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EVALUATION OF PASSIVE BELTS FOR DIFFERENT SIZE OCCUPANTS

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16. Abstract

This report presents findings of a combined analytical and experimental research program to: (1) determine the effect of independent variation of the vertical and longitudinal position of the upper anchor point of the Volkswagen Rabbit passive belt on the performance of the restraint system for occupants ranging in size from a 6 yr. old child to a 95th percentile adult male, and (2) to design and develop a vertically adjustable upper anchorage for the VW passive belt and evaluate the performance in impact sled tests. From analyses of results from 40 sled tests (80 occupant exposures) simulating both 30 MPH frontal and angled barrier crashes it is concluded that the location of the existing, fixed anchor point in the 2-door model Rabbit is close to the optimum for the overall range of adult size occupants in terms of performance but the belt geometry does not comply with proposed criteria for belt fit. The data indicate that the comfort zone specified for shoulder belts is too low and increases the likelihood of belt-induced injuries to the lower abdomen due to occupants rolling over the belt.

A vertically adjustable anchor designed for installation inside the door window frame and B-pillar of the 1976 2-door Rabbit is described. Static and dynamic strength proof-tests performed demonstrate that the adjustable anchor is capable of withstanding the belt loads developed during a crash with an adequate margin of safety.

17. Key Words
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Occupant Crash Dynamics
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PREFACE

This final report is submitted in partial fulfillment of the documentation requirements of Contract No. DOT-HS-8-02045 and covers work performed under Phase I of the research program. The Phase II full-scale crash test evaluation of passive belt Volkswagen Rabbit automobiles equipped with adjustable upper anchors is contained in Report No. 6407-V-2. Results of frontal barrier impact tests of two 1980 model Volkswagen pickup trucks modified by the installation of the VW Rabbit passive belt restraint system that were also performed as a special task of the Phase II effort are presented in separate volumes designated as Interim Report Nos. 6407-V-3 and -V-4.

The author gratefully acknowledges the contributions of Mr. Bruce Donnelly of Calspan who assisted in the formulation of design concepts and the performance of sled tests and of Mr. Sheridan Smith, also of Calspan, who was responsible for the detail design and preparation of engineering drawings of the adjustable anchor components, subassemblies, and vehicle installation.

The NHTSA Contract Technical Monitor for this project was Mr. John Morris, Head of the Occupant Packaging Branch of the Vehicle Engineering Research Division.

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the National Highway Traffic Safety Administration.

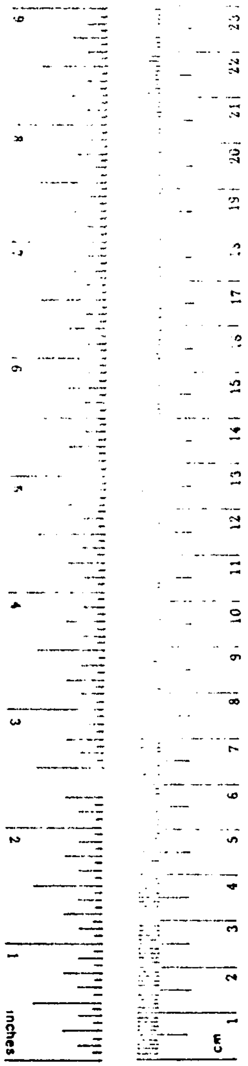
This report has been reviewed and approved by:

Kenneth C. Hendershot, Head
Transportation Research Department
Calspan Advanced Technology Center

METRIC CONVERSION FACTORS

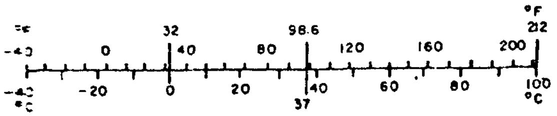
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

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1. INTRODUCTION

The efficacy of restraint belts in reducing injuries to motorists in automobile accidents has long been recognized and conclusively demonstrated by results of numerous studies of highway accident experience. Since 1968 when automobiles sold in the U.S. were first required to have lap and shoulder belts for front seat occupants, many improvements such as emergency locking retractors and single-buckle lap and shoulder belts have been developed which provide increased comfort and convenience over earlier restraint system designs. Unfortunately, however, despite these advances the vast majority of people still do not wear the safety belts.

Federal legislation has been enacted requiring, by model year 1984, that all new passenger cars be equipped with some type of passive restraint for front seat occupants and many manufacturers are developing, or already have available, passive belt restraint systems for their vehicles. Since passive belts are automatically deployed and positioned on the occupants without the need for any action on their part to "buckle up", it is expected that use of passive belts will increase substantially over the approximately 15 to 20 percent usage rate of current manual (i.e., "active") seat belts reported in Reference 1.

Surveys of motorists conducted for the National Highway Traffic Safety Administration (NHTSA) have indicated that comfort and convenience problems are among the main reasons why people choose not to use existing restraint belts (e.g., References 2, 3). Improperly fitting shoulder belts which rub against the neck, tend to fall off the shoulder, or cross over the breast of females is one cause of discomfort often cited. The problem of providing good fitting shoulder belts is made difficult not only because of limitations in the location of anchor points imposed by vehicle configuration and body structural design but also because of the need to accommodate a wide range of occupant sizes and seat adjustment positions.

An adjustable anchor for the shoulder belt has been proposed as a means of allowing improved comfort and fit for different size occupants that could possibly lead to increased safety belt utilization. This report presents findings from the initial phase of a two-phase research program in which an adjustable anchorage for the existing passive belt system of the Volkswagen Rabbit vehicle was developed and the safety effectiveness of the system was evaluated. According to the background information of the contract statement of work, "In consumer interviewing to determine ways of improving the safety belt system in the VW Rabbit, a significant proportion suggested that the diagonal belt is positioned too high on a smaller person. In crash testing of the VW Rabbit, it has been suggested that the diagonal belt may be positioned too low on a larger occupant; this positioning may lead to rotation of the occupant out of the diagonal belt during certain crash situations". Specifically, the objectives of the Phase I study were to

(1) Determine how the performance of the VW Rabbit passive belt restraint is affected by independent variation of the vertical and longitudinal location of the upper belt anchorage for occupants ranging in size from a 6 year old child to a 95th percentile adult male.

(2) Design and develop a consumer acceptable, vertically adjustable upper anchor for the Rabbit passive belt and evaluate the performance in impact sled tests.

The passive restraint system developed by Volkswagen has been available as an option in their Rabbit automobiles since 1975. It basically consists of only a shoulder belt and a knee bolster to control the motion of the lower body. The lower end of the belt terminates at an emergency locking retractor mounted inboard on the frame structure of the bucket seat so the location of that anchor relative to the occupant is unaffected by longitudinal adjustments of the seat position. The upper end of the belt is connected to an emergency release buckle fixed to the rear edge of the door window frame which is strengthened by an interlock with the "B"-pillar to support the belt loads developed in a crash. When the door is opened, the belt is carried forward away from the occupant's torso to permit easy entry and egress from the car; when the door is closed, the belt falls into place across the shoulder and chest as the retractor takes up the slack.

The 1976 two-door model Rabbit was the particular vehicle considered in this program. The effect of upper belt anchor location on restraint system performance was first investigated by computer simulations described in the following section. However, the performance evaluations were mainly accomplished on the basis of comparisons of data generated in over 40 sled tests using an actual two-door Rabbit body buck and restraint system hardware installed on the Calspan accelerator sled. The results from these sled tests with different size occupants in which the location of the upper belt anchor was varied up to ± 6 inches in the vertical direction and up to ± 8 inches horizontally from the original, baseline position are summarized and discussed in Section 3. The design and test evaluation of the vertically adjustable upper anchor developed for the passive belt Rabbit is described in Section 4 and conclusions and recommendations stemming from this research are presented in Section 5.

In the second phase of the program, the performance of the passive restraint system was further evaluated in a series of full-scale crash tests of VW Rabbit vehicles equipped with the developed adjustable upper belt anchorage. The results of the Phase II crash tests are contained in the second volume of the final report on this research program.

2. COMPUTER SIMULATION STUDY

One of the specified program tasks was an analytical investigation of occupant responses to vehicle impacts using computer simulation techniques. The objective of the study was to provide preliminary insight on how the performance of the restraint system would be affected by changes of the vertical and longitudinal location of the upper belt anchor.

2.1 Methodology

The simulations were performed using the three-dimensional Crash Victim Simulation computer program (CVS III) developed by Calspan (Reference 4). The runs were remotely executed on the government computing facility located at Edgewood, Maryland where all input and output data for each run were also stored on magnetic tape files to enable future access of the data by NHTSA personnel if desired. A total of 31 computer simulations were made which, in addition to changes of the upper anchor location, included simulations of 50th and 95th percentile male occupant sizes, driver and right front passenger seating positions, and frontal and 30-degree angled barrier impacts.

To the extent possible, inputs to the simulation model were based on directly measured data. For example, measurements of the vehicle interior were made to accurately define the locations and geometry of belt anchorages and interior contact surfaces such as the seat, knee bolster and steering wheel in the model. Measurements of dummies placed in the vehicle were also made to insure the initial equilibrium positions of the occupants were properly matched in the simulations. Vehicle longitudinal deceleration time history data from crash tests of VW Rabbits were supplied by the CTM. Observations of vehicle motion in 30-degree angled barrier impacts have shown that lateral translation and rotation of the compartment does not usually occur until quite late in the impact so that the direction of the deceleration is mainly longitudinal. From analyses of measured vehicle longitudinal and lateral acceleration data and occupant trajectories in such tests by various investigators (e.g., References 5, 6), it has been found that a fixed angle of 12 to 15 degrees for the resultant acceleration vector relative to the vehicle longitudinal axis provides a good approximation for kinematic equivalence between impact sled and full-scale angled barrier tests. Both the analytical and sled simulations of the full-scale 30-degree angled barrier impact configuration were therefore performed using unidirectional accelerations with the vehicle oriented at a constant yaw angle of 12 degrees.

Information on the force-deflection characteristics of the VW restraint belt, knee bolster and seat required as input to the computer program was very limited so it was necessary to assume estimated properties based on available "typical" data from various sources. Data from a 1973 static test of VW belt webbing was modified to account for the effects of dynamic loading, dummy torso compliance and spool-off from the emergency locking retractor. The increased stiffness of the webbing that occurs with a rapid rate of loading was based on data presented in Reference 7. Webbing spool-off from the retractor as a function of belt load was determined from high speed film and load cell data recorded in an earlier sled test of the VW restraint system reported in Reference 8.

The compliances of the upper torso of the 50th and 95th percentile male dummies were measured in static tests which provide a better source of data for modifying belt webbing force-strain properties to account for the effects of dummy compliance than heretofore was available. In these tests, the dummies were supported in a supine position on a rigid surface and the chest loaded by means of an inextensible steel strap positioned in the manner of a torso belt as shown in Figure 2-1. The loads were applied by pulling on the upper end of the strap and the force at each end, the corresponding change of belt length resulting from the deformation of the torso, and the posterior deflection of the sternum were recorded.

Figure 2-1 TEST SET-UP FOR MEASUREMENT OF DUMMY CHEST COMPLIANCE

The effective belt stretch due to dummy torso compliance is shown in Figures 2-2 and 2-3 for the Alderson Part 572 50th percentile and the 95th percentile male dummies, respectively. The latter dummy thorax is somewhat stiffer but the reduced stiffness evident in the plots for the 50th percentile dummy beginning at about 2 inches of effective belt elongation is probably the result of lateral displacement of the rib cage. The center of the sternum was noted to have displaced approximately 1 inch to the left of the mid sagittal plane when the load measured at the upper end of the belt was about 1200 lb.

Because of the need to use estimated values for many of the model input parameters, a simulation of the earlier sled test of the VW restraint system (Reference 8) was performed to determine if the overall system appeared reasonably well characterized. Based on the good correlation of the CVS model results for head and chest resultant acceleration and belt load time histories

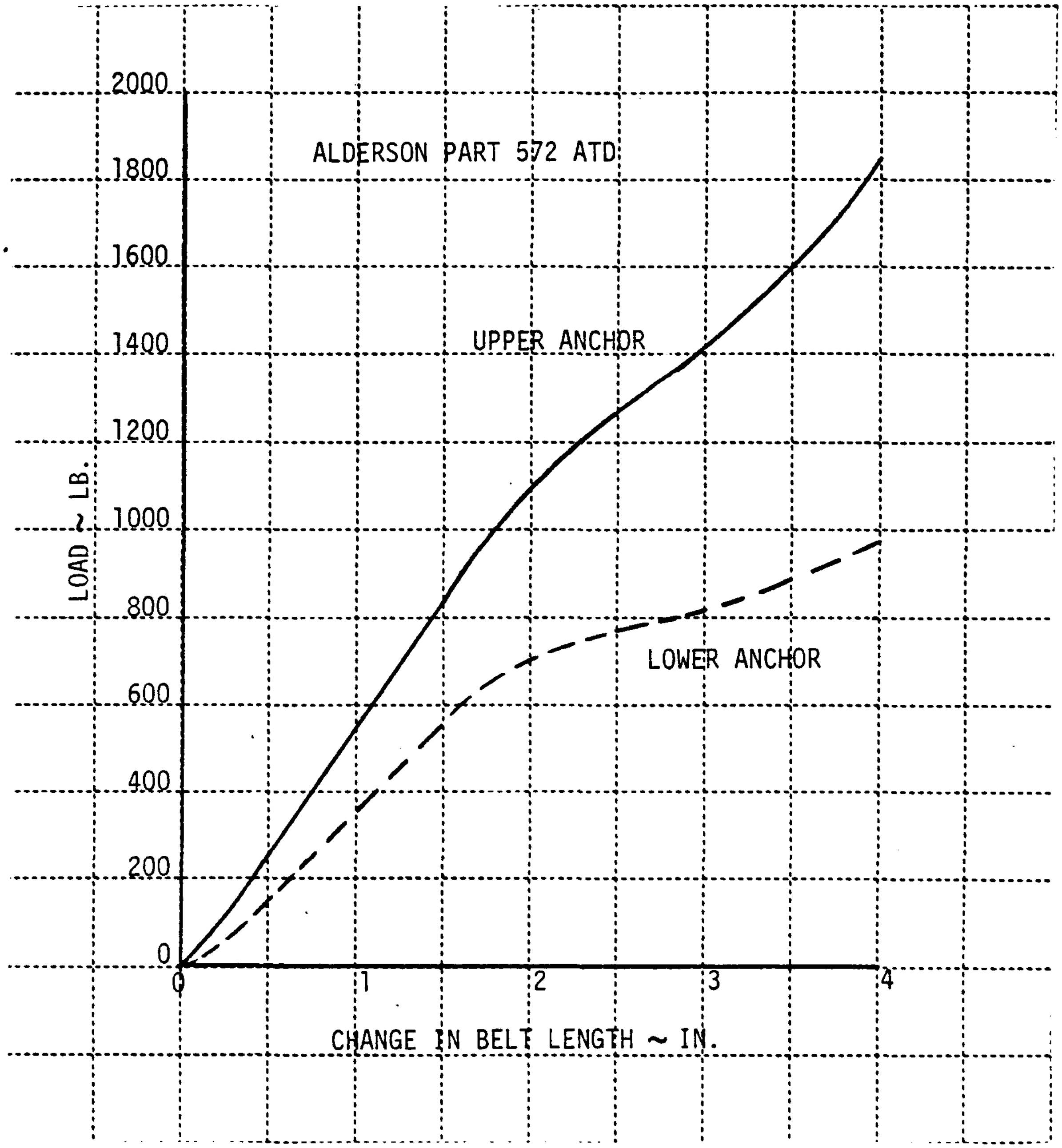


Figure 2-2 EFFECTIVE TORSO BELT STRETCH DUE TO CHEST COMPLIANCE OF 50TH PERCENTILE MALE DUMMY

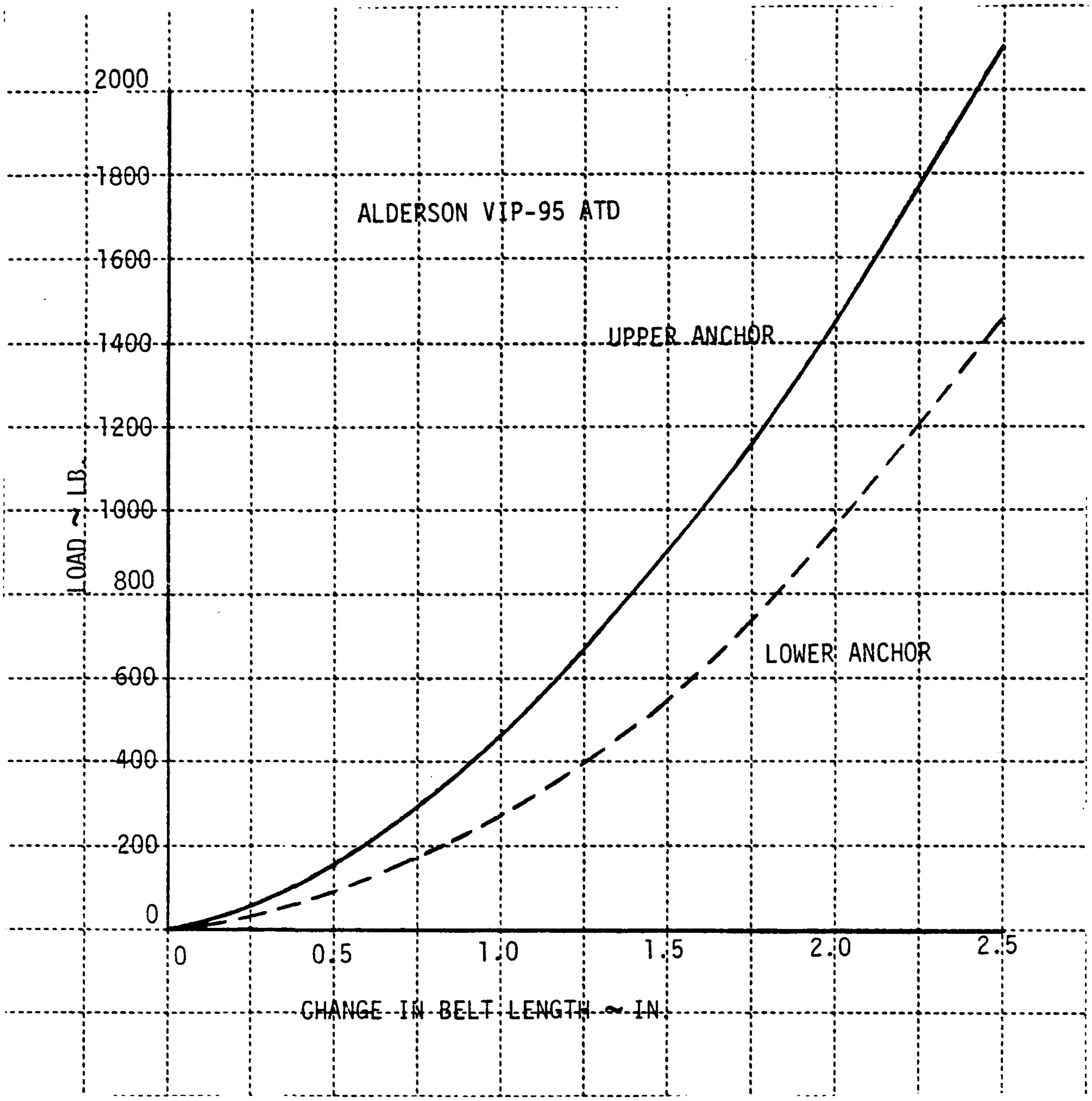


Figure 2-3 EFFECTIVE TORSO BELT STRETCH DUE TO CHEST COMPLIANCE OF 95TH PERCENTILE MALE DUMMY

with the data measured in the sled test, it was concluded that the properties of the restraint system were adequately approximated by the input data set used.

2.2 Simulation Results

Results of the computer simulations of the 50th percentile male occupants with the upper belt anchor at the baseline location of the two-door model VW Rabbits and at points 6 inches above and below that position are summarized in Table 2-1. The ± 6 in. range of vertical adjustment is nearly the maximum as limited by the height of the window opening in the door. The results indicate a weak trend of reduced values of the injury and other restraint performance criteria (i.e., peak belt loads and occupant forward excursion) with lowering of the belt anchor. This trend is consistent for both the driver and passenger seating positions and for each direction of vehicle impact deceleration. It may be noted that the predictions for the driver and passenger are virtually identical for corresponding simulated conditions because the forces from contact of the driver with the steering wheel were not large. (The inputs to the computer program were set up to indicate the occurrence of occupant contacts but with no forces for contacts of the abdomen with the steering wheel or of the head with the windshield. Femur loads were also assumed to be limited to 2000 lb. for knee bolster penetrations greater than 3.5 inches.)

The predicted slightly improved performance of the restraint system for lower positions of the anchorage results from the reduced length of the belt which decreased from 44.9 inches when the anchor was at the highest elevation to 40.2 inches with the anchor located 6 inches below the baseline position. The longer belt is less stiff because the strain (and hence force) is smaller for a given elongation and, as may be seen from the table, resulted in increased forward excursions of the head and chest. In the model, only the length of the upper portion of the belt was affected by changes of the upper anchor position because the locations of the inboard anchor and of the belt reference point on the torso (which together with the upper anchor point define the belt plane)

Table 2-1 SUMMARY OF 50TH PERCENTILE MALE SIMULATION RESULTS - EFFECT OF ANCHOR POINT VERTICAL LOCATION

Run No.	Veh. Impact Decel. Direction	Anchor Position	Peak Head Res. Accel. ~ G	HIC/ Ave. G	Peak Chest Res. Accel. ~ G	CSI/ MSEC	Knee Bar Defl. ~ In. Left/ Right	Belt Load ~ Lb. Up'r/ Lw'r	Head Fw'd Excursion ~ In.	Chest Fw'd Excursion ~ In.	Other(1) Interior Contacts
						RF PASSENGER					
1	Frontal	Baseline	43.2	239/33	37.6	213/150	4.5/4.2	1866/886	20.4	12.2	None
2	Frontal	6 in. Up	46.8	298/37.3	37.1	217/150	4.5/4.4	1841/1203	23.2	13.9	1
3	Frontal	6 in. Dn.	37.9	196/29.6	37.2	194/150	4.5/4.0	1778/750	20.7	12.1	None
4	12° Rt. Obl.	Baseline	44.6	258/35.2	37.5	226/200	3.7/3.9	1901/1395	17.5	10.7	None
5	12° Rt. Obl.	6 in. Dn.	39.8	193/30.6	35.8	185/200	3.7/3.7	1744/1131	17.5	10.4	None
6	12° Lt. Obl.	Baseline	37.7	203/28.5	31.5	-	4.3/3.5	1686/487	18.7	11.5	None
7	12° Lt. Obl.	6 in. Dn.	33.5	164/25.5	31.1	138/155	4.3/3.4	1579/450	18.2	11.1	None
						DRIVER					
8	Frontal	Baseline	43.2	259/31.7	38.5	218/150	4.1/4.5	1874/861	20.2	12.1	2,3,4
9	Frontal	6 in. Up	49.8	375/39.3	37.3	240/150	4.4/4.5	1850/1004	22.4	13.5	1,2,3,4
10	Frontal	6 in. Dn.	38.5	277/31.9	36.3	198/150	4.0/4.5	1770/736	20.0	12.0	2,3,4
11	12° Lt. Obl.	Baseline	44.5	260/35.3	37.3	226/200	3.9/3.7	1902/1397	17.5	10.7	4
12	12° Lt. Obl.	6 in. Dn.	39.8	193/30.5	35.8	185/200	3.7/3.7	1740/1121	17.5	10.3	4

(1) Contact Code As Follows:

1 - Head Hits Windshield
2 - Head Hits Str'g. Wheel
3 - Chest Hits Str'g. Wheel
4 - Abdomen Hits Str'g. Wheel

were assumed to be invariant. Thus, except for minor variation of the belt tangency points on the torso contact ellipsoid defined in the model, the orientation of the belt on the occupant was essentially the same for all of the simulation runs. This was a potential source of error in the model predictions because, as is shown later in Sections 3.3 and 3.4, the position and angle of the belt as it crosses over the upper torso both vary with changes of the upper anchor location.

Results of simulations of a 95th percentile male occupant for different vertical locations of the upper anchor are presented in Table 2-2. Like those of the 50th percentile occupant, these results indicate a tendency toward improved restraint system performance with lowering of the anchor point. Although the differences in the responses due to anchor location again are not very large, this trend is seen to be stronger for the larger size occupant. The length of the belt in the simulations of the 95th percentile occupant ranged between 42.4 and 38.5 inches for anchor point locations 6 inches above and below the baseline position, respectively. These lengths are shorter than in the simulations of the 50th percentile male because of the difference in the longitudinal position of the seat (and hence also the inboard anchor) in the vehicle. The seat was defined to be at the center of the adjustable range in the simulations of the 50th percentile occupant and fully (i.e., 3.9 inches) aft for the larger size crash victim.

The computer simulations show that the belt loads cause the occupants to twist outboard during the impact. This kinematic behavior created a problem in the simulations of left and right oblique vehicle impacts for the passenger and driver, respectively. In those configurations, the occupant tends to slip out from under the restraint belt and the motion of the torso resulted in failure of the logic associated with the computation of instantaneous length of the belt approximately 155 milliseconds after vehicle impact. For this reason, and also because the effect of belt anchor locations appeared to be the same as observed for the other conditions investigated, those combinations of seating position and vehicle impact direction were not simulated for the larger size occupant.

Table 2-2 SUMMARY OF 95th PERCENTILE MALE SIMULATION RESULTS - EFFECT OF ANCHOR POINT VERTICAL LOCATION

Run No.	Veh. Impact Decel. Direction	Anchor Position	Peak Head Res. Accel. ∿ G	HIC/ Ave. G	Peak Chest Res. Accel. ∿ G	CSI/ MSEC	Knee Bar Defl. ∿ In. Left/ Right	Belt Load ∿ Lb. Up'r/ Lw'r	Head Fw'd Excursion ∿ In.	Chest Fw'd Excursion ∿ In.	Other(1) Interior Contacts
						RF PASSENGER					
13	Frontal	Baseline	42.1	299/32.4	43.3	306/150	6.9/5.8	3090/1925	17.6	12.4	None
14	Frontal	6 In. Up	54	415/41.2	50.5	384/150	7.0/6.3	3516/2176	20.1	14.2	None
15	Frontal	6 In. Dn.	35.8	268/27.3	38.1	254/150	6.8/5.3	2706/1654	18.7	12.5	None
16	12° Rt. Obl.	Baseline	50.4	386/39.0	48	355/200	5.8/5.4	3156/2336	15.6	11.6	None
17	12° Rt. Obl.	6" Dn.	41.0	279/30.4	40.9	273/200	5.8/4.9	2695/1959	16.3	11.5	None
						DRIVER					
18	Frontal	Baseline	42.2	299/32.4	43.2	306/150	5.7/6.9	3089/1925	17.6	12.4	1
19	Frontal	6 In. Up	54	416/41.2	50.5	384/150	6.3/7.0	3515/2178	20.1	14.2	1
20	Frontal	6 In. Dn.	35.7	263/27.1	38.1	254/150	5.3/6.8	2706/1653	18.7	12.5	1
21	12° Lt. Obl.	Baseline	50.4	387/39.0	48	355/200	5.4/5.8	3156/2336	15.6	11.6	1
22	12° Lt. Obl.	6 In. Dn.	40.9	281/29.6	41	273/200	4.9/5.8	2696/1959	16.3	11.5	1

(1) Contact Code As Follows:

1 - Abdomen Hits Steering Wheel

The results from a series of computer simulations in which the longitudinal position of the belt upper anchor was varied are presented in Table 2-3. A trend of improved restraint performance with more rearward anchor location is evident in the results for both sizes of occupant; however, again the effect is not very strong and is manifested primarily in reduced peak chest accelerations. The increase of belt length resulting from changing the anchor point from 8 inches forward to 8 inches aft of the baseline position was 13.4 and 11.9 inches for the 50th and 95th percentile occupants, respectively. The predicted belt loads for the larger dummy appear to be unrealistically high but the results for both occupant sizes indicate a reduction of the peak belt load as the anchor point is moved aft due to the increased length of the belt.

In summary, the computer simulations indicate that, with the possible exception of femur loads, the restraint system performance is very good and results in occupant responses well below the occupant protection requirements of Federal Motor Vehicle Safety Standard (FMVSS) No. 208. The model results also show that the performance of the restraint system is not very sensitive to changes of the belt upper anchor location but may be improved slightly for anchor positions below or aft of the existing attachment point in the vehicle.

Table 2-3 SUMMARY OF FRONTAL IMPACT SIMULATION RESULTS - EFFECT OF ANCHOR POINT LONGITUDINAL LOCATION

Run No.	Occupant Percentile	Anchor Position	Peak Head Res. Accel. ∿ G	HIC/ Ave. G	Peak Chest Res. Accel. ∿ G	CSI @ 150 MSEC	Knee Bar Defl. ∿ In. Left/ Right	Belt Load ∿ Lb. Up'r/ Lw'r	Head Fw'd Excursion ∿ In.	Chest Fw'd Excursion ∿ In.	Other(1) Interior Contacts
						RF PASSENGER					
23	50	8 In. Fwd	43.8	228/32.9	41.2	237	4.5/4.2	2228/1159	20.1	11.8	None
24	50	4 In. Fwd	42.9	230/33.2	39.4	225	4.5/4.1	2067/949	19.6	11.7	None
1	50	Baseline	43.2	239/33	37.6	213	4.5/4.2	1866/886	20.4	12.2	None
25	50	4 In. Aft	43.2	250/33	36.7	202	4.4/4.4	1745/831	21.9	13.0	None
26	50	8 In. Aft	42.7	267/32.7	35.7	193	4.5/4.3	1625/827	23.3	13.8	None
27	95	8 In. Fwd	48.9	323/34.7	53.6	366	7/5.9	3791/2375	19.9	13.4	None
28	95	4 In. Fwd	43.4	295/32.4	46.6	321	7/5.7	3399/2162	17.7	12.3	None
13	95	Baseline	42.1	299/32.4	43.3	306	6.9/5.8	3090/1925	17.6	12.4	None
29	95	4 In. Aft	42.9	314/33.2	42.1	302	6.9/5.9	2937/1800	18.8	13.1	None
						DRIVER					
30	95	8 In. Fwd	48.9	324/34.7	53.6	386	5.9/7	3790/2375	19.9	13.4	1
18	95	Baseline	42.2	299/32.4	43.2	306	5.7/6.9	3089/1925	17.6	12.4	1
31	95	8 In. Aft	44.7	326/33.2	41.5	297	6.0/6.8	2794/1724	20.4	13.9	1

(1) Contact Code As Follows:

1 - Abdomen Hits Steering Wheel

3. SLED TEST EVALUATION OF THE EFFECT OF UPPER ANCHOR LOCATION

Analysis and evaluation of the effects of varying the location of the upper anchor of the VW Rabbit passive belt on the performance of the restraint system was mainly accomplished by dynamic testing with the Calspan HYGE accelerator sled. In this section the methodology is described and the results of the test program are presented and discussed.

3.1 Test Methodology

3.1.1 Sled Body Buck

A test buck was fabricated from an available 1976 two-door VW Rabbit that had sustained only minor damage to the passenger compartment in a crash test. The structure forward of the firewall and aft of the B-pillar was removed and the roof was also cut away to facilitate photographic coverage. The body was externally reinforced and braced at the front and rear as required for mounting on the sled and for maintaining the geometry of the compartment interior in the repeated exposures to the high force levels of the simulated crashes.

The doors were removed as was the windshield which was replaced with plexiglass for safety purposes. The interior of the vehicle was unchanged except for a bracket to support the steering wheel/column assembly and structural reinforcement of the A- and B-pillars and of the floor under the seats. Steel plate and tubing were attached to the B-pillars for anchoring the upper end of the restraint belt at the desired vertical and longitudinal positions. These "boiler plate" anchors were used in all of the tests except one series of five runs in which the performance of the adjustable anchor device was evaluated. The adjustable anchor hardware was installed in the door and B-pillars only on the passenger side of the body buck.

3.1.2 Test Conditions and Configurations

- Crash Deceleration Pulses

Longitudinal acceleration data measured in 30 MPH frontal and angled barrier impact tests of the VW Rabbit were supplied by the sponsor and used to select a sled metering pin and operating conditions that would provide acceleration pulses reasonably representative of the actual vehicle crash responses. The match achieved between the acceleration time histories measured in full-scale crashes and those used in the sled test program is shown in Figure 3-1. For the frontal barrier impact simulations, the sled pulse of 26 G peak acceleration and 93 msec. duration produced a velocity change of 30.9 MPH compared to 34.9 MPH obtained from integration of the crash test acceleration data which indicates an appreciable vehicle rebound velocity occurred if the impact speed was nominally 30 MPH. The vehicle acceleration time histories with angled barrier crashes were very closely approximated by the 19 G, 143 msec. pulse used in the sled tests.

- Instrumentation

A complement of 21 electronic transducers were used to measure the various dynamic responses in each sled test. The instrumentation consisted of triaxial accelerometer packages in the head and chest and load cells in the femurs of each dummy, load cells to measure the force at the upper and lower ends of the restraint belts and an accelerometer mounted on the sled to monitor the crash pulse. The amplified transducer signals were recorded both by magnetic tape recorders and by the Calspan Digital Data Acquisition System (DDAS) operating in the on-line mode. The digitized data were processed by DDAS computer programs which calculated values of the Head Injury Criteria (HIC) and produced hard copy time-history plots of the reduced data within one hour after each test. The analogue data were also displayed on multi-channel strip charts which are presented in Appendix A for each sled run.

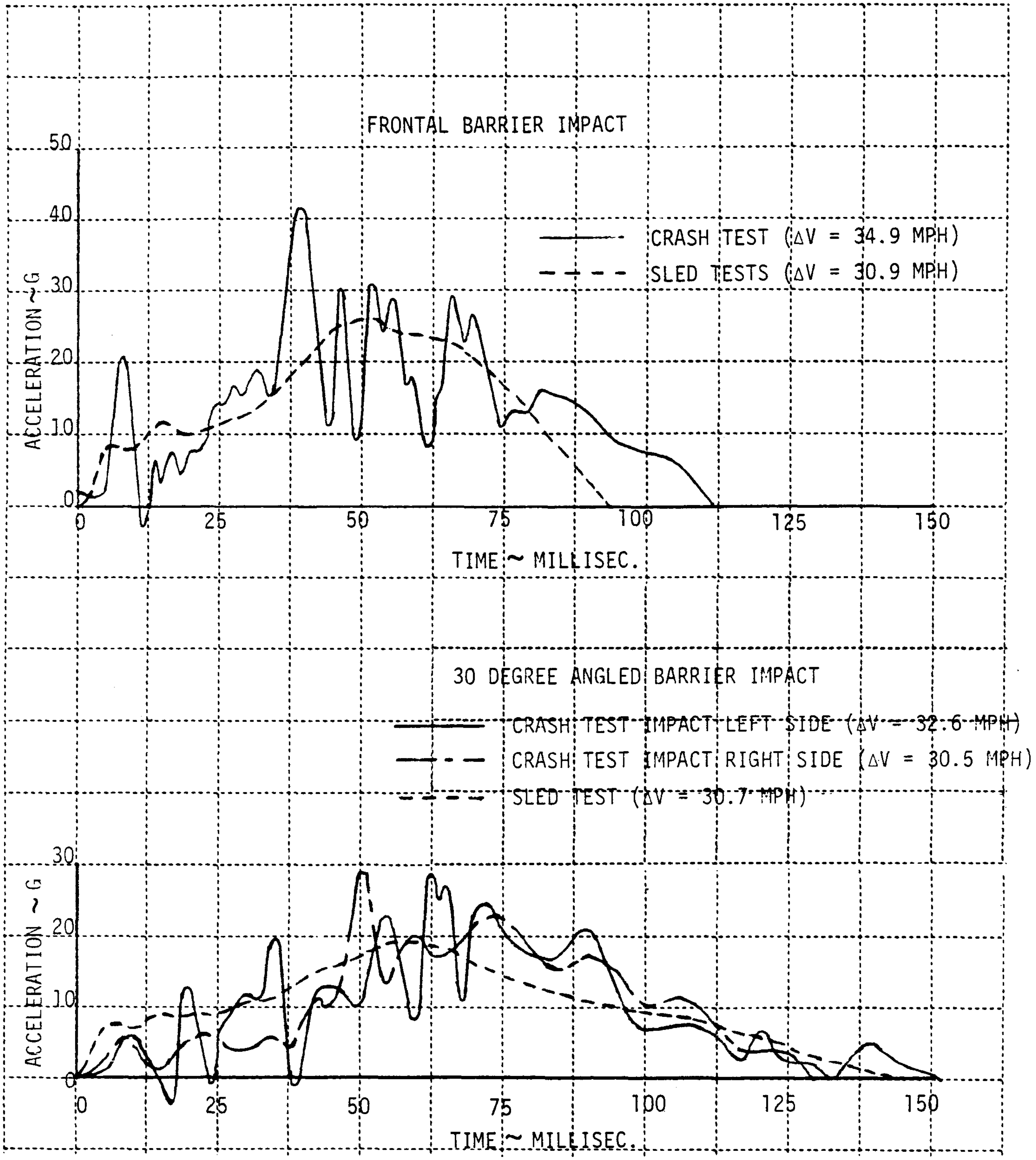


Figure 3-1 SLED TEST SIMULATION OF VW RABBIT ACCELERATIONS IN FULL-SCALE BARRIER IMPACTS

Four high-speed motion picture cameras were mounted onboard the sled to provide a visual record of dummy kinematics and interaction with the restraint system. Three cameras provided lateral views from each side of the body buck for showing the kinematic responses of the driver and passenger dummies and an elevated front view through the windshield for observing the position of the restraint belt on the torso of each dummy and for detecting occurrences of belt roping, loading of the neck or underride of the rib cage. The fourth camera photographed, with the aid of mirrors, the inboard end of the restraint belts for measurement of the amount of belt spool-off from the emergency locking retractors. Other photographic coverage included two on-board Polaroid sequence cameras for "quick look" assessment of occupant kinematics and pre- and post-test still pictures showing the initial configuration and the final rest positions of the dummies as well as damage to compartment interior components.

- Test Configurations

The sled test program consisted of 40 sled runs with dummies occupying both the driver and passenger seats, thereby providing 80 occupant exposures to simulated crashes for evaluating the performance of the restraint system with various locations of the upper belt anchor. Tests were conducted using the three adult size dummies (i.e., 50th and 95th percentile male and 5th percentile female) as both drivers and passengers restrained by belts anchored at the same locations. A typical test configuration is illustrated in the photographs of Figure 3-2. Only two tests were performed with a 6 year old child size dummy because it was evident that the restraint system would not protect such a small size occupant whose legs are not properly restrained by the knee bolster so as control the motion of the lower torso,

The position of the upper anchor was varied between 8 inches ahead and aft of the normal location in the vehicle (termed the baseline position herein) and between 6 inches above and below the baseline position. The 8 inch forward location is very close to the configuration of the passive belt in a four-door model Rabbit vehicle and the ± 6 inch range in the vertical direction

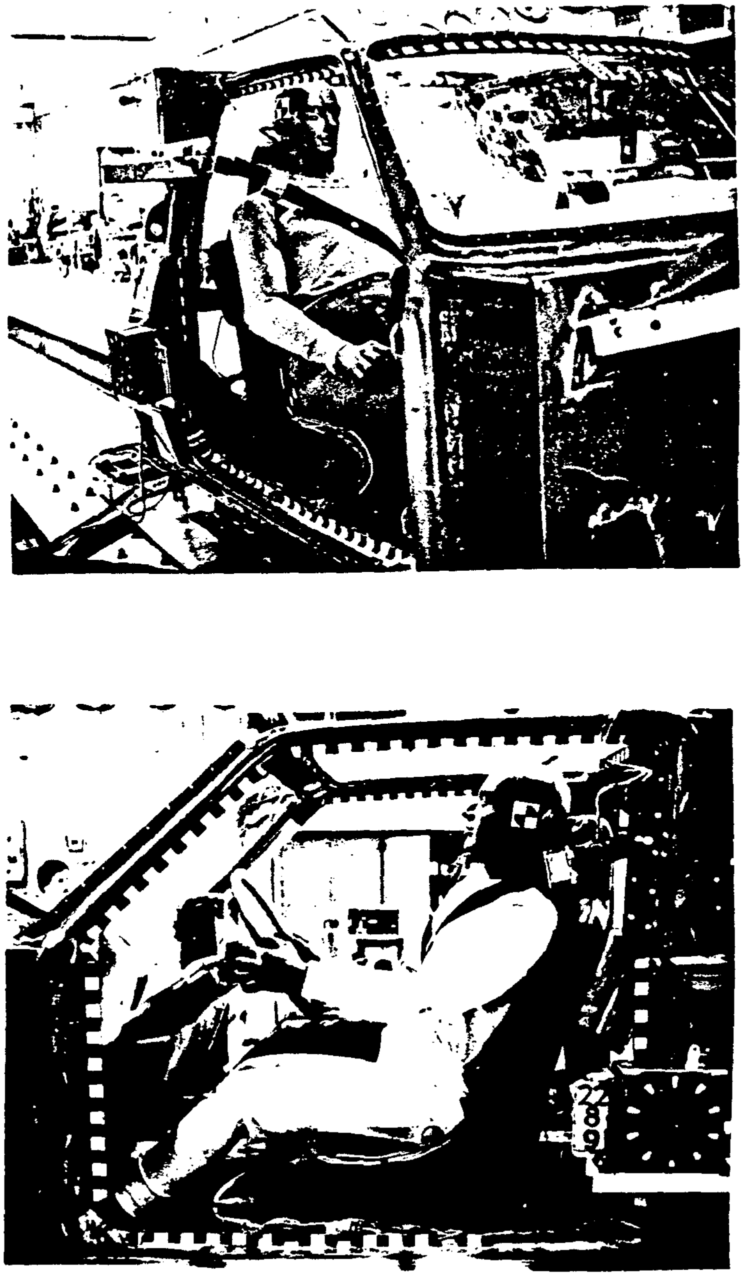


Figure 3-2 TYPICAL SLED TEST CONFIGURATION

is about the limit that can be accommodated by the height of the door window opening. Each size adult dummy was tested with the belt anchored at these extremes of longitudinal and vertical location and at the baseline position which provided the data base required for comparing and evaluating the performance of the restraint system with the anchors relocated. Other anchor point locations investigated were 4 inches forward and aft with the 50th percentile dummy, 2 and 3 inches down with the 5th percentile dummy and 2 inches down and 1, 3 and 5 inches up from the baseline position in tests of the 95th percentile male dummy. Replicate runs were made for many of the test configurations.

Most of the tests were performed with the seats in the usual position for the various size occupants, i.e., fully-forward, mid-, and fully-aft for the 5th, 50th, and 95th percentile dummies, respectively. However, a few non-standard configurations were also tested. These included tests of the 5th percentile dummy with the anchor 8 inches forward of the baseline but with the seat in the mid- and fully-aft positions, and two sled runs in which the inboard belt anchor was moved 6 inches forward to enable the belt to fall within the comfort zone on the 50th percentile dummy defined in Reference 9. This location of the inboard anchor was determined by placing a 50th percentile dummy in the body buck with the seat in the mid-position and moving the retractor ahead in small increments until the belt, when withdrawn from the retractor and released, appeared to naturally fall within the comfort zone that had been outlined on the dummy torso. The retractor was then bolted in place under the seat to a bracket welded to the seat frame structure. The increased width and height of the seat cushion at the more forward station of the retractor caused interference between the cushion and the belt which made it difficult to accurately determine the minimum required shift of the anchor.

Damaged components such as the steering wheel, knee bolster and seats were replaced with new parts for each sled run. New restraint belt webbing of the same length as the original equipment belts provided by the vehicle manufacturer was also used for each test.

3.2 Test Results

3.2.1 Baseline Upper Anchor

Occupant response data from all of the sled tests performed with the upper belt anchor at the baseline position of the two-door Rabbit vehicle are summarized in Table 3-1 and corresponding measurements of the restraint belt geometry, loads and spool-off from the emergency locking retractors are given in Table 3-2. One of the points of particular interest shown by these data tabulations is that the values of the peak head acceleration and HIC for the 5th percentile dummy are consistently higher than those of the larger dummies and exceeded the allowable limit of 1000 in each of the frontal impact tests even when the head did not strike any part of the vehicle interior.

The responses of the 50th and 95th percentile dummies were well below the injury criteria limits in all tests except that of the driver in Run No. 2330 for which the impact speed was increased to 38.5 MPH. In that test the chest resultant acceleration was only 1 G above the 60 G injury criterion but the femur loads were substantially greater than the 2250 lb. limit specified in Federal Safety Standard No. 208. As noted in Table 3-1, the 50th percentile driver head struck the steering wheel in all but one test, including the run in which the belt position on the dummy was within the comfort zone (Run No. 2329). The low values of the response measures for both the driver and passenger dummies of Run No. 2329 suggest that the performance of the restraint system might be improved by relocating the inboard anchor 6 inches forward of the normal position but too few tests of that configuration were performed to be conclusive.

A problem of repeated failure of the 95th percentile dummy neck was experienced as indicated in Table 3-1. In each instance, one or both of the 7 x 19 wire cables contained in the rubber neck failed which was signalled by "hash" produced in the head and chest accelerometer data. Examination of the head acceleration data from an earlier test of the dummy (Run No. 2226) also showed some "hash" but, since the data traces reflected a grazing contact with

Table 3-1
OCCUPANT DATA FROM BASELINE UPPER ANCHOR SLED TESTS

Stitching →

RUN NO.	ATD SIZE	SEAT POSITION	HEAD			CHEST		FEMUR LOAD ~LB.		NOTES
			RESULT. ACCEL. G	HIC	FORWARD EXCURSION IN.	RESULT. ACCEL. G (3 ms)	CSI (200 ms)	LEFT	RIGHT	
FRONTAL IMPACTS										
2227	5	DR/FWD	100	1491	16.4	55	460	865	1030	
2283	5	DR/FWD	235	1941	18.4	52	470	850	800	1
2229	5	PASS/FWD	88	1183	21.5	43	370	790	890	
2286	5	PASS/FWD	123	1420	20.5	49	435	1060	1050	
2221	50	DR/MID	47	388	20.3	39	285	975	1250	
2277	50	DR/MID	61	469	22.1	33	230	1190	1400	1
2289	50	DR/MID	119	593	22.1	42	350	1450	1125	1
2329	50	DR/MID	50	272	22.8	29	200	1520	1800	1,7
2330	50	DR/MID	132	721	26.3	61	250	2570	2800	1,7,8
2221	50	PASS/MID	54	438	21.2	37	240	900	1100	
2273	50	PASS/MID	36	208	23.2	34	160	1100	1175	2
2329	50	PASS/MID	36	177	27.2	33	145	1120	1240	2,7
2273	95	DR/AFT	48	407	22.5	35	260	1650	1250	
2286	95	DR/AFT	150	626	26.2	41	315	1975	2000	4
2227	95	PASS/AFT	60	N.G.	22.0	31	395	775	1515	5
2228	95	PASS/AFT	65	N.G.	20.3	31	280	950	1260	5
2277	95	PASS/AFT	60	N.G.	23.8	38	300	1350	1250	5
2283	95	PASS/AFT	N.G.	N.G.	24.5	40	280	1200	1700	5
2284	95	PASS/AFT	62	545	25.5	36	260	950	1525	3
2229	6 yr.	DR/MID.	123	3716	–	48	260	–	–	6
2230	6 yr.	DR/MID (LAP BELT)	>300	3925	–	>200	>5000	–	–	6
12^o RIGHT OBLIQUE IMPACTS										
2236	5	DR/FWD	65	624	15.4	38	230	750	800	
2237	5	PASS/FWD	58	672	14.7	36	195	850	840	3
2234	50	DR/MID	43	333	20.6	28	140	1030	780	1
2234	50	PASS/MID	40	334	19.2	30	160	1000	840	2
2237	95	DR/AFT	37	252	19.7	30	150	1600	1080	
2236	95	PASS/AFT	64	306	17.5	26	150	950	1510	3,4

NOTES:

1. HEAD HIT STR'G WH'L
2. RIB UNDERRIDE
3. NECK LOADING
4. HEAD HIT "B" PILLAR
5. ATD NECK CABLE FAILURE
6. STR'G WH'L/COL. REMOVED
7. INBOARD ANCHOR 6 IN. FW'D OF NORMAL POSITION
8. SLED VELOCITY 38.5 MPH

Table 3-2
RESTRAINT BELT DATA FROM BASELINE UPPER ANCHOR SLED TESTS

RUN NO.	ATD SIZE	SEAT POSITION	BELT GEOMETRY		BELT LOAD ~ LB.		RETRACTOR SPOOL-OFF IN.	NOTES
			POSITION IN. (a)	CROSSING ANGLE DEG.	UPPER	LOWER		
FRONTAL IMPACTS								
2227	5	DR/FWD	-1.5	61	1550	1040	4.5-5	
2283	5	DR/FWD	-1.8	56	1450	1025	4	
2229	5	PASS/FWD	-2.1	51	1740	600	5	
2286	5	PASS/FWD	-1.3	58	1625	1190	5	
2221	50	DR/MID	2.9	53	2300	N.A.	N.A.	
2277	50	DR/MID	1.5	48	1850	1325	N.A.	
2289	50	DR/MID	2.2	50	2075	1300	7	
2329	50	DR/MID	0.1	51	1625	900	–	1
2330	50	DR/MID	0.4	51	2110	1340	–	1,2
2221	50	PASS/MID	2.6	54	2025	1175	N.A.	
2273	50	PASS/MID	2.0	49	1775	1325	6	
2329	50	PASS/MID	0.8	51	1885	985	–	1
2273	95	DR/AFT	5.2	47	2400	1375	6.5	
2286	95	DR/AFT	5.5	46	2150	1590	6	
2227	95	PASS/AFT	4.2	46	2365	1490	4.5-5	
2228	95	PASS/AFT	4.9	44	2600	N.A.	5.5-6	
2277	95	PASS/AFT	5.2	44	2175	1750	5	
2283	95	PASS/AFT	6.8	44	2125	1500	5-6	
2284	95	PASS/AFT	7.3	47	1875	1675	6	
2229	6 yr.	DR/MID	–	–	1220	850	3.5	
2230	6 yr.	DR/MID (LAP BELT)	–	–	1330	900	5.5	
12° RIGHT OBLIQUE IMPACTS								
2236	5	DR/FWD	-1.5	59	1160	730	4.5	
2237	5	PASS/FWD	-2.0	57	1300	820	3.5	
2234	50	DR/MID	0.7	47	1570	830	5-5.5	
2234	50	PASS/MID	0.5	46	1700	980	5	
2237	95	DR/AFT	3.7	50	2160	1040	6	
2236	95	PASS/AFT	5.2	44	1600	1060	5	

(a) DISTANCE ABOVE (+) OR BELOW (-) 16" STERNUM REF. POINT ON ATD

NOTES:
1. INBOARD ANCHOR 6 IN. FW'D OF NORMAL POSITION, RETRACTOR SPOOL-OFF NOT MEAS.
2. SLED VELOCITY 38.5 MPH

the windshield header, neck failures were neither suspected nor recognized early in the sequence of tests. Because of the high frequency of such failures which prevented calculation of meaningful HIC values (in most cases peak head and chest resultant accelerations and CSI could be estimated with sufficient accuracy), it was decided after consulting with the CTM, to modify the dummy by substituting the neck of a Part 572 50th percentile ATD. The modification was easily accomplished since it was only necessary to drill several holes in the upper and lower neck adaptors to match with existing tapped holes in the end plates of the Part 572 dummy rubber neck. Moreover, removal of the spacer in the 95th ATD neck assembly compensated for the longer Part 572 rubber neck so that the overall length of the neck remained very nearly the same (within 1/16 in.). Modified 95th percentile dummies were used in tests subsequent to sled Run No. 2283 without further difficulty.

Measurements of the initial geometry of the belt presented in Table 3-2 show that with respect to the same reference point on each of the dummies (i.e., 16 inches above a horizontal, rigid seat with the dummies sitting erect), the belt crossed lower and at a steeper angle on the torso of the 5th percentile dummy. From the data for the 50th percentile ATD it may be seen that moving the inboard anchor forward lowered the position of the belt on the torso but the crossing angle did not change much. The 51 degree angle measured in those tests is near the minimum of the calculated possible range of 55 ± 6.3 degrees that will allow the belt to lie within the comfort zone.

As would be expected, the belt load data show an increase of the maximum force with increased occupant size due to the greater mass of the torso. However the difference in belt forces does not appear to have had much effect on the amount of belt extracted due to tightening of the remaining webbing wound on the spool of the emergency locking retractor.

3.2.2 Vertical Variation of Upper Anchor Position

Data obtained from sled tests in which the elevation of the upper restraint belt anchor was varied from the baseline position are listed in Tables 3-3 and 3-4. To facilitate analysis and evaluation of the results and the identification of possible trends in the performance of the restraint system with changes of the vertical location of anchor, data from these tests and from those of the baseline anchor location presented earlier are depicted graphically in Figures 3-3, 3-4 and 3-5 for the tests performed with the 5th percentile female and the 50th and 95th percentile male size dummies, respectively.

Considering first the results for the 5th percentile dummy, it may be noted from Table 3-3 that the driver head struck the steering wheel both in the test with the anchor 6 inches down and in one of the two tests with the anchor located 6 inches up. As indicated in Table 3-1, a similar head contact occurred in one of the baseline anchor tests. The high head accelerations produced in those contacts also resulted in high HIC values but, as previously pointed out, HIC numbers close to or greater than 1000 were measured in several of the 5th percentile dummy tests in which there was no impact of the head with the vehicle interior.

The data for both the driver and passenger dummies shown in Figure 3-3 exhibit a trend of increasing magnitude of the chest resultant acceleration, severity index, femur load and peak belt load with increasing elevation of the upper anchor. From this and the low values of head response measured in the tests with the anchor moved down one would naturally conclude that reducing the height of the anchor results in improved restraint system effectiveness. However, this is but one of several instances in the sled test program where low values of these performance evaluation parameters belie the actual performance of the restraint as revealed by the high speed films of occupant kinematics and body areas loaded by the belt. For example, in the test with the anchor 6 inches below the baseline, the 5th percentile passenger dummy rotated over the belt to the extent that the head struck the dash panel.

Table 3-3
OCCUPANT DATA FROM SLED TESTS WITH UPPER ANCHOR RELOCATED VERTICALLY

RUN NO.	ATD SIZE	SEAT POSITION	ANCHOR LOCATION	HEAD			CHEST		FEMUR LOAD ~ LB.		NOTES
				RESULT. ACCEL. G	HIC	FORWARD EXCURSION IN.	RESULT. ACCEL. G (3 ms)	CSI (200 ms)	LEFT	RIGHT	
FRONTAL IMPACTS											
2280	5	DR/FWD	6" UP	154	1366	17.9	58	540	720	800	1
2284	5	DR/FWD	6" UP	100	999	17.4	51	510	775	1000	
2327	5	DR/FWD	2" DN	58	615	16.9	45	365	825	890	
2281	5	DR/FWD	6" DN	IMPROPER BELT ATTACH. – TEST N.G.							
2282	5	DR/FWD	6" DN	162	1539	17.7	48	410	775	750	1
2280	5	PASS/FWD	6" UP	54	545	19.7	44	400	675	650	
2285	5	PASS/FWD	6" UP	87	967	20.0	53	470	1075	1050	3
2328	5	PASS/FWD	2" DN	49	299	19.7	46	345	910	915	2
2282	5	PASS/FWD	3" DN	38	183	22.2	43	310	650	675	2
2281	5	PASS/FWD	6" DN	119	499	26.2	36	200	600	625	1,2
2278	50	DR/MID	6" UP	68	699	21.6	39	340	1425	1575	3
2279	50	DR/MID	6" DN	75	883	28.3	41	250	1360	1700	1,2
2278	50	PASS/MID	6" UP	61	541	19.5	40	330	1150	1075	
2279	50	PASS/MID	6" DN	74	667	34.2	39	240	950	1275	1,2
2285	95	DR/AFT	6" UP	57	644	26.2	50	370	2000	1820	3
2328	95	DR/AFT	3" UP	197	1191	24.7	38	325	1540	1655	3,4
2287	95	PASS/AFT	6" UP	69	595	24.0	36	280	1250	2130	3
2326	95	PASS/AFT	5" UP	78	708	24.5	39	265	840	1750	2
2330	95	PASS/AFT	1" UP	(80)	(452)	N.G.	(52)	(630)	(1730)	(1650)	5
2327	95	PASS/AFT	2" DN	34	240	31.0	27	130	1060	1400	2
12° RIGHT OBLIQUE IMPACTS											
2292	5	DR/FWD	6" UP	69	327	16.4	40	245	500	500	1
2292	5	PASS/FWD	6" UP	60	633	19.5	37	200	775	750	3
2290	50	DR/MID	6" UP	40	353	20.3	31	200	1400	1075	
2291	50	PASS/MID	6" UP	100	343	18.0	33	200	850	1240	3,4
2291	95	DR/AFT	6" UP	45	445	23.7	36	220	1800	1100	3
2290	95	PASS/AFT	6" UP	190	471	19.5	35	220	750	1900	3,4

NOTES:

1. HEAD HIT STR'G WH'L AND/OR DASH
2. RIB UNDERRIDE
3. NECK LOADING
4. HEAD HIT "B" PILLAR
5. SLED VELOCITY 38.5 MPH, BELT STITCHING FAILED @ 66 msec.

Table 3-4

RESTRAINT BELT DATA FROM SLED TESTS WITH UPPER ANCHOR RELOCATED VERTICALLY

RUN NO.	ATD SIZE	SEAT POSITION	ANCHOR LOCATION	BELT GEOMETRY		BELT LOAD ~ LB.		RETRACTOR SPOOL-OFF IN.	NOTES
				POSITION IN. (a)	CROSSING ANGLE DEG.	UPPER	LOWER		
FRONTAL IMPACTS									
2280	5	DR/FWD	6" UP	-1.8	59	1375	1025	4	
2284	5	DR/FWD	6" UP	-0.6	66	1450	1325	4	
2327	5	DR/FWD	2" DN	-1.8	54	N.A.	N.A.	–	1,2
2281	5	DR/FWD	6" DN	-2.0	49	TEST N.G.			
2282	5	DR/FWD	6" DN	-1.8	50	1175	N.A.	3.5-4	2
2280	5	PASS/FWD	6" UP	-2.0	57	1740	1100	4	
2285	5	PASS/FWD	6" UP	0.2	64	1700	1225	5	
2328	5	PASS/FWD	2" DN	-1.0	58	1540	895	–	1
2282	5	PASS/FWD	3" DN	-1.8	52	1425	1000	4-4.5	
2281	5	PASS/FWD	6" DN	-2.5	49	1250	800	4	
2278	50	DR/MID	6" UP	2.0	62	1850	1450	5.5	
2279	50	DR/MID	6" DN	-2.9	35	1525	1125	5	
2278	50	PASS/MID	6" UP	2.0	56	2100	1350	4	
2279	50	PASS/MID	6" DN	-3.5	32	1150	1175	4.5	
2285	95	DR/AFT	6" UP	8.5	58	2220	1450	5.5	
2328	95	DR/AFT	3" UP	5.0	56	2275	1675	–	1
2287	95	PASS/AFT	6" UP	8.3	57	2250	1475	6	
2326	95	PASS/AFT	5" UP	5.9	52	2140	1440	–	1
2330	95	PASS/AFT	1" UP	6.1	46	(2600)	(1750)	–	1,3
2327	95	PASS/AFT	2" DN	0.4	35	1970	1650	–	1
12° RIGHT OBLIQUE IMPACTS									
2292	5	DR/FWD	6" UP	0	63	1200	775	4.5	
2292	5	PASS/FWD	6" UP	-0.3	61	1250	N.A.	4-4.5	2
2290	50	DR/MID	6" UP	4.3	59	1650	1060	5.5-6	
2291	50	PASS/MID	6" UP	3.9	59	1360	1000	5.5-6	
2291	95	DR/AFT	6" UP	8.4	58	1950	1050	6	
2290	95	PASS/AFT	6" UP	9.5	53	2250	1300	6	

(a) DISTANCE ABOVE (+) OR BELOW (-) 16" STERNUM REF. POINT ON ATD

NOTES:

1. RETRACTOR SPOOL-OFF NOT MEASURED
2. LOAD TRANSDUCER FAILURE
3. LOADS (MAX.) @ BELT STITCHING FAILURE IN 38.5 MPH TEST

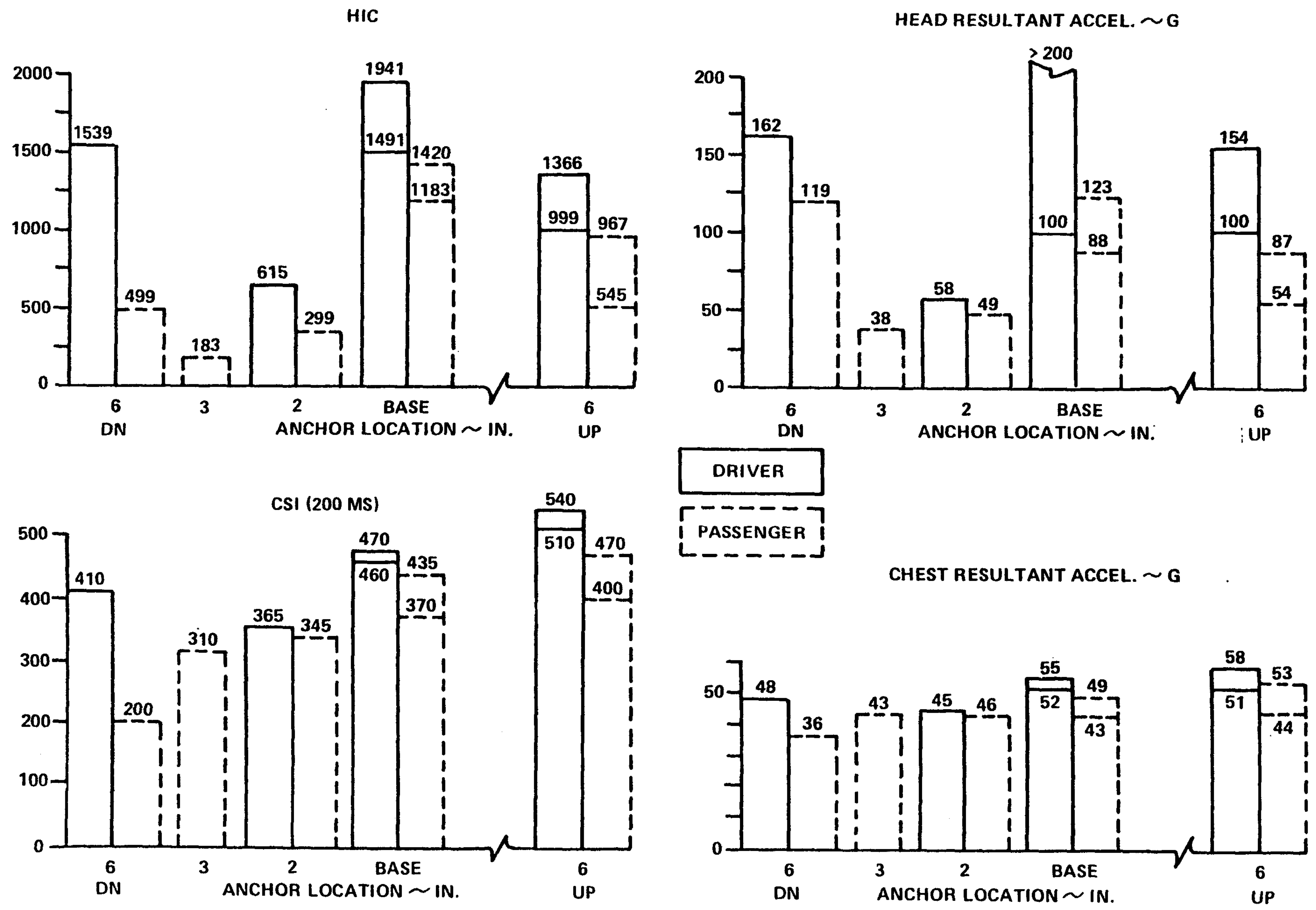


Figure 3-3 EFFECT OF UPPER ANCHOR VERTICAL LOCATION ON RESTRAINT PERFORMANCE ~ 5th PERCENTILE FEMALE OCCUPANTS, FRONTAL IMPACT

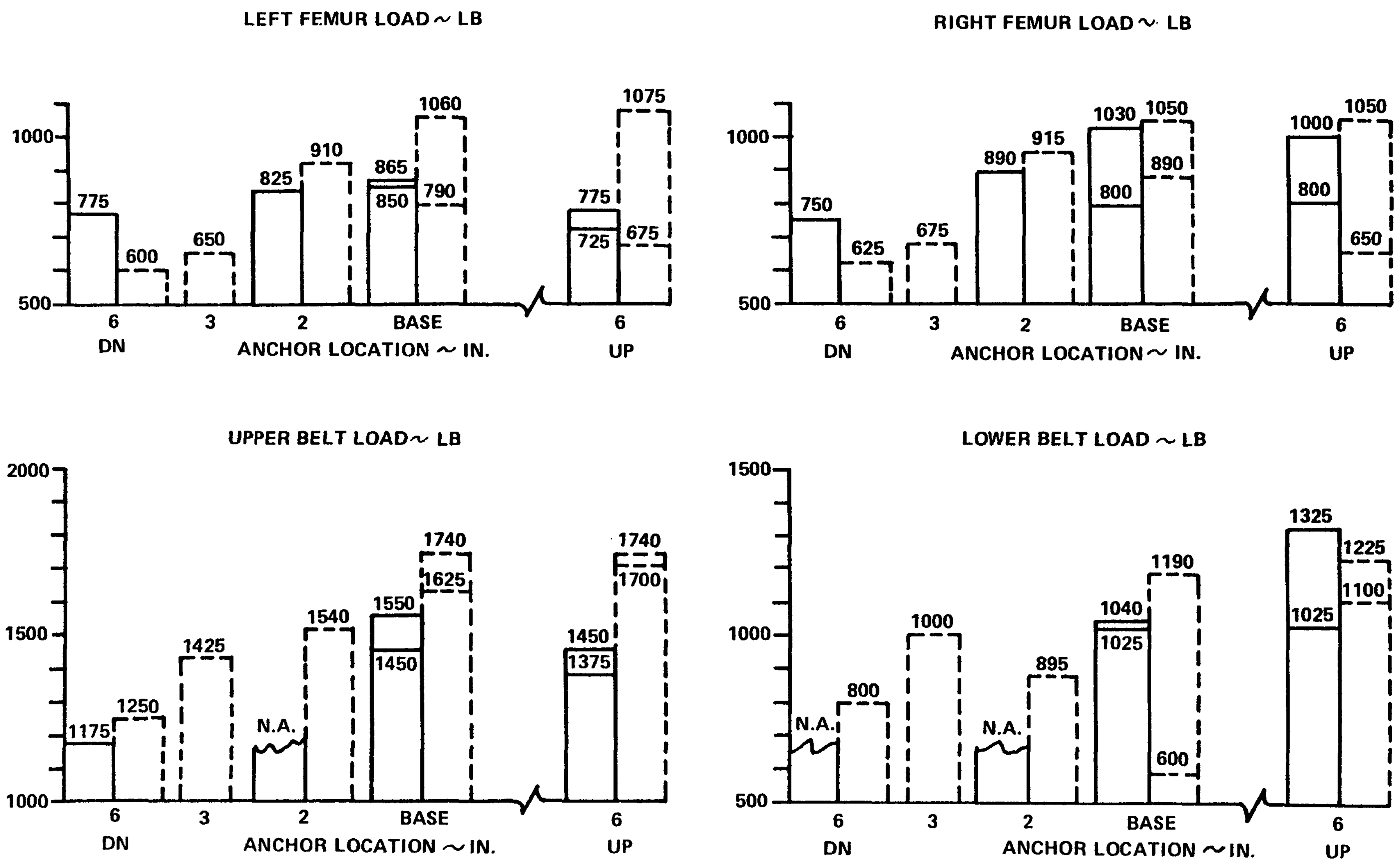


Figure 3-3 (Cont.) EFFECT OF UPPER ANCHOR VERTICAL LOCATION ON RESTRAINT PERFORMANCE ~ 5th PERCENTILE FEMALE OCCUPANTS, FRONTAL IMPACT

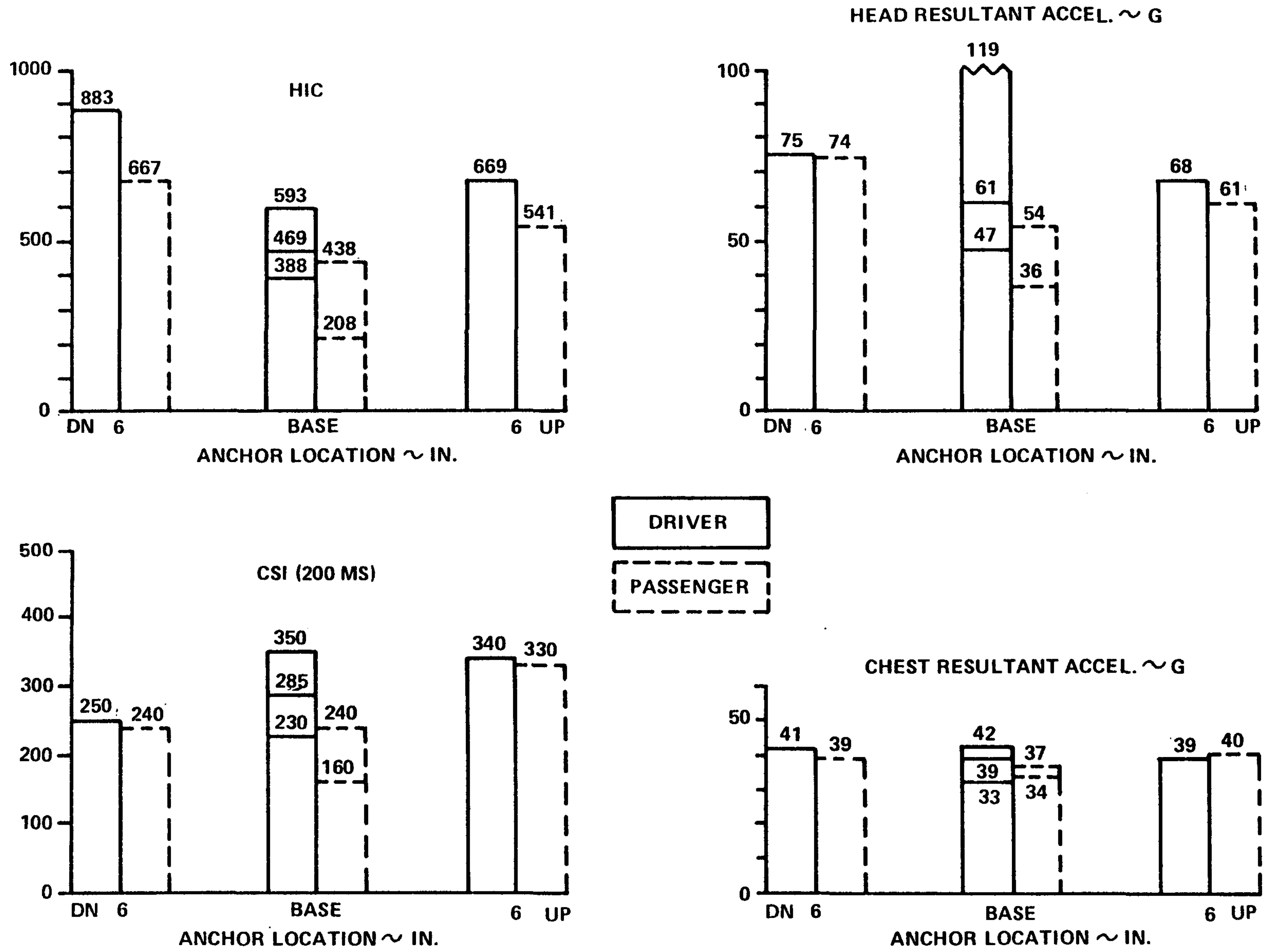


Figure 3-4 EFFECT OF UPPER ANCHOR VERTICAL LOCATION ON RESTRAINT PERFORMANCE ~ 50th PERCENTILE MALE OCCUPANTS, FRONTAL IMPACT

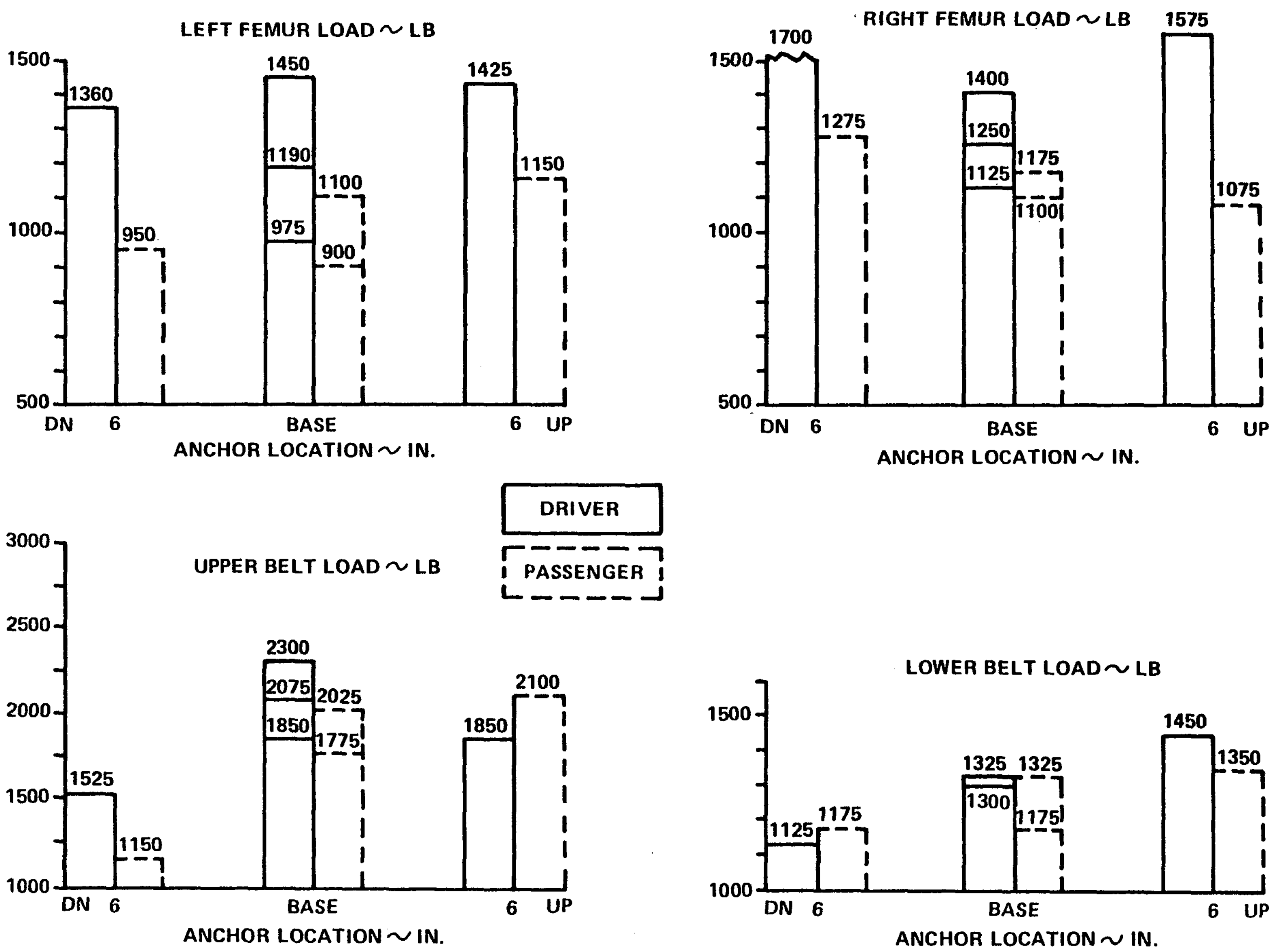


Figure 3-4 (Cont.) EFFECT OF UPPER ANCHOR VERTICAL LOCATION ON RESTRAINT PERFORMANCE ~ 50th PERCENTILE MALE OCCUPANTS, FRONTAL IMPACT

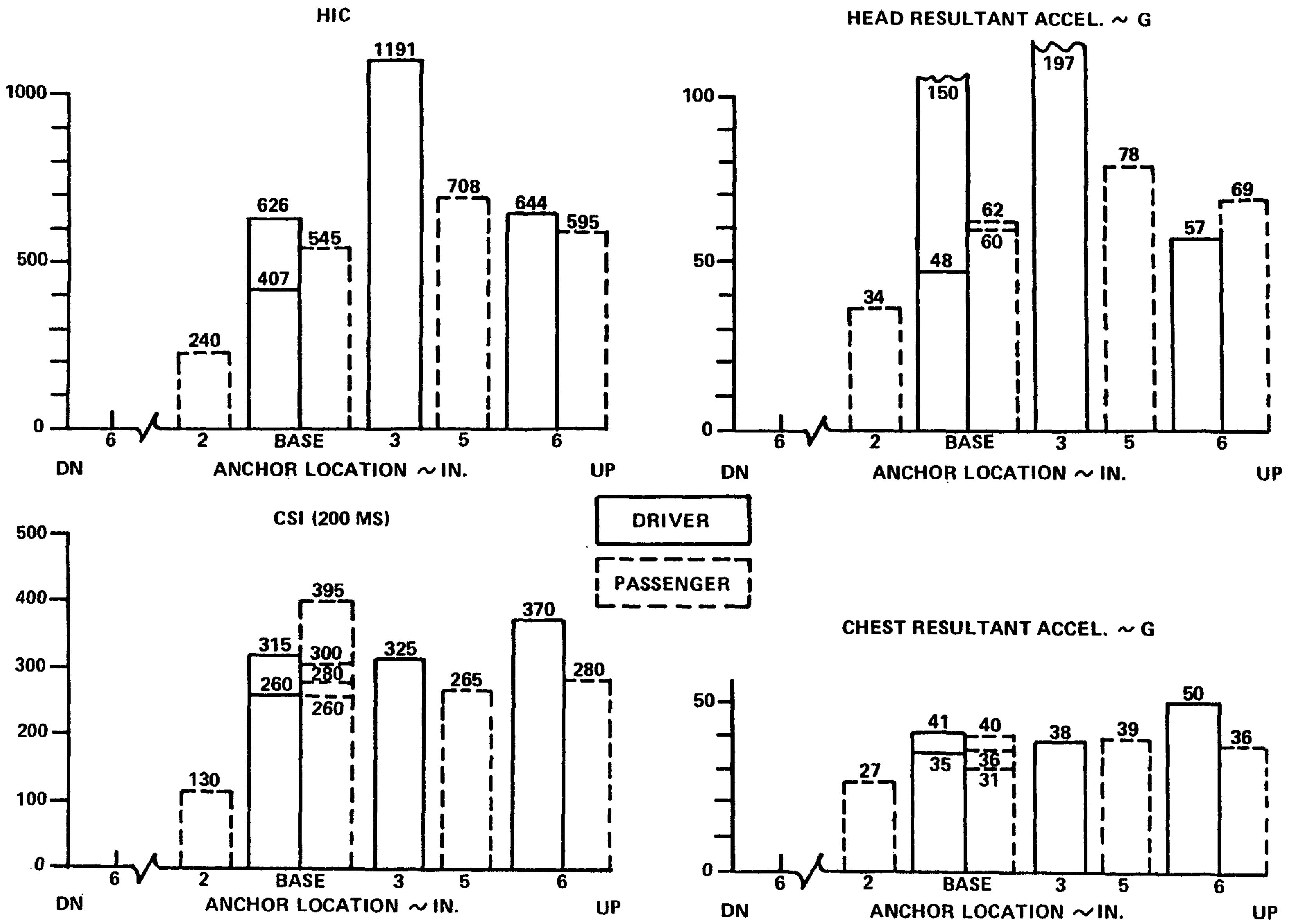


Figure 3-5 EFFECT OF UPPER ANCHOR VERTICAL LOCATION ON RESTRAINT PERFORMANCE ~ 95th PERCENTILE MALE OCCUPANTS, FRONTAL IMPACT

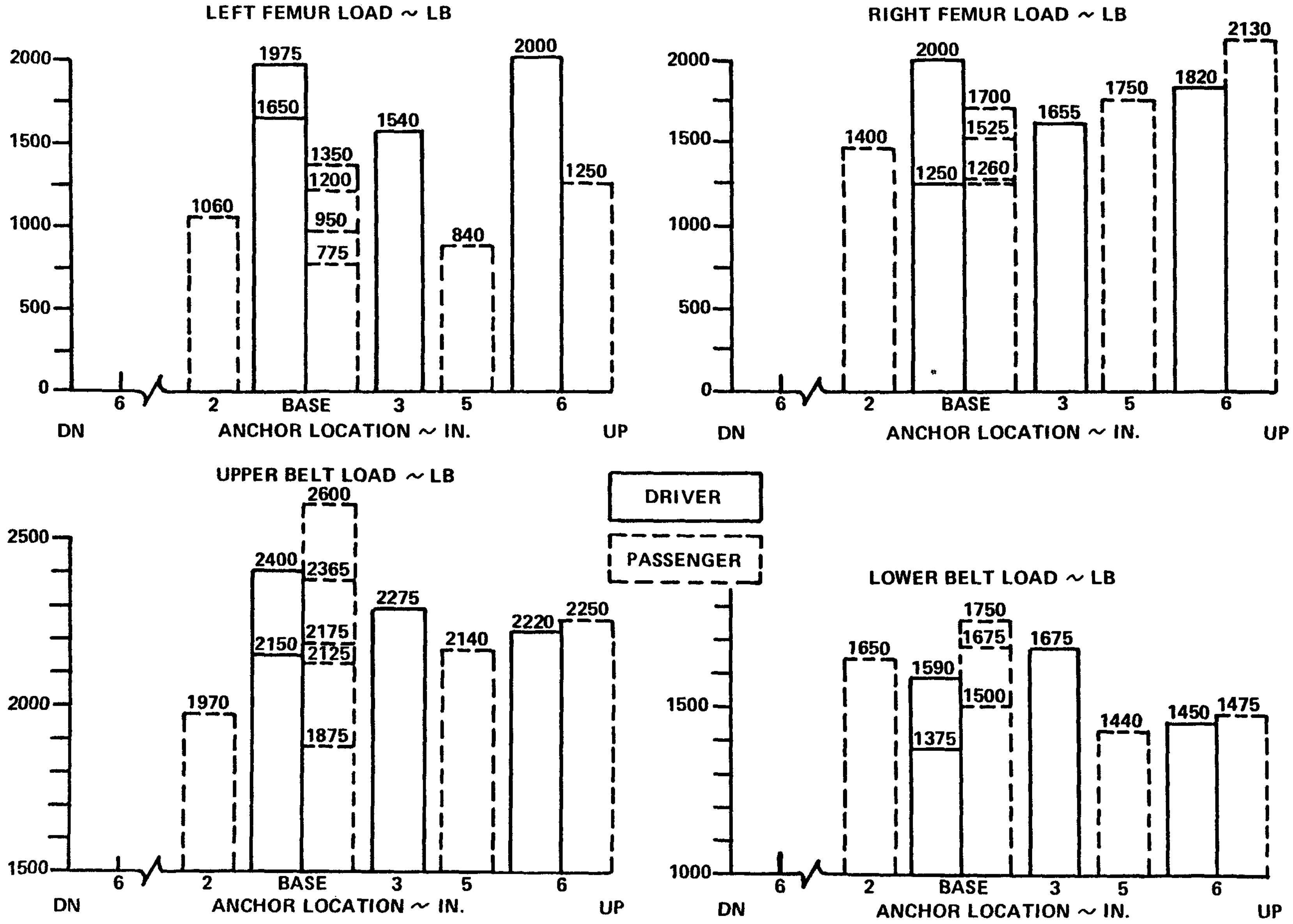


Figure 3-5 (Cont.) EFFECT OF UPPER ANCHOR VERTICAL LOCATION ON RESTRAINT PERFORMANCE ~ 95th PERCENTILE MALE OCCUPANTS, FRONTAL IMPACT

Similar rolling over the belt with consequent underriding of the rib cage and severe loading of the abdominal region also occurred when the anchor point was both 2 inches and 3 inches below the baseline position.

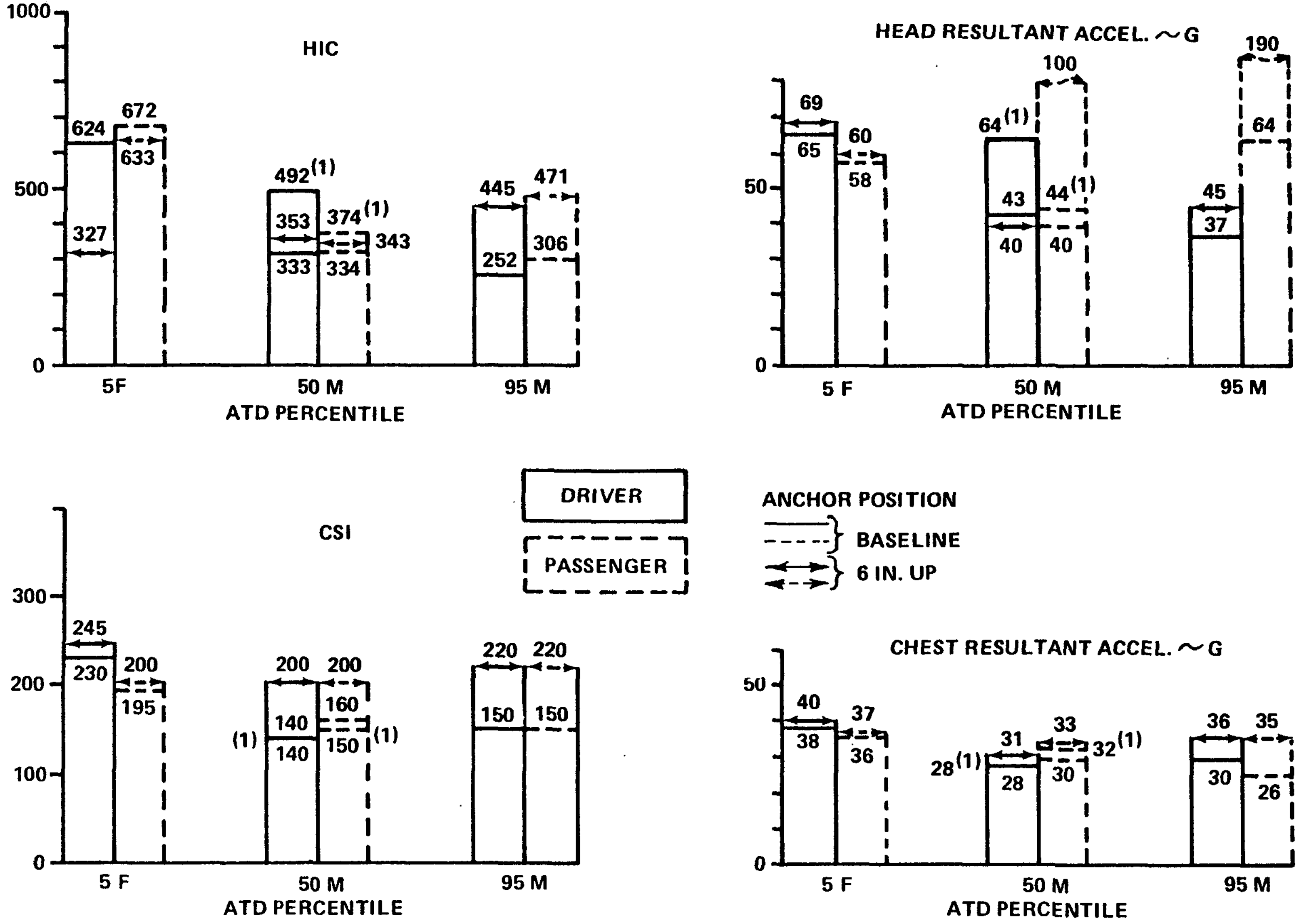
No definitive trends are seen in the data for the 50th percentile (Figure 3-4) or 95th percentile (Figure 3-5) male size occupants as either a driver or passenger. In the tests of the 50th percentile dummy with the anchor 6 inches down, the head of the driver struck the steering wheel and the passenger hit the dash with the side of the head as the torso rolled over the belt and twisted outboard nearly 90 degrees. Note that although the peak driver head acceleration was considerably less than the 119 G recorded in one of the baseline tests (Run No. 2289), the HIC value was greater because of the different character of the head resultant acceleration response.

The 95th percentile driver dummy also experienced very high head accelerations in two frontal impact tests (Run 2286 with the baseline anchor and Run 2328 with the anchor 3 inches up) as a result of striking the B-pillar during rebound. In one case the HIC number was greater than the allowable value of 1000 but none of the injury criteria were otherwise exceeded in any of the tests. It may be noted that, again, the lowest values of the responses were measured in the test of the passenger dummy with the belt anchored below the normal position in the vehicle. However, the movies show that the overall restraint performance was very poor because the dummy torso rolled over the belt which caused severe loading of the abdomen and nearly allowed the head to strike the dash. The measured forward excursion of the head C.G. in this test was 31 inches or nearly 8 inches more than the average of previous tests of the baseline anchor configuration. Poor kinematic response and underride of the rib cage by the belt was thus found to occur in all of the tests conducted with the upper anchor lower than the baseline position.

Comparisons of the frontal impact data for the baseline and the higher belt anchor configurations presented in Figures 3-3, 3-4 and 3-5 give little or no indication of a preferred anchor location for any of the three sizes of dummies. However, the data obtained in the 12 degree right oblique impact tests, summarized in Figure 3-6, are quite consistent in showing a tendency of somewhat decreased restraint system performance with the anchor elevated 6 inches. Moreover, the degradation of performance appears to vary with occupant size, with the responses of the 5th percentile female being least affected and those of the 95th percentile male dummy affected most by ~~the raise~~ raising the ~~of~~ belt anchor. The films of the tests show that the higher anchor increased the likelihood and severity of the belt loading the neck of all three size occupants in both the frontal and oblique impacts. This was particularly true of the tests with the 95th percentile dummy in which the belt, clearly appearing to cross too high on the torso initially, can be seen to slide up the chest and severely load the neck as the dummy moves forward in the compartment.

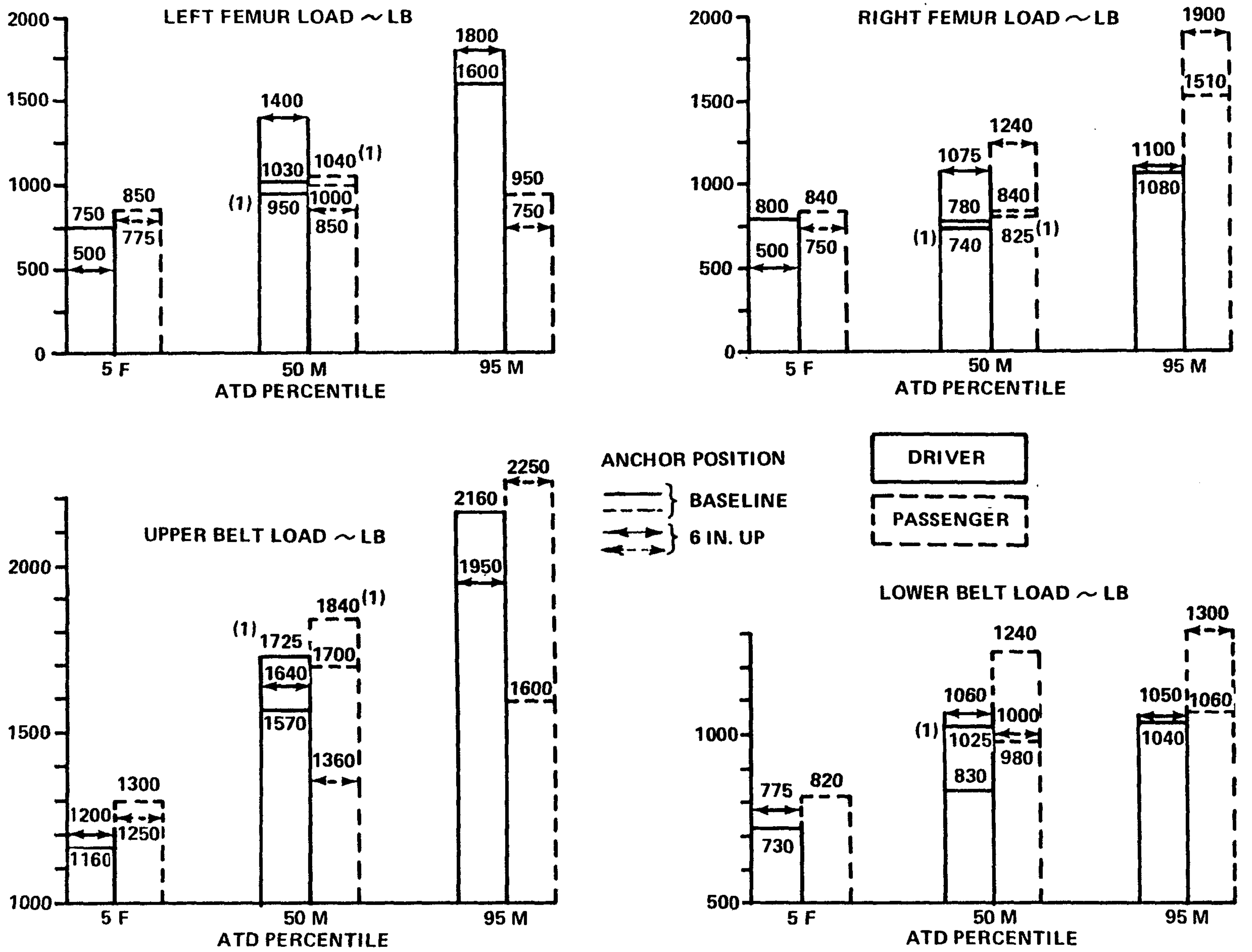
As noted in Table 3-3, both the 50th and 95th percentile passenger dummies struck the B-pillar during rebound in oblique impact tests with the anchor 6 inches up. A similar impact also occurred in the oblique angle, baseline anchor test of the larger dummy in the passenger seat. The occupant interaction with the belt was different for the driver and passenger because, with the buck yawed to the left, the inboard motion of the driver tended to cause the belt to slip off the left shoulder in contrast with the passenger who moved outboard or into the belt that crossed over the opposite shoulder. It is doubtful that the kinematics of the driver dummies were representative of human responses in these and some of the frontal impact tests because the belt can be observed to catch in the opening between the left clavicle and upper arm whereas it is more likely that it would slip completely off the shoulder of a human occupant.

The observed differences in occupant dynamic behavior with changes of the upper anchor location result from differences in the geometry of the belt as it crosses over the upper torso and shoulder of the occupant. The effect of the vertical location of the anchor on the belt geometry is shown in Figure 3-7. Each data point is the average of all measurements made with the dummies in both the driver and passenger seats. The curves show that the belt



(1) RESULT WITH UPPER BELT ANCHOR LOCATED 8 IN. FWD.

Figure 3-6 RESTRAINT PERFORMANCE FOR RIGHT OBLIQUE IMPACT



(1) RESULT WITH UPPER ANCHOR LOCATED 8 IN. FWD

Figure 3-6 (Cont.) RESTRAINT PERFORMANCE FOR RIGHT OBLIQUE IMPACT

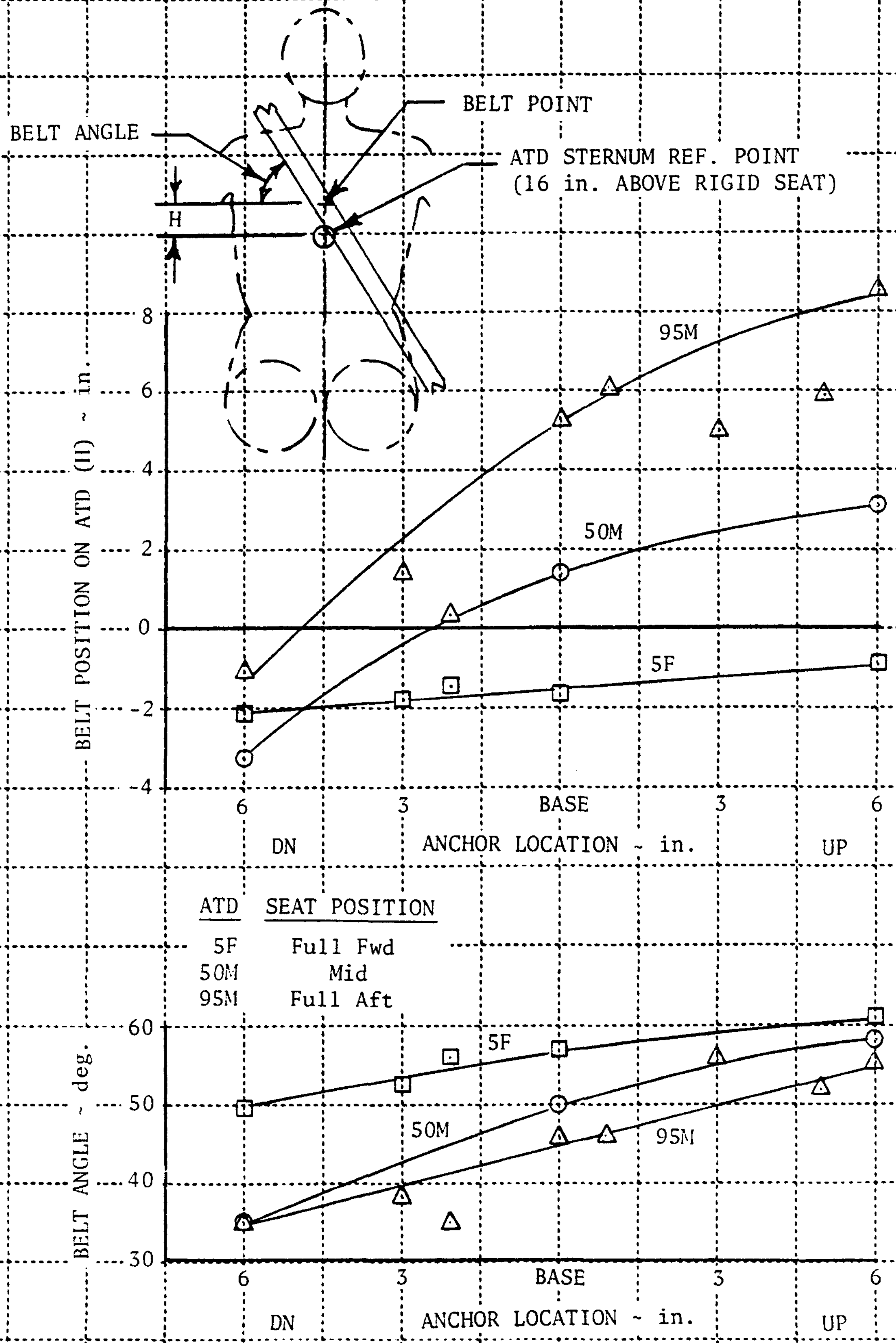


Figure 3-7 EFFECT OF BELT ANCHOR VERTICAL LOCATION ON BELT GEOMETRY

crosses higher on the torso and at a steeper angle when the anchor is moved upward. With respect to the same reference point on each of the dummies (i.e., 16 inches above a horizontal, rigid seat with the dummies sitting erect), the point at which the belt crossed the mid-sagittal plane is lowest for the 5th percentile female and highest for the 95th percentile dummy. The reverse is true for the crossing angle of the belt in relation to occupant size. The curves also show that the belt geometry for the largest dummy is affected the most by changes of the anchor point.

Of particular interest are the measurments of the position and angle of the belt on the 50th percentile dummy which are shown crossed-plotted in Figure 3-8 for comparison with the calculated limit envelope of geometry variation that allows the belt to lie within the comfort zone specified in Reference 9. It may be seen from this figure that the passive belt in the 2-door model VW Rabbit does not lie within the comfort zone because it crosses too high on the dummy torso. Moreover, the data indicate that changing the vertical location of the upper anchor does not allow the belt to be positioned within the zone.

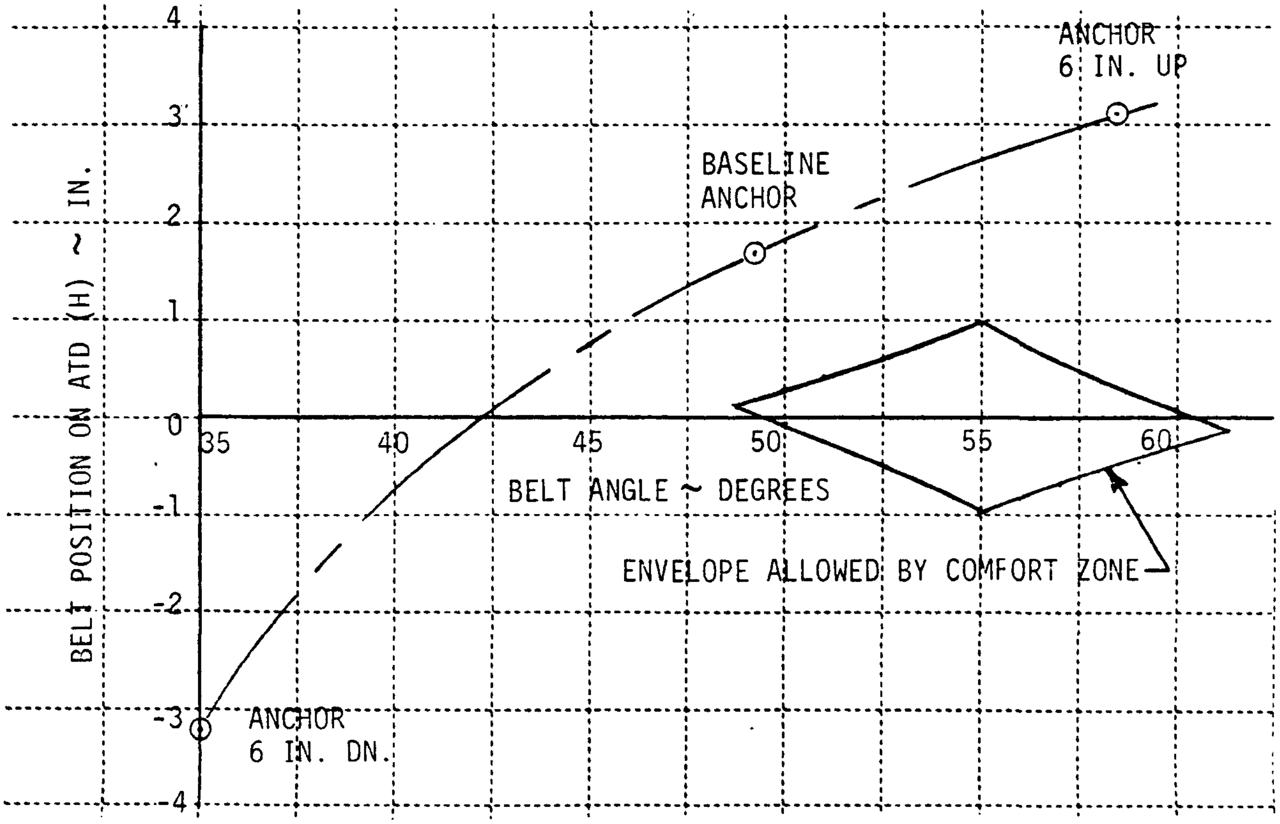


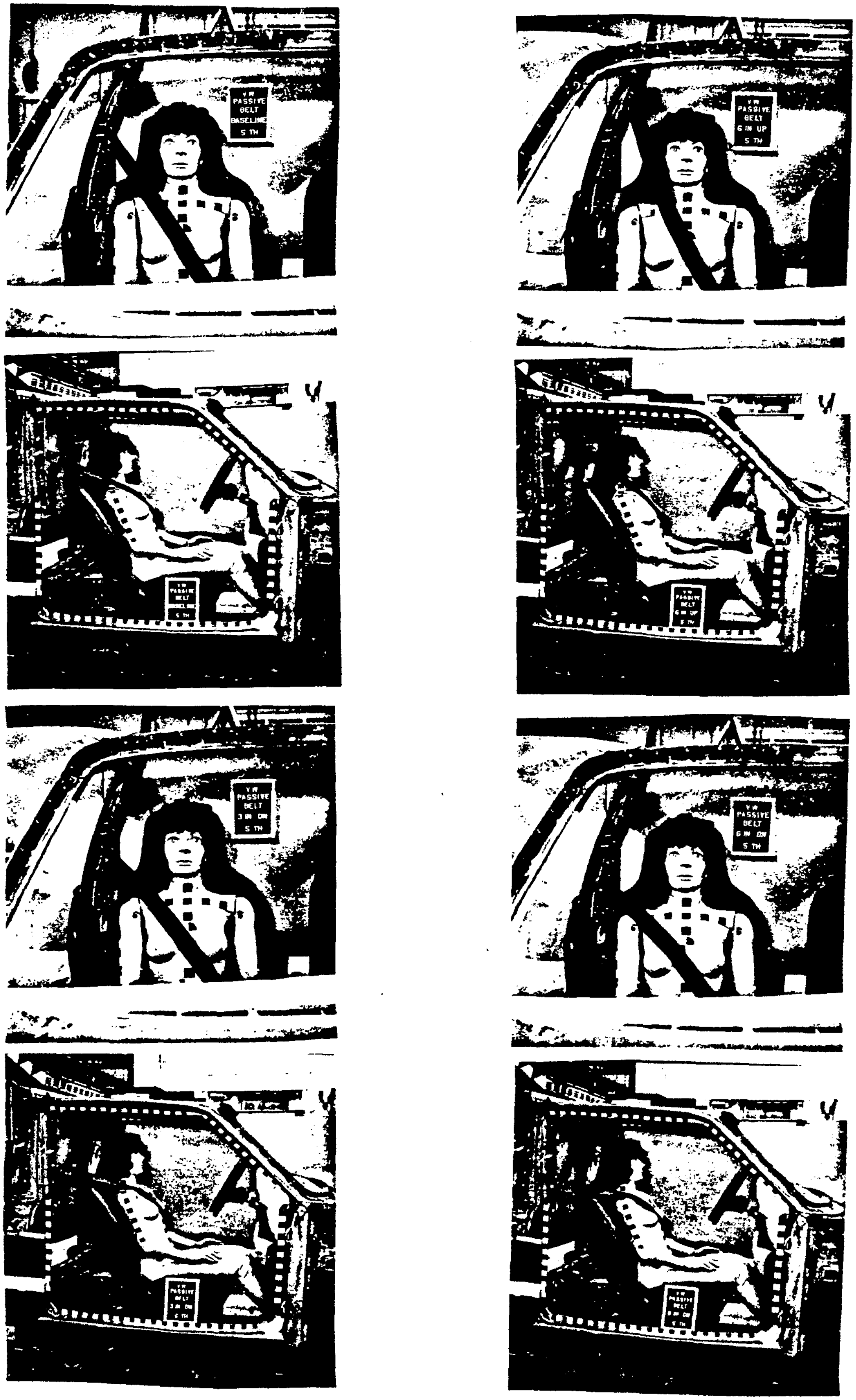
Figure 3-8 BELT POSITION AND ANGLE COMPARED TO COMFORT ZONE REQUIREMENTS

In some instances the belt geometry measurements of replicate configurations varied over a rather wide range. In part this resulted from some shifting of the upper torso skin jacket on which the sternum reference point was marked as well as small differences of the dummy position in the seat among the various tests. However, the measurement discrepancies stem primarily from the difficulty of determining the "natural" position of the belt because friction and/or surface irregularities of the dummy skin can keep the belt in place along various paths that give an equally "natural" appearance. Typical orientations of the belt on the various size dummies for different vertical locations of the upper anchor are illustrated in the photographs of Figure 3-9.

3.2.3 Longitudinal Variation of Upper Anchor Position

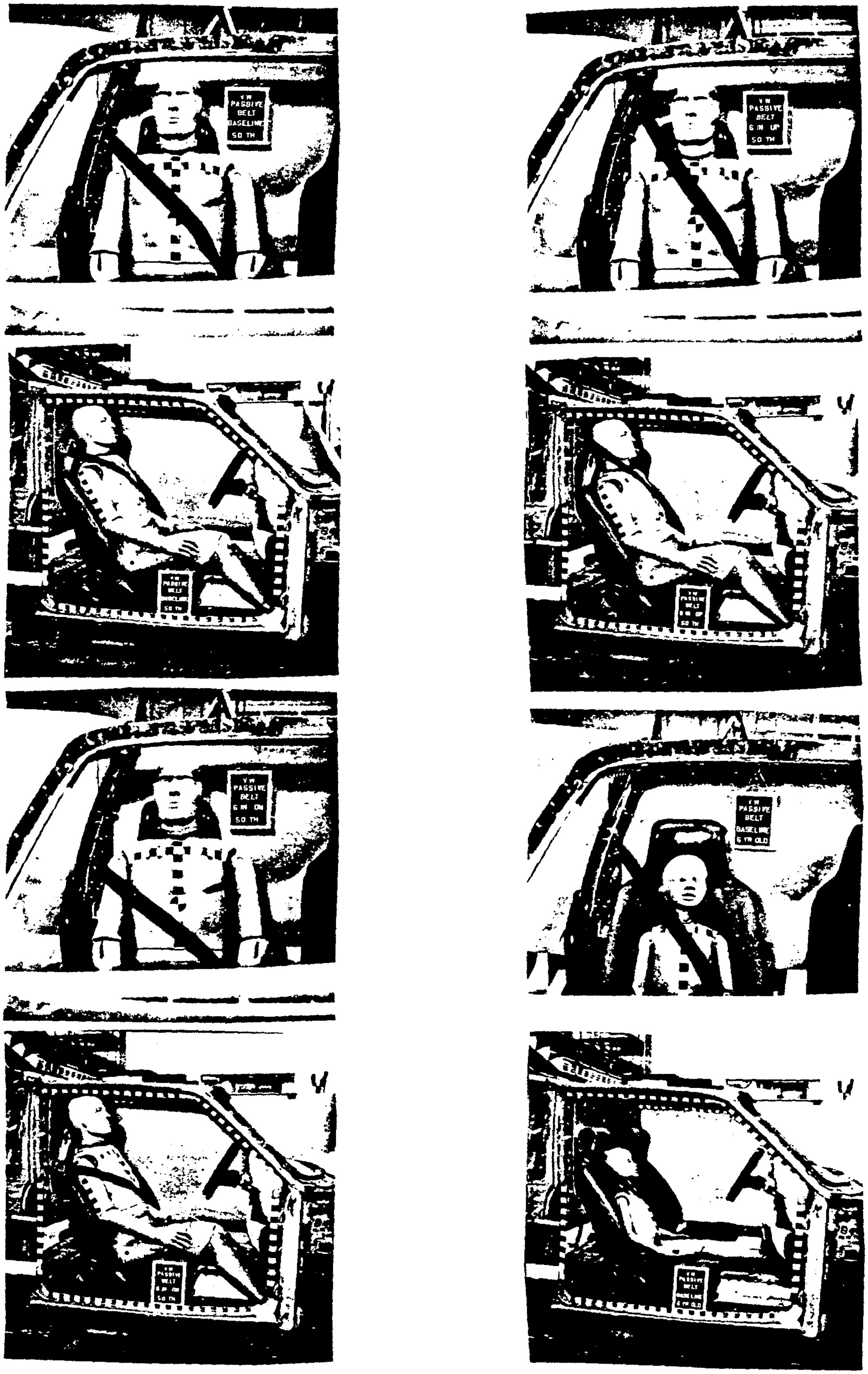
Data from sled tests in which the belt was anchored forward or aft of the baseline position are given in Tables 3-5 and 3-6. The results for each size occupant are depicted separately in the bar charts of Figures 3-10, 3-11 and 3-12 together with data measured in the baseline anchor tests for comparison.

Considering first the tests with the 50th percentile dummy, for which the data are most comprehensive since they include tests with the anchor at the intermediate locations of 4 inches forward and aft of the baseline, Figure 3-11 indicates little effect of varying the anchor point in the longitudinal direction. A slight trend of decreasing chest resultant acceleration and severity index with more forward anchor location is evident in the passenger data but the peak accelerations of both the driver and passenger are well below the 60 G injury criterion for all anchor positions. The driver chest responses are consistently higher than those of the passenger which may be a reflection of driver abdomen contact with the steering wheel rim, particularly in the tests with the anchor point ahead of the baseline position.



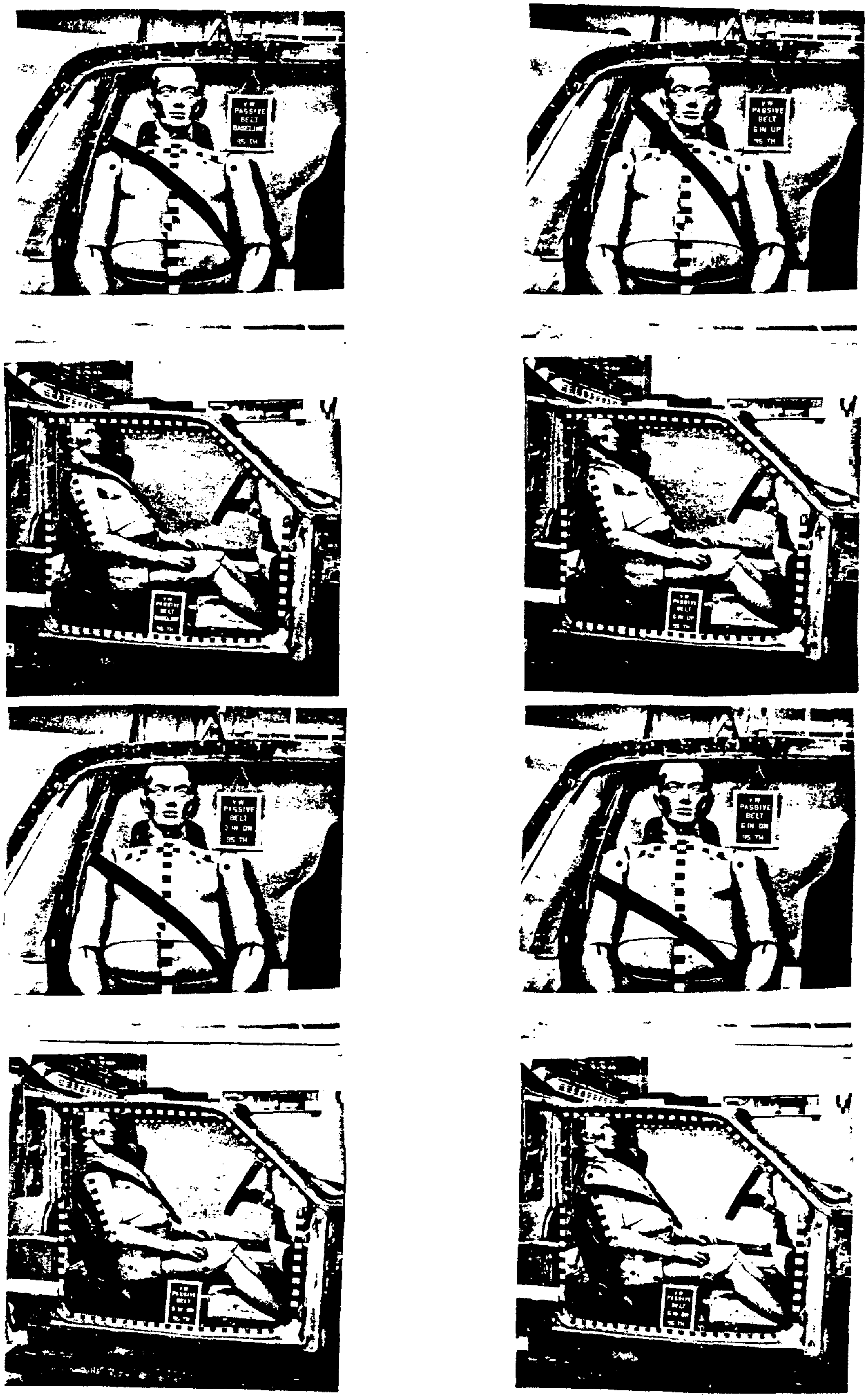
(a) 5th PERCENTILE FEMALE

Figure 3-9 RESTRAINT BELT ORIENTATION FOR DIFFERENT VERTICAL LOCATIONS OF THE UPPER ANCHOR



(b) 50th PERCENTILE MALE & 6 YR. OLD CHILD

Figure 3-9 (Continued)



(c) 95th PERCENTILE MALE

Figure 3-9 (Continued)

Table 3-5

OCCUPANT DATA FROM SLED TESTS WITH UPPER ANCHOR RELOCATED LONGITUDINALLY

RUN NO.	ATD SIZE	SEAT POSITION	ANCHOR LOCATION	HEAD			CHEST		FEMUR LOAD ~ LB.		NOTES
				RESULT. ACCEL. G	HIC	FORWARD EXCURSION IN.	RESULT. ACCEL. G (3 ms)	CSI (200 ms)	LEFT	RIGHT	
FRONTAL IMPACT											
2228	5	DR/FWD	8" AFT	99	1225	16.4	53	430	830	875	
2226	5	DR/FWD	8" FWD	>200	2313	19.4	58	540	940	790	1
2276	5	DR/MID	8" FWD	80	782	22.6	55	515	1150	1100	6
2326	5	DR/AFT	8" FWD	72	779	24.3	56	510	950	815	6
2230	5	PASS/FWD	8" AFT	81	1272	19.0	45	360	830	870	
2231	5	PASS/FWD	8" FWD	76	1096	24.2	50	320	810	870	2
2274	5	PASS/AFT	8" FWD	BELT HARDWARE FAILURE – TEST N.G.							
2275	5	PASS/AFT	8" FWD	68	683	25.5	55	410	1300	1000	2
2222	50	DR/MID	8" AFT	55	468	16.8	45	340	1050	1300	
2223	50	DR/MID	4" AFT	54	598	19.3	48	180	1350	1440	
2224	50	DR/MID	4" FWD	77	557	23.3	47	290	1250	1440	1
2225	50	DR/MID	8" FWD	78	1058	26.8	47	310	1320	1440	1,2
2231	50	DR/AFT	8" FWD	51	403	25.8	36	185	1300	740	2,6
2222	50	PASS/MID	8" AFT	54	590	17.7	41	300	800	1140	
2223	50	PASS/MID	4" AFT	53	536	20.2	36	260	850	1200	
2224	50	PASS/MID	4" FWD	50	505	24.2	34	212	825	1210	2
2225	50	PASS/MID	8" FWD	48	489	27.7	27	165	800	1100	2
2275	95	DR/AFT	8" AFT	78	487	23.2	38	260	1750	1800	3,4
2288	95	DR/AFT	8" AFT	59	590	23.0	43	320	2375	1300	3
2274	95	DR/AFT	8" FWD	87	725	29.0	42	300	1800	1675	1
2287	95	DR/AFT	8" FWD	75	720	29.2	43	300	2050	1940	1
2276	95	PASS/AFT	8" AFT	60	N.G.	21.8	32	260	950	1800	3,5
2288	95	PASS/AFT	8" AFT	58	488	22.3	40	300	1350	2400	3
2226	95	PASS/AFT	8" FWD	68	528	27.0	35	200	775	1550	2
2289	95	PASS/AFT	8" FWD	73	615	28.5	38	260	1740	1700	2
12° RIGHT OBLIQUE IMPACTS											
2235	50	DR/MID	8" FWD	64	492	23.4	28	140	950	740	1,2
2235	50	PASS/MID	8" FWD	44	374	22.0	32	150	1040	825	2

NOTES:

1. HEAD HIT STR'G WH'L
2. RIB UNDERRIDE
3. NECK LOADING
4. HEAD HIT "B" PILLAR
5. ATD NECK CABLE FAILURE
6. STR'G WH'L/COL. REMOVED

Table 3-6

RESTRAINT BELT DATA FROM SLED TESTS WITH UPPER ANCHOR RELOCATED LONGITUDINALLY

RUN NO.	ATD SIZE	SEAT POSITION	ANCHOR LOCATION	BELT GEOMETRY		BELT LOAD ~ LB.		RETRACTOR SPOOL-OFF IN.	NOTES
				POSITION IN. (a)	CROSSING ANGLE DEG.	UPPER	LOWER		
FRONTAL IMPACTS									
2228	5	DR/FWD	8" AFT	-1.4	59	1460	950	4	
2226	5	DR/FWD	8" FWD	-1.6	54	1740	1250	7	
2276	5	DR/MID	8" FWD	-2.3	49	2100	1490	N.A.	
2326	5	DR/AFT	8" FWD	-2.0	49	2290	1525		1
2230	5	PASS/FWD	8" AFT	-1.3	56	1540	850	3.5	
2231	5	PASS/FWD	8" FWD	-2.1	50	1660	1020	4-4.5	
2274	5	PASS/AFT	8" FWD	-2.0	49	(1700)	(1400)	5.5	2
2275	5	PASS/AFT	8" FWD	-2.4	44	2075	1660	6.5	
2222	50	DR/MID	8" AFT	3.2	53	2150	1200	5	
2223	50	DR/MID	4" AFT	3.0	55	2080	1250	5	
2224	50	DR/MID	4" FWD	1.5	47	2220	1170	5	
2225	50	DR/MID	8" FWD	-0.3	44	2020	1150	5	
2231	50	DR/AFT	8" FWD	-0.1	45	2180	1430	5	
2222	50	PASS/MID	8" AFT	2.5	55	1950	1150	4.5	
2223	50	PASS/MID	4" AFT	2.6	54	2100	(1150)	4.5	3
2224	50	PASS/MID	4" FWD	0.9	48	2050	1110	5	
2225	50	PASS/MID	8" FWD	-0.8	45	1750	1085	5.5	
2275	95	DR/AFT	8" AFT	6.8	52	2000	1425	5	
2288	95	DR/AFT	8" AFT	7.9	54	2050	1300	5	
2274	95	DR/AFT	8" FWD	4.0	39	2500	1025	7	
2287	95	DR/AFT	8" FWD	2.7	38	2350	1375	8	
2276	95	PASS/AFT	8" AFT	6.0	52	2175	1650	4	
2288	95	PASS/AFT	8" AFT	7.8	56	1900	1275	4.5	
2226	95	PASS/AFT	8" FWD	2.2	34	2490	1325	7	
2289	95	PASS/AFT	8" FWD	4.9	38	2650	1540	8	
12° RIGHT OBLIQUE IMPACTS									
2235	50	DR/MID	8" FWD	1.0	43	1725	1025	4.5-5	
2235	50	PASS/MID	8" FWD	0.5	46	1840	1240	N.A.	

(a) DISTANCE ABOVE (+) OR BELOW (-) 16" STERNUM REF. POINT ON ATD

NOTES:
1. RETRACTOR SPOOL-OFF NOT MEASURED
2. MAX. BELT LOADS AT BELT HARDWARE FAILURE
3. MAX. LOWER BELT LOAD AT TRANSDUCER FAILURE

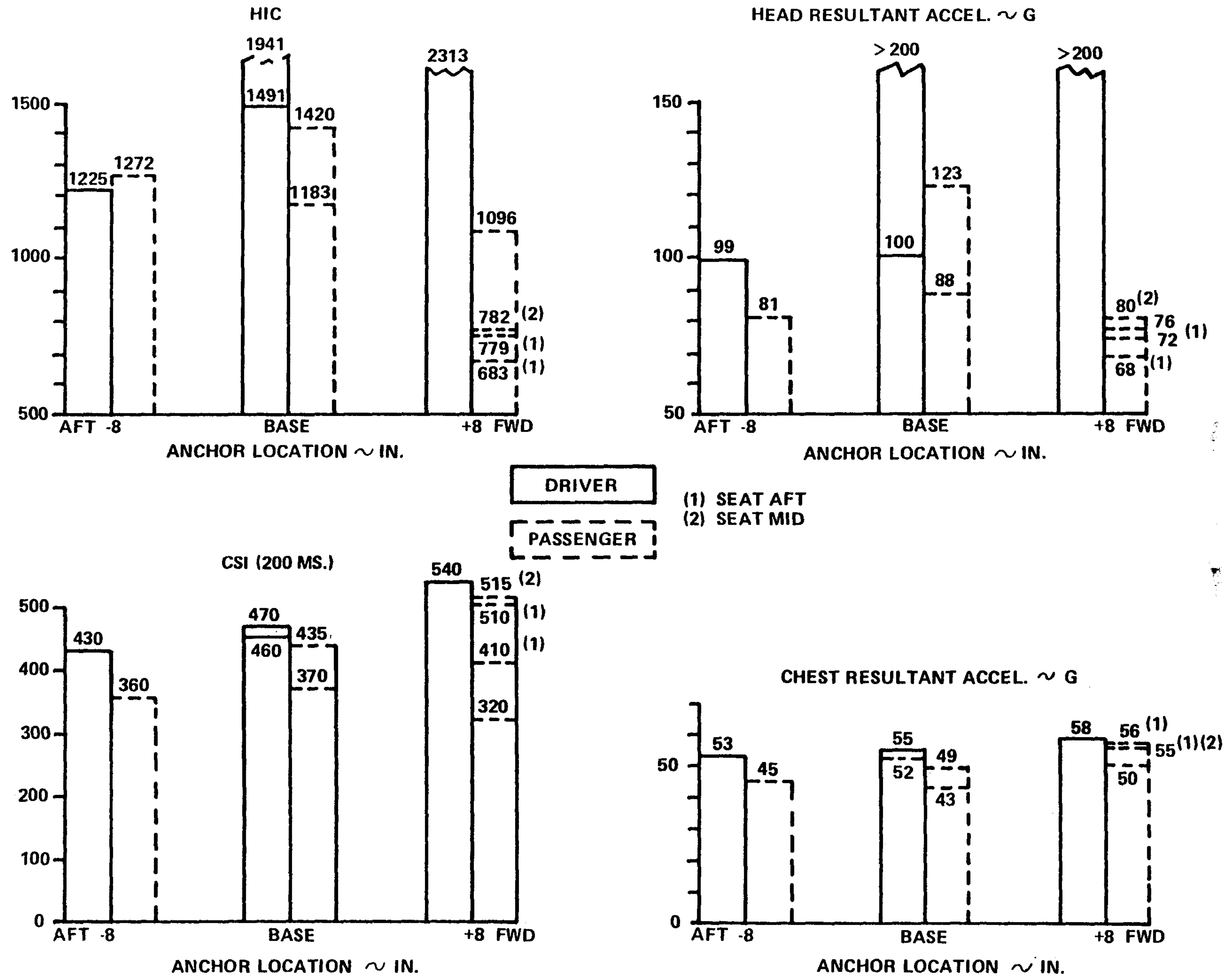


Figure 3-10 EFFECT OF UPPER ANCHOR LONGITUDINAL LOCATION ON RESTRAINT PERFORMANCE ~ 5th PERCENTILE FEMALE OCCUPANTS, FRONTAL IMPACT

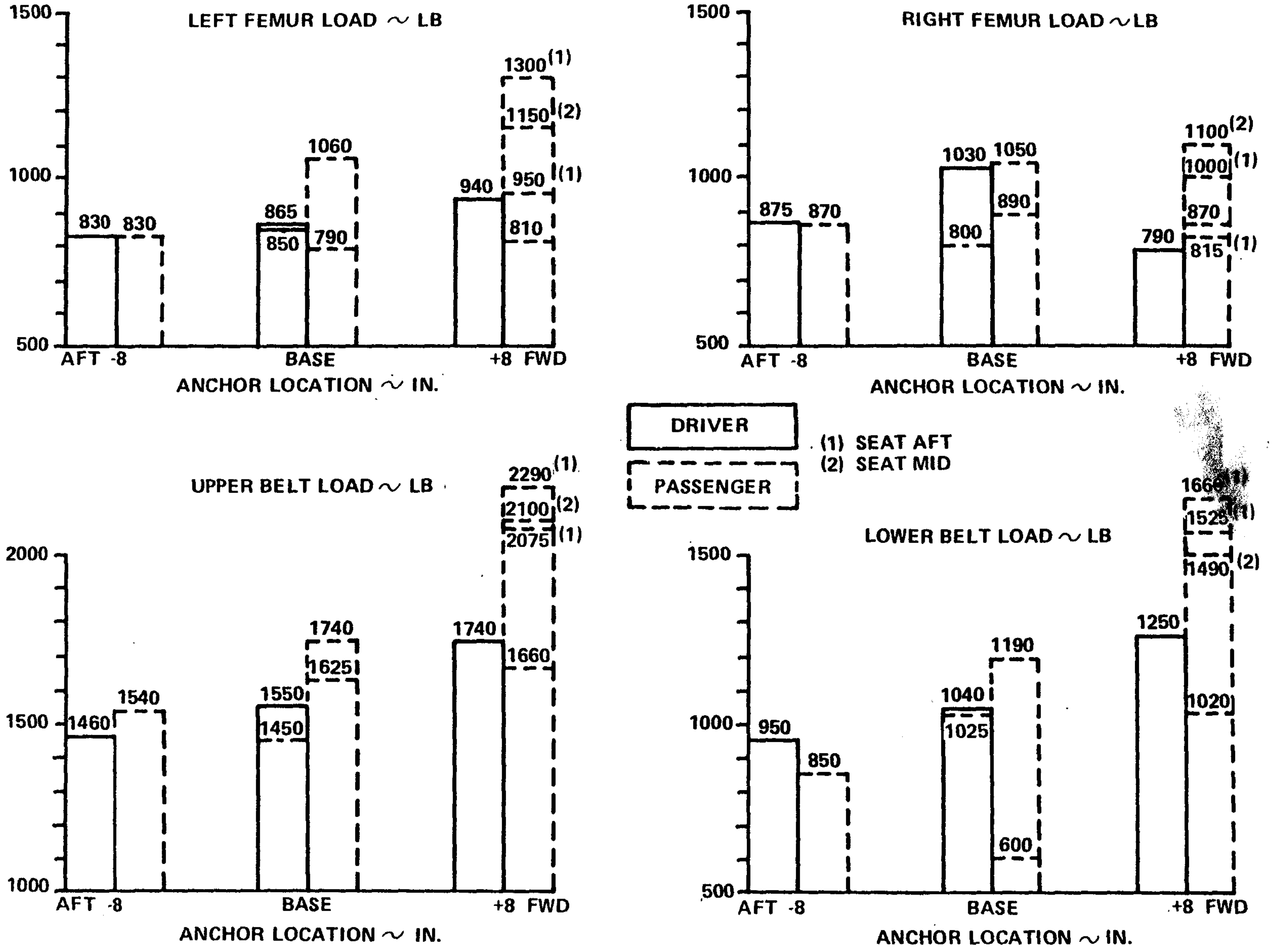
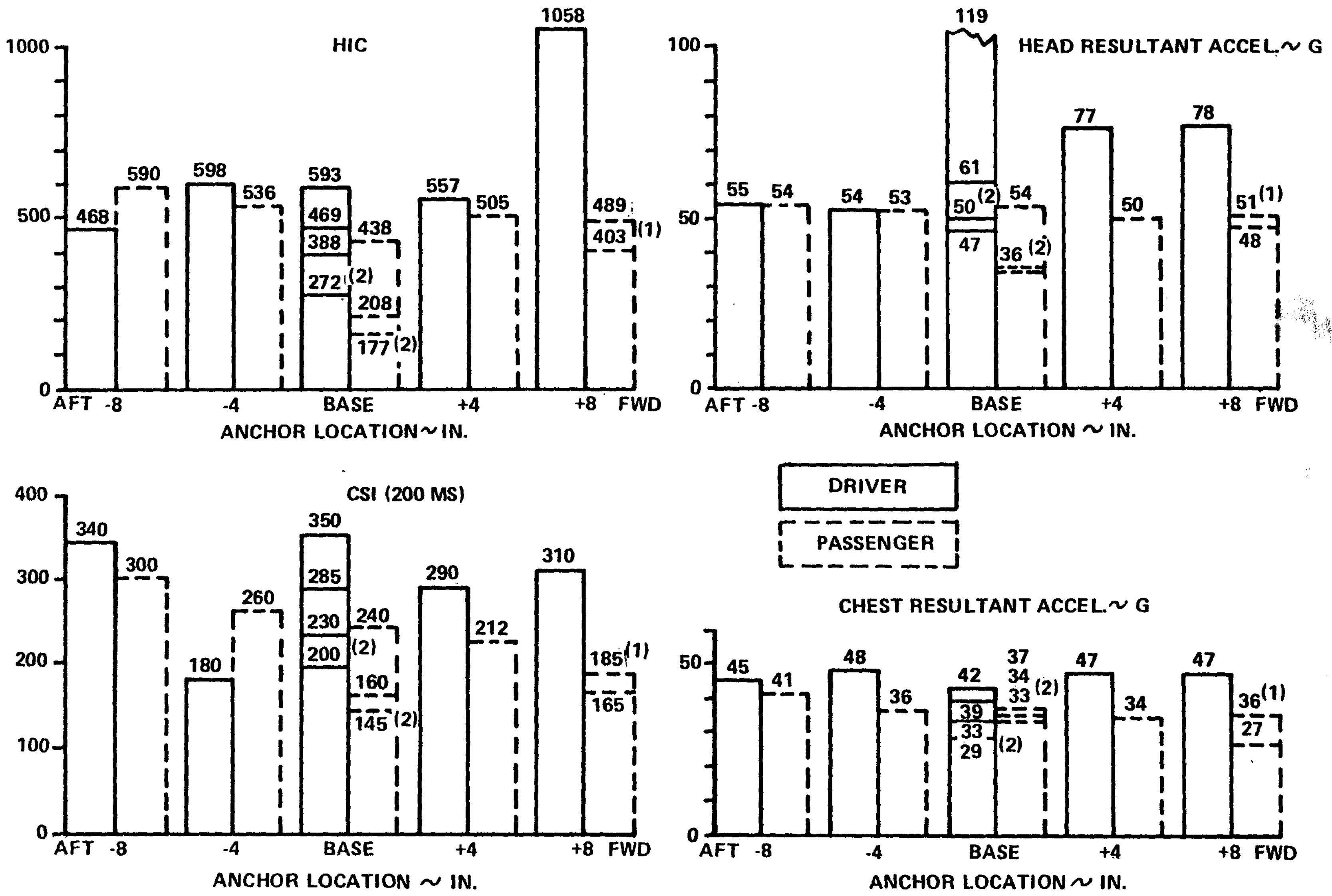
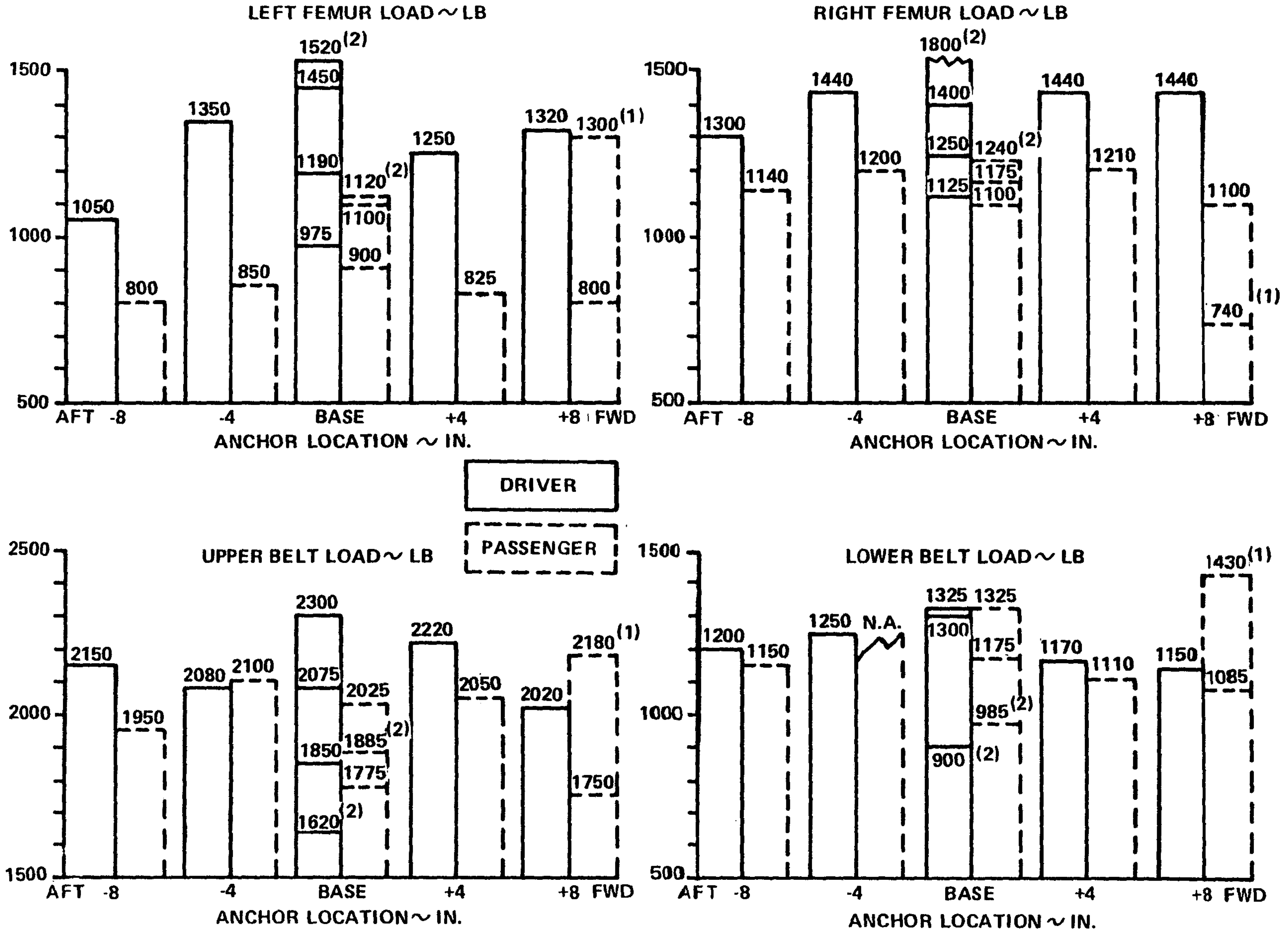


Figure 3-10 (Cont.) EFFECT OF UPPER ANCHOR LONGITUDINAL LOCATION ON RESTRAINT PERFORMANCE ~ 5th PERCENTILE FEMALE OCCUPANTS, FRONTAL IMPACT



(1) DRIVER POSITION WITH SEAT FULL AFT & STEERING WHEEL/COLUMN REMOVED
(2) INBOARD ANCHOR 6 IN. FWD

Figure 3-11 EFFECT OF UPPER ANCHOR LONGITUDINAL LOCATION ON RESTRAINT PERFORMANCE ~ 50th PERCENTILE MALE OCCUPANTS, FRONTAL IMPACT



(1) DRIVER POSITION WITH SEAT FULL AFT & STEERING WHEEL/COLUMN REMOVED
(2) INBOARD ANCHOR 6 IN. FWD

Figure 3-11 (Cont.) EFFECT OF UPPER ANCHOR LONGITUDINAL LOCATION ON RESTRAINT PERFORMANCE ~ 50th PERCENTILE MALE OCCUPANTS, FRONTAL IMPACT

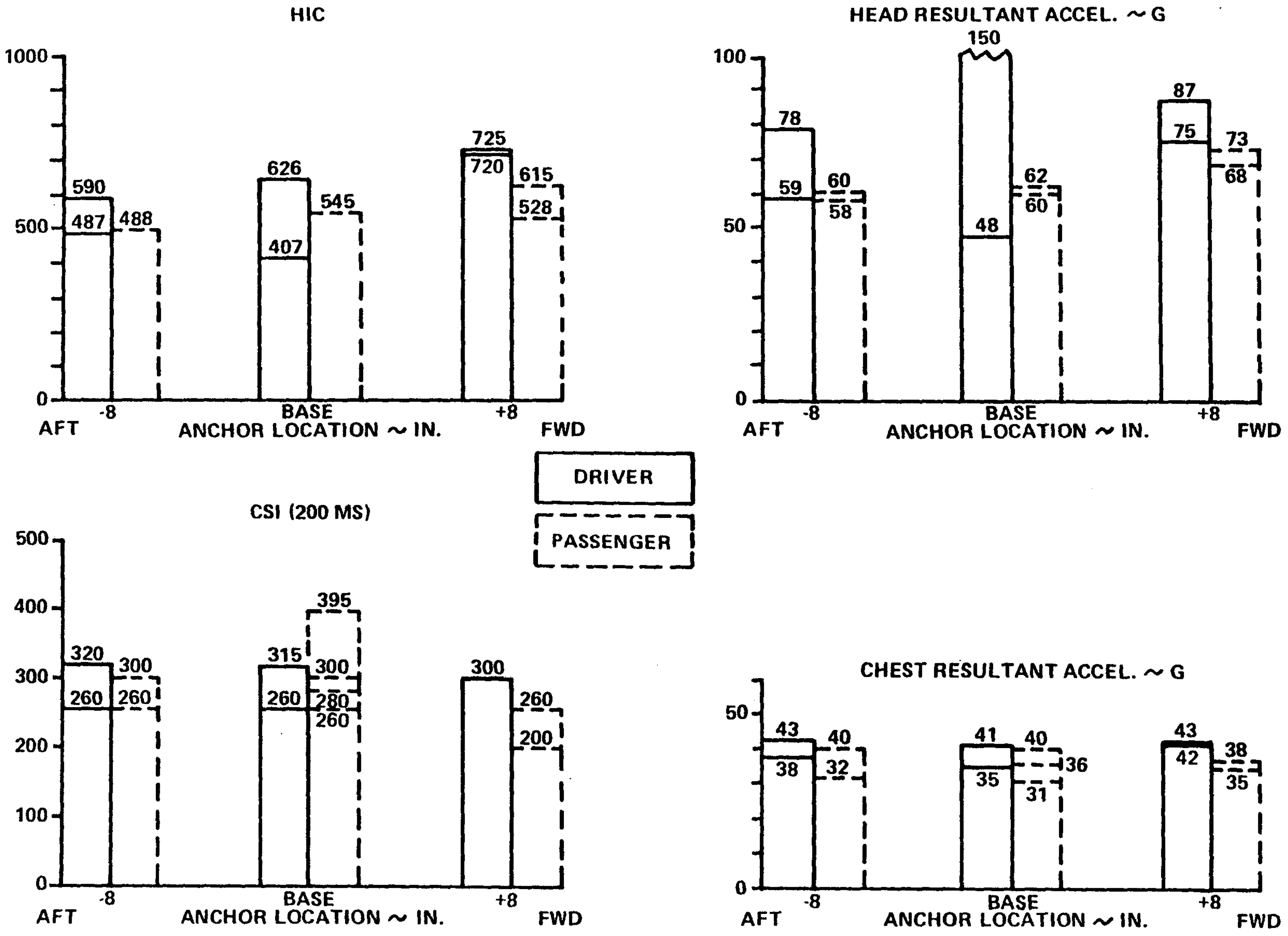


Figure 3-12 EFFECT OF UPPER ANCHOR LONGITUDINAL LOCATION ON RESTRAINT PERFORMANCE ~ 95th PERCENTILE MALE OCCUPANTS, FRONTAL IMPACT

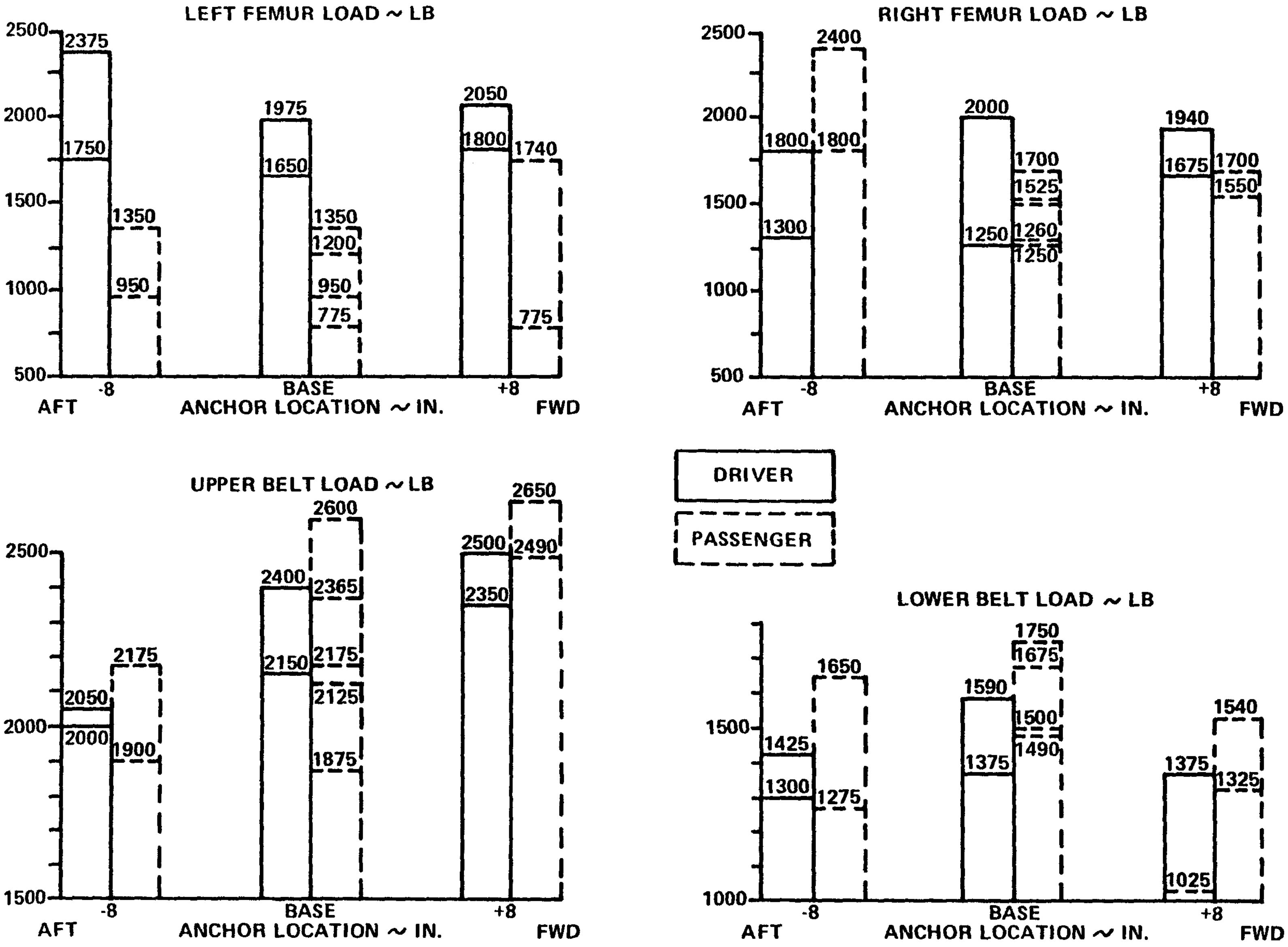


Figure 3-12 (Cont.) EFFECT OF UPPER ANCHOR LONGITUDINAL LOCATION ON RESTRAINT PERFORMANCE ~ 95th PERCENTILE MALE OCCUPANTS, FRONTAL IMPACT

As noted in Table 3-5, the head of the 50th percentile driver dummy struck the steering wheel in both tests with the anchor forward of the baseline. Although the peak head resultant accelerations were nearly the same, the HIC exceeded the allowable value of 1000 in the test with the anchor located 8 inches forward. Otherwise, the head responses for both the driver and passenger appear to be comparable and unaffected by changes of the belt anchor point.

No trend is exhibited by the femur or belt load data as a function of anchor location. The maximum femur loads are all seen to be much lower than the 2250 lb. injury criterion but it is of interest to note that those of the driver were somewhat higher than the passenger femur loads. This could be due to the additional support of the knee bolster provided by the steering column. Since the knee bolster is attached to the vehicle only at the ends, bending deflections tend to be larger near the center which might account for the fact that the loads measured on the left (i.e., inboard) leg of the passenger dummy were consistently lower than those of the right leg.

The response comparisons shown in Figures 3-10 and 3-12 for the tests of the 5th percentile female and 95th percentile male dummies, respectively, also indicate that the performance of the restraint system in general is not very sensitive to the longitudinal location of the upper anchor. However, the HIC comparisons for both size occupants do show a trend of increasing values as the anchor is moved more forward in the vehicle. This is particularly true of the driver whose head contacted the steering wheel in both tests of the 95th percentile ATD and in the test of the smaller dummy when the anchor was 8 inches forward of the baseline. The HIC values of the 95th percentile occupants were all less than 1000 but those recorded for the 5th percentile dummy in both the driver and passenger seats exceeded that limit in every test except the three in which the seat was not in the fully forward position.

A trend of higher loads at the upper end of the belt with changes of the anchor from aft to forward of the baseline is also evident in the data of both size dummies. Somewhat surprisingly, this is not reflected in the measurements of the chest maximum resultant acceleration or severity index of the 95th percentile ATD but there is some evidence of a similar trend in the chest responses of the smaller dummy.

The data from the tests of the 5th percentile passenger* with the anchor at the 8 inch forward location show that the dummy responses (except HIC) and belt loads increased substantially when the seat was in either the mid- or full-aft positions of the adjustable range (approximately 8 in.) instead of the normal, fully-forward position. Since the clearance between the belt and dummy shoulder (and hence the effective slack) increases as the seat is moved rearward, higher response magnitudes were not unexpected. As indicated previously, the 8 inch forward anchor position in the 2-door Rabbit used in this program corresponds very closely to the relative location of the anchor in the 4-door model of the vehicle.

One of the effects of moving the anchor point further ahead is an increased tendency for the belt to underride the rib cage of occupants of all three sizes as noted in Table 3-5. Another finding is that the forward excursion of the head is also affected by anchor location. This is illustrated in Figure 3-13 where the measurements from films of both the tests of the horizontal and of the vertical variation of the anchor point are plotted. Head excursion in and of itself is not a particularly important response parameter except as it relates to the potential for injurious head contact with the vehicle interior. Hence, the magnitude of forward excursion is more important for the driver occupants due to their proximity to the steering wheel which was frequently struck by the head of the dummies.

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*For some tests the dummy was actually in the driver seat but the steering/ column was removed to provide, in effect, a passenger configuration.

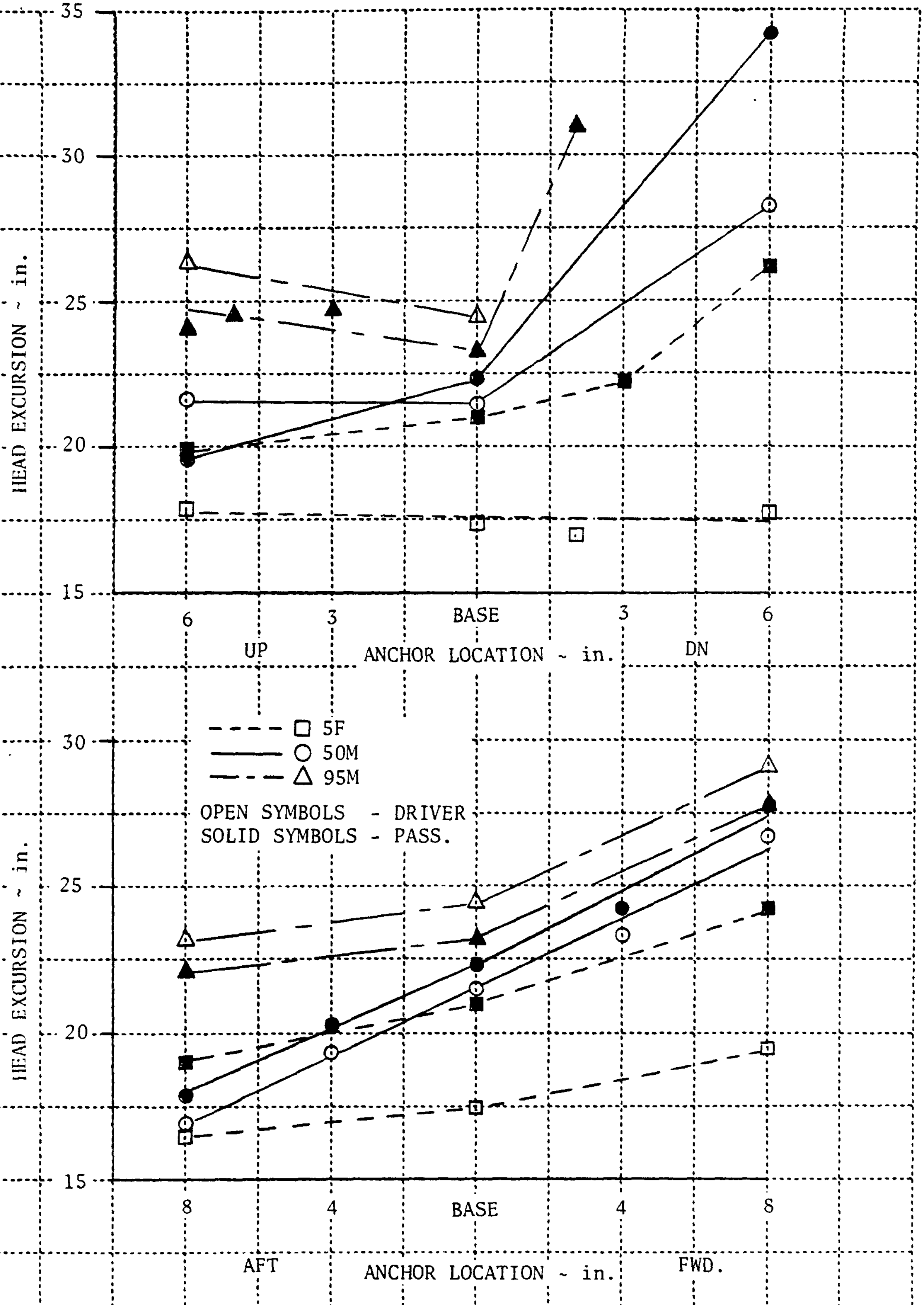


Figure 3-13 EFFECT OF UPPER ANCHOR LOCATION ON HEAD FORWARD EXCURSION

Although results for a few anchor locations are limited to only one test, a trend of increased head travel with more forward location of the upper anchor is indicated by the lower set of curves of Figure 3-13. This trend, which was also observed in the study reported in Reference 10, is consistent for all three dummy sizes and for both drivers and passengers. It should be noted that in some instances, particularly for the driver, the excursion may be limited because of contact with the steering wheel. The plots tend to indicate that head excursion is less sensitive to rearward than to forward relocation of the upper anchor from the baseline position and that the 5th percentile female dummy is least affected by changes of anchor position. At the 8 inches-forward location (i.e., the baseline position for the 4-door Rabbit) the anchor is still behind the shoulder of the female dummy but not for the other dummies because of the difference in the position of the seat. The tests were conducted with the seat in the full-forward, mid, and full-aft positions for the 5th, 50th and 95th percentile occupant sizes, respectively. The different effective belt slack that results from the different relative positions of the seat (and, hence, the inboard anchor attached to it) and upper anchor is believed to be one of the main reasons why the head excursion increased with the size of the dummies. It is well to point out that the larger head excursions of the 50th and 95th percentile dummies were mostly offset by the increased distance to the steering wheel with the seat in the mid- and full-aft positions so the likelihood of head contact was no more, and perhaps even less, than that of the 5th percentile female dummy. Analysis of the data indicates that the threshold of excursion for driver head contact with the steering wheel is approximately 17, 21:5 and 26 inches for the 5th percentile female and the 50th and 95th percentile male dummies, respectively.

21.5 ?

Figure 3-13 also indicates that raising the anchor as much as 6 inches above the baseline did not appreciably affect the head excursion of any of the dummies compared to the results for the baseline position. As discussed earlier, the dummies rotated over the belt in the tests with the lower anchor points and the head excursions were therefore considerably greater.

The manner in which the geometry of the belt on the torso of the different size dummies varies with the longitudinal location of the upper anchor is shown in Figure 3-14. Both the belt position and the angle at which the belt crosses the torso decrease as the anchor is moved forward. As was the case for vertical adjustment of the anchor, the change of belt geometry with longitudinal anchor position is least for the 5th percentile female dummy. In part this may result from a normal tendency to position the belt between the breasts but a conscious effort was made to allow the belt to assume a "natural" configuration for each test.

Comparison of the belt geometry measurements for the 50th percentile dummy listed in Table 3-6 with the comfort zone envelope shown in Figure 3-8 reveals that changing the fore-aft position of the upper anchor will not cause the belt to fall within the comfort zone. It may be noted that although the belt of the 4-door Rabbit appears to provide a better fit than that of the 2-door model with respect to the sternum crossing height, the angle at which the belt crosses the torso is too low so the belt does not lie within the bounds of the comfort zone.

Photographs illustrating the orientation of the belt on the various size dummies with the upper anchor at different longitudinal positions are presented in Figure 3-15. (Refer to Figure 3-9 for pictures with the belt anchor at the baseline position.)

3.2.4 Film Analysis of Restraint Performance

The performance of the restraint system with the upper anchor at the various locations was also evaluated based on a careful review of the high speed films of all of the tests to observe occupant kinematics and possible injurious interactions with the belt such as underriding of the rib cage or loading of the neck. Factors considered in assessing the overall performance from the films included contact of the head or chest with the forward interior of the vehicle, belt loading of the neck, underriding of the rib cage causing

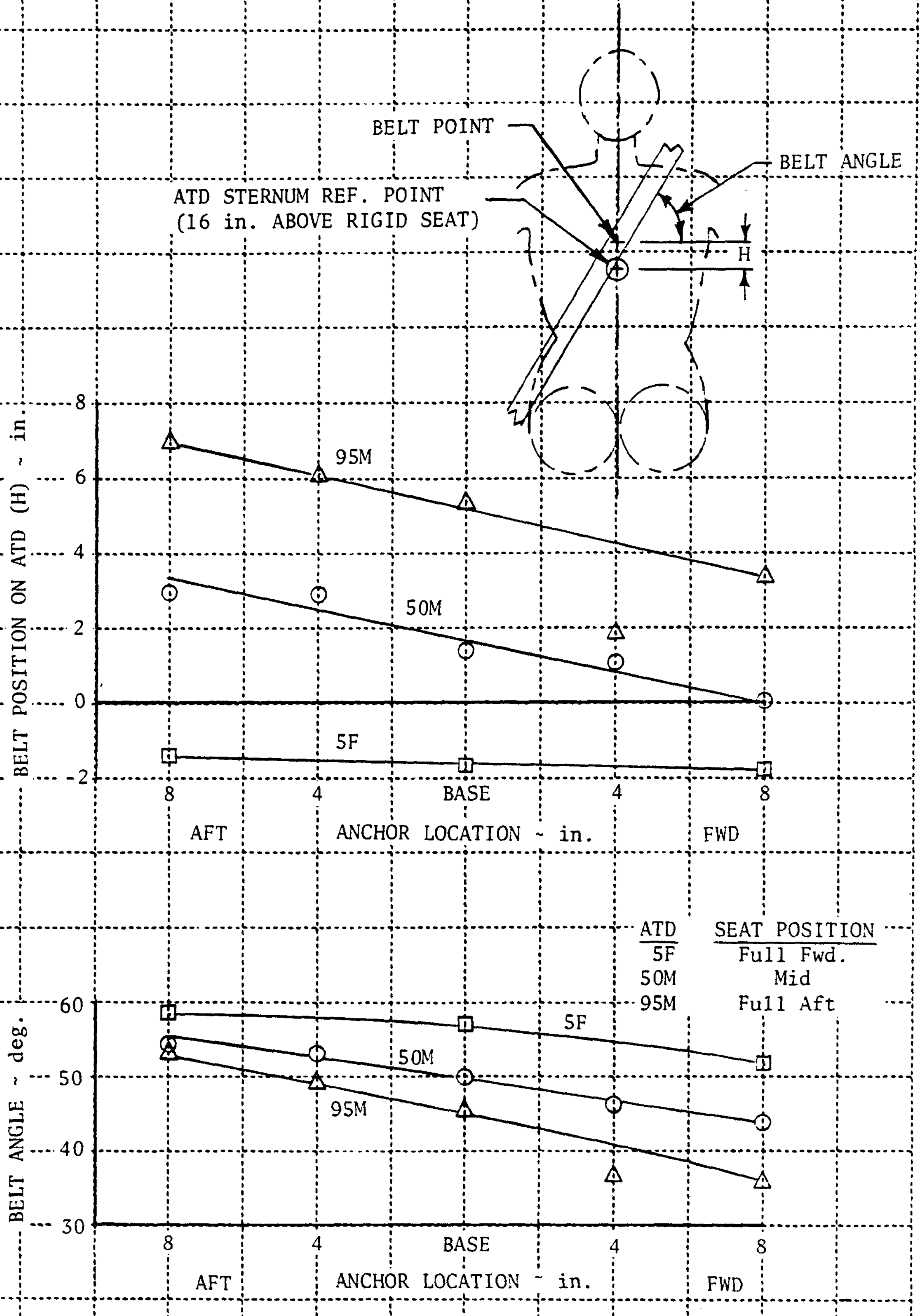
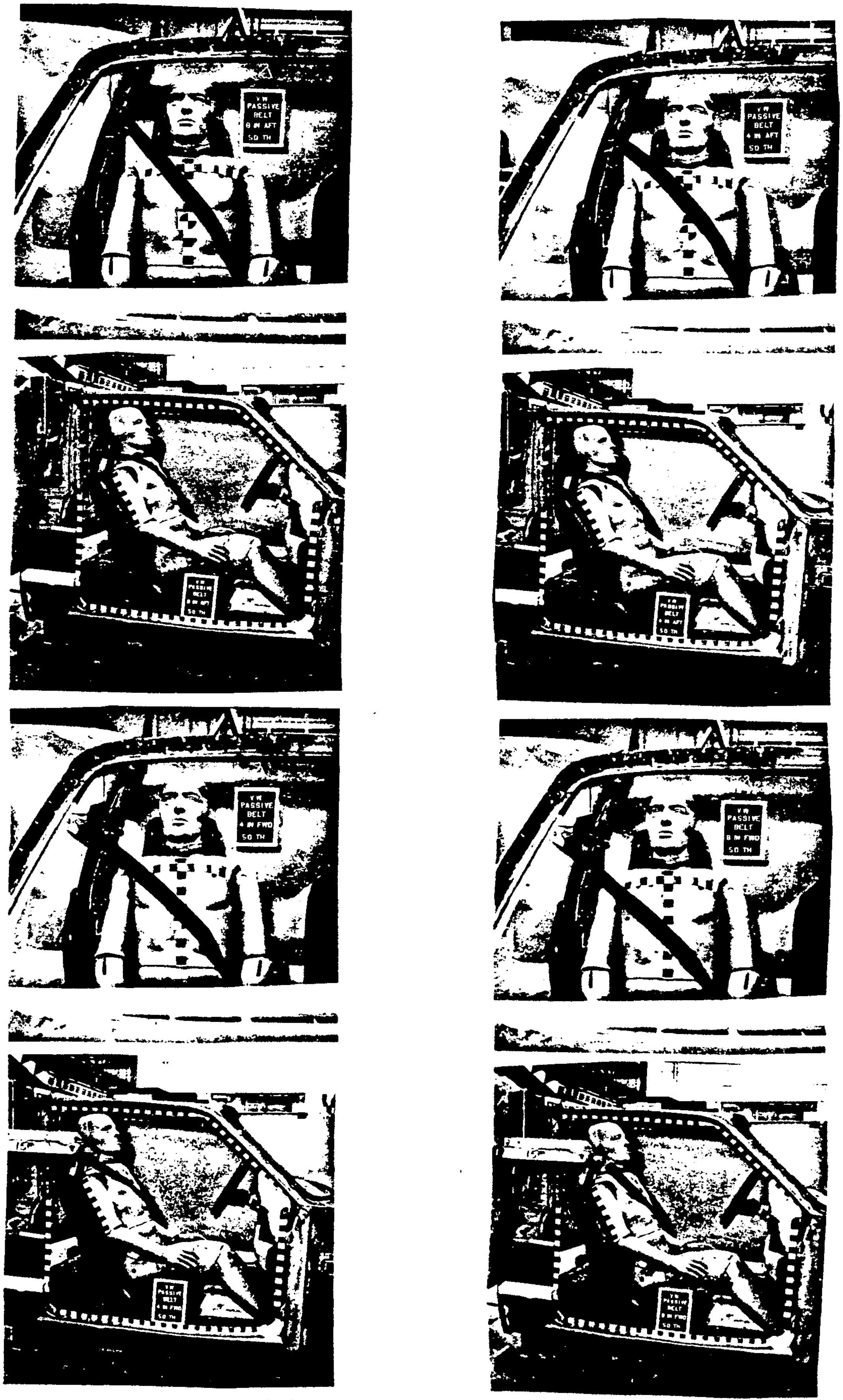


Figure 3-14 EFFECT OF BELT ANCHOR LONGITUDINAL LOCATION ON BELT GEOMETRY

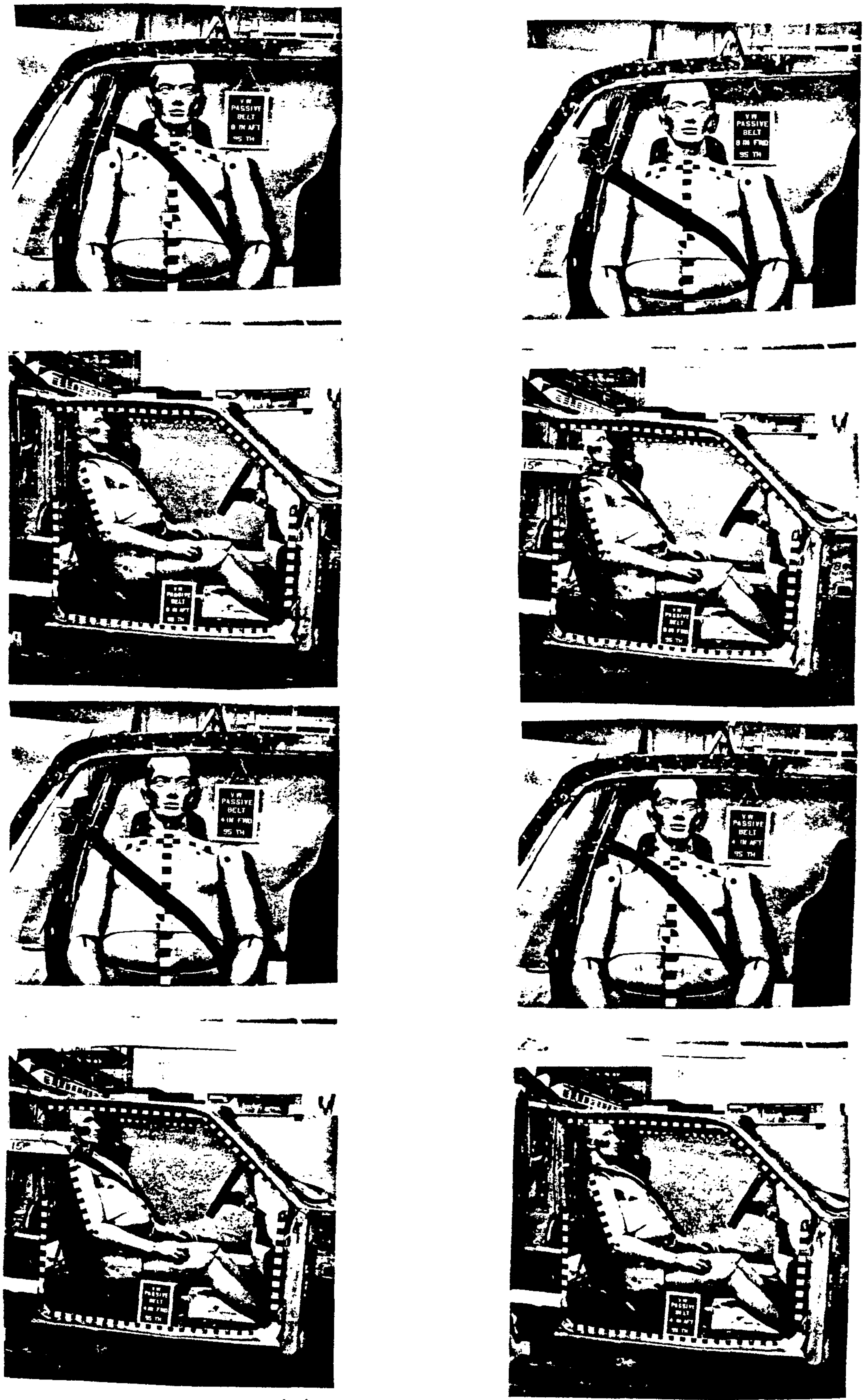
(a) 5th PERCENTILE FEMALE

Figure 3-15 RESTRAINT BELT ORIENTATION FOR DIFFERENT LONGITUDINAL LOCATIONS OF THE UPPER ANCHOR



(b) 50th PERCENTILE MALE

Figure 3-15 (Continued)



(c) 95th PERCENTILE MALE

Figure 3-15 (Continued)

the belt to load the abdominal region, the tendency of the belt to slide upward on the torso and load the breast in the case of the female dummy, and the forward and rebound kinematic responses of the occupants. The restraint performance with respect to each factor was rated Very Good, Good, Fair, Poor or Very Poor based on a subjective judgement of the severity of the particular response. In the case of occupant kinematics, the extent of twisting of the torso and the tendency to roll over or submarine under the belt, the attitude during rebound, and the degree to which rebound was in a direction other than straight back into the seat so as to increase the potential for hazardous contact with the other occupant or with the B-pillar were all elements considered in evaluating the aspect of performance.

Results from the analysis of the films are presented in Tables 3-7, 3-8 and 3-9 for sled tests conducted with the 5th percentile female and the 50th and 95th percentile male dummies, respectively. Although the evaluation procedure is recognized as being inherently imprecise, the tabulated results do provide some valuable insight to how changes of the anchor location affected the performance in general. Moving the anchor point aft of the baseline position had little effect on the performance of the restraint system with the 5th percentile female and 50th percentile male dummies but tended to produce more neck loading and poorer kinematic response with the 95th percentile dummy. The Very Poor overall rating of the 95th percentile passenger dummy in test No. 2288 stems from the fact that the dummy submarined and the belt severely loaded the neck. Compared to the baseline anchor position, the performance with the anchor located forward appears to be less satisfactory for all three occupant sizes. This is particularly true for the driver position because of the increased severity of head and chest contacts with the steering wheel. Anchoring the belt further forward also resulted in the belt underriding the rib cage of the dummies in nearly every test but was more severe for the two larger male dummies and this aspect of the restraint performance was deemed to be very poor for the passengers in Test Nos. 2225 and 2226.

Table 3-7 FILM ANALYSIS EVALUATION OF RESTRAINT SYSTEM PERFORMANCE IN TESTS WITH 5TH PERCENTILE FEMALE ATD

	SLED RUN NO.	ANCHOR LOCATION	HEAD CONTACT	CHEST CONTACT	NECK LOADING	RIB UNDERRIDE	BREAST LOADING	FORWARD KINEMATICS	REBOUND KINEMATICS	OVERALL PERFORMANCE
	DRIVER									
	2227	BASE	VERY GOOD	GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2283	BASE	POOR	FAIR	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	GOOD
	2228	8" AFT	VERY GOOD	GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2226	8" FWD	FAIR	POOR	VERY GOOD	GOOD	GOOD	VERY GOOD	VERY GOOD	FAIR
	2280	6" UP	FAIR	FAIR	GOOD	?	GOOD	VERY GOOD	VERY GOOD	FAIR
	2284	6" UP	VERY GOOD	FAIR	GOOD	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	GOOD
	2282	6" DN	VERY POOR	FAIR	VERY GOOD	?	VERY GOOD	VERY GOOD	GOOD	POOR
	2327	2" DN	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
OBLIQUE IMPACT	2236	BASE	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2292	6" UP	GOOD	GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	PASSENGER									
	2229	BASE	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2286	BASE	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2230	8" AFT	VERY GOOD	VERY GOOD	GOOD	VERY GOOD	FAIR	VERY GOOD	VERY GOOD	GOOD
	2231	8" FWD	VERY GOOD	VERY GOOD	VERY GOOD	FAIR	VERY GOOD	FAIR	GOOD	GOOD
	2275	8" FWD(1)	VERY GOOD	VERY GOOD	VERY GOOD	FAIR	GOOD	FAIR	GOOD	FAIR
	2326	8" FWD(1)	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD
	2276	8" FWD(2)	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
	2280	6" UP	VERY GOOD	VERY GOOD	GOOD	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	GOOD
	2285	6" UP	VERY GOOD	VERY GOOD	FAIR	VERY GOOD	POOR	VERY GOOD	VERY GOOD	FAIR
	2281	6" DN	POOR	VERY GOOD	VERY GOOD	VERY POOR	GOOD	VERY POOR	VERY POOR	VERY POOR
	2282	3" DN	VERY GOOD	VERY GOOD	VERY GOOD	VERY POOR	GOOD	VERY POOR	VERY POOR	VERY POOR
	2328	2" DN	VERY GOOD	VERY GOOD	VERY GOOD	VERY POOR	VERY GOOD	POOR	POOR	POOR
OBLIQUE IMPACT	2237	BASE	VERY GOOD	VERY GOOD	FAIR	VERY GOOD	FAIR	VERY GOOD	VERY GOOD	FAIR
	2292	6" UP	VERY GOOD	VERY GOOD	FAIR	VERY GOOD	POOR	VERY GOOD	VERY GOOD	FAIR

(1) SEAT AFT
(2) SEAT MID

Table 3-8 FILM ANALYSIS EVALUATION OF RESTRAINT SYSTEM PERFORMANCE IN TESTS WITH 50TH PERCENTILE MALE ATD

	SLED RUN NO.	ANCHOR LOCATION	HEAD CONTACT	CHEST CONTACT	NECK LOADING	RIB UNDERRIDE	FORWARD KINEMATICS	REBOUND KINEMATICS	OVERALL PERFORMANCE
	DRIVER								
	2221	BASE	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2277	BASE	FAIR	GOOD	VERY GOOD	GOOD	GOOD	GOOD	GOOD
	2289	BASE	FAIR	GOOD	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	GOOD
	2329	BASE (3)	FAIR	GOOD	VERY GOOD	GOOD	GOOD	FAIR	GOOD
	2330	BASE(3)(4)	VERY POOR	POOR	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	POOR
	2222	8" AFT	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2223	4" AFT	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2224	4"FWD	FAIR	FAIR	VERY GOOD	?	VERY GOOD	GOOD	FAIR
	2225	8" FWD	VERY POOR	POOR	VERY GOOD	FAIR	VERY GOOD	GOOD	POOR
	2278	6" UP	VERY GOOD	FAIR	FAIR	VERY GOOD	VERY GOOD	VERY GOOD	GOOD
	2279	6" DN	VERY POOR	VERY POOR	VERY GOOD	VERY POOR	VERY POOR	VERY POOR	VERY POOR
OBLIQUE IMPACT	2234	BASE	FAIR	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD
	2235	8" FWD	POOR	GOOD	VERY GOOD	FAIR	GOOD	FAIR	FAIR
	2290	6" UP	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD
	PASSENGER								
	2221	BASE	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD	GOOD	VERY GOOD
	2273	BASE	VERY GOOD	VERY GOOD	VERY GOOD	POOR	FAIR	FAIR	FAIR
	2329	BASE (3)	VERY GOOD	VERY GOOD	VERY GOOD	FAIR	POOR	POOR	POOR
	2222	8" AFT	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2223	4" AFT	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD
	2224	4" FWD	VERY GOOD	VERY GOOD	VERY GOOD	FAIR	GOOD	FAIR	FAIR
	2225	8" FWD	GOOD	VERY GOOD	VERY GOOD	VERY POOR	POOR	FAIR	POOR
	2231	8" FWD(1)	VERY GOOD	VERY GOOD	VERY GOOD	POOR	GOOD	FAIR	FAIR
	2278	6" UP	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2279	6" DN	POOR	VERY GOOD	VERY GOOD	VERY POOR	VERY POOR	VERY POOR	VERY POOR
OBLIQUE IMPACT	2234	BASE	VERY GOOD	VERY GOOD	VERY GOOD	FAIR	GOOD	FAIR	GOOD
	2235	8" FWD	VERY GOOD(2)	VERY GOOD	VERY GOOD	POOR	GOOD	FAIR	FAIR
	2291	6" UP	VERY GOOD	VERY GOOD	VERY POOR	VERY GOOD	GOOD	FAIR	POOR

(1) SEAT AFT
(2) HEAD HIT "B" PILLAR DURING REBOUND
(3) INBOARD ANCHOR 6" FWD
(4) 38.5 MPH TEST

Table 3-9 FILM ANALYSIS EVALUATION OF RESTRAINT SYSTEM PERFORMANCE IN TESTS WITH 95TH PERCENTILE MALE ATD

	SLED RUN NO.	ANCHOR LOCATION	HEAD CONTACT	CHEST CONTACT	NECK LOADING	RIB UNDERRIDE	FORWARD KINEMATICS	REBOUND KINEMATICS	OVERALL PERFORMANCE
	DRIVER								
	2273	BASE	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
	2286	BASE	VERY GOOD(1)	GOOD	GOOD	VERY GOOD	VERY GOOD	FAIR	GOOD
	2275	8" AFT	VERY GOOD(1)	GOOD	FAIR	VERY GOOD	VERY GOOD	GOOD	GOOD
	2288	8" AFT	VERY GOOD	FAIR	VERY POOR	VERY GOOD	FAIR	POOR	POOR
	2274	8" FWD	FAIR	POOR	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	FAIR
	2287	8" FWD	POOR	POOR	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	FAIR
	2285	6" UP	VERY GOOD	GOOD	VERY POOR	VERY GOOD	GOOD	GOOD	POOR
	2328	3" UP	VERY GOOD(1)	GOOD	FAIR	VERY GOOD	VERY GOOD	FAIR	GOOD
OBLIQUE IMPACT	2237	BASE	VERY GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD
	2291	6" UP	VERY GOOD	GOOD	VERY POOR	VERY GOOD	VERY GOOD	FAIR	POOR
	PASSENGER								
	2227	BASE	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD	GOOD	GOOD
	2228	BASE	VERY GOOD	VERY GOOD	VERY GOOD	FAIR	GOOD	FAIR	FAIR
	2277	BASE	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	POOR	POOR	POOR
	2283	BASE	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	VERY GOOD	GOOD	VERY GOOD
	2284	BASE	VERY GOOD	VERY GOOD	POOR	VERY GOOD	FAIR	POOR	POOR
	2276	8" AFT	VERY GOOD	VERY GOOD	FAIR	VERY GOOD	GOOD	GOOD	GOOD
	2288	8" AFT	VERY GOOD	VERY GOOD	VERY POOR	VERY GOOD	VERY POOR	VERY POOR	VERY POOR
	2226	8" FWD	GOOD	VERY GOOD	VERY GOOD	VERY POOR	FAIR	FAIR	FAIR
	2289	8" FWD	VERY GOOD	VERY GOOD	VERY GOOD	FAIR	GOOD	POOR	GOOD
	2287	6" UP	VERY GOOD	VERY GOOD	VERY POOR	VERY GOOD	POOR	VERY POOR	VERY POOR
	2326	5" UP	VERY GOOD	VERY GOOD	VERY POOR	VERY GOOD	GOOD	POOR	POOR
	2327	2" DN	VERY GOOD	VERY GOOD	VERY GOOD	VERY POOR	VERY POOR	VERY POOR	VERY POOR
OBLIQUE IMPACT	2236	BASE	VERY GOOD(1)	VERY GOOD	VERY POOR	VERY GOOD	FAIR	POOR	POOR
	2290	6" UP	VERY GOOD(1)	VERY GOOD	VERY POOR	VERY GOOD	POOR	VERY POOR	VERY POOR

(1) HEAD HIT "B" PILLAR DURING REBOUND

In contrast with the good performance observed for the driver in sled run 2329 with the inboard anchor moved ahead to position the belt in the comfort zone of the 50th percentile dummy, the performance in restraining the passenger was deemed poor. The films show that the passenger twisted outboard approximately 90 degrees as the torso rolled over the belt and the left side of the head came very close to striking the dash panel. There was very little rebound as the dummy torso remained pitched forward over the belt after the crash. In this test, and in several others as mentioned previously, the belt appeared to catch in the shoulder opening between the clavicle and the upper arm which could account for the poor kinematic response. Note that except for the severity of the driver head and chest contact with the steering wheel in test No. 2330, which is attributable to the much higher speed of that test, the performance of the restraint configuration was deemed comparable to the baseline tests.

Raising the anchor point by 6 inches increased the frequency and severity of neck loading and, in the case of the female dummy, shear loading of the breast by the belt. Neck loading was particularly a problem with the 95th percentile dummy for which the belt clearly appeared to be positioned too high on the torso. The films show that while restraining the dummy the belt slides upward on the chest and under the inboard arm pit which results in severe loading of the neck. Belt contact with the neck was also more of a problem for the passenger dummies in the oblique impact tests. Since the sled buck was oriented to simulate impacts on the right front corner, the occupants of the passenger seat were thrust toward the diagonal belt which crossed over the right shoulder whereas the drivers tended to move from under the belt crossing over the opposite shoulder.

As discussed in Section 3.2.2, the kinematic response was generally very poor and the abdominal region was severely loaded as a result of the extreme rotation of the upper torso over the belt that occurred in the tests with the anchor below the baseline position.

The overall performance ratings shown in Tables 3-7, 3-8 and 3-9 were used to assess the performance of the restraint system with the different anchor positions in relation to the performance of the baseline configuration. Each test with a relocated anchor was compared to all applicable[*] baseline tests and the frequencies (driver and passenger combined) of better, equal, or worse restraint performance tabulated. The results for the vertically relocated anchor are summarized in Table 3-10 and in the performance comparison matrices of Figure 3-16. It may be seen from Table 3-10 that the performance was judged to be worse in 18 of the 20 possible comparisons of tests with the anchor lowered. Moreover, Figure 3-16 shows that the performance was considerably degraded. In that figure, cells above and to the right of the shaded diagonal represent poorer performance with the relocated anchor; conversely, entries in cells below and to the left of the diagonal indicate the performance was improved over that of the baseline configuration. Clearly, the farther a cell is from the diagonal, the greater the improvement or degradation. Only in the test of the 5th percentile driver with the anchor 2 inches lower was the performance judged to be equal to or better than with the anchor at the baseline location.

The situation is much better for elevated anchor points but somewhat inferior performance is still indicated for the 5th percentile female with the anchor raised 6 inches and the 95th percentile dummy, in particular, did not fare well. It may be seen that the performance with the latter dummy was increasingly degraded as the anchor was moved further from the baseline. It is well to note also that the restraint performance in the baseline anchor tests was most variable for the 95th percentile size occupant and ranged from very good to poor.

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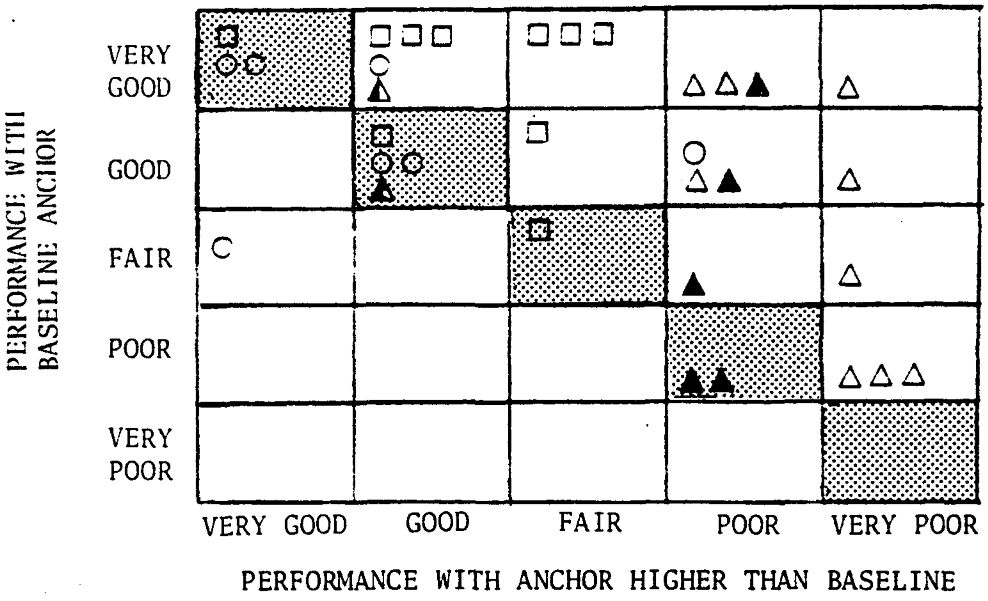
[*] For example, in Table 3-7, the overall performance for the driver in sled runs 2280 and 2284 can be compared with each of baseline test Nos. 2227 and 2283 (i.e., four comparisons) but not with run No. 2236 which was an oblique angle baseline test or with the baseline tests for the passenger.

Table 3-10

RESTRAINT PERFORMANCE WITH ANCHOR RELOCATED VERTICALLY RELATIVE TO BASELINE SYSTEM PERFORMANCE

ATD SIZE	**RELATIVE PERFORMANCE**			
	BETTER	**EQUAL**	**WORSE**	**TOTAL**
		ANCHOR 6 IN. UP		
5F	0 (0)*	3 (30)	7 (70)	10
50M	1 (14)	4 (57)	2 (29)	7
95M	0 (0)	0 (0)	9 (100)	9
TOTAL	1 (4)	7 (27)	18 (69)	26
		ANCHOR 5 IN. UP		
95M	0 (0)	2 (40)	3 (60)	5
		ANCHOR 3 IN. UP		
95M	0 (0)	1 (50)	1 (50)	2
		ANCHOR 2 IN. DOWN		
5F	1 (25)	1 (25)	2 (50)	4
95M	0 (0)	0 (0)	5 (100)	5
TOTAL	1 (11)	1 (11)	7 (78)	9
		ANCHOR 3 IN. DOWN		
5F	0 (0)	0 (0)	2 (100)	2
		ANCHOR 6 IN. DOWN		
5F	0 (0)	0 (0)	4 (100)	4
50M	0 (0)	0 (0)	5 (100)	5
TOTAL	0 (0)	0 (0)	9 (100)	9

*VALUES IN ( ) INDICATE PERCENT OF ROW TOTAL.



ATD

□ *5F*
○ *50M*
△ *95M*

RELOCATED ANCHOR POSITIONS

OPEN SYMBOLS - 6 IN. UP OR 6 IN. DN.
HALF OPEN SYMBOLS - 3 IN. UP OR 3 IN. DN.
SOLID SYMBOLS - 5 IN. UP OR 2 IN. DN.

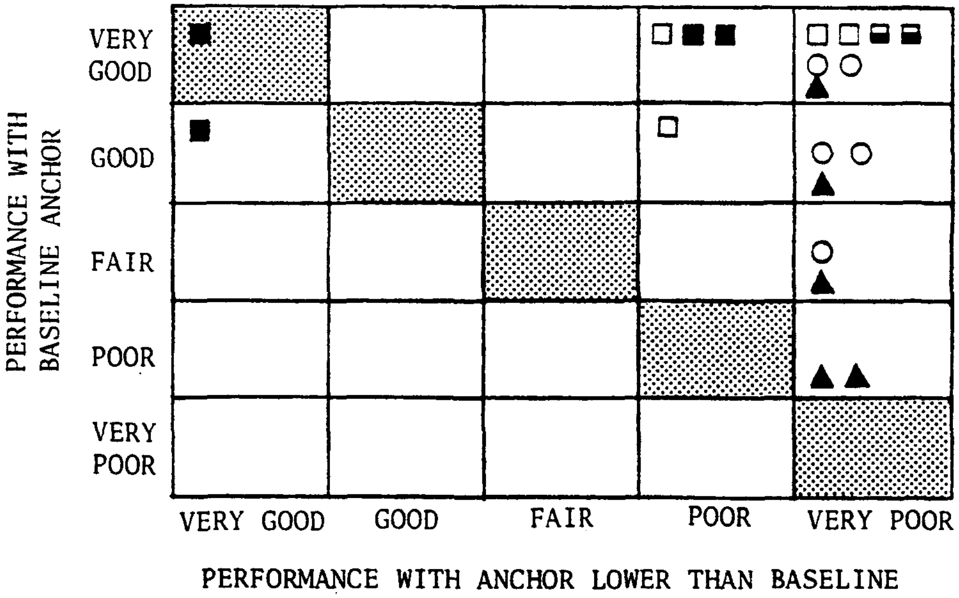


Figure 3-16 PERFORMANCE RATING COMPARISON FOR VERTICAL VARIATION OF UPPER ANCHOR LOCATION

The performance as judged from the films of the tests with the anchor varied longitudinally are similarly compared to the baseline anchor test results in Table 3-11 and Figure 3-17. The tabulated data shows that, with the exception of the 50th percentile male, restraint effectiveness with the anchor point 8 inches aft tended to be degraded for the other dummies of smaller and larger size. The performance rating comparison matrix at the top of Figure 3-17 shows, however, that the performance with the 5th percentile female occupant was only slightly inferior whereas, again, the 95th percentile male dummy generally experienced more frequent and greater losses of protection. In contrast with this is the indication that the performance with the 50th percentile dummy is at least as good and, indeed, is even somewhat improved when the belt is anchored aft of the normal location. The overall performance was deemed Very Good for both the driver and passenger in both tests with the anchor located 4 inches and 8 inches rearward.

The performance comparisons for forward locations of the anchor presented in the lower matrix of Figure 3-17 indicate a tendency toward less satisfactory performance for all three sizes of dummies. Since the 8 inch forward position closely approximates the existing location of the anchor in a 4-door model Rabbit, the open symbols of this chart in effect provide a direct comparison of the performance of the restraint system as currently installed in 2-door and 4-door vehicles. The results indicate that the restraint offers somewhat less protection to occupants of the 4-door model, especially those represented by the 50th percentile male size dummy. Although the performance with the anchor located 8 inches forward was deemed worse than the baseline tests more often than not with the 95th percentile dummy, there were none-the-less several instances of improved performance and the results are therefore less conclusive concerning the effect of the difference of anchor location.

Table 3-11

RESTRAINT PERFORMANCE WITH ANCHOR RELOCATED LONGITUDINALLY RELATIVE TO BASELINE SYSTEM PERFORMANCE

ATD SIZE	RELATIVE PERFORMANCE			
	BETTER	EQUAL	WORSE	TOTAL
	ANCHOR 8 IN. AFT			
5F	1 (25)	1 (25)	2 (50)	4
50M	3 (60)	2 (40)	0 (0)	5
95M	3 (21)	2 (14)	9 (64)	14
TOTAL	7 (30)	5 (22)	11 (48)	23
	ANCHOR 4 IN. AFT			
50M	3 (60)	2 (40)	0 (0)	5
	ANCHOR 4 IN. FORWARD			
50M	1 (20)	0 (0)	4 (80)	5
	ANCHOR 8 IN. FORWARD			
5F	0 (0)	0 (0)	4 (100)	4
50M	0 (0)	0 (0)	7 (100)	7
95M	5 (36)	2 (14)	7 (50)	14
TOTAL	5 (20)	2 (8)	18 (72)	25
	INBOARD ANCHOR 6 IN. FORWARD			
50M	0 (0)	2 (40)	3 (60)	5

*VALUES IN ( ) INDICATE PERCENT OF ROW TOTAL.

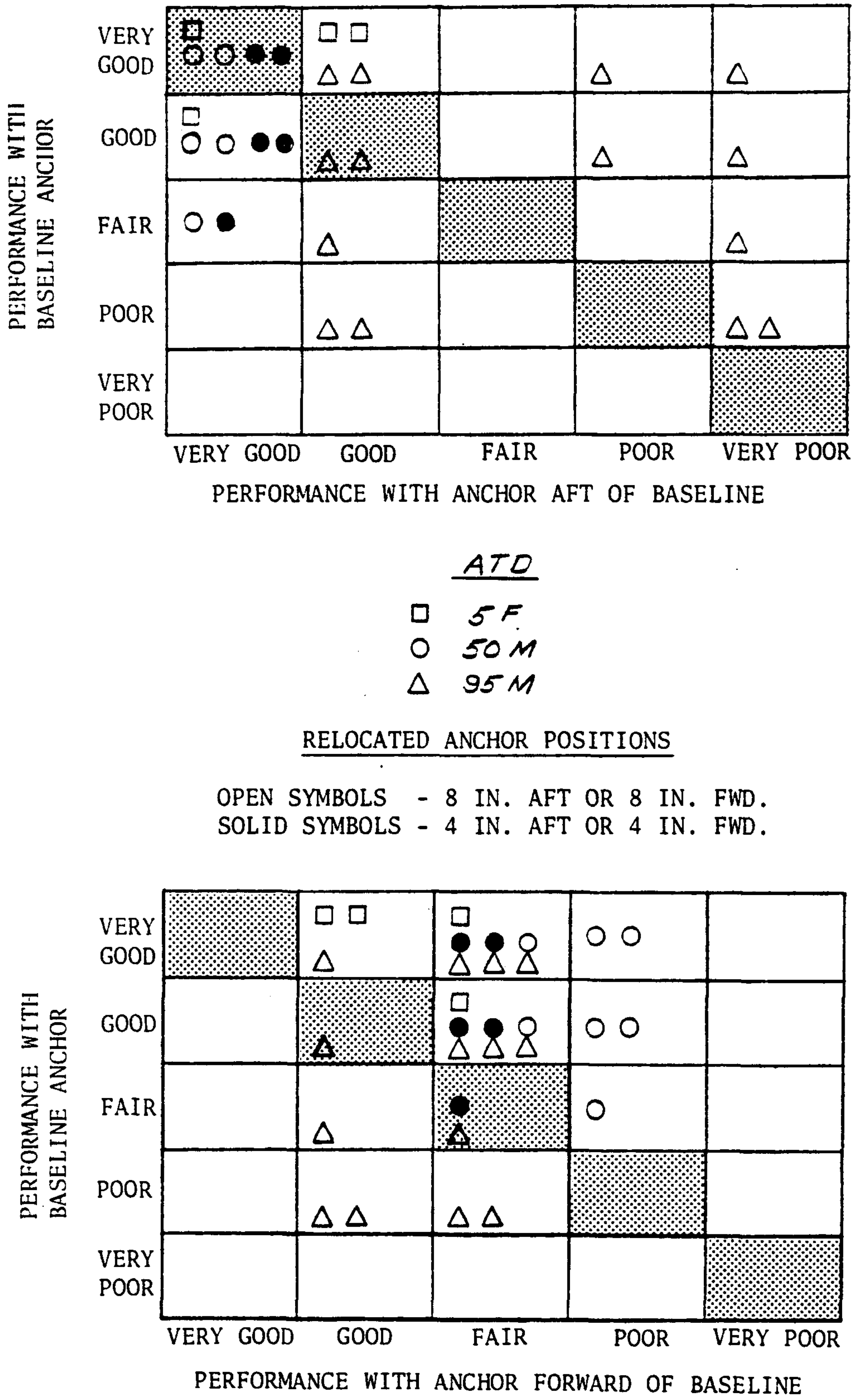


Figure 3-17 PERFORMANCE RATING COMPARISON FOR LONGITUDINAL VARIATION OF UPPER ANCHOR LOCATION

In summary, the foregoing analysis of the film data indicates that the existing anchor location in the 2-door model Rabbit is close to the optimum for the entire range of adult size occupants. Such a finding quite naturally leads to the conclusion that a capability for adjusting the anchor perhaps should not be provided since it would allow the possibility of occupants selecting a position for increased comfort, but at the expense of a reduced level of crash protection. Although this indeed might be true, it is well to mention certain aspects of the problem that point to the need for exercising caution in drawing any firm conclusions regarding the merits of an adjustable anchor.

First, in addition to the subjective nature of the evaluation, performance metrics were more or less considered of equal weight in classifying the overall restraint performance. Thus, for example, there was no distinction between a "Fair" classification for rib underride in a baseline test and the same category for neck loading in a test with the relocated anchor in rating the overall performances whereas the injury potential actually could be much different for the two types of loading. Furthermore, the benefits/costs are not necessarily the same between all categories, e.g., the performance loss associated with a change from "Very Good" to "Good" may not be as great as from, say, "Fair" to "Poor".

The frequency distribution of occupants of different size is also an important consideration. Since the 50th percentile male dummy is probably representative of a greater proportion of motorists, it would be logical to give more weight to the results for that size occupant. It was previously noted that elevating the anchor had little effect on the overall performance and some improvement was indicated for the more rearward locations with the 50th percentile dummy. Hence, there is a possible trade-off between degraded protection for motorists near the extremes of the size range and improved performance for a greater number of occupants that must be considered.

Finally, and perhaps most important aside from cost considerations, is the question of whether or not adjustable anchors would result in increased use of safety belts provided in vehicles. It seems clear that if, by virtue of allowing better fit and increased comfort, adjustable anchors would result in more people wearing the belt, a net overall safety benefit might be realized even though the anchor may not always be adjusted to the position that affords the best protection. The consideration of how occupant comfort might be affected by changes of the upper anchor point was beyond the scope of this study. However, based on the comments of several people of different sizes after trying out the restraint belts in a 2-door VW Rabbit equipped with vertically adjustable upper anchors, it is the author's opinion that adjustable anchors are not likely to improve the comfort of the belts in that vehicle for the vast majority of occupants.

4. DESIGN AND DEVELOPMENT OF ADJUSTABLE ANCHORAGE

4.1 Conceptual Design

There were three basic requirements specified for the design of the vertically adjustable anchor for the Rabbit passive belt. These were: (1) the anchor must not be capable of being disconnected, (2) the device must allow adjustment to a minimum of three positions including the location of the existing fixed anchor and at points both above and below the present location, and (3) the emergency release buckle must be retained in its original location at the upper, outboard end of the belt. In addition, simplicity of design, convenience of operation, hazard to occupants, ease of fabrication, possibility of retrofit, etc., were among the important factors considered in achieving the objective of a practical, consumer-acceptable installation.

Several preliminary design concepts for an adjustable anchor device were formulated and evaluated in the light of the aforementioned criteria. In these design studies, the major difficulty was perceived to be the limited space available for attaching the mechanism to or within the door frame and for providing the mechanical interlock needed to suitably transfer the belt loads into the B-pillar throughout the range of adjustment. Since it appeared that any scheme would require substantial modification of the door frame and B-pillar structures, an after-market type of device that would permit a simple, add-on retrofit installation in the Rabbit vehicle was not deemed feasible. Although a design that would be amenable to fabrication by mass-production techniques was emphasized, the question of manufacturing processes required to produce modified door and body stampings for assembly and installation of the device at the time of original vehicle fabrication was not addressed in detail.

The conceptual design deemed most promising among the several candidate configurations considered and which was selected for detail design, development and fabrication of prototype units is illustrated in Figure 4-1. The adjustable anchor mechanism consists of three component subassemblies: (1) a guide track within a U-shaped member having a tongue or flange that interlocks with the B-pillar, (2) the adjustable slide to which the existing VW emergency release buckle is attached, and (3) the latch portion of the interlock which is mounted on the B-pillar. Figure 4-2 is a photograph showing each of these subassemblies.

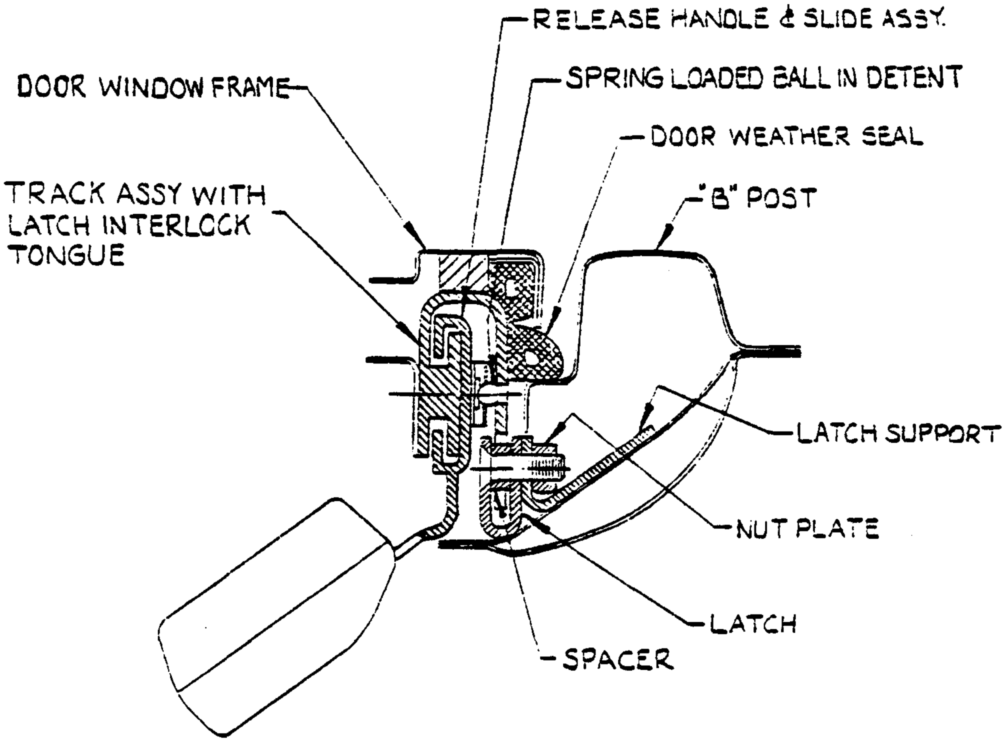


Figure 4-1 DIAGRAM OF VERTICALLY ADJUSTABLE UPPER BELT ANCHOR CONFIGURATION

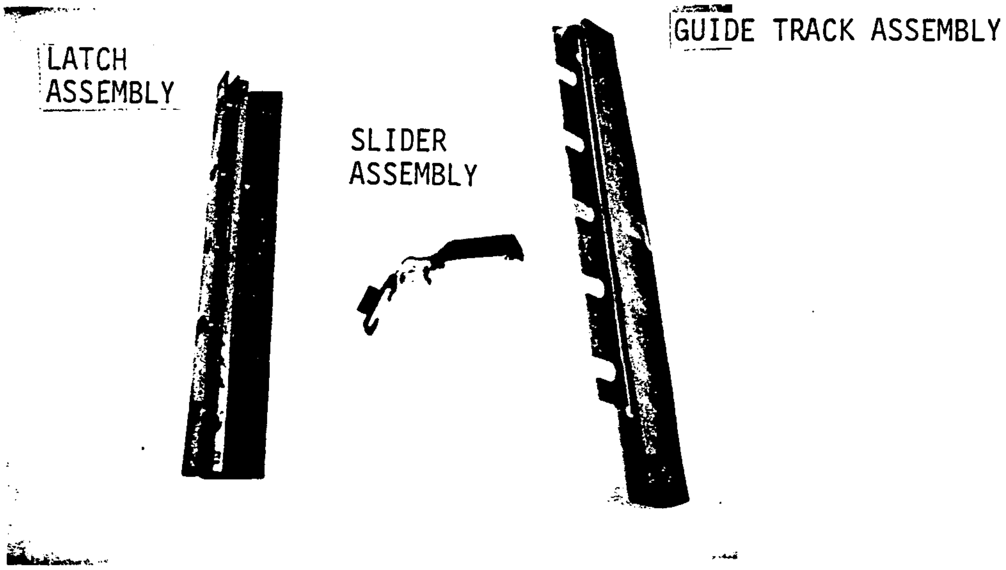


Figure 4-2 ADJUSTABLE ANCHOR SUBASSEMBLIES

As may be seen from Figure 4-1, the guide track and slider are contained within the door window frame which was partially cut away to provide the opening required for installation of the prototype anchors that were fabricated in this program. Similarly, it was necessary to remove a section of the outer sheet metal of the B-pillar to permit welding of the latch support bracket to the internal diagonal member. Except for the cutout required to clear the latch support, this section of outer skin was reattached to the B-pillar and latch support by welding and silver soldering to provide a neat, finished appearance to the installation. The latch is secured to the B-pillar with five screws which provide reinforcement against spreading of the latch under load and also permits easy adjustment of clearances with the interlocking tongue on the door by shimming.

The track assembly which includes a spacer contoured to fit the lateral curvature of the outer door skin, is also welded in place inside the window frame. The adjustable range of the anchor is from 2 inches below to 5 inches above the normal, fixed-anchor location. A spring loaded ball engages detent holes spaced one inch apart in the track mount to maintain the slider at the adjusted height.

The anchor is readily adjustable with the door either closed or open by grasping the emergency release buckle and applying the small force required to disengage the ball from the detent and move the slider to the desired position. A disadvantage is that the buckle might be difficult to reach for some people, particularly in the two-door model Rabbit with the seat positioned fully forward. However, a worm gear cable drive mechanism similar to that used to raise and lower the windows of the Rabbit vehicle could easily be added which would allow convenient adjustment of the anchor from a normal seated position.

Photographs of the adjustable anchor installation in the Rabbit automobile are presented in Figure 4-3. Note that the opening cut in the window frame extends beyond the lower end of the track which allows the buckle and slider assembly to be replaced, if desired, by removal of a screw in the track mount that otherwise prevents the anchor from being disconnected. In a production installation, this opening would be covered with a suitable trim cap to improve the appearance.

The design of the adjustable anchorage is documented in a set of nine detail and assembly drawings furnished to the sponsor and identified as Calspan Drawing Nos. TR79-E15-001 through TR79-E15-009.

4.2 Component Static Tests

Static tests of the adjustable anchor hardware were performed to determine if the strength of the components was sufficient to withstand the loads developed in the restraint belt in a crash. The tests were performed on a Southwark-Emery hydraulic tensile testing machine using the setup shown in Figure 4-4. The interlock latch that normally is attached to the "B" pillar was mounted on a fixture designed to provide a direction of loading similar to that for an actual vehicle installation. The anchor carrier was placed at

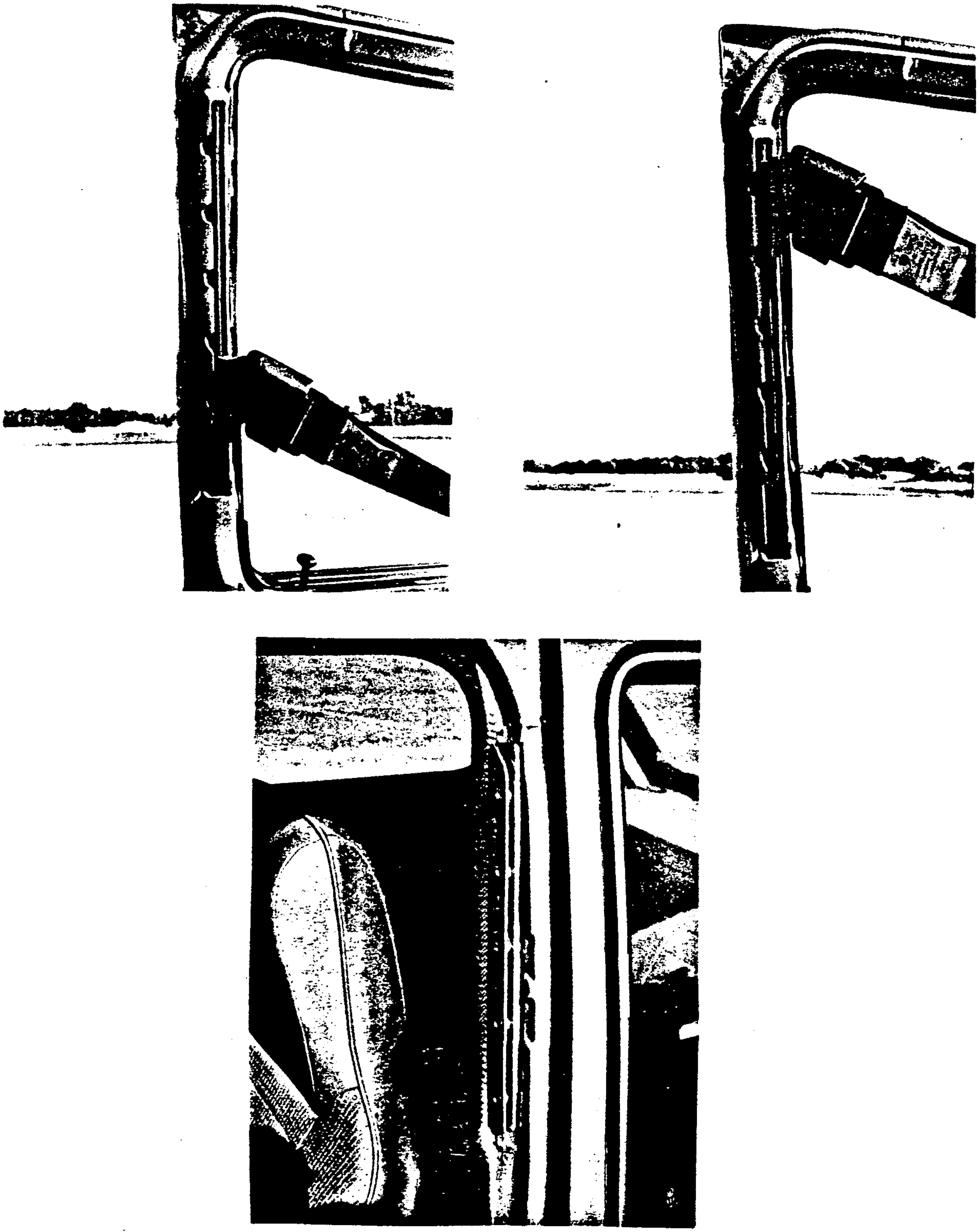
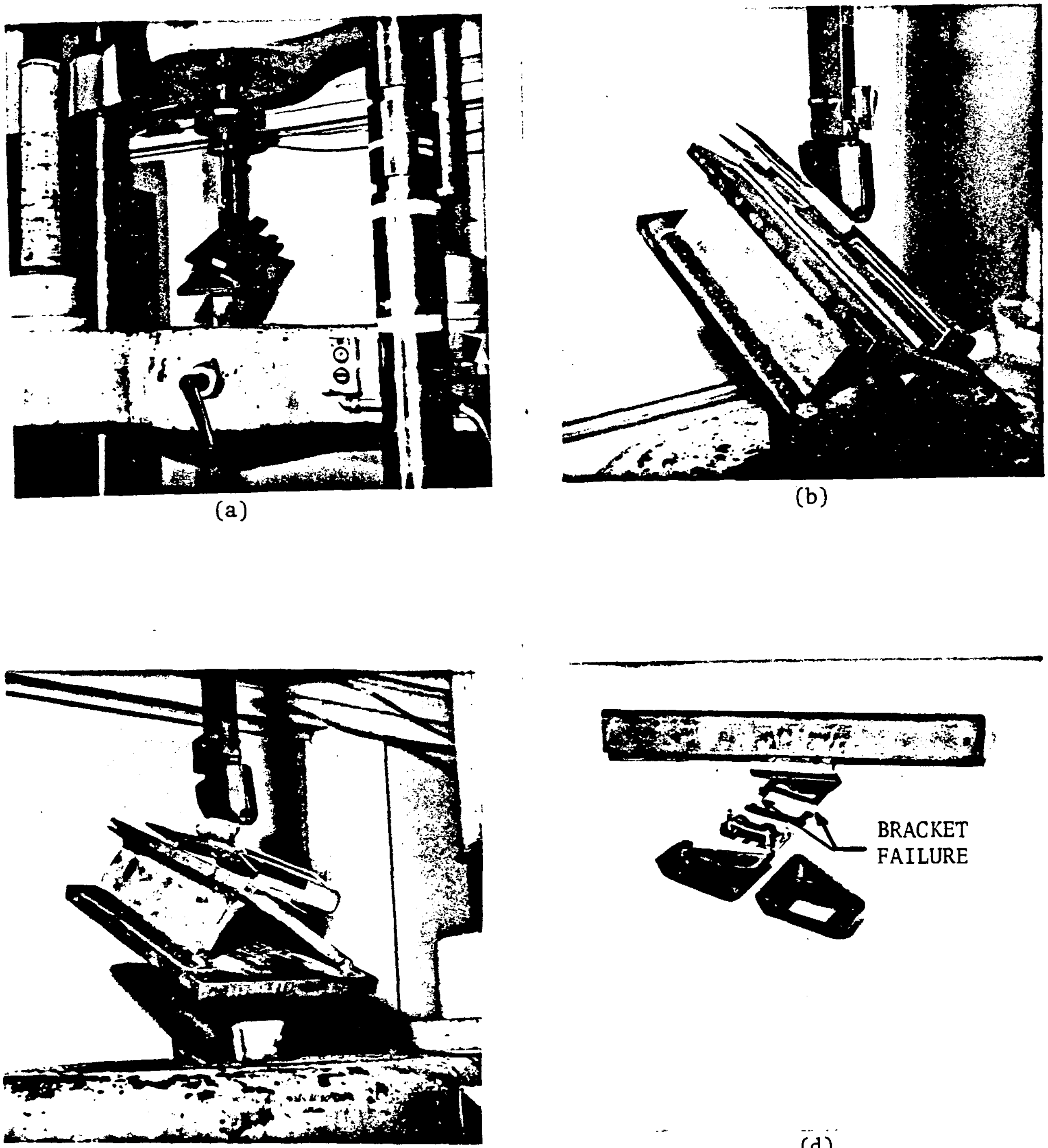


Figure 4-3 ADJUSTABLE BELT ANCHORAGE INSTALLATION IN VW RABBIT



(a) (b) (c) (d)

Figure 4-4 TENSILE TEST OF ADJUSTABLE ANCHOR ASSEMBLY the mid-point of the adjustable range to provide the most severe loading condition. A bar was connected to the latch plate of the VW emergency release buckle instead of the belt webbing to facilitate clamping by the upper carriage of the testing machine and a load cell was installed in this link to record the tensile force. Loads were applied through pin connections to the tensile machine to insure alignment of the reaction forces, thereby avoiding bending moments that otherwise might be introduced through use of the rigid bar instead of belt webbing.

Two tests of a prototype adjustable anchor assembly were performed followed by two additional tests of the existing, unmodified VW emergency release buckle hardware. In the first test of the adjustable anchor, the weld at the end cap of the track mount channel started to fail at a load of 2400 lb. The deformation of the carrier guide track assembly and the failure of the end cap weld can be seen in Figure 4-4(c). Loading was continued to a maximum value of 2900 lb. during which time the threads of nuts on several of the screws securing the interlock latch to the fixture became stripped and the test was therefore terminated.

For the second test, the guide track assembly was straightforward, the end cap was rewelded, and a high strength screw was provided at the upper end of the channel like that at the opposite end as a further measure to prevent spreading of the channel. In addition, a steel bar with threaded holes was used as a nut plate for securing the latch to the fixture.

A maximum load of 3450 lb. was applied before a failure of the original VW emergency release buckle occurred. This failure is indicated by the arrows shown in the photograph of Figure 4-4(d). At that load the adjustable anchor hardware, though deformed, was still intact.

To check if the release buckle bracket might have been weakened by the welding and heat treat process used in attaching it to the slider of the adjustable anchor, two tensile tests of unmodified emergency release buckle assemblies were performed. In each of those tests there was no structural failure but the male latch plate released from the buckle as a result of distortions of the buckle mechanism. These failures occurred at applied loads of 3800 lb. and 4300 lb., respectively. The results of the static tests indicated that the modifications to the mounting bracket of the VW emergency belt release buckle for adapting it to the adjustable anchor device did not seriously compromise the load carrying capacity of the original equipment, if at all.

Although FMVSS 209 which specifies requirements for seat belt assemblies does not directly address the type of assembly used for the VW Rabbit passive belt system (i.e., a single belt torso restraint), Paragraph 4.4b2 specifies that the components in the upper torso restraint portion of a Type 2 belt assembly must withstand a minimum force of 1500 lb. Paragraph 4.4b3 specifies that hardware common to pelvic and upper torso restraints must withstand at least 3000 lb. The static tests of the adjustable anchor hardware demonstrated a load capacity that exceeds these requirements. Moreover, the material strength is substantially higher for dynamic, impulsive type loads like those developed in a crash, so the failure load of the adjustable anchor is probably as high as 4000 lb. or more.

4.3 Dynamic Tests of Final Design Installation

The performance of the adjustable anchor under dynamic loading conditions was evaluated by impact sled testing of a complete final assembly installed in the door and B-pillar on the passenger side of the sled test buck. Five sled runs (Run Nos. 2326-2330) were performed using the same anchor hardware for all of the tests. The main purpose of these runs was to strength proof test the complete prototype hardware installation under realistic dynamic loading conditions. In addition, it was important to check that the anchor would remain at the adjusted location and not be pulled downward by the vertical component of the belt load since, except for the retention force of the spring-loaded detent ball, the anchor slider is not positively locked in position.

The peak upper belt loads measured in this series of sled tests ranged from a minimum of 1540 lb. with the 5th percentile female dummy as the passenger to a maximum of 2600 lb. in the 38.5 MPH test using the 95th percentile male dummy. As noted in Tables 3-3 and 3-4, the stitching in the belt loop attachment to the latch plate of the emergency release buckle failed at t = 66 milliseconds in the latter test (Run No. 2330) so the applied belt load was substantially less than the maximum which otherwise would have been developed in this high speed test.

Satisfactory performance of the adjustable anchor device was demonstrated in each of the five sled tests. In those tests in which the anchor was positioned above the minimum elevation, post-test inspection revealed that the carrier slider had fallen to the lowest position. However the high-speed films show that the carrier remained fixed in place under the applied belt loads and did not begin to move downward until well after the belt had become slack during rebound of the dummy. Apparently the force of the spring holding the small ball in the detent to keep the carrier in place was reduced as a result of the small deformation of the guide track channel section that occurred so as to allow the carrier to slide down when the belt was no longer loaded.

The only damage to the adjustable anchor in any of the tests was a slight bend (i.e., spreading) of the door channel interlock with the "B" pillar latch which also showed some local deformation after the last, high-speed sled run. This minor damage was repaired by hammering the latch interlock tongue of the track assembly to straighten the bent section after each test. Because the same adjustable anchor hardware was repeatedly used in all of the evaluation sled tests with no structural failures, it is concluded that the design satisfies strength requirements with an adequate safety factor and hence is capable of withstanding the dynamic belt loads developed during an actual vehicle crash.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions are drawn from the results obtained in the study:

1. The location of the existing, fixed upper anchorage of the passive belt restraint in the 2-door model Volkswagen Rabbit is close to optimum for the overall range of adult size occupants in terms of performance. Lower anchor positions produce poor occupant kinematics and increase the possibility of abdominal injuries from the belt underriding the rib cage as occupants roll over the belt. Restraint performance with the anchor located higher is degraded, particularly for 95th percentile size occupants, due to increased belt loading of the neck.

   Moving the anchor up to 8 inches aft of the baseline position also resulted in an increased tendency for the belt to load the neck of the largest dummy but had little effect on the protection afforded to 5th percentile female or 50th percentile male size crash victims. On the other hand, the severity of driver torso and head contacts with the steering wheel is increased for all size occupants for more forward anchor locations.

   The passive restraint system also does not provide adequate protection to small children, in large measure because the motion of the lower torso is not properly controlled by contact of the legs with the knee bolster. (In recognition of this problem, the owner's manual provided by the vehicle manufacturer cautions against use of the passive belt system by persons less than 55 inches tall and recommends that children always sit in the rear seat and wear lap belts.)

2. Although the number of sled tests performed with belt geometry conforming to the comfort zone was too few to be conclusive, the data from all of the tests with the 50th percentile dummy generated in this program suggest that such geometry is not optimum from the standpoint of restraint performance. Very good performance was consistently demonstrated when the belt was positioned 2 to 3 inches above the specified 16 inch sternum reference point (and at an angle of about 55 degrees as recommended). The lower belt positions required by the comfort zone, and particularly when in combination with smaller crossing angles, results in poor kinematic responses and increases the tendency for occupants to roll over the belt.

3. The second objective of the program was successfully accomplished in that a vertically adjustable upper anchorage design for the Volkswagen Rabbit passive restraint belt was developed and demonstrated to be feasible. Because the device is designed for installation within the door window frame and B-pillar structure, it offers the advantages of a neat appearance and of not creating a hazard to occupants since there is no protrusion into the passenger compartment. For the same reason, however, it is more suited to installation during the original manufacture of the cars rather than to retrofit of existing vehicles.

4. Injury criteria values often do not reflect the actual performance of restraint systems and must be augmented by film analyses for proper evaluation of system effectiveness. This was vividly demonstrated by some tests in which improved performance was indicated by lower values of the injury criteria whereas the actual restraint system effectiveness as revealed by the films was clearly unsatisfactory because of severe belt loading of the neck and/or abdominal regions and the attendant potential of producing serious injuries to human occupants.

5. The fit of the shoulder belt of the 2-door Volkswagen Rabbit automobile does not comply with the comfort zone specification that has been proposed by the NHTSA for inclusion as a part of the Occupant Crash Protection Safety Standard No. 208. Moreover, the data from this study indicate that independently changing the vertical or longitudinal location of the upper anchor does not cause the belt to lie within the comfort zone envelope.

6. Frontal impacts constitute a more severe crash environment for which the demand on the performance of the restraint system to provide protection for the occupants is greater than in 30 degree barrier type collisions at the same speed because of the higher magnitude and shorter duration of the vehicle deceleration pulse.

5.2 Recommendations

1. The full-scale car crash tests planned for Phase II of the project should be performed to evaluate the performance of the adjustable anchor passive belt system installed in vehicles under actual crash conditions and to provide confirmation of the findings from the sled tests performed in Phase I documented herein.

2. Additional sled tests should be performed to explore the effectiveness of the restraint system for different size occupants when the belt geometry is varied over the range of position and crossing angles defined by the envelope of the comfort zone that has been recommended for assuring proper fit of shoulder belts.

3. More work is needed to better define the regions of upper and lower shoulder belt horizontal and vertical anchor point locations that provide the geometry required for belts to fit within the comfort zone envelope.

4. A study should be conducted to evaluate the merit of adjustable anchors in terms of the balance between the benefit of increased belt utilization that might occur due to improved occupant comfort and the potential for decreasing the safety of occupants who could unknowingly use anchor locations that result in reduced restraint system effectiveness.

5. The position and crossing angle of the belt on the occupants of all vehicles involved in future crash tests should be measured and reported to provide information which would help in establishing a correlation between belt geometry and the performance of the restraint system.

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