Test 5

The guardrail installation for this test was identical to that used for tests 3 and 4.

In this (essentially head-on) test, a 2068-kg (4560-lb) 1970-model automobile impacted the turned-down terminal section at an angle of 5.5° and a speed of 89.0 km/h (55.3 mph). On impact, the vehicle depressed the rail in a manner similar to that of the vehicle in test 4. It then continued astraddle of the rail, exhibiting a low-amplitude, oscillatory pitching and rolling motion, and eventually stopped on the top of the rail approximately 57 m (188 ft) from the end anchor. The position of the vehicle and the damage to the guardrail are shown in Figure 24. Twenty-six posts were split, broken, or bent over. The maximum average 0.050-s longitudinal deceleration was approximately 3 g and the peak values were all below 5.5 g. The extensive damage to the undercarriage of the vehicle is shown in Figure 25. The repairs to the guardrail consisted of replacing 26 posts and eight 7.6-m (25-ft) sections of rail.

In some installations, e.g., bridge abutments and other fixed obstacles, the approach length of guardrail may be less than the 57 m (188 ft) traveled by this test vehicle. If a vehicle became captive at the end of the rail, it could impact the obstacle from which it was being protected. To obtain some indication of the potential severity of such impacts, a curve of velocity versus distance traveled by the test vehicle was developed from the documentary movie film and is given in Figure 26. To avoid the possibility of such head-on impacts, guardrail terminals should be flared away from the roadway.

CONCLUSIONS

A relatively simple method of modifying the turned-down ends of guardrail terminals has been developed. This method should eliminate or greatly minimize the probability that a vehicle impacting them will ramp and roll over. The hardware used in the design are either standard guardrail components or items that are readily available commercially.

Successful crash tests were conducted as described in the NCHRP Recommended Procedures (4). In three of the tests, the vehicle impacted the modified terminal section, depressed the rail, and rode over it without rolling over.

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Design of Barrel Trailer for Maximum Collision Protection

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This report describes a Texas type, steel-barrel trailer developed by the Highway Wayside-Equipment Research Office and the Equipment Office of the Ontario Ministry of Transportation and Communications. When attached to a sign truck, the trailer provides maximum crash protection for occupants of impacting automobiles in rear collisions at impact speeds of up to 100 km/h (60 mph). This means that restrained occupants will survive such collisions without serious injuries. (Crash protection is expected to be somewhat less for angular impacts.) The trailer can be towed at traveling speed and backed up at slow speed on a closed traffic lane. For full protection of a working crew, the trailer should be attached to the kind of heavy sign truck that is presently used in maintenance operations. Although the trailer is an extra piece of equipment and requires special driver skill in backing, it is recommended for use on high-speed highways with high traffic volumes, expressways, or freeways. The trailer reduces impact severity considerably and is more effective than nontrailer attachments at impact speeds of 80 km/h (50 mph) or less. The first prototype tried on the road has been involved in two collisions. In both instances, the impact attenuation and redirectional capabilities of the steel barrels were sufficient to prevent injuries. The connections between the barrel modules, which were originally welded, now consist of bolts and hard rubber spacers and are still being developed.

In September 1974, a car traveling at an estimated speed of 130 km/h (80 mph) struck the rear of a sign truck that was protecting a night crew who were making illumination measurements. The driver of the car was killed instantly, and the truck was severely damaged (Figure 1).

Although there were warning systems in operation and the driver was exceeding the legal speed limit, the case nevertheless dramatically illustrates the need for greater protection from such collisions for the driving public. The solid backs and rigid bumpers of the trucks now in use are road hazards of the greatest severity. Moreover, in the following year, from December 1974 to November 1975, there were 34 collisions with Ministry of Transportation and Communications sign trucks in three major districts in Ontario (Toronto, Ottawa, and Hamilton).

Because of these accidents, the Highway Wayside Equipment Research Office and the Equipment Office have initiated the development of a protective trailer for sign trucks. Prototypes have been designed and built, and their operations tested. The attachment of a barrel trailer can reduce the probability that a straight or angular rear or side collision will be fatal or result in serious injuries from about 0.7 to 0.33 (1).

DESCRIPTION OF TRAILER

Figure 2 shows the first prototype trailer in operation. Details of the design are shown in Figures 3 and 4. The trailer is made of 18-gauge paint drums, 0.9 m (3 ft) high and 0.6 m (2 ft) in diameter, with 355-mm (14-in) holes on their tops and bottoms. The barrels are tied together with adjustable steel cables and welded together by means of flat steel connectors that arch over the rims (but this design is now being changed by the substitution of bolted connections).

A cable suspension, which was added before major use, is supported on top of the barrels by a stirrup.

The trailer has the following operational features.

1. It can be pulled on smooth or moderately rough roads at a normal traveling speed without touching the

Figure 1. Damage to truck after fatal accident.

Figure 2. Operational test of crash trailer.

Figure 3. Design features of first trailer.

Figure 4. Cable suspension of barrels on first trailer.

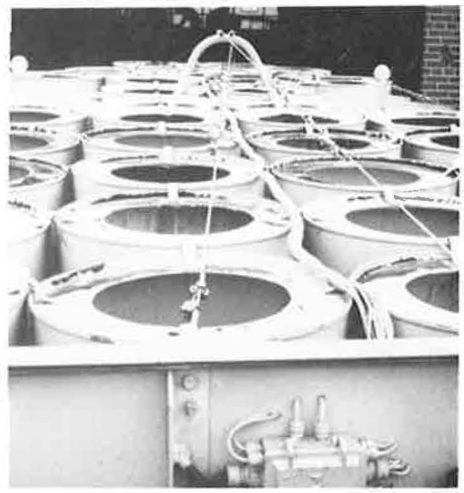
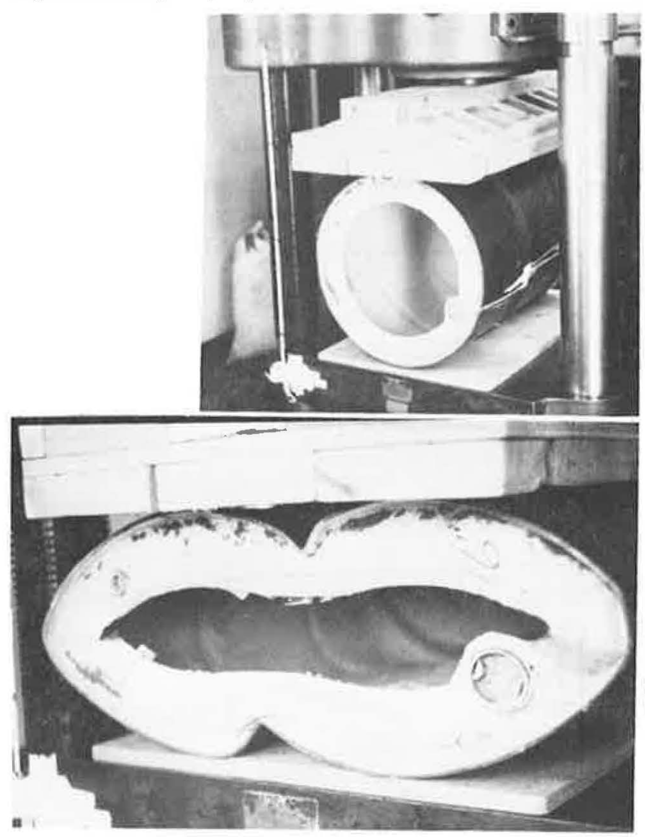


Figure 5. Testing of open paint drums.



ground if the distance of the barrels from the ground is 200 mm (8 in) or more when the trailer is standing on a horizontal plane surface.

2. It can be backed up easily by a skilled driver at a speed appropriate for setting markers.

The connection to the truck during the backing up operation is flexible, and the angular-impact behavior of the design in this situation cannot be predicted without field testing.

DESIGN FOR IMPACT ATTENUATION

The trailer can be connected more rigidly for nondriving or stationary conditions by tautly engaging the chains. In this situation, the impact behavior can be predicted fairly accurately if the crash properties are known and the hitch connections are sufficiently strong. Thus, design calculations are presented for a straight rear impact.

Crushing Force of Barrels

Although there are data for crush forces of steel drums (2, 3), crush testing for static forces or a slow loading rate was performed. The testing procedure is shown in Figure 5. Typical crushing forces and deformations of barrels are shown in Figure 6. The results of actual

Figure 6. Typical force deformation of steel drum.

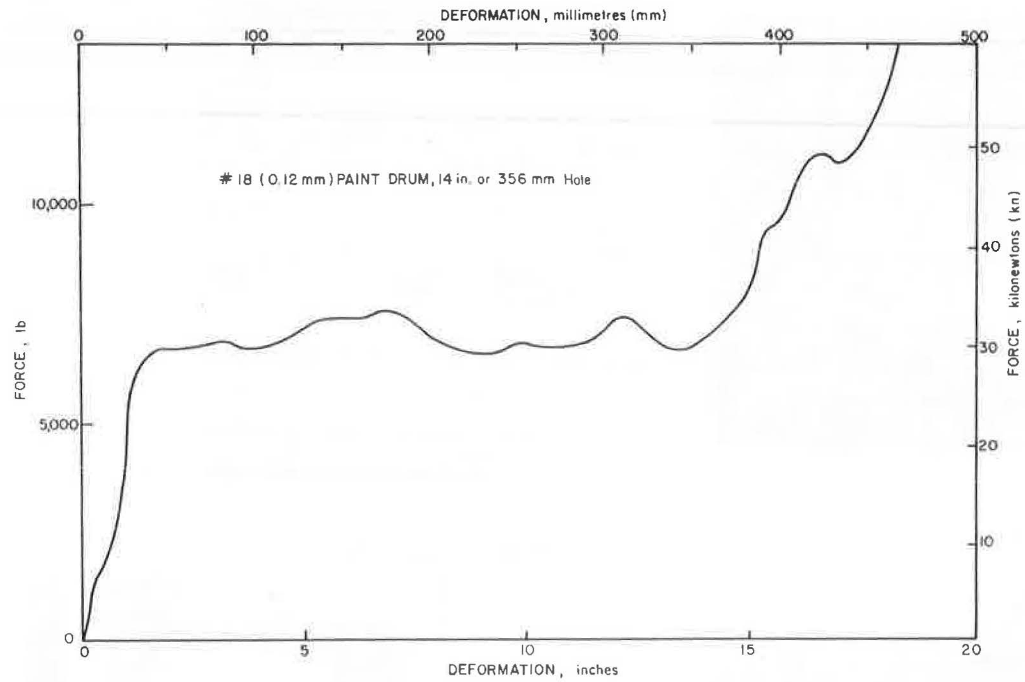
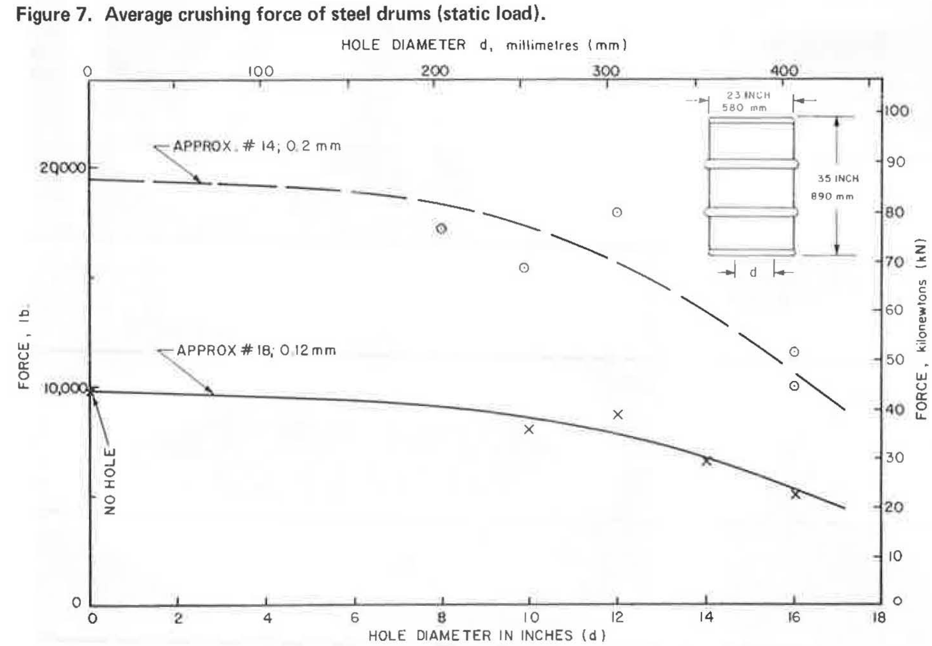


Figure 7. Average crushing force of steel drums (static load).



tests are plotted in Figure 7 (the wall thickness of the barrels used in these tests could be measured only approximately). The design criteria are given below (1 km/h = 0.6 mph and 1 kg = 2.2 lb).

Property	Criterion
Impact speed, km/h	100
Impact angle, °	0
Range of automobile weights, kg	800 to 2000

Dynamic Equations

The following equations, which may be used for the design, are derived from the physical laws of momentum and energy conservation:

$$v = mV/(m + M) \tag{1}$$

$$s = v^2/2gf \times (m + M)/M' \tag{2}$$

$$e = \tfrac{1}{2}mV^2 - (m + M)v^2 \tag{3}$$

where

V = impact velocity of automobile,

Figure 8. Velocity after impact.

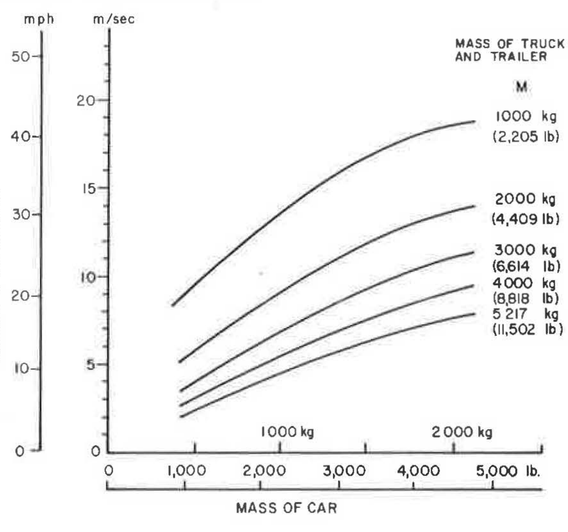
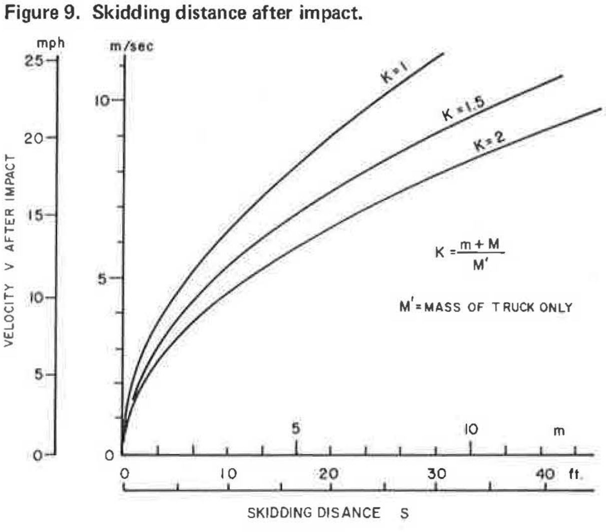


Figure 9. Skidding distance after impact.



v = velocity of total mass after impact,
M = mass of truck and trailer,
M' = mass of truck only (weight on braking wheels),
m = mass of automobile,
s = skidding distance after impact,
g = acceleration of gravity [$9.81\ m/s^2$ ($32.2\ ft/s^2$)],
f = coefficient of friction (assumed to be 0.7), and
e = energy absorbed by crushing material.

These equations are independent of the crushing material and its attenuation mechanics. Their solutions

Figure 10. Dissipated impact energy.

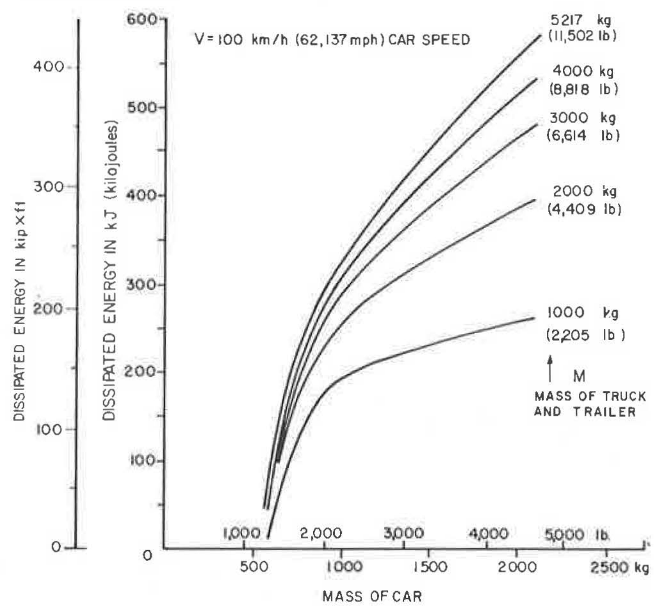


Figure 11. Average automobile deceleration.

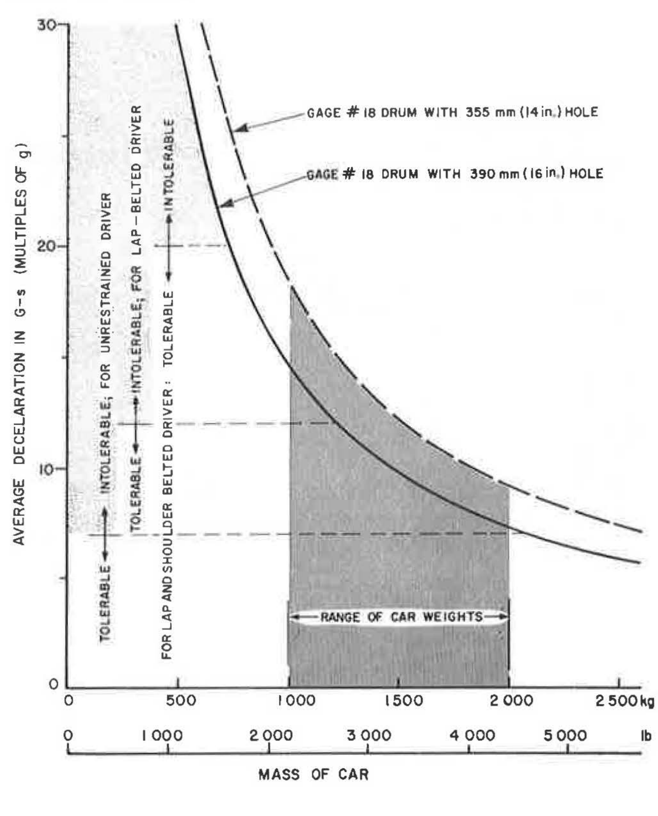


Figure 12. Design layout and angular impact force components.

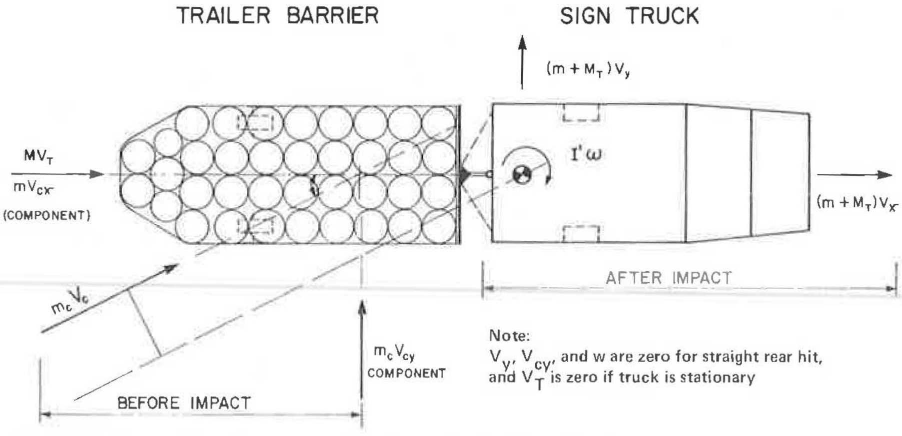
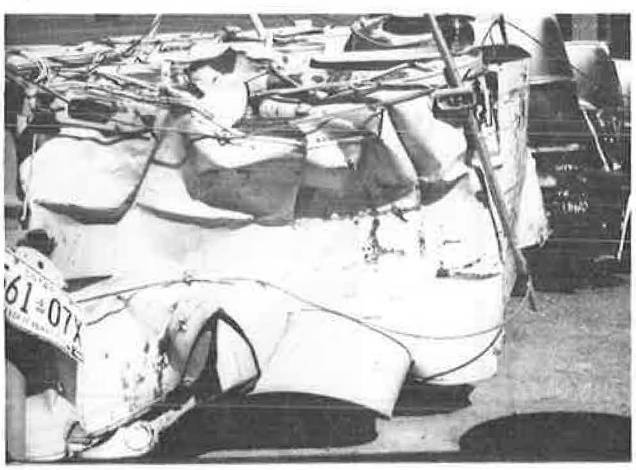


Figure 13. Damaged crash trailer after glancing-blow collision with automobile.

Figure 14. Wrecked crash trailer after angular rear collision with truck.



are plotted in Figures 8, 9, and 10 for an impact speed of 100 km/h (62.14 mph).

Crush Design

We can assume that the energy (e) is dissipated by crushing the steel drums. In this design there are nine rows of drums with four drums in each row.

For a drum made of 0.12-mm (18-gauge) steel with 405-mm (16-in) holes in its top and bottom, the static average crushing force for 65 percent of the total diameter [381 mm (15 in)] is approximately 24 kn (5400 lb). A dynamic factor of 1.5 must also be applied (2, 3). Thus, the energy-absorbing capacity for one drum is at least

$$E_1 = 1.5 \times 0.381 \times 24\ 000 = 13\ 716\ \text{J} \qquad (4)$$

and, for a row of four drums,

$$4E_1 = (m \times G \times g) \times D = (\text{dynamic force} \times \text{distance}) \qquad (4a)$$

where G = multiple of g for average deceleration and D = crushing distance or stroke of one drum. Therefore, we have $G = 4E_1/mgD = [(4 \times 13\ 716)/(9.81 \times 0.381)] \times 1/m$ or $G_{16} = 14\ 680/m$. The corresponding expression for drums with 355-mm (14-in) holes is $G_{14} = 18\ 350/m$; i.e., an energy absorption of 17 145 J/drum.

These estimated average decelerations are plotted in Figure 11 for a wide range of automobile weights.

What number of drums should be used in the design? For a total mass (M) of 5217 kg (11 500 lb), the dissipation energy is 555 000 J for a 2000-kg (4400-lb) automobile (from Figure 10). The number of drums (n) is then $n_{16} = (555\ 000/13\ 716) = 40.4 = 40$ and $n_{14} =$

Figure 15. Modified crash trailer.

$(555\ 000/17\ 145) = 32.4 \approx 32$, where n_{16} and n_{14} are the numbers of drums having 405-mm (16-in) and 355-mm (14-in) holes respectively. The final design has 37 drums with 405-mm (16-in) holes. This design permits tolerable average decelerations for lap and shoulder-belted drivers in the range of automobile weights indicated in Figure 11, and drivers of heavier automobiles would need only lap belts to have the same degree of protection that lap and shoulder-belted drivers have in smaller automobiles. The design layout is shown in Figure 12.

The average crushing force and therefore the average deceleration are the same for both low and high impact speeds. Fewer barrels are crushed by lighter automobiles. The truck skids a longer distance after impacts from heavier vehicles (Figure 9).

Angular Impact

Lack of knowledge about the parameters of the system (such as the mass moment of inertia of the truck and trailer combination) makes it impossible to evaluate the angular-impact behavior of the design. But, it can be anticipated that less energy will be absorbed by crushing as energy is dissipated by the friction that will accompany rotation or spinning of the system. The average deceleration will depend on the impact angle and the point of contact.

COLLISIONS WITH THE FIRST PROTOTYPE TRAILER

The first prototype, as shown in Figures 2, 3, 4, and 13, was used in the summer of 1975 to protect the operation of a low-speed paint striper. Within 3 months, there were two collisions.

The first collision occurred on the Queen Elizabeth Way, eastbound, at 5:25 a.m. on June 22, 1975. The driver of the sign truck gave the following report. The truck was traveling at a speed of 10 to 13 km/h (6 to 8 mph) in the center lane behind the striper, which was painting the two broken lines simultaneously. The trailer was hit a glancing blow by a compact automobile having an estimated speed of 105 to 113 km/h (65 to 70 mph). Only one barrel and its attached light fixtures were damaged. The automobile, which had several occupants, was redirected, crossed two lanes, and drove on without stopping. If the trailer had not been attached, the automobile would probably have crashed into the right rear corner of the truck. This means that considerable accident costs and possibly human lives were saved in this accident. The damage to the trailer is shown in Figure 13.

The second collision occurred in the right-hand lane of Highway 400, northbound, at 1:20 p.m. on July 14, 1975. The sign truck with the trailer attached was traveling at a speed of about 16 km/h (10 mph) behind the striper. The trailer was hit at a slight angle by an empty 2700-kg (3-ton) truck, traveling at about 100 km/h (60 mph). The driver of the impacting truck applied the brakes before the crash and thus the truck impact speed was probably reduced. The barrels on the right-hand side of the trailer were fully or partially crushed, and the trailer was pushed under the sign truck. The damage to the trailer was beyond repair (Figure 14). The driver of the impacting truck was uninjured although he would probably have suffered injuries if his truck had hit the right-hand corner of the sign truck.

FURTHER DEVELOPMENTS

The trailer design was modified after an evaluation of the accident performance of the first prototype. The modifications are shown in Figure 15. A cable suspension supported by a stirrup was mounted on top of the barrels to increase stability during rough driving operations, and a bolted connection that uses steel washers and hard rubber spacers between the barrels is being developed.

At the present stage of development of the trailer, several questions remain unanswered:

1. What are the exact barrier-resistance characteristics for a straight rear impact?
2. What is the behavior of the trailer at an angular impact of 15 or 25°?
3. What is the performance of bolted connections between barrels?

Testing under controlled conditions and supplementary computer simulations will be necessary before these questions can be answered. This topic has been discussed by Jung and Billings (4, 5).

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