Development of JAMA-JARI Pedestrian Child and Adult Head-Form Impactors

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ABSTRACT

Head injuries are the most common cause of pedestrian deaths in car-pedestrian accidents. To reduce the severity of such injuries, the International Organization for Standardization (ISO) has proposed subsystem tests in which child and adult head-form impactors are impacted upon a car bonnet top. The ISO designated the mass of the child head-form impactor as 3.5 kg (i.e., the average mass of a 6-year-old child's head), and that of an adult as 4.5 kg. However, such head-form impactors have not been developed so far. Therefore, in the present study we report the development of new child and adult head-form impactors according to the requirements of the ISO subsystem test procedures. The technical specifications, including the location of the center of gravity, the location of the seismic mass of accelerometers, the moment of inertia, and first natural frequency of the impactors, were summarized. Then, the results of biofidelity certification tests of the skin of these newly developed impactors were investigated.

INTRODUCTION

Head injuries are the most common cause of pedestrian deaths in car-pedestrian accidents [1], and countermeasures against them are of the highest priority in traffic safety strategy. The key element in this strategy is improvement of the safety performance of the car front. The most common method of evaluating this performance is subsystem tests using head-form impactors. The present study focuses on the tests proposed by the International Organization for Standardization (ISO) that were used as a basis by the Japan Ministry of Land, Infrastructure and Transport (Japan MLIT) when developing proposals for Japanese standards for the evaluation of car-front safety performance in terms of pedestrian head protection.

In the subsystem test procedure proposed by the ISO, two distinct head-form impactors are used to simulate the child and adult pedestrian's head. The mass of the child head-form impactor has been designated as 3.5 kg (i.e., the average mass of a 6-year-old child's head), and that of an adult as 4.5 kg [2][3]. The ISO has also specified the biofidelity requirements for both child and adult head-forms in terms of the peak value of the resultant gravity center (CG) acceleration measured in drop tests. Since the mass of a child head-form impactor is smaller than that for an adult, its head acceleration at the impactor center of gravity is higher than for the adult head-form (Table 1).

As summarized in Table 1, any impactor built according to the Japan MLIT standard proposal [4] fulfills the ISO specifications [2][3]. However, the opposite may not be true. To ensure reliability and accuracy when evaluating car safety performance, the MLIT proposal [4] contains more specific requirements regarding an impactor's inertia moments, CG position, the position of the seismic mass of accelerometers, and the impactor dynamic characteristics (Table 1). For instance, to improve accuracy and repeatability of the acceleration measurement, the Japan MLIT proposal requires greater precision when attaching accelerometers than ISO specifications. For the same reason, this proposal requires that the first natural frequency of an impactor should be above 5000 Hz. This requirement is aimed at preventing aliasing when digitizing the acceleration data (sampling rate is typically 10000 Hz).

Both ISO [2][3] and Japan MLIT [4] requirements are quite demanding. No impactors that fulfill these requirements have been built so far. Therefore, in the present study, we developed prototypes of new child and adult head-form impactors specifically to meet the requirements of ISO/Japan MLIT proposals. They are referred to as JAMA-JARI child and adult head-form impactors. This paper summarizes the technical specifications of these newly-developed impactors, such as the location of CG, moments of inertia, location of seismic mass of accelerometers, first natural frequency, and the results of their biofidelity tests. Moreover, the manufacturing process is discussed in some detail.

Table 1 Specifications of child and adult head-form impactors proposed by ISO and Japan MLIT

Parameter		Specification	
		ISO *	Japan MLIT**
Mass of child head-form		3.5 kg	3.5 ±0.07 kg
Mass of adult head-form		4.5 ±0.1 kg	4.5 ±0.1 kg
Diameter		165 mm	165 ±1 mm
Location of C.G.		±10 mm from Ge.C.	±2 mm from Ge.C.
Moment of inertia	around Y axis	Not specified	from 0.0075 to 0.0200 kgm^2
	around Z axis	Not specified	Not specified
Seismic mass location of accelerometer	in direction of measurement axis	Not specified	±10 mm from Ge.C.
	in direction perpendicular to measurement axis	Not specified	±1 mm from Ge.C.
First natural frequency		Not specified	over 5000 Hz
Corridor of resultant acceleration in drop certification test	child head-form	245 G - 300 G	245 G - 300 G
	adult head-form	225 G - 275 G	225 G - 275 G

*: ISO/TC22/SC10/WG2 N622 and N623

**: 12th IHRA/PS N230, Adelaide, Australia 20-22 November, 2002

C.G.: Center of gravity; Ge.C.: Geometric center

Y and Z axes are shown in Figure 12.

SPECIFICATION, DEVELOPMENT AND MANUFACTURE OF PROTOTYPE JAMA-JARI HEAD-FORM IMPACTORS

The JAMA-JARI child and adult head-form impactors consist of the core and what is called the skin (Figure 1).

Core of Head-form Impactors

Core of the JAMA-JARI child and adult head-form impactors are made of aluminum (A2024BR T4/JIS H4040). A steel plate (SS400/JIS G3101) is attached to the bottom surface of the core, (Figure 2) in order to secure the impactor on the magnetic holding system. This arrangement is commonly used in Japan to secure the head-form impactor before propulsion in tests for evaluation of car-front safety performance (Figure 3). The bottom surfaces of the core of the JAMA-JARI child and adult head-form impactors have two M2 nylon screws for a European-type propulsion fixture system (Figure 4). The nylon screws are designed to break so as to release the impactor during propulsion [6].

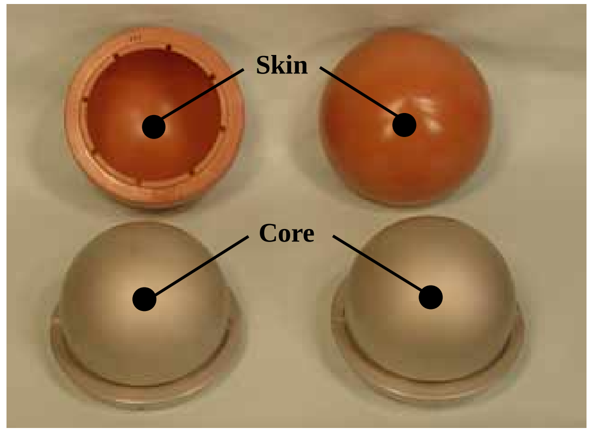

Figure 1. JAMA-JARI child (left) and adult (right) head-form impactors consisting of core and skin.

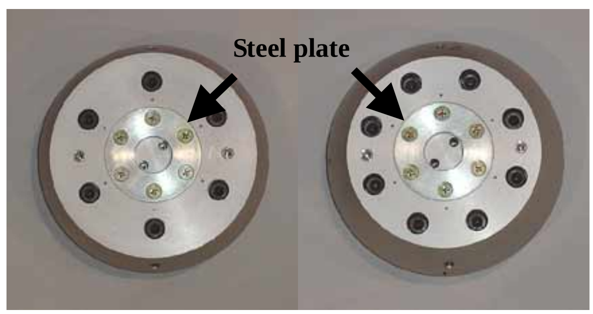

Figure 2. Steel plates attached to the bottom surface of the cores of the child head-form (left) and adult head-form (right) impactors (reverse side view).

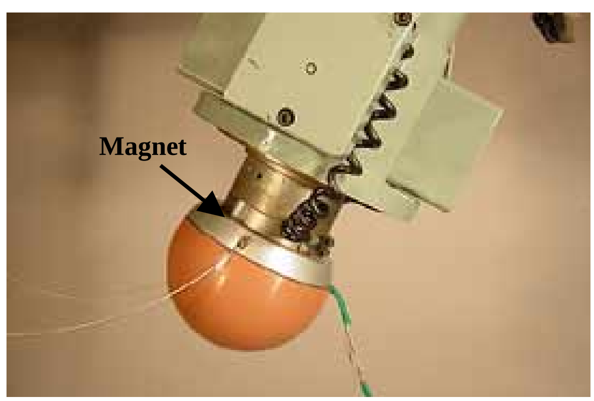

Figure 3. Magnetic system holding a head-form impactor.

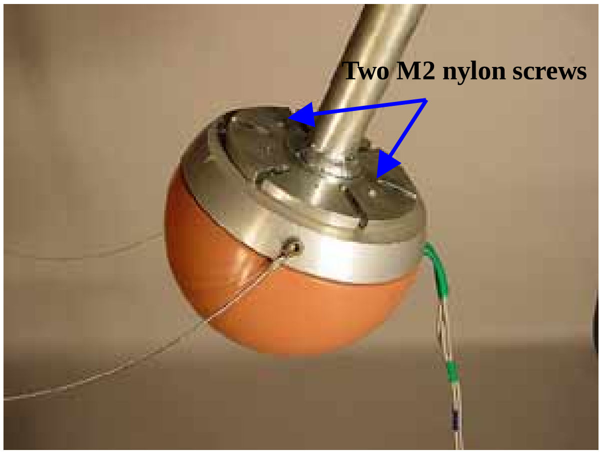

Figure 4. Head-form impactor holding method using two M2 nylon screws.

Skin of Head-form Impactors

JAMA-JARI child and adult head-form impactors feature a newly developed skin for use with both impactors. The skin is made of polyvinyl chloride (PVC), which is a combination of polymer, plasticizer, stabilizer, and vinyl toner color. The polymer (powder) is the main material in PVC. The plasticizer (liquid) controls the skin plasticity, and the stabilizer is added to ensure uniform distribution of all four PVC components. When manufacturing the skin, the components are mixed, placed into a mold after removing the air bubbles, then heated to 180°C for one hour. The skin is then removed from the mold (Figures 5 and 6).

The present development of the head-form impactor skin was done using a trial and error process, since the preliminary test results for the impactor biofidelity certification indicated that both the relative contents of the PVC components and methods applied when mixing them appreciably affect the skin properties. The relative contents of the PVC components and the method for mixing them were repeatedly tested so that the resultant skin would indeed comply with the ISO/MLIT biofidelity requirements when used with both child and adult head-form impactors (Figures 7 and 8).

Figure 5. Mold for skin production.

Figure 6. View of new JAMA-JARI head-form impactor skin.

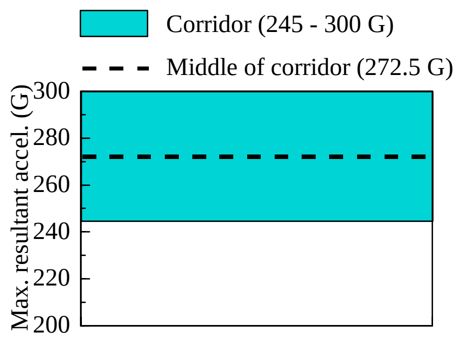

Figure 7. Corridor of resultant acceleration used in drop certification test of child head-form impactor.

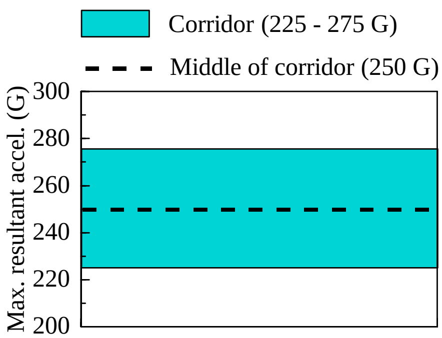

Figure 8. Corridor of resultant acceleration used in drop certification test of adult head-form impactor.

Assembly of JAMA-JARI Child and Adult Head-form Impactors

JAMA-JARI child and adult head-form impactors are shown in the assembled condition in Figure 9. The skin is fitted on the core spherical forms. Six M8 bolts and eight M8 bolts are used to secure the core spherical body to the end plate of the JAMA-JARI child and adult head-form impactors, respectively (Figure 10). Both these impactors are equipped with three accelerometers installed near the impactor gravity centers (Figure 11) in order to measure acceleration in the respective direction of the impactor's three inertia axes.

Figure 9. JAMA-JARI child (left) and adult (right) head-form impactors in assembled condition.

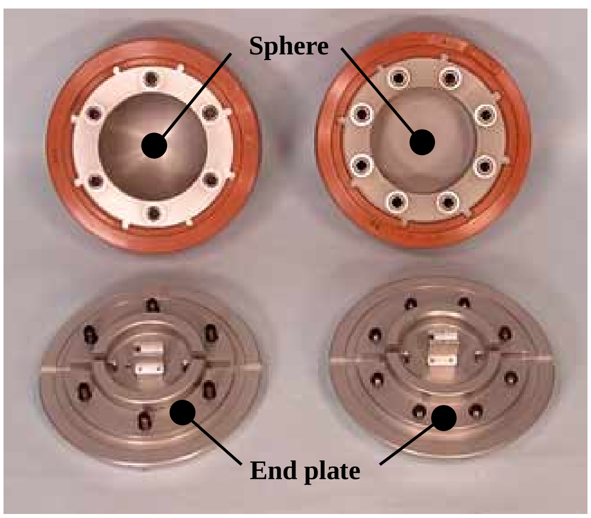

Figure 10. JAMA-JARI child (left) and adult (right) head-form impactors in disassembled condition.

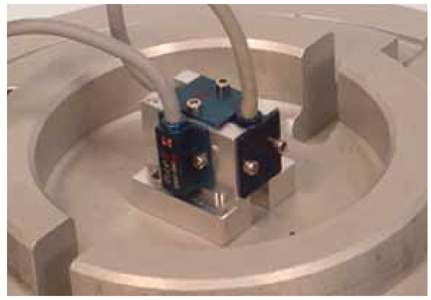

Figure 11. Accelerometers mounted on JAMA-JARI head-form impactor.

VERIFICATION OF GEOMETRY, MASS/ INERTIA PROPERTIES AND PERFORMANCE OF JAMA-JARI PROTOTYPE HEAD-FORM IMPACTORS

At first, the location of the center of gravity, moment of inertia, the location of the seismic mass of the accelerometers, and the first natural frequency of the newly developed impactors were investigated. Then, their perfomance was verified by biofidelity certification according to the ISO [2][3] specification. The results were then compared to the requirements proposed by ISO [2][3] and Japan MLIT [4]. When verifying the mass/inertia properties, the impactor Z-axis was defined in the propulsion direction as shown in Figure 12.

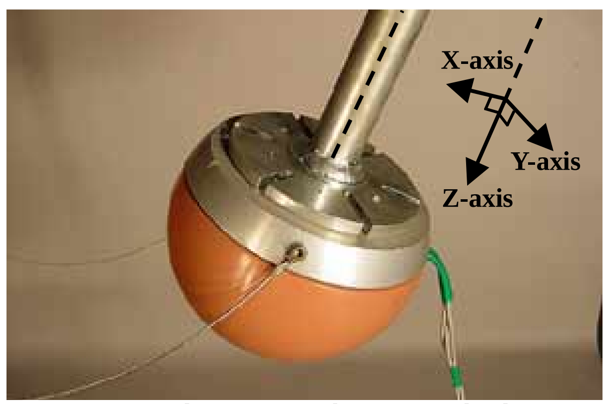

Figure 12. Coordinate axis with Z-axis in the direction of propulsion.

Method

<u>Mass</u> – The masses of the new head-form impactors were measured using a digital scale with an accuracy of 0.1 g. During the mass measurement, the accelerometer cables were removed.

<u>Outer Diameter</u> – The outer diameter of the head-form impactors was measured by means of a vernier.

Position of Gravity and Geometric Centers of Head-form Impactors – The position of the impactor gravity center on the Z-axis was determined using the arrangement shown in Figure 13. It consists of two scales (1 and 2) and a plate supported on two fulcrums placed on the scales. The Z-axis coordinate (Z) of the impactor gravity center was determined with reference to the endplate bottom surface using the following formula:

$$(L_2+Z) \times (W_1+W_2) = L_3 \times W_2 \,, \qquad (1)$$

where L_2 is the distance from the fulcrum placed on the scale 1 to the endplate bottom surface and L_3 is the distance between fulcrums placed on the scales 1 and 2. W_1 and W_2 are the forces measured by digital scales 1 and 2, respectively (Figure 13).

In addition to the position of the gravity center, the distance dZ between the impactor gravity center and the impactor sphere geometric center along the Z-axis was determined. This distance is one of the key parameters describing the impactor geometry and mass properties, and was calculated using the following formula:

$$dZ = | Z - L_1 | \,, \qquad (2)$$

where L_1 is the distance from the endplate bottom surface to the impactor sphere geometric center.

The maximum accuracy of the present method when determining dZ was not greater than 0.05 mm. This is sufficient accuracy since the Japan MLIT requires $|dZ|$ to be below 2 mm.

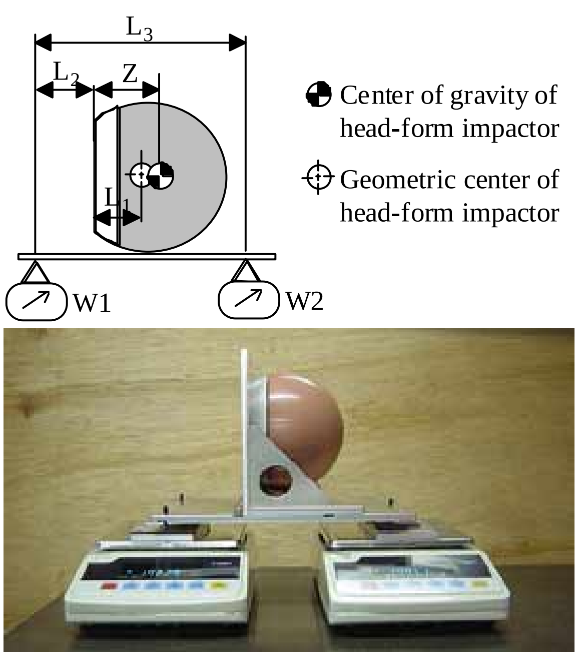

Figure 13. Measurement of location of center of gravity.

Moment of Inertia – To verify if the JAMA-JARI child and adult head-form impactors fulfill the requirements proposed by the Japan MLIT [4], the moments of inertia around both Z and Y axes of these impactors were measured. The measurements were done in respect to the axes through the geometric center of the head-form impactor sphere. The torsional pendulum method used was shown in Figure 14, and the following formula was thus applied when determining these moments of inertia:

$$I_1 = C \times (\tau / 2\pi)^2 \,, \qquad (3)$$

where I_1 is the moment of inertia in respect to the axis through the impactor sphere geometric center, C is the stiffness of the torsional spring, and τ is the measured vibration period. Then, the moments of inertia in respect to the axes through the center of gravity of head-form impactors were calculated using the parallel axis theorem:

$$I = I_1 + m \times dZ^2 \,, \qquad (4)$$

where I is the moment of inertia in respect to the axis through the center of gravity, I_1 is the moment of inertia in respect to the axis through the impactor sphere geometric center, m is the head-form impactor mass, and dZ is the distance between the center of gravity and the geometric center in the Z-axis direction (Figure 12).

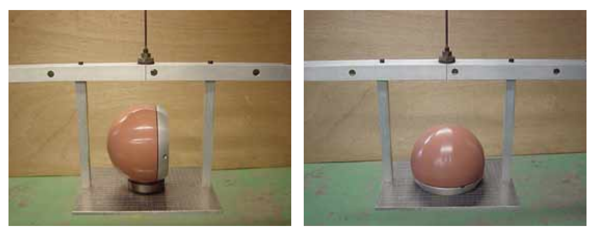

Figure 14. Measurement of moment of inertia around Y-axis (left) and Z-axis (right) through geometric center of head-form impactor.

Location of Seismic Masses of Accelerometers – A beam accelerometer is conceptualized as a thin beam with a seismic mass fixed to one end of the beam, with the other end of the beam incorporated into the housing of the accelerometer [5] (Figure 15). The seismic mass location depends on the type of accelerometer used. In the present research, the three ENDEVCO type 7264B accelerometers used to determine the location of the seismic mass (Figure 11) are conventionally employed for this purpose by the Japan Automobile Research Institute (JARI). The location of the seismic mass of each accelerometer was designed to be on the axis of the gravity center coordinate (Figure 16). However, the Japan MLIT has adopted the seismic mass location as the distance from the geometric center. To determine the location of the accelerometers, the distance from the center of gravity to the geometric center should be measured.

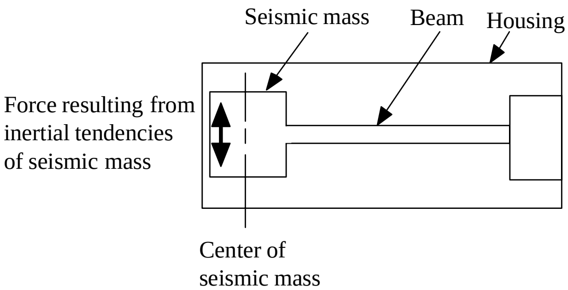

Figure 15. Conceptualization of a beam accelerometer showing seismic mass.

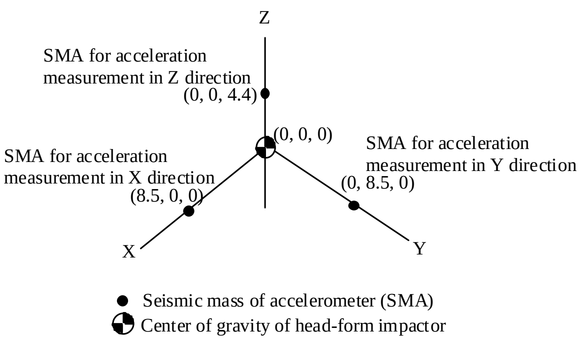

Figure 16. Design concept of seismic mass location of accelerometers (unit: mm).

First Natural Frequency according to Hammering Test – The first natural frequency is obtained by a hammering test using the core of the head-form impactor. The sphere and endplate were assembled by securing with M8 screws at a fastening torque of 17 Nm. The skin is removed in this hammering test. Three small accelerometers (NEC 9G10S; 0.15 g) were mounted directly on the three ENDEVCO 7264B accelerometers in order to measure the response. The sphere was impacted by a steel-headed hammer in order to measure the input signals (force). A force of approximately 20 N was applied. The sample frequency of acceleration and force of the hammer were 20 kHz. The power spectra of the input and response accelerations were determined using the FFT algorithm.

Drop Certification Test – The setup of the drop certification test was shown in Figure 17. The child and adult head-form impactors were dropped from a height of 376 mm in such a way as to ensure instant release onto a rigid supported flat horizontal steel plate (55 mm thick and 610 mm^2) below with a clean dry surface. The child and adult head-form impactors were dropped at a drop angle of 60 degrees, i.e., close to the mean drop angle proposed by the ISO (53 or 54°) and category 1 of the Japan MLIT (65°). The drop tests were performed three times for child and adult head-form impactors, respectively. The head-form impactor was rotated 120° around Z-axis after each test. The temperature of the test room was 21.4°C. The skin was soaked for 24 hours in the test room until the drop test was performed. The results of the drop certification test were assessed by means of the maximum resultant acceleration calculated from three axis accelerations, then compared with the proposed corridor (Figures 7 and 8).

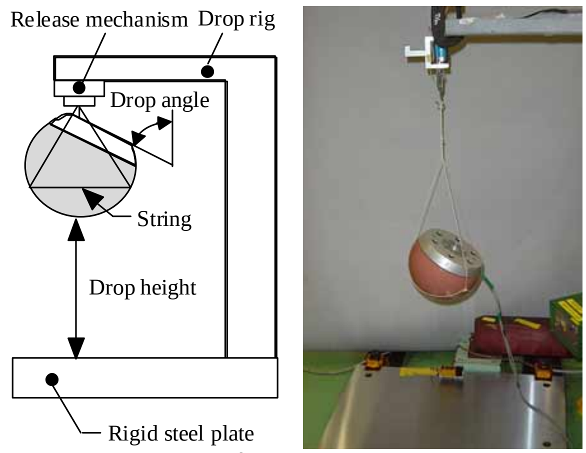

Figure 17. Drop certification test.

Results

Mass, Outer Diameter, Location of Center of Gravity, Moment of Inertia, Seismic Mass Location of Accelerometers, First Natural Frequency – Table 2 summarizes the various child and adult head-form parameters (mass, outer diameter, location of center of gravity, moment of inertia, seismic mass location of accelerometers, first natural frequency of manufactured prototype) tested in the present study in terms of the ISO and Japan MLIT specifications. The manufactured prototype JAMA-JARI child and adult head-form impactors fulfilled these technical specifications.

The relationship between the seismic mass location of the accelerometers on the axis of the coordinates for the gravity center and geometric center of head-form impactor is shown in Figure 18. The geometric center of the head-form impactors was located 0.4 mm below the center of gravity in the Z direction, because the location of the seismic mass of each accelerometer was designed to be on the axis of the gravity center coordinate. On the other hand, the location of the seismic mass of each accelerometer was regulated by the coordinate of the geometric

Table 2 Parameters measured in relation to ISO and Japan MLIT specifications

Parameter		ISO Specifications*	Japan MLIT Specifications**	Manufactured JAMA/JARI child head-form (present study)	Manufactured JAMA/JARI adult head-form (present study)
Mass of child head-form		3.5 kg	3.5 ±0.07 kg	3.504 kg	-
Mass of adult head-form		4.5 ±0.1 kg	4.5 ±0.1 kg	-	4.494 kg
Diameter		165 mm	165 ±1 mm	164.5 mm	164.5 mm
Location of C.G.		±10 mm from Ge.C.	±2 mm from Ge.C.	0.43 mm from Ge.C.	0.36 mm from Ge.C.
Moment of inertia	around Y axis	Not specified	0.0075 - 0.0200 kgm^2	0.0089 kgm^2	0.0115 kgm^2
	around Z axis	Not specified	Not specified	0.0104 kgm^2	0.0123 kgm^2
Seismic mass location of accelerometer	in direction of measurement axis	Not specified	±10 mm from Ge.C.	Maximum 8.5 mm from Ge.C.	Maximum 8.5 mm from Ge.C.
	in direction perpendicular to measurement axis	Not specified	±1 mm from Ge.C.	Maximum 0.4 mm from Ge.C.	Maximum 0.4 mm from Ge.C.
First natural frequency		Not specified	over 5000 Hz	7424 Hz	8496 Hz

*: ISO/TC22/SC10/WG2 N622 and N623

**: 12th IHRA/PS N230, Adelaide, Australia 20-22 November, 2002

C.G.: Center of gravity; Ge.C.: Geometric center

center of the head-form impactor [4]. The seismic mass location of the accelerometers and the center of gravity on the coordinate of the geometric center of the head-form impactor were shown in Table 3. The seismic mass of the accelerometer is located within 8.5 mm of the measurement axis. The seismic mass of the accelerometer in the direction perpendicular to the measurement axis is located within 0.4 mm of the measurement axis. These values fulfilled the specification proposed by the Japan MLIT.

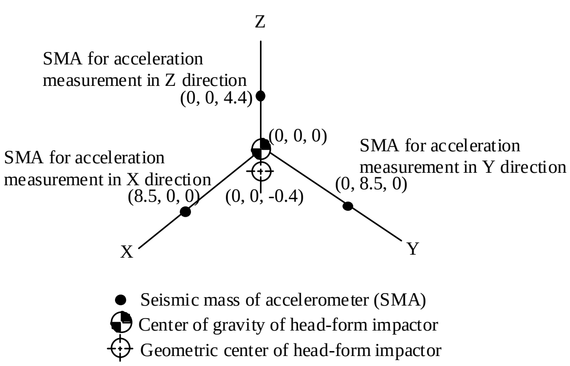

Figure 18. Relationship between seismic mass location of accelerometers on the axis of coordinate of gravity center and geometric center of head-form impactor (unit: mm).

Table 3 Seismic mass location of accelerometers and center of gravity in the coordinate of geometric center of head-form impactor (unit: mm)

		Coordinate of geometric center		
		x	y	z
Seismic mass of accelerometer for direction of	X-axis measurement	8.5	0.0	0.4
	Y-axis measurement	0.0	8.5	0.4
	Z-axis measurement	0.0	0.0	4.8
Center of gravity		0.0	0.0	0.4

Drop Certification Test Results using Child Head-form Impactor – The maximum resultant acceleration measured with the JAMA-JARI child head-form impactor rotated 120° around Z-axis after each test is shown to comply with the proposed corridor in Figure 19.

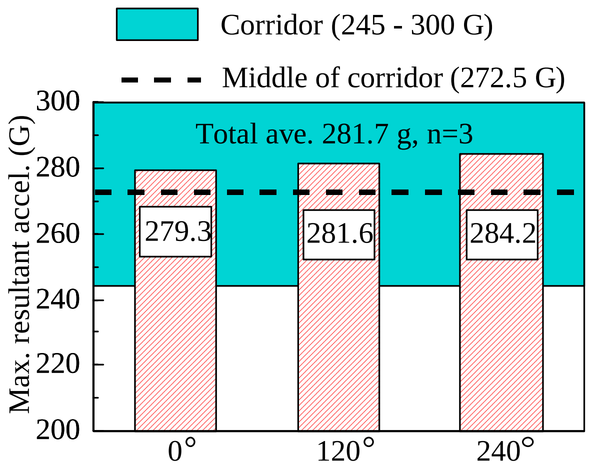

Figure 19. Maximum resultant acceleration measured from drop certification test using JAMA-JARI child head-form impactor in comparison to the proposed corridor.

Drop Certification Test Results using Adult Head-form Impactor – The maximum resultant acceleration measured for JAMA-JARI adult head-form impactor rotated 120° around Z-axis after each test in comparison with the proposed corridor is shown in Figure 20. The adult head-form impactor proved to be compliant. The tested skin is the same as that used in the child head-form impactor drop certification test. They fulfilled the proposed corridor. Hence, the same newly developed skin can fulfill both proposed corridors of drop certification tests for child and adult head-form impactors.

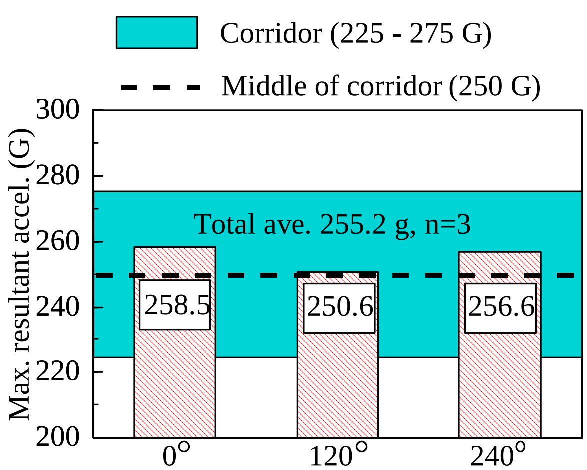

Figure 20. Maximum resultant acceleration measured from drop certification test using JAMA-JARI adult head-form impactor in comparison to the proposed corridor.

Therefore, the manufactured prototypes of the JAMA-JARI child and adult head-form impactor both fulfilled all the technical specifications required by ISO [2][3] and the Japan MLIT [4].

DISCUSSION

In the present study we developed new child and adult head-form impactors which satisfied the technical specifications mandated by the ISO [2][3] and Japan MLIT [4]. The above-mentioned three uni-accelerometers (ENDEVCO 7264B) were equipped in the head-form impactors. Users wishing to employ another type of accelerometer can do so, provided the accelerometer mount is redesigned according to specifications.

The result of the drop certification test demonstrated that the performance of the just-produced skin was within the satisfactory corridor (Figures 18 and 19). However, given the repeated impact to the critical car-front location in the experimental vehicle test, the properties of the skin could conceivably change. The impact durability of this newly developed skin should thus be investigated.

All results shown in the present study were obtained with the prototype JAMA-JARI head-form impactors. The technical specifications must be checked if the head-form impactor is mass produced.

The specifications mandated by the Japan MLIT are more detailed than those proposed by the ISO. The present research confirmed that compliance with the detailed specifications of the Japan MLIT is technically feasible.

Following the requirements proposed by the Japan MLIT in the present study, the ISO drop certification test was conducted to evaluate the impactor skin performance and overall impactor biofidelity. The impactor natural frequency was verified in a separate test in which the impactor core was struck by a hammer. The key benefit of conducting separate tests to verify the skin performance and impactor vibration characteristics is the high repeatability and reliability of the measurements. However, this is not the only method for evaluation of these performance and characteristics in the field today. For instance, the EEVC/WG17 [7] proposed to simultaneously investigate the skin performance and vibration characteristic using a test in which the head-form impactor is impacted laterally by a ram with a mass of 1 kg. However, a result with high repeatability using this test method is unlikely, because matching up the ram line of impact through the center of gravity of the head-form impactor could be difficult. As the repeatability of this method has not been verified so far, we did not use it in the present study.

In Japan, pedestrians account for 28% of all road fatalities annually [1]. The pedestrian body region most severely injured in fatal car-pedestrian accidents has been the head. Therefore, the Japan MLIT will have new regulations in place as of 2005 to govern the pedestrian head safety performance of passenger cars. Plans call for the program involving head impact severity assessment in relation to the car-front to be launched in 2003 by the Japanese new car assessment program (J-NCAP). The head-form impactor specification of J-NCAP will meet the specifications staked out by the Japan MLIT. The newly developed JAMA-JARI child and adult head-form impactors investigated and found to be compliant in the present study are available for the coming assessment tests.

CONCLUSION

The following are the overall conclusions obtained from the present study.

1. New child and adult head-form impactors were developed by JAMA-JARI. The technical specifications of the prototype JAMA-JARI child and adult head-form impactors manufactured as described in this paper fulfilled both the ISO and Japan MLIT requirements. Therefore, they can be used for safety performance assessment tests conducted by the Japan MLIT and J-NCAP.
2. Both the magnetic holding system and the nylon screw breaking system can be used to hold the newly-developed head-form impactors in a launch device when performing a safety impact test using a car.
3. A new system to measure the location of the center of gravity with 0.05 mm accuracy was developed.
4. The study proved that the same newly developed skin can be used with both child and adult head-form impactors.
5. The present study demonstrated that compliance with the detailed specifications of the Japan MLIT is technically feasible.

ACKNOWLEDGEMENT

This work was carried out under contract between the Japan Automobile Research Institute (JARI) and Japan Automobile Manufacturers' Association (JAMA). The authors are indebted to the members of the JAMA pedestrian working group for their valuable suggestions on the current project for JAMA-JARI head-form impactor development.

FURTHER INFORMATION

Cores used in the new JAMA-JARI adult and child head-form impactors are available from S•Tech Co., Ltd., Japan (http//www.s-techinc.co.jp, or info@s-techinc.co.jp).

The skin for the new JAMA-JARI head-form impactors is available from Jasti Co., Ltd., Japan (www.jasti.co.jp, or info@jasti.co.jp).

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