Dynamic Tests of Automobile Passenger Restraining Devices

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•THE APPLICATION of dynamic test methods to automobile safety belts is not a new idea. Indeed, the type of seat belt in use in American cars today was developed through information from dynamic tests of restraining devices for aviation by Stapp (1), and for automobiles by Mathewson and Severy (Table 6, 2). The latter performed their studies with controlled collisions of actual automobiles, with the vehicles, the passengers (usually dummies), and the seat belts instrumented to determine the magnitudes and durations of the forces produced in actual accidents. Similar controlled collision studies using automobiles have been done by research engineers of automobile companies (3). In addition to these research activities, laboratory dynamic tests have been used for several years for certifying seat belts for public sale in California by the California Highway Patrol (4) and in Sweden by the National Institute for Materials Testing. Another laboratory dynamic test device has been used for some years in auto safety research at the University of Minnesota (5).

In spite of these examples of the use of dynamic methods in laboratory tests of automobile seat belts during recent years, there has been a general reluctance in the seat belt field to accept dynamic testing. During 1962, however, an increased interest developed, both here and abroad. The British Standards Institution, the Inland Transport Committee of the U. N. Economic Commission for Europe, and automobile and seat belt manufacturers in the United States and Great Britain have been considering adopting such a method. Indeed, several of these organizations have built dynamic test equipment during the past year. Very recently, the Society of Automotive Engineers and the Federal Supply Service (G. S. A.) have become interested. Nevertheless, dynamic testing is still not an accepted method in official or semi-official standards (6, 7) in the United States, except in California.

The objections raised against dynamic testing are mainly three: (a) that dynamic testing offers no advantage over static testing; (b) that even were it to offer advantages, it cannot be controlled well enough to constitute a standard test; and (c) that dynamic tests are much more expensive than static ones. Although the economic problem is not a subject for discussion at this forum, dynamic testing is sufficiently important to warrant an intensive effort to develop an economically feasible method, and there are indications that the problem can be solved satisfactorily. In any case, only the first two objections are discussed here.

The basic reason for even considering dynamic testing is that, in actual use, seat belts are subjected to dynamic loading conditions; that is, very large loads are applied in very short time intervals to elastic structures that respond to short-interval loading in a different way than they respond to slower loading (8). The mathematical physics of phenomena of this general type is described elsewhere (9, 10, 11). These treatises leave no doubt that qualitative and quantitative differences in effects exist between a transient and a relatively slow application of force to an elastic system; consequently, a dynamic test method should provide a closer simulation of actual use conditions than

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a static test. The question is really whether a particular laboratory dynamic test simulates the dynamic force and time conditions of severe car collisions more closely than the static tests now in general use.

Fortunately, controlled automobile collision studies have provided some data on the magnitudes and durations of forces generated in automobile collisions. These data can be used to judge whether a laboratory dynamic test, such as the Swedish one, gives a close simulation of actual collision conditions. Table 1 gives some of the dummy deceleration and lap belt loading data from controlled car crashes at the Ford Motor Company (3) and at the Institute for Transportation and Traffic Engineering (12). The data represent severe collisions into fixed barriers and head-on collisions.

The Swedish dynamic test (described in detail in the Appendix) attempts to simulate severe crash conditions. It has been criticized as possibly being too severe because of the short stopping distance of its cart—a lead cone at the front of the cart causes it to stop in about 3 in. from an impact speed of 25 mph when it strikes the fixed barrier. The impact speed and the short stopping distance of the cart have been known, but because no other data have been available, it has been possible to speculate that dummy decelerations and belt loadings were very much higher, and durations very much shorter, than those typical of actual severe car collisions. For these reasons the Swedish test method was considered likely to be yielding a poor simulation of car collision conditions. Instrumented tests with the Swedish method have now been made and are reported herein, so that comparisons with controlled car collisions are now possible.

Before proceeding to make these comparisons, it must be noted that the two sets of controlled car collision data in Table 1 are themselves not strictly comparable. The UCLA data included both belt loads and dummy decelerations, but the seat belts used in their tests were 3 in. wide instead of the conventional 2 in. On the other hand, the Ford tests used belts of conventional width, but furnished only belt load data; no dummy decelerations were reported. Comparison of the UCLA and Ford belt load data indicate that the UCLA tests at 21-mph impact speed produced roughly the same forces as the 27- to 29-mph Ford tests.

Table 2 gives the results of instrumented runs made with the Swedish test rig during the summer of 1962; these runs were made with conventional lap belts. Comparison of Tables 1 and 2 shows that the dummy decelerations and the belt loadings generated in the 21-mph Swedish test, and the durations of these, were of the same order of mag-

TABLE 1

FORCES GENERATED IN CONTROLLED CAR CRASHES USING LAP BELTS

Type of Collision	Ref. No.	Impact Speed (mph)	Dummy Decelerations		Belt Loadings	
			Peak (g)	Duration[a] (millisec)	Peak (lb)	Duration[a] (millisec)
Two-car, head-on	11	21	44	55	7,000	60
		21	40	60	5,000	60
		21	30	90	-	-
		21	34	60	4,500	65
		27	48	90	7,500	45
		27	38	80	5,000	80
		47	55	95	9,000	130
		52	72	90	9,000	135
		52	73	95	15,000	150
Car, fixed barrier	3	27	-	-	5,700	75
		29	-	-	5,800	65

[a] Durations of deceleration are for 5g and over; durations of loading are for 1,000 lb and over, because of indefiniteness of endpoints in many cases.

nitude as those observed in the UCLA and Ford controlled car collisions at 21- to 29-mph impact speeds; in fact, the ranges of the Swedish test data overlap the ranges found in the controlled car collisions in all factors involved.

TABLE 2

FORCES GENERATED IN SWEDISH DYNAMIC TESTS USING LAP BELTS AND RIGID DUMMY

Impact Speed (mph)	Dummy Deceleration		Belt Loading	
	Peak (g)	Duration[a] (millisec)	Peak (lb)	Duration[a] (millisec)
21	32	60	5,400	52
21	25	47	5,400	50
21	35	50	6,600	50
21	27	63	5,700	63
15	22	45	3,800	42
15	23	43	4,000	49
15	30	40	5,200	42
15	-	-	5,300	50
15	20	45	4,400	58
15	29	43	5,400	44

[a] Durations of deceleration are for 5g and over; durations of loading are for 1,000 lb and over, because of indefiniteness of endpoints in many cases.

These comparisons, and the graphs of the instrument data shown in the Appendix demonstrate that, contrary to the earlier speculations, the Swedish cart's short stopping distance (and its consequently very high deceleration) do not control the deceleration of the dummy nor the load on the belt. The major part of the stopping of the dummy occurs after the cart is completely stopped (8). The major factors that control the dummy deceleration and the belt load are the impact velocity, weight of the dummy, and the elongation characteristics of the seat belt itself. It is therefore not surprising that the Swedish test method generates forces of the same magnitudes and durations as those of actual collisions.

On the other hand, the static test methods prescribed in the official Federal Government specification (6) and in the SAE standard (7), which is official in some States, impose loadings on the belt relatively slowly, so that the peak loading is reached in a time period of the order of 2 min, several thousand times as long as the loading durations observed in car collisions. Thus, it is clear that the Swedish test method produces a very much better simulation of actual belt loadings than the static method.

The reproducibility of the impact speed has been studied by the Swedish laboratory, using microswitches along the track. The variations have been found to be within ± 0.3 mph at 25 mph, so that the variation in kinetic energy does not exceed ± 2.5 percent. This demonstrates good control of the cart speed. At the three speeds studied (15, 21, and 25 mph), the stopping time remained fairly constant at about 18 millisec, but the peak decelerations increased considerably at the higher impact speeds (Table 3). (A detailed study of the deceleration characteristics of the cart will be published shortly by Aldman; the cart decelerations shown in Table 3 and in the graphs in the Appendix are average values and typical patterns included only to illustrate the order of magnitude and the time relationship between the decelerations of the cart and the dummy.)

In the testing of seat belts, it is the reproducibility of the dummy decelerations and the belt loadings which is of primary concern. Table 4 gives a summary of the dummy decelerations and belt loadings for various test conditions: impact speeds of 15 and 21 mph using lap belts and a rigid dummy, and impact speeds of 21 and 25 mph using harnesses and a jointed dummy. In addition to the average peak values, the ranges of the dummy decelerations and the belt loadings in each case are also presented. There is considerable overlapping of ranges among the various test conditions. However, when differences among the belts themselves are taken into account, a good deal of this overlapping is eliminated, and, moreover, some of the effects of differences in design of the belts are learned.

TABLE 3

SWEDISH TEST CART

Impact Speed (mph)	Stopping Time (ms)	Deceleration[a] (peak g)
15	19	54
21	17	86
25	17	150

[a] Durations of deceleration are for 5g and over; durations of loading are for 1,000 lb and over, because of indefiniteness of endpoints in many cases.

The term "harness" is used in this report to designate any seat belt that restrains the upper torso, whether it has a

TABLE 4

AVERAGE FORCES AND DURATIONS IN SWEDISH TEST

Device	Type of Dummy	Position of Accelerometer	Impact Speed (mph)	No. of Runs	Dummy Decelerations (peak g)		Belt Loads (peak lb)		Avg. Duration[a] (millisec)	
					Avg.	Range	Avg.	Range	Decel.	Loads
Lap belts	Rigid	Lower body	15	6	25	20- 30	4, 700	3, 900- 5, 400	43	48
			21	9	30	25- 35	6, 100	4, 700- 7, 500	55	54
Harness	Jointed	Chest	21	8	62	35- 82	6, 000	4, 000- 8, 100	50	60
			25	7	88	40-112	7, 800	6, 300-11, 000	51	58

[a] Durations of deceleration are for 5g and over; durations of loading are for 1,000 lb and over, because of indefiniteness of endpoints in many cases.

lap strap as well. It therefore includes diagonal chest straps, combinations of lap straps and diagonal chest strap, and combinations of lap strap and double shoulder straps.

The jointed dummy used by the Swedish laboratory for testing harnesses was found unsuitable for testing lap straps; the rigid dummy was made for the purpose of testing lap straps alone. The accelerometer was located on the lap of the rigid dummy and in the chest of the jointed dummy.

WEBBING ELONGATIONS

Table 5 gives the averages and ranges of dummy decelerations and belt loadings for various test conditions, but this time broken down into separate groups on the basis of known differences in webbing elongation. The "high elongation" webbings were those ranging from 21 to 29 percent elongation under a 2, 500-lb load (using the SAE test method) and the "low elongation" webbings were in the 14 to 15 percent range. Most of the overlapping has been eliminated for any given set of test conditions by this grouping on the basis of webbing elongation, and the apparent reproducibility of the results is improved considerably.

Ranges within groups have not been entirely eliminated, however, because as was stated earlier, the characteristics of the belts themselves influence the deceleration of the dummy and the loads on the belt, and the belts within each group were not completely alike: variations of webbing elongation existed within each group (small variations are known to exist even among different pieces of webbing from a single roll), and, among the harnesses, the geometric configurations of the harnesses themselves varied; e.g., some had the chest strap anchored to the doorpost, others to the floor. The 25-mph runs are not separated into elongation groups because only high elongation webbings were used in these runs. The comparisons are not complete because of still another factor—the three low-elongation lap belts tested at 21 mph broke when they reached the peaks noted. Had they not broken, the 21-mph peaks may have been higher, and overlapping may have been completely absent as it was in the 15-mph tests in which no breakage occurred.

In spite of the qualifications just described, the separations between the high and

TABLE 5

EFFECTS OF WEBBING ELONGATION

Device	Type of Dummy	Impact Speed (mph)	Dummy Deceleration (peak g)				Belt Load (peak lb)				Avg. Duration[a] (millisec)			
			High Elong.		Low Elong.		High Elong.		Low Elong.		Decel.		Loads	
			Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	High	Low	High	Low
Lap belt	Rigid	15	22	20-23	29	29-30	4, 100	3, 900-4, 400	5, 300	5, 200-5, 400	45	42	50	45
		21	30	25-35	Broke at	30-35	5, 800	5, 400-6, 600	Broke at	6, 200-7, 500	55	Broke	54	Broke
Harness	Jointed	21	55	40-70	78	72-82	5, 500	4, 000-7, 300	6, 800	5, 600-8, 100	50	53	65	58

[a] Durations of deceleration are for 5g and over; durations of loading are for 1,000 lb and over, because of indefiniteness of endpoints in many cases.

low elongation groups were sufficiently consistent to demonstrate that differences in webbing elongation produce substantial differences in effects. In accidents of equal severity (that is, equal impact velocity and equal vehicle stopping distance), the low elongation webbing produced deceleration peaks and belt load peaks about one-third higher than the high elongation webbing. Because of this difference, it was observed that lap belts whose low elongation webbings were stronger in static tests (7,200 lb as against 6,800 lb) did not survive the dynamic tests at 21 mph, whereas the lower-strength high elongation belts did survive.

The implication of these observations is very significant in weighing the respective merits of the static and dynamic tests. In static testing there is an assumption that belts withstanding equal static loadings are equally meritorious and can therefore survive equally severe crash conditions. But the tests show that in collisions in which all other conditions are equal, a difference in webbing elongation produces different loads on the belts. With respect to this phenomenon, the dynamic test is certainly superior in that it permits the elongation characteristics of the belt to influence the load on the belt, whereas the static tests ignore this factor completely.

Incidentally (inasmuch as it does not bear on the matter of test methods), these tests show that low elongation webbings place more load on the body being restrained than do high elongation webbings; a 33 percent decrease in elongation (e.g., from 21 to 14 percent elongation) produced an increase of roughly 33 percent in load, with virtually no change in the duration of the loading. This is a point that should be considered in designing seat belts from the medical point of view.

LOCATIONS OF THIRD ANCHOR

Test results on harnesses, grouped in this case by location of the chest strap anchor (either shoulder-high on doorpost, or on the car floor behind the seat) are given in Table 6. These data indicate that the location of the third anchor does affect the dummy deceleration and its rate of onset, the belt load, and the durations of the forces. Perhaps the most significant of these differences is that the floor-anchored chest straps produce the highest peak decelerations of the upper torso and yet require more time to stop the dummy than do those anchored to the doorpost shoulder high. The significance of these apparently contradictory effects of anchor location is revealed by a different kind of study (high-speed photography) described later. Only one point should be emphasized here—that a study of this type is possible with a dynamic test using a jointed full-size dummy, but a static test would reveal nothing along these lines.

All of the observed effects of different webbing elongations, and some of those of different anchor locations, could have been derived from theoretical considerations, or, at least, they are reasonable and self-consistent in hindsight. For example, lower elongation webbing could be expected to decrease the stopping distance of the dummy,

TABLE 6

EFFECTS OF LOCATION OF CHEST STRAP ANCHOR OF HARNESSES

Impact Speed (mph)	Dummy Decel. (peak g)		Belt Load (peak lb)		Avg. Duration[a] (millisec)			
					Deceleration		Loads	
	Doorpost Anchor	Floor Anchor	Doorpost Anchor	Floor Anchor	Door	Floor	Door	Floor
21	59	64	7,000	5,400	32	61	48	67
25	72	100	8,800	7,000	37	61	48	66

[a] Durations of deceleration are for 5g and over; durations of loading are for 1,000 lb and over, because of indefiniteness of endpoints in many cases.

TABLE 7

BASIC TEST DATA

Run No.	Impact Speed (mph)	Dummy[a]	Belt Type[b]	Elong. (%)	Third Anchor	Dummy Decel.		Belt Loading					
						Peak (g)	Duration[c] (millisec)	Peak (lb at anchors)				Duration[c] (millisec)	
								Left	Right	Third	Total	Total	Notes[d]
3	25	J	LD	21	Door	85	25	2,500	4,400	2,000	8,900	37	
4			LD	21	Door	92	27	4,000	4,500	2,500	14,000	53	
5			LD	21	Floor	105	63	1,800	3,300	2,400	7,500	75	
6			LD	21	Floor	108	70	1,700	3,500	2,400	7,600	72	
7			L2S	21	Floor	112	60	2,400	2,400	1,500	6,300	58	
8			LD	-	Door	40	60	1,800	2,600	2,200	6,600	53	1, 3
9			LD	-	Floor	75	51	2,700	1,400	2,300	6,400	58	1, 3
14	21	J	LD	21	Door	70	26	1,900	3,100	2,300	7,300	53	
15			LD	14	Door	72	24	2,100	3,800	2,200	8,100	40	
16			LD	21	Floor	42	57	1,800	2,200	1,200	5,200	75	
17			LD	14	Floor	82	55	2,200	2,900	1,500	6,600	72	
18			L2S	21	Floor	55	66	1,500	1,600	900	4,000	68	
19			L2S	14	Floor	78	80	2,000	2,100	1,500	5,600	61	
20			LD	-	Door	35	46	1,500	2,200	1,900	5,600	50	1, 3
21			LD	-	Floor	65	48	2,000	2,100	1,200	5,300	58	1
51	21	R	L	21		32	60	2,600	2,800	-	5,400	52	3
52			L	21		25	47	2,800	2,600	-	5,400	50	3
53			L	21		35	50	3,300	3,300	-	6,600	50	
54			L	14		30	-	3,500	3,700	-	7,200	-	2
55			L	14		35	-	3,750	3,750	-	7,500	-	2
56			L	29		27	63	2,850	2,850	-	5,700	63	1, 3
57			L	23		35	-	3,100	3,100	-	6,200	-	1, 2
58			L	23		25	-	2,700	2,000	-	4,700	-	1, 2
59			L	15		30	-	2,700	3,500	-	6,200	-	1, 2
60	15	R	L	21		22	45	1,900	2,000	-	3,900	42	
61			L	21		23	43	2,000	2,000	-	4,000	49	
62			L	14		30	40	2,500	2,700	-	5,200	42	
63			L	14		-	-	2,400	2,900	-	5,300	50	
64			L	29		20	45	2,200	2,200	-	4,400	58	1
65			L	15		29	43	2,700	2,700	-	5,400	44	1

[a] J = jointed full-size dummy, without arms, with soft abdomen, 154 lb, accelerometer in chest; R = rigid dummy, torso and thighs only, seated position, 150 lb, accelerometer in lower back.

[b] L = lap strap only; D = diagonal chest strap only; LD = combination belt, lap and diagonal chest straps; L2S = combination belt, lap and two shoulder straps.

[c] For decelerations of 5g and over, for total belt loads of 1,000 lb and over, and for individual anchor loads of 500 lb and over.

[d] 1 = belt included buckle; all others continuous webbing from anchor to anchor to minimize chance of slippage; 2 = webbing broke at or near peak load; 3 = slippage in one anchor.

which would increase its deceleration rate, resulting in turn in an increased peak load on the belt. Nevertheless, the ability of the Swedish test method to demonstrate these reasonable effects with a high degree of consistency is another factor that increases confidence in the method.

Table 7 gives the pertinent test data obtained in 30 runs. Several typical graphs of instrument data are in the Appendix, which also contains descriptions of the Swedish dynamic test equipment and the instruments used in this study.

One final point deserves mention—with the Swedish test method, peak belt loads up to 11,000 lb and peak dummy decelerations up to 112g were observed with the use of floor-anchored combination lap and chest strap belts. That these values are not atypical of severe automobile crashes is indicated by the controlled car crash data given in Table 1, in which peaks as high as 15,000 lb and 73g were observed with lap belts alone. The question of whether such forces are tolerable by the human body is beyond the scope of this report, but the data indicate the ways in which the designs of harnesses may be changed to avoid excessively high peaks.

Valuable as the test data presented herein may be, they also indicate that considerably more exploration of the performance of seat belts by dynamic methods would be profitable, particularly in the evaluation of current models and in the development of better designs and materials.

RESTRAINT OF UPPER TORSO

The data that have been presented up to this point have had a bearing on problems involving decelerations of the belt wearer and loads on the belts themselves. But such instrumented runs furnish no direct information on how well a particular type of belt limits the body's forward motion; that is, on how well it restrains the wearer. The problem of restraining the upper torso to minimize head and chest injuries is considered particularly important in automobile accidents.

It is still another advantage of the Swedish dynamic test method that it can be used to observe by means of high-speed photography the degree of restraint of parts of the body by belts of various geometric configurations. A study of this kind was also performed in the summer of 1962 on nine models of harnesses then available in the United States. This study revealed, among other things, that diagonal chest straps alone may permit the wearer to slide out from under the belt or suffer severe internal injuries, and that combination belts with shoulder-high anchors for the chest strap limit the forward motion of the upper torso to about one-half that permitted by floor-anchored chest straps. These tests are described in detail elsewhere (13, 14); however, (a) the larger forward motion permitted by floor-anchored chest straps correlates well with the longer stopping time observed in the instrumented tests, and (b) the floor-anchored chest straps first permit the shoulders to lean forward into the chest strap and then produce a sudden very high peak deceleration when the dummy has leaned forward as much as it will go (compare dummy deceleration curves in Figs. 3 and 4 of the Appendix, for example).

Not all types of dynamic test apparatus are capable of producing information of this type. For example, the California Highway Patrol equipment is unable to observe restraint of the upper torso because it uses as its dummy a body block that is equivalent to the hips alone; it is therefore suitable only for testing lap belts. Modification of this equipment to make it capable of testing harnesses is likely because several harnesses are now on the American market. It is also likely that laboratory apparatus for dynamic testing of seat belts for quality control in manufacturing (or other routine testing) will not need to be capable of demonstrating restraining characteristics if these characteristics have been shown to be satisfactory in the design development stage. But the restraining characteristics of any new design, even if it is only a "slight" modification of an old design, should be tested first for its restraining characteristics in equipment of the kind used in Sweden.

SUMMARY AND CONCLUSIONS

Results of instrumented tests of seat belts by the Swedish dynamic test method have shown that (a) the peaks and durations of the decelerations of the belt wearer, as well as the loads on the belts, are of the same order of magnitude as those observed in controlled car crashes of a severe nature, (b) the characteristics of the belt itself exert a major influence on the deceleration rate of the belt wearer and on the magnitude and duration of the load on the belt, and (c) belts made of webbings found to be equally strong by the standard static test are not necessarily equally resistant to the forces developed in collision conditions of equal severity. These facts taken together indicate a clear superiority of dynamic testing over static testing.

The results have also demonstrated that the laboratory dynamic test is capable of producing information on the performance characteristics of belts of different geometric configurations and of various materials, to aid in evaluation and development of better safety belts. The specific effects of different webbing elongations and of third-anchor locations (for combination lap and chest strap belts) have also been demonstrated. The standard static tests are incapable of furnishing research and development information of this type.

In view of the need to develop seat belts that are effective in restraining the upper torso and are conventient to install and to don, more extensive use of dynamic testing is clearly called for.

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Appendix

Apparatus

The apparatus used in these tests is located in Stockholm, Sweden, at the Statens Provningsanstalt (National Institute for Materials Testing). An over-all view is shown in Figure 1 (details are shown in Fig. 14).

The cart, constructed of steel beams, is 7.5 ft long and 2.3 ft wide, with the wheels mounted outside the frame. The wheel base is 4.6 ft, and the lateral distance between wheel centers is 2.8 ft. The cart weight is approximately 660 lb, including the bucket seat which is rigidly fixed on the frame, with its front edge about 6 in. behind the front wheel axles.

The cart is accelerated by a 2,200-lb falling weight connected to the cart by a cable; the pulley system has a mechanical advantage of 2, and the net acceleration imparted to the cart is 0.9g. When the acceleration is applied for a distance of 23 ft, a speed of 25 mph is achieved; lower speeds are obtained by appropriately shortening the run. The falling distance of the weight is so adjusted that the cart reaches the desired speed 5 ft before impact, and runs free to impact.

To cushion the impact, a lead cone (90 mm long, with 40- and 50-mm diameters at the ends) is fastened to the front of the cart. The cart frame has suitable cross-members behind the seat to accommodate any kind of floor anchor, and a braced vertical post to accommodate shoulder-high anchors.

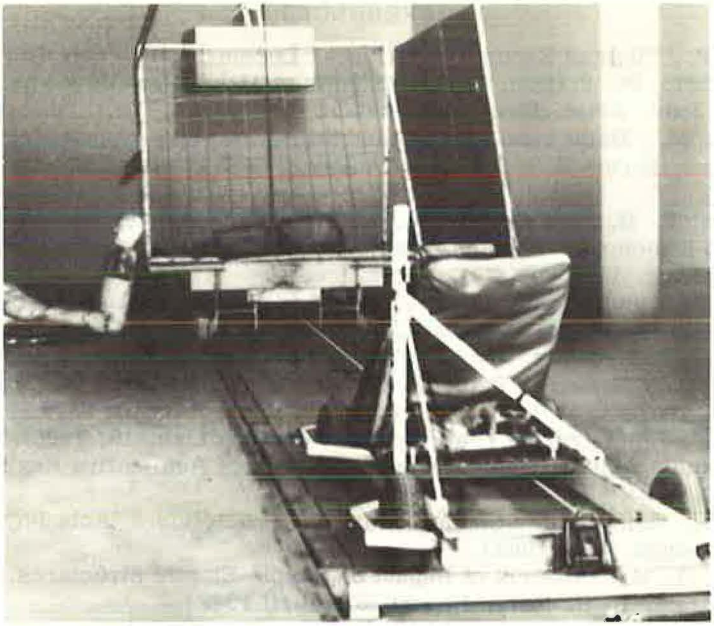


Figure 1. Swedish dynamic test equipment, looking down the track toward the barrier— falling weight is at top center, behind fixed barrier; cart held at starting point by quick-release mechanism fixed in floor; jointed dummy shown at left.

Dummies

The dummy used for harness tests is jointed; that is, its head, chest, pelvic section, and parts of the leg are made of wood, and between the wood parts are heavy sponge rubber blocks (between the hips and the chest, and parts of the legs). Steel plates are also used in some sections. The various parts are kept together by chains and springs running through the center of the parts. Thus the neck, the midsection, the thighs, and the legs are capable of being flexed. The various parts weigh as follows: head, 10.6 lb; breast, 36.3 lb; abdominal section, 17 lb; pelvic section, 51.7 lb; legs (including thighs) 38.5 lb. Total weight is 154 lb. The length of the dummy is approximately 5 ft 8 in.

The dummy used for lap belt tests is rigid, constructed of wood and steel channel. It consists only of that part of a body between the neck and the knees; it has no head, arms, or legs. It is in a sitting position, and its hip section, where the lap belt rests on it, is shaped like the body block used in the SAE, GSA, and California tests. As on these body blocks, the lap is covered with a layer of sponge rubber. The weight of this dummy is 150 lb. Figure 2 shows this dummy seated on the cart's bucket seat and some details of the cart itself.

Instrumentation

The instruments used were an accelerometer, and three load cells mounted directly on specially constructed ladder brackets through which the webbings were threaded for attachment to the anchors. Two dual beam oscilloscopes, with Polariod cameras, were used to record the instrument data.

Accelerommenter:	Statham Model KPF 402; range ± 200 g; output linear up to 750 cps. Used in conjunction with low pass filters; 370 cps with the rigid dummy, 530 cps with the jointed dummy.
Load cells:	Bonded strain gages, Philips 9812; range 4,400 lb.
Oscilloscopes:	Tektronix Type 502, dual beam; range 0-100 kc.

Plots of the instrument data obtained in 11 typical runs are shown in Figures 3 through 13. The cart deceleration curves shown are not determined in this study, but are typical curves obtained in a separate study by Dr. Aldman; these typical curves were inserted here only to show the order of magnitude of the cart deceleration and the time-relationship between the deceleration of the cart and the dummy.

Figure 2. Swedish dynamic test cart, with lead cone fixed on front end—rigid dummy shown in bucket seat, held by lap belt.

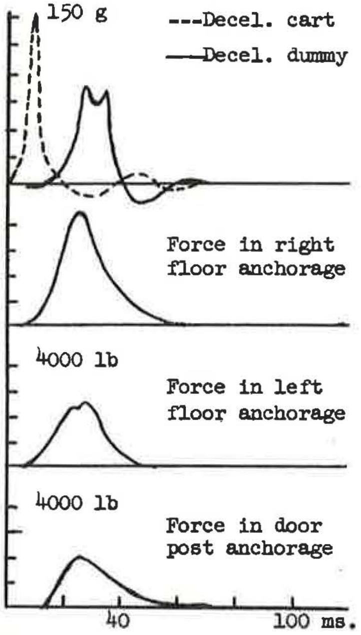


Figure 3. Test 3: 25 mph, jointed dummy; combination lap and chest strap, third anchor on doorpost; 21 percent elongation webbing.

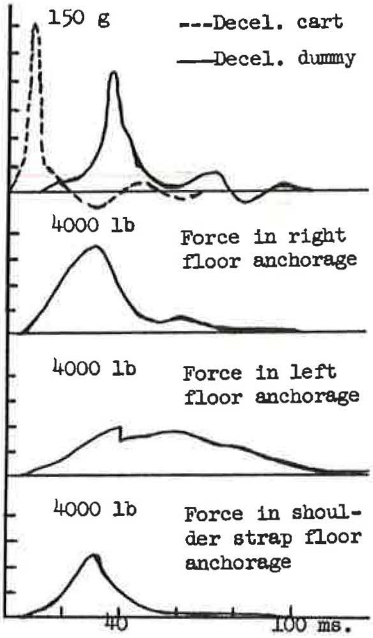


Figure 4. Test 5: 25 mph, jointed dummy; combination lap and chest strap, third anchor on floor; 21 percent elongation webbing.

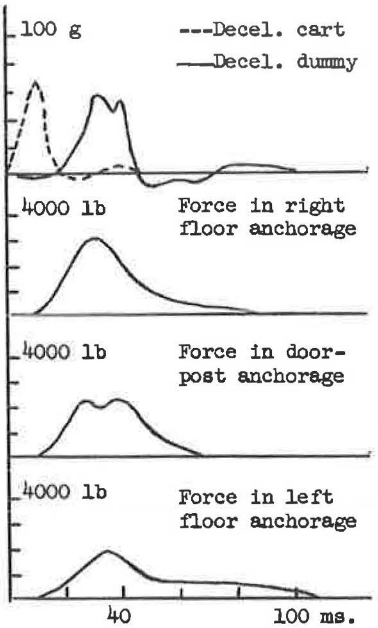


Figure 5. Test 14: 21 mph, jointed dummy; combination lap and chest strap, third anchor on doorpost; 21 percent elongation webbing.

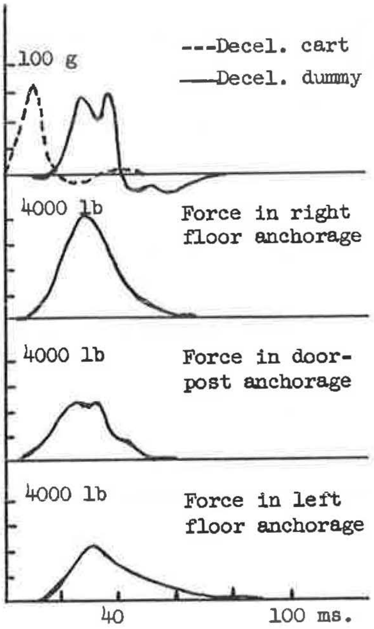


Figure 6. Test 15: 21 mph, jointed dummy; combination lap and chest strap, third anchor on doorpost; 14 percent elongation webbing.

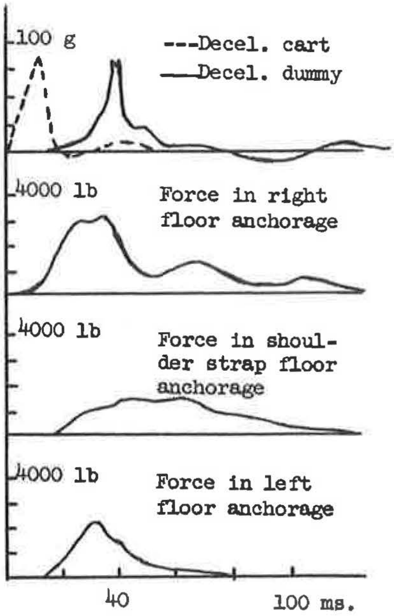


Figure 7. Test 17: 21 mph, jointed dummy; combination lap and chest strap, third anchor on floor; 14 percent elongation webbing.

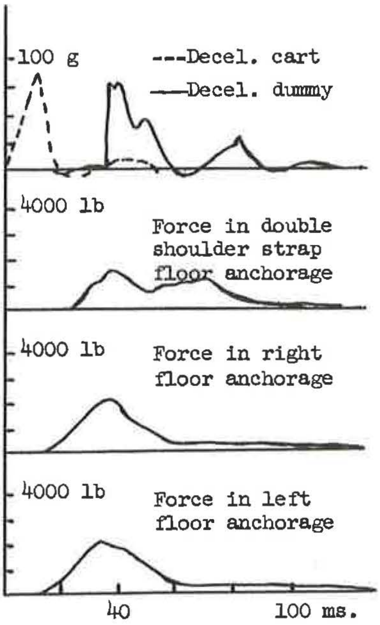


Figure 8. Test 19: 21 mph, jointed dummy; combination lap and double chest strap, third anchor on floor; 14 percent elongation webbing.

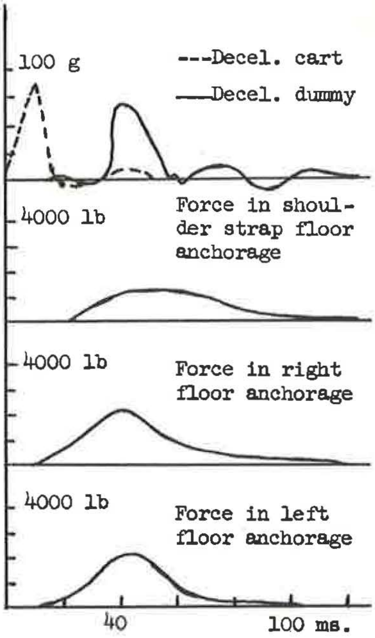


Figure 9. Test 21: 21 mph, jointed dummy; combination lap and chest strap, third anchor on floor; elongation not determined.

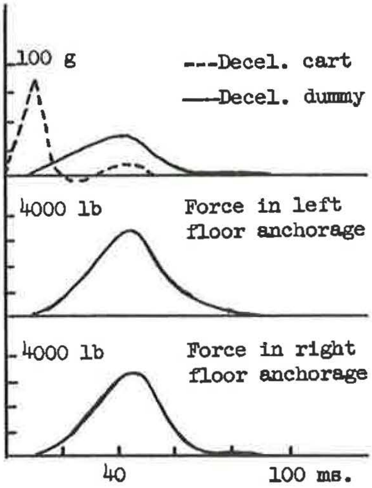


Figure 10. Test 53: 21 mph, rigid dummy; lap strap only, 21 percent elongation webbing.

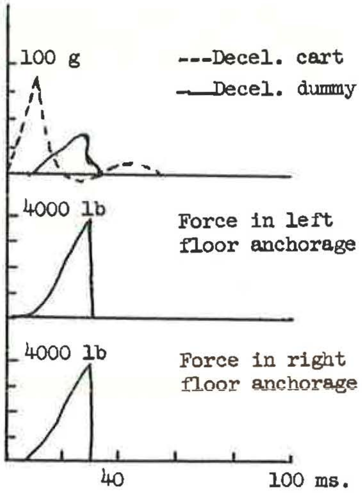


Figure 11. Test 55: 21 mph, rigid dummy; lap strap only, 14 percent elongation webbing.

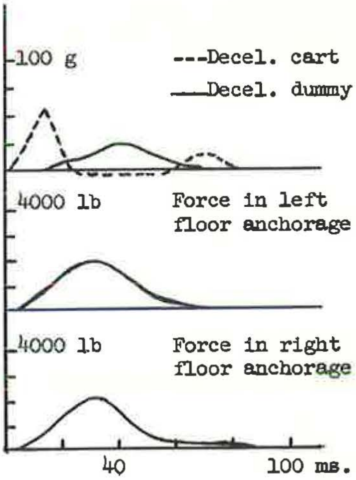


Figure 12. Test 60: 15 mph, rigid dummy; lap strap only, 21 percent elongation webbing.

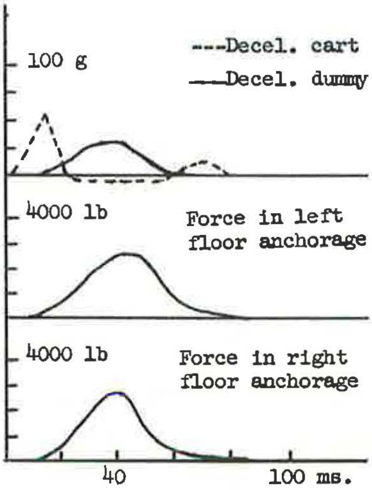
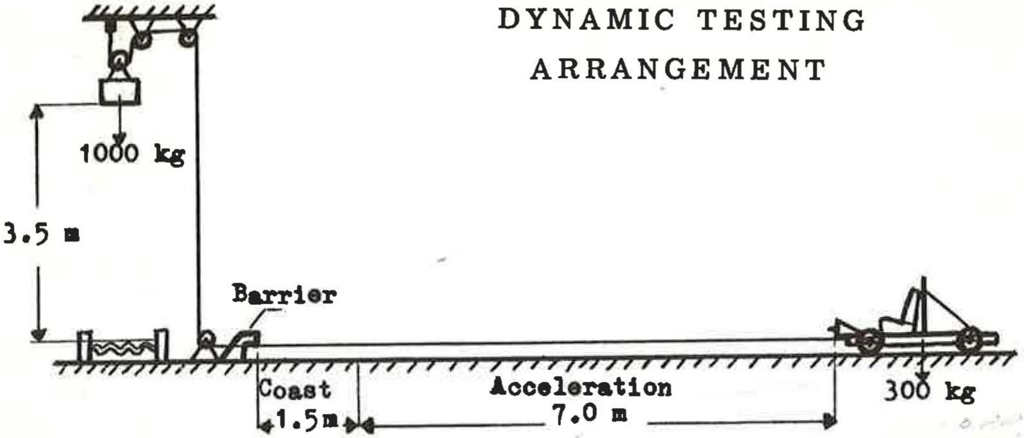
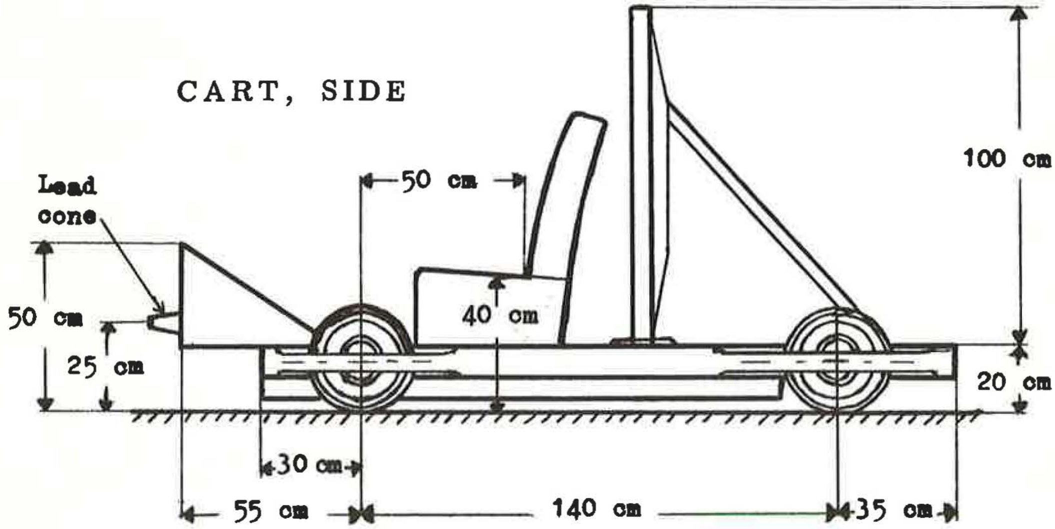


Figure 13. Test 62: 15 mph, rigid dummy; lap strap only, 14 percent elongation webbing.

DYNAMIC TESTING ARRANGEMENT



CART, SIDE



CART, FRONT

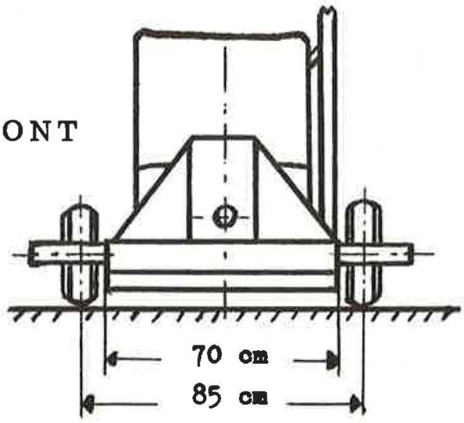


Figure 14. Details of test apparatus.