International Journal of Engineering Science and Advanced Technology (IJESAT)
Vol 24 Issue 08, AUG, 2024

A Study on "Application of Geo Textiles in Design of Pavement"

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Abstract : *Geo-Textiles are made from polypropylene, polyester, polyethylene, polyamide (nylon), poly vinylidene chloride, and fiberglass. Polyester, Poly-propylene etc are the most used. Sewing thread for geo-textiles is made from Kevlar or any of the above polymers. The physical properties of these materials can be varied using additives in the constituents and by changing the manufacturing methods used to form the molten material into thin films. Yarns are made from fibers which have been collected and twisted, a process also referred to as spinning. geo-textiles as used in pavement design and drainage application. Geo-textile functions described include pavements, filtration, and drainage. There are several applications of geo-textiles in highway design. Even within the highway application of geo-textiles, further division is necessary for its clarity. Geo-textiles highway applications can be divided into two different areas, which are known as unpaved roads and paved roads.*

Keywords: Carbon Nanotubes, Dimethyl sulfoxide, High-Resolution Transmission, Electron Microscopy.

Introduction: Geo-textiles are made from polypropylene, polyester, polyethylene, polyamide (nylon), poly vinylidene chloride, and fiberglass. Polyester ,Poly-propylene etc are the most used. Sewing thread for geo-textiles is made from Kevlar or any of the above polymers. The physical properties of these materials can be varied by the use of additives in the constituents and by changing the manufacturing methods used to form the molten material into thin films. Yarns are made from fibers which have been collected together and twisted , a process also referred to as spinning. (This modification is completely different from the concept spinning, as it is used to describe the process of extruding thin films from a molten materials). Yarns are also composed of very long fiber materials (filaments) or comparatively short pieces cut from thin films (staple fibers).

1.2.2 Geo-textile Manufacture.

1.2.2.1 In woven construction materials the bundled yarns, which runs along with the length of the panel machine direction, which are inter connected with yarns called fill or filling yarns, which run perpendicular to the length of the panel (woven direction as shown in Figure 1.1). Woven construction produces geo-textiles with high strengths and moduli in the warp and fills directions and low elongations at rupture. The modulus varies depending on the rate and the direction in which the geo-textile isolated When woven geo-textiles are pulled on a bias, the modulus decreases, all together the ultimate bearing strength may increase. The construction can be varied so that the finished geo-textile has equal or different strengths in the warp and fill directions. Woven construction produces geo-textiles with a simple pore structure and narrow range of pore sizes or openings between fibers. Woven geo-textiles are commonly plain woven, but are sometimes made by twill weave or leno weaves (a very open type of weave). Woven geo-textiles can be composed of monofilaments or multifilament yarns. Multifilament woven construction produces the highest strength and modulus of all the constructions but is also the highest cost. A monofilament variant is the slit-film or ribbon filament woven geo-textile. The fibers materials are thin and flatten and made by polymer sheets of plastic material into thin strips. This type of woven geo-textile is relatively inexpensive and is used for separation, i.e., the prevention of mixing of two different materials such as coarse aggregate and fine-grained soil.

1.2.2.2 Manufacturers literature and engineering materials books should be consulted for better description of woven geo-textiles and knitted geo-textile processes of manufacturing .

1.2.2.3 Nonwoven geo-textiles have been extensively for filtration, separation and drainage function and also to form impermeable barrier. There is a phenomenal increase abroad in the use of non woven geo-textiles for function. Such geo-textile filters offer several advantages due to their superior performance. The other process weaving or knitting and they are generally thicker than woven products. These geo-textiles may be made either from continuous filaments or from staple fibers. The fibers are generally oriented randomly within the plane of the geo-textile but can be given preferential orientation.

In the spun-bonding process, filaments are extruded, and laid directly on a moving belt to form the mat, which is then bonded by one of the processes described below.

Geo-synthetics are Synthetics Polymer or natural materials used to solve general engineering problems related to design of pavements. The problems which are caused on rural roads on soft soil can be easily solved to some extent using Geo-synthetics Polymers. Polymer materials are poly-propylene, poly-ethylene, nylon, poly-ester etc. Natural geosynthetic materials are produced from natural materials like coconut waste(coir), jute, sisal and many more. The manufacturing procedure of Geo-textiles defines two different key terms, the cross-machine direction (XD) and machine direction (MD). The MD is parallel to the longitudinal unrolled roll length direction, likewise XD corresponds to the shorter length and transverse direction.

A geo-textile is similar to a fiber material which is generally prepared by interweaving together lots of yarns in a well close-knit pattern. The pattern is very tight enough to filter fine aggregates and coarse aggregate particles, thus an apparent opening size (AOS) typically demonstrate the openings holes of geo-textile.

APPLICATIONS OF GEO-SYNTHETICS IN HIGHWAYS

There are several applications of geo-synthetics in highway design. Even within the highway application of geo-synthetics, further division is necessary for its clarity. Geo-synthetic highway applications can be divided into two different areas, which are known as unpaved roads and paved roads. It is important to differentiate between the two different pavements, since different construction theories, physical phenomenon, design methodologies and failure criteria are utilized for each case.

2.2.1 Unpaved Road

An unpaved road bears loads across undeveloped terrain. Typically, such grades are crossed with a minimum amount of preparation that allows for an efficient movement of relatively few, but heavy, load repetitions. Rutting in the wheel paths is allowed but typically desired to be four inches or less in depth. Regarding or leveling of the ruts can be performed but is not typically, considered for an initial design of a layer of select granular material, which is placed upon the subgrade as a surface course. The purpose of this surface course is to transfer the surface load to the subgrade while spreading out the load to the subgrade, which effectively reduces the intensity of pressure on the subgrade (Steward et al. 1977).

A geosynthetic placed properly does improve an unpaved road. The most effective location of the geosynthetic is below the select granular material and on the subgrade surface (Das et al. 1998). In this location the geosynthetic provides separation, lateral restraint of the upper granular course and a tensioned membrane effect when strained extensively. A geotextile separates a granular course from a fine-grained subgrade, due to its relatively small apertures or apparent opening size (AOS). However, a Geo-grid also provides separation due to its less than 100 percent open area and better lateral restraint of upper granular particles. Due to interface friction and interlock with many individual ribs, a Geo-grid provides superior lateral restraint of the upper granular course, whereas the geotextile relies exclusively on interface friction for lateral restraint (Steward et al. 1977). The tensioned membrane effect requires that the geosynthetic be extensively strained (i.e., deeply rutted) for this mechanism to contribute a significant benefit.

2.2.2 Paved Road

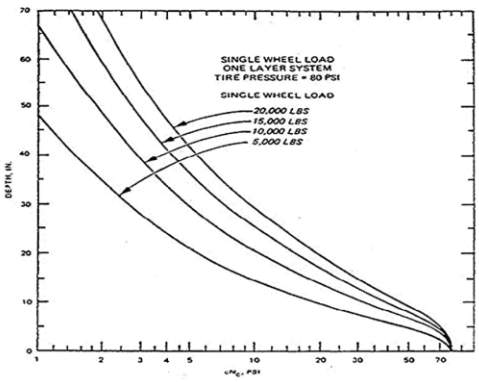
The other application is the paved road. This application also encompasses the unpaved application since during construction of a paved road relatively few repetitions of trucks heavily loaded with construction materials traverse the partially completed (unpaved) highway grade. This often leads the road to critical stage. Then, construction is completed with placement of an asphalt surface course, thus the highway is paved and open to the public. The opened highway is exposed to many repetitions from loaded truck traffic; however the intensity of subgrade load is considerably less due to the greater stiffness of the surface course. Benefits of an underlying geosynthetic during construction are apparent, but as time and greater numbers of load cycles pass, the benefits are not as clear for the paved road (Barksdale et al. 1989).

Geo-grids and geo¬-textiles are the two types of geo-synthetics most widely used in pavement systems at aggregate subgrade interface to reinforce or stabilize pavements. Field evidences suggest that both Geo-grid and geotextile could improve the performance of pavement sections constructed on weak soil. Several investigators have reported significant effects of pavement stabilization using geotextile reinforcement to improve the bearing capacity of subgrade soil. Steve et al. (2005) conducted a field demonstration to study how the performance of highway pavements is improved with Geo-textiles. In his research a field demonstration was conducted using a 21-m section along a Wisconsin highway (USH 45) near Antigo, Wisconsin, that incorporated three test sub-sections. Three different Geo-synthetics including a woven geotextile and two different types of Geo-grids had been used for stabilization. Observations made during and after construction indicate that all sections provided adequate support for the construction equipment and that no distress seems to be evident in any part of the highway. Large-scale experiments conducted on working platforms of crushed rock (breaker run stone or Grade 2 gravel) overlying a simulated soft subgrade. The tests were intended to simulate conditions during highway construction on soft subgrades The other application is the paved road. This application also encompasses the unpaved application since during construction of a paved road relatively few repetitions of trucks heavily loaded with construction materials traverse the partially completed (unpaved) highway grade. This often leads the road to critical stage.

REFLECTIVE CRACK TREATMENT FOR PAVEMENTS

3.3.1 General.

Geo-textiles can be used successfully in pavement rehabilitation projects. Conditions that are compatible for the pavement applications of geo-textiles are AC pavements may have transverse cracks as well as longitudinal cracks but are relatively smoother and structurally sound, and PCC pavements that have minimum slab movement. The geographic location and climatic condition of the project site plays an important part in determining whether or not geo-textiles can be successfully used in pavement rehabilitation. Geo-textiles have been successful in reducing and retarding reflective cracking in dry climates when temperature and moisture changes are less likely to contribute to movement of the underlying pavement; whereas, geo-textiles in cold vertically.



From figure 3.3 a 1 CBR

Determine the required aggregate thickness with geo-textile reinforcement. From figure 3.3 a 1 CBR is equal to a C value of 4.30. Choose a value of 5 for NC since very little rutting will be allowed. Calculate CNC as: CNC = 4.20(5) = 21. Enter figure 3.6 with CNC of 21 to obtain a value of 14 inches as the required aggregate thickness above the geo-textile. Select geo-textile requirements. Survivability requirements in tables 3.2 and 3.3.

Grab Tensile Strength:

Grab tensile strength IS a Uniaxial test where the specimen IS wider than the test clamps. This test is carried out as per ASTM 0 – 4632 the tensile strength added by the unclamped portion of the specimen is primarily Influenced by geo textile construction. A 100mm x 200 mm specimen is placed centrally in a set of parallel 25 mm x 50 mm clamps such that the clamps are spaced 75 mm apart A CRE tester evaluates the strength of these samples at a speed of 300 mm/mm.

Tear Strength testing:

This test method determines the tear propagation characteristics of the fabric and strength required In doing so. The test was carried out as per ASTM D-4533.

Bursting Strength testing:

The fabric bursting test was executed as per ASTM 0 3786. This test helps to establish the strength of fabric under high pressure.

Puncture strength testing:

The test was carried out as per ASTM D- 4833 to evaluate Its resistance to puncture.

Aperture opening size test:

This test estimate the permeability characteristics of the fabrics was executed as per ASTM D-4751.

Water Permittivity test:

This is yet another test to evaluate the water permittivity of the geo textile fabrics. It was carried out as per ASTM 0-4491-94.

Protected Soil (Percent Passing No. 200 Sieve)	Piping[1]	Permeability	
		Woven	Nonwoven[2]
Less than 5%	AOS (mm) <0.6 (mm) (Greater than #30 US Standard Sieve)	POA [3]> 10% $k_G > 5k_S$	
5 to 50%	AOS (mm) < 0.6 (mm) (Greater than #30 US Standard Sieve)	POA > 4% $k_G > 5k_S$	
50 to 85%	AOS (mm) < 0.297 (mm) (Greater than #50 US Standard Sieve)	POA > 4% $k_G > 5k_S$	
Greater than 85%	AOS (mm) < 0.297 (mm) (Greater than #50 US Standard Sieve)		$k_G > 5k_S$

[1] When the protected soil contains appreciable quantities of material retained on the No. 4 sieve use only the soil passing the No. 4 sieve in selecting the AOS of the geotextile.
[2] k. is the permeability of the nonwoven geotextile and k_S is the permeability of the protected soil.
[3] POA = Percent Open Area.

Fig: Geo-textile Filter Design Criteria Table 4.1.

LIFE CYCLE COST ANALYSIS

6.1 PAVEMENT STRUCTURE CONSIDERATIONS

Life Cycle Cost Analysis can be used to determine the relationship between performance and cost when geo-textiles are incorporated in pavements. The AASHTO 1993 Pavement Design Guidelines were used in this study. Pavement reliability is considered as 70%, and the standard deviation is considered as 0.49 (secondary road). Table 4.1 shows the matrix of possible secondary road pavement design combinations based on four different HMA thickness (50, 75, 100, and 125mm), four different granular base thicknesses (100, 150, 200, and 250 mm), and four different sub-grade strengths (CBR=0.5, 2, 6 and 8%). The design layer coefficient was considered as 0.44 for the HMA layer and the drainage coefficient as 1.0. Using a combination of the aforementioned pavement composition and characteristics, there are 64 design combinations; however, only a fraction of these combinations are considered to be realistic and somewhat representative of secondary road traffic conditions. According to the foreign DOT traffic count data in 2004, the annual average daily traffic (AADT) of a secondary road varies from several hundred to several thousand. Therefore, 25 design combinations based on the traffic features of the secondary roads in the state of Virginia were selected on which to conduct the cost-effectiveness analysis comparison in this study. The 25 representative designs are designated 1 through 25 in Table 6.1.

Pavement Structures Considered Table 6.1

HMA Thickness (mm)	Base Thickness (mm)	Sub-grade Strength (*CBR %)			
		0.5	2	4	6
50	100				1
	150			2	3
	200		4	5	6
	250		7	8	9
75	100			10	11
	150		12	13	14
	200		15	16	
	250		17		
100	100		18	19	
	150		20		
	200		21		
	250		22		
125	100				
	150		23		
	200	24			
	250	25			

***California Bearing Ratio , (ref) represents the reference design**

USER COSTS AND WORK ZONE EFFECTS

When construction maintenance activities are undertaken on highway sections that continue to allow traffic on the facility, a system of traffic controls and protective barriers are instituted to ensure worker and traffic safety. Traffic management in work zones is influenced by the type of infrastructure, environment, traffic characteristics, duration, type of work, and available sight distance. Work zone configurations are tradeoffs, balancing contractor efficiency against traffic speeds and safety. When vehicle flows are light, impacts on speed and safety may be slight. As demand increases, however, such impacts rise substantially and rapidly. Modeling these impacts must therefore not only incorporate work zones' impact on speed, but must also account for how those changes in speed translate into estimates of user costs. In addition to the impact of speed on traditional user costs, increased traffic through a work zone impacts the amount of accidents and fuel consumption in work zones.

THE DISCOUNT RATE

All the pavement cases considered in this study have different rehabilitation timings. Therefore, comparisons were made using inflation-adjusted dollars. A discount rate is then used to account for the time value of money. This provides an agency, planner, or decision maker with a way to compare future expenditures with those occurring in the present. In a proper economic analysis, all future costs and benefits are discounted to the present, accounting for the prevailing and expected interest and inflation rates. Since the future value of a sum of money in the present is greater owing to compounding interest, the reverse must also be true. The present value of a future sum is worth less than it would be at the present. Because an economic analysis can be highly sensitive to the discount rate, it must be selected with care. Here, this section will discuss how the interest rate and inflation rate can be used to determine a proper value for the discount rate. Also discussed are some common values that are suggested by various agencies in the United States.

The discount rate can be calculated from the interest rate and the inflation rate that may be expected over the life of the highway project. The equation to calculate the discount rate is as follows:

The difficulty in predicting interest and inflation rates over the life of the project is somewhat attenuated by using the discount rate. The Federal Highway Administration has recommended standard discount rates for use in various highway pavement projects. The level of the discount rate depends largely on the type of agency that is financing the work. The rate also depends on the agency's cost of funds, tax-exempt status (for bond investors), creditworthiness (based on ratings by investment banks), and many other factors. In general, the following rates have been recommended for the indicated entities. In this study, a 2.5% discount rate was used to similar state municipal condition.

Recommended Discount Rates. Table 6.2

Agency Type	Appropriate Discount Rate
State/ Municipal	2.50%
Federal/ Long Term Project	3.50%
Privately Funded Projects	4.50%

RESULTS AND DISCUSSION

7.1 AGENCY AND USER COST COMPARISON

Most of the studies related to the incorporation of geo-synthetic materials in pavement systems report that by using geo-textiles in pavement, the service life of the pavement can be extended. Hence, the question here is how much money can be saved relatively if the pavements incorporate geo-textiles. Therefore, the focus here was aimed at transforming the engineering benefit into economic profit. The following sections present the agency and user costs of the 25 representative pavement designs. All the values presented are transferred back to the net present value of the initial construction year.

7.2 AGENCY COSTS

The agency costs of the 25 pavement design alternatives were compared. Three design methods show similar initial construction costs. Al-Qadi's and Perkins' designs show a little higher value in initial construction cost since these design methods incorporate geo-textiles in the pavement, which slightly increases initial construction costs.

However, if this can provide the engineering benefits as stated in the design of pavement, the future maintenance costs will show effective savings in terms of cost considerations. The maintenance costs are calculated.

7.2.1 User Costs

In many cases, while state highway engineers conduct a LCCA, the user cost components are believed to be difficult to quantify, thus they are usually excluded from LCCA. This exclusion has resulted in total cost underestimation. In this study, three work zone induced user cost components are considered: delay, fuel consumption and accident cost.

In terms of the work zone induced user costs, user delay costs usually occupy the highest proportion among the three user cost components. User delay costs are mainly affected by the amount of traffic on the roadway. As a result, roadways with higher traffic volumes will have higher user delay costs.

7.2.2 Total Cost

Using the aforementioned information, the total life cycle cost for the 25representative design alternatives is calculated. It is worthwhile to notice that when only agency costs are included in the LCC analysis, the difference among the three design methods is not obvious. However, when the user costs are taken into consideration, the three design methods are clearly distinguished from one another. Al-Qadi's design method suggests that when a geo-textile is placed in a pavement as a separator, the range of the total pavement life cycle cost savings can be as high as 70% to as low as 40%. This depends on the selected design alternative. When Perkins' design method is used, the suggested total pavement life cycle cost savings varies from no savings to 70% savings compared to the AASHTO's design method.

7.3 SENSITIVITY ANALYSIS

The ideal situation in the sensitivity analysis would be to alter a particular design feature and to experience as large a percentage increase as possible in service for the smallest possible percentage increase in cost. The following section will investigate which design feature of a flexible pavement, such as thickness of HMA, thickness of the base, sub-grade strength, structure number, and TBR value, improves cost-effectiveness.

7.4. THICKNESS OF HMA

The most common parameter for designing a pavement is the thickness of the HMA layer. The thickness of the HMA is investigated here to see the how changing the thickness of this layer influences the cost-effectiveness ratio. with sub-grade CBR=2% with a base layer thickness of 150mm, both designs suggest that the thicker HMA layer will give the higher cost-effectiveness ratio. When the sub-grade.

CBR increases to 4%, a similar result can be observed. However, further increasing sub-grade strength using Perkins' design method suggests the opposite trend in the cost effectiveness ratio. This trend, in which thicker HMA layers give lower cost effectiveness. In addition, when the thickness of the base layer is also evaluated, at a base thickness of 100mm, Al-Qadi's design method still suggests that with an increase in the thickness of the HMA, the cost-effectiveness ratio of the design alternative will increase. The opposite trend is observed when Perkins' method is used.

7.4.1 Thickness of Granular Base

The second layer in flexible pavement design is the granular base layer. The following comparison shows the effect of changing the base thickness on the cost effectiveness ratio Perkins' design methods. Under the condition of sub-grade CBR=0.5% with an HMA thickness of 125mm, there is a slight 8% increment in the cost-effectiveness ratio when Al-Qadi's method is used. Under the same condition, Perkins' design method suggests a 16% increment.

7.4.2 Structure Number

If the influence of the HMA and the base layer are combined and converted into a single parameter, the structure number (SN), the effect of the variation of the SN on the cost-effectiveness ratio can be seen, the sub-grade CBR is varied from 2% to 6%. The plot shows the changing of the SN versus the cost effectiveness ratio. It is clearly shown that there is no direct proportion between increasing the SN and an increase in the cost-effectiveness ratio.

7.4.3 Strength of Sub-grade

The same pavement design alternative is chosen to see the effect of sub-grade strength on the cost effectiveness ratio. For example, when SN=2.05 and 1.81 were reviewed, Al-Qadi's design method shows that by increasing the strength of the sub-grade, the cost-effectiveness ratio of the pavement increases. However, Perkins' design method gives the totally opposite result from Al-Qadi's design method. Perkins' method shows that by increasing the strength of the sub-grade, the cost-effectiveness ratio of such a pavement alternative will decrease.

7.5 COST-EFFECTIVENESS RATIO PREDICTION

One thing worth investigating is if the traffic benefit ratio obtained from these two design methods can be directly related to the cost-effectiveness ratio for a particular design alternative. In this way, one could use the TBR value to estimate the cost effectiveness ratio of a selected design alternative instead of going through a lengthy LCCA process. For the representative design alternatives. They show that for both Al-Qadi's and Perkins' design methods; there are no particular trends between the traffic benefit ratio and the cost-effectiveness ratios of a selected design alternative.

Another potential design feature of flexible pavement, equivalent single axle load (ESAL), was also considered. The designed ESAL for a particular pavement was used to predict the corresponding cost-effectiveness ratio for the pavement.

The plot of the designed ESAL value versus the cost-effectiveness value using Al-Qadi's design method. The result shows that a simple power law equation can be found to predict the cost-effectiveness ratio of a pavement when the 20 year traffic design alternative is less than 160,000 ESALs. However, if Perkins' design method is used, no feasible model can be found between the designed ESALs and the cost-effectiveness ratio for the pavement.

CONCLUSION AND RECOMMENDATIONS

8.1 SUMMARY

Geo-textiles have been used in pavements to either extend the service life of the pavement or to reduce the total thickness of the pavement system. However, the economic benefits of using this material are still perfectly not clear from engineering point of view. Most of the geo-textile related life cycle cost analysis studies only account for agency materials cost. In this case study, a complete comprehensive life-cycle cost analysis of geo-synthetics like geo-textiles stabilized pavements, including initial cost of construction, future cost of maintenance, rehabilitation of the pavement, and user costs benefits is considered.

Two design methods were used to quantify the improvements of using geo-textiles in pavements. One was developed at Virginia Tech by Al-Qadi in 1997, and the other was developed at Montana State University by Perkins in 2001. Based on these two methods, the Traffic Benefit Ratio (TBR), defined as the ratio of the number of load cycles needed to reach the same failure state for a pavement section with geo-textiles to the number of cycles needed to reach the same failure state for a section without geo-textiles, is taken and combined with an AASHTO pavement design method .

In this study, a comprehensive life-cycle cost analysis framework was developed and used to quantify the initial and the future cost of 20 different representative design alternatives. A 45-50 year analysis cycle data was used to calculate the cost-effectiveness ratio for the design methods of pavement. The costs which were considered in the LCCA process include agency costs and user costs.

Four different flexible pavement design features were shortlisted for test the degree of influence of the frame's variables. An initiative to predict the cost-effectiveness ratio for a particular individual pavement design from the base input of the design was also made.

8.2 FINDINGS AND CONCLUSIONS

A comprehensive life cycle cost analysis framework which have been developed in this case study in order to consider the economical benefits of using geo-synthetics like geo-textiles in design of pavements. The result of benefits has been quantified in terms of cost-effectiveness ratio. The findings in this study are limited to the design features, unit costs and performance models assumed in this analysis.

During the study several findings were uncovered. Using Al-Qadi's design method, it was found that when the designed ESAL value is greater than 30,000, the user costs will be greater than the agency costs over the 50 year analysis period. However, no such pattern was found when Perkins' design method was adopted. In addition, the results showed that a simple power law equation could be found to predict the cost effectiveness ratio of a pavement when the 20 year traffic design alternative is less than 160,000 ESALs. However, if Perkins' design method was used, no feasible model could be found between the designed ESALs and the cost-effectiveness ratio. Three flexible pavement design parameters were also evaluated. The following findings are made with respect to these parameters:

HMA thickness variation was investigated. It was found that at the same Sub-grade strength and same base thickness, the cost-effectiveness ratio will increase when Al-Qadi's design method is used. However, the percentage increase in cost effectiveness decreases with an increase in the thickness of the HMA. When Perkins' design method is utilized, an increase in HMA layer thickness would increase the cost effectiveness of the pavement only if the sub-grade CBR is less than 2% with a base layer thinner than 250mm and an HMA thickness less than 100mm.

A granular base thickness increase resulted in an increase in cost-effectiveness in both design methods. However, a greater increase in base thickness obtained a smaller percentage increase in cost-effectiveness.

Structure number was thought to be a common parameter to characterize the strength of pavement. However, during the sensitivity analysis, this feature does not show a regular pattern in the cost-effectiveness ratio among the different structure numbers for both design methods.

Sub-grade strength is an important feature in the performance model. When Perkins' design method was used, the stronger the sub-grade, the smaller the cost effectiveness ratio was gained. A similar pattern was found when Al-Qadi's design method was used. However, there was a difference between these methods.

Although the benefit decreased when the strength of the sub-grade increased, overall, Al- Qadi's design method still showed improvement in cost effective value. By contrast, Perkins' design method suggests that with an increase of sub-grade strength from CBR=0.5% to 6%, the cost-effectiveness ratio would decrease.

8.3 CONCLUSIONS

Based on the information evaluated and the inputs established for the LCCA over the 45 years analysis period, the following conclusions are made:

For agency costs, Al-Qadi's design method suggests that there is a 20% reduction among the 25 preventative pavement design alternatives, and Perkins's design method gives from no cost reduction to a 35- 40% cost reduction.

For user costs, Al-Qadi's design method suggested 70% cost reduction among the 25 representative pavement design alternatives. Perkins' design method gives from almost no cost reduction to a 85% cost reduction.

The cost effectiveness ratio from the two design methods shows that the lowest cost-effectiveness ratio using

Al-Qadi's design method is 1.7 and the highest is 3.2. The average is 2.4. For Perkins' design method, the lowest value is 1.01 and the highest value is 5.7. The average is 3.0.

8.4 RECOMMENDATIONS FOR FUTURE WORK

This study is mainly intended to propose a cost-effectiveness analysis framework that can be used to operate similar analysis. It presented a framework on how to quantify engineering benefits into economic benefits by performing life cycle cost analysis. Included in this study are models that predict pavement performance, suggest rehabilitation designs, and predict user costs and accident rates at different work zones. Many of these models need to be improved by using more reliable parameters and be calibrated to specific local considerations. This is especially applicable to the different pavement performance models. Research should be undertaken to replace these models and to improve the calculated qualities of the framework using mechanistic as well as deterministic approach.

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