홍수피해액을 활용한 차량별 침수 위험 기준 설정 연구

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Establishing Flood Risk Criteria for Vehicles based on Flood Damage Assessment

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[요 약]

최근 기후변화로 인한 반복적인 홍수와 시가지 내 도로 침수는 차량의 정량적 손실과 인명 피해를 증가시키고 있다. 이에 도로 침수로 인한 차량과 인명 손실 대비를 위한 홍수위험 관련 연구가 다양하게 진행되고 있다. 그러나 주로 인명 피해를 예방하기 위한 홍수위험 및 예방 대책 수립을 중심으로 연구가 이루어졌으며, 차량과 관련된 연구는 미미한 수준이다. 본 연구에서는 침수심에 따른 차량의 경제적 손실을 평가하여 홍수위험 기준을 제시하고자 한다. 이에 대상 차량을 4가지(승용, SUV, 화물트럭, 버스)로 선정하고, 침수심별 기계적 손상과 홍수피해액을 활용하여 침수 위험 기준을 제시하였다. 분석 결과, 침수로부터 차량 피해를 저감하기 위해서는 침수심이 20cm이상인 침수지역은 회피하거나, 차량 진입을 제한할 필요가 있는 것으로 분석되었다. 향후 본 연구의 침수심별 홍수위험 기준을 활용하여 도로 내 차량 통행기준 및 침수대책 수립에 활용되기를 기대한다.

[Abstract]

Recent recurrent flooding and road flooding, driven by climate change, have been increasing both human casualties and quantitative losses to vehicles. While various studies have been conducted focusing on measures to prevent human casualties, research related to vehicles remains limited. This study aims to assess the economic losses to vehicles based on flood depth and propose flood risk criteria. Four types of vehicles were selected as the study subjects, and flood risk criteria were established using mechanical damage and flood damage costs for different flood depths. The analysis revealed that areas with a flood depth of 20 cm or more should be avoided, or vehicle entry should be restricted, to mitigate vehicle damage from flooding. It is expected that the flood risk criteria based on flood depth proposed in this study will be used in the future to establish vehicle traffic regulations and flood mitigation measures for roadways.

Ⅰ. Introduction

Recently, localized flood damage in Korea has been occurring frequently due to flash floods and heavy rains linked to climate change, resulting in increased financial losses and loss of life [1],[2]. In areas where flooding occurs due to heavy rainfall, if roads that facilitate the movement of people and goods are submerged, it can lead to mechanical damage to vehicles used in economic activities, as well as pose significant risks to the lives of those traveling in those vehicles [3],[4].

To effectively respond to and mitigate flood damage on roads, it is essential to understand the extent of damage to vehicles. Additionally, preparing for such events requires assessing the potential physical damage and recognizing in advance the level of flooding that could harm vehicles.

According to the report on the analysis of traffic accident characteristics during the summer rainy season in [5], an analysis of flooded vehicles in Gangnam-gu, Seoul, from 2006 to 2012 indicated that flooding occurred when rainfall exceeded 35 mm per hour. Furthermore, during rainfall, the slipping accident rates on highways and general roads were 2.44 and 1.43 times higher, respectively, compared to conditions without rainfall. When a vehicle driving on the road becomes submerged due to flooding, mechanical damage may occur depending on the flooding depth and the location of the vehicle's internal components. In Korea, the Ministry of Land, Infrastructure and Transport (2022) categorizes submerged vehicles into internal combustion engine vehicles and electric vehicles [6]. Kim et al. presented the relationship between submergence depth and damage rate by vehicle type as a relative function, incorporating expert opinions [7]. This information was then used to develop a loss model for assessing the impact of water-related disasters.

To reduce damage caused by flooding, it is important to prepare in advance and provide information about potential flooding before it occurs. If this information is not available, it is essential to recognize the risk of flooding and either take a detour or avoid driving on flooded roads. The Ministry of the Interior and Safety of Korea provides guidelines for vehicle users in their Natural Disaster Action Guidelines [8]; however, these guidelines primarily focus on minimizing casualties.

As previously mentioned, while ensuring safety and preventing loss of life are crucial, the value of assets has also been increasing with societal development. In particular, urban areas experience frequent flooding on roadways, which simultaneously affects both vehicles and their occupants. As of 2023, the number of registered vehicles in South Korea stands at approximately 25.95 million, and this number continues to rise. In densely populated urban areas, the concentration of vehicles is also high, leading to an increase in vehicle damage caused by flooding. However, research on flood damage, particularly focusing on vehicle-related losses, remains limited. Therefore, continuous research is needed to develop effective prevention measures and countermeasures for vehicle-related flood damage.

Therefore, in this study, we select representative vehicles to assess the extent of damage caused by road flooding and evaluate the mechanical damage corresponding to flooding depth. Additionally, we aim to determine the risk of vehicle flooding on the road and establish standards for vehicle exposure during such flooding.

Ⅱ. Selection of Representative Vehicles

There are limitations in assessing flooding damage across all vehicles, particularly in identifying specific heights and affected components. Therefore, this study aimed to select representative vehicles based on their physical characteristics. We chose vehicles that are commonly sold and registered in Korea, as well as those that closely resemble the average vehicle in terms of design. As a result, four types of vehicles were selected as representatives: sedans, SUVs(sports utility vehicle), cargo vehicles, and passenger buses.

The heights of various components for each vehicle were selected and categorized as shown in Table 1. Although there may be slight differences in vehicle heights depending on the type, the locations of these components were assumed to be relatively consistent across the vehicles. When flooding occurs on roadways due to a flood, vehicles are affected by the

flow velocity and the depth of the water. However, it is difficult to define the relative size and scale of the flow velocity, and there are limitations in determining the vehicle's speed and condition (on/off) based on flooding. Therefore, these factors were excluded from the analysis.

Ⅲ. Calculating Flood Damage by Vehicle Type

3-1 Maintenance Scope of Domestic Flooded Vehicle

The Ministry of Land, Infrastructure and Transport (2022) defines a flooded vehicle as one where the interior floor is submerged [6]. Flooded vehicles are categorized into two types: partial flooding and complete flooding. Insurance and maintenance

Table 1. Classification and maintenance scope according to flooding criteria

Vehicle Type	Vehicle Parts	Height(cm)	No.	Visualization
Sedan	Side skirt	18	1	
	Sidestep	25	2	
	Wheel housing	70	3	
	Belt line	100	4	
	Overall height	145	5	
	Exhaust	30	6	
	Trunk door	67	7	
SUV	Side skirt	20	1	
	Sidestep	48	2	
	Wheel housing	79	3	
	Belt line	116	4	
	Overall height	168	5	
	Exhaust	30	6	
	Tailgate	67	7	
Cargo truck	Side skirt	30	1	
	Sidestep	48	2	
	Rear deck	70	3	
	Belt line	129	4	
	Overall height	197	5	
	Exhaust	50	6	
	Tailgate	70	7	
Bus	Side skirt	30	1	
	Indoor floor	35	2	
	Wheel centerline	45	3	
	Wheel housing	105	4	
	Belt line	145	5	
	Indoor ceiling	265	6	
	Overall height	318	7	
	Exhaust	50	8	
	Rear engine flap	75	9	

Table 2. Number of parts items and unit price per vehicle

Vehicle Type	Parts price	Number of parts items	Quantity (units)	Unit price (KRW)	Total (KRW)
Sedan (Sonata DN8)	1,000 won or more	1,451	2,106	32,046	67,487,988
	1,000 won or less	916	3,211	286	918,070
	Total	2,367	5,317	12,866	68,406,058
SUV (Santa Fe TM)	1,000 won or more	1,492	1,876	44,649	83,762,176
	1,000 won or less	957	3,549	285	1,010,068
	Total	2,449	5,425	15,626	84,772,244
Cargo Truck (Porter II, 2020)	1,000 won or more	1,252	1,667	31,765	52,953,039
	1,000 won or less	1,059	3,455	280	967,802
	Total	2,311	5,122	10,527	53,920,841
Bus (Aero City CNG Ultra Low Floor)	1,000 won or more	1,868	3,741	48,566	181,685,461
	1,000 won or less	1,216	7,738	249	1,925,367
	Total	3,084	11,479	15,995	183,610,828

companies may classify these vehicles as total loss or repairable based on their assessment.

3-2 Quantification of Mechanical Damage Based on Flood Depth by Vehicle Type

Vehicles consist of approximately 20,000 parts. To establish flooding standards for vehicles, the damage amount associated with the depth of flooding was calculated. The unit prices and quantities of each part for the representative vehicles are organized in Table 2, as presented in Table 1. The number of parts was categorized into approximately 150 items based on part type. Upon investigating the prices of each vehicle's parts, it was found that the total cost of the parts exceeded the vehicle's purchase price. Consequently, if the calculated damage amount exceeded the vehicle's purchase price, the purchase price was used as the flood damage amount.

Additionally, when flooding occurs, foreign substances and water infiltrate the vehicle's components, leading to a significant reduction in their performance. Therefore, this study assumes that if the floodwater reaches the vehicle's components, the components will be replaced. The replacement cost of the components was then used to calculate the flood damage costs.

3-3 Calculating Damage Amount by Vehicle Height

Before determining the flood damage amount (repair costs) for a vehicle, it is necessary to estimate the damage to each component based on the flood depth. To do this, the minimum and maximum heights were established according to the location of each part group within the vehicle, categorized by function. The damage amount was estimated by calculating the arithmetic sum of each flood height and the corresponding part items. Notably, labor costs for repairs were excluded, and the damage amount was calculated using only the cost of the parts [9].

IV. Definition of Flooding Criteria and Risk Levels by Vehicle Type

In this section, the vehicle damage amounts corresponding to flood depth by vehicle type were calculated. The damage amount for each vehicle was determined as the total cumulative cost of the parts based on their locations within the vehicle. Additionally, the extent of damage for each vehicle type was assessed, leading to the definition of flooding criteria and risk levels based on the calculated results.

4-1 Crisis Alert Level

The national crisis warning system is divided into four stages: Blue, Yellow, Orange, and Red, in accordance with the standard manual for disaster crisis management [10]. This structure allows ministries, agencies, and local governments to carry out response activities tailored to each stage. Ultimately, the goal is to foster public understanding and encourage voluntary participation in overcoming dangerous situations [11]. In this paper, the following assumptions were made to define the crisis warning levels related to road flooding:

- Blue (Attention): Water accumulates in a section of the road.

– Yellow (Caution): Water reaches below the side steps.

– Orange (Alert): Water reaches below the side skirt of a car.

– Red (Severe): Water on the road exceeds 30 cm in depth.

4-2 Analysis of Crisis Alert and Risk Level by Vehicle Type

The side skirt of a sedan vehicle is located approximately 20 cm above the ground. Normally, when water immersion depths are less than 20 cm, the components at the bottom of the vehicle come into contact with water. Since the interior floor height is around 25 cm, prolonged contact with water significantly increases the risk of rust. Additionally, water entering through the vent between the radiator grille and the hood panel at the front of the vehicle can serve as an inlet to the engine cylinder, potentially causing the engine to stall.

In general, it has been analyzed that the damage level of sedan vehicles increases rapidly at low submergence depths due to their low height and the location of most operational components at the bottom. Table 3 outlines the mechanical damage to sedan-type vehicles based on water depth, as well as the qualitative risk levels related to the maintenance scope presented in Table 1. It was found that 80% of the vehicle sustained damage when the submergence depth reached approximately 100 cm, confirming that serious damage occurs with prolonged submersion.

SUV-type vehicles have side skirts positioned about 20 cm above the ground, allowing them to operate even when encountering water due to road flooding below this depth, similar to sedan. However, prolonged contact with water increases the risk of rust. SUVs typically have a higher ground clearance than sedans, with interior flooding occurring at around 45 cm. If water enters the vent connected to the engine at the front, it can cause the engine to stall and result in serious damage to the vehicle.

Additionally, if the flooding depth reaches 66 to 67

Table 3. Mechanical damage and risk level by the flood water depth of sedan

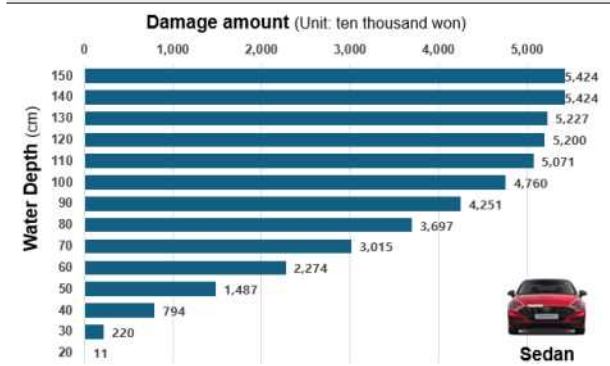| Flood Risk Levels	Flood Depth (cm)	Mechanical Damage
Level 1 – Blue (Attention)	10	no abnormality
Level 2 – Yellow (Caution)	18	chassis parts
Level 3 – Orange (Alert)	25	interior floor, interior floor wiring
Level 4 – Red (Severe)	30	exhaust, interior trim
	40	engine room mechanical and electrical devices, seats
Out of Level (Vehicle stop)	50	tires 4/5 or more, interior fuse box
	60	door lock, generator flooding
	67	water entering inside engine cylinder, trunk flooding
Damage amount to vehicle according to water depth		

Table 4. Mechanical damage and risk level by the flood water depth of SUV

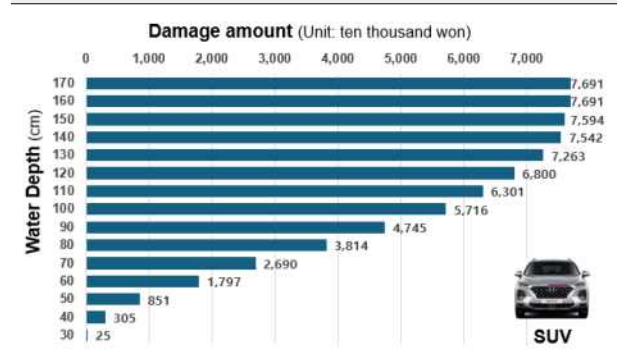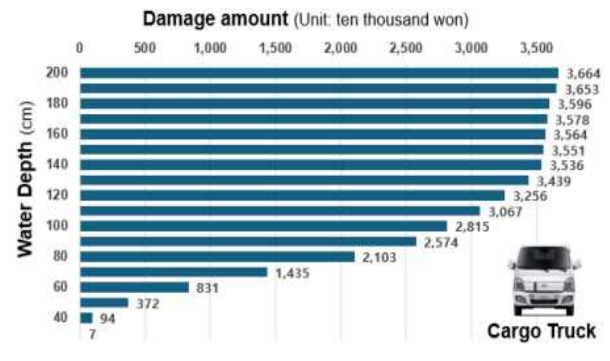| Flood Risk Levels	Flood Depth (cm)	Mechanical Damage
Level 1 – Blue (Attention)	10	no abnormality
Level 2 – Yellow (Caution)	20	chassis parts
Level 3 – Orange (Alert)	30	exhaust
Level 4 – Red (Severe)	48	interior floor, interior floor wiring
Out of Level (Vehicle stop)	67	trunk, interior trim, interior fuse box
	79	water entering inside engine cylinder
	116	all major parts submerged
Damage amount to vehicle according to water depth		

Table 5. Mechanical damage and risk level by the flood water depth of cargo truck

Flood Risk Levels	Flood Depth (cm)	Mechanical Damage
Level 1 – Blue (Attention)	10	no abnormality
Level 2 – Yellow (Caution)	30	chassis parts
Level 3 – Orange (Alert)	48	interior floor, power transmission, chassis wiring
Level 4 – Red (Severe)	50	exhaust, interior trim, engine electrical system
Out of Level (Vehicle stop)	70	engine room mechanical device, electrical device
	129	all major parts submerged

Damage amount to vehicle according to water depth

Table 6. Mechanical damage and risk level by the flood water depth of bus

Flood Risk Levels	Flood Depth (cm)	Mechanical Damage
Level 1 – Blue (Attention)	10	no abnormality
Level 2 – Yellow (Caution)	30	chassis parts
Level 3 – Orange (Alert)	35	interior floor
Level 4 – Red (Severe)	45	tires 4/5 or more
	50	passenger seats, chassis devices
Out of Level (Vehicle stop)	75	engine Room mechanics and electrical Devices
	145	water entering inside engine cylinder

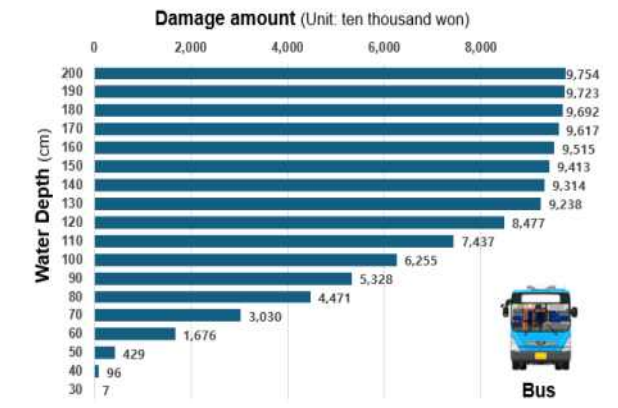Damage amount to vehicle according to water depth

cm, approximately the height of the trunk floor, water can infiltrate most major components, leading to significant damage. The mechanical damage and risk levels for SUV-type vehicles evaluated in this study based on flooding depth are presented in Table 4.

Tables 5 and 6 present the results of calculating the degree of mechanical damage and the extent of damage based on the flood water depth of vehicle for cargo trucks and buses, respectively. These tables also define the risk levels associated with water depth for each type of vehicle.

4-3 Generalization of Risk Level According to the Flood Water Depth of Vehicle

In the case of road flooding, the area below the tire centerline of the vehicle is considered normal driving conditions and can typically be managed with simple maintenance and repairs. However, since the drive shaft is connected to the tire centerline, lubricants

Table 7. Definition of risk level according to the flood water depth of vehicle

Flood Risk Levels	Flood Depth (cm)	Vehicle operation status	Driving a vehicle on the road, or mechanical damage
Level 1 – Blue (Attention)	10	possible	same as normal operation, below minimum ground level
Level 2 – Yellow (Caution)	25	possible	low-speed driving (under 10 km/h), check chassis components after driving
Level 3 – Orange (Alert)	30	moving	exhaust and interior flooding, quickly evacuate the flooded area
Level 4 – Red (Severe)	40	impossible	turn off the engine, unlock the doors, and get out of the vehicle
Out of Level (Vehicle stop)	60	impossible	serious damage to the vehicle

within the drive shaft may be compromised due to flooding. Additionally, for flooding above the tire centerline, potential damage to affected components must be assessed. Therefore, while qualitative judgments regarding the depth of flooding and potential damage to vehicle parts are necessary, the risk level associated with flooding depth is comprehensively generalized, as shown in Table 7, based on the information presented in Table 1 and Section 4.2.

Ⅴ. Conclusions

There are numerous assessments of human risk in the event of heavy rain or flooding, but establishing quantitative criteria for asset damage, particularly for vehicles, presents challenges. Therefore, this paper proposes flood risk criteria based on mechanical damage to vehicles during road flooding. Specifically, it assesses the vulnerability of damaged assets by evaluating the degree of mechanical damage to vehicles in relation to flooding depth. First, four types of vehicles commonly sold in Korea were selected, and the degree of mechanical damage was estimated by correlating vehicle parts with specific flooding depths. Based on the calculated results for each type, flooding criteria and risk levels were defined for each vehicle type, leading to a comprehensive generalization of risk levels according to the flood water depth of vehicle.

In this study, vehicle flood risk levels were defined as Level 1 (Attention), Level 2 (Caution), Level 3 (Alert), Level 4 (Severe), and Out of Level (Vehicle Stop), with corresponding flood depths of 10 cm, 25 cm, 30 cm, 40 cm, and 60 cm, respectively. The flood depths for each risk level were defined for four representative vehicles. Among them, the sedan, which has the lowest ground clearance, exhibited the lowest flood depths, while the cargo truck and bus showed similar criteria at Level 1 and Level 2, with flood depths of 10 cm and 30 cm, respectively.

The study confirmed that as flood depth increases, vehicle damage rises sharply, but the rate of damage growth decreases beyond a certain height. Based on these findings, it was concluded that it is essential to quickly evacuate or move out of the flooded area when roadways are inundated.

This study aims to demonstrate that by utilizing the vulnerability of damaged assets and assessing the degree of mechanical damage to vehicles, alongside risk criteria for human safety during road flooding, more effective flood risk criteria can be established. It is expected that the results of this study will be utilized in the future to establish traffic restriction criteria for vehicles during roadway flooding caused by floods, as well as to determine the minimum installation standards for road flooding

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