ALPINE EDUCATION GUIDEBOOK - BOOK 2

THE GUIDEBOOK FOR COACHES AND OFFICIALS

MOST DIFFICULT

Chapter 8
Skiing Forces, Risk, and Risk Reduction

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ALPINE SKI RACING EDUCATION SERIES
New York State Ski Racing Association (NYSSRA)

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8.1 What is "Mechanics"?

Mechanics is the study of bodies in motion and the forces that govern them. Several terms must first be defined to pursue the subject, including: distance, time, velocity, acceleration, mass, and force. These may seem familiar to the reader, but they take on a more precise meaning when applied to mechanics.

Galileo began to describe the behavior of bodies in motion. His famous experiment where he dropped two objects of different mass from the bell tower in Pisa (*The Leaning Tower of Pisa)*, demonstrated that acceleration is equal for objects of different mass (weight). Therefore, theoretically, there is no advantage for a ski racer to be large, or small. The acceleration imparted by gravity on falling objects was shown to occur at a constant rate.

Sir Isaac Newton also concerned himself with bodies in motion. The catalyst of his curiosity, an apple falling from a tree, has been inscribed into legend. Newton defined mass and developed a mathematical method for describing the behavior of bodies in motion: the calculus.

Kinetics describes the motion of bodies and the energy of that motion. To understand the kinetics of objects, velocity and acceleration are taken into account. ***Velocity*** is distance traveled in a period of time. It is equivalent to speed, but a value for direction is implied with velocity where as none is implied for speed. ***Acceleration*** is the change of velocity during a period of time; i.e.: is the object traveling faster and faster, or is it slowing?

Newton's first law of motion states that, if the vector sum of the forces acting on an object is zero, then the object will remain at rest, or remain moving, at constant velocity. The first law, then, describes the concept of ***inertia***, and we'll describe this in more understandable terms later.

Newton's second law of motion states that a net force on an object will accelerate the object at a rate proportional to the strength of the force and in the same direction as the force. The second law describes the actions of forces and their effects, and we'll talk about the action of forces in skiing and their effects.

Newton's third law of motion states that an object experiences a force because it is interacting with some other object, and that the force exerted by object 1 on object 2 must be equal to the force exerted by object 2 on object 1 but in the opposite direction (actions and reactions must be equal and opposite). Newton's third law is sometimes described as the law of conservation of momentum. It asserts that no energy can be lost.

In simple terms, all of a systems energy shall either contribute to motion, or be consumed by friction. ***Friction*** is a major concern of the ski racer, and actually describes the sport from engineer's point of view: ***Ski racing is the efficient management of kinetic energy, while on skis, so as to maximize motion by minimizing friction.***

For work to be performed, such as moving a body, energy is required. In mechanics, energy is required to do work. ***Work*** is the ***result (output)*** of the application of energy to move a body a given distance over time. If energy is applied, but the object doesn't move, no work is done. The energy must then be lost in friction (heat).

If an object is lifted, such as a ski racer going up a ski lift, work is done and energy has been stored in the form of ***potential energy***. The release of the potential energy, such as a ski racer exploding from the start gate and beginning a descent, releases the ***potential energy*** in the form of ***kinetic energy***, the energy of motion.

This has been a very quick review. We'll expand these concepts in a little more detail, and give examples where they describe ski racing. The examples we will give should help lend more concrete meaning to the abstract concepts.

8.2 The Motive Forces:

For those inquiring minds that find the following discussion to be insufficient for their curiosity, the author suggests that they explore the topic further in any one of a number of engineering texts on the kinetic energy of solid bodies, or aerodynamics. Both topics are subsets of mechanical engineering, or classical Newtonian physics.

The author has made an attempt to describe the topics in approachable terms. Wherever possible, the technical descriptions will be applied to skiing and ski racing so as clarify the ideas. I also hope to entertain and enlighten the reader, who is assumed to have a working knowledge of skiing, if not necessarily of physics. Stick with it. We believe it will become more clear before we're through.

8.2.1.1 Energy:

Force is the action of one body on another. Here we're talking about any physical body, i.e.: one that occupies space and exhibits mass. The action of force from one body to the other will result in the ***acceleration*** of the second body (Newton's 3rd law). Think of two pool balls knocking together. The first ball transmits a portion of its force to the other, which accelerates the second ball.

This transmission of force, and the acceleration of the second body, may be halted by a counteracting force. Think of the pool balls in a rack formation being struck by the cue ball. Some of the balls in the center of the formation accelerate very little. Why? Because the force transmitted to them is counteracted upon by the mass of the next ball in the formation. The next ball is accelerated instead (unless it too is counteracted against).

For a body to be displaced (***set into motion***) against resistance (***friction or inertia***), ***work*** must be done upon it.

Energy is a measure of the ***work*** that a body may perform. There are two forms of *energy* pertinent to this discussion: ***potential energy*** and ***kinetic energy.***

When a body is held so that it can do work when released, we say that its energy is in the form of ***potential energy.*** Think of a large weight held in the air by a rope. The gravity pulling on the weight establishes *potential energy*. If the rope were cut, the *potential energy* would then be released and transformed into ***kinetic energy.***

This leads us to the second form of *energy*. ***Kinetic energy*** is the *energy* expressed by a body in motion. After the rope is cut, and the weight accelerates through a fall, the *energy* expressed by the motion is said to be in the form of *kinetic energy.*

Ski racing is the efficient management of the *kinetic energy* that is the result of a release of *potential energy.* As the racer is transported up the hill on the ski lift, the *potential energy* of the *system* (the racer) is being raised by the work of the lift acting upon it (elevating the racer). The *system* is the *mass* of the skier and their equipment being *lifted* to a higher elevation. When a racer enters the start gate, their elevation above the finish line is equivalent to their *potential energy.* When they exit the start gate they are releasing that *potential energy*, and transform it into *kinetic energy,* as they descend the hill.

It is interesting to note here that their speed is limited by the distance that they must travel over the course of their descent. In other words, if they're 400 meters above the finish line, and the ski course is 1400 meters in length (not very steep), their acceleration and terminal speed will be lower than if they were the same 400 meters above the finish but the ski course were only 900 meters in length (steep). In more obvious terms: the more quickly they descend the greater they will accelerate and the faster they will travel. This is a direct manifestation of what speed is: it is a ratio of distance and time (i.e.: miles-per-hour; kilometers-per-hour; feet-per-second; meters-per-second; etc.).

8.2.1.2 Time:

Time is a ***measure*** that may be used to mark the sequence of a series of events. The concept of *time* is familiar to everyone.

We know that a ski racer is *timed* during their descent from the start to the finish. A low elapsed time means that the racer was able to efficiently transform their *potential energy* into *kinetic energy* (travel faster). The racer was also able to manage the ***counteracting forces***, principally ***sliding friction*** and ***aerodynamic drag***, so as to reduce their effect. The lower the elapsed time, the more proficient the racer was in managing those fundamentals through the course of their descent.

8.2.1.3 Inertia:

Inertia is a property of matter. It is defined as a resistance to any change in state of motion (Newton's 1st law). If a body is at rest (no motion), it wants to stay at rest. If it is in motion, it does not want to stop unless counteracted upon.

Think of a bowling ball. If it is at rest on the floor, kicking it could result in injury because it has great inertia (it doesn't want to move), a consequence of its large mass (relative to your foot). If it's rolling down the alley, it does not want to stop just because there are a few bowling pins in its way. Because of its great (belligerent) inertia, it moves the pins out of the way as it charges through the pin set (which is the object of the game).

Large ski racers have more *inertia* than small ski racers. Why? For an answer to that question, we must explore the properties of *mass.*

8.2.2.1 Mass:

For our purposes ***mass*** is a measure of ***inertia***. The greater the mass of a body, the more *inertia* it possesses. The bowling ball has great *inertia* because it is heavy (has great mass); whereas a tennis ball has a slight *inertia* because it has less *mass* (relative to the bowling ball).

One would think that large ski racers may have an advantage over small ski racers. This has not been shown to be true. Why? Because a skier with greater *mass* must also manage greater ***centrifugal forces*** in the turns, greater sliding friction on their skis, and greater aerodynamic drag due to their greater bulk.

A turn is a rotation of the skier's racing line about an axis. The force of *inertia,* that is in many ways a product of *mass,* exerts force upon the skier to continue in a straight line. That force is known as ***centrifugal force.*** The skier must counteract that force by holding an edge and exhibiting strength, a form of force.

The force that the skier exerts to counteract the *centrifugal force* is known as ***centripetal force***. *Centrifugal force* exerts an influence in an attempt to maintain a linear forward *inertia*. ***Centripetal force*** is applied by the racer to resist that influence and describe an arcing path of descent, or turn.

Skiers that possess greater *mass* must exert greater *centripetal force* in the turns. Whether a smaller skier or a larger skier has any advantage is difficult to say. It is a general trend that downhill skiers tend to be large and technical event skiers tend to be small. While that trend can be demonstrated, size has not been found to be a predictor of success.

It can be said that larger racers usually exhibit fewer perturbations in their acceleration, but that effect is often offset by the larger profile that they present to the sea of air that they must pass through, which results in a greater potential for ***aerodynamic drag,*** and the greater ***sliding friction*** that they manifest on their skis.

8.2.2.2 Velocity:

The velocity of an object is the rate of change of motion. ***Velocity*** is a term that, by convention, implies a direction. However, for the purpose of our discussion that distinction is not required.

Think of velocity as being equivalent to *speed.* Speed may be measured in miles per hour, kilometers per hour, meters per second, feet per second, etc. These ratios all couple ***distance with time***. In other words, velocity is expressed as a rate where ***distance*** is used as a measure of displacement in ***time***.

Let's simplify that: velocity may be though of as a time measured rate of change within a given distance (displacement), or *speed*.

Ski racers are engaged in a contest whereby they all attempt to travel over a fixed distance in the least amount of time. In other words, they're all trying to go fast (duh). We gage their results in this endeavor by measuring the ***elapsed time*** of their descent. What their velocity was at any given moment is not important. What their ***average total velocity*** was, over the full course of descent, is important. It separates the winners from the losers.

8.2.2.3 Acceleration:

Just as velocity is the rate of change in distance, ***acceleration*** is the rate of change in velocity. Think of acceleration as the answer to the question, "How much faster are we moving now than we were a moment ago?" Conversely, negative acceleration may be thought of as, "How much slower are we moving now than we were a moment ago?"

Positive acceleration, an increase in the velocity rate, we will refer to as ***acceleration***.

Negative acceleration, a decrease in the velocity rate, we will refer to as ***deceleration***.

A skier racer wants to ***accelerate*** from a standing position at the start to their ***terminal velocity in*** the shortest possible time. The more quickly they achieve their *terminal velocity*, the greater the rate of their *acceleration.* The craft of coaching is, in essence, the endowment of the racer with the technical skills that are necessary for them to achieve the highest possible rate of *acceleration,* so as to reach the greatest *terminal velocity*, rather than a sub optimal value of either.

8.2.3 Kinetic Energy (Energy of Motion):

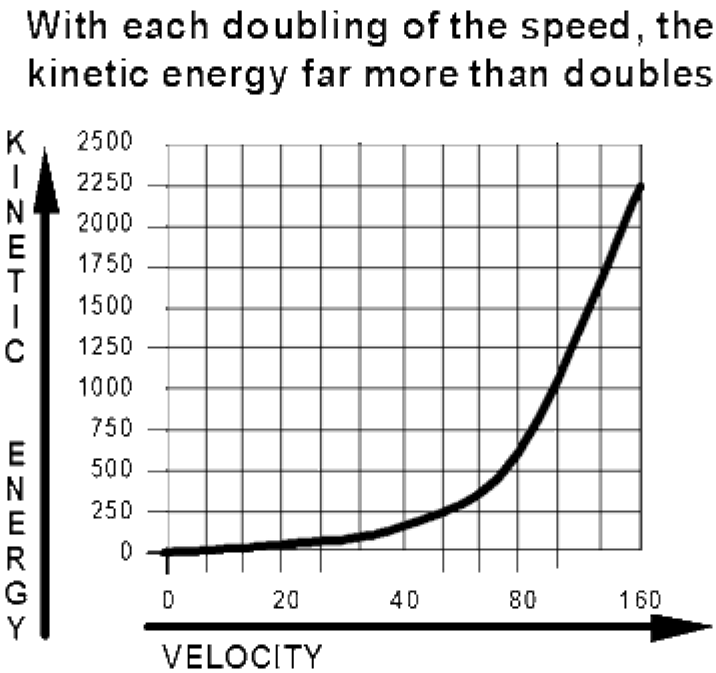
The Kinetic Energy Formula:

$$E = 1/2mv^2$$

<u>Where:</u>
E = kinetic energy
v = velocity *(distance / time)*
m = mass (equivalent to weight)

Kinetic Energy is calculated from the measured values of ***mass, distance,*** and ***time.*** Recognize that the value for velocity (speed) is squared. ***In practical terms this means that any increase in speed will result in a greater increase in kinetic energy.***

Consider for a moment the motor vehicle stopping distances that are published in student driver booklets. ***For every 10 mph increase in speed the stopping distance almost <u>doubles</u>.*** That means that



at 60 mph it takes almost twice as far, or twice the amount of time, to stop as at 50 mph.

Go back and look at the formula. Think about how squaring the velocity exponentially ramps the energy curve. After all, braking is nothing more than the dissipation of kinetic energy, as heat, through friction. The greater the kinetic energy, the more friction we need to dissipate it as heat.

Since the size of the tire's adhesion patch is fixed, and the size of the brake pads total surface area is fixed, the greater ***kinetic energy*** of a vehicle traveling at higher speed will require greater time to dissipate the total energy. Put another way: since the size of the tire's adhesion patch does not expand, and the total surface area of the brake pads doesn't expand, then the braking time (or distance) must expand to accommodate the greater ***kinetic energy***. Remember that the formula must balance across both sides of the equal sign.

Here, the important point to recognize is that ***kinetic energy*** expands ***exponentially*** relative to ***velocity***. Think of a six ounce hammer. If you rest its head on the head of a large spike nail, it barely imparts enough force on the nail to make a slight impression on a block of wood. Now, ***swing*** that hammer with gusto, and it strikes with tons of force, enough to separate the cellulose fibers at the point of the nail and overcome the friction of the parting wood against the nail shaft. In other words, it will ***forcefully drive*** the nail into the wood. It's the ***velocity*** that does it.

Turned around, this explains why a 225 horsepower vehicle, that can attain a speed of 105 mph, can't go twice as fast as a 135 horsepower vehicle, that can attain a speed of 90 mph. To go twice as fast as 90 mph it will probably require in excess of 600 horsepower!

In other words, it is not possible to bring a body up to a high velocity without doubling, and redoubling, the input energy devoted to acceleration. For those readers who may recall the original Volkswagen Beetle, with it's 43 horsepower air cooled engine, it struggled to maintain 65 mph on a level road. Modern engines with multiple valves per cylinder and their more efficient fuel injection systems raise that horsepower threshold considerably. The Saturn has no trouble accelerating to 85 mph while in fifth gear. The difference is the horsepower to weight ratio. To double the vehicle speed requires more than a doubling of the horsepower.

For those who desire a treatment of this topic in greater depth, please refer to any of the general texts available on the mechanics of solids, specifically those that describe work and energy or kinetic energy.

8.3 Impact:

The collision between two bodies where forces result is called ***impact.*** Once again, here we're talking about any physical body, i.e.: one that occupies space and exhibits mass. Impact results in the dissipation or redirection of the kinetic energy of the objects impacting each other.

Let's illustrate the forces of impact by imagining how it would feel to jump from a building from various heights. How would it feel to jump from a window on the second floor? How would it feel from the 10th floor? As a body falls freely through air, it accelerates. The speed that the body achieves the moment before impact can be referred to as the terminal (final) velocity. Let's compare the terminal velocity achieved in a fall to the average speed achieved in the various disciplines:

ALPINE DISCIPLINE	KM/H (Potential)	MPH (Potential)	DISTANCE (in Meters)	DISTANCE (in Feet)	FLOOR (Equivalent)
Downhill	130 km/h	80 mph	66 m	216 feet	18 th
Super-G	100 km/h	65 mph	40 m	130 feet	11 th
Giant Slalom	80 km/h	50 mph	25 m	80 feet	7 th
Slalom	50 km/h	30 mph	10 m	32 feet	3 rd

So, by way of illustration, a downhill racer may achieve 130 kilometers per hour in speed, which is 80 miles per hour. If a body, traveling at that speed, hits a solid and immovable object it is equivalent to falling 66 meters onto a street, or a fall of 216 feet, which would be equivalent to a fall from about the 18th floor. We see that even at slalom speeds, impact with an immovable object is the equivalent to a fall from the 3rd floor.

Question: would you be willing to jump from a third floor window (equivalent to slalom speeds) onto a mattress on the sidewalk? If not, then I assume that you'd also be unwilling to ski into a mattress erected on a vertical obstacle on the ski course. Be sure, then, to visit Chapter 9: Nets, Cushions, and Fences, for illustrations of alternatives.

A straight line that runs perpendicular to the plane of contact between the two bodies is called the ***line of impact.***

When the centers of gravity of both bodies lie on that line, the impact is called ***central impact.*** Think of a direct ***head on collision*** *(frontal direct impact)* between two motor vehicles, or when a motor vehicle collides on center with a bridge abutment.

When the centers of gravity are not coincident, the impact is called ***eccentric impact.*** Think of an offset head on collision *(frontal offset impact)* where two motor vehicles meet off center to each other, and impart a spin and lateral deflection of both vehicles after collision. Such an result would be expected if only the region near the driver side headlamps, of both vehicles, met and the rest of the vehicles were offset from each other.

A form of eccentric impact, wherein the bodies graze each other at shallow angles, is called ***oblique impact.*** Think of motor vehicles that ***side swipe (lateral** offset impact)* each other, or a motor vehicle that scrapes down the length of a lane barrier, eventually grinding to a halt.

We have described three forms of impact:
Central impact describes the collision of two bodies where their centers of gravity come together on ***coincident lines of impact.*** Think of a ***direct head on collision*** between two motor vehicles.
Eccentric impact describes the collision of two bodies where their centers of gravity come together on ***independent lines of impact***, that they are ***offset*** from each other so as not to be *coincident.* Think of an ***offset head on***

collision between two motor vehicles, that results in vehicle rebound and spin out.

Oblique impact describes the collision of two bodies where their centers of gravity come together at shallow angles, such that they glance off each other and their original vectors of approach are redirected. Think of a ***glancing collision*** between a motor vehicle and a lane barrier where the vehicle grinds to a controlled halt against the barrier.

These three conditions of *impact* will be used to further describe approaches to *competitor protection*: *central impact; eccentric impact;* and *oblique impact.*

Do you remember Newton's laws, reviewed above? Let's return to the *Law of Conservation of Energy* for a moment (Newton's 3rd law):

The Law of Conservation of Energy:

The sum of energy is constant, and cannot be lost, but only transformed into another state of energy.

The other valid states of energy are either:
kinetic (the energy of motion)
heat (raising the temperature of the body or its surroundings, principally through friction)

When two bodies collide, ***kinetic energy*** is absorbed in the deformation of the bodies. A subsequent period of restoration, that we may term ***rebound,*** may or may not be total. *Complete restoration of the energy of deformation* is termed ***elastic impact*** or ***elastic rebound. Incomplete*** *restoration of the energy of deformation* is termed ***inelastic impact*** or ***inelastic rebound.***

When a rubber ball descends in a fall to a hard floor, it deforms in elastic compression when it collides with the floor. When that elastic compression rebounds the energy of restoration is restored in the acceleration of the ball rising off the floor. Some energy is lost in the friction of the elastic deformation, some is lost in friction between the ball and the floor's surface, but the transaction is considered essentially elastic. The ball bounces back. There was an ***elastic impact.***

When an egg descends in a fall to a hard floor, it deforms in fracture and disassembly. All of the energy is dissipated in the process of fracture and disassembly and no restoration is possible. The egg splatters. There was an ***inelastic impact.***

Now, in truth, no energy is lost in *inelastic impact* and, therefore, does not need to be *restored.* What we mean is *restored as kinetic energy* and not lost to *friction,* or *transformed into heat*.

We have described two impact mechanisms:

Elastic impact is the condition where the energy of deformation is fully, or almost fully, restored as kinetic energy after *impact.*

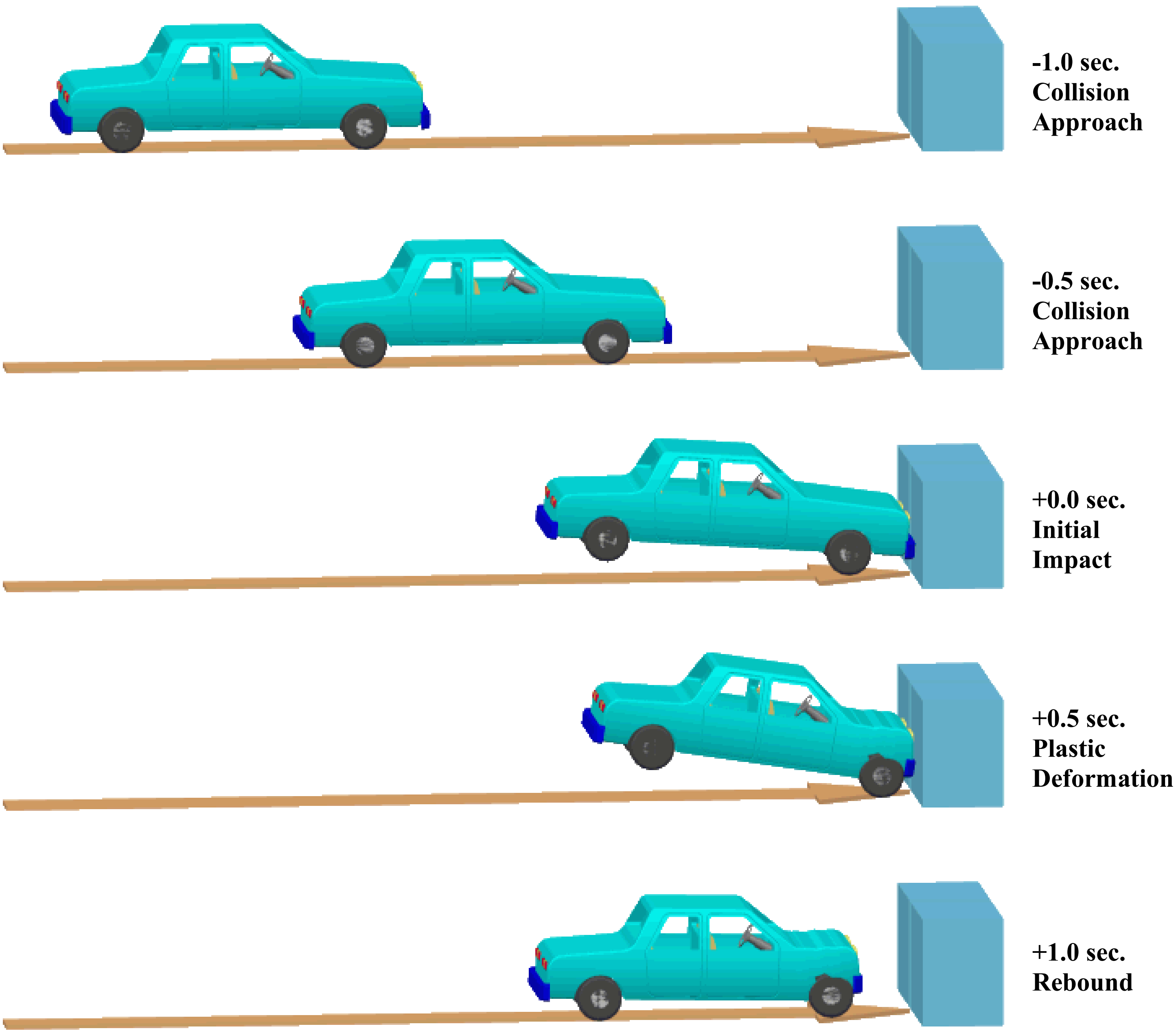
Inelastic impact is the condition where the energy of deformation is *not* fully restored as kinetic energy after *impact*, but is instead lost to friction.

Our discussion assumes two theoretical outer limits of elasticity: *absolute elastic* and *absolute non elastic,* also known as *plastic.* The term *elastic* refers to a body's ability to regain it's structure or form after the pressure is released.

8.3.1 CENTRAL IMPACT

INELASTIC

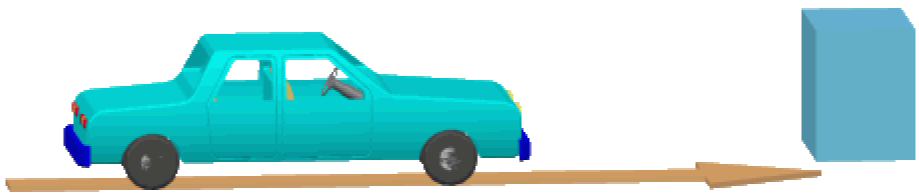
The central impact, illustrated here, shows a motor vehicle in a direct collision with two permanently emplaced concrete barriers.



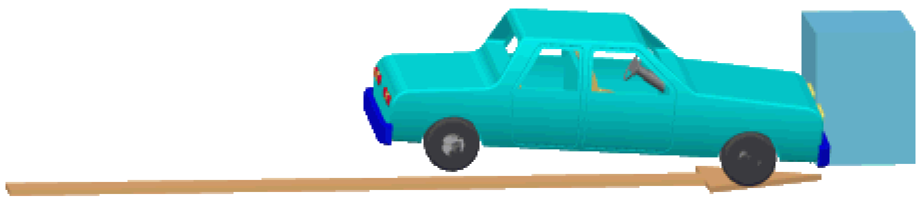
8.3.2 ECCENTRIC IMPACT

WEAKLY ELASTIC

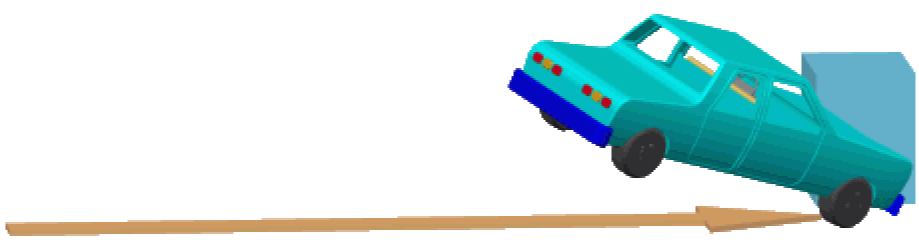
The eccentric impact, illustrated here, shows a motor vehicle in an off center collision with one permanently emplaced concrete barrier.



-0.5 sec.
Collision
Approach

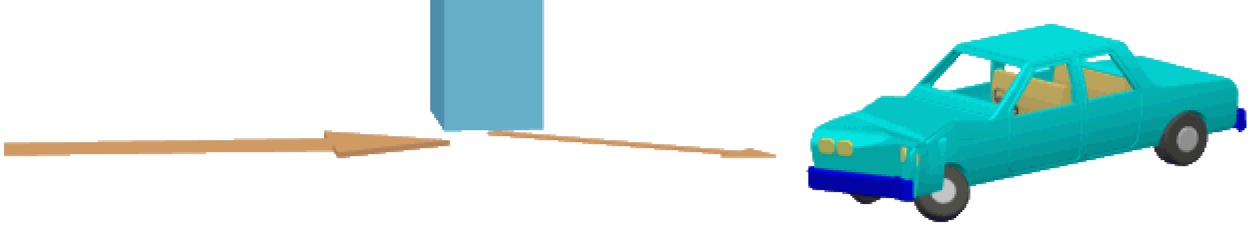


+0.0 sec.
Initial
Impact



+0.5 sec.
Plastic
Deformation
& Rotation

+1.0 sec.
Rebound

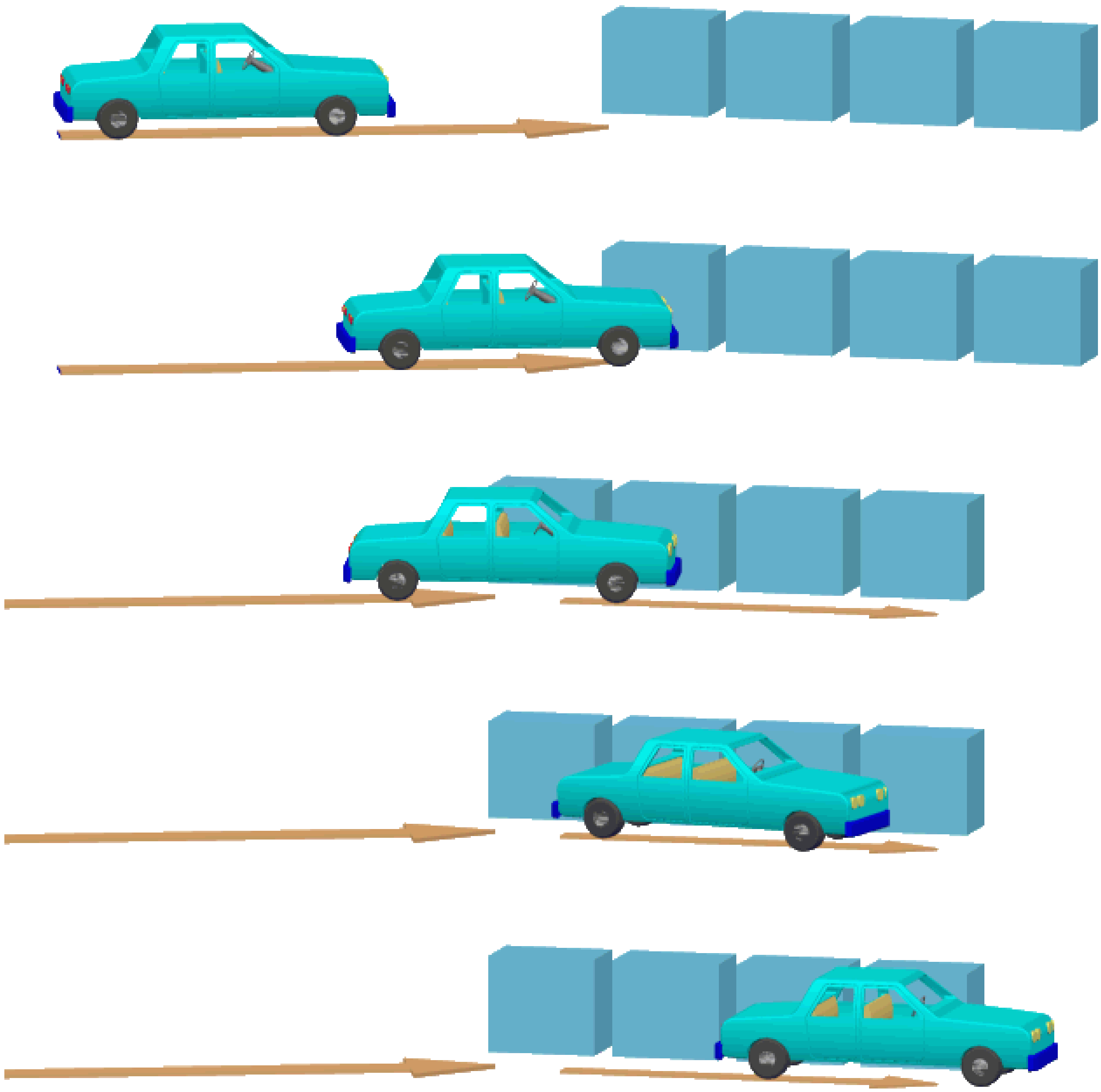


+1.5 sec.
Redirected
Path of
Travel

8.3.3 OBLIQUE IMPACT

SLIGHTLY ELASTIC

The oblique impact, illustrated here, shows a motor vehicle in a side-swipe collision with four permanently emplaced concrete barriers.



-0.5 sec. Collision Approach

+0.0 sec. Initial Impact

+0.5 sec. Plastic Deformation & Rotation

+1.0 sec. Rebound

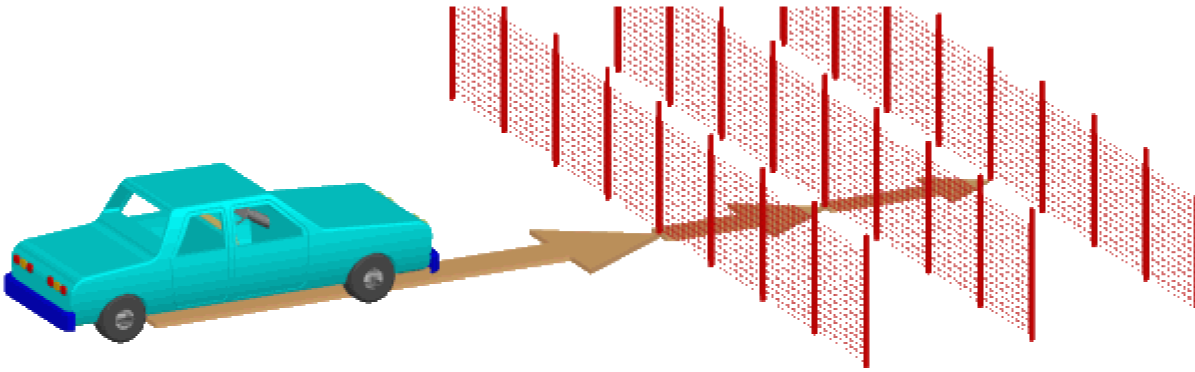
+1.5 sec. Redirected Path of Travel

8.3.4 CENTRAL IMPACT

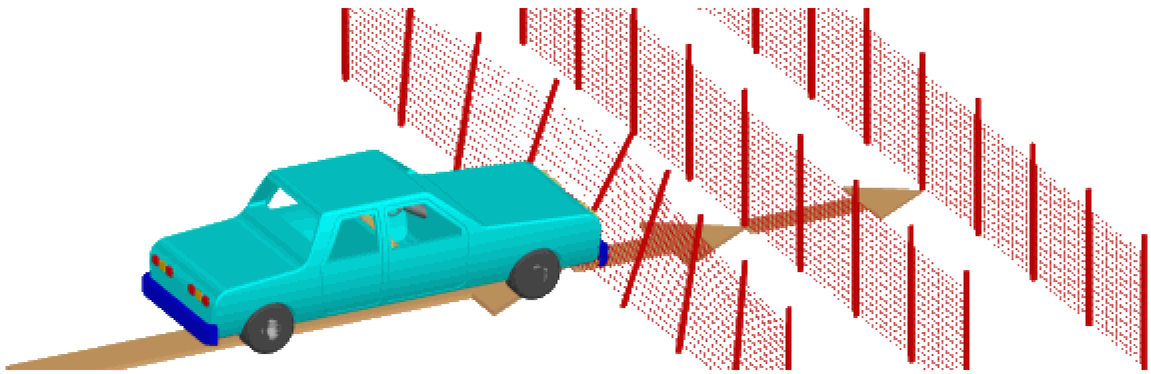
ELASTIC "B" NET SYSTEM

The central impact, illustrated here, shows a motor vehicle in direct collision with three "B" Nets supported by polycarbonate poles. The polycarbonate poles flex and provide an elastic cushion to the impact. They will rebound to their original position after the vehicle is removed, ready for another collision.

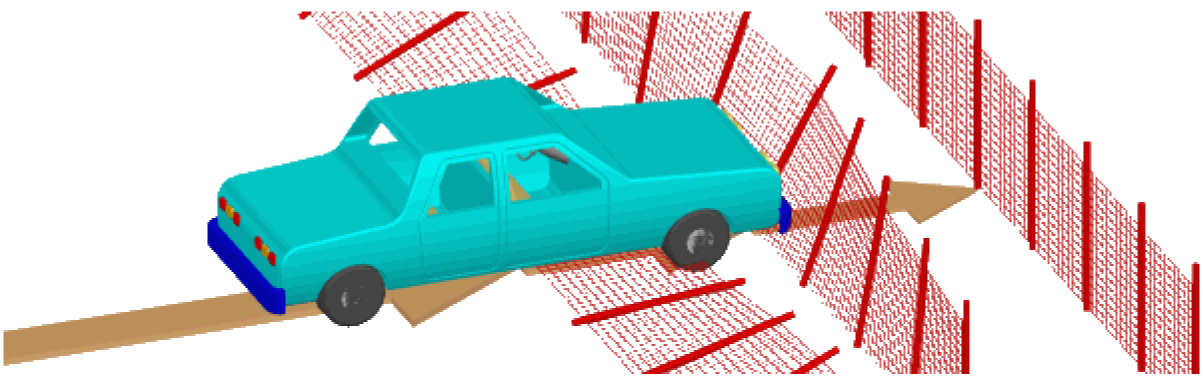
For more information about nets and cushions, including their use and installation, see Chapter 9 -- Nets, Cushions, and Fences



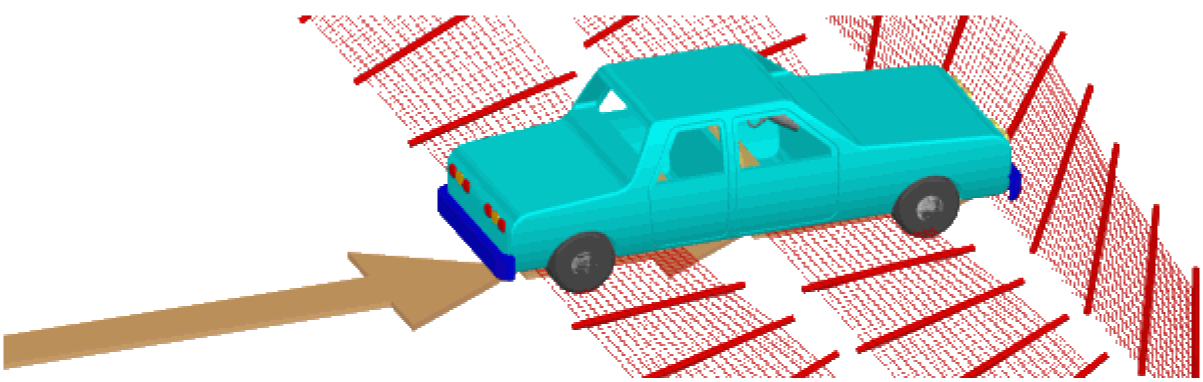
-0.50 sec.
Collision Approach



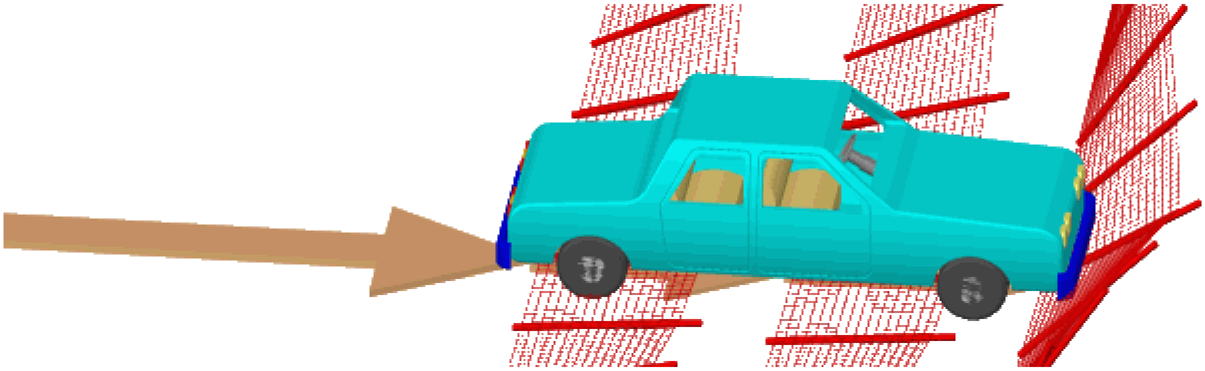
+0.00 sec.
Initial Impact at Full Speed



+0.85 sec.
Elastic Deformation of Net 1 and Speed Reduced by 30%



+1.80 sec.
Elastic Deformation of Net 2 and Speed Reduced by 65%



+3.00 sec. Elastic Deformation of Net 3 and Vehicle at Full Stop

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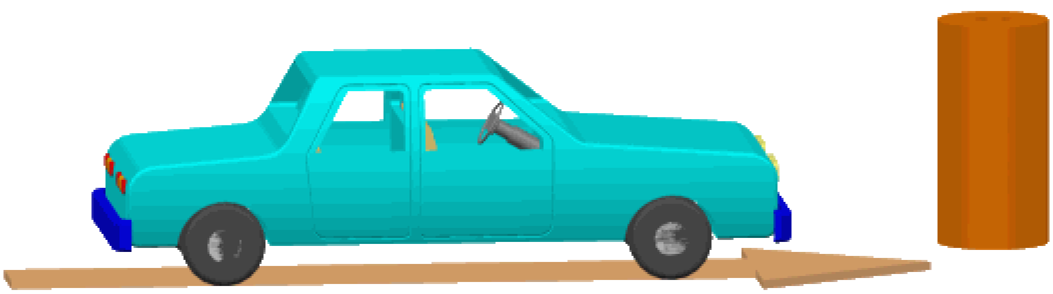
8.3.5 ECCENTRIC IMPACT

ELASTIC FOAM CUSHION

The eccentric impact, illustrated here, shows a motor vehicle in an off center collision with a high density closed cell foam cylinder. The closed cell foam provides elasticity, and effectively distributes the forces over a large surface area. It rebounds to its original form after the vehicle has passed by.

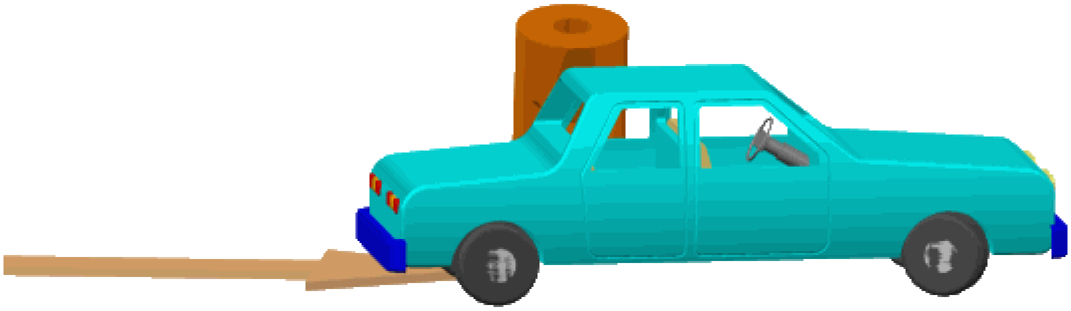
For more information about nets and cushions, including their use and installation, see ***Chapter 9 -- Nets, Cushions, and Fences***



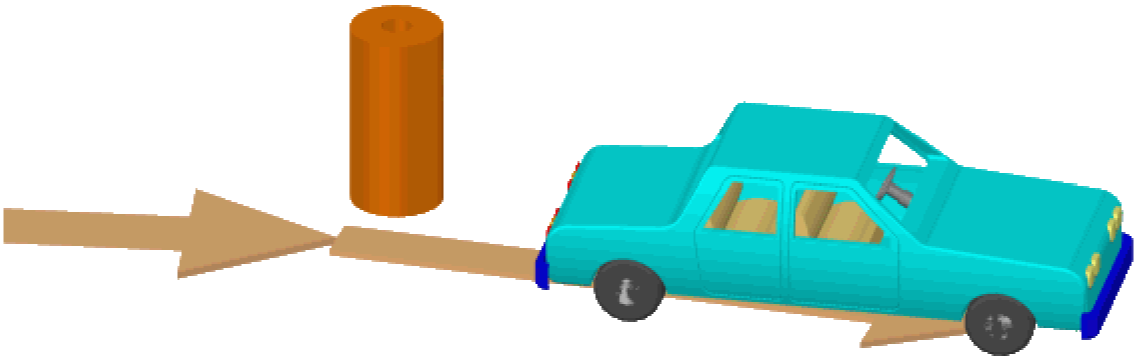
-0.5 sec. Collision Approach

+0.0 sec. Initial Impact

+0.40 sec. Plastic Deformation of Foam & Rotation of Vehicle



+0.80 sec.
Rotation &
Translation
of Vehicle



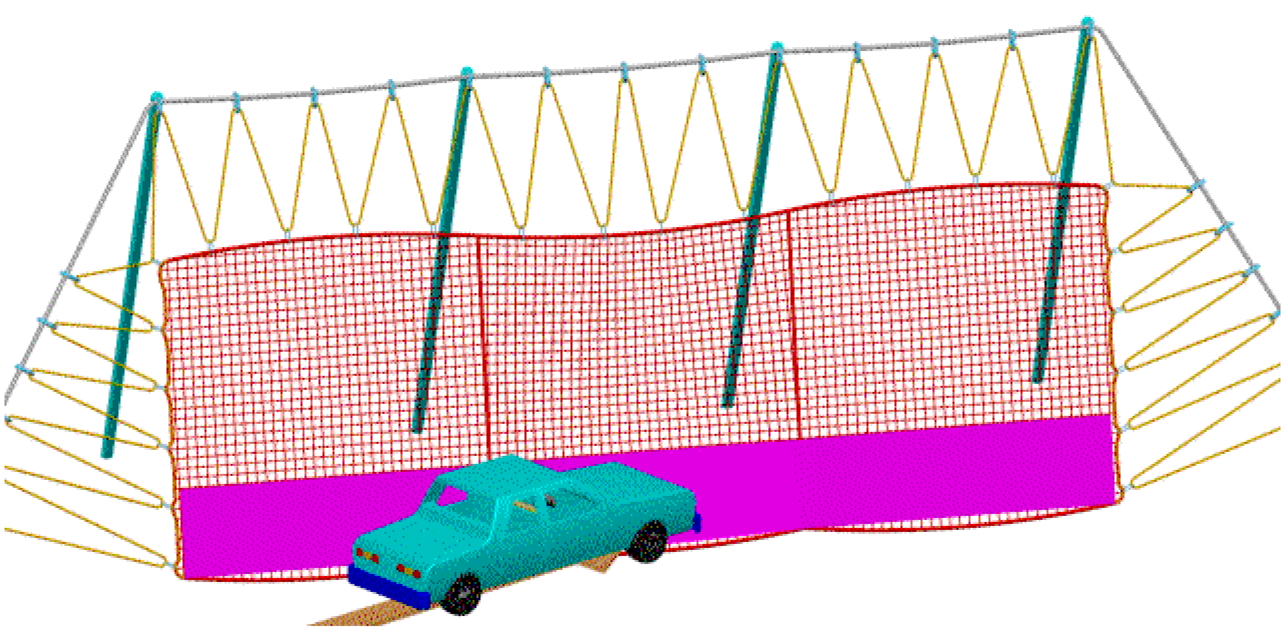
+1.20 sec.
Slightly
Redirected
Path of
Travel

8.3.6 OBLIQUE IMPACT

ELASTIC "A" NET & SLIP SHEET

The oblique impact, illustrated here, shows a motor vehicle in a side-swipe collision with an elastic "A" Net system. The "A" Net flexes to absorb the impact The top slip sheet resists penetration of the net and, more importantly, provides some protection from snagging that may shear the net strands. The reader may observe that the "A" net resembles a trampoline mounted near vertically (75º to 85º from vertical) .

For more information about nets and cushions, including their use and installation, see Chapter 9 -- Nets, Cushions, and Fences.



+0.0 sec.
Initial
Impact
.
(Ropes
Stretch and
Gather
Slightly in
Center as
Net Bulges
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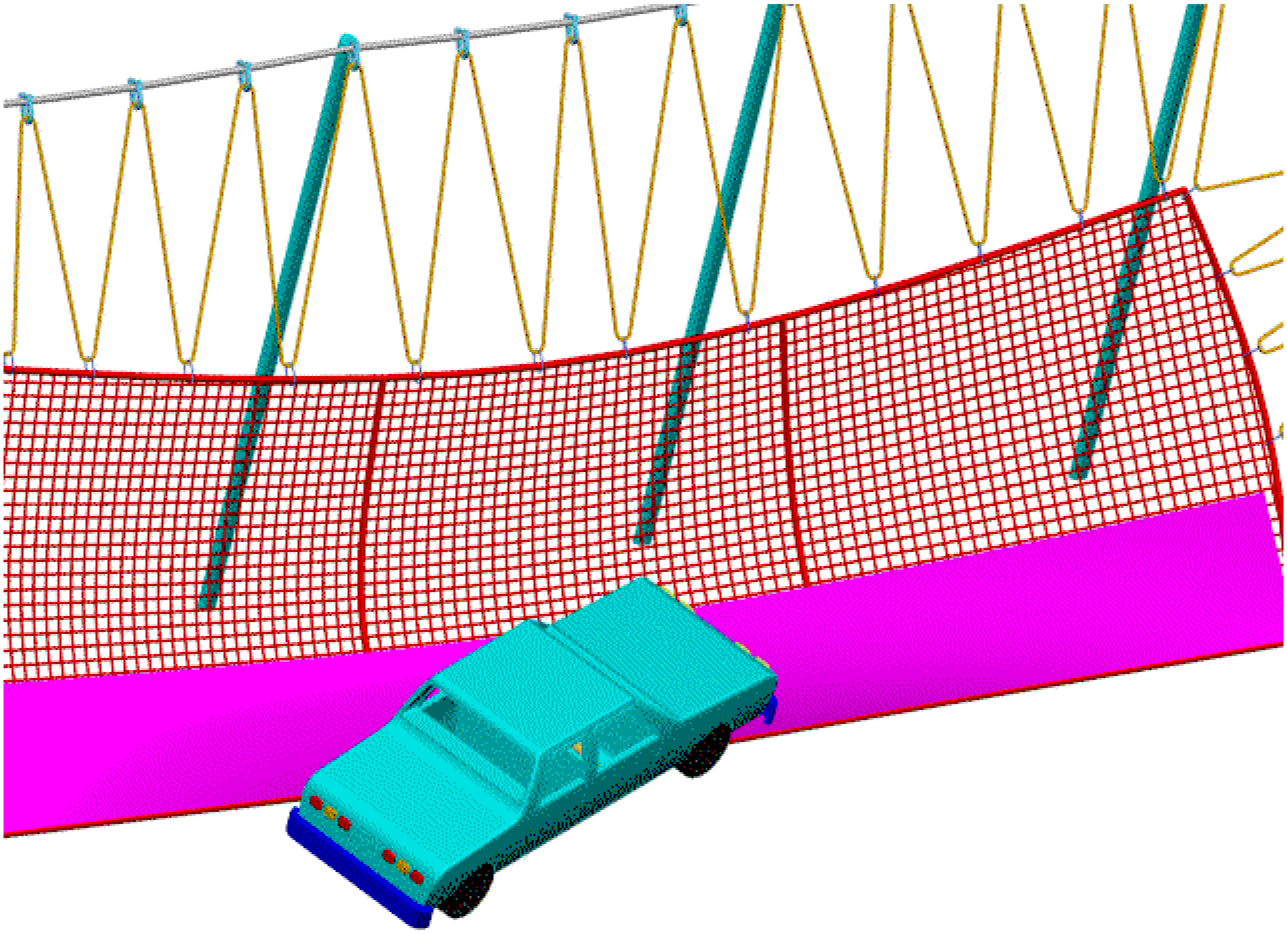
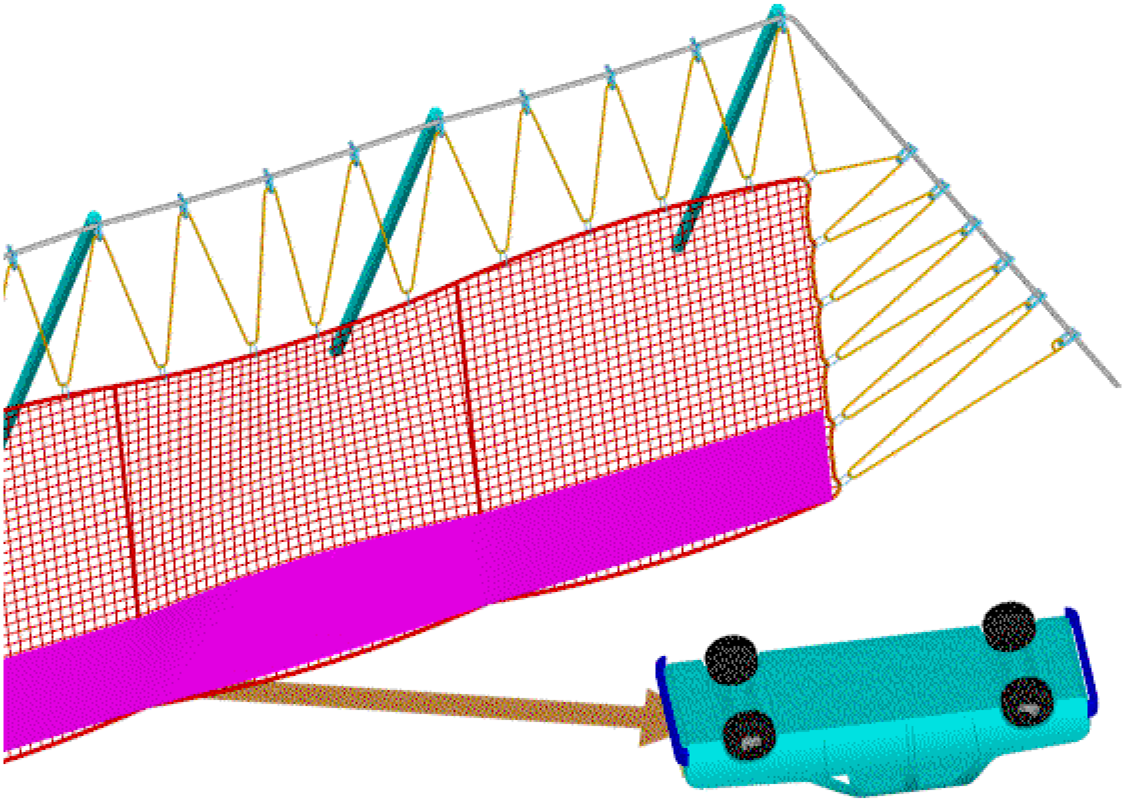


+0.75 sec.
Plastic Deformation & Rotation, Speed Reduced by 20%.
.
(Ropes Stretch and Gather in Elastic Support of Net Center, Where Impact Is Forcing a Bulge.)

+1.6 sec.
Deep Bulge Impacted Into Net, Speed Reduced by 65%.
.
(Ropes and Net Have Stretched to their Limit, Nose of Car Falls Back to Snow Surface as Tail Rises Up Slip Sheet.)



+2.5 sec. Elastic Rebound of Net and Expulsion of Vehicle, Redirected Path of Travel.

The ***peak force*** that we are referring to is described as a multiple of the force of gravity, abbreviated as ***G***. In other words, a 5 pound body, traveling at ***x*** velocity, impacts in an inelastic collision with a force equivalent to 10 pounds, or ***2 Gs.***

G-force in a collision is calculated using the following formula:

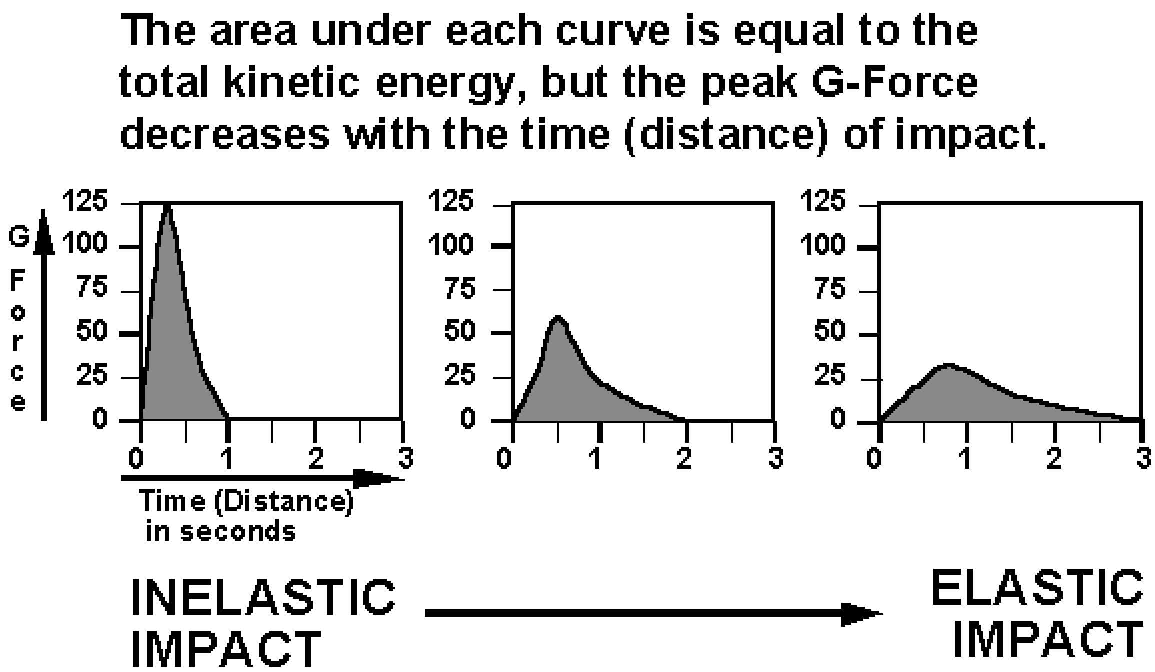
G's = .0333 X (miles per hour)^2 ÷ Distance.
In other words, multiply the square of the body's speed, in mph, times .0333 and divide it by the stopping distance in feet. This formula is more accurate for a direct impact, a ***central impact*** or an ***eccentric impact,*** but a glancing collision, or ***oblique impact,*** is more complicated because the kinetic energy is more fully restored. That is a good thing, as the result is lower 'G-forces'.

It has been generally accepted by the Aerospace Industry that a human body is capable of withstanding up to 7gs without risking life threatening injury. It is important, as well, to keep in mind that these assumptions also include the assumption that the human body is in top physical condition and well fitted in a flight suit and pilots chair. It is possible to build warplanes capable of turns and maneuvers that would impart forces in excess of 9gs on the pilot, but it is believed that the pilot would not survive. Therefore, only pilotless drones should be designed that could execute such a maneuver.

What can we learn from the formula?

We learn that even a 10 m.p.h. reduction in speed dramatically reduces the ***potential force of impact*** (because the speed is squared).

We learn that stretching the collision out over a greater distance will *cushion* or *buffer* the force, and reduce the ***peak force of impact.***



To put those lessons into a summary form:

Extending the distance within which a traveling body decelerates, will reduce the peak force to which it is subjected when stopping.

Deceleration Principle:
Extend the ***DISTANCE***
to **Reduce** the ***SHOCK!***

The energy of forward motion must be absorbed by the human body when a stop occurs, or dissipated through an adequate region of deceleration. As we have said, a collision involves two results: the body impacting another body, and the internal organs impacting inside of the body. By providing a buffer, or region of deceleration, we can help to avoid exceeding the design limits of the human components, and thereby reduce the risk.

The risk of internal trauma, that is the result of abrupt acceleration or deceleration, can be reduced. Recall that a probability of an accident can be reduced somewhat, but not entirely eliminated. An infinitesimal chance is still a chance. However, several mechanisms can reduce this risk, and also contribute to a reduction of risk for external trauma. The most important principle that helps to reduce the risk of trauma is to reduce the opportunities for ***inelastic central impact***, and establish conditions whereby impact, should it occur, will be more ***elastic*** and principally ***oblique impact.*** In this way, the peak force that may be realized is reduced, and the risk of trauma is reduced as well.

This fundamental principle is so important, we are going to emphasize it:

Risk Reduction:
To reduce the risk of trauma, reduce the opportunities for ***inelastic central impact***, and establish conditions whereby impact will be more ***elastic*** and principally ***oblique impact.*** In this way, the peak force that may be realized upon impact is

reduced, and the risk of trauma is reduced as well.

Extending the distance within which a traveling body decelerates, will reduce the peak force to which it is subjected when stopping.

Think of the crash, witnessed by millions on television, of Herman Maier in the 1998 Nagano Olympic downhill. Mr. Maier approached a headwall and lost his balance when he was ejected into the air. Because his skis were in the air over his head, he was unable to exert sufficient *centripetal force* to resist his *linear forward momentum* that was now transporting him out of the ideal racing line. At this moment, the only braking motion that he could offer was the *aerodynamic drag* that he effected by stretching the bulk his form out of his tuck.

His path through the air described an arc from the lip of the jump to the first point of *impact* below. That first *impact* was *oblique*, as the slope tapered down and away. He was slightly redirected but not halted. It was also *elastic* in that he twisted and began to tumble but continued on his way without fracture or disassembly. There may also have been a moment of *dry friction* as his helmet and shoulder grazed the slope.

His *central impact* with the first net was almost entirely an *elastic impact.* The net offered token resistance, which slightly slowed his velocity, but collapsed out of his way. I am sure that there was some minor compression of Mr. Maier's soft tissues, but that seemed to exhibit *elastic rebound.* The first net also exhibited *elastic rebound,* after it released his muscular form into the second net, and popped back up into its original position.

The *Hermanaiter's* impact with the second net was equally *central* and equally *elastic* as his encounter with the first. Perhaps some of his soft tissue was compressed as the net offered some resistance. Certainly the net deformed out of his way. However, his velocity was somewhat reduced further, and the net rebounded to its original position after unceremoniously dumping him into the snow field beyond. Again, a classic *central impact* that exhibited good *elastic rebound.*

Finally, Mr. Maier tumbled through a field of loose, chopped snow that fell away downhill. *Sliding friction* through this landing area offered him his final *oblique impact,* and he further *decelerated* until he *skidded* to a halt a little farther down the hill. He was slightly bruised, evidence that the rebound of his soft tissue was not entirely *elastic,* but displayed otherwise good health. I was left with the impression that he experienced more emotional trauma than he did physical trauma.

For the television viewer, it was a very joyous moment to see him stand up and flap his arms. His next reaction was to begin climbing up the slope, which I witnessed with utter incredulity.

My incredulity should have been tempered by my understanding of what I had just witnessed. The outcome, Herman's intact physical health, was logical (if not guaranteed). In each phase of the acrobatic display, Mr. Maier either experienced a very shallow *oblique impact,* or a *central impact* that was almost fully *elastic.* He was gradually brought to a controlled halt in soft snow. All of these measures had been planned by the Race Organizer, although they had hoped that no one would test those measures.

His reaction at the press conference after the race was priceless. When asked what was going through his mind as he flew off the jump, his response was, "No gold today!" He subsequently went on to win the gold medal in the next men's race. I have always wondered if he ever went back to kiss those nets.

8.4 Risk and Risk Reduction:

Let's recall our basic axiom:

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Competitor Protection: **is the introduction of any measure that is believed to help reduce a portion of the risk to which the competitor may be exposed.**
Risk Reduction: To reduce the risk of trauma, reduce the opportunities for ***inelastic central impact***, and establish conditions whereby impact will be more ***elastic*** and principally ***oblique impact.*** In this way, the peak force that may be realized upon impact is reduced, and the risk of trauma is reduced as well.
Extending the distance within which a traveling body decelerates, will reduce the peak force to which it is subjected when stopping.
Deceleration Principle: **Extend** the ***DISTANCE*** to **Reduce** the ***SHOCK!***

The measures to which we refer are guided by three basic options.

Recall that water safety class trains the lifeguard to remember a simple phrase: ***reach, throw,*** and ***go***. This phrase contains the three basic options that should govern the choices the lifeguard will make when a swimmer is in distress.

First, ***reach*** for the swimmer with a pole, ladder, water craft, or any object that the swimmer can grasp. If none are available then ***throw*** anything that the swimmer can grasp to aid him, a buoy, a floatation ring, a life jacket. Last, if none of those options are available, ***go*** into the water and execute a personal rescue.

The lifeguard is taught to follow these guidelines in sequence. In other words, *going* into the water should be considered *last* because it is the least attractive option. ***Reaching*** is preferable to ***throwing****,* which is preferable to ***going***.

In the same manner, we shall consider a basic approach to ***competitor protection***. To that end, we have identified three options that should govern our approach: ***avoidance****,* ***deflection****,* and ***deceleration***.

Competitor Protection Measures: ***Avoidance*** ***Deflection*** ***Deceleration***
Remember: ***avoidance*** is preferable to ***deflection,*** which is preferable to ***deceleration.***

Like the water safety motto, these options should be considered in the order that they are listed.

Avoidance is preferable to ***deflection,*** which is preferable to ***deceleration.***

8.4.1 Avoidance:

Competitor Protection Measures: ***Avoidance*** ***Deflection*** ***Deceleration***
Remember: ***avoidance*** is preferable to ***deflection,*** which is preferable to ***deceleration.***

The first step in any of the measures introduced to help reduce risk should be to avoid the circumstance that seem to introduce the risk. Let's consider an impractical example. Suppose that we're setting a race course, and in the middle of the trail where we're setting stands a snow making hydrant. It should be obvious that one of two courses of action should be considered: set the course so that it ***avoids*** the hydrant so as not to pose a risk, or remove the hydrant.

The example was impractical because most ski areas have removed snow making hydrants from trails and placed them along the edge, or in the woods near to the edge. However, the illustration of the principle is instructive.

First, and always, seek to avoid risky circumstances. For example:

- Avoid Fixed Obstacles (Snow Making Hydrants; Trees; Ravines; etc.).
- Follow Homologation Guidelines for the Trail.
- Be aware of changing weather conditions (rime; fog; deep snow; etc.).
- Course sets that require unnatural technique or acrobatic efforts.
- Be conscious of the abilities of all the competitors.
- Watch guard to keep the fall zones clear and unobstructed.
- Maintain an adequately sized finish area.
- Offset the bottom gate pole in flushes and hairpins.
- Maintain control of access to, and movement on, the race trail.

Maintain control of access to, and movement within, the finish area.
Homologation guidelines include generally accepted standards for trail widths on a discipline by discipline basis. It is recommended that Slalom trails be a certain width, Giant Slalom trails another, etc. These guidelines may change from time to time so we won't list specific values here. However, one of the reasons for the trail width guidelines is to afford the course setter the opportunity to avoid minor blemishes when necessary. These may include soft spots, thin cover, and crowd control measures. Another is to afford adequate room to effect a large enough turn radius, generic to each discipline.

If the race course is shrouded in fog or rain, unfavorable visibility exists, wait until conditions are favorable. ***Avoidance*** of unfavorable conditions includes those provided by mother nature. If the athlete is not exposed to conditions of seriously reduced visibility, the athlete will ***avoid*** the increased risk associated with reduced visibility. Experienced Referees, and the teamwork of a Race Jury, can make responsible judgments of this kind.

One of the duties of the Technical Delegate is to recommend to the Jury the withdrawal of permission to start for any competitor who, in the TD's judgment, lacks the ability to ski the course with good racing technique. Of course, the Jury can also act to do the same without the expressed recommendation of the TD. By ***avoiding*** the circumstance where a competitor is exposed to a technical challenge that seems to be beyond their ability, risk is reduced.

The course setter, through their experience, knows that various terrain features may pose a greater technical challenge for the racer. Through the appropriate use of hairpin sets, to effect transitions across the hill, and control gates, the course setter may set so as to ***avoid*** unfavorable terrain features. By ***avoiding*** unfavorable terrain features the course setter may help to reduce risk.

A gate panel may disturb the racer's balance if the racer gets entangled in it. The Chief of Course knows that it is possible to attach panels to one pole only, leaving the panel unfastened on the turning pole so that it may slip free if caught by the racer. The Organizer may also supply the Chief of Course with panels that are constructed to break free, through the use of tear away velcro strips or by other means, if an entanglement occurs. By ***avoiding*** the establishment of sources of entanglement, the Chief of Course may reduce the risk of entanglement.

Consider another guideline: wherever possible, keep the ***fall zones*** clear. This is classic avoidance reasoning. Once again, the *fall zone* is an area where there is a *somewhat higher probability* of a racer sliding and coming to a stop after a fall. There is no *certainty* that racers will land in the fall zone, but a somewhat greater *probability* exists that they will. Therefore, it may be possible to reduce the risk to the racer by keeping the fall zones clear. This guideline falls under the principle of ***avoidance***.

"Rule of Thumb" for estimating *Fall Zone* distance:

Maintain an unobstructed area below the gate line of:

-- approximately 3 racer lengths for Slalom.

-- approximately 6 racer lengths for Giant Slalom.

-- approximately 12 racer lengths for Super-G.

-- approximately 24 racer lengths for Downhill.

Increase this basic distance by the percent grade of the slope.

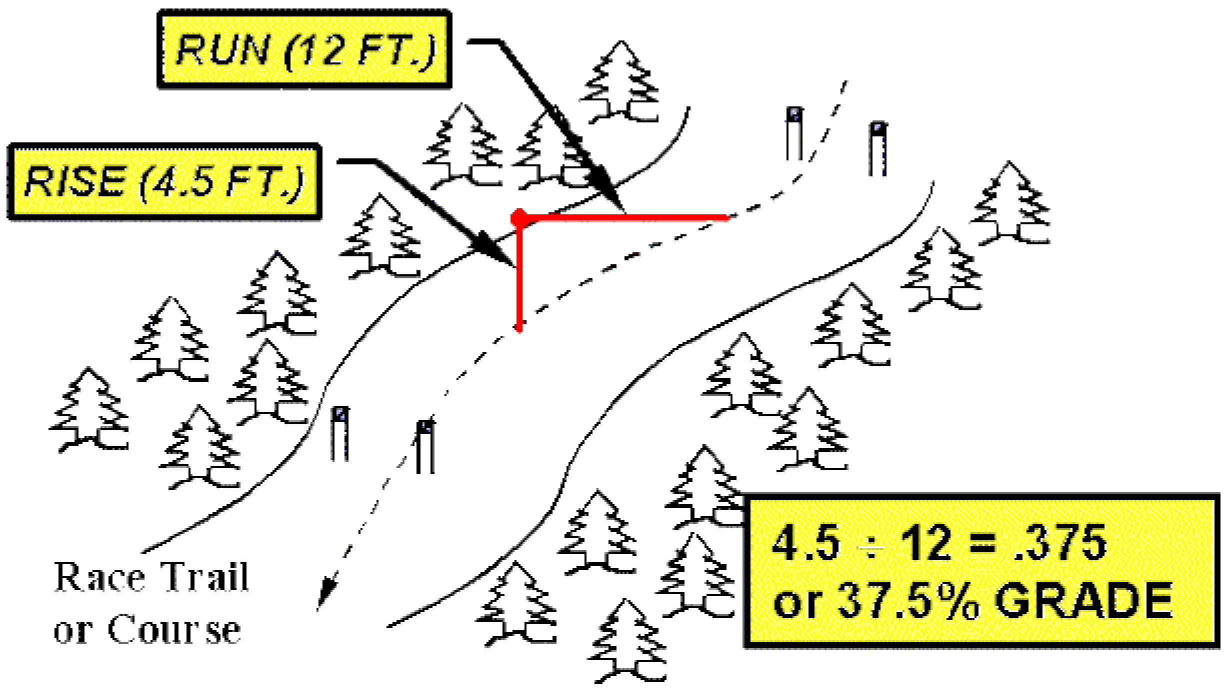
Example for a slope of 25% grade (25%=.25):

A GS racer is 6 feet tall and:

6 feet x 6 lengths = 36 feet + (36 feet x .25) = 45 feet

There are also guidelines for how large to make the finish area. This is done to ***avoid*** the possibility of having the racer run out of room before they effect a complete stop. The size of the finish area is dictated by the average speed expected in the event. Generally, finish areas are constructed of a given depth for each discipline.

Return for a moment to our discussion regarding ***percent grade.*** If the finish area extends over a slope that pitches down and away from the finish area it may be prudent to make the finish larger than the recommended norms for the event. We know, for example, that a skier gliding down a slope of 15% grade experiences an additional motive force equivalent to 15% of their weight. This is a silly example because it would be unlikely that a finish area would be set on a pitch that is so steep. But let's assume that this is the case; it's not inconceivable. In this case, it would probably be a good idea if the finish area were made 15% deeper than the recommended norm for the discipline. This would help to ***avoid*** any problems.



In speed events especially, but to a lesser degree generally, the race organizer should maintain control of access to the course, and movement on the race trail. Controlling movement on the trail will help to avoid the possibility of a collision between a skier, or spectator, and a racer.

In the same manner, control must always be maintained over access to, and movement within, the finish area. This is true for all disciplines at all times. Generally, only a competitor, entering the area by crossing the finish line, should be allowed access to the finish area. Exceptions may be made for course maintenance, but controls should be in place to hold racers or provide another means of helping to ensure that the course worker doesn't interfere with a racer.

Much of what falls under this guideline is common sense. The author maintains the viewpoint that common sense is not all that common. However, it is also recognized that a Jury and Race Committee can bring many talents and many viewpoints together. The effect that those individuals can have when working on a race is often greater than the sum of their parts. What one person fails to see another may recognize. The *common sense* that is most effective is the *common sense of the team*.

What do we mean by the *common sense of the team?* By this we mean that it's always a good idea to have more than one pair of eyes, more than one head, examining the procedures and looking for ways to improve. A *race jury* is usually composed of experienced individuals and having more than one official of experience helps ensure that fewer things are overlooked.

But more than that, one individual may make a judgment with good intention that another advises against because a detail was overlooked. With the very best of intentions an experienced official can make an error in judgment because a detail was overlooked, or because something wasn't reported to them. Having several officials of experience helps ***avoid*** these oversights because one official will see or hear something that the other missed.

The members of the *race jury* should work together in support of one another, and function as a team. By keeping their purpose focused on providing the best possible competitive experience for each racer, the *race jury* will ***avoid*** problems and ensure a successful outcome.

Remember: ***avoidance*** is preferable to ***deflection,*** which is preferable to ***deceleration.***

.

Competitor Protection: **is the introduction of any measure that is believed to help reduce a portion of the risk to which the competitor may be exposed.**

..

Risk Reduction: To reduce the risk of trauma, reduce the opportunities for ***inelastic central impact***, and establish conditions whereby impact will be more ***elastic*** and principally ***oblique impact.*** In this way, the peak force that may be realized upon impact is reduced, and the risk of trauma is reduced as well.
Extending the distance within which a traveling body decelerates, will reduce the peak force to which it is subjected when stopping.

8.4.2 Deflection:

Competitor Protection Measures: ***Avoidance*** ***Deflection*** ***Deceleration***
Remember: ***avoidance*** is preferable to ***deflection,*** which is preferable to ***deceleration.***

Where possible, the preferred method of managing the potential for collision is to ***deflect*** the object away from the collision. To use the terminology that we have just learned: conditions should be established whereby the last line of defense before a *central impact* can occur would be to introduce an *oblique impact.* An *oblique impact*, by its nature, allows the colliding body to continue along a ***deflected*** path that is oblique from the path of incidence to the collision.

The principle of deflection presumes that the body in collision will be deflected into a clear area where it can continue along an unobstructed path of travel, and decelerate to a stop.

- Set Nets in front of fixed obstacles to deflect, not to catch.
- Set slip sheets on nets and fences where oblique impact may occur.
- Deploy foam ramps in front of finish timing equipment.
- Deploy mattress fences that funnel a racer over the finish line.

- Employ the natural fall line of the slope to direct the racers line.
- Ensure that “landing zones” are located on down slopes.

That's a fancy way of saying that the body glances off of something and continues along another path. The ***deflection*** will be a shallow angle, of less than 90 degrees by definition, and preferably less than 35 degrees in practice. The important point in this is that the body is not halted but is allowed to continue on and dissipate its kinetic energy along a redirected path. Depending upon the nature of the impact the body may surrender some of its kinetic energy in collision, but enough is maintained to allow it to proceed.

Consider a closely allied sport, the aerial ski jumps. In aerials the athletes are sometimes launched three or four stories above the ground to provide them space and time to perform their most complicated tricks. Yet, they consistently land and ski down an outrun without catastrophe. I have personally witnessed them landing on backs, shoulders, and hips as well as their skis, and walk away from the fall.

How is this accomplished?

When the athlete lands they are landing on a slope that is steeply pitched so that they impact it obliquely. The energy of their fall is ***deflected*** down the slope rather than halted abruptly. Also, the snow cover on the landing area is chopped to be light and fluffy and provide an additional cushion from the impact. Maintenance of the snow pack depth, and the degree of chop (or *fluffiness*) in the snow, is an activity that keeps several people busy throughout the competition.

Remember, stretch the stop out over a greater distance and the kinetic energy is dissipated with less impact force (refer to the formula for G-forces at the beginning of this section). The longer a time given to stop, or conversely the greater the distance, the less will be the peak force of impact. In common language, work to provide an easy, gentle stop instead of a forceful, abrupt one.

For alpine skiing, the same principles apply. The race course should be generally directed down the fall line, and netting should run in lines parallel to the fall line. In this way, a racer should seldom be directed straight into nets or cushions, but instead collide with them (in the event of a loss of control) at shallow angles.

Additionally, ***slip sheets*** may be installed where impact with a net is likely, to reduce the chances of entanglement. ***Slip sheets*** increase the probability that the racer is ***deflected*** off the net and is redirected down the slope. A ***slip sheet*** is a tight nylon mesh that resists penetration by skis, poles, hands, elbows, etc. It is installed on the race course side of the net.

Other techniques of ***deflection*** are also employed in alpine ski racing. For example, foam ramps are often anchored in front of timing equipment. These devices resemble oversized chock blocks, the blocks used to prevent motor vehicles from rolling away during repair operations. Some have described them as oversized door stops. Should a racer's line direct them into collision with the timing equipment, the ramps will ***deflect*** the racer up and over the equipment, thus avoiding a *central impact*. The racer's kinetic energy can then be dissipated in a gentler stop in the finish area.

In a similar fashion, it is not uncommon to see large mattresses erected on either side of the approach to the finish line. These oversized cushions are planted in a line that funnels the racers line over the finish line. In keeping with the general principles of ***deflection,*** these cushions should not be erected to stand at a perpendicular across the line of approach through a fall zone. They should be erected to ***deflect*** a racer that deviates from the racing line, and redirect them over the finish line, where they can dissipate their kinetic energy through the finish area.

"A" nets, when hung in front of lift towers, are often anchored into a wedge shape. In this way, a racer whose lines directs them towards the tower will be ***deflected*** to either side of the tower.

Cushions and pads may be hung on television towers, trees, snow making hydrants, or other structures of a permanent nature. These cushions are usually the last line of defense behind a primary net that is intended to ***deflect*** the skier away from the structure. Even as a secondary measure, the pads are typically hung so as to ***deflect*** the skier back onto the unobstructed trail, rather than catch them.

Remember: ***avoidance*** is preferable to ***deflection,*** which is preferable to ***deceleration.***

Competitor Protection: **is the introduction of any measure that is believed to help reduce a portion of the risk to which the competitor may be exposed.**

..

Risk Reduction: To reduce the risk of trauma, reduce the opportunities for ***inelastic central impact***, and establish conditions whereby impact will be more ***elastic*** and principally ***oblique impact.*** In this way, the peak force that may be realized upon impact is reduced, and the risk of trauma is reduced as well.
Extending the distance within which a traveling body decelerates, will reduce the peak force to which it is subjected when stopping.

8.4.3 Deceleration:

Competitor Protection Measures: ***Avoidance*** ***Deflection*** ***Deceleration***
Remember: ***avoidance*** is preferable to ***deflection,*** which is preferable to ***deceleration.***

Extending the distance within which a traveling body decelerates, will reduce the peak force to which it is subjected when stopping.
For more information about nets and cushions, including their use and installation, see ***Chapter 9 -- Nets, Cushions, and Fences.***

Deceleration Principle: **Extend** the ***DISTANCE***

to **<u>Reduce</u>** the ***SHOCK!***

This is the guiding principle of ***deceleration***. Provide a sufficient space, or a soft and springy net, that will **<u>slowly</u>** reduce a speeding athlete and bring them to a controlled halt, without an abrupt stop. Often, several collapsible nets are used that present a token resistance and reduce a racer's speed step by step, net by net. Remember Herman Maier's crash through two nets? The nets were designed to collapse, only maintaining erect long enough to slow his speed by 30-40%. For the most part, large run out areas, free of obstacles, are the most effective tools to give a skier time to slow down and stop.

Remember, *s_t_r_e_t_c_h* the stop out over a greater distance and the kinetic energy is dissipated with less impact force. The longer a time given to stop, or conversely the greater the distance, the less will be the peak force of impact. In common language, work to provide an easy gentle stop instead of a forceful, abrupt one.

This is the principle behind motor vehicle crash testing technology. The front and rear extensions of the automobile are sacrificed as cushions to reduce the peak force of impact on the passenger cage. The familiar industry term ***crush zone*** illustrates this idea. By sacrificing the car frame and body members, designing them to progressively crush down, the collision is extended over a longer distance, cushioning the impact and thereby reducing the peak force. The vehicle is ***decelerated***, rather than abruptly forced to halt.

Think of the acrobats in a high wire circus act. When they drop into the net it *s_t_r_e_t_c_h_e_s* down, and then rebounds back up, like a trampoline. In fact, a trampoline is another illustration of our point. Both illustrate the effect of a body, traveling at speed, impacting a net (or trampoline), that stretch and dissipate the kinetic energy through a buffer zone, thereby cushioning the impact. Rock climbers, too, use ropes that stretch like rubber bands, so that a fall is cushioned when the rope pulls taught.

In fact, the most graphic example is bungie-cord jumping. The ropes used by bungie jumpers are the same as those used by rock climbers. Imagine the result if the jumpers used inelastic nylon or steel cable. It's not a pretty picture. They would very quickly be at *the end of their rope* when the cable pulled taught. By stretching a long distance, the bungie-cord slowly transforms the kinetic energy into elastic potential and heat (by friction). The great distance of stretch reduces the peak force to a level that is tolerable for the jumper's internal organs, muscle, and tendon.

Nets are usually erected on a race course using the same principles. Rather than catching the racer and pulling them to an abrupt halt, they enable the racer to be ***decelerated*** through a buffer zone, and cushion the impact. Recall that first principles suggest that nets be erected in such a manner that they should first ***deflect*** the racer back onto the course (and ***slip sheets*** may be included to reduce the risk of entanglement). But, in the event that the racer's line directs them in a *central impact* with the net, the net should stretch, collapse, or otherwise cushion the impact.

Remember: ***avoidance*** is preferable to ***deflection,*** which is preferable to ***deceleration.***

Competitor Protection:

is the introduction of any measure that is believed to help reduce a portion of the risk to which the competitor may be exposed.

.. <u>Risk Reduction:</u>

To reduce the risk of trauma, reduce the opportunities for ***inelastic central impact***, and establish conditions whereby impact will be more ***elastic*** and principally ***oblique impact.*** In this way, the peak force that may be realized upon impact is reduced, and the risk of trauma is reduced as well.

Extending the distance within which a traveling body decelerates, will reduce the peak force to which it is subjected when stopping.

. **Deceleration Principle:**

Extend the ***DISTANCE***
to **Reduce** the ***SHOCK!***