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ON BREACHED BUILDING ENVELOPES AND INCREASED INTERNAL PRESSURES

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ABSTRACT

A wind-tunnel procedure is described that may be used to evaluate the design cladding pressures on a building where an envelope breach has occurred; either from breakage or an operable window being left open. Cladding designers are increasingly concerned with this possibility; particularly in the hurricane areas of the world. This physical modelling technique allows the external peak pressures to be transmitted into the connected internal space, and so add to the net pressure across the remaining portion of the intact building envelope.

1. INTRODUCTION

The new United States wind standard [1], ASCE 7-98 (Section 6.5.9.3), allows the designer to account for the added internal pressure due to breached glazing from, say, flying debris or to maintain the building integrity via shutters or laminated glass. A similar choice is given to the designer in the Australian wind code [2], AS1170-Part 2 (Section 2.4.2) for tropical cyclone regions. An interesting distinction is that the latter document defines a test piece of debris and associated velocity, within the code, that may be used to assess the adequacy of a possible screen or shutter. The US standard refers the reader to other testing procedures, such as the ASTM Standard E1886-97 [3] or SBCCI SSTD 12-97 [4].

The same designer choices (protect the glazing or higher net loads) may also be used when a site-specific, building-specific wind-tunnel study is used to obtain the design cladding pressures. The theory behind these now routine wind-tunnel procedures may be found in Cermak [5]. The relatively recent development of using several hundred simultaneous pressure transducers in the model study allows these broken-window scenarios to be explored more fully, and so give the designer more confidence in the final glazing design. The procedure used to obtain the breached-envelope design pressures, via physical modeling, is discussed here using the example of a 12-storey office building in Cambridge, Massachusetts. The general massing of the Genzyme Headquarters, designed by House and Robertson Architects of Los Angeles, California, is shown in Figure 1.

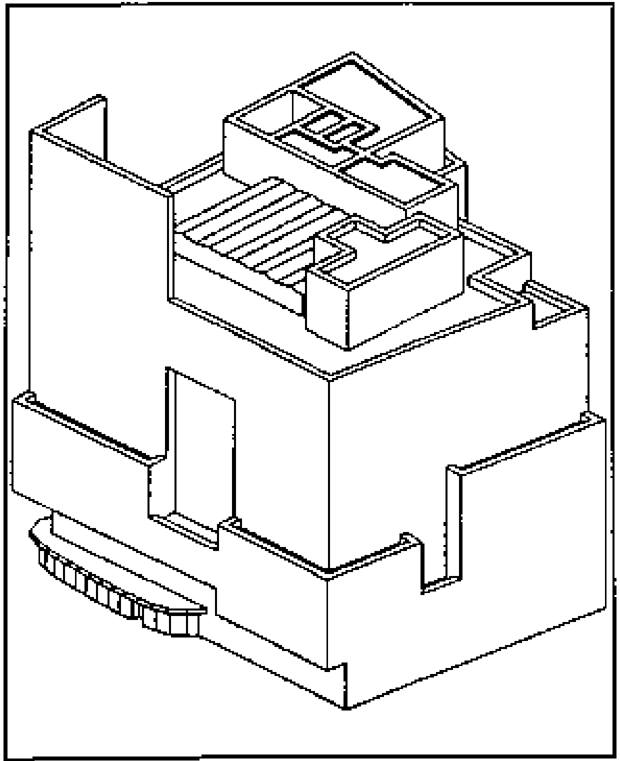

Figure 1: The 1:300 Genzyme Headquarters pressure model viewed from the southwest.

This corporate headquarters building has many locations with computer-controlled operable windows which, if left open during a design wind event, would pressurize the connected internal space. This adds to the net pressure on the remaining external glazing at the periphery of this connected space, and so may increase the probability damage in the case of a high-wind event. The following discussion will focus on the external glazing of a large, L-shaped room on the twelfth floor. Readers interested in the technical details of the simultaneous pressure technique, and its alternative uses, should see references [6] and [7]. The horizontal expanse of operable windows is shown in Figure 2, and the associated pressure taps in this area are identified in the same figure.

2. THE PRESSURE MODEL

When designing the model care must be taken to ensure that pressure taps are placed in representative glazed areas around the external walls of the internal space of interest. In the case of a residential building it may be assumed that each unit on each floor acts as a sealed entity with regard to the transmission of internal pressures. Obviously the more open floor plan of a commercial building, with partial height partitions, may require consideration of pressure taps on all sides of the structure. The connected internal space at level 12 in Figure 2 is only adjacent to the south and west walls due to the internal office geometry. There are hundreds of pressure taps on the model, but only the eleven associated with the operable windows and external surface on level 12 are shown in Figure 2. Taps 419 to 423 are on the west face, while taps 609 to 614 are on the south face. Note that near the vertical edges of the building there are tap pairs placed close together. This is a

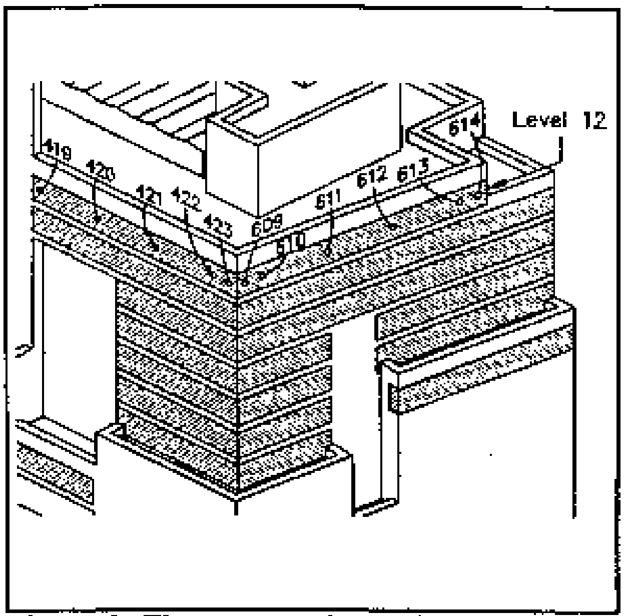

Figure 2: The common internal space on level 12 has tap numbers 419 to 423 (west) and 609 to 614 (south) contributing to the open-window internal pressure analysis.

layout commonly used to define the large spatial pressure gradient at the edge zone. The 1:300 model was connected to 511 sensitive pressure transducers (defined in [6]), and placed within a model of the surrounding Cambridge built environment on a turntable at the downwind end of a large boundary-layer wind tunnel. The physical model was then ready for simultaneous data collection over a full range of 360° wind azimuths.

3. DATA COLLECTION/REDUCTION

Simultaneous, real-time pressure data are collected in time-series form for later analysis. The time-series data record is 16 seconds long in the wind tunnel - corresponding to the scaled time of a passing storm or hurricane design event. At each wind azimuth (10 degree increments) the pressure time series for each tap is collected simultaneously in five sequential experiments. Next, the real-time pressure differences between any tap of the set of eleven and any other tap connected to the same internal space is searched for the maximum value, by both time of action and wind azimuth. Then the five peaks obtained (each time series differential pair) are averaged to yield a more statistically reliable ergodic peak value for each of the eleven taps [8]. For example, the largest peak negative pressure on the west face *may not* occur at the same wind azimuth or instant in time as the largest peak positive pressure on the south face. In this manner the loads on any unfailed, or closed, windows may be estimated from the transmitted external pressure, to the internal space, via a window opened by the occupant or destroyed by flying debris during the design storm. It is worth noting that the transmission of the highest, peak, external pressure seen in the record for the worst wind direction may be unduly pessimistic. The client may opt for a percentile level of risk to be input at this point in the data reduction, and so use the second or third most extreme peak for design purposes. In addition, if the internal volume is sufficiently large (e.g. an expansive, enclosed stadium) an analytic model may be used to reduce the magnitude of the external pressure transmitted into the internal volume.

Table 1: 100-Year Individual Tap and Simultaneous Pressure Data.

Tap Number [-]	Largest Negative [Pa]	Wind Direction [deg]	Largest Positive [Pa]	Wind Direction [deg]	Simultaneous Negative [Pa]	Simultaneous Positive [Pa]
419	-1460	130	1010	260	-2300	2060
420	-1390	90	1010	250	-2200	1960
421	-1340	90	860	270	-2590	1820
422	-1960	180	810	270	-2970	1580
423	-2250	190	810	230	-3300	1530
609	-1250	250	1300	180	-1770	3160
610	-1200	250	1480	190	-1820	3160
611	-1100	330	1480	190	-1680	3260
612	-1250	80	1440	200	-1530	3110
613	-1340	140	1340	200	-1530	2830
614	-1770	140	1150	190	-1630	2590

Notes:

Largest negative ignoring direction or time = -3730 Pa

Largest positive ignoring direction or time = 3730 Pa

4. RESULTS

The data for the taps surrounding the connected internal space in Figure 2 are shown in Table 1. The largest, external, peak, 100-year, negative pressure on this part of the building is -2250 Pa for a wind coming from 190 degrees. Similarly, the largest, external, peak, 100-year, positive pressure on this part of the building is +1480 Pa also for a wind coming from 190 degrees. Thus, in this case (not generally true) the largest positive and negative external pressures influencing this twelfth-floor strip occur at the same wind azimuth of 190 degrees. If these data are simply differenced (ignoring time correlation and, typically, directional influences) the net, 100-year, design peak pressure on the remaining peripheral glazing would be ± 3730 Pa. However, by searching the time-series data (shown in Figure 3) the truer, correlated, design, peak pressures are shown to be -3300 Pa and +3260 Pa. Thus, the designer can use physical modelling to obtain more reliable design pressures on the curtainwall, whether it has operable portions or there is the possibility of flying debris damage.

5. CONCLUSIONS

By collecting simultaneous, time-series, pressure data in the wind tunnel one can assess the impact of facade openings around a connected internal space. This approach may be used for designs where operable windows are left open during a design storm, or if the architect is concerned about a breached building envelope from flying debris [9]. In either case, the results account for the added internal pressure created by an opening and its degree of temporal and directional correlation.

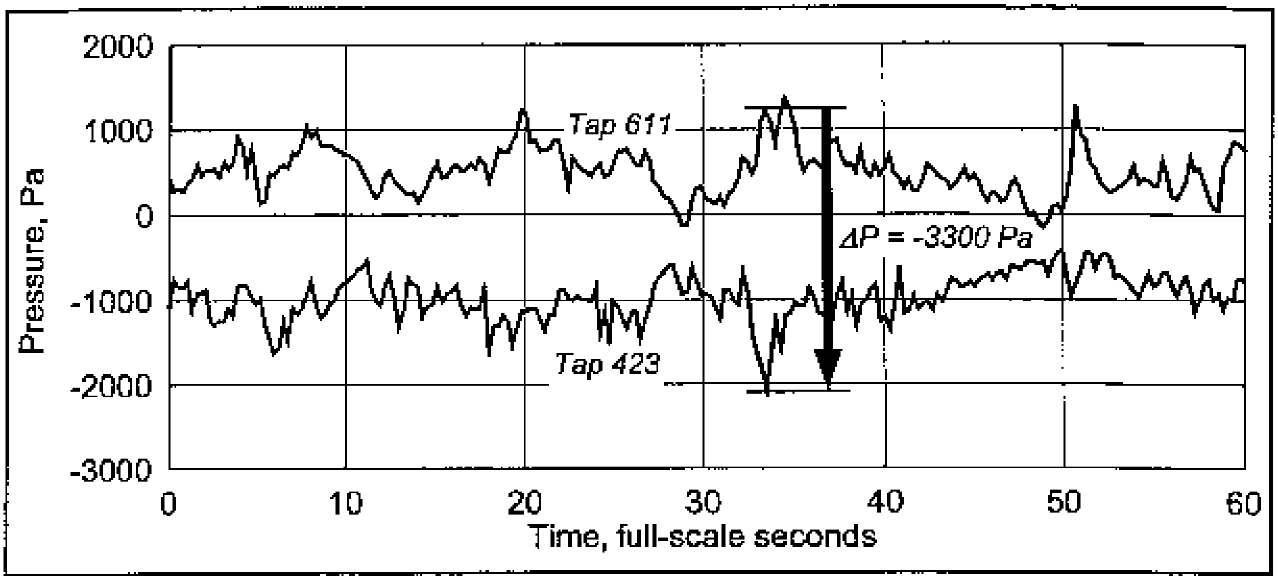

Figure 3: Time-series "snapshot" of the data that caused the highest, negative, differential, peak, design pressure in the level twelve area of Figure 2.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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