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FEASIBILITY OF CONCRETE PIPE CRASH CUSHIONS

A Test And Evaluation Report On Contract No. CPR-11-5851

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The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the Federal Highway Administration.

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INTRODUCTION

One full-scale vehicle crash test was conducted on a system composed of reinforced concrete sewer pipes embedded 4 ft-3 in. in the soil. This crash cushion is shown in Figures 1 and 3. The results of this crash test are presented in this report.

Pendulum tests were conducted by the Southwest Research Institute (SwRI)[1*] on various transite, vitrified clay, and concrete pipes (see Table 1). The purpose of these tests was to acquire force and energy data; and thereby determine the feasibility of crash cushions constructed of the readily available materials mentioned above. These crash cushions would be economical and easy to install at ground level sites. A reinforced concrete sewer pipe tested by SwRI (30 in. O.D.) was chosen for use in the prototype crash cushion which was built and tested at TTI. The pipes used in the crash cushion and the pipe tested by SwRI had the same dimensions and were embedded in the soil to the same level.

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*Superscript numbers refer to corresponding references at the end of this report.

TABLE 1

PIPE DIMENSIONS

(After Michie and Bronstad[1])

Test Number	Material	O.D. (in.)	I.D. (in.)	Length (in.)	Height Above Grade (in.)
1	Transite Class 2400	11.4	10	66	30
2	Transite Class 2400	20.3	18	66	30
3	Vitrified Clay	21.5	17	63	30
4	Concrete Sewer Regular	23.0	18	51	24
5	Concrete Sewer Extra Strong	30.4	24	51	24
6	Concrete Sewer Extra Strong (reinforced)*	30.0	24	75	24

*Reinforcement was 3 x 8-6/8 welded wire fabric. The 8-ga wires were longitudinal, and the 6-ga wires were circumferential.

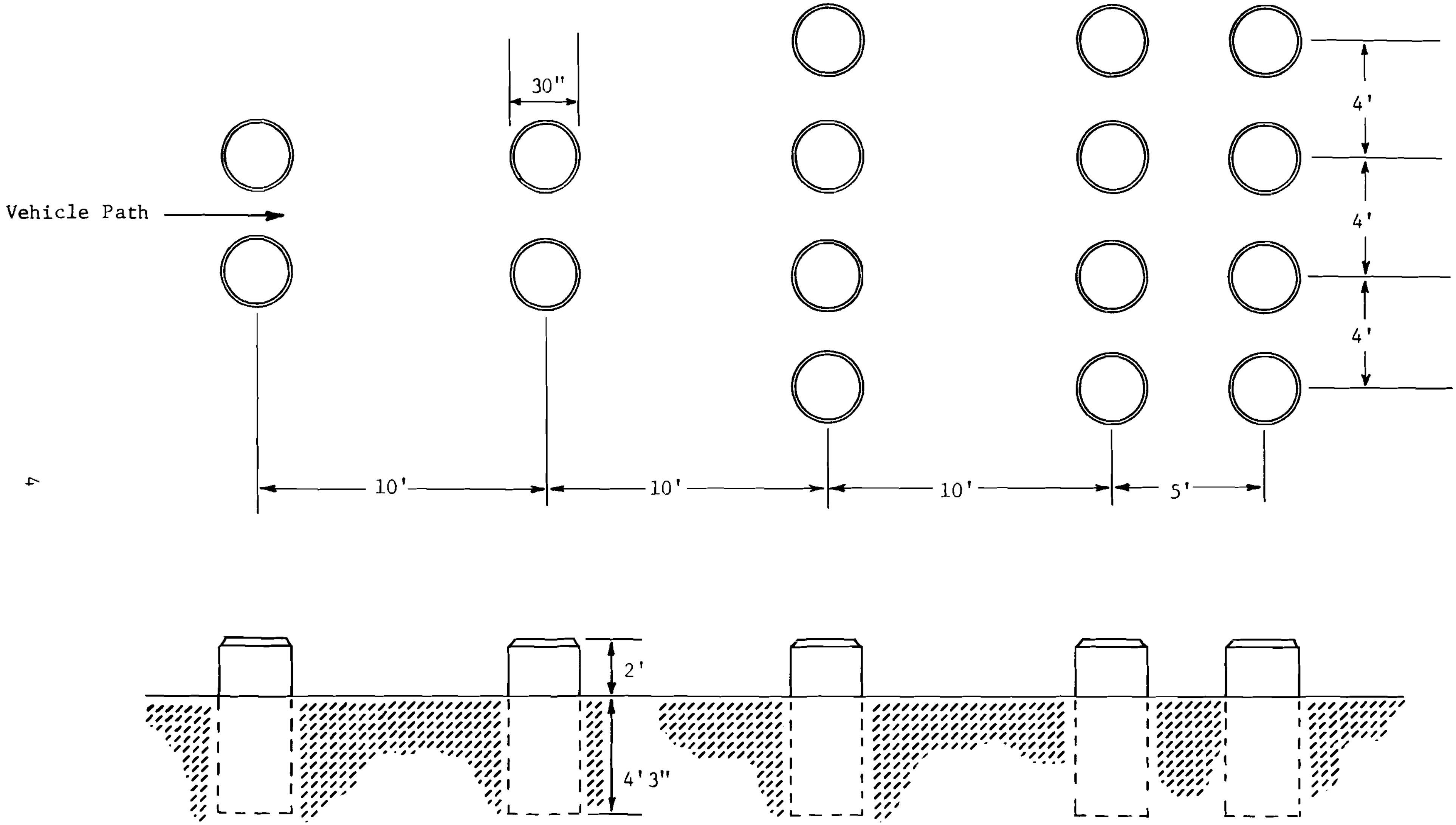

FIGURE 1, CONFIGURATION OF REINFORCED CONCRETE PIPE CRASH CUSHION

DESIGN CONSIDERATIONS

Results of pendulum tests conducted on individual pipes at SwRI are presented in Table 2. The extrapolation of the pendulum test data to a hypothetical vehicle collision was viewed with extreme caution since it was felt that the failure mechanism of a pipe, when subjected to a rigid pendulum impact, would be significantly different from the failure mechanism of the same pipe when impacted by the deformable front end of an automobile. For example, the accelerometer traces which were developed by pendulum tests showed the main pendulum impact deceleration pulse to be very high, with a duration of only 3 to 5 msec. The energy spent in fracturing the pipe was therefore very low and probably not indicative of the energy that would be expended by a vehicle. If the peak force from the pendulum data is used to calculate energy loss in a vehicle crash test, a rather high value is obtained. This is explained in more detail in a later section. For this reason, the use of pendulum data was considered somewhat questionable for the prediction of energy losses during full-scale crash tests.

Lacking a reliable prediction method, the decision was made to conduct a full-scale crash test on a reinforced concrete sewer pipe crash cushion, since it seemed apparent that this pipe would give the highest values of fracture energy. By starting with the highest value, it was assumed that some interpolation could be made in predicting the fracture characteristics of the smaller pipes.

TABLE 2

PENDULUM TEST RESULTS

(After Michie and Bronstad[1])

Test	Impact Velocity (V_I, fps)	Pulse Duration (t, msec)	Fracture Energy (KE, ft-kips)	Velocity Change (ΔV, fps)	Peak Force (kips)
1 Transite	29.3 (20.0 mph)	2.8	1.64	0.44	22.6
2 Transite	29.8 (20.4 mph)	4.2	3.78	0.91	40.7
3 Vitrified Clay	28.1 (19.2 mph)	2.5	5.35	1.34	70.6
4 Concrete	28.4 (19.4 mph)	2.5	5.50	1.39	79.5
5 Concrete	28.6 (19.6 mph)	3.2	6.72	1.71	78.5
6 Reinf. Concrete	29.0 (19.8 mph)	3.8	8.58	2.16	82.8

Pendulum Weight = 2300 lbs

BARRIER DESCRIPTION

Sixteen reinforced concrete sewer pipes were arranged in five rows (3 rows, 4 pipes wide; and 2 rows, 2 pipes wide) as shown in Figure 1. The first 4 rows were 10 ft apart (center to center). The last row was only 5 ft behind the row preceding it. The pipes were spaced 4 ft apart (center to center) laterally. These reinforced concrete pipes had an outside diameter of 30 in. and a length of 75 in. The reinforcement was 3 x 8-6/8 welded wire fabric. The 8-ga. wires were longitudinal, and the 6-ga. wires were circumferential. The pipes were embedded 4 ft 3 in. in the soil and the interior of the pipes was filled with soil to ground level. Details of a single pipe are shown in Figure 2.

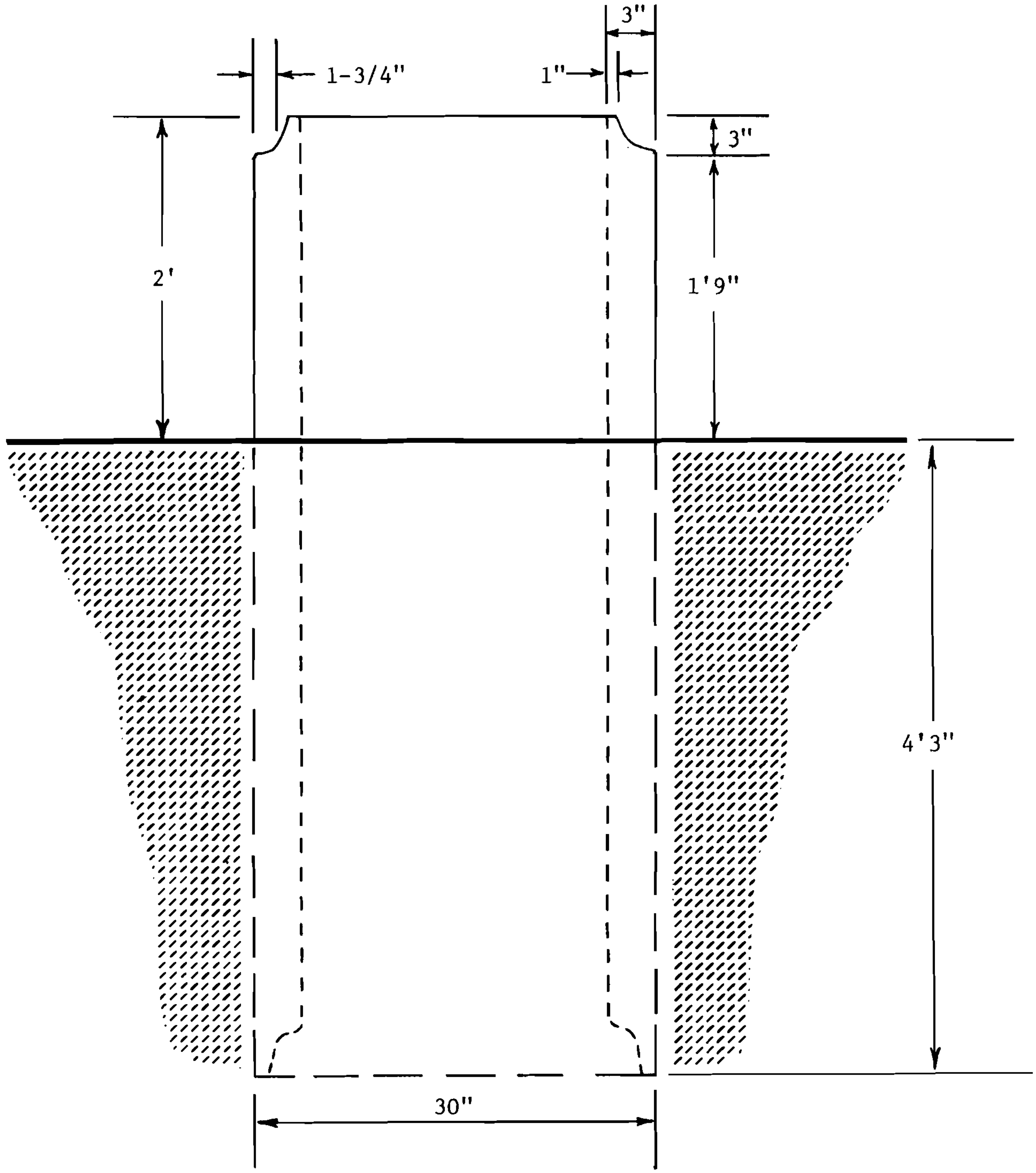

FIGURE 2, DETAILS OF ONE REINFORCED CONCRETE PIPE

INSTRUMENTATION

For this test, two strain-gage-type accelerometers were mounted on the frame of the vehicle, one on the left frame member and one on the right. Both accelerometers measured decelerations along the vehicle's longitudinal axis, i.e. along the path of the vehicle. A tri-axial electromechanical acceleration measuring device (Impact-O-Graph) was located on the right rear floorboard of the vehicle. This device is used as a secondary source of acceleration information.

An Alderson anthropometric dummy, weighing 160 lb, was placed on the driver's side of the vehicle. A lap belt was fastened across the dummy's pelvic region. A strain-gage load cell was connected to the lap belt to measure the force on the lap belt during impact.

The signals from the two accelerometers and the load cell were transmitted by telemetry to a ground station where they were recorded on magnetic tape. These data were then passed through an 80 Hz low-pass filter to reduce the effects of "ringing", and then displayed on Visicorder paper. The Impact-O-Graph records accelerations with a stylus on its own roll of chart paper, and is independent of the other electronic instrumentation.

Two high-speed cameras located perpendicular to the vehicle path were used to record the crash event. Both high-speed films had timing lights so that elapsed time at any point could be calculated. A stadia board marked in 3 in. increments on the right side of the vehicle was used in determining distance traveled. These distances were measured on a Vanguard Motion Analyzer. Initial speed was then computed from the time-displacement data obtained.

TEST DESCRIPTION

A 3950 lb Chevrolet impacted the system head-on at a speed of 40.5 mph. After shattering the two pipes in the first row, the vehicle ramped, became airborne, and finally came to rest on top of the third row of pipes (see Figure 3). The first row of pipes was completely shattered and the soil was disturbed when the pipes began to tilt in the ground (see Figure 4), but the rest of the system remained intact and sustained little damage. Average longitudinal deceleration from the film was 9.2 g's over 4.3 ft of travel and 0.105 sec (accelerometer traces showed no significant longitudinal forces on the vehicle after this time). Although vertical accelerations were obviously significant, they were not determined. Vehicle damage was moderate, with a front-end deformation of 1.3 ft.

A summary of the pertinent data obtained is presented in Table 3. Time-displacement data from the high-speed films are given in Table 4, and reproductions of the accelerometer force traces are shown in Figure 6.

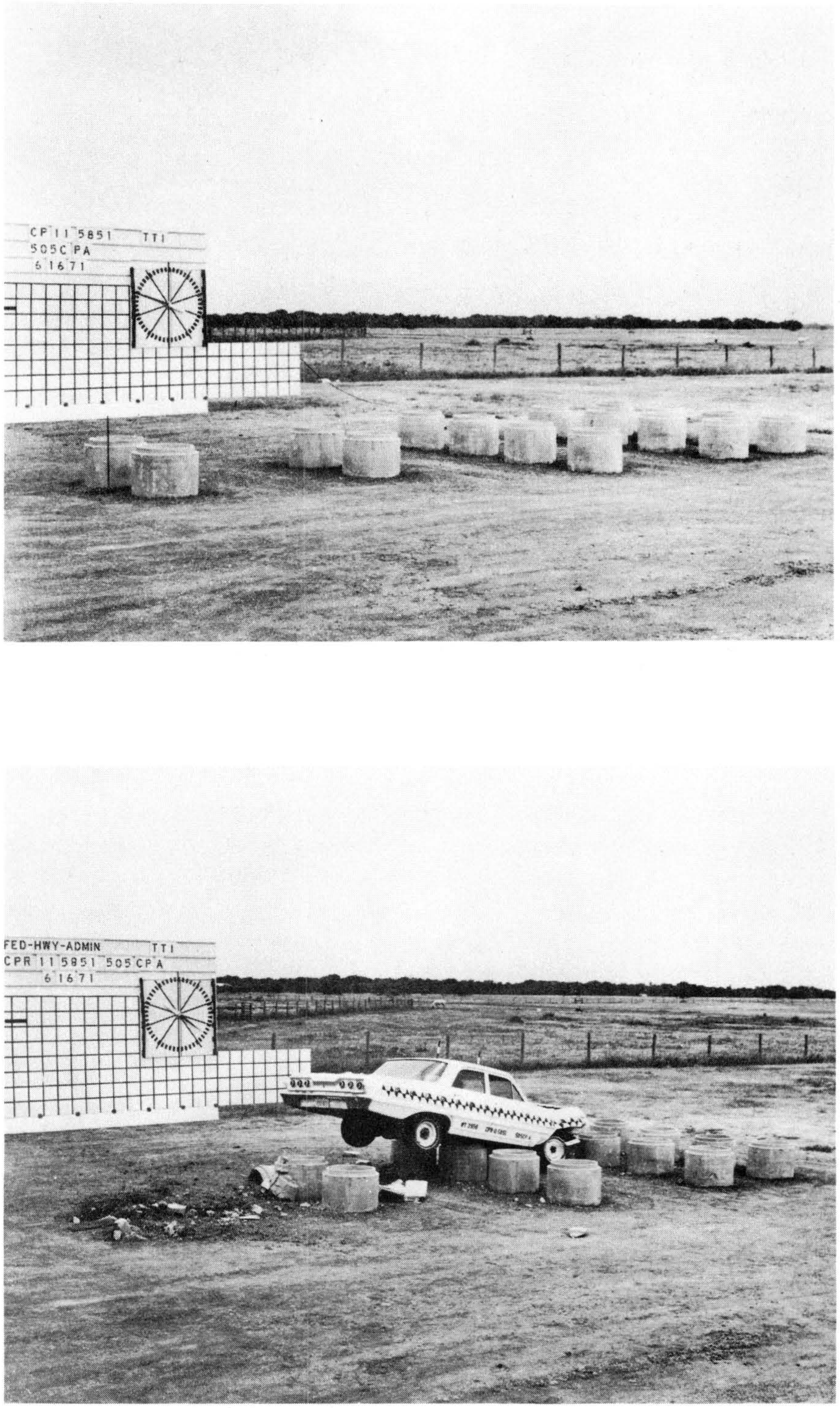

FIGURE 3, BARRIER BEFORE AND AFTER TEST 505 CP-A.

FIGURE 4, CONCRETE PIPE BEFORE AND AFTER TEST 505 CP-A.

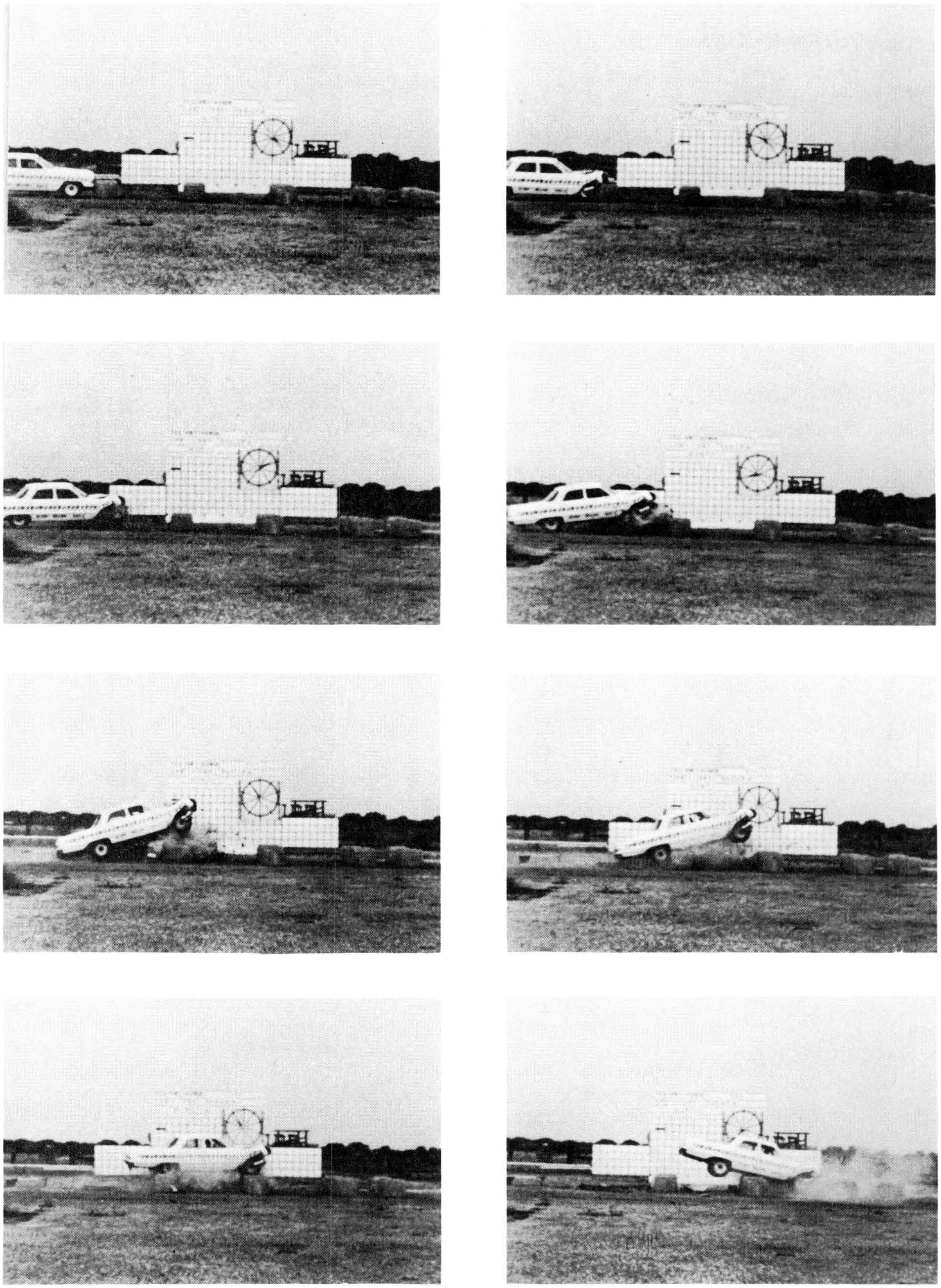

FIGURE 5, SEQUENTIAL PHOTOGRAPHS OF TEST 505 CP-A.
(View Perpendicular To Barrier)

TABLE 3

SUMMARY OF DATA

Test 505 CP-A

VEHICLE	
Year	1963
Make	Chevrolet
Weight, lb	3950
FILM DATA	
Initial Speed, fps	59.4
mph	40.5
Final Speed,* fps	31.7
mph	21.6
Distance traveled,* ft	4.3
Average Deceleration, g's $(V_i^2 - V_f^2) / 2gS$	9.2
Duration,* sec	0.104
Initial Kinetic Energy, Kip-ft	216.5
Final Kinetic Energy, Kip-ft	61.6
ACCELEROMETER DATA	
Maximum Deceleration, g's	20.3**
Average Deceleration, g's	6.8**
Time, sec	0.104
OTHER DATA	
Residual Front Deformation, ft	1.3

*Taken when accelerometer pulse goes back to zero.
**Average of right and left frame members.

TABLE 4

HIGH-SPEED FILM DATA

Test 505 CP-A

Time (msec)		Displacement (ft)	
-42		-2.48	V_i = 59.4 fps (from -2.48 to 0)
-31		-1.86	
-21		-1.30	
-10		-0.68	
0	Impact	0	
21		0.96	
42		2.02	
63		2.85	
84		3.57	
104		4.24	V_f = 31.7 fps (from 4.24 to 6.89)
125		4.95	
146		5.63	
167		6.18	
188		6.89	
208		7.52	
229		8.15	
250		8.72	
271		9.26	

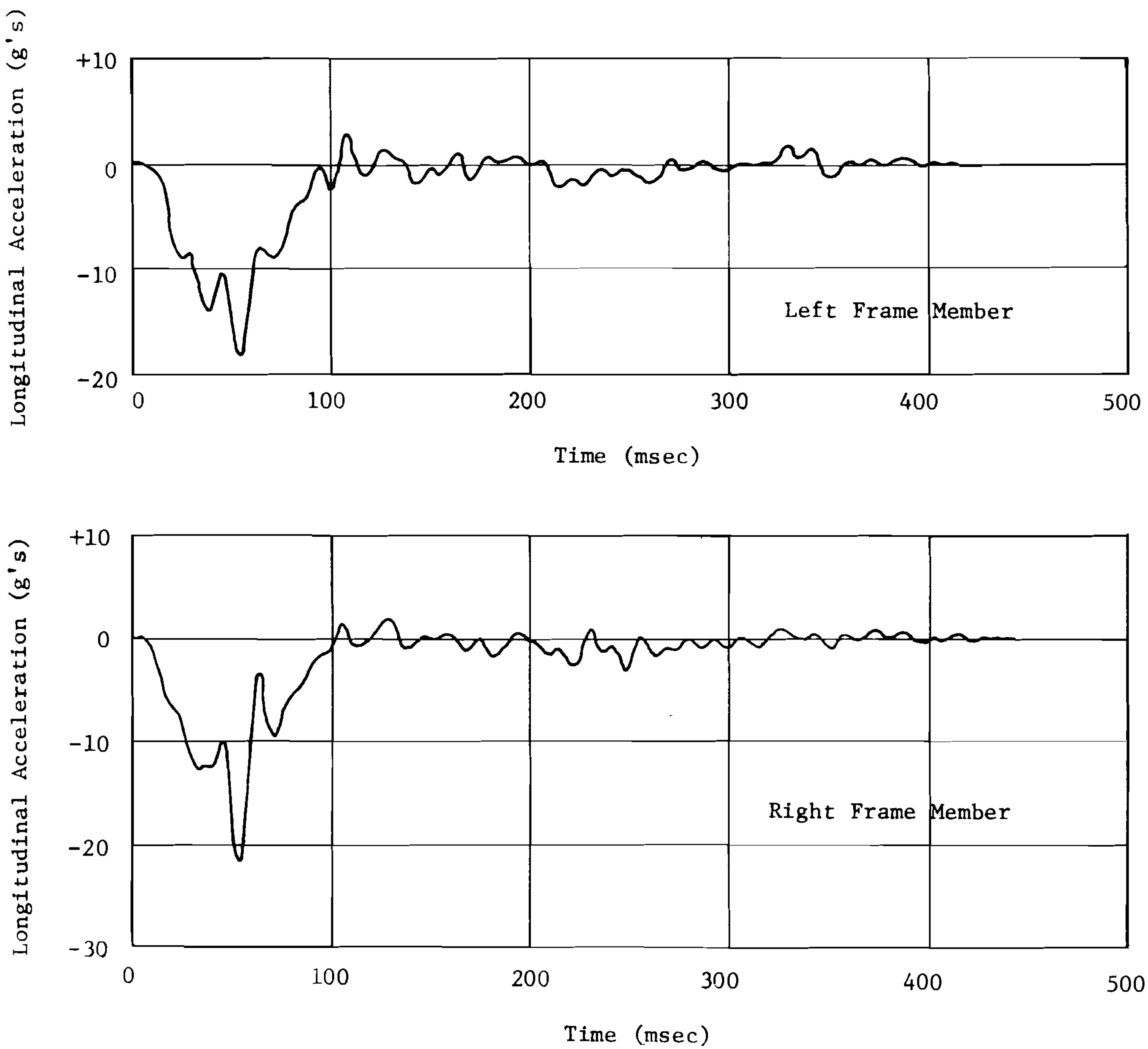

FIGURE 6, ACCELEROMETER DATA, TEST 505 CP-A.

DISCUSSION

As discussed previously, the energy losses during the pendulum tests were much lower than those losses expected in a vehicle crash test. In an effort to gain some insight from the pendulum tests, it was estimated that the impact force during a vehicle collision would vary in direct proportion to the amount of vehicle front end crush, finally reaching the maximum force observed in the pendulum test. The slope of the unit force or acceleration versus crush distance graph is defined as the crushing coefficient. Edwards, et al[2] and Emori[3] have shown that the crushing coefficient of the front end of a vehicle varies from 9 g's/ft* to 12.5 g's/ft**. A crushing coefficient of 10 g's/ft, which is within the above range, was the assumption used in the following computations.† If the weight of an impacting vehicle is 4000 lb, then the crushing coefficient in kips/ft is:

$$10 \text{ g's/ft} \times 4000 \text{ lb} = 40{,}000 \text{ lb/ft} = 40 \text{ kips/ft.}$$

If the pipe fractured under the same maximum force in a vehicle test as it did in a pendulum test (approximately 80 kips), it would be necessary to crush the front end of a 4000 lb vehicle 2 ft:

$$\text{Crushing Distance} = \frac{80 \text{ kips}}{40 \text{ kips/ft}} = 2 \text{ ft.}$$

The total energy expended in crushing the vehicle front end under these assumptions would be the area under the force versus crushing distance curve which is shown in Figure 7. The area under this curve is:

$$E = \frac{F_m \times d}{2} = \frac{80 \text{ kips} \times 2 \text{ ft}}{2} = 80 \text{ kip-ft.}$$

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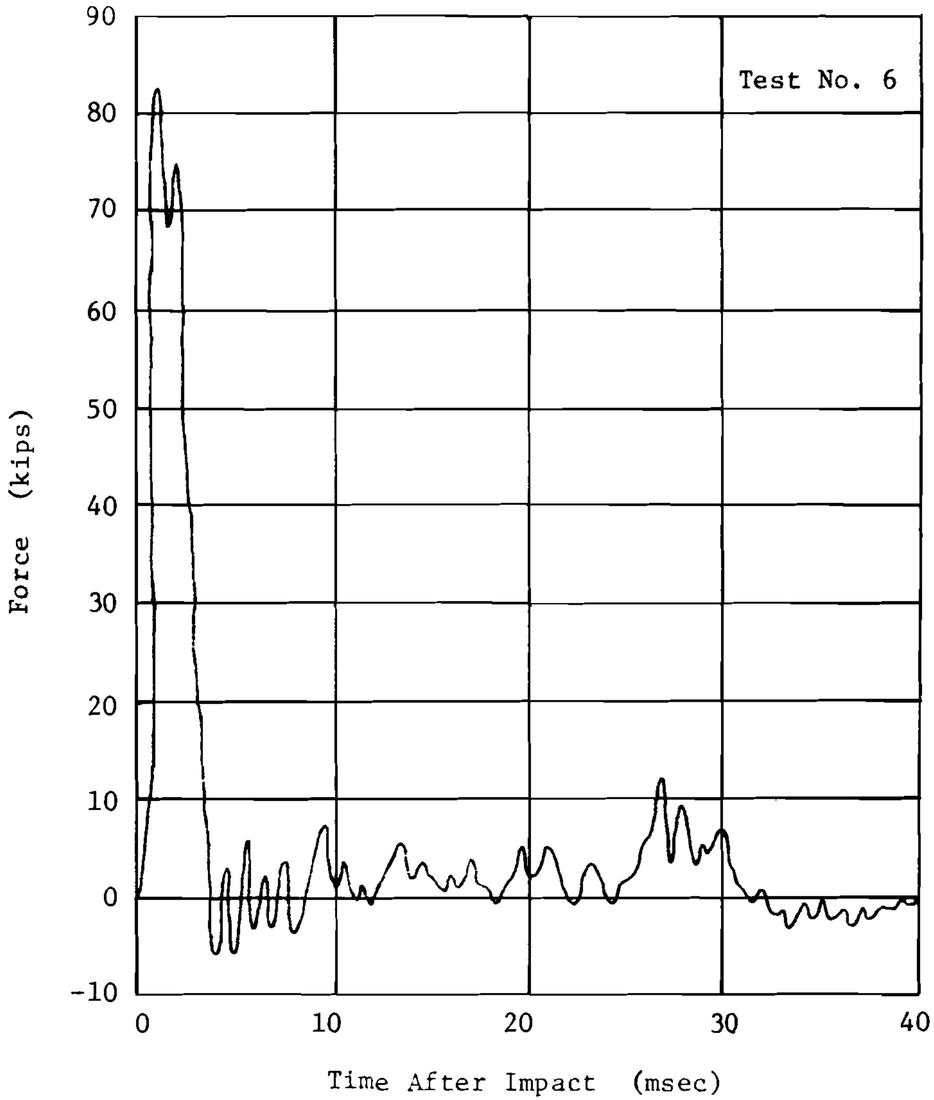
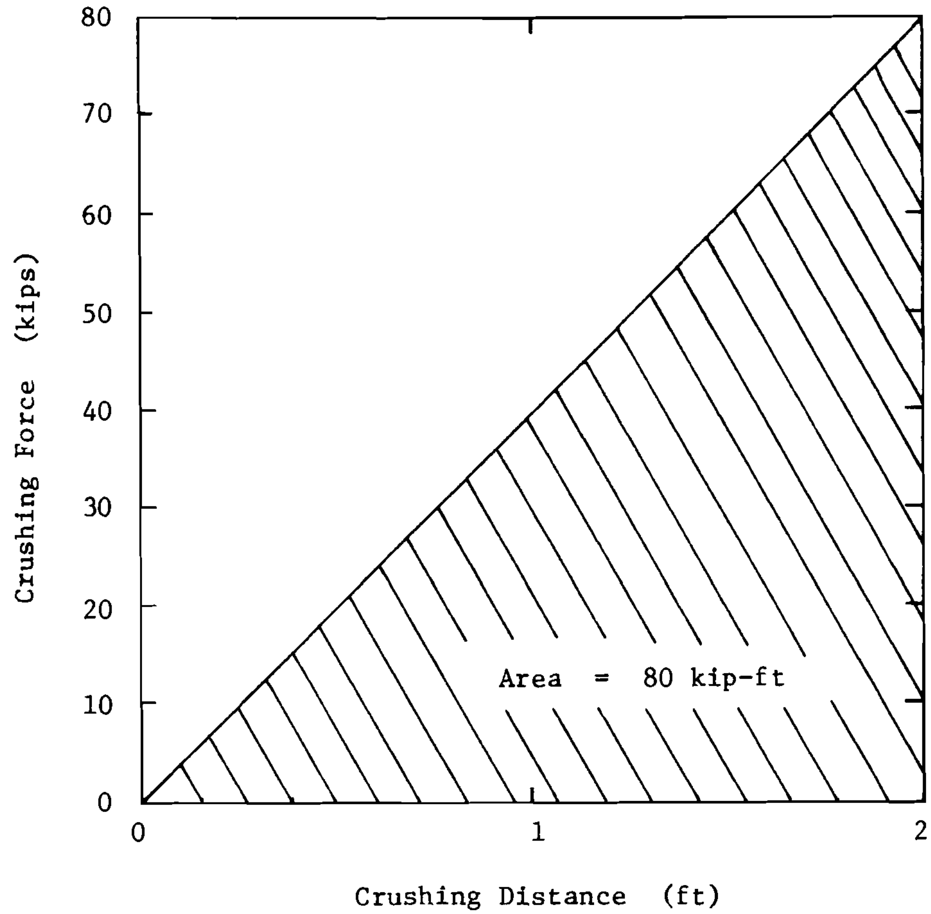
*Based on impacts with rigid poles.

**Based on impacts with flat rigid walls.

†Another reference which was pointed out to the authors at the later date gave a crushing coefficient of 5 g's/ft determined by frontal collision with a 14.5 in. diameter pole. This reference is: McHenry, Ray, et al., Cornell Aeronautical Laboratory, Inc., PB 175 919, pp. 62-68.



PENDULUM DATA FROM TEST #6
(After Michie and Bronstad[1])



ESTIMATED ENERGY EXPENDED
IN CRUSHING OF VEHICLE FRONT

FIGURE 7

Therefore, during an impact with the first two pipes, it was estimated that the energy lost would be 160 kip-ft.

The following computations show that our original estimate of energy loss due to front end crush was somewhat high. Since the residual front end crush from Table 3 is 1.3 ft, the dynamic crush was estimated to be 1.5 ft. From the above, the maximum force due to each pipe in the first row is:

$$F_m = \text{slope x crush distance} = 40 \text{ kips/ft x } 1.5 \text{ ft} = 60 \text{ kips.}$$

The total vehicle crushing energy loss is:

$$E = \frac{F_m \text{ x } d}{2} = \frac{60 \text{ kips x } 1.5 \text{ ft}}{2} = 45 \text{ kip-ft.}$$

Therefore, for two pipes, the vehicle is expected to absorb 90 kip-ft. The actual energy loss after 4.3 ft of vehicle travel was 155 kip-ft. This leaves 65 kip-ft of energy to be accounted for--in fragmentation and acceleration of pipes, deformation of the soil, abrasion of pipe fragments against the under side of the vehicle, ramping of the vehicle, and inaccuracy in estimating energy losses due to vehicle front end crush.

Another consideration which was felt to be of great significance in the design of a cushion is the fact that the crushing characteristic of the front end of the vehicle does not remain constant, but should increase after each row of pipe is encountered. As the crushing coefficient increases, the pulse duration for each row of pipe should decrease, resulting in a decrease in the energy lost during each new pipe impact. Since severe ramping occurred during impact with the first row of pipes, there was no indication of the magnitude of the assumed change in the crushing characteristic of the vehicle front end or of the decrease in amount of energy lost during subsequent impacts.

CONCLUSION

Since the reinforced concrete pipe tested gave a maximum deceleration of approximately 20 g's, and an average deceleration of approximately 9 g's, it would be desirable to reduce these deceleration levels in any subsequent tests. A better selection of pipe might be the transite 20 in. O.D. pipe which was used in Test #2 in the report by Michie and Bronstad.[1] This should reduce the deceleration levels to approximately 5 g's average and 10 g's maximum. By reducing the force level developed by each row of pipe, the ramping tendency should also be reduced. Whether or not this ramping tendency can be reduced to a level which would make this type of cushion feasible is a matter of speculation.

It was shown that concrete pipe crash cushions have the capability of absorbing enough kinetic energy to stop a vehicle in a reasonable distance, and thus should be considered a definite possibility for development.

REFERENCES

1. Michie, J. D. and Bronstad, M. E., "Impact Tests Of Nonmetallic Pipe Sections," Report prepared for U.S. Department of Transportation, Federal Highway Administration on DOT Order No. 1-1-1360, April 1971.

2. Edwards, Thomas C., Martinez, J. E., McFarland, William F., and Ross, Hayes E., "Development of Design Criteria For Safer Luminaire Supports," NCHRP Report No. 77, Highway Research Board, 1969.

3. Emori, Richard I., "Analytical Approach to Automobile Collisions," SAE Paper 680016, Engineering Congress, Detroit, January 1968.