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Full-scale downburst damage versus boundary layer wind tunnel pressures: a survey analysis

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SUMMARY:
On the night of January 29, 2016 a thunderstorm event was registered in Porto Alegre, Brazil. The winds caused damage throughout the majority of the city, leaving more than 220,000 houses without electricity and thousands without water. An approaching cold front encountering moist warm air led to the formation of a supercell over the whole metropolitan area. The event was defined as a macroburst by meteorologists due to its characteristics and destruction patterns, but only three anemometers recorded velocity readings of the event. This meteorological event offered an opportunity to check and compare, in full-scale and under a downburst flow, the behaviour of buildings previously tested in a conventional Boundary Layer Wind Tunnel. Six 80m tall buildings and two football stadiums were analysed. The buildings presented damage to the façade cladding, while the stadiums remained undamaged. In three of the most affected building the pressure distribution diagrams on the building façades, obtained from the wind tunnel study, show a direct correspondence with the damaged zones of the full-scale buildings analysed. Although the flow characteristics of downburst winds and conventional boundary layer simulations of synoptic winds may be different, it may be concluded from the full-scale survey that the use of current conventional wind tunnel simulations is still a valuable tool in the prediction of wind loads of most meteorological events that generate extreme winds in Brazil.

Keywords: Downburst, Macroburst, TS Winds, Wind Tunnel, Wind, Full-scale damage

1. INTRODUCTION

On the night of January 29, 2016, the city of Porto Alegre, in the southern state of Rio Grande do Sul, Brazil, was struck by a severe meteorological event. The winds caused damage throughout the majority of the city, leaving more than 220,000 houses without electricity and thousands without water. Brazilian meteorological services indicated that an approaching cold front encountering moist warm air led to the formation of a supercell over the whole metropolitan area. The temperature reached 40ºC, which is normal for summer in Porto Alegre and usually leads to the formation of thunderstorms and extreme winds (Loredo-Souza, 2012), but this particular event had a longer duration (more than 20 minutes) and sustained high wind speeds. Meteorologists and Wind Engineers had a common understanding that this severe event was a downburst.

The maximum gust measured was 33.2 m/s, at the INMET Station. At the airport, the maximum gust recorded was 24.2 m/s and at the downtown harbor the maximum measured gust was 27.2 m/s. From the damage characteristics, meteorologists estimate that over large areas the wind speed reached around 28 m/s and in a few neighbourhoods 42 m/s. Trees and cars were knocked-over throughout the city. A non-whirl pattern was observed and nothing was really thrown up, eliminating the hypothesis of a tornado. Besides, videos and eyewitnesses report strong downward winds followed by horizontal winds. Several damages occurred to buildings, particularly to the façades. Fig. 1 shows some examples of failures occurred during the event. This meteorological event offered an opportunity to check and compare, in full-scale and under a downburst flow, the performance of buildings previously tested in a conventional Boundary Layer Wind Tunnel.

Figure 1. Examples of damages occurred during the Porto Alegre January 29, 2016, downburst event.

2. DOWNBURSTS IN BRAZIL

2.1. Downbursts

Downburst is a term first coined by Fujita (1985) and is described as a strong dense column of cold air caused by a downdraft that descends towards the ground and induces a strong burst of divergent winds, called outburst. In space scale aspects, a downburst may be classified as a microburst, which generates an outburst up to 4 km, and a macroburst, with a range bigger than the previous value. Fig. 2 shows the typical lifetime of a microburst.

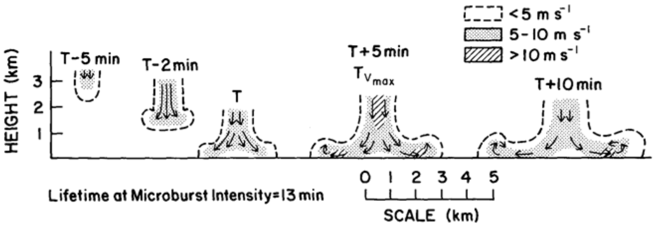

Figure 2. Typical downburst lifetime (Hjelmfelt, 1988)

In terms of vertical variation, the velocity profile of a downburst event (in the ground spreading process) differs from the typically observed atmospheric boundary layer (ABL) profiles as indicated in Fig. 3. This may be paramount for very tall buildings, but for those studied in this work (not taller than 80m) this is not a big issue, although little is known regarding the turbulence structure of the downburst flow.

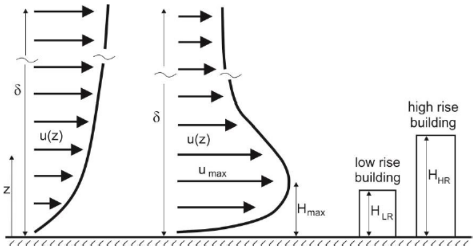

Figure 3. Schematic of an atmospheric boundary layer profile, on the left, and the velocity profile in the outflow of a downburst, on the right (Bertsch and Ruck, 2015)

2.1. The Porto Alegre event and previous cases in Brazil

A downburst event is a very unique meteorological phenomenon and several factors need to be observed before confirming its occurrence. The severe weather event observed in Porto Alegre can be defined as a macroburst mainly due to the pattern of destruction, but if radar images were available with a better and reliable resolution the event could be better understood. The satellite image of Fig. 4 shows a supercell well developed above the city at the same time the strongest wind gusts were registered.

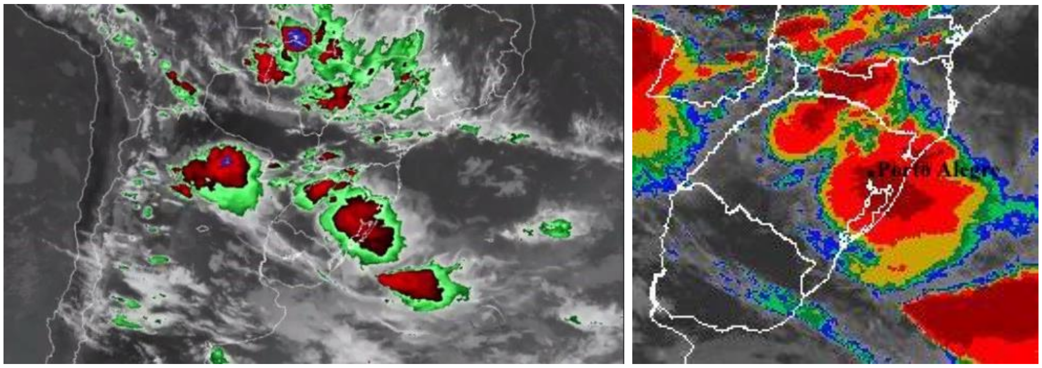

Figure 4. Satellite image of the supercell over Porto Alegre on 30/01/2016 00:45:51 UTC (REDEMET, 2016)

As Garstang et al. (1989) suggested, supercells are typical weather systems that might be able to generate downbursts. But there are several meteorological parameters, such as those shown in the Table 1, that can be used to describe a typical range found during a downburst occurrence (Lima and Loredo-Souza, 2015). Also presented are the corresponding characteristic values obtained during the event in analysis, where it is possible to verify the abrupt change of the predominant meteorological parameters. Due to data limitations of the Automatic Weather Stations of Brazilian Meteorological Service, for Equivalent Potential Temperature and Mixing Ratio the instantaneous values at the hour mark in which the downburst was registered as well as those of the previous hour were used. For other parameters, maximum and minimum amplitudes in the hour of the event were used, and they all describe a sudden change to ambient conditions during the event.

Table 1. Typical meteorological parameters values for a downburst occurrence and those observed for Porto Alegre Weather Station (A801) during the event in analysis

Characteristics	Typical Downburst Value Range	Reference	Porto Alegre
Decrease between surface and colder layer near the 700hPa (K)	> 20	(Atkins and Wakimoto 1991)	Data not available
Wind gust (m/s)	>10 (Minimum); 25 - 50 (significant damaging events)	(Garstang *et al*. 1998)	33.2
Effective decrease of instant equivalent potential temperature (K)	> 4	(Garstang *et al*. 1998)	14.93
Temperature decrease (°C)	> 5	(Garstang *et al*. 1998)	5.5
Dew point decrease (°C)	-	-	1.8
Atmospheric pressure increase (hPa)	> 2.4	(Caracena and Maier 1987)	2.4
Saturated instant mixing ratio decreasing (g/kg)	>3.5	(Garstang *et al*. 1998)	1.70
Relative humidity decrease (%)	-	-	22
Registered precipitation along downdrafts (mm/h)	> 0.5	(Garstang *et al*. 1998)	37.4

As shown in Table 2, some weather stations around Porto Alegre also presented wind gusts higher than 10 m/s, but only Campo Bom (A884), 42 km from Porto Alegre, presented substantial pressure peak, followed by a large decrease in temperature, raising the possibility of another downburst occurrence within the “Greater Porto Alegre” area. However, Canela (A879) and Bento Gonçalves (A840), respectively located 85km and 100km from Porto Alegre, had strong wind gusts, but no spike in pressure. Temperature reductions might be justified by the approaching of cold air with a front gust, also explaining the change in wind direction.

Table 2. Meteorological parameters obtained from weather stations around Porto Alegre

Characteristics	Canela	Campo Bom	Bento Gonçalves
Decrease between surface and colder layer near the 700hPa (K)	Data Not Available	Data Not Available	Data Not Available
Wind gust (m/s)	17.3	13.8	12.2
Effective decrease equivalent potential temperature (K)	17.41	18.84	No decrease registered
Temperature decrease (°C)	3.7	7.6	1.4
Dew point decrease (°C)	4.4	5.0	0.7
Atmospheric pressure increase (hPa)	1.2	3.7	1.0
Saturated instant mixing ratio decreasing (g/kg)	4.35	3.67	No decrease registered
Relative humidity decrease	8	29	11
Registered precipitation along downdrafts (mm/h)	0.6	6.4	0

The data available in Table 1 is relevant to this study because all but one of the typical meteorological parameters for a downburst occurrence were registered during the event of January 29th, 2016, confirming the hypothesis that such strong phenomena struck the urban area of Porto Alegre. Previous studies have indicated that the southern part of Brazil is susceptible to downburst occurrence (Lima and Loredo-Souza, 2015). The main concern about the recent event remains in regard to building safety, since it is not yet fully understood to what extent the wind characteristics generated by downbursts are different to those of the Extended Pressure Systems, or synoptic winds (Letchford and Chay, 2002). This may leave structures susceptible to failures, risking lives and causing major economic losses, like those which were observed in this downburst event in Porto Alegre.

3. ATMOSPHERIC BOUNDARY LAYER WIND TUNNEL TESTS

This meteorological event offered an opportunity to check and compare, in full-scale and under a downburst flow, the behaviour of buildings previously tested in a conventional Boundary Layer Wind Tunnel. Six 80m tall buildings and two football stadiums were analysed. Figure 5 shows the models inside the Prof. Joaquim Blessmann Boundary Layer Wind Tunnel of the Universidade Federal do Rio Grande do Sul (Blessmann, 1982) and Fig. 6 the main characteristics of one of the simulated winds.

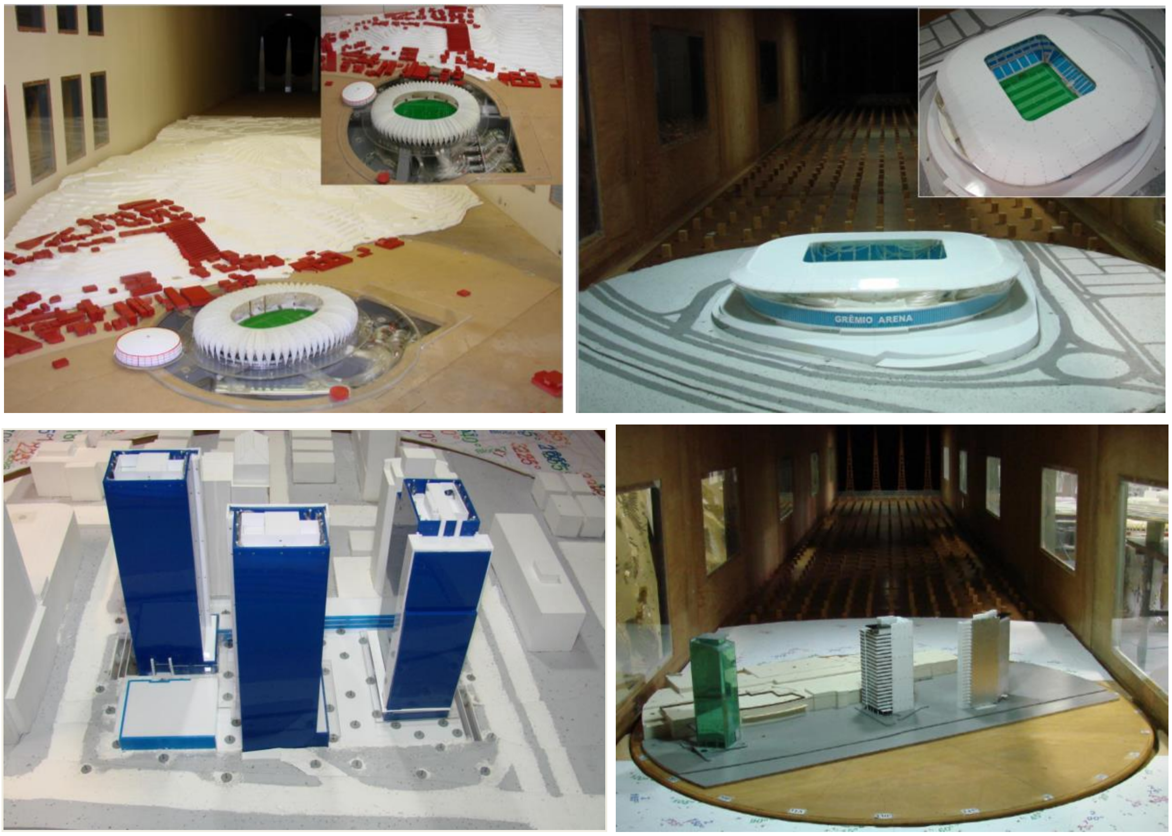

Figure 5. Models inside the wind tunnel: two soccer stadiums and six 80m high buildings

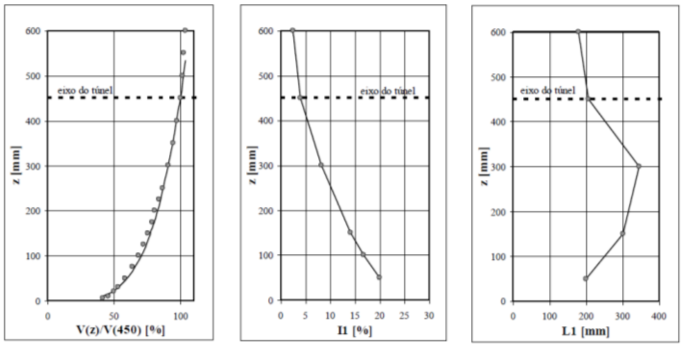

Figure 6. Main characteristics of one of the simulated winds: mean velocity profile, turbulence intensity and integral length scale of the longitudinal component of turbulence

All models were instrumented with pressure taps and instantaneous pressure measurements were taken over all model surfaces. Fig. 7 shows the mean pressure coefficient distribution for one of the buildings, and incidence angle of wind. Due to space limitations, the pressure coefficient distributions for other buildings are shown in the next section, together with the damage configurations.

Figure 7. Mean pressure coefficient diagrams on buildings façades from boundary layer wind tunnel tests (suction = red, yellow; pressure = blue) for the central building indicated

4. FULL-SCALE PERFORMANCE

A map with more than 400 cases of damages through the city, registered by Metroclima (2016), is shown in Fig. 8 together with the places where official velocity measurements were available. The damages are separated, according to the icons: felled trees, structural/cladding damage (gears) and fire. The density was higher than the map is presenting, but for clarity only severe damage is shown. Also indicated in Fig. 8 are the locations of the structures for which the wind tunnel tests results were available.

Regarding the wind velocities, even if the worst-case estimate is assumed, resulting in larger velocities than those effectively measured, the reference wind gust velocity recommended for Porto Alegre by the Brazilian Wind Code is 46 m/s (Fig. 9). This means that the resulting damages were not caused by an unpredicted phenomenon, but rather due to possible misunderstanding of the design specifications and/or operational conditions of the structures and cladding.

Analysing the performance of the structures, it is possible to verify that the stadiums remained undamaged, while the trees and surrounding structures were seriously damaged as can be seen in Fig. 10. During the design stage, modifications and improvements were made to the stadium structures due to the wind tunnel tests results.

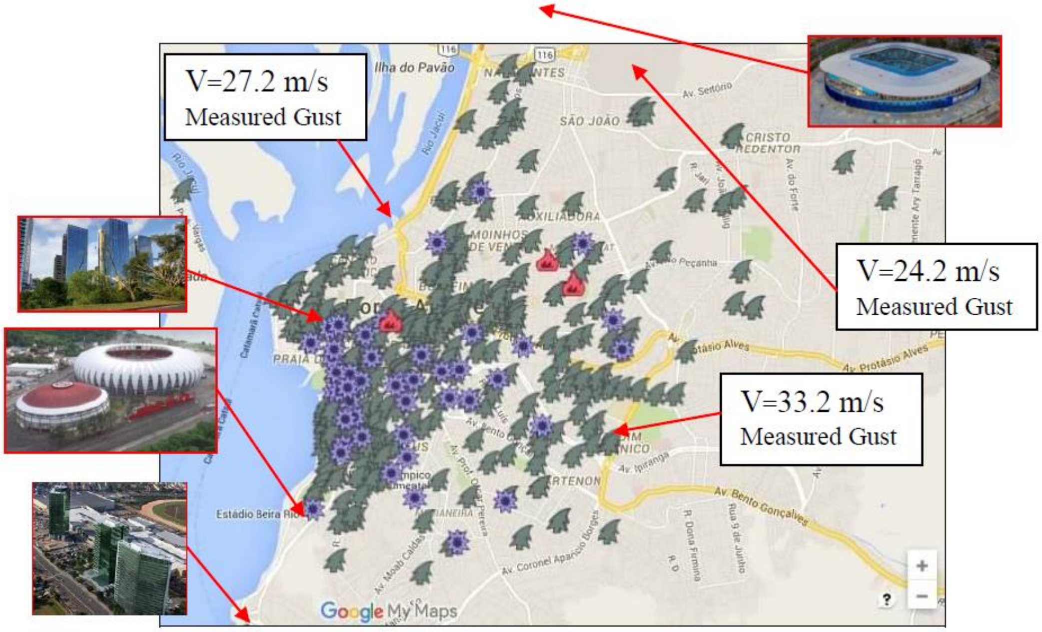

Figure 8. Map indicating the damages suffered in the Porto Alegre January 29, 2016, downburst event, the places and values of the official velocity records and the locations and buildings for which boundary layer wind tunnel results were available (adapted from Metroclima, 2016)

For the group of buildings, the performance was different. All of them presented damage to their façades (Figs. 11 to 13), but in very distinct patterns. For the first group of three buildings shown in Fig. 11, for which some pressure coefficients diagrams are shown in Fig. 7, the evidence shows that the windows that were kept closed and locked did not suffer any damage, while some of those which were open, or even closed but not locked, were ripped out or broken by the wind action.

In three of the most affected buildings (Figs. 12 and 13) the façades had two types of cladding elements: glass and granite plates. It is possible to observe that the most severe damages occurred to the granite cladding, which has a specific support configuration as indicated in Fig. 14. It is very interesting to note that the pressure distribution diagrams of the building façades, obtained from the wind tunnel study, show a direct correspondence to the damaged zones of the analysed full-scale buildings.

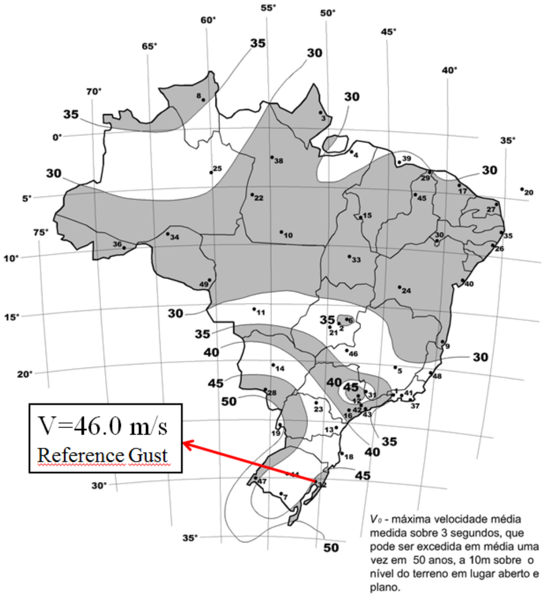

Figure 9. Map from the Brazilian Wind code with the 3s gust reference wind speeds, in m/s, at 10m height. The reference velocity for Porto Alegre is highlighted (NBR-6123)

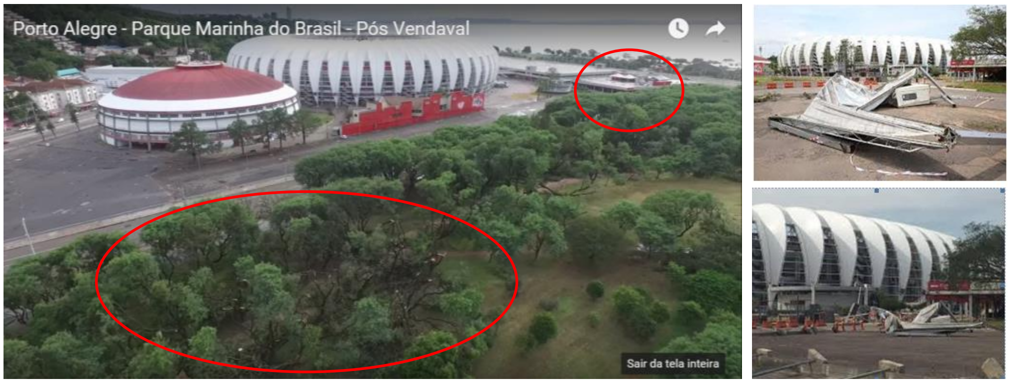

Figure 10. Full-scale damage to surroundings caused by downburst and no damage to stadium

Figure 11. Full-scale damage to cladding elements: some windows that were not locked were destroyed

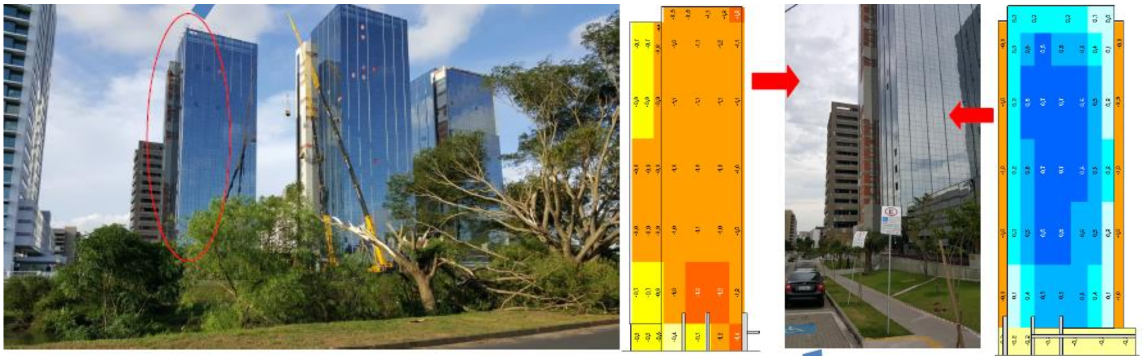

Figure 12. Full-scale damage caused by downburst and mean pressure coefficient diagrams on buildings façades from boundary layer wind tunnel tests (suction = red, yellow; pressure = blue) for Tower A

For Fig. 13 the correspondence between pressure distribution and damage to the granite cladding is very evident. The granite plate supporting system, shown in Fig. 14, does not seem to be designed to withstand wind pressures from the magnitude reached in the event, remembering that the design wind code velocity was not reached. Regarding the glass cladding, some damage occurred, but in a much smaller amount, being some ripped out when left open or broken due to the impact with windborne debris.

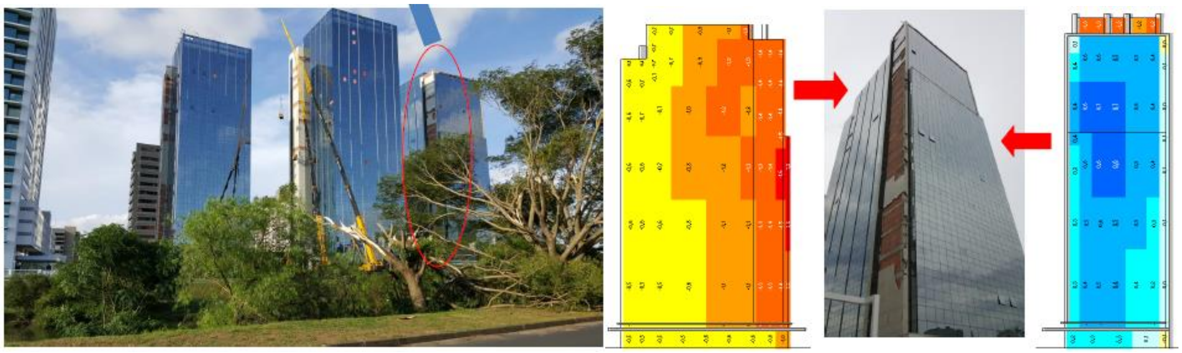

Figure 13. Full-scale damage caused by downburst and mean pressure coefficient diagrams of building façades from boundary layer wind tunnel tests (suction = red, yellow; pressure = blue) for Tower C

4. CONCLUSIONS

From what has been stated above, it is possible to conclude that the Porto Alegre meteorological event of January 29, 2016 may be classified as a macroburst. But even though extensive damages have occurred to several buildings, there is no evidence that the wind velocities have reached the code defined magnitude.

Although the flow characteristics of downburst winds and conventional boundary layer simulations of synoptic winds may differ, it may be concluded from the full-scale survey that the use of current conventional wind tunnel simulations is still a valuable tool in the prediction of wind loads of most of the meteorological events that generate extreme winds in Brazil. This conclusion is valid for the buildings analysed in this research, which are not taller than 80m. Nevertheless, more research is necessary in order to better understand the differences in loading generated by non-synoptic winds.

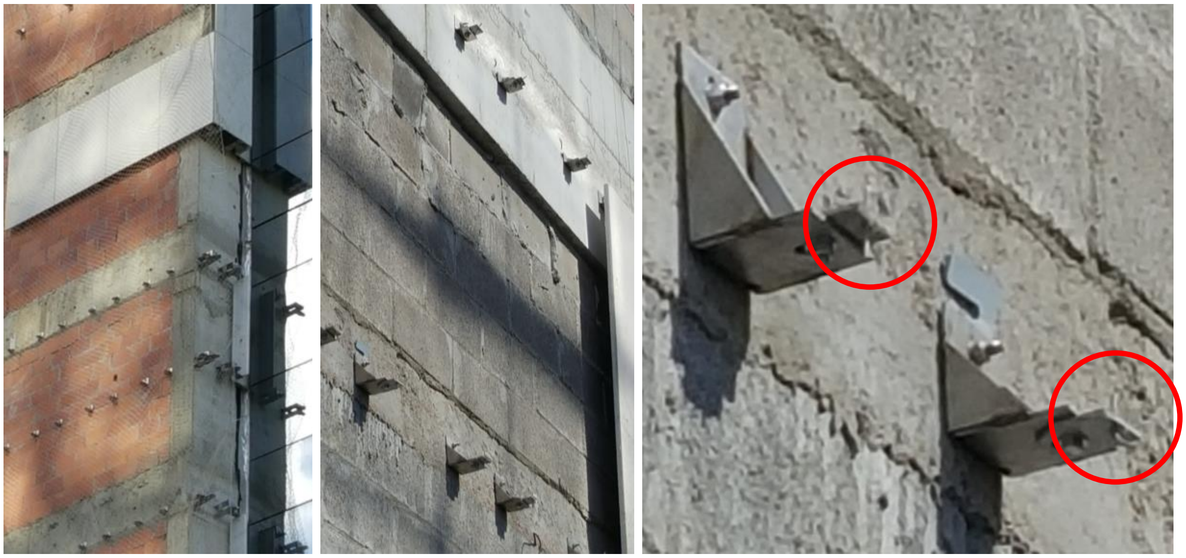

Figure 14. Full-scale damage caused by downburst and granite plate supporting system

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