Carbon footprint: a tool to quantify the impact of road construction on the environment

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Abstract: A variety of materials are used in the construction of roads. Materials like sand, gravel, asphalt, bituminous and crushed stone are used widely. In India, Guidelines for the design of Flexible Pavements, published by Indian Roads Congress (IRC 2001) are followed. Flexible pavements are considered to include the pavements which have bituminous surfacing and granular base and sub base courses conforming to IRC Standards. Carbon footprint is a measure of the effect of human activities on the environment, and in particular on climate change. Here it has been used as an indicator to study the impact of the construction material used in the building, maintenance and repair of the highway. The objective of this paper is the calculation of the carbon footprint of a stretch of NH-228 in Gujarat state in India. This tool can even help to choose the construction materials which will be have lesser impact on the environment.

Key Words: Carbon footprint, CO$_2$ emissions, road construction, flexible pavements

1. INTRODUCTION

Much research has been done on the mobility and commuting using indicators like travel distance, modal choice, travel time, vehicle speed etc. But while evaluating the impact of mobility on environment or on global warming, CO$_2$ emissions or carbon footprint appears as a preferable measure. The carbon footprint accounts for the direct as well as for the indirect CO$_2$ emissions. The transportation sector consumes large amount of energy and draws upon natural resources. In such a scenario, the carbon footprint can act as a means to measure the amount of pressure a road, highway or an overpass would exert on the earth. This study aims at the calculation of the carbon footprint of a national highway and the associated road works. Such study can be integrated with the transportation planning to control the transport activities harmful to the environment (Zuidgeest 2006).
2. ROAD PAVEMENT

A highway pavement is designed to support the wheel loads imposed on it from traffic moving over it. Additional stresses are also imposed by changes in the environment. It should be strong enough to resist the stresses imposed on it and should be thick enough to distribute the external loads on the earthen subgrade, so that the subgrade itself can safely bear it. For satisfactorily performing the above functions, the pavement should have many desirable characteristics. These are:

- It should be structurally sound enough to withstand the stresses imposed on it.
- It should be sufficiently thick to distribute the loads and stresses to a safe value on the subgrade soil.
- It should provide a reasonably hard wearing surface, so that the abrading action of wheels (pneumatic and iron typed) does not damage the surface.
- It should be dust proof so that the traffic safety is not impaired.
- Its riding quality should be good. It should be smooth enough to provide comfort to the road users at the high speeds at which the modern vehicles are driven.

2.1. Pavement Courses

A pavement consists of one or more layers. The topmost layer is the surfacing, the purpose of which is to provide a smooth, abrasion resistant, dust free, reasonably water proof and strong layer. The base, which comes immediately next below, is the medium through which the stresses imposed are distributed evenly. Additional help in distributing the loads is provided by the sub base layer. The subgrade is the complicated natural earth immediately below the pavement layers. The top of the subgrade is also known as the formation level.

In a concrete road, the concrete slab itself acts as the wearing surface and distributes the load. The slab may be directly placed on the subgrade, or, in case of weak soils, a base and subbase may be interposed between the slab and the subgrade.

2.2. Pavement Types

From the point of view of structural performance, pavements can be classified as:

1. Flexible: A flexible pavement is essentially a layered system, which has a low flexural strength. Thus, the external load is largely transmitted to the subgrade by the lateral distribution with increasing depth. Because of the low flexural strength, the pavement deflects momentarily under load but rebounds to its original level on removal of load. The pavement thickness is so designed that the stresses on the subgrade soil are kept within its bearing power and the subgrade is prevented from excessive deformation. This implies that in a flexible pavement, the subgrade plays an important role as it carries the vehicle loads transmitted to it through the pavement. The strength and smoothness of the pavement surface depends to a great extent on the permanent deformation suffered by the subgrade and its resistance to such deformation. If the pavement itself is very strong, but it is constructed on loose and poor subgrade, it can fail.

2. Rigid: A rigid pavement derives its capacity to withstand loads from the flexural strength or beam strength (modulus of elasticity), permitting the slab to bridge over minor irregularities in the subgrade, subbase or base upon which it rests. This implies that the inherent strength of the slab itself is called upon to play a major role in resisting the wheel load. Minor imperfections or localized weak spots in the material below the slab can be taken care of by the slab itself. This is not to underrate the role of the subgrade soil. In fact, a good, stable and uniform support is necessary for a rigid pavement as well. But as
long as a certain minimum requirement is met with in this regard, the performance of the rigid pavement is more governed by the strength of the slab itself than by the subgrade support.

3. Semi-rigid: A semi-rigid pavement represents an intermediate state between the flexible and the rigid pavement. It has much lower flexural strength compared to concrete slab, but it also derives support by the lateral distribution of loads through the pavement depth as in a flexible pavement. Typical examples of the semi-rigid pavement are the lean-concrete base, soil-cement and lime-puzzolana concrete construction.

4. Composite: A composite pavement is one which comprises of multiple, structurally significant layers of different- sometimes heterogeneous composition. A typical example is the brick- sandwiched concrete pavement, which has been tried in India. It consists of top and bottom layers of cement concrete which sandwich a brick layer in the neutral axis zone. The design of composite pavement lies outside the well established fields of flexible or rigid pavement design.

2.3. Comparison between Rigid and Flexible Pavements

1. Life: A well designed concrete slab has a life of about 40 years whereas the life of a flexible pavement generally varies from 10 to 20 years. Even this shorter life can be achieved only with extra maintenance input.

2. Maintenance: A well designed cement concrete pavement needs very little maintenance. The only maintenance needed is in respect of joints. Bituminous surfaces, on the other hand, need great inputs in maintenance. Sealing cracks, making good potholes, resurfacing and resealing are done very frequently.

3. Surface characteristics: A good cement concrete surface is smooth and free from rutting, potholes and corrugations. Thus the riding quality of a cement concrete surface is always assured. In a bituminous surface, it is only the asphaltic concrete surface that can give comparable rideability.

4. Penetration of water: A cement concrete slab is practically impervious, except at joints. If joints are sealed, and well maintained, water will not penetrate and soften the subgrade. A bituminous surface is not impervious. Water can find its way into the lower layers through cracks and pores. Such water can impair the stability of the pavement.

5. Glare and night visibility: Concrete pavements have a grey color which can cause glare under sunlight. Colored cement can reduce the glare. Black bituminous pavements are free from this defect. On the other hand, bituminous roads need more street lighting.

6. Traffic dislocation during construction: A cement concrete pavement requires 28 days before it can be thrown open to traffic. On the other hand, a bituminous surface can be thrown open to traffic shortly after it is rolled. Further traffic will facilitate its compaction.

7. Environmental considerations during construction: During construction of a flexible pavement where bituminous layers are to be provided, the process of heating of bitumen and aggregates and mixing them together in hot mix plants, can prove to be much more hazardous to the environment than cement concrete construction where no heating of any material is involved.

8. Overall economy on a life cycle basis: A good quality road is costly to construct, but once constructed, such a road requires little maintenance and results in savings in vehicle operating costs. Keeping these considerations in mind, various investigations carried out in India, on the comparative economy of a flexible pavement and a rigid pavement have proved that on overall economic considerations, a rigid pavement is far more economical than a flexible one, in the long run.
3. Construction Material

The overall development of any country depends on a good and well connected road network. All other infrastructure developments, in turn, get benefited by such wide spread road network. For highway construction and maintenance world over including India, millions of tons of mineral aggregates are used. Most of the regionally and locally occurring good quality rocks, gravels and sands are the sources of road construction materials. However, depending on the locale, aggregates of minor quality may also have to be used for highway construction and maintenance sometimes for economic reasons, preservation of the environment and also in order to avoid large hauling distances. (Indoria 2009)

India has diverse geographical regions with different terrains, climate, rainfall, traffic pattern and availability of construction materials coupled with a wide range of soil types. Therefore, a standard method of design or a uniform technique of construction cannot hold good to meet the requirements of all areas and thus appropriate design and different technologies based on area specific conditions are adopted. Locally occurring materials like soil, gravel, moorum, laterite, sand, and emerging materials like mine waste, industrial slag, jute geo-textile, soil-enzymes, etc. can be effectively used singly or in combination with other materials as an alternative to conventional materials, with significant economy after studying their physical and engineering properties for their suitability in road construction. (Indoria 2009).

3.1. Aggregates

Mineral material like sand, gravel and crushed stone can be collectively called as aggregates. These constitute the major part of the pavement structure. These are generally used with binding material to form compounds like bituminous concrete and Portland cement concrete (Mathew 2009). These are usually prepared from natural rock. The manufactured aggregates used are often the bye products of other industries (Mathew 2009). Road aggregates differ in their grain size, shape, texture and their gradation. Besides being strong to tolerate the wheel load, they should be hard and tough to resist the rubbing due to traffic. Flaky and elongated particles have relatively lesser strength and durability in comparison to cubical, angular or rounded particles (Khanna & Justo 1993). The Portland cement concrete should be clean and free from clay lumps, silt and other organic matter. Similarly the bituminous mix shouldn’t have excess of elongated pieces, clay balls, dust etc. To prevent the stripping off of the bituminous coatings, the aggregates used in the bituminous pavements should have less affinity with water (Mathew 2009). Aggregates should always be tested for their strength, water absorption, hardness, toughness and shape before they are used in construction.

Different aggregates exhibit diverse properties and are used by the highway engineers in accordingly. Gravel aggregates are obtained from river beds and are have small rounded structure. Sand aggregate is produced from weathering of rock and is an example of fine aggregate. Coarse aggregates can be further classified into hard and soft aggregates. The hard aggregates are used to resist the adverse weather conditions and the abrasive action of heavy traffic loads. Whereas the soft aggregates like moorum, kankar, laterite, brick aggregates and slag are used for low cost road constructions (Khanna & Justo 1993).

3.2. Cement

Cement in a general sense is adhesive and cohesive material which is capable of bonding
together particles of solid matter into a compact durable mass. Cement industry is one of the most energy intensive industries. India stands fourth in the World’s cement manufacturer. Cement can be manufactured either from natural cement stones or artificially by using calcareous and argillaceous materials. The Indian cement industry manufactures about 13 kinds of cements and the Ordinary Portland cement constitutes nearly 70% of the total produce (Schumacher & Sathaye 1999). Portland cement is widely used in constructing pavements. The cement concrete pavements are able to withstand the heavy traffic even under adverse conditions (Khanna & Justo 1993). Some of the common varieties of this cement which are used are: Ordinary Portland cement, Portland Pozzolana Cement and Portland Slag Cement (Das & Kandpal 1999).

It is also used to stabilize the sub-base and base courses. It has been observed that the cement slurry has also been used in building of roads and for filling. It holds the aggregate particles together to form the concrete. It is a result of various chemical combinations of calcium carbonate, silica, alumina, iron ore and small amounts of some other materials. Varied percentages of these compounds give rise to different physical and chemical properties of the cement (Schumacher & Sathaye 1999).

3.3. Concrete

 Aggregate, cement and water are the main constituents of concrete. Often different admixtures are also added to enhance their characteristics. The strength of the concrete is governed by the ratio of the weight of the water and the weight of the cement (Sjunnesson 2005). It is used for various purposes. Some of them are pavement of roads, reinforcement using concrete piles, making slabs, piers etc.

Cement Concrete is a product obtained artificially by hardening of the mixture of cement, sand, gravel and water in predetermined proportions. Concrete has enough strength in compression, but little strength in tension. Due to this, plain concrete is weak in bending, shear and torsion. Hence the use of plain concrete is limited to applications where great compressive strength and weight are the principal requirements and where tensile stresses are either totally absent or are extremely low (Punmia & Jain 2009). The reinforced cement concrete is the concrete with more tensile strength. With incorporation of steel the mechanical properties of the concrete improves (Elsaigh et al. 2005). A concrete can be singly reinforced, doubly reinforced, over reinforced or under reinforced. Plastic reinforced and polypropylene fibre reinforced concrete is also increasingly being used for road pavements and other road constructions (Walia 2004). Unlike steel reinforced concrete plastic reinforced concrete is resistant against corrosion and doesn’t require an extra layer of concrete for protection.

3.4. Steel

The Carbon dioxide emissions of the developing countries from steel production nearly constitute 5-15 % of their total Carbon dioxide emissions. The steel production in India broadly takes place through the integrated iron and steel plants and through numerous secondary steel producers (Price et al. 2001). Steel is often mixed with concrete and enhances its properties.

Steel slag is one of the by products formed during steel manufacture. It is a hard, dense and a dark coloured material. Due to its high strength and durability, it can be used as an aggregate.
for the surface layers of the pavement. It can also be used as a part of sub base material. Since the steel slag has high frictional and abrasion resistance, it is widely used on industrial roads, parking areas and intersections. It has a tendency to crack but it can be overlooked in presence of its all other properties (Ahmedzade & Sengoz 2009).

3.5. Bitumen

Bitumen is defined as a viscous liquid or a solid consisting essentially of hydrocarbons and their derivatives, which is soluble in carbon disulphide. It is substantially non-volatile and softens gradually when heated. It is black or brown in colour and possesses waterproofing and adhesive properties. It is obtained by a refinery process, which case it is known as petroleum bitumen. It is also found as a natural deposit, in which case it is known as native bitumen or natural bitumen (Kadyali & Lal 2008). Today, the main use of bitumen is in the road making industry for construction and maintenance. In road making, bitumen products are typically applied with mineral aggregate. The strong adhesion that occurs between the bitumen and mineral aggregate enables the bitumen to act as a binder, with the mineral aggregate providing mechanical strength for the road. Bitumen can now be made from non-petroleum based renewable resources such as sugar, molasses and rice, corn and potato starches. Bitumen can also be made from waste material by fractional distillation of used motor oils, which is sometimes disposed by burning or dumping into landfills. Non-petroleum based bitumen binders can be made light-colored. Roads made with lighter-colored pitch absorb less heat from solar radiation, and become less hot than darker surfaces, reducing their contribution to the urban heat island effect.

3.6. Lime

Lime is a general term used for various forms of basic chemicals produced from calcium carbonate rocks such as limestone (CaCO3) and dolomite. Lime is made by heating limestone (calcium carbonate) to high temperatures. This process, known as calcining, results in quicklime, or calcium oxide. Hydrated lime (calcium hydroxide) is produced by reacting quicklime with sufficient water to form a dry, white powder. In construction, lime’s traditional use is in mortar and plaster, because of its superior plasticity, workability and other qualities. Its dominant construction use today is in soil stabilization for roads, airfields, building foundations and earthen dams, where it upgrades low quality soils into usable base and subbase materials. It is also used as an additive in asphalt, in which it improves the cohesion of the asphalt, reduces "stripping "and retards the aging process. Dolomitic lime is also used in the production of masonry mortar and stucco, and high calcium lime is used in the production of aerated autoclaved concrete.

4. Pavements Layers

Given below is a list of activities and the pavement layers which form a part of the current highway (NH-228) under study:

4.1. Site Clearance and Dismantling

Site clearance means removing all the buildings and facilities from a site. It might also include ground remediation where soil has been contaminated radiologically or by other agents. The area should be cleared of bushes, vegetation, grass, branches, trees and saplings. The main purpose of site clearance is to remove existing buildings, waste, vegetation and, most importantly, the surface layer of soil referred to as topsoil. It is necessary to remove this
layer of soil, as it is unsuitable to build on. This surface layer of soil is difficult to compact down due to the high content of vegetable matter, which makes the composition of the soil soft and loose. The topsoil also contains various chemicals that encourage plant growth, which may adversely affect some structures over time. Once the site clearance is complete, excavations for the foundations can start.

4.2. Earth Work

Under Earthwork, the subgrade soil is prepared to bring it to the desired grade. It includes excavation of soil, transportation of soil, spreading earth, construction of embankments, construction of earthen shoulder, preparation of subgrade and soil compaction.

4.3. Subgrade

The subgrade is the complicated natural earth immediately below the pavement layers. Subgrades are commonly compacted before the construction of a road, pavement or railway track, and are sometimes stabilized by the addition of asphalt, soil cement, Portland cement or lime. It is the foundation of the pavement structure, on which the subbase is laid. The success or failure of a pavement is more often than not dependent upon the underlying subgrade. Preparation of the subgrade for construction usually involves digging, in order to remove surface vegetation, topsoil and other unwanted material, and to create space for the upper layer of the pavement. This process is known as subgrade formation or reduction to level. Depth of water table, depth of bedrock, compaction and CBR value are the factors that are considered while determining the suitability of the subgrade. (Pike 2005)

4.4. Granular Subbase

Granular materials such as large sized stone boulders, broken stones, brick ballast or broken kankar are extensively used as subbase of road pavement. In the present case (Grading 1), it is composed of 90% aggregates and 10% stone dust. The entire thickness of a flexible pavement to withstand the superimposed load due to traffic need not consist of costly materials such as bituminous concrete or macadam, but on going down from the surface, cheaper and lower quality material may be substituted. This is because the stresses go on diminishing at lower depths. Granular bases and subbases are extensively used taking advantages of their low cost, local availability and the diminishing stresses in the lower layers. (Kadyali and Lal, 2008)

4.5. Wet Mix Macadam Base

Wet Mix Macadam is a specification in which a well-graded aggregate is mixed with water in a mechanical mixer and the resultant mixer is laid by pavers and compacted. The aggregate is usually crusher-run, and includes fine also. Because of the close grading, the course will have good interlock with excellent density and high stability. The moisture content is usually in the range of 2-5% by weight. (Kadyali and Lal, 2008)

4.6. Bituminous Macadam

Bituminous Macadam shall consist of the construction of one or more courses of compacted crushed aggregates, premixed with a bituminous binder, laid immediately after mixing. It is an open graded construction suitable for base and binder courses and should not be used as
wearing course as such. It may be used as a temporary riding surface when covered with an appropriate seal coat.

In the bituminous macadam pavement, the foundation is macadam, upon which a bituminous material that penetrates at least 2 in (5 cm) into the foundation is poured, forming an impervious binder. In the bituminous-mixed macadam pavement, a mixture of crushed rock, ground glass and other additives, and bituminous binder is spread over a macadam foundation and rolled into a compact mass.

Here in this report, we considered BM layer (grading 2) to be made of 100% aggregates and 3.5 % bitumen (by weight of total mix)

4.7. Profile Corrective Course

Most bituminous overlay works require the construction of a corrective course in order to correct the camber of the existing structure and rectify local irregularities in the longitudinal profile. The profile corrective course may be laid as part of the overlay/strengthening or as a separate layer. In the former case, the material for the profile corrective course should be the same as that of the overlay/strengthening course. If it is laid as a separate layer, it must have a specification at least the equivalent of the layer over which it is to be laid. (Raina’s manual)

In the present case, profile corrective course is made of bituminous macadam.

4.8. Dense Bituminous Macadam (DBM) Course

The dense bituminous macadam consists of course aggregate, fine aggregate and filler in suitable proportions with required binder content. For compacted thickness upto 50mm, grading 1 will only be used while for thickness greater than 50 mm, grading 2 could be used. In the present case, a DBM course of grading 2 has been provided which consists of 98% stone aggregate, 2% lime and 5 % bitumen(by weight of total mix).

4.9. Bituminous Concrete (BC) Wearing Course

Asphaltic concrete or Bituminous Concrete is a pavement specification composed of a thoroughly controlled hot mixed material having graded mineral aggregate(97%), filler(lime 3%) and bitumen(5.5% by weight of total mix). The course aggregate commonly used crushed stone, crushed slag and crushed gravel(shingle). The fine aggregate normally used is stone dust, natural stone or a mixture of both. Durability, imperviousness, load spreading property and good skid resistance are some of the advantages of bituminous concrete wearing course. (Kadyali and Lal 2008)

4.10. Semi Dense Bituminous Concrete (SDBC) Course

It is used as a wearing course and contains 70% stone aggregates, 27% stone dust (sand), 3% lime and 5% by weight of bitumen

5. Carbon footprint

Carbon footprint is a measure of the impact of our activities on the environment, and in particular on climate change. A carbon footprint is made up of the sum of two parts, the primary footprint and the secondary footprint. The primary footprint is a measure of direct emissions whereas the secondary footprint is a measure of the indirect emissions from the whole lifecycle of the products manufactured and their eventual breakdown. The direct
consequence of increased carbon footprint is global warming and climate change. Definitions of carbon footprint from grey literature are given in table 1.

Table 1: Definitions of carbon footprint from grey literature

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP (2007)</td>
<td>The carbon footprint is the amount of carbon dioxide emitted due to your daily activities- from washing a load of laundry to driving a carload of kids to school.</td>
</tr>
<tr>
<td>British Sky Broadcasting (Sky) (Patel 2007)</td>
<td>The carbon footprint was calculated by measuring the CO₂ equivalent emissions from its premises, company owned vehicle, business travel and waste to landfill. (Patel 2006)</td>
</tr>
<tr>
<td>Carbon Trust (2007)</td>
<td>ñ® a methodology to estimate the total emission of greenhouse gases (ghg) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions). ñ® a technique for identifying and measuring the individual greenhouse gas emissions from each activity within a supply chain process step and the framework for attributing these to each output product (referred to as the product carbon footprint).</td>
</tr>
<tr>
<td>Energetics (2007)</td>
<td>ñ® the full extent of direct and indirect CO₂ emissions caused by your business activities.</td>
</tr>
<tr>
<td>ETAP (2007)</td>
<td>ñ® the carbon footprint is a measure of the impact human activities have on the environment in terms of the amount of ghg produced, measured in tones of carbon dioxide.</td>
</tr>
<tr>
<td>Global Footprint Network (2007)</td>
<td>ñ® the demand on biocapacity required to sequester (through photosynthesis) the carbon dioxide (CO₂) emissions from the fossil fuel combustion.</td>
</tr>
<tr>
<td>Parliamentary office of science and technology (POST 2006)</td>
<td>ñ® a carbon footprint is the total amount of CO₂ and other greenhouse gases, emitted over the full cycle of a process or product, it is expressed as grams of CO₂ equivalent per kilowatt hour of generation (GCO₂eq/kWh) which accounts for the different global warming effects of other greenhouse gases.</td>
</tr>
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Source: Thomas Wiedmann and Jan Minx (2007)

6. METHODOLOGY

6.1. Study Area

National Highway 228 from Kim River to Dandi in Gujarat State

National Highway 228 (NH 228) connects Sabarmati Ashram at Ahmedabad to Dandi. The highway covers a distance of 386 in the state of Gujarat. Starting at Sabarmati Ashram, the national highway 228 passes through Aslali, Navagam, Matar, Nadiad, Anand, Borsad, Kankapura, Kareli, Ankhi, Amod, Derol, Ankleshwar, Mangrol, Umrachi, Bhatgam, Delad, Surat, Vanjh, Navsari and Kardi. The development of the Dandi Heritage Route was first announced on the 75th anniversary of the famous Dandi Kooch or Salt March and an outlay of about Rs 750 crore was proposed. But, now this has grown to over Rs 2,100 crore only for construction of the national highway. The 10 metre road has a 2 metre halfway. The 386-km route has 12 major bridges, 58 minor bridges and over 450 small bridges which either pass over a canal or pipeline. At some places, the existing roads have been converted while for nearly 50 km, a new road has been built. (Reporter 2010). The work on strengthening first
phase of Dandi Heritage Route was flagged off by Union minister of state for road transport, KH Muniyappa at Dandi in Navsari on 2\textsuperscript{nd} March 2009. The first phase is the existing road between Ahmedabad and Navsari, other than NH-8. The project is funded by Central government and executed by the state government. (Reporter 2009)

6.2. Calculation of the Carbon footprint

The studied area consisted of many parts. It had the pavement, bridges, underpass, walkways, road junctions, ROBs, and culverts. Carbon footprint for each of these parts has been calculated. It was calculated as follows:

i) The detailed estimate of the construction material was gathered. It served as the baseline dataset. Data in it was presented in different measurable units. In order to make the calculations easy all were converted to a single measurable unit.

ii) Initially the volume of all building materials used was tabulated. Wherever it wasn’t given, it was calculated with the help of standard formulas. E.g. for calculating the volume of the concrete used in the pile foundation, the structure of pile was assumed as cylindrical in shape. Likewise many assumptions were taken to carry the study further.

iii) The data on the CO\textsubscript{2} equivalents is generally available in terms of mass i.e. the amount of carbon dioxide which is emitted on manufacturing one tone of a material. Due to this, densities of all materials were searched and masses were calculated.

iv) Then the net CO\textsubscript{2} emissions were calculated in kg. This represents the carbon footprint of the pavement.

6.3. Assumptions

Following assumptions were taken:

i) The Carbon dioxide equivalent for the Earth work was taken as nil (Barrett et al. 2002)

ii) The Carbon dioxide equivalent of Wet mix macadam has been taken as same as of macadam.

iii) For calculating the mass of bituminous concrete, bituminous macadam, profile corrective course, dense bituminous macadam and semi dense bituminous concrete the densities and volumes of their constituents have been considered.

iv) The weighted average was found to estimate the CO\textsubscript{2} emissions of bituminous concrete, bituminous macadam, profile corrective course, dense bituminous macadam and semi dense bituminous concrete.

v) At all other places where cement was used, the CO\textsubscript{2} equivalent of dry ordinary Portland cement was used.

vi) Stone aggregate has been considered as the crushed part of natural stone and all calculations have been done accordingly.

vii) Miscellaneous items like precast kerb, Jamuna sand etc. were not considered due to lack of availability of data on them.

viii) The density of plain cement concrete and reinforced cement concrete is assumed to be the same i.e. 2400 kg/cum.

7. RESULTS:

Total CO\textsubscript{2} emissions from the materials used in the pavement = 20,683.038 tonnes
Total CO\textsubscript{2} emissions from the materials used in the culverts = 4,931.040 tonnes
Total CO\textsubscript{2} emissions from the materials used in the bridges = 4,871.506 tonnes
Total CO\textsubscript{2} emissions from the materials used in the underpass = 451.424 tonnes
Total CO2 emissions from the materials used in the road over bridges (ROBs) = 2,594.119 tonnes

Hence, the Carbon Footprint of the National Highway 228 = 33,531.127 tonnes
The length of the highway is 386 km. Hence the Carbon Footprint of the highway can also be taken as 86.868 tonnes/km

8. Discussion and Conclusion

The Carbon footprint is a good sustainability indicator and it gives a fair idea about the environmental effectiveness of an activity. It is a tool which helps us to assess what to chose and what not to such that we can take better decisions. It gives an idea about the amount of environmental impact, a product, a city or an activity imposes. It can be very helpful for planning and policy making. Like in the National Highway 228, it can be seen that the carbon footprint of the highway is very high. The severity of the situation can be analyzed from here itself. Besides, the carbon footprint of the pavement is much greater than any other road works. This can be attributed to the fact that the pavement is composed of different layers, each of which uses a large quantity of cement, aggregates and sometimes lime also. These form the foundation of the highway and are required in huge quantities too. But at the same time, their environmental implications are also very acute.

The construction materials form the main part of a new road, highway or a flyover and these not even deplete the natural resources but also at times turn out to be uneconomical. The transportation of these also adds to the emissions. To decrease these emissions, the use of locally available materials should be encouraged. A huge proportion of the total waste generated in our country is the construction waste which is dumped in landfills (ignoring the fact that if properly processed, it can be reused). Waste materials like fly ash, slag, plastic, rubber should be used wherever possible. Steps should be taken to popularize recycling of materials and their use. This will not only reduce the waste but decrease the pressure on natural resources. Research work should be encouraged to find alternative construction material which emits less GHGs and thus have a lower carbon footprint. Minimizing the amount of resources used, reducing wastage and encouraging the use of renewable energy are some of the steps that should be adopted. Concrete which require less cement and less water during mixing is also available these days. Rocks should be crushed on site as it will reduce the need of importing aggregates. Cut and fill should be balanced to reduce the need for import and export of fill. Geotextiles which prolong the pavement life, reduce maintenance and decrease the amount of fill and aggregates needed should be used. Geotextiles can eliminate the amount of undercut necessary on a
project and/or some of the aggregate base material. The use geosynthetics in road construction goes far beyond the reduction of the carbon footprint. In addition to CO$_2$ reduction, the use of geotextiles significantly conserves our natural resources. Also, energy efficient instruments should be used to decrease the emissions from machinery. Bitumen emulsions, which are fluid at ambient temperature and require little or no heating before application should be utilized as they are easy to apply and free of volatile organic compounds (VOC). Lack of data is a big hurdle to propel the research in this sector. Formation of datasets and building up of inventories should be encouraged.

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