Median Barriers: One Year's Experience and Further Controlled Full-Scale Tests

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Development of two types of barriers for use in the medians of California freeways was reported at the 39th Annual Meeting. As outlined in that report, it was planned to continue studying these two barriers under actual operating conditions.

This report covers one year of operation and additional full-scale collision tests of cable-chain link barriers. The before-and-after operational studies indicate that (a) the barriers were successful but need some improvement; (b) the total accidents increased when the barriers were installed, but the head-on fatalities were virtually eliminated; and (c) the maintenance cost of the cable-chain link barrier was more than the metal beam barrier, but this was offset by the higher first cost of the metal beam barrier. Controlled collision tests resulted in an improved design of the cable-chain link barrier.

• IN THE SUMMER of 1959, two types of median barriers were developed and tested for use on California freeways. These were the cable-chain link barrier, hereafter referred to as "cable," and the blocked-out metal beam barrier, hereafter referred to as "beam." Details of the barriers, and tests leading to their adoption, were reported in HRB Bulletin 266 (*1*).

Since the latter part of 1959, several miles of median barriers conforming to these developed designs have been placed on California freeways. The status of California's barrier construction program as of September 1961 is given in Table 1.

To compare the performance of the two types of barrier, the first contracts were split, providing some of each type in each contract. These are referred to as test sections. One test section was on the Santa Ana Freeway in Los Angeles where 3.17 mi of cable barrier were erected end-to-end with 2.57 mi of beam barrier; the other test section was on the Nimitz Freeway in Oakland where 3.87 mi of cable barrier were erected end-to-end with 2.87 mi of beam barrier.

TABLE 1

Barrier	Net Miles of Barrier-Divided Highway		
	Cable	Beam	Total
Constructed	31.5	16.8	48.3
Under construction	47.0	15.1	62.1
Budgeted (prelim. rept. received)	38.5	11.6	50.1
Total	117.0	43.5	160.5

Before-and-after accident records on these test sections have been examined. In addition, a complete operational study, including both construction and maintenance problems, has been made.

These studies indicated that (a) improvements in design details of the cable barrier were desirable and (b) more information was needed concerning the effect of the cross-section and profile of the highway surface on the trajectory of a fast-moving automobile.

The barrier deficiencies were analyzed and certain changes made. The corrected designs then were tested by a new series of controlled full-scale collisions. Exhibit 1 in the Appendix shows an over-all view of the collision test site. The results of both the operational study and the controlled tests are given in this report. Plates outlining the details of each test are included in the Appendix.

SUMMARY

1. Head-on accidents were virtually eliminated by the barriers. On the Santa Ana and Nimitz test sections, there were 49 cross-median accidents in the before period, including 8 fatal accidents, and there were two cross-median accidents in the after period, one of which was fatal.

2. Total accidents and injury-accidents increased in the locations where barriers were installed.

3. The freeway test sections with the cable barrier experienced a smaller increase in the over-all accident rate than did those with the beam barrier. There was no proof that the accidents involving the cable barrier were less severe. However, the findings of the controlled impact tests indicated that high speed collisions with the cable barrier would result in much less severe injury to vehicle occupants, and it is believed that in general the accidents involving the cable barrier are less severe.

4. The maintenance cost of the cable barrier is considerably higher than that of the beam barrier. First cost of the beam barrier is much greater than the cable barrier. It would require some 19.5 yr for the total expenditure to balance.

5. More accidents are evident involving the cable barrier. The proportion of single-vehicle accidents is much higher with the cable barrier than with the beam barrier. There is no indication that drivers are more reluctant to swerve into the beam barrier, but there are indications that there may be more hit-and-drive-away accidents involving the cable.

6. There was little difference in the cable barrier accident rate between the sections with 12- and 22-ft medians, and the maintenance cost per mile was essentially the same. There was no evidence to indicate that the deflection of the cables led to collisions by permitting momentary encroachment in the opposing lanes.

7. In installations other than the test sections, two vehicles climbed up and over the cable barrier and there were indications that others made partial climbs up the barrier.

Subsequent controlled collision tests indicated this tendency could be minimized by removing the lower cable from the original design. The revised design is shown in Exhibit 2, (Appendix).

8. In addition to the two vehicles that climbed the cable barrier two vehicles jumped barriers. One on the Santa Ana test section was apparently due to the car striking a curb in front of the barrier. The other was not on the test sections and was judged to result from the barrier being too low in relation to the plane of the roadway super-elevated surface.

Subsequent controlled collision

tests indicate that a 30-in. high barrier should be placed at or before the point of intersection of the shoulder slope and ditch slope. If it is necessary to place the barrier down the ditch slope, then it should be placed no further down the slope than will result in the top of the barrier being at least 27 in. above a horizontal projection from the point of intersection of the slopes.

9. Analysis of controlled collision test results indicate that the cable in a cable-chain link barrier should be placed no higher than 33 in. above and no lower than 27 in. above the ground line (or surface of control elevation).

10. Details of design of the cable barrier should be such that no fixed restraints exist insofar as the cable clamps or chain link fabric are concerned. A design incorporating these features as well as improvements for maintenance purposes is shown in Exhibit 2.

11. Expanded metal for a more effective headlight screen substituted in place of the chain link fabric makes little change in the cable barrier performance.

OPERATIONAL EXPERIENCE

Effectiveness of Barriers in Preventing Accidents

Both types of barrier have proven effective in accomplishing the purpose for which they were designed. Including installations in addition to the "test sections," they have been struck hundreds of times, and only two head-on accidents have occurred at locations where they are in place. The two head-on accidents were the result of vehicles that climbed or jumped clear over the barrier. Only one of these head-on accidents occurred within an experimental section. The other happened on the Ventura Freeway.

In addition to these two crossovers, which resulted in head-on collisions, two other crossovers took place. One was a small sports car that passed through the cable barrier under the top cable; the other resulted from a car traveling at high speed up the superelevation of a curve and jumping high enough to clear the top cable. The barrier in this latter case was located in the bottom of the ditch of a typical "saw-tooth" cross-section. Only the first of these accidents was within an experimental section.

Three partial crossovers occurred during the year. Two were within an experimental section, both of which involved truck-trailer combinations with the beam barrier on the Nimitz Freeway. In each case the barrier failed, but the trucks were stopped short of serious encroachment in the opposing lane. The third took place on the Ventura Freeway and involved a cable barrier. The automobile in this case came to rest on top of the barrier, half on one side and half on the other, but entirely within the median.

Effect of Barriers on Over-all Accident Record

As described previously, test sections of both types of barrier were erected on the Santa Ana Freeway and the Nimitz Freeway for the purpose of comparing the effectiveness of the two types of barrier.

Although there is no way of being sure that the differences between sections are attributable solely to the difference in type of barrier, it was thought that as many extraneous factors as possible would be eliminated by an end-to-end comparison on the same freeway where traffic volume remains approximately uniform, and, in fact, the very same vehicles pass by first one type of barrier and then the other.

TABLE 2

BEFORE-AND-AFTER RECORD, SANTA ANA AND NIMITZ FREEWAY TEST SECTIONS

Test Section	Barrier		All Reported Accidents						Injury Accidents [1]					
			Before		After		Change		Before		After		Change	
	Type	Length (mi)	No.	Rate Per MVM [2]	No.	Rate Per MVM [3]	In Rate	%	No.	Rate Per MVM [2]	No.	Rate Per MVM [2]	In Rate	%
Santa	Cable	3.17	120	1.08	153	1.30	+0.22	+20	55	0.49	56	0.48	−0.01	− 2
Ana	Beam	2.57	74	0.80	107	1.12	+0.32	+40	26	0.28	41	0.43	+0.15	+53
Nimitz	Cable	3.87	185	1.51	250	1.90	+0.39	+26	71	0.58	105	0.80	+0.22	+38
	Beam	2.87	146	1.55	216	2.13	+0.58	+37	—[3]	—[3]	95	0.94	—[3]	—[3]

[1] Including fatalities.

[2] Number per million vehicle-miles. Injury-accident rate of 0.49 per MVM shows over 2,000,000 car-miles (total life of about 30 cars) of travel accumulated for each accident serious enough to cause minor injuries to occupants.

[3] Where beam barrier installed, there was a change in enforcement agency jurisdiction between before and after periods. Because of change in reporting methods and definition of injury, rate in before period not known.

TABLE 3
BEFORE-AND-AFTER RECORD, HOLLYWOOD FREEWAY BETWEEN HARBOR FREEWAY AND BENTON WAY[1]

Accidents	Before		After		Change	
	No.	Rate	No.	Rate	Rate	%
All	242	2.10	266	2.21	+0.11	+5
Injury	158	1.37	155	1.29	−0.08	−6

[1] Beam Barrier, 1.68 mi; ADT = 190,000.

Comparisons between cable barrier on one freeway and beam barrier on another should be interpreted very cautiously, because there are so many other potential variables that could affect accident rates that the difference owing to type of barrier can be smothered in irrelevancies.

The Santa Ana test sections were between the Long Beach Freeway and Buhman Avenue, and the Nimitz Freeway test sections were between High Street and Washington Avenue. These are both 6-lane freeways with 12-ft medians. The average daily traffic was between 90,000 and 100,000 on all sections. Grades are practically level and alignment is excellent.

Before-and-after statistics, using one year prior to construction as the before period and one year after completion as the after period (omitting the period during construction), are given in Table 2 for the Santa Ana and the Nimitz test sections. In addition, Table 3 gives the statistics for a section of the Hollywood Freeway.

The following points are made about the Santa Ana test sections:

1. Before barriers were erected on either section, the section where beam barrier was later erected had a much lower accident rate than the section where the cable barrier was erected.
2. The total accident rate increased significantly after erection of the barriers, on both sections.
3. The percentage increase on the section with the beam barrier was much greater than the percentage increase on the section with the cable barrier.
4. Although total reported accidents increased where the cable barrier was installed, accidents severe enough to cause injuries did not increase. Where the beam barrier was installed, the injury accident rate increased by 53 percent. This increase cannot be directly related to cars that crashed into the barrier, however.

The following points are made about the Nimitz test sections:

1. The over-all accident rates were about equal on both sections before the barriers were erected on either section.
2. The accident rates increased significantly after erection of the barriers, on both sections.
3. The increase in accident rate was somewhat greater on the beam section than on the cable section (37 percent against 26 percent).
4. During the after period, 42 percent of the reported accidents on the cable section resulted in injuries, and 44 percent of the reported accidents on the beam section resulted in injuries. This is about the normal ratio for all freeways.

Although not included in the test sections, the Hollywood Freeway installation is listed to show the effect of extremely congested traffic. The following points are made regarding this beam barrier installation:

1. The rates were high before and after. This is probably characteristic of extremely congested freeways. (Although these rates are considered high for urban freeways, they are still only about one-third the rate on urban arterials other than freeways.)
2. The barrier did not affect the rates, either over-all or injury.
3. The ratio of injury accidents to total accidents (60 percent) is very high. It is possible that many non-injury accidents are being overlooked on this section.

The barriers have generally resulted in an increase in over-all accidents, except on the Hollywood Freeway where the volume is 190,000. An earlier study (*2*) had indicated that barriers would increase accidents on roads where the volume is less than 130,000.

The percentage increase in both the all-accident rate and injury-accident rate was greater where the beam barrier was placed than where the cable barrier was placed, although the sample is so small and other unaccounted-for differences in rates are so large that these differences could be due to reasons other than difference in barrier types.

It may be significant that the rise in accidents on the cable barrier section of the Santa Ana was not accompanied by a rise in the injury-accident rate. However, the rise in injury accidents on the Nimitz cable section was just as great as the rise in all-accidents on this section.

The ratio of all-accidents to injury-accidents lies in the expected range of 2.2 to 2.8 in the before and after samples for both types of barrier in the test sections. This is significant because it shows that the increase in reported accidents is not comprised of mere fender-benders or fence-scrapers.

Accidents Involving the Median

Although head-on accidents were virtually eliminated by both types of barrier, in general there was a rise in accident rates where the barriers were installed on freeways having traffic volume less than 130,000 vehicles per day. One explanation would be that without a barrier many vehicles are able to encroach on the median without suffering a reportable accident, whereas after the barriers are installed, they strike a barrier. Table 4 gives the relation between the number of cars hitting the barrier and the rise in accidents when barriers are installed.

TABLE 4

PROPORTION OF INCREASE IN ACCIDENT RATES ACCOUNTED FOR BY ENCROACHMENT IN MEDIAN

Test Section	Barrier	Over-All Increase in Accidents (rate per MVM)	Accidents Involving Median: Before (rate per MVM)	Accidents Involving Median: After (rate per MVM)	Accidents Involving Median: Increase (rate per MVM)	Proportion of Increase [a] (%)
Santa Ana	Cable	0.22	0.17	0.33	0.16	73
	Beam	0.32	0.23	0.15	(0.08) [b]	0
Nimitz	Cable	0.39	0.22	0.53	0.31	80
	Beam	0.58	0.19	0.52	0.33	57

[a] Accounted for by accidents involving the median.
[b] Decrease.

In Table 4 a considerable proportion (57 to 80 percent) of the increase can be accounted for by collisions with the barrier except in the case of the Santa Ana beam section. Before reaching any conclusions, the over-all increase in the accident rate on the Santa Ana beam section was 50 percent greater than the increase on the Santa Ana cable section. The decrease in rate of accidents involving the median on the Santa Ana beam section is one of the inexplicable things frequently encountered when making a statistical study involving small numbers.

In events associated with barrier collisions, as Table 4 shows, a lot more drivers are getting involved with the median than before the barriers were erected. What the table does not show is the number of times the median was violated in the before period with no resulting accident.

There has been speculation that people are deliberately driving into the cable barrier on the theory that it is softer than the car ahead. In an effort to explore this possibility, Table 5 was prepared, classifying the accidents involving the barrier according to events preceding the collision. There is also a subjective classification in the right-hand two columns as to whether the vehicle was deliberately or involuntarily driven into the barrier. This classification represents the analyzer's judgment, based on reporting officer's opinion, statements by the drivers, and statements of witnesses, as well as on the events.

In addition to data on the test section of cable-chain link barrier, information is also included concerning a cable-chain link installation on the Ventura Freeway so as to point out certain differences probably influenced by different median design features.

From Table 5, the following points may be seen:

1. On the test sections, 58 percent of accidents involving the beam barrier were two-or-more-car accidents, whereas only 39 percent of accidents involving the cable barrier were two-or-more-car accidents. On the Ventura Freeway, only 20 percent involved more than one vehicle.

2. About one-fifth of the median barrier collisions were deliberate, a sort of "fielder's choice," in which the driver thought he was choosing the less severe consequences. This ratio was the same for the cable barriers as for the beam barriers, although on the Ventura Freeway only two "deliberate" swerves resulted in reported accidents. This freeway has 8-ft paved shoulders in the median, whereas the test sections on the Santa Ana and Nimitz Freeways have curbs and only a 6-ft half-width.

3. On the test sections, 86 percent of collisions with the beam barrier and 55 percent of collisions with the cable barrier were associated with maneuvers such as rear-end and sideswipe collisions or near-collisions.

4. On the test sections, 22 percent of the cable barrier collisions and 4 percent of the beam barrier collisions were due to erratic driving, drifting, and unknown reasons. Erratic driving refers to cars observed by witnesses to be driving erratically for some time before colliding with the barrier.

5. Unknown, miscellaneous, drifting, and sleep accidents (nearly all involving only one car) accounted for 19 of the 26 collisions with the cable barrier on the Ventura Freeway. This relatively high proportion is owing more to a lack of other kinds of accidents than to an excessive number of these kinds. The fact that there were only 7 accidents associated with rear-end and sideswipe maneuvers is probably attributable to the shoulders and absence of curbs. It was also determined that 16 of the 26 on the Ventura Freeway were at night.

TABLE

MEDIAN BARRIER ACCIDENTS CLASSIFIED BY ASSOCIATED EVENTS ONE

Barrier Type	Freeway	Single Vehicle		Multi-Vehicle		Avoid Rear-End Accidents: Deliberate Action		Avoid Rear-End Accidents: Lost Control		Unsafe Lane Change: Avoiding		Unsafe Lane Change: Making		Knocked into Barrier By: Sideswipe		Knocked into Barrier By: Rear-End	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Chain	Santa Ana	23		15		8		2		2		1		3		1	
	Nimitz	37		23		5		12		8		0		2		5	
	Total	60	61	38	39	13	13	14	15	10	10	1	1	5	5	6	6
	Ventura	21		5		2		0		1		0		2		2	
Beam	Santa Ana	5		7		1		5		2		1		1		0	
	Nimitz	16		22		7		11		5		0		2		5	
	Total	21	42	29	58	8	16	16	32	7	14	1	2	3	6	5	10

[1] Because of sleep, drink, inattention, etc.

Repeated crash tests demonstrated conclusively that when a car collides with the cable barrier there is far less shock and that there should be far fewer injuries for a given number of barrier collisions. The first year's experience on the test sections is given in Table 6.

Contrary to expectation, experience of one year does not show conclusively that collisions with the cable barrier are less severe than with the beam. Observations and actual measurements of test crashes showed that deceleration rates, which are closely related to injury potential, are significantly less with the cable. There were so few serious injuries involving collisions with either type that it is believed the measured evidence of physical tests outweighs the statistical evidence, in which chance plays a major part.

Maintenance records show that the number of repairs of the cable barrier greatly exceeds the number of reported accidents involving the barrier. On the other hand, there have been reported accidents involving the beam barrier that did not require repairs.

Table 7 shows that collisions were much more likely to damage the cable barrier, and that for a given number of reportable accidents there is more disruption to traffic caused by barrier repairs, as well as additional maintenance cost. It does not necessarily show that there were more drive-away or hit-and-run collisions with either type, but it does show definitely that about one-third of the collisions with the cable barrier were so minor that the vehicles were able to drive away.

Construction and Maintenance Costs

Initial Cost.—By the end of the 1960-61 fiscal year, approximately 49 mi of barrier had been installed. Average unit prices for the barriers are given in Table 8. The unit price of beam barrier was 2.6 times that of the cable barrier. In later contracts, the unit price of cable barriers has declined.

Maintenance Costs.—Maintenance costs of the two types of barrier during the 1-yr period after construction are given in Table 9. The average yearly cost of repair is given in

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YEAR AFTER CONSTRUCTION, TEST SECTIONS AND VENTURA FREEWAY

Ran into Barrier After: Side swipe No.	%	Ran into Barrier After: Rear-End No.	%	Erratic Driver No.	%	Drifted into Barrier[1] No.	%	Misc. No.	%	Unknown No.	%	Deliberate Action No.	%	Involuntary Action No.	%	Total Accidents No.	%
1		3		2		2		8		5		11		27		38	
0		1		8		3		14		2		11		49		60	
1	1	4	4	10	10	5	5	22	23	7	7	22	22	76	78	98	100
0		0		1		5		4		9		2		24		26	
0		1		0		0		0		1		2		10		12	
0		2		0		1		5		0		10		28		38	
0	—	3	6	0	—	1	2	5	10	1	2	12	24	38	76	50	100

TABLE 6

SEVERITY OF REPORTED ACCIDENTS INVOLVING MEDIAN BARRIERS

Test Section	Barrier	No. of Vehicles Colliding with Barrier	No. of Collisions Involving Injuries: Serious	Minor Wounds, Contusions	Total	Fatal Accidents: No.	Type
Santa Ana	Beam	12	0	3	3	0	
	Cable	38	3	9	12	1	Cross-median, head-on
Nimitz	Beam	38	7	11	18	2	1 suicide, 1 truck driver ejected when truck hit barrier
	Cable	60	8	19	27	2	1 motorcycle, 1 spinning car, occupants ejected

TABLE 7

COMPARISON OF REPORTED ACCIDENTS WITH BARRIER REPAIRS

Test Section	Barrier	No. of Accidents Reported	No. of Repairs
Santa Ana	Beam	12	25
	Cable	38	60
Nimitz	Beam	38	37
	Cable	60	91

TABLE 8

Barrier	Cost of Barrier ($): Per Lin Ft	Per Mi
Single metal beam	5.84	30,700
Double metal beam	8.31	43,800
Double metal beam on steel posts (structures)	14.53	—
Cable-chain link	3.25	17,100

terms of cost per mile, cost per accident, and cost per million vehicle-miles of travel or exposure. The unusually large cost per mile for the beam barrier on the Nimitz Freeway was due to the two accidents involving truck-trailer combinations.

The annual cost per mile of $2,078

TABLE 9

COST OF BARRIER REPAIRS FOR ONE YEAR AS REPORTED BY MAINTENANCE DEPARTMENT

Barrier	Freeway	Length (ft)	Million Vehicle-Miles	No. of Repairs	Cost ($)			
					Total for One Year	Per Repair	Per Mile-Year	Per MVM
Chain	Nimitz	3.87	131.65	91	6,879.53	75.60	1,777.66	52.26
	Santa Ana	3.17	117.21	60	7,848.16	130.80	2,475.76	66.96
	Subtotal	7.04	248.86	151	14,727.69	97.53	2,092.00	59.18
	Ventura	2.35	78.06	43	4,782.00	111.21	2,034.89	61.26
	Total	9.39	326.92	194	19,509.69 [1]	100.57	2,077.71	59.68
Beam	Nimitz	2.87	101.30	37	3,658.41	98.88	1,274.71	36.11
	Santa Ana	3.29	127.66	21	1,205.26	57.45	366.20	9.50
	Subtotal	6.16	228.96	58	4,863.67	83.90	780.00	21.25
	Bayshore	1.43	53.42	4	599.88	149.97	419.50	11.23
	Total	7.59	282.38	62	5,463.55 [1]	88.10	720.00	19.35

[1] Approximately 60 percent of this recovered from vehicle owners whose cars damaged barrier.

for the cable barrier was 2.9 times the $720 per mi cost of the beam barrier. With a $1,358 per mi difference in the annual cost of barrier repairs, it requires 19½ yr for the damage cost of the fence barrier to equal the difference in construction cost between the two barriers. However, approximately 60 percent of the damage costs have been recovered, hence the actual difference in the maintenance costs to the State was $540 per mi.

At $540 per mi per yr, it would require 49½ yr to make up the difference of $26,700 per mi in initial cost.

More important than cost is the hazard to both maintenance workers and the traveling public of continual maintenance in the median. There is also a certain amount of congestion caused by such operations. In this regard, comparison of the two types should include the bulkiness of equipment and size of crew required, the time per job, as well as the number of repairs required. The width of median is also important in this respect.

This report covers a limited amount of experience acquired during the year following initiation of the barrier construction program. Although there are indications regarding the effectiveness of the barriers, both in preventing cross-median head-on collisions and in increasing over-all accident rates, the experience so far should be interpreted with caution and only tentative conclusions should be made at this time. Additional data are being accumulated covering more extensive sections of barriers over a greater period of time. It is planned to continue the investigation. In the meantime, barriers are being installed on all 8-lane freeways and on freeways where the average daily traffic exceeds 60,000 per day. It has been shown in the 1959 study and confirmed by 1960 experience that four-fifths of all the cross-median head-on fatal accidents occur on these high-volume freeways.

OPERATIONAL FAILURES

Special detail studies were made from time to time of all accidents, as well as of each accident where vehicles passed over, went through, or climbed the barriers. These observations were made of accidents with all installations of the new designs of median barriers rather than only on the test sections.

Over all, during the past year three vehicles passed over new designs of barriers, three went through, and one came to rest on top of a barrier. The three crossovers all involved cable barrier. Two of these were the result of jumps due to causes unrelated to the cable barrier and therefore could have occurred over any 30-in. high barrier. One was the result of the vehicle hitting a curb and jumping high enough to clear the barrier cable. The second was a high-speed vehicle that jumped over the barrier after leaving the road on the outside of a curve. The barrier in this case was placed in a low ditch section where the roadway had been rotated to provide for superelevation. This provided the car with an inclined ramp from which to jump.

The third crossover and also the case of the vehicle coming to rest on top of the barrier also occurred on cable-chain link designs. The cause was the same in both cases. The original cable barrier design called for a tension cable attached 9 in. above the ground, and that the chain link fabric be firmly clamped between the lower cable and the post. In both of these accidents and in many others resulting in only partial climbing, it was found that the vehicles approached at a low angle (less than 15 deg) and high speed. Under these conditions of impact, a post and the firmly secured chain-link fabric, combined with the lower cable, served as a ramp for the front colliding wheel to get started in an upward direction. Such a start often elevated the automobile before the car body had an opportunity to penetrate the barrier far enough to provide for restraint by the top cable. Thus the car tended to ride the barrier down.

Two of the penetration-type accidents involved trucks colliding with the blocked-out metal beam barrier and resulted in a complete failure of the system. The third penetration involved a small sports car hitting the cable barrier between posts at a high angle of collision and passing between the lower and upper cables. This car had a front end clearance of 29 in. and an over-all height of 33 in., exclusive of the windshield.

A careful analysis of the above barrier crossovers indicates that they could be divided into two categories: one group that probably could be precluded by improvements in design and another that reasonably could not be prevented by a physical barrier. For instance, in the case where the vehicle hit the curb, the car apparently jumped higher than the 30 in. necessary to clear the barrier cable. Because cars have been reported, as a result of accidents, to have jumped as high as 8 to 10 ft and in other cases to have cartwheeled, it would not be reasonable to build a barrier high enough to contain every chance accident that might occur.

Because of the required strength involved, it is also not considered practical to design a barrier that will effectively and completely resist the collision of the heaviest trucks. In the two failures on beam barriers that occurred during this past year, the barrier was completely destroyed within the collision area. However, in neither case did the truck penetrate more than a few feet onto the opposing roadway. In other words, even in failure the barriers provided sufficient resistance so as reasonably to contain the vehicles.

The third penetration was an accident unique to the cable barrier in that very small sports cars can penetrate below the top barrier cable under conditions where the angle of collision is relatively high (over 30 deg). At smaller angles of collision it is probable that the fence post combined with the cable would still function as a positive barrier against penetration of this type of car.

Analysis of the above failures indicated that the beam barrier was functioning about as well as could be expected; however, it appeared that further development work should be done on the cable barrier. Studies indicated that it should be possible to make improvements to prevent the tendency of cars to climb the barrier and also that it would be worthwhile to investigate the possible prevention of penetration by sports cars.

The accident in which the car jumped the barrier after leaving the outside of a curve showed that further information should be gathered concerning the effect of differences of grade and elevation on the trajectory of a moving vehicle. Such information could be used to determine the placement of a barrier.

Maintenance of the cable barrier showed certain improvements of details to be desirable. Most of the effort during maintenance was expended in replacing the posts and concrete footings, so this detail was worthwhile of redesign. With one exception, no problems were encountered in maintaining the cables. In one case of collision with the cable barrier, it was necessary to cut the cable so as to remove the vehicle (in this case the vehicle was a truck-trailer combination). This break was repaired by a cable splice using cable clamps and presented no real problem.

CONTROLLED COLLISION TESTS

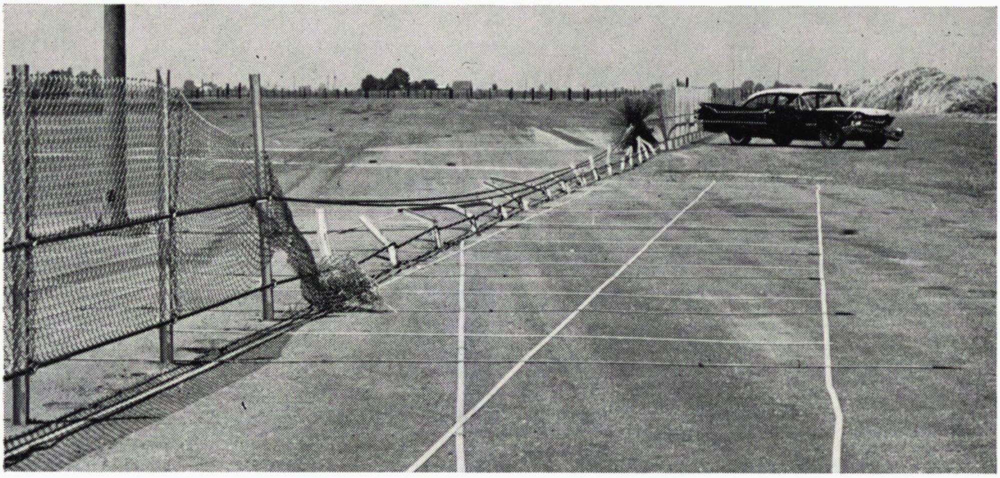
To develop details to correct the discussed failures, the nine tests were performed. In addition to testing corrective details, certain substitute details were also tested: (a) alternate post footings, (b) highway guardrail-type cable, (c) alternate cable turnbuckles, (d) cable splices, and (e) expanded metal light screen. Exhibit 3 (Appendix) shows the different footings tested and Exhibit 1 shows the over-all test site layout. Exhibits 4 through 12 give the pertinent facts concerning each test.

ANALYSIS OF CONTROLLED TESTS

A crossover type of accident considered intolerable is one where the vehicle climbs the side of a cable barrier and knocks it down as the vehicle passes on over. This type of accident is unique to the cable barrier. As stated previously, analysis of this type of crossover indicated that it was the result of a deficiency in the details of design rather than in the basic flexible barrier concept. Controlled collision tests for the purpose of analyzing these deficiencies were made at flat angles and high speed; first on the original design (Test 1), altered only by moving the chain link fabric outside the lower cables, and then by elimination of the lower cable entirely as in all tests following Test 1, except Test 7.

Elimination of the chain link fabric from the lower cable clamps resulted in an improvement in the action. However, high speed moving pictures revealed that the lower cable alone gave the left front end of the car an upward impetus as the front colliding wheel passed over the junction of the cable and the post. Thus, under certain circumstances it would be possible for the car to continue on upward. Removal of the lower cable resulted in penetration of the barrier by the vehicle with no tendency toward upward movement and no loss in barrier action. Post collision investigation of details of the damaged test barriers indicated that the elimination of the lower cable resulted in no loss of barrier effectiveness but did cause a slight loss in stiffness of the system behind the collision. However, any barrier damage due to this loss of rigidity was insignificant.

One of the original design considerations in placing the lower cable in the system was that it would serve



TEST NO. 1

Fabric: Chain link on impact side of barrier. Fabric under top cable but not contained under bottom cable.

Cables: 3 each 3/4 inch - 6 x 19 IWRC - 1 @ 9 inches and 2 @ 30 inches above pavement.

Post Footing: Type "A" 8 inch x 30 inch PCC (See Exhibit 3)

Purpose: To test current design for correlation with previous test series (1959). This test was also an attempt to duplicate the climbing that has occurred on the Ventura Freeway.

Performance: See Exhibit 4. Left front wheel raised 14 inches off pavement while climbing over lower cable. A slight yawing occurred near end of run with a violent 180° "spin out" approximately 100 feet from impact.

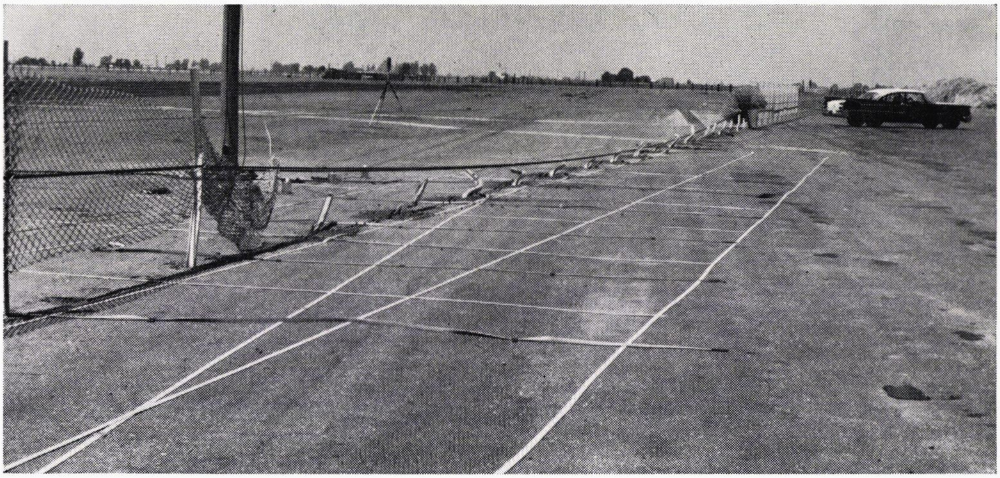
Maximum encroachment on traveled side: 21 feet.

Maximum encroachment on opposing side: 5½ feet.

Opposing side 4 foot or more encroachment for 6/10 seconds.

Opposing side 5 foot or more encroachment for 3/10 seconds.

Barrier Damage: Approximately 130 feet of mesh gathered up between top cables at point of spin-out. No cable fitting damage or failures. Damage was typical of that recorded during 1959 test series. Slight cracking of post footings was result of "green" concrete. No posts pulled out of footings. There was no appreciable movement of the post footings.



TEST NO. 2

Fabric: Chain link on impact side of barrier. "U" of cable clamp on impact side. Fabric contained under cable.

Cable: 2 each 3/4 inch - 6 x 19 IWRC @ 30 inches above pavement.

Post Footing: Type "A" 8 inch x 30 inch PCC (See Exhibit 3).

Purpose: To test current design with deletion of bottom cable. All other parameters same as Test No. 1.

Performance: See Exhibit 5. All wheels remained on pavement throughout run. A slight yawing occurred 30 feet before a violent 280° "spin out" approximately 110 feet from impact.

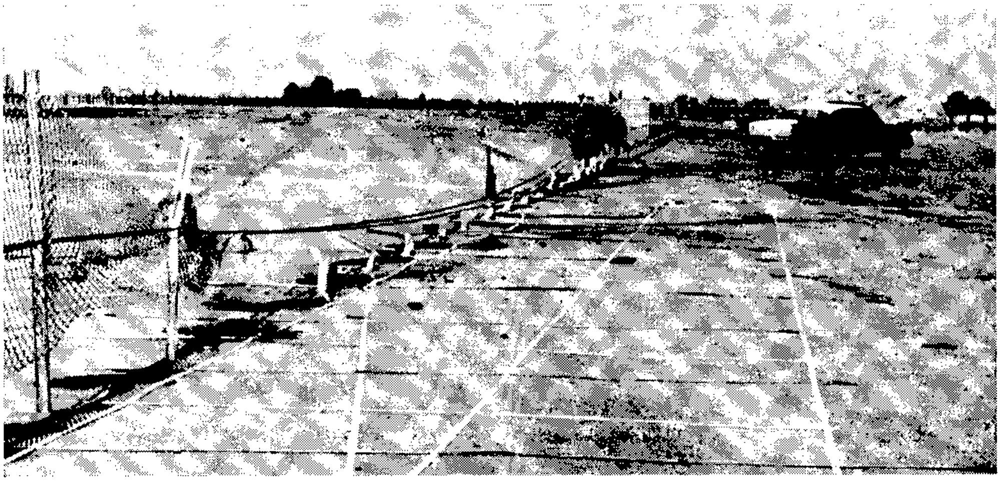
Maximum encroachment on traveled side: 29 feet.

Maximum encroachment on opposing side: 5½ feet.

Opposing side 4 foot or more encroachment for 6/10 seconds.

Opposing side 5 foot or more encroachment for 5/10 seconds.

Barrier Damage: Approximately 130 feet of mesh gathered up between cables at point of "spin out". Fabric and post damage was very similar to that of Test No. 1. Slight cracking of post footings was result of "green" concrete. No posts pulled out of footings. There was no appreciable movement of the post footings.



TEST NO. 3

Fabric: Chain link on impact side of barrier. "U" of cable clamp on impact side. Fabric contained under cable.

Cable: 2 each 3/4 inch - 6 x 19 IWRC @ 30 inches above pavement.

Post Footing: Type "D" Sheet Metal socket in PCC with 12 inch long wood wedge (See Exhibit 3).

Purpose: To test "2 cable" design with socket type post footings. All other parameters same as Test No. 2

Performance: See Exhibit 6. All wheels remained on pavement throughout run. No appreciable yawing. Violent 300° "spin-out" occurred approximately 125 feet from impact. Second post ahead of impact was pulled out of socket and carried down cables to point of "spin-out". Cable clamp was not completely stripped from post.

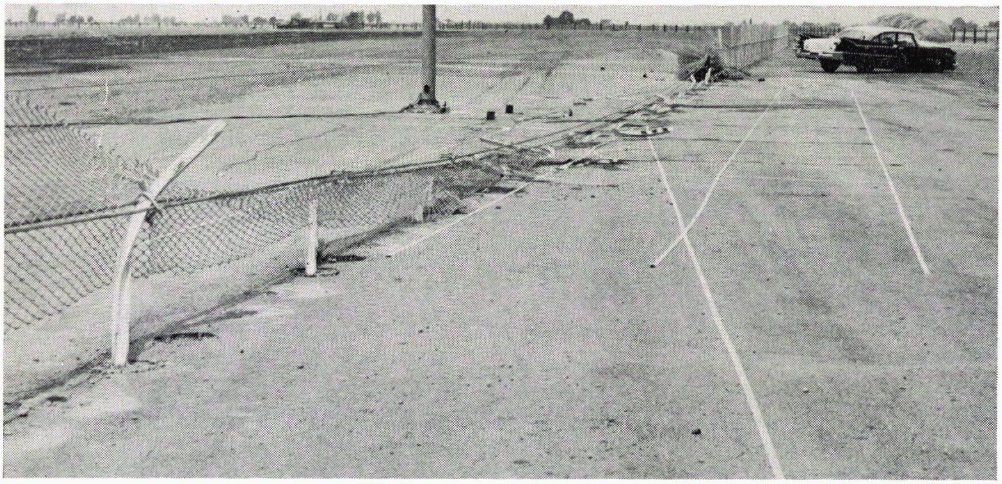
Maximum encroachment on traveled side: 23 feet.

Maximum encroachment on opposing side: 6 feet.

Opposing side 4 foot or more encroachment for 9/10 seconds.

Opposing side 5 foot encroachment for 6/10 seconds.

Barrier Damage: Approximately 125 feet of mesh gathered up between cables at point of spin-out. Fabric and post damage was very similar to that of Tests No. 1 and 2. One post pulled out of socket footing. Twenty posts pulled between 1/2 inch and 2 inches out of sockets. Slight cracking of footings was not severe enough to prevent re-use on Test No. 5.



TEST NO. 4

Fabric: Chain link and "U" of cable clamps on opposite side from impact. Fabric contained under cable.

Cable: 2 each 3/4 inch - 7 x 7 Highway Guard Cable @ 30 inches above pavement.

Post Footing: Type "C" 8 inch x 12 inch PCC (see Exhibit 3).

Cable Fittings: 2 each Type II Pipe Turnbuckles with swaged pulls located 100 feet ahead of point of impact.

Purpose: To compare with Tests No. 1, 2, and 3, the effect of collision with fabric fastened on opposite side from impact. To compare retention efficiency of 12 inch deep post footing with that of the 30 inch post footing. To compare susceptibility to jamming of cable clamps on pipe type turnbuckle with previous (1959) tests on Type I drop forged turnbuckles (see Exhibit 2).

Performance: See Exhibit 7. All wheels remained on pavement until spin-out. Fabric and clamps jammed at turnbuckle, tearing entire front fender off vehicle. Violent 270° "spin out" at 115 feet from impact. During first part of spin, left side of car raised 18 inches. Right front of car tore next to last post out of footing and stripped it from the cables. No yawing occurred during run.

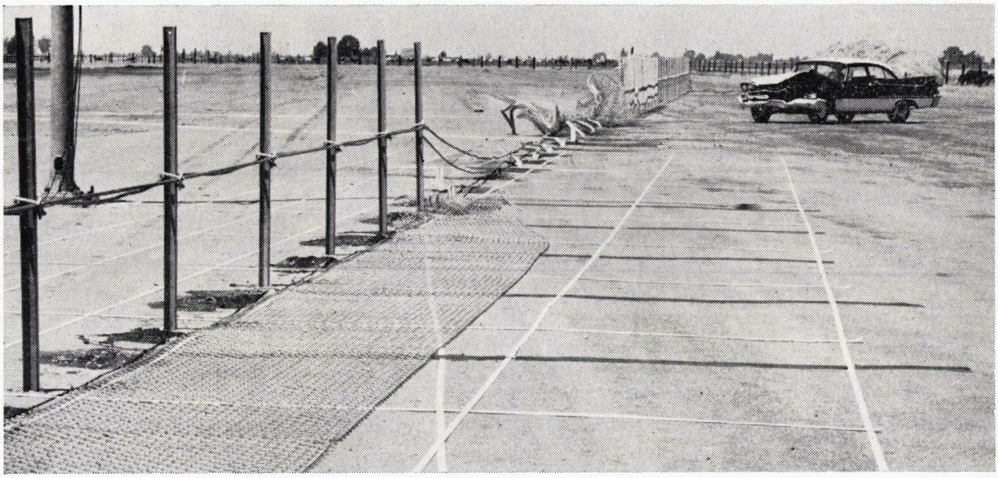
Maximum encroachment on traveled side: 19 feet.

Maximum encroachment on opposing side: 6 feet.

Opposing side 4 foot or more encroachment for 5/10 seconds.

Opposing side 6 foot or more encroachment for 1/10 seconds.

Barrier Damage: Approximately 90 feet of fabric gathered up between cables at point of "spin out". There was no failure of the turnbuckles; however, the cable was badly kinked adjacent to the cable pull on the front turnbuckle (impact side) and also 10 feet ahead of point of spin-out where post had pulled out of footing. Footing failure and cracked footings were result of "green" concrete.



TEST NO. 5

Fabric: Chain link on impact side of barrier. "U" of cable clamps on opposite side. Fabric not contained by cable.

Cable: 2 each 3/4 inch - 7 x 7 Highway Guard Cable @ 30 inches above pavement.

Post Footing: Type "D" Sheet metal socket with 3/4 inch x 2 inch x 24 inch wood wedges. (See Exhibit 3).

Cable Fittings: 2 each Type II Pipe Turnbuckles located 50 feet (impact side) and 58 feet (opposite side) ahead of point of impact. Preformed dead-end on each cable 100 feet behind point of impact.

Purpose: Repeat test on Type II Pipe Turnbuckles with fabric outside of cable not contained by cable or clamps. Also a repeat test on the socket type post footing with a longer wood wedge in an attempt to retain posts in sockets.

Performance: See Exhibit 8. Car started "spin-out" approximately 70 feet from point of impact due to posts #2 and #3 pulling out of sockets and jamming at the second turnbuckle located 58 feet ahead of impact. Posts, clamps and fabric passed over first turnbuckle located 50 feet ahead of impact and jammed on second turnbuckle. The vehicle carried entire bundle 10 feet further as dead-end located 100 feet behind point of impact failed. Fabric fastened with 12 gage steel tie wires was torn from posts for 70 feet behind point of impact and fell to pavement.

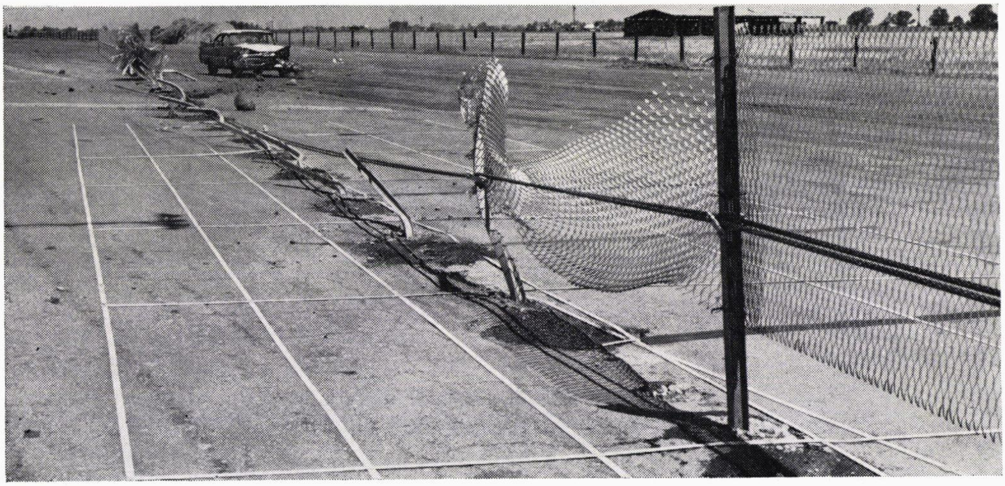
Maximum encroachment on traveled side: 24 feet.

Maximum encroachment on opposing side: 7 feet.

Opposing side 4 foot or more encroachment for 5/10 seconds.

Opposing side 6 foot or more encroachment for 2/10 seconds.

Barrier Damage: Preformed dead-end failed under extreme loading caused by posts and clamps jamming on turnbuckle. The dead-end had been removed from a cable used on a previous installation. During removal, a critical amount of aluminum oxide coating was stripped from the inside of the weave resulting in insufficient friction for the assembly to retain the cable under normal collision loads. Socket type post footings from Test No. 3 were re-used for this test. No additional cracking was noted.



TEST NO. 6

Fabric: Expanded steel mesh on impact side of barrier. "U" of cable clamp on impact side. Fabric not contained by cables. Fabric 18 gage galvanized steel, 1.33 inch x 3 inch diamond, 8 foot 4 inch x 42 inch panels.

Cable: 2 each 3/4 inch - 6 x 19 IWRC @ 30 inches above pavement.

Post Footing: Type "C" 8 inch x 12 inch PCC (see Exhibit 3).

Purpose: To test effectiveness during collision of expanded metal fabric compared to previous tests on chain link fabric. Also a re-test on the 8 inch x 12 inch concrete collar type post footing.

Performance: See Exhibit 9. All wheels remained on pavement throughout run with a very slight yawing of vehicle. Post No. 11 pulled out of footing; however, there was no measurable change in vehicle reaction when compared to Test No. 2 on 8 inch x 30 inch PCC footings. The expanded metal fabric reacted very similarly to chain link fabric under identical collision conditions. Very smooth deceleration to 160^{o} spin-out at approximately 80 feet from impact.

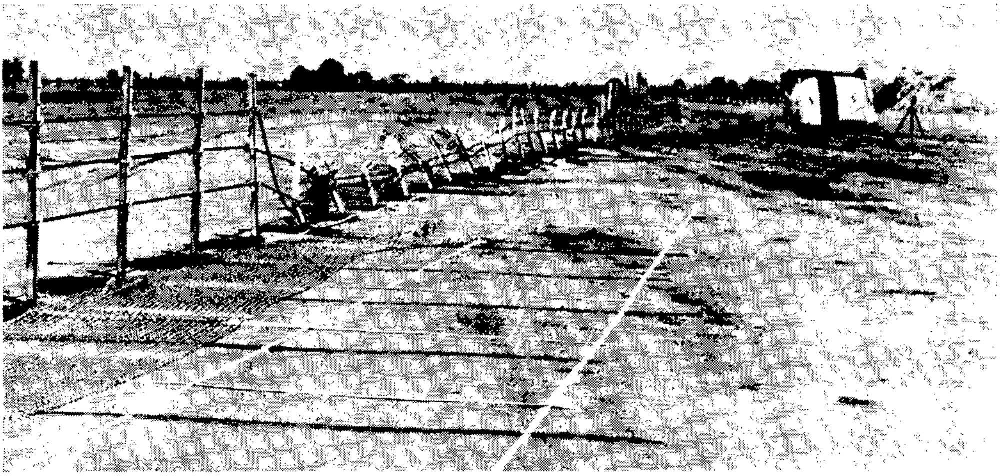
Maximum encroachment on traveled side: 18 feet.

Maximum encroachment on opposing side: 6 feet.

Opposing side 4 foot encroachment for 4/10 seconds.

Opposing side 5 foot encroachment for 3/10 seconds.

Barrier Damage: Fourteen panels (112 feet) of expanded metal gathered up at point of spin out. The severe cracking of all post footings in the collision zone and complete failure of one was due to "green" concrete.



TEST NO. 7

Fabric: Chain link on impact side of barrier. Fabric not contained by cable. "U" of clamp on impact side.

Cable: 3 each 3/4 inch - 6 x 19 IWRC @ 20 inches, 32 inches, and 44 inches above pavement.

Post Footing: Type "D" sheet metal socket in PCC with 3/4 inch x 2 inch x 24 inch wooden wedges. Voids filled with 200-300 pen. asphalt. (See Exhibit 3)

Cable Fittings: 3 each preformed cable splices 125 feet ahead of point of impact.

Purpose: To compare the efficiency of 3 cables at different heights with that of the preceeding tests on 2 cables at the same height. To test the retention of the posts in sockets by the addition of paving asphalt.

Performance: See Exhibit 10. The vehicle crossed the two bottom cables approximately 10 feet from point of impact and was retained by the top cable for 130 feet. All wheels were clear of the pavement for 80 feet. At a point 100 feet from impact, the vehicle was nose down on the left front wheel, rolling to an angle of 45 degrees and yawing to the left at a 30° angle. High speed data films show evidence that the compressed tire and spring of the front suspension, added to the lateral energy stored in the deflected cable, was impetus for the final roll of the vehicle in a direction opposite to that attained at the point of spin out.

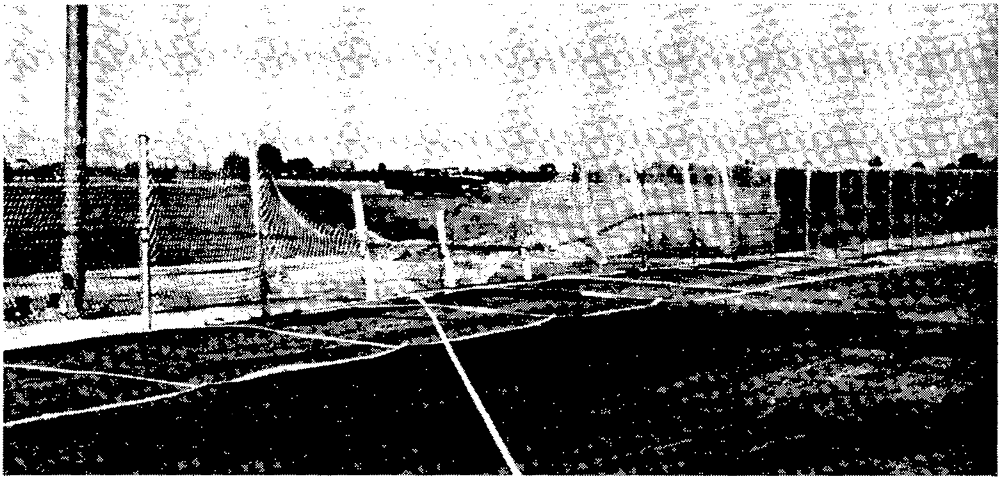
Maximum encroachment on traveled side: 18 feet.

Maximum encroachment on opposing side: 5½ feet.

Opposing side 4 foot encroachment for 1-1/10 seconds.

Opposing side 5 foot encroachment for 1/10 seconds.

Barrier Damage: The preformed cable splice located 125 feet ahead of impact failed as the windshield post sliding along the cable passed the frayed ends of the splice. At this location, the failure had no appreciable effect on the vehicle reaction; however, had the splice been installed 20 feet closer to the point of impact, the vehicle would have rolled over the barrier as the splice released.



TEST NO. 8

Fabric: Chain link on impact side of barrier. "U" of cable clamps on impact side. Fabric not contained by cables.

Cable: 2 each 3/4 inch - 6 x 19 IWRC @ 30 inches above slope grade, 18 inches above crown of ramp.

Post Footing: Type "B" sheet metal socket with 200-300 pen. asphalt. (See Exhibit 3)

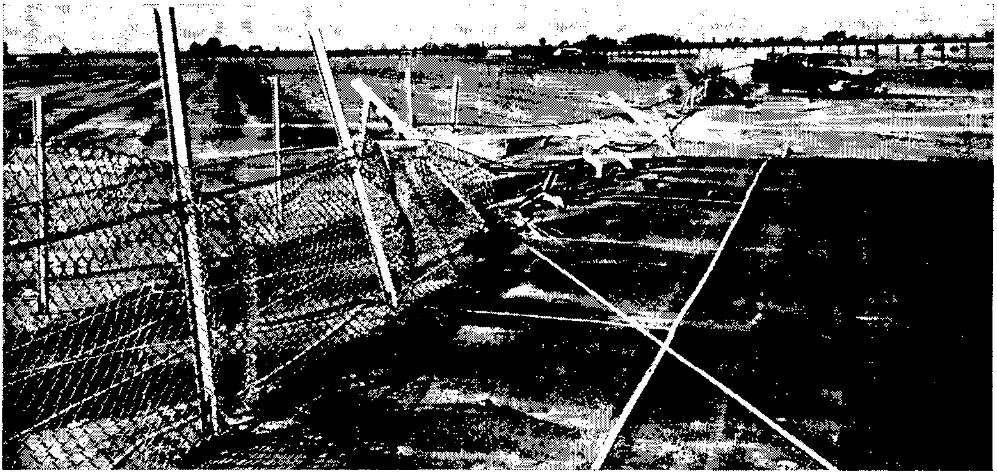
Cable Anchor: 3 foot diameter x 2 foot deep PCC.

Top Tension Wire: 7 gage spring steel wire 57 inches above slope grade.

Purpose: To test for retention of vehicle on a simulated 8 degree super-elevated curve with 6:1 side slope in the median.

Performance: See Exhibit 11. The vehicle left the crown of the ramp and traveled airborne 17 feet to point of impact. Data films show that the vehicle had dropped only 2 inches along the trajectory from the crown of the ramp to the barrier. At the point of impact, the cables were below the center of the bumper at an effective height of 20 inches. The bumper contacted the post forcing it back and down and the cable was carried down with the post. The left front tire contacted the barrier at an intersection of post and cable further forcing the cable down and rolling over with no tendency to snag. As the vehicle progressed across the barrier each wheel was successively forced into its wheel well. There was no tendency for any part of the vehicle to snag on the cables. The 7 gage tension wire cracked the top of the windshield before failing at the 3/8 inch turnbuckle located 150 feet behind the point of impact.

Barrier Damage: Post collision height of cables at point of impact was approximately 8 inches above the crown elevation of the simulated super. No post footings were cracked.



TEST NO. 9

Fabric: Chain link on impact side of barrier. "U" of cable clamps facing impact. Fabric not contained by cable.

Cable: One 3/4 inch - 6 x 19 IWRC @ 30 inches above crown of superelevated ramp. Cable on impact side of barrier.

Post Footing: Type "B" sheet metal socket filled with 200-300 pen. asphalt (see Exhibit 3)

Cable Anchor: 3 foot diameter x 2 foot deep PCC.

Tension Wire: 7 gage spring steel @ 58 inches above crown of ramp.

Purpose:

1. To retest vehicle retention on an 8% superelevated curve by moving the barrier constructed for Test No. 8 to within 1 foot of the crown and placing the cable at 30 inches above a horizontal projection of the superelevation crown.
2. To determine the encroachment on the opposing side when barrier is constructed with a single cable.
3. To test the efficiency of the single cable envelope barrier design as a possible alternate method of construction on superelevated curves having a sloped center drainage ditch.

Maximum encroachment on traveled side: 16 feet

Maximum encroachment on opposing side: 12 feet

Opposing side 10 foot encroachment for 4/10 seconds: Measured from centerline of front cable.

Opposing side 2 foot encroachment for 2/10 seconds: Measured from centerline of rear cable.

Performance: At point of impact the cable made contact with the vehicle between the headlight and bumper and was contained in the fender over the front left wheel as it progressed through collision. The vehicle continued level and airborne as it left the ramp in a trajectory similar to that of Test No. 8 for approximately 20 feet. The snubbing action of the cable forced the front of the car down just prior to contact with the rear cable in the envelope design. The vehicle continued through collision snubbed nose-down by the front and rear cables through the transition of single cables to double cables with a very smooth deceleration to 180° spin-out at approximately 130 feet from point of impact.

Barrier Damage: 125 feet of fabric was gathered up at point of spin out. Seven post footings were cracked due to "green" PCC. None of the posts were moved from the asphalt filled sockets.

to trap the car in the median area as it attempted to return to the on-side roadway at the end of the collision path. Operation experience showed that at a flat angle of collision, whether or not the lower cable was in position, the car tended to spin at the end of the collision path back into the traveled lane. This was verified by test collisions. A review of the accident reports from both the Nimitz and the Santa Ana test sections indicated that this vehicle reaction was typical of a majority of the collisions that occurred on the freeway and that in no case had a secondary collision resulted from this spin-out.

Two other details of construction were tested and adopted as a result of these studies. The original design called for a standard turnbuckle every 500 ft along the cable. Because the smoothness of deceleration of the colliding vehicle with the cable-chain link barrier depends primarily on the friction brake effect of the cable clamps stripping from the posts, it is important that this action proceed unhindered if possible. Test 4 showed that when the test collision vehicle progressed along the cable through a turnbuckle, the clamps and the contained mesh jammed at the turnbuckle. This resulted in an abrupt deceleration and violent spin-out of the colliding vehicle. This defect was also illustrated by the General Motors (*3*) tests of 1960.

Tests 4 and 5 were made to judge the effect of repositioning chain link fabric outside the cables. This design eliminated binding, and at the same time the removal of the chain link to the outside of the cable had no appreciable effect on the rate of deceleration of the car.

As was originally anticipated, the cable-chain link barrier on the Nimitz and Santa Ana test sections were subjected to a great deal of collision damage. The Maintenance Department found the most costly single item was the removal and replacement of the steel posts and their concrete footings. In addition to replacing the concrete and post, it was necessary for the posts to set in the new footings for at least 24 hr before the cable and chain link could be rehung on the post. This required two trips under heavy traffic conditions. It was decided that, if economically feasible, a post socket design or an otherwise modified footing could solve this problem.

Two designs were developed and successively tested. One was a concrete collar around the upper 1 ft of the footing and the second a socket in a full depth footing. In the first, the principle was that the earth below the collar would furnish support for the barrier while the collar was curing. Thus the barrier fabric and cable could be re-erected immediately.

In two test collisions, the concrete collar-type footing was used and in five the socket type.

The collar-type footing proved adequate. However, several of the footings broke during collision. It was therefore necessary to remove the concrete piecemeal before backfilling the hole and redrilling for the new footing. Though this design proved adequate, it is considered practical only for locations where the soil is fairly tight and free of rocks.

Several methods of holding the posts in the sockets were considered. Among these were the use of steel wedges, bolts, set screws, wood wedges, sand (plain and also topped with sulfur), sulfur, and asphalt. All were discarded in favor of asphalt. However, it was considered necessary to determine the minimum restraint needed to keep the post in place during collision. Therefore, tests were made using an oversize socket with the posts held in place only with wooden wedges (Tests 3 and 5). In each of these two tests at least one post pulled out.

Analysis of the pictures indicates

that during the early part of a collision, the posts are subjected to a substantial vertical force. Sufficient resistance must be offered to prevent uplift of the posts during this period of vertical loading.

These two tests proved that wooden wedges alone provided insufficient resistance. Therefore, because sand has little or no internal resistance, it also was discarded. Steel wedges, throughbolt or set screws could be made to work but were discarded because of cost and possibility of jamming. Sulfur would also work but was discarded because of potential corrosion in addition to the difficulty of cleanout or reheating of the sulfur during repair.

After completing tests using wooden wedges alone, the sockets were filled with asphalt which in Tests 7, 8, and 9 proved to be adequate. Tests 8 and 9 used sockets that fit the posts, but the socket for Test 7 was oversized with the space taken up by a wooden wedge. Grade 200-300 paving asphalt was chosen. Asphalt proved able to resist the shock loading with no movement. At the same time, the damaged post could be removed by a slow pull and a new post placed by slow pressure. In a controlled laboratory test, it was found that a pull of 700 lb was necessary to remove a post from an asphalt-filled socket when tested at 0 F. It took 1 min to complete the removal.

Of particular interest are Tests 8 and 9. Here a cross-section of highway found on many California freeways was simulated in which an 8 percent superelevation intersected a 6:1 sloped center drainage ditch. Actual barrier installations have been placed in the center of the ditch which is coincident with the centerline of the freeway median area, with the thought that the cars on a collision course would follow the 6:1 side slope down to the barrier. Test 8 showed that when the barrier was 6 ft away from the edge of the shoulder at the bottom of the simulated ditch, the car traveling at a 20-deg angle of collision would pass on over the barrier. After a study of the car's trajectory this was remedied in Test 9 by duplicating the previous test conditions but moving the barrier up the slope of the ditch to within 1 ft of the edge of the simulated shoulder, thus giving the car an opportunity to penetrate the barrier and become engaged under the cable.

Analysis of the trajectory of the car in the pictures of Test 8 indicates that a barrier to be effective should be placed no lower than 27 in. above a horizontal projection from the top edge of an approaching 8 percent grade. This is about the maximum superelevation that will be encountered in roads that justify the use of median barriers. The best solution for this condition is to place the barrier at the top or before the top of the superelevation. If it is necessary to place the barrier on the ditch side of the cross-slope, then the barrier cable should be no lower than 27 in. above the crown nor higher than 33 in. above the ground surface.

Test 6 used expanded steel mesh instead of chain-link fabric. No difference in barrier action was noted. However, first cost and maintenance costs of the expanded fabric will be markedly higher than for the chain link-fabric. This is due primarily to the higher first cost of the expanded metal, but it will also be affected by the fact that this material is furnished at present only in short panels.

In Tests 4 and 5 the use of 7 by 7 highway guard cable was substituted for the 6 by 19 IWRC cable usually used. This 7 by 7 cable was more difficult to handle during repairs and placement. In addition its cross-section did not lend itself to proper adjustment during the tightening of the cable to post clamps. In general these tests seemed to indicate that the

TABLE 10

Camera No.	Type	Rate (frames/sec)	Lens	Location
1	Fastax	1,200	12.5-mm	100 ft behind barrier
2	Photosonics	400	12.5-mm	Tower covering preimpact
3	Photosonics	400	12.5-mm	Tower covering impact
4	Photosonics	400	12.5-mm	Tower covering post impact
5	Photosonics	400	4-in.	Rear ground mount
6	Photosonics	400	4-in.	Front ground mount
7	Photosonics	400	12.5-mm	In crash vehicle
8	Photosonics	400	1-in.	Rear platform

cross-section and relative stiffness of the 7 by 7 cable to the 6 by 19 cable make the latter cable more desirable for use as a flexible barrier member.

TEST PROCEDURE AND INSTRUMENTATION OF TEST COLLISIONS

With the exception of the type of the cars, and speed and angle of approach, this series of tests was conducted in the same manner as the full-scale tests reported in 1960 (*1*).

So as to simulate more nearly the type of accident that seemed to cause problems with the cable barrier, heavier cars (over 4,000 lb) driven at higher speeds (over 80 mph) and colliding at flatter angles (10 deg or less) were used.

Because this series of tests was designed to test refinements of design rather than the over-all effectiveness of the barriers, the instrumentation was not as complex as that previously used. Decelerations were determined from an analysis of the high-speed data films rather than from decelerometers mounted in the vehicle and the dummy.

The anthropometric dummy was unrestrained, and his movements through collision were observed by a high-speed data camera mounted inside the vehicle.

The photographic instrumentation was approximately as used previously, except that the cameras differed from those listed in the previous test (*1*). The 16-mm data cameras gave 100 percent reliability rather than the 25 to 50 percent reliability obtained in the past (Table 10).

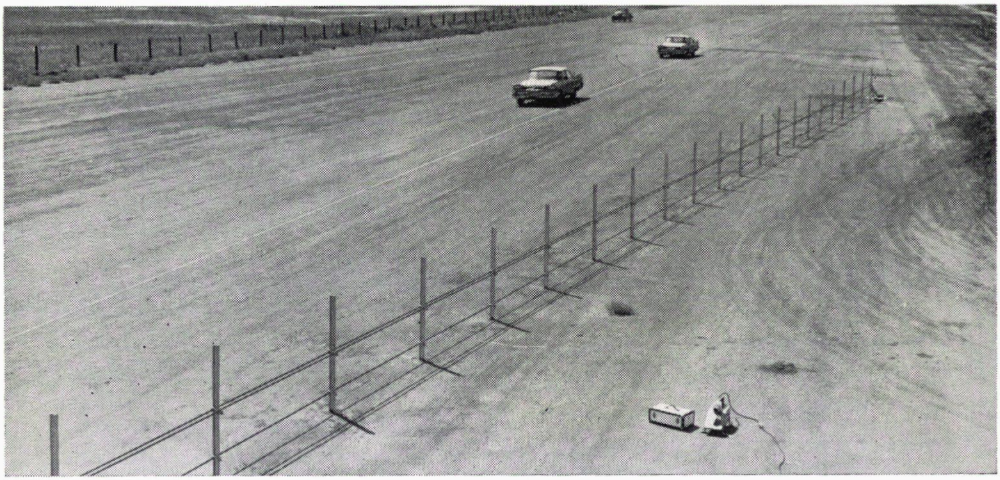
In addition to the 16-mm cameras, one Bolex and one Bell and Howell 24 frames per sec camera were placed at various locations for documentary coverage. All sequence pictures shown in the exhibits were recorded with a 70-mm Hulcher Mod. 20 camera at a rate of 20 frames per sec.

REFERENCES

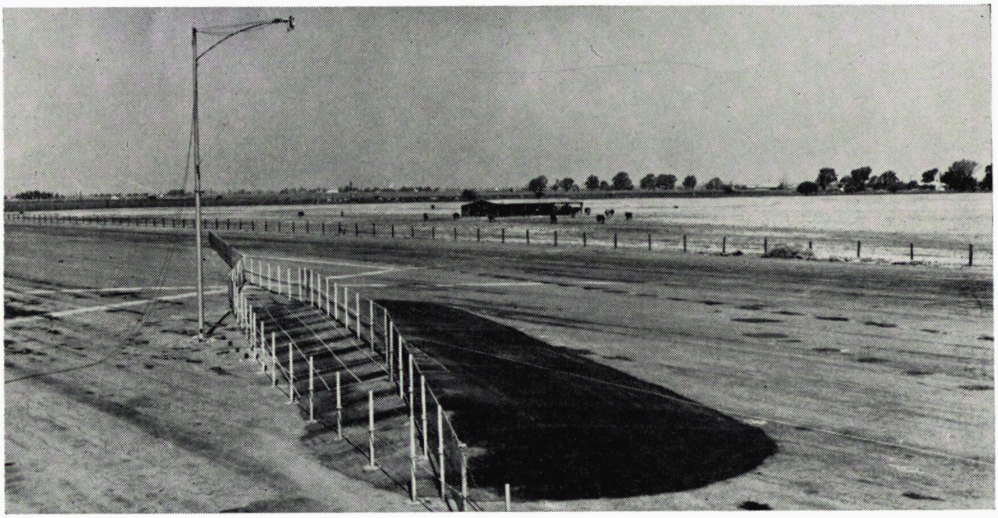
1. BEATON, J. L., and FIELD, R. N., "Dynamic Full-Scale Tests of Median Barriers." HRB Bull. 266, 78-125 (1960).
2. MOSKOWITZ, K., and SCHAEFER, W. E., "California Median Study: 1958." HRB Bull, 266, 34-62 (1960).
3. CICHOWSKI, W. G., "Automobile to Chain Link-Cable Barrier Collision." General Motors Report PG-12387.

APPENDIX

EXHIBIT 1

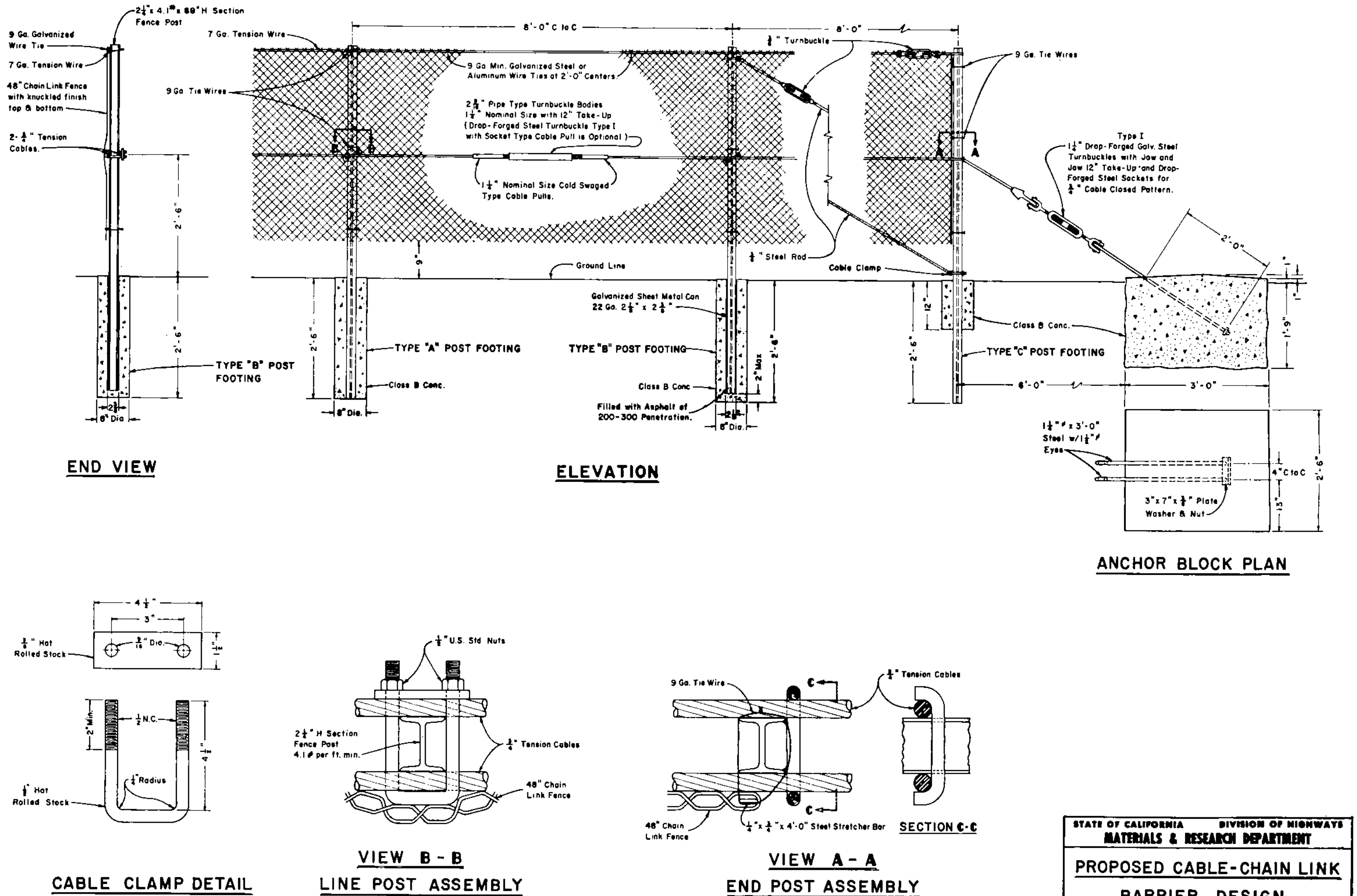


Crash vehicle on 7° collision course, followed by control car. Chain link fabric was deleted from first 200 ft on 600-ft installations. Ground-mounted data camera in right foreground.



Typical photographic instrumentation installation, showing data camera tower, ground grid, and guide tape intersecting point of impact at 20°.

EXHIBIT 2

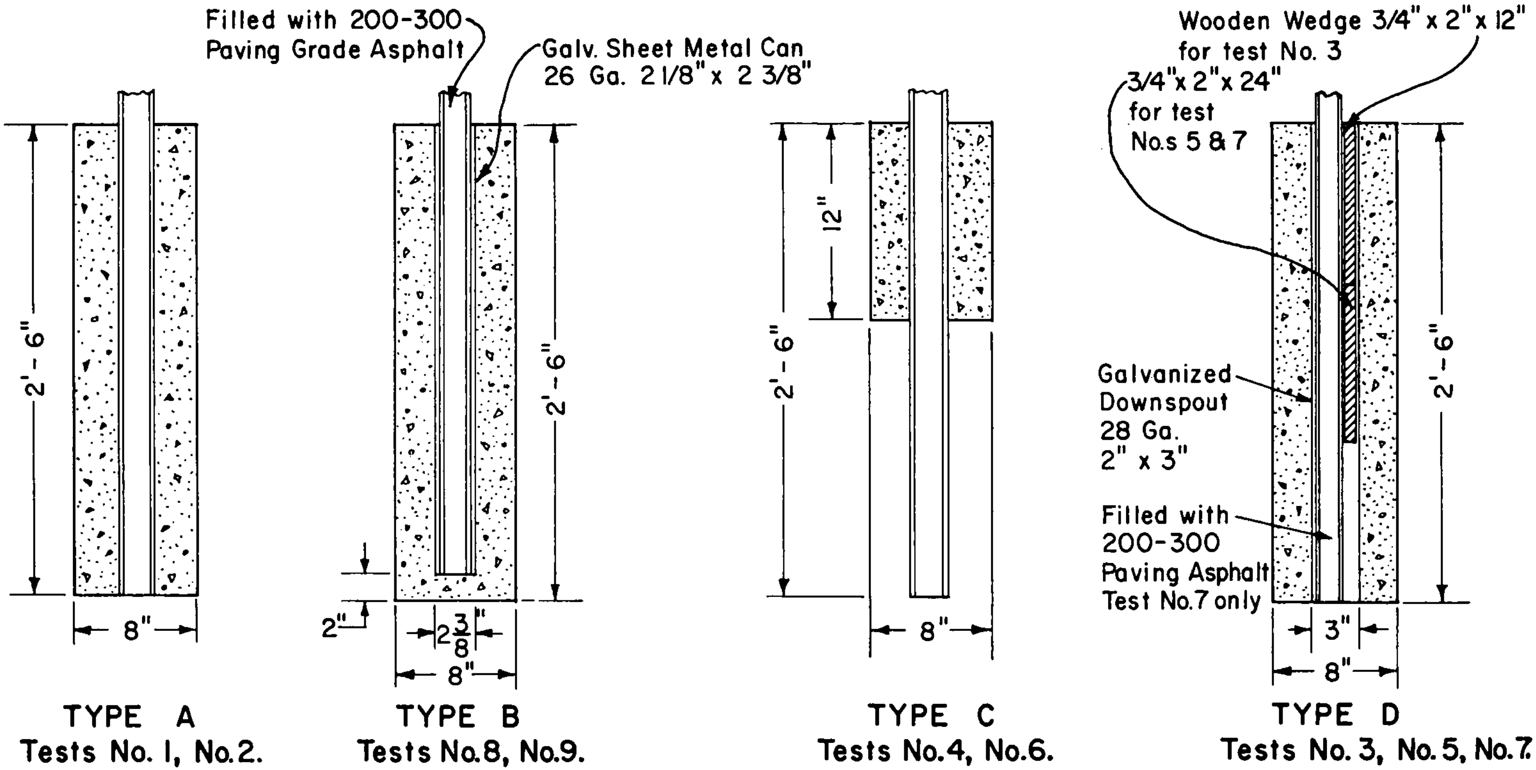


STATE OF CALIFORNIA — DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPARTMENT

PROPOSED CABLE-CHAIN LINK BARRIER DESIGN

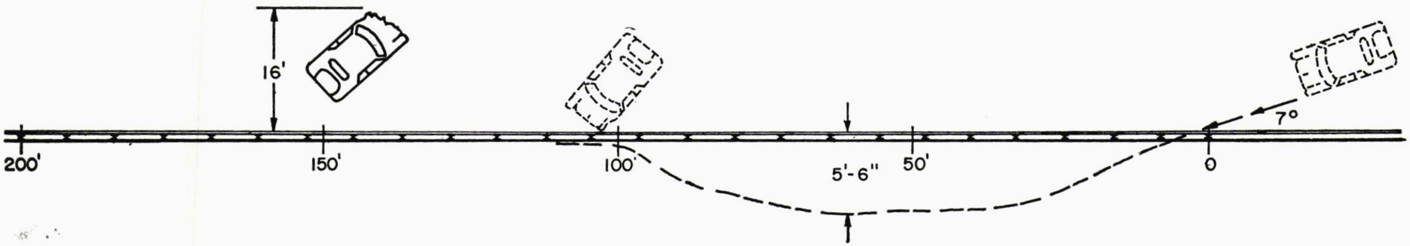
DATE 12-1-61	SUBMITTED BY [signature]	C-456
DRAWN BY R.P.	APPROVED BY [signature]	SHEET NO. 1
CHECKED BY R.N.F.		OF 1 SHEETS

EXHIBIT 3



NOTE: CLASS B CONCRETE USED FOR ALL TYPES

POST FOOTING DETAILS



FENCE .... 48" chain link at 9" above pavement.
CABLE .... 3/4" 6x19 IWRC 1 at 9" and 2 at 30" above pavement.
POST FOOTING .... Design A
POST SPACING .... 8' O.C.
LENGTH OF INSTALLATION. 600'
GROUND CONDITION .... Dry

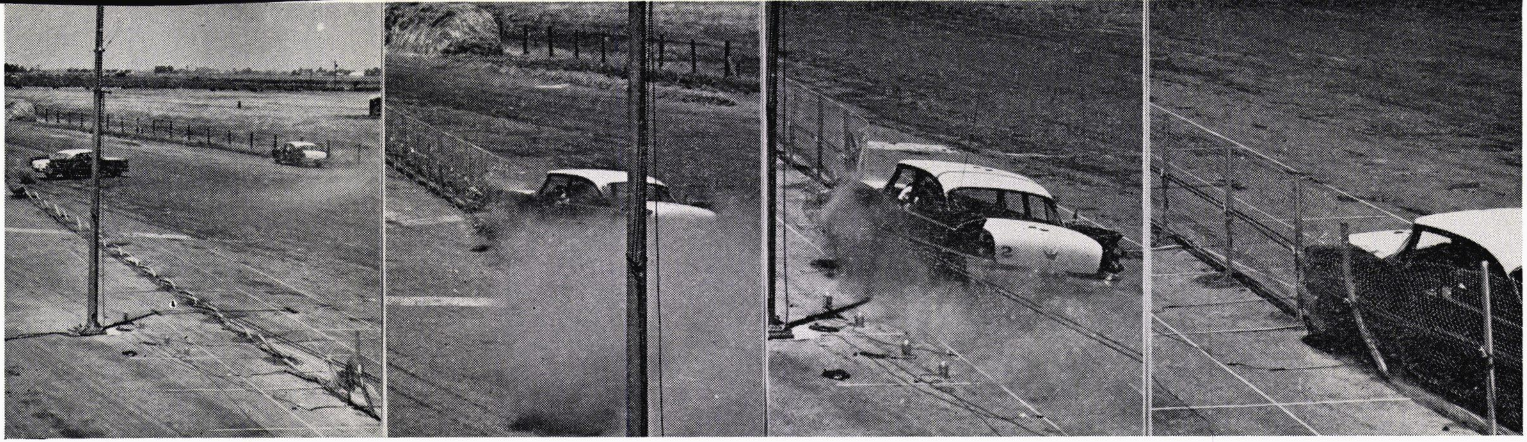
FENCE DAMAGE .... 152' damaged
CABLE FITTING DAMAGE .... none
CABLE DAMAGE .... none
POST DAMAGE .... 19 damaged
POST FOOTING DAMAGE .... 7 cracked
MAX DYNAMIC DEFLECTION OF CABLES .. 5 1/2
VEHICLE DECELERATION (PEAK LONG) .. 6.5g's
VEHICLE DAMAGE .... $ 350

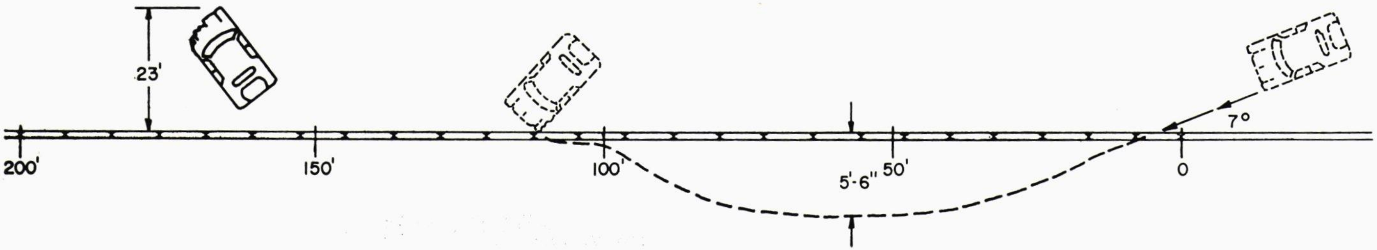
TEST NO. 1
DATE 6-8-61
VEHICLE .... Dodge 59 Sedan
SPEED .... 78 MPH
IMPACT ANGLE .... 7°
VEHICLE WEIGHT ... 4300 lbs.
(W/DUMMY & INSTRUMENTATION)

EXHIBIT 4

STATE OF CALIFORNIA — DIVISION OF HIGHWAYS — MATERIALS & RESEARCH DEPT

EXHIBIT 5



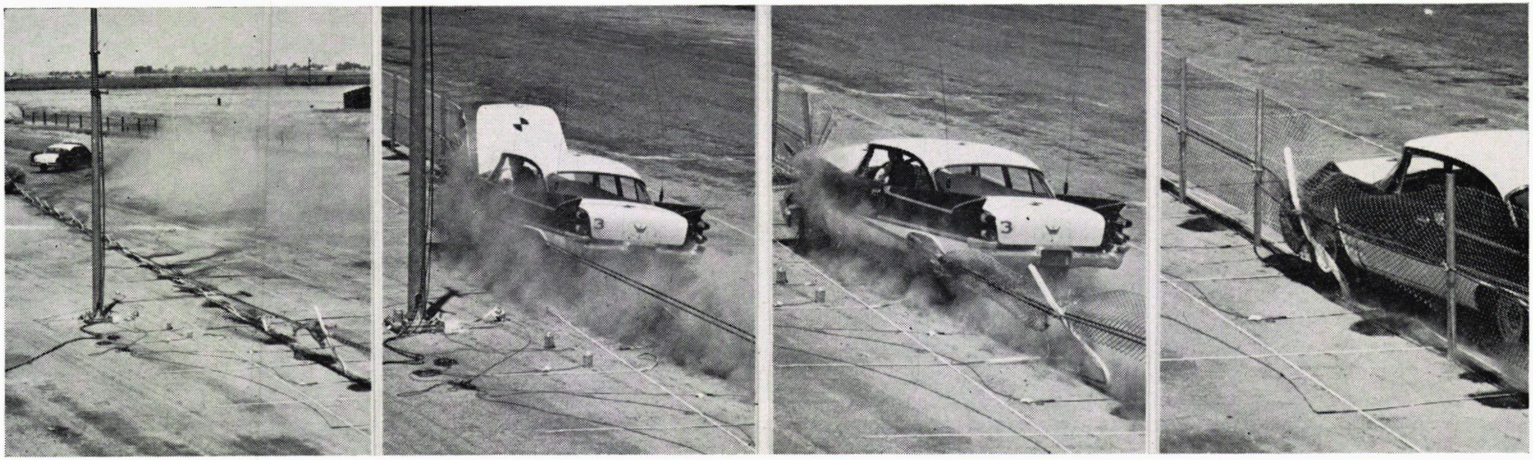


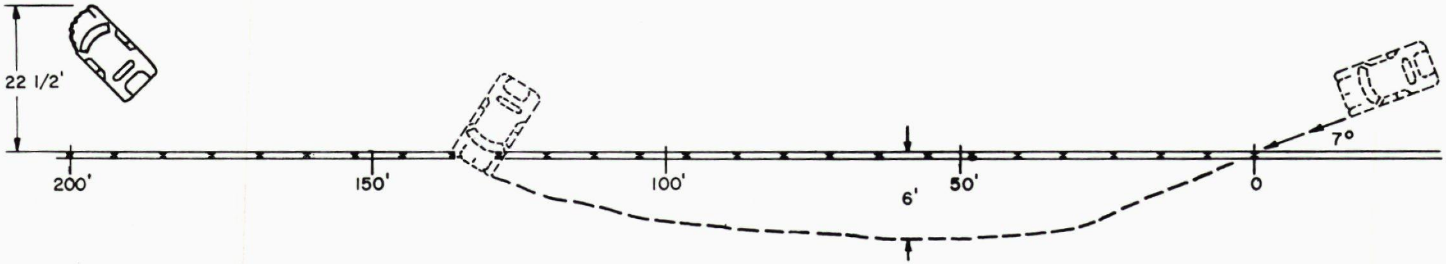
FENCE	48" chain link at 9" above pavement.
CABLE	3/4" 6 x 19 IWRC 2 at 30" above pavement.
POST FOOTING	Design A
POST SPACING	8' O.C.
LENGTH OF INSTALLATION	600'
GROUND CONDITION	Dry

FENCE DAMAGE	140' damaged
CABLE FITTING DAMAGE	none
CABLE DAMAGE	slight fraying
POST DAMAGE	19 damaged
POST FOOTING DAMAGE	12 cracked
MAX. DYNAMIC DEFLECTION OF CABLES	6'
VEHICLE DECELERATION (PEAK LONG.)	2.4 g's
VEHICLE DAMAGE	$350

TEST NO.	2
DATE	6-13-61
VEHICLE	Dodge 59 Sedan
SPEED	84 MPH
IMPACT ANGLE	7°
VEHICLE WEIGHT	4300 lbs. (W/DUMMY & INSTRUMENTATION)

STATE OF CALIFORNIA — DIVISION OF HIGHWAYS — MATERIALS & RESEARCH DEPT.





FENCE	48" Chain link at 9" above pvmt.	FENCE DAMAGE	152' Damaged	TEST NO.	3
CABLE	3/4" 6 x 19 IWRC 2 at 30" above pavement.	CABLE FITTING DAMAGE	None	DATE	6-19-61
POST FOOTING	Design D	CABLE DAMAGE	None	VEHICLE	Dodge 59 Sedan
POST SPACING	8' O.C.	POST DAMAGE	20 Damaged - 1 Pulled Out	SPEED	86 M.P.H.
LENGTH OF INSTALLATION	600'	POST FOOTING DAMAGE	5 Cracked	IMPACT ANGLE	7°
GROUND CONDITION	Dry	MAX. DYNAMIC DEFLECTION OF CABLES	6'	VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4300 lbs.
		VEHICLE DECELERATION (PEAK LONG).	4 G's		
		VEHICLE DAMAGE	$ 350		

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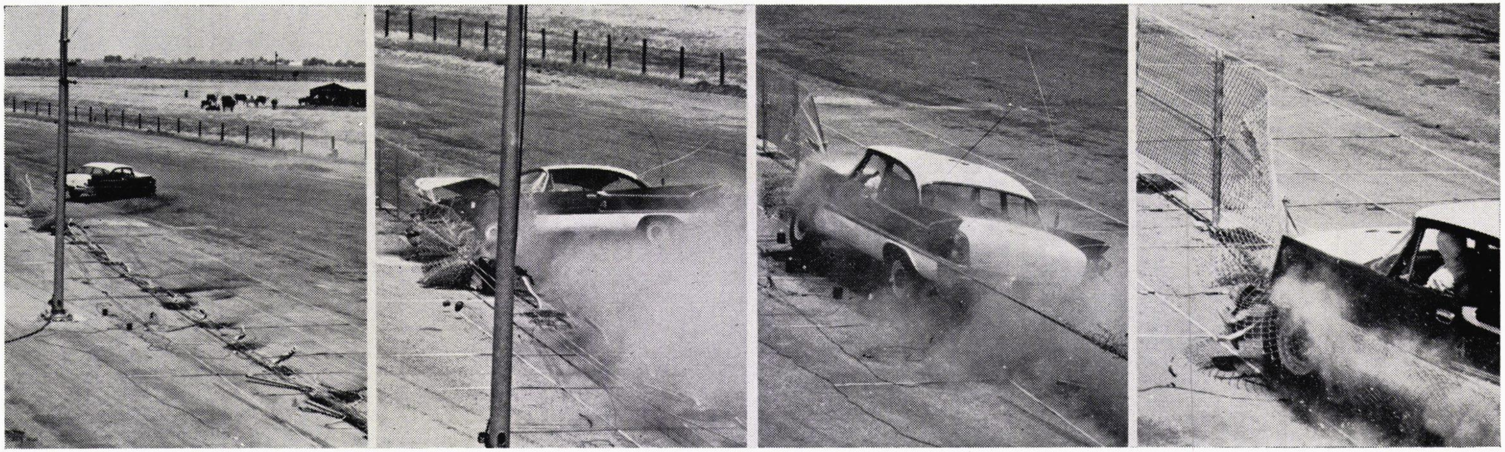
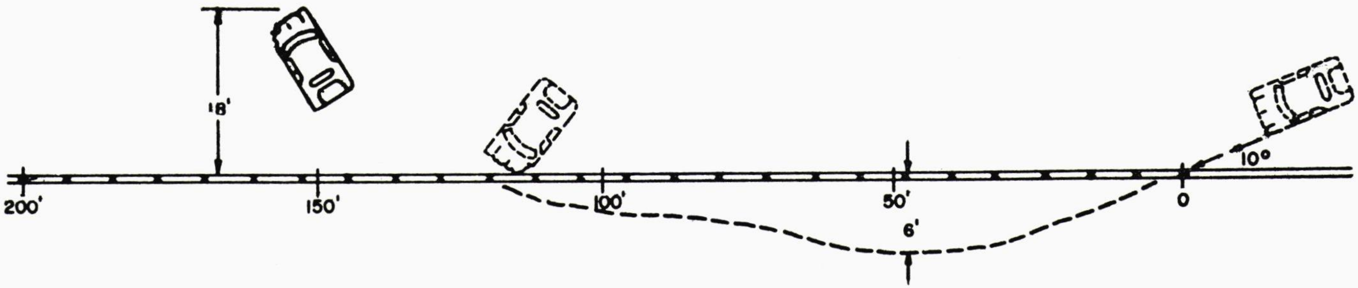
EXHIBIT 6

EXHIBIT 7





FENCE	48" chain link at 9" above pavement.	FENCE DAMAGE	136' damaged	TEST NO.	4
CABLE	3/4" 7x7 2 at 30" above pavement.	CABLE FITTING DAMAGE	1 turnbuckle slightly bent	DATE	6-26-61
POST FOOTING	Design C	CABLE DAMAGE	none	VEHICLE	Dodge 59 Sedan
POST SPACING	8' O.C.	POST DAMAGE	17 damaged—1 pulled out	SPEED	76 MPH
LENGTH OF INSTALLATION	600'	POST FOOTING DAMAGE	16 cracked—1 failed	IMPACT ANGLE	10°
GROUND CONDITION	Dry	MAX DYNAMIC DEFLECTION OF CABLES	6'	VEHICLE WEIGHT	4300 lbs. (W/DUMMY & INSTRUMENTATION)
		VEHICLE DECELERATION (PEAK LONG)	3.6 g's		
		VEHICLE DAMAGE	$700		

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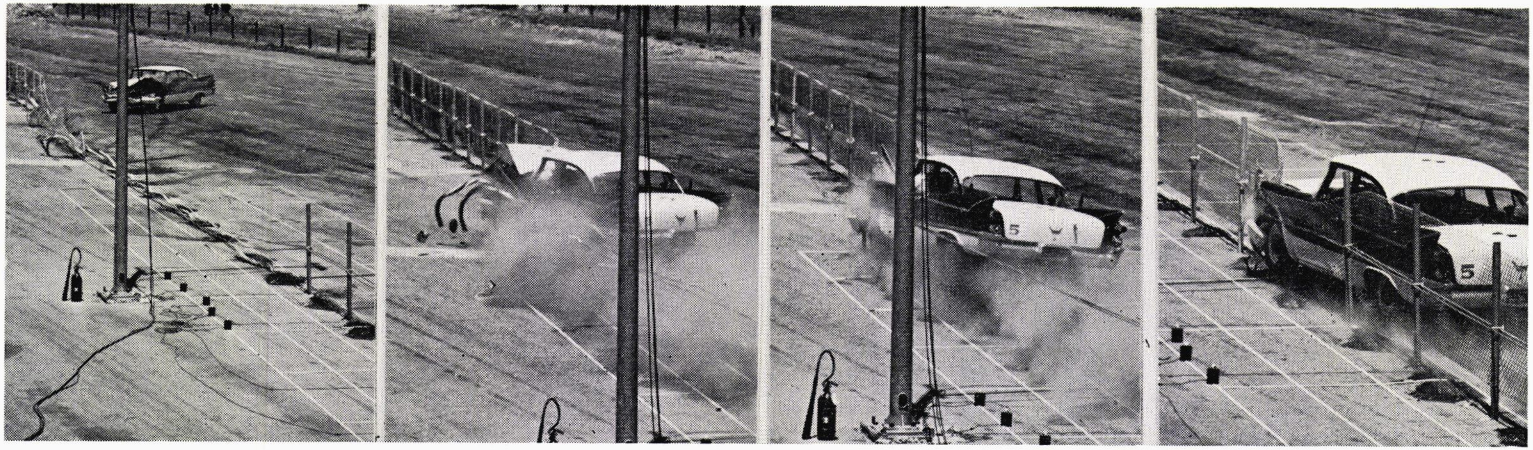
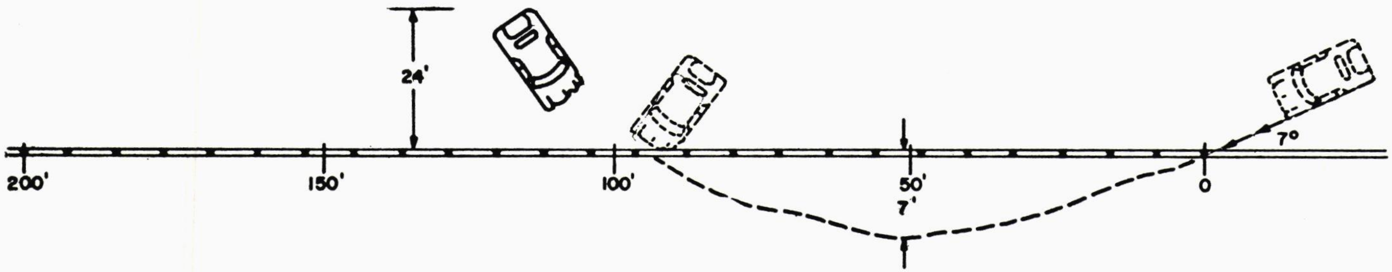
EXHIBIT 8





FENCE	48" chain link at 9" above pavement.	FENCE DAMAGE	112' damaged	TEST NO.	5
CABLE	3/4" 7x7.2 at 30" above pavement.	CABLE FITTING DAMAGE	1 deadend failed	DATE	6-30-61
POST FOOTING	Design D	CABLE DAMAGE	none	VEHICLE	Dodge 59 Sedan
POST SPACING	8' O.C.	POST DAMAGE	15 damaged-2 pulled out	SPEED	84 MPH
LENGTH OF INSTALLATION	600'	POST FOOTING DAMAGE	10 cracked	IMPACT ANGLE	7°
GROUND CONDITION	Dry	MAX. DYNAMIC DEFLECTION OF CABLES	7'	VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4300 lbs.
		VEHICLE DECELERATION (PEAK LONG)	4.8 g's		
		VEHICLE DAMAGE	$ 350		

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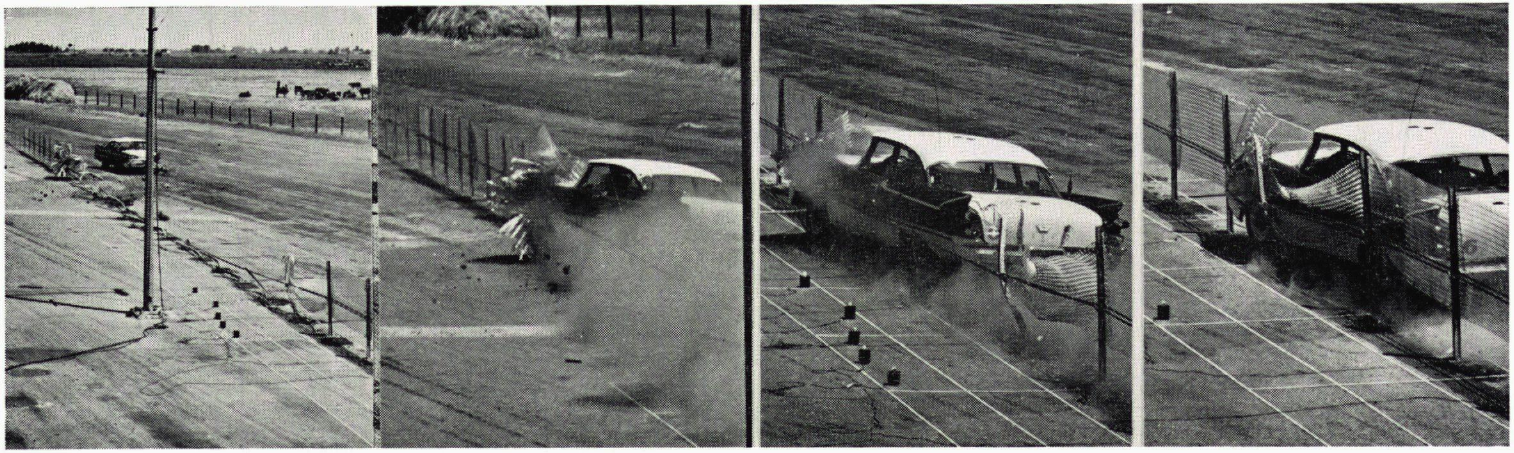
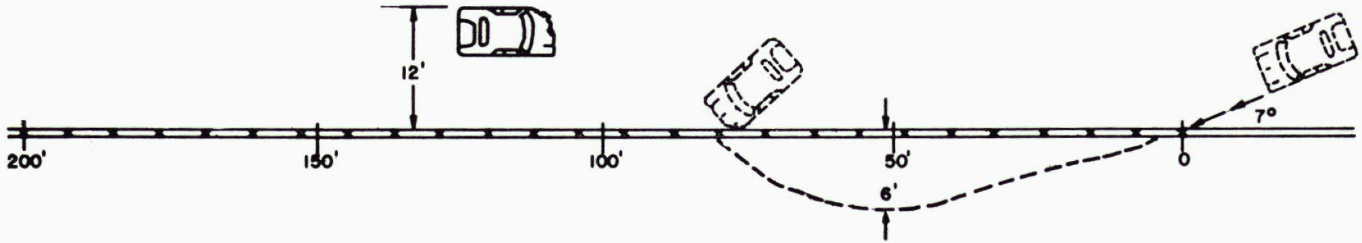




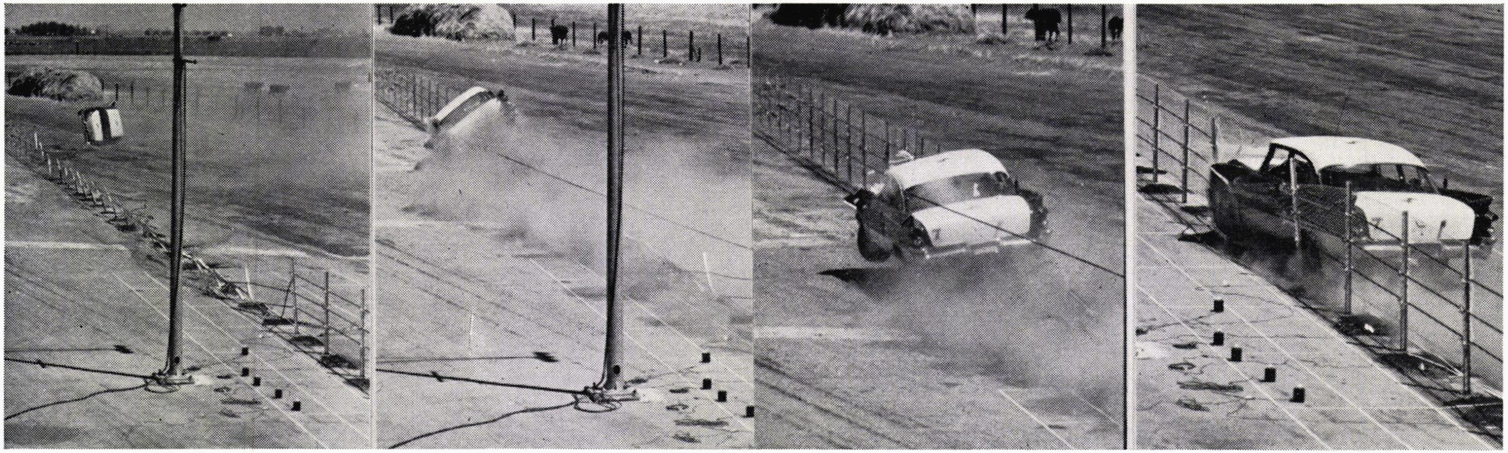
FENCE . . . 42". 18 ga. steel expanded metal 1.35" x 3" diamond at 15" above pavt.
CABLE . . . . 3/4". 6 x 19 IWRC 2 at 30" above pavement.
POST FOOTING . . . . Design C
POST SPACING . . . . 8' O.C.
LENGTH OF INSTALLATION . 600'
GROUND CONDITION . . . . . Dry

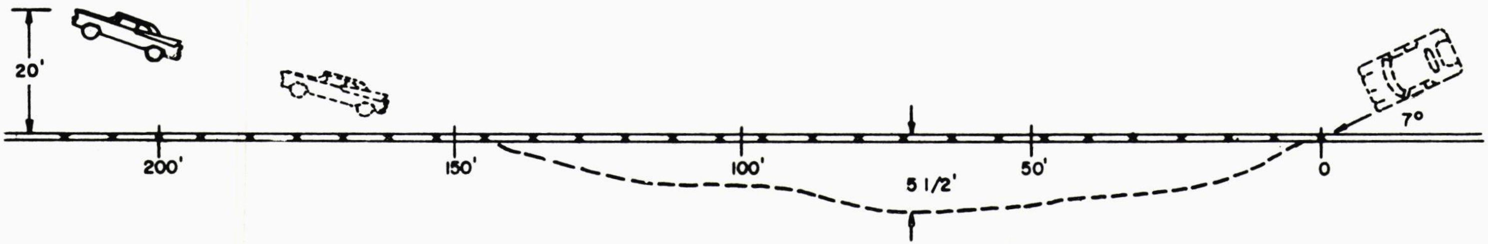
FENCE DAMAGE . . . . 136' expanded metal damaged
CABLE FITTING DAMAGE . . . . none
CABLE DAMAGE . . . . none
POST DAMAGE . . . . 16 damaged, 1 pulled out
POST FOOTING DAMAGE . . . . 15 cracked, 1 failed
MAX. DYNAMIC DEFLECTION OF CABLES . . 6'
VEHICLE DECELERATION (PEAK LONG) . . 3 g's
VEHICLE DAMAGE $350

TEST NO. 6
DATE 7-10-61
VEHICLE . . . . Dodge 59 Sedan
SPEED . . . . 75 MPH
IMPACT ANGLE . . . . 7°
VEHICLE WEIGHT . . . 4300 lbs.
(W/DUMMY & INSTRUMENTATION)

STATE OF CALIFORNIA — DIVISION OF HIGHWAYS — MATERIALS & RESEARCH DEPT.

EXHIBIT 9





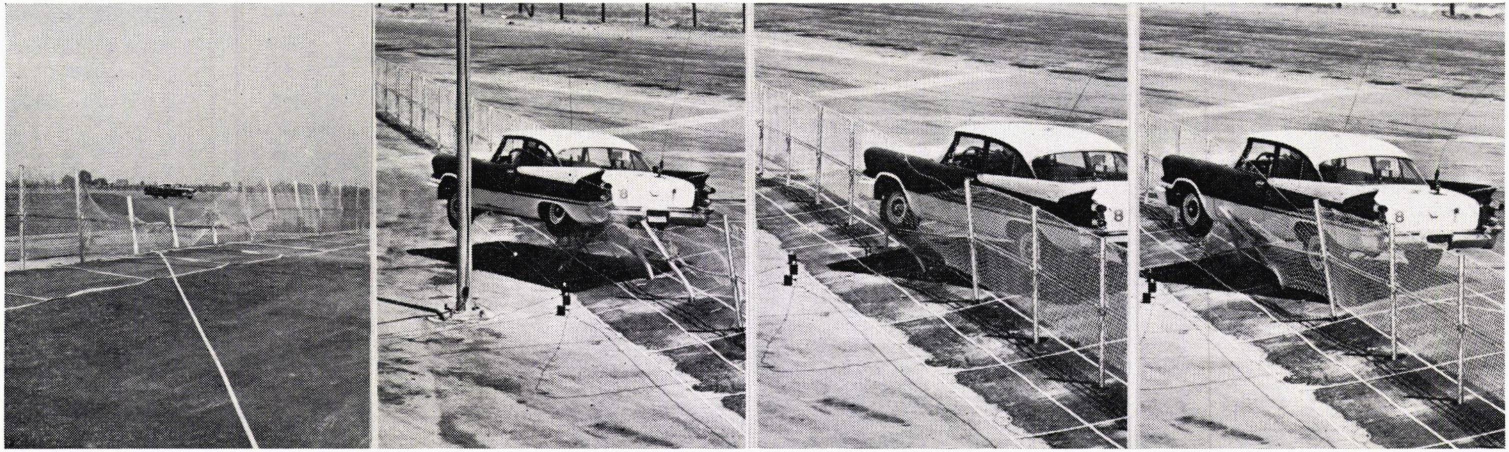
FENCE.........48" chain link at 9" above pavement.
CABLE........3/4" 6x19 IWRC 3 at 20" 32" and 44" above pavement
POST FOOTING........Design D
POST SPACING........8' O.C.
LENGTH OF INSTALLATION . 600'
GROUND CONDITION.....Dry

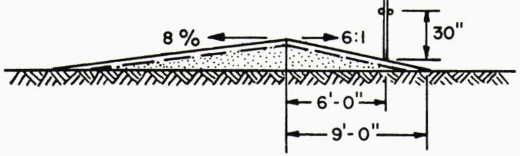
FENCE DAMAGE.................184' damaged
CABLE FITTING DAMAGE...........preformed splice failed
CABLE DAMAGE..............none
POST DAMAGE........ ....19 damaged
POST FOOTING DAMAGE.........12 cracked
MAX. DYNAMIC DEFLECTION OF CABLES . 5 1/2'
VEHICLE DECELERATION (PEAK LONG) . . 6.8g's
VEHICLE DAMAGE.............Total loss

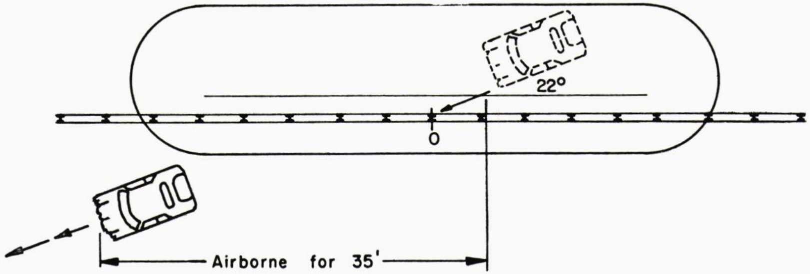
TEST NO..........7
DATE...........7-14-61
VEHICLE........Dodge 59 Sedan
SPEED.........77 MPH
IMPACT ANGLE . . . 7°
VEHICLE WEIGHT. . . 4300 lbs.
(W/DUMMY & INSTRUMENTATION)

STATE OF CALIFORNIA — DIVISION OF HIGHWAYS — MATERIALS & RESEARCH DEPT.

EXHIBIT 10







FENCE	48" Chain link at 9" above pavement.
CABLE	3/4" 6 x 19 IWRC 2 at 30" above pavement.
POST FOOTING	Design B
POST SPACING	8' O.C.
LENGTH OF INSTALLATION	400'
GROUND CONDITION	Dry

FENCE DAMAGE	35' damaged
CABLE FITTING DAMAGE	none
CABLE DAMAGE	none
POST DAMAGE	7 damaged
POST FOOTING DAMAGE	none
MAX. DYNAMIC DEFLECTION OF CABLES	Vehicle jumped barrier
VEHICLE DECELERATION (PEAK LONG.)	1.7 G's (at end of jump)
VEHICLE DAMAGE	$ 150

TEST NO.	8
DATE	8-18-61
VEHICLE	Dodge 59 Sedan
SPEED	74 MPH
IMPACT ANGLE	22°
VEHICLE WEIGHT	4300 lbs. (W/DUMMY & INSTRUMENTATION)

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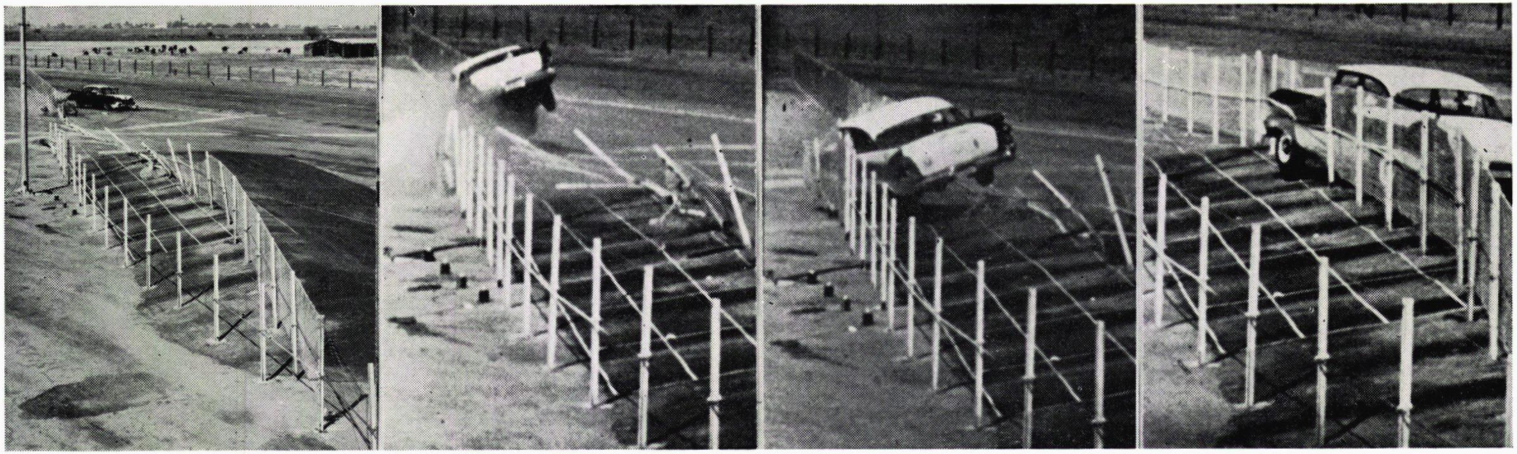
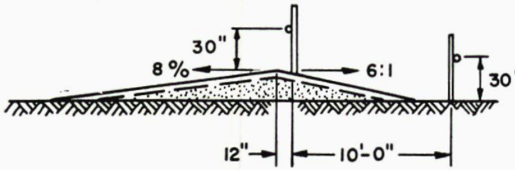
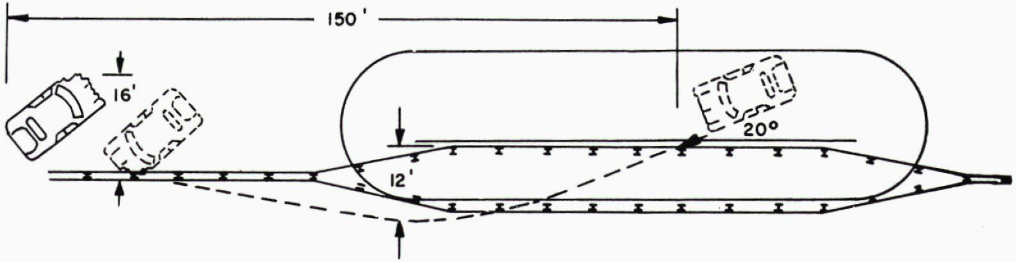
EXHIBIT 11



Earth Ramp with 2" PMS





FENCE	48" chain link at 9" above pavement.
CABLE	3/4" 6 x 19 IWRC 2 at 30" above pavement.
POST FOOTING	Design B
POST SPACING	8' O.C.
LENGTH OF INSTALLATION	400'
GROUND CONDITION	Dry

FENCE DAMAGE	136' damaged
CABLE FITTING DAMAGE	none
CABLE DAMAGE	none
POST DAMAGE	22 damaged – 11 slightly bent
POST FOOTING DAMAGE	7 anchors cracked
MAX. DYNAMIC DEFLECTION OF CABLES	12'
VEHICLE DAMAGE	$ 750

TEST NO	9
DATE	9-29-61
VEHICLE	Dodge 59 Sedan
SPEED	82 MPH
IMPACT ANGLE	20°
VEHICLE WEIGHT	4300 lbs. (W/DUMMY & INSTRUMENTATION)

EXHIBIT 12

STATE OF CALIFORNIA — DIVISION OF HIGHWAYS — MATERIALS & RESEARCH DEPT.