

Wheelchair Tiedown and Occupant Restraint System Loading Associated with an Adult Manual ANSI WC19 Transit Wheelchair with a Seated 50th percentile ATD Exposed to Rear Impact

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ABSTRACT

Proper securement of wheelchairs in motor vehicles is vital in providing wheelchair users an adequate level of safety in a crash. Thus far loading on WTORS has mostly been examined under frontal impact conditions. Because of the inherent crash dynamic differences rear impact loading of WTORS is expected to differ greatly. In this study three identical, reinforced, manual, folding, X-braced ANSI WC19 wheelchairs were subjected to an ISO proposed rear impact crash pulse. WTORS loads were measured and compared to frontal impact WTORS loading. Rear impact produced substantially higher loads in the front tiedowns, when compared to frontal impact. These differences in loading are important to proper WTORS design, and thus protection of wheelchair-seated occupants subjected to rear impact events.

KEY WORDS

wheelchair transportation, rear impact, wheelchair securement, occupant restraints, ANSI/RESNA WC 19

BACKGROUND

For persons with disabilities, access to transportation is necessary for integration into society. The Americans with Disabilities Act (ADA) has been instrumental in assuring transportation access to individuals with disabilities for purposes of employment, education, and recreation (1). Out of the 2.3 million wheelchair users in the U.S. (2), a substantial number are not able to transfer from their wheelchair to a motor vehicle seat during transportation. It is necessary to afford these wheelchair users the same level of safety as occupants seated in motor vehicle seats.

The primary purpose of any wheelchair is to provide mobility for people with disabilities. Many of these wheelchairs are not designed to serve as a seat in a motor vehicle. This is substantiated by catastrophic failures shown in preliminary rear impact sled tests done by the University of Michigan Transportation Research Institute (UMTRI) (3). Some commercial wheelchairs are designed to be crashworthy in a frontal impact, by complying with ANSI/RESNA WC19 (4). However, the dynamics of a rear impact collision, and thus the wheelchair, securement system and occupant restraint loading are likely to differ greatly from those experienced in frontal impact. It is important from a safety and product design perspective to investigate the loading conditions associated with rear impact events, as they will directly affect WTORS, and ultimately wheelchair-occupant response to impact.

In order for both tiedown and wheelchair manufacturers to design securement systems and transit wheelchairs that are safe in a rear impact event, they must understand the loading associated with rear impact. Rear impact collisions are responsible for 43.5% of all motor vehicle crash related injuries (5) and 5.4% of fatalities (6). This data is based on occupants utilizing standard motor vehicle seats that are rigidly secured to the vehicle. Because wheelchairs are structurally less stable than a motor vehicle seat and after-market securement systems must be used, higher injury and death rates may occur in wheelchair-seated occupants for a given rear impact event.

METHODOLOGY

Three identical, reinforced, manual, folding, X-braced wheelchairs (25.1 kg) that comply with WC19 were subjected to a rear impact crash pulse. The wheelchair-seated occupant was represented by a 50th percentile Hybrid III anthropomorphic testing device (ATD – 78.3 kg), while the pulse (25.8 km/h, 14 g) was as described in the proposed ISO/TC 173 rear impact standard (Figure 1) (7).

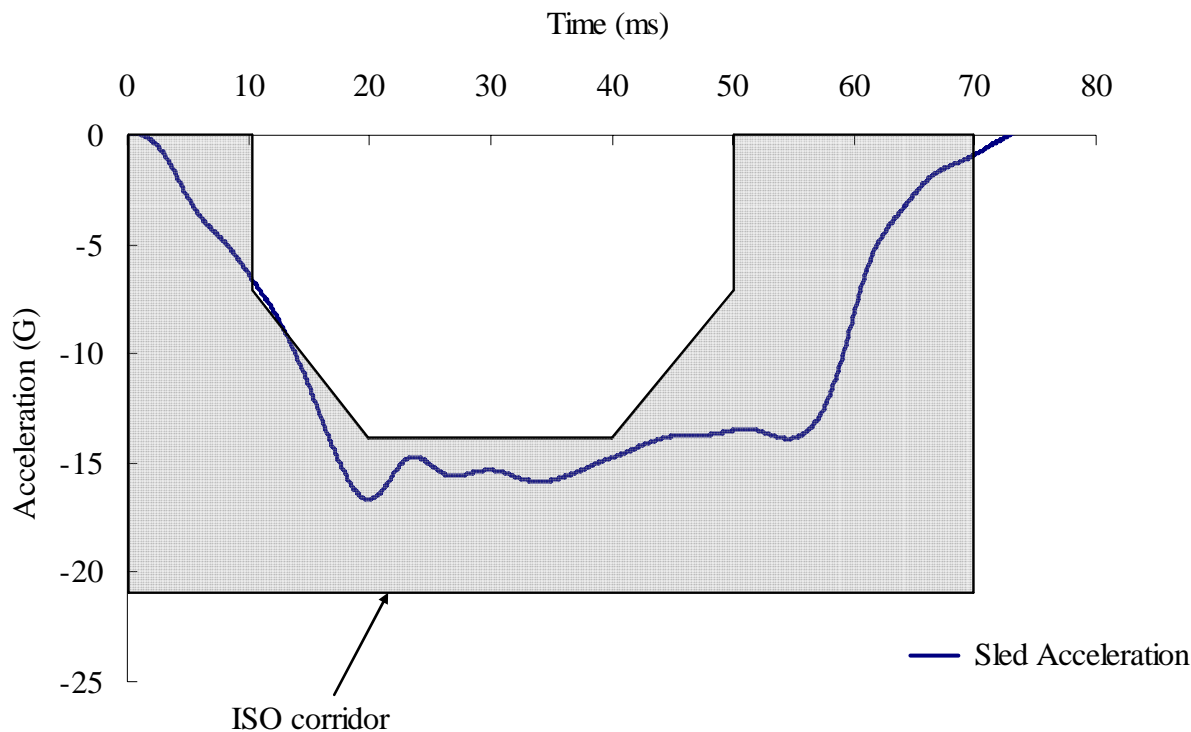


Figure 1. Typical sled deceleration pulse vs. proposed ISO/TC 173 rear impact standard corridor (shaded).

Conforming to ANSI WC19, a surrogate, vehicle-mounted, 3-point lap and shoulder belt, occupant restraint system (ORS) restrained the ATD during the impact, while the wheelchair was secured with surrogate, 4-point strap-type tiedowns. The tiedowns and ORS were both equipped with calibrated strain-gage based load cells, measuring tension forces in the webbing during the impact sled test. Three-bar belt load cells (Denton Corp.) in the lap/shoulder belt and in the rear tiedowns measured the forces during the impact event, while instrumented rod-ends measured front tiedown loads. The sampling rate and filtering were in accordance with SAE J211 standard (8).

RESULTS

Figure 2 shows a side view frame sequence for a typical rear impact test. The sequence begins at $t = 0$ ms and ends at $t = 300$ ms. After the deceleration pulse begins, the ATD loads against the seatback, as the front casters are lifted off the ground, and the wheelchair rotates slightly on the rear wheels. The ATD head excursion peaks around 150 ms, followed by the rebound, during which the ATD begins moving forward.

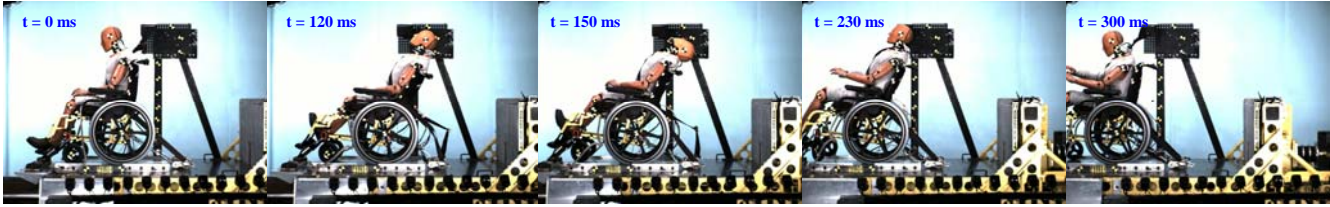


Figure 2. Frame sequence (left to right) of typical rear impact test.

During the testing, front tiedown loads greatly exceeded rear tiedown loading, but were symmetrical across left and right sides (Figure 3). Peak tiedown loads for each impact test are provided in Table 1. Front tiedowns were subjected to substantially higher forces during the initial 170 ms of the pulse, peaking at 75ms (Figure 3). This is largely due to the fact that the front tiedowns serve as primary means of securing the wheelchair and resisting its rearward motion during rear impact. The rear tiedowns experienced slightly higher loading than the front tiedowns after 170 ms in association with the rebound of the event (Figure 3).

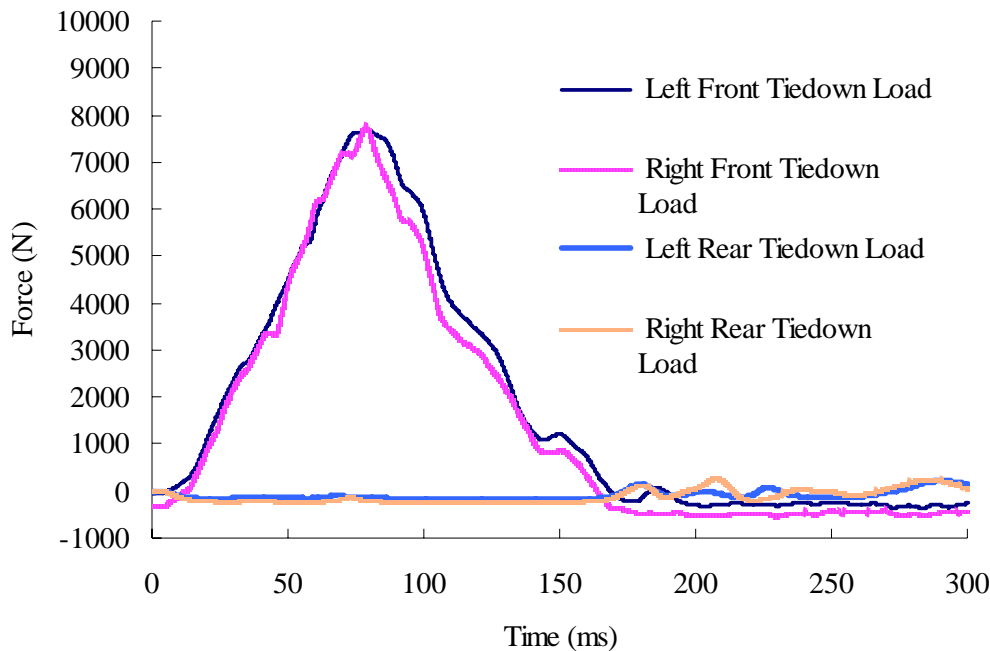


Figure 3. Typical loading of four-point tiedown system during rear impact sled test.

The shoulder belt (SB) loading remained relatively low and constant throughout the impact, while the lap belt (LB) loading was negligible only during the first 170 ms. At $t > 170$ ms the LB loading increased considerably, peaking around 225 ms, and zeroing again at $t = 300$ ms (Figure 4). Maximum ORS loading during each sled test is provided in Table 1.

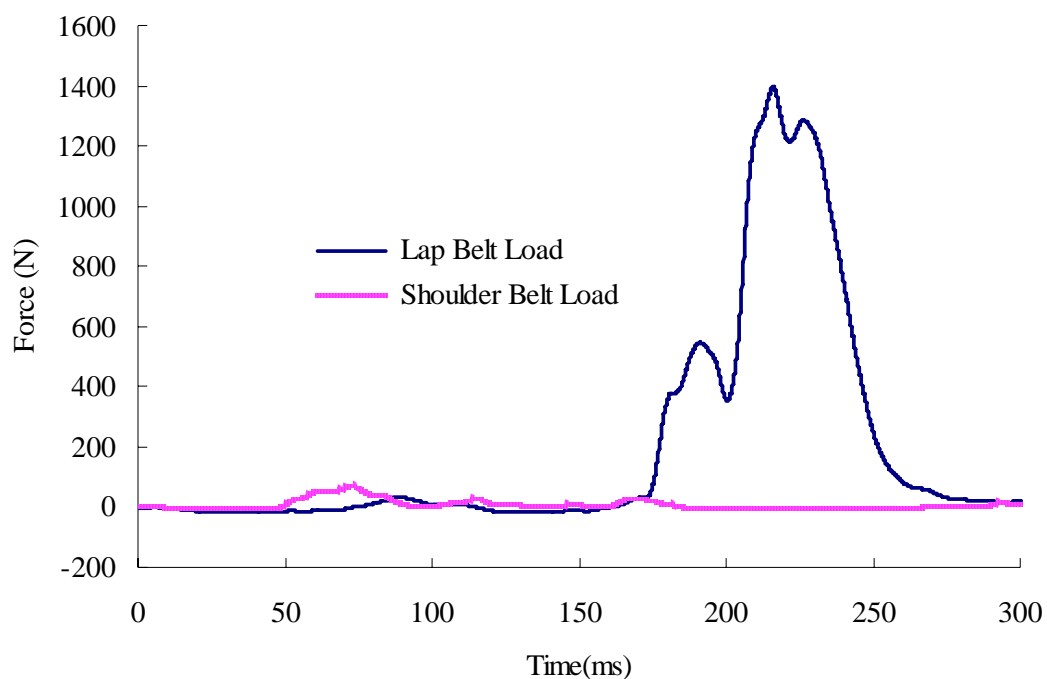


Figure 4. Typical three-point occupant restraint system loading during rear impact sled test.

Test	LFTD max (N)	RFTD max (N)	LRTD max (N)	RRTD max (N)	LB max (N)	SB max (N)
PV0603	7851	7415	13	124	4*	64
PV0604	7718	7197	101	5	1865	60
PV0605	7695	7733	223	257	1395	68
Mean Peak	7754	7449	112	129	1088	64
Standard Deviation	84	270	105	126	968	4

Notes:

Abbreviations

- LFTD – Left Front Tiedown
- RFTD – Right Front Tiedown
- LRTD – Left Rear Tiedown
- RRTD – Right Rear Tiedown
- LB – Lap Belt
- SB – Shoulder Belt

* Force not measured accurately during pulse, because lap belt slipped from anchor point

Table 1. Maximum wheelchair tiedown and occupant restraint system loading during rear impact.

DISCUSSION

Rear tiedown loading during rear impact was found to be negligible in comparison to front tiedown loading. The front tiedowns were subjected to higher forces during the initial 170 ms of the crash pulse, because they serve as key securement of the wheelchair and resist its rearward motion (relative to the vehicle) during rear impact. This loading is increased as the ATD starts loading the wheelchair's seat back, transferring an additional load to the front tiedowns. After 170 ms, the front tiedown loads decrease, and the rear tiedowns experience relatively minor loading. This indicates that the front tiedowns bear drastically higher loads during the impact, while the rear tiedowns are only loaded during the wheelchair rebound. The ATD's rebound load is carried mostly by the lap belt. This WTORS loading scenario was anticipated due to the "forward facing" wheelchair set up and rear impact dynamics. As shown in Figure 2, the ATD pushes against the seatback, as the casters are lifted off the ground and the wheelchair rotates slightly on the rear wheels. This results in the extensive loading of the front tiedowns. The rebound phase follows after the ATD's peak head excursion, during which the ATD begins moving forward, loading the lap belt. Substantially higher forces occurred in the front tiedowns. With the exception of the "rebound phase", the ORS forces were negligible.

In comparison with our study, computer simulated front tiedown loads reached only 100 N, under proper securement of a heavy power wheelchair (85 kg) in frontal impact when the rear wheelchair securement points were located at the same vertical height as the wheelchair center of gravity (9). However, this study also showed that increasing the height of the rear securement point above the wheelchair center of gravity, inducing rearward wheelchair rotation, may increase front tiedown loads. UMTRI reports measured left-front tiedown (LFTD) and right-front tiedown (RFTD) load peaks of 456 N and 2095 N, respectively in a frontal impact of a 33.2 kg manual wheelchair and a 50th percentile ATD (3). In this series of tests the wheelchair mounted lap belt, which incorporated the lower SB anchorage, allowed for the SB to laterally rotate the ATD and wheelchair resulting in asymmetrical front tiedown loads. Also of interest, the wheelchair used in these tests was substantially heavier than the wheelchair used in our study (33.2 kg vs. 25.1 kg). Despite, these differences, the rear impact dynamics in our study resulted in notably higher loads of up to 7851 N in the front tiedowns. This was the case because the wheelchair and ATD were faced opposing the direction of motion, requiring the front tiedowns to act as the primary securement during the impact. Despite the fact that the established frontal impact crash pulse (48 km/h, 20g) is more severe than the proposed rear impact crash pulse (25.8 km/h, 14 g), the front tiedowns were under much higher loads in rear impact than they were during frontal impact rebound. It is imperative that front tiedowns are designed to withstand loads associated with a rear impact collision.

Rear tiedown loads were approximately 6230 N in a frontal crash of a comparable manual wheelchair (10). This is substantially higher than the peak 257 N rear tiedown loading found in our study of rear impact loading. Lower forces in the rear tiedowns in a rear impact are due to the majority of the loading being carried through the front tiedowns. The minor loads on the rear tiedowns are a result of the wheelchair rebound.

In a frontal impact (9), (10), the lap and shoulder belts, along with the rear tiedowns, reached higher loads than during rear impact. In rear impact the seat back resists the excursion of the ATD, ultimately transferring this load through the wheelchair frame onto the front tiedowns.

A study by Leary et al. reported a frontal impact average peak LB load of 12760 N (9). In contrast, our findings in rear impact tests indicate a LB peak load of 1865 N in rear impact conditions. The peak SB load was much higher in frontal impact (Leary, 9790 N), and merely 68 N under rear impact conditions. The differences in ORS loading are due to the rear impact dynamics and ATD loading the ORS primarily in rebound.

This study confirms that WTORS forces differ greatly between the frontal and rear impact scenarios and provides quantitative comparisons with loads from frontal impact tests and computer simulations. It is critical that both tiedown and wheelchair manufacturers become aware of these differences, so that they can design safer and more effective securement systems, as well as securement points on WC19 wheelchairs.

It is important to note that the test protocol and crash pulse used in this study are from a proposed ISO rear impact standard (7), which has not yet been adopted by ISO. A limitation of this study is that one type of manual wheelchair make and model was used for all tests; other manual wheelchairs may generate different WTORS loading. Furthermore, a power wheelchair, having higher mass is anticipated to produce higher WTORS loading. Other variables that may affect WTORS loads include securement point location and geometry, ATD mass, and crash pulse severity.

CONCLUSION

In a frontal impact rear tiedowns limit forward movement of the wheelchair, while the LB and SB limit forward excursion of the occupant. During rear impact, the front tiedowns act as the primary securement of the wheelchair. Our study found front tiedown loading in rear impact to be substantially higher than previously reported front tiedowns loads in frontal impact. These differences in loading must be accounted for in the design of WTORS and wheelchairs to assure wheelchair user safety in both frontal and rear impacts.

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