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# Occupant Risk Estimation

G

for 1500A Vehicle

### G1. INTRODUCTION

n the design of staged attenuation systems, it is necessary to evaluate the performance of attenu- ation devices with a wide range of vehicles in terms of size and mass. The current evaluation

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criterion focuses on the 2nd and 90th percentile vehicles and requires testing with a 2,425-lb (1,100- kg) small car vehicle (1100C) and a 5,004-lb (2,270-kg) pickup truck (2270P). The smaller 1100C vehicle tests the lower end of the device’s performance and poses a severe test of the occupant risk measures due to the small mass of the vehicle, while the 2270P vehicle evaluates the maximum struc- tural and energy dissipation capacities of the device.

There is concern that design of crash cushions, terminals, and truck-mounted attenuators (TMAs) to meet the upper and lower bounds of the vehicle fl eet does not adequately address the performance of attenuation devices with mid-size sedan vehicles, especially with respect to devices with staged en- ergy-absorption systems. In order to address this issue, a test with a 3,307-lb (1,500-kg) sedan vehicle (1500A) has been added to the test matrices for terminals and crash cushions, Tests 38 and 45, respec- tively. An optional test, No. 54, has also been added to the test matrix for TMAs. Due to the cost of conducting an additional crash test with the 1500A vehicle, a procedure has been developed to deter- mine whether or not Tests 38, 45, and 54 are necessary for a given terminal or crash cushion design.

The procedure consists of estimating the occupant risk values for the 1500A test based on the ac- celeration trace obtained from Tests 31, 41, or 51. Tests 31, 41, and 51 consist of the 2270P vehicle impacting with its centerline aligned with the centerline of the test article. These tests involve heavier vehicles impacting under the same conditions as Tests 38, 45, and 54. Thus, the acceleration traces from these tests can be used to identify the need for the 1500A tests. The acceleration traces can be integrated to obtain the force-defl ection characteristics of the test article. The force-defl ection data can then be applied to the smaller vehicle in order to obtain reasonable estimates of the Occupant Impact Velocity (OIV) and Occupant Ridedown Deceleration (ORD). Note that this analysis will be conservative because the heavier mass of the 2270P vehicle and its higher crush stiffness will produce higher impact forces than will be experienced during a mid-sized vehicle impact. Therefore, if the force versus defl ection analysis predicts that the terminal, crash cushion, or TMA will meet evaluation guidelines for OIV and ORD for 3,307 lb (1,500 kg), Tests 38, 45, or 54 are not recommended.

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### G2. OCCUPANT RISK VALUES FOR 1500A VEHICLE

The procedure for estimation of the occupant risk values for 3,307-lb (1,500-kg) vehicles is based on the longitudinal acceleration trace from Tests 31, 41 or 51. The analysis described below is based exclu- sively on the CFC 180 fi ltered longitudinal acceleration trace. Lateral and vertical accelerations have virtually no effect on the results of the occupant risk values in head-on crashes with attenuator systems.

G2.1 PROCEDURE DETAILS

1. Defi ne initial conditions and known variables.

*a*2270*P*−*CFC*180 = *CFC*180 longitudinal acceleration, m/s

2

*m*2270*P vo* 2270*P t*2270*P*

*msedan vosedan*

= test vehicle mass, kg

= test impact velocity, m/s

= time from accelation data acquisition, s

= 1500 kg

= 27.78 m/s

(Eq. G2-1)

1. Integrate the CFC 180 acceleration trace to obtain the longitudinal change in velocity at each time,

*i*

*t* .

2270*P*

Δ*v*2270*P* = ∫*a*2270*P*−*CFC*180*dt*2270*P*

Δ*vi*

= *ai*

+ *ai*−

⎛ Δ*t*

*P* ⎞ + Δ*vi*−

(Eq. G2-2)

2270*P*

( 2270*P*−*CFC*180

1

2270

*P*−*CFC*180 )⎜

⎝

2270

⎟

2

⎠

1

2270*P*

1. Calculate the actual longitudinal velocity of the 2270P vehicle at each time, *ti* .

2270*P*

*v P* = *vo*

*i*

− Δ*vi*

(Eq. G2-3)

2270 2270 *P* 2270

*P*

1. Integrate the longitudinal velocity of the 2270P vehicle to obtain the displacement of the vehicle. Although the displacement of the impacting vehicle is not the same as the deformation of the test article, in order to simplify the analysis, they will be assumed to be the same. This step identifi es the estimated displacement of the test article at every data point in the longitudinal acceleration fi le.

δ2270 *P* = ∫*v*2270 *P dt*2270 *P*

δ*i* = (*vi*

+ *vi* −1

⎛ Δ*t*2270 *P* ⎞ + δ*i* −1

2270 *P*

2270 *P*

2270 *P* ⎜ 2 ⎟

2270 *P*

(Eq. G2-4)

⎝ ⎠

*i*

δ

2270 *P*

*i*

test article

= δ

1. Calculate the longitudinal force on the 2270P vehicle, which is equivalent to the force exerted by the test article on the impacting vehicle. This step produces an estimated deceleration force at every

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data point in the longitudinal acceleration fi le that corresponds with the test article deformation calcu- lated in Step 4.

*i i*

*F*2270*P*

= *m*2270*P a*2270*P*−*CFC*180

*i i*

*F* = *F*

test article 2270*P*

(Eq. G2-5)

1. The calculated force versus displacement curve generated in Steps 4 and 5 is then applied to a 3,307-lb (1500-kg) sedan impacting the system at 62 mph, 91 ft/s (100 km/h, 27.7 m/s). The work done by the attenuation system at every time step can be calculated as follows:

*W*test article = ∫ *F*test article *d*δtest article

*W i* = (*F i*

+ *F i* −1

)⎛ δtest article − δtest article ⎞ + *W i* −1

(Eq. G2-6)

test article test article test article ⎜

*i i* −1

2 ⎟ test article

⎝ ⎠

1. The longitudinal velocity of the 3,307-lb (1,500-kg) sedan at every time step can then be calculated based upon an energy balance using the work-energy derived for the test article.

*KE*1

+ *W* 1−2

= *KE*2

sedan test article sedan

1. *m* (*vi* −1

)2 + (*W i* −1

− *W i*

)= 1 *m*

(*vi* )2

1. sedan sedan test article test article

2 sedan sedan

(Eq. G2-7)

1 *m* (*vi* −1

)2 + (*W i* −1

− *W i* )

*i*

*v*

=

sedan

2 sedan sedan test article test article

1. *m*
2. sedan
3. Calculate the time interval for the sedan at each load step based on the average velocity between subsequent steps and the displacement of the test article.

*v*avg =

change in displacement change in time

*vi* + *vi* −1

*vavg*

= sedan sedan

2

2(δ*i*

− δ*i* −1 )

*ti* = test article test article + *ti* −1

sedan

*vi* + *vi* −1

sedan

(Eq. G2-8)

sedan test article

1. Calculate the change in velocity for the sedan vehicle at each time, *t*sedan .

*i*

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Δ*vi* = *v*

− *vi*

(Eq. G2-9)

sedan 0sedan

sedan

1. Integrate the change in longitudinal velocity of the sedan vehicle to obtain the occupant displace- ment for the sedan vehicle at each time, *ti* . The longitudinal occupant impact velocity is then

sedan

*i i*

identifi ed as the Δ*v*sedan at the step in which δocc sedan reaches 24 in. (600 mm).

δocc sedan = ∫ Δ*v*sedan *dt*sedan

*i i*

(Eq. G2-10)

δ *i* = (Δ*vi*

+ Δ*vi* −1 ) ⎛ *t*sedan − *t*sedan ⎞ + δ *i*−1

occ sedan sedan sedan ⎜

2 ⎟ occ sedan

⎝ ⎠

1. Calculate the estimated acceleration of the sedan vehicle based on the force of the terminal and the mass of the sedan at each time, *ti* .

sedan

*i*

*a*

sedan

*F i*

= test article

*m*sedan

(Eq. G2-11)

1. Calculate the 10 ms average acceleration versus time for the sedan vehicle. Note that the time interval varies throughout the analysis. Initially the time interval will be very nearly the data collection interval asso- ciated with the 2270P test. Because the velocity of the 1500A vehicle will decay more rapidly, the calculated time intervals will increase. The changing time interval complicates the average acceleration calculation procedure. Thus, calculation of the 10 ms average values involves searching forward 10 ms in time from the current time and calculating the corresponding change in velocity over the actual time period. The actual time interval will seldom be exactly 10 ms. In recognition of the conservative nature of this analysis technique, it is recommended that the selected intervals be no less than 10 ms. In other words, it is recommended that the forward search be conditional on the time interval being greater than or equal to 10 ms.

Search 5 ms backward:

5 ms backward *i*

*i*−5 ms

Δ*v*sedan

= Δ*v*sedan − Δ*v*sedan

Search 5 ms forward:

5 ms forward *i*

*i*+5 ms

Δ*v*sedan

= Δ*v*sedan − Δ*v*sedan

change in velocity

(Eq. G-12)

*a*sedan 10 ms average =

*i*

*a* =

sedan 10 ms average

change in time

5 ms forward 5 ms backward

Δ*v* − Δ*v*

sedan sedan

5 ms forward 5 ms backward

*t*sedan

− *t*sedan

The procedures described above allow the calculation of estimated occupant impact velocity and 10 ms average accelerations for a 1500A vehicle striking a staged attenuation system. If the estimated OIV and RA values are found to comply with the evaluation criteria set forth in Chapter 5, the attenuation system can be considered to comply with the requirements of Tests 38, 45, or 54. Note that this analysis procedure has proven to be conservative in that it tends to overestimate occupant risk values for the 1500A vehicle.

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This fi nding is attributable to the fact that the foregoing procedure ignores the reduced stiffness and mass of the 1500A vehicle relative to the 2270P vehicle. The increased stiffness of the 2270P vehicle reduces the total vehicle crush that occurs during an impact with an attenuator. Vehicle crush contributes to the energy dissipation during a head-on crash and reduces occupant risk values. Further, the much higher mass of the 2270P vehicle generates higher impact forces during a momentum transfer event. Actual impact forces applied to a lighter 1500A vehicle would be signifi cantly lower.

444 N Capitol St. NW Ste. 249 Washington, DC 20001

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