Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 2, Issue 16; October-December, 2015 pp. 54-59

http://www.krishisanskriti.org/Publication.html

An Overview on the Performance of Open Graded Friction Courses in Road Accident Reduction and in Replenishing the Ground Water Sources

Soorya Ann Koshy[1], S.N. Sachdeva[2] and B.G. Sreedevi[3]

[1]*Post Graduate Student NIT Kurukshetra Kurukshetra, Haryana.*
[2]*NIT Kurukshetra Kurukshetra, Haryana*
[3]*National Transportation Planning and Research Center (NATPAC) Thiruvananthapuram, Kerala*
E-mail: [1]sooryaannkoshy@gmail.com, [2]snsachdeva@yahoo.co.in, [3]bgsreedevi@yahoo.com

Abstract—*Open Graded Friction Course (OGFC) is a permeable wearing course mixture that is being progressively used in pavement surfacing around the world. This special purpose mixture is characterized by high percentage of interconnected voids due to the open gradation adopted, which makes the OGFC mixture highly permeable compared to other Hot Mix Asphalt mixtures. The improved surface permeability enhances the safety benefits of the pavement especially during wet weather conditions. This technique of porous pavement when designed appropriately can also recharge the ground water in exploited or in critical areas. This paper presents an overview mainly on road accident reduction and replenishment of ground water sources, on roads laid with OGFC surfacing. The paper analyzes the safety benefits of OGFC mixture and the technique of design and construction adopted for recharging the ground water sources. Firstly, accident rates on sections of road, before and after the construction of OGFC were analyzed and it indicated that the OGFC surfacing benefited in reducing injuries and fatalities on roads. It was also reported that there was a slight but consistent increase in accident rates immediately following the construction of OGFC. But a fully Bayesian before-after safety analysis reports that the safety effectiveness of OGFC road surface, or any other safety infrastructure, largely rely on its interrelationship with the road user and has less influence in road accident reduction. Secondly, in the present scenario rain water harvesting should be highlighted, as the demand for water supply is alarmingly increasing. A porous bituminous surface allows the storm water to percolate into the deeper soil and helps in its harvesting, when designed suitably. The synopsis helps the town planners, engineers and architects to understand the effectiveness of OGFC along with its detriment.*

Keywords*: Open graded Friction Courses (OGFC) gradation, permeability, accidents, ground water sources, fully Bayesian, porous pavements.*

1. INTRODUCTION

Pavement drainage is imperative for the structural and functional integrity of the pavement components and helps to mitigate the hazards caused due to the flooding of storm water on the road surface. Open Graded Friction courses is an open graded Hot Mix Asphalt (HMA) mixture characterized with high surface drainability and is being recommended for high-speed road-corridors, high-volume roads and expressways, which has become popular in recent years in European countries, South Africa ,United States, New Zealand, Australia and many Asian countries like Japan, Malaysia and so on. Open graded mixes are called by various agencies around the world like Porous Asphalt (PA) commonly used in European Countries and New Zealand, Open Graded Friction Course (OGFC) or Porous Friction Courses (PFC) or Permeable Wearing Courses (PFC) in the United States and Open Graded Asphalt (OGA) in Australia.

OGFCs when laid over the conventional nonpermeable pavement layer, improves the surface drainability, reduces pavement noise , reduces risk of hydroplaning and wet skidding, improves night vision and decrease splash and spray (90-95% reduction), fuel consumption, tire wear and enhances surface friction, especially in wet weather conditions. Open graded mixes are composed of high quality coarse aggregates with little fines and bitumen or Modified bitumen. Due to high interconnected voids in the mix the rainwater drains vertically through the OGFC to the underlying impermeable layer and then moves laterally to the day lighted edge of the pavement [1]. Uniform grading of OGFC mixtures indicates that typically 50-60% of the aggregate particles are approximately of the same size with high percentage of internal air voids and these mixtures typically have low filler material passing 0.075-mm sieve size, limited to 2-5% of the total mass of the aggregates [2, 3].Bitumen content is slightly higher than the dense mixes with the same maximum aggregate sizes to create a substantial mixture. Modified Bitumen like Polymer Modified Bitumen (PMB), Rubberized Bitumen - Crumb Rubber Modified Bitumen (CRMB), Natural Rubber modified Bitumen (NRMB) and Styrene-Butadiene-Styrene (SBS) Modified Bitumen, Reclaimed Polyethylene Modified

Bitumen (RPEB) and Neat bitumen with fibre modifiers such as cellulose fibres, polyester fibres and mineral fibers, improves the durability of the mixture and also combat the draining of binder from the mixture [4-9]. The mixture being a combination of uniformly graded aggregates with higher percentage of binder content, tends to drain out from the mix owing to the gravity during storage, hauling and placing operations. This phenomenon of draining of bitumen from the mix and leading to thin film of binder on aggregates is known as Draindown.

OGFC mix design has to be proof against raveling, delamination and loss of permeability during its course. Verhaeghe et al. [9] based on the studies on porous pavements concluded that aggregate gradation should be such as to result in atleast 20% voids in the compacted mix. The thickness of the compacted mixture usually varies in the range of 25 – 40 mm. Stone on stone contact is an essential criteria in the selection of the aggregate gradation of OGFC mixes. Only those gradation satisfying the stone on stone contact condition, that is, voids in coarse aggregate in the dry rodded condition should be greater than the voids in the compacted paving mixture ($VCA_{DRC} > VCA_{MIX}$) and with high air voids should be selected as the aggregate gradation (NAPA).The Optimum Binder Content is decided based on the draindown value (≤ 0.3%), Cantabro Unaged Abrasion Test (≤ 20%), Cantabro Aged Abrasion Test (≤ 30%) and air voids (≥ 18%) [1].The design of OGFC should be carried out using SuperPave Gyratory Compactor (SGC) or the Marshall compactor, or any other suitable form of compaction [10, 11]. The air voids was found to decrease by 3% to 4%, about one-fifth of initial voids after construction due to the clogging of voids, i.e. permeability of the mix dropped sharply [12]. A concept of Double Layer Porous Friction was introduced to reduce the permeability loss due to clogging. The double layered mix consist of fine graded top layer and coarser graded bottom layer [13-15]. Fig. 1 shows the structure of single layer OGFC over regular asphaltic layer.

Fig. 1: PFC (OGFC) layer laid over the regular asphaltic layer.[27]

An expansive study on literature revealed that vehicle crashes are more likely to occur on wet surface. But only few studies have been carried to identify the safety benefits of OGFC. This paper draws a brief record of accidents from the various reports mainly in Texas, United States. Also a brief discussion of how OGFC can be designed to store the storm water under pavement bed of parking lots and in low trafficked roads. This revolutionary technology prevents the stagnation of storm water and becomes a reserve under the pavement surface. The design, construction of which is briefly outlined in this paper.

2. QUANTIFICATION OF THE REDUCTION OF WET WEATHER ACCIDENTS USING OGFC.

In order to warrant the expensive construction of OGFC, a statistical evaluation of its safety benefits is essential. In the United States, the Texas Department of Transportation (TxDOT) is currently laying Permeable Friction Course over the impermeable pre-existing layer owing to its advantages. The evaluation included number of sections from across Texas constructed between 2003 and 2011[16] and they concluded that OGFC indeed reduces the number of accidents, injuries and fatalities on Texas roads. The conclusion was drawn based on the accident data obtained from the Crash Records Information System (CRIS) compared before and after the construction of OGFC, also a slight but consistent increase in accident rates were observed immediately following the construction of OGFC [16]. A meta-analysis of different safety studies were performed in European countries [17] to determine the safety benefits of OGFC. Interestingly the analysis were that the OGFC estimates of safety effectiveness were very small and rarely statistically significant. Generally, the literature on the effectiveness of porous mixes in reducing wet-weather crashes is limited and often inconclusive. In study conducted, the safety effectiveness of PFC was evaluated using a fully Bayesian before–after safety analysis [18].The following briefly discuss about the fully Bayesian before-after safety analysis along with its conclusions.

2.1 A Fully Bayesian before-after safety analysis on Texas roads [18].

In this study, PFC was evaluated for its safety effectiveness using a fully Bayesian before–after safety analysis. Empirical Bayes (EB) and Fully Bayes (FB) approaches are the commonly used techniques for performing before–after safety analysis [19]. Although for more than a decade, empirical Bayes (EB) methods have been widely recognized as statistically defensible safety evaluation tools in observational before–after studies, EB has some limitations such that it requires the calibration and development of a reliable safety performance functions (SPFs) [19]. When a fairly large reference group is not available the uncertainty in the EB safety estimates may be underestimated. This is because standard errors (uncertainty) of the estimated regression coefficients and dispersion parameter in SPFs is not reflected in the final safety effectiveness estimate of EB [19]. The multivariate fully Bayesian before-after safety analysis has been researched by Park et al. [20], also by many scholars, which concluded that compared to other traditional methods and the EB methods, Fully Bayesian safety analysis provided precise crash predictions.

In the Fully Bayesian (FB) safety analysis, firstly, road segments were divided into two groups, roads overlaid with PFC and non-PFC material across Texas; the non-PFC or reference road segments selected were similar to their PFC counterparts in terms of site specific features. Secondly, a negative binomial data generating process was assumed to model the underlying distribution of crash counts of PFC and reference road segments to perform Bayesian inference on the safety effectiveness. A data-augmentation based computationally efficient algorithm was employed for a fully Bayesian estimation. The objective of these approaches were to evaluate the average reduction in crashes solely caused by the treatment (PFC) while the reduction in crashes due to other factors are ignored. Reference or comparison sites (non PFC sites) are basically incorporated into before–after safety analyses to model the crash trends in the absence of treatments. Any further reduction in crashes in addition to that observed at reference sites is considered as the safety effectiveness of the treatment with PFC. The conclusions of the study are provided below.

2.1.1 Conclusion of the study [18].

The findings of the fully Bayesian before-after study on Texas road segments were in agreement with the findings of the European studies, that the porous mixes did not exhibit the anticipated performance in safety levels under wet weather conditions. The hypothesis that the PFC treatment on the roads is effective in crash reduction has not been accepted, which reveals that the PFC treatment is not effective in reduction of accident. The study suggests that the safety effectiveness of the PFC surface mainly depends on its interrelationship with the road user and the safety infrastructure. It was observed that the road user tends to speed up on PFC road surface when it rains, because of the reduced splash and spray and the riding quality it offers. Thus the treatment is only effective when speed regulations are strictly imposed to maintain reduced speed limits under severe rain.

Fig. 2: OGFC surfacing on left lane (reduced splash and spray) and right lane without OGFC [28].

Even though results of the study on the safety benefits were not favorable, the author clearly mentions that undoubtedly PFC improved the Level of Service under severe rain allowing road users to drive at the posted speed limits. In addition to it, the environmental benefits of PFC is excellent as it reduces the road noise and improves the run-off quality of the rain water, these qualities attract the engineers to continue using the PFC mixes. The Fig. 2 shows the effectiveness of the lane with PFC treatment in reducing the splash and spray.

3. OPEN GRADED FRICTION COURSES FOR STORM WATER MANAGEMENT

Traditionally pavement surfaces are designed such as to allow the rain water and runoff to flow through them till they drain into the nearby catch basin or into the inlet openings of the side drains. The concepts of porous pavements prevents the runoff of the rain water by allowing it to flow vertically through the pavement structure. The potential benefits of porous pavements includes water treatment by removal of pollutants, reduced or elimination of the need of curbing and storm sewers and it recharges the ground water and the local aquifers. This technology of porous pavements is used for parking lots, recreational areas, or low trafficked streets and roads. OGFC mixes are widely adopted due to its hydraulic conductivity, high drainability, storm water quality benefits, reduced runoff and evaporation losses on the road surface [22-26].

In India, the Jaipur Development Authority (JDA) has used the porous pavement in a parking lot and it is believed to be the first ever porous pavement constructed in India for rain water harvesting. The alarming degradation of ground water has to be attended by the town planners, civil engineers and the architects. By the integration of rainwater harvesting technique in the design of buildings, parking lots and low trafficked roads, the plunging of ground water can be minimized. The design, construction and maintenance of Porous Asphalt (or OGFC) pavements for rainwater harvesting are mentioned below [21].The typical roof top rainwater harvesting requires vertical down pipes, a silting pit with steel screen and a soaking well. The use of these 3 things are not required when rainwater is allowed to flow into a porous pavement layer where it get stored in the stone reservoir below. By the integration of porous pavements in the parking lots and the rainwater from the roof top, the rain water is dispersed into porous pavements which gets stored in the stone reservoir course below. In the top, Porous Asphalt layer of thickness 50-100 mm (typically 75 mm) is laid, below which is a stone choking layer, stone reservoir course, non-woven geotextiles or a stone filter course and all of these is laid over an uncompacted natural soil subgrade. Fig. 3 shows the typical cross section of Porous Asphalt pavement system.

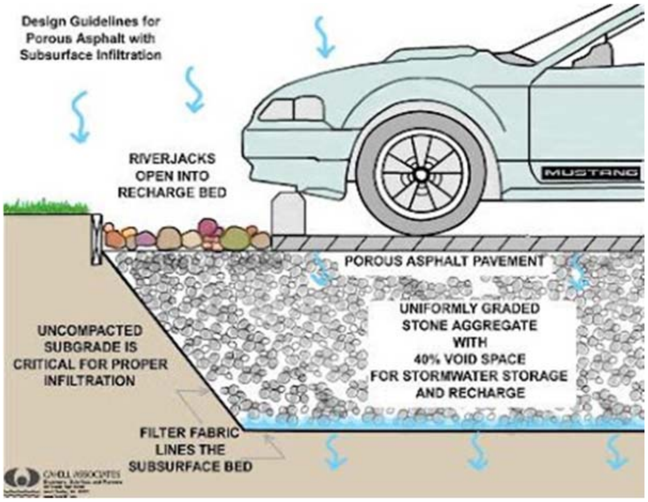

Fig. 3: Typical cross-section of Porous Asphalt pavements for rainwater harvesting [29].

3.1 Design and Construction of Open Graded Friction Courses

The following are the guidelines for the construction of the various layers of a pavement to facilitate harvesting of rainwater [21].

- The in-situ soil is recommended to have permeability infiltration rate of 12.5 mm per hour. However, the infiltration rate of 2.5 mm per hour is also acceptable, where the thickness of the stone reservoir course should be suitably increased.
- Primarily soil investigation should be carried out by boring and/or test pit to determine the permeability, the depth of high water table and the depth to bedrock.
- The construction site should be not selected where the local soil is clayey, when bedrock is close to pavement, when location has high water table and should not be constructed in areas with blowing sand. That is, the adjacent ground should be either paved or covered with grass.
- Subgrade: The subgrade should be an uncompacted natural soil bed i.e. it should not be filled up land. The soil bed should be preferably flat, slope of the natural soil bed should be limited to 5%. Care should be taken to avoid the compaction of the subgrade soil by the construction equipment.
- Above the uncompacted subgrade a non-woven geotextiles is used as a separation layer, so as to prevent the choking of top layers due to the migration of subgrade soil. Alternatively, 75mm thick stone filter course consisting of 10-25 mm size aggregates can be laid above the uncompacted subgrade.
- Next a stone reservoir course is laid over, which consists of clean, uniformly graded 40-75 mm size crushed aggregates, typically of 225 mm thick. The crushed aggregate compacted layer should contain more than 40% voids to accommodate the intensity and the amount of rainfall prevailing in the region and the thickness should be increased if additional water from rooftop or from adjacent dense surfaced roads is to be stored.
- Above the stone reservoir course, a stone choking course is laid so as to stabilize the stone bed and to facilitate the paving of bituminous layer over it. A 25-50mm thick choking layer with 12.5mm nominal size aggregates is used to fill the open spaces in stone reservoir course.
- Finally the Porous Asphalt pavement is laid over the stone choking layer. The pavement surface is designed based on the guidelines of the US Manual on Design, Construction and Maintenance of Open Graded Friction Courses (OGFC). The mix should provide the required hydraulic conductivity so as to allow the storm water to freely enter into the bottom layers and allows to percolate into the subgrade (natural soil) finally.

The ponding of rainwater on the surface is rapidly reduced by the use of porous asphalt pavements. Thus many agencies around the world use this technology in parking lots, low trafficked roads and streets and in recreational areas. There is hardly any evaporation loss of the storm water and also the water gets filtered during its course down to the subgrade, removing the harmful contaminants from the storm water. The rooftop rainwater harvesting systems when integrated with the porous parking lots or streets, the need for deep bore wells or deep pits are eliminated. The Central Ground Water Board (CGWB), in India, has identified about 800 regions where ground water is plunging at an alarming rate. The regions included areas in Rajasthan, Madhya Pradesh, Haryana, Punjab, Gujarat, Bihar, Tamil Nadu and Delhi. The Ground Water Advisory Council on Artificial Recharge under the Ministry of Water Resources recommended to recognize technologies for ground water recharge for urban areas. The Public Works Department of the various states should attend to this problem with prime importance.

Fig. 4: General view of Porous Asphalt pavements (right) and dense asphalt pavement (left) during a monsoon season [21]

The design of the Porous pavement for replenishing the ground water tried by the Jaipur Development Authority (JDA) in a parking lot was found to be successful. The figures 4 and 5 are the photographs of the parking lot employed with porous pavement along with dense asphalt pavement section in one side, constructed in Gandhi Nagar Railway station in Jaipur.

Fig. 5: Water from a tanker hose penetrating directly porous pavement [21].

4. CONCLUSIONS

An overview on the effectiveness of Open Graded Friction Courses in road accident reduction and in the replenishment of ground water sources could give us an idea of how this special purpose surfacing course can be utilized for safety benefits (Risk reduction) and for recharging the depleting ground water sources. The studies on the safety benefits of OGFC mixes concluded that its utilization did not reduce any accidents effectively when compared to the roads without the OGFC treatment, even though the treatment has many advantages. The studies suggests that the safety effectiveness mainly depends on interrelationship of the road user with the infrastructure. These pavements has the potential to minimize the road accidents but certain measures (law enforcements) has to be adopted suitably based on the area and the characteristics of the road user. The studies also suggests that OFGC pavements can be suitably constructed to serve the purpose of storm water management. The design and construction of the porous pavements should be carefully done so that the water do not get stagnated in any of the layers below.

5. ACKNOWLEDGEMENT

I take this opportunity to express my sincere gratitude to Mrs. Salini. U, Scientist working in NATPAC, Thiruvananthapuram, for her wholehearted help rendered during the laboratory procedures on OGFC.

REFERENCES

[1] Kandhal, P.S, "Design, Construction, and Maintenance of Open Graded Asphalt Friction Courses". *National Asphalt Pavement Association NAPA*, 2002.

[2] Saiton, A., "Advantages of asphalt rubber binder for porous asphalt concrete." *Transportation Research Record, 1265,* 1990, 69-81.

[3] Kandhal, P. S., Mallick, R. B. "Open graded friction courses;State of practice.",*NCAT Rep No. 98-7,*National Center for Asphalt Technology, Washinton,DC.

[4] V.S., Punith, A., Veeraragavan. "Characteristics of OGFC mixtures containing Reclaimed Polyethylene Fibres". *Journal of Materials in Civil Engineering, 10.1061/ (ASCE) MT. 1943-5533.0000162,* 2011, 335-341.

[5] S. N., Suresha, George Varghese, A. U., Ravi Shankar, " A comparative study on properties of Porous Friction Course mixes with neat bitumen and modified binders", *Construction and Building Materials 23*, 2009, 1211-1217.

[6] A. U., Ravi Shankar, S. N., Suresha, G. M. V. S., Saikumar, "Properties of Porous Friction Course Mixes for Flexible pavements". *Indian Highway, March 2014,* 19-29.

[7] V. S., Punith, S. N., Suresha, Sridhar Raju, Sunil Bose, A., Veeraragavan., "Laboratory Investigation of Open Graded Friction Course mixtures containing Polymers and Cellulose Fibres", *Journal of Transportation Engineering, 10.1061/ (ASCE) TE. 1943-5436.0000304.,* 2012, 67-73.

[8] Allex, E. Alvarez, Elvia, M., Amy Epps Martin, Oscar J. Reyes, Geoffrey S. Simate, Lubinda F. Walibita, "Comparison of Permeable Friction Course mixtures fabricated using asphalt rubber and performance grade asphalt binders", *Construction and Building Materials 28,* 2012, 427-436.

[9] Varhaeghe, Rust, F.C., Vos, R. M., Visser, A. T., "Properties of polymer and fibre modified porous asphalt mixes", *Asphalt Rev,* 1994, 13(4), 17-23.

[10] S. N., Suresha, Varghese George, A. U., Ravi Shankar, "Evaluation of Properties of Porous Friction Course Mixes for Different Gyration Levels", *Journal of Materials in Civil Engineering, 10.1061/ (ASCE) 0899-1561(2009)21:12(789),* 2009, 789-796.

[11] S. N., Suresha, Varghese George, A. U., Ravi Shankar, "Characteristics of porous friction courses for different Marshall compaction efforts", *Construction and Building Materials 23,* 2009, 2887-2893.

[12] Huber, G., "Performance survey on open-graded friction course mixes", *Synthesis of Highway practice, vol. 284. Washington, DC, National Cooperative Research Program,* 2000.

[13] S. N., Suresha, George Varghese, A., Udaya Ravi Shankar, "Laboratory and Theoretical evaluation of clogging behavior of Porous Friction Course mixes", *International Journal of Pavement Engineering,11:1,*2010, 61-70.

[14] Hardiman, M. Y, “The Comparison of Engineering Properties between Single and Double Layer Porous Asphalt made of Packing Gradation”, *Civil Engineering Dimension, Vol.10, No.2, ISSN 1979-570X,*2008, 82-88.

[15] Hamzah, Hardiman, “Characteristics of the clogging behavior of Double Layer Porous Asphalt”, *Journal of the Eastern Asia Society for Transportation Studies, Vol. 6,* 2005, 968-980.

[16] F. S., Andre, A. P., Jorge, “Quantification of the reduction of wet weather accidents using Porous Friction Courses”, *Procedia-Social and Behavioral Sciences, 96,* 2013, 2745-2755.

[17] Rune Elvik, Poul Greide, “Road safety effects of porous asphalt: a systematic review of evaluation studies”, *Accident Analysis and Prevention, Volume 37, issue 3, 10.1061 / j.aap. 2005.01.003,* 515-522.

[18] F. S., Andre, A. P., Jorge, Prasad Buddhavarapu, “A Fully Bayesian before-after analysis of Permeable Friction Course (PFC) pavement wet weather safety”. *Accident Analysis and prevention, 80,* 2015, 89-96.

[19] Bhagwant Persaud, Craig Lyon, “Empirical Bayes before-after safety studies: Lessons learned from two decades of experience and future directions”, *Accident Analysis and Prevention, Volume 39, Issue 3,* 2007, 546-555.

[20] Park, E.S., Park, J., Lomax, T.J., “A fully Bayesian multivariate approach to before–after safety evaluation”. *Accid. Anal. Prev. 42,* July2010, 1118–1127.

[21] P.S., Kandhal, Sapan Mishra, “Design, Construction and Maintenance of Porous Asphalt Pavement for Rainwater Harvesting”, *Indian Highways,* March 2014, 34-49.

[22] Allex, E., Amy Epps Martin. , Cindy Estakhri, P. E., “Drainability of Permeable Friction Course Mixtures”, *Journal of Materials in Civil Engineering, 10.1061/ (ASCE) MT .1943-5533.0000053.,* 2010, 556-564.

[23] J., Brandon Klenzendorf, Randall Charbeneau, Brad Eck, Michael Barrett.”Measurement and Modeling of Hydraulic Characteristics of Permeable Friction Course (PFC)”, *T & DI Congress,* 2011, 803-813.

[24] Micheal. E. Barrett, “Stormwater Quality benefits of Permeable Friction Courses”, *Water Environmental and Water Resource Congress, copyright ASCE,* 2006, 1-10.

[25] Sridebi Basu, Ranadeep Basu, “Naturalized Stormwater structure for Roadside Drainage in India”, *Water Environmental and Water Resource Congress,* 2013, *ASCE,* 2900-2999.

[26] Michael Barrett, Laura Sampson, B. S., “Treatment of Highway Runoff using Permeable Friction Course”, *Green Streets, Highways and Development,* 2013, *ASCE,* 135-146.

[27] Bradley J Eck, http://bradeck.net/research/olympus-digital-camera/,2010.

[28] Texas A&M Transportation Institute,*Texas Transportation Researcher, volume 45,* http://tti.tamu.edu/2009/09/01/out-of-harms-way/

[29] Metropolitan Area Planning Council, Boston, http://www.mapc.org/resources/low-impact-dev-toolkit/permeable-paving