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Design of Stadium Structures - A Safety First Approach

Projet des structures de stades sous l'angle de la sécurité

Der Entwurf von Stadien unter dem Primat der Sicherheit

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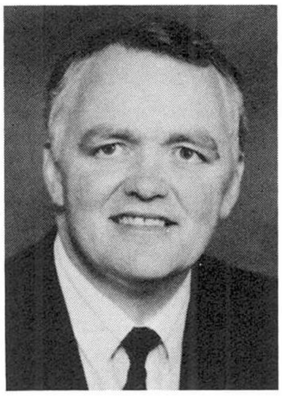

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SUMMARY

The paper discusses the redevelopment work on Football Stadia which has taken place as a result of the requirements that spectators at the Major Stadia in Britain require to be seated prior to the beginning of the 1994-95 season. It also highlights where major deficiencies exist in the British Building Regulations and in Codes of Practice relating to the design process for Major Stadia.

RÉSUMÉ

L'article traite des travaux de réhabilitation des stades de football, à la suite des prescriptions devant entrer en vigueur en Angleterre pour la saison 1994-95 et impliquant que les installations les plus importantes puissent offrir aux spectateurs uniquement des places assises. L'auteur souligne en outre les insuffisances essentielles existant dans les prescriptions et normes techniques du bâtiment en vigueur dans ce pays, relatives au déroulement du projet des stades de grande capacité.

ZUSAMMENFASSUNG

Der Beitrag behandelt die Modernisierungsarbeiten an Fussballstadien, die aufgund der Forderung nötig wurden, dass für die Zuschauer in Grossbritanniens bis zur Saison 1994-95 grössere Stadien mit Sitzplätzen vorhanden sein müssen. Er weist ausserdem auf wesentliche Mängel in den britischen Bauvorschriften und Normen bezüglich des Ablaufs beim Entwurf grösserer Stadien hin.

1. INTRODUCTION

In Britain, it is Football stadia which generate, on a regular basis, the highest concentrations of people in a confined space. Since 1902 there have been 6 major tragedies at football grounds, each involving the loss of more than 25 lives and leaving many hundreds of individuals with serious physical damage and psychological impairment. There have been 10 major reports dealing with safety at football grounds since 1924, each making recommendations for additional measures to improve safety. Statistics from the disasters and a list of the reports are detailed in a paper by the author, UK Football Stadia – The Way Ahead [1].

The disaster at Hillsborough in 1989 with 95 deaths involved the largest loss of life. The report by Lord Justice Taylor which followed the disaster has also had the largest influence on changing the form of Britain's stadia.

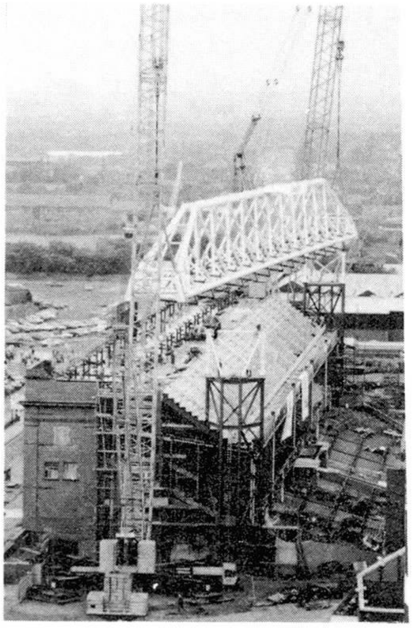
This paper reviews some of the projects completed post Hillsborough and discusses where design guidance and regulations may yet be deficient.

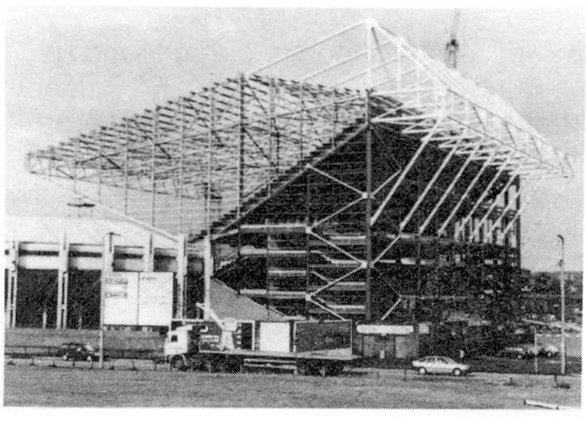
2. EXISTING STATE OF THE ART

All projects are different. Each has its own highlights and features of design or construction which are particular only to it. To illustrate this point the author has chosen 6 projects, constructed since 1991, each representing a major project and each illustrating a different approach to achieving the requirement for seated spectator accommodation.

Ibrox Stadium : Glasgow

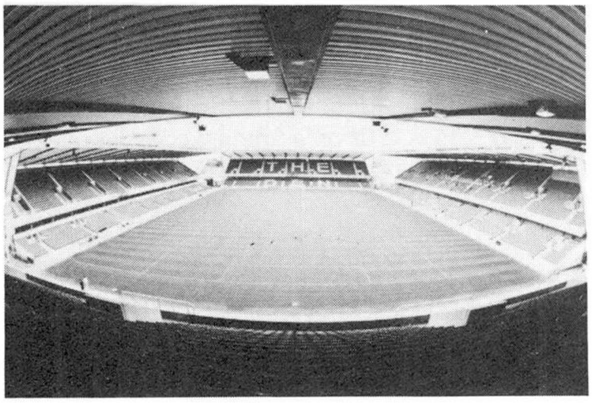
Ibrox Stadium was redeveloped in the early 1980s by the conversion of the standing terraces on the East, West and North sides of the pitch to seated accommodation for 25,000 spectators. In 1989 the Club decided to upgrade the South Stand accommodation by adding an additional seating deck above their existing Main Stand. The new deck, which affords column free viewing to the upper tier spectators, is covered by a new roof supported on a 145 metres clear span tubular steel girder. This is the longest span stadium girder of its type in Britain. The plate opposite shows lifting of the roof girder over Ibrox Main Stand.





Elland Road Stadium : Leeds

While Ibrox Main Stand Girder is the longest "goalpost" type girder in Britain, the longest cantilever structure is currently at Elland Road, Leeds. This structure has a clear cantilever roof span of 51 metres and provides cover for approximately 17,000 seated spectators on the East side of the ground. The front seating deck is supported directly on the ground while the middle and upper decks are of precast concrete supported on a steel frame structure. The plate opposite shows the stand under construction.

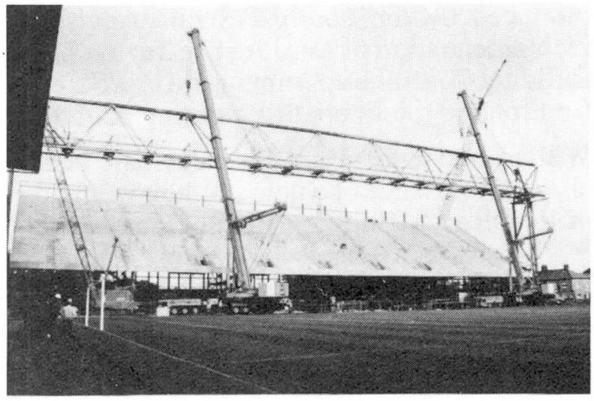


The Den Stadium : Lewisham : London

The first major British club to invest in a completely new stadium, post Hillsborough, has been Millwall Football Club. Their new 20,000 seated stadium incorporates many features which are designed to attract non–football events. Provision has therefore been made for increased levels of toilet provision, refreshment kiosks, hospitality suites etc. The seating decks are supported on a steel frame and the roof is of cantilever design. The roof spans vary from 23.5 metres to 25.5 metres. The plate opposite shows a view of the finished stadium from the rear of the South Stand.

Filbert Street Stadium : Leicester

Unlike most other clubs, Leicester City FC chose not to develop their secondary stands but to concentrate in the first instance on replacing their Main Stand. The new 9,000 seat Main Stand at Filbert Street incorporates a high level of facilities which not only have a match day role but also can be used for other non–sport purposes. The precast concrete seating decks at Filbert Street are supported on a steel frame, and the clear span roof takes its principal support from a 111.5 metres span "goal post" framework. Plate opposiite shows a view of the stand under construction.

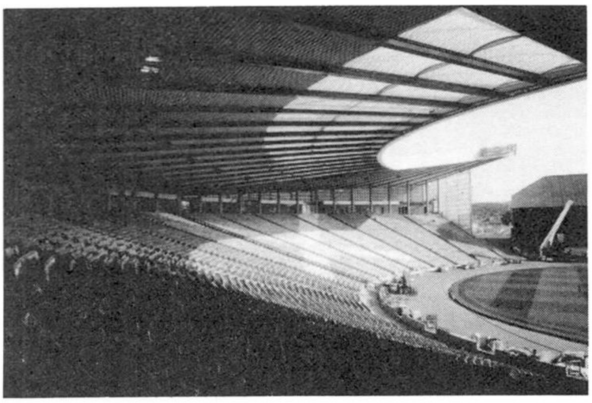


Murrayfield Stadium : Edinburgh

Murrayfield is the home of Scottish Rugby and hosts the Scotland Home International matches. Since 1992, it has undergone major redevelopment which, by September 1994, will see completion of a 67,500 all seated, bowl stadium. The roofs are all of cantilever design with a maximum clear span in the West Stand of 48.5 metres. The exposed roof trusses are fabricated from self weathering steel and have been left unpainted. The precast concrete seating decks are supported on a steel frame. Plate opposite shows Murrayfield in July 1993 with the East, North and South Stands complete and the West Stand under construction.

Hampden Park : Glasgow

Hampden Park is the traditional International ground for Scottish soccer. In 1937 its terraces accommodated its record crowd of over 149,000 spectators. Since then alterations have reduced the extent of the terraces and stands. Work on converting the terraces to seating commenced in 1993 and by 1996 a 60,000 capacity all seater stadium is programmed to be in place. The Hampden Redevelopment is relatively unique as it has retained the previous terrace profile, but has added roof cover and provided seating. The roof is of cantilever form with a maximum clear span of 42 metres. Plate opposite shows the East Stand nearing completion.



In terms of structural form there is relatively little which is consistent between the six stadia listed. Three, Elland Road; Murrayfield and Hampden Park are of bowl design, whilst Ibrox; Millwall and Leicester have four individual stands. Two, Ibrox and Leicester, have goal post roof support and four adopt the cantilever roof form. All with the exception of Elland Road have underslung cladding with trusses exposed above the roof. Leeds is overclad with trusses exposed beneath the decking. All six stadia have seating decks supported either directly on the underlying soil or on a precast concrete deck supported on structural steel. Only Hampden and Murrayfield incorporate translucency in the roof cover.

3. DESIGN CRITERIA

All stadia in Britain require to satisfy the requirements of the Building Regulations [10] which refer to British Standards Codes of Practice and to the "Guide to Safety at Sports Grounds" [3]. The latter document incorporates rules for design developedas a consequence of previous disasters, particularly those at Ibrox Stadium in 1979 and at Bradford in 1985. Other guidance is available principally that produced by the Football Stadia Advisory Council, a body set up, post Hillsborough, on the recommendation of Lord Justice Taylor. Design proposals are subject to audit by the Local Authority Building Control Department and by a Safety Committee representing Police, Fire Officers, Building Control and the Football Licensing Authority.

With formal audit procedures it would be reasonable to assume that the level of risk associated with poor performance of a new stadium would be very low. It must be appreciated, however, that Codes of Practice and Building Regulations were not written specifically for stadium construction and there are aspects of design which apply uniquely to large stadia construction. These particular design requirements may not be adequately covered by current design standards. Among the more significant considerations are:

- Dynamic Response of Roofs
- Dynamic Response of Seating Decks
- Progressive Collapse

3.1 Dynamic Response of Roofs

Design static wind loading on stadia roofs can be obtained from Codes of Practice and guidance notes or from the results of wind tunnel tests. Figure 1 shows the results of wind tunnel tests carried out on the East Stand at Murrayfield [5] and indicate that the values given in the British Code, CP3, Chapter 5 [4], were in this case conservative.

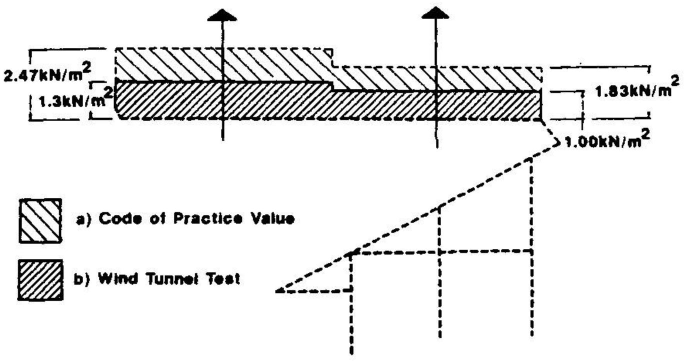


Fig 1 Murrayfield East Stand - Static Wind Pressures

With increasing spans, static loading is no longer the only consideration and natural frequency and wind excitation become of equal or greater significance. While there exists a great many references which can be used for static loads cases, very few equivalent sources of data are available to aid the designer to assess dynamic loading and associated structural response.

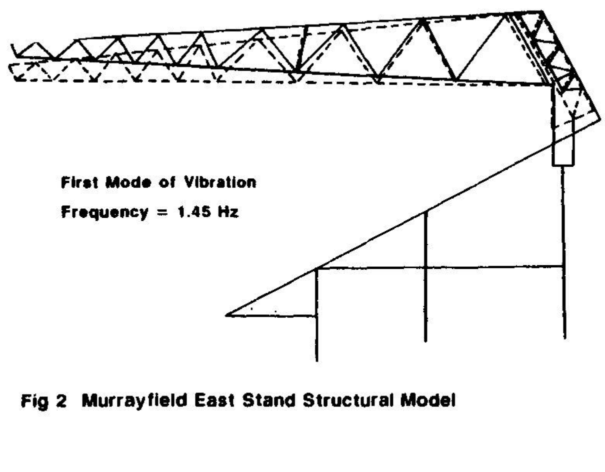


Fig 2 Murrayfield East Stand Structural Model

For the final phases at Murrayfield, with large cantilever roofs extending to 48.5 metres, it was decided by the designers that a rigorous check on dynamic performance was justified. The wind tunnel testing programme was therefore modified to produce a wind loading spectrum suitable for use as data for the Lucas software.

The results of the dynamic analyses for the 42.5 metre span North Stand indicated that the deflection range under the maximum dynamic case was 40 mm as compared to the static deflection range under wind loading of 350 mm. It was also noted, however, that dynamic behaviour was very sensitive to span of structure and to its stiffness. A paper describing in detail the dynamic analyses of the Murrayfield stands is in the course of preparation and will be completed after the opportunity has been gained to carry out dynamic performance tests on all the completed stadium roofs.

No reference is currently made in Codes of Practice to oblige designers to carry out dynamic analyses to verify the adequacy of their structural models. From experience, the author is of the opinion that rigorous analyses, including obtaining data from model tests is justifiable for all cantilever roof spans greater than 45 metres, or for roof trusses where the computed natural frequency approaches unity. It is also important that major roof structures are instrumented and monitored to create a reliable database of real performance from which analytical methods can be calibrated and informed design judgements can be made.

3.2 Dynamic Response of Seating Decks

Given that spectators in major stand structures are often influenced by music, chanting, rhythmical stamping and other similar co–ordinated activity where the crowd acts in unison, it is an omission that there is no mandatory requirement to address the question of dynamic performance of seating decks and their supporting structure. Although well documented problems have occurred, namely in a temporary stand at Corsica and in the Maracana stadium in Brazil [6], to date no criteria have been published or rules laid down to require designers to consider this important subject.

Published data would suggest that although small numbers of people indulging in aerobics can act in unison at frequencies up to 3 Hz, large crowds cannot co–ordinate their motion at frequencies greater than 2.5 Hz. This would imply that seating decks should be designed, therefore, on the assumption that they may be subjected in all directions to forcing frequencies of up to 2.5Hz.

Insufficient data currently exists for stadium designers to carry out accurate modelling of crowd activity and to correlate it with any degree of accuracy to the response of a particular stand structure. It is nevertheless of concern that no reference is made in Building Regulations, Codes of Practice or design guides for stadia in Britain that designers should compute the natural frequencies of the fully loaded spectator decks of their proposed structures and compare them with the potential frequencies of activity which might be generated by future occupants.

Further research and testing of completed structures under crowd loading is required to formulate a reliable design procedure and compliance parameters. Nevertheless minimum standards could be set from existing data. It is the author's view that until more definitive information becomes available seating decks should not have a natural frequency less than 3.5 Hz.

3.3 Progressive Collapse

Following the progressive collapse of a multi–storey block of flats at Ronan Point in London the British Building Regulations were revised to require that all structures in excess of 5 storeys high incorporate special provision to prevent disproportionate collapse consequent on the failure of a structural element.

In spite of the disastrous consequences which would ensue following the collapse of an occupied stand structure no special provision is made in British Building regulations to require that disproportionate collapse be considered as a design issue on stadia roofs or stadia deck structures.

It is the author's view that this is a serious omission from the Regulations and that all stadia structures should be designed to avoid disproportionate collapse following the failure of any one member. Such provision has been incorporated in the roof structures illustrated in Plates 3, 5 and 6 by designing the secondary roof trusses, which span between the main trusses, to carry the loading of a failed truss laterally to the primary trusses on either side. The primary trusses are also designed such that at ultimate capacity they can sustain the resulting additional loading.

In the case of the structure illustrated in Plate 4, the main "goal post" girder is designed with a double truss arrangement in the triangular form, shown in Fig 3. Should any one member of either truss fail the remaining structure is capable of sustaining the roof loading without collapse.

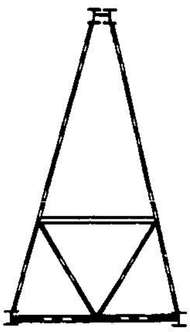


Fig 3 Leicester Main Stand Roof Girder Cross Section

The disastrous consequences of failure of a roof truss or seating deck are sufficient reasons for amending the Building Regulation to require a progressive collapse limitation on stadium design, but there are other special considerations which make such a requirement for stadium roofs even more pressing. Among the most important are:

- Stadium roofs are exposed, uninsulated and unheated and can, therefore, be exposed to micro-climates with high levels of condensation and thermal movements.
- Stadium roofs can be subject to very low temperatures, with the consequent increased risk of brittle fracture in steel components.
- Stadium roofs are subjected to dynamic excitation from wind loading leading to cyclic stressing and consequent increased potential for fatigue.
- Elements of stadium roofs can be inaccessible resulting in inspection and maintenance difficulties.

With regard to partial collapse following the failure of an element supporting the seating deck, the form of these elements is such that the rules contained in the Building Regulations for designing five storey buildings could readily be applied.

In addition to the requirement for specific clauses in the Building Regulations relating to stadia, there is the parallel need to focus the attention of Club Directors and Owners that they carry the primary responsibility for inspection, maintenance and repair of the complex structures which comprise their stadium. Currently the main focus of attention of most Club Directors is the performance of the team and the financial status of the Club. Too often stadium inspection and maintenance is relegated to an issue of minor importance where action need only be considered if Local Authority Safety Teams insist that maintenance work or additional safety measures are necessary.

CONCLUDING REMARKS

The six examples of post Hillsborough stadium developments illustrated testify to the progress being made to upgrade the spectator accommodation at major sporting venues in Britain. Standards have been set by the Building Regulations, Codes of Practice, The Guide to Safety at Sports Grounds, FSADC publications and guidance available from FIFA and other interested bodies.

In some fundamental areas the guidance available for designers is significantly deficient. In particular, research and guidance are required to address critical issues such as limiting design values for dynamic performance of both roofs and seating decks and to establish rules for limiting disproportionate collapse should a local structural failure occur.

Too often government input and finance into upgrading stadia design rules has been limited to an inquiry in the aftermath of a major disaster. Large stadia incorporate specialist structures and consideration of the issues discussed in this paper should not be neglected until the need to do so is proven by a disaster.

REFERENCES

1 REID WM., UK Football Stadia : Engineering for Crowd Safety Elsevier – 1993
2 The Building Regulations 1991. HMSO 1991 ISBN 0–11–015887–3.
3 Guide to Safety at Sports Grounds. HMSO 1990 ISBN 0–1–1–341001–8.
4 CP3 Chapter V : Loading. British Standards Institution.
5 REID WM., TRAVERS J., Wind Tunnel Testing of Sports Stadiums – Construction of Building Materials Vol 5 3 September 1991
6 BATISTA R., : Structural Dynamic Analysis of Maracana Stadium : Bench Mark : Sept 1993