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Determination of wind speed and associated loads over the sports facility collapsed during the severe windstorm of 24 January 2009 in Sant Boi de Llobregat (Barcelona)

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Abstract

The severe windstorm of 24 January 2009, caused by an explosive cyclogenesis, affected coastal and precoastal areas of the northeast of the Iberian Peninsula, where damages were numerous and significant, both in urban areas and in forests. One of the most important effects was the collapse of a sports facility in Sant Boi de Llobregat (10 km southwest of Barcelona), killing four children. The objective of this study is to estimate the wind speed over the sports facility and calculate the suction of the wind on the roof of the building, and the consequent collapse of the walls. To get a first approximation, a simulation of the episode around the time of maximum wind gust was inspected using the mesoscale model MM5. In the second part, the damage around the collapsed facility was analyzed, with which we note the fact that a truck was dragged and knocked over by the wind. This analysis allows for the conclusion that, in conjunction with the maximum wind gust, there was a sudden and very local shift in the wind, which caused the gust to hit the building head on. Based on this observation, the wind speed on surface and at 7 m (roof of the building) was estimated, and the suction of the wind was calculated.

Key words: explosive cyclogenesis, MM5, wind speed estimation, aerodynamic charges

1 Introduction

The episode of severe wind that hit the northern third of the Iberian Peninsula around 24 January 2009 was caused by the formation of an explosive cyclogenesis over the Atlantic (Sanders and Gyakum, 1980), which quickly shifted to the north of the Cantabrian sea and the south of France, driving very strong northwest winds to Catalonia (Agencia Estatal de Meteorología, 2009). Areas climatologically not too windy, such as the Catalan coast and the central precoastal area, were affected by steady winds that exceeded 100 km h^{-1} for hours (Servei Meteorològic de Catalunya, 2009), with widespread destruction in many towns, including Sant Boi de Llobregat, where the collapse of a sports facility (a batting tunnel) killed four people.

We present an analysis of local atmospheric conditions in the area of the accident. First, in Section 2, the results of a numerical simulation using the mesoscale model MM5 (Grell et al., 1994) are presented. This way, the prevailing wind direction and speed in the area are obtained. Section 3 shows the results of fieldwork carried out to determine the direction and intensity of the wind, based on *in situ* analysis of the damage caused by it around the collapsed facility. Analyzing the distance that a truck, that was parked aside the accident, was displaced after being dragged and knocked over by the wind at the time of maximum gust, the wind speed could be determined at 2 and 7 m, the height of the batting tunnel roof. In Section 4 the loads caused by the suction effect of the wind on the roof was calculated. Finally, Section 5 presents the conclusions.

2 Simulation of the episode

To analyze the direction and speed of this episode of severe wind, the fifth generation of the mesoscale model from

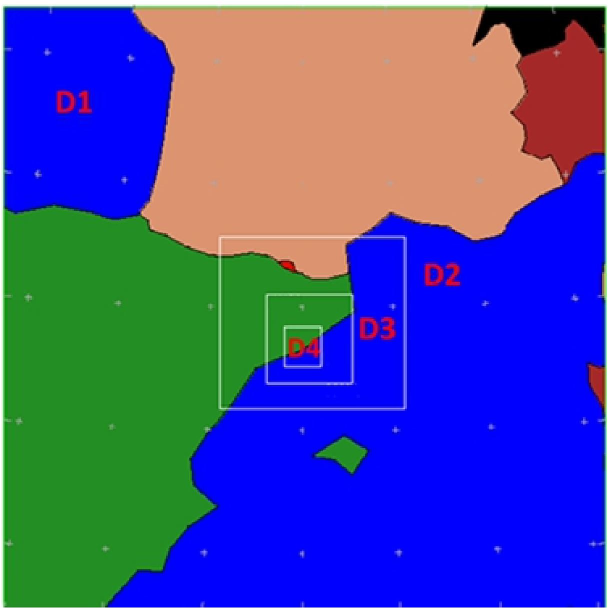

Figure 1. Domains used in the simulation with the MM5 model.

Pennsylvania State University and NCAR (MM5, Grell et al., 1994) was used. Four nested domains were defined (see Figure 1) with respective resolutions of 27, 9, 3 and 1 km. The smaller domain is centered approximately on the Llobregat delta. The initial and boundary conditions are updated every six hours with data from the ECMWF operational analysis. For the two smaller domains, topography and land use have a spatial resolution of 30 arcseconds, approximately 0.9 km. The following parameterizations were used for the different physical processes: the Kain-Fritsch model to consider the effects of convection on scales not solved by the grid in the two larger domains, and no model of cumuli formation in both smaller domains, the MRF scheme for processes in the mixed layer, a simple ice scheme for the cloud microphysics, cloud-radiation parameterization for a diagram of atmospheric radiation. The choice of these diagrams appears to be the best for episodes like the one studied (Braun and Wei-Kuo, 2000; Wisse and Vilà-Guerau de Arellano, 2004; Srinivas et al., 2006; Miao et al., 2009).

Figure 2 shows the wind field obtained from the simulation at 10 UTC on 24 January 2009, 15 minutes before the accident. The simulation was started two days before, on the 22^{nd} at 00 UTC. In all domains the prevailing wind is northwest. For domain 1 (Figure 2a), a cyclonic rotation around a minimum of pressure is observed, which according to the model is located in the center of France, with maximum values up to 25 m s^{-1}. In domains 2 and 3 (Figures 2b and 2c), we can see how the northwest flow loses intensity and shifts towards the north coast, while in the central and southern coast it is still strong and coming from the northwest.

In domain 4 (Figure 2d) the wind is still from the northwest. Figure 3 represents speed and wind direction for this domain. The highest places and the mountain slopes facing northwest show higher values of wind intensity (purple and red), while the valleys protected by mountain ranges show lower values of wind speed. The site of the accident, indicated with a black dot in Figure 3, is protected by the Garraf and Ordal range, with speeds that at 10 UTC reached values close to 20 m s^{-1} (Figure 3a), with a northwest component (Figure 3b).

The result of the simulation for wind speed in domain 4 acceptably reproduces the measurements obtained by the meteorological stations in this area (see Figure 4 for the location of stations). Throughout the Llobregat valley (Figure 4) the records show average speeds between 70 and 85 km h^{-1} measured at 2 m from the ground, except Begues and Sant Feliu de Llobregat, which are at 10 m. The simulation acceptably reproduces both the intensity and direction of the wind.

Table 1 shows the maximum wind gusts over a period of 30 minutes, between 10 and 10:30 UTC for different automatic stations. The maximum gust occurred at 10:15 UTC in all cases.

Figure 5 shows the wind field along a vertical cut along the prevailing wind direction (red line shown in Figure 2d). This figure shows a strong flow in the levels closed to the surface (less than 200 m).

An analysis of the three separate components of the wind was also done, emphasizing the large stratification of u and v components of the wind (Figure 6) and the high vertical wind speed generated by the interaction with the topography, which reaches heights over 3000 m.

The simulation describes with good approximation the inspected event, especially the wind speed and direction, but it is not useful to explain the events concerning the damaged facility. As it will be shown in Section 3, the observational evidence points to an intensification of the wind speed and a sudden local change of direction, that the model is not able to reproduce. Therefore, it is necessary to search an alternative method to estimate the wind speed and the loads on the building, which is described in the next section.

3 Experimental determination of the maximum wind speed

On 26 January 2009, two days after the storm subject of this study, there was fieldwork carried out consisting in analysis of the effects of the wind around the sports facility. Figure 7 shows the results of this study. The red arrows indicate the direction where the different bodies were knocked or fell toward, and the yellow lines indicate where the bodies were photographed.

Two important facts can be drawn from the analysis of the damage. First, there was a sudden shift in the local wind direction, which is a key factor to explain the collapse of the sports facility, as described in Section 4. This sudden shift in direction is probably due to an orographic factor. A small hill protects the baseball field from the northwest wind, with an altitude variation of over 40 m. A brief in-

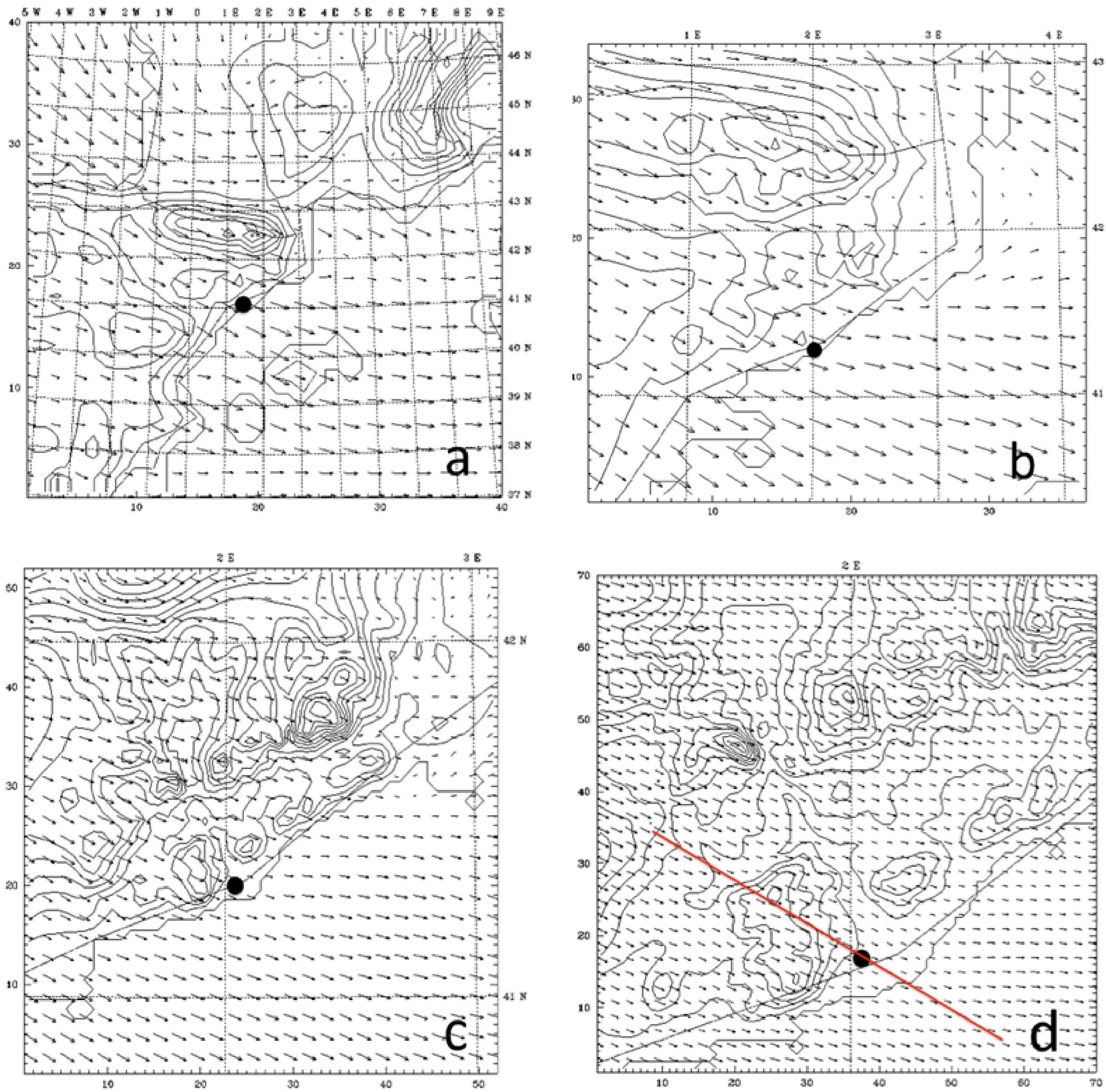

Figure 2. Wind direction and speed at 1000 hPa at 10 UTC in the four defined domains in the MM5, where the topography in contour lines and the cut in the NW-SE direction are also shown for later analysis.

tensification of the wind could have generated a small relative low on the baseball field that had caused a rotation of the air over it, turning south over the baseball field and attacking the sports facility head on. The fact that witnesses describe the formation of a swirl of sand on the baseball field, coinciding with a brief intensification of the wind and the collapse of some structures analyzed in Figure 7, including the sports facility, would confirm this hypothesis.

The second point to note is that the wind knocked down a truck (marked with X in Figure 7). This observation, together with data from several witnesses, is key to estimate the speed of wind gust, and therefore the wind loads on the building.

3.1 Estimation of wind speed based on the truck which was knocked over

At about 250 m from the scene of the accident, a truck (see Figure 8) that was parked on a flat surface and asphalted street was moved transversely due to the wind to a distance of 20 cm, until it fell into an embankment in the stream of Fonollar. The wind struck perpendicular to the vehicle, which was parked on a nearly horizontal surface.

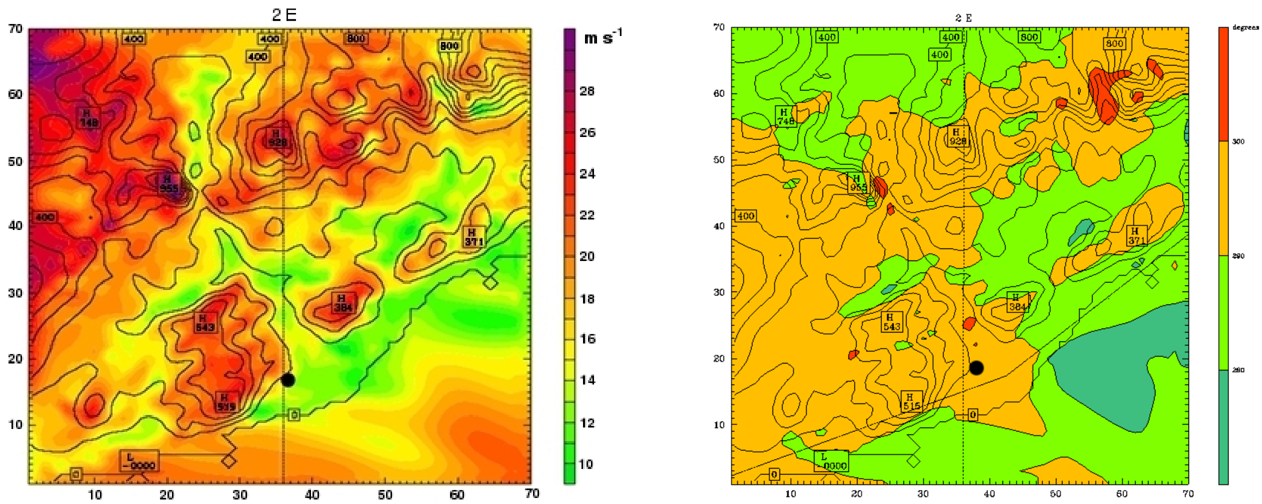

Figure 3. Wind speed (a, left) and direction (b, right) in the smallest domain obtained with the MM5 simulation at 10 UTC of 24 January 2009 at 1000 hPa. The black dot indicates the position of the damaged facility in Sant Boi de Llobregat.

Table 1. Maximum gust registered in the meteorological stations of the Meteoclimatic network (www.meteoclimatic.com) located near the sports facility and at some distance from it. All of them occurred at 10:15 UTC, and the height of the anemometer is 10 m.

Site	Distance and direction to each meteorological station near the sports facility (km)	Maximum gust wind (km h^{-1}) between 10 and 10:30 UTC
Sant Feliu de Llobregat	7, N	132
Begues	14, W	130
Gavà	10, SW	121
Esplugues de Llobregat	6, NE	118
Sant Vicenç dels Horts	7, NNW	113
Sant Boi	0.5, N	111
Castelldefels	12, SW	115

From these facts, we can estimate the wind speed on the truck. Assuming that the force of friction between the tires of the truck and the ground was identical to the wind force on the truck, from Newton's second law we can establish the equation $F_d = F_f$, where F_d is the force of the wind acting perpendicular to the truck, and F_f the dynamic force of friction between the tire and the asphalt.

The force of the wind on the surface side of the truck can be expressed from the aerodynamic resistance force of an object subjected to the action of the wind, such as:

$$F_d = \frac{1}{2} \cdot \rho \cdot C_d \cdot S \cdot v^2 \qquad (1)$$

where C_d is the drag coefficient of the truck when the wind hits transversely on it, ρ is the density of the air, which at 15°C has a value of 1.18 kg m^{-3}, S is the truck surface perpendicular to the wind direction and v is the wind speed. Under these conditions, the truck can be modeled as a parallelepiped, with a drag coefficient around 2 (Moalic et al., 1987). But this is an approximate value, so to determine it accurately we would need to make accurate measurements in a wind tunnel. To take into account this fact, we accept an uncertainty of $\pm 10\%$. S can be estimated from the data in Figure 8, being approximately 20 m^2. This estimate is also subject to a certain degree of uncertainty, estimated at 10%.

The friction force can be calculated by:

$$F = \mu\, mg \qquad (2)$$

where μ is the friction coefficient of the tires with the ground. According to Li et al. (2006), we accept a value around 0.95, with an uncertainty of $\pm 5\%$. The mass m of the truck is 2720 kg, g is the acceleration of gravity, 9.81 m s^{-2}.

By equating the expression of the wind with the friction force, the value of the wind speed can be obtained:

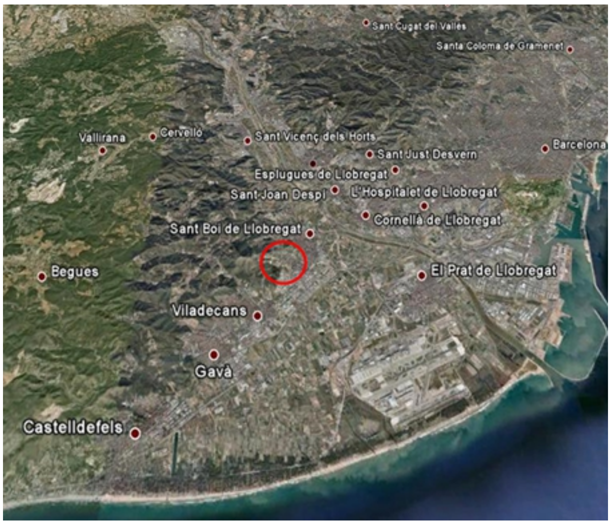

Figure 4. Map of the Sant Boi area, and nearby stations shown in Table 1. The red circle indicates the position of the collapsed sports facility.

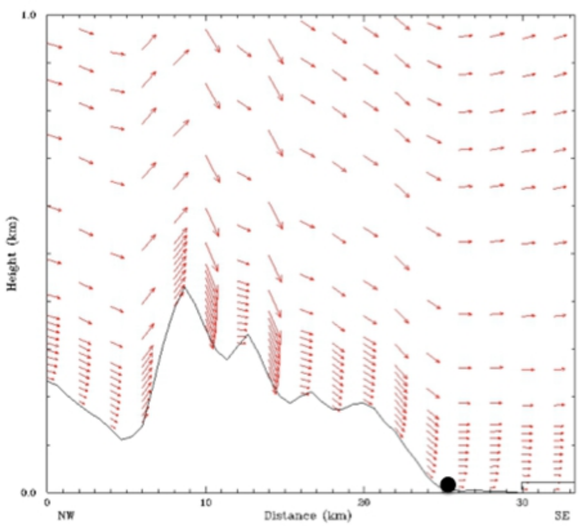

Figure 5. Wind field obtained with the MM5 model along the vertical cut represented by the black line in Figure 2d. The black dot indicates the position of the site of the accident.

$$v = \sqrt{\frac{2\mu\, mg}{C_d \rho S}} \qquad (3)$$

Given the uncertainty of the magnitudes used, two different statistical treatments have been done. In the first case there was a uniform probability distribution assumed between the extremes, $Y - \Delta Y$, $Y + \Delta Y$ of the magnitudes considered. This way, a first approximation of the most likely value of the wind speed is pbtained, giving a broad range of values. The probability distribution of the speed obtained with this hypothesis is shown in Figure 9.

The average value of the speed calculated in this way is 118 km h^{-1}, and the statistical analysis of the constant probability distribution indicates that the standard deviation of the probability distribution is 6.3 km h^{-1}. This allows us to assert that there is a probability of 68% that the speed reached a value between 112 km h^{-1} and 124 km h^{-1}, and a probability of 95% that it reached a value of between 105 km h^{-1} and 131 km h^{-1}.

In the second case it was considered that the magnitudes subject to uncertainty follow a Gaussian probability distribution with a standard deviation equal to the estimated uncertainty. This way we can have an more acurate estimation of the probability for the different most likely ranges of wind speed. With this assumption, the probability distribution of the wind speed obtained is shown in Figure 10, which shows that the value of maximum probability, 118 km h^{-1}, is within the maximum probability range of speeds obtained with the uniform probability distribution. In this case, the probability that the wind reaches 118 km h^{-1} is 16% and the value is between 112 and 125 km h^{-1} with practically a 100% probability.

Using this value for the most likely wind speed, in Section 4 we will estimate the aerodynamical loads over the building due to this sudden strong wind gust.

4 Calculation of the loads on the roof of the batting tunnel

The effect of the wind on buildings with a low height has been studied by several authors (Uematsu and Isyumov, 1999; Wu and Sarkar, 2006; Cope et al., 2005; Krishna, 1995; Senthooran et al., 2004; Chen and Zhou, 2007; Endo et al., 2006). The most important effects in these buildings are concentrated on the ceiling. The wind causes a suction effect mainly in the windward area. This effect is highest on the ceiling corners. When the wind hits a building with gable roof transversely, such as that of the damaged building, there is also a significant suction effect just behind the line of change of the roof slope. Evidence available suggests that a single opening located windward wall can be dangerous for the stability of the roof, but many openings in the walls which are parallel to the wind direction or downwind help to reduce the suction effect on the roof of buildings (Sharma and Richards, 2005).

4.1 Quantification of the suction effect on the roof of the batting tunnel

There are standardized methods to calculate the maximum force exerted by the wind on buildings, based on wind speed. This information is collected by the state building codes and standards. In our study we used the European standard prEN 1991-1-4:2004 prepared by the Technical Committee CEN/TC250 "Structural Eurocodes", which studies the action of wind on buildings of different shapes. This standard has been adopted by AENOR as UNE-EN 1991-

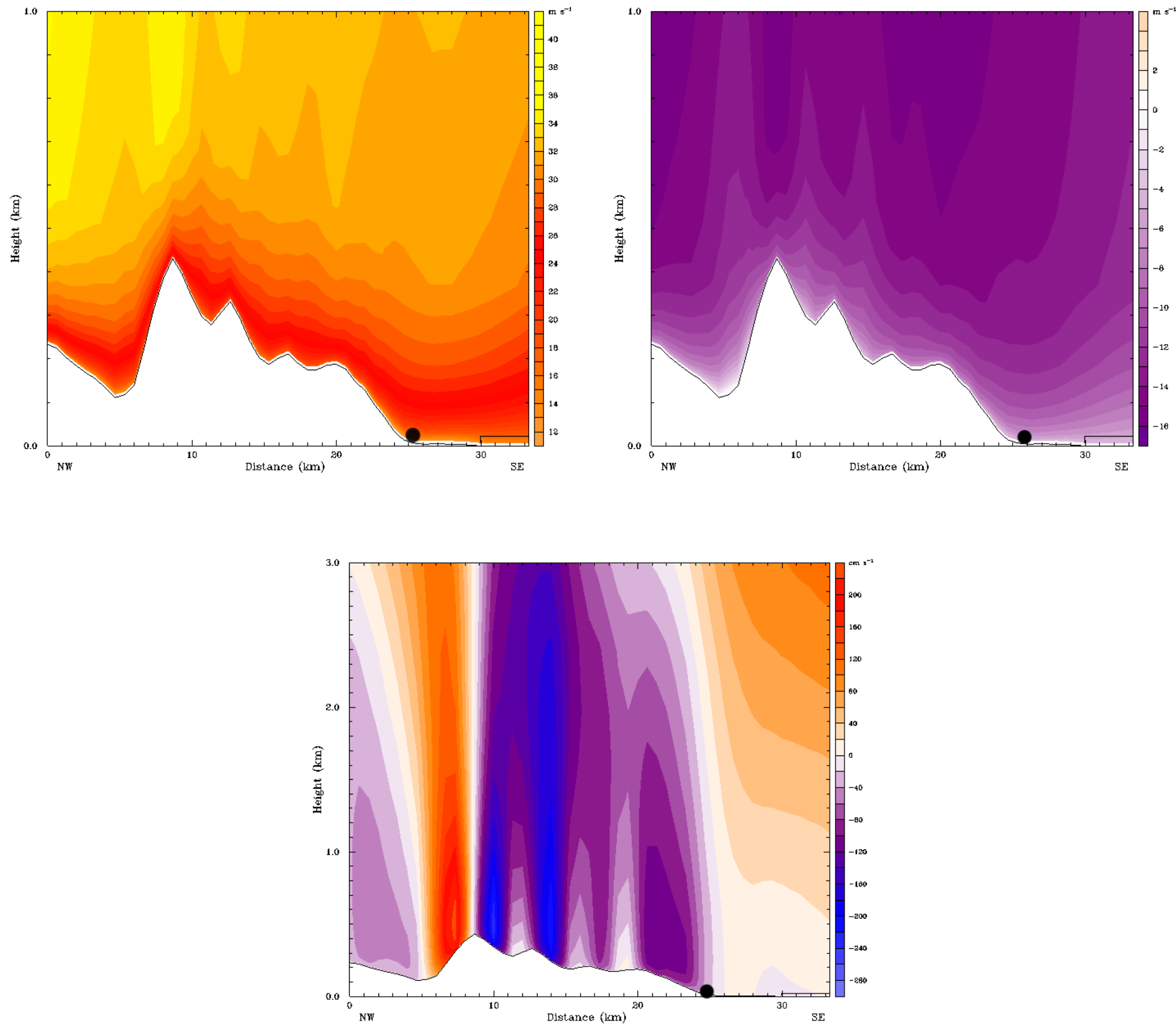

Figure 6. At the top, the horizontal components of the wind (u and v respectively), with a high stratification and a high vertical gradient. At the bottom, the vertical component of the wind in a 3000 m slice, where significant rises and drops of the wind, up to 3 m s^{-1}, can be observed.

1-4:2007 standard and published in the Boletín oficial del Estado (2007). This standard provides, on one hand, how to calculate the effective dynamic pressure, on the other, the aerodynamic coefficients applicable depending on the shape of the building.

The UNE-EN 1991-1-4:2007 is designed to work with annual or seasonal mean values, and thus defines the basic wind speed as the value of the average wind speed at 10 m high for 10 minutes that is only exceeded with a probability of 2% in a year. Given the fact that the episode of wind considered is exceptional, we consider that the speed of 118 km h^{-1} calculated in the previous section from the movement of the truck is a reasonable value for estimating basic wind speed. But this speed, as indicated, is the speed at a height of 2 m. The UNE-EN 1991-1-4:2007 allows calculating the wind speed by height from a logarithmic-type model that includes the roughness of the land and the orographic factor (Boletín oficial del Estado, 2007). The evidence shown in Section 3 indicates that at the time of the accident the wind turned south, and therefore the ground in front of the batting tunnel is that of the baseball field, which corresponds to the definition of land type II: an area with low vegetation and obstacles (trees, buildings) at a distance of at least 20 times its height. This qualification makes it possible to get the necessary parameters to estimate wind speed at the desired height, in our case 7 m high, which gives us the basic wind speed at 7 m of 160 km h^{-1}.

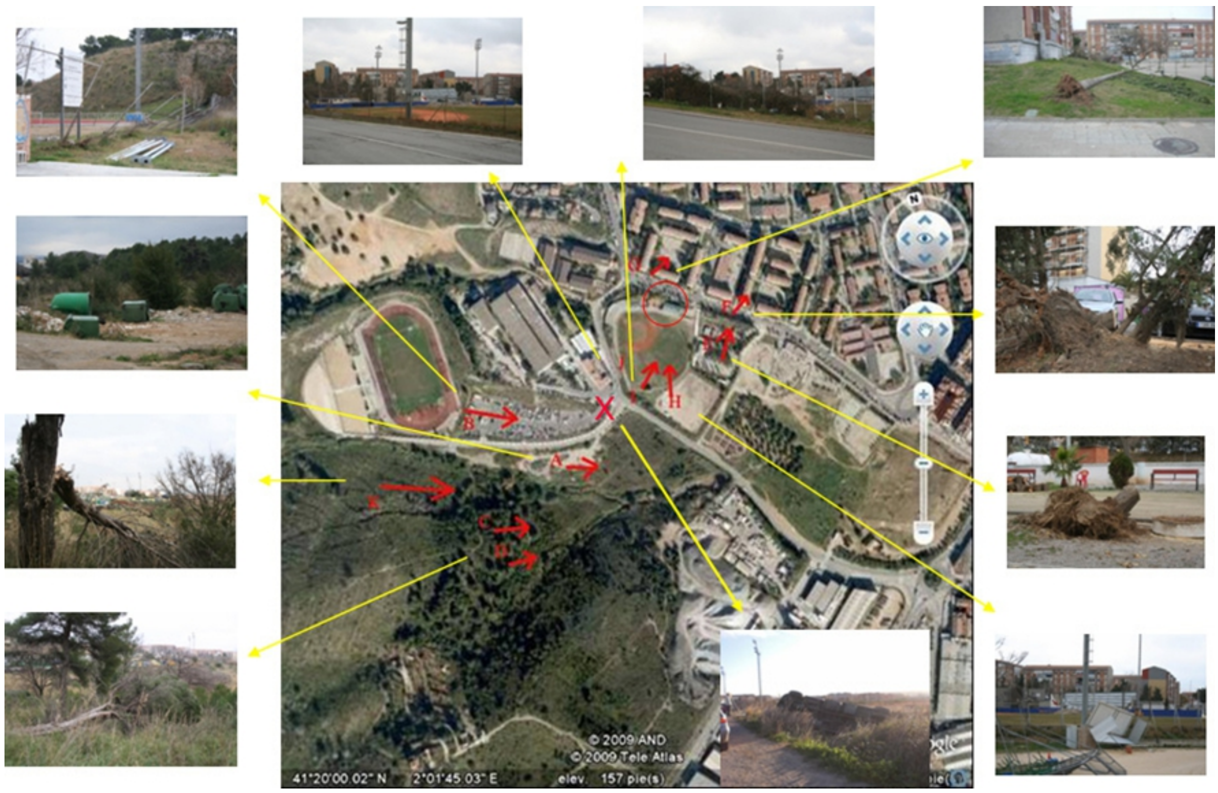

Figure 7. *In situ* analysis of the damage around the facilities of the Sant Boi baseball camp. The red circle indicates the location of the collapsed facility. The red arrows indicate the direction (not the intensity) towards which the different strewn elements were found. The small pictures indicate those elements.

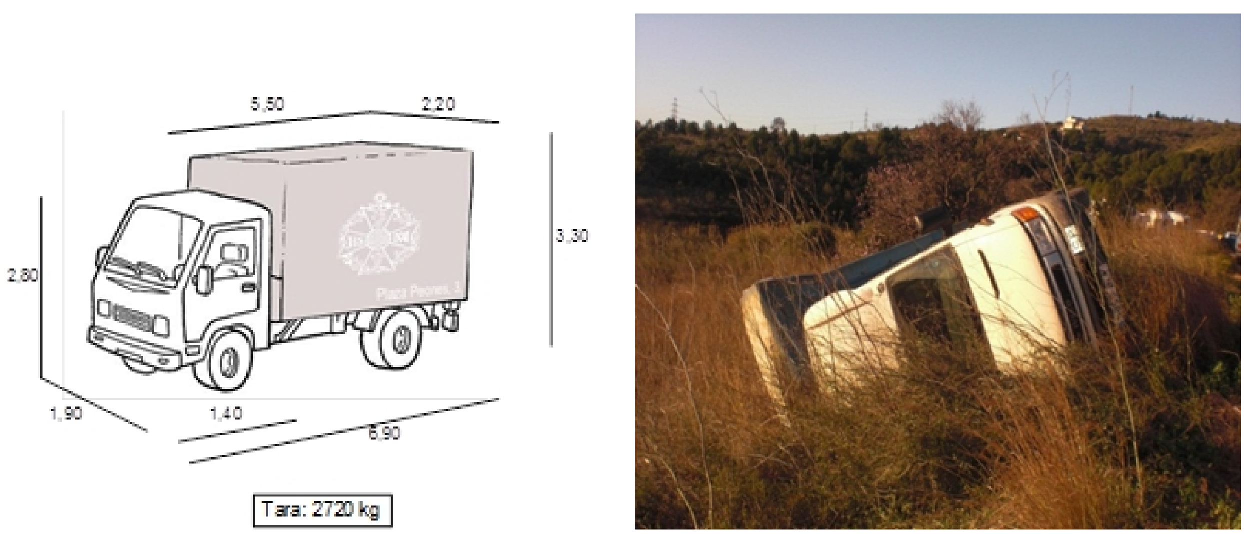

Figure 8. Characteristics and dimensions of the truck dragged by the wind (a, left), which was transversely moved by the wind until it fell into the Fonollar stream (b, right).

Table 2. Conditions in the moment of the accident. Transversal wind (θ = 90°) at 160 km h^{-1} at a height of 7 m. Maximum dynamic pressure: 29.3 hPa.

Area	Surface (m^2)	Pressure coefficients		Force (N)		Equivalent weight (kg)	
		Suction	Compression	Suction	Compression	Suction	Compression
F	4.90	-0.8	0.3	-11000	4000	-1173	440
G	24.36	-0.7	0.3	-50000	21000	-5101	2186
H	114.38	-0.2	0.3	-67000	101000	-6843	10264
J	34.16	-0.9	0.1	-90000	10000	-9196	1022
I	114.38	-0.3	0.1	-101000	34000	-10264	3421
Sums				-331000	174000	-33748	17772

Table 3. Conditions at 2 m. Transversal wind (θ = 90°) at 118 km h^{-1}. Maximum dynamic pressure: 19.6 hPa.

Area	Surface (m^2)	Pressure coefficients		Force (N)		Equivalent weight (kg)	
		Suction	Compression	Suction	Compression	Suction	Compression
F	4.90	-0.8	0.3	-8000	3000	-783	294
G	24.36	-0.7	0.3	-33000	14000	-3408	1461
H	114.38	-0.2	0.3	-45000	67000	-4572	6858
J	34.16	-0.9	0.1	-60000	7000	-6145	683
I	114.38	-0.3	0.1	-67000	22000	-6858	2286
Sums				-221000	116000	-22550	11875

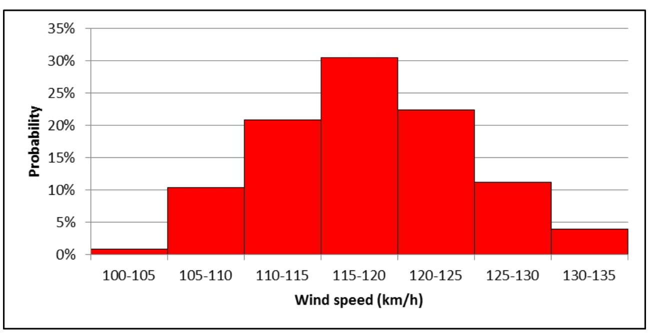

Figure 9. Probability distribution according to the wind speed. The most probable value is a wind speed between 115 and 120 km h^{-1}, with a probability slightly over 30%.

Kasperski (2007) proposes a way to determine the effective dynamic pressure from the basic wind speed, obtaining the value of 29.31 hPa at the time of the accident. Once this value is found, in order to calculate the loads that the building was subject to it is necessary to apply the corresponding aerodynamic coefficients, defined and described by the standard UNE-EN 1991-1-4:2007 and several authors (Cope et al., 2005; Banks et al., 2000; Krishna, 1995). For buildings with gable roofs, UNE-EN 1991-1-4:2007 divides the roof into different areas and differentiates the interaction between the wind and the roof if the wind affects the building transversely or lengthwise. These coefficients depend in all cases on the slope of the roof, which in the case of the batting tunnel was 14° (Figure 11).

These coefficients, however, are inaccurate. The batting tunnel had 10 lattice windows that were permanently open, and, as described above, this has an effect on the aerodynamics of a building (Sharma and Richards, 2005). The effect of the openings is also included in the UNE-EN 1991-1-4:2007. There is a distinction between buildings with dominant walls when the openings are concentrated on the same wall; in the case of the batting tunnel there were no dominant walls, because the openings were uniformly distributed along the walls of the building. In this case, if the openings are less than 30% of the surface of the walls, such as the batting tunnel, they produce a small correction of the pressure coefficients on the ceiling that depends on the incident wind direction and on the relationship between the height and depth of the building, defined as the length of the building measured in the wind direction. Sharma and Richards (2005) allow the correction of the aerodynamic coefficients that correspond to a building with a certain opening. Tables 2 and 3 show these aerodynamic coefficients, which are necessary for calculating the pressures on the building shown in Tables 4 and 5. The different parts of the building are indicated with the capital letters F, G, H, I and J, as shown in Figure 11. We have studied the situation at the time of the accident, with transversal wind (θ = 90°) at a speed of 160 km h^{-1} at 7 m high (Table 2), and for the purpose of comparison the force in the same longitudinal wind conditions (θ = 0°) was also calculated, shown in Table 4. Additionally, in order to contextualize the study, the calculations with the speed and turbulence of the wind at ground level (118 km h^{-1}) were repeated, which can be found in Tables 3 and 5.

Table 4. Conditions in the moment of the accident. Longitudinal wind at 160 km h^{-1} at a height of 7 m. Maximum dynamic pressure: 29.3 hPa.

Area	Surface (m^2)	Pressure coefficients (suction)	Suction force (N)	Equivalent weight (kg)
F	3.48	-1.1	-11224	-1145
G	7.40	-1.1	-23877	-2436
H	57.47	-0.4	-67383	-6876
I	225.24	-0.3	-198079	-20212
Sums			-311788	-31815

Table 5. Conditions at 2 m. Longitudinal wind at 118 km h^{-1}. Maximum dynamic pressure: 19.6 hPa.

Area	Surface (m^2)	Pressure coefficients (suction)	Suction force (N)	Equivalent weight (kg)
F	3.48	-1.1	-7500	-765
G	7.40	-1.1	-15954	-1628
H	57.47	-0.4	-45024	-4594
I	225.24	-0.3	-132352	-13505
Sums			-208329	-21258

4.1.1 Loads on the building with transversal wind ($\theta = 90°$)

In Table 3 we see that the pressure coefficients take two values, negative and positive. As mentioned before, this is because in these conditions the flow over the roof is very turbulent. Sometimes the flow causes a suction effect that tries to raise the roof, and the maximum value of the force is then given by the coefficient of negative sign, while sometimes the wind compresses the roof down, and the maximum value of the force is then provided by the coefficient of positive sign. We observed that the suction effect is about twice the compression for all wind speeds. In fact, the collapse of the building occurred when the ceiling was rising, as recorded by the surveillance cameras of the local police station, located near the site of the accident, and was therefore a consequence of the suction effect and not of a compression effect. The compression forces are shown for informational purposes only and may not have played any role in the accident.

The data obtained show that when the wind speed increases, the force does it much more quickly. Thus, while the increase in the speed from its value at 2 m - 118 km h^{-1} - to the value corresponding to a height of 7 m - 160 km h^{-1} - is 35%, the suction force changes from 22 t to 33 t with an increase greater than 50%.

4.1.2 Loads on the building with longitudinal wind ($\theta = 0°$)

Unlike in the case studied with transversal wind, with longitudinal wind the force is always suctioning.

The summary of the global loads resisted by the building in all before calculated conditions is shown in Table 6.

The data in this table indicate that the total suction force acting on the building is very similar whether the wind is transversal to the building or longitudinal. The difference between the two values, when considering the same wind conditions, is 7% and it is not significant for purposes of calculation. But when the wind strikes the building of the batting tunnel longitudinally ($\theta = 0°$) the building would be partially protected by the small hill and the community center of the Baseball Club, a building similar in height located to the west-northwest of the batting tunnel. Therefore, the west-northwest wind would not be as dangerous for the stability of the building, and it supported the windstorm from the west with no difficulties. Unfortunately, when turning south the wind hit the building transversely, full force ($\theta = 90°$). If, as the data collected in the field seem to indicate, the change in the wind direction was due to an increase in its speed, the maximum intensity wind hit the building where it was

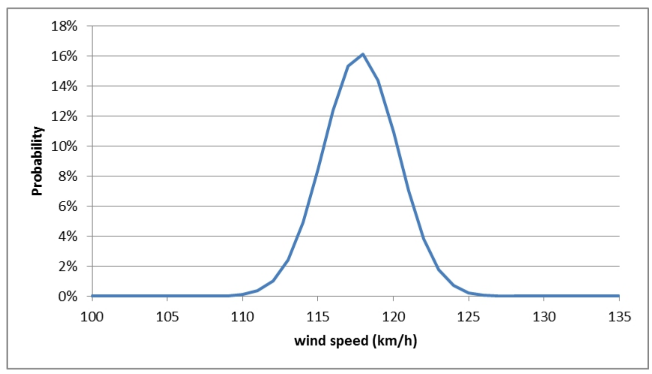

Figure 10. Most probable speed distributions from a Gaussian distribution. The most probable speed is 118 km h-1, with a probability of 16%.

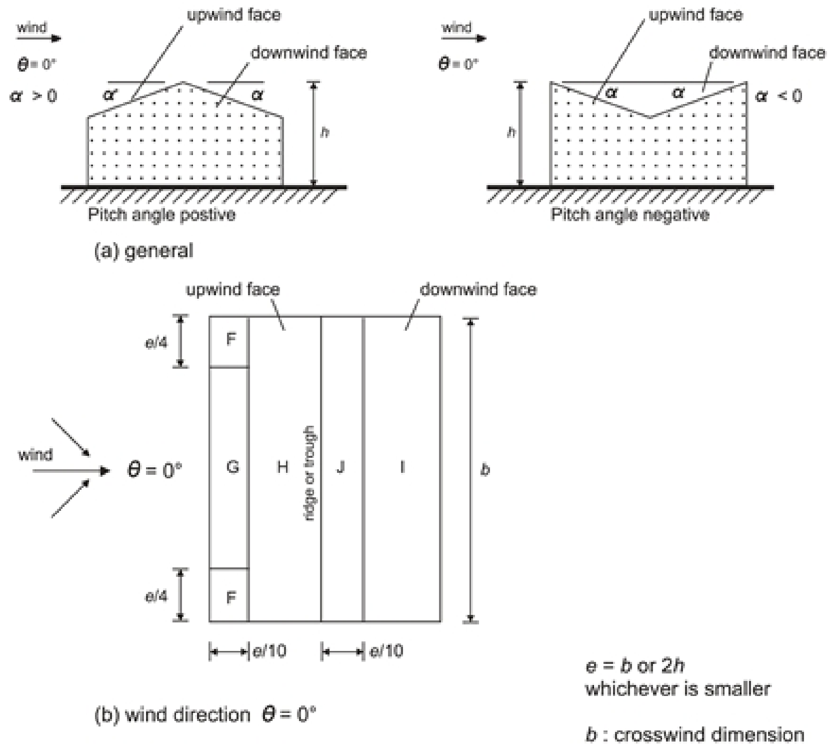

Figure 11. Different areas defined by the UNE-EN 1991-1-4:2007 when a building is hit by the wind, for longitudinal ($\theta = 0°$) and transversal ($\theta = 90°$) wind. Source: *Boletín Oficial del Estado* of 8 October 2007.

Table 6. Calculated loads on the building in the considered conditions. The reference values have been determined with the UNE 1991-1-4:2007 standard.

Height	Speed ($km\ h^{-1}$)	Maximum dynamic pressure (hPa)	Transversal wind Maximum suction (N)	Transversal wind Maximum compression (N)	Longitudinal wind Maximum suction (N)	Excess over the reference value
Reference values	99	11.2	126292	66502	119060	
2 m	118	19.6	220990	116375	208328	75%
7 m	160	29.3	33073	174165	311787	162%

unprotected. As the calculations done indicate, with winds of 160 km h^{-1} the loads on the building exceeded by up to 162% those that would be supported according to the reference values calculated using the UNE 1991-1-4:2007. Even considering the wind at 118 km h^{-1} at 2 m high, the charges have been increased by 75% compared to reference values.

5 Conclusions

On 24 January 2009 there was an explosive cyclogenesis that affected the northeast of the Iberian Peninsula. The pressure dropped about 36 hPa in 24 h in the center of this depression (Agencia Estatal de Meteorología, 2009). The atmospheric conditions were modeled with the MM5 model, confirming that the prevailing wind was from a west-northwest component in the four domains used. The simulation is not useful to explain the causes that lead to the collapse of the facility, because the change in wind speed and direction took place at a very small scale, below 100 m and during a very short time.

A simulation with a model able to provide higher temporal and spatial resolution could provide more detailed information and contribute to the understanding of this singular event.

The inspection of the effects of the event is taken here as an alternative method to look for the causes of the wind change. This inspection shows that the topography of the area near the baseball field significantly affected the direction of the wind. The moment of the collapse of the batting tunnel (10:15 UTC) coincides with the time when the maximum gust was recorded at the Viladecans Observatory. The analysis on the ground and the gathered witnesses described a sudden turn in the wind, which the numerical simulation does not reproduce at the smaller scale (1 km resolution). There was a sudden shift to southwest right at the moment that the maximum gust, the collapse of the facility and the damage were observed. This is probably due to the topography. There are various signs that confirm this hypothesis. The most significant, a tree that broke toward the northeast near the *pétanque* field close to the batting tunnel that according to witnesses broke simultaneously to the accident in the tunnel. Wind speed in the area was estimated from the analysis of the truck that was dragged on the asphalt and then knocked over. This speed is 118 ± 21 km h^{-1}, with 95% probability.

To estimate the wind loads on the facility we used the standard AENOR from 2007, considering the roughness of the land, the topography, the effect of the rear buildings, the intensity of the turbulence, a parabolic profile of the wind and the effect of the lattice windows. We considered two conditions, with wind at ground level (2 m) and ceiling level (7 m). With longitudinal wind the suction reaches its maximum at 28 t (2 m) and 42 t (7 m) but was probably much lower because the batting tunnel was protected by a small hill and the community center of the club. With a transversal wind the maximum suction could reach 23 t (2 m) and 35 t (7 m). The calculations made indicate that the building is slightly more stable with transversal wind than with longitudinal wind. If the building of the club had not been located in the longitudinal direction, the accident probably would have occurred with winds from the west, which would have picked up the roof rotating it on an axis transversal to the building. As the building was protected against longitudinal wind, it was probably the change in the wind direction that caused an abrupt increase in the suction on the roof, and thus the ceiling was raised rotating on an axis longitudinal to the building. The effect of the lattice windows does not seem significant, and in any case, it would help increase the stability of the building.

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