WIND DRIVEN RAIN IMPACT ON A TALL BUILDING FACADE

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To determine the trajectories and the impact of rain drops on the façade of a tall building, a particle tracking method is employed from steady state simulation of turbulent flow around the building. The simulation is performed for the upper part of the building comprising a detailed louver system. Rain is trapped at relative high rates on the roof and the penthouse, with Local Intensity Factors (LIF's) of the order of 1. The upper parapets and upper floors get a fair amount of wetting with LIF's of the order of 0.6. The wetting decreases downwards reaching values of 0.2 to 0.25 at the level of the louver system.

Key Words : Wind Driven Rain (WDR), Partical Tracking Method, Local Intensity Facotr (LIF)

1. INTRODUCTION

Wind driven rain (WDR) is the rain falling obliquely due to blowing wind and is one of the main sources of moisture on the building surfaces. Due to three dimensional complicated flow structures around a building, the wetting pattern of rain impact on the building surface is not uniform. The non-uniform moisture distribution on the building surface can cause water leakage entering into the building envelope, frost damage, moisture induced salt migration and structural cracking due to thermal and moisture gradients, etc[1].

The assessment of WDR intensity has been studied in three ways, experimental [2,3,4], semi-empirical [5], and numerical methods [6-10]. Due to the difficulty of controlling the experimental conditions, CFD techniques have been developed since the initial study of Choi [6]. For the validation of CFD results, Hangan compared his CFD results with experiments [11]. Blocken also carried out experimental and CFD investigations of WDR for lowrise buildings[12,13].

Using the commercial CFD software, FLUENT, the current study presents a numerical investigation of WDR impact on a tall building facades covered with a complicated louver system. The study employed the worst WDR scenario identified from the meteorological data. The height and width of the building foot print are around 240m and 46m, respectively. Only top 10 floors including roof structures of the original building was modeled, see Figure 1.

The WDR data was obtained from the local airport near the building construction site. Based on the analysis of these data, it was identified the critical wind condition occurring from a wind of 10 mph (4.47 m/s) (measured at 10 m height) coming from 223 degrees from North, see Figure 2. This wind direction corresponds to one of the horizontal plane symmetry axis of the building. For this wind direction the statistical maximum rain-fall was of around 4 mm/hr. The worst wind direction in terms of wind intensity corresponds to approximately 330 degrees from true North which is a symmetric situation as well. Therefore our wind-driven rain simulation indirectly addresses both maximum wind and maximum rain cases.

2. METHODOLOGY

2.1 NUMERICAL SETUP

Number of computational cells used for this simulation is around 500,000. Segregated solution scheme is employed to solve the momentum equations and the pressure equation. For turbulence model, RNG k-epsilon model considering standard wall functions for near-wall treatment was used. At inlet boundary, uniform inlet velocity of 15 mph (6.7 m/s) was used. For the pressure-velocity coupling, SIMPLEC was used and discretizations for momentum, turbulence kinetic energy and turbulence dissipation rate, first order upwind scheme was used.

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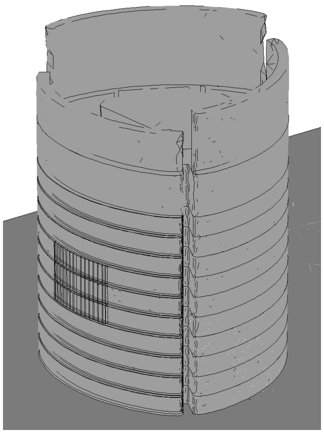


Fig. 1 Perspective view of the building: Top 10 floors including roof structures

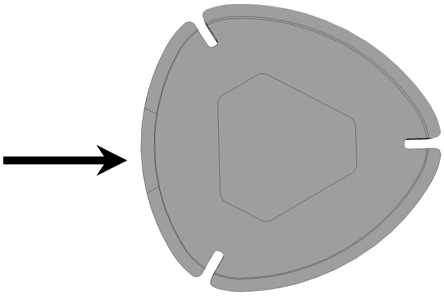
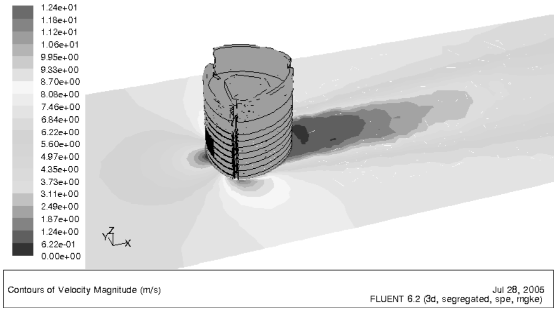


Fig. 2 Top view of the building and wind direction

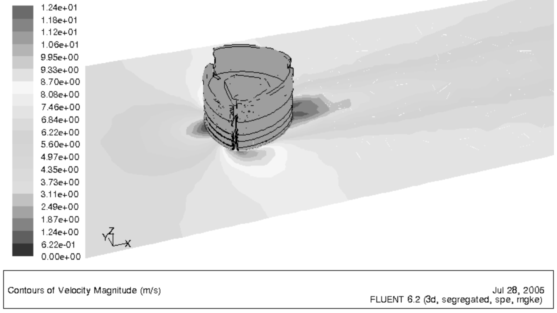
2.2 PARTICLE TRACKING MODEL

After a steady state simulation of the flow field around the building a Particle Tracking Method was employed to determine the trajectories and the impact of rain drops on the main face of the building. Figure 3 shows the results from the steady state simulation in terms of velocity contours on the horizontal planes for sections passing lower, mid and top part of the model.

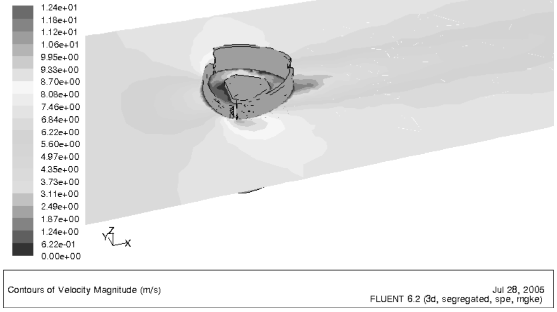
Rain drops of various diameters were injected into the flow with an average diameter of approximately 1.8 mm and captured on various pre-defined zones on the building façade. For more details on the procedure and comparisons with restricted laboratory experimental results refer to [11].



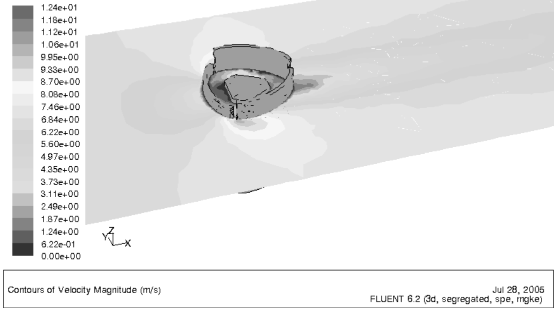
(a) Lower part of the model



(b) Mid part of the model



(c) Top part of the model



(d) Roof of the model

Fig. 3 Velocity contours

The upper part of the tower only was simulated and the louver system was detailed for 3 floors of the building: floors 5, 6 and 7 from the top of the building, as represented in Figure 1. This approach is motivated by the fact that in wind-driven rain it is the upper part of the building which is wetted the most. For the detailed louver system, the inner wall, and the slab area between the louvers and the inner wall and outside the louvers

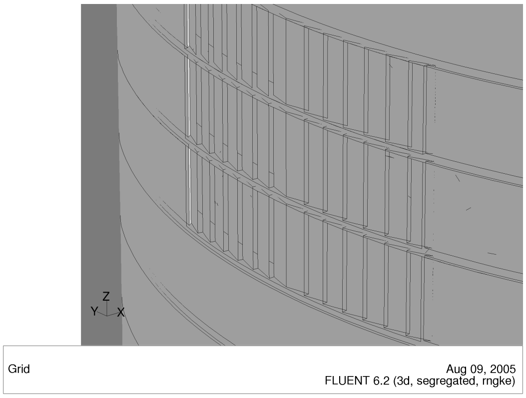


Fig. 4 Details of louver system

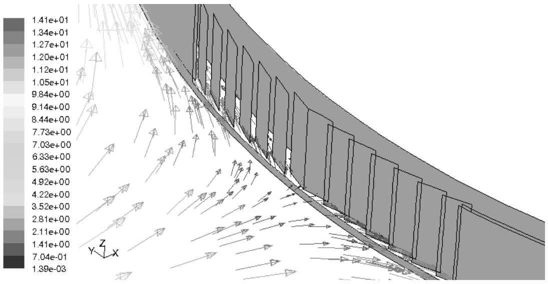


Fig. 5 Vector plot: Wind flows through the louvers and move along the inner wall surface

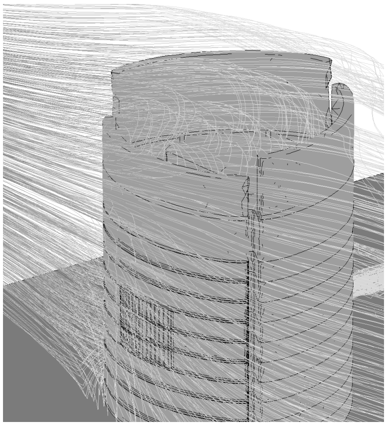


Fig. 6 Trajectory of rain droplets impinging on the building surface

have been modeled in detail, Figure 4,5 shows the vector plots of the wind approaching the detailed louver system and passing through the louvers and moves along the inner surface. The rest of the building façade was simply modeled as porous wall regions. The detailed region, centered with the critical wind-driven rain direction, provides information on the rain penetration inside the curtain wall while the rest of the porous wall zones provide general wind-driven rain information on the rest of the upper part of the tower.

Based on the number of particles trapped on every pre-defined zone, the simulation determines the mass flow rate of rain impacting these zones. The mass flow rate impacting every zone is then divided into the initial rain fall of approximately 4mm/hr and the Local Intensity Factors (LIF) on any of the trapping zones are obtained. Therefore, for any zone "i" the corresponding LIFi can be expressed as:

$$LIF_i = \frac{3600\Phi_i}{A_i R_o} \quad (1)$$

where Φ_i [kg/s] is the mass flow rate of water trapped on zone"i", A_i the surface area of zone "i" and R_o the undisturbed rainfall [mm/hr].

3. RESULTS

The estimated penetration of rain inside the curtain wall is minimal. The current simulation results show that there is practically no rain trapped on the inner wall surface. This result is in formal agreement with flow visualizations produced in the wind tunnel test of the building. The wind flow, and therefore the raindrops transported by the flow comes to a halt at the stagnation point on the front part of the building. From here the mean flow field and raindrops deviate laterally around the building face or up above the parapets following paths towards the wake of the building. While heavier particles tend to penetrate on the cantilever slab zone in front of the louvers and in between louvers and the inner wall, the lighter ones follow the path around the building described before, see Figure 6. Therefore wetting will occur on the slab zone (mostly outside of the louvers) but not at any extent on the inner wall.

3.1 LOUVER SYSTEM

For the louver system the maximum rain impact is observed on the cantilevered slab in front of the louver system (LIF = 0.96), Figure 7 for raindrop trajectories and Figure 8 for LIF's. Light wetting occurs on the slab between the lovers and the inner wall (LIFmax=0.157).

It should be considered that the numerical simulation only provides estimates of rain impacting various surfaces

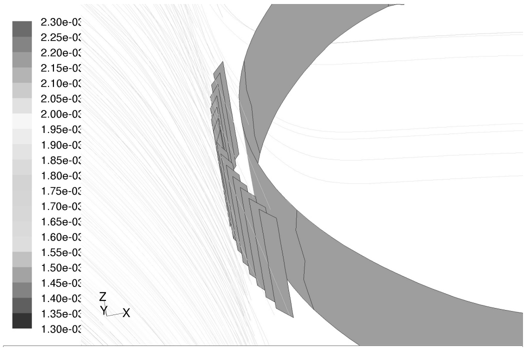


Fig. 7 Rain trajectories: Isometric view of louvers and inner wall region

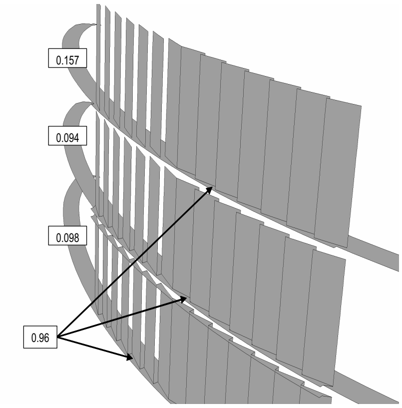


Fig. 8 LIF's: Isometric view of louvers and inner wall region

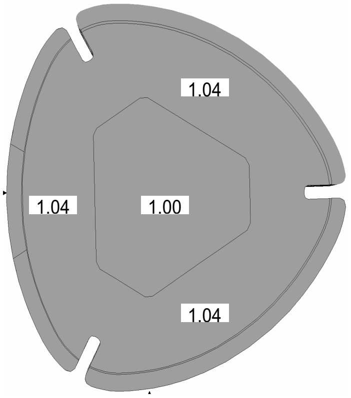


Fig. 9 Local intensity factor (LIF): Top view

but does not take into consideration the run-off. If we conservatively assume that all the water impacting (for example the louvers) would run-off onto the slab, the effect would be a sum of LIFs from louvers and slab that would give: 0.209 (upper level louvers, Figure 5) +0.157 (the upper level exterior slab, Figure 6) = 0.36.

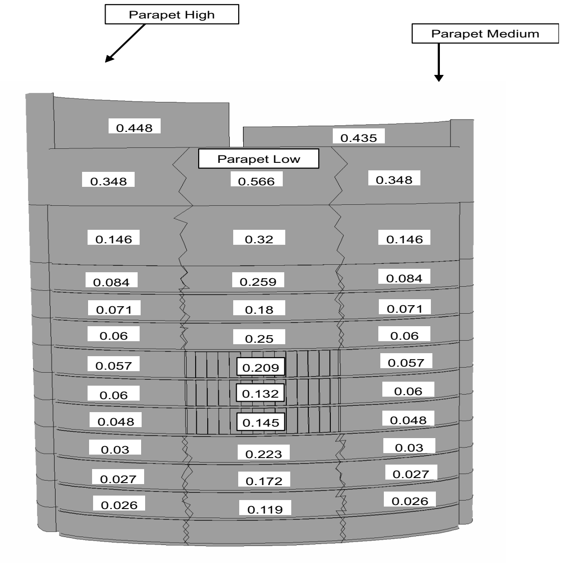


Fig. 10 Local intensity factor (LIF): Front facades

3.2 TOP OF THE BUILDING

Rain is trapped at relative high rates on the roof and the penthouse, Figure 9. When looking at the building from the wind face, Figure 10, it is clear that most of the rain is trapped top of the building: parapet, and upper floors and decreasing downwards.

In regards to the top of the building it is generally expected that the roof area gets a LIF of the order of one (direct rain) while some high LIF values may occur on the top part of the building. The CFD simulation indicates these panels have LIFs of up to 0.566 for the wind direction examined. While this is not unusual for a tall building, it would be important in this building to drain this rain impact water before it migrates down the building and potentially into the louvered system below.

Theoretically for rain storms below 20 mm/hr rain-fall the LIFs should not vary dramatically from the ones estimated herein. However, the flow rate wetting of any of the zones will increase proportional to the rain fall rate.

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