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Construction tolerance effects of reinforced posts on crash performances of an open-type guardrail system

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ABSTRACT

A finite element impact simulation study was performed to gain an insight about the crash test details considering construction tolerance effects of the reinforcement of posts in an open-type guardrail system. Accuracy of the simulation was verified using qualitative and quantitative comparisons with a full-scale crash experiment of trucks and cars. Subsequent simulation results present that the improved model performs much better in containing and redirecting the impacting vehicle in a stable manner. The numerical results for various parameters are verified by comparing different models with dynamic responses and passenger safety evaluations determined in the barrier from the crash simulation.

1. Introduction

Transportation growth has significantly improved the quality of living and attracted attention of researchers from various fields. However, this advancement has raised an important issue regarding the capabilities of current road facilities in meeting prevalent demands. Road facilities are subjected to various traveling loads, and severe accidents are inevitable in unexpected situations. Accidents are one of the most serious problems and the number of accidents is increasing day by day [19]. Typically, roadside barriers are supposed to be flexible to reduce damage during an accident [1,5]. Their performance is evaluated in terms of passenger protection, displacement of the installation and the impact behavior of vehicles after a collision. The impact behavior of barriers and vehicles are mainly assessed by measuring the displacement of these elements [2,22].

The development of new roadside safety hardware systems such as barriers requires iterative cycles of conceptual design and full scale vehicle crash testing. Most of the conceptual design process is based on engineering and mechanical understanding, previous development experience, and intuition. In addition, full-scale experiments must be performed in the restricted specification and this process can be quite costly and time consuming. Therefore, an optimal predesign through the numerical simulation could be dominant for reducing the cost and time in full-scale experiments [20]. Consolazio et al. [7] performed impact simulation and full-scale crash testing of a low-profile concrete work zone barrier. Whitworth et al. [23] evaluated the safety performance of a system and the crashworthiness of a modified W-beam guardrail design for the effect of certain guardrail design parameters such as rail mounting height and routed/non-routed block outs. Borovinšek et al. [4] performed a simulation of crash tests for high containment levels of road safety barriers.

The protection of passengers is assessed by measuring the acceleration and angular velocity and using this data to determine the passenger safety index. The MASH [17] of the United States uses OIV (Occupant Impact Velocity) and ORA (Occupant Ridedown Acceleration) to determine the passenger safety index, while Europe's CEN (European Committee for Normalization) uses THIV and ASI (Acceleration Severity Index) [10]. However, limitation of the works mentioned is that they only analyze roadside barriers constructed in an idealized construction environment. In real conditions, unexpected errors can occur during construction, especially for post members. Posts in the barrier system play a dominant role in the absorption of an impact energy due to a car crash. In order to enhance their bearing capacity after driven posts, stiffener plates are additionally driven to reinforce the posts. Depending on the aggregates used for field embankment or construction errors, reinforcing plates are undesirably rotated in the middle of the stiffened post. This phenomenon in the real structure results in a difference between the simulation and the full-scale road test. Besides construction errors, there exist various uncertainties in real conditions. In the restricted scope of our study, we are focused on construction errors of reinforcing plates to improve a bearing capacity of posts.

In a dynamic crash simulation, the dynamic friction coefficient, air resistance, and changes in the physical properties of the material should

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Table 1
Structural performance test condition for a truck crash.

Class	Impact velocity (km/h)	Weight of the vehicle (kg)	Impact angle (deg)	Reference impact level (kJ)
SB1	55	8000	15	60
SB2	65			90
SB3	80			130
SB3-B	85			150
SB4	65	14,000		160
SB5	80			230
SB5-B	85			270
SB6	80	25,000		420
SB7		36,000		600

Table 2
Passenger safety test condition for a small car crash.

Class	Impact velocity (km/h)	Weight of the vehicle (kg)	Impact angle (°)
SB1	60	900 or 1300	20
SB2, SB4	80		
SB3	100		
SB5, SB6, SB7			
SB3-B, SB5-B	120		

be also considered. Of these, changes in the physical properties affect the results most significantly. This is because the level of hardening is different by the velocity at the time of impact [6]. Specifically, in the case of a crashing object built with steel, the hardening should be considered in accordance to the strain velocity. This property can be obtained through a dynamic tensile test. However, to obtain the constitutive equation experimentally, considerable expense must be incurred to perform a number of dynamic tensile tests. A typical alternative is to use a constitutive equation that can induce dynamic characteristics in quasi-static test data. Cowper-Symonds (CS) and Johnson-Cook models are used most widely [8]. The CS model is suitable for intermediate or low speed crash interpretations as it cannot reflect the heat generated in the material and the subsequent softening. In addition, it does not violate the isotropic hardening principle. Thus, the composition equation is simpler, and easier to apply in the simulations. The Johnson-Cook model can reflect the changes in the physical properties due to the heat [11]. Thus, it can realize the thermal damage and the softening effect due to the heat in a high-speed collision through constitutive equations. Car crashes usually occur at medium or low speeds. Lee [14] studied a crash-induced vibration and safety assessment of breakaway-type post structures made of high anticorrosion steels based on the CS model. In this study, we consider strain rate effects using the CS model to improve the accuracy of our simulations.

Parameter studies are focused on nonlinear dynamic responses of roadside barriers and passenger safety evaluations subjected to crash loads such as truck or small car, while considering construction tolerances in the real environment. In addition, the numerical results are verified by comparing them with the measurement data obtained from experimental works on full-scale roadside barriers.

2. Theoretical formulation

2.1. Crash test condition

Among the various roadside installations, the guardrails distribute the impact energy or neutralize it through transformation. Guardrails are structures intended to prevent a car from getting exiting the road and at the same time satisfying the requirements for passenger safety. For these conditions to be applied, more data from a full-scale crash test should be collected. However, conducting a full-scale crash test is expensive and requires many trials and errors to obtain professional know-how. The best way to lessen these constraints is to use computer simulation crash tests and estimate the structural performance and passenger protection capability of the guardrails.

In the instructions, while it is possible to design guardrails through structural calculations, computer simulations, and live car crash tests, it was recommended that full-scale crash tests are conducted. Table 1 shows test conditions to assess the strength of the guardrails [18]. In the table, the proportion of heavy duty vehicle was increased in consideration of the current traffic conditions and test conditions were endowed with such larger vehicles. With the 8000 kg vehicle as the standard, the upper class was 14,000 kg, truck 25,000 kg, or a truck of 36,000 kg was determined to be used. In the instruction, the guardrail performance test criteria is based on the heavy duty vehicle that can maximize the impact load. Table 2 shows test conditions to measure

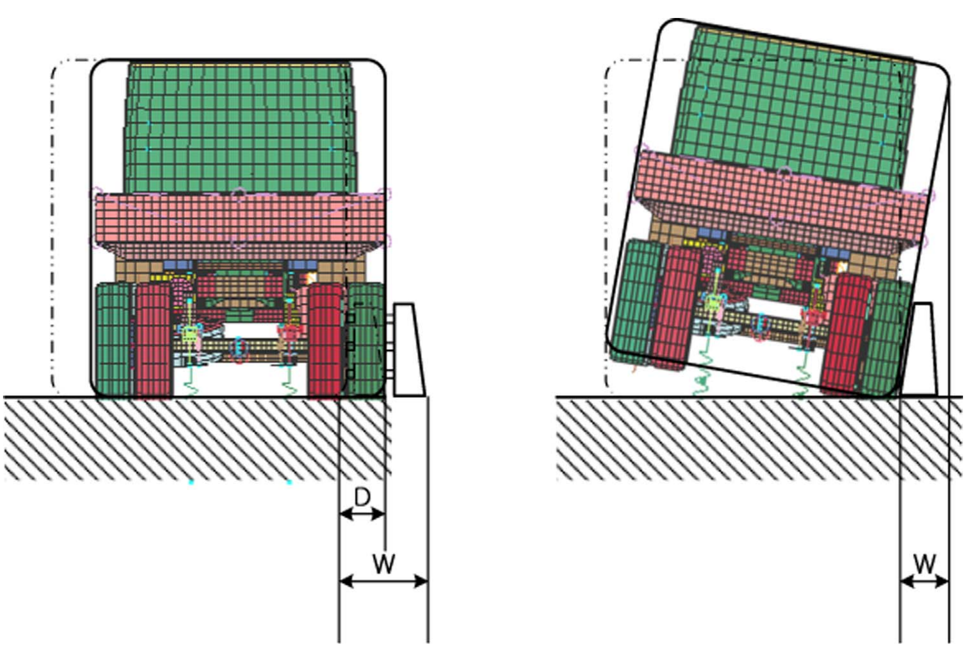

Fig. 1. Maximum dynamic deflection (D) and vehicle intrusion (W).