LARGE FABRIC COVERINGS FOR ARENAS AND STADIA AND STRUCTURE/WIND INTERACTIONS

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Fergus McCormick currently leads the Structural Engineering team on the 2012 Olympic Stadium. He has worked around the world and designed and delivered some of the most high profile complex and award-winning engineering projects of recent years. He has worked on four projects winning the Institution of Structural Engineers Special Award. Projects in the past include the BA London Eye, The City of Manchester Stadium and timber gridshell roofs. He is a multi-disciplinary designer delivering expertise on all fields of building engineering with particular technical specialisms in cable structures, long-span structures, dynamics and moving structures and wind engineering. He is a sector specialist in Sports Stadia. For Buro Happold he is currently the Structural Leader for Astana Stadium Retractable Roof; Kirkby Stadium, Everton Football Club; Lansdowne Road Stadium and The London 2012 Olympic Stadium.

Matthew Birchall leads Buro Happold's global fabric membrane activities and is Buro Happold's technical expert in this field. His is a structural engineer by training with also Architectural qualifications. His current work specialises in the field of form-active structures, including the design and analysis of fabric and membrane structures. His work consists of both conceptual/architectural design and analysis/detailed design. He is currently Project Director of several high profile projects.

Matthew has assisted in the development of non-linear dynamic finite element analysis software and vehicle impact modelling. He is currently co-ordinating research into advance structure/wind interactions and new fabric element formulations. Matthew is experienced in sustainable design and recently led a European market study into Building Integrated Photovoltaics. He currently contributes to Northumbria University's postgraduate Architecture programme.

1.0 LARGE FABRIC COVERINGS FOR ARENAS AND STADIA

1.1 Introduction

Buro Happold has been the Engineer on a series of recent stadia and arena. These include two of the most high profile large fabric roof coverings of recent times: the London Millennium Dome completed in 1999 and the London 2012 Olympic Stadium, currently in construction and two further projects: Tsing Dao in China (for which Buro Happold was checking advisor) and the proposed Water Polo Arena for the London 2012 Olympic Games.

The paper presents some background to each project describing how fabric was the natural covering material of choice for each of these venues. The differences between the structure and fabric of each building are contrasted to show differences in approach and decisions made to determine an applicable solution to each different brief. The issues explored are:

- Durability and lifespan;
- Structural performance (strength/stiffness);
- Maintenance;
- Fire performance;
- Cost;

The London Millennium Dome

The London 2012 Olympic Stadium copyright Olympic Delivery Authority


Aerial view of the London 2012 Olympic Stadium Nov 2010 copyright Olympic Delivery Authority


Aerial view of the London 2012 Olympic Stadium Nov 2010 copyright Olympic Delivery Authority

A key feature of both roofs of the Millennium Dome and the 2012 London Olympic Stadium is flat fabric with limited curvatures to minimise the costs and uses of secondary systems thus enabling very effective economic roofing.

1.2 Millennium Dome

The roof of the Dome is a huge cable net, 320m in diameter and clad in 80,000m2 of tensioned PTFE coated glass fibre fabric. It is an innovative feat of engineering yet simple in concept, and was the recipient of the prestigious MacRobert Award in 1999. The roof surface is shaped like a spherical cap. Twelve 100m-high steel masts extend from the roof that support a tensioned net of steel cables, arranged radially on the surface of the Dome and held in place by hangar and tie-down cables at 25m intervals. An inner layer of covering reduces thermal gain and improves thermal and acoustic performance. *(For a detailed description see Ref 1).*

Tension structures generally rely on the shape of the stressed surface for their performance under load. Forces are resisted by the tension and the curvature, the greater the curvature the less the tension required to resist a given load. Over the past 25 years the accepted form of fabric structures became the anticlastic doubly curved surface. Within this surface the down loads are taken by one set of cables or yarns in the fabric, while the up loads from wind are taken by the other. Constructing the structural surface with this minimal surface shape stiffens it against loads.

The structural concept of the Dome departed from this. It is innovative but apparently very simple. Tensioned steel cables are arranged radially on the surface of the dome and held in space at the nodes by hanger and tie-down cables at 25m intervals. The surface is defined as a spherical cap. Between the cables, flat, tensioned, coated fabric is used as cladding. . While this concept is simple, there are dangers associated with the resulting deflections particularly from ponding caused by snow or heavy rain. To ensure that the structure works satisfactorily it is necessary to understand the behaviour of the materials and the structure as a whole and to get the details and the geometry right.

The roof was originally designed in PVC coated polyester when the Dome was expected to have a short design life and the aim was to minimise costs. However, in June 1997 the new Government made it clear that all options should be kept open regarding the long term use of the Dome. This completely changed the basis on which the fabric was chosen and a subsequent review concluded that PTFE coated glass fibre was a more appropriate material. The change to PTFE/glass did not affect the steel and cable structure but the fabric connection details were changed. It was imagined that material will give a lower translucency and poorer colour rendering than the selected PVC options but it will look better externally and will continue to do so for a long time.

It is interesting that the Dome is having a very successful second life as part of the covering for the O2 Arena and internal malls, restaurants and other shops.

1.3 2012 London Olympic Stadium

The Olympic Stadium for the London 2012 Games is to be constructed on an island site within the Olympic Park near Stratford in East London. Designed to accommodate a capacity of 80,000 spectators for the Games, the Stadium will be converted to a 25,000 seat venue in the longer term.

The Stadium will provide facilities for elite athletes, the media and the Games Family. These will include changing areas, an indoor warm-up track, race management space, restaurants, press conference rooms, broadcast studio space and all necessary support and service facilities.

Buro Happold is working as part of ‘Team Stadium’ an integrated design and construction team led by Sir Robert McAlpine, and including Populous as architects.

The innovative design features a lightweight, cable-supported roof and a simple de-mountable superstructure. The roof of the 2012 London Olympic Stadium is around 22000m² of tensioned PVC*. (For outline descriptions, see references 2 and 3).*

The roof is a system exhibiting cables working in different ways. Pairs of radial spoke cables are tensioned between chords of the external trussed compression ring and an inner tension ring. The whole cable net is pre-tensioned prior to installing the fabric cladding and the lower radial spoke cables carry the tensioned fabric cladding. At heart it is an example of a bicycle wheel type structure which has become common in some ways for many sports stadia. The sophistication comes from the expedient use of simple flat fabrics minimising the number of secondary roofing steel components shaping the fabric. The system has been rapid and effective to construct.

The potential further disadvantage with these designs is their overall similar appearance and lack of distinction. They can appear as a ‘product design’ rather than ‘architecture’. Over the next years it falls on all architects and engineers to explore the possibilities of innovative solutions and try and shake up the appearance of these systems rather than repeat systems which are starting to be formulaic.

However, it is believed that this design is a fine example with a real sense of purpose for its selection is the roof of the proposed 2012 London Olympic Stadium (designed by Buro Happold and Populous™. The London Stadium had as its initial brief the view that the roof and upper tier might be removed after the Games. The whole stadium was developed with tenets of ‘embrace the temporary’ and ‘touch the ground lightly’. The roof structure is inherently lightweight and structurally efficient, with a much reduced tonnage particularly when compared to other recent heavy Olympic stadia roofs at Athens and Beijing. The cladding design is simpler than other fabric roofs, developed by integrating economic effective flat fabric and straight cables technologies from The Millennium Dome, also designed by Buro Happold.

The primary structural system for each roof clearly demonstrates how fabric inherently works well with cable supported roofs. The distinction is made between the nature of the Millennium Dome being a mast supported roof and the London 2012 Olympic Stadium being a closed bicycle wheel system. The structural system of the Millennium Dome roof creates external vertical and horizontal reactions at the ground from the tie downs and masts whereas the support system of the London 2012 Olympic Stadium roof is predominantly vertical from the perimeter inclined columns. However, many of the tie-downs and other horizontal reactions of the Dome were linked by a large diameter circular ground beam and thus, the lateral forces are, to some extent, contained in the same way that we feel those in the bicycle wheel are.

The form of the roof as been carefully developed using CFD and a virtual wind tunnel to provide appropriate level of wind protection to competitors to facilitate a pre-eminent Olympic athletics event. The design has been integrated from the start for the sports lights and also (for the first time we believe) for the extensive aerial cabling for the Olympic opening and closing ceremony. The scope, scale and approach for the lightweight roof has been tuned as a piece of engineering design apposite for coverage to a building with a one-off major Olympic event, but also with opportunities for sustainable reuse potential for coverage to a potential smaller local and national legacy community stadium after the Olympic stadium seating bowl is reduced in size after the Games.

The Stadium's roof is made up by 112 panels of white material stretched between an outer truss and an inner tension ring. Material was fitted by a team of 23 expert abseilers. The cover creates the correct conditions on the field of play for athletes and provides protection for two-thirds of spectators.

The use of flat fabrics is presented as structurally efficient, but it is acknowledged that this is also embodies fashion trends of architects and engineers moving away from the more 'peaky' shapes showed in projects such as Tsing Dao with more accentuated curvatures.

Tsing Dao, China

For the choice of fabric, we see a different approach to the Dome. In order to provide an economic cost option, allowing a limited life span for a temporary covering, the roof membrane is constructed from PVC coated polyester fabric. Also, by contrast to the Millennium Dome whose fabric was formed of two layers, that of the London 2012 Olympic Stadium is of a single layer.

A key criteria requested in the design was that fabric was fire rated to Class B-s3, d0 or better when tested in accordance with BS EN 13823 with classification according to BS EN 13501-1. This criteria was tested against a number of fabrics, but did certainly have consequences for limiting the range of specific types available for adoption.

The choice of PVC has influenced the detailing and the fabric includes many simple site welded panels with cover strips for resilience against water ingress.

The steelwork and primary cabling was delivered by a steel sub-contractor to the Main Contractor Sir Robert McAlpine. The fabric and metal hardware and secondary cabling was delivered as a separate fabric sub-contract to the Main Contractor Sir Robert McAlpine.

Post-contract and prior to the production of the cutting patterns, samples of the fabric was analysed at Newcastle University for independent biaxial stiffness, compensation and strength testing.

Fabric was delivered to site in bundles which were craned into position onto 'cargo' netting suspended from the main primary steel cables. The fabric was then unfurled and connected to the primary cables.

Buro Happold worked to develop all details for the fabric and fabric-steel interface. These were generally all agreed and developed unchanged by the fabric supplier.

1.4 Water Polo Arena

The fabric on the Water Polo Arena is proposed as an elegant mixture of white translucent, white opaque and silver opaque pvc coated polyester. However the key feature is the proposal of phthalate-free material for sustainability reasons. The paper describes the approach to the specification of this for the project.

2.0 STRUCTURE-WIND INTERACTIONS

2.1 Introduction

Studies for such an advanced project such as the London 2012 Olympic Stadium tend to make one consider the different aspects of wind regimes as applied to stadia and long span structures. *(For a general description of issues related to wind in stadia see reference 4).*

There are many aspects to consider for both serviceability and strength and stability. An important aspect of the engineer's judgement is knowing and being able to choose the appropriate technology to assess performance.

The paper briefly considers two state-of-the-art techniques being explored by Buro Happold. The former is used in practice by the firm in the assessment of a specific sports related serviceability performance and was used on the Stadium, the second is still somewhat in its research stage.

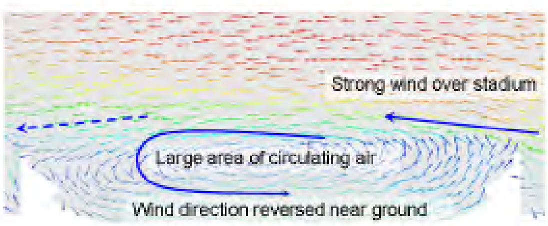
2.1 2012 Olympic Stadium

Complex CFD was used to analyse the wind regime on the track and field on the London 2012 Olympic Stadium. *(For more details see reference 5, to be published).* A key issue for the Games is trying to ensure that any track and field records will not be invalidated by excessive wind speeds at ground level offering assistance to athletes. Moreover, it is also important that general gustiness and wind speeds are controlled to ensure appropriate comfort levels to athletes. Consideration was given to limiting or eliminating the roof covering and innovative CFD was instigated to explore this. The analysis revealed that a certain covering benefited in attenuating windiness at track and field level and the roof area was developed with a series of parameters to an optimised surface.

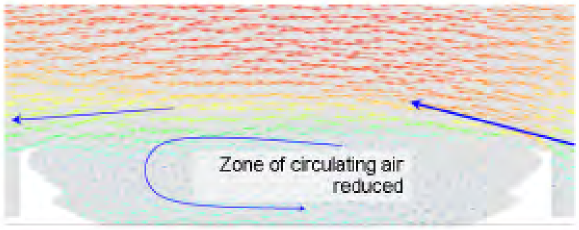
A set of results are shown for analyse undertaken in a parametric study with various amounts of roof covering.

The study considered wind exceedance over 2m/s and general comfort conditions of athletes. The study was undertaken using 3D steady RANS CFD modelling based upon a simplified stadium geometry. This allowed rapid assessment of a range of options at the preliminary design stage, well in advance of the later wind tunnel testing, carried out at detailed design stage.

Such an application is apt for CFD which has certain limitations towards generation on wind loading, but is reasonably well-established for environmental modelling.



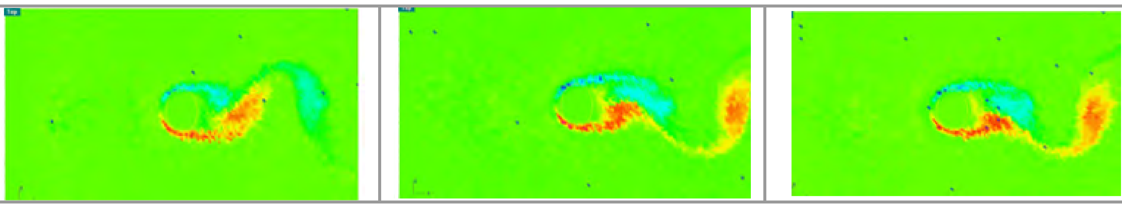
Analysis image of wind speeds of stadium with no roof



Analysis image of wind speeds of stadium with partial roof covering

2.2 Smooth particle hydrodynamics

Brief discussion is presented of exploratory research in the field looking to use smooth particle analysis to generate loadings of structures subject to fluid actions. This cutting edge fluid modeling is being undertaken in collaboration with Bath University.



Analysis images of fluid displacements derived from smooth particle hydrodynamic studies.

Our ability to confidently push the limits of Tensile Architecture and create new directions for this topic will rely on an increasing confidence in how the structures will behave, and this relies on accurate representations of material behaviour and applied loading, allied to appropriate numerical analysis and simulation.

Inherently, fabric structures can be of unusual geometrics and of large displacements and the applicability of standard code methods requires always a measure of judgement on the most complex structures. Even wind tunnel testing can have limitations over its applicability to lightweight form-active structures.

The aim of any alternative methodology is to try and model coupled behaviour of wind and fabric and their interaction.

Buro Happold and the University of Bath have undertaken some recent studies with Smoothed Particle Hydrodynamics (SPH) offering a method for assessing the flows of wind over complex forms. It aims to discretise the fluid flow into individual smart particles that can interact with each other and with the structural elements, whilst modelling turbulence and laminar effects dynamically. Although much of the analysis work to date with SPH has been qualitative, this method has already proven to be a useful tool in assessing real-time fluid flow and the dynamic interaction between flexible structures and wind. The next steps will be to expand the range of wind- structure interactions that are possible, and thence to quantitatively correlate the analysis results with in-situ and other tests.

The presentation at the conference will briefly outline the current potential of SMART Particles, the software developed by Buro Happold for this purpose, and explore the potential benefits of dynamic simulation in real design scenarios. *(For more details, see reference 6).*

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