NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-795

Modular Disposable Can (MODCAN) Crash Cushion: A Concept Investigation

JET PROPULSION LABORATORY
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PREFACE

The work described in this report was performed by the Applied Mechanics Division of the Jet Propulsion Laboratory.

ACKNOWLEDGMENT

The authors are particularly grateful to C. Larson and R. Taylor for their cooperation in supplying certain empty beverage cans used in conducting the experiments.

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ABSTRACT

This paper presents details concerning a conceptual design investigation of an improved highway crash cushion system. The system is referred to as a modular disposable can (MODCAN) crash cushion. It is composed of a modular arrangement of disposable metal beverage cans configured to serve as an effective highway impact attenuation system. Experimental data, design considerations, and engineering calculations supporting the design development are presented. Design performance is compared to that of a conventional steel drum system. It is shown that the MODCAN concept offers the potential for smoother and safer occupant deceleration for a larger class of vehicle impact weights than the steel drum device.

I. INTRODUCTION

In the early 1960's the first serious investigations were conducted aimed at developing safe and effective crash barrier systems for application on our nation's highways. The function of these systems was to provide impact protection at locations of rigid highway obstacles such as roadway gores, tunnel entrances and bridge and freeway abutments. Since that time, considerable progress has been made in developing several such cushions (Ref. 1), and many are now installed on our highways.

Although these systems are considered by many to be effective from an engineering standpoint, the question remains as to whether other crash cushion designs might provide better performance at comparable or reduced system costs. This paper describes the results of an investigation which indicates that such an improved device may be conveniently developed. The device is referred to as a modular disposable can (MODCAN) crash cushion and consists of a modular arrangement of disposable metal beverage cans configured to serve as an effective highway impact attenuation system.

The MODCAN concept was developed as part of an in-house research program aimed at investigating various types of crushable elements which could be used in crash barrier systems. Pertinent details of this program as well as a description of the concept are presented in this paper. It is shown that the MODCAN concept offers the potential for smoother and safer impact protection (lower average g level) for a larger class of vehicles (heavier impact weights) than the presently used steel barrel crash cushion system. In addition, there may be cost advantages in favor of the MODCAN concept, but these will require further investigation to fully substantiate.

II. EXPERIMENTAL INVESTIGATION

A series of static tests was performed on several different types of crushable elements which were considered as candidate elements for a highway crash cushion system. The purpose of these tests was to gather fundamental baseline data and to compare the energy-dissipating characteristics of the various candidates to each other and to the standard steel drum (Ref. 2) crushable unit. The test data are summarized in Table 1.

Table 1. Crushable element baseline data (lateral crushing mode)

Category	Item	Material	Energy-dissipating characteristics				Cost factors	
			E_D, in./lb	σ_{CR}, lb/in.^{2}	$\bar{E}_D$, in.-lb/in.^{3}	ϵ, %	C_U, $ est.	E_D, in.-lb/¢
Drums (Refs. 2 and 3)	55-gal drum	Steel	108,000	8	9	71	10.00	108
Spheres	Sphere, 2.5" diam x 0.035" wall	Glass	8	1	1	98	0.50	0
	Lightbulb, 2" diam x 0.020" wall	Glass	4	1	1	98	0.30	0
	Sphere, 4" diam x 0.040" wall	Polypropylene	590	15	18	80	0.80	7
	Sphere, 4" diam x 0.040" wall	Polyethylene	720	18	22	80	1.00	7
	Sphere, 8" diam x 0.065" wall	Steel	77,500	25	290	81	10.00	78
	Sphere, 4" diam x 0.040" wall	Aluminum	4850	97	135	83	5.00	10
	Sphere, 8" diam x 0.025" wall	Aluminum	6500	20	25	79	5.00	13
	Sphere, 13.5" diam x 0.065" wall	Aluminum	83,000	50	65	86	10.00	83
Disposable containers	12-oz beverage can	Aluminum	560	24	23	76	0.03	190
	12-oz beverage can (axial)	Aluminum	340	8	14	72	0.03	110
	16-oz beverage can	Aluminum	530	14	18	83	0.03	180
	12-oz beverage can	Steel	980	35	43	83	0.03	330
	12-oz beverage can (axial)	Steel	1340	37	53	80	0.03	450
	30-lb refrig can	Steel	67,000	90	[illegible]	83	0.50	1340
	8-oz beverage bottle	Glass	12	1	1	95	0.06	1
Other	4" diam cylinder float	Copper	460	10	46	82	4.00	1
	3" diam muffin cup	Aluminum	140	7	5	92	0.03	47
	2" domed cylinder	Steel	9200	960	1010	66	0.60	150
	4 x 6 x 4" deep block; 1 lb/ft^3	Styrofoam	1400	19	14	77	0.056	250

E_D = usable energy dissipated.

σ_{CR} = average crushing stress (avg. crushing force/max. cross-sectional area).

$\bar{E}_D$ = energy dissipated per unit volume.

ϵ = stroke efficiency.

C_U = estimated unit cost.

E_D^* = energy dissipated per penny.

As shown in Table 1, the technical parameters used in determining the energy-dissipating characteristics were the energy dissipated in crushing the elements (E_D), the associated average crushing stress (σ_{CR}), the energy-dissipation density ($\overline{E}_D$), and the element stroke efficiency (ϵ), which is the ratio of the "bottoming out" stroke of the element to its original length. In addition, rough estimates were made of element costs (C_U), and these are given under the cost factors column of Table 1. Perhaps the most interesting cost factor of all is the final cost column, which presents an estimate of the amount of crushable energy which can be dissipated for a penny ($E_D{}^*$). This factor is based solely on estimated element costs and does not include the other important considerations of system fabrication, installation and maintenance.

As can be seen in Table 1, three categories of element types were investigated Heavy emphasis was placed initially on spherical units since these were felt to be promising candidates for which energy-dissipating characteristic data were totally lacking. During the course of these experiments, however, empty metal beverage cans were also tested. The two types of beverage cans investigated were aluminum beer cans and steel soda pop cans. A visual inspection determined that they were free of structural damage. Their test performance was determined and the results are presented in the "disposable containers" category of Table 1. In addition, other convenient energy-dissipating elements were tested and their performance is given in the final experimental category.

The results obtained from these baseline experiments showed that empty metal beverage cans were superior to the spheres, especially glass spheres, which showed inadequate crushing characteristics. Therefore, emphasis was placed on empty metal beverage cans as energy dissipating elements of a crash cushion system.

The data obtained from the baseline tests (Table 1) indicated that both from a performance and cost point of view the metal disposable beverage cans provided an advantage over the standard 55-gal drum attenuator. In addition, preliminary calculations made at this point indicated that there was a packaging advantage in favor of an equivalent number of beverage cans necessary to dissipate the same total crushable energy as the 55-gal drum. Specifically, it was determined that the same amount of energy dissipated by crushing a drum could also be dissipated by crushing a beverage can arrangement in about 1/3 the volume required for the drum. This was felt to be encouraging as it increased the number of design options available in pursuing the MODCAN design concept.

Experimental activity then concentrated on testing a stacked array of beverage cans to determine performance knockdown factors to be expected when scaling from a single to a multiple element arrangement. The crushing characteristics of such an array would thus be more representative of the field application. The test setups depicting the initial and final crushed configurations of the cans are shown in Figs. 1 and 2, respectively. Spherical element arrays were also tested in this manner, and the initial and final crushed configurations are shown in Figs. 3 and 4, respectively. The results of the static tests are given in Table 2, with the scaling factors derived from the ratio of the multiple to single element data given in Table 3. The data of Table 2 were used in concept design development to be discussed later.

An unsuccessful attempt was made to perform dynamic tests on certain of the arrays at representative vehicle impact velocities using an existing "slingshot" test facility. Checkout runs made on this device using styrofoam as the energy-absorbing medium (Fig. 5) revealed that alignment problems existed with the sabot. Resolution of these difficulties was beyond the scope of this investigation; however, the facility does present an attractive means of conducting such tests in the future.

III. SYSTEM STUDIES

A. DESIGN CRITERIA AND CONSIDERATIONS

The MODCAN concept was developed to satisfy, at a minimum, the design criteria for highway crash cushions as specified in Ref. 4. These criteria are given as follows:

Vehicle weight range	2000 to 4500 lb
Vehicle speed	60 mph
Impact angle	Up to 25° as measured from the direction of the roadway

Average permissible vehicle deceleration	12 g maximum while preventing actual impacting or penetration of the roadside hazard
Maximum occupant deceleration onset rate	500 g/sec

The criteria are intended to provide a survivable environment for safety-belted occupants of vehicles during crash barrier impacts.

Although these criteria are quite specific regarding mechanical features of the design, other considerations must also be given to the design of crash cushion systems. These considerations, including the criteria given above, are summarized in Fig. 6. As shown in Fig. 6, crash cushion system design must also consider cost, environmental and social factors. These factors are recognized as important design considerations (Refs. 1, 3) and have been included in the MODCAN design development.

B. APPROVED BARRIER SYSTEMS

In a recent publication (Ref. 3), the Federal Highway Administration (FHWA) has approved five specific crash barrier systems for highway application. These systems are shown in Fig. 7. The steel drum and Hi-Dri Cell sandwich systems are examples of attenuation devices which dissipate energy mainly by barrier crushing. The others fall into the class of crash cushions which dissipate energy largely by momentum transfer.

It is also interesting to note the vehicle redirectional capability of the approved systems. All units, with the exception of the Hi-Dri Cell cluster and Fitch Inertial Barrier System, are designed with side panel structures to redirect impacting vehicles back into the traffic flow stream. The Fitch system is designed to "capture" vehicles which impact it, whether head on or in side angle impacts. Only one, the Hi-Dri Cell cluster, is designed to do a little of both.

The MODCAN concept has been designed as a crushable barrier system intended to "capture" vehicles during impact. Thus, by its physical nature, it is analogous to the steel drum design without the vehicle redirectional limitation.

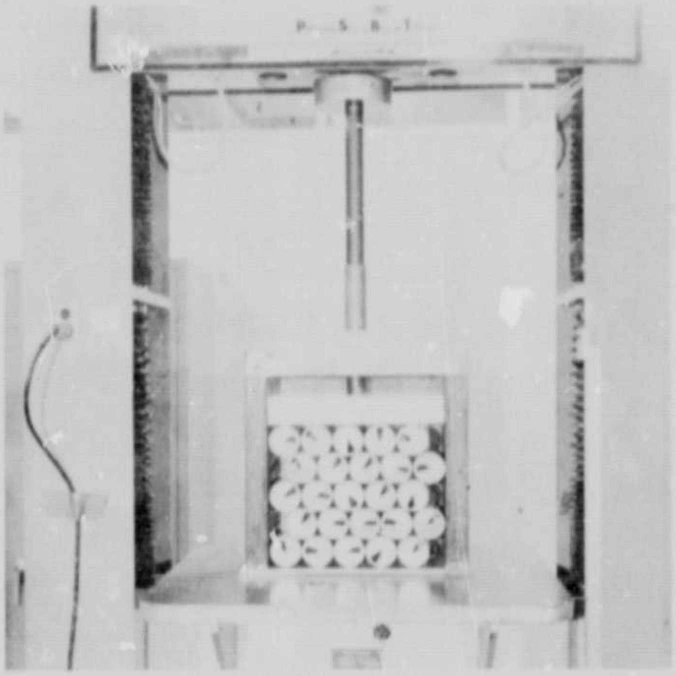


Fig. 1. Test setup for crushing of stacked beverage can array

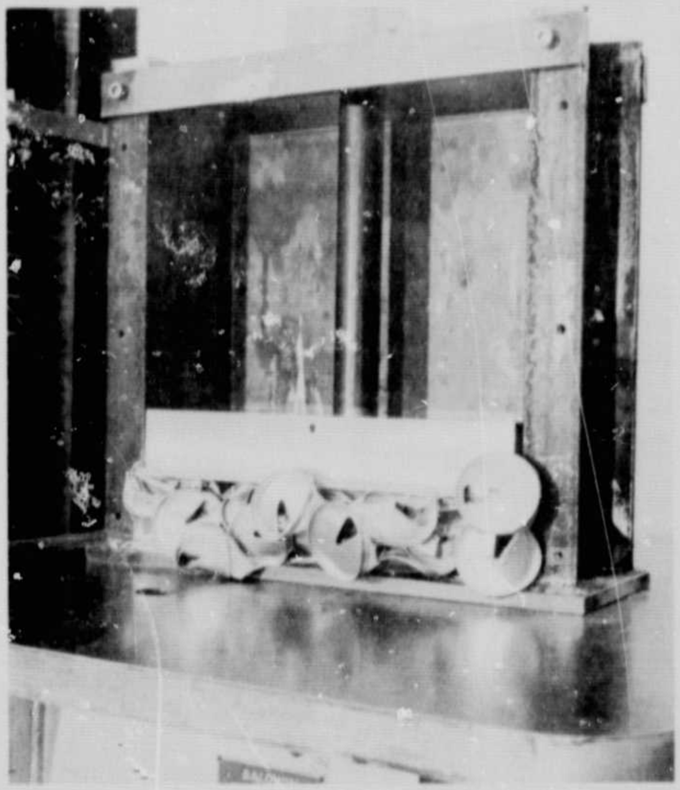


Fig. 2. Final crushed configuration of stacked beverage can array

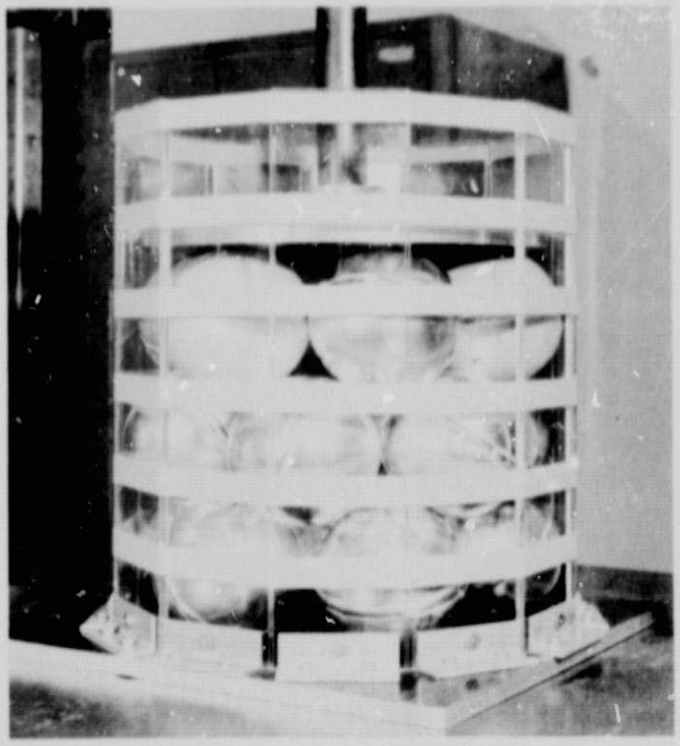


Fig. 3. Test setup for crushing spherical element array

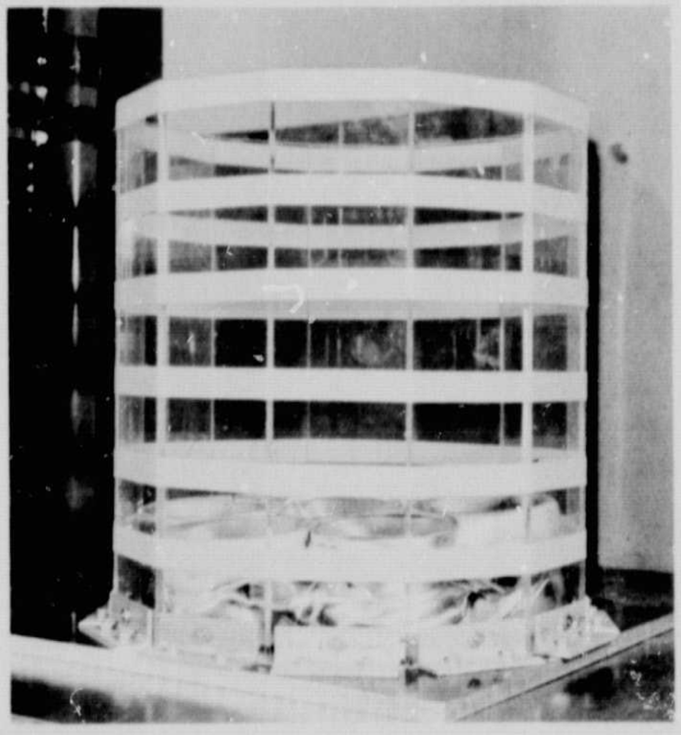


Fig. 4. Final crushed configuration of spherical element array

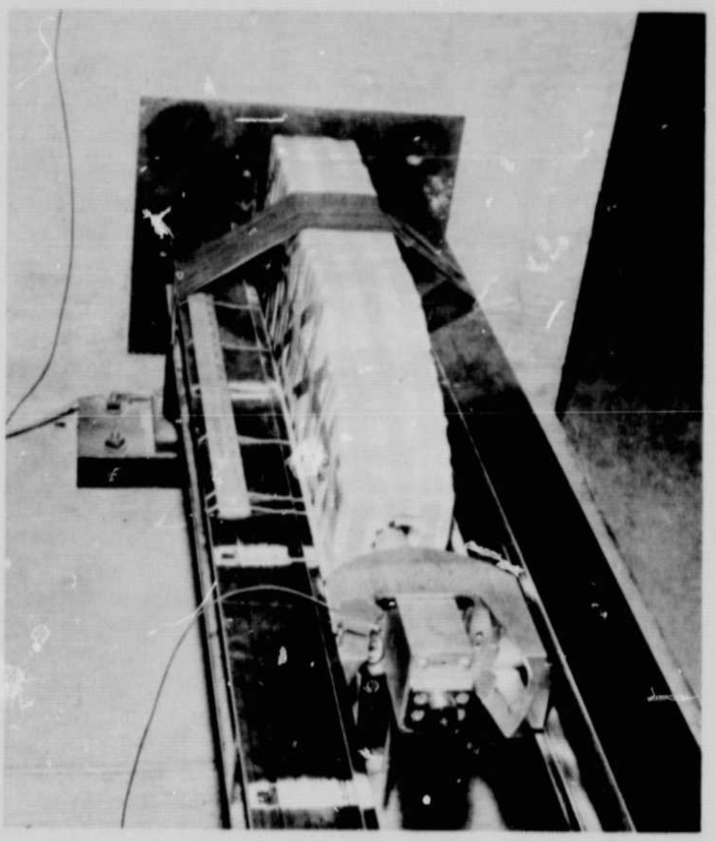
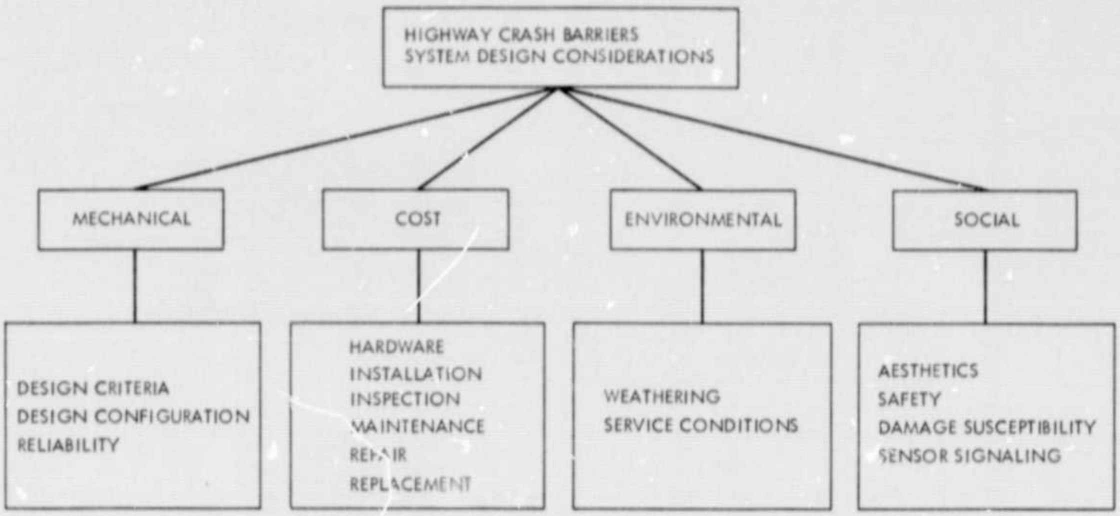


Fig. 5. Impact test facility



MECHANICAL

DESIGN CRITERIA: 2000 lb $\leqq$ VEHICLE WEIGHT $\leqq$ 4500 lb SPEED = 60 mph; IMPACT $\leqq$ 25° MAX g $\leqq$ 12; ONSET RATE $\leqq$ 500 g/sec.

DESIGN CONFIGURATION: SIMPLE DESIGN CONCEPT; MINIMUM OF PARTS; FLEXIBILITY TO ADAPT TO FIELD CONDITIONS; SMOOTH STOPPING.

RELIABILITY: REPEATABLE PERFORMANCE DURING IMPACT.

COST (MINIMUM REQUIRED)

HARDWARE: ENERGY DISSIPATING ELEMENTS + SUPPORTING STRUCTURE.

INSTALLATION: MANPOWER REQUIRED TO INSTALL DEVICE + PARTS DELIVERY + SPECIAL TOOLING.

INSPECTION: MANPOWER REQUIRED TO INSPECT DEVICE.

MAINTENANCE: MANPOWER REQUIRED TO MAINTAIN DEVICE + PARTS.

REPAIR: MANPOWER REQUIRED TO REPAIR DEVICE + PARTS.

REPLACEMENT: DEVICE REPLACEMENT REQUIRED DUE TO LIMITED LIFETIME EXPECTANCE WITHOUT USAGE.

ENVIRONMENTAL

WEATHERING: NO DELETERIOUS EFFECT ON FUNCTION DUE TO ENVIRONMENTAL EXPOSURE INCLUDING BIOLOGICAL ATTACK.

SERVICE CONDITIONS: MUST OPERATE SATISFACTORILY UNDER EXTREME THERMAL AND MOISTURE EXPOSURE.

SOCIAL

AESTHETICS: DRIVER MUST FEEL CONFIDENT TO USE DEVICE; GOOD FIELD APPEARANCE; NO DRIVER DISTRACTION.

SAFETY: FREE FROM HAZARDS OF FIRE AND CHEMICAL CONTAMINANTS; NO DISLODGEMENT OF HAZARDOUS ELEMENTS ON ROADWAY; LOW RISK OF FATALITY OR HOSPITALIZING INJURY WHEN USED.

DAMAGE SUSCEPTIBILITY: TAMPERPROOF.

SENSOR SIGNALING: CRASH SENSOR(S) TO NOTIFY POLICE AND AMBULANCE PERSONNEL.

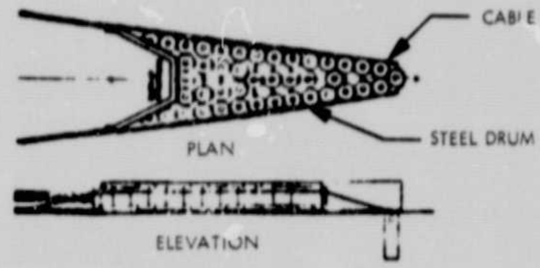
Fig. 6. Crash cushion design considerations

STEEL DRUMS

STEEL DRUMS WITH CABLE GUIDES AND SIDE PANELS.

SO-CALLED "TEXAS BARREL" SYSTEM.

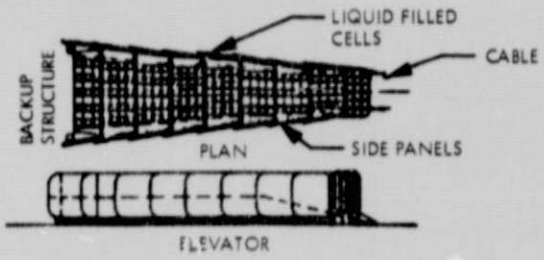
NON PROPRIETARY.



HI-DRO CELL SANDWICH

LIQUID-FILLED CELLS WITH CABLE GUIDES AND SIDE PANELS.

PROPRIETARY.

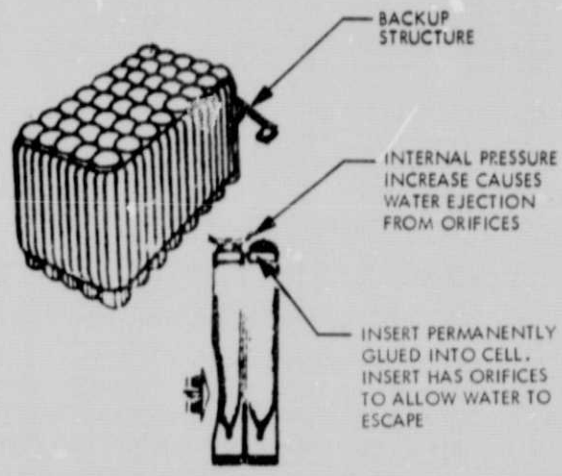


HI-DRO CELL CLUSTER

LIQUID-FILLED CELLS WITHOUT GUIDE CABLES OR SIDE PANELS.

LIMITED TO IMPACT SPEEDS OF 45 mph OR LESS.

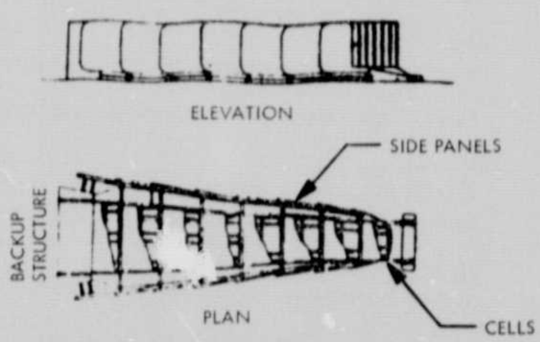
PROPRIETARY.



HI-DRI CELL SANDWICH

VERMICULITE CONCRETE CELLS WITH CABLE GUIDES AND SIDE PANELS.

PROPRIETARY.



FITCH INERTIAL BARRIER SYSTEM

FREESTANDING SAND-FILLED PLASTIC CONTAINERS.

PROPRIETARY.

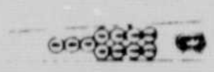


Fig. 7. FHWA - approved crash cushion systems

Table 2. Multiple element crushing data

Category	Item	Material	Energy-dissipating characteristics					Cost factors	
			E_D, in.-lb		σ_{CR}, lb/in.^{2}	E_D, in.-lb/in.^{3}	ϵ, %	C_U, $ est.	E_D, in-lb/¢
			Total	Unit					
Spheres	Top layer 6 Middle layer 7 Bottom layer 7 Total $\overline{20}$ Sphere, 4" diam x 0.40" wall	Polyethylene	12,180	610	12	18	75	16.00	7
	Top layer 6 Middle layer 7 Bottom layer 7 Total $\overline{20}$ Sphere, 4" diam x 0.40" wall	Aluminum	59,420	2970	72	83	62	100.00	6
	Top layer 5 Middle layer 5 Bottom layer 5 Total $\overline{15}$ Sphere, 8" diam x 0.025" wall	Aluminum	70,520	4700	37	18	67	75.00	9
Disposable containers	Top layer 5 2nd layer 4 3rd layer 5 4th layer 4 5th layer 5 Total $\overline{23}$ 12-oz beverage can	Steel	21,180	920	38	35	74	0.69	307
	Top layer 5 2nd layer 5 3rd layer 5 4th layer 5 5th layer 5 Total $\overline{25}$ 12-oz beverage can	Aluminum	10,930	440	20	18	77	0.75	146

Table 3. Scaling factors: ratio of multiple element to single element data

Category	Item	Material	Scaling factors E_D	σ_{CR}	$\bar{E}_D$	ϵ
RTOP concept	Top layer 6 Middle layer 7 Bottom layer 7 Total 20 sphere, 4" diam x 0.40" wall	Polyethylene	0.85	0.69	0.82	0.94
	Top layer 6 Middle layer 7 Bottom layer 7 Total 20 sphere, 4" diam x 0.040" wall	Aluminum	0.61	0.74	0.61	0.75
	Top layer 5 Middle layer 5 Bottom layer 5 Total 15 sphere, 8" diam x 0.025" wall	Aluminum	0.72	1.85	0.72	0.85
Waste materials	Top layer 5 2nd layer 5 3rd layer 5 4th layer 5 5th layer 5 Total 25 12-oz beverage can	Steel	0.94	1.09	0.81	0.89
	Top layer 5 2nd layer 5 3rd layer 5 4th layer 5 5th layer 5 Total 25 12-oz beverage can	Aluminum	0.78	0.85	0.72	1.00

C. MODCAN DESIGN CONCEPT

The MODCAN design concept is shown schematically in Fig. 8. It is composed of an array of rectangular prism-shaped modules interconnected by tension cross-ties to develop satisfactory transfer of the crushing load during vehicle impact. The layout and sizing of the modular array are based on preliminary design studies reported in the next section. In field application the device would be anchored to the roadway surface through a series of guidewires to aid in uniform crushing performance. The lower cable system and the upper tension cross ties will be designed to prevent gross transverse buckling during lateral impact.

The modules are composed of empty aluminum beverage cans arranged with the longitudinal axes of the cans parallel to each other and the highway surface.

D. MODCAN PRELIMINARY DESIGN

1. Module Development

For preliminary design purposes a rectangular-shaped module (Fig. 9) was developed with overall volume and configurational features similar to that of a steel drum. This approach was taken since it appeared to provide a reasonable means of physically handling the various elements and layers of the module and facilitated direct comparison of overall system performance of the MODCAN concept with that of the steel drum device. A comparison of the physical characteristics of the module and steel drum units is as follows:

	Height, in.	Cross section, in.	Volume, $in.^3$
Steel drum:	35.0	23.0 diam	14,500
Module:	35.5	19.5 x 17.0	11,000

The above configurational requirements of the module were based on a 7-layer, 46-can/layer configuration as shown in Fig. 9. Each vertical layer is composed of the same type of can although it is possible to stack layers of different types of cans. Each of the internal cans of a given layer are nested to be in 6-point contact with adjacent cans to provide maximum lateral stability during crushing. This nesting pattern gives rise to the layer packaging scheme as shown in Fig. 10.

The external surface of the development module is a metal hardware cloth mesh which is wrapped around the stacked 7-layer array and is cinched down with metal wraparound straps. As indicated by the rectangular-shaped modules in Fig. 8, the actual number of layers and cans in a field application module will depend on local site conditions.

2. Module Energy-Dissipating Capability

Using the data given in Tables 1, 2 and 3 the static energy-dissipating capacity of the preliminary design module was estimated. This estimate was developed for both steel and aluminum beverage can modules in both the longitudinal and transverse crushing directions. The results are summarized as follows:

Module type	Crush orientation	E_D, ft-lb	P_{CR}, lb
Aluminum can	Longitudinal	8,000	3,600
Aluminum can	Transverse	10,000	10,000
Steel can	Longitudinal	30,000	13,500
Steel can	Transverse	20,000	20,000

Based on these results the aluminum can module oriented with the cans parallel to the main direction of crush was chosen as the MODCAN preliminary design module configuration. The selection was made since a significant amount of crushable energy could be obtained at the lowest possible crushing force. This module characteristic is desirable in an attempt to arrest impacting vehicles at the lowest possible deceleration levels.

Through subsequent static testing of the full-scale module shown in Fig. 9, it was determined that the energy dissipated by longitudinally crushing the module was approximately 8400 ft-lb with an average crushing force of 4000 lb.

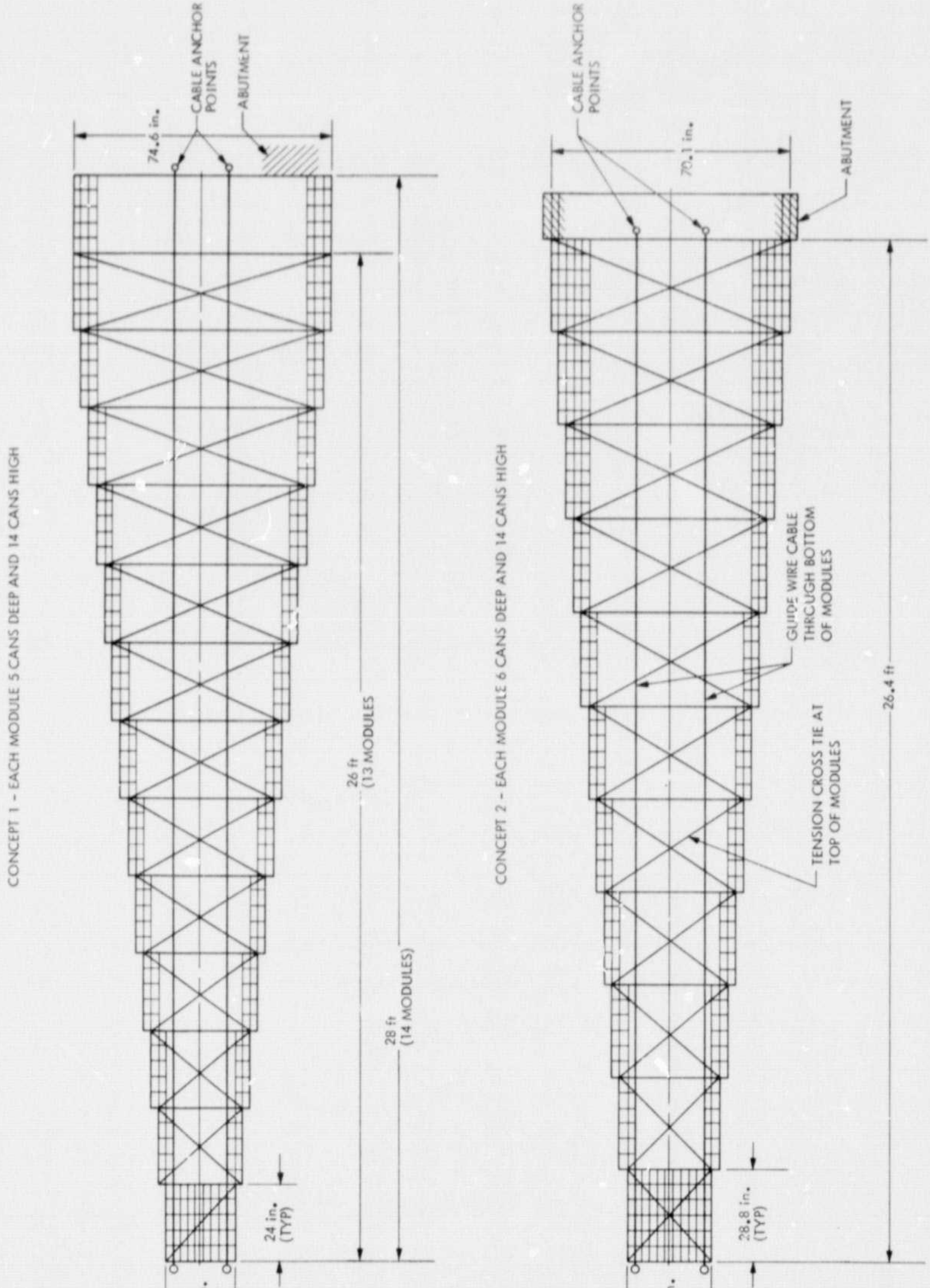


Fig. 8. MODCAN design concepts

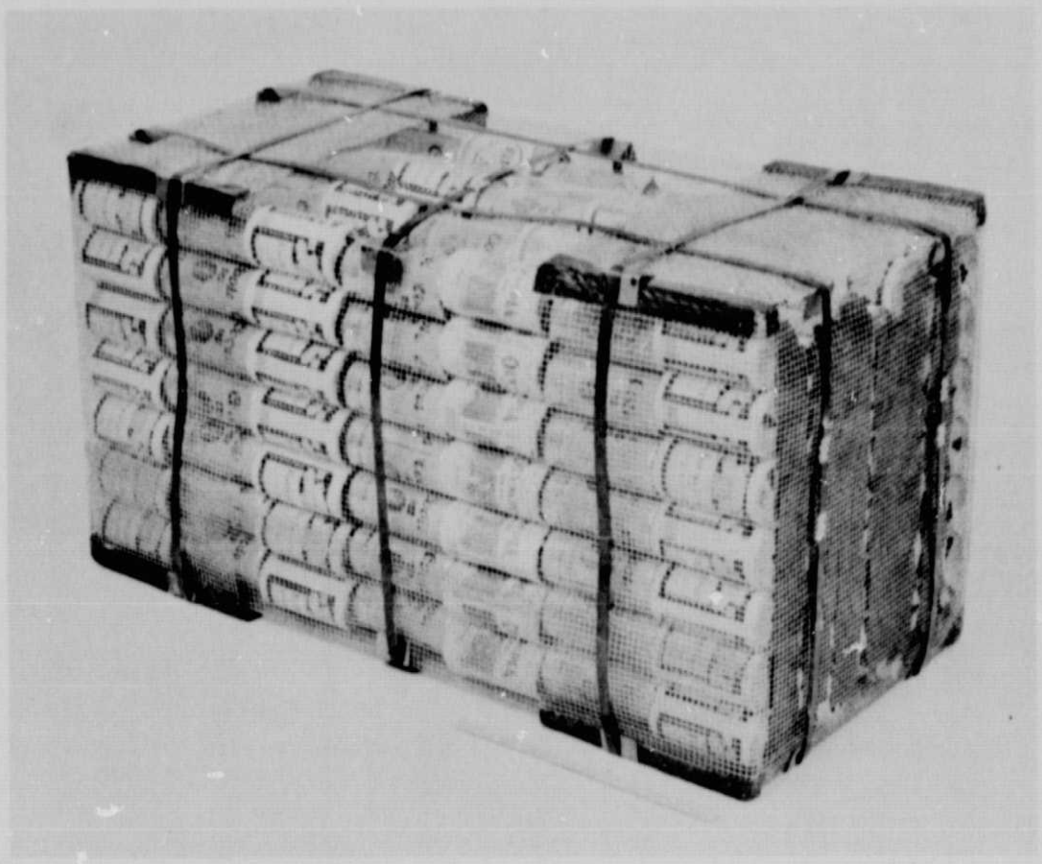


Fig. 9. Full-scale module of MODCAN crash cushion

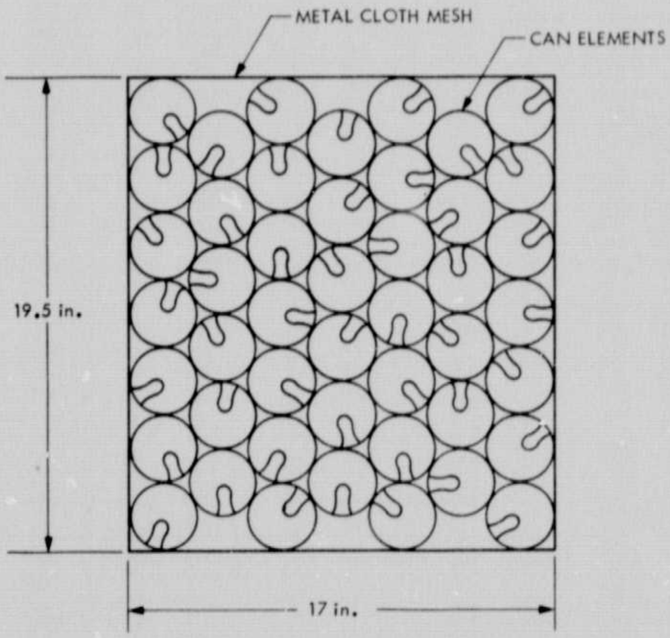


Fig. 10. Typical module layer construction

Since the agreement between the results of this single module test and the analytical predictions is relatively close, no attempt was made to refine the system design calculations given below.

3. System Design Development

The MODCAN preliminary design was developed based on the procedures suggested in Ref. 3 for sizing a steel drum crash cushion. This approach provided a means of sizing a candidate field installation (Fig. 8) and comparing anticipated performance to that of the steel drum device. Accordingly, a design layout was evolved which satisfies system design constraints for vehicle weights from 2000 lb minimum to 4500 lb maximum. The design solutions for each impacting vehicle weight are shown in Figs. 11 and 12, respectively. The numbers in parentheses indicate corresponding steel drum performance values.

In each of these solutions a dynamic load factor increase of 1.5 over static crush data (Ref. 3) was used to estimate module dynamic crush performance. Also, each of the modules shown in these figures represents two horizontal layers of individual modules of the type shown in Fig. 9. This is necessary to keep the overall height of the system at the same level as the steel drum device.

As can be seen in both vehicle impact cases, the MODCAN concept results in lower occupant average deceleration levels than the corresponding steel drum cushion. Furthermore, the substantially lower deceleration levels offered during the initial part of the crushing stroke suggest a smoother deceleration during the vehicle impact event. In addition, it appears that vehicles weighing up to 4850 lb can be satisfactorily arrested in comparison to a maximum allowable vehicle impact weight of 4700 lb for the steel drum device. Thus it can be said that the MODCAN concept offers the potential for smoother and safer occupant deceleration for a larger class of vehicle impact weights than the steel drum crash cushion system.

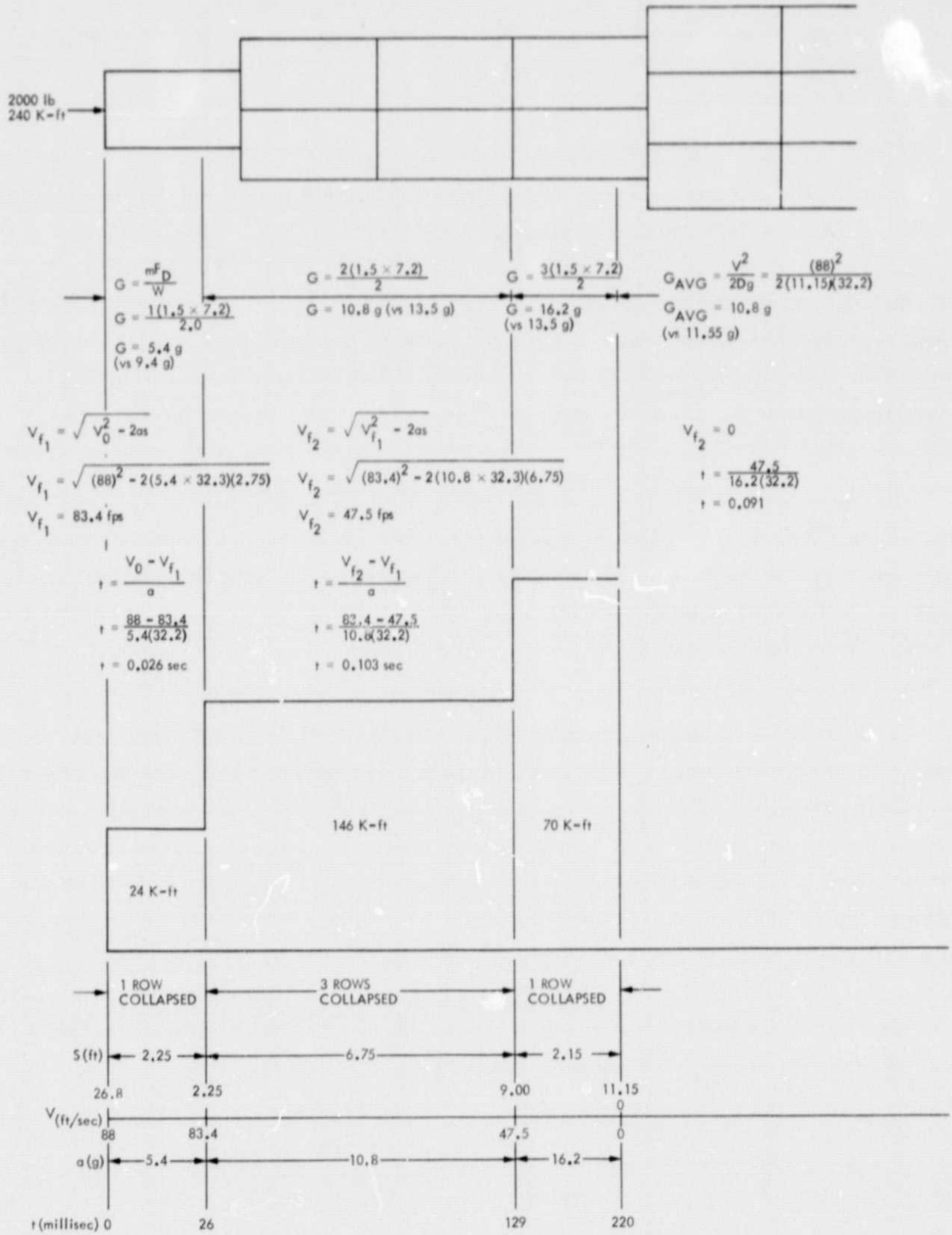


Fig. 11. Preliminary design calculations for 2000-lb-vehicle impact

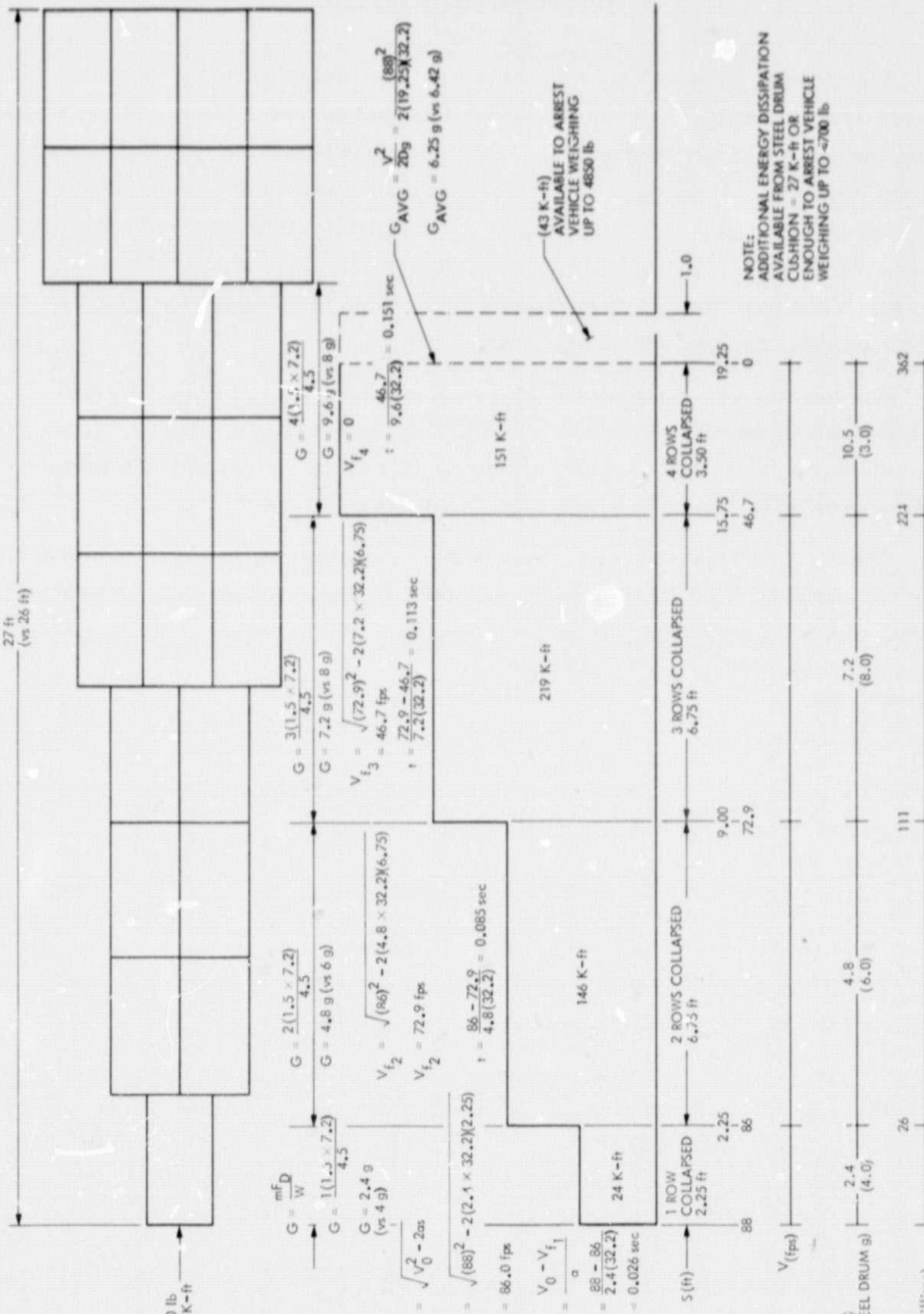


Fig. 12. Preliminary design calculations for 4500-lb-vehicle impact

IV. FUTURE ACTIVITIES

The results obtained thus far in a concept investigation of a crash barrier system (MODCAN) composed of disposable metal beverage cans have shown the potential for improved performance benefits over similar crash cushion systems. However, much work remains before these benefits can be achieved. Perhaps the most urgent requirement is to proceed with the fabrication and full-scale prototype demonstration testing of a MODCAN system. This will serve to establish a firm technical basis for detailed system design and specifications.

In addition, the matter of economics must be carefully addressed. It is necessary to develop expected system cost data relating to such factors as fabrication, installation, maintenance and repair. Here the prototype development cost data will serve as a most useful guide.

Finally, it is necessary to disseminate the results of these investigations to potential highway users for subsequent implementation. Only then can the benefits of this research contribution be fully realized to the advantage and protection of the driving public.

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