HEAD INJURY RISK EVALUATION FOR STANDING PASSENGERS IN RAIL TRANSPORT

Marie-Christine Chevalier, Gaëtan Hanen, Thomas Robert
Université de Lyon, F-69622, Lyon, France ;
INRETS, UMR_T9406, LBMC, Bron ; Université Lyon 1, Villeurbanne.

ABSTRACT

This study focuses on the risk evaluation of head injury resulting from an impact against a grabpole for standing passengers in rail vehicles submitted to a 100ms 5g crash pulse. Through a combined physical and numerical approach using a Free-Motion Headform and a grabpole, the injury risk was evaluated from the HICd and analysed in the perspective of improving the vehicle interior design in public transportation. Head injury risks were generally found to be moderate (HICd<500). However, injuries may be more severe in some situations complicating the evacuation of passengers from the vehicle.

Keywords: impactors, injury criteria, trains, head, finite elements method

BACKGROUND AND OBJECTIVES

This study was conducted within the European project SafeInteriors, devoted to the improvement of interior design for urban rail vehicles in regard to the passengers' safety. One of the characteristics of these occupants is that they are usually non-restrained. In case of a crash, they are thus likely to impact various components of the environment. Furthermore they must be able to quickly evacuate the vehicle to limit the risk of serious post-crash consequences. Therefore acceptable injury levels are lower for this population than for automotive occupants.

Earlier studies in the SafeInteriors project showed that grabpoles are usually the closest obstacles to standing passengers and that head is the most exposed part of the body in case of impact. Such head impacts may complicate the evacuation of the occupants, as they might induce loss of consciousness. In order to evaluate the injury hazard of grabpoles, the SafeInteriors consortium proposed: 1/ an occupant reference impact scenario; 2/ an experimental methodology to estimate the injury risk induced by head impacts against grabpoles; 3/ injury thresholds relevant to the situation of public transportation.

Using these tools, the present study aims to: 1/ Experimentally estimate the head injury risks in the reference scenario for impact against a basic grabpole currently used in rail transport; 2/ Develop a numerical model able to evaluate such injury risks and validate it from experimental results; 3/ Use this numerical model to evaluate the standard grabpole in impact situations diverging from the reference scenario but still likely to happen.

TEST METHOD AND MATERIAL

REFERENCE SCENARIO AND INJURY ASSESSMENT TOOLS

The occupant reference scenario was identified by the consortium from initial results of the project (SafeInteriors, 2008) and multi-body simulations for a standing passenger submitted to a deceleration of 5g during 100ms. It resulted in the following reference impact parameters: horizontal head angle of 24.5°, impact velocity of 5.23m/s, impact point of the head on the grabpole at 1.75m above the floor and sagittal plane of the head coinciding with the midline of the grabpole.

The consortium determined the most appropriate tool for assessing the injury potential of grab poles to be the NHTSA Free-Motion Headform in free flight and calculating the resultant acceleration 3ms clip and the HICd criteria (SafeInteriors, 2010). The latter is a criterion which takes into account the loss of body mass caused by the use of a sole headform (CFR-49, 2005):

$$HICd=0.7566*HIC_{FMHmeasured} + 166.4$$

EXPERIMENTS

A series of free flight impacts against a grabpole were performed. The impactor used was the FMVSS201 Free-Motion Headform made of a Hybrid III skull and a skin layer without nose and mounted on the sled of a vertical free-fall test rig (Van Ratingen, 2003). The sled and headform were connected during their fall. A few centimetres before the impact, the headform was released and the sled decelerated, thus allowing the headform to freely impact the bar with well controlled impact parameters. The grabpole was fixed horizontally on a rigid structure under the rig: the 'upper' extremity of the grabpole was fixed by a pin while its 'lower' extremity was sleeved in a 4cm-long socket, as classically mounted in rail vehicles. As for its fixings, its design, dimensions (35mm diameter, 2.1m long and 2mm thick) and material were representative of standard furniture available in rail vehicles. A simplified schematic view of the rig is presented in Figure 1.

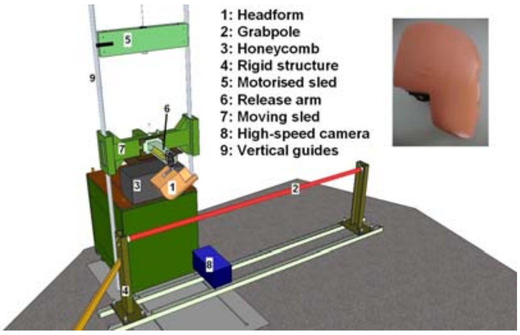

Figure 1: test rig and Free-Motion Headform (detail)

The headform was equipped with three orthogonal standard accelerometers. In addition, three high-speed video cameras recorded the tests. Acceleration curves were processed using HyperGraph®. Video data were analysed with MotionTrack® to track targets, evaluate impact velocity, assess verticality of the fall and the absence of rotation (both parameters were checked and validated in each case).

In addition to the reference scenario, a few configurations including different impact velocities or impact points were tested to offer enough variability in physical data for the validation of the numerical model. It included two scenarios at 4.75 and 5.50m/s and one impact at 1.6m from the pole extremity instead of 1.75m. Each configuration was tested at least twice and the grabpole was changed after each test.

SIMULATION

The experimental set-up was numerically reproduced by a finite-element model using the Altair Radioss® software. The Free-Motion Headform model provided by Altair (Altair, 2008) is composed of two solid-element components, a skull and a skin layer (see Figure 2, left). A sensor provides head acceleration at its centre of gravity. The grabpole was modelled using over 3000 shell-elements. Boundary conditions were chosen so that the upper part of the pole was fully constrained while its lower part was free in a fixed socket. Contacts were modelled using the penalty method. The desired velocity was applied to the headform positioned close to the pole.

The grabpole material was modelled with a Johnson-Cook law whose properties were first taken from the literature (Mousavi, 2005) and then adjusted in order to fit the experimental data of the reference test in terms of values of HICd, curve shape and duration and peak amplitude. Alternative experimental scenarios were successfully simulated to assess the model capacity to reproduce experimental results, thus validating the model.

Following this step, the model was used to study the influence of different impact parameters on the HICd value. The main effects of the impact velocity, impact point and offset were investigated by varying successively each of these three parameters (4.75 to 6.7m/s, 1.1 to 2m and up to 100mm for the velocity, the impact point and the offset respectively). The simulation points are presented on Figure 3.

RESULTS

PHYSICAL TESTING

Full results for the 10 tests are exposed in Table 1.

Table 1. Physical Test Matrix and Results

Test	1	2	3	4	5	6	7	8	9	10
Velocity (m/s)	5.23			4.75			5.50		5.23	
Position on pole (m)	1.75			1.75			1.75		1.60	
Offset (mm)	0			0			0		0	
Horizontal head angle (°)	24.5°			24.5°			24.5°		24.5°	
HICd	340	334	334	298	294	300	364	377	299	302

NUMERICAL RESULTS

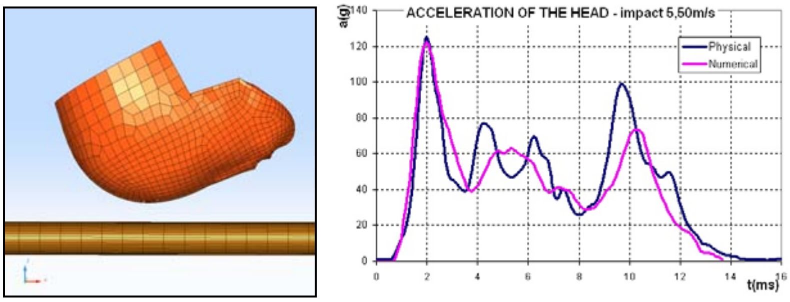

Figure 2: Numerical Model: Free-Motion Headform (left), and comparison to physical headform accelerations for test7 (right).

The material properties were adjusted using the experimental data of the reference scenario. Using the fitted model, the respective influence of the impact velocity, impact point and offset were numerically investigated while keeping other parameters identical to the reference scenario. They are displayed in Figure 3.

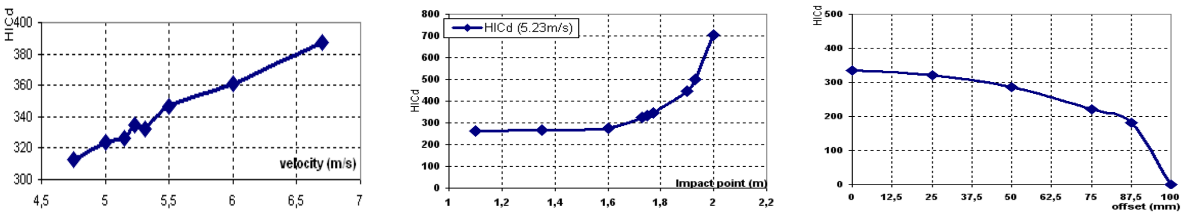

Figure 3: Influence of velocity (left), impact point (middle) and offset (right) on HICd in simulations

DISCUSSION

The physical tests were very repeatable in terms of HICd (less than 4% variation within each configuration, see Table 1) and the Free Motion headform demonstrated a good sensitivity to changes in input parameters. Reference scenario led to a mean HICd of 333 and it can be seen that HICd increases with impact velocity as expected. Typically the SafeInteriors consortium proposed to consider that HICd=500 as a threshold between moderate and severe injuries: in this later case, passengers are likely to have more difficulties to evacuate due to an increase of possible unconsciousness duration. In this study, experimental HICd values are lower than 500: this is a moderate level but it does not statistically exclude the fact that some passengers may still have difficulties in evacuating quickly the train after the impact.

The physical reference test was numerically modelled with finite-element software and validated. This model was extended to satisfyingly reproduce physically-observed behaviour (linear evolution of HICd in regard to impact velocity, see Figure 3 left), to investigate additional scenarios and to describe the effect of each parameter on injury risk. Such a numerical model might be useful in the future to reduce the number and costs of repeated physical testing sessions.

Some observations can be formulated regarding the variability of impact configuration. Notably, the injury risk strongly increases when the impact occurs close to the fixing, as presented on Figure 3 (middle). Tall passengers (over 190cm) are thus likely to be more severely injured during such impacts. This should be addressed in the future improvements of grabpole and fixings design to reduce risks as much as possible, while sustaining all the normative requirements for interior furniture of rail vehicles.

On Figure 3 (right) the HICd diminishes when offset increases. Variation is gradual and offset seems not to be of critical importance in the severity of an injury, if compared to velocity or more specifically height of impact point. However this statement has to be carefully considered. Indeed, impacts with offset imply a rotation of the head which may cause injuries: this is not taken into account by the HICd which is based on linear acceleration only.

Limitations of this study are related to the HIC and Free-Motion Headform. HIC was designed to estimate skull fractures resulting from direct contact between the head and a flat object. Impact against a grabpole, due to its shape, may produce higher concentration of load resulting in more severe injuries such as facial or local depressed fractures: further work would be necessary to evaluate the efficiency of more specific injury criteria. Moreover the validated use of the Free Motion Headform only includes frontal impacts, even if Lowne (2001) demonstrated that lateral impact data can be extracted from frontal tests with the Free-Motion Headform. In addition, this impactor is only appropriated for 50th percentile humans. Its characteristics are notably too different from the head of a child to include this population in our study. Limitations also concern the range of considered velocities. For lower values, such as in a case of emergency braking (Robert, 2005), it is not sure whether the Free-Motion Headform is relevant anymore, as HICd is no longer reliable for low levels of decelerations. These limitations should be assessed and considered in the future to develop new tools for these scenarios.

CONCLUSION

A simple methodology to evaluate the injury potential of rail vehicle interior equipments was implemented and validated. By using a single impactor and numerical tools instead of a full standing crash test dummy, a good knowledge of the head injury risk level depending on the impact parameters was gathered. The evaluation of interior furniture in trains through numerical simulation was validated as an alternative to numerous physical tests. Even if injury risks are not life threatening, improved designs should be suggested to reduce them, especially for specific populations such as tall people.

Such an approach could be used by designers of public transportation and as input for future recommendations in railway standards.

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