Kufa Journal of Engineering
Vol. 11, No. 4, October 2020, P.P. 31-45
Received 18 November 2019, accepted 15 July 2020

STUDYING THE EFFECT OF HIGHWAY CHARACTERISTICS ON GUTTER DESIGN BY SIMULATION MODEL

Lamia A. Ahmed[1] and Ahmed A. Dakheel [2]

[1] Prof. Civil Engineering Department, Basrah University, Iraq. Email: lamia.jaleel@gmail.com

[2]Lecturer. Civil Engineering Department, Thi -Qar University, Iraq. Email: ahmedmsc173@gmail.com

http://dx.doi.org/10.30572/2018/kje/110403

ABSTRACT

Gutters are used to drain water way off to the Inlet. This process significantly reduces the phenomenon of hydroplaning and thus reduces traffic accidents. The main objective of this study is to evaluate the effect of the characteristics road (manning's coefficient, longitudinal slope, and cross slope) on the capacity of gutter, and spread as well as the change which was clarified for all gutters types.

Two simulation models have been developed in this study, which represent the major components of the system. These models are spread Model (SM), Gutter Capacity Model (GCM), and the first model studies spread if rain information is available, while the second model studies a gutter capacity if no rain information is available.

The study reached at the conclusion: gutter capacity is inverse proportion with manning's coefficient and directly proportional with cross slope and longitudinal slope for road. Affect spread is different according to form gutter.

KEYWORDS: Gutter, types of gutter, road drainage, Um Qaser port, hydroplaning

1. INTRODUCTION

When rain falls on a surface of pavement are framing a thin layer of water lead to increasing in thickness as it flows to the sides of the roadway see Fig. 1. This accrual of water on travel lanes can beat on the performance of a highway by decreasing the skid resistance of vehicle, detention the traffic flow, increasing potential for vehicle hydroplaning and visibility problems, and quicken roadway deformation.

Also, the water may be freezing which lead to making vehicle manoeuvre is very difficult. The main purpose of design highway drainage are diminish that problems by aggregation runoff in gutters and stoppage it by using storm water inlets that thereafter direct flow to subsurface conveyance systems, culverts, or ditches (Nicklow, 2004).

In addition it is supply to the road users a safety during the design storm. If the rainfall event with high-intensity can arise a large quantity of surface runoff which leads to water pounding and flooding in roads if the surface drainage is poorly designed and the runoff cannot be drained quickly. Poor surface drainage lead to delays to vehicles and accidents due to the reduction of skid resistance, difficulty of steering the vehicle because of pounding water ,hydroplaning, and leakage of visibility due to spray and splash. Therefore, storm drain inlets are usually using to intercept all or a portion of the accumulated runoff due to the rainfall. In order to determine the surface drainage capacity are using the gutter geometry and highway as key elements to determine surface drainage capacity (Fang, et al. 2008).

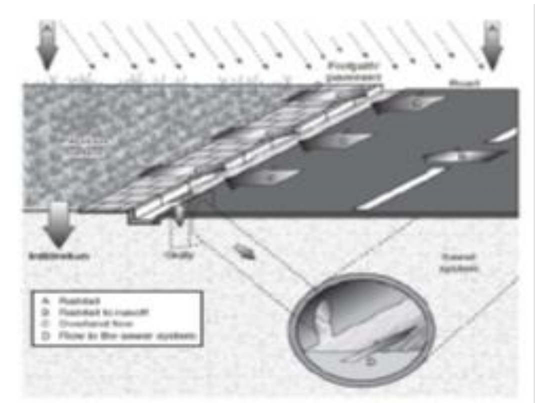

Fig. 1. Methods of road drainage (Butlers and Davies, 2004).

The principle aim that will study Studying the effect of highway characteristics on gutter capacity and spread in order to achieve the objectives can be summarizing:-

1- Development of a computer model that calculates gutter capacity.
2- Development of a computer model that calculates the spread of gutter.

2. BACK GROUND

2.1. Gutters

The pavement runoff is intercepted by using the gutters, then it carried along roadway shoulder to storm drain inlet. In urban settings the curbs installed in combination with gutters where the development of roadside not permit due to topographic conditions.

Gutters formed incorporate with curbs are available in 0.3 through 1.0 meter widths. Gutter designed with a steeper cross, usually 80 mm per meter or same as the pavement cross slope. They form a triangular channel which convey runoff equal to or less than the design flow without interruption of the traffic. When a design flow occurs, the conveyed water surface spreads to include not only the gutter width, but also parking lanes, and portions of the travelled surface (Brown S.A. et al, 2009).

2.2. Hydroplaning

As the depth of water flowing over roadway surface increases, the potential for hydroplaning increases. When a rolling tire encounters a film of water on the roadway, the water is channeled through the tire tread pattern and through the surface roughness of the pavement (Anderson et al., 1995). Hydroplaning is gliding of a car's tires across a wet surface, and it occurs when a tire face more water than it can clutter. Water pressure in the front of the wheel pushes water under the tire, and the tire is then separated from the road surface by a thin film of water and loses traction. The result is loss of steering, braking and power control. Rubber tires have sock that are designed to channel water from beneath the tire. This creates higher friction with the road surface which lead to prevent or minimize instances of hydroplaning. When speed exceeds the 89 km/hr and depth above 2mm the hydroplaning will occur (Brown S.A. et al, 2009).

2.3. Rational Method

Rational Method is famous equation used to calculation the peak flow from small areas, given as (Brown S.A. et al, 2009):

$$Q = \frac{CIA}{360} \tag{1}$$

Where;

Q : The peak Flow, m^3/s.

C: Runoff coefficient (Dimensionless).

I: Rainfall intensity for design area, mm/hr.
A: Drainage area, hectares, ha.

The important assumptions inherent in the rational formulas follows (Johnson and Ragan, 2002):

1. The drainage area must be less than 80 hectares (200 acres).

2. The peak flow occurs when the entire watershed is contributing.

3. The highest peak discharge occurs at a storm that has duration equal to time of concentration

4. The rainfall intensity is uniform over a storm time duration equal to the time of concentration.

5- The 10-year rainfall intensity is assumed to produce the 10-year peak discharge.

2.4. Gutter Capacity

The calculations of gutter flow are important to consolidate the pavement section, spread of water on the shoulder, or parking lane. To compute the flow in triangular channels must be modification of the Manning's equation because of the hydraulic radius in the equation does not adequately describe the gutter cross section when the top width of the water surface more than 40 times the depth at the curb. (Brown S.A. et al, 2009)

2.5. Gutter Types

A- Gutter Sections and Conventional Curb

Conventional gutters start at the inside base of the curb and usually extend from the curb face toward the roadway centreline a distance of 0.3 to 1 meter. This gutter can have:-

1. Conventional Gutters of Uniform Cross Slope (Fig. 2-a).
2. Composite Gutter Sections (Fig. 2-b).
3. Conventional Gutters with Curved Sections (Fig. 2-c).

As illustrated in Fig. 2. Uniform gutter sections have a cross-slope which is equal to the cross-slope of the travel lane adjacent to the gutter. Gutters having composite sections are depressed in relation to the adjacent pavement slope. That is, the paved gutter has a cross-slope which is steeper than that of the adjacent pavement. Curved gutter sections are sometimes found along older city streets or highways with curved pavement sections (Brown S.A. et al, 2009).

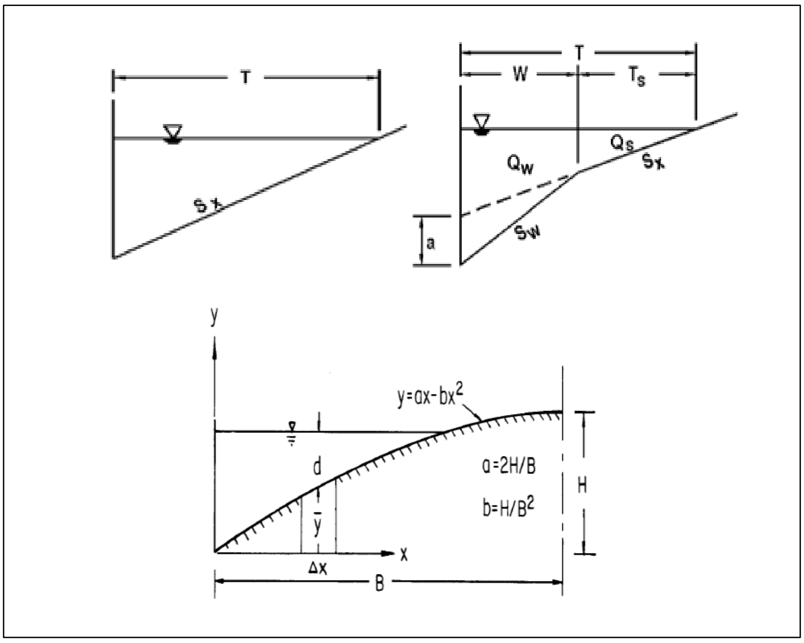

Fig. 2. Typical gutter sections Conventional Curb and Gutter Sections (Brown S.A. et al, 2009).

B- Shallow Swale Sections
This gutter contained three types:-

1. V-shape gutter (Fig. 3-a).
2. V-shape median (Fig. 3-b).
3. Circular Sections (Fig. 3-c).

As illustrated in Fig. 3 a small swale section of circular or V-shape have adequate capacity to convey runoff from the pavement to a location suitable for interception. As an example, in order to protect the embankment from erosion must be the control of pavement runoff fills (Brown S.A. et al, 2009).

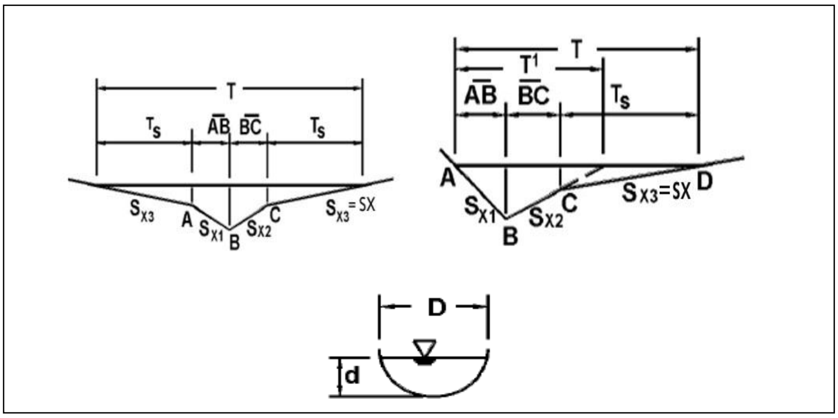

Fig. 3. Typical gutter sections Shallow Swale Sections (Brown S.A. et al, 2009).

2.6. The Basic Equations for gutter

The basic equations of gutter design are those describing variation of the three components manning's coefficient, cross slope and longitudinal slope. These equations have the following general form shown in equation (2) (Brown S.A. et al, 2009).

$$Q= (0.376/n)S_X^{1.67}SL^{0.5}T^{2.67} \quad (2)$$

$$T=[(Qn)/(0.376S_X^{1.67}SL^{0.5})]^{0.375}$$

Where;

n : Manning's coefficient.

Q : Flow rate of gutter , (m^3/s).

T : (spread) (m).

S_X : Cross slope (m/m).

SL : Longitudinal slope (m/m)

3. METHODOLOGY

Gutter capacity and spread (GCAS) model is divided into two parts: first, Spread Model (SM), shown the effect of highway characteristics on spread, the information of rain was provided to find the peak flow and spread. Rational method is computation peak flow used equation (1) and rainfall intensity, while spread calculated to different types of gutters .SM choosing the correct gutter, which owns a smaller spread, and reduces traffic accidents.

Second, Gutter Capacity Model (GCM), shown the effect of highway characteristics on gutter capacity, but lack of information, determine the design spread according to roadway types, then gutter capacity calculated for different types of gutters. GCM choosing the correct gutter, which owns a bigger capacity, and accounts for the largest amount of rain that exposed the way.

GCAS is developed based on the assumption that the manning's coefficient, cross slope and longitudinal slope as variables.But when variables constant will be use type of pavement smooth texture for manning's coefficient 0.013 (Brown S.A. et al, 2009), cross slope 2 % due to have little effect on driver effort in steering (Johnson, 1984) and optimal longitudinal slope 0.35 % (Jeong, 2008).GCAS model is divided into two parts: first, SM this part needed to find the relation of rainfall intensity in Basrah city, the relation which is proposed by Maha (2013):

$$\mathbf{I} = \frac{7.95\, Tr^{297.85\times10^{-3}}}{tc^{666.67\times10^{-3}}} \quad (3)$$

Where;

I : Rainfall intensity (mm/hr).

Tr: Return period (year).

tc: Time concentration (hour).

The study used a 10-year return period , used less time concentration 5 minutes (Highway Design Guide, 2005).Also used drainage area6475 m^2 (3-lane and 2 m footpath with 500 m length of road).Second, GCM this part used three types of road arterial, collector and local streets on different types of gutters.

4. RESULTS AND DISCUSSION

4.1. The Effect of Manning's Coefficient on Spread

Figs. 4 and 5 were shown the relationship between manning's coefficient(n) and spread (T) at a constant value of cross slope(2 %) and longitudinal slope (0.35 %). From these figures, the spread has been increase with increasing the manning's coefficient for all types of gutters, except composite gutter sections in Fig. 4 and circular sections in Fig. 5 the spread decreases this is due to the gutter features which increases the flow and then the spread is decreased, while V-shape median in Fig. 4 the spread is not affected by the manning's coefficient due to a large cross-section and symmetrically to has spread without effect by the manning's coefficient.

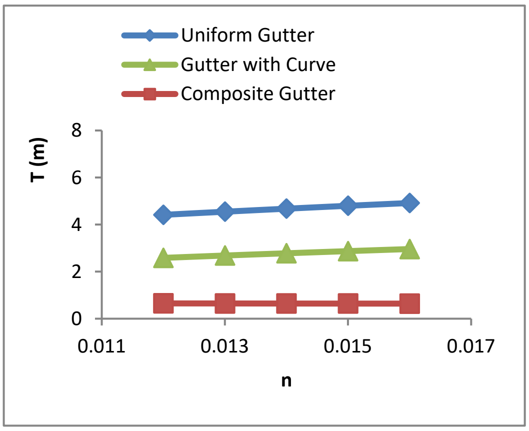

Fig. 4. The Relationship between Spread and Manning's Coefficient for Conventional Curb and Gutter Section.s

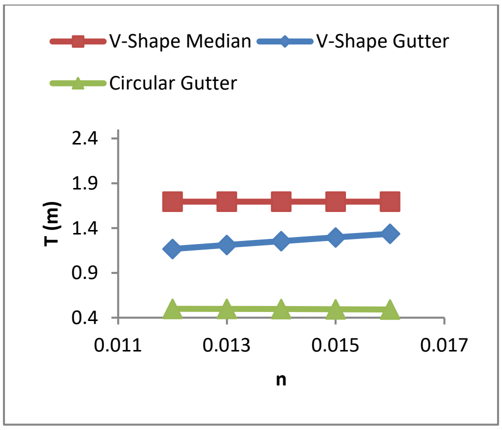

Fig. 5 The Relationship between Spread and Manning's Coefficient for Shallow Swale Sections.

4.2. The Effect of Cross slope on Spread

Figs. 6 and 7 were shown the relationship between cross slop (S_X) and spread (T) at a constant value of manning's coefficient(0.013) and longitudinal slope (0.35 %). From these figures, the spread has been decrease with increasing the cross slope for all types of gutters, except composite gutter sections in Fig. 6 the spread is begins to decreases and then increases this due to rate S_W/S_X increasing with increase cross slope, while circular sections in Fig. 7 the spread is not affected by the cross slope due to not enter cross slope to calculate spread.

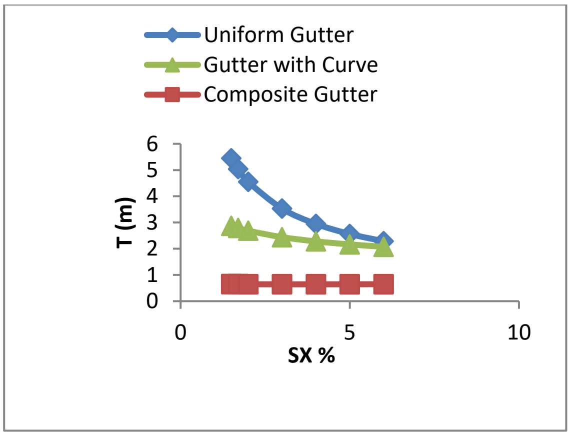

Fig. 6. The Relationship between Spread and Cross slope for Conventional Curb and Gutter Sections.

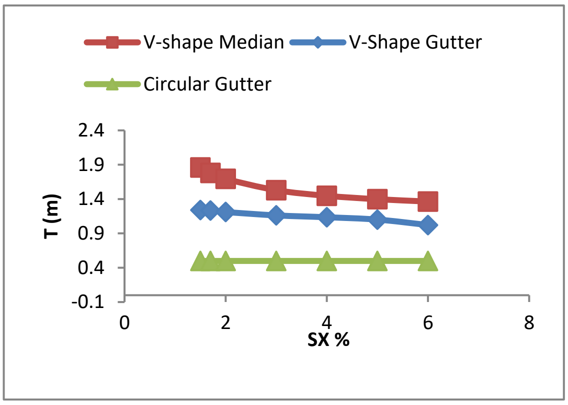

Fig. 7. The Relationship between Spread and Cross slope for Shallow Swale Sections.

4.3. The Effect of Longitudinal Slope on Spread

Figs. 8 and 9 were shown the relationship between longitudinal slope(S_L) and spread (T) at a constant value of manning's coefficient(0.013) and cross slope (2 %). From these figures, the spread decreases with increases the longitudinal slope for two types of gutters, while composite gutter sections in Fig. 8 and circular sections in Fig. 9 the spread are increased this due to cross section of these gutter small compared with flow in roads, while for conventional gutters with curved sections and V-shape median in Figs. 8 and 9 respectively the spread are not affected by longitudinal slope due to drainage in conventional gutters with curved sections depended on curve in pavement and V-shape median a large cross-section and symmetrically to has spread without effect by longitudinal slope.

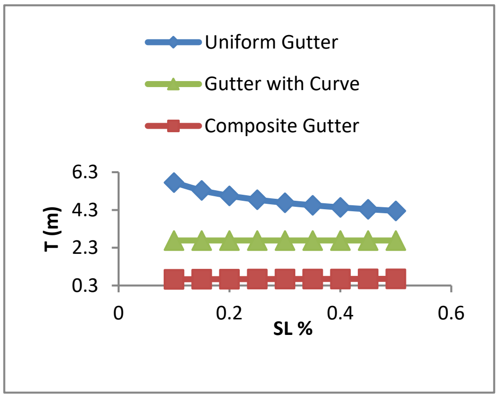

Fig. 8. The Relationship between Spread and longitudinal slope for Conventional Curb and Gutter Sections.

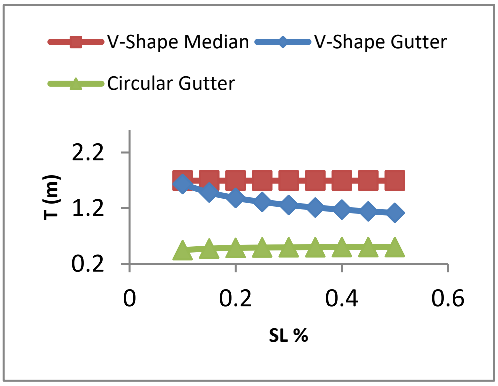

Fig. 9.The Relationship between Spread and longitudinal slope for Shallow Swale Sections.

4.4. The Effect of Manning's Coefficient on Gutter Capacity

Figs. 10 to 13 were shown the relationship between manning's coefficient(n) and gutter capacity (Q) at a constant value of cross slope(2 %) and longitudinal slope (0.35 %). From these figures, the gutter capacity increases with types of roads (arterial, collector and local streets) and decreases with increases the manning's coefficient for all types of gutters. The rate of change is clear in type of road arterial and the large value of gutter capacity is clear in conventional gutters with curved sections. Also the result showed, circular gutter sections with diameter 0.5 m cannot on capaciousness flow due to the spread to roads user in this study great than diameter the gutter.

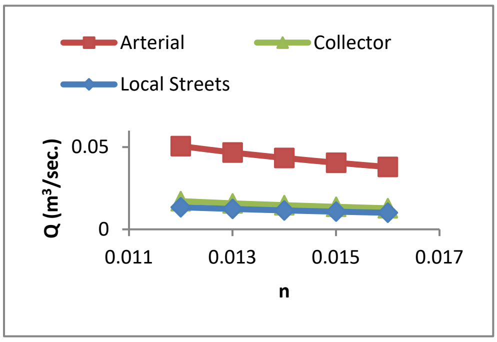

Fig. 10. The Relationship between Flow Rate and Manning's Coefficient for Conventional Gutters of Uniform Cross Slope.

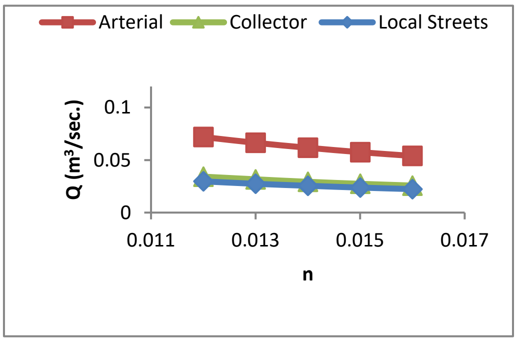

Fig. 11. The relationship between Flow Rate and Manning's Coefficient for Conventional Guttes with Curved sections.

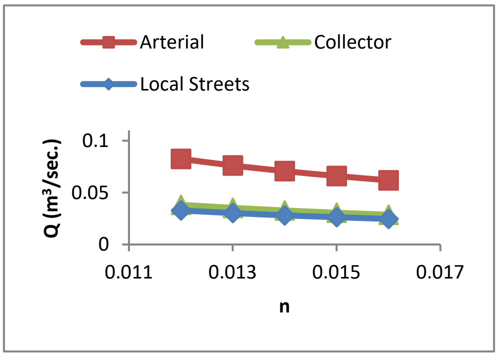

Fig. (12) The Relationship between Flow Rate and Manning's Coefficient for V-Shape Gutter.

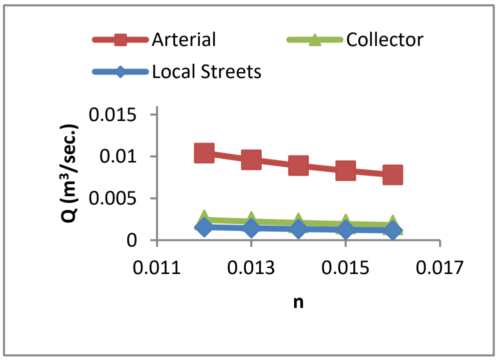

Fig. (13) The Relationship between Flow Rate and Manning's Coefficient for V-Shape Median.

4.5. The Effect of Cross slope on Gutter Capacity

Figs. 14 to 18 show the relationship between cross slop(S_X) and gutter capacity (Q) at a constant value of manning's coefficient(0.013) and longitudinal slope (0.35 %). From these figures, the gutter capacity increases with types of roads (arterial, collector and local streets) and increases with increases the cross slope for all types of gutters. The rate of change is clear in type of road arterial and the large value of gutter capacity is clear in conventional gutters with curved sections. Also the result showed, circular gutter sections with diameter 0.5 m cannot on capaciousness flow due to the spread to roads user in this study great than diameter the gutter.

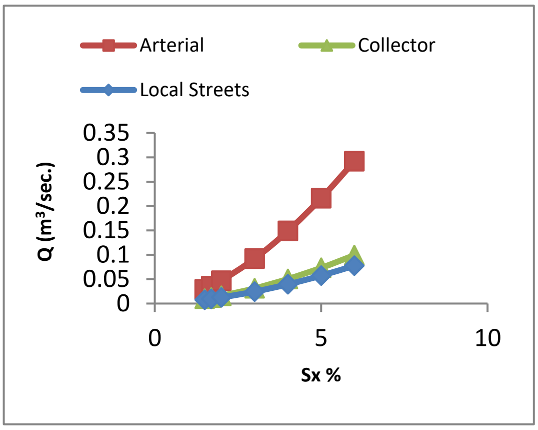

Fig. 14. The Relationship between Flow Rate and Cross Slope for Conventional Gutters of Uniform Cross Slope

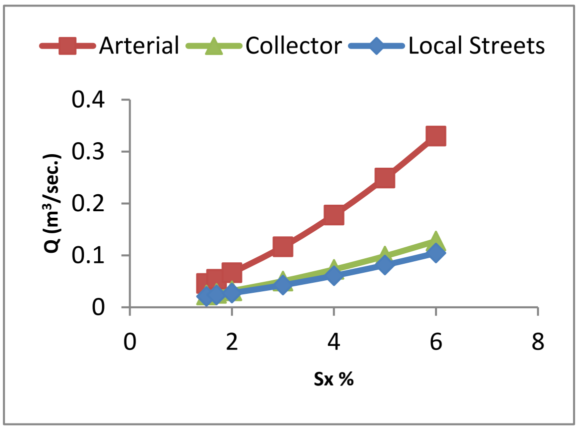

Fig. 15. The Relationship between Flow Rate and Cross Slope for Composite Gutter Sections.

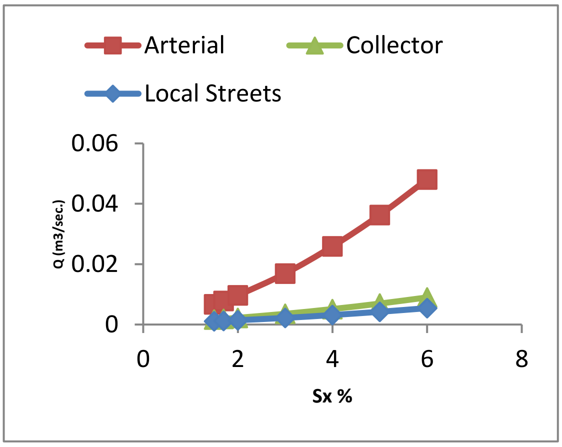

Fig. (16) The Relationship between Flow Rate and Cross Slope for Conventional Gutters with Curved Sections.

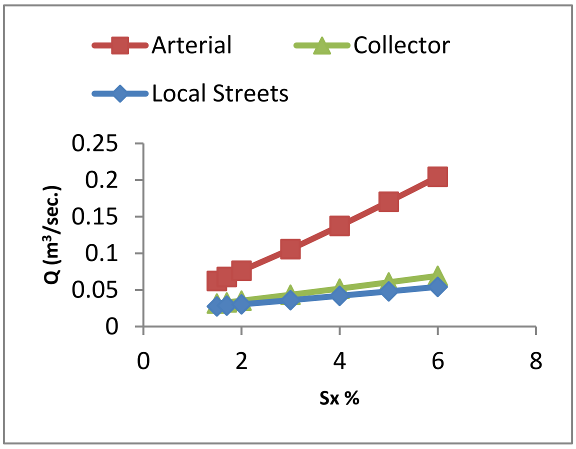

Fig. 17. The relationship between flow rate and cross slop gutter.

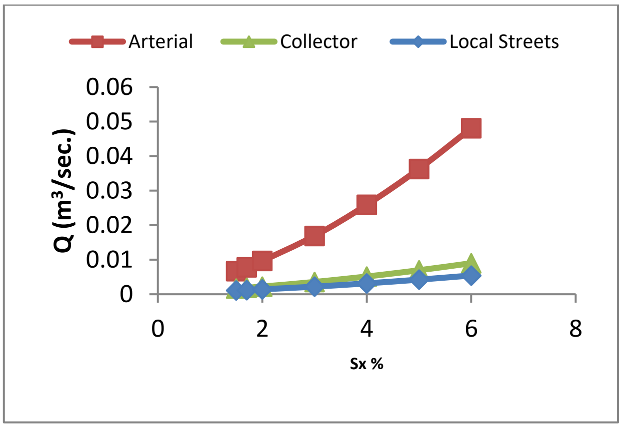

Fig. 18. The Relationship between Flow Rate and Cross Slope for V-Shape Median.

4.6. The Effect of Longitudinal Slope on Gutter Capacity

Figs. 19 to 23 show the relationship between longitudinal slope(S_L) and gutter capacity (Q) at a constant value of manning's coefficient(0.013) and cross slope (2 %). From these figures, the gutter capacity increases with types of roads (arterial, collector and local streets) and increases with increases the longitudinal slope for all types of gutters. The rate of change is clear in type of road arterial. The result showed, circular gutter sections with diameter 0.5 m cannot on capaciousness flow due to the spread to roads user in this study great than diameter the gutter. Also the result showed, the longitudinal slope not have affect of gutter capacity in the conventional gutters with curved sections this due to drainage in gutter depended on curve in pavement.

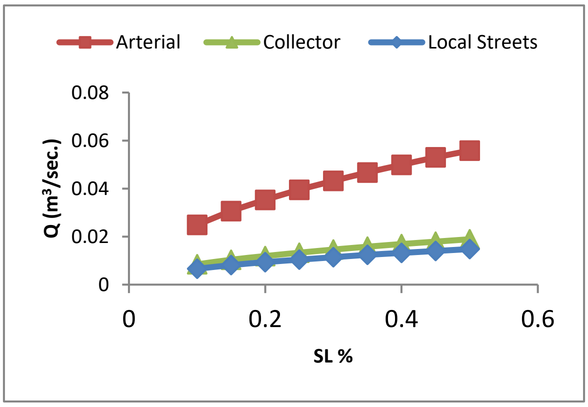

Fig. 19. The Relationship between Flow Rate and Longitudinal Slope for Conventional Gutters of Uniform Cross Slope.

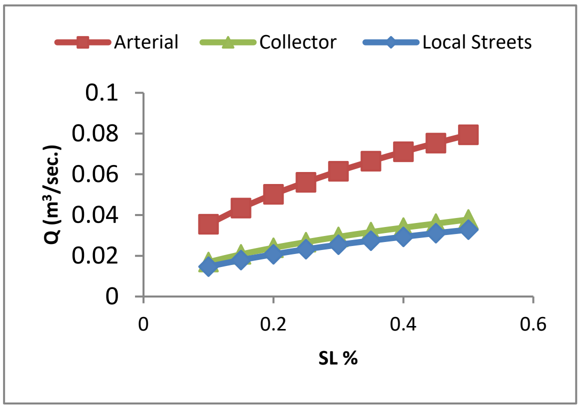

Fig. 20. The Relationship between Flow Rate and Longitudinal Slope for Composite Gutter Sections.

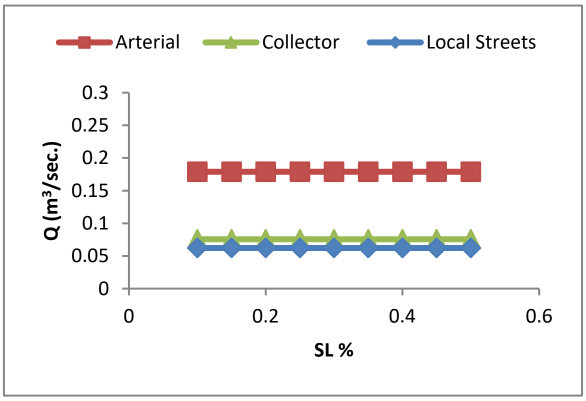

Fig. 21. The Relationship between Flow Rate and Longitudinal Slope for Conventional Gutters with Curved Sections.

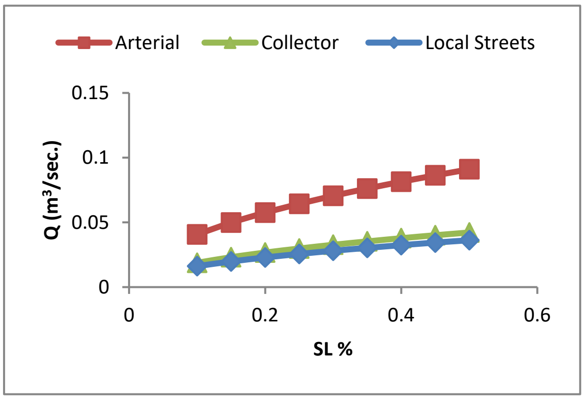

Fig. 22. The Relationship between Flow Rate and Longitudinal Slope for V-Shape Gutter.

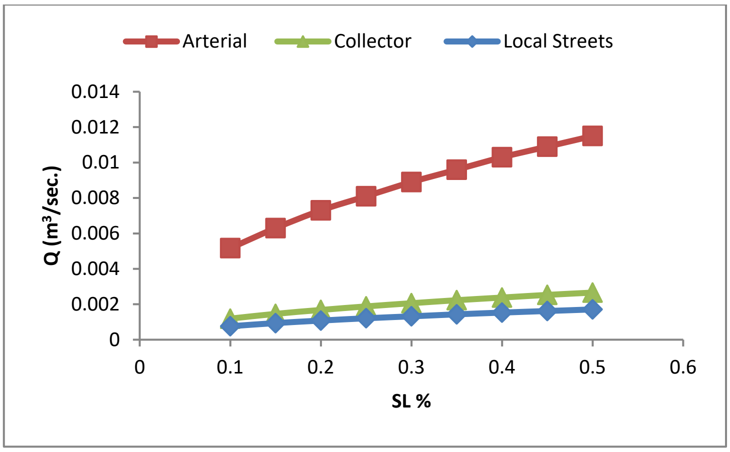

Fig. 23. The relationship between flow rate and longitudinal slope for V-Shape Medians.

5. CASE STUDY

The application is drawn from areal project in Um Qaser Port-Basrah province. It includes road type of divided with footpath and islands. Gutter used from type conventional gutters of uniform cross slope. The in-situ road profile is shown in plate 1. The road properties are as follows:

Cross Slope = 1.5 % m/m, Longitudinal Slope = 0.5 % m/m, Manning's coefficient = 0.013, Lane width = 4.16 m, Gutter width = 0.5m, Road length =700 m, Curb width = 0.15m, Footpath = 0.5 m, Island width = 3 m. The results are shown in Fig. 24. the correct gutter is conventional gutters with curved sections to has great flow 0.065 (m3/sec.), and gutter from type V-Shape median to has less flow 0.0027 (m3/sec.), also the results are shown circular gutter sections cannot on capaciousness flow due to diameter 0.5 m less than spread on road. Conclude conventional gutters of uniform cross slope in this case independent on standard criteria of design.

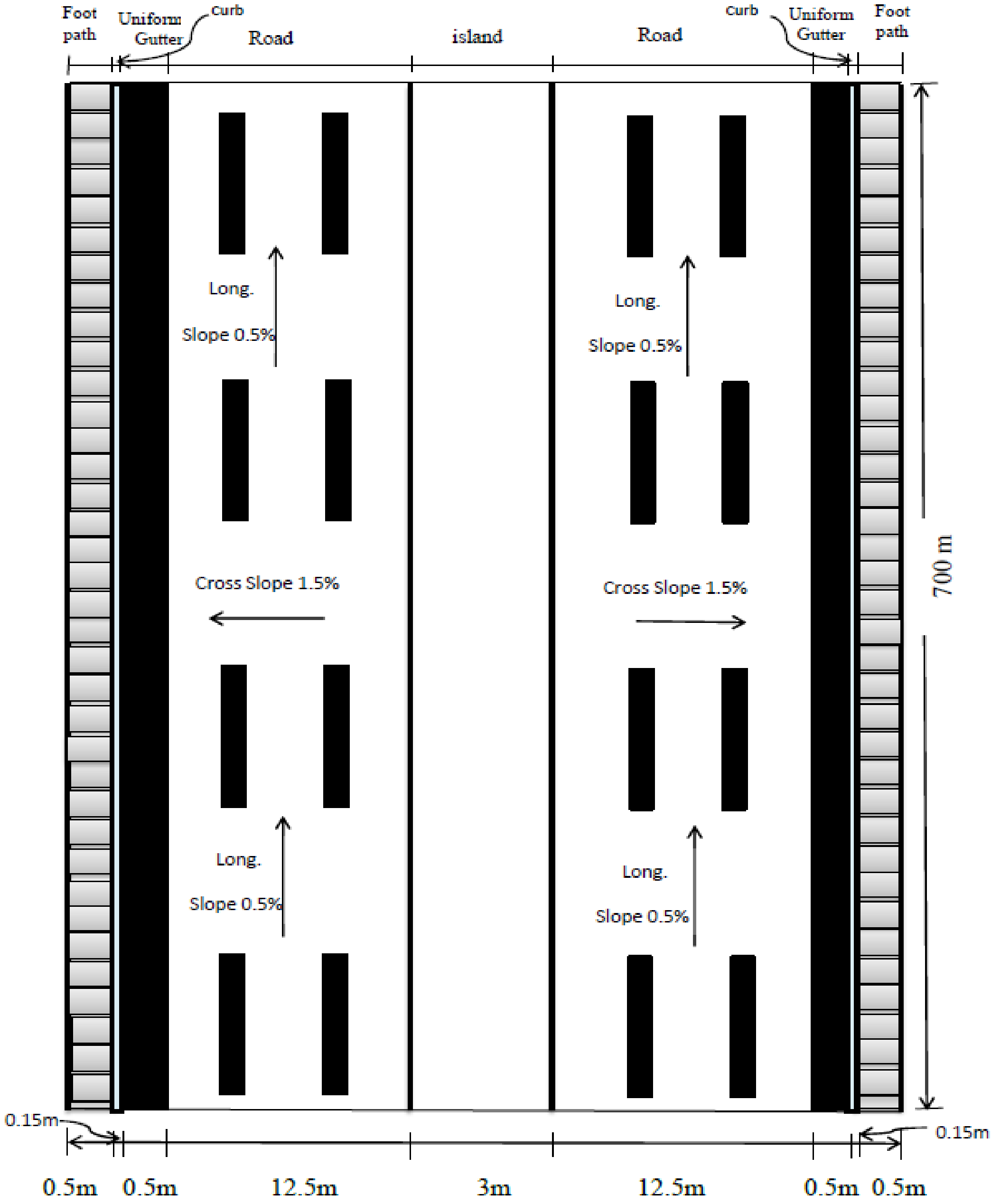

Plate 1. Road profile for Um Qaser Port.

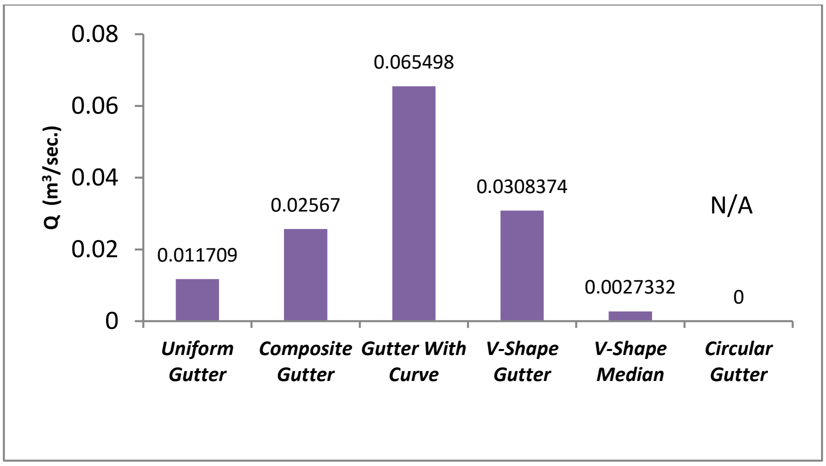

Fig. 24. The Relationship between Flow Rate and different types of gutter.

6. CONCLUSIONS

Can be summarised the conclusions as follow**:**

1. Digital simulation model proved to be effective and powerful tool for simulating characteristic of roadway.
2. GCAS model can be used for design of gutters for all types of roadway for drainage areas smaller than 80 ha.
3. When cross slope (S_X), longitudinal slope (S_L) and manning's coefficient (n) 0.02, 0.001, 0.013 respectively, it is found that the circular gutter sections is more efficiency which has less spread (0.446 m) compared with the other gutters types. But the circular gutter sections can not use when is diameter 0.5 m or less to has flow in road.
4. When cross slope (S_X), longitudinal slope (S_L) and manning's coefficient (n) 0.06, 0.0035, 0.013 respectively, it is found that the conventional gutters with curved sections is more efficiency which has great flow (0.309 m^3/sec.) compared with the other gutters types.
5. There is directly relationship between spread and manning's coefficient, except composite gutter sections and circular gutter sections the relationship is inversely, while spread for V-shape median not affected by manning's coefficient.
6. There is inverse relationship between spread and cross slope, except composite gutter sections the relationship is begins to decrease and then increase, while spread for circular sections not affected by the cross slope.
7. There is inverse relationship between spread and longitudinal slope, except composite gutter sections the relationship is directly proportional, while spread for conventional gutters with curved sections and V-shape median are not affected by longitudinal slope.

8. Gutter capacity is inverse proportion with manning's coefficient.
9. Gutter capacity is directly proportional with cross slope and longitudinal slope.

7. ACKNOWLEDGEMENTS

The author would like to thank the staff of Civil Engineering department at the University of Basrah for facilities they offered**.**

8. REFERENCES

Anderson, D.A., Reed, J.R., Huebner, R.S., Henry, J.J., Kilareski,W.P., and Warner, J.C..Improved Surface Drainage of Pavements, NCHRP Project I-29, Pennsylvania Transportation Institute, Pennsylvania State University, Federal Highway Administration, Washington, D.C. 1995.

Butler, D. and Davies, J., Urban drainage, 2nd edition, MPG Books Ltd, 2004.

Brown, S.A., Schall, J.D., Morris, J.L., Doherty, C.L., Stein, S.M., and Warner, J.C., Urban Drainage Design Manual, Federal Highway Administration, 3rdedition, Report No. FHWA-NHI-10-009 HEC-22, September, 2009.

Fang, X., Jiang, S., and Alam, R. S., "Flow Simulations for Curb Opening Inlets with Different Longitudinal and Cross Slopes", World Environmental and Water Resources Congress, ISBN (print): 978-0-7844-0976-3, Publisher: American Society of Civil Engineers, May, 2008.

Highway Design Guide, Stat of main, USA, 2005.

Johnson, P.A., and Ragan, R.M..Highway Hydrology, Hydraulic Design Series No. 2, Second Edition, Publication No.FHWA-NHI-02-001, Federal Highway Administration, Washington, D.C. 2002.

Johnson, L. F., and Fred F.M. " Drainage of Highway Pavements", Report No. HEC No. 12, FHWA-TS-84-202, March, 1984.

Jeong, J., "A Hydrodynamic Diffusion Wave Model for Stormwater Runoff on Highway Surfaces at Superelevation Transitions", Ph. D. thesis, the Faculty of the Graduate School of the University of Texas, Austin, May, 2008.

Maha, A. F., "Highway Drainage Simulation Model", M. Sc. thesis, College of Engineering, University of Basrah, 2013

Nicklow, W. J., Stormwater Collection Systems Design Handbook, Copyright © 2004 The McGraw-Hill Companies,Southern Illinois University Carbondale, 2004.