RAPID-DECELERATION TESTS of CHEST-LEVEL SAFETY BELT

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SYNOPSIS

This paper presents the engineering and safety aspects in the development, method of mounting, and testing of an automobile safety belt and attachments. Thirteen individual tests were made under controlled conditions in the field. In the series of tests, the automobile and driver were decelerated at rates up to approximately 3.5 G.

Under ideal conditions a vehicle cannot be decelerated at a rate faster than about 0.9 G and passengers are exposed to the danger of at least minor injuries at even lesser rates. On the basis of measurements on nontelescoped sections, it is known that in a headon collision between two cars, each traveling at 35 to 40 mph., average decelerations of around 16 G's are produced. In such accidents the driver, and especially passengers, are subjected to considerably higher decelerations. In the simulated collision decelerations described in this report, the driver of the test car was uninjured in any of the 13 trials.

On the basis of these tests, it is indicated that if properly designed safety belts are installed and used in automobiles, a substantial reduction in both the frequency and severity of injuries to car occupants can be effected.

THE purpose of this research was to secure sufficient data to substantiate, or possibly render invalid, the hypothesis that rapid decelerations encountered in automobile collision need not, in many cases, result in death or even serious injury to the motorist, but rather, in no injury whatever, if the motorist is so protected that he is decelerated with, and at substantially the same rate as, the intact portion of the crashing vehicle in which he is riding.

Of the many conceivable protective devices, the type which acted as a restraining barrier, preventing the accident victim from striking the windshield, dash-panel, or other parts of the car, seemed to be most worthy of experimentation. An automobile safety belt possessing the desired quality was, therefore, built into a test car (Fig. 1).

The deceleration equipment consisted of a Navy aircraft tailhook secured to the rear of the test car and four suitably connected 1-ton reinforced-concrete sled-type blocks.

The tests were performed by successively driving the car into engagement with the low-slung connecting cable of the concrete block train. Commencing with an engaging speed of about 15 mph., the speed was gradually increased to 25 mph. The 25 mph. run produced automobile decelerations which briefly reached 3.4 G, as determined from a frame-by-frame analysis of motion picture film. However, the smooth-curve plot of Figure 7 has averaged out these short-interval high decelerations so that the value shown more closely represents the deceleration to which the driver was subjected. The decelerations, as shown by a decelerometer mounted on the car, and the effectiveness of the safety belt for various rates of deceleration, were recorded by a motion-picture camera mounted on, but outside, the car, to the left of the driver. The overall deceleration pattern of the test car was recorded by a second motion-picture camera located at a favorable ground position. The film record of the ground camera provided, by means of a frame-by-frame analysis, an independent method of calculating the deceleration rates.

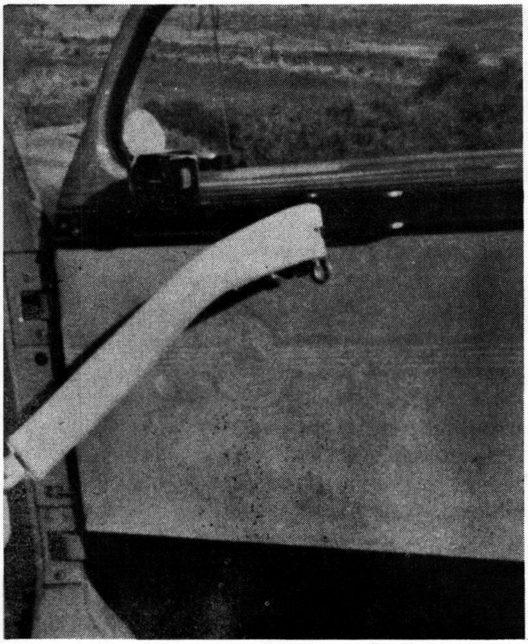

Figure 1.

Deceleration Equipment

Perhaps the most desirable type of equipment for automotive-deceleration tests would be an installation of the Naval Aircraft Field Carrier Arresting and Launching Gear. If this gear were at all obtainable, the delay in its procurement and installation would have made it unlikely that it could have been made operational in time to meet the schedule of this research project.

A means was devised which served the purpose equally as well as the desired gear, and with considerably less investment in time and money. A naval aircraft tailhook and supporting mechanism was obtained from a wrecked airplane and was mounted on the rear of the test car. The hook was positioned so that it trailed behind the car with its tip about 1 in. above the ground. This tailhook rig is illustrated in Figure 2.

The arresting gear consisted of four flat concrete blocks joined by 25 ft. of 3/4-in. standard hoisting steel cable. Two concrete blocks were placed on each side of the dirt test road with the connecting cable stretched across the road between them. The cable was propped up by wood blocks to about 2 or 3 in. above the road. The test car was driven over this cable at various speeds to get a variation of maximum deceleration caused by the tailhook engaging the arresting cable and pulling the blocks together as well as in the direction of the car's motion (Fig. 3).

Instrumentation for these tests included the use of two motion-picture cameras, one mounted on the test car and the other on the ground near the point of maximum deceleration. A decelerometer was mounted in the test car

Figure 2.

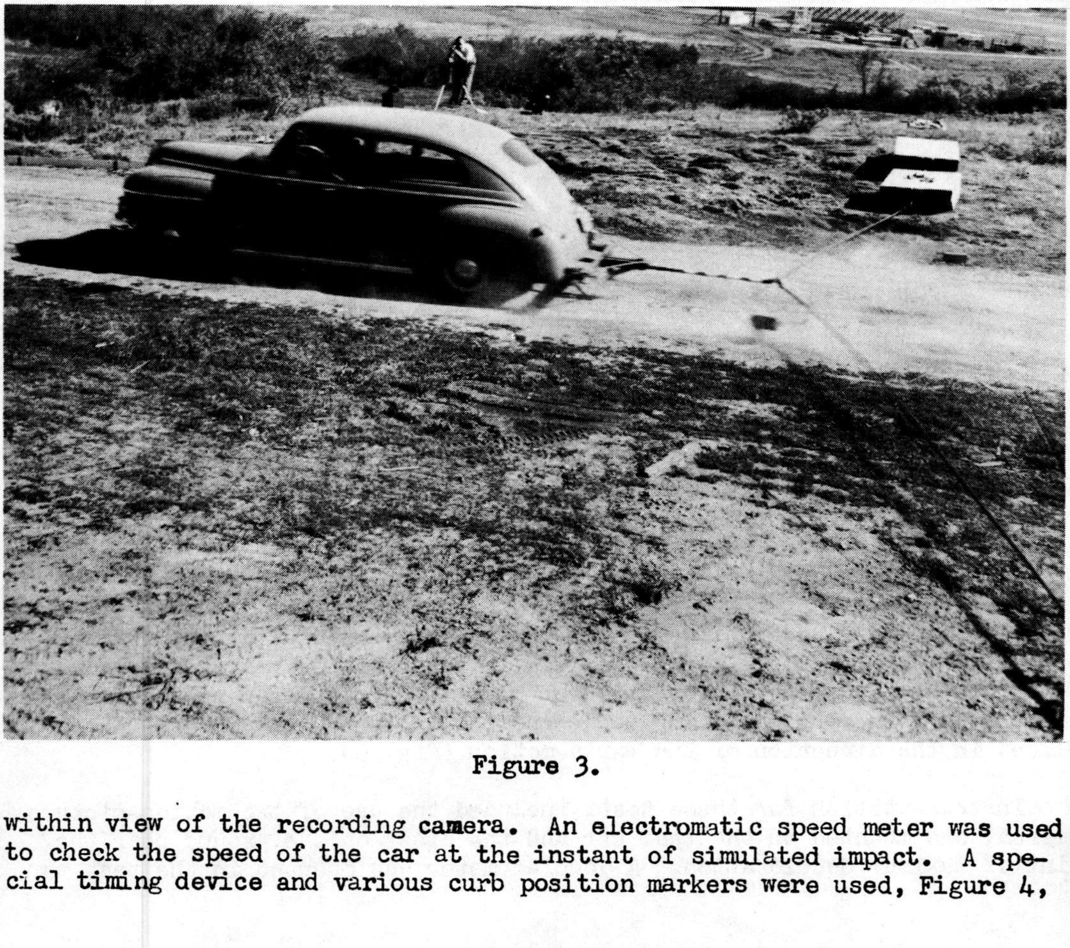

Figure 3.

within view of the recording camera. An electromatic speed meter was used to check the speed of the car at the instant of simulated impact. A special timing device and various curb position markers were used, Figure 4, so that deceleration could be calculated from a frame-by-frame analysis of the motion-picture film. This instrumentation made it possible to record the protective qualities of the crash belt so that these data could be studied carefully at a later time under more favorable conditions. The car camera was attached to the vehicle by a bracket and in a position which viewed the driver and the effects of impact on him together with the decelerometer included to give the rate of deceleration.

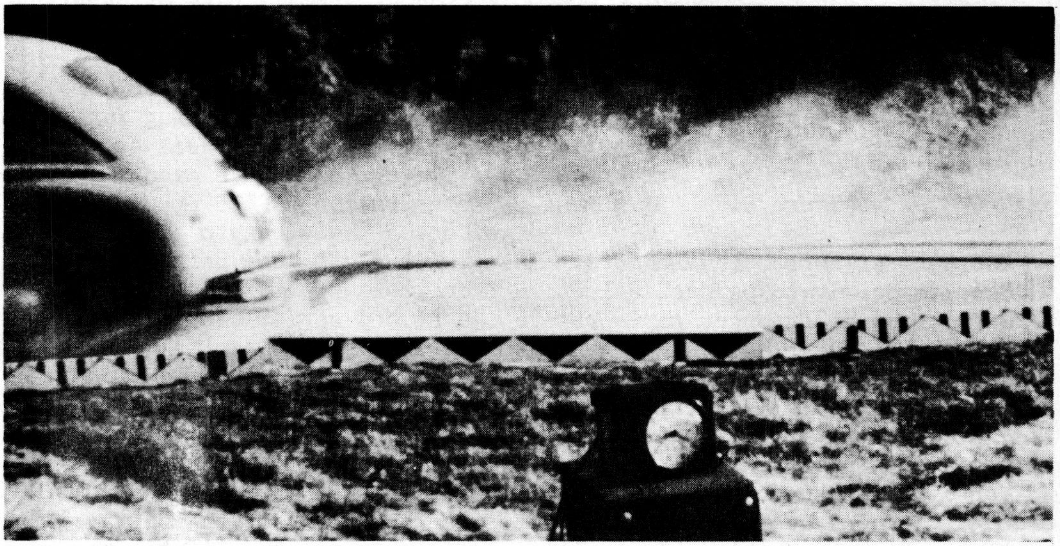

Figure 4.

Deceleration Tests

In addition to the mechanical arresting gear shown in some of the photographs of this report, the following modifications were made in order to prepare the test car for a nondestructive rapid-deceleration test. Not more than 4 gal. of gasoline were left in the fuel tank. The air cleaner was removed from the carburetor, and the spare tire, jack, and tools were removed from the trunk. Two electrical clip leads were connected across the terminals of the ignition lock so that the engine could be turned off from the gear shift by the act of dropping the two electrical leads held together by the same hand that was used for shifting gears.

The first series of tests were conducted primarily to check the operation of the deceleration equipment while the second series of tests were directed toward the study of the effectiveness of the automobile safety belt. For the second series, two additional pieces of equipment were used: an electromatic speed meter which functions on the Doppler principle was used to provide an additional means for speed determination of the test car, and an aircraft gun-sight camera, modified with a wide-angle, short-distance lens was mounted by a bracket 3 ft. outside the left-front window, as shown in Figure 5.

A fork lift was used to adjust each pair of 1-ton concrete blocks in such a position that the connecting cable was stretched perpendicularly

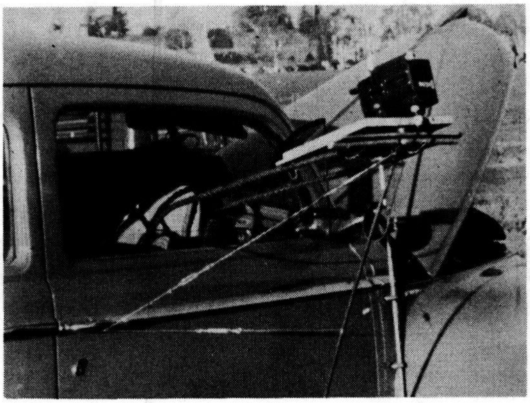

Figure 5.

across the dirt road. The test car was first driven at 10 mph. over the cable having only one concrete block on each end. The car tailhook engaged the cable which dragged the blocks and decelerated the car satisfactorily, but at 20 mph., the blocks were dragged to a trailing position at a small rate of deceleration, indicating that higher rates of decelerating could be attained more effectively from the use of two pairs of blocks. The remaining runs were made with the latter set up.

The sixth run was made at a speedometer reading of 35 mph.,[1] which exceeded the strength of some of the arresting gear supporting members. The yielding of these parts allowed the tailhook assembly to be partially torn from its supports. The weak members were replaced by stronger parts before the second series of tests were made.

The second series of runs were conducted in the following manner: The cable and blocks were placed in the proper position by the driver of the fork lift and the stationary cameras manned.[2] The test car was driven up the road about 1,000 ft. and then turned around. The driver held the ignition leads in his right hand, and with his left hand, switched on the car's motion-picture camera as the vehicle was accelerating. The car was accelerated in second gear to the desired test speed and was then shifted into neutral. Following this, the ignition leads were dropped to stop the engine as the test driver slid sideways in the seat to the front passenger position. Almost as soon as the driver assumed this position, the tailhook engaged the cable and decelerated the car. The car camera recorded the test driver's thrust against the safety belt.

For the final run, which was at a speed of about 25 mph., a deceleration of approximately 3.4 G was briefly obtained[3], but not without causing structural failure of arresting hook brackets (Fig. 6). Two 5/8-in. bolts snapped, a 4-in. 7.7-lb.-per-ft. steel I-beam, 40 in. long, bent at the center to a 6-in. deflection, and the tailhook assembly, for the second time, was partially torn from its housing. The test driver had on this and on previous runs experienced a severe snap of the head forward, though this event was not accompanied by any pain or after discomfort. The computed 3.4 G applied to the 160-lb. driver indicated that the safety belt had to withstand an induced body weight of approximately 500 lb. Less than a 10-in. length of the 3-in.-wide belt was used to resist this 500 lb. load,

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[1] - Frame-by-frame analysis has shown this to be approximately 25 mph.

[2] - 16 mm. Cine Special II, and a 4- by 5-in. Speed Graphic. The camera mounted on the test car was a modified 16-mm. G.S.A.P.

[3] - The accelerometer mounted on the car showed, according to the photographic record, a peak deceleration reading of 7.6 G, as reported in the synopsis published in January 1953 in HRB's ABSTRACTS. However, subsequent analysis of the motion-picture records indicates such a high rate of deceleration could not have existed over a long-enough period of time to be of significance for this study. Therefore, the values computed from motion-picture records of car motion have been used throughout.

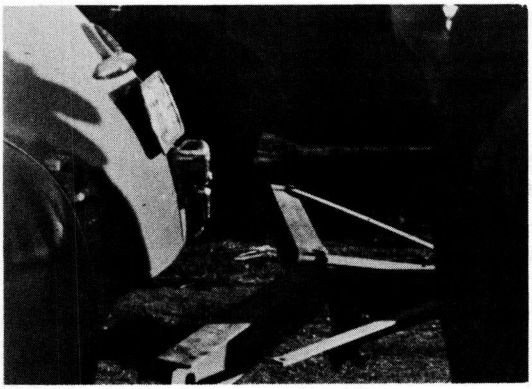

Figure 6.

which means that less than $\frac{1}{4}$ sq. ft. of the chest area had a 500-lb. load applied.4/ This is equivalent to 2,000 lb. per sq. ft. and is probably the reason why the test driver during this final run experienced a sharp pain, in the vicinity of the backbone at the height of the safety belt, which persisted for several hours after this last test run. Apparently the force applied to the chest wall was transmitted by the ribs to the backbone, causing discomfort in the muscle tissue paralleling the backbone at this point.

This condition suggests the need for a belt, or belt saddle, wider than 3 in. to give more adequate distribution of deceleration forces. A $4\frac{1}{2}$-in. belt would probably provide satisfactory protection for the majority of accidents, but such a belt may prove objectionable to the wearer, owing to the possible inconvenience or discomfort which the greater width may cause.

Deceleration Curves

Figure 7 shows a composite graphing of: (1) A family of curves portraying the theoretical deceleration pattern for a car decelerated from different initial speeds by means of the concrete-block drag-method just described. The data for plotting these curves were obtained by solving the equations of motion (shown in the appendix) on a differential analyzer. (2) Two experimentally obtained deceleration curves for a car having an initial velocity of approximately 23 and 24 mph. and which has been decelerated by the concrete-block drag method (developed from frame-by-frame analysis method). (3) An experimentally obtained deceleration curve for a Chevrolet-Ford head-on collision at the approximate speeds of 25 and 18 mph., respectively.

The differential analyzer curves show that greater initial rates of deceleration are obtained for correspondingly higher initial velocities but that this deceleration differential for various initial velocities becomes relatively insignificant after the first $\frac{1}{2}$ sec. of deceleration.

The experimentally obtained drag-block deceleration curves for initial velocities of 23 and 24 mph. compare favorably with their theoretically determined counterpart after the first 0.2 sec. of deceleration. The deviation of the experimental from the theoretical deceleration pattern for the first 0.2 sec. is in the direction which makes the experimental curve more closely resemble the deceleration pattern of the headon crash. The drag-block curves have been oriented with respect to the headon collision curve so that the principal peak deceleration appears at about the same time after impact. This superposition demonstrates that the drag-block method produces

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4/ - The effect of the frictional restraint offered by the seat is considered negligible for these approximations.

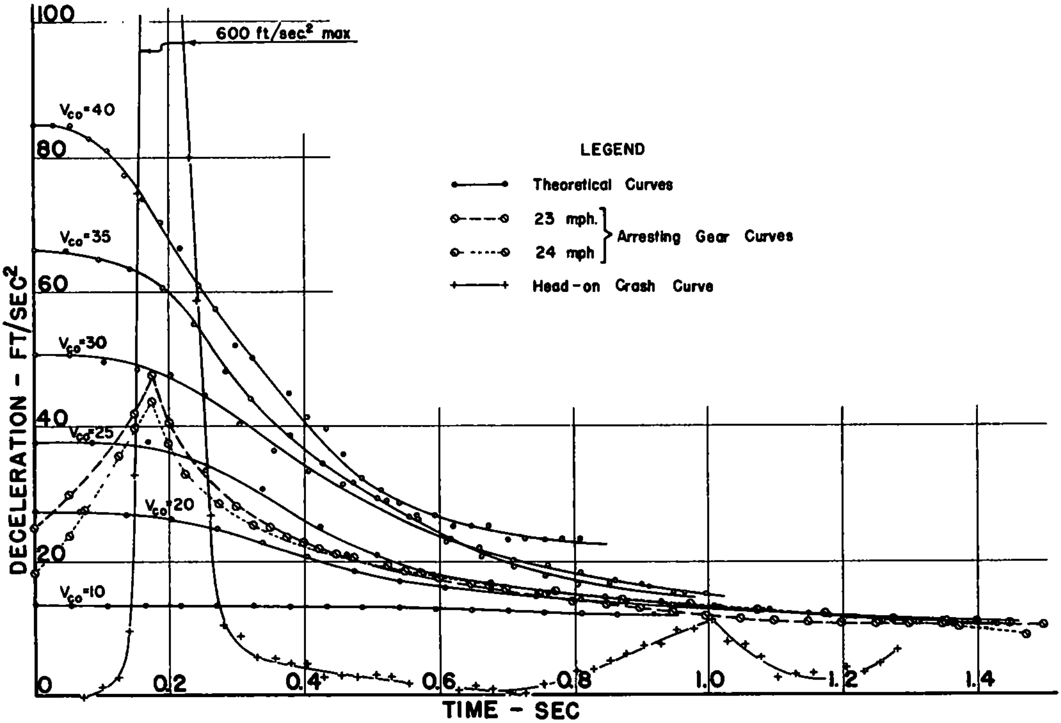

Figure 7.

a much-smaller peak deceleration during a much longer period of time than is shown for the headon collision. This condition illustrates one of the difficulties in developing a nondestructive means for decelerating an automobile in a manner which corresponds sufficiently close to the conditions that prevail in an average automobile collision so that a reasonable appraisal of safety devices may be made. It is for this reason that the institute has, for the past year, been developing equipment for testing various motorist restraints by means of experimentally staged automobile collisions with fixed objects.

Discussion of Error for the Decelerations Determined From the Frame-by-Frame Analysis of Motion-Picture-Film Records

A Bausch and Lomb Contour Measuring Projector was used to measure distances which a car moved in successive frames relative to a calibrated marker within the photographed field. The time for the incremental change of car position per frame was determined from an electric timing device, also in the field of vision, for the concrete-block deceleration runs, and by a 60-cycle light beam imposed on the edge of the camera film for the high-speed camera used in recording the headon collision.

Micrometers facilitate measurement of displacements of the table of the Contour Measuring Projector to an accuracy of 0.0002 in. However, the grain size of the film's emulsion and other inherent sources of error introduce additional errors of reading. To determine the total error due to film reading, 10 readings of one frame representing the most-defined and 10 of the least-defined frame of this film sequence were made and from this, two times the standard deviation of the measurements was determined to be of the order of ± 0.0005 inch.

In order to test the effect of this maximum error on the decelerations ultimately developed from the distance measurements, a series of frames covering a typical peak deceleration were analyzed. To each of the distances measured, a maximum deviation of +0.0005 in. and again -0.0005 in. were applied, thus forming three values of distances for each frame. In differentiating these distances with respect to time, the negative distance was matched with the succeeding positive and this, in turn, with the succeeding negative, so the resulting velocity expressed a maximum error as compared with the velocity determined from the normal reading. This same procedure was again applied to the differentiation of velocity. Although amplified to the extreme, the errors in deceleration did not vary from the observed values more than an average of ± 0.18 G, or about 13 percent. By this particular method, the errors in deceleration may vary from the observed values by a maximum of ± 0.18 G, or a possible error of about 13 percent. In view of the complexity of the mechanical system involved, an error of the above-mentioned magnitude is not considered unreasonable. Furthermore, within a 13-percent variation of G forces, the dynamic response of the human body will not be significantly changed. Nevertheless, it would appear to be desirable to accurately determine the error inherent in frame-by-frame analysis.5/

5/ - In the future, this problem will be evaluated by calibrating the Camera-Contour measuring Projector-Graphical Analysis systems simultaneously by a procedure suggested by Heinz Haber, which involves a trial run made on a test object dropped from a suitable height several yards in front of the camera. The necessary timing and calibration marking devices will be included in the photographed field. The deviation from one G acceleration thus calculated from a frame-by-frame analysis will, at once, be apparent.

REVIEW AND CONCLUSIONS

The tests reported in this paper were undertaken in an attempt to determine the effects of rapid deceleration on a motorist restrained by a safety belt having a fixed configuration. The entire range of decelerations were not, of course, initially known. Of necessity, the testing program ended with the failure of certain parts of the arresting gear at which point the maximum deceleration was reached.

On the basis of the tests reported herein and motor vehicle accident statistics6/ the following conclusions appear to be warranted:

1. Deaths and serious injuries have been incurred by motorists riding in crashing vehicles in which the deceleration rates were of a low order of magnitude. The tests reported suggest that injuries sustained as a direct result of forward impact can either be prevented entirely or greatly minimized through the use of a safety belt equal or superior to the one described above.

2. The chest-type safety belt provides an effective means of protecting a vehicle occupant against the results of forward impact forces without placing objectionable restraints on the body.7/

3. The chest-type belt overcomes the greatest single weakness of the lap-type belt by preventing pivoting at the waist. Thus, violent impact between the head and the steering wheel, dashboard, windshield, or other interior part of the vehicle is prevented.

4. While more statistical data are needed to accurately portray the facts, it is undeniable that a substantial number of fatal automobile accidents are directly attributable to vehicle occupants being catapulted through doors which have been forced open by forces resulting from impact. In a selective study of 209 collisions8/ involving 97 fatalities, one author attributes 32 of the fatalities to door failures. The chest-type belt, by virtue of the fastening arrangements, has the quality of preventing accidental opening of car front doors during or immediately following impact.

5. The results of the tests described were sufficiently favorable to indicate the desirability of further investigation of the potential benefits of safety belts in automobiles. Such an investigation is in the advanced planning stage by the Institute of Transportation and Traffic Engineering.

6/ - "Accident Facts," annual publication of National Safety Council.

7/ - A safety belt of the type described was consistently used by the junior author on an extended cross-country trip of 9,000 mi.

8/- Harper, William W., "Prevention and Reduction of Injuries in Traffic Collisions", Parachute Corp. of America, 6625 Sunset Blvd., Hollywood, California

ACKNOWLEDGEMENT

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APPENDIX

THE DIFFERENTIAL EQUATIONS FOR THE CONCRETE BLOCK DRAG METHOD

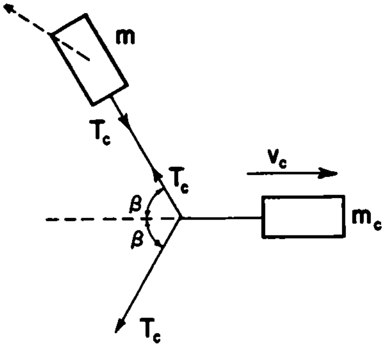

Figure A

A free-body diagram of the forces involved during the deceleration of an automobile by the concrete block drag method is illustrated. As the car decelerates the blocks are pulled into line with the car's motion.

The cable force T_c varies with the angle β. It was this nonlinearity which made the use of the analyzer desirable. For differential analyzer solution the equations of motion of the system were expressed as:

$$(1)\quad \frac{dV}{dt} = -\frac{2m}{2m + m_c}\frac{d}{dT}(\dot{\beta}\sin\beta) - \frac{2fr}{(2m + m_c)v_{co}^2}\,\frac{V + \dot{\beta}\sin\beta}{\sqrt{\dot{\beta}^2 + 2\dot{\beta}\,V\sin\beta + V^2}}$$

$$(2)\quad \frac{d}{dT}(\dot{\beta}\cos\beta) = \frac{m_c\tan\beta}{2m}\,\frac{dV}{dT} - \frac{fr}{mv_{co}^2}\,\frac{\beta\cos\beta}{\sqrt{\dot{\beta}^2 + 2\dot{\beta}\,V\sin\beta + V^2}}$$

Where: m = mass of one pair of blocks
m_c = mass of the car
f = Friction force (assumed constant)
v_c = Instantaneous car velocity
v_{co} = Velocity of car immediately after impact
r = one-half the cable distance between the centers of mass of the pairs of concrete blocks
β = angle of cable with respect to direction of car
V = dimension less velocity of car, (v_c/v_{co}) where v_c is the instantaneous car velocity and v_{co} is v_c the instant of impact.
T = dimensionless time, (tv_{co}/r) where t is time in seconds.