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16. Abstract (Limit: 200 words)

Whenever a traffic control plan is developed that utilizes temporary barriers, it is important to define acceptable barrier deflection criteria. However, the acceptable deflection criteria can be expected to vary, depending on the application. When temporary concrete barriers are used on the edge of a bridge, the risk of the entire line of barriers falling off of the deck requires that deflection limits be selected to preclude such behavior in almost all impact scenarios. Hence, it is recommended that at the edge of a bridge deck, design deflection limits should be selected to contain more than 95 percent of all crashes. In all other barrier applications, the consequences of a barrier exceeding the design deflection criteria are not severe. In these situations, a more modest deflection limit criterion based on an 85th percentile impact condition is more appropriate.

Previous crash testing according to NCHRP Report No. 350 has shown that most temporary barrier systems have produced large lateral deflections, high vehicle climb, and high roll angles when subjected to such an extreme impact. However, it is generally accepted that the Test Level 3 (TL-3) strength test with a ¾-ton pickup truck represents an extreme impact severity that is infrequently encountered in real world accidents. Additional crash tests could be conducted to determine the deflection of temporary barriers at reduced impact condition but the cost would be extremely high. Therefore, computer simulation was used to estimate the deflection of barriers impacted under the 85th percentile impact conditions. Finally, recommendations were made pertaining to the two different design deflection limits that should be used for the Iowa temporary concrete barrier.

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1 DEFLECTION LIMITS

Temporary concrete barriers are normally used to protect motorists from serious work zone hazards, such as deep drop-offs, heavy construction equipment, and opposing traffic. Temporary barriers are also used to protect highway workers from the risk of being struck by an errant vehicle. Whenever a traffic control plan is developed that utilizes temporary barriers, it is important to define acceptable barrier deflection criteria. However, the acceptable deflection criteria can be expected to vary, depending on the application. In some cases, the deflection criteria should be selected to virtually eliminate any chance of the barrier being displaced too far. The best example of such a situation is where the barrier is used on the edge of a bridge deck. A conventional temporary concrete barrier can be pulled off of the bridge by a single segment that is pushed off of the deck. As a result, the risk to workers and traffic below the bridge is extremely high, and deflections that could lead to such behavior should be avoided if possible. Under this situation it is generally accepted that barriers should be designed to contain almost all impacts without allowing the center of gravity of any barrier segment to extend beyond the edge of the bridge.

On the other hand, temporary concrete barriers are more frequently used in applications where high lateral deflections are less catastrophic. Examples of these situations include barriers used to separate traffic on two-lane, two-way traffic operations, protect motorists from heavy construction equipment, or protect workers on the ground in the construction zone. When used to separate traffic, barrier deflections up to 600 mm (2 ft) would not cause a significant problem for opposing traffic. Even in narrow construction zones, traffic lanes of less than 3-m (10-ft) wide are rare, and a 600-mm (2-ft) lateral barrier displacement would not intrude significantly into the paths of oncoming traffic. Although larger deflections could begin to intrude into the normal paths of oncoming traffic, the risk of an accident involving opposing traffic is still relatively low. Even when a vehicle in the opposing lane strikes a deflected barrier, the impact angle associated with any resulting crash would be expected to be extremely low. For this situation, the consequences of exceeding the deflection limit are not catastrophic.

Further, when barriers are used to protect motorists from heavy construction equipment, the risk of a catastrophic accident would be relatively low. Although heavy construction equipment is often used in highway work zones, the period of time that such equipment is in close proximity to any given section of the barrier is relatively limited. Remember that much of a temporary barrier's deflection occurs after the impacting vehicle has been redirected and the barrier is sliding freely along the ground. Hence, even when heavy equipment is placed close to a barrier and a high energy impact occurs immediately adjacent to the hazard, the impacting vehicle would likely be successfully redirected without incident. Thus, the risk to motorists of a barrier deflecting beyond the design limit is very low in this application.

There is a similar effect for temporary barriers used to protect construction workers. When compared to the total period of construction, the time that workers are immediately behind the barrier is relatively limited. Again, since vehicles are redirected long before the barrier reaches its maximum lateral displacement, an impacting vehicle would not directly contact workers standing near the barrier. Instead, the barrier could be expected to slide into the workers at a very low speed. Again even when temporary barriers are used to protect construction workers, the consequences associated with a barrier deflecting beyond the design criteria are relatively modest.

In summary, when temporary concrete barriers are used on the edge of a bridge, the risk of the entire line of barriers falling off the deck requires that deflection limits be selected to preclude such behavior in almost all impact scenarios. Hence, it is recommended that at the edge of a bridge deck, design deflection limits should be selected to contain more than 95 percent of all crashes. In all other barrier applications, the consequences of a barrier exceeding the design deflection criteria are not severe. In these situations, a more modest deflection limit criterion based on an 85^{th} percentile impact condition is more appropriate.

2 IMPACT CONDITIONS

NCHRP Report No. 350 (1) recommends that temporary barriers be tested under the same criteria as permanent barrier systems. Therefore, in order to be used on high speed facilities, temporary barriers are tested under the Test Level 3 (TL-3) criteria which involves a 2,000-kg (4,409-lb), ¾-ton pickup truck impacting the barrier at a speed of 100.0 km/hr (62.1 mph) and at an angle of 25 degrees. When subjected to such an extreme impact, most temporary barrier systems have produced large lateral deflections, high vehicle climb, and high roll angles. Most pin and loop barrier systems have deflected more than 1200 mm (4 ft) when subjected to the TL-3 testing criteria. However, it is generally accepted that the TL-3 strength test with a ¾-ton pickup truck represents an extreme impact severity that is infrequently encountered in real world accidents.

Data collected from crashes with poles and narrow bridges have been used to estimate distributions of speeds and angles associated with ran-off-road crashes (2). As shown in Table 1, only 18 percent of freeway accidents involve impact speeds greater than 100.0 km/hr (62.1 mph) and only 15 percent involve impact angles greater than 25 degrees. Further analysis of the data from reference 2 indicates that less than 3 percent of all accidents involve both an impact speed greater than or equal to 100.0 km/hr (62.1 mph) and an impact angle greater than or equal to 25 degrees.

Although data from reference 2 clearly indicates that the TL-3 strength test represents an extreme impact condition, it is not sufficient for identifying expected barrier deflections. A number of research studies have shown that the Impact Severity (IS), as defined below, is a good indicator of the degree of loading and the lateral deflections of longitudinal barriers (3,4,5).

$$IS = \frac{1}{2}\ m\ [\ v \sin\theta\ ]^2$$

where:

m = mass of impacting vehicle
v = velocity of impacting vehicle
θ = angle of impact.

IS adds the effect of the mass of the impacting vehicle to provide a good measure of the severity of impact and the magnitude of the resulting barrier deflections. Although vehicle impact conditions may be somewhat correlated to vehicle weight, there has been no research to date that either indicates such a correlation or that it would be very strong. Further, speed studies have shown very modest correlations between passenger vehicle mass and operating speed which indicates that the correlation between accident speed and vehicle mass should be very weak. Therefore, in order to estimate the expected distribution of impact severities, the mass distribution for vehicles involved in ran-off-road crashes was assumed to be independent of the impact speed and angle distributions. Mass distributions for vehicles involved in ran-off-road crashes, shown in Table 1, have been determined from the National Accident Sampling System - Crashworthiness Data System (6).

When the mass distribution shown in Table 1 is combined with the speed and angle distributions from reference 2, the distribution of IS values for passenger cars and light trucks can be developed. The distribution shown in Figure 1 was developed by assuming that impact speed and angle distributions for freeways from reference 2 are independent of the vehicle mass distributions. Impact severity distributions were first developed for each vehicle class shown in Table 1, and the separate distributions were then combined based on the portion of traffic represented by each class. Note that impact speeds and angles used to develop Figure 1 were based on accidents that occurred during the time when the national speed limit reduced operating speeds on rural freeways. However, remember that this data is being used to evaluate accidents in construction zones where operating speeds are generally reduced in a manner similar to that associated with the national speed limit. Therefore, although the distribution of IS values shown in Figure 1 may be too low for modern, free-flowing, rural freeways, it should provide a reasonable estimate of impact conditions for construction zones where temporary barriers are utilized.

As shown in Figure 1, the 95th percentile IS value is just below 120 kJ (88.5 kip-ft). This value is not far below the IS value associated with the TL-3 strength test of 138 kJ (101.7 kip-ft). Therefore, it is reasonable to utilize deflections measured during full-scale crash testing under TL-3 impact conditions when selecting barrier deflection limits for use on the edge of a bridge deck. However, the 85th percentile IS value, which is more appropriate for all other applications of temporary concrete barriers, is closer to 55 kJ (40.5 kip-ft). An IS value of 55 kJ (40.5 kip-ft) would correspond to a ¾-ton pickup truck impacting the barrier at a speed of 58 km/hr (36 mph) and at an angle of 27.1 degrees. Barrier deflections under this impact condition would be much less than those observed when a barrier is subjected to crash testing under the NCHRP Report No. 350 recommendations.

Table 1. Freeway Speed and Angle Distributions from Accident Data

Impact Speed (km/hr)	Distribution % Exceeding	Impact Angle (degrees)	Distribution % Exceeding
20	99	5	90
40	88	10	67
60	63	15	44
90	37	20	26
100	18	25	15
120	8	30	8
		35	4

Table 2. Mass Distribution

Vehicle Type		Vehicle Make and Model	Average Weight (kg)	GES Distribution (%)
Passenger Vehicle	Small Sedan	Toyota Tercel Geo Metro	1835	11.5
	Small Sedan	Ford Escort Toyota Corolla	2408	17.5
	Medium Sedan	Toyota Camry Honda Civic	2718	24.6
	Medium Sedan	Ford Taurus Honda Accord	3065	7.4
	Large Sedan	Cadillac Deville Buick LeSabre	3553	3.2
	Large Sedan	Lincoln Town Car Ford Crown Victoria	3930	3.1
Light Trucks	Small Van	Plymouth Voyager Ford Aerostar	3257	3.8
	Large Van	Ford E-150	4189	2.5
	Small Pickup	Ford Ranger Chevrolet S10	3023	19.6
	Standard Pickup	Chevrolet 1500, 2500 Ford F-150, 250	4258	
	All Pickups		3711	
Sport Utility Vehicle	Small SUV	Suzuki Samuri Geo Tracker	2150	6.8
	Mid-size SUV	Ford Explorer Jeep Cherokee	3668	
	Large SUV	Chevrolet Suburban Ford Expedition	4940	
	All SUV		3544	

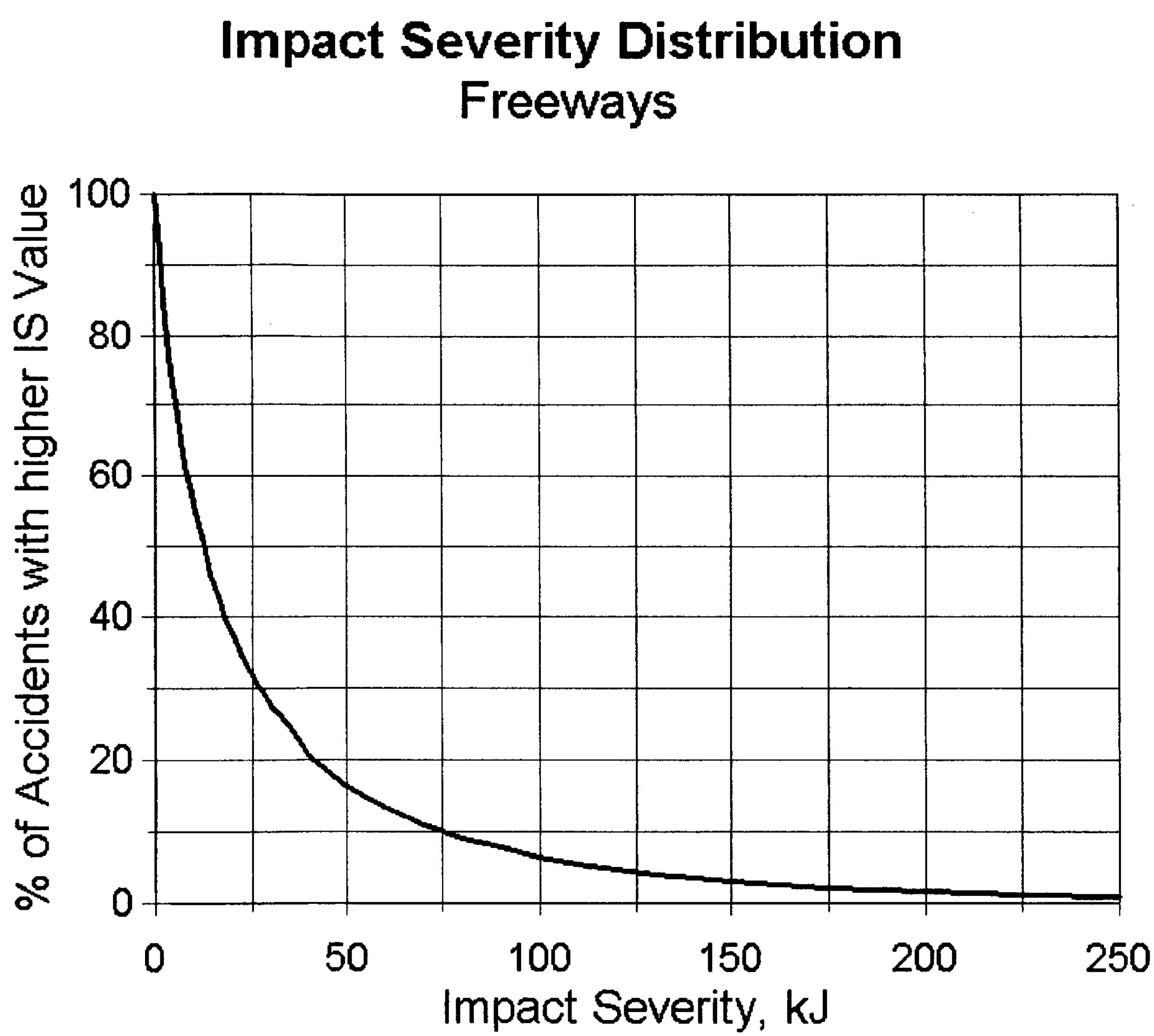

Figure 1. Impact Severity Distributions for Freeways

3 IMPACT MODELING

Although additional crash tests could be conducted to determine the deflection of temporary barriers at this reduced impact condition, the cost would be extremely high. Computer simulation of the impact conditions can be used to estimate the deflection of barriers impacted under the 85th percentile impact conditions. This process involves using LS-Dyna to model the behavior of the barrier system when subjected to full-scale crash testing. After the model has been calibrated to accurately predict barrier deflections for the high energy crash test conditions, the impact conditions are revised and the barrier deflections are estimated for the lower energy crash. Figure 2 shows the LS-Dyna model of the Iowa temporary barrier (7,8), and Figure 3 plots the predicted and actual deflections of the barrier subjected to full-scale crash testing. Note that simulation predicted both the general shape and maximum extent of barrier deflections with a reasonable degree of accuracy. Based on the findings of these simulations, it was concluded that LS-Dyna could be used to estimate the barrier deflections associated with the 85th percentile impact condition.

Results of the LS-Dyna model of the ¾-ton pickup truck impacting the Iowa temporary barrier under the 85th percentile impact condition at a speed of 58 km/hr (36 mph) and 27.1 degrees is shown in Figure 4. The maximum deflection predicted during this crash test was 600 mm (2 ft). Based on this analysis, the design deflection limit for the Iowa temporary barrier should be set at 600 mm (2 ft) for all applications except when it is used at the edge of a bridge deck.

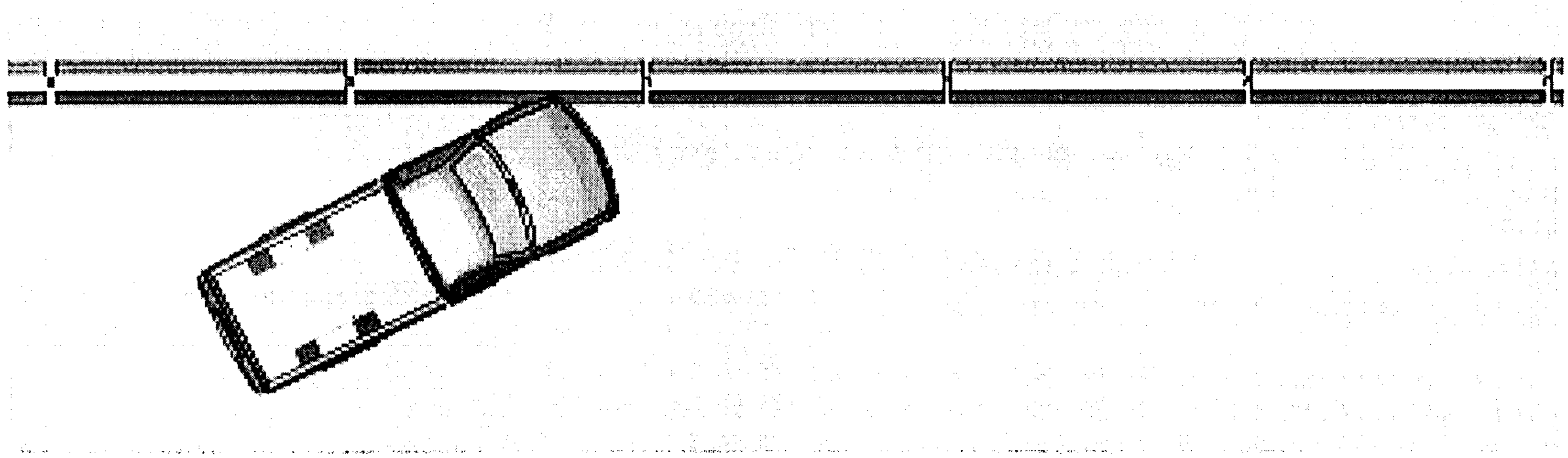

Figure 2. LS-Dyna model of the Iowa temporary barrier

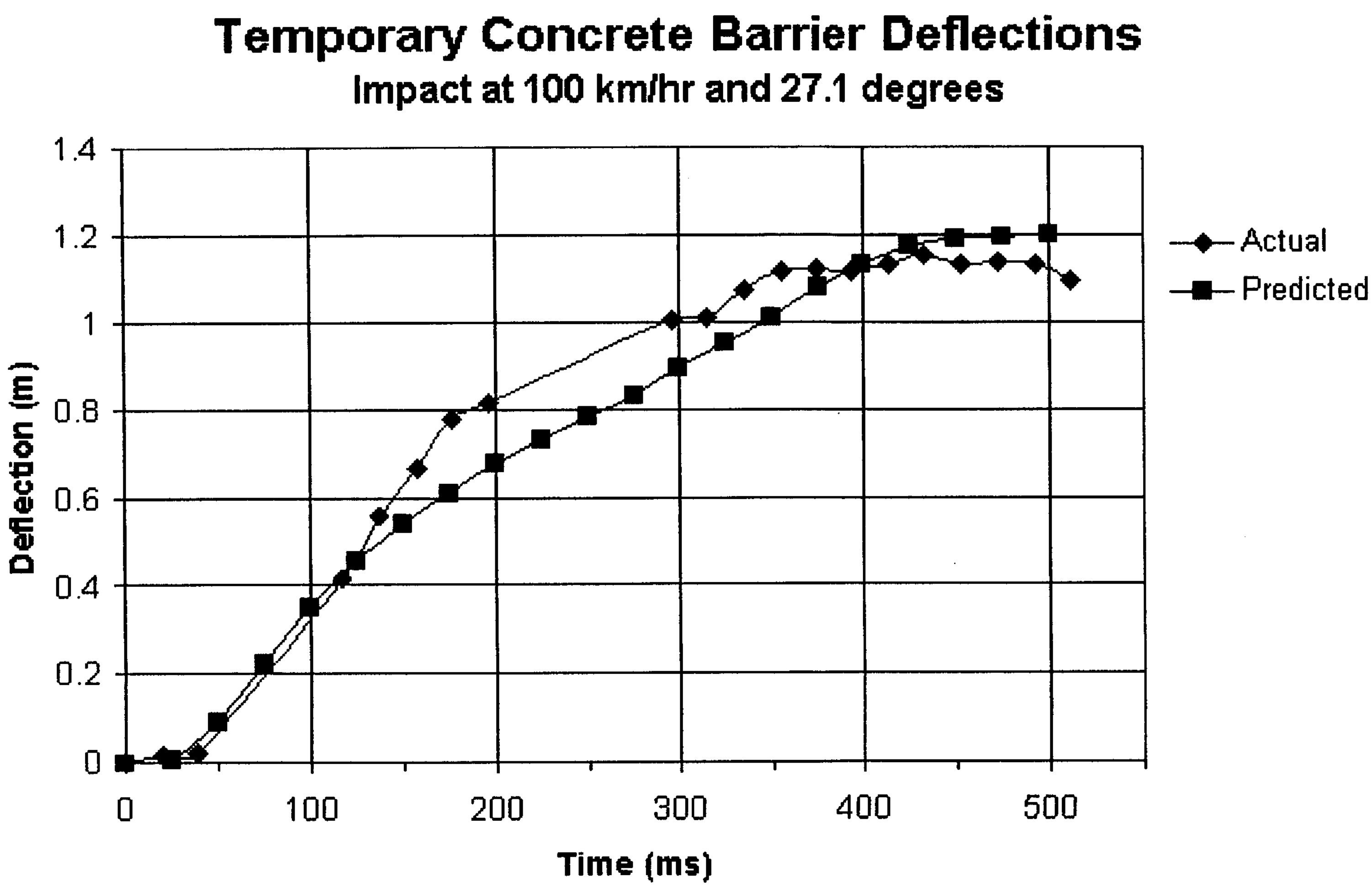

Figure 3. Predicted and actual deflections of the temporary concrete barrier subjected to full-scale crash testing

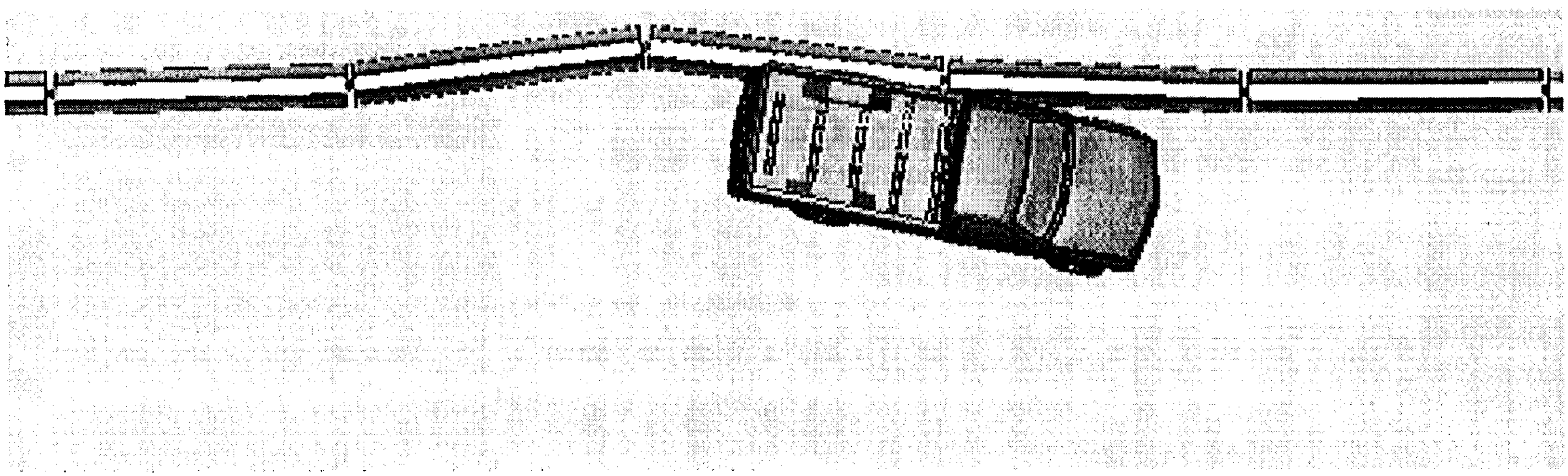

Figure 4. 85th percentile impact results of the LS-Dyna model of the Iowa temporary barrier (58 km/hr and 27.1 degrees)

4 CONCLUSIONS

As summarized within this report, two different design deflection limits should be used for the Iowa temporary concrete barrier. When the barrier is used in a free standing mode, immediately adjacent to the edge of a bridge deck, the design deflection limit should be the distance that the barrier was deflected during full-scale crash testing, 1.04 m (41 in.). For all other applications, the design deflection limit should be set at 600 mm (2 ft). This distance corresponds to the distance that the Iowa temporary barrier could be expected to deflect under the 85th percentile impact for passenger cars and light trucks.

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