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Experimental and numerical study of polymeric foam efficacy in portable water filled barriers

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ABSTRACT

Portable, water filled road safety barriers are used to provide protection and reduce the potential hazard due to errant vehicles in areas where the road conditions change frequently (e.g. near road work sites). As part of an effort to reduce excessive working widths typical of these systems, a study was conducted to assess the effectiveness of introducing polymeric foam filled panels into the design. Surrogate impact tests of a design typical of such as barrier system were conducted utilising a pneumatically powered horizontal impact testing machine up to impact energies of 7.40 kJ. Results of these tests are utilised to examine the barrier behaviour, in addition to being used to validate a couple FE/SPH model of the barrier system. Once validated, the FE/SPH model it utilised as the basis for a parametric study into the efficacy and effects of the inclusion of polymeric foam filled panels on the performance of portable water filled road safety barriers. It was found that extruded polystyrene foam functioned well, with a greater thickness of the foam panel significantly reducing the impacting body velocity as the barrier began to translate.

1. Introduction

Temporary road safety barriers are commonly used around road work zone where there is an increased need for protection for all road users. The assessment and evaluation of the impact capacity and performance characteristics of these portable barriers in impact scenarios is vitally important in informing the design and use of these systems. In addition to the physical characteristics of a barrier, it is also necessary to quantify the performance characteristics of a barrier system as well, with the relevant international standards providing a number of evaluation criteria which are used to assess a system's effectiveness [1,2]. The full-scale vehicular testing programs prescribed in these standards, which are used as the basis of road safety barrier evaluation, have been very successful in determining the performance of these systems, with the recent update to the relevant document in the United States [3] featuring larger mass test vehicles and stricter evaluation criteria and reporting conditions.

While full-scale testing is very effective in assessing the performance of road safety barrier systems, the significant costs associated with properly conducting such tests prevents this testing from being suitable in the early stages of barrier system's development [4]. Surrogate experimental testing, where the system is examined by a surrogate body in a repeatable impact scenario, are occasionally used to comparatively evaluate the road safety barrier systems. In addition, surrogate testing systems are able to produce the data required to validate developmentally efficient computational models, while minimising the financial and time costs associated with full-scale testing. Pendulum-based surrogate testing systems have been used in assessing fixed and rigid road safety structures [5,6], with bogie-based systems also successfully used in the evaluation of a number of devices [7]. Analytical models of vehicular impacts into road safety barriers have to been shown to predict with reasonable accuracy crush depths and peak impact loads [8], however their scope is limited to impacts with rigid, concrete safety barriers.

It the past two decades, the computational modelling of road safety devices has been shown to be an effective and efficient way of studying the impact response of these system. In particular, explicit finite element (FE) based modelling techniques have widely been used in representing the impact behaviour of a number of road safety barriers, including fixed concrete barriers [9], traffic

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light poles [10] wire rope safety barriers [11], guardrails [12] and portable concrete barriers [13]. The current paradigm of model validation via full-scale experimental impact testing ensures that costs associated with producing a functional, validated model of a road safety barrier system may be prohibitively high for new barrier systems. Analysis – either experimental or computational – of portable, water filled road safety barriers (PWFB) has been relatively sparse in comparison to other types of road safety barriers, though there use is relatively widespread [14].

The paper reports on the development of a couple FE and smooth particle hydrodynamic (SPH) model of a typical portable, water filled road safety barrier utilising a pneumatically driven surrogate horizontal impact testing system in order to provide experimental impact data which is used to assess the validity of the coupled model, as well as assisting in the characterisation of the PWFB impact behaviour. The function and response of the experimental surrogate impact testing system is reported on, with the experimental tests also assessing the effect of externally mounted polymeric foam filled panels on the impact performance of the barrier. The construction of the coupled FE/SPH model is detailed, in particular the development of accurate material models for the constitute parts of the barrier is described. The validated computational model is subsequently utilised to explore the effects and efficacy of the inclusion of polymeric foams in a portable water filled road safety barrier during impact.

2. Experimental impact testing

2.1. Horizontal impact system

The horizontal impact testing system consists of three major mechanical sub-systems (i.e. the impact cart, the propulsion system and the fixed frame), in addition to the control and data acquisition systems. The system has been design to be able to examine the impact response of a wide range of structures and provides the capability to examine a range of impact scenarios (e.g. variable impact mass, velocity and impacting geometric and boundary conditions).

The testing system was installed at the Banyo Project Pilot Plant Facility of the Institute of Future Environments, part of the Queensland University of Technology. The frame of the rig is fixed a reinforced strong floor via two M48 bolts which clamp the steel channel sections of the frame to the floor (Part D of Fig. 2).

The impacting body of the testing system is the impact cart, which travels horizontally along two fixed guiderails, restricting the motion of the cart to a single, translational degree of freedom (Part A of Fig. 2). The target-end of the cart was fitted with a tube section, constructed from Schedule 40 NPS 10 steel pipe, 1180 mm wide and 273 mm in diameter (Fig. 1). The impacting head can be exchanged for a different design, as required by the demands of the testing.

The height of impact can be varied, with an impact height of 585 mm used in the testing described in this paper. The total mass of the impact cart can be varied using a set of masses secured just rearward of the impact end of the cart (Fig. 1), with a minimum mass of 105 kg and a mass of 300 kg used in the experiments of this paper.

The impact cart is propelled along the guiderails by the expansion of a set of rubber air bellows, which are mounted to the fixed frame of the testing rig. The air bellows are mounted to, and form part of, a pressure vessel (Part B of Fig. 2) which is filled with compressed air to a predetermined level based upon the required impact energy for a given test. The expansion of the air bellows, and hence acceleration of the impact cart, is restrained by a pneumatically actuated, quick release mechanism (Part C of Fig. 2). The firing of the quick release mechanism, along with the operation of pneumatic control valves used in the filling of the pressure vessel, safety systems and data acquisition, is managed by a LabView program which runs on a dedicated, remote PC.

The testing system featured a number of systems to ensure the integrity of the impact system's structure during an impact test. The pneumatic fill process for the pressure vessel is controlled by a system of pneumatic valves, which were designed to evacuate in an over-pressure (e.g. pressure above 8.00 bar) or power loss events, with the pneumatic lines regulated to a maximum gauge pressure of 7.00 bar. In the case of the impact cart not being fully arrested during a test, the system features an aluminium crush tube device, which will absorb the vehicles remaining kinetic energy once the cart has travelled 555 mm relative to the expansion of the rubber air bellows. The crush tube was design such that it would be able to absorb the maximum rated kinetic energy of the system and that the walls of the tube would fail in the sequential concertina mode shape [15]. Another important safety feature of the rig was the exhausting of the compressed air post-firing, which was throttled so that a secondary impact between the impact cart and the air bellow would be dampened, reducing any shock induced by the collision. Lastly, a number of proximity sensors were installed on the rig as part of the safety system to ensure that the system was properly mechanically setup before the system could be energised.

For the surrogate testing described in this paper, the impact performance of the portable road safety barrier is described in terms of the post-impact kinematics of the impact cart. The kinematics of the impact cart were determined via three separate instrumentation methods.

A proximity probe mounted to the fixed frame of the system was used in conjunction with a toothed rail attached to the cart. This setup was used to give a digital measure of the relative displacement of the cart, with the spacing of the teeth on the rail giving an effective output resolution of 5 mm.

A string potentiometer (Firstmark Controls model 62-55-8442) was mounted to the fixed frame, with the free end of the wire string attached to the rear end of the cart. The string potentiometer was installed such that the deceleration of the cart during an impact would manifest as a tensile pulse in the wire, rather than as a compressive wave which may have negatively affected the accuracy of the output. This setup produced an accurate analogue output of the cart's absolute displacement, though a noticeable amount of noise was observed in the instantaneous signal (i.e. variation in the order of ± 1.0 mm).

A 100 *G* rated single axis accelerometer (Silicon Designs 2260-100) was mounted on the front end of the cart to record a time history of the cart's acceleration. The mounting location and method of the 100 *G* accelerometer was chosen in order to reduce any noise in the accelerometer's output associated with the vibration of the impact cart's steel frame (where *G* is the acceleration

Fig. 1. The interchangeable impact head used in the experimental testing.