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THE EFFECT OF WIND-DRIVEN RAIN ON CLADDING PRESSURE OF BUILDINGS UNDER WIND AND RAIN CONDITIONS

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1 INTRODUCTION

It is a common occurrence that wind and rain occurs together. During phenomena such as thunderstorms, hurricanes, typhoons and other storms, wind is usually accompanied by rain. In regions like the tropic, the rain is especially heavy. It has long been an uncertainty as to how much does the rain contributes towards increasing the wind pressure on the cladding. This paper attempts to answer this question by using computational fluid dynamics techniques to obtain the average pressure due to raindrops impinging on building faces.

Recently, with the advancement of computational fluid dynamics a better understanding of wind-driven rain and the interaction of wind, rain and building can be established. This paper proposed a framework for the calculation of the increase of pressure on building faces due to wind-driven rain. The method takes into consideration of the local effect of wind flow around the building on the raindrops, the trajectory of raindrops close to the building, velocity of raindrops hitting the building face and intensity of wind-driven rain on the building face. Calculations are done on a rectangular building. The increase in pressure on the building faces due to the effect of wind-driven rain is obtained. It is found that the increase is only a few percent of the dynamic wind pressure even for heavy rains.

2 STUDY OF WIND-DRIVEN RAIN

2.1 Background

Wind-driven rain (w.d.r.) is a topic that has long been investigated. In the early days, w.d.r. were observed in the open and w.d.r. intensity on full-scale buildings were measured. In the late 80's a fully analytical approach using numerical solutions of the computational fluid dynamic method was developed by Choi(1994) and this method is extended in the present study to calculate the w.d.r. pressure.

2.2 Calculation of w.d.r.

The study of wind-driven rain around a building and the raindrops hitting on a building face can be divided into five steps. (1) Wind flow pattern around the building is computed to obtain the velocity vectors in the flow domain. (2) Raindrop trajectories moving towards and around the building are calculated for drops of various diameters; velocity normal to the building face at impact is also obtained. (3) Wind-driven rain intensities hitting different parts of the building face are then calculated for raindrops of a rainstorm. (4) The amount of rain water per unit volume of air during a storm of certain intensity together with the drop size distribution are needed for the estimation of the mass of rain water, and (5) The average cladding pressure due to w.d.r. is calculated from the change of momentum of the raindrop; the total contribution is obtained by integrating drops of all sizes.

Step 1: Wind flow pattern around the building
Wind flow pattern around a building is computed using the computational fluid dynamics method. A finite volume numerical scheme is used to solve the turbulent flow k-ε model. Velocity vectors over the flow domain obtained from solving the set of equations are used in the next phase of calculation.

Step 2: Raindrop trajectory
A raindrop moving through the air is acted upon by two forces – its self weight and the drag force by the surrounding moving air on the raindrop. Equations of motion are set-up to solve for the position and the velocity of the raindrop at each time step until it hits on the building face using an iterative procedure. The velocity component of the raindrop normal to the building face, $U(r)_{wdr}$, as it hits the building is obtained.

Step 3: Wind-driven rain intensity
To calculate the intensity of wind-driven rain impinging onto the building face, raindrops (radius r) are generated at a regular spacing with known intensity, Ir, at a distance far upstream of the building. Computing the trajectories of the raindrops, the locations of impact of the drops on the building face can be determined. Thus, the ratio of the intensity of the raindrops (radius r) landing on certain location on the building face to the intensity Ir is equal to the number of raindrops per unit area landing on the location to the number of raindrops per unit horizontal area being generated. This ratio is termed the local effect factor, LEF(r), which is a function of the drop radius.

Step 4: Amount of rain water per unit volume of wind & drop size distribution
The overall effect of wind-driven rain due to a rainstorm is the overall combined contributions from raindrops of all sizes. The amount of raindrop of one size in a storm is different from those of other sizes; knowledge on the proportion of raindrops of different sizes in a storm is required. Studies of drop size distribution of rainfall have been carried out in many countries(Laws & Parsons 1943; Mualem & Assouline 1986). In the present study, the result of Best(1950) who investigated rainfalls in USA, Canada and UK, is used. His study gave the drop size distribution of raindrops and the volume of rain water by the following equations

$$F = 1 - \exp\left[-(x/a)^n\right] \tag{1}$$

where $a = A\,I^p$
$W = C\,I^r$

F=fraction of liquid water in the air with drop diameter less than x (mm); I=rainfall intensity (mm/hr); W(I)=amount of liquid water per unit volume of air (mm^3/m^3); A, C, p, r and n are constants with values 1.30, 67, 0.232, 0.846 and 2.25 respectively.

Step 5: Cladding pressure due to wind-driven rain

As the raindrops hit on the building face, forces will be generated due to the change of momentum. The average pressure on the cladding due to drop size r will be the force per unit area on the cladding due to raindrops of size r. The overall wind-driven rain pressure on the building face due to a rain storm is the overall combined contributions from raindrops of all sizes which is the sum of the contributions from each drop size weighted by the distribution probability. The pressure due to wind-driven rain is expressed in terms of the dynamic wind pressure, q, as a pressure coefficient $Cp(I)_{wdr}$ as follows:

$$Cp(I)wdr = \frac{1}{q}\int \rho W(I)f(r)LEF(r)U(r)_{wdr}^{2}\,dr \qquad (2)$$

Where ρ is the water density; W(I) is the volume of rain water per unit volume of air at rainfall intensity I; f(r) is the probability density of drop size distribution; LEF(r) is the w.d.r. local effect factor and $U(r)_{wdr}$ is the raindrop velocity normal to the building face at impact, and $q=1/2\rho_{air}V_{roof}^2$ is the dynamic wind pressure at roof height.

3 RESULTS OF STUDY

Studies were carried out using the method as outlined above on rectangular buildings of different height to width ratios. Velocity vectors were obtained in the 3-dimensional domain using the k-ε turbulent flow model. Raindrop trajectories were solved using motion equations.

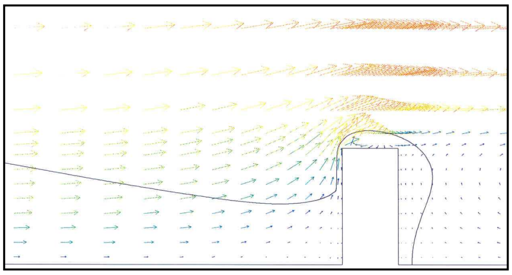

Figure 1a: Trajectories for 0.5mm raindrop

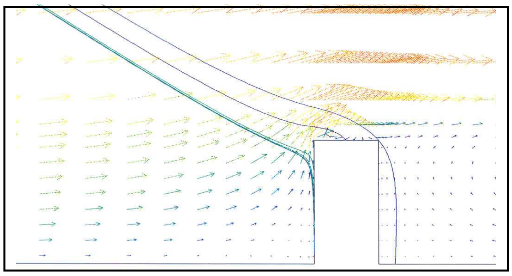

Figure 1b: Trajectories for 5.0mm raindrop

Figures 1a and 1b show the trajectories for raindrops of 0.5mm diameter and 5.0mm diameter around the building; wind velocity vectors are also shown. It can be seen clearly how the local flow affects the raindrops. The smaller raindrop is carried along by the wind almost horizontally until it comes close to the building where it is carried up and over the building. Raindrops not close to the centre-plane are swept sideways around the building. Larger raindrops are less affected by the local flow. As they come close to the front of the building where wind speed is almost zero, they fall almost vertically down due to their weight.

The velocity component normal to the building face at the point of impact is obtained. The w.d.r. intensity expressed as the LEF(r) factor is calculated. Their values are given in the following figures for the 0.5mm and 5.0mm diameter rain drops. The front face of the building is divided into 3 vertical strips and 4 horizontal bands, i.e. 12 zones. The velocity expressed as roof height velocity ratio is given at the corner points of a zone. The LEF(r) factor is average value of a zone. As the problem is symmetrical, values on half the building face are given.

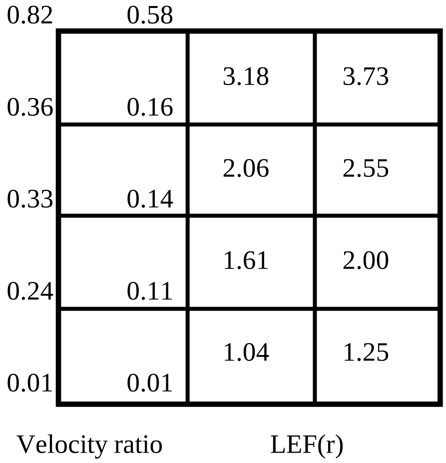

Figure 2a: Values for 0.5mm raindrop

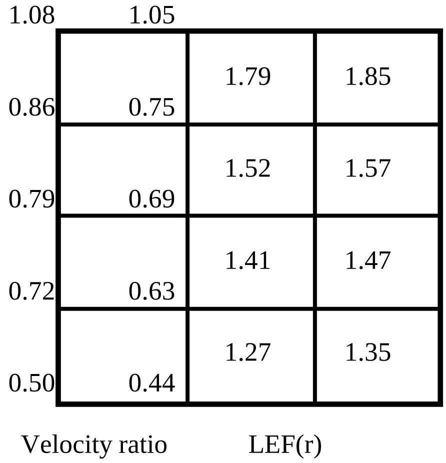

Figure 2b: Values for 5.0mm raindrop

The result is for a building 40m high by 10mX10m at a roof height wind speed of 19m/s. It can be seen that the at the top corner, the w.d.r. intensity for the small diameter raindrops are 3.73 times that of normal rainfall and 1.85 times for the 5.0mm raindrop. The velocity of the raindrop normal to the building face at impact for the 0.5mm raindrop varies from almost zero at ground level to 0.82 that of the roof height wind speed at the top building corner; for the bigger raindrop it is about 50% at ground level to 108% at the top corner.

Using Equation 1, the volume of rain water in the wind and with the drop size distribution, the mass of rain water of certain size per unit volume of wind can be calculated. Together with the velocity ratio and LEF(r) values just obtained, equation 2 can be used to obtain the average cladding pressure due to w.d.r. As Equation 1 is a function of the rainfall intensity I, the pressure coefficient also varies with I. $Cp(I)_{wdr}$ at the corner points for I=100mm/hr and 200mm/hr are given in Figure 3. It can be seen that even for a rainfall intensity of 200mm/hr, the average pressure due to w.d.r. hitting on the building face is highest only about 2.2% of the dynamic wind pressure at the top corner of the building.

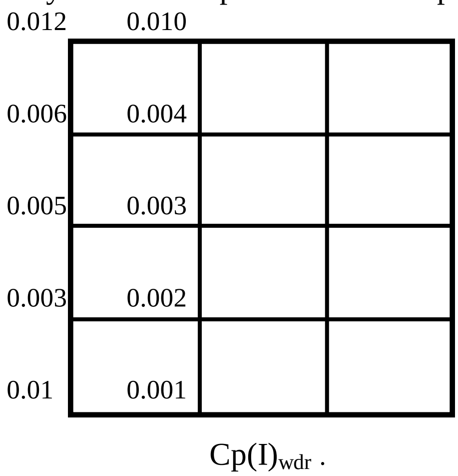

Figure 3a: Values for I=100mm/hr

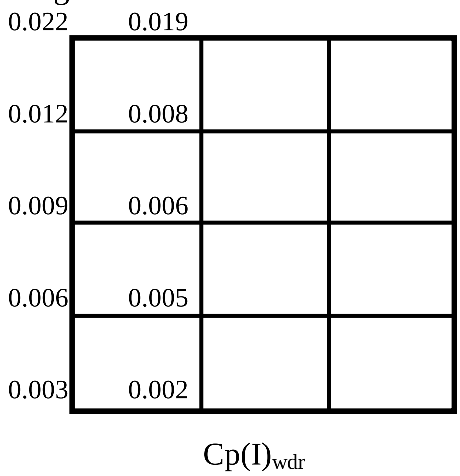

Figure 2b: Values for I=200mm/hr

4 CONCLUSIONS

- A frame work for the calculation of the average cladding pressure due to w.d.r. hitting on building faces is proposed. Results of the calculation shows that the increase in pressure due to w.d.r. raindrops is only a few percent of the dynamic wind pressure.