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Wind tunnel testing of sports stadiums

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Abstract

The paper describes the importance of wind tunnel testing of scale models to determine wind pressure and air flow distribution on and around major stadium complexes. The effects of wind on major grandstands is considered from a static, dynamic and environmental viewpoint. Examples are given of typical results from the wind tunnel tests for the roof of the East Stand at Murrayfield Stadium, Edinburgh, and for the playing surface at Ibrox Park, Glasgow.

Modern trends towards covered, column free, seated grandstands have created the need for large clear span roof structures. With their open fronts, grandstand structures can generate high internal and external wind pressures. These pressures are difficult to predict accurately from existing codes of practice (CP) and wind loading handbooks, as such references cannot adequately make allowance for the individual features within a typical stadium complex. As an example the variations of nose detail for three stadium roofs are illustrated in Figure 1. It can readily be appreciated that the wind pressures on the roof cladding behind these details will vary considerably and that accurate analytical prediction of these variations is difficult.

The design process is further complicated by the need to verify that grandstand structures are dynamically stable and are not susceptible to excitation by transient wind loadings.

To obtain reliable data for the static and dynamic loading conditions and to verify that the proposed geometrical layout does not generate unacceptable environmental conditions within and around the stadium, laboratory wind tunnel tests on scale models have been employed with great success on a variety of projects.

The discussion which follows is based on experience gained from wind tunnel tests carried out by BRE on behalf of Thorburn plc as part of the design process for grandstands at Ibrox Park (Glasgow)[1], Murrayfield Stadium (Edinburgh), Hampden Park (Glasgow) and City Ground (Nottingham). All the tests were carried out on 1/300 scale models with a wind velocity of one-third actual.

Static loading

Wind tunnel tests on scale models provide the designer with static pressures generated by wind flow over the instrumented structures. As the model is rotated, pressures for all wind directions are obtained and worst cases can be identified for both local and global conditions.

A model of the East stand at Murrayfield Stadium, Edinburgh, was tested in the BRE Laboratory at Garston in 1982. A typical cross-section through the grandstand is shown in Figure 2. The cantilever spans 29.5 metres and the total length of the stand is 134 metres. The cladding is underslung with exposed steelwork above.

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The nose feature, which has a significant effect on the roof pressures generated is indicated in Figure 1. An analysis was carried out using CP 3: Chapter V,[2] and pressure coefficients derived from the Wind Loading Handbook.[3] The pressures predicted were analytically compared with the worst case of those measured in the wind tunnel. The results are indicated in Figure 3. For simplicity the wind tunnel tests have been idealised but rigorous interpretation would reduce even further the roof pressures shown.

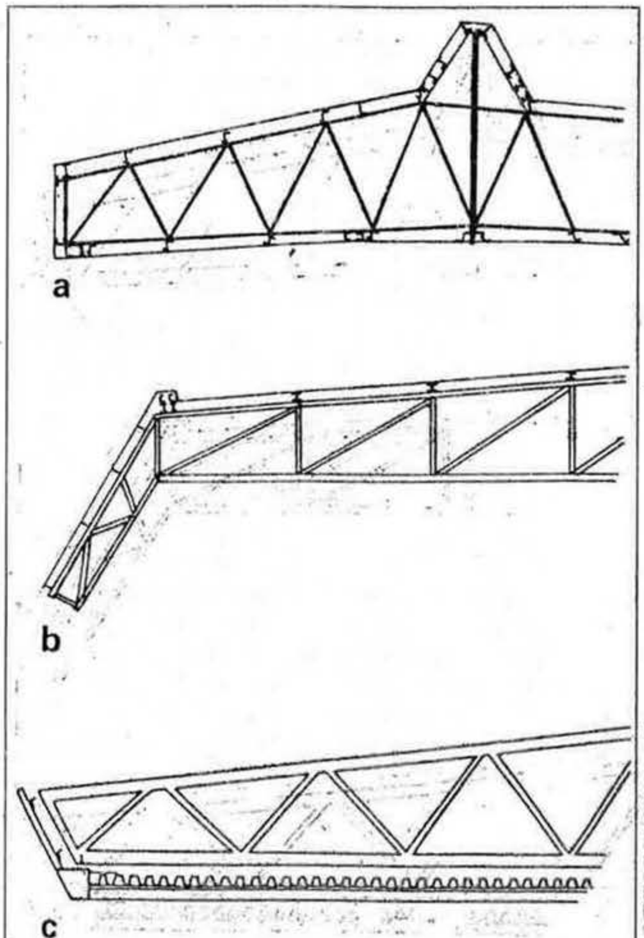

Fig 1 Typical roof details: (a) Ibrox Park, Glasgow – East and West stands; (b) PSV Eindhoven – main stand; (c) Murrayfield, Edinburgh – East stand

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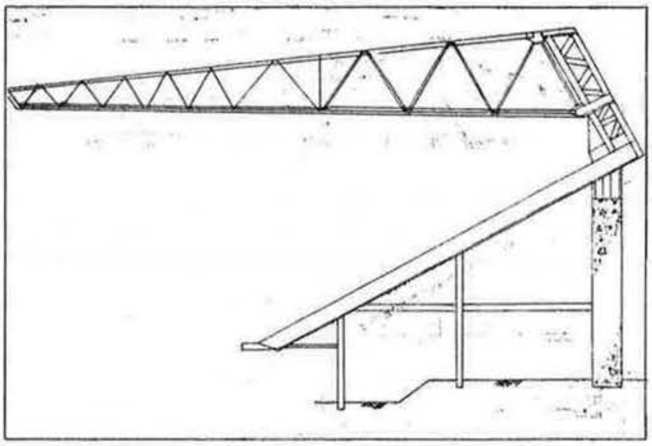

Fig 2 *Typical cross-section of structure – the East stand at Murrayfield, Edinburgh*

An interesting aspect of the wind tunnel test for Murrayfield relates to enclosing the ends of the grandstand. It had been believed that end closures of the type adopted would result in the development of very high positive pressures within the stand, thus increasing upward loads on the roof structure. The wind tunnel test results did not, however, support this concern.

For the Murrayfield stadium the reduction in static pressures indicated by the wind tunnel, compared to those assessed on the basis of the code of practice and wind loading handbook, was very significant. For this particular case it was considered that the relatively high parapet at the nose had a major influence on the suction pressures on the roof. This assumption was verified indirectly by repeating the tests with slots introduced behind the nose to equalise locally the pressures above and below the roof membrane. It was found that the pressure differences measured with the slots open and closed were not great and this was taken as verification that the nose parapet was a major influence in modifying the roof wind pressures.

Dynamic assessment

Conventional building structures would not normally require categorisation relating to their response to imposed transient loadings. Such buildings behave, and are designed, as static structures when subjected to wind loads and no consideration of dynamic behaviour is therefore necessary.

Long span, relatively flexible structural elements such as modern grandstand roofs do not automatically fall into the static category. Since wind-induced dynamic behaviour will result in amplification of statically determined displacements, forces and stresses, categorisation of such structures in accordance with their susceptibility and sensitivity to dynamic behaviour is essential.

Current Codes of Practice for the design of building structures do not address the subject of static/dynamic categorisation. BRE Digest 346 and the Designers Guide to Wind Loading of Building Structures propose methods for simplified and rigorous categorisation of structures with respect to static, mildly dynamic or dynamic behaviour. The classification procedure relates to the actual displacement of the structure at its first mode of vibration to the corresponding static displacement.

Figure 4 shows the first two modes of vibration for the Murrayfield East grandstand. These occur at frequencies of 1.45 Hz and 1.37 Hz respectively. For a particular mode, the frequency, the damping ratio and the wind energy available determine the degree of excitation which will occur. In most cases stadium structures of this type are only mildly dynamic. But further test data and field measurements are required to verify design assumptions. Wind tunnel testing can be used to estimate the forcing function using a static model to determine the model response.

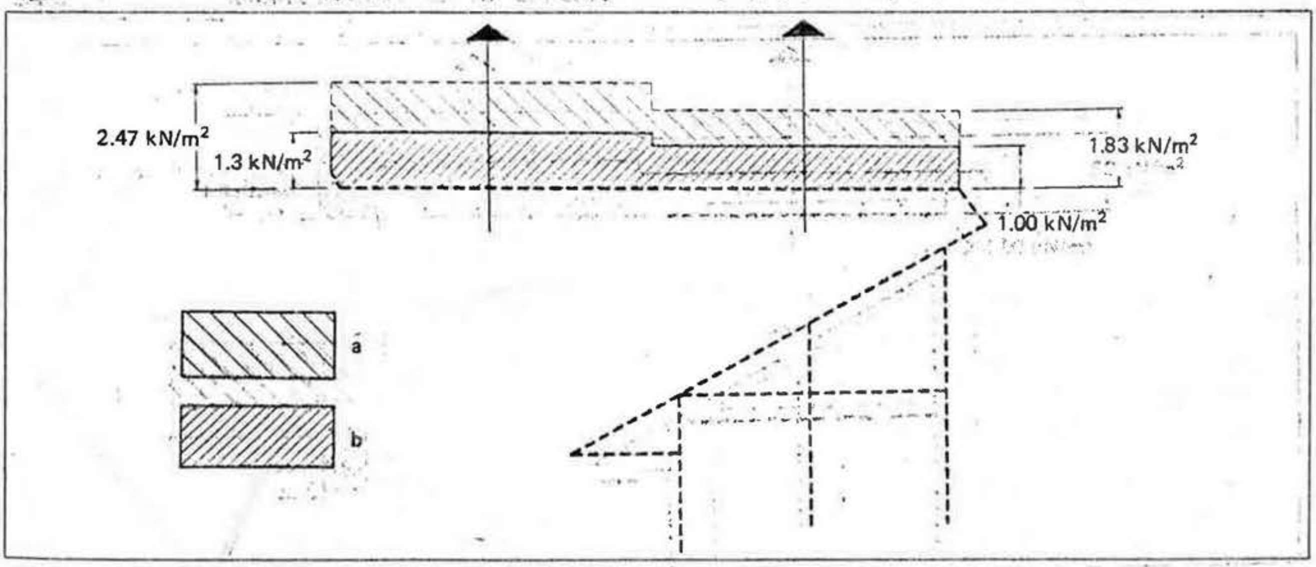

Fig 3 *Static design wind pressures on roof, class C structure (East stand at Murrayfield).*
Key: *(a) static design wind pressure determined in accordance with CP3, Chapter V, Part 2 and the BRE wind loading handbook for roof uplift condition; (b) static design wind pressure determined from BRE wind tunnel tests for roof uplift condition*

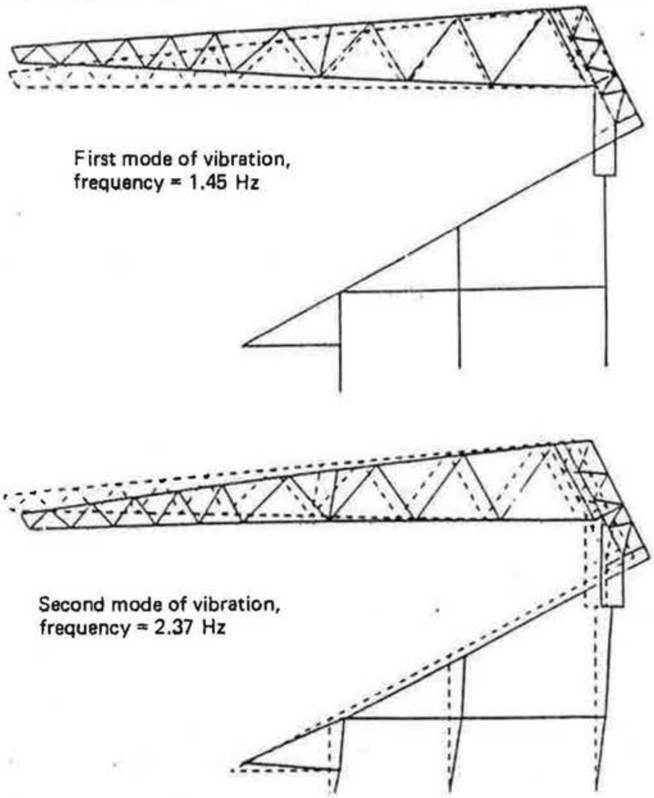

Fig 4 Natural frequency modes 1 and 2; the East stand at Murrayfield, Edinburgh

Fig 5 A close-up view of the model of Ibrox Park stadium in the BRE wind tunnel (photo – Crown Copyright)

Environmental effects

Sports stadiums are often sited in urban locations in close proximity to other buildings. While the impact of spectator movements around stadiums is well documented there is little published data on the influence of air flow around large grandstands. Where sensitive situations exist in close proximity to a proposed new structure, wind distribution variations for the pre- and post-construction condition can be modelled in a wind tunnel test. This involves extending the wind tunnel test to include tappings in the roofs and walls of adjacent sensitive structures.

An adverse influence from enclosing a stadium is the shading afforded to the grass playing surface by adjacent

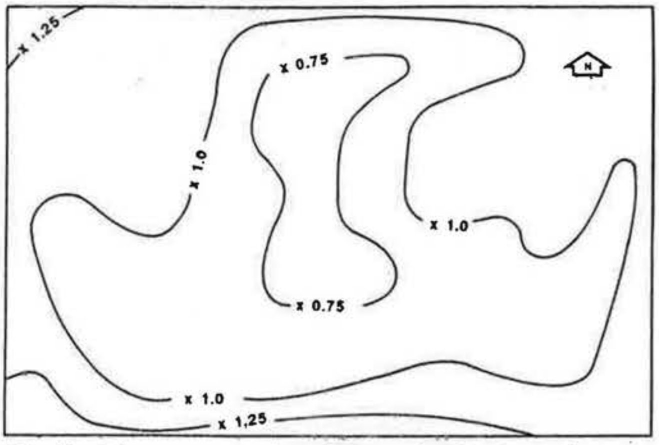

Fig 6 Maximum wind speed over the playing surface at Ibrox Park, Glasgow, for all wind directions expressed as a ratio of pre-redevelopment conditions

large roofs. This adverse effect can be exacerbated by reduced air circulation at playing surface level and it is therefore important to establish the influence of grandstand construction on wind flow over the pitch. Wind tunnel tests to model the air flow over the pitch have been carried out for a number of projects including the development of Ibrox Park, Glasgow (Figure 5), where tests were made to model the wind flow variations as each phase of the development was completed. Figure 6 shows the wind flow intensity over the Ibrox Park playing surface after completion of Phase 3, expressed as a ratio of pre-development conditions. From the diagram it can be seen that a 25% increase in air flow was predicted adjacent to the open corners of the stadiums but a corresponding 25% reduction was seen near the centre of the playing surface.

Concluding remarks

The unique characteristics of each individual situation does not readily permit accurate prediction of the influence of wind on stadium structures and the immediate environment around them. Experience has shown, however, that wind tunnel testing of scale models provides a cost effective means for obtaining design pressures on structures, determining static or dynamic behaviour and for studying the influence of layout, shape and form on the air flow in and around stadiums. Tests on stadiums incorporating major clear span structures have demonstrated that the actual loading is significantly less than could be deduced from Codes of Practice and published literature and this has allowed designers to achieve significant savings on structures and cladding elements.

References

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Comparison of accelerated and natural weathering of coil-coated galvanised steel

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Abstract

Flat coil-coated galvanised steel samples from two sources were cut, bent and subjected to exposure at two natural weathering sites for five years. Results were compared to two accelerated salt-spray replicated tests. The paper discusses methods of measuring corrosion and compares performance of coated products. Cyclic weathering followed by salt-spray testing produced similar results to natural exposure tests when substrate pitting was examined but not when coating blistering was examined. Salt-spray pitting and blistering results were not similar to natural exposure results. Pitting of the substrate was regarded as a more accurate measure of coated metal performance than coating blistering, though removal of the coating is necessary. There was a large variation in T bend results for all exposures. Conclusions were that combination test methods should be further examined. Cyclic weathering followed by salt-spray testing proved a useful indicator of natural exposure results, but was less useful for product comparison work.

There is a widespread interest in the use of standard accelerated test methods for durability predictions of coated metal products for product development and for service performance assessment[1-4]. The salt-spray test is widely criticised[5-6] as being unable to reproduce degradation similar to that found naturally. The xenon arc light exposure test (a cyclic weathering test) was found to be of some value to product development[6] and provided useful comparative information on similar systems. Appleman has reviewed accelerated test methods and found that cyclic weathering tests can provide valuable screening data for products[5]. Natural weathering gives the best prediction of durability performance[6]. Campbell, Martin and McKnight reviewed various cyclic testing involving salt-spray cycles[7]. These tests have been developed by different industries and government bodies and have limited usage beyond the instigator.

This project examines the combination of the salt-spray test with a standard cyclic weathering test; the xenon-arc light exposure test. These tests are both covered by standard test methods (ASTM B117[8] and ASTM G26[9]) and facilities to perform these tests are readily available.

Experimental

Flat coil-coated galvanised steel sheet was received from two different sources. The coatings were silicon-modified polyester over an epoxy primer. Two different pretreatments had been applied to the galvanised sheets; one source used a chromate pretreatment and the other a phosphate pretreatment.

The sheets were cut into samples. Each sample had a 90 degree bend and a 180 degree bend (Figure 1). The 90 degree and 180 degree bends were bent over formers to the following T-bend diameters: 2T; 4T; 5T; 6T; 8T; 10T; 12T; 16T; 20T. For each T-bend diameter there were eight samples from each source. Samples were examined for coating microcracking along the axis of the 90 degree and 180 degree bends, and rated by comparison at 20× magnification with the photographic standards in ASTM D661 (1981)[10]. Microcracking was plotted against T-bend (Figure 2).

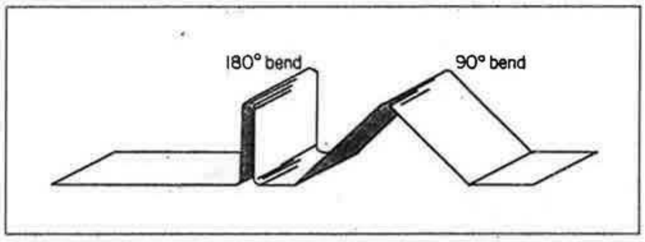

Fig 1 Sketch of samples used for testing. Overall dimensions: accelerated weathering samples 230 × 79 mm; outdoor weathering samples 300 × 123 mm

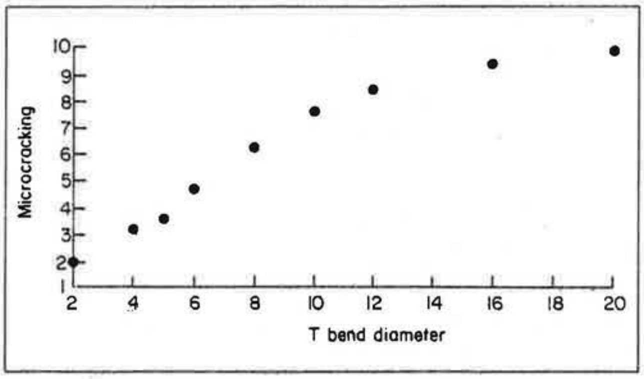

Fig 2 Microcracking for each T bend diameter

Four different exposure regimes were used, involving two natural weathering sites and two accelerated testing methods. Two replicates from each source were tested in each exposure.

Natural weathering testing involved sample exposure for five years with samples facing north and exposed at 45 degrees to the horizontal. One site, Otaki, was classified severe marine and the other, Judgeford, rural marine. Samples were exposed at the Otaki site in June 1983 and at the Judgeford site in April 1983. Samples

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