Wind-Related Disaster Risk Reduction in China - From the Viewpoint of Wind Engineering

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ABSTRACT: This paper consists of three parts summarizing briefly the wind-related disaster risk reduction activities in China. Although varied unfavorable climate phenomena co-exist in China, typhoon that hits frequently the southeast coast area of China is comparatively a dominant factor responsible for the wind-related damages in China. In this paper, some records of typhoon in China are introduced at first. An example of typhoon damages to human life and properties is then provided, in order to supply a general wind-related damage image in China. Finally some measures to prevent the collapse of non-engineering houses are introduced.

KEYWORDS: Low rise building, typhoon, wind-related disaster risk reduction.

1 OVERVIEW OF TYPHOON IN CHINA

As illustrated by the basic wind speed map of China (Figure 1), which has been formed based on the statistical records made in more than 350 stations with 35-40 year wind speed recording over the country, China generally contains two strong wind regions that can be categorized by different strong wind origins. The main contributor to the strong wind in the northwest region is monsoon, while the main reason for the strong wind in the southeast coast area is typhoon. The strong wind in the northwest area often brings damages to the crops and structures, and seasonally enhances the spread of sand storm to the east that causes serious environmental problems on the cities downwind. Meanwhile, the typhoon hits frequently the southeast coast area of China and causes critical damages to the property and human life every year. Although tornado, downburst and other transient winds occur and bring damages to China also, typhoon that hits frequently the southeast area of China is comparatively a dominant factor responsible for the wind-related damages because of the high density of population and importance of economical development in this area. Therefore, the typhoon-related damage in the southeast region is focused in this paper.

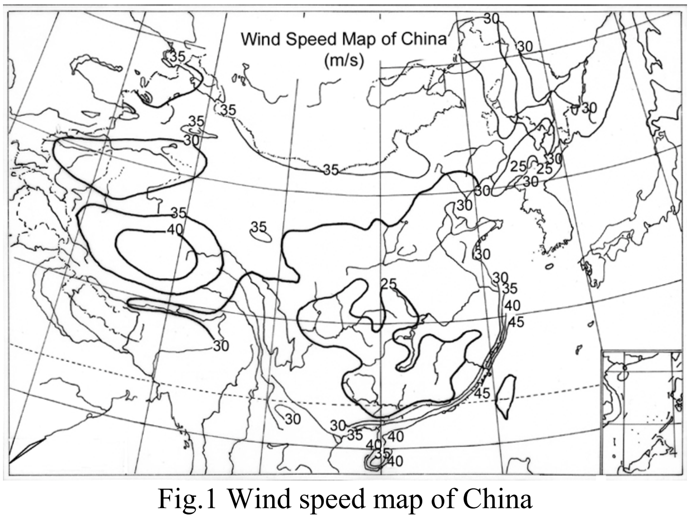
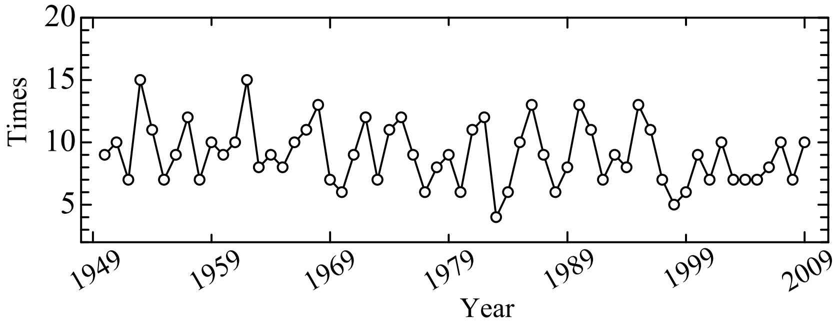


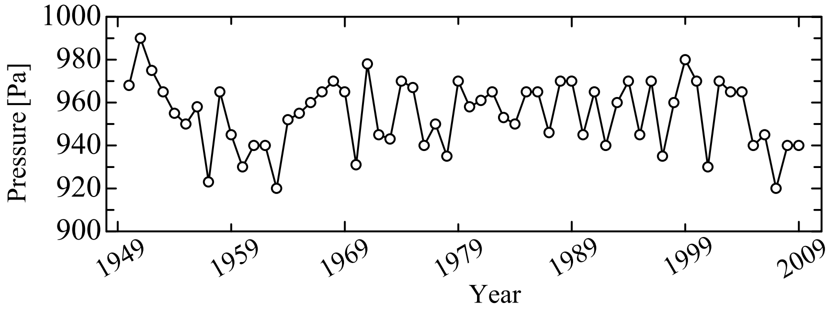
Fig.1 Wind speed map of China

According to the typhoon database of Chinese Academy of Meteorological Science[1)], there are totally 543 typhoons that landed on mainland China from 1949 to 2008, which means that there are averagely 9 typhoons hit China every year. Figures 2c-d illustrate the annual variations of annual landing times, annual minimum center pressure and annual maximum gust wind speed caused by the typhoons landed in China. Although the graphs exhibit deviation, it can be found that the annual landing times, minimum center pressure and maximum gust wind speed of typhoon are almost constant.

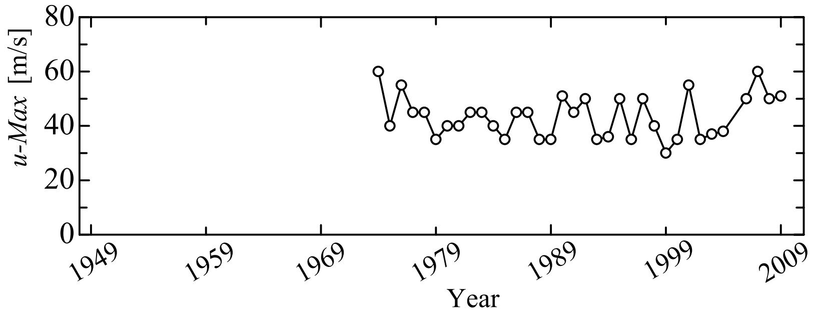
As summarized in Table 1, typhoon has caused severe damages in China. We are further analyzing the wind-related damage data now, and the results will be presented later. Here, an example of typhoon damages to human life and properties is provided, aiming to supply a general wind-related damage image in China.



(a) Typhoon landing times during 1949-2008



(b) Annual minimum centre pressure



(c) Maximum gust wind speed

Fig.2 Annual variations of typhoon data

Table 1 Typhoon damages in China

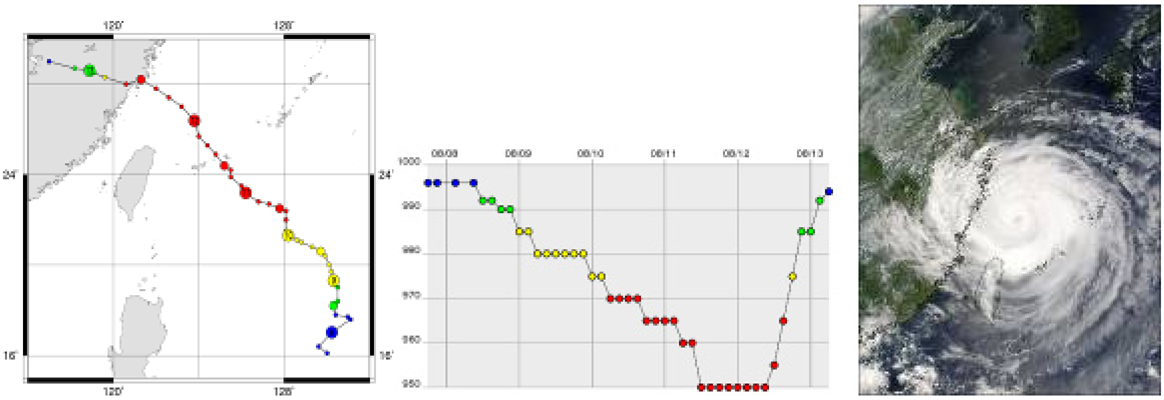
	Death	Missing	Damaged Ship	Collapsed Building (Unit)	Economic Loss (hundred million RMB）
1982	59		926	335330	
1983	228		103	66159	
1984	76		31	93346	42
1985	1030		4236	834472	28
1986	843	46	4102	386347	15
1987	343	8	390	153699	14
1988	229	37	1244	106809	58
1989	552	407	13	304979	93
1990	807	69	3300	269048	
Averaging	463		1594	283000	41.6

2 TYPHOON RANANIM

Typhoon Rananim landed at Shitang Town, Wenglin City, Zhejiang Province in southeast China on August 12, 2004. It passed through four areas, Taizhou, Wengzhou, Lishui and Quzhou, in 15 hours, causing an estimated direct financial loss of about 2.2 billion US dollars. It was a strong, large-scale typhoon with a central pressure of 950hPa at landing, a width of 180Km and a wind speed over grad 10 (Grad 10: 24.5m/s to 28.4m/s). Totally, 164 persons died and 24 were missing. Collapse of buildings was the main reason for injury and death. Besides the damage to house structures, damage to house roofs, cladding material, agricultural plastic houses etc., was also severe. According to the China Meteorological Administration, this was the worst storm to hit mainland China since Typhoon 199713, which killed 236 people. It was also the strongest to hit mainland China in the nearly 50 years since Typhoon 195606.

2.1 *Typhoon Rananim*

Figures 3a-3b illustrate the route and the center pressure of Typhoon Rananim, which originated on August 8, 2004 at 12:00 UTC over the east Philippine Sea. It developed into a strong, large-scale one to the south of Okinawa Prefecture, Japan on August 10 at 15:00 JST (UTC+9). It passed between the Miyako-jima island and Tanama-jima island of Okinawa on the night of August 11 with a center pressure of 950hPa and a maximum velocity of 40m/s. The recorded maximum instantaneous velocity was 42.2m/s at Ishigaki at 16:21 JST and 48.8m/s at Miyagoko-jima at 20:10 JST. Three persons were injured when Typhoon Rananim passed Okinawa. It hit southeast China on August 12 at around 20:00 with a sustained center pressure of 950Pa. It moved through Zhejiang province for 15 hours and finally died on



(a) Track map (UTC) (b) Central pressure chart (c) True-color image

Figure 3 Information of Typhoon Rananim [2)]

August 13 at 6:00 UTC. Figure 3c shows an image of Typhoon Rananim, captured by NASA's Terra satellite on August 12 at 2:40 UTC.

It is noted that typhoon Rananim was reported as 200413 in Japan but 200414 in China. We checked the reason for this difference with the Japan Meteorological Agency and the Shanghai Typhoon Institute, China Meteorological Administration. The reason was that it was recognized by each country independently from their own observations. Although the same criteria are adopted among the different countries, it is possible for a typhoon to be recognized as a tropical cyclone or a tropical cyclone to be recognized as a typhoon by different countries according to the measured wind speed, because observation data are not shared among countries. The difference in typhoon number implies that a typhoon numbered before 200413 in China is not recognized by WMO. To avoid confusion, the international number and name are used in this report.

Turning to Typhoon Rananim, Zhejiang Meteorological Bureau released the information that typhoon Rananim would probably land on the Zhejiang Coastal Line on August 9, and confirmed the future landing of Rananim on August 11. Available safety measures were taken to reduce wind damage to human life and property while typhoon Rananim was being traced by a Chinese satellite (No. 2B Wind and Cloud) and Doppler radars. 400,000 people were moved from unsafe houses and builders' temporary sheds to safe houses. This proved to be an effective method for preventing injury to humans.

Typhoon Rananim had the following characteristics:

1) It caused the worst storm damage to China since Typhoon 199713. The central pressure at landing was 950hPa, which was its minimum pressure. Its recorded maximum instantaneous velocity was 58.7m/s (grad 17) at Jaojiang ward, Taizhou city, which is at the center of the typhoon route and about 20Km from the landing point. This was more than the maximum instantaneous velocity (57.0m/s) recorded for Typhoon 199713 (Winnie, minimum pressure of 915hPa, 955hPa at landing). The average 10-minute wind speed was 45m/s (grad 17). According to the China Meteorological Administration, Rananim was the strongest in nearly 50 years since Typhoon 195606 (Wanda, minimum pressure of 915hPa, 945hPa at landing) hit mainland China. In addition, the maximum instantaneous velocity recorded at Shitang Town, where Rananim landed and the author visited, was 43.8m/s at Songmen station.

2) Historical heavy rain was recorded during the typhoon. As it passed, 275 hydrological stations recorded 100mm in 72hr, 79 stations recorded 200mm in 72hr, and 36 stations recorded 300mm in 72hr. The heaviest rain record was at Leqing Town, which recorded 916mm in 72hr, 874mm in 24hr, and 662mm in 12hr, which corresponds to one quarter of the average annual rainfall. It was the heaviest on record in Zhejiang Province. Heavy rain caused mud flows that killed 28 person at Leqing, and floods in cities.

3) A very large area was affected by strong wind and heavy rain. The diameter of the strong wind circle with wind velocity of grad 10 was over 180Km. Accompanying the strong wind, an area of 2,300km2 (2.3% of the land area of Zhejinag Province) had a rain amount of over 500mm in 72 hr, and an area of 100km2 had a rain amount of over 700mm in 72 hr. The duration of Typhoon Rananim in Zhengjiang Province was 15 hours.

4) Typhoon Rananim came when water levels were high at the upper flood tide time. The flood tide level was 7.42m in the Haimeng area, which was close to the historical record.

According to the typhoon database of Chinese Academy of Meteorological Science1), there are totally 243 typhoons that landed on mainland China from 1949 to 2001, among which 22 typhoons landed at Zhejiang Province. There were four strong typhoons that caused great damages in Zhejiang Province from 1949, which were Typhoon 195606 (Wanda), Typhoon 199416 (Fred), Typhoon 199713 (Winnie) and Typhoon 200413 (Rananim). Comparison of the typhoon damage will be shown later.

One of the authors visited the Wenzhou Evening News, the Wenlin Daily News, the Wenlin Metrological Station and the Weilin Architecture Bureau. They also carried out a site survey of Wenglin city and Shitong town on Aug.19-20, one week after the typhoon landed.

2.2 *Typhoon damages*

1) Damage to house

The collapsed houses that caused injuries were mostly farmers' dwellings in the countryside. They were commonly 2-3 storey structures with concrete frames, brick walls and tile roofs. Figure 5 shows an example of a somewhat larger dwelling. The roof and side wall supported each other. There were two types of tile system for dwellings. In the first, the wooden plate or small bricks were laid out over the rafters, and then the tiles were laid out (Figure 6). In the other, the tiles were laid directly onto the rafters (Figure 7). The latter type was rarely used recently in this area. Furthermore, there were generally two kinds of tile. One was the Chinese traditional type, as shown in Figure 7, and the other had a similar shape to the Japanese tile, as shown in Figure 6. When Typhoon Rananim passed, a great amount of damage occurred on roof tilts. On the S87 road from Wenglin city to Shitong town, which is about 10km long, over 50% of dwellings suffered severe to moderate damage to their roofs, irrespective of the dwellings' age. Collapses of this kind of houses killed 109 persons, and was the primary cause of death and injury. The collapse mechanism seemed that, the house roof was first broken by the strong wind, which removed the support for the brick or stone walls, resulting in their collapse (Figure 8). It was also noticed that the collapsed houses were on open areas some distance from the villages, where the wind speed was greater. In addition, traditional Shitong houses were built of stone. Figure 9 shows a collapsed stone house that had no actual structural frame.


Fig.5 Structure of dwelling


Fig.6 Tile roof


Fig.7 Tile roof


Fig.8 Collapsed house

It was noticed that stones or bricks were put on the roofs of some houses to protect the ceilings from strong wind (see Figures 9 and 10). This misguided action was ineffective in preventing ceilings from blowing off, but possibly increased the amount of windborne flying debris. The method of laying nets on house roofs, which was used in Kyushu, Japan, was a more effective method [2)]. In the countryside, farmers usually build their houses in their traditional manner rather than following relevant national codes such wind resistant design standards. This is one of the reasons for the poor wind resistant performance of their houses. In addition to dwelling collapses that caused injuries, many old, unsafe, low-rise structures in the countryside collapsed during the typhoon.

2) Damage to work sheds and factory buildings

Most work sheds and factory buildings in the countryside are one-story structures with steel sheet or slate roofs. These buildings were also seriously damaged during the typhoon. Figure 11 shows the roof of a factory building that flew away. Figure 12 shows an example of a roof that fell down during the typhoon. Figure 13 shows the steel frame of a factory building whose roof and wall were totally destroyed.

Damage to the work sheds shown in Figures 14 and 15 was much more severe: They completely collapsed.

Fig.9 Collapsed stone house

Fig.10 Stone placed in roof to protect roof

Fig.11 Damage to factory building roof

Fig.12 Broken roof

Fig.13 Roof completely destroyed

Fig.14 Damage to work shed


Fig.15 Damage to work shed


Fig.16 Collapse of advertising board


Fig.17 Collapse of advertising board


Fig.18 Collapse of tree


Fig.19 Flood at an elementary school


Fig.20 Repairing electricity pole


Fig.20 Damage to fishing vessels


Fig.21 Damage to plastic house

Wind damage in the city included collapse of advertising boards (Figure 16 and 17), collapse of trees (Figure 18), flooding in downtown areas (Figure 19), and collapse of electricity poles (Figure 20). Flying of windborne debris hit buildings and cars, causing damage to glass.

Fig.20 shows a fishing vessel that was pushed aground by the strong wind and large tide. Fig.21 shows an agricultural plastic house that was destroyed.

3) Summary of losses

Totally, 164 persons died and 24 persons were missing in Typhoon Rananim. 13 million people were affected. 460,000 people were asked to move from their unsafe houses to safe houses before the typhoon landed. The causes of deaths are summarized in Table 2. Collapse of building was the dominant cause.

Typhoon 200413 was the 2nd strongest typhoon in mainland China since 1956. Three strong typhoons landed in this period before Typhoon Rananim. Table 3 compares the numbers of deaths caused by four strong typhoons. The numbers reduced with time. This is because of the improvement of typhoon prediction, and the appropriate measures taken to mitigate damage, e.g. movement of residents to safe locations.

Table 2 Causes for deaths

Cause	Death number
Collapse of building	109
Boulder flow	28
Strong wind	9
Flood	12
Falling down of telegraph poles etc.	5
Others	1
Total	164

Table 3 Decrease of numbers of deaths

Typhoon	195606	199416	199713	200413
Death	4925	1126	236	164

Damage to engineering structures, communication facilities and economic losses are summarized below:

1) Engineering Structures:

Damaged water gates: 206 sets; Damaged sea walls: 563 km; Destroyed hydrological stations: 99; Various destroyed buildings: 64,300 units or rooms

2) Communication Facilities

Broken highways: 579 sections; Damaged length of highways: 1,163 km; Destroyed transmission lines: 3,342 km; Destroyed communication lines: 1,152 km

3) Economic Loss

Affected farmland: 3,919 km^2, Disaster cropland: 1,897 km^2, Disaster aquatic products: 160,000 t, Lost livestock: 55,000, Direct economic loss: 2.2 billion US dollars

2.3 *Lessons from Typhoon Rananim*

1) Importance of typhoon forecasting

Predictions on when and where a typhoon will land and the route will take play important roles in mitigation of typhoon damage to life and property. For a developing country like China, where farmers' dwellings are constructed without complete compliance with national structural codes and the public disaster-prevention systems are not advanced, movement of persons and property in strong wind areas that may suffer damage seems to be an effective method. This requires correct typhoon forecasting and information.

2) Wind resistant roof structure

Damage to roofs of low-rise buildings, e.g., dwellings and factory buildings, was too severe in this typhoon. It caused direct damage to life and property inside buildings. Utilization of a fixed link between the side wall and ceiling, and utilization of high strength materials for ceilings may be considered to enhance the wind resistance of roof structures.

3 SOME MEASURES TO PREVENT THE COLLAPSE OF NON-ENGINEERING HOUSES

There are a lot of governmental organizations including universities and research institutes working on wind hazard mitigation in China. As shown in the example above, non-engineering houses are easily damaged in the strong wind, and low stiffness is one of the reasons for structural failure. For the traditional Chinese dwelling house, once the edge of the roof is damaged, roofing system de-attaches from the wall and even the rafter may be blown off together with roofing material. In order to improve the wind-resist performance of dwelling houses, China Academy of Building Research once recommended some practical measures. Follows are the examples.

1) Use metal fittings to extend the beams or pillars, as shown in Figure 22.

2) Fix the pillar as stable as possible, as shown in Figure 23.

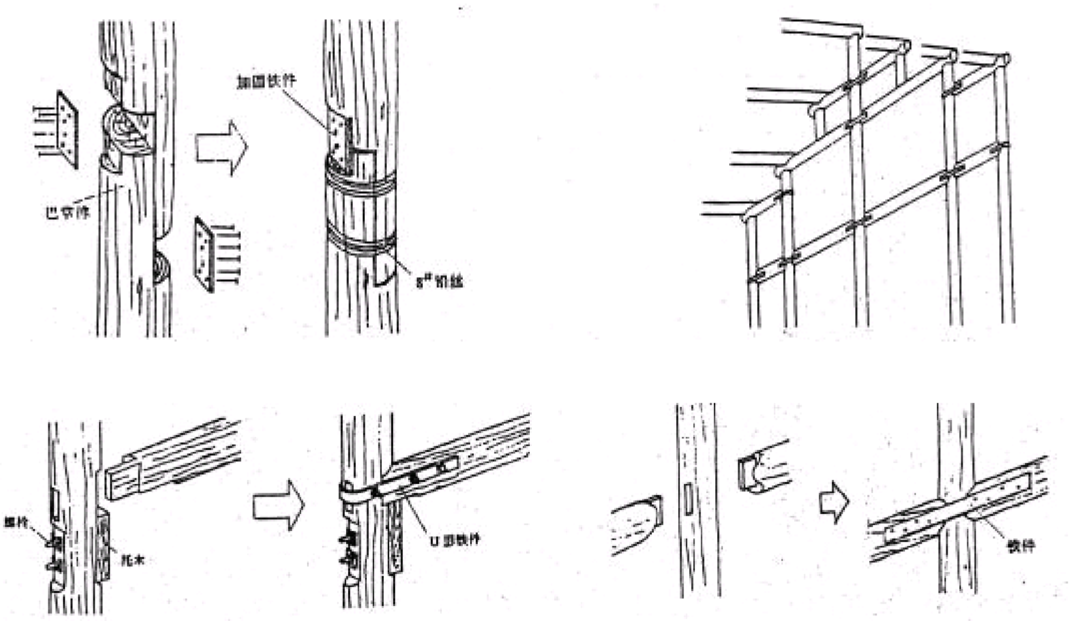


Figure 22 Extension of beams and pillars

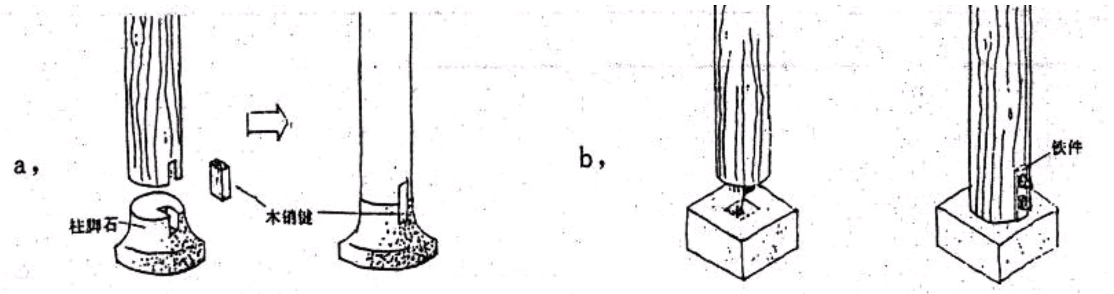


Figure 23 Fixing of pillars

4 CONCLUSIONS

This paper overviews the wind-related disaster risk reduction activities in China. Some records of typhoon are introduced at first. An example of typhoon damages to human life and properties is provided, in order to supply a general wind-related damage image in China. In addition, some measures to prevent the collapse of non-engineering houses are introduced.

5 REFERENCES

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