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A mathematical model for determination of structural value of geotextile in pavements

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Abstract

The use of geotextiles to postpone reflective cracks in asphalt overlay is a popular practice, so researchers are eager to calculate its structural value. This research study has focused on this issue for geotextiles used in the roads of Iran. Twelve sections from the Tehran-Qom road were tested; each examined before and after construction of the overlay. The tests were of the Falling Weight Deflectometer type, and at least twelve tests were conducted each time. The data from five sections (four for developing the model and one for evaluating the output) allowed a new mathematical model to be developed. For the seven remaining sections, some foreign and Iranian geotextiles were used as interlayers. The mean structural value for all of the geotextiles was equivalent to that of a 2.92 cm-thick Hot Mix Asphalt overlay, while that for only the Iranian sections was equivalent to 2.28 cm. Economic evaluations, based on construction costs, showed that in 2011 the use of geotextiles was economical in Iran, because fuel and bitumen subsidies had been eliminated and different geotextile brands had been brought to market in the country.

Keywords: Structural value, Geosynthetics, Geotextile, Falling Weight deflectometer, Non-destructive test, Hot mix asphalt

1. Introduction

In recent decades, many different polymers have been produced and released onto the market to be used in pavements, in order to enhance their serviceability. One group of these polymers is known as geosynthetics, which are also called geotextiles. With the advancement of modern technology, the textile industry can produce these geotextiles using polymeric fibers that have an excellent tensile strength. These are widely used in asphalt concrete pavements [1, 2, 3], and geosynthetics are quite useful in constructing roads on low strength, weak soils [4, 5, 6]. During the last two decades, geotextile have found widespread application in pavement design, and hence many questions have been raised regarding their properties. Two of the most important questions are in term of their structural and economical value, considering the resulting pavement durability. To determine the answers, to these questions, considerable research effort has been carried out in many countries. Part of this research has been to develop a model for the determination of the structural value of geotextiles by constructing a test road using various Iranian-made and imported geotextiles, and studying their structural values in pavement layers.

Road construction authorities should be convinced of the use of geotextiles if their application is economical; therefore it is necessary to compare their technical efficiencies with that of the asphalt overlay. Determination of the structural value of a geotextile and its comparison with that of the Hot Mix Asphalt (HMA) will encourage those authorities to make informed decisions on its application, as the costs of both are known.

1.2. Literature review

In the 1990s, researchers of California Department of Transportation showed that an interlayer of geotextile functioned similarly to 3 a cm-thick HMA overlay, and that the construction cost was only about 50 percent [7].

To justify the economic use of geotextiles, some researchers have considered the pavement thickness reduction on the basis of an equivalent thickness. Predoehl's early works show that before constructing the overlay, one layer of geotextile would

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function similarly to a 2.54 cm-thick HMA overlay [8].

According to Holtz's findings in 1998, the cost of a geotextile interlayer equals that of a 1.5 cm-thick HMA overlay [7]. In 1999, Carmichael and Marienfeld determined that the cost of a geotextile interlayer was equal to that of a 1.27 cm-thick HMA layer, but with an equivalent structural thickness of approximately 3.3 cm [9]. According to these studies, asphalt pavement overlays with thicknesses less than 5 cm (with or without geotextiles) are prone to early cracks [1].

These studies also showed that using geotextiles for pavement rehabilitation resulted in a longer life span and improved durability of the pavement. It also increased the pavement service cycle, equating to the performance of a 2.5 to 4.5 cm-thick HMA layer. The research studies proved that the cost of procurement, transportation and installation of a geotextile interlayer in a pavement was equivalent to that of a 1.5cm-thick HMA layer (also including supply, transport and installation). They also concluded that the use of a geotextile interlayer is economic and optimal only when the asphalt overlay thickness constructed over it is greater than 4 cm.

Batton and Lyton (2007) stated after many years of research that the flexible and rigid pavement overlay thicknesses should be determined assuming that no geosynthetic interlayer is present. Generally, when geosynthetic is used, the thickness of the overlay should not be taken as less than that found by standard methods.

According to the above findings and based on the research studies carried out at the Texas Transportation Institute, no structural value should be considered for geosynthetic materials in the process of pavement design, hence there is no reduction in the thickness of the asphalt layers, and more specifically; the overlay [1].

In 2006, Sprague studied some pavements that had been built in Greendale, South Carolina between 1996 and 1997, by evaluating their serviceability indexes. The study had two phases, where 34 sections were studied in phase one and 37 sections in phase two; with similar results. The study showed that using geotextiles along with HMA is more economically justifiable in comparison with other existing methods. In this study, the Pavement Serviceability Index (PSI) was graded from 0 to 100. If the grade attributed to a pavement is less than 25, the most cost-efficient remedy would be cold recycling and patching before installing the geotextile. If the grade is between 25 and 50, a geotextile interlayer with a 4 to 5 cm-thick HMA overlay would be the most economic choice. For cases where the grade is over 50, the construction of an asphalt overlay (either with or without geotextile) would be adequate and financially suitable [10].

In brief, these studies show that the structural value of a geotextile interlayer is equivalent to that of a 2.5 to 4.5 cm-thick HMA overlay, and they suggest that under certain conditions, an asphalt pavement with a geotextile interlayer is the most economic option. All of these studies confirm that the installation of geotextile under an asphalt overlay is beneficial with due consideration to technical aspects [11]. In order for the geotextile to have the correct and optimum function, the asphalt pavement thickness should lie in a range, which has a minimum of 5 cm. The studies specified above used the “life cycle cost” method and destruction trend analyses to determine the structural value of geotextile interlayers. However, considering the lack of statistical data and maintenance information, such analyses have not been practicable in Iran. Therefore, in this research study, a newly developed technique and Falling Weight Deflectometer (FWD) tests have been applied to determine the structural value of geotextile interlayers.

2. Research site

To evaluate the geotextiles, part of the old Tehran–Qom road was studied, consisting of twelve sections (six with geotextiles, one full-depth HMA section as the control specimen and five full-depth HMA sections to develop the model). The beginning and end point of each section is given in Table 1, with respect to the starting km of the project route. The pavement cross section consisted of subgrade, subbase, base and asphalt layers as shown in Figure 1. Note that the base and subbase layers could not be differentiated at several studied points.

3. Model development

To develop a model for the determination of the structural value of geotextiles, FWD tests were carried out on full-depth HMA sections from km 1+605 to km 2+100 in accordance with the requirements of the ASTM D4694-07 standard [12]. The FWD test equipment used in this study was the Dynatest Model 8000. The distances of the sensors from the center of the load plate are presented in Table 2. Based on the method specified in the 1993 edition of AASHTO (Guide for design of pavement structures), the effective modulus of all pavement above the subgrade (E_P) and the effective structural number (SN_{eff}) of the existing pavement for each test were determined

Table 1 Section boundaries from the beginning of the route

Section No	Beginning in the east band	End in the east band	Beginning in the west band	End in the west band
1	0+00	0+149	0+00	0+152
2	0+149	0+299	0+152	0+302
3	0+299	0+449	0+302	0+452
4	0+449	0+595	0+452	0+595
5	0+595	0+745	0+595	0+745
6	0+745	0+895	0+745	0+890
7	0+895	1+020	0+890	1+012
8	1+020	1+195	1+012	1+195

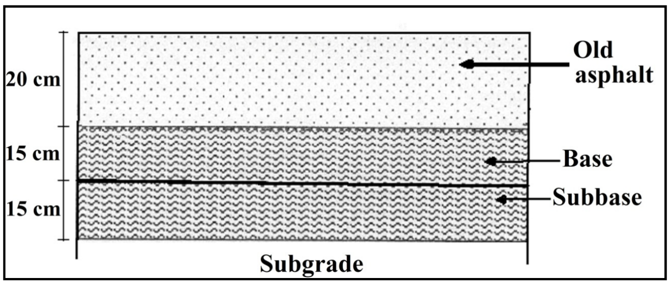

Fig. 1 Pavement cross section before the overlay and the interlayer construction

Table 2 The location of the FWD sensors

Sensor No	1	2	3	4	5	6	7
Distance from center of loading plate(cm)	0	20	40	60	90	120	150

from equations 1 and 2, respectively. The overlay thickness was then calculated from equation 3 [13]. Based on the existing data, the required and the constructed overlay thicknesses of each full-depth asphalt section were calculated. These are shown in Table 3.

$$d_0 = 1.5pa\left\{\frac{1}{M_R\sqrt{1+\left(\frac{D}{a}\sqrt[3]{\frac{E_P}{M_R}}\right)^2}} + \frac{\left[1-\frac{1}{\sqrt{1+(\frac{D}{a})^2}}\right]}{E_P}\right\} \quad (1)$$

Where:

d_o: Deflection measured at the center of the loading plate (and adjusted to a standard temperature of 22.5°C), inches

p: NDT load plate pressure, psi

a: NDT load plate radius, inches

D: Total thickness of pavement layer above the subgrade, inches

E_p: Effective modulus of all pavement layer above the subgrade, psi

M_R: Subgrade resilient modulus found from the applied load and the deflection of the farthest sensor, psi

Having determined E_p, SN_{eff} can be calculated from equation 2 [13].

$$SN_{eff} = 0.0045 D\sqrt[3]{E_P} \quad (2)$$

Where:

SN_{eff}: Effective structural number of the pavement

The other parameters have been previously defined. The asphalt overlay thickness is then determined from equation 3.

$$D_{ol} = \frac{SN_{ol}}{a_{ol}} = \frac{(SN_f - SN_{eff})}{a_{ol}} \quad (3)$$

Where:

SN_f: Structural number of the new pavement

D_{ol}: Required overlay thickness, inches

SN_{ol}: Required overlay structural number

a_{ol}: Structural coefficient of the asphalt overlay

Using the thicknesses in Table 2 and having found the overlay thickness using by the destructive method, the following relationship can be assumed:

$$D = a(H_1 - H_2) + b \quad (4)$$

Where:

D: Overlay thickness, cm

a, b: model variables

H_1, H_2: The overlay thicknesses of each section, before and after the overlay construction

Their values have been calculated using equation 5 as proposed in the Iranian Code for this purpose.

$$H = \sum_{i=1}^{n} D_{ol_i} + 1.6 \times \sigma_{n-1} \quad (5)$$

Where:

D_{ol_i}: Overlay computational thickness in each FWD test

σ_{n-1}: Standard deviation of the data in each section.

Model variables can be found using linear regression relationships and the data in Table 4. In this manner, a and b have been determined to be 1.024 and -0.3, respectively. In this case, the correlation coefficient R2 is 0.918, which suggests proper correlation between the input data of the model. The linear regression relationship is shown in the graph in Figure 2. Substituting the a and b values into equation 4, equation 6 is generated. as follows:

Table 3 Overlay thicknesses before and after the construction of the full-depth asphalt sections

Location of full-depth asphalt section, cm	Required overlay thickness before overlay construction (H_1), cm	Required overlay thickness after overlay construction (H_2), cm	H_1-H_2, cm	Actual overlay thickness, cm
1+605 to 1+730	2.31	-4.08	6.39	6.3
1+730 to 1+855	5.41	-0.9	6.31	6.1
1+855 to 1+980	4.23	-1.65	5.88	5.7
1+980 to 2+100	3.19	-2.64	5.83	5.8

Table 4 Overlay thicknesses before and after the construction of the full-depth asphalt sections

Type of geotextile	Mass per unit area (gr/cm^2)	Melting point (ºc)	Longitudinal grab breaking (N)	Transverse grab breaking (N)
	ASTM D5261	ASTM D276	ASTM D4632	ASTM D4632
PGM14	150±7	160	656±69	539±78
PG50-50	307±5	141	972±78	883±59
PG100-100	415±4	145	972±78	883±59
Iranian Type 1	195±5	250	375±39	414±39
Iranian Type 2	222±5	232	607±137	872±118
Iranian Type 3	195±10	226	318±39	416±49

$D = 1.024(H_1 - H_2) - 0.3$ (6)

Pavement structural value reduction over time may be due to factors such as traffic load and destruction caused by environmental considerations. Considering the short time between the two phases of the nondestructive tests, the structural value fluctuations here can be assumed to be due to the construction of the overlay and the geotextile interlayers.

The structural value of the asphalt overlay can be taken to be equal to that of the existing thickness, considering the accepted quality and proper compaction of the overlay. Therefore, in sections where there are interlayers present, the structural value of the geotextile interlayer can be obtained from the following relationship that has been developed in this research study:

$D_{Geo} = 1.024(H_1 - H_2) - 0.3 - D_{ol}$ (7)

Where:

D_{Geo}: Structural value of the geotextile interlayer, cm

D_{ol}: Constructed overlay thickness, cm

To verify the model, the data from the first section (the first 150 meters of the project route) as constructed with full-depth HMA was input into the model and the resulting error rate was studied. The non-destructive structural values of this section (before and after the overlay construction) were 3.54 and -2.68 cm, respectively, and the constructed overlay thickness was 5.9 cm (a negative overlay thickness shows that the pavement structural value is more than required during its service life). Substituting these values into equation 7, the structural value of the geotextile interlayer is equal to 0.17 cm. Noting that there was no geotextile in this section, the model correctness is therefore verified.

4. Evaluating the structural value of geotextile

To carry out this evaluation, three foreign-made and three Iranian products were installed in sections 2 to 8. To collect practical results in this research study, an effort was made to use products that were commonly used in Iran, which were placed between the HMA layers and under the overlay according to Figure 3.

The brands used in this research study constitute a high percentage of the geotextiles used in Iran, but new brands should first meet the specifications of the AASHTO M-288 standard, and then their structural values may be found in field studies. The average value found from the results of this research is only an estimation of the structural values of the new brands.

Some geotextile standard tests, including mass per unit area, melting point and transverse and longitudinal grab breaking load, were carried out on the geotextiles used in this research, the results of which are shown in Table 4.

In Table 5, the geotextile brands are given in column 2 and the asphalt overlay thicknesses for all seven sections under study before and after overlay construction, determined by the non-destructive method, are given in columns 3 and 4, respectively. For all the sections, FWD tests have been carried out according to the ASTM D4694 standard specifications. All data, including loading rates, number of blows, weight arrangements and the distances between sensors were given to the device operator. Seven deflectometers were used, the arrangement of which is shown in Figure 4. The process of data collection in the sections containing geotextile was similar to that used in the sections for model development.

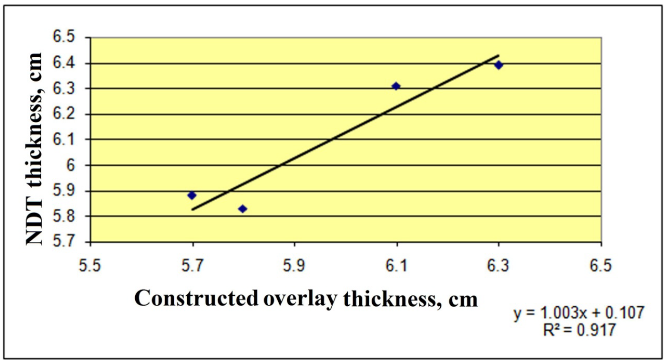

Fig. 2 Constructed and calculated overlay thicknesses

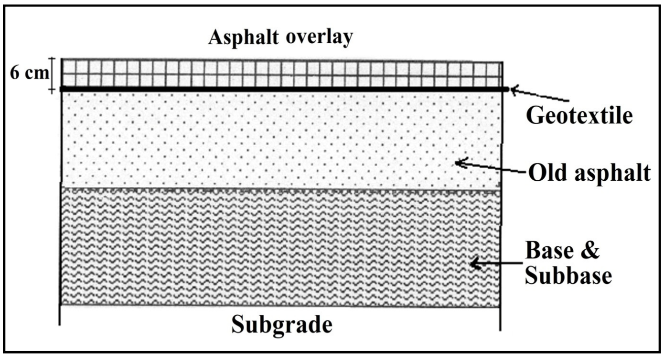

Fig. 3 Placement of geotextile interlayers into the pavement

Table 5 Overlay NDT thickness for each section before and after overlay construction

Section No	Geotextile brand	NDT overlay thickness before construction, cm	NDT overlay thickness* after construction, cm
2	PGM14	12.00	0.92
3	PG50-50	10.28	3.03
4	PG50-50	11.02	2.85
5	PG100-100	4.88	-3.17
6	Iranian Type 1	10.39	0.19
7	Iranian Type 2	6.32	-1.63
8	Iranian Type 3	2.60	-4.60

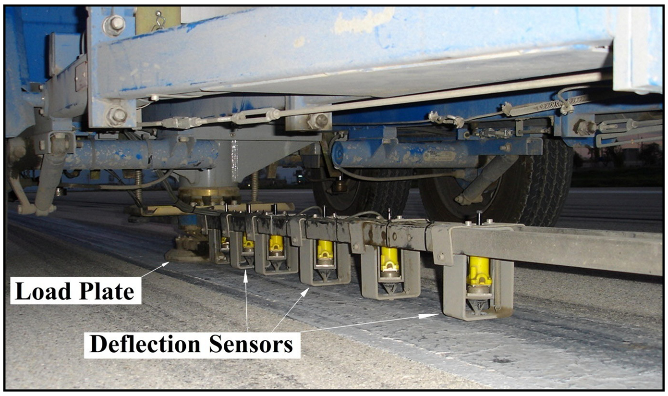

Fig. 4 Constructed and calculated overlay thicknesses

5. Data analysis for each section

5. 1. Section 1

This is at the beginning of the route, and was used as the control section in this research. FWD tests were carried out at six points along this section and the data obtained from the three loadings at each point was used in the calculations according to the AASHTO method).

The data obtained for this section has been used for the verification of the model developed in this research.

5.2. Section 2

Geotextile PGM-14, a product from the Polyfelt Company, was used in this section. FWD tests were carried out at six points along this section and the data obtained from the three loadings at each points was used in the calculation according to the AASHTO method.

Non-destructive test results, both before and after the installation of the geotextile interlayer and the overlay construction in this section, revealed that the required overlay thicknesses are 12 and 0.92cm of HMA, respectively. Considering the existing 6.1 cm-thick constructed overlay in this section, the geotextile structural value (based on the developed model) found from equation 7 was for a 4.95cm-thick HMA overlay. The structural value of geotextile PGM - 14 used in section 2 confirms the efficiency and correct operation of this product in this section.

5.3. Sections 3 to 8

The structural values of the geotextiles in sections 3 to 8 were found with the application of equation 7 in the same manner as described for section 2. The geotextiles used and their structural values are shown in Table 6. The geotextile structural value found for PGM 50-50 in section 4 equated to that of 3.96 cm-thick HMA. This validates the efficiency and correct operation of the PGM50-50 geotextile in this section, whereas this same product did not function quite as well in section 3. This can be attributed to the excessive bitumen applied on certain points of this section as a tack coat, which may have increased the ductility of the pavement material; therefore resulted in the excessive displacement of the FWD sensors.

Table 6 Geotextile structural values from equation

Section No	Geotextile brand	Geotextile structural value
2	PGM14	4.95
3	PG50-50	1.22
4	PG50-50	3.96
5	PG100-100	1.74
6	Iranian Type 1	4.04
7	Iranian Type 2	1.84
8	Iranian Type 3	0.97

Two years after the overlay construction, there was some bleeding in section 3; therefore it was decided that it should be omitted for more precision in the overall results.

The structural value of the geotextile PGM 100-100 in section 5 was found to be less than expected. Non-destructive tests on sections 3 and 5 revealed that glass fibers do not affect the enhancement of the pavement structural value. This of course does not mean that the fibers are not useful in the prevention of reflective cracks, but this needs to be checked in the field.

Considering the existing 6.1 cm-thick overlay in section 6, the geotextile structural value was found to be equivalent to a 4.04 cm-thick HMA overlay. This confirms the efficiency and correct structural operation of the type 1 Iranian geotextile used in this section.

In section 7, the geotextile structural value was determined to be equivalent to a 1.84 cm-thick HMA overlay. This validates the average quality of the type 2 Iranian geotextile. Considering the existing 6.1 cm-thick pavement in section 8, the geotextile structural value was found to equate to that of 0.97 cm-thick HMA, which also confirms the average quality of the type 3 Iranian geotextile used in this section. This type does not have a very good tensile strength at low strains, which is the cause of its poor structural function. The low tensile strength of this geotextile was determined in the grab test and is shown in Table 4, which is one of the reasons why it exhibits only an average performance after installation.

In sections 3 and 4, PGM 50-50 was used, a product of the Polyfelt Company that is reinforced with glass fibers. These fibers reach their maximum tensile strength at low strain levels; therefore the glass fibers can help prevent the propagation of the reflective cracks in the overlay.

In section 5, use was made of PGM 100-100 (of the same company), which has more glass fibers as compared with the previous product; therefore there is a greater resistance to reflective cracks. Field evaluations in this research study yielded structural values equivalent to 1.22, 3.96 and 1.74 cm-thick HMA for the reinforced products in sections 3, 4 and 5, respectively. Therefore, according to equation 7, the average structural value of the products reinforced with glass fibers in this research study was equivalent to that of 2.36 cm-thick HMA. The average structural value of the unreinforced products according to equation 7 was equivalent to 2.95 cm-thick HMA. Therefore, it is concluded that the presence of glass fibers does not affect the structural value of the geotextiles, and in some cases the structural values of the reinforced products are even less than those of the unreinforced ones. The average structural value of the geotextile used in the six sections (after the elimination of section 3 due to bleeding) was equal to that of 2.92 cm-thick HMA. Predoehl determined this value to be 2.54 (Predoehl, 1990) while Carmichael and Marienfeld reached a value equivalent to that of 3.3 cm-thick HMA (Carmichael and Marienfeld, 1999). Their evaluation methods were based on the geotextile performance during its life cycle. Many other researchers found the geotextile structural value to be between 2.5 and 4 cm-thick HMA; therefore the results of this study are compatible with the body of academic work in this field.

An important application of the structural value is in the technical and economic evaluation of a geotextile. According to the studies carried out by the Iranian authorities, the average cost of the six brands of geotextiles (PGM 14, PGM 50-50, PGM 100-100 and three Iranian products) used in this project is equivalent to that of 2.81 cm-thick HMA, which shows that geotextiles have nearly the same cost as the full depth asphalt. A reason for this is that the asphalt production cost in Iran is very low, due to the low cost of fuels and the subsidies attributed to bitumen.

The economic data used to obtain the above results are for the year 2009. Presently, Iran is facing even lower costs for the application of geotextiles (compared with full-depth asphalt), because the subsidies have recently been cut and there is a greater production of these materials in Iran, meaning their use is gradually becoming more economically viable.

The economic evaluation for the year 2011, based on the construction cost, shows a more economic application of geotextiles compared with that in the year 2009. Considering these evaluations, the application of geotextiles in this context is economically justified

6. Conclusions

In this research study, a model has been developed based on the results of non-destructive FWD tests carried out on four test sections. To verify the model's correctness, the data related to a control section has been used. Equation 7, with which one can determine the structural value of geotextile interlayers in equivalence to HMA pavements, is an empirical formula produced and applied for the first time in this research.

- The average structural value found for different geotextiles used in this research (after the elimination of section 3 due to bleeding) based on the developed model equals that of a 2.92 cm-thick HMA overlay, which is in the range of the data gathered from other studies on this issue.

- FWD is a globally accepted device for the measurement of pavement structural values. This device proved satisfactory in the present research, such that there were obvious differences between pre and post overlay construction results. This mint that evaluation of geotextile became possible.

- Results obtained from sections 2, 6, 7 and 8 show that the structural values for unreinforced PGM14, and types 1, 2 and 3 Iranian geotextiles are equivalent to 4.95, 3.96, 1.84 and 0.97 cm-thick HMA overlay, respectively. This gives an average structural value of 2.95 cm-thick HMA. Therefore, their use may be advocated and they can be useful in road construction projects.

- Based on the analyses carried out, types 1, 2 and 3 of the Iranian geotextiles had structural values equal to those of 4.05, 1.84 and 0.97 cm-thick HMA overlays, respectively. Therefore, the average structural values of types 1 and 2 Iranian geotextiles compare very closely with those of the foreign brands, and they can be used to improve pavement quality.

- One of the most important issues affecting the interpretation of geotextile field test results is correct, sufficient and even placement of the tack coat layer under the geotextile. If the tack coat is excessive, it will cause bleeding and the pavement will become very flexible, which will affect the FWD test results.

- The amount of dynamic loading in the FWD tests must be carefully selected so that a real evaluation of the results is possible.

- Economic evaluations, based on construction costs, show that the cost of using geotextiles in pavements is almost equal to that of the equivalent Hot Mix Asphalt (considering the 2009 price list in Iran). However, with price changes due to the elimination of bitumen and fuel subsidies and the reduction in the price of geotextiles, their use from an economic point of view is justified in 2011.

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References

[1] Button, J.W. and Lytton, R.L.: 2007, Guidelines for Using Geosynthetics with Hot Mix Asphalt Overlays to Reduce Reflective Cracking, In Transportation Research Board 2007 Annual Meeting CD-ROM, Transportation Research Board of the National Academies, Washington D,C.

[2] Khodaii, A. and Fallah, Sh.: 2009, Effects of Geosynthetic Reinforcement on the Propagation of Reflection Cracking in Asphalt Overlays, International Journal of Civil Engineering. Vol. 7, No. 2, pp. 131-140.

[3] Moghaddas Tafreshi, S.N. and Asakereh, A.: 2007, Strength evaluation of wet reinforced silty sand by triaxial test, International Journal of Civil Engineering. Vol. 5, No. 4, pp. 274-283.

[4] Barnhart, V.T.: 1989, Field Evaluation of Experimental Fabrics to Prevent Reflective Cracking in Bituminous Resurfacing, Report No. R-1300, Materials & Technology Division, Michigan Transportation Commission. Lansing, Michigan.

[5] Naeini, S. A. and Ziaie Moayed. R.: 2009, Effect of Plasticity Index and Reinforcement on the CBR Value of Soft Clay, International Journal of Civil Engineering. Vol. 7, No. 2, pp. 124-130.

[6] Pak, A. and Zahmatkesh, Z.: 2011, Experimental study of geotextile's drainage and filteration propertis under different hydraulic gradients and confining pressures, International Journal of Civil Engineering. Vol. 9, No. 2, pp. 97-102.

[7] Holtz, R.D. Christopher, B.R. and Berg, R.R.: 1998, Geosynthetic Design and Construction Guidelines, Publication No. FHWA HI-95-038, NHI Course No. 13213, National Highway Institute, Federal Highway Administration, U.S. Department of Transportation.

[8] Predoehl, N.H.: 1990, Evaluation of Paving Fabric Test

Installations in California, Report No. FHWA/CA/TL-90/02. California Department of Transportation, Sacramento, California.
[9] Carmichael, R.F. and Marienfeld, M.L.: 1999, Synthesis and Literature Review of Nonwoven Paving Fabrics Performance in Overlays, In Transportation Research Record No. 1687, Geotechnical Aspects of Pavements, TRB National Research Council, Washington, D.C., pp 112-124.
[10] Sprague, C.J.: 2006, Study of the Cost-Effectiveness of Various Flexible Pavement Maintenance Treatments, In Transportation Research Circular Maintenance Management 2008. Presentations from the 11th AASHTO-TRB Maintenance Management Conference, Number E-C098.TRB, National Research Council, Washington D.C, pp 45-53.
[11] Young, S.D. Sung, H.B. and Kwang, W.K.: 2009, Estimation of relative performance of reinforced overlaid asphalt concretes against reflection cracking due to bending more fracture, Construction and Building Materials, Volume 23, Issue 5, Pages 1803-1807.
[12] ASTM.: 2010, Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device, ASTM D4694 – 09, Volume 04.03.
[13] AASHTO.: 1993, AASHTO Guide for Design of Pavement Structures, AASHTO, Washington D.C., USA.