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Application of CFD simulations of wind-driven rain (WDR) on the new roof extension for San Mames new football stadium

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ABSTRACT

The new San Mames Stadium, recently awarded in the World Architecture Festival as the best Sports building completed in 2015, is the new home of football team Athletic Club of Bilbao. After the new stadium was finished, IDOM was commissioned by the Club to assess potential upgrades in the roof with the aim of improving the spectators' comfort on rainy days. The selected solution, the erection of a cable-roof extension which increases the roof spans by 13–23m, was eventually carried out during the summer break of 2016.

This paper describes the assessment process carried out by IDOM, focusing on the 3D Computational Fluid Dynamics (CFD) simulations of wind flow and Wind-Driven Rain (WDR) for the original stadium roof and for different roof alternatives. The performance of each potential alternative is evaluated and compared under different rain events. The wind-flow patterns are determined by steady-state RANS simulations, whereas the WDR trajectories are estimated by means of Lagrangian particle tracking.

Field measurements of wind velocities and wetting patterns on the stands were also taken during the whole assessment process in order to correlate the results obtained from the CFD analyses. Furthermore, some wind tunnel testing were also performed in parallel in order to assess, in a qualitative way, the effects of each potential alternative on the wind-flow patterns and compare them with the CFD results.

1. Introduction

The new San Mames Stadium, recently awarded in the World Architecture Festival as the best Sports building completed in 2015, is the new home of the Athletic Club of Bilbao football team. This new stadium, with capacity for 53500 spectators, is classified as a UEFA Five-Star Stadium, having been selected as one of the host venues in the UEFA EURO 2020 (see Llarena et al. (2016) for further details of San Mames stadium structure).

San Mames was conceived as an open stadium not only due to its beneficial effects on the natural grass and natural ventilation, but mainly to preserve the traditional essence of football in Bilbao. The stadium configuration was based on a downward sloped roof (approx. 9°) and an enclosed stand arrangement (which according to studies previously carried out by Persoon et al. (2008) and van Hooff et al. (van Hooff et al., 2011) provide the best wind-driven rain (WDR) shelter among the analysed open stadiums), as well as equipped with a 55-m cantilever roof which reached the borderline between bottom stands and field (see Fig. 1).

Nevertheless, some typical adverse rain conditions of the region and the special location of the stadium (at the top of a slope close to Bilbao's sea inlet) cause that the spectators comfort was, unavoidably, affected by wind-driven rain during some football events. Hence, at the end of season 2014–2015, IDOM was commissioned by the Club to assess potential upgrades in the roof with the aim of improving the spectators' comfort on rainy days. As such upgrade was aimed to be constructed during the upcoming summer break of 2016, the development of a proper approach for the assessment process (see Fig. 2) was necessary to comply with the tight schedule.

Firstly (Stage 0), a comprehensive review of the status of CFD studies of WDR (especially on the stands of football stadia) was carried out with the aim of identifying the most suitable calculation methodology for the purposes of this project. In parallel, an exhaustive analysis of available meteorological data was performed to determine the most representative WDR scenarios. Then (Stage 1), a CFD computational model of the stadium was elaborated by following the guidelines provided by previous research studies (Persoon et al., 2008; van Hooff et al., 2011) and validated by correlating the WDR results obtained from the CFD analyses with existing field measurements (wind velocities and wetting patterns on the stands). Afterwards (Stage 2), once the accuracy of CFD model was

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Fig. 1. Views and section of original new San Mames stadium.

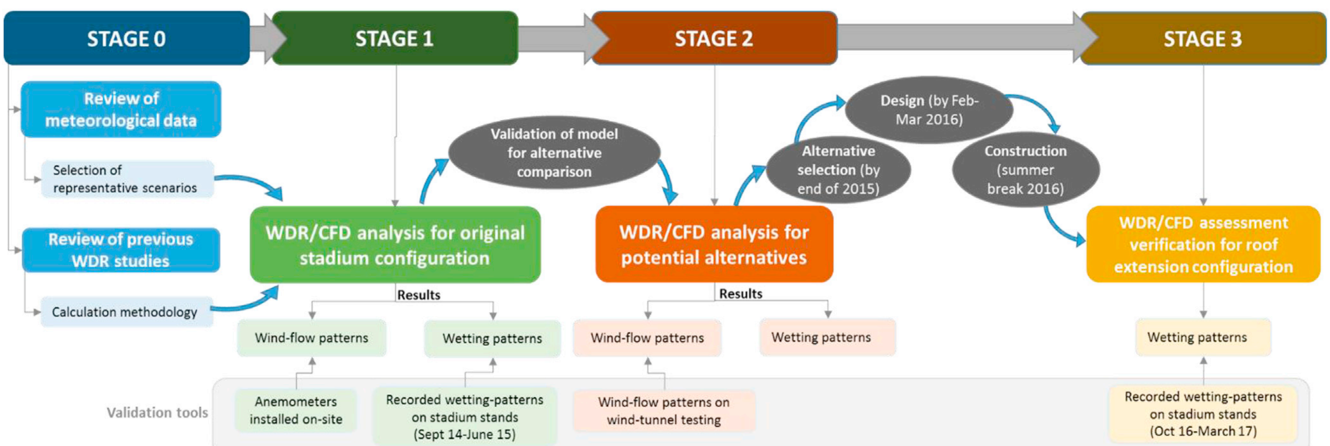

Fig. 2. Schematic representation of the assessment process.

considered suitable for the project needs, the performance of different roof alternatives was evaluated and compared under different rain events. Furthermore, some wind tunnel testing was also performed in parallel in order to assess, in a qualitative way, the effects of each potential alternative on the wind-flow patterns and compare them with the CFD results. Finally, after the final solution was selected (erection of a cable-roof extension which increases the roof span by 13–23m) and constructed, the previously estimated performance of roof extension has been verified (Stage 3) by means of some additional field measurements (wetting patterns).

2. Review of previous WDR studies and analysis meteorological data

2.1. Review of previous CFD studies of WDR

A comprehensive review of previous CFD studies of WDR, such as Choi (1993) and Blocken et al. (2009), has been carried out in order to identify the most suitable calculation methodology for this project. This review has been specially focused on the WDR studies for football stadia carried out by Persoon et al. (2008) and Van Hooff et al. (van Hooff et al., 2011), which have resulted considerably useful for the purposes of this application. In accordance to the basic criteria indicated by these studies, the wind-flow patterns are determined by steady-state RANS simulations, whereas the WDR trajectories are estimated by means of Lagrangian particle tracking (LPT). Although this last method presents some disadvantages as high time-consumption or inability of accurately modelling the turbulent dispersion of raindrops that could be mitigated by an Eulerian approach as stated by Blocken et al. (2009) and assessed by Kubilay (2014), the precision of the results was considered suitable for the purposes of this study.

2.2. Analysis of meteorological data

CFD simulations were preceded by an exhaustive analysis historical meteorological data available. This allowed the setting of appropriate simulation conditions to evaluate the performance of each potential alternative under real meteorological conditions. The selected parameters are shown in Table 1.

Predominant wind directions during rain events are between north and north-west. From this range, wind directions of 276°, 306° and 336° were selected for the simulations and the sensitivity of the system to the variation of wind direction was observed (wind direction of 306° coincides with the longitudinal axis of the stadium). Although 216° direction (coinciding with the transversal axis of the stadium) is not a predominant wind direction during rain events, it has been also considered for some scenarios (especially for correlation purposes).

A wind velocity sensitivity analysis was also carried out by using three