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Determining the Hydrologic Index for Prioritization of Strengthening the Components of Transportation Networkagainst Flood (Golestan Province Case Study)

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Abstract: Flood does not leave equal impacts on the transportation network components. Each component of the network demonstrates a different level of resistance against flood based on its hydrologic and structural design. This has a special significance when a component of the network, which plays a very pivotal role in transportation of passengers and goods, does not show enough resistance against the flood and is destroyed due to that. The purpose of the present investigation is to determine the hydrologic index and merge that with the accessibility index – presented by the author in a previous paper – for strengthening the network components against flood. For this purpose the road networks of Golestan province was chosen as the case study. First the maximum instantaneous discharge was determined based on the maximum daily discharge. Next, the maximum passable discharge for the bridges was determined. Finally, the risk coefficient as a result of destruction of the bridges due to flood was determined. The acquired values were utilized as a coefficient for the accessibility index in the previous paper. According to the obtained values, strengthening the different network components were prioritized in the occurrence of flood.

Key words: flood peak, hydrometric station, maximum instantaneous discharge, return period, risk coefficient

INTRODUCTION

One of the most important research-related issues in the occurrence of natural disasters such as storm, flood and earthquake is strengthening the different components of the transportation network before the occurrence of such disasters. In the realm of transportation, this idea could be developed in terms of different components of the transportation networks and prioritizing the strengthening process against flood. Some of the indexes, which play paramount roles in prioritizing the significance of the components of the transportation network, are accessibility and hydrologic indexes.

In the accessibility index referred to in the last study, the significance of each component was determined based on its role in creating accessibility for major production and attraction regions of passenger and goods. In the present study, however, we are trying to merge accessibility and hydrologic indexes in a way in which the significance of each component is determined based on the risk coefficient due to destruction because of flood. This would be considered as a coefficient in the accessibility index of that component. To do this, the road network of Golestan province was chosen as the case study.

MATERIAL AND METHODS

The methodology of the present research could be categorized into the following:

- Extracting the statistics related to the daily and instantaneous maximum discharge, of the rivers in the region in the annual statistical year,
- Assessing and analyzing the instantaneous maximum discharge or flood peak based on different return periods,
- Determining the capacity of water passing from the bridge sections,
- Determining the risk coefficients of the destruction of bridges in the links understudy,
- Merging the risk coefficient with the accessibility index proposed in the previous study[1],
- Prioritization of the strengthening of the network components based on the new merged index

The Assessment of Flood Peak Through Using the Maximum Daily Discharges for Different Return Periods: In this part of the investigation, using the information and statistics of the hydrometric stations,

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the flood peaks have been assessed. In order to do this, the statistics related to the maximum instantaneous discharge and maximum daily discharge of these stations have been collected since the start of these stations. In table 1, the name and characteristics of the understudy region have been illustrated[1,7].

The mathematical relation between the maximum instantaneous discharge and maximum daily discharge could be defined as follows[3]:

$\mathbf{Q_P = a + b\ Q_D\ ,\ n\ ,\ r}$

and

$\mathbf{Q_P = a\ Q_D^{\ b}\ ,\ n\ ,\ r}$

In which:

Q_P: the maximum instantaneous discharge in the station/m^3 per second

Q_D: the maximum daily discharge in the station/m^3 per second

n: the number of years which have the statistics related to the instantaneous and daily maximum discharge

r: correlation coefficient

a and b: calibration coefficient of the model.

In order to assess the maximum instantaneous discharge for different return periods, the Hydrologic Frequency Analysis(HYFA) Software was used[2,4].

In this method, different statistical distributions such as Log Normal with 2 and 3 parameters, Gumbel, Pearson, Log Pearson Type 3, gama with 2 parameters and etc. have been regressioned to the completed statistics of maximum instantaneous and daily discharge in the hydrometric stations. According to the values of χ^2test and the least square method, the best normal distribution have been selected and using them, the maximum instantaneous discharge has been assessed in the selected hydrometric stations for different return periods. The process of calibrating the correlational relationships for some of the hydrometric stations has been illustrated in the graphs 1 to 3.

In table 2, the values of the flood peaks assessed in the selected hydrometric stations have been shown for different return periods.

Determining the Capacity of Water Passing from the Bridge Sections: In order to determine the capacity of water passing in each of the understudy bridges, the Maning relation has been utilized as follows. Thanks to its simplicity and applicability in different conditions, it has various applications in designing canals. In this section, also, regarding the required precision in this stage of the investigation, the Maning relation has been used to determine the capacity of water passing of the bridges[6].

$$Q = \frac{1}{n} A R^{2/3} S^{1/2}$$

In which:

Q the passable discharge from the bridge section (m3 /s)

n: Maning Coefficient, according to the observation conducted in some of the bridges and the empirical tables, in the references the coefficient was considered to be 0.03

A: the area of the bridge section (m^2)

RL: hydraulic radius of the bridge (m), which equals to $R = \frac{A}{P}$

P: the wetted periphery (m)

S: Longitudinal slope (m/m)

Determining the Risk Coefficient of the Destruction of the Bridge in the Under-study Roads: If in the lifetime considered for technical structures, the flood amount exceeds the equivalent amount for the hypothesized return period, the structure is destroyed or at least is damaged[2].

If we consider p as the probability of the occurrence of an incident, the value of q will be the probability that the incident would not happen:

$\mathbf{q = 1 - p}$

the probability of flood not to happen in n year or the reliability of that would be:

$\mathbf{R = (1 - p)^{\ n}}$

Considering the definition of the return period of flood T, we can present the reliability as follows:

$\mathbf{R = (1 - 1/T)^{\ n}}$

Therefore, the probability of the occurrence would be:

$\mathbf{R' = 1 - (1 - 1/T)^{\ n}}$

Considering what was mentioned before and regarding the previously mentioned equations, the risk coefficient for each of the under-study bridges have been presented in table 3 based on the number of the related links.

Table 1: Name and characteristics of the rivers and hydrometric stations in the under-study region

No	Name of station	Name of river	Geographical characteristics			Station facilities			Year of start
			longitude	latitude	Height	Scale	Bridge	Liminograph	
1	Araz koose	Gharah soo	′ 09 ° 55	′ 13 ° 37	34	+	+	+	1344
2	Galikesh	Oghan	′ 27 ° 55	′ 15 ° 37	250	+	+	+	1344
3	Gonbad	Gorgan rood	′ 09 ° 55	′ 15 ° 37	36	+	+	+	1334
4	Jangaldeh	Narmab	′ 23 ° 55	′ 11 ° 37	190	+			1344
5	Pas poshteh	Narmab	′ 21 ° 55	′ 11 ° 37	180	+		+	1344
6	Ramian	Gharah chai	′- ° -	′- ° -					
7	Anjir ab	Anjir ab	′22 ° 54	′50 ° 36	75	+			1353
8	Yasaghi	Kafsh giri	′14 ° 54	′50 ° 36	6	+			1353
9	Nahar khoran	Ziarat	′28 ° 54	′46 ° 36	500	+			1345
10	Khorooji	Garmabdasht	′33 ° 54	′48 ° 36		+			1374
11	emamzadeh	Gharn abad	′36 ° 54	′48 ° 36	500	+			1348

Determining the Composed Index and Prioritization of the Road Transportation Network Components: At this stage, the risk coefficient of the bridge destruction is utilized as a coefficient for the accessibility index presented in the previous paper[1], and the final composition index is presented for prioritization of the road transportation network components based on the following equation[5]:

$$R^1 = R * \sum_{i=1}^{24} (A_i - A_i^j)$$

In which:

R: the risk coefficient of the destruction of the link

A_i: the accessibility of area i before the loss of link *j*

A_i^j: the accessibility of area i after the loss of link *j*

R^1: the final composed index

According to this, the value of the final composed index for different links of the province road network have been assessed and finally prioritized. The results are illustrated in table 4.

According to the results of table 4, the final prioritization of the links in Golestan Province road network are as follow:

Number of link	23	4	5	17	2	3	9	8	18	14
Precedence	1	2	3	4	5	6	7	8	9	10

The related curves of the prioritization of the strengthening the road network components against flood according to accessibility index (previous paper[1]) and the proposed composed index in the present study are illustrated in Graphs 1 and 2.

Conclusion: The obtained results of the maximum instantaneous discharge of the rivers in under-study region are indicative of the high precision of the calibrated correlations in different hydrometric stations. In addition, the obtained results of the assessment of the capacity of water passing in the existing rivers shows the high validity of Maning relation for being used in rectangular bridge section.

In the final prioritization of Golestan province road networks, it can be observed that the link no. 23 which has been considered the 3rd priority in the previous study[1], in the present study has been considered the 1st factor due to its high risk coefficient. Also, the link no. 17 has been placed in a higher priority compared to link 2, this happened in the opposite order in the previous study[1].

Generally, it can be concluded that merely using the accessibility index(as in the previous paper[1]) does not suffice in prioritizing the road network components against flood. Consequently, another index needs to be assessed simultaneously with the accessibility index. This index is in fact the risk factor of the destruction of the bridge due to flood. In the composed index a merged form of these two proposals have been presented.

Table 2: The values of peak flood in the selected hydrometric stations for different return periods

No	Name of station	Name of river	Selected distribution	Return period (year)							
				2	5	10	20	25	50	100	200
1	Arazkooseh	Gharah soo	Gama (2 parametric)	100	146	175	201	209	234	258	281
2	Galikesh	Oghan	Log-normal (2 parametric)	33	82	131	194	218	302	404	529
3	Ghazaghli	Gorgan rood	Log-normal(3 parametric)	113	172	219	269	286	342	403	469
4	Jangaldeh	Narmab	Pearson (type 3)	54	127	190	256	278	350	424	501
5	Ramian	Gharah chai	Log-normal (2 parametric)	36	78	116	162	178	234	300	376
6	Anjirab	Anjir ab	Log-normal (2 parametric)	8	16	23	32	35	45	57	70
7	Yasaghi	Kafshgiri	Log-pearson (type 3)	12	26	36	45	48	56	64	71
8	Naharkhoran	Ziarat	Pearson (type 3)	3	10	18	27	30	41	53	65
9	Kosar dam	Garmabdasht	Gama (2 parametric)	1.6	2.1	2.4	2.6	2.7	3.0	3.2	3.4
10	Emamzadeh	Gharn abad	Log-normal (2 parametric)	0.7	2.0	3.5	5.5	6.2	9.1	12.9	17.6
11	Taghi abad	Jafar abad	Log-pearson (type 3)	25	56	84	115	125	160	198	240
12	Astlo	Mohamad abad	Log-pearson (type 3)	2.4	3.5	4.3	5.3	5.6	6.6	7.8	9.1
13	Zarrin gol	Sormeh rood	Log-normal (2 parametric)	7	12	16	20	21	26	31	36
14	Zarrin gol	Zarrin gol	Log-normal (2 parametric)	22	45	65	87	95	123	154	189
15	Agh ghala	Gorgan rood	Log-normal(3 parametric)	117	196	265	342	370	462	567	685
16	Siah ab	Gharah soo	Gama (2 parametric)	16	27	34	40	42	49	55	61
17	Bandar torkaman bridge	Gharah soo	Pearson (type 3)	1.3	1.8	2.2	2.4	2.5	2.8	3.0	3.3
18	Niyaz abad	Gharah soo	Gama (2 parametric)	14	30	43	55	59	71	84	96

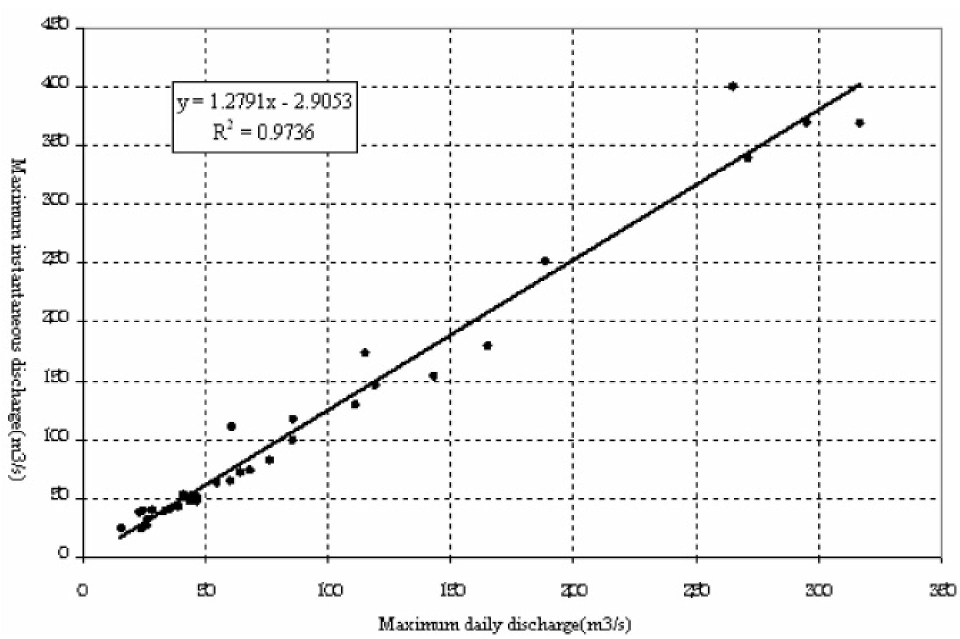


Fig. 1: The Correlation of the maximum instantaneous discharge in Gonbad hydrometric station

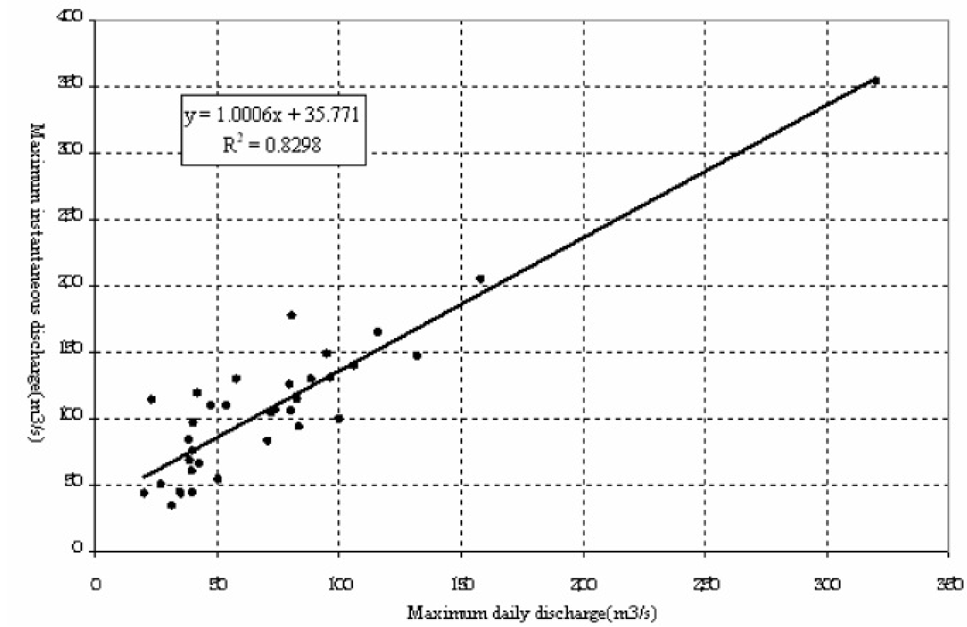


Fig. 2: The Correlation of the maximum instantaneous discharge in Arazkooseh hydrometric station

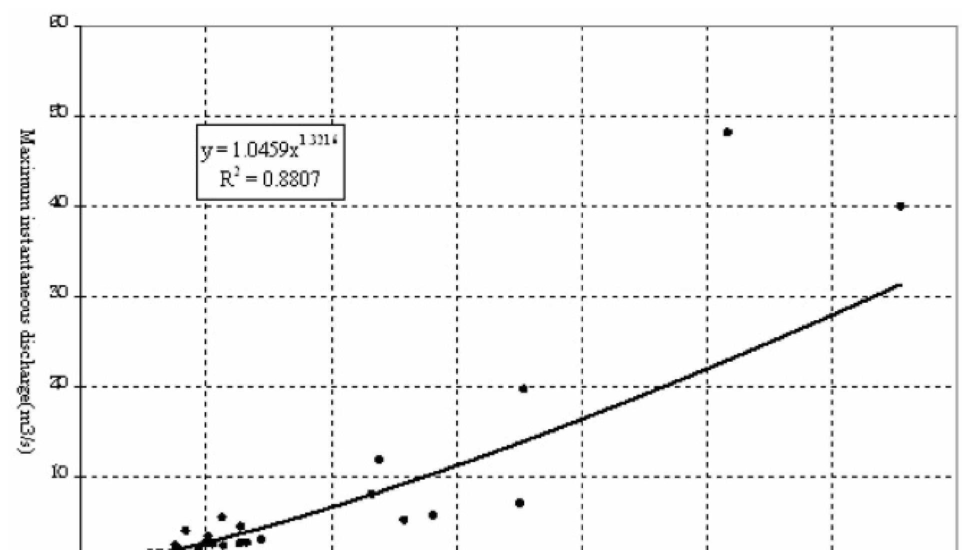


Fig. 3: The Correlation of the maximum instantaneous discharge in Naharkhoran hydrometric station

Table 3: The assessment of capacity and risk coefficient of the under-study bridges

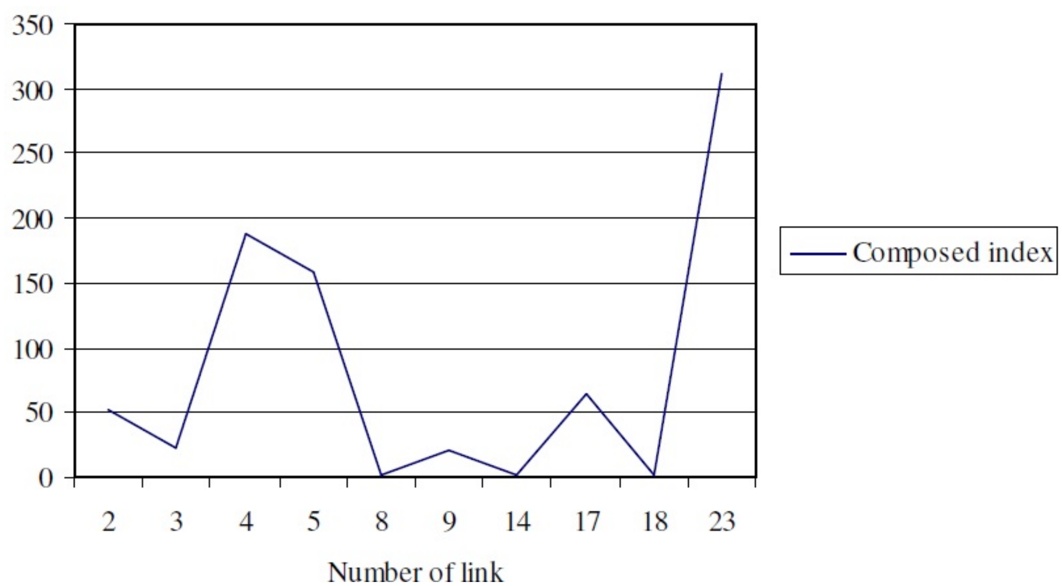
No	Number of link	river	Number of bridge section	Average length of bridge (m)	Average height from riverbed (m)	Width of bridge (m)	Capacity of bridge (m^3/s)	Name of station	Safe return period (year)	Risk coefficient (%)
1	2	Kafshgiri	1*6	10	3.30	11	109	Yasaghi	500	8
2	2	Anjir ab	3*7	25	3.20	1	499	Anjir ab	500	8
3	3	Gharn abad (emamzadeh)	1*7	9	3.40	11	198	emamzadeh	500	8
4	3	Jafar abad	3*7	25	3.70	11	663	Taghi abad	500	8
5	4	Mohamad abad	3*7	25	4.30	11	571	Ostlo	500	8
6	5	Zarrin gol	4*10	47.5	4	11	1112	Zarrin gol	500	8

Table 3: Continue

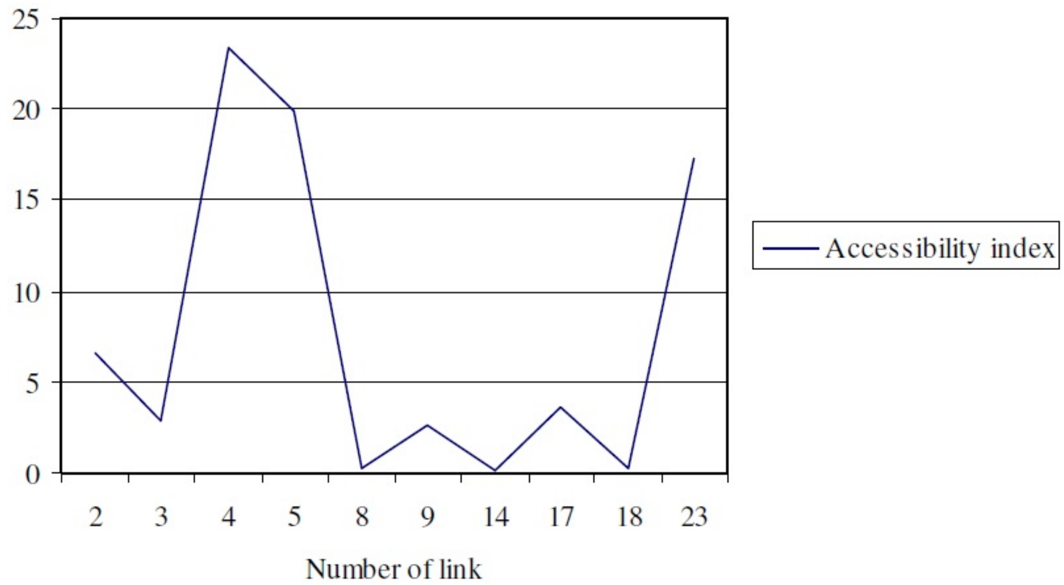
7	5	Ghareh aghaj	1*18	21	7.50	11	1207	Ramian	500	8
8	8	Oghan	1*17	18	7	8	972	Galikesh	500	8
9	9	Gharah soo	3*20	64	12.8	11	2557	Araz koose	500	8
10	14	Gorgan rood	1*14.5	17.5	7.40	8	269	Agh ghala	200	18
11	17	Gharah soo	3*5	22	3.10	8	61	Siyah ab	200	18
12	18	Gharah soo	8+10.50+8	32.5	4.50	8	215	Niyaz abad	500	8
13	23	Gorgan rood	6+23+6	39	7.50	9	657	gonbad	200	18

Table 4: The assessment of final composed index for different links of the road transportation network in Golestan Province.

No	Number of link	Accessibility index *1000 (α = 0.5)	Risk coefficient (%)	Final composed index
1	2	6.58	8	52.64
2	3	2.83	8	22.64
3	4	23.4	8	187.2
4	5	19.9	8	159.2
5	8	0.23	8	1.84
6	9	2.66	8	21.28
7	14	0.07	18	1.26
8	17	3.61	18	64.98
9	18	0.23	8	1.84
10	23	17.3	18	311.4



Graph 1: Prioritization of Strengthening the road transportation network against flood based on the proposed composed index.



Graph 2: Prioritization of Strengthening the road transportation network against flood based on the accessibility index (previous paper[1])

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