Pedestrian Level Wind Investigations using the Erosion Technique and Computer Image Processing.

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Abstract
The increasing height of buildings in the core centres of cities compared to those in the surrounding areas has been shown to cause higher velocity winds at pedestrian level, causing uncomfortable or dangerous situations for inhabitants. This problem has been recognised by many municipal authorities, which now require new developments to undergo wind tunnel testing. The Department of Mechanical Engineering at The University of Auckland performs these investigations for developments in the Auckland central business district using the erosion technique. A number of disadvantages have been identified in using this technique which could be reduced through the use of an image processing system. An image processing system has been developed to improve the technique. It replaces the observer with a camera and computer to determine the erosion patterns and pedestrian categories automatically from test results. The methodology used to develop the image processing system is presented in this paper, including the results of initial erosion material investigations and typical outputs from the system.

Introduction
In the last 20 years there has been an increasing awareness of the effects on pedestrian level winds of buildings that are considerably higher than surrounding buildings. Many municipal authorities have recognised this problem and put in place by-laws that require the wind tunnel testing of proposed new building developments.

The Department of Mechanical Engineering at The University of Auckland performs a large number of these tests for proposed new building developments in Auckland City. The accepted method is the erosion technique using small irregular shape cork grains as the erosion material. These small grains, averaging 2mm in diameter, are sprinkled over the area of interest and their movement recorded for a number of wind velocities and approach directions. Knowing the wind velocity that causes the material to move and measuring a reference velocity at a point above the model which is unaffected by the buildings the proportion of time a certain wind speed is exceeded can be calculated using wind climate data. This proportion of time can them be compared against criteria for the area and pedestrian comfort categories assigned to various locations around the area of interest.

A number of disadvantages have been identified from the use of this technique, specifically subjectiveness of different individuals in recording of patterns, and the time taken to perform a complete test. Recent developments in computer-based image processing systems have been seen as a way of improving the technique. Research at The University of Auckland has focused on developing an image processing system that can be used with the erosion technique to improve the accuracy and decrease testing time, automatically recording the erosion patterns and calculating the pedestrian categories from the wind tunnel measurements.

Erosion Material Investigation
The initial focus of the research was to determine a suitable erosion material to be used with the developed image processing system. Included in this investigation was the determination of a suitable colouring of the building model and erosion material.

The criteria used to analyse the performance of a material are as follows,

1. Aerodynamic characteristics
   - reaction to wind
   - apparent threshold speed
2. Appearance in images
   - size
   - visual information transmission
   - image processing ease

Firstly, the existing erosion material used at The University of Auckland was tested to determine whether it would be adequate for combining with the image processing system, or whether another material would need to be found.

The irregular shape of the cork grains caused their reaction to the wind to vary, depending on how the individual grains landed when they were sprinkled over the area of interest. If a grain landed in an unstable position the threshold wind velocity required to move the grain would be considerably lower than that of a grain that landed in a stable position. The imaging performance of cork grains was poor, a single grain occupying only a single pixel in the image. This, combined with the poor aerodynamic performance made it difficult to determine the eroded areas accurately. Due to this poor performance it was decided to investigate alternative erosion materials. The alternative materials investigated were black pepper corns and bran flakes.

Of these two alternative materials tested, the bran performed the best based on the criteria given above. The bran was spread as a uniform layer approximately 2mm in depth across the whole area of interest, instead of being sprinkled at a low density like cork. This layer made it simple to observe the erosion patterns and identify them using image processing techniques. It was also found that painting the building model black improved the visual appearance and imaging processing of the eroded areas because it increased the contrast between the model and material.

Since a new material had been chosen it was necessary to determine the threshold velocity that caused the bran to erode. To simulate typical conditions the bran is exposed to during an erosion test a rectangular bluff body was used. The bran was spread around this object and the wind velocity increased. The bran was allowed to erode for a period of time, then the erosion pattern was then traced on to the board underneath and the bran removed. A hot-wire probe was used to measure the mean and peak velocities and turbulence intensity around this traced area. The threshold velocity was determined to be 2.3± 0.4 m/s.

The Developed Image Processing System

The system was developed around a standard desktop personal computer with a Data Translation DT3155 frame grabber and a National Instruments analogue to digital board installed in it. The system can be divided into two processes: acquisition, and processing of the data to obtain a pedestrian category map.

Acquisition Process.

Initially the system requires the operator to input the temperature, barometric pressure, wind directions to test and the building configuration. After this is done the operator spreads the material around the area of interest and follows any on- screen prompts from the program.
The system acquires a number of images for each direction as follows,

- model with no erosion material
- model with erosion material before test begins
- model with material eroded at each wind speed

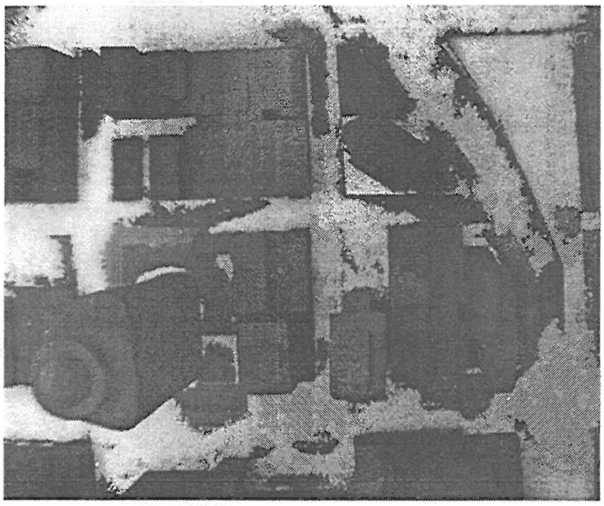

Figure 1: Typical acquired erosion image

Figure 1 shows a typical image acquired by the system during an erosion test. For each of the test wind velocities the dynamic pressure is sampled at a reference point 500mm above the wind tunnel floor. This point is unaffected by the building model and represents a position 200m above the actual city ground level which is to calculate the reference velocity V_{ref}.

At the end of each wind direction test the acquired images are stored on the computer's hard disk in order to minimise the amount of memory required during a test. This also provides the operator with data that she/he can review to check the validity of the results.

Processing for Pedestrian Categories.

The processing of pedestrian categories can be separated into four steps, image enhancement, object information extraction, image correlation and processing for pedestrian categories.
The image enhancement stage takes the raw images acquired during the erosion test and processes them to highlight the eroded areas. Various image processing techniques are used in this stage, including image subtraction, thresholding and opening and closing. The resulting image from this processing is a black and white binary image such that the white represents the eroded areas and the black represents the background objects.

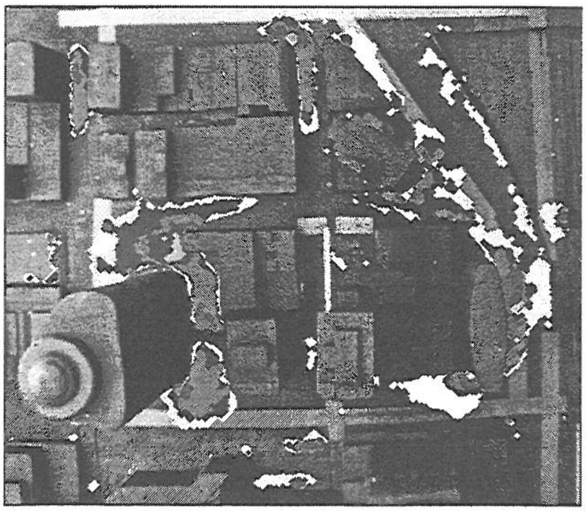

Figure 2: Typical computer generated erosion pattern (wind approach from right of image)

The information extraction process takes the binary images and generates chord tables of the eroded areas so this can be used to draw them on the image of the model without material. A chord table is generated by scanning each horizontal line of pixels in the image, and recording the *(x,y)* co-ordinates where each line segment of white pixels begins and ends.

Using this chord table information the erosion patterns are drawn on the reference image for the particular direction. Each speed erosion pattern is drawn in a different grey intensity so false colouring can be used to highlight the different areas that have eroded. A typical erosion pattern is shown in Figure 2, with false colouring highlight the different areas shown in this image as varying grey scales.

An important step is the alignments of each direction image to the reference zero direction image. To do this a correlation function is used, having the accuracy of within 1 pixel. The correlation function also has to account for some translation in the image, as the camera can never be exactly positioned above the centre of rotation of the turntable. For each wind direction a nominal angle of rotation is known within ±2 degrees. Each of the wind direction images without material is filtered using Sobel horizontal and vertical gradient operators, resulting in images that just contain the edges of the buildings. Each of these gradient images is rotated back to 0-degrees by the nominal angle ±2 degrees, resulting in five images. From the centre of each of these images a 300x300-pixel image or mask is obtained. Also the 0-degree image is subject to the same filtering processes and a 400x400-pixel mask obtained from its centre. The smaller masks are then passed over the 0-degree mask in a typical linear filtering fashion. The results are five 400x400-pixel images that contain the correlation data that are searched for the largest value, indicating the best alignment. The correlation result image where the value is found gives the angle of rotation and the position of this value will give the *(x,y)* translation, when related to the centre of the 400x400 image, to align original image with 0-degrees reference image.

Using the correlation information the erosion maps for each direction are rotated back to the reference direction. Since the eroded area caused by each test free stream wind speed is drawn in a different intensity each image can just be scanned for the known intensities and the appropriate velocity ratio, $V_{material}/V_{reference}$, inserted.

Using the Weibull distribution with the correct coefficients for the climate data over the area of interest, the proportion of time a certain wind speed is exceeded can be calculated for all pixels in the images. To determine the total proportion of time the wind speed is exceeded for all directions, the times at each pixel location in each direction image are summed together. The resulting proportion of time values are compared against the pedestrian criteria for the area of interest and wind comfort categories assigned. These categories are drawn on the 0-degree reference image using set grey intensities so false colouring can again be used to highlight them. The result of this process is a useful image that shows the developer's building positioned in the image and the resulting pedestrian categories.

Conclusions.

Bran flakes have been determined to be the best erosion material of the three tested to use with the image processing system. The layer of the material over the area of interest allows simple analysis to determine the eroded areas. Colouring the building model black further enhances the visual appearance and simplifies the image processing required.

An image processing system has been developed and the preliminary results of testing indicate show that it has improved the erosion technique. The erosion patterns produced clearly show, using false colouring, the eroded areas and have removed the subjectiveness associated with the manual operator recording system. Further tests including a comparison between the results of the manual system and the computer are still to be carried out and will hopefully validate the more automated approach developed.