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16. Abstract A series of 20-g decelerations of a crash sled was conducted to determine the magnitude of head impact decelerations while wearing various types of restraint equipment in small confined areas. Restraint webbing loads and head impact decelerations are presented for three directions of impact (straight forward, and 90° to left and right). Restraint webbing undoubtedly reduces head impact velocities, especially in the forward direction. However, this study shows that, in most instances, head strikes may be expected even while using upper and lower torso restraint because of the close proximity of surrounding structure in general aviation aircraft. Introduction of upper torso restraint along with lap belts in general aviation aircraft will not relieve the need for de-lethalizing surrounding structures.			
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EFFECTIVENESS OF RESTRAINT EQUIPMENT IN ENCLOSED AREAS

I. Introduction.

Numerous research scientists have investigated the effectiveness of various restraint devices during deceleration utilizing instrumented dummies, volunteer human subjects, and various primates.^{1 2 3 4 5 6 7 8} However, in all cases, tests were conducted with a seat mounted openly on a crash sled in such a manner as to allow freedom for kinematic motions in all directions, limited only by the restraint equipment being tested. Since man, as an operator of a vehicle, spends most of his time during transportation in a small enclosed area sitting next to rigid structure on his left, within 2 to 4 feet of structure on his right, and within 18 to 20 inches from rigid structure in front of him, this study was conducted to determine head impact forces on surrounding structures and body kinematics while wearing seven different designs of restraint equipment in an enclosed area. For economy reasons, sections of automobile bodies instead of aircraft fuselages were utilized in these tests. Decelerations were measured in the forward and in both lateral directions.

II. Test Equipment and Procedures.

Four automobile bodies (a 1961 Chevrolet, a 1961 Ford, a 1965 Mercury, and a 1965 Plymouth) sectioned just anterior to the firewall and just aft of the back of the front seat, were purchased from a local salvage yard and rigged for mounting on the CAMI crash sled. Sled impact velocity was programmed for approximately 29 miles/hour (42.53 ft./sec.) to produce a peak deceleration of 20 g's. Actual test results indicated a peak terminal sled velocity of 42.3 ± 1 ft./sec. and all impact tests with the exception of test runs Numbers 3 (17 g's) and 20 (23 g's) had peak decelerations of 20 g's. Photographic coverage of the event was provided to record both top and side views at 24, 400, and 2000 frames/second.

Three 250-g CEC Model 4-202-0001 strain gage accelerometers were mounted tri-axially in the head of an Alderson F-50 anthropometric dummy to measure forward, lateral, and vertical head impact decelerations. Belt load transducers manufactured in the CAMI machine shops were calibrated on a 5000-pound capacity Dillon dynamometer prior to test procedures. Output signals for the belt load transducers and accelerometers were recorded on a CEC Model 5-124A oscillographic recorder in conjunction with a Sanborn 550M signal conditioning system.

A total of 24 tests was conducted to evaluate the effectiveness of whole body restraint systems for head protection. Seven different types of restraint equipment were used for these tests in the forward and in both lateral test positions. For comparison, one test was made in each of the three directions with the dummy unrestrained. These seven different designs of restraint equipment are shown diagrammatically in Figures 2 through 8, 10 through 16, and 18 through 24. The restraint equipment tested consisted of (1) a single diagonal chest strap without seat belt (as used in some foreign cars) (Figure 2), (2) a single diagonal chest strap with a separate seat belt (as installed on over 10,000,000 late-model American cars) (Figure 3), (3) the so-called three-point restraint system—diagonal chest strap with lower end attached to one-half of the seat belt and upper end attached to the "B" post (Figure 4), (4) a three-point harness identical to that described above with the exception that the upper end of the chest strap goes over the shoulder and seat back and is attached to the floor structure behind the seat (Figure 5), (5) a double chest strap arrangement with the lower ends sewn to the lap belt, near the seat back and pan intersection, and the upper ends joined behind the neck to form a single strap which, in turn, passes over the seat back and attaches to the floor structure behind the seat (Figure 6), (6) a restraint system the

same as number 5 with the exception that the shoulder straps are crossed behind the neck and pass over the seat back to separate floor attachments (Figure 7), and (7) the Pacific Scientific quick-release harness in which shoulder straps and lap belts plug into a quick-release buckle. In these tests, the common upper torso strap passed over the seat back to a fixed floor attachment instead of going into an inertial reel (Figure 8).

III. Results.

Head impact forces with various structures and restraint webbing loadings, as well as vertical forces on the neck from centrifugal forces, along with time readings of each peak force occurrence from the time the crash sled began deceleration, are shown diagrammatically in Figures 1 through 24.

Forward Decelerations: Figure 1 demonstrates, as other researchers have shown repeatedly, that the unrestrained human body slides forward in an erect sitting posture until the knees contact the lower instrument panel, at which time the upper torso flexes forward into the windshield and/or control column. In the case depicted, the head penetrated the windshield (1965 Plymouth) at about the same time that the neck contacted the upper steering wheel rim.

In studying Figures 2 through 8, the following observations are made:

All harness configurations allowed the driver's head to impact the steering wheel rim and/or hub.

Deceleration impact force was proportional to the length of shoulder strap webbing in designs anchored to the "B" post and roof structure; i.e., the longer the webbing, the greater the impact force with increase in stretch distance.

In designs where shoulder straps traversed the top of the seat and anchored to the floor structure behind the seat, head impact force varied with yield characteristics of the seat back structure—the top of the seat flexed forward 6 to 8 inches.

Head impact force with steering structures varied between 45 and 107 g's (forward and lateral head forces were vectored since there was usually some degree of head rotation). These

forces could be tolerated without serious injury on well-designed structures, but would cause serious facial fractures and head injuries in most current transportation vehicles.

A vertical peak force of 20 to 40 g's was recorded in all forward deceleration tests and, since this peak force occurred approximately 0.02 seconds before head impact, it may be assumed that the stress resulted from centrifugal force, producing considerable stretching of the neck along the radius of motion.

In general, as would be expected, the fewer the number of straps restraining the body, the higher the webbing loads. For example, when only a single upper torso strap was used without a seat belt (Figure 2), the total strap load exceeded 2200 pounds and would have been higher, but lack of a seat belt allowed the knees to impact the lower dash panel, taking some of the deceleration load off of the chest strap. With the body totally restrained by using both chest strap or straps and lap belt, total strap loading was approximately 3000 pounds. Attaching shoulder straps to the lap belt as in Figures 4, 5, 6 and 7 substantially increases (nearly doubles) the strap loading on that portion of the lap belt that serves as a common attachment for both a shoulder strap and a portion of the seat belt.

Lateral Impact—Occupants thrown to the left: In comparing Figures 10 through 16 with that of the unrestrained dummy in Figure 9, it is clear that none of the seven different restraint systems offers any appreciable protection against head impact in this direction (as attested to by low readings on the restraint webbing) since the occupant is seated in such close proximity to side structures on his left. The following observations are, however, worthy of note:

a. Impact of the side of the head may occur against the "B" post or against the door glass, depending on slight variations in the angle of impact. Head impact against the "B" post in this study ranged from 110 g's to 158 g's; these levels would probably be fatal since the loads were concentrated on such a small area of the head due to rigid, nonyielding construction of the post. Head impact forces to break the door glass were 100 and 122 g's for pre-1965 laminated glass as compared with only 44 and 60 g's for tempered glass used in 1965 and later-model vehicles. According to Lissner,⁹ none of these

forces against yielding glass is sufficient to produce skull fracture.

b. As shown in Figure 10, the lap belt is an absolute necessity in this type of impact to prevent ejection. Use of the single shoulder strap without a seat belt in Figure 10 allowed the buttocks to be ejected out the door, and permitted the strap to catch under the chin, putting an 800-pound load on the webbing. In such situations, the body slides down the strap and a knife-action is produced on the neck which has been reported to decapitate the occupant.¹⁰

c. In Figures 14 and 15 (double shoulder straps), it will be noted that the strap forces are considerably higher, especially on the strap over the left shoulder. A double shoulder strap system running *through* a strong integrated seat could offer considerable protection against left side impacts.

20-g Right Side Impact: In the unrestrained test, the dummy (Figure 17) slid across the seat in a sitting position in less than 0.3 seconds and the right side of its head impacted on the right "B" post with a force of 150 g's. Body impact caused the door to open and the dummy was ejected.

In all instances of single strap restraint over the left shoulder, the upper torso slipped sideways out of the shoulder strap and the body folded to the right, over the seat belt, with the head striking the seat cushion (Figures 18, 19, 20 and 21). These lateral head impacts with the seat cushion, varying between 20 and 50 g's, are insignificant; however, lap belt loads between 1675 and 2550 pounds cutting into the side of the abdomen would probably cause some internal injuries.

Double strap shoulder restraint over the seat back in conjunction with a seat belt allowed some lateral motion of the trunk, but held it almost upright (Figures 22, 23 and 24). In these tests the side of the head hit the top of the seat back with insignificant forces varying from 49 to 73 g's and abdominal loads from seat belts were significantly reduced (975 to 1925 lbs.).

IV. Discussion.

Caution should be used when the results of the cinematics of the body along with head impact forces presented in this study are applied to gen-

eral aviation aircraft because of the difference of internal measurements of the occupant spaces. The front seat of an automobile is approximately 5 feet wide, while that of popular general aviation aircraft varies from 3 to 4 feet, with a large majority of seats only about 3.5 feet wide. A previous study¹¹ has shown a side displacement of the head from the centerline of the body (in the sitting position, with seat belt restraint) in excess of 36 inches during application of a one-g force. Since the centerline of the body is approximately 12 inches from the left side of the aircraft, only 2 to 2½ feet of clearance are available to the right side for prevention of head impact with side structures. Hence, the kinematic motions allowed to the right side (without head impact) with the types of restraint equipment shown in Figures 18 through 21 would be expected to allow head impact with the right side of the cabin in most general aviation aircraft. Only the double shoulder strap designs shown in Figures 22 through 24 sufficiently restrained side motions of the body to protect the head in small aircraft.

In the forward deceleration tests, the maximum motion of the head was approximately 14 inches in the horizontal plane and 14 inches in the vertical plane. This compares favorably with Chandler's study¹² of human subjects in which he reports a forward horizontal motion of the head of 1.03 feet during a 12-g deceleration. Young¹³ has reported 22 to 24 inches of horizontal displacement of a dummy's head with a vertical drop of 16 to 18 inches, while the dummy was restrained by a single strap shoulder harness during decelerations from velocities between 40.6 and 41.3 feet/second. In the same report¹³ he showed that double shoulder strap harnesses restrict the forward motion of the head to a range of 10 to 18 inches and the vertical motion to 16 to 20 inches. It is probable, therefore, that forward head motions in the tests presented in this report were limited by impact with the steering assembly and that, when these measurements are corrected and applied to general aviation aircraft, occupants of the front seat can be expected to experience head impact with the upper instrument panel and control wheel, even while wearing shoulder harness restraint, if they are exposed to decelerations of the magnitude tested in these studies.

V. Conclusions and Recommendations.

As demonstrated by the test dummy, restraint of the human body by the use of belts during crash decelerations is difficult. In the small cockpit area of general aviation aircraft, a single diagonal chest strap used in conjunction with a lap belt may reduce, but will not prevent, head impacts during forward and side decelerations. A double shoulder strap-lap belt design of restraint equipment can further reduce crash injuries, especially in crashes involving decelera-

tion forces which will throw the pilot to the right side of the cockpit, provided that it is designed as an integral part of a strong seat or fastened to a strong aircraft structure near the seat. The findings given in this report indicate that even with the upper torso and lap belt restraints, front seat occupants will suffer injuries from forward and side crash impact forces under the acceleration conditions of the test; therefore, engineers should stress design of structures in the cockpit area to minimize injuries from head impact.

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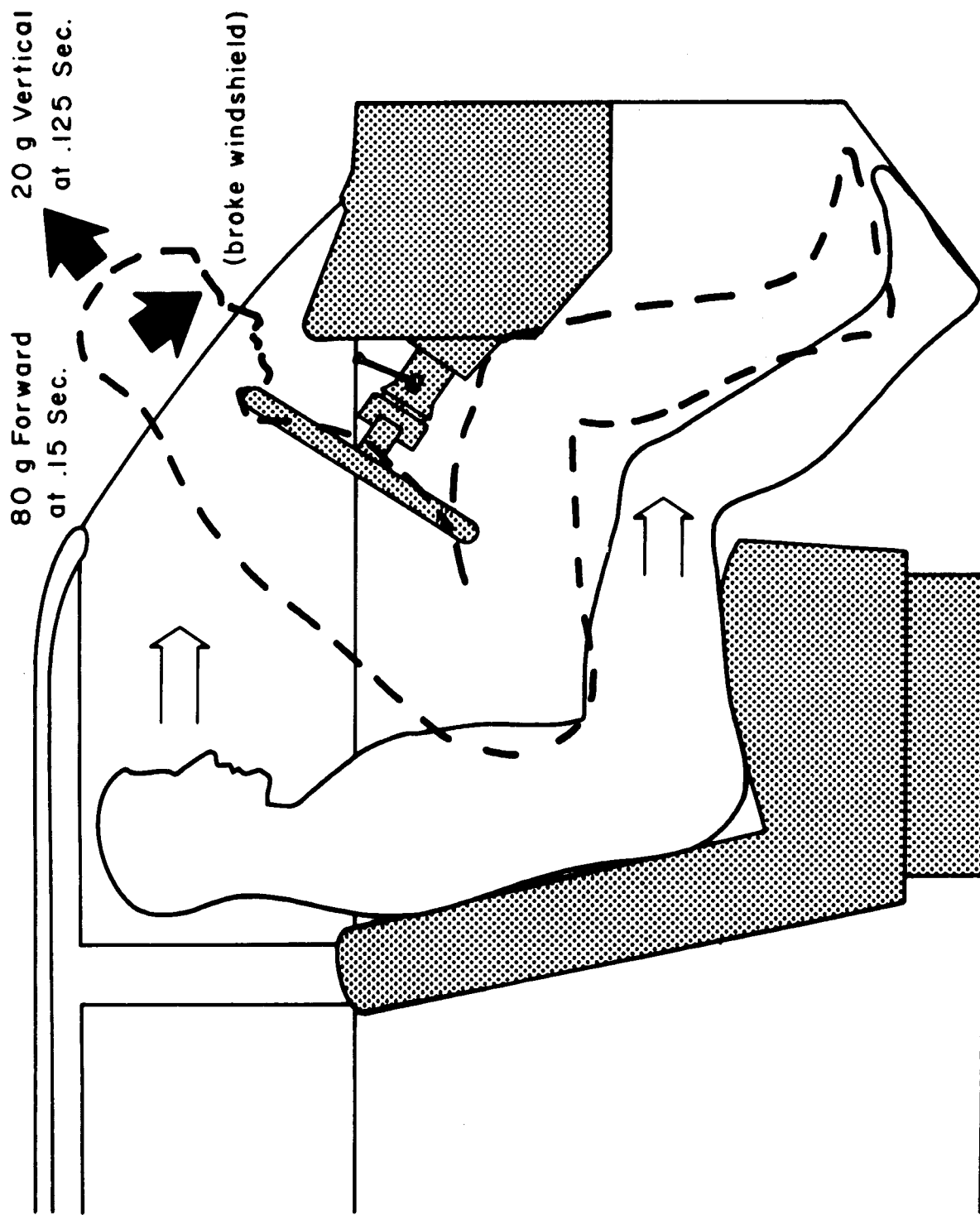


FIGURE 1. Dummy unrestrained, forward deceleration.

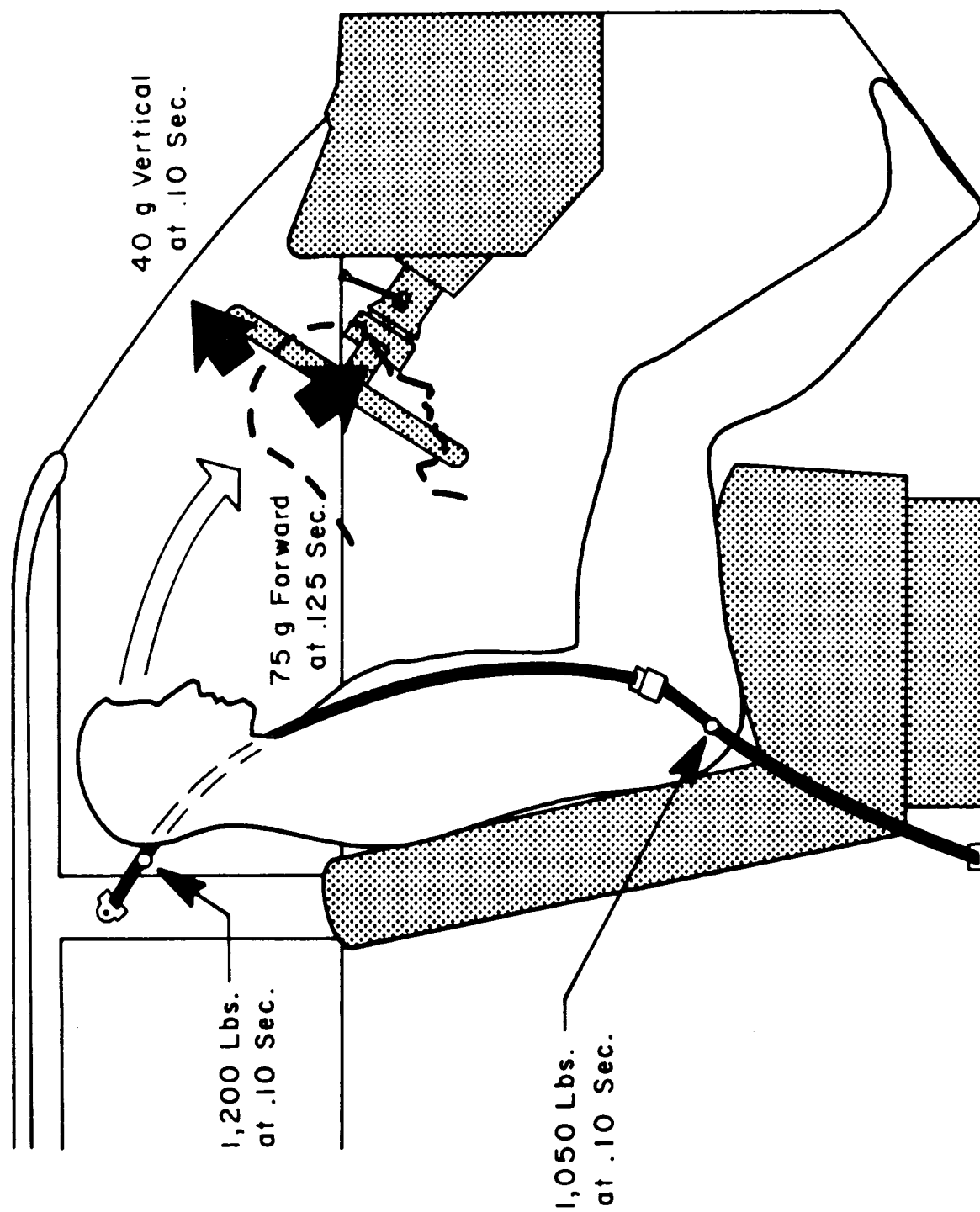


Figure 2. Dummy restrained by single diagonal chest strap, no seat belt, forward deceleration.

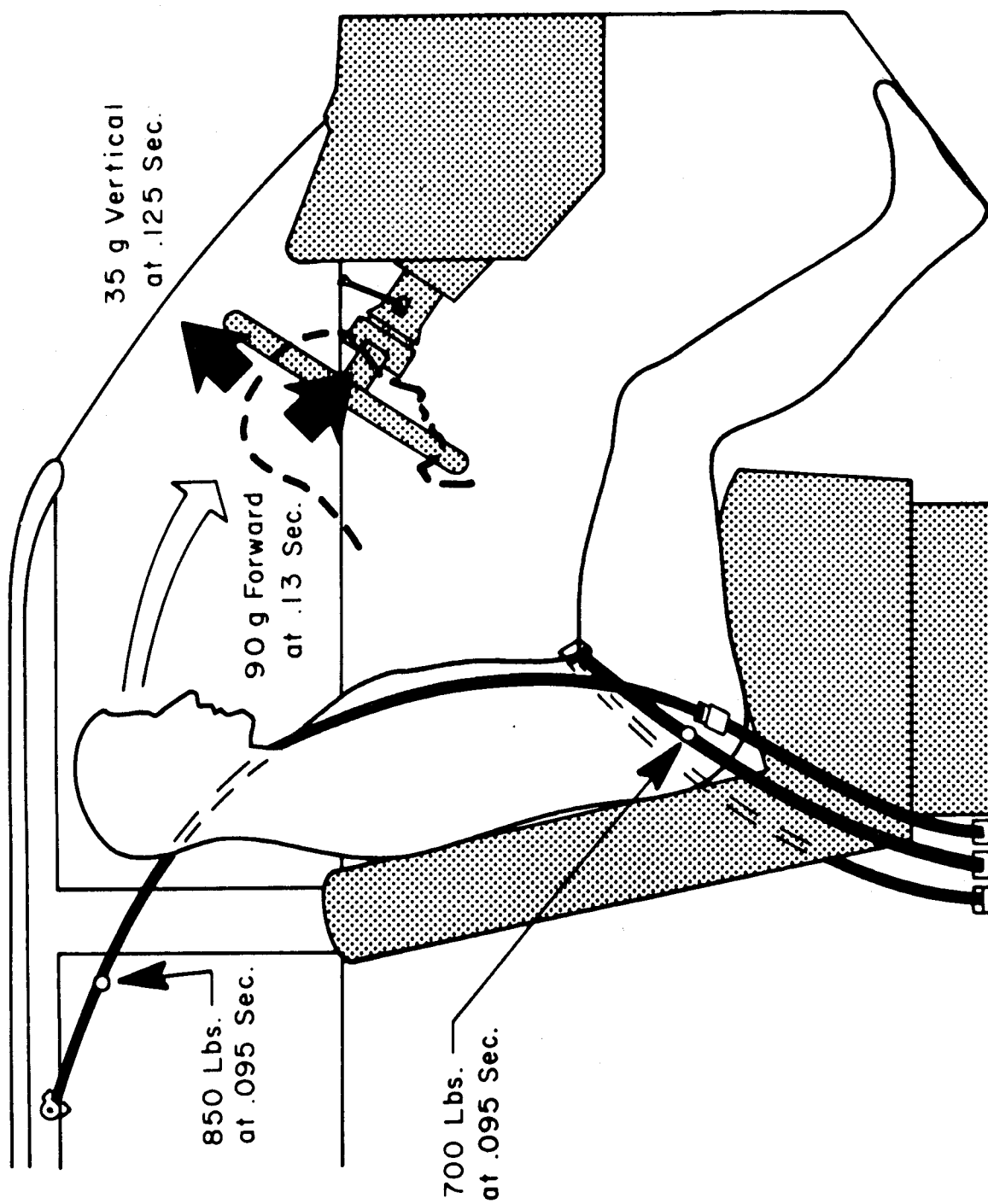


FIGURE 3. Single diagonal chest strap and a separate seat belt, forward deceleration.

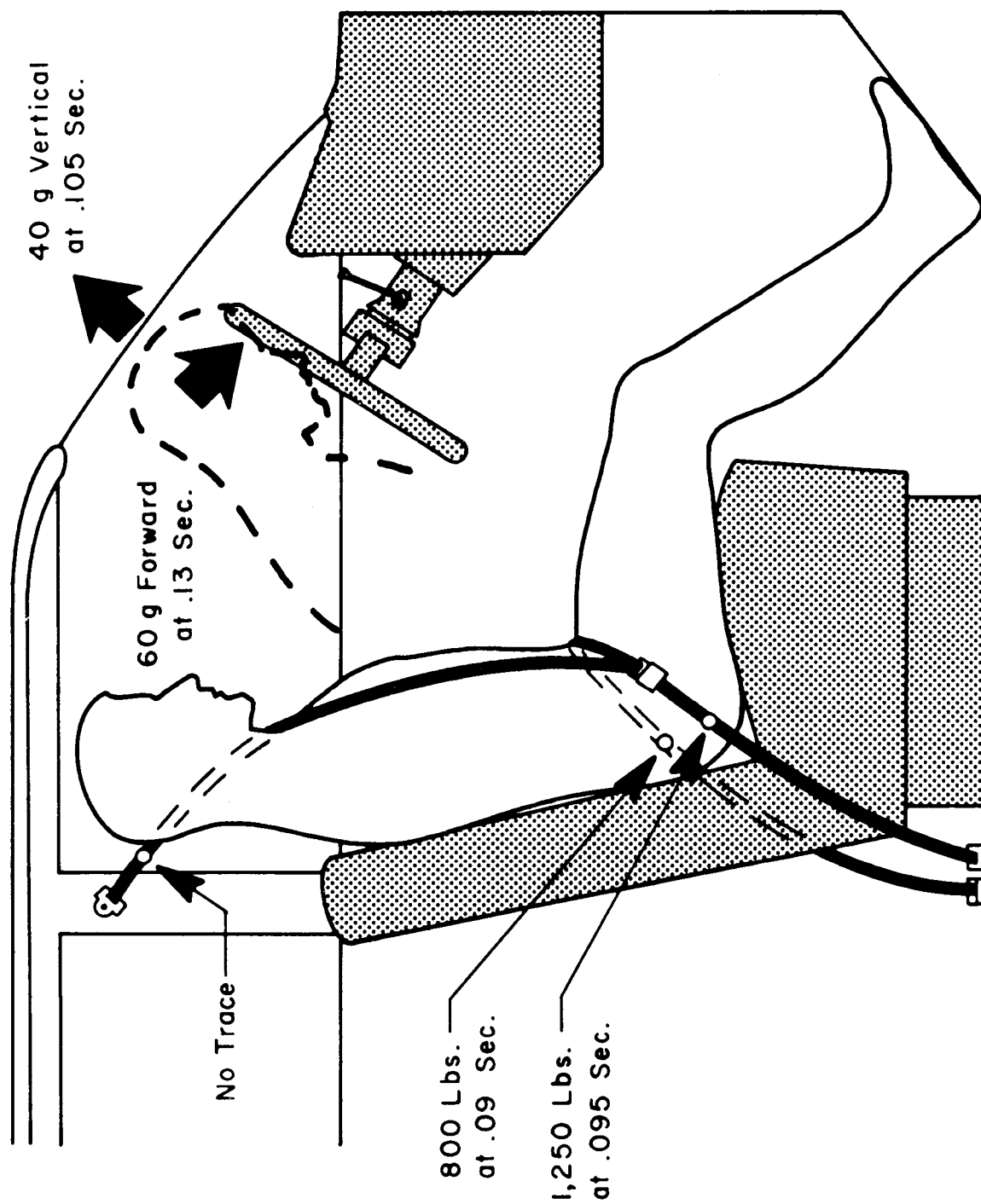


FIGURE 4. Three-point restraint system (diagonal chest strap with lower end attached to one-half of the seat belt and upper end attached to the "B" post), forward deceleration.

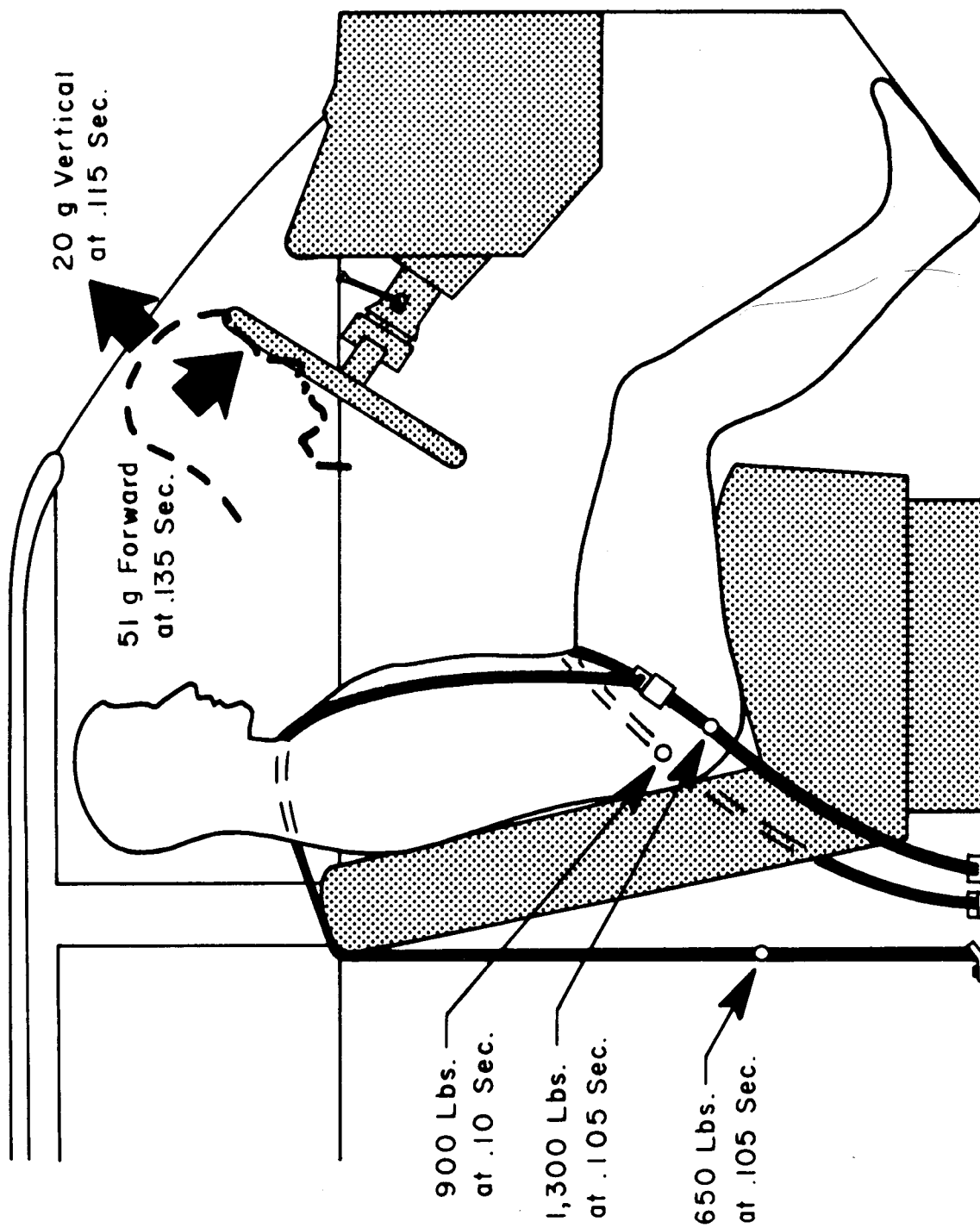


FIGURE 5. Three-point restraint system with chest strap going over seat back and anchored to the floor behind the seat, forward deceleration.

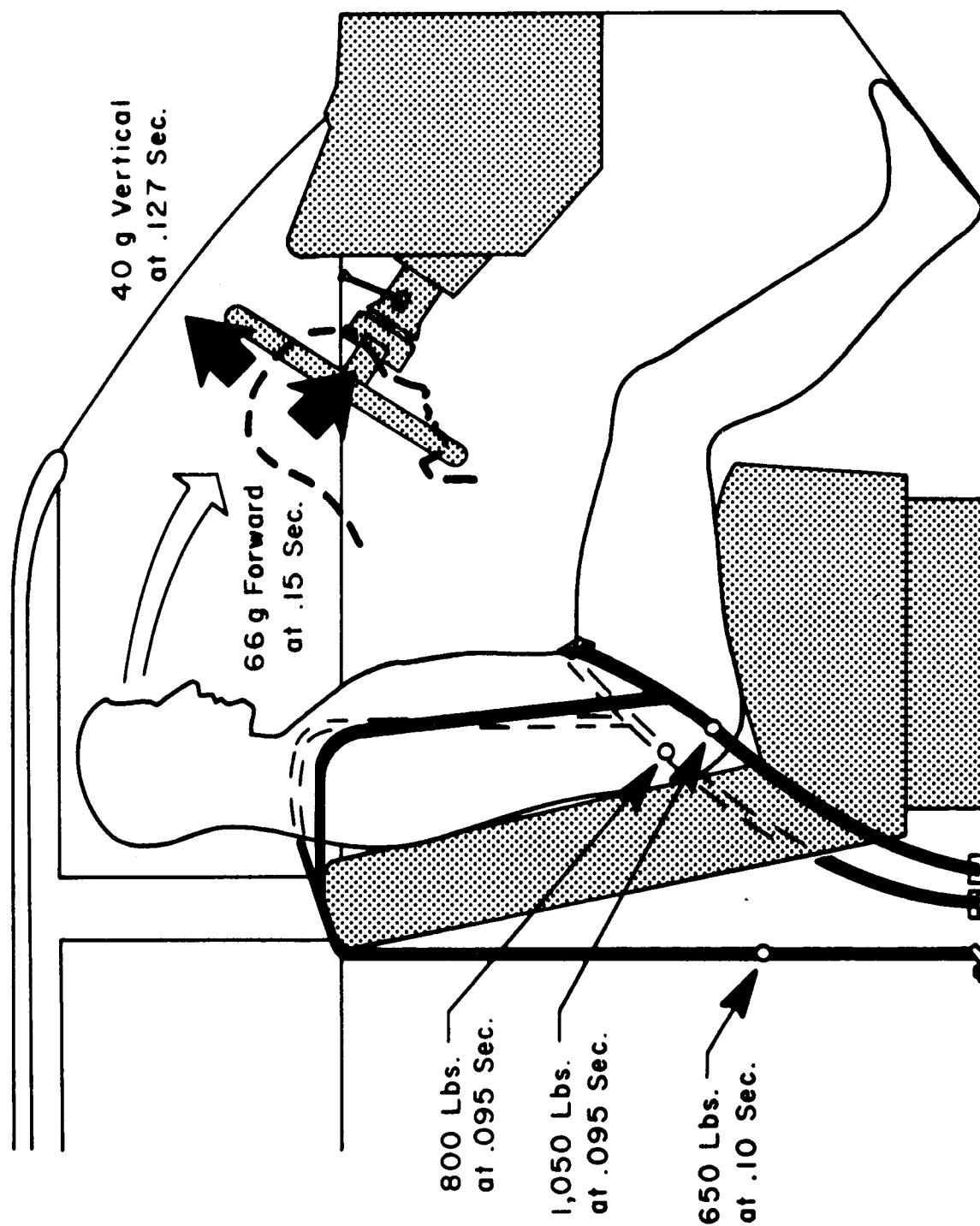


FIGURE 6. Double chest strap with lower ends sewn to lap belt near the seat intersection and upper ends joined behind the neck to form a single strap which, in turn, passes over the seat back to a floor attachment, forward deceleration.

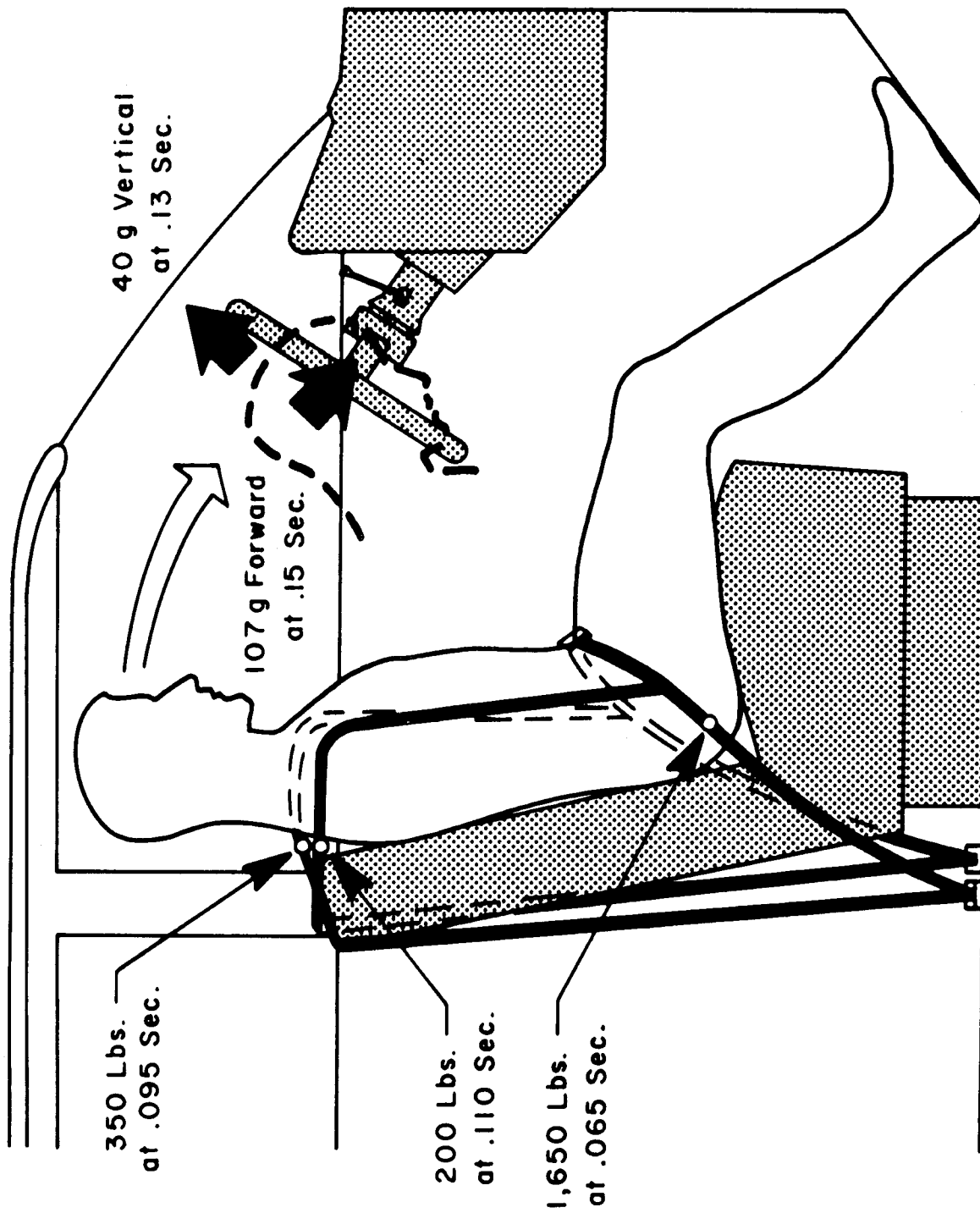


FIGURE 7. Double chest straps sewn to seat belt, crossed behind seat, and extending to separate floor attachments, forward deceleration.

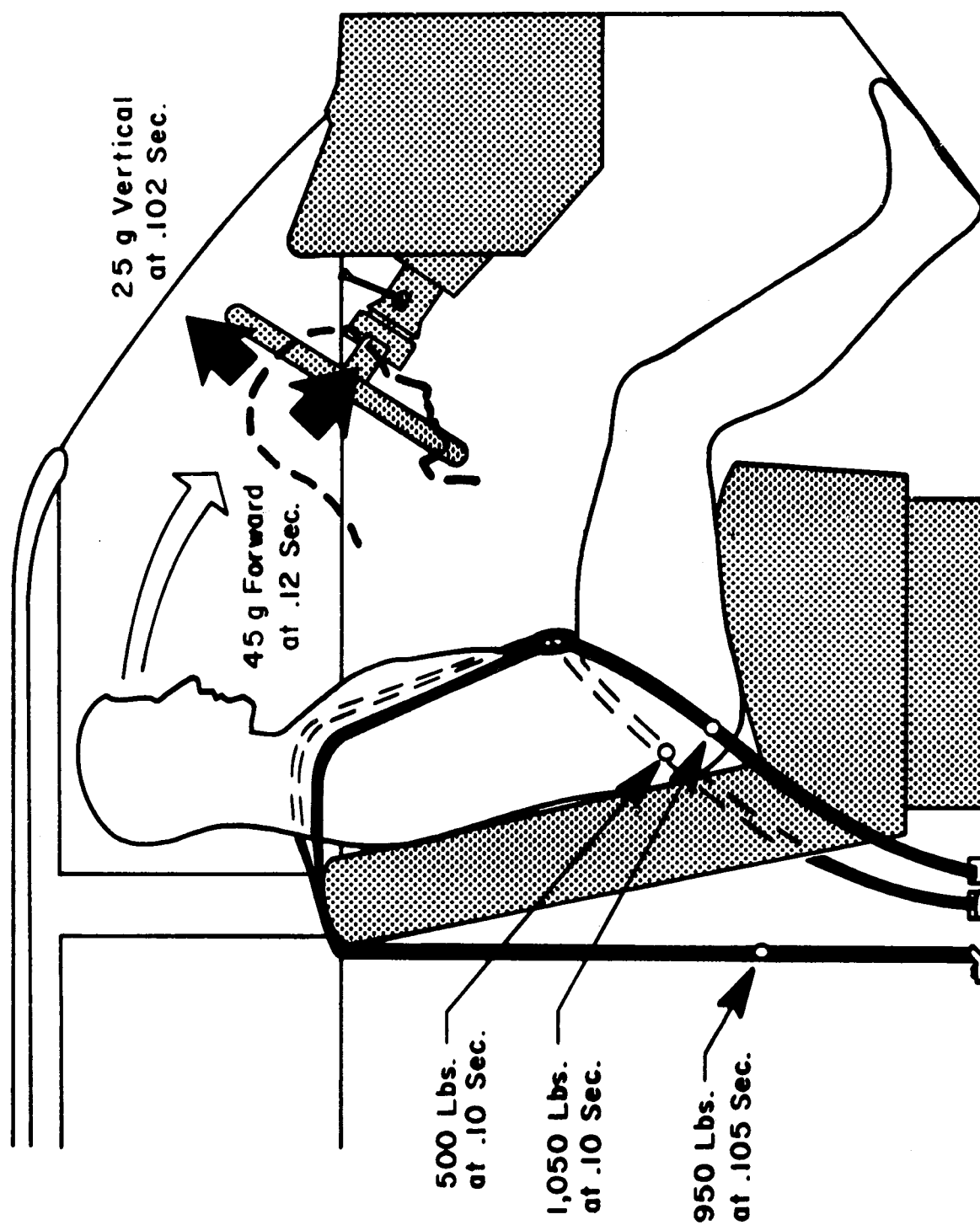


FIGURE 8. Pacific Scientific quick-release restraint equipment. Double chest straps converge to one behind the neck and attach to floor structure behind the seat, forward deceleration.

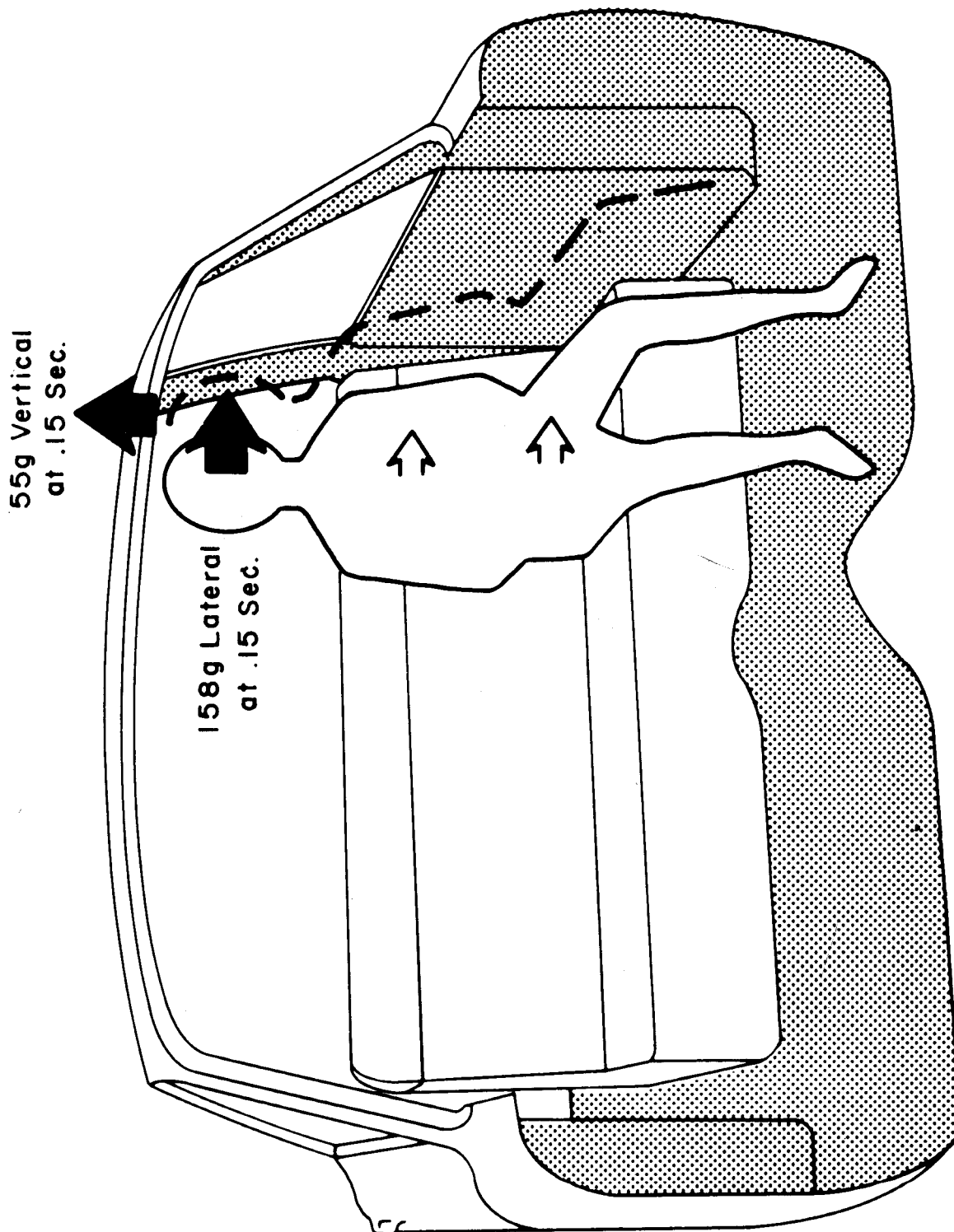


FIGURE 9. Dummy unrestrained, left side impact.

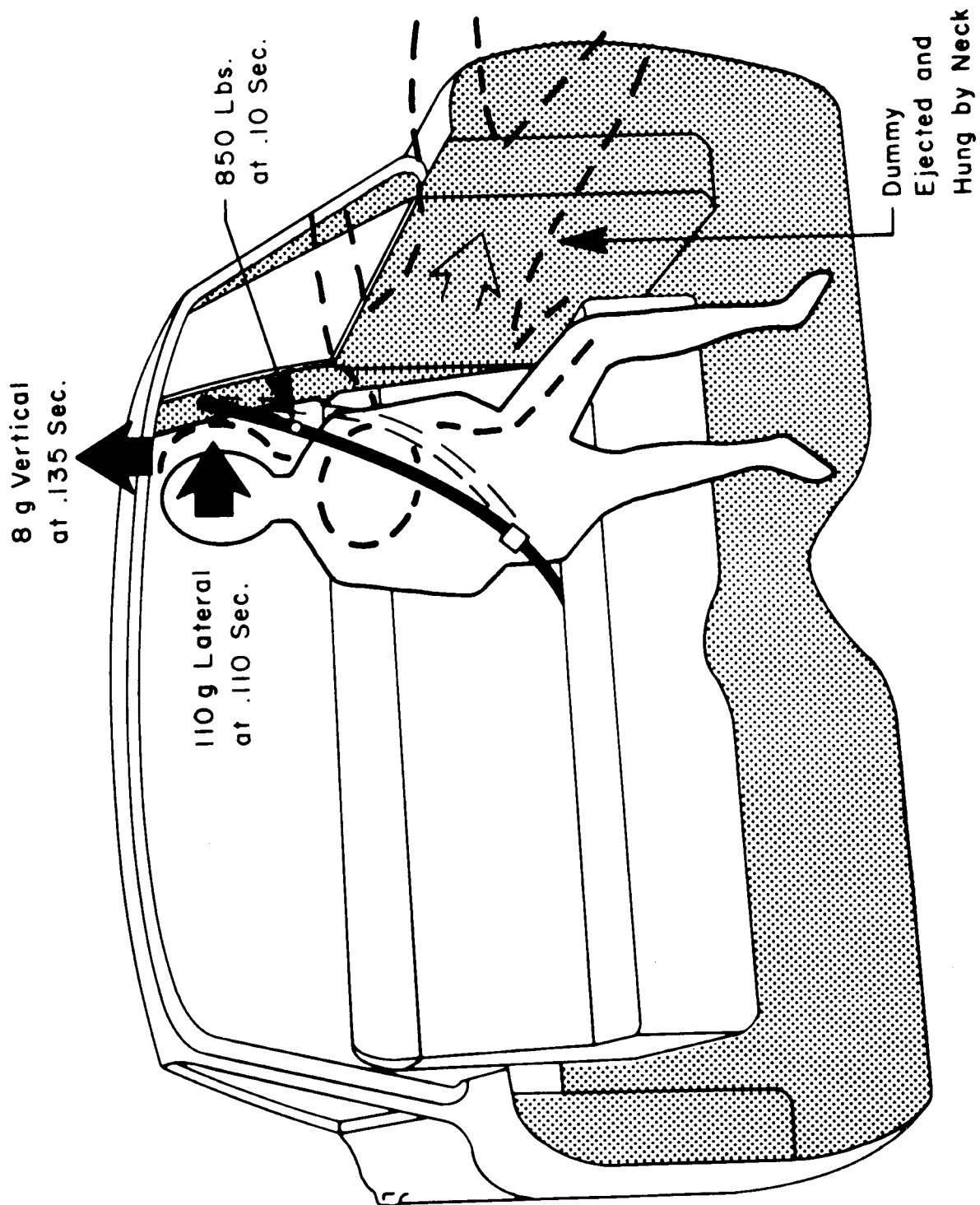


FIGURE 10. Dummy restrained by single diagonal chest strap, no seat belt, left side impact.

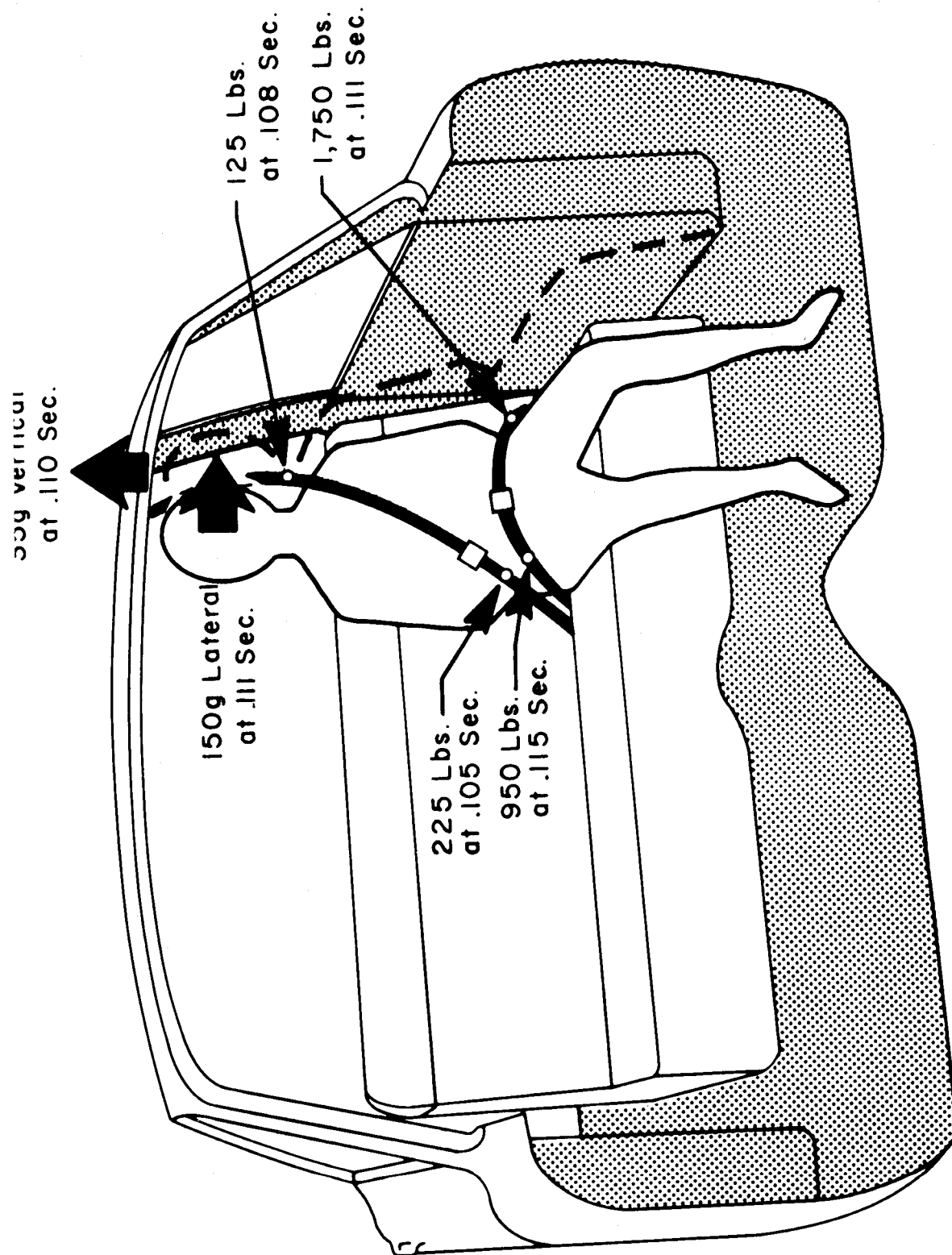


FIGURE 11. Single diagonal chest strap and a separate seat belt, left side impact.

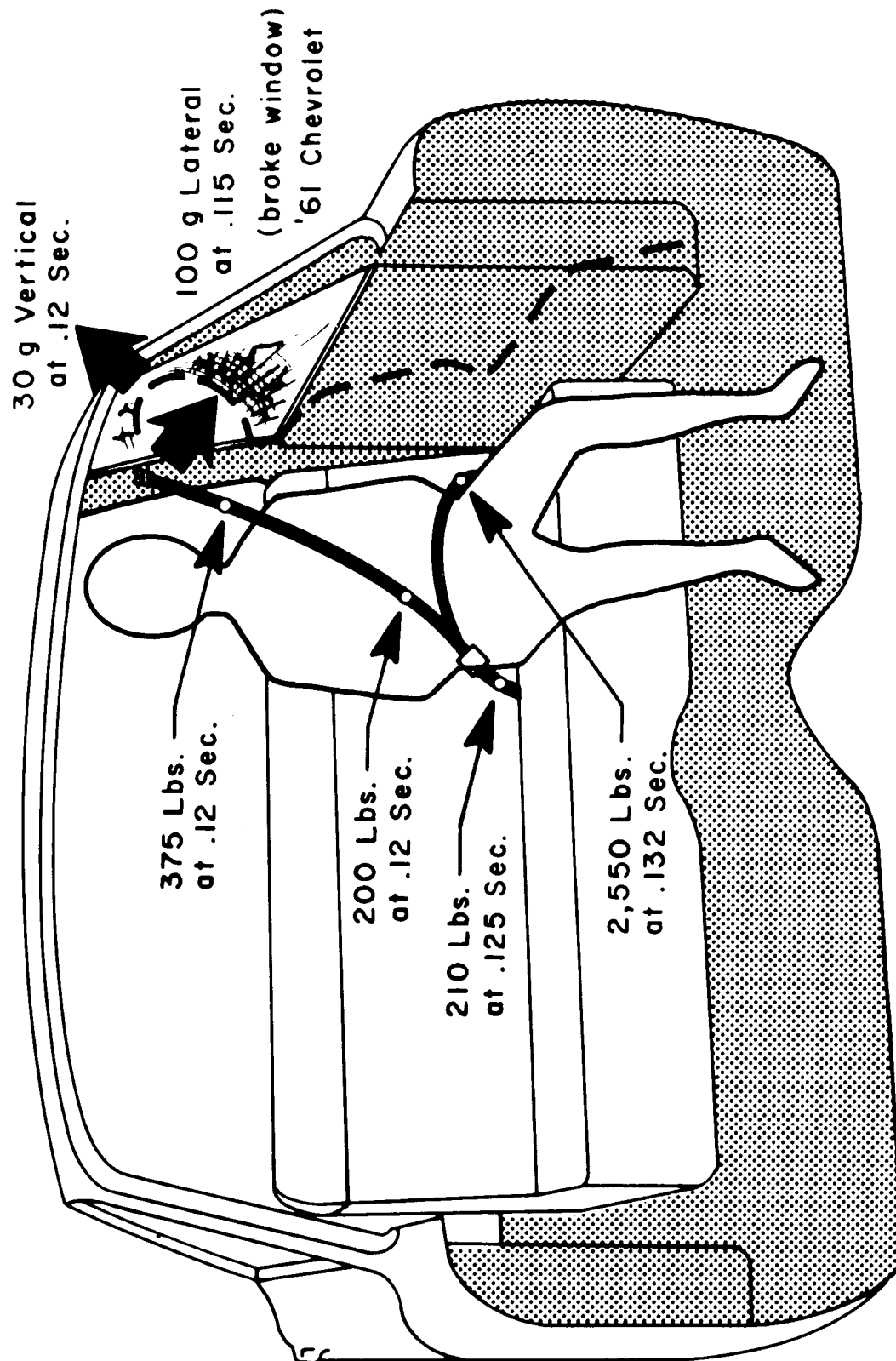


FIGURE 12. Three-point restraint system (diagonal chest strap with lower end attached to one-half of the seat belt and upper end attached to the "B" anchor) left side, front

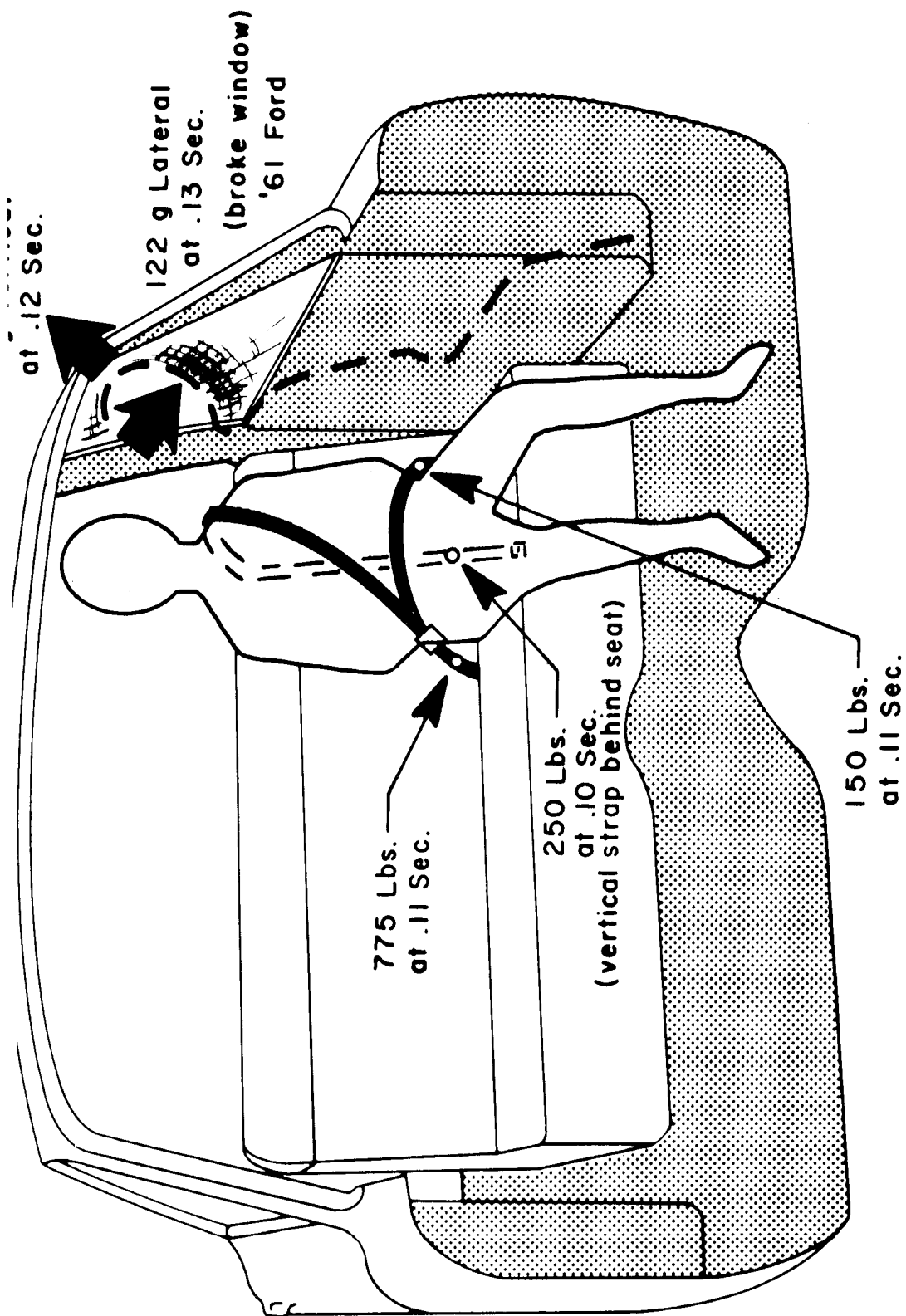


FIGURE 13. Three-point restraint system with chest strap going over seat back and anchored to the floor behind the seat, left side impact.

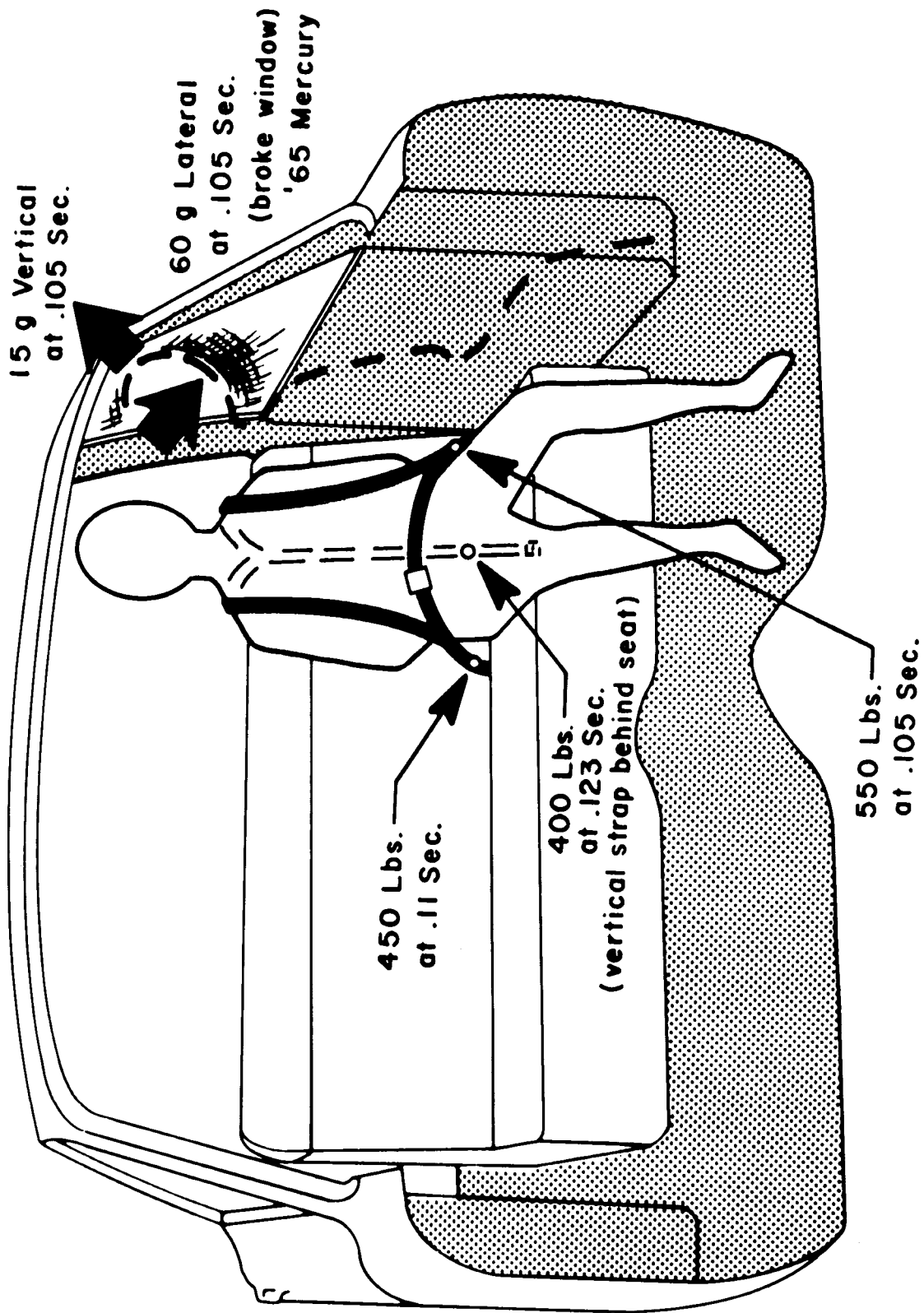


FIGURE 14. Double chest strap with lower ends sewn to lap belt near the seat intersection and upper ends joined behind the neck to form a single strap. The seat back to a floor attachment left side impact.

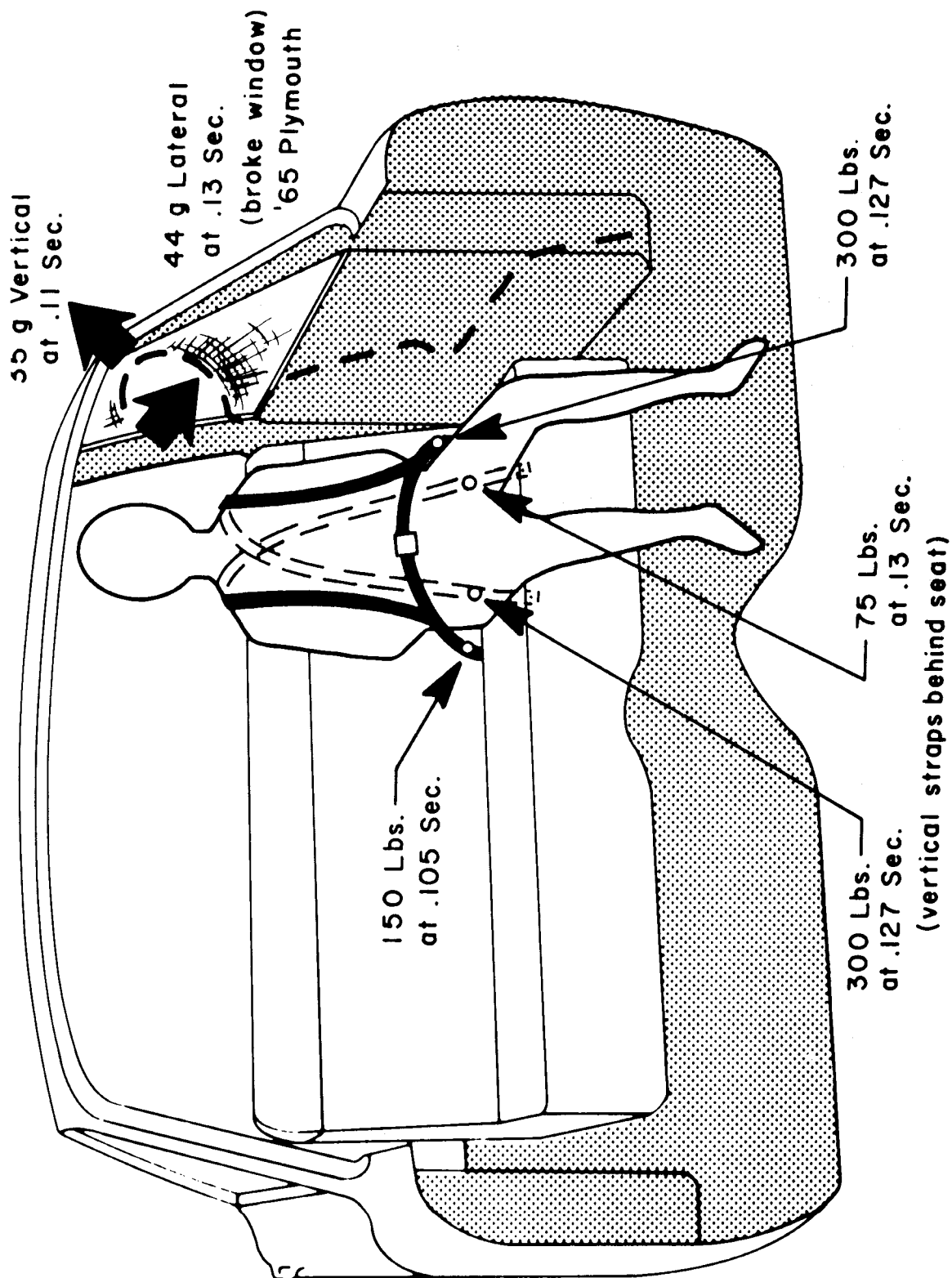


FIGURE 15. Double chest straps sewn to seat belt, crossed behind seat and extending to separate floor attachments, left side impact.

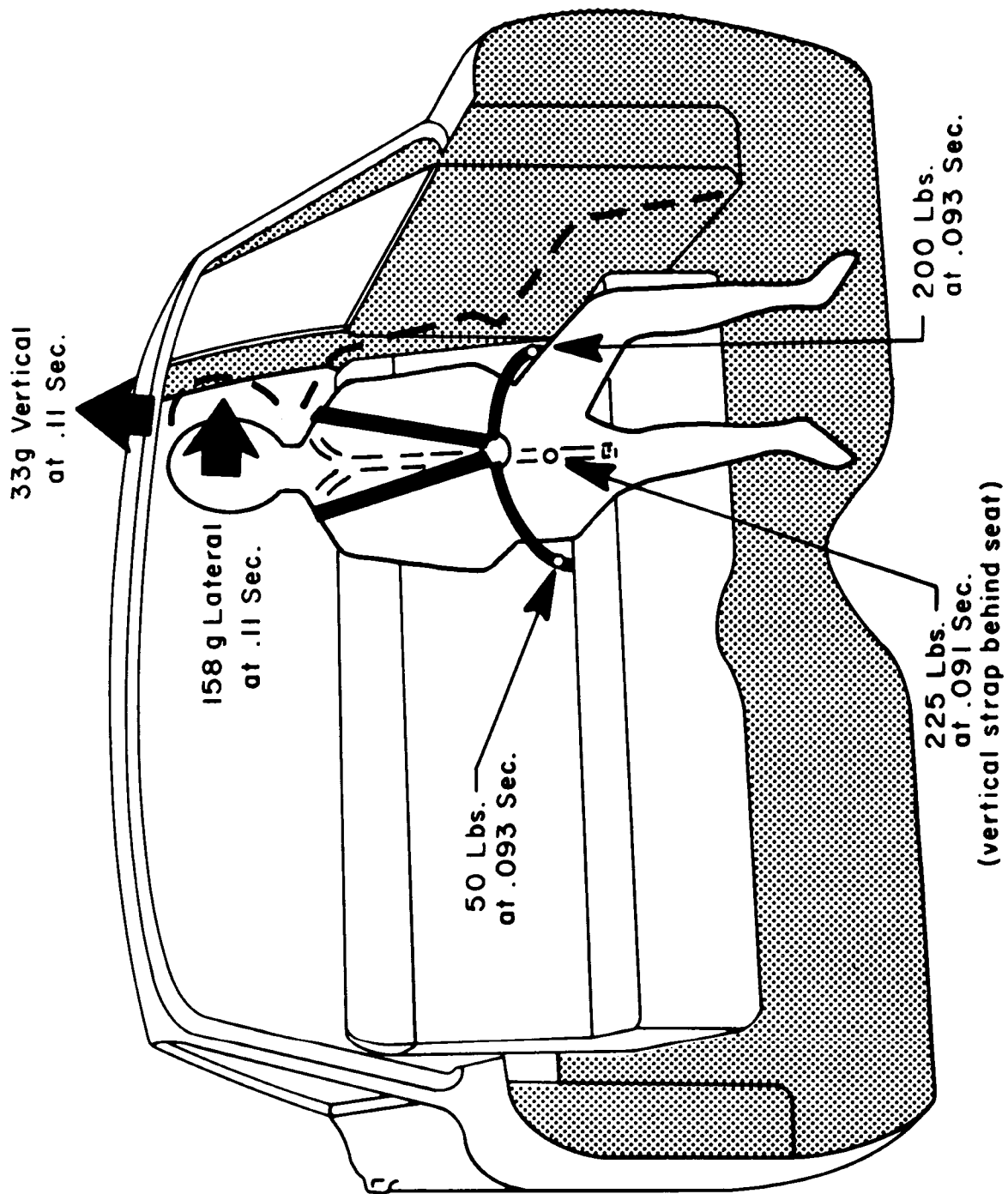


FIGURE 16. Pacific Scientific quick-release restraint equipment. Double chest straps converge to one behind the neck and attach to floor structure behind the seat left side inboard.

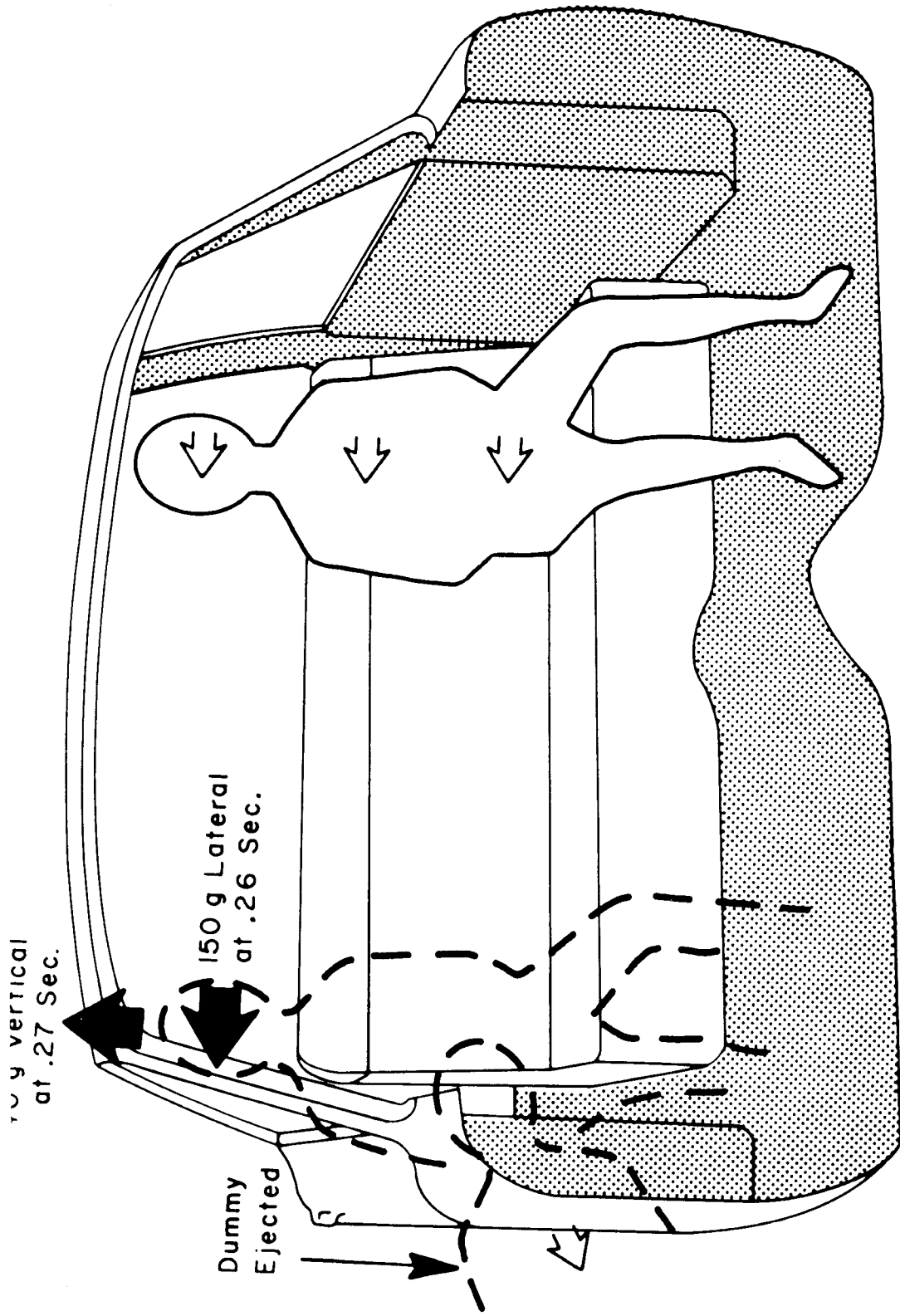


FIGURE 17. Dummy unrestrained, right side impact.

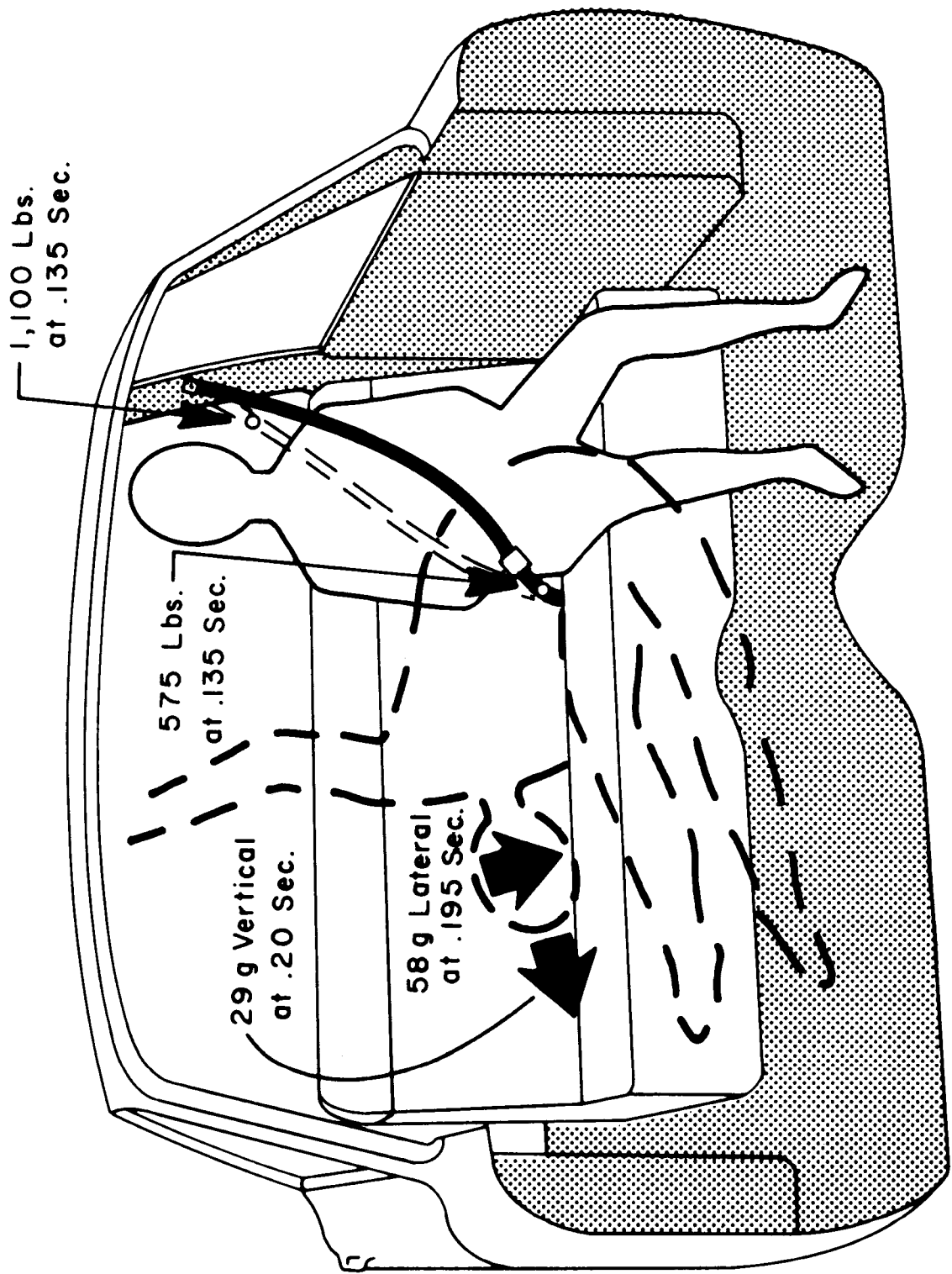


FIGURE 10. Forces sustained by sinola diagonal chest strap, no seat belt, right side impact.

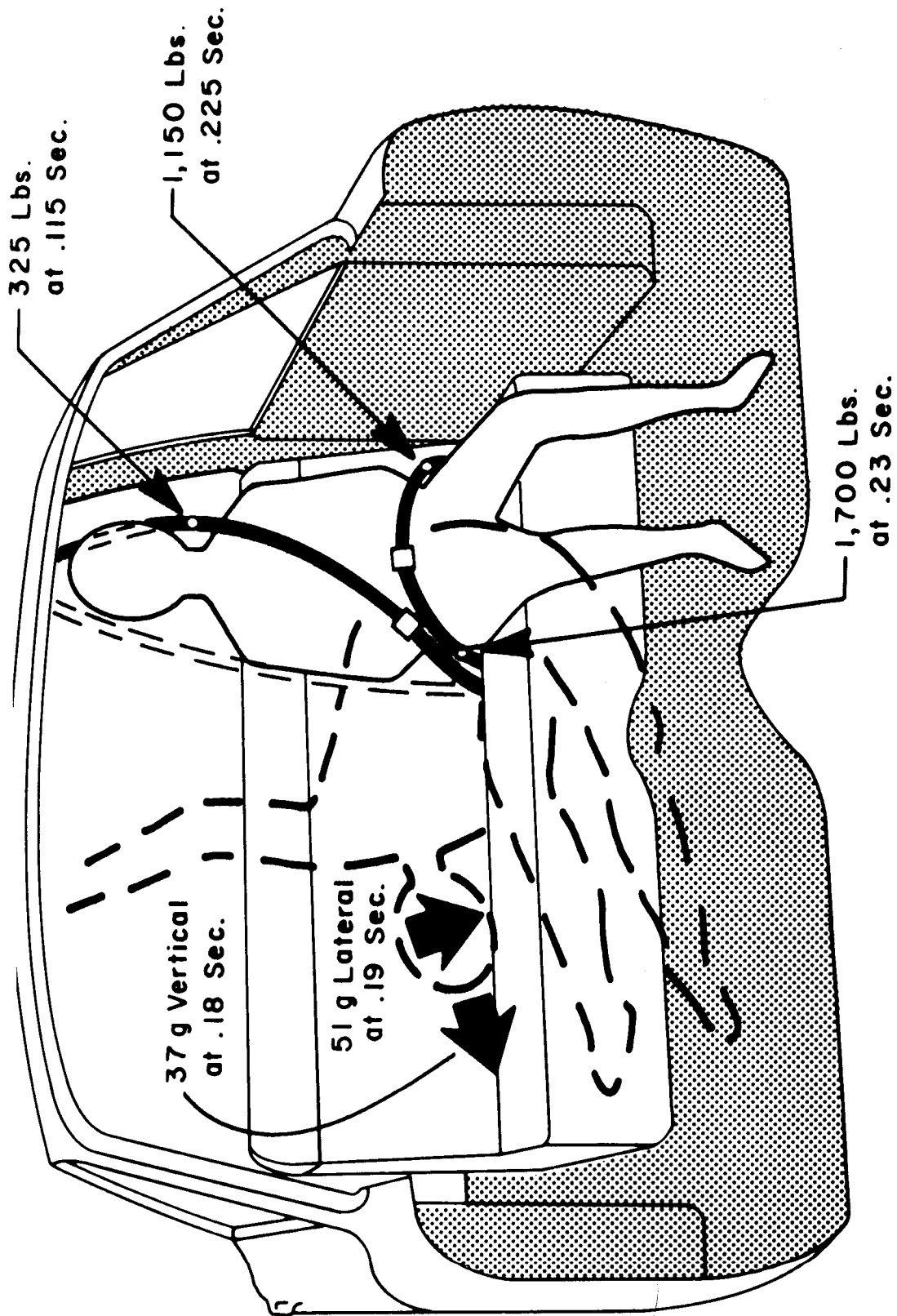


FIGURE 19. Single diagonal chest strap and a separate seat belt, right side impact.

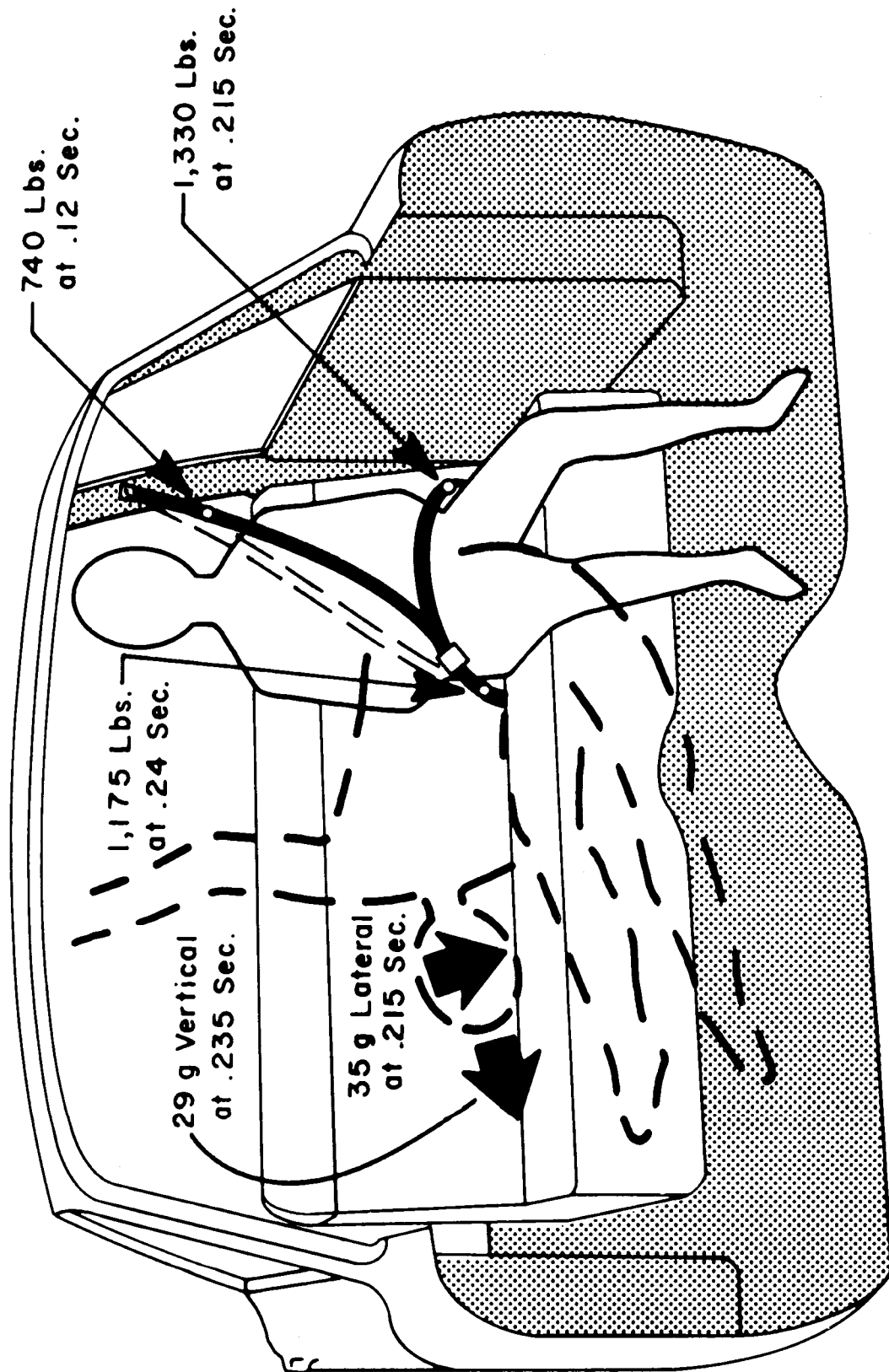


FIGURE 20. Three-point restraint system (diagonal chest strap with lower end attached to one-half of the seat belt and upper end attached to the "B" post), right side impact.

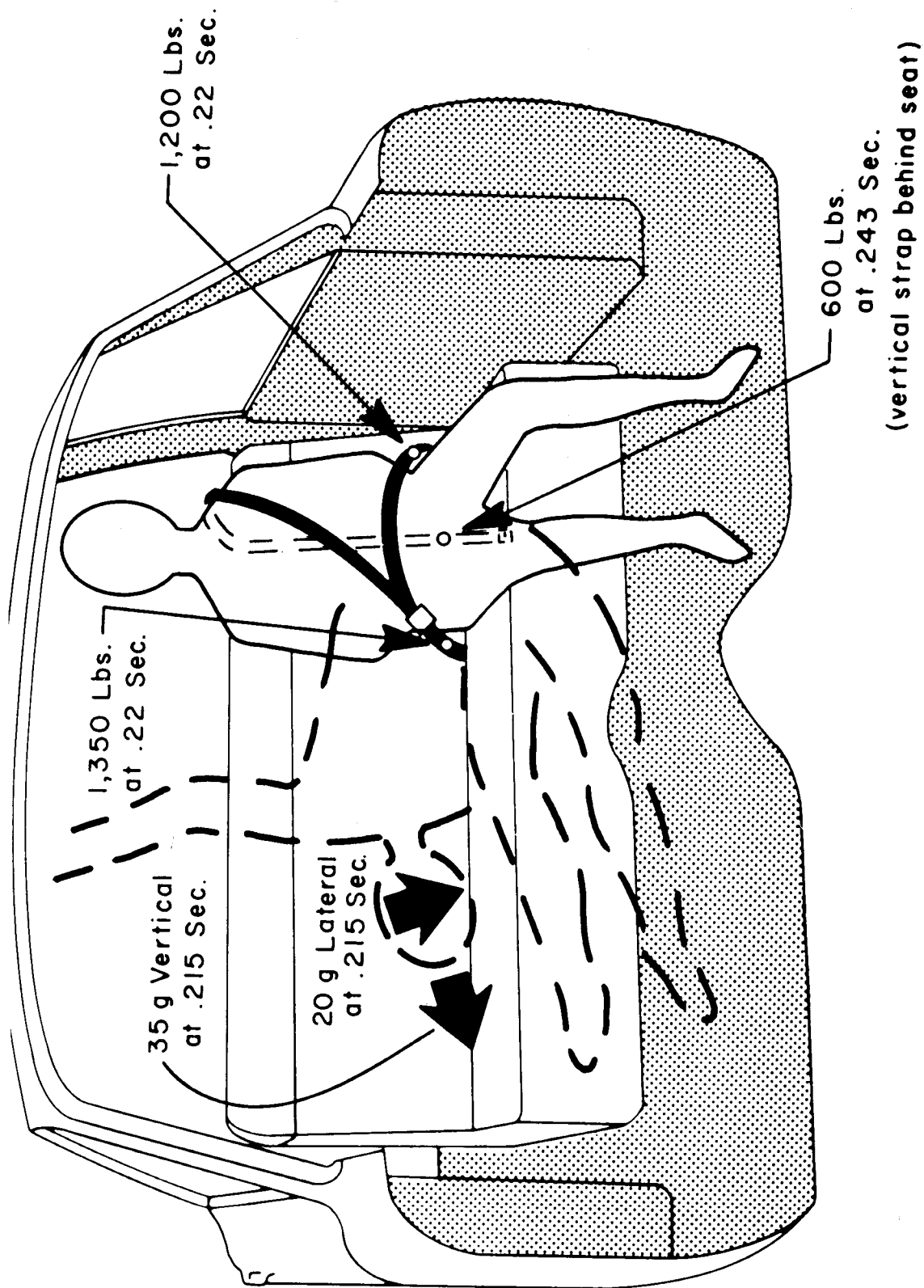


FIGURE 21. Three-point restraint system with chest strap going over seat back and anchored to the floor behind the seat, right side impact.

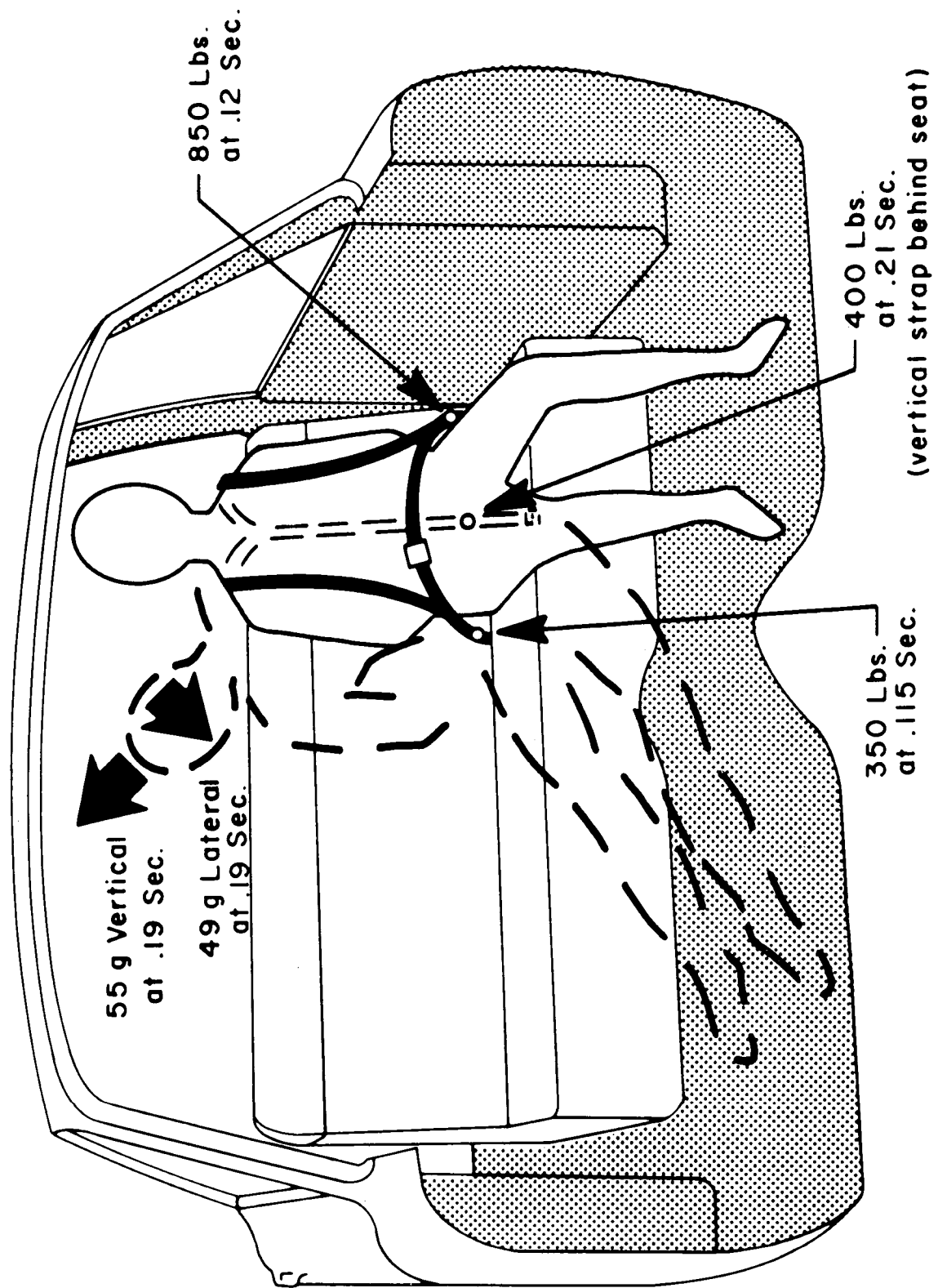


FIGURE 22. Double chest strap with lower ends sewn to lap belt near the seat intersection and upper ends joined behind the neck to form a single strap as the seat back to a floor attachment right side impact.

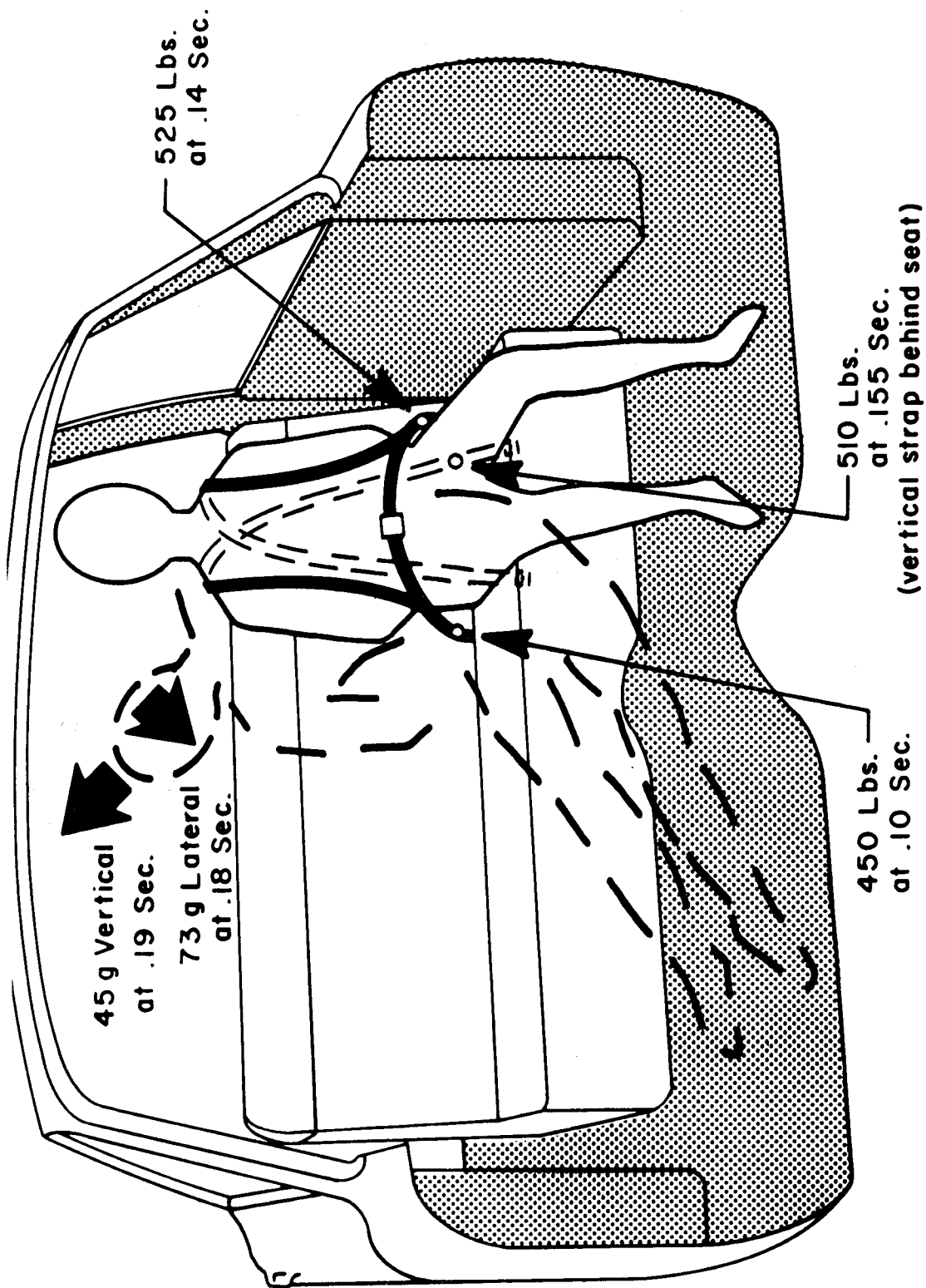


FIGURE 23. Double chest straps sewn to seat belt, crossed behind seat and extending to separate floor attachments, right side impact.

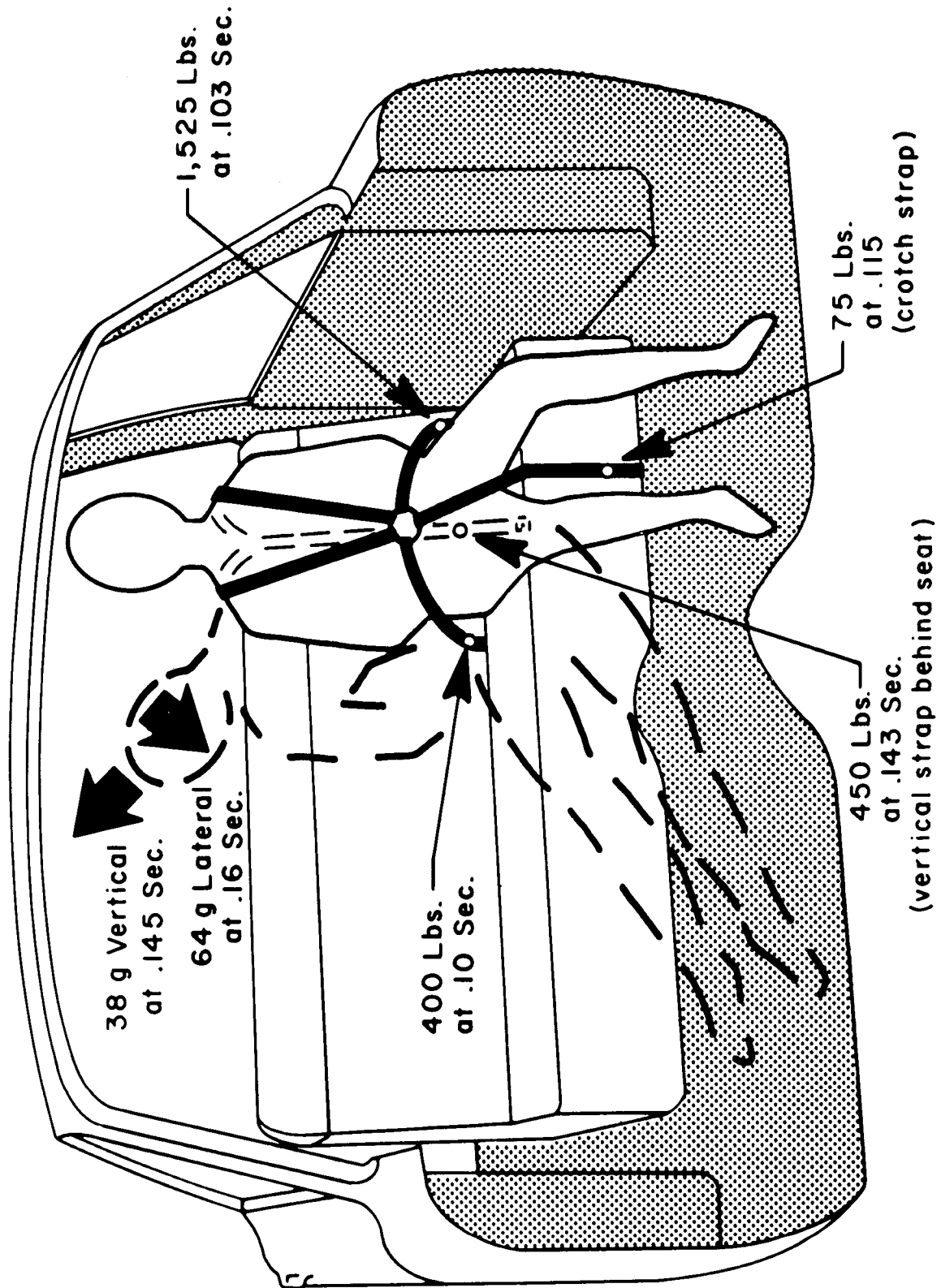


FIGURE 24. Pacific Scientific quick-release restraint equipment. Double chest straps converge to one behind the neck and attach to floor structure behind