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A REVIEW OF THE DRAGNET VEHICLE ARRESTING SYSTEM AS APPLIED TO RUNAWAY TRUCK ESCAPE RAMPS

Special Report

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16. Abstract

The DRAGNET vehicle arresting system was reviewed for application in truck escape ramps. The Arizona Department of Transportation (ADOT) currently uses gravel arrestor beds to stop vehicles that lose braking power on sustained grades. Gravel arrestor beds have cost between one and two million dollars to build. The DRAGNET system was reviewed as a possible improvement over gravel arrestor beds, both in terms of cost and safety.

Calculations were performed on a configuration of DRAGNETs to determine the stopping distance and deceleration for the ADOT arrestor bed design vehicle (80,000 lbs entering at 90 mph). A safety factor of two was applied to the kinetic energy of the incoming vehicle in all designs. Also, sand barrel arrays were recommended for the end of all DRAGNET truck escape ramps. Two other configurations in which the longitudinal spacing of the nets was varied were used with two additional vehicle weights, each entering at four different speeds, to construct a table of occupant impact velocity, ridedown decelerations, and distance traveled.

The results of the evaluation showed that a DRAGNET system to stop the ADOT design vehicle with a with a maximum ridedown deceleration of .45 g's and a safety factor of two would require 25 net assemblies. ADOT has a gravel arrestor in the design phase that was used as a basis for an economic evaluation. A DRAGNET truck escape ramp would be 21% higher for first cost. The maintenance for a gravel arrestor bed is between \$300 and \$500 per entry while a DRAGNET system would cost between \$50,700 and \$97,500 per entry.

17. Key Words
DRAGNET, truck escape ramp, deceleration, design vehicle, net assembly, arrestor bed, safety

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INTRODUCTION

The Dragnet Vehicle Arresting System was originally developed for the United States Navy to stop jet aircraft on aircraft carriers. The Entwistle company of Hudson, Maine manufactures the system for the Navy. Roadway Safety Services, Inc. of Ronkonkoma, New York distributes the system to state transportation agencies.

The FHWA approved the use of Dragnets as a crash cushion in 1983. The 1989 AASHTO Roadside Design guide lists the DRAGNET as a crash cushion. Applications for the DRAGNET system listed in the AASHTO guide are: 1) opposite the approach road at a "T" intersection, 2) temporary road or ramp closures, and 3) in conjunction with longitudinal barrier to shield the opening between twin bridges[1].

Background

The Arizona Department of Transportation (ADOT) currently uses gravel arrestor beds to stop runaway trucks. Gravel arrestor beds have cost between one and two million dollars depending on site conditions and length of the bed. ADOT is currently engaged in a research project to better understand the relationship between gravel arrestor bed design parameters and stopping characteristics. The arrestor bed project is being conducted by researchers from Arizona State University (ASU).

ADOT was approached in February, 1991 by Roadway Safety Services with the DRAGNET system. Roadway safety listed runaway truck ramps as a potential application for DRAGNET. When initially approached by the vendor ADOT considered three ways of using the DRAGNET for runaway truck ramps: 1) a configuration of nets at the end of the gravel arrestor bed for added safety, 2) a configuration of nets before the gravel bed to reduce the length, and 3) a configuration of nets as a stand alone system. The third option is the one reported in this study.

Description

A DRAGNET consists of anchor posts, energy-absorbing reels of steel tape, and a net assembly[1]. A DRAGNET system consists of several DRAGNETs lined up along the longitudinal direction of the arrestor bed. A drawing of the component parts is shown in Figure 1. The case which contains the steel tape is a steel weldment with a cover fastened with 6 each 1/4 - 20 hexhead bolts. The cover is removed to replace the tape assembly after impacts. All components of the case are treated with flame-sprayed aluminum prior to painting to weather-proof. The assembly is warranted for 10 years. Delivery of a system requires 8-10 weeks.

Potential Benefit

The potential benefits of the DRAGNET system for truck escape ramps include: 1) controlled deceleration with little damage to vehicle and passenger, 2) ease and quickness with which the system can be put back into service after a hit, 3) good predictability of the stopping distance if the vehicle speed and weight are known.

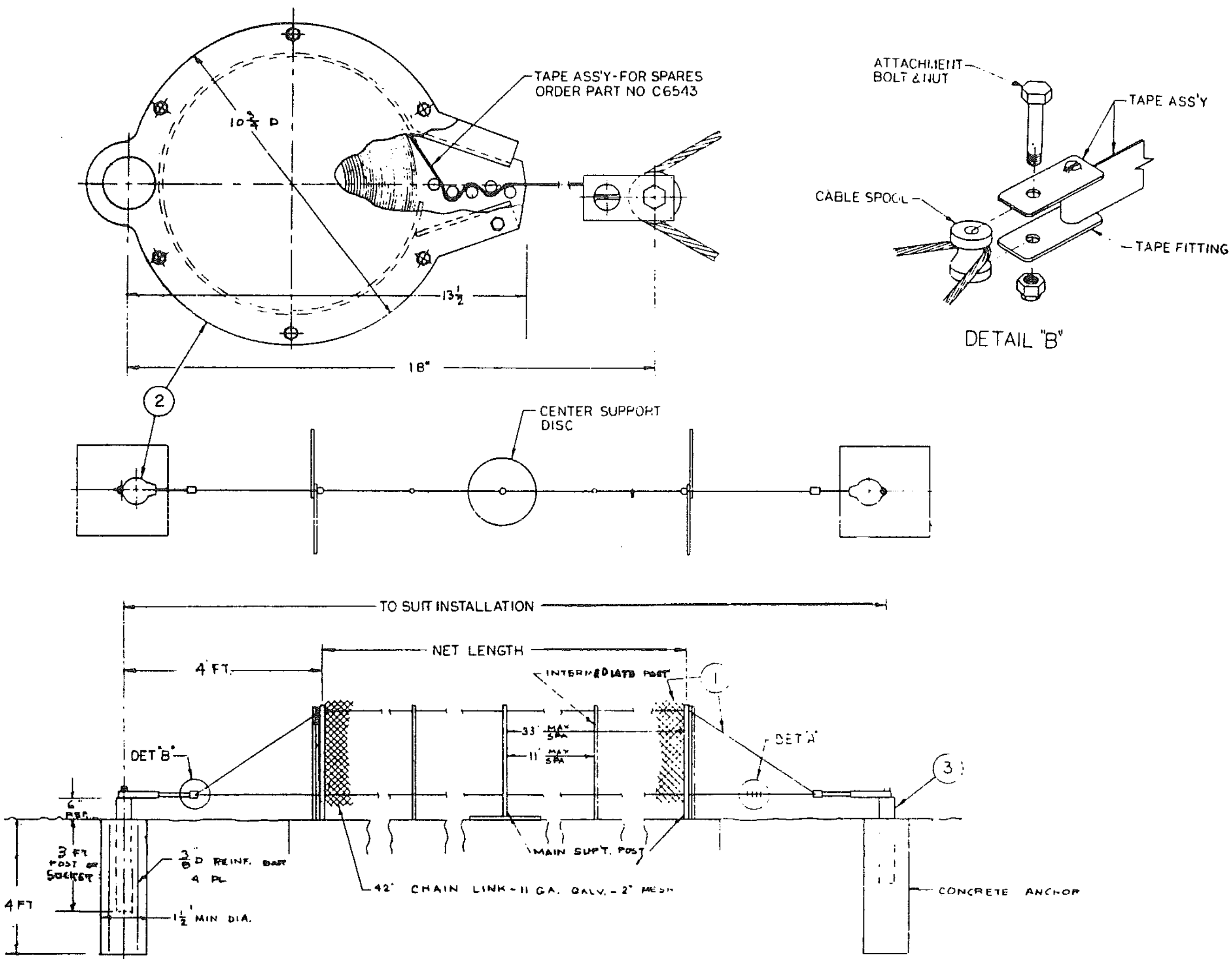

FIGURE 1 DRAGNET ASSEMBLY

DESIGN

Concerns

There are several concerns about the DRAGNET system when applied to runaway truck escape ramps that will be discussed as a preface to the design calculations:

1) lack of testing,
2) maximum deceleration rates for trucks and passenger vehicles,
3) safety factor,
4) guardrail placement, and
5) performance data.

The first concern is the lack of testing of the system. The only highway related crash testing of the system was conducted in 1969 by the Texas Transportation Institute (TTI). The TTI study consisted of six crash tests with vehicle weights ranging from 1460 lbs to 4520 lbs with speeds ranging from 42 mph to 62 mph. It is very difficult if not impossible to extrapolate the results of the TTI testing to truck escape ramps designed to stop an 80,000 lb tractor trailer entering the ramp at 90 mph. The testing did result in several conclusions: 1) the height of the net was an important factor, and should be positioned to completely entrap the front of the vehicle, 2) longer stopping distances result in lower deceleration forces, and 3) the performance of the system was very good in four of the six tests[2].

The second concern is maximum deceleration that will be used to design for trucks and passenger vehicles. Truck escape ramps are constructed primarily for tractor trailers that lose braking power on sustained grades. However, passenger cars do enter the ramps either because of driver error or possibly loss of brakes. For trucks the design criteria is the maximum deceleration that will not produce load shifting. For passenger vehicles there are two criteria, which come from the National Cooperative Highway Research Program (NCHRP) report 230. The first criteria for passenger vehicles is the maximum velocity which an unrestrained passenger will strike the interior of the vehicle. NCHRP 230 limits longitudinal passenger change in velocity to 30 feet per second. The second criteria is the maximum ridedown deceleration or the maximum deceleration that both the vehicle and passenger experience after contact. NCHRP 230 limits the ridedown deceleration, both in the longitudinal and transverse direction to 15 g's[3].

The third concern is a safety factor for the DRAGNET runaway truck ramp. The literature provided by Roadway Safety Inc. makes no mention of a safety factor[4]. Personal communication with the Roadway Safety indicated they feel the safety factor comes from the rolling resistance of the truck, and any positive grade that is available. The safety factor that will be applied to the DRAGNET design in this study will be two. This design will also require an array of sand barrels with an attenuation capacity of 25 mph at the end of the ramp. The safety factor selection was based on four reasons: 1) no previous testing with an 80,000 lb vehicle entering at 90 mph, 2) it is an experimental system with mechanical parts, 3) there is no performance history by which to estimate long term effects, and 4) reported variability in the design tape force is 5%.

The fourth concern is the placement of guardrails. The proposed DRAGNET design requires guardrail placed along both sides of an arrestor bed approximately 14 ft apart. The narrow separation between the guardrails is designed to prevent jackknifing of the trailor and to produce the largest resultant force vector from the DRAGNET tapes. As a vehicle first encounters a DRAGNET the force component in the longitudinal direction is minimal. As the vehicle moves beyond the contact point the longitudinal force vector rapidly increases until a maximum value is obtained (i.e., the design value).

Unfortunately the narrow spacing designed to prevent jackknifing and produce the most efficient dissipation of tape energy creates a safety hazard. The substantial supports required to restrain the DRAGNETs during deployment constitute a safety hazard. For example, if a vehicle missed the center of the arresting area by only 7 ft it would contact almost rigid support posts attached to the DRAGNET. Increasing the width from 14 ft to a greater, safer width, reduces the efficiency of the DRAGNET system and the effectiveness of preventing jackknifing.

The fifth concern is the lack of performance data. Although the system has seen considerable use by the Navy, the use or reuse of cables , fencing, and support posts, in an arrestor bed is untested.

Assumptions

The assumptions used in this design analysis were: 1) an 80,000 lb truck enters the bed at 90 mph with no brakes, 2) maximum deceleration rate that will not produce load shifting is .5 g's 3) the grade is considered level, and 4) no rolling resistance.

Principle

The DRAGNET runaway truck escape ramp works on the principle of energy dissipation. There are several chain link nets, each spanning the width of the ramp, lined up along the longitudinal direction of the ramp, which provide the drag to stop the truck. Each net is attached to two energy dissipators which are attached to posts that are embedded into the ground. When the truck enters the ramp it engages each net successively until all of it's energy has been dissipated.

The energy dissipation provided by DRAGNET is the result of a metal tape pulled through a series of pins. The force required to pull the tape through the pins is independent of the speed with which it is pulled. The force is dependent on the gauge of the tape and on the configuration of the pins. The energy is dissipated through friction and deformation of the tape. A certain amount of heat is released in the process. The heat generated is not discussed in the DRAGNET literature[4].

The ADOT TRUCK ESCAPE RAMP POLICY states that the design entry speed will be no less than 90 mph; no design weight is given because the equation for arrestor bed length does not include this factor[5]. The maximum legal weight limit for trucks in Arizona is 80,000 lbs. Therefore the design vehicle used in the analysis weighs 80,000 lbs and enters the ramp at 90 mph.

The design of a DRAGNET system is based on the kinetic energy of an incoming vehicle. The equation for kinetic energy is:

$$K.E. = 1/2MV^2 \qquad \text{(eq. 1)}$$

where M = mass in slugs
V = velocity in ft/s
K.E. = kinetic energy in ft-lbs

For this application a convenient form of the equation is:

$$K.E. = WV^2/2g \qquad \text{(eq. 2)}$$

where W = weight in lbs (M x g)
g = acceleration due to gravity in ft/s^2

For the design vehicle the K.E. is 21,644,720.50 ft-lbs and after applying a safety factor of 2 it is 43,289,441.0 ft-lbs.

Cost Comparison of Available Tapes

The available tapes are: 1) 4500 lbs with 75 ft runout, 2) 4500 lbs with 200 ft runout, and 3) 9000 lbs with 40 ft runout. Two tapes and one net comprise a net assembly. The energy dissipation potential of one net assembly is the rating of each tape in pounds, multiplied by two, multiplied by the length of tape pulled through the pins. Table 1 gives a cost comparison for individual replacement tapes. Based on the results of Table 1 the net assembly with two 4500 lb tapes and 200 ft runout will be used in all remaining calculations and will be referred to as one ***net assembly***.

TABLE 1 COST COMPARISON OF ENERGY DISSIPATING TAPES

Tape Rating (lbs)	Tape Length (ft)	Energy Dissipation (ft-lbs)	Cost for replacement	Cost per ft-lb dissipated
4500	75	337,500	800.00	$ 0.0024
4500	200	900,000	1950.00	$ 0.0024
18,000	40	720,000	5,000	$ 0.0069

Maximum Deceleration for Design Vehicle

The maximum average deceleration in any 10 ft interval was chosen based on three criteria: 1) Federal Motor Carriers Safety Standards, 2) a value consistent with deceleration rates currently experienced in ADOT's gravel arrestor beds, and 3) a convenient increment available with a given number of DRAGNETs. The information on the first two criteria come from the study conducted by ASU[6]. The study reported the following information about criteria one:

> "The U.S. Department of Transportation Federal Highway Administration Federal Motor Carrier Safety Regulations, 49 CFR 390-397 specify acceleration values for which cargo must be restrained during deceleration. In sections 393.100 through 393.106 these regulations can be found. Depending on the type of cargo the loads must be restrained to against deceleration values as large as 1.8 g's or as small as 0.4 g's in the longitudinal direction. Standards require that cargo be secured to resist a deceleration of 0.40 g's" [5].

Criteria two is determined from full scale testing was performed in December of 1989 by ASU in one of ADOT's six gravel arrestor beds located at milepost 283 in the northbound direction of interstate 17. Decelerations reported in the study ranged from 0.36 g's to 0.42 g's[7]. The decelerations were obtained from plots of velocity versus time. Decelerations were determined by graphically fitting curves to the data points obtained from radar records.

The third criteria is an integer multiple of nets engaged at any one time. If three ***net assemblies*** are engaged at any one time, the deceleration will be 0.34 g's. If four ***net assemblies*** are engaged at any one time, the deceleration will be 0.45 g's, and if five nets are engaged at any one time the deceleration will be 0.56 g's. The value used for the design example is 0.45 g's.

Example

If the energy dissipation potential of one ***net assembly*** is divided into the total kinetic energy of the design vehicle it can be seen that 24.05 nets are required. A net assembly with less energy dissipating potential could be used to make up the difference. But, in order to maintain a system that is homogenous with respect to replacement parts 25 ***net assemblies*** were selected.

Table 2 shows the calculations for a system of DRAGNETS designed to stop the design vehicle with a maximum deceleration rate of 0.45 g's. In this configuration (to be referred to as ***net configuration one*** hereafter) the 25 nets are placed at 0 ft, 40 ft, 50 ft, 60 ft, 200 ft, 240 ft, 250 ft, 260 ft, 400 ft, 440 ft, 450 ft, 460 ft, 600 ft, 640 ft, 650 ft, 660 ft, 800 ft, 840 ft, 850 ft, 860 ft, 1000 ft, 1040 ft, 1050 ft, 1060 ft, and 1200 ft. The interval between 0 ft and 40 ft is to allow passenger vehicles to enter without exceeding the guidelines of NCHRP 230. Calculations in the table require the K.E. equation and the following kinematic equation:

$$V^2 = V_0^2 + 2a\,(X - X_0) \qquad \text{(eq. 3)}$$

Where V = final velocity in ft/s
V_0 = initial velocity in ft/s
a = acceleration in ft/s^2
X = final position in ft
X_0 = initial position in ft

The calculations proceed by determining the initial kinetic energy of the incoming vehicle. After impacting the net and traveling 10 ft a certain amount of K.E. will be dissipated (for one ***net assembly*** 9,000 lbs x 10 ft = 90,000 ft-lbs). Subtracting the dissipated K.E. from the initial K.E. gives the final K.E. after 10 ft. Using the K.E. equation the velocity after 10 ft can be determined. With the initial velocity (V_0) and the final velocity (V) and the change in distance ($X - X_0$ = 10 ft) the average acceleration (in this case deceleration) in the 10 ft interval can be solved for with eq. 3.

TABLE 2 DECELERATION HISTORY FOR ***net configuration one***

Distance Traveled (ft)	Kinetic energy dissipated (ft-lbs)	Kinetic energy remaining (ft-lbs)	Speed (ft/s)	Average deceleration (g's)	comments
0	0	43289441	186.6762		net #1
10	90000	43199441	186.48	0.1125	
20	90000	43109441	186.29	0.1125	
30	90000	43019441	186.09	0.1125	
40	90000	42929441	185.90	0.1125	net #2
50	180000	42749441	185.51	0.225	net #3
60	270000	42479441	184.92	0.3375	net #4
70	360000	42119441	184.14	0.45	
80	360000	41759441	183.35	0.45	
90	360000	41399441	182.56	0.45	
100	360000	41039441	181.76	0.45	
110	360000	40679441	180.96	0.45	
120	360000	40319441	180.16	0.45	

TABLE 2 (CONTINUED)

130	360000	39959441	179.35	0.45	
140	360000	39599441	178.54	0.45	
150	360000	39239441	177.73	0.45	
160	360000	38879441	176.91	0.45	
170	360000	38519441	176.09	0.45	
180	360000	38159441	175.27	0.45	
190	360000	37799441	174.44	0.45	
200	360000	37439441	173.61	0.45	net #5 (replaces net #1)
210	360000	37079441	172.77	0.45	
220	360000	36719441	171.93	0.45	
230	360000	36359441	171.08	0.45	
240	360000	35999441	170.23	0.45	net #6 (replaces net #2)
250	360000	35639441	169.38	0.45	net #7 (replaces net #3)
260	360000	35279441	168.52	0.45	net #8 (replaces net #4)
270	360000	34919441	167.66	0.45	
280	360000	34559441	166.79	0.45	
290	360000	34199441	165.92	0.45	
300	360000	33839441	165.05	0.45	
310	360000	33479441	164.17	0.45	
320	360000	33119441	163.28	0.45	
330	360000	32759441	162.39	0.45	
340	360000	32399441	161.50	0.45	
350	360000	32039441	160.60	0.45	
360	360000	31679441	159.69	0.45	
370	360000	31319441	158.78	0.45	
380	360000	30959441	157.87	0.45	
390	360000	30599441	156.95	0.45	
400	360000	30239441	156.02	0.45	net #9 (replaces net #5)
410	360000	29879441	155.09	0.45	
420	360000	29519441	154.15	0.45	
430	360000	29159441	153.21	0.45	
440	360000	28799441	152.26	0.45	net #10 (replaces net #6)
450	360000	28439441	151.31	0.45	net #11 (replaces net #7)
460	360000	28079441	150.35	0.45	net #12 (replaces net #8)
470	360000	27719441	149.38	0.45	
480	360000	27359441	148.41	0.45	
490	360000	26999441	147.43	0.45	
500	360000	26639441	146.44	0.45	
510	360000	26279441	145.45	0.45	
520	360000	25919441	144.45	0.45	
530	360000	25559441	143.44	0.45	
540	360000	25199441	142.43	0.45	
550	360000	24839441	141.41	0.45	
560	360000	24479441	140.38	0.45	
570	360000	24119441	139.34	0.45	
580	360000	23759441	138.30	0.45	
590	360000	23399441	137.25	0.45	
600	360000	23039441	136.19	0.45	net #13 (replaces net #9)
610	360000	22679441	135.12	0.45	
620	360000	22319441	134.04	0.45	
630	360000	21959441	132.96	0.45	

TABLE 2 (CONTINUED)

640	360000	21599441	131.86	0.45	net #14 (replaces net #10)
650	360000	21239441	130.76	0.45	net #15 (replaces net #11)
660	360000	20879441	129.65	0.45	net #16 (replaces net #12)
670	360000	20519441	128.52	0.45	
680	360000	20159441	127.39	0.45	
690	360000	19799441	126.25	0.45	
700	360000	19439441	125.09	0.45	
710	360000	19079441	123.93	0.45	
720	360000	18719441	122.76	0.45	
730	360000	18359441	121.57	0.45	
740	360000	17999441	120.37	0.45	
750	360000	17639441	119.16	0.45	
760	360000	17279441	117.94	0.45	
770	360000	16919441	116.71	0.45	
780	360000	16559441	115.46	0.45	
790	360000	16199441	114.20	0.45	
800	360000	15839441	112.92	0.45	net #17 (replaces net #13)
810	360000	15479441	111.63	0.45	
820	360000	15119441	110.32	0.45	
830	360000	14759441	109.00	0.45	
840	360000	14399441	107.66	0.45	net #18 (replaces net #14)
850	360000	14039441	106.31	0.45	net #19 (replaces net # 15)
860	360000	13679441	104.94	0.45	net #20 (replaces net # 16)
870	360000	13319441	103.55	0.45	
880	360000	12959441	102.14	0.45	
890	360000	12599441	100.71	0.45	
900	360000	12239441	99.26	0.45	
910	360000	11879441	97.79	0.45	
920	360000	11519441	96.30	0.45	
930	360000	11159441	94.78	0.45	
940	360000	10799441	93.24	0.45	
950	360000	10439441	91.67	0.45	
960	360000	10079441	90.08	0.45	
970	360000	9719440.99	88.45	0.45	
980	360000	9359440.99	86.80	0.45	
990	360000	8999440.99	85.11	0.45	
1000	360000	8639440.99	83.40	0.45	net #21 (replaces net #17)
1010	360000	8279440.99	81.64	0.45	
1020	360000	7919440.99	79.84	0.45	
1030	360000	7559440.99	78.01	0.45	
1040	360000	7199440.99	76.13	0.45	net #22 (replaces net #18)
1050	360000	6839440.99	74.20	0.45	net #23 (replaces net #19)
1060	360000	6479440.99	72.22	0.45	net #24 (replaces net #20)
1070	360000	6119440.99	70.19	0.45	
1080	360000	5759440.99	68.09	0.45	
1090	360000	5399440.99	65.93	0.45	
1100	360000	5039440.99	63.69	0.45	
1110	360000	4679440.99	61.38	0.45	
1120	360000	4319440.99	58.97	0.45	
1130	360000	3959440.99	56.46	0.45	
1140	360000	3599440.99	53.83	0.45	

TABLE 2 (CONTINUED)

1150	360000	3239440.99	51.07	0.45	
1160	360000	2879440.99	48.15	0.45	
1170	360000	2519440.99	45.03	0.45	
1180	360000	2159440.99	41.69	0.45	
1190	360000	1799440.99	38.06	0.45	
1200	360000	1439440.99	34.04	0.45	net #25 (replaces net #21)
1210	360000	1079440.99	29.48	0.45	
1220	360000	719440.994	24.07	0.45	
1230	360000	359440.994	17.01	0.45	
1240	360000	-559.00621	#NUM	#NUM	vehicle has stopped

PARAMETRIC ANALYSIS.

From the analysis presented it is known that 25 net assemblies are required to stop the design vehicle. The two remaining design parameters that can be varied are the length of the ramp and the maximum deceleration rate. It is desirable to minimize both the length and the maximum deceleration rate. As already mentioned the maximum deceleration rate is dependent on the maximum number of nets actuated at any one time. The length of the ramp is dependent on how the nets are spaced.

Stacking Tapes

The literature provided by Roadway Safety Inc. lists "stacking of tapes" as an option. Stacking is when four tapes (two on each side) are attached to one net. This allows the designer to have a net assembly with a stopping power that is an integer multiple of one ***net assembly***. Staking of tapes has not been tested. The post assembly to which the tapes are attached would need to be modified to withstand the additional force. Stacking of tapes can reduce the length required for the DRAGNET system to stop a runaway truck. For instance, in ***net configuration one*** if the tapes at 40 ft and 50 ft are stacked the overall length will be reduced by 10 ft. No tape stacking was considered in the sensitivity analysis.

Net Configurations for Analysis

Two additional net configurations were examined: 1) ***net configuration two***, with six nets in any 200 ft interval with the same scheme of net placements as the ***net configuration one***, 2) ***net configuration three***, with eight nets in any 200 ft interval with the same scheme of net placement as ***net configuration one***. For each of the three cases three vehicle weights were used: 80,000 lbs, 60,000 lbs, and 4,500 lbs. The 80,000 lb vehicle represents a truck loaded to the maximum legal load, the 60,000 lb vehicle represents a ten wheel dump truck completely loaded, and the 4,500 lb passenger vehicle corresponding to the heaviest vehicle in NCHRP 230. For each vehicle weight four entry speeds were used, 90 mph, 80 mph, 70 mph, and 60 mph. Figures 2-4 show the results.

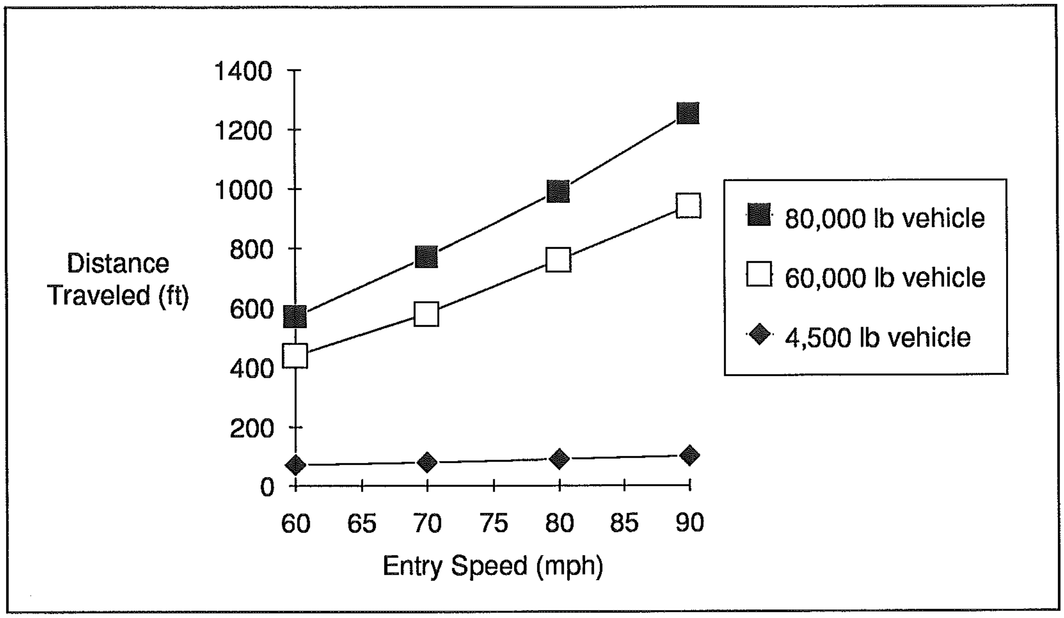

FIGURE 2 DISTANCE VERSUS ENTRY SPEED FOR ***net configuration one***

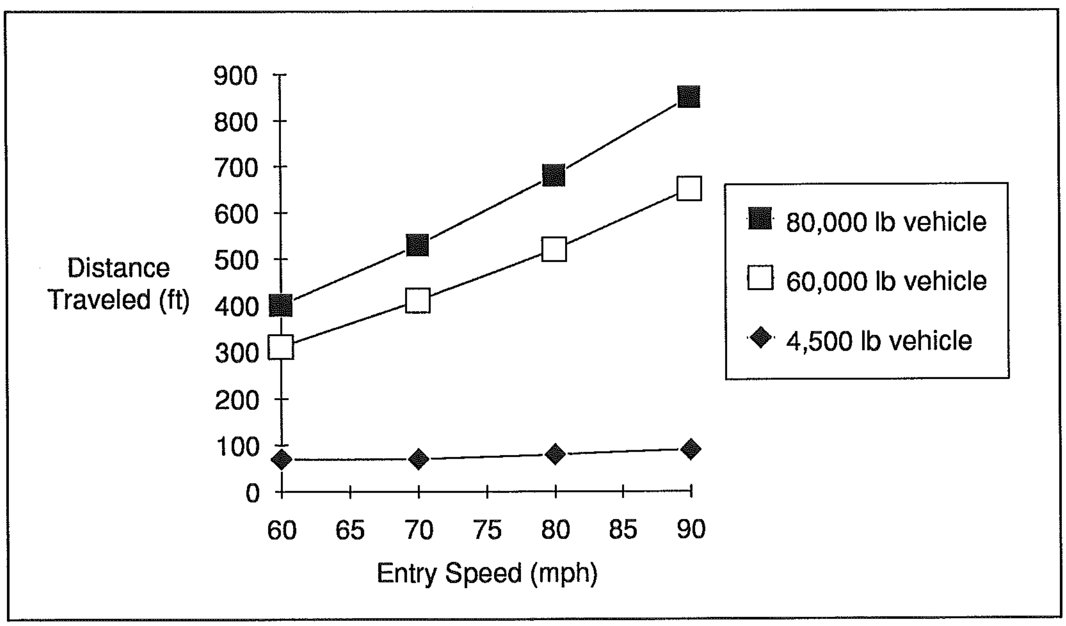

FIGURE 3 LENGTH VERSUS ENTRY SPEED FOR ***net configuration two***

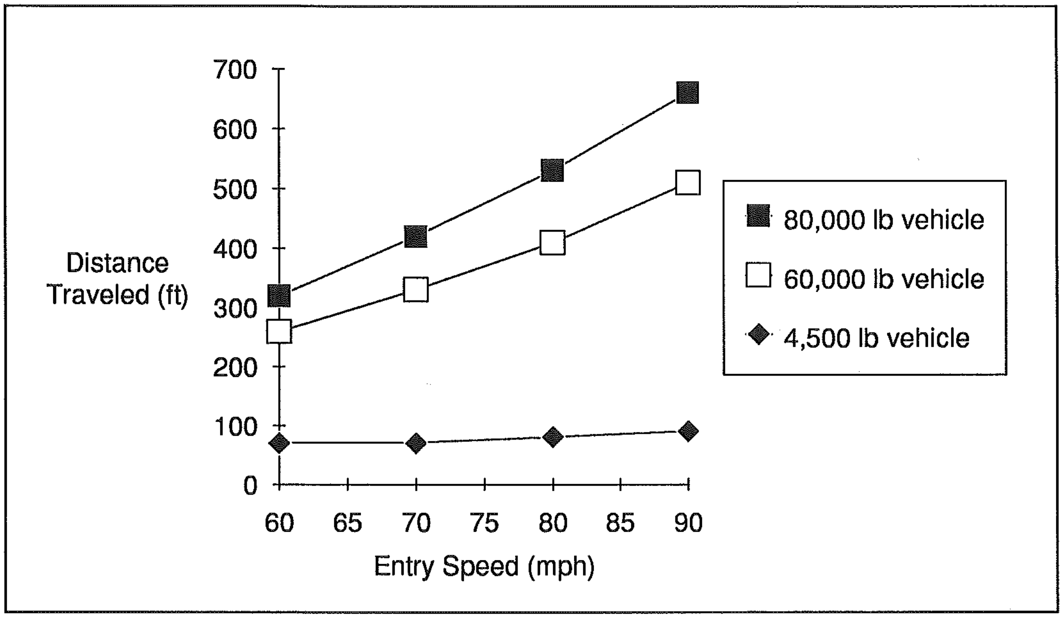

FIGURE 4 LENGTH VERSUS ENTRY SPEED FOR ***net configuration three***

Deceleration Values and Impact Velocities

As already stated the maximum allowable ridedown deceleration for unrestrained passengers is 15 g's. The NCHRP 230 guidelines specify 30 feet per second as the maximum impact velocity. Trucks have the additional concern of load shifting. Table 3 shows the maximum deceleration values and impact velocities obtained for each case in the sensitivity analysis.

TABLE 3 MAXIMUM DECELERATION RATES AND IMPACT VELOCITIES

Net Configuration	Vehicle weight (lbs)	Entry Speed (mph)	Maximum Deceleration (g's)	Impact Velocity (ft/s)
1	80,000	90	.45	7.3
	80,000	80	.45	7.2
	80,000	70	.45	6.8
	80,000	60	.45	6.8
	60,000	90	.60	8.3
	60,000	80	.60	8.1
	60,000	70	.60	8.0
	60,000	60	.60	7.5
	4,500	90	8.0	16.1
	4,500	80	6.0	16.5
	4,500	70	4.0	16.4
	4,500	60	4.0	16.1
2	80,000	90	.68	8.7
	80,000	80	.68	8.4
	80,000	70	.68	8.1
	80,000	60	.68	7.7
	60,000	90	.90	9.8
	60,000	80	.90	9.5

TABLE 3 (CONTINUED)

	60,000	70	.90	8.8
	60,000	60	.90	8.0
	4,500	90	8.0	15.4
	4,500	80	6.0	15.3
	4,500	70	4.0	15.3
	4,500	60	4.0	15.9
3	80,000	90	.90	9.3
	80,000	80	.90	8.7
	80,000	70	.90	8.2
	80,000	60	.90	7.7
	60,000	90	1.2	10.1
	60,000	80	1.2	9.6
	60,000	70	1.2	8.8
	60,000	60	1.2	8.0
	4,500	90	8.0	16.1
	4,500	80	6.0	16.5
	4,500	70	4.0	16.4
	4,500	60	4.0	16.1

ECONOMIC EVALUATION

ADOT has a runaway truck escape ramp in the preliminary design phase that has a cost estimate of $1,080,040. There are twenty nine items listed in the cost estimate, Table 4 shows the four highest cost items that account for 67% of the total cost.

TABLE 4 GRAVEL ARRESTOR BED COSTS

Item	Cost
excavation	$339,870
aggregate	$182,215
borrow	$105,238
mobilization	$93,000

The gravel arrestor bed will be approximately 1100 ft in length and the DRAGNET truck escape ramp will be approximately 1240 ft in length. The aggregate and the 25 DRAGNET assemblies can be compared on an equal basis. The purchase of 25 DRAGNET assemblies will cost $312,500 which is 71.5% higher than the aggregate costs. The DRAGNET ramp will be 12.7% longer than he gravel arrestor bed which could, depending on site conditions, increase excavation and borrow costs by 12.7%. There is also the additional cost of guardrails and a sand barrel array. Based on a cost of $12.85 per linear foot of guardrail the cost would be $31,868 for a 1240 ft ramp. Sand barrel array for the DRAGNET ramp is estimated to cost $5000. Considering all the above mentioned costs it is estimated that the DRAGNET ramp will be 21% higher for first cost.

After each entry the cost to restore the gravel arrestor bed to usable condition is between $300 and $500. This cost includes charges for: 1) transportation and use of equipment, and 2) labor for transportation and use of equipment. If the design vehicle enters the DRAGNET arrestor bed and all 25 nets are actuated all 50 tapes will have to be replaced. The cost of one replacement tape is $1950. For 50 tapes the cost is $97,500. Also if any of the chain-link nets get excessively deformed they may have to be replaced at a cost of $1750 each. One additional expense could be incurred with the DRAGNET system and that is the guardrail. If a truck should damage the guardrail it would also have to be repaired.

HISTORICAL EXPERIENCE

The DRAGNET has been used successfully by the New York Department of Transportation since 1982 to provide safety for construction crews on closed roadways. No state has a installed a DRAGNET in a truck escape ramp. Several states have expressed interest in using the DRAGNET technology for truck escape ramps, they are: 1) Hawaii, 2) Washington, 3) Colorado, and 4) New York. Each states experience are listed below:

Hawaii: The state of Hawaii has an arrestor bed in the design phase at this time. The bed is on a downgrade and has a topographical length constraint of 600 ft. Hawaii has used a 70,000 lb truck entering the bed at 70 mph as the design vehicle. They are trying to limit the deceleration to 1.0 g's for trucks and 7.0 g's for passenger vehicles. Their preliminary design calculations indicate that they accept the DRAGNET method of using the average deceleration over the entire stopping distance in calculations. They are using an array of sand barrels at the end of the ramp and are not including a safety factor in the design.

Colorado: The state of Colorado is interested in the technology mainly to supplement gravel arrestor beds in case of frozen gravel or as a safety precaution in the case of beds that are of suspect length. They have no beds in the planning or design phase.

Washington: The state of Washington has experience similar to Colorado.

New York: The state of New York wanted to design a truck escape ramp system where several nets would be suspended above the escape ramp. An electronic system would sense the weight and speed of the incoming vehicle and drop the proper configuration of nets onto the ramps. The cost for the electronics alone on this system was in excess of $140,000. Because the cost was so high and they felt it was unsafe to install a single system of nets (due to wide variation in vehicle weights) the project was discontinued. It is interesting to note that when New York has used the DRAGNET for road closure applications they have had a maintenance worker watch the system the entire time it is in operation. The maintenance worker serves two purposes, first he can put the system back in service with one half hour, and second he records the name of the driver who will be asked to pay for replacement tapes and any other damage. Cost to errant drivers is usually $5000.

RECOMMENDATION

This report has examined the DRAGNET vehicle arrestor system as applied to runaway truck escape ramps. A design was presented that included a safety factor of two applied to the initial kinetic energy of the design vehicle and an array of sand barrels designed for an attenuation capacity of 25 mph at the end of the ramp. A parametric analysis was performed using designs that had a safety factor of two and arrays of sand barrels at the end in order to show the effects of decreasing the length of a DRAGNET system on passenger. Table 3 has presented passenger impact velocities and ridedown decelerations for all designs used in the study. The DRAGNET system has a serious problem associated with placement of guardrails. A runaway truck requires sufficient confinement by guardrails to prevent jackknifing but the ends of the guardrail pose a serious hazard to an out of control vehicle. The cost analysis shows that the DRAGNET system is approximately 21% more expensive for first cost and possibly 200% more expensive to maintain.

The recommendation of the Arizona Transportation Research Center (ATRC) is against the DRAGNET vehicle arrestor system as a stand alone truck escape ramp. The system is better suited for lane closures as is evidenced by the New York DOT experience. The ATRC is also recommending that if the DRAGNET truck escape ramp should ever become economical to use that full scale testing be conducted before the system is put into service.

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