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Autor: Dickson, Michael

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Engineering for Crowd Safety

Projet en vue de la sécurité des foules

Projektieren für die Sicherheit von Menschenmassen

Michael DICKSON
Structural Engineer
Buro Happold
Bath, UK

Michael Dickson, born in 1944, was educated at the Cambridge Univ. , UK where he gained a degree in Mechanical Sciences and Cornell Univ., USA where he took a Masters Degree in Structural Engineering and Town Planning.

SUMMARY

This paper describes a method of appraisal by spectator capacities within a framework understood by management and determined by the characteristics and conditions of the ground and the skills of the management. Passive and active elements of crowd management within the overall procedure of appraisal are given, and engineering values for crowd loadings and barrier design are discussed in relation to acceptable stand capacities.

RÉSUMÉ

La communication présente une méthode d'évaluation de la masse de spectateurs dans un lieu public, en fonction des caractéristiques de l'installation et des possibilités de gestion du mouvement de la foule. Les éléments actifs et passifs de cette gestion revêtent une importance réelle dans cette évaluation. Les données techniques des charges dues aux déplacements et le dimensionnement des barrières et palissades sont à confronter à la capacité admissible des tribunes.

ZUSAMMENFASSUNG

Der Beitrag beschreibt eine Methode gedacht für das Management zur Beurteilung des Zuschauerfassungsvermögens abhängig vom Zustand der Anlage und der Managementfähigkeiten. Bei der Beurteilung spielen aktive und passive Elemente des Zuschauermanagements eine Rolle. Die Ingenieurdaten für die Belastung durch Menschenmassen und die Bemessung von Abschrankungen werden in Beziehung zu zulässigen Tribünenkapazitäten gesetzt.

INTRODUCTION

Over the last century the United Kingdom has built up a widely ranging stock of sports grounds, leisure and sporting facilities. In the case of football stadia, facilities were added in a piecemeal way as the fortunes of clubs prospered but often without proper thought for future planning and maintenance, so essential to public safety (Ref 1).

Attendances peaked in the 1960s and, except in individual key fixtures, are now considerably less - perhaps only 17 million as against 40 million per season. This decline in attendances has led to further pressure on the ability of grounds to fund new better facilities - ones more orientated to the modern community - or to adequately maintain or manage these facilities.

The direct result has been instances in which some facilities have failed in an engineering sense to provide for the necessary public safety with the results that accidents - often during key fixtures - have occurred. Ibrox, Birmingham, Bradford etc - are cases in point. Despite wide reporting of these instances, to the contrary, in statistical terms football spectating still remains statistically safe (between 1945-84 English League attendances of 1,100,000,000 with less than 50 fatalities which is a comparative death risk per hour/10^8 of about .001 - or 1/100 of that of death risk from fire while still at home watching the match on television.

A few years back Britain had three separate major problems at football grounds in a very short period: a bad incident at Birmingham, a wall collapse when conflict in the crowd between British supporters and others led to a crowd surge at Hysel Stadium, and a bad fire in a stand at Bradford. All led to loss of life and a government inquiry was set up. After its report the Institution of Structural Engineers, using past research, started to produce a new code of practice for appraising such grounds but before it was published there was another disaster at the Sheffield Wednesday ground which led to another government inquiry. The code subsequently produced contains the experience of these incidents. This paper is about this work. A conference was held subsequent to it and the author recommends interested people to read both documents. (Ref 2 and Ref 3).

Basic Requirements for Stadia

It is perhaps remarkable that arenas such as the Coliseum in Rome of elliptical form surrounded by tiered seating and with provision for sun shading vela are so similar to modern stadia even though at 1:19 the tiers are rather steeper than would be allowed today. It has even been calculated that the 50,000 capacity of the Coliseum could be exited at today's rates through the 80 exits in 8 minutes - similar to today's standards where stands are of mainly incombustible construction.

Much has been written on the necessary standards for sports stadium for various uses (Ref 7). Suffice to say that the plan forms ideal for good viewing football need to keep the spectator within 90m from the centre spot or 150m from the furthest corner. If space is limited, stands on the west side should be preferred, so more can view the game with the sun behind them.

Clearly, in order to fit more people into the ground, added tiers are the best solution. Straight tiers of increasing slope are cheaper but require more land. Layered tiers are more expensive but have the advantage of bringing the viewers closer to the game which, for smaller objects such as hockey, tennis, etc may be critical.

This leads to a series of physical solutions to problems relating to the free flow of people entering and leaving, the dangers of crowd pressure and, certainly for older stadia, the risks of fire and smoke. Add to this crowd behaviour and the breadth of the problem starts to be understood:

The Problem:

It is obvious that the lack of uniformity of stadia - and of people - is such that one has to see appraisal as a systems problem:

Sports grounds are aggregations of enclosures for large number of people to arrive, be comfortable and safe in and to easily depart from under a wide range of operating conditions

It is essential to understand location (and image) within the city infrastructure needs to be clearly understood, so that controlled entry (and exit) and suitable provision for access, parking, signage and provision for emergency services can be made.
Overall layout and its individual elements and sub-enclosures have to be clearly defined by drawings. So that enclosures, crowd flow networks and spectator reservoirs can be identified and then corroborated by inspection.
The structural configuration and condition understood.
Fire safety and other emergency potentials.
The way management plans its activities, organises the ground, the stewards and supporting equipment.

The Process of Appraisal:

There are four principle aspects:

Assessment of acceptable capacities both of individual enclosures and for entry/exit and evacuation to prevent crowd densities ever exceeding safe upper limits.
Appraisal of the condition and compliance of all structural elements so that adequate factors of safety against collapse remain at the accepted upper limits of crowd density.
Examination for fire (or other emergency) safety.
Survey of the constructional condition of all elements to eliminate sub-standard fabric, tripping, hazards, hazards of combustion etc.

Appraisal needs to be comprehensive if it is to be reliable. It is the application of logic and method to the scale of the problem at hand under the judgement of a competent person which is the creative part of the process. [Fig 1]. Appraisal has to be tailored to match the size and type of ground under consideration and the type of match or venue. A large ground or an especially high profile event clearly needs more refined appraisal than does a small low capacity event.
When high or unusual attendances are expected, appraisal may need to be refined in order to justify these high occupation levels. Such circumstances may require the upgrading of both

'passive' fabric elements of the ground and 'active' stewarding and crowd management provision and further evaluation of various emergency "What if?" scenarios. Potential disruptive behaviour by the crowd, outbreak of fire or other reasonable credible emergency scenarios are likely to form part of this further stage of assessment. This should include further probing of the preparedness of crowd management functions.

1. **Appointment of a Qualified Person** - Responsible for the terms and conditions of the safety certificate.
2. **Terms of Reference for Appraisal** - Sufficiently wide to ensure that the ground and its individual parts fits together as a safe system under all likely 'what if' situations.
3. **Information Gathering** - Collection of formal drawn information representative of the operation of the arena and condition of the ground and its elements.
4. **Inspection** - Inspection by a competent person of all entrance areas, stairways, ramps, viewing areas etc. for any hazards, checking geometrical compliance, identifying principal enclosures, inspecting all barriers and handrails for spacing and layout. Identify potential fire hazards.
5. **Initial Assessment** - The safe maximum capacities of each viewing enclosure will need to be checked in view of actual condition and configuration.
6. **Testing of Barriers** - and record results. Modify acceptable capacities if necessary.
7. **Inspection During Use** - To witness the interaction of 'passive' and 'active' functions of crowd control, and the quality and organisation of the stewarding, fire detection and fire fighting power.
8. **Report**

Figure . The procedure of appraisal

Once complete, the results of the appraisal needs formalising with at least the following documents :-
City plans, showing location of facility within infrastructure.
Plan and section for individual stands and their capacities together with flow networks and relevant reservoir capacities and net densities. Together with seating arrangement and standing arrangements.
Staircase arrangements for location of barriers, split-up areas.
Entry, exit, turnstiles showing location of barriers, split-up areas.
Résumé of main stand capacities by individual enclosure their turnstile and exit capacities.
Stewarding plan.
Fire Plan.

Copy of attendance and incident log for all previous venues and fixtures.

Assessing the Maximum Acceptable Capacity for a stadium is not an exact science and much further research is required.

Patterns of crowd flow, densities and capacity are only available for empirical observation (Ref 4, 5 & 6) and so a robust judgement should be applied.

Safe capacity of single enclosure

Capacity in an all seated enclosure is those seats within 14 seats of a gangway and where no seat is more than 30 metres from the nearest exit to a place of safety following the direction of the seats and gangway. Configurations of header barriers at exit staircase will need to be such that the total exit width from a particular enclosure is sufficient to allow evacuation within the Available Safe Evacuation Time (ASET).
Clearly for disabled people there are problems encountered with step seating, where evacuation has to take place without causing disruption to the majority exiting. Planned escape routes for the disabled will need to be complemented by a well rehearsed management procedure for such an emergency if overall Acceptable Capacities are not to be affected.

Normal bodied crowds are comprised of people of many shapes and sizes whose average body size can be based on a body ellipse occupying about $0.135m^2$ ($1.5ft^2$) (74 persons per $10m^2$). Occupation of sub-way cars and similar close packed circumstances results in a 450mm x 600mm body ellipse with an equivalent area $0.21m^2$ ($2.3ft^2$). This in reality is a density of 47 persons per $10m^2$ and equates to the higher but tolerable levels for queuing densities. Capacity of any standing area can then be assessed by the following :-

$$C = \frac{47}{30} \times A_e \times C_f$$

A_e = the net area (m^2) for spectators less gangways, areas for which barrier allocation is substandard and from which the event cannot clearly be seen.

C_f is a number from 1-3 reflecting the general condition of surface and repair of the enclosure.

In reality within any individual enclosures densities up to 54 person $10m^2$ and slightly beyond are safe and would enable reasonable conditions when based on the net area of occupation. Arrangements for ticketing and control into a particular enclosure have to ensure that this calculated capacity C cannot be exceeded. Active stewarding is then necessary to ensure that even densities of occupation are achieved.

Capacity of Enclosures for Safe Evacuation

Notional evacuation, times should not exceed 7 minutes since the expectation is that crowds can become restive if longer departure times are experienced. [Ref. 6]. However the capacity of most enclosures or grounds will be determined by the concept of the Available Safe Evacuation Time in a fire or other emergency situation. (ASET) The duration to be allowed for emergency evacuation depends on the range and configuration of safety criteria of which perhaps access to a place of safety is the most significant. The ISE report goes some way to organising these criteria to enable rational choice of appropriate time. Depending on the fire safety of the particular stand periods of between 2.5 and 4 minutes would seem appropriate for stands of category 1 construction (which are stands of potentially more combustible materials where it is possible to justify that lateral spread of fire will not inhibit escape or fire fighting operations). For category 2 stands which are of essentially compartmented incombustible construction and where all means of escape are adequate in respect of potential smoke logging, times of between 4 minutes up to a possible maximum if 8 minutes are acceptable. Safe escape times for either category can only be increased beyond the minimum by the incorporation into the Operating Manual of additional safety measures.

In determining capacities by this concept the other variable results from the human component as defined by maximum flow rates that are appropriate for safe (or comfortable) evacuation. Design for the passage widths for crowd evacuation through portals, along passageways, up and down ramps and stairs needs to be based on a choice of acceptable flow figures. Choice of clean forms without hazard or discontinuity and the selection of proper splitter and header barriers should affect the chosen design flow figures. Much further research of these values either by observation, and/or by development of suitable physical, analog or numerical flow models of crowd flows is urgently required.

For appraisal 'The Guide to Safety at Sports Grounds allows the figure of 40 persons per unit width along stairways (whether up or down) and 60 persons per unit width along passageway and through portals. A unit width is defined as a complete unit of 550mm assumed to be free from obstructions and hazards liable to cause tripping, etc.

Evacuation Rates	Portals/Passageways	Persons/unit width/min.	Stairs Down/Up	Persons/ unit width/ min.	Notes
Green Guide		60		40	
From Journal flow F Sports Stadia Design Terminals	26 p/ft/mm 21-26 p/ft/mm	47 37-47	21/19 p/ft/min 15/12 p/ft/min	39/35 27/22	Down/up stairs
Department of Transport TD 2/78	20p/ft/min	37	14p/ft/min	26	
SICON Observation Gateway Observation Passageway	35p/ft/min Peak 24p/ft/min Average 24p/ft/min Maximum 20p/ft/min Average		25p/ft/min ·20p/ft/min		Averaged are 7 minutes
Turnstiles peak from H.S. E. Study for Hillsborough	Peak Average	1000p/hour 680/hour			From Hillsborough report
Green Guide ·		660/hour			Actual figures must be proven, if less then use in calculation.

Figure . Pedestrian flow rates

The suggested flow rates when multiplied by reasonably assessed ASET times give performance requirements in relation to exit widths, stair widths etc. which have generally to date give safe results. Nevertheless it can be seen from Figure that the actual flow rates suggested are in fact higher than those recommended by the Department of Transportation for use in pedestrian subways and higher than those recommended for unit width of sports stadium design and passenger terminal usage within the USA. For category 2 stands, American usage, tolerates longer ASET times combined with smaller flow rates/unit width resulting in roughly similar Acceptable Capacity but in supposedly more comfortable conditions for the spectator. [Ref. 7].

Conclusion

Design of safe and comfortable venues for spectators or its appraisal is a difficult task and requires many judgements to be made during the process if it is to gain a reasonable degree of safety for spectators under all operating conditions. Wide ranging engineering knowledge is required to be used with a reflective spirit. Above all the process has to interact with the practicalities of managing, operating and controlling real crowds. The essential linking commodity is a reliable address system coupled to clear and unambivalent signage. The subject requires considerable further research.

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