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Forensic Engineering Analysis of Golf Course, Cart, Club and Ball Accidents

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Abstract

With over 27.8 million golfers and more than 16,000 golf facilities in the United States, golf is a non-contact sport with statistically low risk for injury. However, research has documented golf related injuries can be disproportionally serious or even fatal. Federal regulations and countermeasures to improve golf safety are outlined. A spectrum of forensic engineering analysis of golf-related incidents illustrates the broad range of resulting trauma. Categories of golf incidents include: cart collisions with other vehicles resulting from mixed use on automotive roadways, cart solo incidents including ejection with and without rollover, errant golf ball impacts, inadvertent golf club impacts, trip and fall incidents as well as golf cart fires.

The objective is a principal called "*vision zero*" golf that reaches toward minimizing trauma while acknowledging that safety can only be achieved by a partnership between the designers of the system (engineers and manufacturers) and the safe users of the system.

Keywords

Golf Cart, Recreational Personal Low Speed Vehicle, Head Impact, Golf Injury, Golf Trauma, Vision Zero

Background

PREVIOUS RESEARCH

Previous studies, although relatively limited in number, document golf specific case studies resulting in injury. For each incident resulting in serious injury, there could be thousands of incidents that go unreported due to the absence of significant trauma. A full spectrum of research is presented including each researcher's suggestions and conclusions (although not necessarily of the authors here).

1. It was concluded in a study by Lindsay, et al., that golf leads other contact sports as one of the primary events responsible for head injuries (and specifically of compound depressed fractures) based on a review of 1900 persons admitted to the neurosurgical unit in Glasgow over a five year period.
2. A 1996 North Carolina study reported that 22 people received golf-cart related injuries: 59%

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of which fell off the cart, 40% of which involved alcohol and 9% of which were in a cart that rolled over. On the order of 59% of individuals received head or face injuries, which ranged from lacerations to skull fracture. The golf carts, which had maximum speeds of 14-18 mph, were not equipped with seatbelts or other vehicle safety devices. The author suggested a need for occupant restraints in golf carts when they are used for roadway transportation.

3. A University of Alabama (UAB) study identified individuals via the National Electronic Injury Surveillance System who visited ER departments for golf cart related injuries and found an estimated 48,255 golf cart related injuries. That study concluded, "Case reports suggest severe, debilitating injuries as a consequence of golf cart incidents."
4. A study by the Medical Center of Georgia based on a review of 33 children (< 17 years) admitted to a Georgia hospital with golf-related injury concluded, "Pediatric golf-related head trauma is a significant cause of sport-associated head injury, sometimes harboring a very dismal prognosis."
5. A second study by the Medical Center of Georgia found that 23% of sports injuries were golf-related, the second largest group. The study analyzed 15 pediatric patients with golf-related injuries and found depressed skull fracture to be the most common injury type.
6. A South East Asian study closely analyzed three cases of serious golf cart-related head injuries (one involved moderate head injury with small cerebral contusion and skull fracture and two involved severe head injury with extensive cerebral contusions) as a result of golf cart falls. The study concluded, "Accidents involving golf buggies can result in serious injuries. Strict compliance with safety rules and incorporating safety features to golf buggies will reduce these injuries."
7. A UK study analyzed 33 patients at the ER department at Glasgow Royal Infirmary with injuries caused by golf clubs. The vast majority of the injuries were to the face and head, including three compound skull fractures. The average age of those injured was 8.1 years.
8. The NC Department of Labor recently reported that OSHA has investigated 15 fatalities involving the unsafe use of golf carts.

FEDERAL REGULATION

According to the National Highway Traffic Safety Administration (NHTSA), a 'golf cart' is considered to be a low speed vehicle (LSV) for limited recreational off-road use with a maximum speed of 15 mph. California has defined a 'golf cart' as "a motor vehicle having not less than 3 wheels in contact with the ground, having unladen weight less than 1,300 lb which is designed to be and is operated at not more than 25 miles per hour and designed to carry golf equipment and not more than 2 persons, including the driver."

In response to petitions from the golf community and associated developments, the NHTSA issued a notice of proposed rulemaking (NPRM) in January 1997 with regards to safety standards for LSVs. As a result of the NPRM and related public and industry comments, Federal Motor Vehicle Safety Standard

(FMVSS) No. 500 – Low Speed Vehicles – was enacted on June 17, 1998. However, FMVSS 500 specifies requirements only for low-speed vehicles operated on public streets and highways. Vehicles not intended for use on public roads are not required to meet the safety requirements of FMVSS 500.

In most US states it is not required that the vehicles be equipped with standard vehicular safety features or that the operators wear any form of safety equipment or be of a certain age or possess an operator's license. California legislature enacted a 1995 law for the cities of Palm Desert and Roseville governing that golf carts used for transportation are required to be equipped with seat belts and covered passenger compartments. Other safety equipment such as headlamps, turn signals, mirrors, stop lamps and windshields may also be included.

Discussion: Golf Safety Strategies

Most serious golf cart related injuries occur when operators or occupants are ejected from the vehicle, involved in rollover collisions, impacted by larger vehicles or strike pedestrians. Two important sources of golf course trauma are mixed use and mis-use.

Mixed use involves the use of golf carts off the golf course wherein the under 1300 lb. mass is no match for automobiles. Like motorcycles, and unlike other full size vehicles, golf carts are not perceived as a hazard to drivers of automobiles making the use of golf carts on roadways designed for automotives potentially hazardous.

The second principal area for golf safety improvement is mis-use. A large percentage of serious injury producing golf cart incidents involve underage drivers that lack the awareness of potential hazards. Although golf carts are viewed as light duty and recreational in nature, carts can reach speeds as high as 15 mph and are often modified to go even faster. Even under 15 mph, it would be generally unreasonable to assume that an automobile would be safe for children to operate. Likewise, it is generally unreasonable to assume that a golf cart driven at these speeds is safe for children to operate. Although this is not intended to be a comprehensive list, consumption of alcoholic beverages while on the golf course overlays altered judgment, hazard and risk. Other potential countermeasure categories under discussion include restraints, roll over protection systems, vehicle handling, visibility and maintenance/storage.

Forensic Engineering Case Studies

Eleven forensic engineering assessments represent a spectrum of golf incidents and injuries. The forensic engineering method is utilized; analysis and findings for each case are presented in summary form.

Case Study 1: Golf Cart versus Fixed Object: Curb / Tree Impact

In San Diego, a golf cart, modified for concessions, was driven along a designated paved pathway when the 18 year old female driver lost control resulting in the cart mounting the left side curb and colliding with an adjacent tree (Figure 1 and Figure 2). The cart was found at rest with both left side tires mounting the curb and both right side tires on the pathway. Forensic evidence observed on the golf cart suggested that there was contact of the golf cart with the tree at the bumper, A-pillar and canopy areas (Figure 3). The cart was not equipped with a seat belt or other restraint device. The golf cart was examined and found to have been modified with the addition of a welded steel ice chest to the rear of the cart.

As a result of the collision, the driver of the cart sustained right extremity injuries (requiring open reduction internal fixation surgery) including the following:

1. Right comminuted distal radial metaphyseal fracture
2. Right ulnar styloid fracture
3. Right triquetral fracture
4. Colles fracture (displaced)
5. Right scapholunate ligamentous injury
6. Possible fusion injury

The available forensic evidence indicated that the crash was most likely caused by driver error rather than mechanical defect. Inexperience may have been a contributing factor as this was her second day on the job and the first time driving the entire route with limited education or training. Dynamically, the additional rear weight of the loaded cooler may have contributed to steering ineffectiveness.

Figure 1
Path traveled by golf cart, shown at point of rest

Figure 2
Golf Cart shown at point of rest. Arrows illustrate concession container weight beyond the rear axle

Figure 3
Forensic Evidence showing contact locations on bumper, A-pillar and canopy

Case Study 2: Fall Off Versus Step Off Golf Cart

On a university campus, a golf cart was utilized to transport employees from building to building. An incident occurred while the golf cart was driven across campus with 4 occupants, 2 front-facing and 2 rear-facing at an estimated 5-10 mph speed. The incident involved one of the rear-facing occupants, whose laptop suitcase fell from his lap onto the ground. Nearly 90 feet after the suitcase had dropped, the man reportedly jumped, fell or stepped from the cart and contacted the asphalt surface, first with his feet, followed immediately by his head.

As a result of the head impact with either the asphalt ground surface or the rear platform assembly of the golf cart itself, the following injuries were sustained (Figure 4):

1. Fracture of the frontal calvarium (midline, linear and sagitally oriented)
    a. Fracture runs along the course of the sagittal suture, extending from above the frontal sinus to the vertex.
2. Right hemisphere subdural hematoma 8 mm thickness
3. Subarachnoid bleeding in right frontal and temporal regions
4. "Significant" swelling over forehead

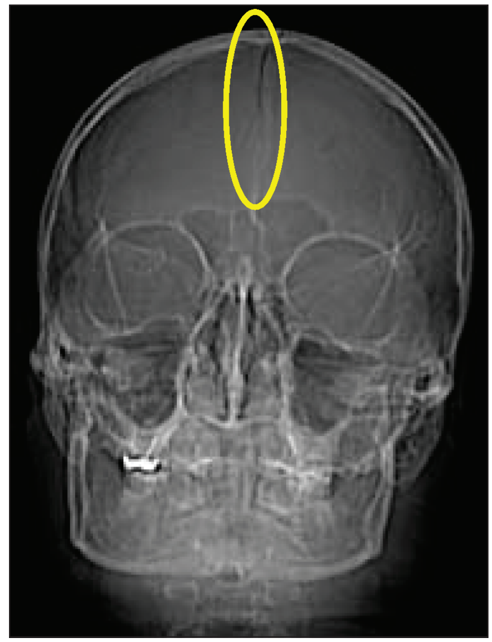

Figure 4
Radiological Image Illustrating
Fracture Trauma Sustained

A forensic engineering analysis of the incident kinematics was conducted in order to determine the likelihood of ejection due to roadway topography versus a self-induced step out of the cart. Coefficient of friction tests conducted on the rear facing seat occupied by the plaintiff (Figure 5) quantified the kinetics required to eject

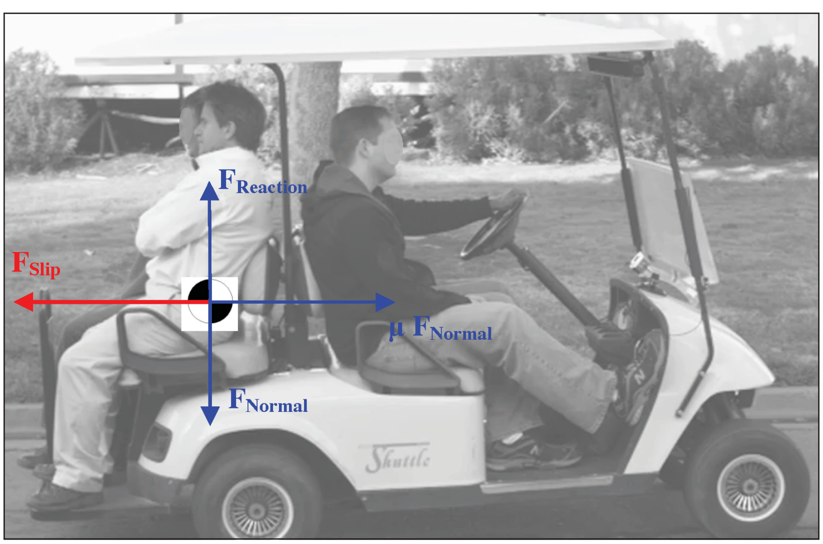

Figure 5
Illustration of exemplar seating configuration with
coefficient of friction diagram overlay

Figure 6
Stuntman testing

the man out of his seat against friction. Figure 6 illustrates stuntman kinematic analysis. Acceleration data associated with the trip across campus indicated that the maximum fore-aft and resultant accelerations produced by the roadway topography were insufficient for inadvertent ejection. Therefore, based upon the testimonial, physical and experimental forensic evidence, the fall from the cart was most likely voluntary (consistent with retrieving his laptop suitcase that had fallen) as opposed to an ejection caused by the alligator cracked roadway topography.

Case Study 3: Fall Off Golf Cart During Turn

In southeast Missouri, an electric golf cart was driven at a maximum speed of 12 to 15 mph when the driver took a sudden turn. A 15 year old male occupant was reportedly riding in the cart in a "playful" fashion and was found to be under the influence of marijuana at the time of the incident. Striking his head on the concrete ground surface, the plaintiff sustained severe head injuries including a temporoparietal skull fracture.

The fracture mechanism was consistent with a fall from the cart as reported. Inverted pendulum testing with the Hybrid III anthropometric test dummy (ATD) was conducted in order to determine if the accelerations resulting from a head-to-concrete impact (Figure 7) would have been sufficient if the plaintiff had been seated. Due to the extremely short time duration involved with a head-to-concrete impact, the Head Injury Criterion (HIC) threshold was exceeded in all experimental trials.

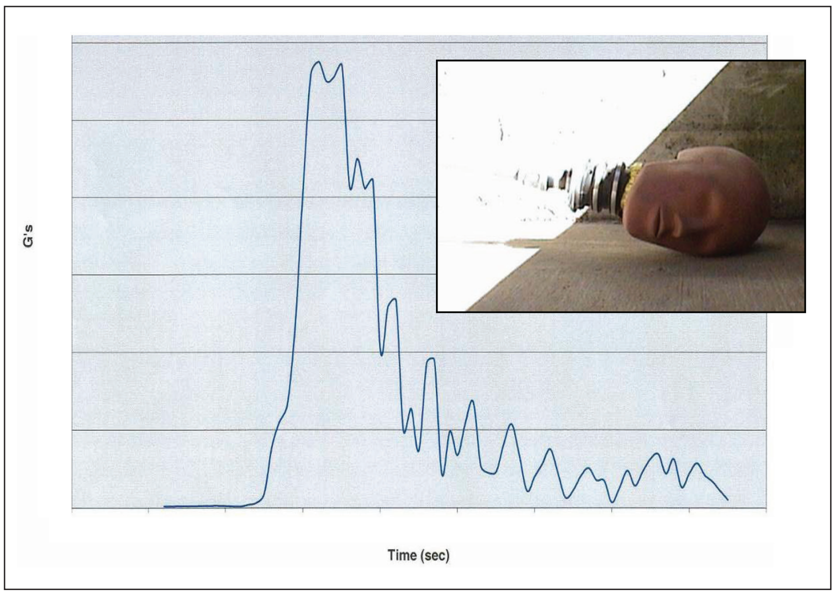

Figure 7
Head to Concrete Testing Exemplar Result

Case Study 4: Fall Off Golf Cart on Poorly Maintained Path

An incident occurred in Illinois involving a player who was allegedly ejected from a golf cart on a poorly maintained alternate cart path. Inspection of the incident scene revealed that there were topographic anomalies present in the area of the ejection including a large pile of brush cuttings and a drainage ditch (Figure 8). Forensic engineering analysis of the scene topography indicated that while the accident was likely caused by irresponsible driving (Figure 9); poor path maintenance, specifically, exposure of the ditch without guarding or warning was also a likely factor.

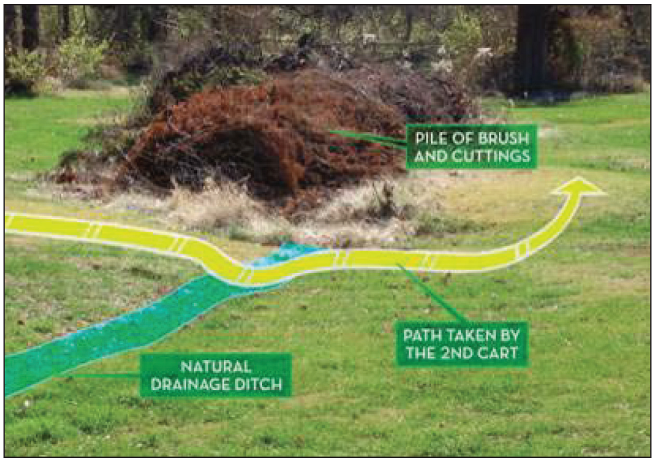

Figure 8
View of golf cart and alternate cart path

Figure 9
Image showing path taken by golf cart

Case Study 5: Golf Ball Impact to the Head

In South Carolina, a 39 year old female instructor was marking a scorecard near the 9th hole green and clubhouse when she was struck in the head by a golf ball (Figure 10). A witness stated that she saw the ball bounce prior to striking the woman. The instructor did not fall, but was found with a golf-ball sized lump on top of her head; there was no reported loss of consciousness.

The plaintiff claimed head/brain injuries as a result of the golf ball to head impact. Medical records reported no objective evidence of brain/skull injury including:

1. No loss of consciousness
2. No tearing/laceration of the skin
3. No soft tissue swelling or dislocation

An engineering analysis of the golf ball trajectory was conducted based on the woman's position in the nearby vicinity of the clubhouse when she was struck by the ball. The angle of departure and departure speed of the ball was calculated based on the distances and known characteristics of the club used (Figure 11). It was found that in order for the ball to clear the clubhouse and bounce prior to striking the 5-foot 9-inch tall woman, the ball would have been traveling at a speed of approximately 27.5 mph upon impact.

Figure 10
Photograph showing approximate location where 39 year old female was struck by golf ball adjacent to 9th green and clubhouse

Testing with the Hybrid III anthropometric test dummy (ATD) was conducted in order to determine the forces and accelerations resulting from a golf-ball-to-head impact from a similar height (Figure 12). The probability of brain injury to the average person was determined to be unlikely in experimental trials.

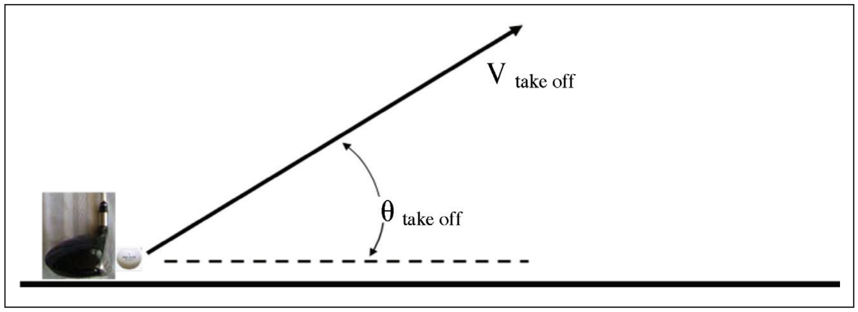

Figure 11
Analysis of golf ball trajectory,
$V_{take\ off}$ ≡ velocity post contact *and* $\theta_{take\ off}$ ≡ trajectory angle

Case Study 6:

Golf Club Impact to the Head

In Chicago, a 12 year old male was struck with the head of the golf club (Big Bertha driver) while he was seated adjacent to the tee. While his partner was taking practice swings, the seated child was struck with the partner's club as it was in the stroke of a full swing. The club reportedly struck the child in the temporal bone (at the area of the left ear) (Figure 13). After impact, the child fell to the ground impacting his head a second time.

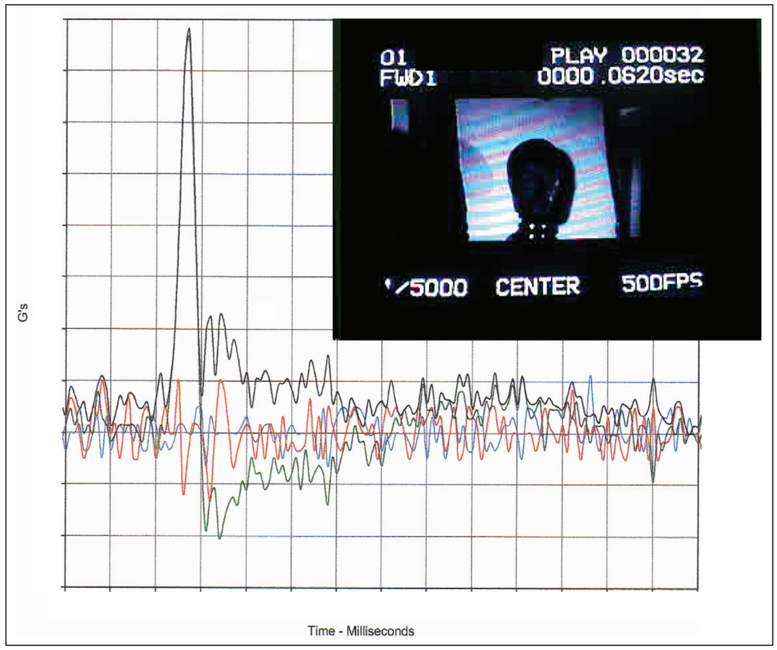

Figure 12
Sample golf ball-to-head impact test plot with Hybrid III ATD as well as high speed video snapshot

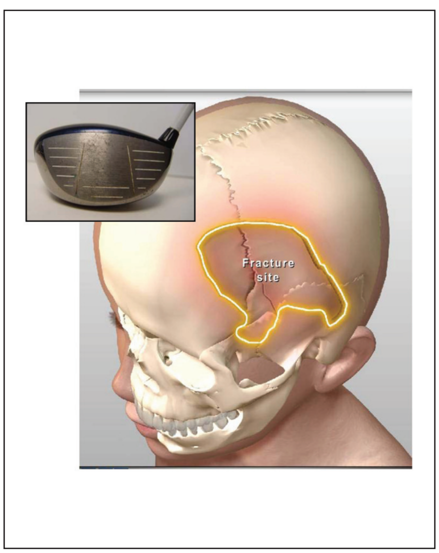

Figure 13
Golf club and resulting impact injury

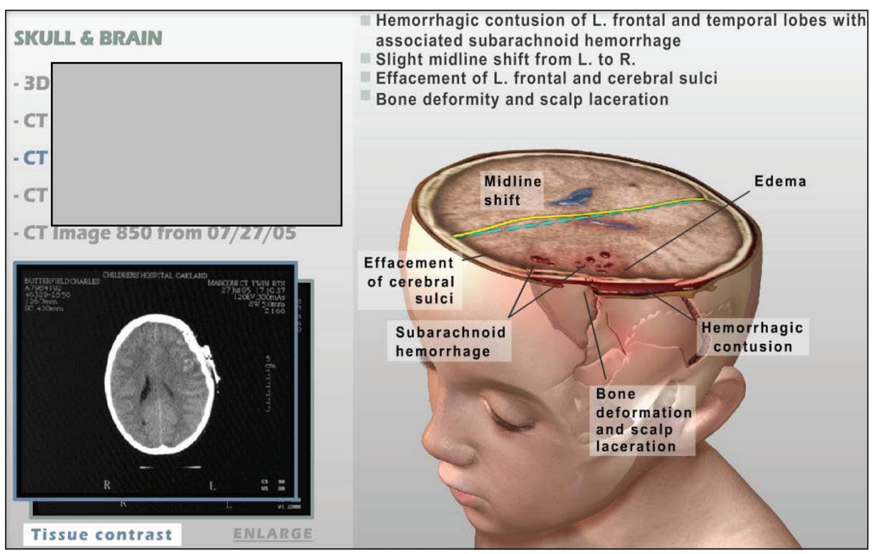

Figure 14
Imagery of resulting injuries

As a result of the incident, the child sustained severe head injuries (Figure 14) including the following:

1. Significant hemorrhagic contusion, generalized brain swelling, subarachnoid hemorrhage and depressed skull fracture.
2. Depressed left parietal skull fracture, craniotomy for removal of depressed skull fragment.
3. Left temporal scalp laceration.
4. Traumatic Brain Injury with right hemiparesis and Broca's aphasia.

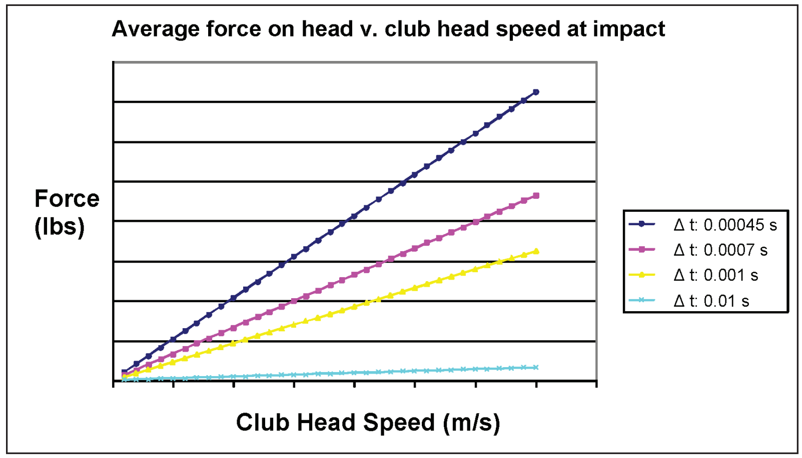

Figure 15
An example of calculated force applied based on club head speed and contact duration

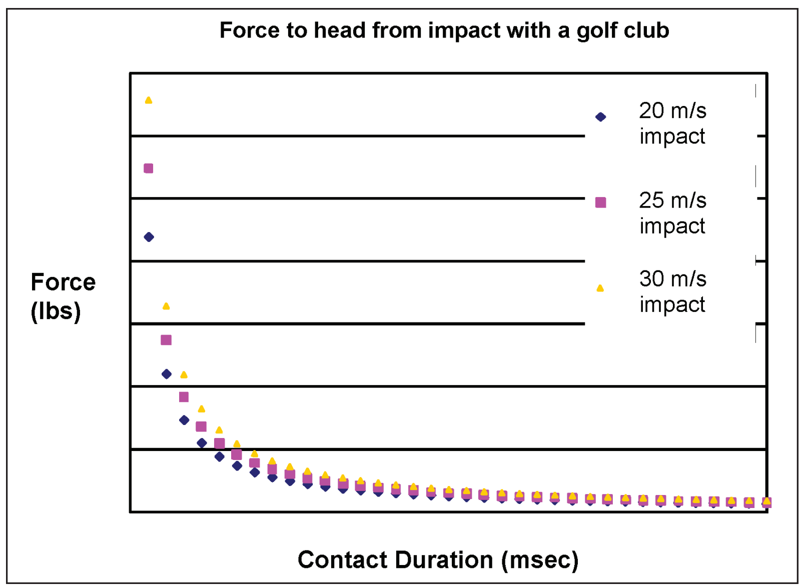

Figure 16
An example of calculated force applied based on club-to-head contact duration

Based on this information, biomedical engineering analysis was conducted in order to quantify impact forces based upon an estimated club-to-head impact speed. An inspection of the club revealed specific size and weight characteristics (Figure 15). The golf club dimensions along with specific child stature information were then used to determine the speed of the club head at the point where it struck the head of the male child. Testing with the "Iron Byron" mechanical driving device suggest that a golf ball remains in contact with the club face for about 450 milliseconds. During the impact phase, the ball is flattened to nearly 2/3 of its original diameter. The ball then leaves the club face at a velocity of about 160 mph, requiring a contact force of over 1700 lb. Based on the calculated club head speed and contact duration, the average force for the club-to-head impact was determined (Figure 16).

Case Study 7: Head Impact due to Fall on Golf Course

In Northern Georgia, a man was severely injured on a golf course when he reportedly walked backward and tripped on a tunnel abutment (Figure 17) and fell to the cart path below (Figure 18). Forensic engineering analysis of the incident location indicated that the man had passed by and through the visible tunnel on previous holes and that the tunnel was obviously marked. To improve, the abutment could have been marked, guarded and/or golfers warned.

Figure 17
View of tunnel abutment from path above

Figure 18
View of tunnel from cart path below where fall occurred

Case Study 8: Highway collision between golf cart and truck

A man was fatally injured after a collision occurred between his golf cart and a truck at a bisection between the golf course and an Indiana State Highway. The golf cart path passed through a tunnel passing below the Highway designed and constructed by the State's Department of Transportation (Figure 19). The players are directed to use the tunnel to traverse the Highway. The carts in use at the time of the accident were approximately three years old.

Figure 19
Photograph showing golf course at bisection with State Highway

Although having playing the course several times before, the decedent crossed the State Highway and drove his golf cart through the public parking lot and out an access driveway, ignoring signs, and customary golf behavior and course policy. At the edge of the Highway, the decedent's passenger warned him of an oncoming truck. Despite his passenger's plea, the decedent proceeded to drive across the Highway and collided with the oncoming truck, ultimately resulting in his fatality. The passenger was able to jump safely from the cart prior to impact.

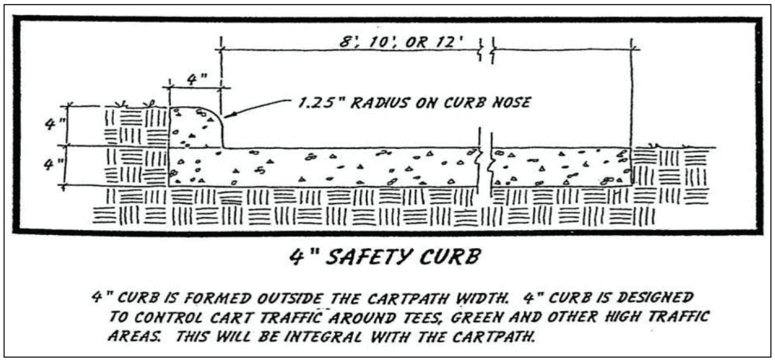

Figure 20
Curb schematic

Figure 21
View of the cart path, curbs and tall fescue grass

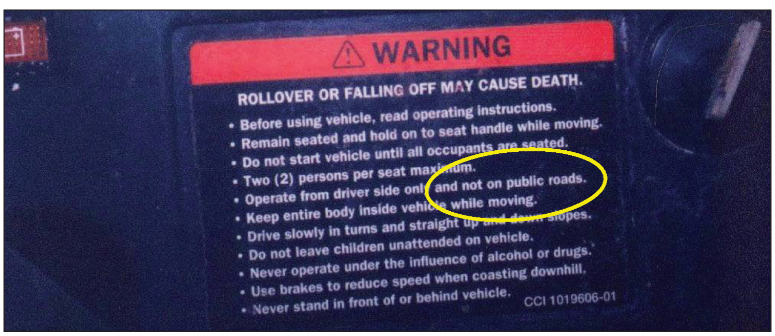

Figure 22
Warning label stating cart should not be operated on public roads

Figure 23
View showing warning sign at the entry to the parking lot

The cart path was found to be a six foot wide, one-way, continuous concrete path with 4” non-mountable vertical curbs (Figure 20) specifically designed to keep carts on the path. The slopes and grades were gentle and provided a clear path for golf cart navigation on the course. The path for crossing the highway was clear, safe and easily found. The tunnel provided for two-way traffic and was 14 feet wide. Further, tall fescue grass, berms, bushes, trees and other landscaping treatments visually define the borders of the course and were an obvious barrier to carts (Figure 21). Warning signs in the cart state, “Operate from driver side only and not on public roads” (Figure 22). Signs were visible throughout the course regarding non-access areas for golf carts (Figure 23).

A detailed analysis of the subject incident revealed that the subject golf course was well-designed, incorporating appropriate design and safety features. The fatal collision was determined to most likely be a result of the decedent’s failure to follow the clear signage, the warnings from the course and staff instruction, his knowledge of the proper safe path and the explicit warning from his passenger.

Case Study 9: Rollover Collision

While on a resort golf course in Oregon, a player and passenger were riding in a golf cart on a wet, leaf-ridden path when the cart skidded and overturned on a steeply sloped bridged area (Figure 24). Forensic engineering analysis established that the cart path exceeded the accepted maximum slope and acted as a drainage swale distributing sand and debris onto the bridge. There were no warning signs alerting of dangerous conditions. It was determined that the likely tripping mechanism for the rollover was the curb which initiated at the bridge where the path curved at the bottom of the slope (Figure 25).

Figure 24
View of the wet, leaf-ridden steeply sloped bridged area

Figure 25
View of the curb
(likely tripping mechanism initiating rollover)

Case Study 10: Fall Off Segway Machine

In Virginia, a man was transporting himself and his golf clubs up a hill on a Segway machine when the machine fell backwards, causing a fracture of the mid left fibula and distil tibia. The Segway machine, as seen in Figure 26, was provided by the golf course as a means for transportation. It was discovered that the man was not riding on the provided pathways, but was riding on a steep un-traveled grass hill. Through analysis, it was determined that the load of the man and the golf clubs was near maximum weight capacity contributing to the inability of the Segway machine to successfully maneuver the hill leading to a fall.

Figure 26
Exemplar Segway machine

Case Study 11: Golf Cart Fire**

A fire occurred in a golf cart storage facility in upstate New Jersey (see Figure 27). A foreign copper wire was found in the battery compartment. It was reported that the golf cart was charging when the charger failed resulting in overheating of the batteries and cables. It was hypothesized that a battery cable failed due to high temperatures, arced and ignited the excess hydrogen. This is significant as golf carts are commonly stored within the clubhouse or the home garage.

Figure 27
Golf cart fire and wiring evidence

Conclusion

Golf is perceived by most as a low-impact leisure sport with minimal associated injury risk; however despite this common perception, this raises awareness of the nature of golf related injuries that can be serious or even fatal. A historical background and eleven forensic engineering case studies demonstrate specific safety risks associated with the use of golf courses, golf carts, golf clubs and golf balls. Seven of the eleven forensic engineering case studies presented involved injury-producing incidents associated with golf cart use.

The sport of golf is one where the "*vision zero*" or "no injury ideal" can be applied with a goal toward eliminating deaths and injuries. In order to approach "*vision zero*" or the goal of eliminating deaths and injuries associated with golf-related incidents: 1) the designers of the system (i.e. golf course, cart path, golf cart) have responsibility for the safety of the system, and 2) the users of the system (i.e. players, cart riders, employees) have a responsibility to follow the rules for proper use determined by the designers of the system (e.g. adhering to speed limits, provided warnings and signs, utilizing protective equipment, following path guidelines, etc.). When users fail to adhere to the rules, through ignorance, intent or lack of skill and/or when products are not optimally designed for safety, detailed forensic engineering analyses of injury producing golf-related incidents can be instrumental in determining the mechanism and causation of trauma. Golf equipment manufacturers, golf course maintenance and architectural designers can then work to continually mitigate the risk through knowledge of the real-world human product interface. Safety can only be achieved by a partnership between the designers of the system (engineers and manufacturers) and the safe users of the system.

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** Image courtesy of W. Smith.*
*** Data and image courtesy of Owens Engineering*

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