ESTABLISH A CRITERIA SET FOR ASSESSING THE FLOOD RISK AT OVERFLOW BRIDGE IN CENTRAL VIETNAM

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ABSTRACT

An overflow bridge is a drainage work in combination with a road, which is built across rivers and streams. In the rainy season, the flood flow over the work is both deep and fast, causing danger to the lives of people, vehicles, and even the overflow bridge itself. So far, in Vietnam there is no official statistics on the number of overflow bridges as well as tools / criteria for assessing their potential risks. This study collects 10 criteria from the three groups of hazard, vulnerability, and exposure to assess the danger level for overflow bridges which was applied in the central region of Vietnam. The weight of each factor is determined by AHP hierarchical analysis. The aggregated criteria value is classified into 3 levels as $C = 1.0 - 1.66$ (Low danger); $C = 1.66 - 2.0$ (Medium danger) and $C = 2.0 - 3.0$ (High danger). This set of criteria is the basis for the management agency to apply in alerting people to reduce flood risks as well as for repairing and upgrading overflow bridges.

Keywords: overflow bridge, flood risk, risk criteria, Central Vietnam, AHP

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1. INTRODUCTION

Vietnam is located in a tropical monsoon climate region, dense river network and a developing country. There are many spillways (overflow bridges) on the roads passing through rivers and streams. Every year, during the rainy season, many unfortunate accidents occur related to traffic through overflow bridge. According to data of the Disaster Prevention Department, in the past 10 years, flood flows on the overflow bridges have swept over 30 cars, hundreds of motorcycles, more than 100 people died and 357 works damaged.

Survey results at spillways in central Vietnam showed that most of overflow bridges are located in small basins, narrow terrain and slopes. Some works are located on the flood discharge route of the reservoirs. Most works in central Vietnam are not equipped with warning systems or flood warning columns. A few works have a flood warning column but the information is often difficult to observe (Figure 1). Therefore, when heavy rains or flooding from the reservoirs, the water flow will focus very quickly on the project. Due to the small aperture of flood drainage, flood usually overflows very quickly. Besides, the timing of flood occurrence and the level of flooding in the overflow area are difficult to accurately predict, so the authorities and local people have many difficulties in proactively preventing and minimizing damage.

Figure 1 Typical types of overflow bridges in Central Vietnam

So far in Vietnam, damages to overflow bridges are often assessed based on actual data without considering the nature of the phenomenon. Quantification of the main causes of such damage has not been taken into account. In addition, Vietnam has not yet assessed their danger level to give appropriate warnings or remedies to minimize damage in each rainy season. Therefore, it is very necessary to have a solution to minimize the damage to the lowest level. The study proposed a set of criteria to assess the danger level of overflow

bridges so that authorities could identify which works are in the alert zone and have a timely response plans.

2. METHODOLOGY

According to (Alexander, 1997), risk is a concept that presents potentially negative effects on people, property or property that may arise from a process. In common language the risk is often used in parallel with the probability of loss. Risks are often seen as the result of hazard characteristics (the physical characteristics of the hazard and its effects), vulnerability (vulnerability to sensitivity) and exposures. Risk can presented conceptually with the following equation:

$$\text{Risk} = \text{Hazard} * \text{Vulnerability} * \text{Exposures}$$

In this study, we calculate risk by setting up criteria groups for hazards, vulnerability and exposures.

2.1. Criteria for Hazards

A hazard is a process, phenomenon or human activity that can cause a hazard casualties or other harm to health, property damage, socioeconomic disruption or environmental degradation. In this study, hazard criteria are defined as a combination of stability, flood factors and the overflow bridges safety.

2.1.1. Stability Factor

This factor considers the stability of human and vehicles under the impact of flood flow at the overflow bridges site. Value of water level and velocity at the work are characteristics to assess the instability of the object under the impact of flood flow (Figure 2a)

2.1.1.1. Human Stability

Human stability under the influence of flow is controlled by four factors: floating force (F_b), thrust of flow (F_D), body weight (F_G) and reaction force (F_n). Floating force (F_b) is determined by (Junqiang Xia, 2014)(Junqiang Xia, 2014) as follows:

$$F_b = g\rho_f (a_1x^2 + b_1x)(a_2m_p + b_2) \quad (1)$$

where

g is the gravitational acceleration (m/s^2);

ρ_f is the density of water (kg/m^3);

$x = h_f / h_p$; h_f is the flow depth (m); h_p is the height of the person (m);

m_p is body weight (kg);

a_1 and b_1 are constants. According the study of (T.D. Shand, 2011)(T.D. Shand, 2011) $a_1 = 0.633$ and $b_1 = 0.367$

a_2 and b_2 are determined based on the characteristics of Asians (Chinese) (Guo, 1995) whose values are respectively $1.015 \cdot 10^{-3} (\text{m}^3/\text{kg})$ and $-4.927 \cdot 10^{-3} (\text{m}^3)$.

Figure 2 Typical modes human and vehicle instability (T.D. Shand, 2011)

The thrust of flow (F_D) is determined by follows equation

$$F_D = \frac{1}{2} A_d C_d \rho_f u_b^2 \quad (2)$$

where

u_b is the velocity at the standing position (m/s);

C_d is the drag coefficient;

A_d is the area of the wet cross-section (m^2), determined by the formula

$A_d = a_d \cdot a_p \cdot h_f \cdot h_p$, when the submerged section is below the waist, $a_d = a_p = 0.19$.

Human body weight (F_G) is divided into 2 force components in the x and y directions:

$$F_{Gx} = m_p g \sin \theta \quad (3)$$

$$F_{Gy} = m_p g \cos \theta - F_b \quad (4)$$

$$\text{Reaction force } F_n = F_{Gy} \quad (5)$$

Stabilization condition is defined as the possibility of being overturned around point O (Figure 2a). The moment balance at point O is given by the equation:

$$F_{Gy} L_{Gy} + F_{Gx} L_{Gx} = F_D L_d \quad (6)$$

where: $L_d = a_h h_f$; $L_{Gx} = a_{Gx} h_p$ và $L_{Gy} = a_{Gy} h_p$; $a_h = a_{Gx} = 0.55$ (Hellebrandt, 1938); $a_{Gy} = 0.05$ (Guo, 1995).

Substituting equations from (1) to (5) into (6), we can get the equation that determines the condition of stability in the flow:

$$u_b h_f = \sqrt{\frac{2g \left(m_p \cos \theta - \rho_f (a_1 x^2 + b_1 x) (a_2 m_p + b_2) \right) a_{Gy} + m_p a_{Gx} \sin \theta}{a_d a_p a_h C_d \rho_f}} \quad (7)$$

Equation (7) shows that when x changes, the $u_b h_f$ criterion for human hardly changes, but only depends mainly on the change of m_p (Figure 3a). Velocity values that endanger for human by weight for each depth of flood level are shown in Figure 3b.

Figure 3a. Relationship between $u_b h_f$ and x

Figure 3b. Relationship between u_b and m_p

According to the survey of nutrition of the Ministry of Health of Vietnam for adults aged 25 - 64 years in the North Central and South Central Coast of Vietnam, the average height of the people is 161.45 cm and weight ranges from 45 – 60 kg, average 49.30kg. Therefore, the dangerous limit $u_b h_f$ is 0.5 - 0.6 m^2/s . Thus, the criteria for the stability of road users under the impact of flow are determined according to Table 2.

2.1.1.2. Vehicles Stability

Vehicles moving through flooded on overflow bridges areas are likely to be unstable due to floating or repulsive forces (Figure 2b, c, d). Some scientists have studied empirical and / or theory such as (Hattersley, 1967), (Foster, 1973), (Keller, 1993) for different vehicles such as Ford Falcon, Morris Mini, Toyota Corolla, Suzuki Swift, Ford Laser, Honda Civic, Ford LTD with different assumed coefficient of friction varying from 0.3 to 1.0 and mainly is 0.3. The stability conditions for vehicles ranged from 0.2 - 1.2 m^2/s (Keller, 1993).

Based on the guidance on the selection of technical scale of rural roads for the National Target Program on New Rural Construction period 2010-2020 according to Decision No. 4927 / QD-BGTVT (dated December 25, 2014) of The Ministry of Transport (Vietnam), the velocity values on the overflow bridge surface and the depth of flows are defined as Table 1.

Table 1 Maximum depth of flow on overflow bridge

Velocity on the overflow bridge surface, u_c (m/s)	≤ 1.5	2.0	2.5
Depth of flow, h_f (m)	0.4	0.3	0.2

Thus, the selected $u_c h_f$ danger limit is 0.5 - 0.6 m^2/s . However, in order to improve safety indicators, the study selected safety threshold according to flood depth $h_f = 0.3\text{m}$ for all vehicles.

Table 2 Stability criteria

Criterias		Level	Value
Human stability	Vehicles stability		
$u_b h_f < 0.5$	$h_f \leq 0.3$	Low danger	1
$0.5 < u_b h_f < 0.6$	$0.3 < h_f \leq 0.4$	Medium danger	2
$u_b h_f > 0.6$	$h_f > 0.4$	High danger	3

2.1.2. Flood Criteria

Flood criteria are composed of three components including flood frequency, flood duration and flood intensity. Most spillways in the central region of Vietnam do not have hydrological monitoring stations, so the determination of this criterion depends on the results of the analysis of survey data.

Survey results show that in the recent 10 years, floods appear more frequently, on average about 2-4 times/year, while before only 1-2 times/year; The duration of inundation is usually from less than 1 day to 3 days; The average flood water level is about 0.3 - 0.5m/h. Local people can estimate flooding time through weather forecasts. Floods of less than 1 day have little impact on traffic activities because the people have actively taken appropriate measures. When the flood time is more than 1 day, people have to go the other way or wait for the flood to recede. In floods with the intensity of less than 0.3m/h, the people are completely able to cope.

According to survey results in more than 40 states in the US, (Motayed A K, 1982) identified flood frequency of less than 2 times / year as favorable, 10 times / year as disadvantage and duration of flood less than 1 day is favorable, 3 days is disadvantage. Therefore, flood criteria for flood frequency, duration of flooding and flood intensity are selected as in Table 3.

Table 3 Flood criteria

Flood criteria			Level	Value
Frequency	Time inundation	Intensity		
1 time/year	< 1 day	< 0.3m/h	Low danger	1
2 - 3 times/year	1-3 days	0.3 - 0.5m/h	Medium danger	2
> 3 times/year	> 3 days	> 0.5m/h	High danger	3

2.1.3. Overflow Bridge Criteria

The overflow bridges in the central region of Vietnam are mostly built on inter-commune and inter-district roads of the type of small constructions with concrete and paved structures, so it is almost impossible to collect design documents. Therefore, the evaluation of construction safety according to the criteria of deformation, displacement, the formation and expansion of cracks in concrete, the degree of vandalism, erosion depends on the observation recorded by the investigator (Table 4)

Table 4 Overflow bridge criteria

Criteria	Level	Value
The original shape, no cracks, stable parts, no deformation	Low danger	1
The original shape, but cracked, moved within the allowed limits	Medium danger	2
Deformation, large cracked parts, roof slopes	High danger	3

2.2. Criteria for Vulnerability

Vulnerability means conditions defined by physical, social, economic and environmental factors or processes that can increase the sensitivity of an individual, community, property or system. affected by danger. This criterion is determined to aggregate the criteria of awareness, resilience; signs, warning systems; and bypass routes.

2.2.1. Awareness and Resilience of Local People

This criterion is built based on the results of the survey for people in traffic and living around the work area by collecting multiple choice questionnaires with questions belonging to two groups of factors, including:

- Knowledge of people about floods when participating in traffic such as: Should or should not go through underground overflows when floods occur? How to identify the depth of flooding? How to capture flooded information?
- The ability of people to handle situations when they are swept away: Can they swim or not? What is the escape skill in a car swept away? How to rescue people swept away? How to rescue cars swept away?

Criteria for knowledge and resilience of the people selected are determined according to Table 5.

Table 5 Criteria of awareness and resilience

Criteria	Level	Value
Meets over 70% of multiple choice questions	Low danger	1
Meet less than 70% of multiple choice questions	Medium danger	2
Meet less than 30% of multiple choice questions	High danger	3

2.2.2. Criteria for Signage, Warning Systems

Warning system, signs on the underground work is responsible for bringing flood information to people in traffic. However, according to the survey results, this system is almost not equipped at underground works in central Vietnam (Figure 2). Criteria for signboards and warning systems are selected according to Table 6.

Table 6 Criteria for signage, warning systems

Criteria	Level	Value
Warning systems, warning speakers available	Low danger	1
Water column and signpost available	Medium danger	2
No warning systems, warning speakers and water column	High danger	3

2.2.3. The criteria for the Flood Avoidance Route

The survey results of overflow bridges in central Vietnam showed that in mountainous areas, traffic density is low, roads are difficult to access, most have no bypass roads. The works in the delta areas have high traffic density, most of which have bypass routes. Currently, GPS applications have made it easier for road users to find an appropriate alternative route. Based on the status of the bypass routes, the study proposed evaluation criteria as follows (Table 7):

Table 7 The criteria for the flood avoidance route

Criteria	Level	Value
Flood avoidance route available, the travel time is less than 1 hour	Low danger	1
Flood avoidance route available, the travel time is more than 1 hour	Medium danger	2
Flood avoidance route not available	High danger	3

2.3. Criteria for Exposure

Exposure is the state of the person, infrastructure, housing, production capacity and other tangible property which located in a vulnerable area. In this study, exposure was limited by people and vehicles through overflow bridge. The higher the density of traffic participation, the higher the risk and vice versa, so the number of turns of people and vehicles participating in traffic through the overflow bridge will be the specific factors for this criterion.

The study has carried out the monitoring of vehicle flow and traffic participants through some typical spillways in the central region of Vietnam. Monitoring data has determined the average daily flow of road users. Monitoring data showed that most of the underground spillways have the traffic of more than 50 people / day. According to (Motayed A K, 1982), if the means of traveling through overflow bridges traffic is less than 5 times / day is convenient and 200 times / day is disadvantage.

In order to ensure safety and suitability with construction characteristics, the study proposed the following vehicle density criteria (Table 8):

Table 8 Criteria for exposure

Average number of vehicles	Number of people	Level	Value
Less than 50 vehicles/day	Less than 5 people	Low danger	1
Less than 200 vehicles/day	Less than 20 people	Medium danger	2
More than 200 vehicles/day	More than 20 people	High danger	3

3. RESULTS AND DISCUSSION

Survey results have shown that risks when people and vehicles through the overflow bridges mainly at the time of floods. Consequently vulnerability criteria related to people's awareness and ability to handle situations are the most important criteria. Besides, the warning system, signage, barriers are the second most important factors causing risks. The flood avoidance route is the third most important factor to reduce the risk of traffic. Criteria for hazards related to flood intensity are the next important criteria because they are the criteria causing the sudden occurrence of floods. However, this criterion is dependent on each flood, so the assessment is only conducted when there are forecast results or for floods that have occurred. The remaining criteria are assessed to have a relatively uniform level of risk. The density of people and vehicles is only really strong when floods occur at a time of high density. However, at this time, it is almost impossible to estimate in advance because the forecast of the incoming flow in these areas is limited. Therefore, this criterion only assesses the average daily traffic volume and the level of risk divided evenly across the time of day. Impact of works safety on road users is taken into consideration when road users through flood flow have limited visibility of the building surface, the building deformation can increase risks.

To estimate the weights of the factors, we used the Analytic Hierarchy Process (AHP) method (Saaty, 1980) for 10 factors belonging to 3 groups of criteria: Hazard, vulnerability and exposure. Factors as mentioned above, including: Frequency of flood, duration of flood, intensity of flood, density of people and vehicles, human stability, vehicles stability, warning systems, avoidance routes, structural work, and awareness and resilience of local people. Weights are calculated based on matrix of 10 x 10 elements and 45 comparison pairs (Table 9 and 10)

Table 9 Pair-wise comparison matrix

Factors	Frequency of flood	Duration of flood	Intensity of flood	Density of people and vehicles	Human stability	Vehicles stability	Warning systems	Avoidance routes	Structural work	Awareness and resilience
Frequency of flood	1	1	0.5	1	1	5	1	0.5	1	0.2
Duration of flood	1	1	0.5	1	1	1	0.2	0.5	1	0.2
Intensity of flood	2	2	1	2	2	2	0.5	1	2	0.5
Density of people and vehicles	1	1	0.5	1	1	1	0.2	0.5	1	0.2
Human stability	1	1	0.5	1	1	1	0.2	0.5	1	0.2
Vehicles stability	0.2	1	0.5	1	1	1	0.2	0.5	1	0.2
Warning systems	1	5	2	5	5	5	1	2	5	1
Avoidance routes	2	2	1	2	2	2	0.5	1	2	0.5
Structural work	1	1	0.5	1	1	1	0.2	0.5	1	0.2
Awareness and resilience	5	5	2	5	5	5	1	2	5	1

Table 10 The result of calculating the weight of the factors

No	Factors	Weights	Rank
1	Frequency of flood	8.40%	5
2	Duration of flood	5.10%	6
3	Intensity of flood	10.60%	3
4	Density of people and vehicles	5.10%	6
5	Human stability	5.10%	6
6	Vehicles stability	4.40%	10
7	Warning systems	21.20%	2
8	Avoidance routes	10.60%	3
9	Structural work	5.10%	6
10	Awareness and resilience	24.40%	1

The consistency ratio (CR) = 0.03

Table 10 showed that there are 3^{10} series of numbers selected. The distribution of the results of the assessment of overflow bridges risks in Central Vietnam is shown in Figure 3 with the largest total value of 3 at 0% and the smallest of 1 at 100%. The result of assessing the danger of overflow bridges based on frequency distribution, if greater than 85% is considered as low danger, less than 50% is high danger, the remaining is medium danger (Table 11).

Table 11 Summing up the criteria

Criteria	Level
$1,0 \leq C < 1,66$	Low danger
$1,66 \leq C < 2,0$	Medium danger
$2,0 \leq C \leq 3,0$	High danger

Figure 3 Risk distribution at overflow bridges

4. CONCLUSION

The application of a set of criteria to assess the danger of overflow bridge is very meaningful in practice. However, when applied, it is necessary to be flexible in specific conditions of each region in order to get the most accurate results. For managers, it is essential to understand the danger of s overflow bridge. Based on this, it is possible to offer the most optimal solutions to minimize the damage or to list the construction of works in order of priority.

Currently, it is difficult to invest in upgrading all the overflow bridge, so it is necessary to find solutions to cope. In particular, raising awareness of the community combined with the construction of automatic warning systems in the overflow bridge will be the most economical and effective solution.

When constructing new or repairing, upgrading overflow bridge, it is necessary to comprehensively consider the alternatives, which can both be a bridge to overcome large floods, and an overflow bridge to overcome small floods to reduce cost of construction.

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