Technical note

# Topple dangers posed by free-standing soccer goalposts

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**Abstract**

The toppling (or 'tip-over') of soccer goalposts has resulted in many human injuries and fatalities worldwide. One design of a soccer goalpost, the 'free-standing' type, is particularly susceptible to toppling. This paper presents analyses of the safety and design issues surrounding free-standing goalposts. First, a mathematical route for the generation of topple data is outlined. Second, data-sets for Mini-Soccer goalposts are used to scrutinise real-world toppling scenarios. Design steps are proposed for reducing the likelihood of (and subsequent severity of injury from) goalpost toppling. The results are compared against current safety provision contained in the British Standards Institution's (BSI) documents BS EN 748:1996 and PAS 36-1/2:2000. It is intended that manufacturers apply the analysis techniques outlined in this paper to gather quantitative data on the safety of their own products.

*Keywords*: design, goalpost, safety, standards, topple

## Nomenclature

| | |
|---|---|
| $A$ | anchoring force |
| $B$ | ballast weight |
| COM | centre of mass |
| $F$ | external tangential force to cause toppling |
| $M$ | goalpost total mass |
| $P$ | pivot point (fulcrum) |
| $X$ | $x$-axis |
| $Y$ | $y$-axis |
| $b$ | backbar length |
| $c$ | crossbar length |
| $d$ | radial distance from $P$ to goalpost COM |
| $e$ | horizontal distance from $P$ to person's COM |
| $f$ | radial distance (swing) from crossbar to person's COM |
| $g$ | acceleration due to gravity |
| $h$ | radial distance from $P$ to application of external tangential force |

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| | |
|---|---|
| $m$ | mass of person or part of person |
| $p$ | back stanchion length part 1 |
| $q$ | back stanchion length part 2 |
| $r$ | back stanchion length part 3 |
| $s$ | sidebar length |
| $t$ | free-fall duration |
| $u$ | upright length |
| $v$ | pre-impact linear velocity |
| $(x, y)$ | coordinate location of goalpost COM from $P$ |
| $\alpha$ | angular acceleration |
| $\beta$ | angle of anchoring force |
| $\phi$ | angle of pull at crossbar |
| $\lambda$ | toppling angle |
| $\theta$ | free-fall angle |
| $\sigma$ | angle of swing on crossbar |
| $\omega_1$ | initial angular velocity |
| $\omega_2$ | pre-impact angular velocity |
| $\varnothing_{1\mathrm{o/s}}$ | outside diameter of crossbar, uprights, sidebars and backbar |
| $\varnothing_{1\mathrm{i/s}}$ | inside diameter of crossbar, uprights, sidebars and backbar |
| $\varnothing_{2\mathrm{o/s}}$ | outside diameter of back stanchion |
| $\varnothing_{2\mathrm{i/s}}$ | inside diameter of back stanchion |

## Introduction

The last 13 years in the UK have seen the deaths of nine children caused by the collapse or toppling of unstable soccer goalposts (Hide 2000). Common causes include the use of goalposts in a dilapidated state and the use of free-standing goalposts with insufficient anchoring systems. A major effort is now underway by manufacturers, grounds staff (Saunders 2001), the Football Association (2000a), and the British Standards Institution (2000a, b) to promote goalpost safety. This paper contributes to the current safety discussions by providing technical analyses of goalpost design and construction.

Common causes of goalpost topple are wind gusts, high-speed ball impacts, individuals hanging on the crossbar and individuals manoeuvring or adjusting the goalpost (Smith 1999). Victims can include people tampering with a goalpost as well as bystanders. Reports show that incidents commonly arise through pulls on the crossbar. Being distant from the fulcrum at the base of the goal, a relatively small pull will achieve the turning moment necessary for topple. Young adults can reach the crossbar of a Mini-Soccer goalpost (an 'intermediate' size goal in common use in the UK) without difficulty, and so are able to provide an outward pull with their feet firmly on the ground. However, players of Mini-Soccer (children aged 7–11 years) are not sufficiently tall to pull outward on the crossbar whilst keeping their feet on the ground. Instead, they can jump up to grab and hang from the crossbar. By swinging, it is then possible to provide turning moments sufficient to cause topple. The more vigorous and purposeful the swing, and the greater the mass of the swinging person, the greater the threat becomes. Two common methods of causing topple from the crossbar of a goalpost can therefore be identified: direct pull and swing.

## Topple theory

Figure 1 shows a 'generic' free-standing soccer goalpost, established after reviewing the range of Mini-Soccer goalposts showcased in the Football Association's catalogue (2000b). The goalpost has: one crossbar *c*, two back stanchions (comprising an angled form of lengths *p*, *q*, and *r*), two sidebars *s*,

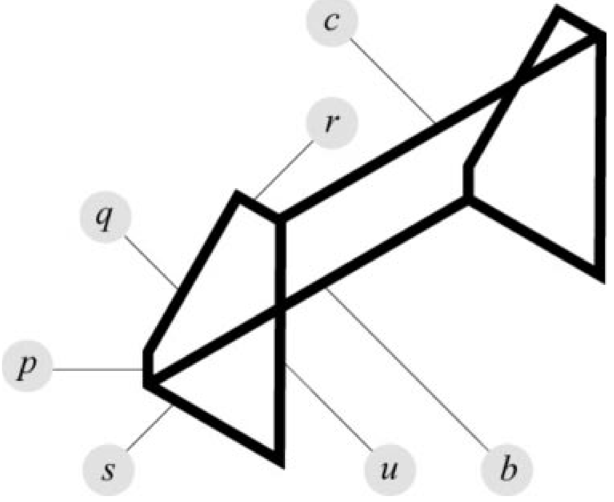

**Figure 1** Anatomy of a 'generic' free-standing soccer goalpost.

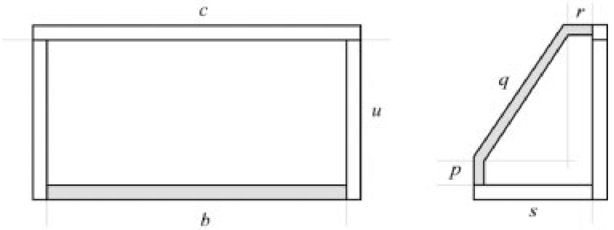

**Figure 2** Orthographic views of the 'generic' goalpost.

two uprights *u* and one backbar *b*. Figure 2 contains orthographic views of the 'generic' free-standing goalpost; the extremities of each member are identified for future reference in this paper. Together, lengths *u* and *b* define the size of the 'goalmouth'. Free-standing goalposts are capable of resting upright on a sports surface under their own weight and do not require connection to under-surface ground sockets. Special anchoring systems are used to pin free-standing goalposts to the ground. For indoor and multi-surface use, screw-in bolts and ballast weights are used. For use on grass various types of u-pegs and spikes are used, as well as ballast. When properly installed, such anchoring systems restrict the goalpost from pivoting about the base of the uprights and toppling forward. In general, anchoring systems attach to the backbar or sidebars. However, through loss of instructions, the loss of anchoring equipment itself, or through insufficient commitment to safety, anchoring equipment is not always installed properly (or at all). The result is erected goalposts that pose an increased topple risk and no longer possess the safety features originally provided by manufacturers.

To quantify the risks associated with goalpost toppling, it was first necessary to construct a model of how toppling occurs. Two stages are involved. First, an external torque is required to tip the structure to its toppling angle. Second, on reaching the toppling angle, the structure will accelerate forward under gravity and any additional pull that may be present, eventually hitting the ground. It is this second stage, a mass moving at speed, that constitutes the primary danger. Figure 3(a)–(c) illustrates the mechanism of goalpost topple, from a state of rest through to a state of topple and then free-fall.

In order to generate toppling data, a series of equations was assembled. The mass and centre of mass of each member of the 'generic' goalpost was determined, from which the centre of mass of the goalpost as a whole ($x$, $y$) was calculated. The toppling angle $\lambda$ was then determined by the following equation:

$$\lambda = \tan^{-1}\left(\frac{x}{y}\right) \tag{1}$$

A step-by-step description of the method is available in Pedgley (2001).

## The initial torque

For a state of topple to be reached, the external torque exerted by a person needs to be equal and opposite to the torque produced by the self-weight of the goalpost in conjunction with any anchoring system. Referring to Fig. 3, the external torque sufficient to cause toppling ($Fh$) is described by the following equation, in which the anchoring force is assumed to act over the centre of the backbar:

$$Fh = (dMg\sin\lambda) + \left(\left(s + \frac{\varnothing_{\mathrm{lo/s}}}{2}\right)A\sin\beta\right) \tag{2}$$

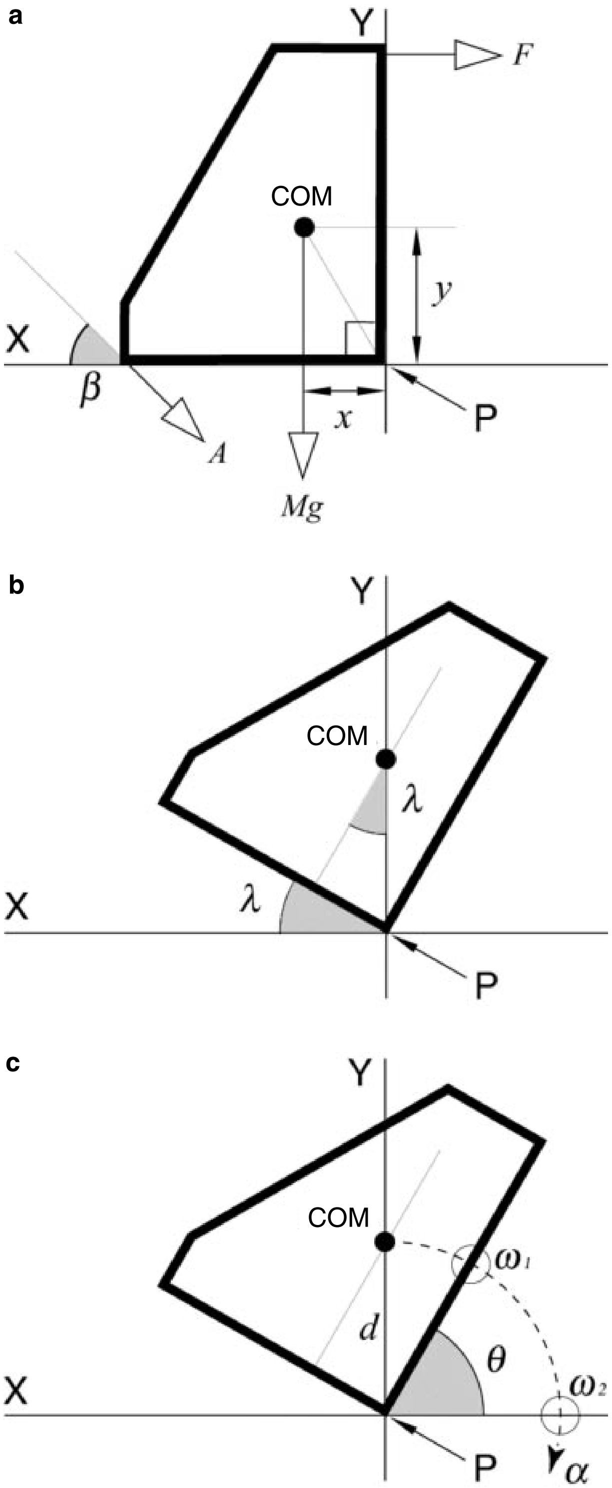

**Figure 3** The mechanism of goalpost topple (a) at rest with external pull, (b) at a state of topple, (c) free-fall.

With zero anchoring force, the external tangential force required to topple the goalpost at a radius of application $h$, is given by Eq. (3):

$$F = \frac{dMg\sin\lambda}{h} \tag{3}$$

This method of calculation has the following assumptions:

- no energy is converted to work by bending parts of the goalpost as the torque is applied;
- deformation of the sports surface at the fulcrum is negligible;
- friction between the sports surface and the goal frame is negligible;
- no other forces act (e.g. wind).

## Free-fall

The angular velocity of all parts of the goalpost just before hitting the sports surface (assumed to be horizontal) was calculated based on the following principle. The pre-impact kinetic energy of the goalpost is equal to the work done by gravity to move the centre of mass of the goalpost about the free-fall circular path $\theta$. Note that the assumptions for Eq. (3) also apply here. The linear velocity $v$ of any part of the goalpost, and the kinetic energy at the centre of mass, could then be obtained.

The time taken for the goalpost to fall through the travel angle $\theta$, and therefore the time available for people to take averting action, was calculated using the following equation:

$$t = \frac{2\theta}{\omega_2} \tag{4}$$

## Factors affecting impact

Some notes of caution should be issued at this point. The centre of mass for a goalpost is at a point in space physically detached from the goal frame and, as such, cannot strike the sports surface. Overall, the transfer and distribution of kinetic energy during and after impact is difficult to predict or measure. As a result, the real-world kinetic energy of individual moving parts (e.g. crossbar, uprights) during topple is likely to be considerably less than the calculated value about the centre of mass.

Various factors define the characteristics and severity of a collision. One problem is in creating a general model for how a goalpost strikes a person and how the objects involved deform. It is reasonable to assume that injury from a falling goalpost will take the form of an initial blunt or penetrative trauma (e.g. blow to the head) followed by a crushing trauma (not necessarily to the same anatomy), caused by being pinned down between the falling goalpost and the sports surface. Choices of materials and construction will affect the characteristics and severity of a collision, in particular the duration of the impact and, hence, the acceleration and force experienced by the victim.

Another factor is the level of plastic/elastic deformation of the human anatomy. Energy transmission and tissue deformation varies between different areas of the body. The age and sex of a victim and their ability to withstand and recover from trauma are additional factors. Finally, people can try to lessen the effect of an impact by 'moving with the blow', effectively increasing the duration of the impact.

For simplification, the values of pre-impact kinetic energy calculated for this paper were based on a 'worst case' scenario, in which a goalpost is free to travel through its entire free-fall angle. For consistency and ease of comparison, all of the energy levels were calculated about the centre of mass.

## Crossbar pull and swing

Figure 4 shows in diagrammatic form the outward pull by two outstretched adult arms on the crossbar of a Mini-Soccer goalpost. Only a component of the exerted pull force $F$ is present in a horizontal direction. Using ergometric data (Appendix A), the angle of pull $\phi$ that a 95th percentile 19–65 year old man can provide at the crossbar of a Mini-Soccer goalpost was found to be approximately 35°. This finding was confirmed in a practical test to determine the magnitude of horizontal pull that an adult is able to provide at the crossbar of a Mini-Soccer goalpost. The test involved the application of incremental quantities of ballast to the backbar of a free-standing aluminium Mini-Soccer goalpost until the backbar could no longer be raised by a crossbar pull (even by vigorous shaking). Four males, within the 95th percentile 19–65 years group, took part in the test. Taking into account both the ballast and the weight of the goalpost, it was found that a maximum horizontal component of approximately 350 N could be applied at the crossbar. This value will be discussed later in relation to the topple data-set for Mini-Soccer goalposts.

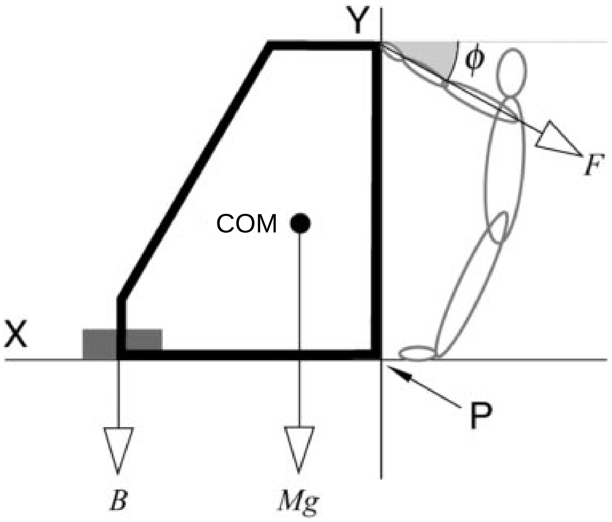

**Figure 4** An adult providing direct pull on the crossbar of a Mini-Soccer goalpost.

Figure 5 shows in diagrammatic form a child swinging with both arms on the crossbar of a Mini-Soccer goalpost. The movement of the child's centre of mass is considered for the purpose of this analysis to be an arc of constant radius $f$ about the crossbar. Each of the forces involved in this situation act vertically about the fulcrum. In equilibrium, just before toppling, the following vertical moment equation is satisfied:

$$e = \frac{Mx}{m} \tag{5}$$

From Fig. 5 it can be seen that the angle of swing $\sigma$ is defined as follows:

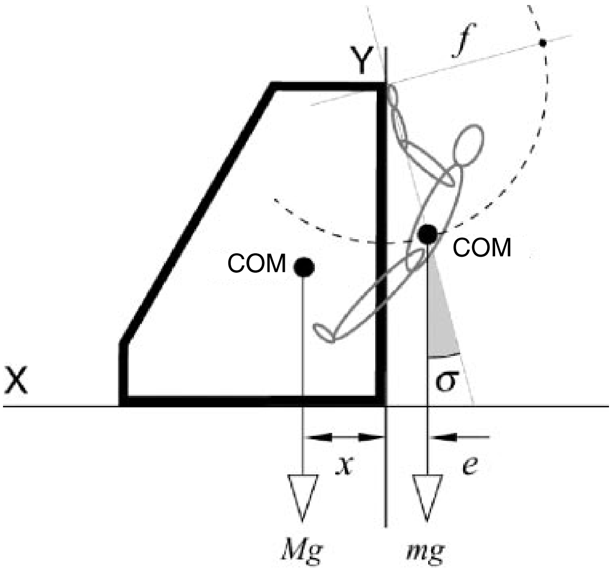

**Figure 5** A child swinging on the crossbar of a Mini-Soccer goalpost.

$$\sigma = \sin^{-1}\left(\frac{e}{f}\right) \tag{6}$$

Combining Eqs (5) and (6) gives a direct expression for the angle of swing required to cause topple.

$$\sigma = \sin^{-1}\left(\frac{Mx}{mf}\right) \tag{7}$$

Swing data for 95th percentile boys aged 8–11 years were generated as part of the topple data-set for Mini-Soccer goalposts.

## Results

The most prolific variations between Mini-Soccer goalposts are achieved through different sidebar lengths and material choices. Using a Microsoft Excel spreadsheet, topple data were generated for 30 generic Mini-Soccer goalposts having different sidebar lengths (25, 33, 50, 66, 75, 100, 125, 133, 150 and 166% of upright length *u*) and different materials, uPVC, aluminium and steel (Appendix B). Commercially available goalposts tend to have sidebar lengths in the range 1–1.5 m (55–82% of upright length *u*). The following dimensional data were used in the calculations, based on products exhibited in the Football Association's catalogue (2000b): $u = 1830$ mm (6 ft); $b = 3660$ mm (12 ft); $p = 100$ mm; $\varnothing_{1o/s} = 70$ mm; $\varnothing_{1i/s} = 65$ mm (2.5 mm wall thickness); $\varnothing_{2o/s} = 45$ mm; $\varnothing_{2i/s} = 40$ mm (2.5 mm wall thickness).

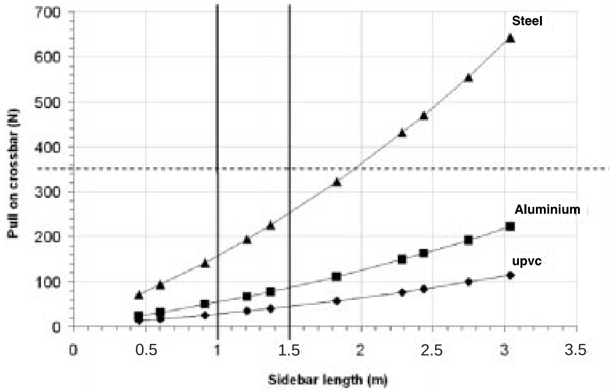

**Figure 6** Direct crossbar pull required from a 95th percentile 19–65 year old man to topple an unanchored Mini-Soccer goalpost of varying sidebar lengths and material construction.

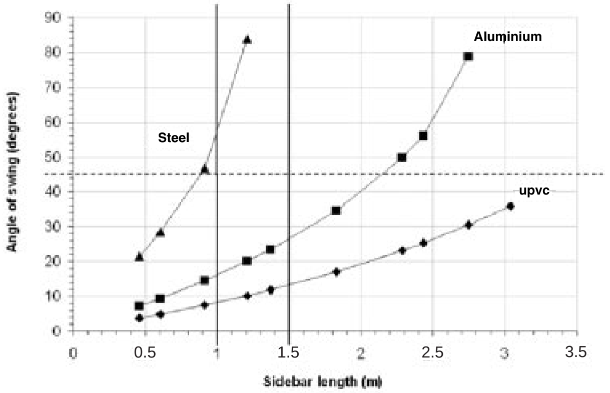

**Figure 7** Angle of swing required from a 95th percentile 8–11 year old boy (420 N) to topple an unanchored Mini-Soccer goalpost of varying sidebar lengths and material construction.

Figures 6–8 are graphs of the tabulated data. The darkened vertical lines marking sidebar lengths 1 and 1.5 m indicate the 'commercial range' of goalposts. Figure 6 shows the direct crossbar pull required from a 95th percentile 19–65 year old man to cause unanchored goalposts to topple. The dashed horizontal line marks the 350 N benchmark pull. Figure 7 shows the angle of swing about the crossbar required from a 95th percentile 8–11 year

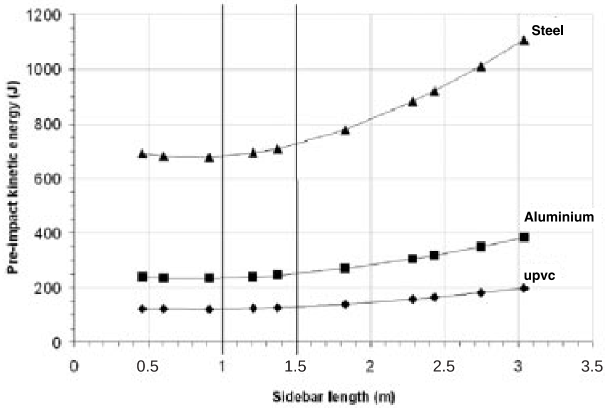

**Figure 8** Pre-impact kinetic energy after free-fall for Mini-Soccer goalposts of varying sidebar lengths and material construction.

old boy (weighing 420 N) to cause unanchored goalposts to topple. The dashed horizontal line in this case marks a 45° benchmark swing. Figure 8 shows the pre-impact kinetic energy of goalposts after free-fall topple.

## Discussion

Every unanchored goalpost poses a safety risk. To assess that risk, an examination needs to be made of both the likelihood of toppling occurring and the severity of any consequential injury.

The likelihood of toppling occurring from a direct pull on the crossbar can be examined through Fig. 6. It can be seen that within the 'commercial range', the benchmark of 350 N is, respectively, 2, 5 and 12 times the pull required to topple unanchored steel, aluminium and uPVC generic goalposts. That is to say, each of the generic goalposts within the 'commercial range' can be easily brought to topple by the direct pull of an adult if anchoring equipment is not installed. Only steel goalposts having sidebar lengths >2 m require a pull in excess of 350 N. The relationship between sidebar length and required external pull within the 'commercial range' is approximately linear, with approximately 60% more pull required for a 50% increase in sidebar length.

Figure 7 can be used to examine the likelihood that a child swinging on the crossbar will cause a goalpost to topple. Within the 'commercial range', relatively small angles of swing are required: 16–26° for aluminium and 8–13° for uPVC. However, significantly greater swings (60–80°) are required to cause equivalent steel goalposts to topple. Indeed, a 420 N child has insufficient weight to topple a steel goalpost with a sidebar length >1.2 m. If it is supposed that the angle of swing reaches a practical maximum at 45°, it can be seen from Fig. 7 that all unanchored aluminium and uPVC goalposts within the 'commercial range' can be easily brought to topple by a child's swing. The same child would not be able to bring a 'commercial range' steel goalpost to topple. The relationship between sidebar length and angle of swing within the 'commercial range' is approximately linear, with an approximately 60% steeper angle required for a 50% increase in sidebar length. Note that if the person's weight is doubled, the angle required to cause topple is halved.

Figure 8 can be used to examine the severity of any injury that may occur as a consequence of goalpost topple. It can be seen that throughout the range of sidebar lengths, the calculated pre-impact energy is directly proportional to material density. That is to say, relative to a uPVC goalpost, identical aluminium and steel posts have an increased pre-impact energy of 1.9 and 5.6 times, respectively. Also, within the 'commercial range', the relationship between sidebar length and pre-impact energy is approximately linear, with an increase in energy of approximately 7% for a 50% increase in sidebar length. For generic goalposts within the 'commercial range', steel versions have a pre-impact energy of approximately 700 J, aluminium 250 J and uPVC 125 J. As noted previously, owing to the large number of factors that affect how a collision takes place, the quoted figures should be taken only as an indicative (but comparatively accurate) guide to injury severity.

On the subject of taking averting action, very little difference in the free-fall time exists between a 25% *u* goalpost (0.52 s) and a 166% *u* goalpost (0.33 s). Opportunities to take averting action are therefore seen as very limited in all practical cases.

## Recommendations for designers

Although some factors affecting goalpost topple are entirely dependent on circumstances, others are within control of the designer. In the first instance, designers should focus on topple prevention by devising effective and easily installed anchoring systems. New innovations such as indoor suction pads, Velcro strips and magnetic connectors could be explored. Anchoring systems should not pose any trip, entrapment or other such safety hazard. Secondly, designers should provide written instructions and warning labels alerting users to goalpost safety. Beyond such basic safety provision, designers should take into account situations in which goalposts are used unanchored. This paper has shown that the 'inherent safety' of a free-standing goalpost can be improved by:

- decreasing the likelihood of topple;
- decreasing the pre-impact kinetic energy from free-fall;
- increasing the proportion of kinetic energy translated into work done to deform the goalpost.

Designers can improve the 'inherent safety' of a free-standing goalpost by focusing on the following factors.

### Mass

A low value for mass results in greater product portability and lower pre-impact energy; a high value (appropriately distributed away from the pivot point *P*) makes it physically difficult to topple the goalpost in the first place. Of particular concern is the backbar. A significant reduction in the external torque required to topple a goalpost arises from having no backbar or one with little mass. A backbar provides considerable stability for an unanchored goalpost; without it, the toppling angle is approximately halved. Overall, the aim should be to avoid goalposts that exhibit high pre-impact energy and are easily tipped over. The centre of mass of the goalpost should be located as low to the ground and as far away from the fulcrum as practicable. Mass can be controlled by material density and member volume (cross-section, length, cut-outs). Figures 6–8 show that a 50% increase in sidebar length (within the 'commercial range') results in a significant (60%) decrease in the likelihood of toppling occurring. However, for the same increase in sidebar length, the pre-impact energy increases by only a small factor (approximately 7%). On this evidence it is recommended that designers fit sidebars of length no <1500 mm to improve the inherent safety of Mini-Soccer goalposts (corresponding to an upright-to-sidebar ratio of 1:0.82). The BSI documents PAS 36-1/2:2000 currently specify that sidebars should be a minimum of 1000 mm in length.

### Surface hardness

A low value for surface hardness results in greater impact deformation and less severe injury; a high value results in greater product durability.

### Geometric stiffness

A low value for geometric stiffness results in greater impact deflection, lower pressure on impact and less severe injury, but consequently less rigid stand-alone members (e.g. members that bend under self-weight); a high value results in more rigid stand-alone members. Geometric stiffness can be controlled by the following properties: material Young's Modulus, member second moment of area, and member length.

### Geometric safety

Geometric safety is difficult to quantify. Pointed edge profiles cause cuts and should be avoided; flat and rounded surface profiles spread the force of any impact, causing blunt force trauma. Geometric safety can be controlled by the cross-section of the member.

### Constructional rigidity

Constructional rigidity is difficult to quantify and relates to product assembly. A structure with flexible joints (e.g. uPVC assemblies) deforms on impact, lessening injury, but has low stand-alone rigidity. This may then be perceived as low quality or considered a 'toy' because of the ease with which it wobbles when transported or struck by a ball. A rigid structure (e.g. fully welded aluminium) may be perceived as higher quality and more 'professional'. Goalposts having hinged side members introduce an additional risk of toppling if those members are not securely fixed.

## Topple safety provision in BS EN and PAS documents

The British Standards Institution (2000a, b, 1996) and the Consumer Product Safety Commission (1995) publish documents covering the toppling of soccer goalposts. In the UK, the British Standard BS EN 748:1996 applies to two sizes of soccer goalpost: full size 'regulation' (24 by 8 ft/7.32 by 2.44 m) and 5 by 2 m, applicable both to socketed and free-standing versions. The Publicly Available Specifications PAS 36-1:2000 (metal) and PAS 36-2:2000 (plastic) apply to goals smaller than 4.9 by 1.85 m, such as those used by small-sided soccer teams (e.g. seven-a-side, five-a-side, Mini-Soccer), applicable both to socketed and free-standing versions. Broadly, the BSI documents describe minimum specifications and performance criteria for safety and include the following mechanical tests for the goal frame.

### Crossbar strength

A downward vertical force of 1800 N (BS EN 748:1996), 800 N (PAS 36-1:2000) and 300 N (PAS 36-2:2000) is applied at the centre of the crossbar for 1 min. For BS EN 748:1996 and PAS 36-1:2000, after 30 min, there should be no permanent deformation of more than 10 mm displacement at the centre of the crossbar. For PAS 36-2:2000, the frame should remain in one piece, unbroken, and it should be possible to reassemble the frame with no difficulty.

### Stability

A forward horizontal force of 1100 N (BS EN 748:1996 and PAS 36-1:2000) and 300 N (PAS 36-2:2000) is applied at the centre of the crossbar for 1 min. The goalpost should not tip over and, in the case of BS EN 748: 1996, should not slide. It is this stability test that seeks to address the topple dangers of free-standing goalposts.

The findings of this paper can be used to highlight weaknesses in the stability tests contained in PAS 36:2000. The links between the topple test forces and 'real life' topple forces appear tenuous. Given that the ability to provide a toppling force is independent of goalpost material, why should the test forces differ for metal and plastic goalposts? The answer is that a balance needs to be struck between 'real life' forces and the 'real life' performance of goalposts. For example, when anchored, uPVC Mini-Soccer goalposts are in general insufficiently rigid to take a horizontal crossbar load in excess of 350 N. A test force >350 N could not be recommended on the basis that few goalposts would remain in a useable state to acquire a 'pass' status. Equally, it can be hypothesized that any form of stability test for plastic goalposts is not strictly necessary and places a requirement on manufacturers to provide over-engineered anchoring systems. The argument in support of this would be along the lines of: 'goalposts of mass less than $x$, constructed wholly from plastic material with a Young's Modulus of $<y$ and a surface hardness less than $z$ pose no realistic injury threat from toppling and are therefore not required to satisfy a topple test'.

However, on reflection, this is not a route to be recommended. Somebody swinging from the crossbar of an unanchored uPVC goal is very likely to cause that goal to topple and may become injured simply through collision with the ground. For plastic Mini-Soccer goalposts, a stability test force of 350 N (50 N greater than currently required) would appear to be reasonable and would provide an additional safety factor when considering children's use (and abuse) of Mini-Soccer goalposts. This magnitude of force allows for practical-sized ballast weights to be used as anchors (satisfied by approximately 40 kg over the backbar).

The same cannot be said for metal Mini-Soccer goalposts. Currently, to meet the 1100 N pull test, a ballast typically of 150 kg is required to be attached to the backbar. This is an unwieldy and wholly impractical quantity of ballast for a 'portable' goalpost and provides good reason for revising the stability test force in PAS 36-1:2000. Ballast is a particularly good anchoring system for indoor and multi-surface use. It is easy to install and does not require a goal to be positioned over sockets in order to be bolted down. As a quick and easy method, ballast is less likely to be overlooked or unused, resulting in fewer goalposts erected in an unanchored state. If the stability test force were lowered to 700 N a ballast of approximately 90 kg would be needed on the backbar. This is still high, but represents a compromise between designing for realistic forces and designing for practicality.

### Unanchored goalposts

Currently there is no safety test for the unanchored state of any of the goalposts covered by BS EN 748:1996 or PAS 36:2000. However, not all goalposts are securely anchored. The presence of an unanchored stability test in any future update of the BSI documents would provide some protection from incidents involving unanchored goalposts. It is important that the inclusion of an 'unanchored test' does not result in confusion. Its role would be to ensure that inherently unsafe goalposts (e.g. those that are heavy and easily knocked over) are unable to meet the standard. Its presence should in no way lessen the message to consumers that all free-standing goalposts should be anchored. In practice, consumers are unlikely to come into contact with the details or results of BSI goalpost tests and so the likelihood of any confusion arising is low.

Goalposts exhibiting high pre-impact energy and that are easily tipped over (in an unanchored state) constitute the highest safety risk. A 'safety index number' could be used to evaluate the inherent safety of any given goalpost. A suitable value could be obtained from the ratio of the calculated pre-impact kinetic energy to the tangential force required at the crossbar to cause topple. Minimum specifications could be determined. If so desired, practical tests could be requested in place of calculations: a crossbar pull test and an impact force analysis.

## Conclusion

This paper has highlighted various factors affecting goalpost toppling and proposed practical ways of improving safety. A mathematical approach suitable for analysing and quantifying the safety of soccer goalposts has been developed and can be applied to the design of other goalposts including hockey, handball, basketball and netball. The paper has shown how in real-life situations, toppling is caused by direct crossbar pull or swinging about the crossbar. Within existing manufacturing capability, manufacturers have opportunities to improve the inherent safety of their goalposts by focusing on geometric configuration, material choices, member cross-sections and constructional details. The British Standards Institution can improve the topple safety provision in its BS EN 748:1996 and PAS 36-1/2:2000 documents by revising the magnitude of test forces and introducing a 'safety index' for goalposts in an unanchored state.

## Acknowledgements

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## References

British Standards Institution (1996) *BS EN 748:1996 Playing Field Equipment – Football Goals – Functional and safety requirements, Test methods*. BSI, London, UK.

British Standards Institution (2000a) *PAS 36-1:2000 Goals for small-sided football – Part 1: Specification for metal goals*. BSI, London, UK.

British Standards Institution (2000b) *PAS 36-2:2000 Goals for small-sided football – Part 2: Specification for plastics goals*. BSI, London, UK.

Consumer Product Safety Commission (1995) *Guidelines for Moveable Soccer Goal Safety*. CPSC, Washington, USA. Available at: <http://www.cpsc.gov/cgi-bin/recalldb/>.

Football Association (2000a) *Goalpost Safety: Play Your Part*. Promotional leaflet, The FA, London, UK.

Football Association (2000b) *Mini-Soccer Goalpost Catalogue 2000*. The FA, London, UK.

Hide, C. (2000) Free-standing goal frames. *ILAM Information Centre Fact Sheet 00/07*. Institute of Leisure and Amenity Management, Reading, UK.

Matweb Materials Property Database (2001) Available at: <http://www.matweb.com> (Accessed 25 October 2001).

Pedgley, O. (2001) A technical investigation into goalpost toppling. *Sports SET Network Internal Report*, Department of Mechanical Engineering, University of Sheffield, UK.

Pheasant, S. (1990) *Anthropometrics: An Introduction*. BSI, Milton Keynes, UK.

Saunders, L. (2001) Safety is the goal. *Leisure Management* 21–4.

Smith, K. (1999) *Daniel's Task Force for Safer Soccer Goals*. Available at: http://members.tripod.com/goalsafety (accessed 25 October 2001).

**Appendix A** Ergometric data for 95th percentile males (Pheasant 1990)

| Ergometric data | 8–11 year old boy | 19–65 year old man |
|---|---|---|
| A. Shoulder height from ground | 1220 mm | 1535 mm |
| B. Standing overhead reach from ground | 1830 mm | 2300 mm |
| C. Outstretched arm length (B–A) | 610 mm | 765 mm |
| D. Elbow height from ground<br>(approximately in line with navel and position of COM) | 945 mm | 1175 mm |
| E. Radial swing on crossbar (B–D) (f) | 885 mm | 1125 mm |
| F. Stature | 1495 mm | 1855 mm |
| G. Body weight | 420 N | 950 N |

**Appendix B** Materials data (Matweb 2001)

| Material | Density (kg $m^{-3}$) | Stiffness (Young's modulus) (GN $m^{-2}$) | Surface hardness (Brinell number) |
|---|---|---|---|
| uPVC | 1400 | 2 | 55 (converted from 80 Shore D) |
| Aluminium alloy 6082 | 2710 | 70 | 85 |
| Medium carbon mild steel | 7850 | 207 | 160 |