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MINIMUM ACCEPTABLE CROSS SLOPES OF ASPHALT ROADS FOR DRAINAGE CONSIDERATION

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Abstract:

In paved roads, storm water drainage is vital. Poor drainage allows water to remain on road surface for longer time periods, which in turn will negative influences traffic safety and flow efficiency. Furthermore, it can increase the water in gress to pavement layers leading to a significantly rapid deterioration of pavement structure.

In straight segments paved roads, pavement cross-slope is essential to drain surface water away from carriageway surface. International and local experiences provide typical values for road cross slope to be used for drainage consideration without considering the characteristics of pavement surface or carriageway width. This paper focuses on establishing practical design criteria and CAD simulation that can help in selecting the minimum accepted pavement cross-slope for drainage taking into consideration the effect of pavement surface conditions, road surface characteristics, and carriageway width.

Keywords:

Surface drainage, cross slopes, mix characteristics, pavement surface conditions.

Introduction and Background:

In paved roads, storm water drainage is vital. Poor drainage allows water to remain on road surface for long periods, which in turn will negative influences traffic safety and flow efficiency.

In areas of intensive rainfall, a somewhat steeper cross slope may be needed to provide better roadway surface water drainage. In such cases, the cross slope for high-pavement types may be increased to 2.5 percent, with a corresponding crown line crossover of about 5 percent. The maximum cross slope should be limited to 4 percent, where three or more lanes are provided in each traffic direction. For all other conditions, a maximum cross slope of 2 percent should be used for high type pavements. Table (1) shows ranges of cross slope values applicable to each type of surface.

Table (1) applicable cross slops regarding surface type

Road surface type	Range in cross-slope rate (%)
High	1.5 – 2.0
Low	2.0 – 6.0

The selection of pavement type is usually determined based on the traffic loads in terms of traffic volumes and traffic composition, soil characteristics, weather, road class, the required pavement performance, availability of materials, energy conservation, initial cost, and the overall annual maintenance and life cycle cost. Attention should also be given to the use of dense or open-graded asphalt wearing surface mixes (1).

Because of the nature of the used surface materials and surface irregularities, low-type surfaces such as earth, gravel, base course or surface dressing need steeper road cross slope on tangents to prevent the absorption of water into the surface. Therefore, cross slopes greater than 2 percent may be considered on these types of surfaces.

A cross slope greater than 1 percent is desirable, and in some cases, a cross slope of more than 1.5 percent is needed to limit inundation to about half of the outer traffic lane. A cross slope of 1.5 percent is suggested as a practical minimum for curbed high-type pavement. Curbs with steeper adjacent gutter sections may permit the use of lesser rates of cross slope. A preferred cross-section treatment is the use of a straight shoulder slope and the avoidance of curbs, whenever practical (1).

The cross slop calculated and affected by gully spacing. A slight variation in cross fall will result in a significant effect in gully spacing in particular on flat sections. As illustrated in Figure (2), an increase in cross fall from 2.5% to 3.0% can increase gully spacing by about 25%. Therefore, a suitable cross fall should be adopted to avoid having gullies at unnecessarily close spacing. On roads with moderate or steep gradients, a suitable cross fall should be provided to ensure surface water flows obliquely to the curb side channels rather than longitudinally along the length of the road. The Transport Planning and Design Manual TPDM suggest a standard cross fall of 2.5%. However, to facilitate surface drainage, a minimum cross fall shall be provided as given in Table (2), except where required along transitions (2).

Table (2) Minimum cross fall

Longitudinal Gradient	**Minimum Cross fall**
1% or less	3%
5% or more	3%
between 1% and 5%	2.50%

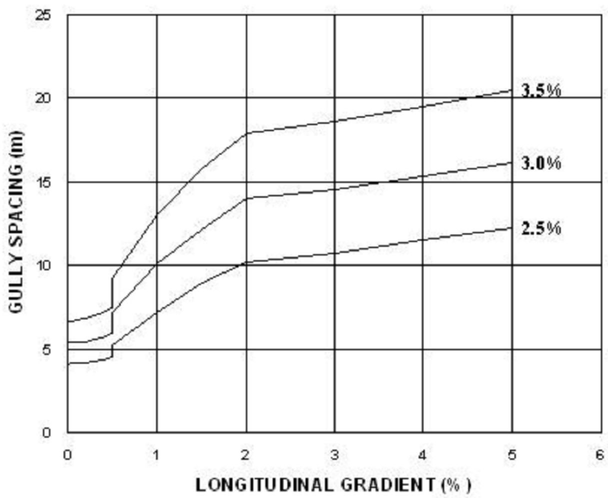


Figure (1) the effect of longitudinal gradient on gully spacing

Concerning minimum grades, flat and level grades may be used on uncurbed roadways without objection, as long as the pavement is adequately crowned to drain the surface laterally. The preferred minimum grade for curbed pavements is 0.5 percent, but a grade of 0.3 percent may be used where there is a high-type pavement accurately crowned and supported on firm subgrade (3).

Cross sections must represent the stream geometry and contain the highest expected water-surface elevation to be considered the community may designate a floodway that will convey the 100-year flood without increasing the water surface elevation of the flood more than 1 ft. (0.3 m) at any point (4).

The equations used to calculate the time off the water flow calculated using the Sheet (Overland) Flow equation.

The travel time obtained from the modified Manning's kinematic solution and is determined in hours, modified from equation (1)

Equation (1) is given by:

$$T_{t1} = \frac{0.007(nL_1)^{0.8}}{P_2^{\,0.5} s^{0.4}}$$

Where:
T_{t1} = Travel time for overland flow (hr)
P_2 = 2-year, 24-hour rainfall depth (in)
n = Manning's roughness coefficient for sheet flow
L_1 = Portion of hydraulic length on which sheet flow takes place (ft)
s = Average slope of the hydraulic length
L_1 (ft/ft)

- The maximum for L1 is 100 feet for unpaved Surfaces and 150 feet for paved surfaces (5). The Manning's equation for uniform flow is the most commonly used conveyance relation in highway drainage design. Manning's roughness coefficients (n values) determined by vegetation type and density, material (rock type, clay soil, gravel), trash, streambed shape, cross section geometry, and any item that may affect stream flow during normal and flood conditions (4), But doesn't take in consideration the paved surface Raveling and cracks occurred by time.

Figure (2) shows the different types of cracks Alligator fatigue cracking, Longitudinal cracks and Non-wheel path cracks

Figures (2): shows the different types of cracks; alligator (fatigue) cracking, longitudinal cracks and non-wheel path cracks.

Research Objectives:

This paper aims to help in selecting the critical cross slop percent needed to facilitate roadway drainage in the critical case of having flat or level grades (0% longitudinal grade) taking in consideration the effect of pavement surface conditions, characteristics of asphalt mix, carriageway width and the rain fall intensity. The results of this paper can also help selecting types of pavement with respect to the amount of rain fall intensity in the entire area.

Research Methodology:

To achieve the desired research objectives a research methodology consists of the following two phases is followed.

Phase one involves the preparing ten asphalt mix specimens five are made from smooth mix (surface course type 4C) and the other five are made from rough mix (binder course type 3D.) All specimens have the same dimension of 10 cm length, 5 cm width, and 0.5 cm thickness as shown in Figure (3)

The asphalt specimens were carefully analyzed to measure the percent and dimension of the surface cracks and groves in each type using X -ray to determine the depth of the crack and inner dimension of the cracks and also microscopic pictures was analyzed to the specimen surface to measure the actual water flow path length

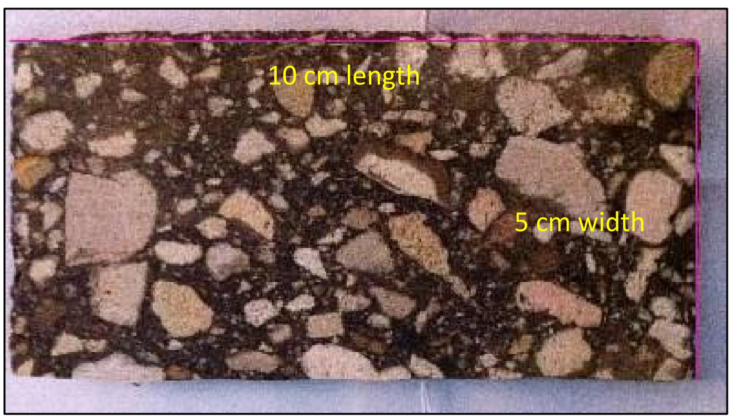


Figure (3) specimen dimension

Phase two CAD simulation model was build using Autodesk Storm and Sanitary Analysis 2012 program (see Figure 4) to simulate a road of width 10 m with variable cross slope ranging from 0 to 4 % and a storm was designed with different rainfall amount ranged from 5 to 50 mm /day. These range was estimated to cover the amount of rain falls values in Egypt specially Cairo and Alexandria as shown in Tables (3) and (4).

Table (3) this table is for the amount of rainfall in millimeters and number of rainy days in Alexandria throughout the year.

Month:	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Total rainfall in MM	52.8	29.2	14.3	3.6	1.3	0.01	0.03	0.1	0.8	9.4	31.7	52.7
Total number of rainy days	11	8.9	6	1.9	1	0.04	0.04	0.04	0.2	2.9	5.4	9.5

Source: world climates (7)

Table (4) this table is for the amount of rainfall in millimeters and number of rainy days in Cairo throughout the year.

Month:	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Total rainfall in MM	5	3.8	3.8	1.1	0.5	0.1	0	0	0	0.7	3.8	5.9
Total number of rainy days	3.5	2.7	1.9	0.9	0.5	0.1	0	0	0	0.5	1.3	2.8

Source: world climates (7)

Also the manning roughness was taken 0.013 for the smooth mix (surface course type 4C) and 0.016 for the rough mix (8) (binder course type 3D) and the flow length was calculated for each asphalt mix from phase one.

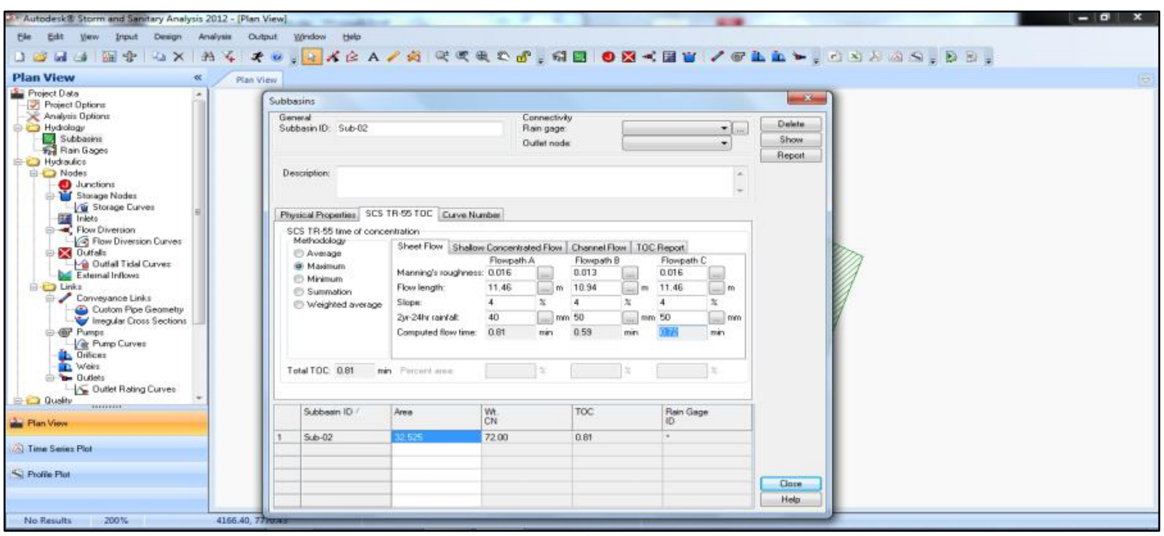
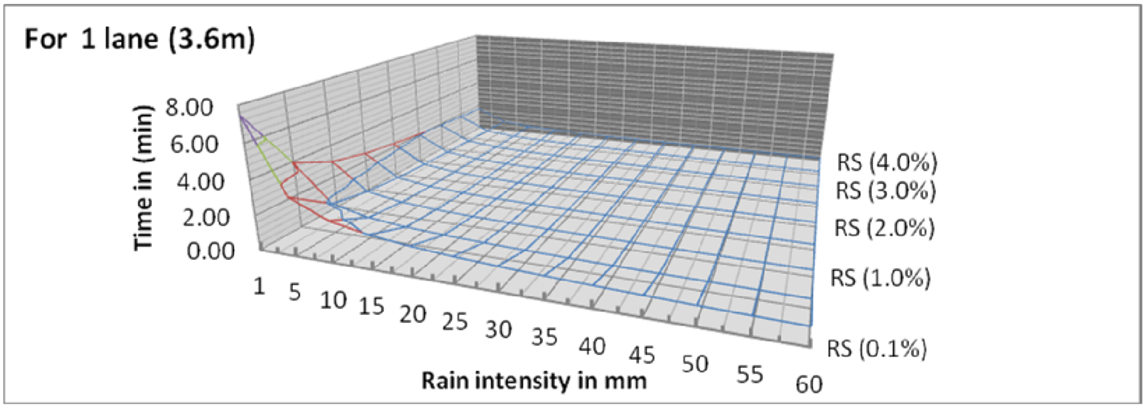


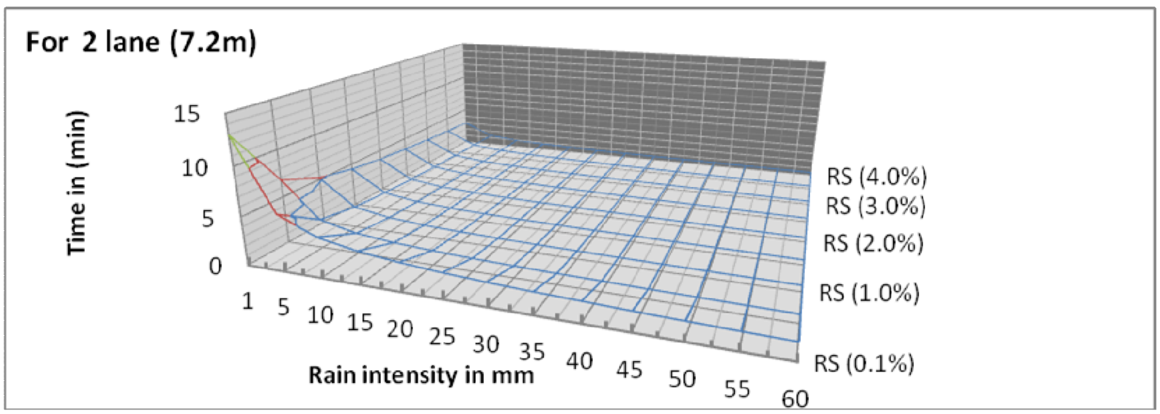
Figure (4) CAD simulation model using Autodesk Storm and Sanitary Analysis 2012 program.

By using the Autodesk storm and sanitary analysis the following charts was designed



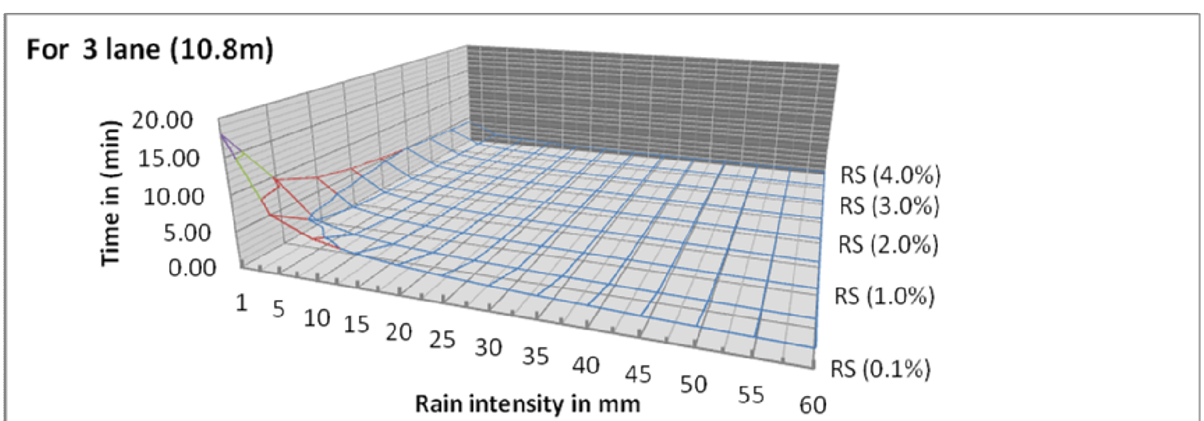
to illustrate the relation between the road widths, side slope with the rain intensity.

Figure (5): Shows the time of rains remains on the road surface consist of 1 lane with



manning coefficient 0.013 with different Cross slope (RS) and rain intensity.

Figure (6): Shows the time of rains remains on the road surface consist of 2 lanes with



manning coefficient 0.013 with different side slope (RS) and rain intensity.

Figure (7): Shows the time of rains remains on the road surface consist of 3 lanes with manning coefficient 0.013 with different side slope (RS) and rain intensity.

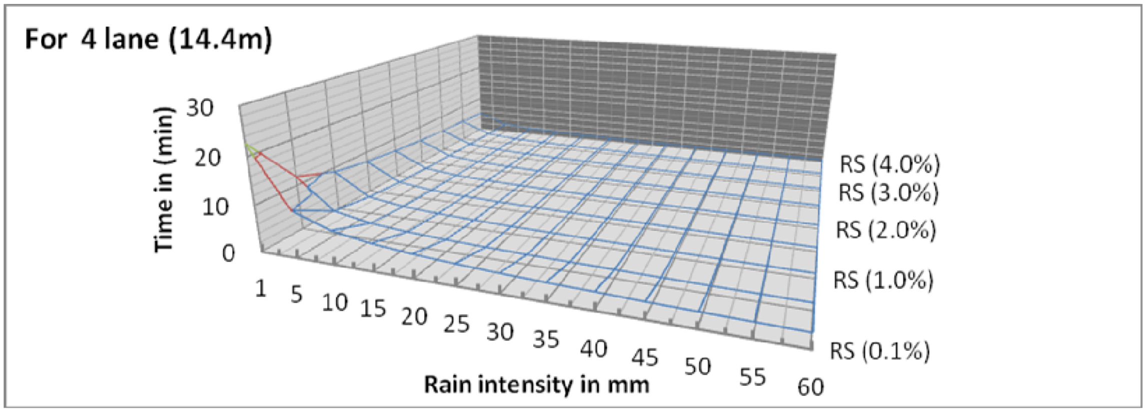


Figure (8): Shows the time of rains remains on the road surface consist of 4 lanes with manning coefficient 0.013 with different side slope (RS) and rain intensity.

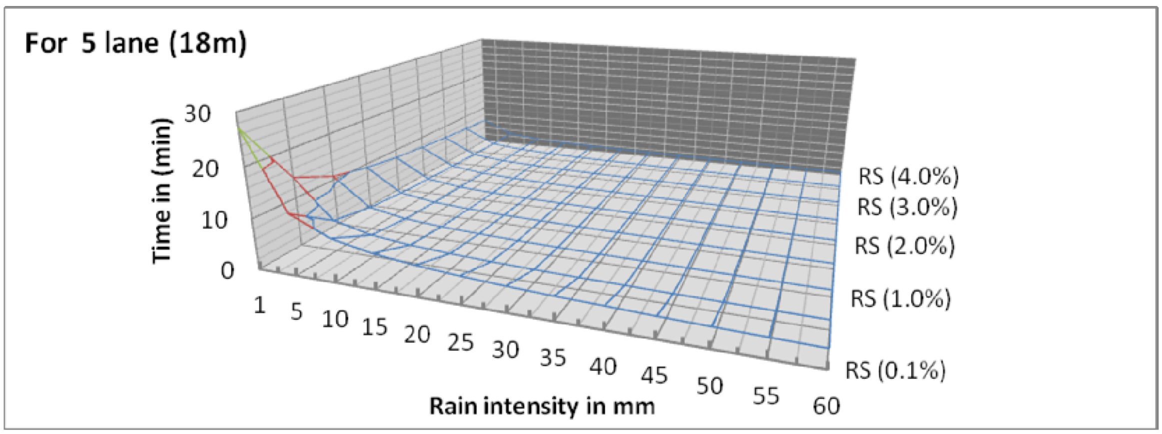


Figure (9): Shows the time of rains remains on the road surface consist of 5 lanes with manning coefficient 0.013 with different side slope (RS) and rain intensity.

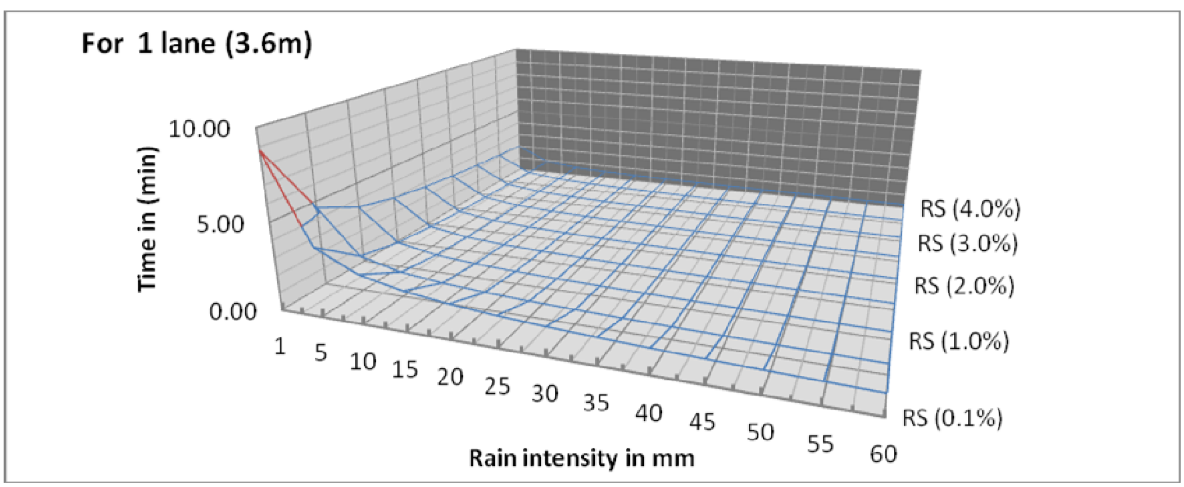


Figure (10): Shows the time of rains remains on the road surface consist of 1 lane with manning coefficient 0.016 with different side slope (RS) and rain intensity.

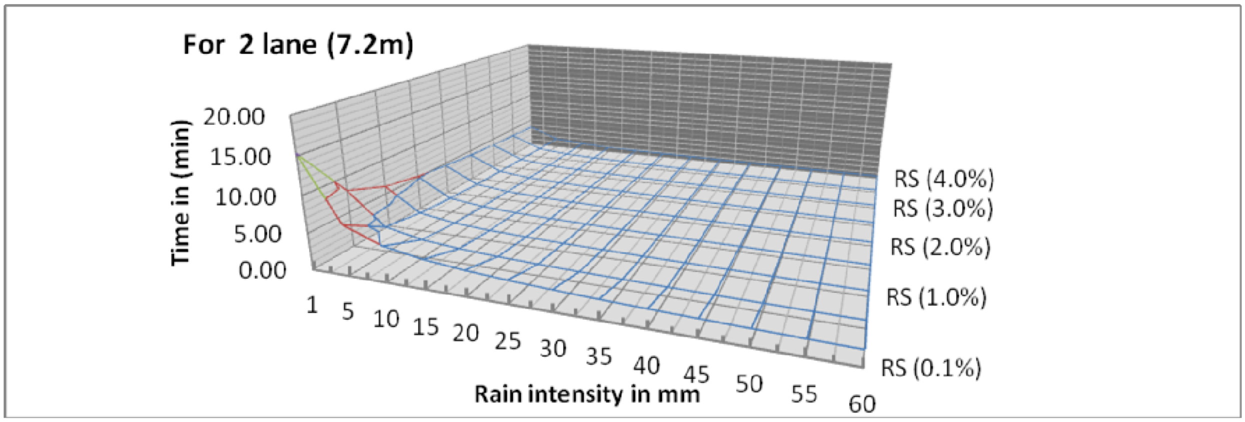


Figure (11): Shows the time of rains remains on the road surface consist of 2 lanes with manning coefficient 0.016 with different side slope (RS) and rain intensity.

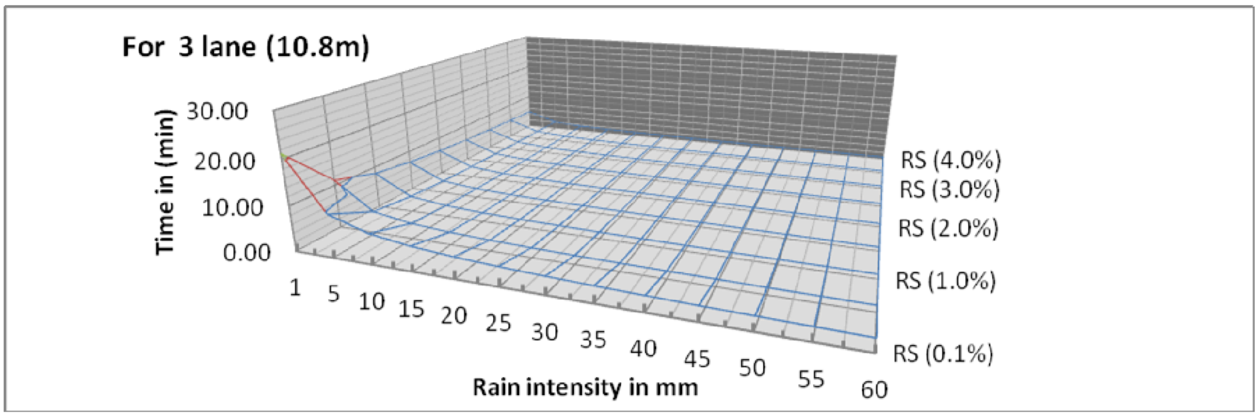


Figure (12): Shows the time of rains remains on the road surface consist of 3 lanes with manning coefficient 0.016 with different side slope (RS) and rain intensity.

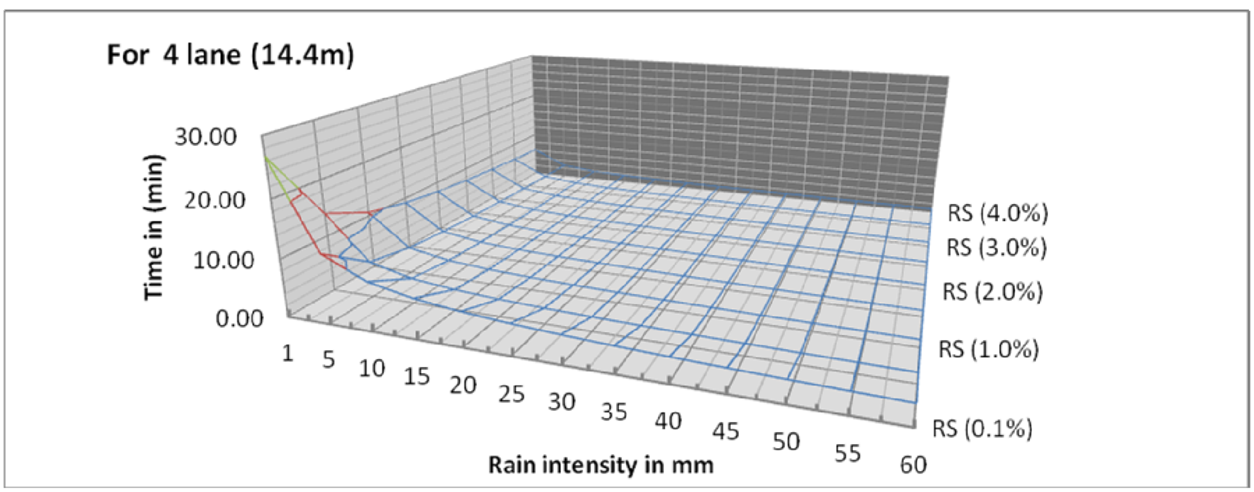


Figure (13): Shows the time of rains remains on the road surface consist of 4 lanes with manning coefficient 0.016 with different side slope (RS) and rain intensity.

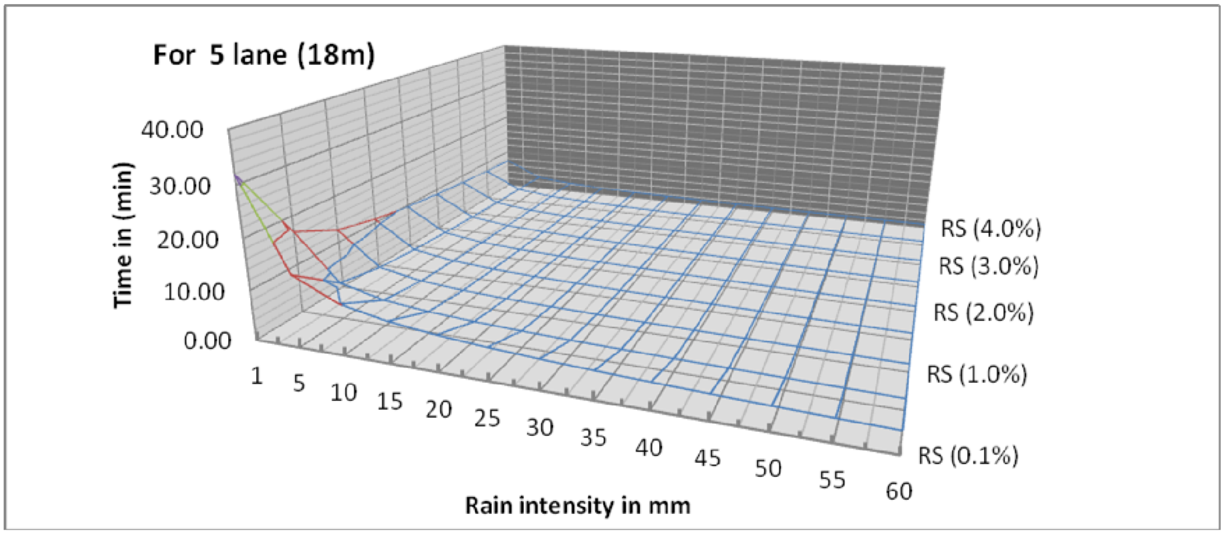


Figure (14): Shows the time of rains remains on the road surface consist of 5 lanes with manning coefficient 0.016 with different side slope (RS) and rain intensity.

Microscopic measurements of water flow

Microscopic measurements of the water flow length as shown in Figure (15) are done to determine the location and dimensions of the cracks inside asphalt specimens. The results are shown in Figures (21) through (23).

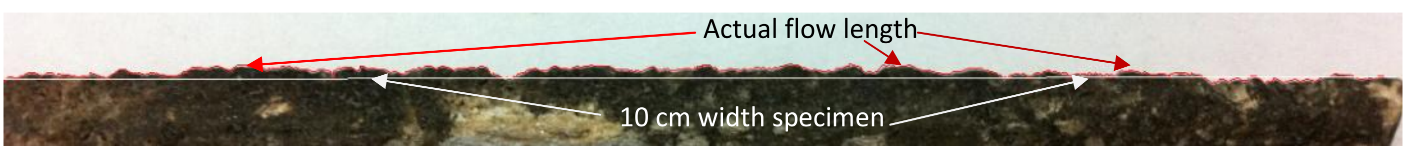


Figure (15) section in the specimen showing the length of the flow path

Figure (16) surface crack appears in the surface of the specimens

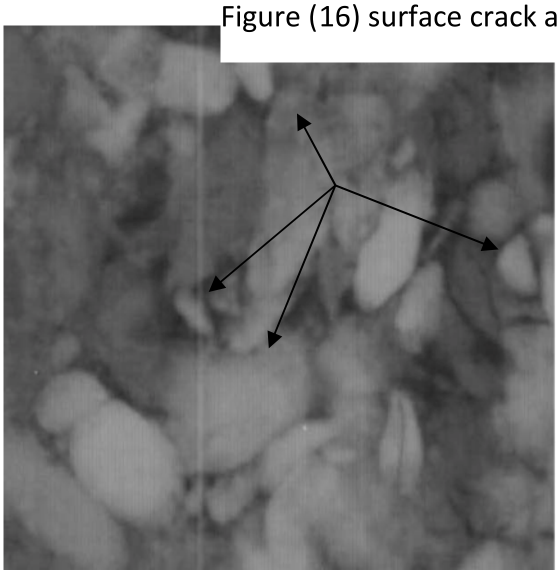


Figure (17) hair cracks appears in the x-ray picture

Figure (18) deep cracks detected in the specimens

From calculating and measuring, the water flow length on both types of mixture it was resulted that the rough asphalt mix water flow length was 11.46 cm which is more than the specimen width by 1.46 cm this is because the water flow throw the cracks and the rough surface which increases the water trip length by 14.6 %.

And for the smooth specimen the flow length was measured to be 10.94 cm which is more than the specimen width by 0.94 cm and about 9.4%.

This result is used as input data in the simulation model so that the data input for the smooth asphalt mix is:

a) Flow length = 10.94 m, manning coefficient (n) = 0.013, cross slop from 0 to 4% and water fall amount ranged from 5 to 50 mm the result can be summarized in Figure (19).
b) Flow length = 11.46 m, manning coefficient (n) = 0.016, cross slop from 0 to 4% and water fall amount ranged from 5 to 50 mm the result can be summarized in Figure (20).
c) Comparison between smooth and rough pavement taking in consideration Cairo weather. The results are shown in Figure (21).

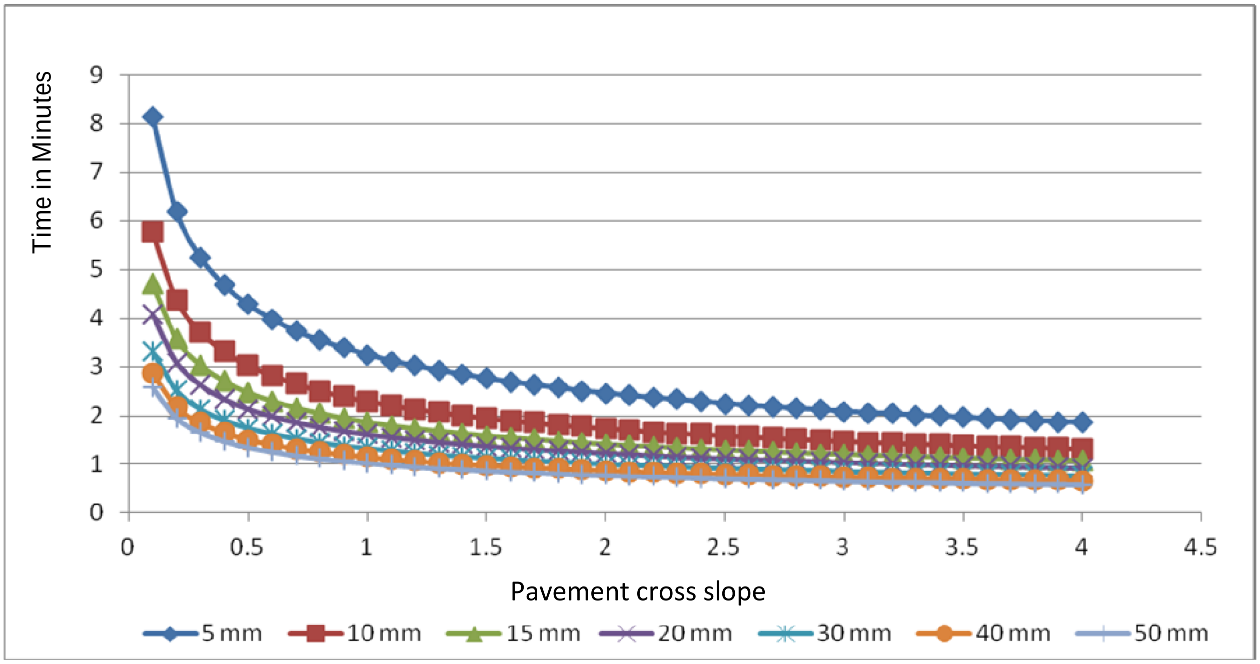


Figure (19) relationship between rain fall intensity and drainage time for smooth pavement

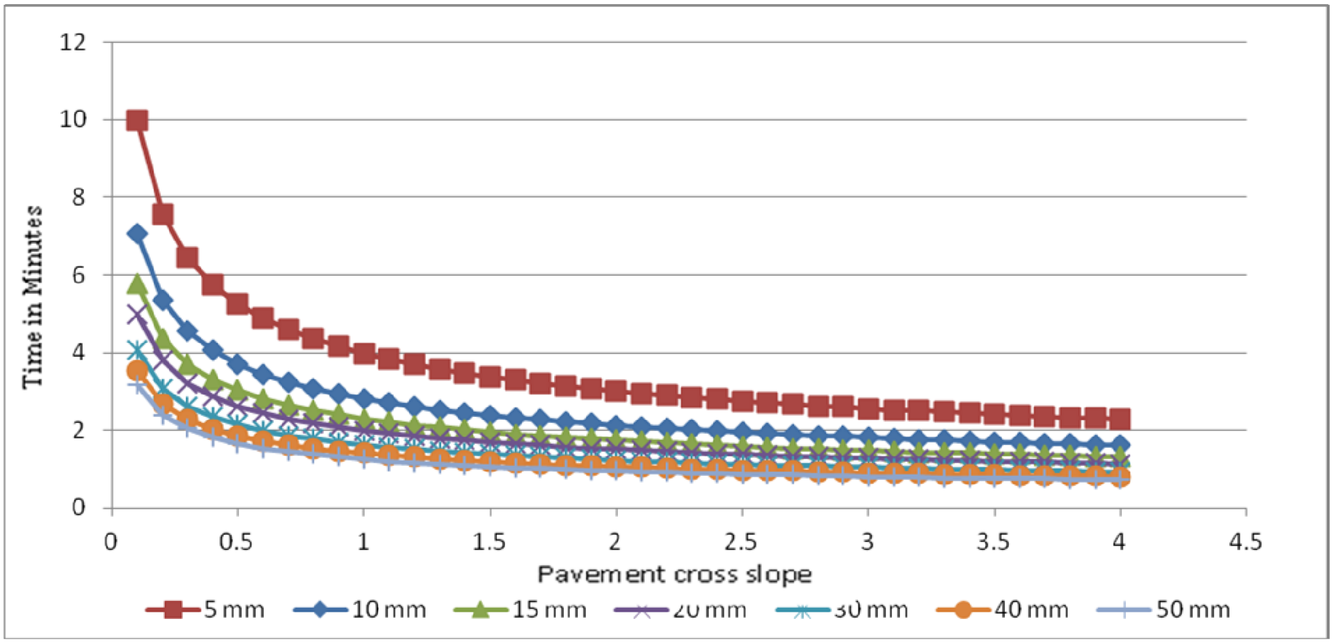


Figure (20) relationship between rain fall intensity and drainage time for rough pavement

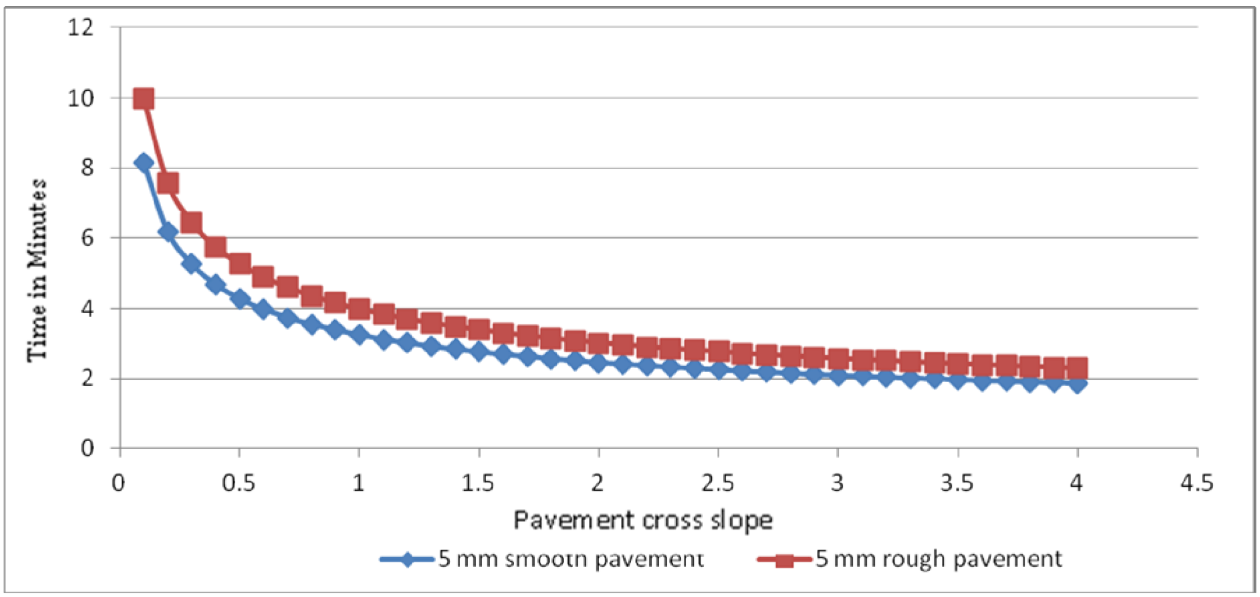


Figure (21) comparison between smooth and rough pavement drainage

Interpretation of results

The results showed that smooth asphalt road surface is more efficient in road surface drainage compared with rough asphalt road surface, as water needs less time to move from road centerline to road edge. Also the microscopic analysis of pavement surface showed that the actual flow length of surface water is influenced by the surface roughness as well as the types and intensities of pavement cracks.

Figure (19) showed that for smooth asphalt pavement surface with rain fall intensities from 10 to 40 mm, normal cross slope of 1.5% to 2.0% is required to ensure good surface drainage, as the required drainage time is almost constant (about 2 minutes). But, for rain fall intensities less than 10 mm a higher road normal cross slope is required.

Figure (20) showed that for rough asphalt pavement surface with rain fall intensities from 10 mm up to 40 mm, normal cross slope of 2.5% to 3.0% is required to ensure good surface drainage, as the required drainage time is almost constant (about 2 minutes). But, for rain fall intensities less than 10 mm it is not recommended to use rough type pavement.

Figure (22) shows that for the same rain fall intensities and same cross slope, smooth asphalt road surface requires lower drainage time than rough asphalt road surface.

Conclusions and recommendations:

- A micro-simulation model for surface water drainage is built for both smooth and rough asphalt road surfaces.
- The actual flow length of surface water on asphalt surface depending on the roughness on the asphalt surface as well as the types and intensities of pavement cracks on the pavement surface.
- The developed drainage model and drainage charts are for 0% longitudinal grades in straight segments of road with different carriageway width and the road cross section has normal crown slope of different values can be used by designers to determine the suitable cross slope according to the rain intensity and pavement type by using charts from figure 5 to figure 14.
- For smooth road asphalt surface (surface layer) and with rain fall intensities up to 40 mm, normal cross slope of 1.5% to 2.0% is required to ensure good surface water drainage. Higher pavement cross slope should be used if the rain intensities is greater than 40 mm.
- Smooth asphalt road surface is more efficient in road surface drainage for high intensity rains compared with rough asphalt road surface, as water needs lower times to move from road centerline to road edge to be drained.

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