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Evacuating a rolled-over school bus: Considerations for young evacuees

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ABSTRACT

Characterizing the strength capabilities of the intended population is necessary to ensure successful operation of emergency exits during mass transportation vehicle evacuations. School buses are often occupied by very young children, and in emergency circumstances, may need to operate a school bus emergency exit without the aid of an adult. The rear emergency door is usually the largest usable and accessible exit following an accident. The purpose of this study was to evaluate the strength capabilities of children in kindergarten through second grade (K-2), and their ability to operate a school bus rear emergency door. Force exertion capabilities of K-2 children were compared to Federal Motor Vehicle Safety Standard (FMVSS) No. 217, which specifies force requirements for school bus exit operation. Force exertions on the rear emergency door handle suggested that K-2 children do not have the strength capabilities to meet the 40 lb maximum permissible operating force specified by FMVSS No. 217. Results also suggested that mean force exertions in the upright orientation are greater than mean force exertions in the rolled-over orientation. Seats obstructing the rear emergency exit were shown to have a statistically significant effect on evacuation time through the rear emergency door of a rolled-over school bus.

1. Introduction

While School bus roll-over accidents are rare, they are extremely complex and often leave occupants injured and/or in unfamiliar orientations (Matolcsy, 2010). The largest usable emergency exit following a school bus roll-over is the rear emergency door. This exit may be oriented three ways following a roll-over: (1) rolled on its right side with the door hinges located towards the ground; (2) rolled on its left (driver) side with the door hinges located towards the sky; or (3) rolled on its roof with the door hinges opposite of the normal upright orientation. Each of these rollover orientations presents the rear door emergency release mechanism at different locations with respect to the occupants in the school bus, compared to the normal upright orientation.

Every emergency exit door has one “high force” and two “low force” access regions (Fig. 1). Federal Motor Vehicle Safety Standard (FMVSS) No. 217 specifies that the maximum permissible force required to unlatch the release mechanism of a school bus rear emergency door not exceed 178 Newtons (~40 lb) in the high force region and 89 Newtons (~20 lb) in low force regions (NHTSA, 2011). Additionally, the rear emergency door opening must be large enough for a parallelpiped (45 inches high, 24 inches wide, and 12 inches deep) shaped object to pass through, keeping the 45 inch dimension vertical and 24 inch dimension parallel to the opening (NHTSA, 2011).

The rear emergency exit access regions defined by FMVSS No. 217 present several concerns with regard to children, the primary occupants of school buses. In particular, the specifications may present a challenge to kindergarten through second grade (K-2) students. First, the access regions are designed to accommodate the physical capabilities and stature of an average adult male (Pollard and Markos, 2009). Children between 5 and 7 years of age possess only a fraction of the strength and stature capabilities of an average adult male (Trade and Industry, 2002). Second, the access regions are designed for the school bus in the upright orientation. In a rolled over orientation, the location of the door handle may present itself in a low force region because of its relative location to the occupants of the bus. This may make it more difficult for an occupant, particularly a young occupant, to exert enough force to unlatch the door. Third, the rear most seats on some school buses may inhibit easy (timely) evacuation in a roll-over situation. The seats in a 2013 model Blue Bird Vision School buses, for example, are 36 inches wide and 42.5 inches tall, and the opening of the emergency exit door is 38 inches wide and 54 inches tall. Due to the close proximity of the last row of seats (in some configurations) to the rear emergency exit, approximately 44% of the rear emergency exit area is obstructed by the seats, and the usable width of the exit is reduced to 17 inches (Fig. 2). This design may be problematic for young children as it may prevent

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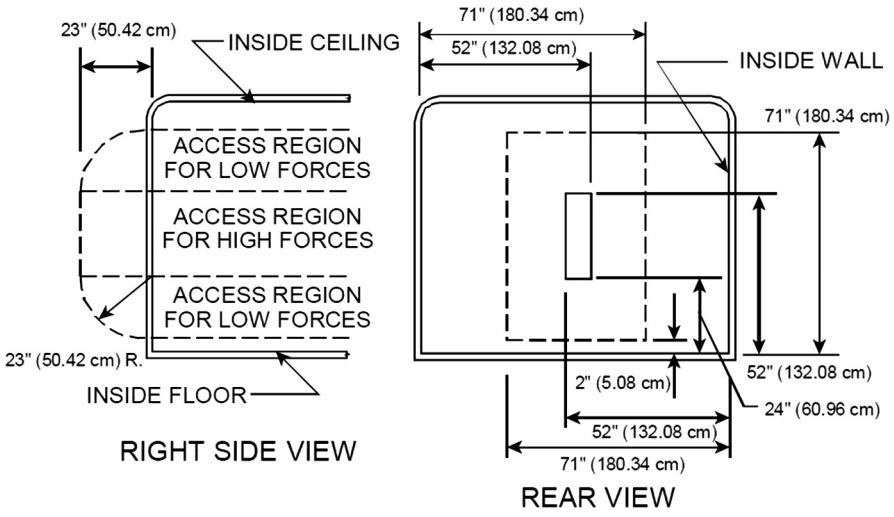

Fig. 1. Access regions for rear emergency exit without obstructions (NHTSA, 2011).

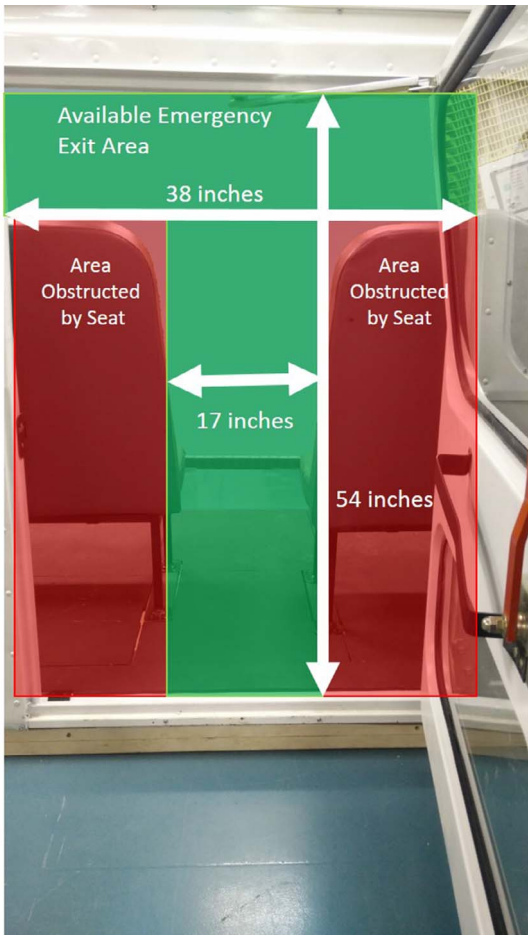

Fig. 2. Rear seat obstruction of the emergency exit.

them from accessing the intended exit area. Finally, when the school bus is rolled-over on its left (driver) side, the hinges are located above the door and gravity causes the door to swing shut. Depending on the size of the passenger, the door must be raised 30–45 degrees from its vertical position to allow enough space for safe exit (Purswell et al., 1970). With the rear emergency door weighing approximately 90 lb, it creates a significant safety hazard, as the swinging door could lead to further injury during evacuation (Purswell et al., 1970) and/or lengthen evacuation times.

In its normal (upright) orientation, the handle on the rear emergency door is pulled upwards to unlatch. However, the location and release direction of the latch is different if the school bus is in a rolled-over orientation. A study sponsored by the Consumer and Competition Policy Directorate of the Department of Trade and Industry measured the strength of children and adults to provide designers applicable data for the design of safer products (Department, 2000). Peak pull force on a cylindrical bar (20 mm round and 300 mm long) similar in size to the door handle (25 mm wide and 483 mm long) on the rear emergency exit door was measured by instructing the subjects to build up to their maximum strength in the first few seconds and to maintain maximum strength for a few additional seconds. While the results of this study indicated that some children between the ages of 2 and 10 years old may be able to exert a pull force necessary to operate a rear emergency door in a rolled over orientation, a large percentage of children would be unable to exert the maximum allowable force (Trade and Industry, 2002). Moreover, the height of the bar was adjusted to the shoulder height of the subjects in the previous study. The location of the door handle on the rear emergency door is fixed and hence may not be ideal for maximal exertion. Additionally, the seats may act as a partial-barrier preventing the occupants from grasping the door handle comfortably, reducing their maximal exertion.

The objective of the current study was to extend these previous efforts and measure the strength capabilities of children and their ability to evacuate through a school bus rear emergency door in both upright and rolled-over orientations. Specifically, we aimed to determine if K-2 children are able to (1) exert the maximum permissible force of 40 lb specified by FMVSS No. 217 to operate the rear emergency door in the high force region with the school bus in both upright and rolled-over orientations, and (2) self-extricate (individually) through the rear emergency exit in a rolled-over orientation. We hypothesized that the students would be unable to exert the 40 lb of force specified by FMVSS No. 217 to operate the rear emergency door in the high force region. Furthermore, we hypothesized that the mean self-extrication time through the rear emergency door would improve when the last row of seats were removed to improve access to the emergency exit area.

2. Methods

2.1. Subjects

One hundred twenty-six (126) K-2 students (22 male/17 female in kindergarten; 21 male/25 female in first grade; 23 male/18 female in second grade) were recruited from Oak Mountain Elementary School in Birmingham, AL (Table 1). Internal Review Board (IRB) letters of