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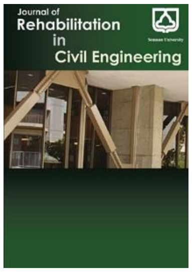

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Study on Drainage of Pavement Layers and Improvement Strategies: Case Study

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ABSTRACT

Road infrastructure facilities have a crucial role in the development of countries by providing connectivity of cities for humans and goods. Moisture intrusion is one of the main pavement damages that can decline the pavement surface conditions and reduce structural strength and load-carrying capacity. The design of the pavement layers needs to collect data about soil properties, regional precipitation, pavement geometries, surface and subsurface drainage properties, and vehicular traffic. In this study, the drainage of the pavement layers of Qom-Kashan Freeway (Amirkabir Freeway) located in Iran has been investigated. In experimental studies, the classification, physical and chemical properties, Atterberg limits and Sand Equivalent (SE), density and moisture of the pavement layers, the load-bearing capacity of the pavement layers materials, and drainage system quality have been evaluated. The classification of materials is mostly of the type (GW-GM) A-1-a and (GP-GM) A-1-b, which are suitable materials for the implementation of the subgrade, sub-base, and base layers. The percentage of weight loss of materials of the sub-base and base layers, with Los Angeles and sodium sulfate abrasion tests, is within the allowable limits. Results of the test of Atterberg limits determination of the pavement layers indicate that most of the materials in the subgrade, sub-base, and base layers are non-plastic (NP). So, the problem of swelling is not observed in these layers. To prevent water permeation into the pavement body, destruction of the bottom layers, and pumping the paving materials, four strategies have been suggested and applied to improve the drainage performance.

1. Introduction

The strength and durability of the pavement reduce by moisture intrusion into flexible pavements. Moisture intrusion into the pavement subgrade can accelerate pavement damage and cause subgrade softening and

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frost action. A suitable drainage system can prevent the entering of moisture into the pavement layers and subgrade and reduce the damage chance [1-3].

Harrigan [4] has studied the positive effect of an edge drain. Appling the edge drain in flexible pavements without a drainage layer decreases fatigue cracking and a more cost-effective design. Additionally, improper drainage maintenance can accelerate pavement damage. Because improperly designed or poorly constructed drainage systems trap moisture inside the pavement structures [5]. Ji and Nantung [6] have researched the moisture of pavement subgrade. So that, increasing pavement subgrade moisture value 2% above optimum moisture value reduces the subgrade resilient modulus as much as 25%. Also, the results of another research have indicated that subgrade moisture values 8% more than optimum can decrease 50% the pavement life and increase 32% construction costs [7]. Moreover, Zaghloul et al. [8] have indicated that a 29% reduction of the moisture value can increase 6 years the flexible pavement service life.

The design of the pavement layers needs to collect data about soil properties, regional precipitation, pavement geometries, surface and subsurface drainage properties, and vehicular traffic [9]. So that, the drainage time parameter (t) is influenced by these above-mentioned data. According to AASHTO [10] design guide, the drainage time parameter has determined the drainage quality of a layer. The drainage time is the required time for 50% draining of the free moisture at saturation conditions in a pavement system.

As defined by AASHTO [10], the drainage quality has a direct effect on the pavement structural number, layer thicknesses design, and pavement performance by applying the drainage coefficient (Cd) for rigid pavements, and the drainage modifier (m) for flexible pavements.

Ji et al. [11] found that the drainage capacity depends on the effect of pavement drainage length, slope, permeability coefficient, and structure design. In this research, they have provided guides for the design of double-layer porous asphalt pavement in different rainfall intensity areas, and the related engineering design.

Farukh and Ravekar [12] found the pavement service life is increased 50% if infiltrated water can be drained off without delay.

Strength reduction in subgrade and base and sub-base, swelling of subgrade soils, asphalt stripping in flexible pavements, strength reduction during frost, and fine particle movement into base and sub-base are deteriorations and damages that can happen due to moisture intrusion [13].

Thus, investigation of the effect of various types of drainage quality on the performance of the pavement and selecting appropriate maintenance strategies is a critical requirement for ensuring stability, preventing the failure of pavement, and reducing the costs of pavement maintenance [14].

The results obtained by Gao et al. [15] indicate that the drainage base mixture needs to have appropriate aggregate grading to ensure a good capacity of water seepage and drainage of voids. Also, the appropriate amount of binder for bounding with aggregate together stably and having enough mechanical strength under traffic load. Good workability of the drainage base mixture also is significant during paving and rolling.

The permeability and structural performance conflict with each other for asphalt stabilized drainage base material. So, the permeability will be decreased and the structural performance will be improved in dense material composition [16, 17]. Increased water content reduces the bearing capacity of the soil, increases the rate of deterioration, and shortens the service life of the road [18, 19].

This research has investigated the drainage of the pavement layers of Qom-Kashan Freeway, Iran. In experimental studies, the classification of the pavement layers materials, physical and chemical properties of the pavement layers, Atterberg limits and Sand Equivalent (SE) of the pavement layers, density and moisture of the pavement layers, the load-bearing capacity of the pavement layers, and drainage system quality have been investigated. To prevent water permeation into the pavement body, destruction of the bottom layers, and pumping the paving materials, strategies have been suggested to improve the drainage performance.

2. Case Study Definition

In this research, the drainage of pavement layers is investigated for Amirkabir Freeway, the direction of Qom-Kashan Freeway in the southeast portion of the province of Qom, and the northwest portion of the province of Isfahan, Iran (Fig. 1).

Fig. 1. Location of Kashan-Qom Freeway in the southeast portion of the province of Qom and northwest portion of the province of Isfahan, Iran

3. Experimental Studies

3.1. Classification of Pavement Layers Materials

In this section, the type of materials used in different layers of pavement has been identified and analyzed by the results of material classification tests. These results are summarized in Table 1.

According to the classification of materials in the subgrade, sub-base, and base layers, it is observed that the classification of materials is mostly of the type (GW-GM) A-1-a and (GP-GM) A-1-b, which are suitable materials for the implementation of the subgrade, sub-base, and base layers.

3.2. Physical and Chemical Properties of Pavement Layers Materials Investigation

To evaluate the quality, physical and chemical characteristics of the materials used for pavement layers in different sections of Amirkabir Freeway, the Los Angeles and sodium sulfate abrasion tests have been performed. These results are indicated in Table 2.

Table 1. Soil classification of layers of different sections of pavement.

Section	**Layer**	**Classification UNIFIED [20]**		**Classification AASHTO [21]**	
Section 1 12+700 km	subgrade	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-a (0)
	sub-base	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-b (0)
	base	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-b (0)
Section 2 30+000 km	subgrade	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-a (1)
	sub-base	poorly-graded gravel with sand and silt	GP-GM	Rubble, Gravel, and Sand	A-1-b (0)
	base	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-b (0)
Section 3 50+200 km	subgrade	Silty sand with gravel	SM	Rubble, Gravel, and Sand	A-1-b (0)
	sub-base	well-graded sand with gravel and silt	SW-SM	Rubble, Gravel, and Sand	A-1-b (0)
	base	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-b (0)
Section 3 70+200 km	subgrade	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-a (1)
	sub-base	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-b (0)
	base	poorly-graded gravel with sand and silt	GP-GM	Rubble, Gravel, and Sand	A-1-b (0)
Section 4 80+600 km	subgrade	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-a (1)
	sub-base	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-b (0)
	base	well-graded gravel with sand and silt	GW-GM	Rubble, Gravel, and Sand	A-1-b (0)

Table 2. Los Angeles and sodium sulfate abrasion tests results.

km	Section 4 80+600 km		Section 3 70+200 km		Section 3 50+200 km		Section 2 30+000 km		Section 1 12+700 km	
Layer	Sodium Sulfate	Los Angeles	Sodium Sulfate	Los Angeles	Sodium Sulfate	Los Angeles	Sodium Sulfate	Los Angeles	Sodium Sulfate	Los Angeles
subgrade	0.3	---	0.2	---	0.4	---	0.3	---	0.5	---
sub-base	0.2	20%	0.3	20%	0.2	19%	0.4	19%	0.3	18%
base	0.3	22%	0.2	21%	0.4	21%	0.4	21%	0.3	22%

According to ASTM C535 [22], the percentage of abrasion of materials of sub-base and base layers, with the Los Angeles abrasion test, should not exceed 50% and 45%, respectively. Also, according to AASHTO T104 [23], the percentage of weight loss of materials of the base layer, with sodium sulfate abrasion test, should not exceed 12% after five tests.

As indicated in Table 2, the percentage of weight loss of materials of subgrade, sub-base, and base layers, with Los Angeles and sodium sulfate abrasion tests, is within the allowable limits of the regulations. Thus, the materials used during the construction of the freeway have acceptable physical and chemical characteristics.

3.3. Atterberg Limits and Sand Equivalent (SE) of Pavement Layers Evaluation

In this section, the results of Atterberg limits and sand equivalent (SE) tests of the materials have been evaluated that are effective on the drainage of the lower layers and also the swelling of the soil. The results of Atterberg limits and the quality of expanding soils are shown in Table 3. The results of Plasticity Index (PI) and Sand Equivalent (SE) tests of different sections of Amirkabir Freeway are indicated in Table 4.

Table 3. Classification of expanding soils

Soil Inflation	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Soil Suction
High	More than 60	More than 35	More than 4
Medium	50-60	25-35	1.5-4
Low	Less than 50	Less than 25	Less than 1.5

Table 4. Plasticity Index (PI) and Sand Equivalent (SE) results

km	(12+700) km		(30+000) km		(50+200) km		(70+200) km		(80+600) km	
Results	PI	SE (%)	PI	SE (%)	PI	SE (%)	PI	SE (%)	PI	SE (%)
Subgrade	NP	-	NP	-	NP	-	NP	-	NP	-
Sub-base	NP	35	NP	37	NP	30	NP	28	NP	32
Base	NP	32	NP	39	NP	33	NP	33	NP	34

According to Table 3 and Table 4, most of the materials in the subgrade, sub-base, and base layers are non-plastic (NP), so the problem of swelling is not observed in these layers.

According to General Technical Specifications of the Road [24]: the minimum value of Sand Equivalent (SE) in the sub-base layer is 25%, and also according to General Technical Specifications of the Road [24]: the minimum value of Sand Equivalent (SE) in the base layer is 40%. In all sections of Amirkabir Freeway, the value of SE for the base layer is less than the allowable limit. It can be due to the occurrence of the pumping phenomenon and the coming up of mud from the lower layers, which is below the cutting sections.

3.4. Density and Moisture of Pavement Layers Investigation

To determine the strength of pavement layers and also to study the drainage of pavement layers, the percentage of density and the percentage of moisture of the layers have been determined, the results of which are given in Tables 6 to 9.

The results of subgrade soil granulation and classification are shown in Table 1. The subgrade soil is coarse-grained in all sections, which according to Table 5 (General Technical Specifications of the Road [24]), the subgrade layer density in Amirkabir Freeway is 100%.

Table 5. Density of subgrade layer

Type of Way	Relative density of all layers less than 30 cm of subgrade		Relative density of layers between 30 cm to subgrade	
	with fine-grained soil	with coarse-grained soil	with fine-grained soil	with coarse-grained soil
Freeway - Highway - Main road and first-class side road	90%	95%	95%	100%
Secondary side roads and rural roads	87%	92%	90%	95%

Table 6. Density and moisture of layers in section 1.

km	Section 1, 12+700 km	
Layer	Density	Moisture
subgrade	89%	11.00%
sub-base	100%	4.00%
base	99%	4.60%

As indicated in Table 6, due to the high percentage of moisture in the subgrade layer in section 1, the occurrence of the pumping phenomenon and the movement of water from the bottom layers to the top have been witnessed. Also, the percentage of density is lower than the allowable limit in the subgrade layer, which has caused structural weakness and reduced the bearing capacity of this section.

Table 7. Density and moisture of layers in section 2

km Layer	Section 2, 30+000 km	
	Density	Moisture
subgrade	93%	6.25%
sub-base	89%	5.90%
base	90%	6.90%

According to Table 7, the density percentage in the subgrade, sub-base, and base layers has caused structural weakness and reduced bearing capacity in section 2.

Table 8. Density and moisture of layers in section 3

km Layer	Section 3, 50+200 km		Section 3, 70+200 km	
	Density	Moisture	Density	Moisture
subgrade	95%	5.10%	100%	6.90%
sub-base	95%	5.40%	95%	7.60%
base	93%	6.00%	96%	6.80%

The density percentage in the subgrade, sub-base, and base layers, at 50 + 200 km and also the sub-base and base layers, at 70 + 200 km has caused structural weakness and reduced bearing capacity in section 3.

Table 9. Density and moisture of layers in section 4

km Layer	Section 4, 80+600 km	
	Density	Moisture
subgrade	97%	4.60%
sub-base	98%	5.60%
base	97%	4.50%

The density percentage in the subgrade, sub-base, and base layers has caused structural weakness and reduced bearing capacity in section 4.

As the test results indicate the percentage of the density of the freeway pavement layers in all four sections do not have the minimum required density, which has reduced the load-bearing capacity and weakness of pavement structures.

3.5. Load-Bearing Capacity of Pavement Layers Investigation

CBR (California Bearing Ratio) test results were used to analyze the load-bearing condition of pavement layers in different sections of the Freeway. According to General Technical Specifications of the Road [24]: the load-bearing capacity of the materials of the sub-base layer, which is done by AASHTO T193 [25] or ASTM D1883 [26] in the laboratory on samples with 100% density and AASHTO T180 [27] (method D), should not be less than 30%. Also, according to General Technical Specifications of the Road [24]: the bearing capacity of the materials of the base layer, which is done by AASHTO T193 [25] or ASTM D1883 [26] in the laboratory on samples with 100% density and AASHTO T180 [27] (method D), should not be less than 80%. As shown in Fig. 2 and Fig. 3, the load-bearing capacity of the subgrade layers in different sections is more than 20%, which is suitable for the subgrade layer. Also, for the sub-base layer, all sections of the Freeway cover the minimum amount of regulations.

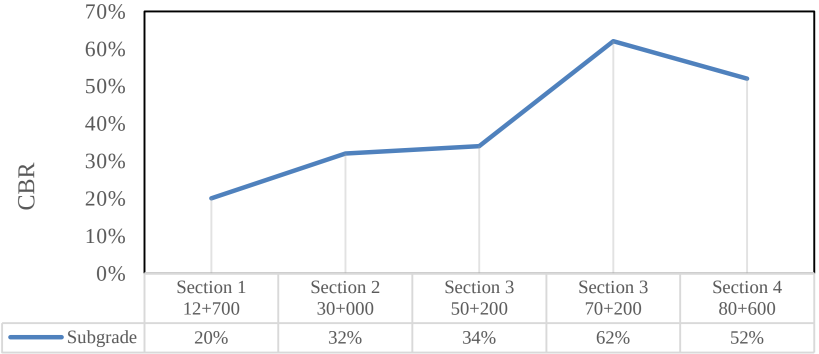

Fig. 2. CBR of subgrade layer in different sections of Freeway

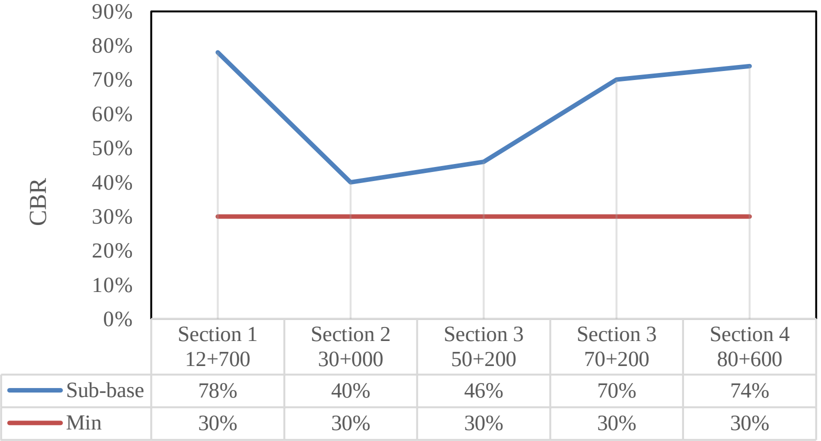

Fig. 3. CBR of sub-base layer in different sections of Freeway.

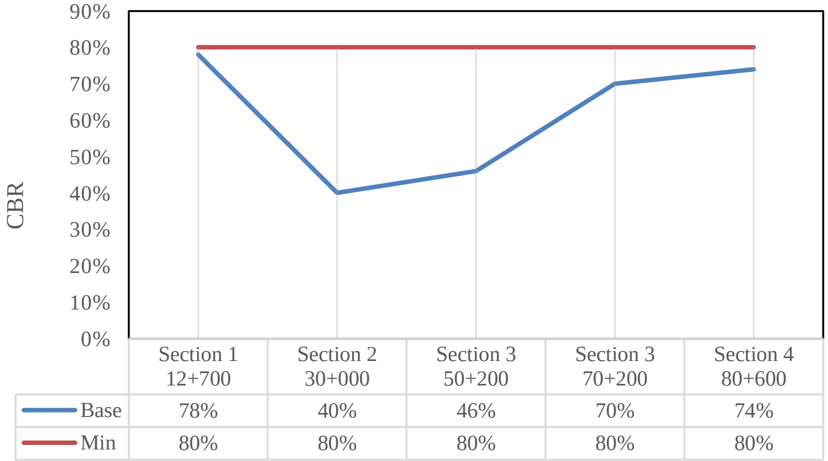

Fig. 4. CBR of the base layer in different sections of Freeway.

As indicated in Fig. 4, it is clear that the California Bearing Ratio (CBR) of the base layer in all sections of the Freeway is less than 80%, required according to General Technical Specifications of the Road [24], which is structurally problematic.

One of the improvement strategies is to stabilize the base layer using cement or lime. Because, in-field observations, when improving the asphalt surface after 7 to 12 cm scraping and cutting of asphalt surface in some sections, such as 30 km (backward side), deep and open reflective cracks are indicated and the destruction of the lower layers of the pavement is visible. Figs. 5 to 7 indicate these reflective cracks.

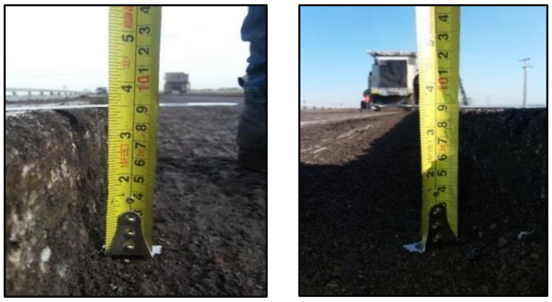

Fig. 5. 7 to 12 cm scraping and cutting of asphalt surface at 30 km (backward side)

Fig. 6. Reflective cracks after 7 cm scraping and cutting.

Fig. 7. Reflective cracks after 10 cm scraping and cutting.

3.6. Drainage System Quality Investigation

Inappropriate drainage and the presence of free water in the base and sub-base layers reduce the elasticity modulus of these layers by more than 50%. Drainage quality for non-asphalt materials of the pavement structure is defined in terms of the length of time after drainage that the water remaining in these materials reaches about 50% of saturated moisture (wet state) [24]. With this definition, pavement materials are divided into five classes in terms of drainage properties and water outlet speed, which are shown in Table 10.

Table 10. Classification of materials in terms of drainage properties.

Drainage Quality	Drainage Time
Excellent	2 hours
Good	1 day
Acceptable	1weak
Weak	1 month
Very weak	It is not repelled

The effect of the amount and quality of drainage is considered by applying the correction coefficients m_i to the layers coefficients, which are described in Eq.(1).

$$SN = \frac{1}{2.5}\left(a_1 D_1 + a_2 m_2 D_2 + a_3 m_3 D_3\right) \qquad (1)$$

where SN is the structural number, m_2 and m_3 are the drainage correction coefficients of the base and sub-base layers, respectively. These coefficients, as a function of drainage quality and the percentage of time that the moisture content of the pavement layers during their service life is close to saturation, are shown in Table 11.

Table 11. Drainage correction coefficients of the base and sub-base layers

Drainage Quality	Percentage of time that the moisture content of the pavement layers is close to saturation		
	Rainfall up to 5%	Rainfall between 5% to 25%	Rainfall more than 25%
Excellent	1.30-1.40	1.20-1.30	1.20
Good	1.15-1.35	1.00-1.15	1.00
Acceptable	1.05-1.25	0.80-1.00	0.80
Weak	0.80-1.15	0.60-0.80	0.60
Very weak	0.75-1.15	0.40-0.75	0.40

The moisture content depends on the amount of annual rainfall, the surface drainage conditions, the different three percentages of Table 2 include 5%, 5% to 25%, and more than 25%, and the coefficients related to different drainage conditions are applicable for hot and dry, temperate and rainy regions, respectively.

As respects, the materials used in the base and sub-base layers have the same quality in terms of drainage during the Amirkabir Freeway construction. It is mainly consistent with the "acceptable" property and above, which has an equal coefficient for each of the three rainfall percentages in Table 2.

However, studies conducted from different sections of Amirkabir Freeway, especially, in two sections of 30 km and 50 km, indicate a lack of proper maintenance of the pavement and right of the road, water permeation from the pavement cracks to the lower layers of the pavement and its non-exit. So, the phenomenon of water scouring of pavement materials has occurred and the initial quality of materials has been lost. In these two sections, after cutting layers, it can be seen the exit of mud from the cracks in Figs. 8 to 12.

Fig. 8. Section 2 of 24 km, movement of mud from the lower layers to the upper layers after precipitation.

Fig. 9. Section 2 of 23 km, movement of mud from the lower layers to the upper layers after precipitation.

Fig. 10. Section 2 of 30 km, movement of mud from the lower layers to the upper layers after precipitation.

Also, after one month of improvement in the section of 30 km, due to the occurrence of precipitation in April and the pumping phenomenon, mud is again observed on the improved asphalt. So, the movement of mud from the lower layers to the upper layers can pave and close the springs in the base and sub-base layers and cause the inability of the base and sub-base layers to drain and water outflow.

Fig. 11. Section 2 of 23 km, removal of mud from the cracks after cutting the top layer.

In section 2 of 30 km and section 3 of 50 km, it has been observed that mud has come up from the reflective cracks after cutting the upper layer with a thickness of 7 cm. In section 2 of 30 km, after precipitation in March and spring, after spotting, due to the pumping phenomenon, mud has been pumped from the lower layers to the pavement surface.

Fig. 12. Section 2 of 22 km, removal of mud from the cracks after cutting the top layer.

According to the above information and Table 12, the drainage coefficient of the base and sub-base layers has been considered 1 and 0.8, respectively.

Table 12. Drainage coefficients of pavement layers (General Technical Specifications of the Road [24])

Pavement Layer	Pavement Condition	Drainage Coefficient
Surface and Liner Asphalt	no mosaic cracks, or very few cracks, or only low-intensity transverse cracks	0.35-0.40
	low-intensity mosaic cracks- less than 10% or medium to high-intensity transverse cracks- less than 5%	0.25-0.35
	low-intensity mosaic cracks- more than 10%, or medium-intensity mosaic cracks- less than 10% or medium to high-intensity transverse cracks- 5 to 10%	0.20-0.30
	medium-intensity mosaic cracks- more than 10%, or high-intensity mosaic cracks- less than 10% or medium to high-intensity transverse cracks- more than 10%	0.14-0.20
	high-intensity mosaic cracks- more than 10% or high-intensity transverse cracks- more than 10%	0.08-0.15

Bitumen Base	Very few or no mosaic cracks, or very few cracks or only low-intensity transverse cracks	0.20-0.35
	low-intensity mosaic cracks- less than 10% or medium to high-intensity transverse cracks- less than 5%	0.15-0.25
	low-intensity mosaic cracks- more than 10%, or medium-intensity mosaic cracks- less than 10% or medium to high-intensity transverse cracks- 5 to 10%	0.15-0.20
	medium-intensity mosaic cracks- more than 10%, or high-intensity mosaic cracks- less than 10% or medium to high-intensity transverse cracks- more than 10%	0.10-0.20
	high-intensity mosaic cracks- more than 10% or high-intensity transverse cracks- more than 10%	0.08-0.15
Base or Sub-base	unchanged materials, without fine-grained soil penetration from subgrade with initial CBR	0.10-0.14
	changed materials, with fine-grained soil penetration from subgrade and decrease drainage properties	0.00-0.10

4. Drainage Performance Improvement Strategies

To prevent water permeation into the pavement body, destruction of the bottom layers, and pumping the paving materials, the following strategies have been presented to improve the drainage performance:

- Leveling the shoulder and roadway and correcting the transverse and longitudinal slope of the roadway to prevent water from entering the pavement subgrade from around the roadway (Fig. 13).

Fig. 13. Leveling shoulder and roadway and correcting the transverse and longitudinal slope

- Dredging bridges along the pavement and roadway to guide surface water (Fig. 14).

Fig. 14. Dredging bridges along the roadway to guide surface water.

- Construction of longitudinal drainage channels with a depth of two to three meters and filling them with rubble (Fig. 15).

This strategy is applicable where the groundwater level is high and prone to pumpings, such as 30 to 10 km and 55 to 45 km. Transverse drainage channels can also be used to drain water from the pavement layers at the bottom of the road, such as 30 km, 50 km, and 6 other sections on the freeway.

Fig. 15. Longitudinal drainage channel

- Reinforcement of derivations and dredging upstream and downstream of bridges to prevent water accumulation in the roadway (Fig. 16).

Fig. 16. Reinforcement of derivations and creating a water pit in the bottom line of the region to prevent flood entering and destruction of the Freeway.

5. Conclusion

Moisture intrusion into the pavement subgrade can accelerate pavement damage and cause subgrade softening and frost action. A suitable drainage system can prevent the entering of moisture into the pavement layers and subgrade and reduce the damage chance. This research has investigated the drainage of the pavement layers of Qom-Kashan Freeway, Iran.

The results of the classification of materials in the subgrade, sub-base, and base layers indicate that the classification of materials is mostly of the type (GW-GM) A-1-a and (GP-GM) A-1-b, which are suitable materials for the implementation of the subgrade, sub-base, and base layers.

The percentage of weight loss of materials of the sub-base and base layers, with Los Angeles and sodium sulfate abrasion tests, is within the allowable limits according to ASTM C535 [22] (should not exceed 50% and 45%, respectively, with Los Angeles abrasion test) and AASHTO T104 [23] (should not exceed 12% after five tests with sodium sulfate abrasion test). Thus, the materials used during the construction of the freeway have acceptable physical and chemical characteristics.

Results of the test of Atterberg limits determination of the pavement layers indicate that most of the materials in the subgrade, sub-base, and base layers are non-plastic (NP). So, the problem of swelling is not observed in these layers.

Moreover, in all sections of Amirkabir Freeway, the value of SE for the base layer is less than the allowable limit (25% for the sub-base layer and 40% for the base layer). It can be due to the occurrence of the pumping phenomenon and the coming up of mud from the lower layers, which is below the cutting sections.

The subgrade layer density in Amirkabir Freeway is 100%. Because, the subgrade soil is coarse-grained in all sections.

Due to the high percentage of moisture in the subgrade layer in section 1 (12+700 km), the occurrence of the pumping phenomenon and the movement of water from the bottom layers to the top has been witnessed. Also, the percentage of density is lower than the allowable limit in the subgrade layer, which has caused structural weakness and reduced the bearing capacity of this section.

The pumping phenomenon has caused the washing of materials of sub-base and base layers. These materials have come up from inside the cracks. Thus, these layers have subsided due to traffic. So, due to changes in soil granulation, these layers do have not the initial density.

California Bearing Ratio (CBR) of the base layer in all sections of the Freeway is less than 80% (required according to General Technical Specifications of the Road [24], which is structurally problematic. One of the improvement strategies is to stabilize the base layer using cement or lime.

In two sections of 30 km and 50 km, lack of proper maintenance of the pavement and right of the road, water permeation from the pavement cracks to the lower layers of the pavement, and its non-exit have been indicated. So, the phenomenon of water scouring of pavement materials has occurred and the initial quality of materials has been lost. Also, after one month of improvement in the section of 30 km, due to the occurrence of precipitation and the pumping phenomenon, mud is again observed on the improved asphalt. So, the movement of mud from the lower layers to the upper layers can pave and close the springs in the base and sub-base layers and cause the inability of the base and sub-base layers to drain and water outflow.

To prevent water permeation into the pavement body, destruction of the bottom layers, and pumping the paving materials, the following strategies as suitable drainage approaches have been applied to improve the drainage performance system:

(I) Leveling shoulder and roadway and correcting the transverse and longitudinal slope,

(II) Dredging bridges along the roadway to guide surface water,

(III) A longitudinal drainage channel, and

(IV) Reinforcement of derivations and creating a water pit in the bottom line of the region to prevent flood entering and destruction of the Freeway.

References

[1] Hall, K.T., Correa, C.T. and Simpson, A.L. (2003a). “Performance of Flexible Pavement Maintenance Treatments in the Long-Term Pavement Performance SPS-3 Experiment”, Transportation Research Record: Journal of the Transportation Research Board, 1823(1), 47-54.

[2] Hall, K.T., Correa, C.T. and Simpson, A.L. (2003b). “Performance of Rigid Pavement Rehabilitation Treatments in the Long-Term Pavement Performance SPS-6 Experiment”, Transportation Research Record: Journal of the Transportation Research Board, 1823(1), 64-72.

[3] Ji, Y., Xie, J. and Liu, M. (2018). “Double-layer Drainage Performance of Porous Asphalt Pavement”, International Conference on Civil, Mechanical and Material Engineering, 1973(1), 48-55.

[4] Harrigan, E.T. (2002). “Performance of Pavement Subsurface Drainage”, NCHRP Research Results Digest, Issue 268, Washington DC, United States.

[5] Wyatt, T.R. and Macari, E.J. (2000). “Effectiveness Analysis of Subsurface Drainage Features Based on Design Adequacy”, Transportation Research Record: Journal of the Transportation Research Board, 1709(1), 69-77.

[6] Ji, R. and Nantung, T. (2015). “Quantification of Benefits of Subsurface Drainage on Pavement Performance in Indiana”, Transportation Research Board 94th Annual Meeting, Washington DC, United States.

[7] Arika, C.N., Canelon, D.J. and Nieber, J.L. (2009). “Subsurface Drainage Manual for Pavements in Minnesota”, Minnesota Department of Transportation.

[8] Zaghloul, S., Ayed, A., Ahmed, Z., Henderson, B., Springer, J. and Vitillo, N. (2004). “Effect of Positive Drainage on Flexible Pavement Life-Cycle Cost”, Transportation Research Record: Journal of the Transportation Research Board, 1868(1), 135-141.

[9] Mneina, A., Shalaby, A., Soliman ,S. and Kass, S. (2018). “Effects of Unbound Granular Materials Gradation Parameters on the Drainage Quality of Pavement Structures”, Innovation in Geotechnical and Material Engineering, Conference of the Transportation Association of Canada, Saskatoon, SK.

[10] AASHTO (1993). “Guide for Design of Pavement Structures”, American Association of State Highways and Transportation Officials, Washington, D.C..

[11] Ji, J., Wang, D., Suo, Z., Xu, Y. and Xu, S. (2018). “Study on direct coal liquefaction residue influence on mechanical properties of flexible pavement”, International Journal of Pavement Research and Technology, 11(4), 355-362.

[12] Farukh, Z.A. and Ravekar, V.P. (2016). "Study on Drainage Related Performance of Flexible Highway Pavements", International Journal On Recent & Innovative Trend In Technology, 2(9), 79-89.

[13] Agarwal, P.K., Gurjar, J. and Choudhary, S. (2014). "Evaluation of Effect of Drainage Quality on the Performance of Low Volume Roads in India", Journal of Advanced Research in Civil and Environmental Engineering, 1(1), 42-52.

[14] Gurjar, J., Agarwal, P.K. and Sharma, M.K. (2013). "A Framework for Quantification of Effect of Drainage Quality on Structural and Functional Performance of Pavement", International Journal of Engineering Research, 2(3), 257-263.

[15] Gao, W., Dong, N., Wang, X. and Zeng, M. (2020). "Test Analysis on Drainage Base Mixture of Asphalt Pavement in Cold Area", 4th International Workshop on Renewable Energy and Development, Sanya, China.

[16] Behnia, B., Buttlar, W.G. and Reis, H. (2014). "Cooling Cycle Effects on Low Temperature Cracking Characteristics of Asphalt Concrete Mixture", Materials and Structures, 47, 1359-1371.

[17] Li, C. (2010). "Study on Properties of Asphalt Pavement Permeable Base", Master Thesis, Northeast Forestry University.

[18] Brown, S.A., Schall, T.B., Morris, J.L., Doharty, C.L., Sterin, S.M. and Warner, J.C. (2009). "Urban drainage design Manuel", Hydraulics engineering circular, No. 22, 3rd edition , FHWA-NHI-10-009.

[19] Tamiru, G. and Ponnurangam, P. (2018). "The Effect of Poor Surface Drainage Structure on Pavement Performance – A Case Study", International Journal of Science and Research, 7(12), 443-449.

[20] ASTM D2487. (2017). "Standard Practice for Classification of Soils for Engineering", ASTM International, West Conshohocken, PA.

[21] AASHTO M145. (2021). "Classification of Soil and Soil-Aggregate Mixtures For Highway Construction Purposes", American Association of State Highways and Transportation Officials, Washington, D.C..

[22] ASTM C535. (2016). "Standard Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine", ASTM International, West Conshohocken, PA.

[23] AASHTO T104. (2020). "Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate", American Association of State Highways and Transportation Officials, Washington, D.C..

[24] "General Technical Specification of Road", (2013). No: 101, Islamic Republic of Iran Vice presidency for Strategic Planning and Supervision, Office of Deputy for Strategic Supervision Department of Technical Affairs, pp. 844.

[25] AASHTO T193. (2017). "Standard Method of Test for The California Bearing Ratio", American Association of State Highways and Transportation Officials, Washington, D.C..

[26] ASTM D1883. (2016). "Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils", ASTM International, West Conshohocken, PA.

[27] AASHTO T180. (2020). "Standard Method of Test for Moisture–Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop", American Association of State Highways and Transportation Officials, Washington, D.C..