CYCLONE CATARINA: DAMAGE AND VULNERABILITY ASSESSMENT

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ABSTRACT

The southern region of Santa Catarina State, Brazil, was shocked by an unusual climatic phenomenon known as Cyclone Catarina that reached the coast on the night of 27 March 2004 causing a severe damage over several coastal municipalities. The objective of this work is to elaborate a damage and vulnerability assessment of the affected communities. Both damage assessment and intensity map were carried out based on a field survey at 22 affected municipalities, covering a route of more than 3,000 km. The intensity map was performed interpolating 260 visited points that were classified according to the overall damage scenario. An interdisciplinary survey team of geoscientists applied a total of 160 questionnaires. Photographs were also taken at the most affected areas in order to assist the vulnerability assessment. In was found that the most affected municipalities were Passo de Torres, Balneário Gaivota, and Balneário Arroio do Silva, all located at the coast, where a great number of edifications were not only damaged but also destroyed. However, these edifications were mainly non-engineering wood-framed and brick houses with concrete-asbestos tile roofs, having a fragile structure with low wind resistance. The most affected communities within the urban areas were of low income. At rural areas, most damage was associated to crop fields of banana, rice, corn, and eucalyptus plantation. As the cyclone displaced towards the interior its intensity diminished, showing a radial destruction pattern. According to the Saffir-Simpson scale and the observed damage level the cyclone Catarina was a class 3 hurricane winds.

Keywords: Cyclone Catarina, damage, vulnerability, assessment, Brazil

1. INTRODUCTION

Starting at the night of 27 March 2004 the southern coastal region of Santa Catarina State in Brazil was affected by an unusual climatic phenomenon, known as cyclone Catarina, which caused severe damages over several municipalities located at the coast. The hurricane intensity winds caused generalized destruction, especially at the coastal communities. Most of the damages occurred on buildings (e.g. houses, gas stations, ware houses, sheds etc.), urban infrastructures (e.g. electricity, telephony, roads etc.), agriculture (e.g. banana, corn, rice etc.), flora and fauna (e.g. trees, birds etc.), some minor injury to people and a few casualties were also observed.

National and international weather forecasting centers stated that this type of phenomenon has never been recorded before in South America. The classification of the phenomenon as a cyclone caused great controversy amongst the scientific community given its complexity and rareness. There are many researches that defend that it was a tropical cyclone (hurricane), others an extratropical cyclone, a polar low, or even a hybrid phenomenon.

Geoscientists from the Natural Disaster Research Group (GEDN) monitored “in loco” the passage of the cyclone and assessed its damages. They consider it as a hybrid phenomenon arguing that it started as an extratropical cyclone, about 1,000 km away

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from the Brazilian coast, and gradually it acquired a circular form with a well defined eye, making landfall with typical hurricane winds.
Natural hazards are threatening events, capable of producing damage to the physical and social system (Alcántara-Ayala, 2002). When the consequences have a major impact on society and/or infrastructure, they become natural disaster. These damages are result of the interaction between process per se (natural hazard) and human system with their vulnerabilities towards them.
According Blaikie et al (1994) in Uitto (1998), vulnerability is defined as the characteristics of a person or groups of people that affect their capacity to anticipate, cope with, resist, and recovery from the impact of natural hazard. Cross (2001) mentions that the vulnerability of both megacities and small communities is determined by their physical and social exposure, disaster resilience, preparedness, and post-event response. However, he also states that small communities are often far more vulnerable to disasters than megacities. When small communities are affected by natural hazards (severe storms, earthquakes, flood, etc.), frequently there is a greater proportion of people affected and structures destroyed than when they occur over megacities. Besides, small communities have a low resilience and post-event response capacity, being more dependent from external aid.
In this context, this work aims to assess the damage and vulnerability over the landfall area of the Cyclone Catarina, based on field survey.

2. STUDY AREA

The study area is situated on a coastal plain located between the South Atlantic Ocean and the steep slopes of Serra Geral range at the southern region of Santa Catarina State (Brazil) (Figure 1). This plane is composed by Marine and Continental Quaternary Sediments with width ranging from 40 to 70 km and altitude ranging from 0 to 20 m. The contact between the plain and Serra Geral shows abrupt changes from 400 – 1100 m with slope gradients higher than 45º (Santa Catarina, 1991). The most important rivers crossing the study area are Mampituba, Urussanga, Araranguá and Tubarão.
The population of 505,690 inhabitants is distributed over an area of 5,538 km^2, corresponding to a demographic density of 91.31 hab/km^2 (IBGE, 2004). The region is of relative low economical relevance when compared to other regions at Santa Catarina State. In the agriculture sector the major seasonal crops are rice, tobacco, corn, and beans; and the most important perennial crops are banana, maracujá and orange. Economical activities at the secondary sector are mainly characterized by carboniferous, ceramic, textile, footwear and nutritious industries, while at the tertiary sector the main activities are commerce, services, and tourism (Santa Catarina, 1991; IBGE, 1999).
This region is frequently affected by different atmospheric systems throughout the year. During the summer, high diurnal temperatures favor intense evaporation and formation of isolated convective systems (ICS), which commonly cause torrential rainfall, strong winds and in some cases even hail in the afternoon (Marcelino, 2003). Another atmospheric system that acts mainly during spring (September-October) is the mesoscale convective complex (MCC) that in some instances can reach the southern coast of Santa Catarina and cause strong winds, rainfall, hail, tornadoes etc. (Silva Dias, 1996; Marcelino, 2003). The frontal transient systems act during the entire year. However, during winter time they are more intense and frequent, causing storms and generating floods, flash floods, hail and tornadoes. During spring time the cold fronts can be associated to the ICS and the MCC, intensifying adverse phenomena that cause natural disasters (Marcelino, 2003). The extratropical cyclones (EC) are disturbances that propagate throughout polar fronts, mainly during winter, and are common in the

Southern South Atlantic Ocean (Satyamurty et al., 1990; Gan, 1992; Varejão-Silva, 2000). When they occur close to the Santa Catarina coast they can generate stormy winds, heavy rainfall, storm surge, and coastal flood.

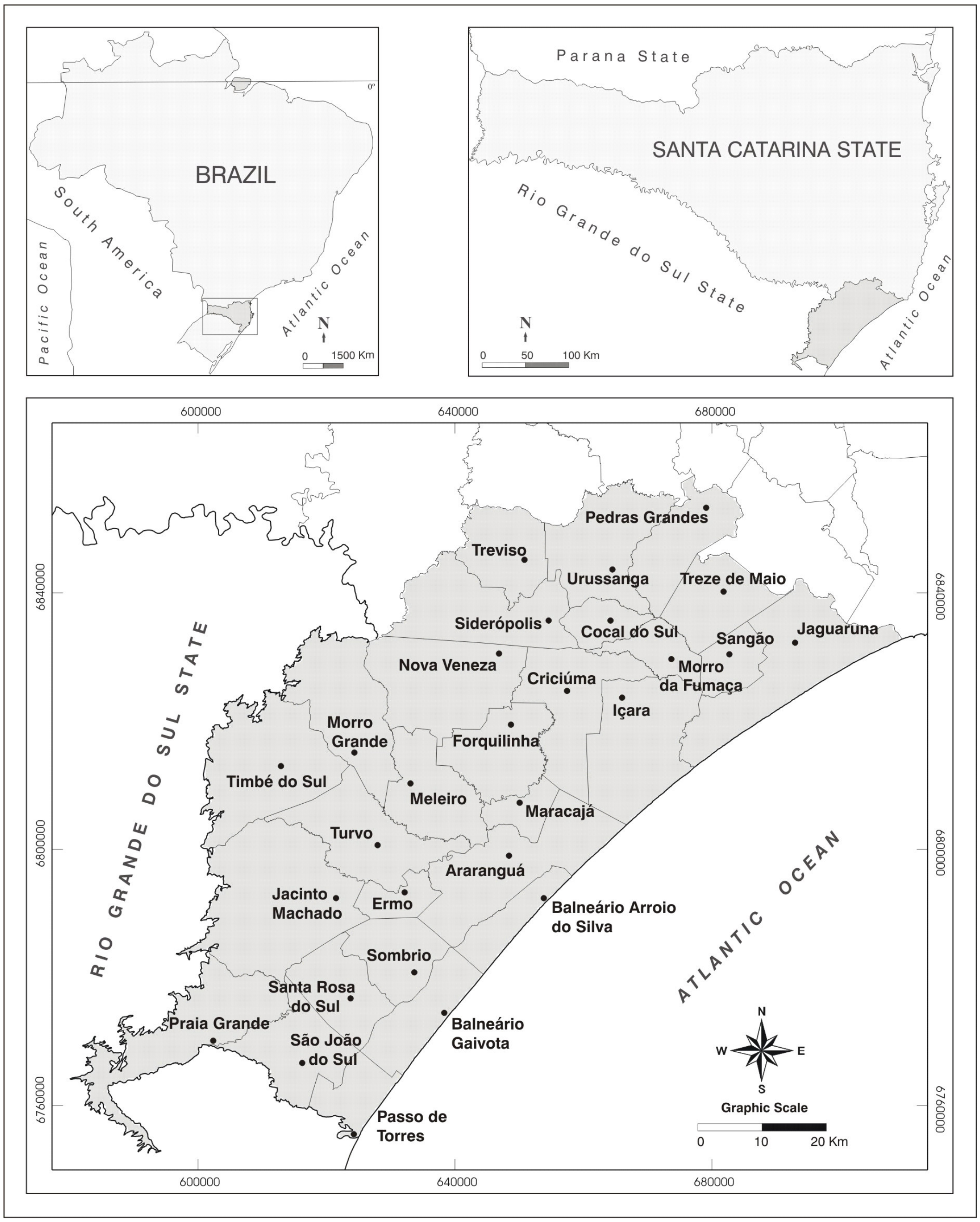

Figure 1 – Location of the study area.

3. Material and methods

The first field survey was carried out on Sunday (March 28th) shortly after the passage of the cyclone. The most affected municipalities were visited, registering photographs of the damages and interviewing the local authorities to gather information about the actual situation of these municipalities. This previous survey was of great importance in order to establish the intensity classes for the Cyclone Catarina damage evaluation survey.

Three days after, a one-week survey was carried out, covering a route of more than 3,000 km, and visiting 22 municipalities within the State of Santa Catarina's affected area. Besides, 160 questionnaires were applied and photographs were taken at the most affected areas. An interdisciplinary group, composed geoscientists, formed the survey team.

A total of 260 GPS points were collected and classified according to the overall scenario of damage. The first question at the observation site was: the damage is high or low? If none of the criteria was met, the damage intensity was classified as medium. Further, the high intensity class was subdivided in high and very high classes. In order to elaborate the Cyclone Intensity Map, grid was generated from these classified points using an interpolation technique with Surfer 8 software. The survey observations were used to classify the phenomenon intensity based on the Saffir-Simpson Scale (Coch, 1994; FEMA, 2000).

The municipalities' socio-economical damage level was obtained from the Damage Assessment (AVADAN) report submitted by each municipality to the State Department of Civil Defense (DEDC-SC) in order to obtain economical aid from federal and state governments.

4. Results and discussion

4.1 Intensity map of cyclone Catarina

A post storm field investigation was conducted a day after the event. Because the damages were still well visible, it was possible to correctly establish the cyclone intensity classes. It is important to stand out that the aim of this fieldwork was to relate damage with wind intensity. At Table 1 there are described the intensity classes that were elaborated in order to classify the sampled points.

Table 1 – Intensity classes of cyclone Catarina

Class	Characteristics
Very High	Generalized damages with complete failure of many non-engineering wood houses, and some masonry houses. Big trees toppled, many trees broken, and total loss in agriculture.
High	Frequent roof loss, structural damages of non-engineering wood houses and some trees toppled and broken.
Medium	Much tile loss, some warehouses and sheds failed, and few trees toppled. Great loss in agriculture.
Low	Some tile loss and trees toppled sparse. Many broken twigs. Major loss in agriculture.

Figure 2 shows the types of damages over edifications frequently observed at the different intensity classes. At the Very High intensity class the pressure from strong winds caused the collapse of many houses, as can be observed at Figure 2a. At the High intensity class there were several cases of roof failure, as can be observed at Figure 2b. At the Medium intensity class there were many roof failure and collapse of tobacco warehouses (Figure 2c). At the Low intensity class there were affected mainly agricultural fields as can be observed at Figure 2d, where the banana field was totally destroyed, and there was just minor roof material failure at an edification located at that site.

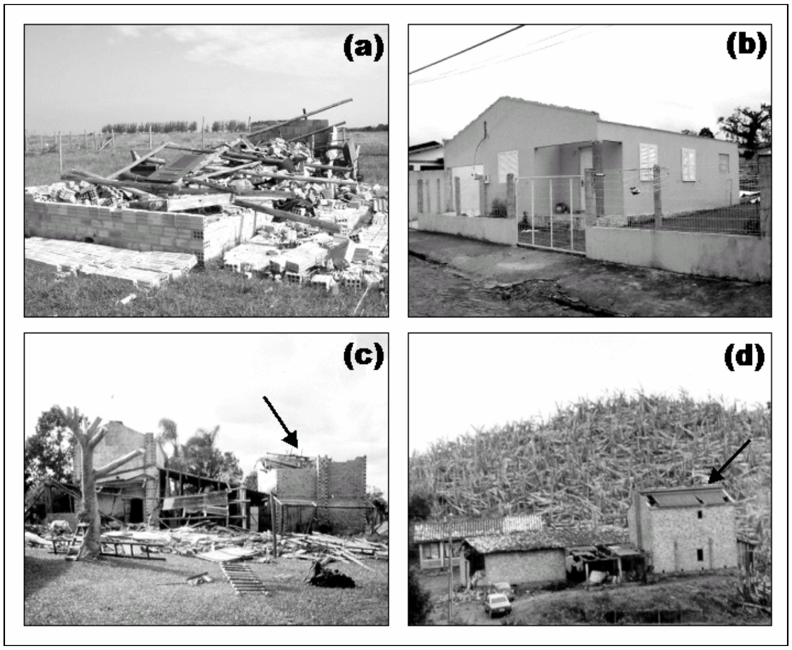

Figure 2 – Examples of the damage intensity classes: (a) Very High class; (b) High class; (c) Medium class; and (d) Low class.

Figure 3 shows the intensity map of Cyclone Catarina, which is directly related to the damage classes, established in Table 1. Areas in reddish were the most impacted by hurricane winds, covering almost the entire municipalities of Passo de Torres, Balneário Gaivota, and Balneário Arroio do Silva. At this region, according to Marcelino et al. (2004), the winds achieved around 120 km/h at the first eye wall and around 180 km/h at the second eye wall. The intensity of the cyclone diminished as it moved from the coast towards the steep slopes of Serra Geral, showing a radial destruction pattern. At the coastal plain, near Serra Geral, there were verified some points with a greater destruction than the surrounding area due to the speedup effect of land surface elevations.

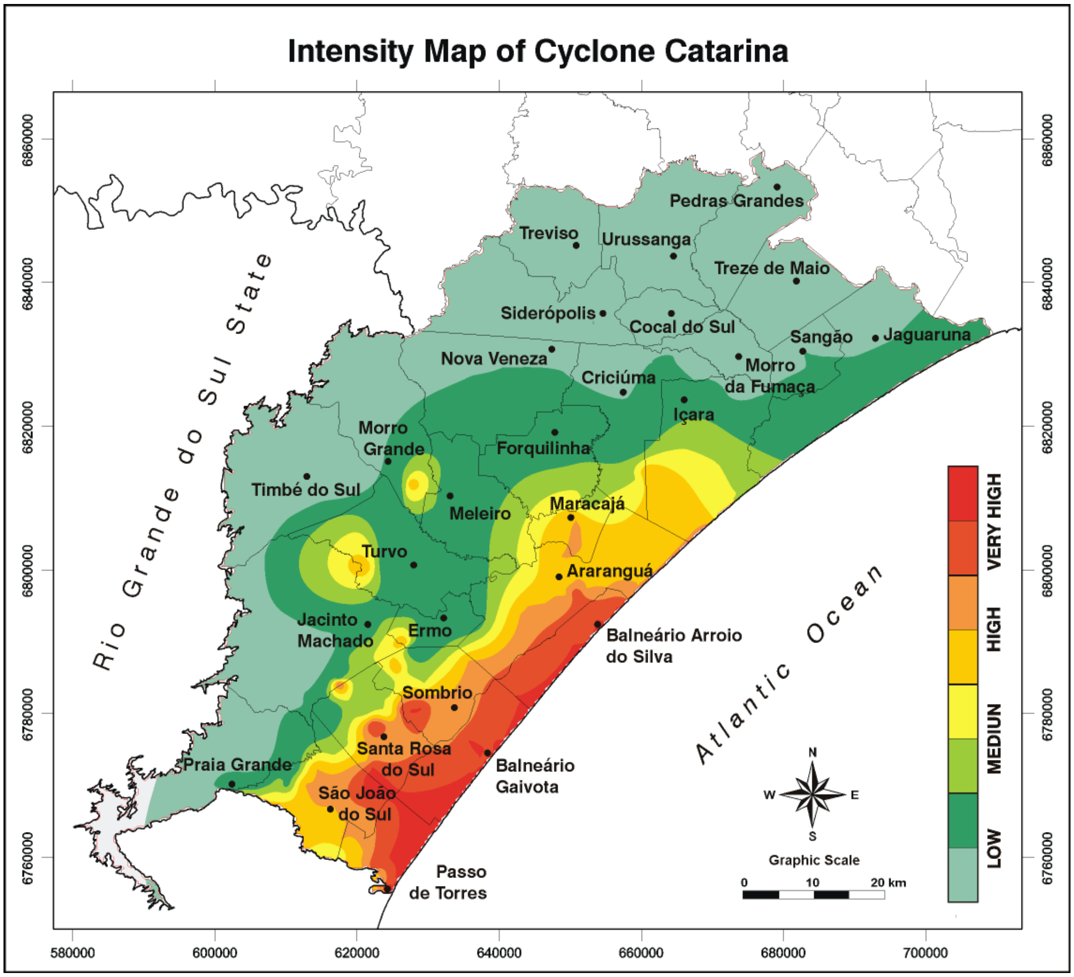

Figure 3 – Intensity map of cyclone Catarina.

4.2 Damage assessment

The landfall area was severely affected, and the damages were more intense over the communities closest to the coast. The damages observed were diverse, ranging form failure to total collapse of roofs and houses (Figure 4).

Many sheds also suffered from total and partial collapse (Figure 5a and 5b). At the rural area, warehouses, which present a type of construction similar to brick houses, were most affected structures (Figure 5c).

At Passo de Torres, many shipyards collapsed, due to the poor wood structure quality and the high walls (6 to 8 m), highly vulnerable to wind pressure (Figure 5d). Besides the widespread roof damage at this municipality (Figure 6a and 6b), it was observed that a non-engineering wood house situated at the southern margin of the Mampituba River at Torres Municipality (Rio Grande do Sul State) was blown approximately 50 m across the river, ending up at the northern margin at Passos de Torres Municipality, Santa Catarina State (Figure 6c).

Figure 4 – Types of damages caused by wind on residences: (a) total roof failure; (b) partial roof failure of a non-engineering wood house; (c) total destruction of a non-engineering wood house; and (d) total collapse of a masonry house.

Figure 5 – Types of damages caused by wind force on sheds: (a and b) total and partial collapse of metallic sheds; (c) partial collapse of tobacco warehouses; and (d) total collapse of a shipyard.

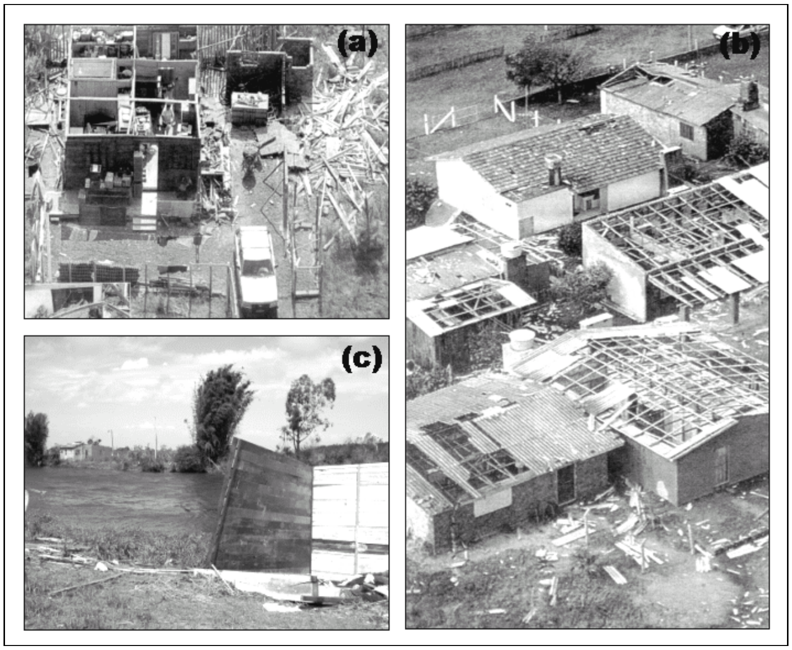

Figure 6 – Types of damages caused by wind force on edifications: (a and b) widespread roof failure; and (c) non-engineering wood house blown across the Mampituba River, divisor between the Rio Grande do Sul and Santa Catarina States.

Another significant damage occurred on forestry, with trees toppled and broken (Figure 9a). Power transmission lines were also highly affected. A sequence of approximately 40 light poles toppled at the road connecting Balneário Gaivota to Sombrio municipalities (Figures 9b and 9c) causing blackout, communication problems, and interruption of water supply.

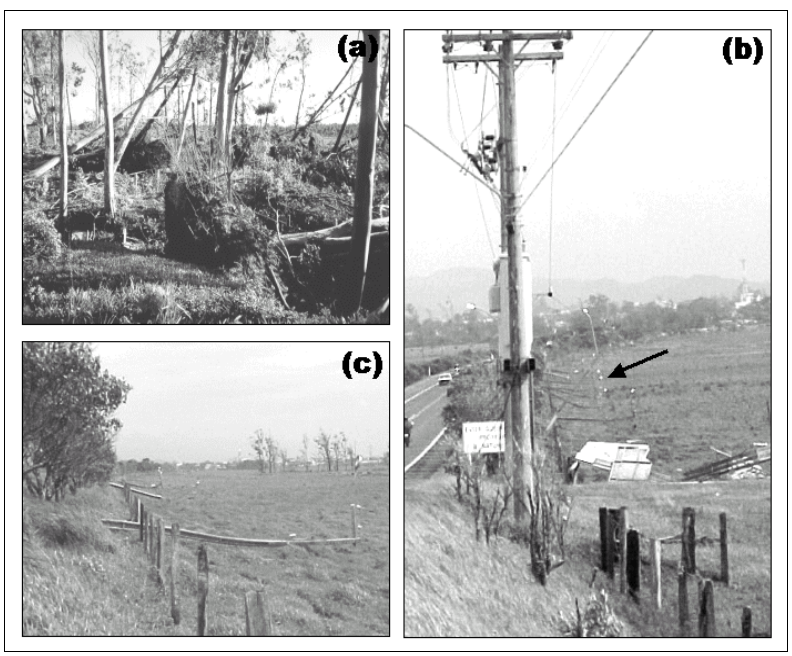

Figure 9 – Severe destruction on forestry (a) and power transmission lines (b and c).

The impact was intense over the fauna. Coastal birds were blown towards the valleys and the mountain range situated 40 km from the coast. Many birds died and sickened due to virus infection and inadequate feeding. It was also noticed an increase on the number and aggressiveness of mosquitoes, and farm animals behaved inappropriately 1 hour before the hurricane.

According to Table 2, 35,873 residences were damaged and 993 collapsed; 2,274 commercial buildings were damaged and 472 collapsed; and 397 public buildings were damaged and 3 collapsed. These structures (40,012) correspond to 26,05% of the total number of structures at the landfall area.

The directed cost[2] with structure losses was US$25,627,616.94 corresponding to 38% of the total loss (US$67,337,773.38). The total amounts of people unsheltered, injured and dead were 33,165, 518, and 4, respectably. It is interesting to notice that most of the injuries occurred during reconstruction and repairing of houses and not during the cyclone's landfall.

Table 2 - Damages on structures caused by Cyclone Catarina.

Type	Amount	%
Residences damaged	35.873	23,35
Residences collapsed	993	0,65
Commercial buildings damaged	2.274	1,48
Commercial buildings collapsed	472	0,31
Public buildings damaged	397	0,26
Public buildings collapsed	3	---
Structures damaged	38.544	25,09
Structures collapsed	1.468	0,96
Total structures affected	40.012	26,05

4.3 Vulnerability assessment

a) Building vulnerability

The wind effect over residences is conditioned mainly to their structural resistance facing wind pressure. In fact, most of the severe damages were associated to the low quality of constructions, due to the inappropriate techniques and the utilization of low resistance material. Other damages are also related to window and door failures due to wind pressure and the impact of windborne debris (missiles). These openings allow the wind to come into the building, producing wind pressures that can be twice as great as those that would result if the building remained fully enclosed (FEMA, 2000).

According to FEMA (2000), other variables can also contribute to wind damage's increase or decrease. Wind loads are influenced by the location of the building site (the general roughness of the surrounding terrain, including open, built-up, and forested areas, can affect wind speed), height of the building (wind pressures increase with height above ground, or the building may be higher than surrounding vegetation and structures and therefore more exposed), surrounding topography (land surface elevations can create a speedup effect), and the configuration of the building.

[2] Direct costs: physical damage, including that to productive capital and stocks, economic infrastructure and social infrastructure (UNDP, 2004).

Thus, most of the damages verified over the landfall area were occurred on non-engineering wood and brick houses. These damages were considerably high, because these structures are constructed with low resistance material and structure. The brick houses usually did not have plaster, beams and columns, resulting in a fragile structure with a poor tie down between roof and walls.

The roof material failure was directly associated to the vulnerability of the different types of tiles and the roof shapes and arrangements in relation to wind direction. The most vulnerable roofs were those covered by 6 mm concrete and asbestos fiber (CAF) tiles. The vulnerability diminished at roof covered by 8 mm CAF tiles. However, the damages were significantly lower at the houses covered by clay tile, regardless of the roof positions and structures.

Regarding to the roof shape and arrangement, the portion facing the highest wind pressure is a fragility point that can trigger its failure and/or collapse. For example, at Figure 10, the most vulnerable roof shape type is represented at example I, with a veranda 2 to 4 m wide. The wind, as it hits the wall, it exerts great pressure, moving upwards and forcing the roof structure. The less vulnerable type is represented at example V, with a cornice (70 to 80 cm), which faces a lower wind pressure.

This can be better explained by using Figure 11 as an example. Both houses have the same type of tile (6 mm CAF tiles), but with roofs arranged differently in relation to the wind direction. At the house highlighted by the black circle (example V), there was just some roof material failure. However, at the house besides (Example I) the whole roof structure collapsed and was thrown approximately 15 m away, due to the presence of a veranda.

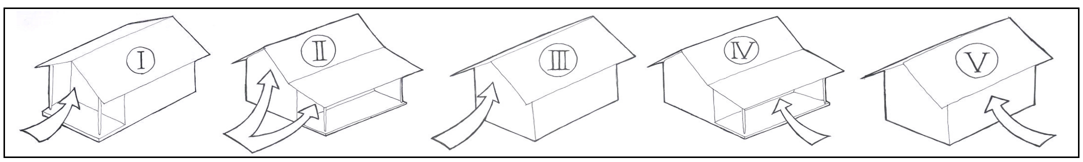

Figure 10 – Vulnerability associated with roof shapes.

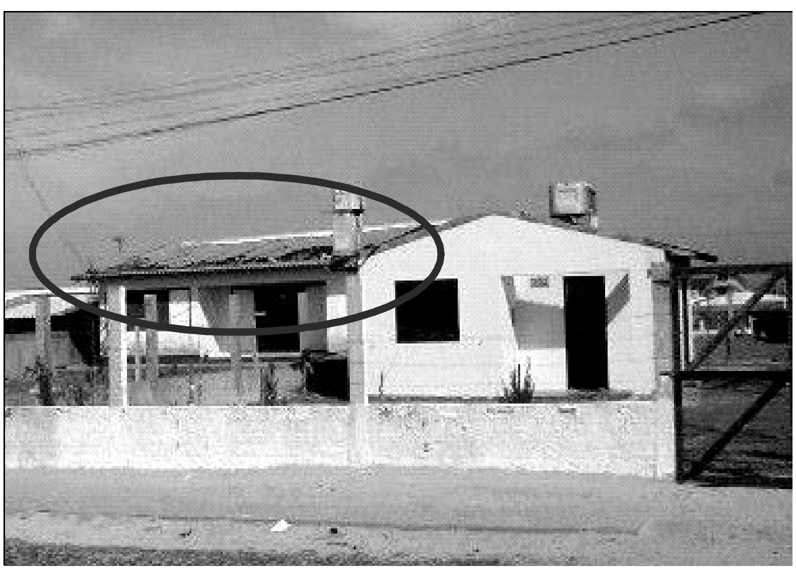

Figure 11 – Vulnerability example associated with roof shapes.

b) Social vulnerability

In general, low income population occupied the most intensely affected areas, with 50% of the familiar income two minimum wages (US$ 200.00) or less. Regarding to housing, most of the residences had 4 to 6 rooms composed of a kitchen, a bathroom, a living room, and two rooms. It stands out that 94% of the houses were of one pavement and more than half (54%) were composed of mix structures (brick/wood houses).

According to the residents, the rain was intense, with long duration, and accompanied by strong winds. During the passage of the phenomena, around 79% of the interviewees protected themselves inside their houses, mainly at a bathroom or a safe room, following the Civil Defense's recommendations. The residents that lived at fragile houses protected themselves over a friend's (33%) or a relative's (52%) house.

The damages that predominated over the affected area were edification roof failure or collapse. Around 81% of the interviewed suffered some type of roof damage, being 30% roof collapse, and 51% roof material failure.

Over the rural area most of the damages occurred on corn (38%), banana (14%), and rice (10%) cultures, commonly cultivated at he affected region. Some rice producers had their loss minimized since they had already collected their harvest. However, at some municipalities, both banana and rice cultures completely collapsed.

Referring to the estimation of losses, it was observed that a great number of the interviewees (31%) did not know how to evaluate their losses and 22% calculated that they lost more than US$ 7,000.00. The difficulty in evaluating the damage can be attributed to the damages caused not only over the house structure, but also over goods, as for instance, furniture and appliances. At the rural area, the interviewees' estimates also presented significant values due to failure or collapse of cultures and/or warehouses and sheds. All municipalities suffered with blackouts and lack of communication and water supply.

In spite no resident seamed to have caught diseases of physical order, most of the interviewees affirmed to be taking some type of medicine, mainly sedatives, due to the great emotional shock.

About 96% of the interviewees had been informed about the occurrence of the hurricane, and the radio broadcasting stations stood out as the main source of information for the population. It is worthwhile to detach the work of the local radios stations in the transmission of the alerts and the recommendations emitted by the State Department of Civil Defense before, during and after the passage of the phenomenon. However, several residents told that they were confused due to the lack of uniformity about the weather forecasts transmitted by different television channels.

It was also asked to the interviewees if they had already lived and/or heard of a phenomenon similar to Catarina. The answer, was unanimously negative, that is, all answered that they had never witnessed a similar phenomenon and of such proportion. However, 59% of the interviewees believe that other phenomenon with similar characteristics and power of destruction can happen over the next years.

4.4. Discussion

The vulnerability could be assessed by analyzing the relation between the affected communities and their capacity in anticipating, coping with, resisting, and recovering from the impact of the cyclone.

The most intensely affected communities were located closest to the shore. Since this region is relatively undeveloped, with small bathing resorts and coastal communities, a great proportion of the residents suffered great loss. At the centre of the bathing resorts the damages were not so high, because a large amount of residences were masonry houses with concrete roofs. However, there were many poor communities, where most of the residences are highly vulnerable to strong wind load (non-engineering wood and brick houses).

Regarding to the anticipation, the local population, meteorologists, civil defense, and decision makers had no experience in leading with this type of phenomenon. In addition, the lack of meteorological stations and waverider buoys made the task of forecasting where, when and how the cyclone would make landfall very difficult. There was also great confusion because there was a conflict between local and national meteorological agencies. The local agency Epagri/Ciram alerted about the risk of the cyclone making landfall with hurricane winds of 150 km/h, while the National Institute for Space Research (INPE) and the National Institute of Meteorology (INMET) emitted alerts that winds of at a maximum speed of 80 km/h would affect the region.

The State Civil Defense Department (DEDC-SC) worked with the possibility of Catarina making landfall with strong hurricane winds. Despite the fact that there was no previous protocol on how to lead with this type of situation, the low number of causalities and injuries reflect the good performance of the DEDC-SC. They had trained 3.000 community leaders and public security authorities in Prevention and Reduction of Disasters and Incident Command System (ICS) between 2003 and 2004 at Santa Catarina State. Also, they followed handbooks on hurricane emergency preparation and response available at FEMA's site and informed the population on how to protect themselves during landfall. They oriented the population to stay at home inside a safe room; look for a close by neighbor or relative if the residence is too fragile; and encouraged the coastal communities to visit friends or relatives at cities located at the interior.

Although those Civil Defense efforts there are still no evacuation plans and alert systems in hurricane situations for Santa Catarina. Pos-event response was not enough because many families did not receive any type of aid at the rebuilt of their residences. In addition, many families that received material aid were due to their linkage to political parties of municipality administrations. There is no natural disaster culture in Santa Catarina State, despite being one of the most affected states in Brazil. In addition, there is a great lack of initiatives regarding to reducing vulnerability between the reoccurrences of the natural disaster. The high vulnerability of Santa Catarina to hurricane extends to other types of hazards, since there are too few investments in forecasting, prevention, and mitigation.

5. FINAL CONSIDERATIONS

The most affected counties were situated on the southern coast of Santa Catarina State, leaving a great number of unsheltered and homeless people. As the cyclone displaced towards the interior its intensity diminished, showing a radial destruction pattern. Based on the damage pattern verified at the landfall area its intensity can be classified as a hurricane class three according to the Saffir-Simpson scale.

Although there were few causalities and injuries, the population affected suffered great material loss from the cyclone. The most vulnerable types of edifications were the non-engineering wood and brick houses. Most of the brick houses have a fragile structure due to the lack of plaster, beams and columns and the wood houses had poor tie down between roof and walls. Regarding to roof vulnerability, gable roofs with a veranda and covered by concrete-asbestos tiles showed the worst performance to wind resistance.

At rural areas, most of the damage was associated to corn, banana, and rice crop failure.

The vulnerability of the region was greatly influenced by the size and development of the cities affected. The most affected communities were of low income and educational level.

Even though prevention and preparedness greatly contributed to the reduced numbers of life loss and injuries, there is lack of a natural disaster culture in Santa Catarina State. It is necessary strong investments in forecasting, prevention, and mitigation in order to reduce community vulnerability.

6. Acknowledgements

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