The safety performance of guardrail systems: review and analysis of crash tests data

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Road environment is the term used to describe road design, traffic management, the roadway and its adjoining surroundings and environmental conditions [61]. Traffic safety is a concern of engineers and planners due to economic loss and social costs incurred by accidents [16]. Frequency and severity of run-off roadway accidents are influenced by different factors such as geometric road features, traffic conditions, driver behaviour and environmental conditions [12]. In a previous study, it was found that inappropriate road conditions, non-traversable obstacles close to roadways, steep side slopes, deep ditches as well as dangerous terminals and transitions caused 35% of injuries [2]. Roadside and median barriers are designed to provide a safe environment for vehicles passing on roads in order to prevent vehicles from running off the roadway and colliding with fixed objects such as trees, poles, steep slope or cliffs, which are determined as more dangerous collisions [1,36,81,88], and redirect the errant vehicles to the passing lane in a safe manner so as to minimise occupant injury [20]. Guardrail system was deemed an ineffective device to reduce accident rates and severity as drivers tend to move away from the guardrail as it is perceived as a roadside hazard [3,19]. Nevertheless, statistics show the guardrail itself may be a severe hazard as approximately 1200 fatalities in the USA were caused by guardrails. It is, moreover, reported that 13% and 2% of guardrail accidents caused vehicle rollover and fatalities, respectively [85]. Overall, an appropriate road restraint system should contain and redirect errant vehicles, deflect and absorb impact energy and limit occupant’s risk factors and dynamic deflection [44].

Guardrail crash performance should be examined before they are used. Usually, two different methods exist to evaluate guardrail impact performance and to minimise occupant injury. One is by conducting real-crash tests and the second utilises an analytical method (e.g. Dynamic Finite Element Analysis) [70]. In a full-scale crash test, which is a traditional and primary method to examine barrier performance, the worst scenario would be evaluated for the vehicle, system and injury to occupants [29].

Any type of vehiclemight be involved in an accident including passenger cars and light trucks with different gross weight, structure and physical dimensions [87], thus the system should satisfy all crashes by each type of vehicle. Light trucks, which involve pickup trucks, vans and sport utility vehicles, account for 50% of total new vehicle purchases, and are shown to have more critical behaviour such as higher rollover possibility than passenger cars when a crash occurs [5]. It is deemed that the most common type of guardrail, a W-beam standard guardrail, was in some cases unable to capture the errant vehicles with higher centre of mass and bumper mounting head which eventually resulted in vehicle rollover [75].

The main aim of this study is to review the performance of different types of guardrail systems based on previous crash tests. A method used in this study includes collection of real-crash test results on guardrail systems and conducts an analysis involving the main factors affecting systems behaviour. Guardrail systems are evaluated to determine the stiffness of different guardrail designs and to compare the behaviour of each system in terms of vehicle trajectory to find the relationships between effective parameters in terms of vehicle trajectory and guardrail performance.

The paper aims to submit evidence of previous crash tested systems with different conditions and designs to (1) present an overview of different models that have been designed in previous researches and (2) provide insight into the development of future systems.

Methodology

In previous researches, while some studies tried to modify shape of the guardrail, most investigations have focused on engineering parameters including: changes to guardrail post embedment, block-out depth, post spacing, splice configuration as well as positioning of curb [72]. To achieve the objectives of this study, a specific strategy is considered. First, the parameters that can affect the performance of guardrail system are defined. In the second phase, those subjected to the TL-3-11 crash tests were classified and compared, and then an analysis was applied to a group of indicator combinations. These indicators consist of guardrail mounting height, post embedment depth and spacing on performance of guardrail systems giving us better understanding of the behaviour of different systems.

Standards definition

In general, roadside barrier designers use intuition, realcrash test methods and engineering-based principles. Analytical methods are less effective when designing systems such as these [86]. Computer programmes are not at a stage where barriers can be certified or more complex problems can be resolved [40]. In the USA, roadside barriers should meet the requirements based on NCHRP Report 350 [78] and recently released criteria, Manual for Assessing Safety Hardware (MASH) [55].

In 1993, NCHRP Report 350 entitled Recommended Procedures for the Safety Performance Evaluation of Highway Features [78] was published, and most of the crash tests were conducted according to these criteria. This report provides a new guideline and introduced the 3/4-ton pickup truck to replace the full-size passenger sedan vehicle used in NCHRP Report 230 [51]. NCHRP Report 350 includes six different test levels to evaluate guardrail system performance. Basically, the lower test levels are used to evaluate the safety barriers on low traffic roadways whereas higher test levels are being used to evaluate the hardware features on high-traffic roadway areas. Test level 1 (TL-1) is designated to qualify the features inside the work zone or lower service level roadways. In addition, test level 2 (TL-2) is mostly used to evaluate the hardware for most local areas and many work zones. Test level 3 (TL-3) is utilised to qualify a wide range of higher service level roadways and high-speed highways. Test level 4 (TL-4) through test level 6 (TL-6) are being used to determine the applicability of features encountered by heavy vehicles and to understand the behaviour of longitudinal barriers during penetration [78].

Among all six test levels, TL-3 is utilised in this study as it is designed for a wide range of higher service level roadways and high-speed highways. Recommended test matrix for TL-3 based on NCHRP Report 350 and MASH are presented in Table 1. It should be noted that 820C and 1100C are passenger sedans, 2000P and 2270P are pickup trucks and the weight of the vehicles is recorded in kgs. During the test the vehicle is directed toward the guardrail system at a specific speed and angle as specified in NCHRP Report 350 or MASH.

The crash test results are different in different impact locations along the barrier. According to NCHRP Report 350 and MASH criteria, the worst test condition should be applied. Thus, critical impact point (CIP) should be selected as a real-crash test to give the worst result [6].

For longitudinal barriers subjected to Test 3–11, CIP is normally selected based on the maximum potential for wheel snagging at a post section with a rail splice. Nevertheless, for a strong-post guardrail system the CIP region could be around 1 metre in area with a rail splice every 3.8 m [77].

In Europe, road authorities are required to use products that meet EN 1317. Road authorities in countries that do not have updated or adequate roadside safety feature specifications should use either the European EN 1317 or the AmericanNCHRPReport 350 criteria or both of themwhen developing roadside safety hardware performance specifications.

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