Rainstorm-runoff harvesting by the lateral gutters in a mountainous roadway

Magdy M. Abo Elela
Irrigation and Hydraulics Dept., Faculty of Eng., Alexandria University, Alexandria, Egypt

In the mild slopes roadways, the surface runoff generated by rainstorms, is collected by the gutters. They are constructed in the longitudinal direction of the roadway to prevent water overflow to occur. In the mountainous roadways, in addition to these gutters, the lateral gutters are constructed in a perpendicular direction of the roadway slope to collect most of the water runoff resulting from the rainstorm and prevent the water overflow to occur. The goal of this study is to determine experimentally the dimensions and number of the lateral gutters in a mountainous roadway to harvest most of the water runoff resulting from the rainstorm.

يتم تجميع المياه السطحية الناتجة من سقوط الأمطار فى الطرق ذات الميول الصغيرة فى الإتجاه الطولى بواسطة مصارف طولية يتم انشاؤها فى الإتجاه الطولى لهذه الطرق وعلى جانبيها وذلك لمنع حدوث غمر مياه الأمطار لهذه الطرق مما يعوق من حركة السيارات عليها.أما فى حالة الطرق الجبلية ذات الميول الكبيرة فى الإتجاه الطولى كما هو الحال فى بعض الطرق فى بعض البلاد العربية مثل لبنان و السعودية و سوريا فإلى جانب المصارف التى يتم انشاؤها فى الإتجاه الطولى فانه يتم إنشاء مصارف أساسية فى الإتجاه العرضى للطريق و عمودية على إتجاه حركة السيارات لكى يتم تجميع معظم المياه السطحية الناشئة من هطول الأمطار. و يهدف هذا البحث الى دراسة معملية لتأثير أبعاد هذه المصارف العرضية (العرض و الطول) وكذلك عددها على كمية المياه السطحية الناتجة من العواصف المطرية والتى يتم تجميعها بواسطة هذه المصارف وذلك فى حالة الطرق الجبلية ذات الميول الكبيرة. فى هذا البحث تم تصميم مجموعتين من المنحنيات بناء على النتائج التى تم الحصول عليها من النموذج المصمم فى هذه الدراسة. و يمكن استخدام أى من هذه المنحنيات فى ايجاد أبعاد وعدد المصارف العرضية اللازم انشاؤها لطريق جبلى لحصاد مياه العاصفة المطرية و ذلك بمعلومية كل من كثافة هذه العاصفة والميل الطولى لهذا الطريق.

Keywords: Rainstorm intensity, Lateral gutters, Relative gutters discharge, Runoff

1. Introduction

In the mountainous roadways, in addition to the gutters that built in the longitudinal direction of the roadways, the lateral gutters are mainly constructed to harvest most of the surface runoff resulted by the rainstorms.

Water harvesting in its broadest sense will be defined as the “collection of runoff for its productive use”. Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses. Water harvesting techniques which harvest runoff from roofs or ground surfaces fall under the term: “rainwater harvesting”. A wide variety of water harvesting techniques for many different applications is known. The factors governing the runoff process can be described in general terms. The more significant factors can be divided into two groups, namely rainfall-event dependent and catchment-area dependent [1]. Apart from rainfall characteristics such as intensity, duration and distribution major factors, which have direct effect on the rainfall-runoff process include, geomorphologic factors, slopes, and size of catchment areas, channel characteristics, soil, vegetation, and uses. The system of water harvesting as presented by Frasier [2] has two main components: firstly, the run-off area (the harvesting area) where induced runoff is to be collected, secondly, the run-on area, where the water is concentrated or stored after being collected from the other area. Various forms of water harvesting have been used traditionally throughout the centuries. Floodwater farming has been practiced in the desert areas of Arizona and northwest New Mexico for at least the last 1000 years [3]. Microcatchment techniques for trees growing, used in southern Tunisia were discovered in the nineteenth century by travelers [4].

The main goal of this paper is to study the dimensions and number of these gutters to harvest most of the surface runoff before reaching downstream part of the mountainous roadway. In the present paper, effect of the lateral gutters dimensions (width and length), their number and slope of the roadway on the collected quantities of the surface runoff are studied.

2. Experimental setup

2.1. The rain and roadway models

The physical model used in the paper consists of two main parts. The first one is shown in fig. 1, which represents the rain model of a horizontal length equals 180 cm. The second part is shown in figs. 2 and 3, which represent the roadway model of a horizontal length equals 180 cm. The roadway model is fixed at different slopes (α = 5°, 10°, 20°, and 30°), and it contains different numbers of the lateral gutters (n = 2, 3, 5 and 6).

The rain model is located above the roadway model. It consists of three vertical perspex plates and one horizontal plate at the bottom. The bottom plate is perforated and contains 576 holes. The diameter of each hole equals 1.5 mm and the distance between each two holes is 2.5 cm. The constant head of water in the rain model can be achieved by using an overflow tube of 2 cm diameter to obtain constant rainstorm intensity. The tank, which is located upstream the rain model, is made from a perspex box. The dimensions of this tank are 40 cm length, 22 cm width, and 70 cm height. Wood plates of 0.4 cm thick, 20 cm width *B*, and different lengths (*L* = 30, 60 and 90 cm) are used to represent the roadway model. At the end of each part of the wood plate, a plastic bucket is fixed representing the lateral gutter that collect water coming from the rain model.

2.2. Procedure of experiments

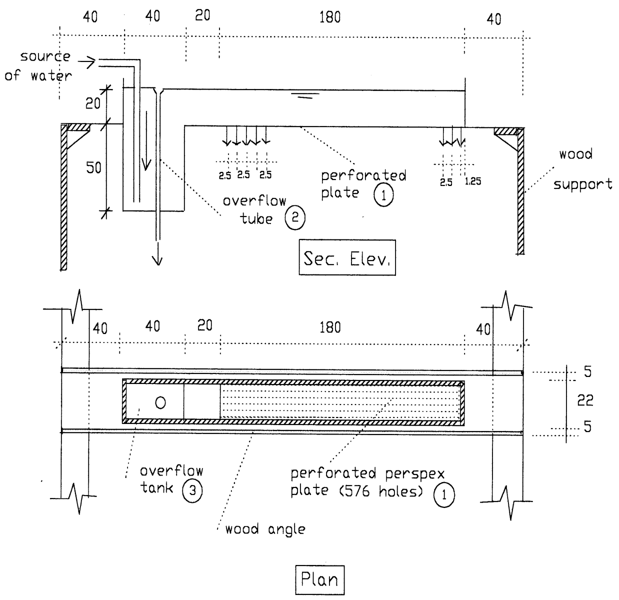
The following procedure was carried out through the experimental tests:

1. For a slope of the roadway model equal to 30° (α = 30°), number of lateral gutters equal to 2 (*n* = 2), gutter width equal to 2 cm (*b* = 2 cm), and a constant water head in the rain model equal to 4 cm (*H* = 4 cm), the constant rainstorm is permitted to fall down above the roadway model and the water surface runoff collected by each gutter is measured.
2. The water head in the rain model, *H*, is changed to 5.5, 10.5 and 15.5 cm, and step No. 1 is repeated.
3. The width of each gutter, *b*, is changed to 4, 6, 8, 10, 12 and 14 cm, and steps No. 1 and 2 are repeated.
4. Number of the lateral gutters, *n*, is changed to 3, 5, and 6, and steps No. 1, 2, and 3 are repeated.
5. The slope of the roadway model, α, is changed to 20°, 10° and 5°, and steps No. 1, 2, 3 and 4 are repeated.

3. Experimental results

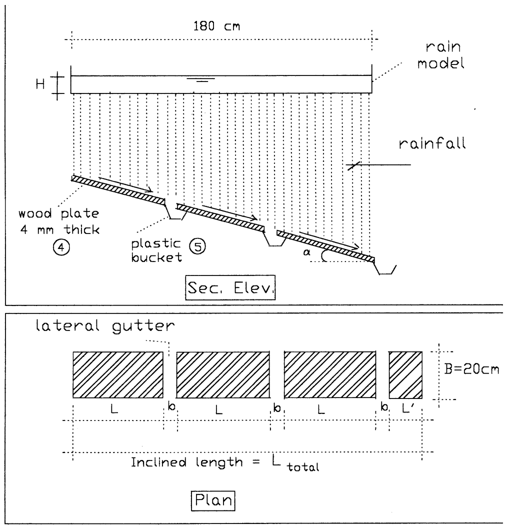
Figs. 4, 5, 6 and 7 show the relationship between relative gutter width *b/B* and relative gutters discharge $q_{gutters}/q_{rain}$ for rainstorm intensity (i) in case of *n* = 5 and α = 5°, 10°, 20° and 30°, respectively. It is clear that, with increasing the relative gutter width *b/B*, the relative gutters discharge $q_{gutters}/q_{rain}$ increases, and it also increases with increasing the rainstorm intensity (i). In case of the small slope of the roadway, the relative gutters discharge $q_{gutters}/q_{rain}$ for any value of the relative gutter width (*b/B*) is bigger than that in the case of the greater slope.

It is known that runoff is generated by rainstorms and its occurrence, and the quantity are dependent on the characteristics of the rainfall event, i.e. intensity, duration, and distribution. The design of water harvesting gutters requires the knowledge of the quantity of runoff to be produced by rainstorms in a given catchments area. Table 1 shows the calibrated rainstorm intensity for each hole of the horizontal perforated plate of the rain model in case of the diameter *d* = 1.5 mm and 2 mm for the water head in the rain model *H* equal to 4, 5.5, 10.5 and 15.5 cm. In the experiments, the diameter of each hole of the perforated plate of the rain model was chosen equal to 1.5 mm. This is the smallest diameter to be obtained in the laboratory. The rainstorm intensity related to the water head *H* = 4, 5.5, 10.5 and 15.5 cm are 13.2, 16.4, 23 and 27.4 cm/min, respectively.



1. Perforated perspex plate,
2. overflow tube of 2 cm diameter, 3. overflow tank.

Fig. 1. Section elevation and plan of the "rain model" (dimensions in cm).



4. Wood plate of 4 mm thick, 5. plastic bucket (lateral gutter)

Fig. 2. Section elevation and plan of the "roadway model" with the lateral gutters.

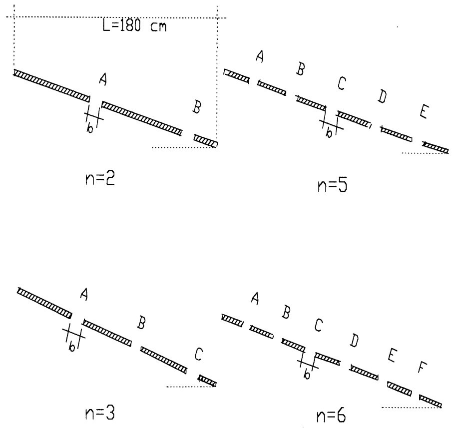


Fig. 3. Section elevation of the "roadway model" with the lateral gutters (case of n = 2, 3, 5 and 6).

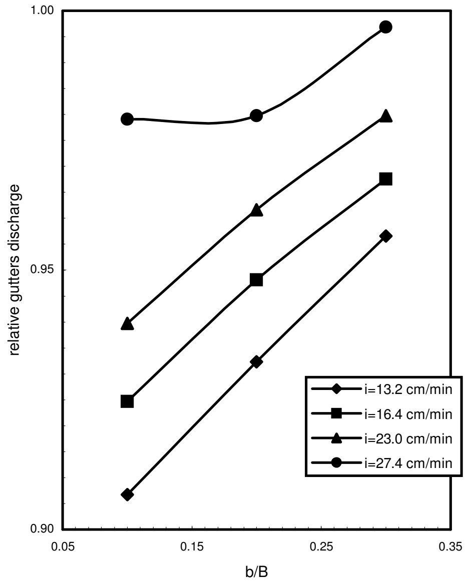


Fig. 4. Relative gutter width b/B versus relative gutters discharge ($q_{gutters}/q_{rain}$) for rainstorm intensity i, (case of n = 5, L/B = 9 and α = 5°.

Two groups of charts are designed and plotted based on the experimental results of the physical model used in this study to determine the dimensions and number of the lateral gutters in a known length of the roadway reach. Figs. 8 to 11 represent the first group of the design charts. These figures show the relationship between the rainstorm intensity i and the relative gutters discharge $q_{gutters}/q_{rain}$ for number of gutters n in case of b/B = 0.1, 0.2, 0.3, L/B = 9 and α = 5°, 10°, 20° and 30°, respectively.

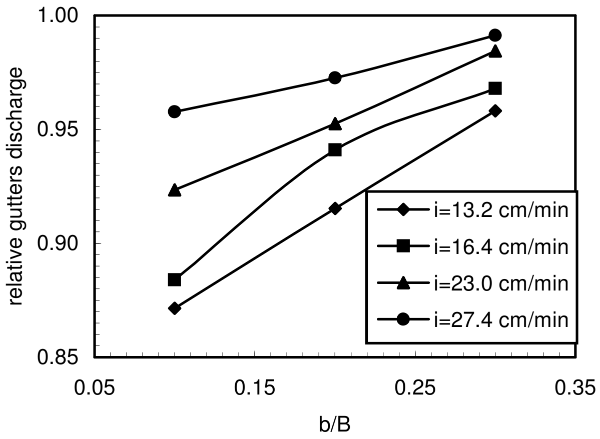


Fig. 5. Relative gutter width b/B versus relative gutters discharge $q_{gutters}/q_{rain}$ for rainstorm intensity (i), (case of n = 5, L/B = 9 and α = 10°).

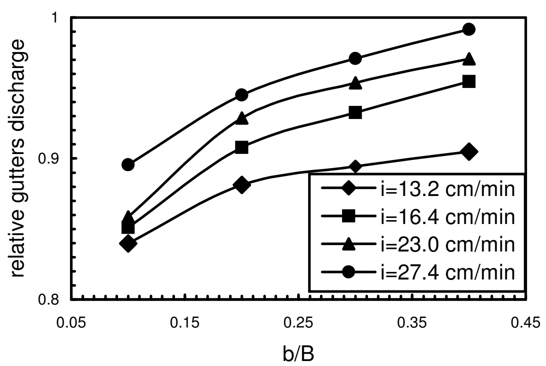


Fig. 6. Relative gutter width b/B versus relative gutters discharge $q_{gutters}/q_{rain}$ for rainstorm intensity (i), (case of n = 5, L/B = 9 and α = 20°).

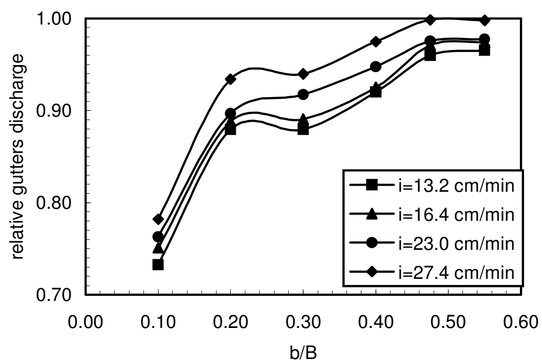
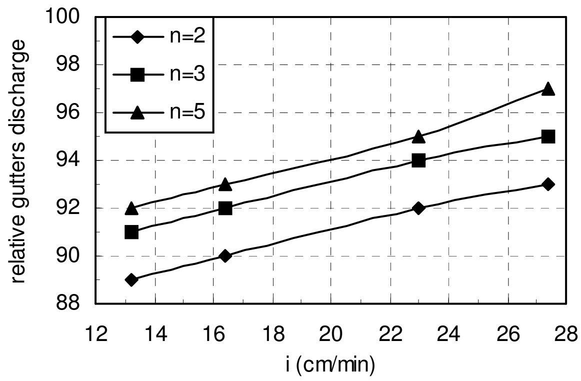
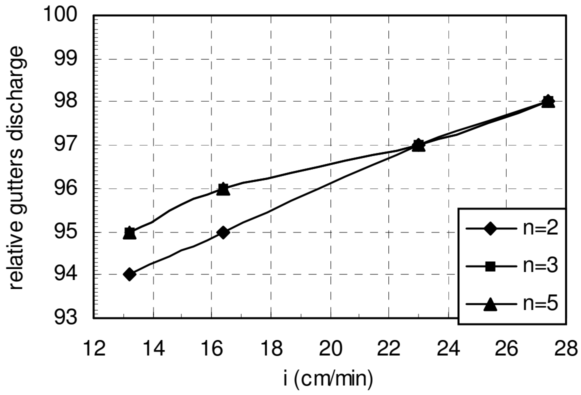


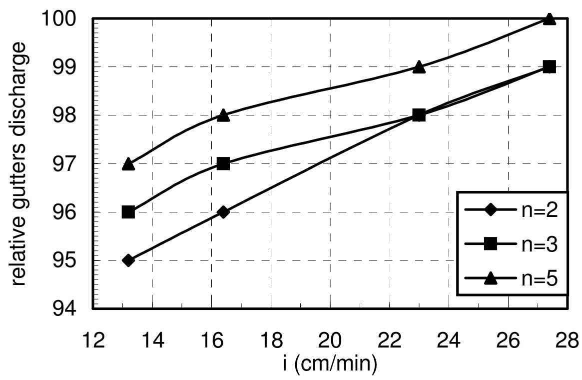
Fig. 7. Relative gutter width b/B versus relative gutters discharge $q_{GUTTERS}/q_{RAIN}$ for rainstorm intensity (i), (case of n = 5, L/B = 9 and α = 30°).



(a) b/B = 0.1

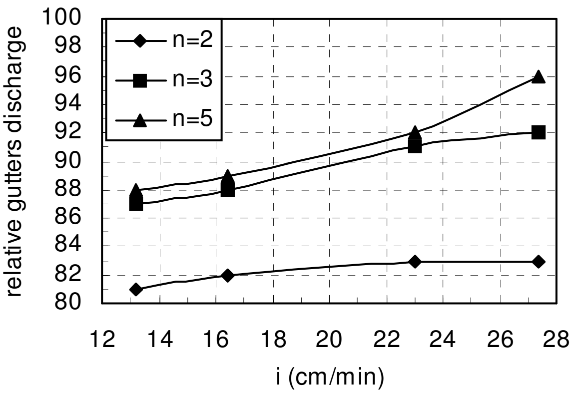


(b) b/B = 0.2

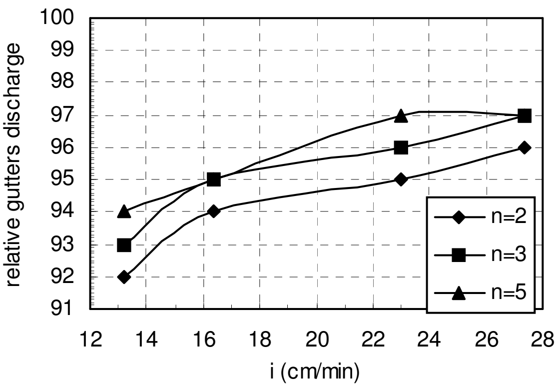


(c) b/B = 0.3

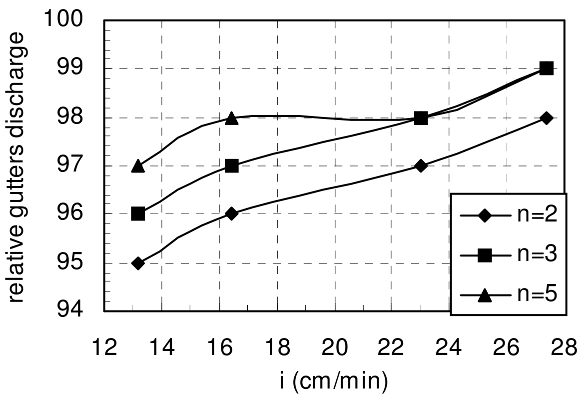
Fig. 8. Rainstorm intensity (i) versus relative gutters discharge $q_{gutters}/q_{rain}$ for number of gutters (n), (case of α = 5°, b/B = 0.1, 0.2 and 0.3, and L/B = 9).



(a) b/B = 0.1

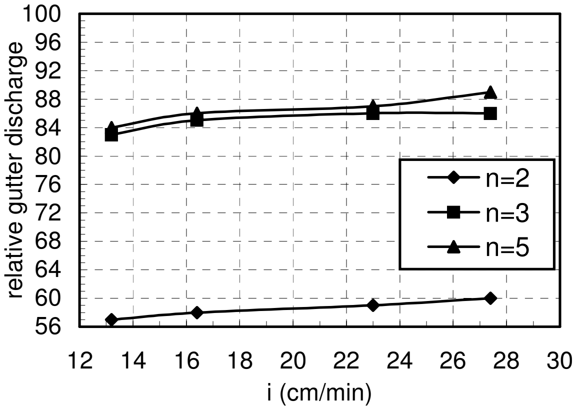


(b) b/B = 0.2

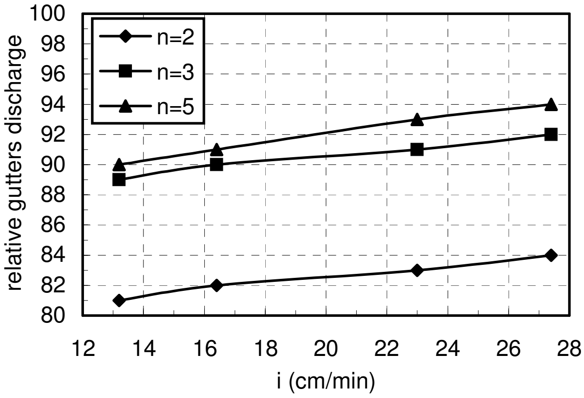


(c) b/B = 0.3

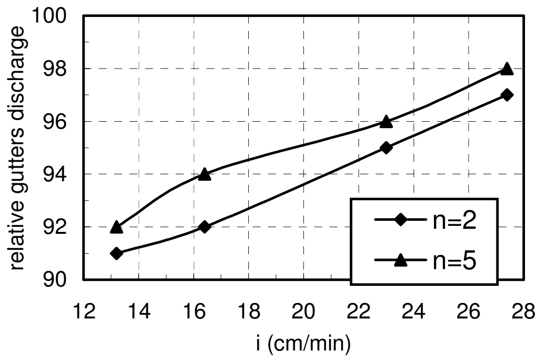
Fig. 9. Rainstorm intensity i versus relative gutters discharge $q_{gutters}/q_{rain}$ for number of gutters n, (case of $\alpha = 10^o$, $b/B = 0.1$, 0.2 and 0.3, and $L/B = 9$).



(a) b/B = 0.1

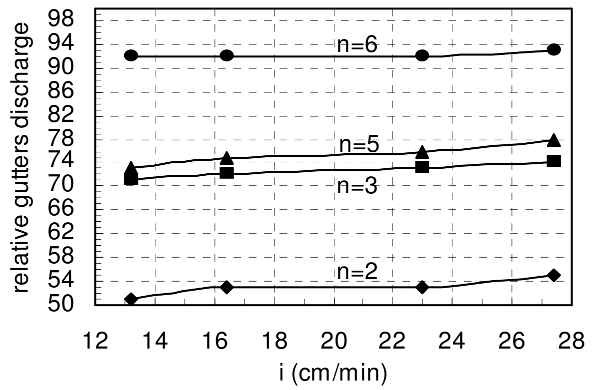


(b) b/B = 0.2

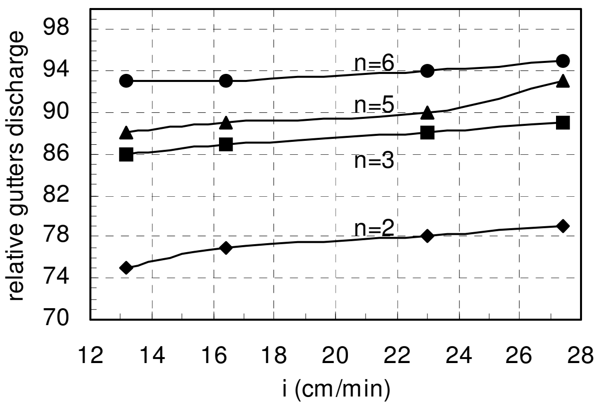


(c) b/B = 0.3

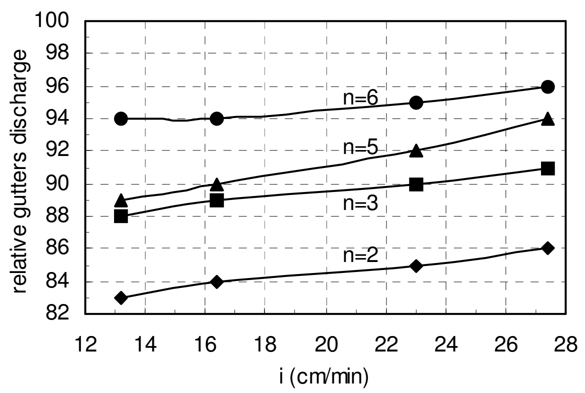
Fig. 10. Rainstorm intensity i versus relative gutters discharge $q_{gutters}/q_{rain}$ for number of gutters n, (case of $\alpha = 20^o$, $b/B = 0.1$, 0.2 and 0.3, and $L/B = 9$).



(a) b/B = 0.1



(b) b/B = 0.2



(c) b/B = 0.3

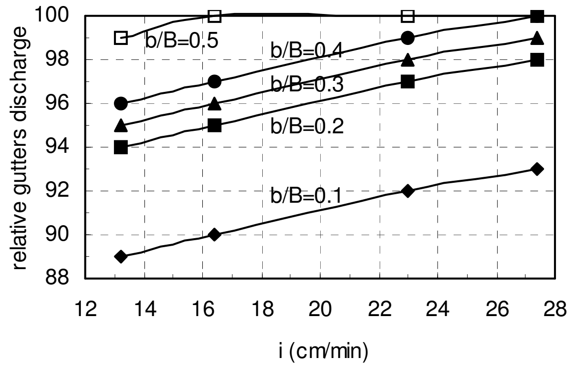
Fig. 11. Rainstorm intensity (i) versus relative gutters discharge $q_{gutters}/q_{rain}$ for number of gutters (n), (case of $\alpha = 30^o$, b/B = 0.1, 0.2 and 0.3, and L/B = 9).

Figs. 12 to 15 represent the second group of the design charts. These figures show the relationship between the rainstorm intensity (i) and the relative gutters discharge $q_{gutters}/q_{rain}$ for the relative gutters width b/B in case of n = 2, 3 and 5, L/B = 9 and $\alpha = 5^o$, 10^o, 20^o and 30^o, respectively. The dimensions of the lateral gutters and their number can be determined using each of the two groups for the known each of the rainstorm intensity i and the longitudinal slope of the roadway (α).

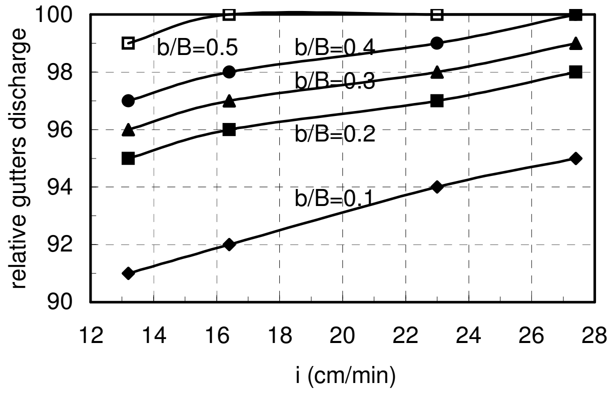
The collected gutters discharges for b/B = 0.1, 0.2, 0.3, 0.4 and 0.5 are represented in table 2 in case of α = 5^o and n = 2. In case of the small gutter width (b/B = 0.1), the collected gutters discharge (q_B) by the second gutter B which is located down-stream part of the roadway is bigger than that (q_A) collected by the first one A which is located in the up-stream part of the roadway.

In this case, it is observed from the experiments that, some amounts of water which fallen on the upper part of the roadway model skip the first gutter A. For b/B = 0.2, q_A approaches q_B. With increasing the relative gutter width (b/B > 0.2), q_A increases and becomes greater than q_B. For the relative gutter width (b/B) = 0.1, the percentage of the collected gutters discharges by the two gutters A and B for the mean rainstorm intensity i = 20 cm/min is 91 %. For (b/B) = 0.2, 0.3, 0.4 and 0.5, the percentages of the collected gutters discharges by the two gutters, for the same case, are 96 %, 97 %, 98 % and 99 %, respectively.

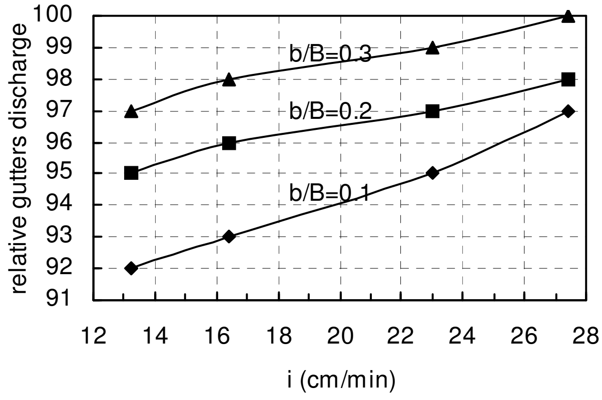
The collected gutters discharges by the two gutters (n = 2) for (b/B) = 0.1, 0.2, 0.3, 0.4, 0.5 and 0.575 are also represented in case of $\alpha = 10^o$. For (b/B) ≥ 0.1, q_B is bigger than q_A. The collected gutters discharges by the two gutters in this case ($\alpha = 10^o$) is less than that collected in case of $\alpha = 5^o$. For (b/B) = 0.1, and for i = 20 cm/min, the percentage of the collected gutters discharges by the two gutters A and B is 82 %. The collected gutters discharges by the two gutters reduce with increasing the longitudinal slope of the roadway. For (b/B) = 0.2, 0.3, 0.4, 0.5 and 0.575, and for i = 20 cm/min, the percentages of the collected gutters discharges by the two gutters A and B are 94 %, 97 %, 98 %, 99 % and 99 %, respectively.



(a) n = 2

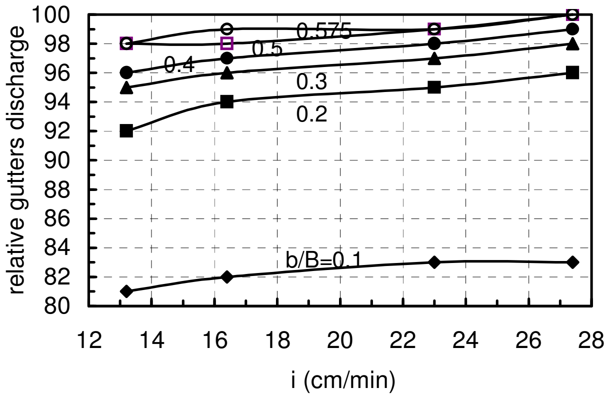


(b) n = 3

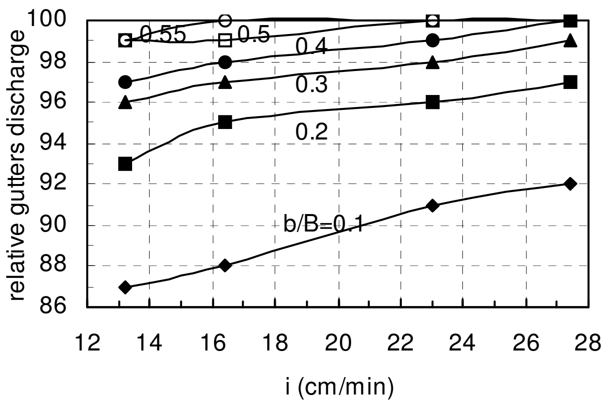


(c) n = 5

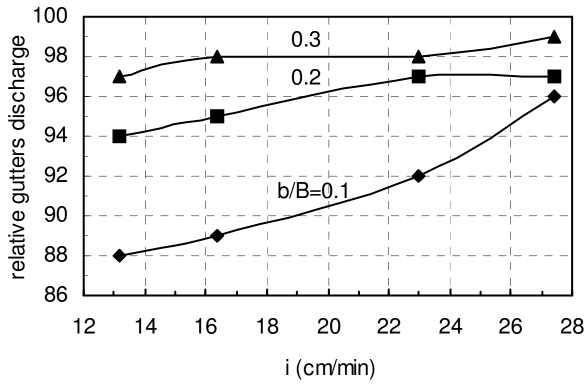
Fig. 12. Rainstorm intensity i versus relative gutters discharge $q_{gutters}/q_{rain}$ for relative gutter width b/B, (case of $\alpha = 5^o$, n = 2, 3 and 5, and L/B = 9).



(a) n = 2

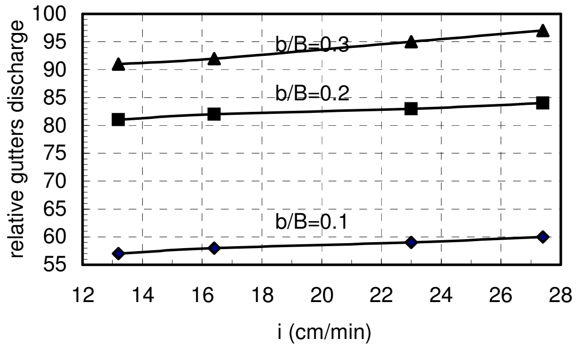


(b) n = 3

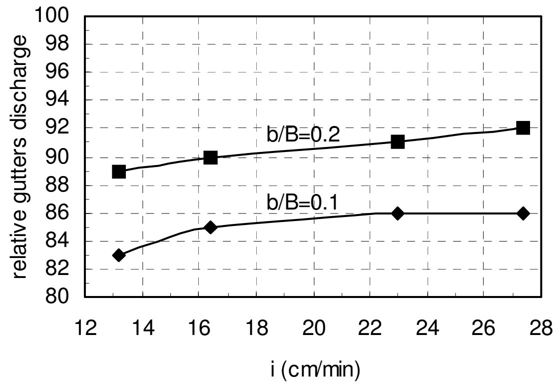


(c) n = 5

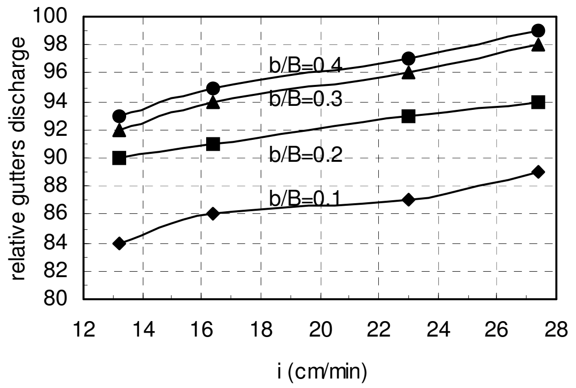
Fig.13. Rainstorm intensity i versus relative gutters discharge $q_{gutters}/q_{rain}$ for relative gutter width b/B, (case of $\alpha = 10^o$, n = 2, 3 and 5, and L/B = 9).



(a) n = 2

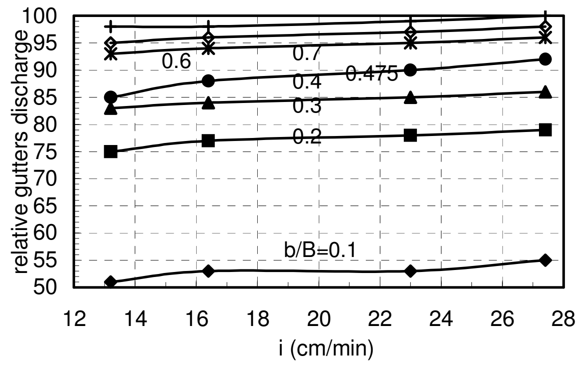


(b) n = 3

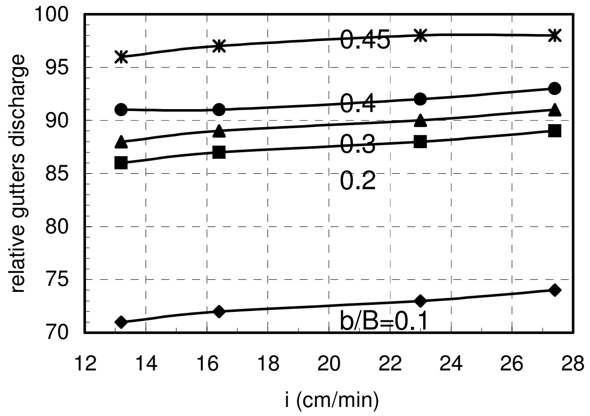


(c) n = 5

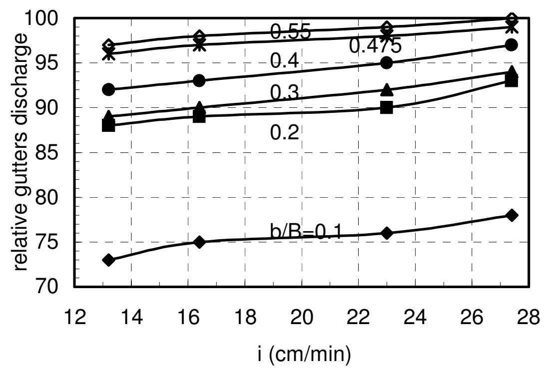
Fig.14. Rainstorm intensity i versus relative gutters discharge $q_{gutters}/q_{rain}$ for relative gutter width b/B, (case of α = 20°, n = 2, 3 and 5, and L/B = 9).



(a) n = 2



(b) n = 3



(c) n = 5

Fig.15. Rainstorm intensity i versus relative gutters discharge $q_{gutters}/q_{rain}$ for relative gutter width b/B, (case of α = 30°, n = 2, 3 and 5, and L/B = 9).

Table 1

Rainstorm intensity for each hole of the rain model (diameter d = 1.5 mm and 2.5 mm) for different water heads (H)

H (cm)	d = 1.5 mm		d = 2.5 mm	
	q_{rain} (one hole) cm^3/min	rainstorm intensity (i) cm/min	q_{rain} (one hole) cm^3/min	rainstorm intensity (i) cm/min
4	82.5	13.2	-	-
5.5	102.5	16.4	312.5	50
10.5	143.75	23	411.25	65.8
15.5	171.25	27.4	492.5	78.8

Table 2
The collected gutters discharges by the two lateral gutters (n = 2) for b/B = 0.1, 0.2, 0.3, 0.4 and 0.5 in case of $\alpha = 5^o$

B Cm	b/B	i cm/min	q_{rain} (1hole) cm^3/min	q_{rain} cm^3/min	q_A cm^3/min	q_B cm^3/min	$q_{gutters}$ cm^3/min	$q_{gutters}/q_{rain}$ %	$q_{gutters}/q_{rain}$ average %
2	0.1	13.2	82.5	47520	19317	23111	42428	89	
		16.4	102.5	59040	24484	28615	53099	90	91
		23.0	143.75	82800	33840	42311	76151	92	
		27.4	171.25	98640	40482	51120	91602	93	
4	0.2	13.2	82.5	47520	22336	22392	44728	94	
		16.4	102.5	59040	28667	27789	56456	95	96
		23.0	143.75	82800	39301	40704	80005	97	
		27.4	171.25	98640	48000	48706	96706	98	
6	0.3	13.2	82.5	47520	23077	22753	45830	95	
		16.4	102.5	59040	29887	27789	57676	96	97
		23.0	143.75	82800	41475	40203	81678	98	
		27.4	171.25	98640	50270	48153	98423	99	
8	0.4	13.2	82.5	47520	24103	22392	46495	96	
		16.4	102.5	59040	30000	28185	58185	97	98
		23.0	143.75	82800	44780	37358	82139	99	
		27.4	171.25	98640	47861	50690	98551	100	
10	0.5	13.2	82.5	47520	24338	22563	46901	99	
		16.4	102.5	59040	31685	26866	58551	99	99
		23.0	143.75	82800	43714	38769	82484	100	
		27.4	171.25	98640	50921	47532	98454	100	

The collected gutters discharges by the two gutters (n = 2) for (b/B) = 0.1, 0.2 and 0.3 are represented in case of $\alpha = 20^o$. For 0.3 ≥ (b/B) ≥ 0.1, q_B is bigger than q_A. The collected gutters discharges by the two gutters in this case ($\alpha = 20^o$) are less than that collected in case of $\alpha = 10^o$. For (b/B) = 0.1, the percentage of the collected gutters discharges by the two gutters A and B for i = 20 cm/min is 58 %. The collected gutters discharges by the two gutters reduces with increasing the longitudinal slope of the roadway. For (b/B) = 0.2 and 0.3, the percentages of the collected gutters discharges by the two gutters A and B for the same case are 83 % and 94 %, respectively.

The collected gutters discharges by the two gutters (n = 2) for (b/B) = 0.1, 0.2, 0.3, 0.4, 0.475, 0.6 and 0.7 are also represented in case of $\alpha = 30^o$. For 0.3 ≥ (b/B) ≥ 0.1, q_B is bigger than q_A. For (b/B) > 0.3, q_A increases and becomes greater than q_B. The collected gutters discharges by the two gutters in this case (α = 30°) are less than that collected in case of α = 20°. For (b/B) = 0.1, 0.2, 0.3, 0.4, 0.475, 0.6 and 0.7, the percentages of the collected gutters discharges by the two gutters *A* and *B* for i = 20 cm/min are 53 %, 77 %, 85 %, 89 %, 95 %, 97 % and 99 %, respectively.

Table 3 shows the collected gutters discharges by the three gutters (n = 3) for (b/B) = 0.1, 0.2, 0.3, 0.4 and 0.5 in case of α = 5°. In case of the small relative gutter width (b/B = 0.1), the collected gutters discharge (q_C) by the third gutter C, which is located in the down part of the roadway, is bigger than that collected by each of the other two gutters *A* and *B* which are located in the upper and middle parts of the roadway model.
In this case, it is observed from the experiments that some amounts of the rainstorm, which were fallen on the upper and middle parts of the roadway model skip the first and second gutters (*A* and *B*) and are collected by the third gutter C. For (b/B) > 0.1, q_B is bigger than q_A and q_C . For (b/B) = 0.1, 0.2, 0.3, 0.4 and 0.5, and for i = 20 cm/min, the percentages of the collected gutters discharges by the three gutters are 93 %, 96 %, 98 %, 99 % and 100 %, respectively. In case of n = 3 and the longitudinal slope of the roadway equal to 10° (α = 10°), and for (b/B) = 0.1, q_C is still bigger than q_A and q_B. The collected gutters discharges by the three gutters in this case (α = 10°) are less than that collected in case of α= 5°. For (b/B) = 0.1, 0.2, 0.3, 0.4, 0.5 and 0.55, and for i = 20 cm/min, the percentages of the collected gutters discharges by the three gutters *A, B* and *C* are 90 %, 95 %, 98 %, 99 %, 100 % and 100 %, respectively. The collected gutters discharges by these gutters are reduced with increasing the longitudinal slope of the roadway.

In case of n = 3 and the longitudinal slope of the roadway equal to 20° (α = 20°), and for (b/B) = 0.1, q_C is still bigger than q_A and q_B. The collected gutters discharges by the three gutters in this case (α = 20°) are less than that collected in case of α = 10°. For b/B = 0.1 and 0.2, and for i = 20 cm/min, the percentages of the collected gutters discharges by the three gutters *A, B* and *C* are 85 % and 91 %, respectively.
Table 3

In case of n = 3 and the longitudinal slope of the roadway equal to 30° (α = 30°), and for (b/B) = 0.1 and 0.2, q_C is also still bigger than q_A and q_B . For b/B > 0.2, q_B is bigger than q_A and q_C. The collected gutters discharges by the three gutters in this case (α = 30°) are less than that collected in case of α = 20°. For (b/B) = 0.1, 0.2, 0.3, 0.4 and 0.45, and for i = 20 cm/min, the percentages of the collected gutters discharges by the three gutters *A, B* and *C* are 73 %, 88 %, 90 %, 92 % and 97 %, respectively.

The collected gutters discharges by the five gutters (n = 5) for b/B = 0.1, 0.2 and 0.3 are represented in case of α = 5°. For 0.3 ≥ (b/B) ≥ 0.1, the collected gutters discharge by the third gutter *C* (q_C) is bigger than that collected by each of the other four gutters *A, B, D* and E. For b/B = 0.1, 0.2 and 0.3, and for i = 20 cm/min, the percentages of the collected gutters discharges by the five gutters are 94 %, 97 % and 99 %, respectively.
In case of n = 5 and the longitudinal slope of the roadway equal to 10° (α = 10°), and for 0.3 ≥ (b/B) ≥ 0.1, α is still bigger than each of q_A, q_B, q_D and q_E. The collected gutters discharges by the five gutters in this case (α = 10°) are less than that collected in case of α = 5°. In case of n = 5 and for (b/B) = 0.1, 0.2. and 0.3, and for i= 20 cm/min, the percentages of the collected gutters discharges by the five gutters *A, B, C, D* and *E* are 91 %, 95 % and 98 %, respectively.
In case of n = 5 and the longitudinal slope of the roadway equal to 20° (α = 20°), and for 0.4 ≥ (b/B) ≥ 0.1, q_C is still bigger than each of q_A, q_B, q_D and q_E. The collected gutters discharges by the five gutters in this case (α = 20°) are less than that collected in case of α = 10°. In case of n = 5 and for (b/B) = 0.1, 0.2, 0.3 and 0.4, and for i = 20 cm/min, the percentages of the collected gutters discharges by the five gutters *A, B, C, D* and *E* are 87 %, 92 %, 95 % and 96 %, respectively.

In case of n = 5 and the longitudinal slope of the roadway equal to 30° (α = 30°), and for b/B = 0.1, the collected discharge (q_E) by the last gutter *E* is greater than each of q_A, q_B, q_C and q_D. For 0.4 ≥ b/B ≥ 0.2, the collected discharge q_D by the fourth gutter *D* is bigger

The collected gutters discharges by the three lateral gutters (n = 3) for b/B = 0.1, 0.2, 0.3, 0.4 and 0.5 in case of α = 5°

B cm	b/B	i cm/min	q_{rain} (1hole) cm³/min	q_{rain} cm³/min	q_A cm³/min	q_B cm³/min	q_C cm³/min	$q_{gutters}$ cm³/min	$q_{gutters}/q_{rain}$ %	$q_{gutters}/q_{rain}$ average %
2	0.1	13.2	82.5	47520	13081	14830	15259	43170	91	
		16.4	102.5	59040	16429	18608	19080	54117	92	93
		23.0	143.75	82800	23969	27158	26565	77691	94	
		27.4	171.25	98640	29318	30732	34091	94141	95	
4	0.2	13.2	82.5	47520	13846	15689	15313	44849	95	
		16.4	102.5	59040	17640	19760	19157	56557	96	96
		23.0	143.75	82800	27789	27692	25017	80499	97	
		27.4	171.25	98640	31277	34796	31034	97107	98	
6	0.3	13.2	82.5	47520	14312	15628	15640	45580	96	
		16.4	102.5	59040	18035	20431	18817	57262	97	98
		23.0	143.75	82800	26182	28822	26095	81098	98	
		27.4	171.25	98640	32967	35484	29314	97765	99	
8	0.4	13.2	82.5	47520	15167	17156	14455	46778	97	
		16.4	102.5	59040	18425	21418	18545	58388	98	99
		23.0	143.75	82800	27194	30090	24882	82166	99	
		27.4	171.25	98640	32727	36486	29172	98386	100	
10	0. 5	13.2	82.5	47520	15820	17362	13846	47029	99	
		16.4	102.5	59040	20571	21333	16800	58705	100	100
		23.0	143.75	82800	28372	31244	22950	82566	100	
		27.4	171.25	98640	34254	36923	27447	98624	100	

than each of q_A, q_B, q_C, and q_E. The collected gutters discharges by the five gutters in this case (α = 30°) are less than that collected in case of α = 20°. For $b/B \geq 0.475$, the collected discharge q_C by the third gutter C is greater than each of q_A, q_B, q_D, and q_E. In case of n = 5 and for b/B = 0.1, 0.2, 0.3, 0.4, 0.475 and 0.55, and for i = 20 cm/min, the percentages of the collected gutters discharges by the five gutters A, B, C, D and E are 76 %, 90 %, 91 %, 94 %, 98 % and 99 %, respectively.

The collected gutters discharges by the six gutters (n = 6) for b/B = 0.1, 0.2 and 0.225 are represented in case of α = 30°. For $0.225 \geq b/B \geq 0.1$, the collected gutters discharge by the fourth gutter D is bigger than that collected by each of the gutter A, B, C, E and F. For b/B = 0.1, 0.2 and 0.225, and for i = 20 cm/min, the percentages of the collected gutters discharges by the six gutters A, B, C, D, E and F are 92 %, 94 % and 94 %, respectively.

In case of n = 6 and the longitudinal slope of the roadway equal to 20° (α = 20°), and b/B = 0.1, the collected gutters discharge by the fourth gutter D is also bigger than that collected by each of the gutter A, B, C, E and F. For b/B = 0.1, and for i = 20 cm/min, the percentages of the collected gutters discharges by the six gutters A, B, C, D, E and F is 95 %. It is concluded from the above analysis, for a certain number of lateral gutters (n = 2 or 3 or 5 or 6), the collected gutters discharges by these gutters reduce with increasing the longitudinal slope of the mountainous roadway. It is also concluded that, for a certain longitudinal slope of the roadway (α), and a constant relative gutter width (b/B), the collected gutters discharges increase with increasing the number of lateral gutters. For example: in case of α = 30 and for b/B = 0.1, and for the mean rainstorm intensity i = 20 cm/min, the percentage of the collected gutters discharges by the two gutters (n = 2) is 53 %. The percentage of the collected gutters discharges by the three gutters (n = 3) for the same case is 73 %. The percentage of the collected gutters discharges by the five gutters (n = 5) is 76 %. The percentage of the collected gutters discharges by the six gutters (n = 6) is 92 %.

3.1. Example application

It is required to determine the dimensions and number of the lateral gutters, which must be constructed in a mountainous roadway if the mean rainstorm intensity in that area is equal to 20 cm/min. The following data are also available: longitudinal slope of the roadway $\alpha = 10^o$, width of the roadway = 6 m, and length of the roadway = 108 m.

Solution

(1) If the First Group of Charts is used (Figs. 8, 9, 10 and 11)

For $\alpha = 10^o$, fig. 9 is used. For fig. 9-a in which b/B = 0.1 (b = 60 cm), the horizontal axis is entered with the value of i = 20, then vertically up to n = 3. In this case, $q_{gutters}/q_{rain}$ = 90 %. For fig. 9-b in which b/B = 0.2 (b = 120 cm), the horizontal axis is entered with the value of i = 20, then vertically up to n = 2. In this case, $q_{gutters}/q_{rain}$ = 94.5 %. For fig. 9-c in which b/B = 0.3 (b = 180 cm), the horizontal axis is entered with the value of i=20, then vertically up to n = 2. In this case, $q_{gutters}/q_{rain}$ = 96.5 %.

From the above, it is better to choose n = 3 and b/B = 0.1 (b = 60 cm) for L/B = 9 where the chosen width is practical. In this case, $q_{gutters}/q_{rain}$ = 90 %. Since L/B = 108/6 = 18, then, number of the chosen lateral gutters = 6 and b/B = 0.1 (b = 60 cm).

(2) If the Second Group of Charts is used (Figs. 12, 13, 14 and 15:

For $a = 10^o$, Fig. 13 is used. For Fig. 13-a in which n = 2, the horizontal axis is entered with the value of i = 20, then vertically up to b/B = 0.1. In this case, $q_{gutters}/q_{rain}$ = 83 %. For b/B = 0.2 (b = 120 cm), $q_{gutters}/q_{rain}$ = 94.5 %. For fig. 13-b in which n = 3, b/B = 0.1 (b = 60 cm), $q_{gutters}/q_{rain}$ = 90 %. For fig. 13-c in which n = 5, b/B = 0.1 (b = 60 cm), $q_{gutters}/q_{rain}$ = 90.5 %. From the above, it is better to choose n = 3 and b/B = 0.1 (b = 60 cm) for L/B = 9 where the chosen width is practical. In this case, $q_{gutters}/q_{rain}$ = 90 %. Since L/B = 108/6 = 18, then, number of the chosen lateral gutters = 6 and b/B = 0.1 (b = 60 cm).

4. Conclusions

In this paper, the dimensions and number of the lateral gutters in a mountainous roadway is determined experimentally to harvest most of the water runoff resulting from the rainstorm. From the experimental results and analysis presented in this work, the following conclusions cab be drawn:

1. Two groups of the design charts are designed and plotted, based on the experimental results, to determine the dimensions of the lateral gutters (width, b, and length, B) and their number in a known length of mountainous roadway reach which harvest most of the surface runoff resulting from the rainstorm. The dimensions of the lateral gutters and their number can be determined using each of the two design charts for the known each of the rainstorm intensity and the longitudinal slope of the roadway at which the collected gutters discharge is maximum.
2. For a mountainous roadway of small relative width of the lateral gutter (b/B = 0.1), the effect of increasing the number of lateral gutters on the collected quantities of the surface runoff resulting from the rainstorms is very small in case of a longitudinal slope less than or equal to 8.8 % ($\alpha = 5^o$). When the longitudinal slope of the roadway is greater than 8.8 % ($\alpha = 5^o$), the pervious effect highly increases.
3. For a mountainous roadway of a moderate relative width of the lateral gutter (b/B = 0.3), the effect of increasing the number of lateral gutters on the collected quantities of the surface runoff resulting from the rainstorms is very small in case of a longitudinal slope less than or equal to 36.4 % ($\alpha = 20^o$). When the longitudinal slope of the roadway is greater than 36.4 % ($\alpha = 20^o$), the pervious effect slightly increases.
4. For the small relative lateral gutter width (b/B), some of the surface runoff skip the

lateral gutters decreasing the collected discharges by these gutters, for any longitudinal slope of the roadway.

5. Increasing the longitudinal slope of the roadway for the same number of lateral gutters decreases the quantities of the collected surface runoff by these gutters. These quantities highly decrease in case of small relative gutter width (b/B) and slightly decrease in case of bigger (b/B).

Nomenclature

b	lateral gutter width, cm,
B	gutter length, cm,
H	water head in the rain model, cm,
i	rainstorm intensity, cm/min,
L	horizontal roadway length, cm,
n	number of the lateral gutters,
a	longitudinal slope of the roadway,
q_{rain}	maximum discharge resulted from 576 holes of the rain model = $i \times$ (180 cm × 20 cm), cm^3/min,
$q_{gutters}$	collected gutters discharges by the lateral gutters, cm^3/min,
q_A	collected gutter discharge by the lateral gutter A, cm^3/min,
q_B	collected gutter discharge by the lateral gutter B, cm^3/min,
q_C	collected gutter discharge by the lateral gutter C, cm^3/min,
q_D	collected gutter discharge by the lateral gutter D, cm^3/min,
q_E	collected gutter discharge by the lateral gutter E, cm^3/min,
q_F	collected gutter discharge by the lateral gutter F, cm^3/min,
b/B	relative gutter width,
L/B	relative length of the roadway reach, and
$q_{gutters}/q_{rain}$	relative gutters discharge.

References

[1] W. Tauer and G.R. Humborg, Runoff Irrigation in the Sabel Zone: Remote Sensing and Geographical Information Systems for Determining Potential Sites (Technical Center for Agricultural and Rural Co-operation, Agricultural University, Wageningen), Verlag Josef Margraf, Wageningen (1992).

[2] G.W. Frasier and LE. Mers, Handbook of Water Harvesting (USARC Agricultural Handbook No 600), US Department of Agriculture, Agricultural Research Service, Washington (1983).

[3] J. Zaunderer and C.F. A. Hutchinson, “Review of Water Harvesting Techniques of the Arid Southwestern US and North Mexico,”. (Draft) Working paper for the World Bank’s Sub-Saharan Water Harvesting Study (1988).

[4] A. Pacey and Cullis, Rainwater Harvesting: the Collection of Rainfall and Runoff in Rural Areas. International Technology Publications, London, UK (1986).

Received July 6, 2003
Accepted November 30, 2003