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Review on Observation and Identification of Carbon Footprints of Highway Construction Materials in India.

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Abstract

Globalization and liberalization policies of the government of India have increased the number of roads and vehicles playing on them. These vehicles mainly consume non- renewable fossil fuels, and are a major contributor of greenhouse gases, particularly CO2 emission. The intensification of Carbon emissions of road construction sector has strived transportation agencies involved in the construction and maintenance of transportation infrastructure, to make their practices and policies greener and more sustainable. Accordingly, environmental consciousness is on rise and has motivated transportation agencies involved in the construction to investigate strategies that reduce the life cycle greenhouse gas (GHG) emissions associated with the construction and rehabilitation of highway infrastructure. The present paper reviews concept of carbon foot printing and assess carbon dioxide emissions and energy consumption for the production of road pavements by means of a literature review.

Keywords- Carbon foot print, bitumen roads, concrete roads, greenhouse gases

I. INTRODUCTION

The exponentially growing population of India has led to an enormous practice of construction activities since the last decade. Construction practices require materials, machineries and fuel leading to greenhouse gas emissions which severely deteriorate the environment, alarming us to take immediate steps aiming at its preservation. Environmental preservation could be best understood as limiting the consumption of natural resources in construction practices. Environmental preservation requires finding new sustainable materials which can reduces the requirements of natural resources like aggregates and bitumen in the construction industry. Road Building Index (RBI) grade-81 is a patented natural soil stabilizer marketed by Alchemist Technology Limited, New Delhi in India. This study aims to reduce greenhouse gas emissions throughout the life cycle of a flexible pavement by treating the subgrade layer of a flexible pavement with RBI grade 81 as it reduces the pavement thickness by enhancing the California Bearing Ratio (CBR) of the subgrade soil.

Global warming has been considered as a real threat to the world. Not only it has a negative effect on living things, but also could damage the environment sustainability. Environmental pollution has been considered as the main contributors to the global warming. There are various types of environmental impact indicators, such as greenhouse gas (GHG) traces, eutrophication potential (EP), acidification potential (AP), human health particles (HH), ozone depletion, and haze [1]. The environmental pollution has also been considered as a major challenge in the construction industry.

II. ROAD CONSTRUCTION

Roads are lines of lands on earth made by humans with various shapes, sizes, and types of construction as the path for people, animals, and vehicles that transport goods from one place to another easily and quickly [2]. Typically, rigid pavement consists of three layers, i.e. concrete slab, subbase course and subgrade (figure 1). Unlike the flexible pavement, the rigid pavement is not made continuously along the road. This is done to prevent large expansion on the pavement surface which can cause some cracks, and to prevent continuous cracking if there is a crack at one point on the pavement [3]. Another way of prevention is by constructing a joint system to connect each segment of the rigid pavement. There are three joint systems, i.e. jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP). Typical rigid pavement construction is shown in Figure 1.

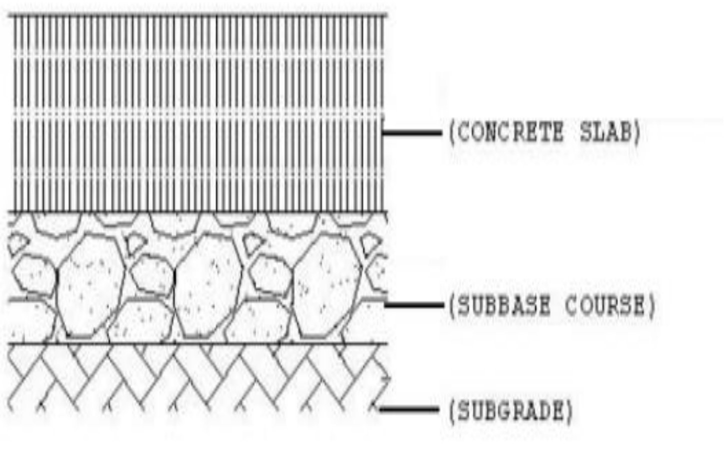

Fig. 1. Typical Rigid Pavement Components.

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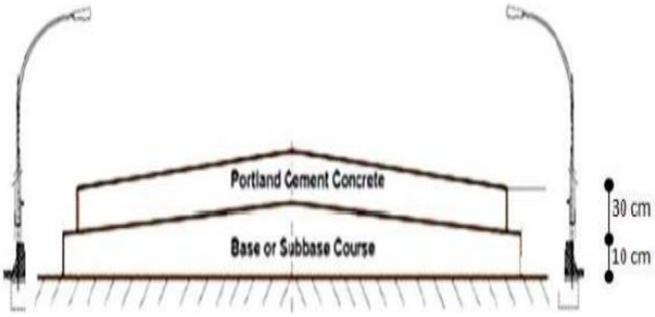

Fig. 2. Typical Cross Section of Rigid Pavement

CONSTRUCTION OF RIGID PAVEMENT

Some heavy equipment is needed for constructing the rigid payment, e.g. excavators, bulldozers, vibrating rollers, dump trucks, mixer trucks, etc. The biggest use of heavy equipment is usually in the process of quarrying and layering the road foundation. For the next process, even though the use of heavy equipment is not as much as at the stage of quarrying, the equipment will be used mainly for handling a larger volume of materials, especially cement and aggregate. In the rigid pavement construction stage, the sequence of work starts from concrete leaning, form work installation, geotextile installation, rebar installation, casting, grooving, and cutting.

III. RESEARCH MOTIVATION

The Roads and Highways make a vital contribution to economic growth in the country by providing employment, social, health and educational services that provide an opportunity to fight against poverty. India has realized the importance of roads and highways and has been giving 1 Tons of Carbon dioxide equivalent – Carbon dioxide equivalent (CO2e) is a scale for measuring the climate effects of different gases, used to compare the emissions from various greenhouse gases based on their global warming potential (GWP), by converting amounts of other gases to the equivalent amount of momentum to the faster development of highways to stimulate economic and social development in the country [4]. Construction of roads and subsequent use of toxic materials, pose an adverse impact on the environment in terms of loss of surrounding natural resources, natural ecosystems and human health. During construction high energy consumption leads to the generation of Carbon Footprint. Therefore, the restoration of the natural environment in the project area is necessary for considering

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environmental requirements throughout the stages of planning, designing, and execution. Road construction projects have to fulfill the criteria of sustainable development goals by providing socially desirable, ecologically feasible and economically viable solutions.

The term carbon footprint has been defined as the total amount of greenhouse gas emissions (CO, CH4, NOx, CFC, PFC, water vapour etc.) produced to support human activities over the life cycle of a product or activity. These carbon emissions are generally expressed as a single component that is carbon dioxide equivalent or CO2e that stands a unit for measuring other GHG emissions1 [2]. The road transport sector is the leading mode of transport and the biggest emitter in the country with 90.1 percent followed by civil aviation sector (5.6 percent) and the railways and domestic water-borne navigation sectors (3.1 and 1.2 percent) of total carbon dioxide equivalent (CO2e) released respectively, as per estimations in 2014 in India [3].

International Road Federation (IRF) states that the effective ways of reducing GHG emissions in the transport sector by improving traffic flexibility and reduction of traffic congestion thus lower fuel consumption and an effective way of reducing greenhouse gas (GHG) emissions [4]. Other specific measures for reducing GHG emissions are also mentioned as enlarging the road network, replacing the crossroads with bridges, building bypasses, eliminating level crossings, effective traffic flow management etc. These require a plan in the design stage and identify the sources of carbon dioxide with the same global warming potential. For example, CO2e of 500 parts per million would reflect a mix of atmospheric gases which warm the earth as much as 500 parts per million of CO2 would warm it.

Carbon emissions being generated by the roads and highways construction activities. This requires the knowledge & vision of environmental science for planning in conservation of natural resources, at the same time engineering and technology is needed for designing stringent environmental policies required for its implementation to maintain the needs of the present without compromising the needs of future generations. Energy efficiency is the important agenda in highway projects to achieve sustainable development in this area. [5]

RESEARCH OBJECTIVES

This Synopsis focuses on

• To draw a methodology for determining greenhouse gas emissions due to the utilization of construction materials based on the Indian specific studies.

• To draw a methodology for determining greenhouse gas emissions due to the vehicles (trucks) used for transportation of construction materials.

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• To reduce the greenhouse gas emissions emitted during the life cycle of a flexible pavement in India by treating its subgrade layer with RBI grade.

CARBON FOOTPRINT OF ROADS

Carbon sources or carbon emission sources are formed in the pavement structure within the boundary of the pavement system, including a series of intermediate products and the unit process of collection. Through data acquisition, the degree of influence and the system boundaries can be reasonably identified. Bitumen pavement construction was divided into two parts, namely, Bitumen mixture production and Bitumen mixture construction. Bitumen mixture production includes aggregate stacking, aggregate supply, bitumen heating, aggregate heating, and mixture mixing. The construction of Bitumen mixture was divided into Bitumen mixture transportation, Bitumen mixture paving, and compaction of Bitumen mixture. In concrete pavements the stages of carbon emission includes the raw materials production, concrete manufactures and concrete pavement construction. The boundary of carbon emission comprises four stages: material manufacture, transportation, construction, and disposal [4]:

$$CE(S) = CE(S1) + CE(S2) + CE(S3) + CE(S4)$$ **Where, CE(S1):**

Carbon emissions at the material manufacture stage; CE(S2): Carbon emissions at the material transportation stage; CE(S3): Carbon emissions at the construction stage; CE(S4): Carbon emissions at the disposal stage.

SCOPE OF THE RESEARCH STUDY

This tool was eventually used to estimate the overall amount of GHG emissions in terms of total kgCO2 equivalent (designated in this Synopsis as kgCO2e). The scope of the research study encompassed: (i) literature review to understand the contribution of the various factors responsible for calculation of carbon footprints and related terms, pertinent to roadway construction projects in India considering life cycle analysis approach and modeling technique; (ii) formulation of a robust and innovative methodology framework incorporating the various stages of construction of roadway infrastructure, including the pavement design factors; (iii) definition of a project as per Indian specifications related to the construction materials, equipment, stages, and pavement design and traffic parameters considering both flexible and rigid pavement systems; (iv) development of a computer tool that evaluates and estimates the total carbon footprints (overall kgCO2e) for different pavement systems; and (v) comparison and analyses of the different combinations of materials, and investigation of their relative effects on the overall kgCO2e.

IV. LITERATURE REVIEW

Shashwath Sreedhar et al. [1] With increasing urbanization and living standards of people in India, there is certainty that there will be a substantial increase in human activities such as transportation infrastructure development, and associated rise in energy demand. Thus, it is imperative that the technical knowhow regarding carbon emissions due to roadway infrastructure is advanced further to accomplish a sustainable environment. Thus, the objective of this research study was to develop a toolkit termed "Carbon Footprint Calculator" to quantify the carbon footprints of the different pavement systems used in highway construction. The tool developed as part of the study incorporated the major contributors of Greenhouse Gas (GHG) emissions including: pavement design aspects; material production and transportation from source to site; construction practices used in the various pavement systems and the expected vehicular operations during the pavement design life. A mathematical model to estimate the overall amount of GHG emissions in terms of total $kgCO_2$ equivalent ($kgCO_2e$) was also developed as a part of this study. In this study, the evaluation of GHGs in terms of carbon footprints for the different pavement systems used in Indian roadway construction was approached from a life cycle assessment perspective. It is envisioned that this tool could be well-utilized by design engineers to optimize pavement design methodology and construction practices in respect of creating a greener sustainable environment.

Nuri Cihat Onat et al. [2] This paper conducts a global review and a macro-level supply chain analysis focusing on carbon footprint of construction industry worldwide for the period between 2009 and 2020 using the Scopus database. A total of 1833 journal articles are revealed with focus on carbon footprint in the field of construction in general, of which only 115 (6% of the total) studies have a macro-level analysis of the construction sector, providing a more holistic overview of the construction sector from various aspects. These macro-level studies were reviewed and classified based on journal, country, year, method, scope of analysis, type of construction, and period. The findings showed that approximately 60% of these studies focus on the Chinese construction industry and the majority of studies analyzed national-level (75%) and city-level (18%) carbon footprints of construction. On the contrary, global-level analysis has a lower share, which accounted for only 6% of reviewed articles. The review showed that more than 20% of studies use the input-output analysis as the main methodological approach to quantify macro-level carbon emission from construction sector, which is followed by the process-based life cycle assessment with 10% share, where more bottom-up approaches are employed. There are only a handful of articles found in the literature using a hybrid life cycle assessment and global multiregional input-output analysis for carbon footprint accounting of construction. Furthermore, there is also no study found in the literature, which presented a comprehensive regional and global supply chain analysis of construction carbon footprints. The results revealed that the largest portion of carbon emissions stem from the regional and global supply chains of the construction industries. The authors concluded that carbon reduction policies should not only consider the limited regional impacts; however, it must take into account the role of indirect, complex and interconnected global supply chains of construction industries.

Cristina Casals Miralles et al. [3] Tourism places pressures on the environment through the services provided (accommodation, food, leisure activities, and transport), meanwhile it is particularly vulnerable to global warming as climate is a crucial component of destinations' attractiveness. As a result, research focusing on the impacts of tourism has increased significantly.

Practitioners consult a plethora of frameworks and publications to environmentally assess tourism but none of the existing guidelines provides specific recommendations making difficult to obtain reliable results that can be properly replicated and compared.

This paper discusses the use of Footprint family indicators in tourism through a review of studies that measure the Water, Carbon, and Ecological Footprint of tourists. Results show a lack of specific data, and an absence of consensus about the system boundaries and methodologies used for calculation. Food production and transportation are the main drivers of environmental burdens. The Footprint indicators help to understand the trade-offs between environmental effects which can be used to prioritize sustainability efforts in the tourism industry. Additionally, this study presents a critical analysis of the influence on the trip's Footprint of the services provided to different rated tourism experiences (high, medium, and low rated) and offers a reflective comparison on the pressure exerted by visitors and the local population.

Farhad Farzaneh et al. [4] Since transportation accounts for a large portion of a city's overall greenhouse gas emissions, cities are looking to lessen this effect by replacing more internal combustion engine vehicles (ICEVs) with electric vehicles (EVs). In this research, two vehicle models of comparable size from each category were compared using life cycle analysis (ICEV and EV). The ICEV is a Ford Transit van, while the EV is a Ford E-transit van, both of which are supposed to have a lifespan of 150,000 km for comparison. Carbon footprint for both vehicles is examined from cradle-to-grave: including raw material production, manufacturing, transportation, operation, and decommissioning. According to the findings, the carbon emissions produced per kilometer by an electric vehicle are considerably lower. The Ford transit van emits 469.1 gCO2-eq/km and the Ford E-transit van emits 363.2 gCO2eq/km during a vehicle's lifetime. The impact of electricity generating in each U.S. states on the carbon footprint of ICEVs and EVs showed that the use of renewable energy sources for power generation would result in a reduction in carbon dioxide emissions. Lifespan sensitivity analysis with 100000 km and 350000 km indicated that the longer life of a vehicle alters the efficiency balance in favor of an electric vehicle.

Zigeng Fang et al. [5] There is an urgent need for all industries to go beyond the existing set of policies against greenhouse gas (GHG) emissions to combat climate change. As the major producer (19%) of GHG, the construction industry needs to optimise its carbon footprint (CF) decision-making processes to provide better management solutions against global warming. Identification and evaluation of the key factors that affect CF decision-making are critical yet limited. Based on our knowledge, no existing study compares the different characteristics of construction projects' CF management approaches through the whole life cycle phases (including assessment, optimisation, and comparison) to enable CF-related knowledge transfer between the building and infrastructure sectors. To meet these knowledge gaps, this paper reviewed 1,465 studies related to infrastructure and building CF projects and selected 31 studies to evaluate academic researchers' contributions toward the different CF decision-making stages for the building and infrastructure projects' whole lifecycle. The paper systematically reviewed and assessed the existing information in five key CF decision-making stages: project drafting stage, methodology choosing stage, data collection stage, CF analysis stage, and CF visualisation stage. A generalised CF decision-making framework is also developed to inform future CF management. The limitations of the existing studies and the benefits of the developed framework were summarised. This study identifies the key information required from the perspective of CF management decision-makers and contributes a universal CF decision-making framework for state-of-the-art CF management practice.

Xianwei Wang et al. [6] The large-scale transportation infrastructure construction in developing countries such as China requires emission estimation method for better project design. This study proposed an empirical method to estimate carbon dioxide (CO_2) emission which was generated from highway construction based on four real projects in southwest region of China. The proposed method estimated the total emission from different steps of construction process (raw material production, material transportation and onsite construction) by different project types (e.g. subgrade, pavement, bridge, and tunnels). The results show that in general over 80 percent of the CO_2 emission was generated from raw material production; the onsite construction and material transportation only accounted for 10 and 3 percent of the whole CO_2 emission, respectively. Moreover, the CO_2 emission from bridge and tunnel constructions was much larger than subgrade and pavement construction. The total CO_2 emission from road, bridge and tunnel constructions was 5229 kg/m, 35,547 kg/m and 42,302 kg/m, respectively. The empirical estimation method of the CO_2 emission proposed in this study can be considered as references for CO_2 emission estimation in other regions which are similar as southwest region of China.

V. CONCLUSION

Highway infrastructure emits large quantities of carbon dioxide over their entire life cycle including emission from production of raw materials and also emission from construction, operation, maintenance, and rehabilitation of the roads. The past emission trends of carbon dioxide from these sectors are investigated through their sources while mitigation and abatement strategies are suggested. This paper brings together, for the first time, a systematic review of the carbon footprint calculator of 21 case study highway from 8 different countries were investigated.

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