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HUMAN TOLERANCE TO IMPACT CONDITIONS AS RELATED TO MOTOR VEHICLE DESIGN - SAE J885a

SAE Information Report

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1. SCOPE

This SAE Information Report provides data regarding human tolerance to impact conditions.

This information is based on currently available knowledge and experience in the biomechanics field. However, in utilizing the information set forth, it must be recognized that both experience and data in the field of biomechanics are limited and, in some cases, unrefined.

It is intended that all portions of the report be subjected to continuing review and that it be revised as additional knowledge and experience would warrant.

2. HUMAN TOLERANCE TO IMPACT

2.1 INTRODUCTION - Impact exposes the human body to force acceleration and pressure versus time histories. Not all kinds of injury can be precisely defined by any one of these terms alone. The reader is therefore cautioned against using them interchangeably or out of technical context. Tests using human subjects riding accelerators are providing data on voluntary tolerance to impact. Obviously, such data are at a subinjury level and there is no accurate means of extrapolating these data to the threshold of injury. Similarly, there is no way of accurately correlating animal studies to human tolerance. However, responsible investigations of injury producing highway accidents and human freefall accidents can provide data concerning both survivable and fatal impulse levels. Additional data, particularly on skeletal tolerance, are being obtained by engineering tests and analysis using cadavers, human volunteers, and clinical observations.

In many cases, interpretation of acceleration readings obtained from instruments mounted to humans or animals is difficult because the components of the body are not rigid in the usual engineering sense. Thus, the measured acceleration cannot be directly converted to a force by the F = ma equation, as the actual force at the point of impact may be substantially different than would be indicated by an acceleration measured some distance from the impact point. The term "acceleration" denotes both positive and negative acceleration (deceleration).

Evaluation of the degree of injury is complicated by the many types of injuries that can occur. Medically, these run from minor bruises, lacerations, and bone fractures to serious fractures and injuries to the brain and other vital organs. Also, it is difficult to evaluate functional impairment of various organs since the impairment may not be evident for several days and may then be masked by other injuries.

Finally, it must be remembered that the tolerance of individual humans to injury will vary: it must be expected that some humans will sustain injuries when exposed to impulses well below the tolerance level of the average human.

Although these data regarding human tolerance to impact conditions and the mechanism of injury causation in motor vehicle accidents is limited, the information to date is sufficiently reliable to justify the combining of preliminary human tolerance data and general engineering design principles in a practical, common sense endeavor to reduce the likelihood of occupant injury during accidents. In applying the following data and principles, it must be recognized that optimum occupant safety is but one requirement of overall vehicle design. Compatibility with other essential requirements, including those relating to overall driving safety, must be considered in applying these data.

2.2 FACTORS AFFECTING IMPACT TOLERANCE -

2.2.1 Location of Measurement (Forcing Function versus Response Function) - Due to the dynamic characteristics of the materials involved in impact situations, the forcing function will, in general, differ from the response in both magnitude and time duration (see paragraph 2.2.8). When injury criteria are given, it is practically always as the response function and not as the forcing function.

2.2.2 Direction of Impact - Most regions of the body can withstand more severe impacts in one direction than can be withstood in another direction. For example, a well distributed impulse applied to the vertebral column of a person in a transverse direction is not nearly as likely to cause injury as one along the axis of the column. With complete body and head support, an acceleration of about 20 g for 100 msec applied parallel to the vertebral column is likely to injure a lumbar vertebra, whereas 60 g for 100 msec applied aft-to-fore through a seat back should cause little or no injury.

2.2.3 Location of Impact - Certain portions of the body are more susceptible to impact injury than others. For instance, severe neck injury can result from a blow that would cause no injury to the forehead.

2.2.4 Area of Contact - The degree of injury is an inverse function of the area of the body contact, up to a maximum impact tolerance level for the particular region contacted. A blow from a sharp pointed object, such as a knife blade, can cause severe injury with little impulse to the body. On the other hand, large impulses with no injury can occur when a large area of the body is contacted, such as occurs when an individual falls into water.

2.2.5 Time Duration of the Impact - High forces, pressures, or accelerations can be tolerated for very short time periods while lower values of these quantities can be tolerated for longer periods of time. Fig. 1 shows this relationship for brain injury in forehead impacts. However, it will be noted that Fig. 1 represents an impact against plane, unyielding surfaces. When an impact occurs against a yielding surface, such as a padded instrument panel, deformation of the skull is reduced. Therefore, under these conditions a higher effective acceleration limit is in order for any specific time duration. A reasonable value for such an impact is believed to be 80 g.

2.2.6 Kinetic Energy - All other variables of the impact situation remaining the same, the degree of injury to a particular body area is a function of the kinetic energy absorbed by that body area during the impact. The energy absorbed by a body area is dependent upon the crush characteristics of the object impacted.

2.2.7 Maximum Force, Pressure or Acceleration - The peak values of such quantities can serve as criteria of damage only for a theoretically brittle material, but are of limited use as indices of bodily injury because they take no account of time exposure to loading.

2.2.8 Dynamic Response - In a mechanical sense, the human body is a complex nonlinear, damped, multimass system. As such, it is subject to dynamic response behavior in any of its many modes of vibration. This means that the response or actual acceleration-time history experienced by the body, or a portion thereof, may differ markedly from the acceleration-time input to the body applied at the point of impact. The response of a single degree of freedom, linear mechanical system to an acceleration-time input is a function of the overall waveform of the input, but for a

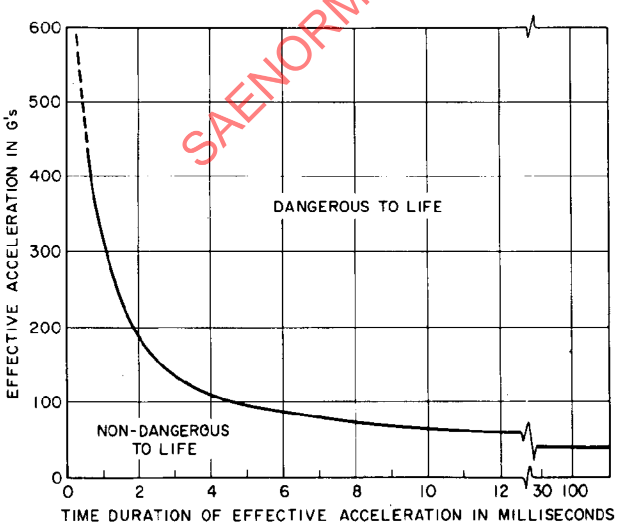


Fig. 1 - Impact tolerance for the human brain in forehead impacts against plane, unyielding surfaces

known system and simple input shapes can often be approximated by the use of the three basic wavefore characteristics:

(a) Time required to reach peak amplitude or average jerk

(b) Peak amplitude

(c) Overall time duration of the waveform

For any pulse duration less than about one-sixth the natural period of a given vibratory mode, the maximum amplitude of response of a single degree of freedom, linear system will be less than that of the input pulse and will be proportional to the area of the pulse waveform. For greater pulse durations, depending upon the nature of the waveform, the maximum amplitude of response can exceed that of the input by as much as 2 to 1 for a linear single degree of freedom system and by greater amounts for more complex systems.

2.3 DISCUSSION - Human tolerance to impact conditions of the type normally experienced in vehicle accidents has been more fully studied with respect to head, chest, knee, and facial injuries, than with respect to injuries to other areas of the body.

Much of the data regarding tolerance of the head to impact have been obtained from forehead impacts. However, there is evidence that the difference in energy necessary to produce skull fracture, when various areas of the head are impacted against a standardized target, is within the variance in fracture tolerance between individuals. There is considerable attentuation of acceleration in deforming soft tissue such as the scalp. To illustrate, a skull with the soft tissue removed will fracture at about 2-3 ft-lb of energy if it strikes a flat unyielding surface, whereas with the soft tissue intact, 35-60 ft-lb are required under the same test conditions.

Chest impact tolerance varies widely with impact conditions. The maximum force levels recommended herein are based on steering wheeltype impacts in which most of the load is concentrated on the sternum, over an area corresponding to a large diameter steering wheel hub. More concentrated or puncturing types of impact will cause injury at much lower force or acceleration levels.

Facial injuries are prevalent during accidents and can occur at low impulse levels, even when the load is not concentrated. Although many of these injuries may be medically classed as "minor," they may be disfiguring and have serious psychological effects on the individual. Also, such injuries may involve impairment of the eyes, ears, nose, and mouth. Therefore, it is essential that avoidance or reduction of facial injuries be carefully considered.

Trauma to the knee-thigh-hip complex can have serious, lifelong crippling effects on the patient. Fracture of the patella (kneecap) and/or injury to the knee joint results from even slow to moderate speed knee impact to a hard surface or small protuberance. A more severe impact to a somewhat yielding or conforming surface might not seriously injure the knee area, but may result in fracture of the shaft or neck of the femur (thigh bone), dislocation of the hip joint, or damage to the hip joint. These injuries sometimes require a hip prosthesis and, in some instances, fusing the joint. The long convalescence and permanent crippling effect of these injuries make their reduction or elimination of major importance.

2.4 TOLERANCE LEVELS - Appraisal of the injury potential of an impact shall be estimated by procedures in paragraphs 2.4.1 and 2.4.2.

2.4.1 Weighted Impulse Criterion - Weighted impulse criterion recognizes the importance of both the magnitude and the time duration of the impulse, which contribute to tissue damage by an amount dependent upon the viscoelasticity of the injured tissue. Published data (see paragraph 4) indicate that a weighting factor should place relatively greater weight upon the ordinate (force, acceleration, or pressure) than upon time duration. This is particularly true of the failure of skeletal components, which are less viscoelastic than soft tissue. For the more viscoelastic materials, the weighting factor should be lower.

Under this criterion, injury potential is proportional to the equation:

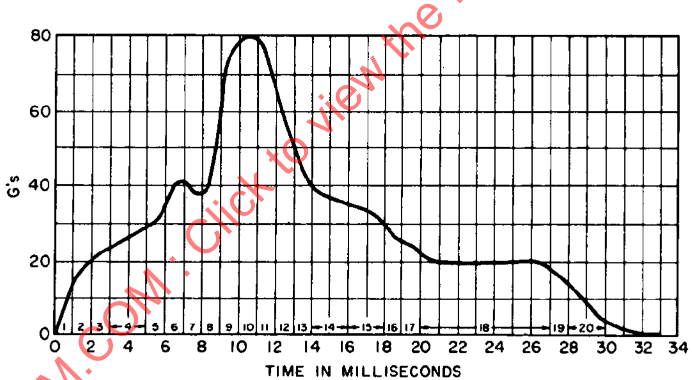
$$SI = \int a^n dt$$

where:

SI = Severity index
a = Acceleration (force or pressure)
n = Weighting factor greater than 1
t = Time

The exponent "n" has a value of 2.5 for head-face impacts. A severity index is obtained by use of Eq. 1 and, where applicable, should be used in determining the injury potential of an impact. The index may be obtained graphically by breaking the time base of the deceleration-time curve into a sufficient number of increments to define the curve, and raising the peak "g" value of the midpoint of the increments to the 2.5 power, and multiplying the number obtained by the time increment in seconds. No time increment need be less than 1.0 millisec. The sum of all the values obtained gives the severity index. Fig. 2 shows a sample curve with the necessary calculations. Table 1 gives severity index limits where this method applies.

2.4.2 Peak Force or Deceleration - Some areas of the body, such as the knee-thigh-hip complex, permit the use of peak force or deceleration as the injury criterion. Therefore, for these areas, Table 1 gives the tolerance limit in peak force or deceleration. These values should ignore all "spikes" of acceleration or force above the general enve-



Calculations

Increment No.	Time of Increment, sec	Midpoint g Value	$g^{2.5}$	Incremental SI Index (Time x $g^{2.5}$)
1	0.001	7	130	0.13
2	0.001	18	1,400	1.40
3	0.001	23	2,500	2.50
4	0.002	27	3,800	7.60
5	0.001	30	4,900	4.90
6	0.001	40	10,000	10.00
7	0.001	38	8,800	8.80
8	0.001	47	15,000	15.00
9	0.001	75	48,000	48.00
10	0.001	80	57,000	57.00
11	0.001	73	46,000	46.00

Increment No.	Time of Increment, sec.	Midpoint g Value	$g^{2.5}$	Incremental S I Index (Time x $g^{2.5}$)
12	0.001	56	23,000	23.00
13	0.001	43	12,000	12.00
14	0.002	37	8,300	16.60
15	0.002	33	6,200	12.40
16	0.001	27	3,800	3.80
17	0.001	24	2,800	2.80
18	0.007	20	1,800	12.60
19	0.001	17	1,200	1.20
20	0.002	10	330	0.66
			Severity Index	286.39

Fig. 2 - Sample calculation of a severity index

lope of the curve, that are 1.0 or less millisec in time duration.

2.4.3 Experimentally Determined Impact Injury Levels - Table 1 provides samples of experimentally obtained impact injury data relating to different body areas. These data indicate moderate injury levels as a combination of magnitude and duration of impact. The levels given are discreet data points only, and cannot be used to extrapolate tolerance levels for other magnitudes of acceleration.

To specify adequately the overall tolerance picture for the entire human anatomy, it will be necessary to obtain experimentally curves similar to Fig. 1 pertaining to the various body areas of interest. Also, it is necessary that such curves be qualified by a specification of the impact characteristics employed, that is, direction of blow and area of contact. A full complement of experimentally obtained tolerance curves such as Fig. 1 for the more vulnerable body areas, and for different impact characteristics would be of great value; considerable effort is currently being devoted to this end.

2.4.4 Distortion or Local Force Application - The above values are seriously limited in their ability to predict quantitative tolerance levels if the force pattern on impact is such as to produce severe distortional strains. In this event, predictions of injury level cannot be made from kinetics alone, and one must judge from experimental and accident statistical data. Such strains might result from contacting a rigid knob, control, or flange.

2.5 INERTIA FORCES - Impact against an object of significant mass with respect to the mass of the body area contacting it can produce high forces on the impacting part of the body, even if the object is designed to break away.

3. GENERAL DESIGN PRINCIPLES

By the application of human tolerance data and the following fundamental engineering principles, it should be possible to reduce the likelihood or severity of injuries which may be expected to result from occupant impact against passenger compartment surfaces in the vehicle. These general principles are:

3.1 Effective absorption of energy by deformation of structure and components when impacted by occupants.

3.2 Use of energy absorbing shielding to cushion and spread the impact.

3.3 Design of structure, components and controls to reduce penetration, laceration, or localized force application.

Table 1 - Experimentally Determined Levels of Impact, Producing Minor to Moderate Injury (Response Function)

Body Area Impacted	Minimum Contact Area, sq in.	Effective Weight, lb	Peak Force, lb	Peak g	Severity Index Limit	Conditions Used to Obtain Tolerance Data
Face* (localized loading)	4	15	600	40	400	Smooth, collapsible, padded surface, with accelerometers mounted on bone opposite impact
Face* (distributed loading)	15	15	1200	80	1000	
Throat	2		150**		-	Force distributed with deforming pad
Brain (skull)	3	15	1500	100	1000	Various surfaces with accelerometers mounted as with "face"
Chest	30	75	1500	-	-	Load cell mounted to conformable chest contact surface
Side Above Pelvis, Below Ribs	10	75	Maximum dynamic protrusion into subject area of 1.25 in.			
Knee-Thigh-Hip Complex (load applied through knees)	3	40	1400	35	-	Load cell mounted to conformable knee contact surface

*Below eyebrows.

**This is considered to be a reasonable value in the opinion of biomechanics investigators, based on the strength of similar human structure throughout the body. The number may be modified as better data is gathered.