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PERFORMANCE OF BUILT ENVIRONMENT IN THE OCT 1999 ORISSA SUPER CYCLONE

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ABSTRACT

The October 1999, Super Cyclone ransacked and devastated vast portions of the Indian State of Orissa, leaving behind a huge trail of death and destruction. Rated as one of the worst cyclones to hit the Indian coast ever, the super cyclone surpassed the tragedy of the 1977 Chirala cyclone, killing nearly 15,000 people and causing extensive damage to property, crops and plantations and communication and transportation networks, estimated to be worth Rs.10,000 crores[2]. A post disaster investigation team representing RMSI surveyed the affected areas to study the performance of built-up environment during the event. This paper summarizes the results of this study and attempts to bring to fore the significance of the lessons learnt from the tragedy.

The residential structures in coastal Orissa, being mostly non-engineered and semi-engineered suffered maximum damage during the cyclone. Rural commercial structures suffered more damage as compared to their urban counterparts due to inferior construction. Among the few industrial structures in the cyclone hit region of Orissa, small and medium size industries suffered severe damage to both structure and contents while large industries suffered only major content damage. Among the public buildings, school buildings suffered much damage during the cyclone. Inadequate design and poor detailing played significant role in triggering and increasing damage in both semi-engineered and engineered structures. Lifeline networks especially the power transmission networks performed badly during the super cyclone.

Building types and construction practices in the region have been identified in the post investigation damage study. Closer look at the failure modes and mechanisms have yielded better insight into the vulnerability of structures with regard to cyclones.

INTRODUCTION

Cyclones are one of the most destructive natural phenomenon that often strike certain coastal regions of the world. These are characterized by wind speeds often exceeding 120 Kmph and are usually accompanied by storm surge and heavy rainfall that cause loss of lives and extensive damage to built-up structures and contents within. North Indian Ocean comprising Bay of Bengal and Arabian sea is one of the cyclone prone regions of the world with an average of about 5 to 6 cyclones per year, out of which 2 to 3 may turn out to be severe. The Indian state of Orissa with a coastline of about 1100-Km is particularly vulnerable to cyclones as frequency of cyclones in the Bay of Bengal is about four times higher than that in the Arabian Sea. Table 1 lists some of the major cyclones in the past that affected India.

The Super Cyclone struck the coast of Orissa in the morning of October 29, 1999 barely 10 days after a less intense cyclone ‘04B’ struck the same state. The super cyclone made landfall close to Saharabedi, a village in the Ersama block of Jagatsinghpur district with an estimated maximum sustained surface wind speed of about 260 Kmph. The minimum central pressure at landfall was estimated to be 912 mb. The cyclone generated high storm surge along a long stretch (100-150 Km) of the coastline near to and north of the landfall point (as high as 30 feet close to Saharabedi). The cyclone remained inland for a period of 36hrs before re-curving back into the sea. The re-curving track and relatively slow movement of the cyclone caused it to shed huge amounts of moisture over the land, in the form of rainfall that averaged around 600mm in six days. Fig 1 shows the track of the super cyclonic storm as released by IMD.

Month and Year	Location	Human Casuality (Approx.)	Loss in (million $)
Nov. 1977	Andhra coast Chirala	10,000	77.8
May 1979	Andhra Coast Machhilipatnam	700	37.8
June 1982	Orissa Coast Paradip	243	111.1
Nov. 1984	Andhra Coast Sriharikota	604	88.9
May 1990	Andhra coast Machhilipatnam	967	499.6
Oct 1999	Orissa coast	15,000	4444.4

Table 1. Major Cyclones to make landfall on the Indian coast

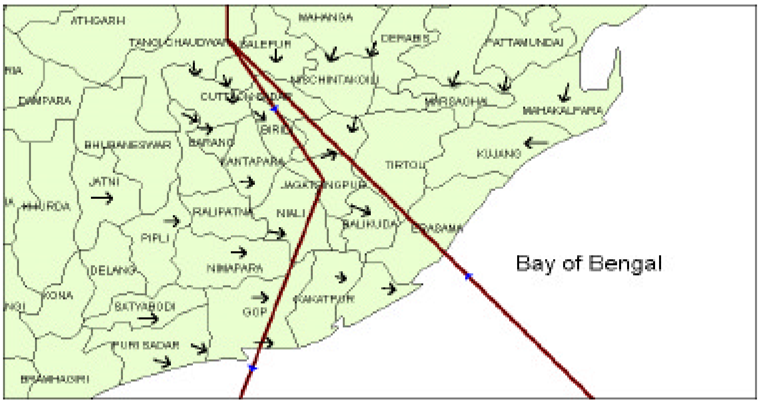

Fig 1. The track of the Super cyclone as released by IMD. The arrows indicate probable direction of Maximum Winds at various locations.

Rated as one of the worst cyclones to hit the Indian coast ever, the super cyclone ransacked and devastated a vast portion of the state spanning over 200 lakh hectares of land in 12 districts. Five districts i.e. Puri, Khorda, Cuttack, Jagatsinghpur and Kendrapara were severely affected. The high storm surge and large scale flooding killed nearly 15,000 people and damaged property, crops, plantations and communication and transportation networks estimated to be worth more than Rs.10, 000 crores[1].

A damage study team representing RMSI undertook reconnaissance of the highly affected region. The objectives were to evaluate the performance of built environment during the super cyclone, to identify building types and construction practices, to develop a building inventory for the region and finally to develop vulnerability functions for typical building types for predicting damage caused during similar events.

METHODOLOGY

The reconnaissance consisted of two separate weeklong site visits to the severely affected districts, first one happening soon after the event and the second one a fortnight later. The on-site damage observations were systematically recorded; using pre-compiled and highly detailed data collection forms. Photographs of representative damaged buildings and structures were taken. Interviews with local people, property owners and government officials were recorded to capture the eyewitness account of the event. The geographic information corresponding to various site locations was recorded with the help of a GPS (Global Positioning System) instrument. A compass was used to measure bearings of the fallen trees, poles etc., at various points along the survey route to assign probable direction of maximum winds (Fig 1). Damage statistics were collected for more than 100 structures covering a wide range of occupancies and building types.

PERFORMANCE OF BUILDINGS

General

In general, the buildings in the cyclone affected region of Orissa including residential, commercial, Industrial and public buildings fared inadequately in responding to the cyclone. The rural buildings being mostly non-engineered or semi-engineered failed miserably in resisting the high-speed winds and storm surge. Failure modes of buildings ranged from blow off of the roof to complete collapse in the residential sector, while failure of roof connections, gable end walls and collapse of steel roof trusses were observed to be significant factors in the failure of the commercial and industrial structures. Among the public buildings, school buildings suffered much damage owing to inferior construction.

Residential buildings

About 20 lakh dwellings were affected by the event, out of which 41.8 % houses were destroyed, 57 % houses were damaged and 1.2 % houses were washed away.

Dwellings in the coastal regions of Orissa are predominantly non-engineered construction though both semi-engineered and engineered also exist. Among the non-engineered, a typical dwelling is a single storied structure with pitched thatch roof on mud walls. The roof cover comprising dried grass and leaves is placed on a bamboo strip frame and the mud walls in most cases are reinforced with bamboo strips.

Fig 2 A typical dwelling in rural Orissa.

Typical damage states of such houses ranged from blowing-off of thatch cover to complete collapse of mud walls either due to surge or due to extreme winds. The typical medium damage state included complete lifting-off of the roof structure along with the bamboo frame, leaving the mud walls still intact. In the surge-affected areas, a few houses withstood the gushing waters and their mud walls were seen to be still intact, though these may have to be demolished due to loss of strength and loss of resistance to water.

The semi-engineered houses are mostly constructed with tiled or corrugated asbestos cement (AC) sheet roof on brick masonry walls, and in some cases random rubble stone masonry walls or precast blocks of plain lime concrete (locally known as 'Panipathar'). The semi-engineered dwellings had the roofing material (tiles or sheets) placed on widely spaced wooden beams without adequate tying. The walls in most cases were not plastered. Failure of such houses ranged from breaking of the tiles / AC sheets to complete lifting-off of the roof structure causing heavy damage to the masonry walls or even collapse of the gable walls. The precast block masonry structures performed well as compared to those using stone or brick masonry.

Only a small percentage of the houses in the cyclone affected region were observed to be of engineered type. These structures with reinforced concrete roof and masonry walls withstood the brunt of the Cyclone and were mostly left untouched. The only minor damage that could be seen in these single or double storied houses was due to secondary effects such as falling trees or wind-borne debris. Failure of inadequately braced brick masonry boundary walls was common in the coastal residential areas.

Commercial buildings

Commercial establishments in urban areas being mostly housed in semi-engineered or engineered structures suffered only minor losses. The losses were in terms of damage to advertisement hoarding and damage to glass windowpanes in office buildings etc. In the rural areas, commercial establishments, which are pre-dominantly semi-engineered construction, suffered partial or total damage. A typical shop in rural areas of coastal Orissa would consist of an enclosure 10 feet by 10 feet made with brick masonry or mud walls and covered with AC sheet roofing. The front of the stall had an overhanging cantilever AC sheet lean-to-roof. Usually the roof above the walls is well protected by additional wall height at the edges or is weighed down by sandbags etc., leaving only the lean-to-roof highly vulnerable to winds. During the cyclone most of the rural shops received partial or total damage to the overhanging cantilever part of the roof.

Poultry sheds were among the most severely damaged commercial structures. These were constructed with low-rise pitched roof having inadequately designed timber beam / truss system, covered with AC sheet roofing on brick masonry walls with large openings. Improper wall design and inadequate connections between the beam / truss system and roof covering highly influenced the performance of the roof system against the cyclone uplift forces. Typical failure modes for these buildings included blowing-off of roof covering along with severe wall damage.

Industrial buildings

Orissa's economy is largely agriculture based and has very few industries especially large ones. During the cyclone, small and medium scale industrial structures such as warehouses and factories suffered more damage as compared to large well-engineered industrial structures. The teams surveyed a number of small and medium scale industrial structures and a few large industries during the reconnaissance.

Warehouses in the region are normally constructed with steel trusses supported on RC columns with brick masonry in-fill walls. The fertilizer warehouse at Cuttack, around 25 km from coast was totally destroyed during the cyclone. The entire roof system and the supporting walls collapsed during the cyclone. This warehouse structure built in 1990 consisted of 12 RC columns with 30cm thick in-fill masonry walls and 60 feet span steel trusses clad with AC sheet roofing. The highly voluminous warehouse structure with large openings allowed the internal pressure to increase excessively during the Cyclone, triggering uplift of truss system and complete collapse of the supporting concrete columns & in-fill walls. Apart from the primary reasons for failure, inadequate design in the form of lack of roof level tie beams and poor detailing was observed. In addition to the structural damage, huge content losses in the form of water damaged fertilizer stocks were observed.

Among the small & medium sized industries surveyed, one of the badly damaged structures was the 1992 built Plywood manufacturing factory in Raghunathpur near Paradip. The factory structure consisted of brick masonry walls with GI sheet roofing on widely spaced timber beams. The GI sheets were secured to the wooden beams using ordinary nails and washers. During the Cyclone most of the GI sheets blew off and rain entered the premises damaging more than 4 lakh square feet of plywood sheets and a number of machinery & equipment.

Among the large industries visited during the reconnaissance were a chemical & fertilizer plant at Paradip and a large sugar factory near Konark. These industries suffered only minor structural damage in the form of loss of AC sheet / GI sheet roof and wall claddings. The content damage was expected to be much higher but no details were available.

Public buildings

Among the public buildings, schools & college buildings were observed to have suffered extensive damage during the cyclone. These are mostly constructed as low-pitched timber truss roof system with AC sheet or GI sheet roofing with brick masonry walls. In most of the school buildings surveyed, the roof sheets were found to be inadequately tied to the widely spaced wooden trusses. To fasten the sheets, either ordinary nails or 'J' bolts were used or brick lining and sandbags were used to weigh down the sheets against the supporting truss. Typical failure modes ranged from damaged roofing sheets to blowing-off of roof covering and gable wall failure. Schools with GI sheet roofing sheets fared better than AC sheet roofs due to better connections. There was heavy content damage in these buildings.

At many places, public halls such as cinema theatres suffered heavy damage due to the cyclone. These structures typically comprise of concrete frames with in-filled masonry walls and steel roof truss system clad with corrugated AC sheet or GI sheet roofing. One of the cinemas surveyed by the team was the completely damaged structure of Lilly talkies at Balikuda. The huge steel truss system of the cinema building came down once the supporting masonry walls failed.

PERFORMANCE OF LIFE LINES AND OTHER STRUCTURES

Power Distribution Network

The super cyclone caused severe damage to lifeline networks in various districts. The power transmission networks were ransacked and in all 39nos. transmission line towers of 220 / 132 kV collapsed and almost 80% of electric poles in the affected districts either got uprooted or damaged. Base failure was observed to be a major reason for damage of electric poles. The reconnaissance team surveyed a number of damaged sub-stations. The failed sub station structures were found to be inadequately designed to resist lateral wind forces.

Radio / Communication Towers

It was surprising to note that some of the well-engineered structures such as microwave communication towers and radio transmission towers collapsed during the super cyclone. The Cuttack radio station incurred much loss when two large (>100 m tall) and 10 small towers totally collapsed during the Cyclone. Lack of proper design and detailing caused the tower structures to buckle near the base when subjected to the heavy wind loads.

DAMAGE ANALYSIS

It is seldom possible to predict the exact structural behavior / response of buildings and structures to extreme wind forces during a cyclone. A detailed post disaster study however provides valuable information about the actual structural performance and typical modes of failures of buildings and structures. This information along with wind data can be used to quantify the extent of damage and then to correlate the damage with hazard intensity for a cyclone affected region.

Quantifying Damage

Building damage due to wind loads depends on a number of factors such as wind speed, building size and geometry, roof shape, terrain conditions, construction quality etc. Further, the magnitude of loss for a cyclone-affected region as a whole is a composite function of the vulnerability of the building types in the region and the inventory (or number & distribution of building types) of the region. Thus for a region for which the damage statistics and inventory information are available, damage to building stocks can be quantified. This done by evaluating Mean Damage Ratio (MDR) for building types with similar characteristics (same building class) such that:

Total Loss incurred = MDR x Total Value

The MDR values pertaining to a building class can be calculated as average of damage ratios (DR) of individual buildings weighted by number of buildings (from the building inventory).

Table 2. gives the damage statistics and MDR values for a government colony at Niali (Lat 20 08 99.7 N, Lon 86 03 78.8 E). This colony situated on the left of the cyclone track contained 24 buildings including 18 residential houses, 5 office buildings and 1 storehouse spread out over an area of about 1sqkm. The construction type did not vary much among the buildings, as the wall type was same for all but roof type differed. The buildings were assigned damage ratios based on the observed damage (Table 3)

S. No.	Building type	Total no. of buildings	No. of buildings	Damage Severity	Damage Ratio (DR%)	Mean Damage Ratio (MDR%)
1	Low rise Residential with AC sheet roof & Brick masonry plastered walls	18	7	None	0	32.5
			3	Minor	15	
			4	Medium	35	
			4	Heavy	100	
2	Low rise Office and other public buildings with AC sheet roof on brick masonry walls	3	0	None		28.3
			1	Minor	15	
			2	Medium	35	
			0	Heavy		
3	Low rise Office building with RC roof on brick masonry walls	1	1	None	0	0
			0	Minor		
			0	Medium		
			0	Heavy		
4	Low rise inspection building with Tiled hip roof on brick masonry walls	1	0	None		15.0
			1	Minor	15	
			0	Medium		
			0	Heavy		
5	Large storehouse (1600 sft) with AC sheet roofing on steel truss with brick masonry walls.	1	0	None		35.0
			0	Minor		
			1	Medium	35	
			0	Heavy		

Table 2. Damage statistics and calculation of MDR for a government colony at Niali

Damage type	% Damage	Description
None	0	No damage
Slight	5	Very little damage to roof cover
Minor	15	Substantial damage to roof covers e.g. Broken tiles, damaged AC sheets.
Medium	35	Roof envelope almost completely damaged and partial damage to walls.
Heavy	100	Roof envelope severely damaged and walls collapsed.

Table 3. Damage ratios assigned to buildings at Niali Government colony based on observations.

Correlating Damage with Hazard Intensity

For a small region with uniform terrain characteristics, as in the case of the above colony, it can be safely assumed that the same value of maximum wind speed (gust) acts on all the buildings. Further, it is known that damage suffered by typical building types (MDR) have a direct relationship with the maximum wind speed (or gust) experienced by the buildings. Hence by evaluating the MDR values for a typical building type at different locations subjected to different wind speeds a 'Wind speed vs. MDR' relationship known as 'Vulnerability function or Damage curve" can be developed.

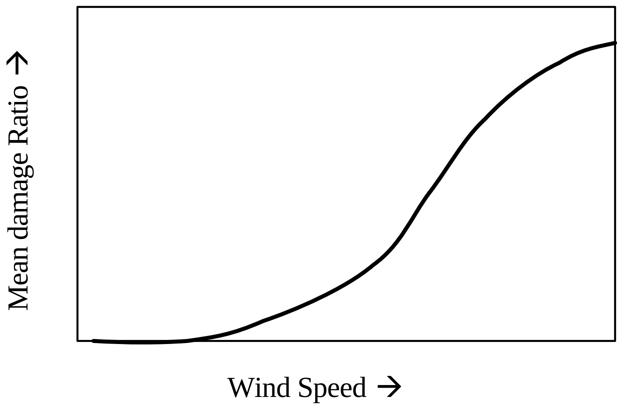

Fig 4. A typical Cyclone building vulnerability Curve

Knowledge of Vulnerability functions along with inventory and value information can help estimation of total loss for a region in case of a cyclone.

CONCLUSION

The post disaster reconnaissance survey conducted in the aftermath of the Super cyclone has, for various building types & occupancies, revealed the severity, failure modes & damage mechanisms and the factors responsible for damage. The Damage study has yielded better understanding of the vulnerability of the structures in the region. Building types and construction practices in the affected region have been identified. A methodology for quantifying and correlating cyclone damage and hazard information for building types is discussed.

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