool, consisting of two combs with an alternating motion closes the slot and ensures the corrugations on each side of the joint are filled. Trimming and compaction are then performed in the traditional manner. This placement equipment is able to install at least 500 joints per day, which corresponds to a daily laying rate of 3,500 tonnes of cement-bound aggregate.

European requirements

Pavement subbase with Active Joints meet European requirements for mechanical strength and stability as well as safety of use. The joint is made from inert material and presents no environmental or health risk. The presence of Active Joint in the subbase is compatible with the recycling of the subbase material.

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For base courses:
- COMPOMODULE H: high modulus asphalt concrete using a special hard bituminous binder
- COMPOMODULE P: high modulus asphalt concrete using polyolefin-modified bitumen
- COMPOMODULE G: high modulus asphalt concrete using bitumen with added asphaltite

For wearing courses:
- COMPOMODULE PR: high modulus asphalt concrete using polyolefin-modified bitumen
- COMPOMODULE GR: high modulus asphalt concrete using bitumen with added natural asphalt

Field of application

Strengthening and new construction of:
- pavements for heavy and channelized traffic
- ascending gradients
- bus lanes
- intersections and roundabouts
- industrial pavements
- airfield pavements

Some references (French department numbers)

A 6 (69), A 9 (66), A 10 Saintes (17),
A 11 (49), A 14 Orgeval-La Défense (78),
A 40 Annemasse (74), A 41 (73), A 43 (38), A 404 (01)
A 46 (69), Lyon northern orbital motorway (69),
A 72 (42), RN 10 (86), RN 141 Limoges (87),
RN 176 (22), RD 106 (49),
Saint-Gildas-des-Bois bypass (44),
Campon bypass (44),
Paris orbital motorway (75).

With their high structural power, COMPOMODULE offers important economies in thickness and an excellent resistance to rutting.
COMPOMODULE H® is a high modulus asphalt composed of a special hard bituminous binder. It offers an excellent resistance to rutting and fatigue. It's applied on base course, new pavement or in overlay. Its use allows important thickness more than classical road base asphalt.

COMPOMODULE H answer the French standard requirements NFP 98-140 «High modulus asphalt» October 1992 (classes 1 and 2).

COMPOMODULE H, called before COMPASPHALT, is subject to Technical Advice N° 40, June 1991 (will be renew).

Some references (French Department number given in brackets)

Motorways:
- A 8 (06) - A 10 in Saintes (17)
- A 13 (78) - A 14 à Orgeval (78)
- A 14 - St-Germain tunnel and toll plaza (78)
- A 26 - St-Quentin-Masnières (02)

Country roads:
- RD 912 Trappes (78) - RD 986 (34)
- RD 34 (34) - RD 68 (34) - RD 700 (22)

Urban areas and industrial estates:
- Paris orbital motorway
- St-Dié (88) - Châlons-sur-Marne (51)
- Nancy (54) - Sète (34) - Nice (06)

National roads:
- RN 10 (87) - RN 117 (64) - RN 138 (37)
- RN 141 at Limoges (87) - RN 7 (84) - RN 9 (11)
- RN 98 at Verlaine (Belgium)