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Hydrological considerations in designing the dimensions of cross drainage culvert in forest road

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ABSTRACT

Hardwood forests of northern part of Iran are located at the latitude of 35˚ 46´ to 36˚ 58´ in mountainous areas. The annual rainfall of the areas is approximately 1000mm. Due to road constructions which are increasingly developing in these areas, it is important to recognize the hydrological considerations and to establish canals and cross-section drainage to prevent the destructive effects of runoffs and upper areas development, on roads. Therefore, 39 sub-areas were considered to determine the culvert diameters for Neka-Zalemrood catchment area. Flow gravity of each catchment was measured using a numerical curve method. Results of this study showed that culvert diameters changed from 11 inch to 62 inch during a 25-years returning period. Due to mountainous nature of the study area, sub-areas with culvert diameters below 24 inch were combined to reach the minimum diameter determined in the magazine number 131 of the Iranian Strategic Planning and Control Organization. Finally, the best culvert diameters were determined for each sub-area.

Keywords: Forest road, Cross drainage Culvert, Curve number method, Sub-area.

INTRODUCTION

Forest road construction involves two positive and negative aspects. Roads are considered as an indispensable part of forest exploitation, silviculture, a forestation and other necessary measures in forests [13]. On the other hand, negative effects of road construction on the environment include: forest area reduction, natural drainage destruction, soil erosion and river sedimentation [2]. Flood occurrence in a region depends on many factors such as drainage network situation [1]. One of the aims of designing the draining networks is to consider the pre-determined instructions for preventing soil erosion, destruction and potential landslides in forest areas based on the forest conditions such as vegetation cover, soil, topography and hydrologic conditions. Furthermore, the water flows which were disordered by road constructions can be restored into their natural situation [4]. To prevent road destructions resulted from up road runoff, it is necessary to conduct water in to ditches and to establish culvert and pipes. Assigning an appropriate diameter size for cross-section drainage and determining proper intervals among these culverts may lead to prevent many irrecoverable types of erosion. In addition, their drained water can be optimally utilized. To determine the dimensions of culvert used for conducting streams and valley water is mainly dependent on the severity of water flow or water discharge amount. Type, dimensions, and the profile view of culvert as well as the different water passage qualifications such as slopes, lengths and water heights in culvert, exit spout are considered as effective parameters on calculating the diameter of culvert, spouts [11]. There are various methods of

estimating the discharge amount. The Curve number method[1] is used to estimate discharge amount in small watershed slacking an adequate an accurate statistics [10, 6]. After estimating the peak flow and headwater the diameter of cross-section drainage can be calculated based on the effective age of construction [11, 5]. The minimum diameter used in some areas was 16 inch [12] and in the rest of areas were about 18 inch [15, 3] however the one for rainy and humid areas is increased to 24 inch [4, 8].

MATERIALS AND METHODS

Study area

The study area was located on northern forests of Iran, in Neka- Zalemrood catchment area at the north latitude of 36˚ 26´ 3" and east longitude 53˚ 15´ 20" with average altitude of 740m. Average annual rainfall of the area was 1000mm, the average minimum temperature was 9.8Cþ and the average maximum temperature was 20.8Cþ. Soil texture of the study area was consisted of loam- clay, loam, and gravel- clay. As it is shown in figure (1), the studying road with the length of 12.60 km is measured in the site using a GPS device.

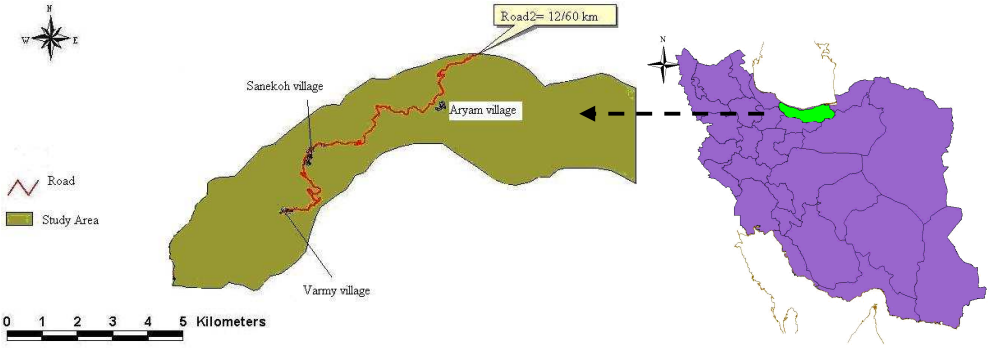

Figure (1)-Study site and road map procedures

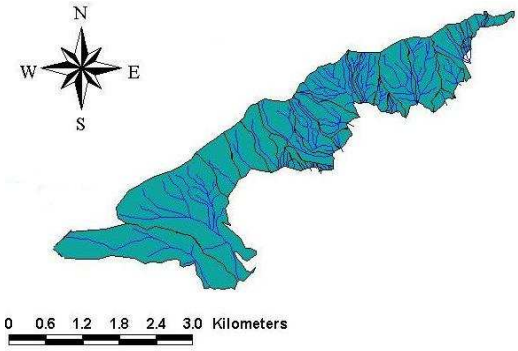

Figure (2)- Study sub area

The study area was divided in to 39 sub-areas using the ArcView software (figure 2). Then, the area of each sub-area was calculated. The time to peak and concentration time of culvert in each catchment were estimated using the Kirpich equation. Then by determining the depth after a 24 hours rainfall using the Smada software, the height of runoff in the study area via water waste estimation for each sub-area was computed ($q = \frac{(P - 0.2S)^2}{P + 0.8S}$) . After calculating the parameters, the instantaneous peak flow for a return period of 25 years($Q = \frac{2.5 \times A \times q}{t_p} m^3/s$) for each sub-area was computed using the Curve number method. Based on the runoff discharge and computed head

[1] American soil conservation service.

water (using the logical relation of $\frac{HW}{D}=1.5$) [11], the diameter of cross-section drainage for each sub-area were estimated. According to instructions which the minimum diameter of culvert installable in mountainous forest roads is considered 24 inch [11], adjacent sub-area with the culvert diameters lower than 24 inch were merged to reach the minimum diameter. Then, they were compared with available diameters in the study area.

RESULTS

Determining the peak runoff discharge via curve number method

Peak runoff discharge was calculated for each sub area using the following equation:

$$Q=\frac{2.5\times A\times q}{t_p}=\text{m}^3/\text{s} \qquad \text{(Equation 1)}$$

Table1- Peak flow discharge m^3/s based on curve number equation for a 25 years return period

sub area	Q_{25}	sub area	Q_{25}
1	0.13	0	0
2	0.34	0	0
3	0.12	34	2.68
4	0.36	35	1.20
5	0.24	36	0.08
6	0.36	37	0.09
7	0.71	38	0.11
8	0.72	39	0.09

Estimating runoff height

Rainfall station reported daily rainfall for 40 years. Water waste level in each catchment was calculated based on table 2.

Table 2- Runoff height (mm) of study sub area for a return period of 25 years

sub area	q_{25}	sub area	q_{25}
1	60.9	0	0
2	60.9	0	0
3	60.9	34	66.6
4	60.9	35	45.4
5	60.9	36	60.9
6	60.9	37	60.9
7	60.9	38	60.9
8	60.9	39	60.9

Time to peak

Time to peak was calculated for culverts in each sub-area using the results of construction time estimation (via Kirpich equation which is frequently used for small area) and according to this relation:

$$t_p=\sqrt{t_c}+0.6t_c$$

Table 3- Time to peak (minutes) for sub area

sub area	tp	sub area	tp
1	1.2	0	0
2	1.8	0	0
3	2.6	34	11.9
4	2.6	35	12.6
5	2.5	36	2
6	2.9	37	1.5
7	4.1	38	1.2
8	3.8	39	1.7

Area of sub area

The area of each sub-area was estimated (table 4), then the results of this estimation was replaced in equation 1.

Table 4- the area of sub area by kilometers

sub area	Area	sub area	Area
1	0.01	0	0
2	0.04	0	0
3	0.02	34	1.93
4	0.06	35	1.33
5	0.04	36	0.01
6	0.07	37	0.009
7	0.19	38	0.009
8	0.18	39	0.01

Determining culvert diameter in terms of peak flow

Sub-area involving culvert diameters less than 24 inches were merged to reach at least the minimum diameter determined. The intervals among cross-section drainage culvert exceed a logical limit; if it led to environment damage. Table (5) shows diameter calculated for each catchment. Comparing these diameters with the available diameters in the area, the suggested diameter was determined.

Table5- A comparison among the available, estimated suggested diameters (cm) in sub area

sub area	available diameters	estimated diameters	Suggested diameters	sub area	available diameters	estimated diameters	Suggested diameters
1	60	34	60	22	-	24	60
2	-	50	-	23	-	28	-
3	-	33	-	24	-	37	40
4	60	51	60	0	0	0	0
5	-	44	60	34	60, 100	113	150
6	-	51	60	35	100	82	100
7	60	67	80	36	-	28	-
8	60	68	80	37	-	30	60
0	0	0	0	38	-	32	-
0	0	0	0	39	-	29	-

DISCUSSION

Results of this study were not consistent with the natural environment. Therefore, it is required to pay more attention to forest hydrology and draining factors for preventing the erosion and floods in future. Based on the determined instructions in Iran, the minimum diameter for culvert to be installable in the site is 24 inch. However the diameter of culvert installed a little distance from each other can be decreased to 16 inch [8]. Therefore, this diameter (16 inch) was suggested for adjacent sub-area of 22 and 24. The Kirpich equation was used to estimate the concentration time, this equation is frequently used for small area [9, 3]. The concentration time has a key role in measuring the discharge amount [15, 7] in curve number method; there is a direct relationship between the concentration time and the discharge based on the runoff height. This finding is also proved by the results of our study, i.e., less runoff discharge existed in a sub-area with less concentration time, therefore, this sub-area needs pipes with smaller diameter [14]. Forest cover increases the reservoir volume for establishing runoffs up to 2.5times, in other words, forests reduce the runoff occurrence to 2.5 times. Assessing the effective factors on runoff discharge showed that the maximum runoff discharge will be reduced as the land use type goes towards forests. In curve number method, water waste level increase as the land use type change into forest cover and as the result of this phenomenon, the discharge amount will be decreased. Poor hydrologic condition of studying sub-area had resulted in a higher curve number and more runoff discharge. A 25-year return period was considered to determine culvert diameters used in forest roads [11, 1]. This time period was selected based on rural areas located at lower ranges of roads and the resulting traffic on that area.

CONCLUSION

Hydrologic studies on forests (forest roads in particular) are essential to establish hydraulic constructions. For this purpose, the study area was divided in to 39 sub-areas and then runoff discharges of sub-area were calculated via curve number method. In the next step, the diameters of cross section drainage culvert were calculated based on runoff discharge and head water related to each sub area according to the results, drainage culvert, diameters ranges from 11 inch to 62 inch. Finally, to reach the minimum diameter installable in the study area, adjacent sub area with drainage culvert diameter lower than 24 inch were combined and then they were compared to the available culvert in the site.

Acknowledgment
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