

Risk Identification and Weight Analysis of Meteorological Disasters on Ancient Buildings

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Abstract. Meteorological disasters impose significant challenges on protection of ancient buildings. By use of Delphi method and Multi-subject research including architecture, meteorology and archaeology, this work identifies major meteorological disasters on ancient buildings. The hierarchical model of risk influential factors is established. It contains four first-grade factors such as wind, flood, lightning and snow disaster, ten second-grade factors and twenty third-grade factors. Then, Analytic Hierarchy Process (AHP) was utilized to calculate weight of those factors. The result showed that lightning disasters had largest threat on ancient buildings among the four major kinds of meteorological disasters. Its weight was the highest of 0.383, followed by that of flood and wind disasters with weight of 0.31 and 0.22 respectively. Snow disasters had the smallest weight of 0.09. Lightning protection measures have significant influence on vulnerability of ancient buildings and on lightning disaster risks. So, to protect ancient buildings against meteorological disasters, besides characteristics of the disasters themselves, all the mentioned factors such as architectural structure, building types and environment should be taken into consideration. Specific protection strategies are then implemented according to weights of different factors.

Keywords: AHP; Protection Ancient Buildings; Identifies Major Meteorological Disasters.

1. Introduction

China's rich ancient civilization has left us huge number of cultural heritages, among which ancient buildings have significant status for their unique structure and inestimable historical value. These buildings witnessed China's long-standing history. They are nonrenewable humanity resource and precious heritage of our ancient civilization.

Meteorological disasters, caused by meteorological factors, are commonly seen natural disasters. They usually include floods, drought, tropical cyclones, strong wind and typhoon, hail, heavy snow, lightning disasters and their derivative disasters [1]. They pose a severe threat to human's lives and assets, as well as ancient buildings. In August 2016, a Buddhist temple dating back to a thousand years ago was destroyed by Typhoon "Sangmei". On 11th May 2004, an ancient temple in Yuncheng, Shanxi was hit by lightning. The derivative fire burnt down the temple and many priceless works of art inside the building. More than 160 pieces of immovable cultural heritage was damaged to different extent by the flood caused by heavy rains on 21st July 2012. Direct economic loss was beyond 800 million RMB and the affected area was over 210 thousand square meters [2].

This work tried to identify potential meteorological disasters faced by ancient buildings and analyze risk factors and their weights, thus contributing to protection of these cultural heritages against meteorological disasters.

2. Risk Identification

2.1 Method of Risk Identification

2.1.1 Delphi Method

The Delphi Method, which is also known as a correspondence survey method through anonymous expert questionnaires, was designed by LAND Co. USA in 1946 [3]. In this study, we adopt the procedures as below. Firstly, we selected a group of experts related to meteorology and architecture. Secondly, each member of the group was sent a questionnaire with background information. Then, the questionnaires were returned to us with experts' comment according to their analysis. After that, a copy of the compiled comments was sent to each participant, along with the opportunity to comment further. At the end of each comment session, all questionnaires were returned and based on which we decided if another round was necessary. These rounds could be repeated as many times as necessary to achieve a general sense of consensus, which was considered as the result of risk identification in our paper.

Theoretically, we can't guarantee that experts' consensus is correct. But this method helped to achieve a more reliable result and weight estimation of meteorological disasters. So, we took this approach to identify the meteorological risk of ancient buildings.

2.1.2 Multi-subject Analysis

Knowledge of one certain subject can hardly support research on meteorology risk assessment of ancient buildings, so it is a Multi-subject issue concerning meteorology, catastrophology, architecture, history, electricity and synoptics. Based on that, we decompose the risk into several layers and analyse the systematic factors of each layer in the perspective of system theory.

2.2 Result of Risk Identification

2.2.1 Strong Wind

According to meteorology, wind disasters refer to casualties or property loss caused by typhoon, hurricanes and wind storms. In China, coastal provinces such as Guangdong, Fujian, Zhejiang and eastern Jiangsu suffer most [4]. A wind disaster could be classified into such three degrees as general, severe and extra-severe as is shown in Table 1 [5].

Table 1. Grade classification of wind disasters

Disaster grade	Wind grade	Wind speed(ground surface)(m/s)
General	6-8	10.8-20.7
Severe	9-11	20.8-32.6
Extra-severe	>12	>32.7

Wind resistance of most ancient buildings is relatively poor because of their architecture structure and aging process during hundreds of years. So, they are commonly seen get damaged or even collapse in strong wind. Roof and side walls are particularly vulnerable.

The roof of an ancient building often has a sloping incline. It is usually the pressure difference between the windward side and leeward side that causes roof damage of the ancient building [6].

A building of 20m height undergoes a basic wind pressure of approximately 0.80kg/m² and a side pressure of as high as 240kg/m². Many ancient buildings have hollow sidewalls and large room spans. This makes them weak in structure and more vulnerable to strong wind [7].

Ancient buildings are prone to be in mountains and woods for fine geomantic omen in traditional Chinese culture. When the wind goes parallel to the mountain slope or with a small angle, its velocity and intensity will be enhanced. So, the topographic feature exacerbates wind disasters to some extent. Compared to stone buildings, wood-built ones suffer more from strong wind.

To sum up, the wind disaster risk of an ancient building (A1) is determined by dangerousness of the wind (B1) as well as wind-resistance of the building itself (B2). The former factor includes such

three sub-factors as wind classification (C1), wind velocity grade (C2) and occurrence frequency (C3). The latter is affected by the following two sub-factors: building structure and material (C4) and topography features (C5).

2.2.2 Lightning

Lightning discharge could cause fierce physical effects like heating, blast waves and electromagnetic radiation, which have massive destructive impact on ancient buildings and tourists inside.

According to meteorology definition, the number of days in a year when a lightning discharge is recorded is called the thunder-day (T) in that area. As stipulated by technical code for protection of building electronic information system against lightning (GB 50343-2012) [8], an area with $T > 90$ is defined as an extra-intense thunderstorm region. Likewise, an area with $40 < T \leq 90$ is defined as an intense thunderstorm region, an area with $15 < T \leq 40$ is defined as a moderate thunderstorm region and an area with $T \leq 15$ is defined as a rare thunderstorm region. For instance, the city of Nanjing, Jiangsu has an average annual thunderstorm day of 33.6 days in 1966-2008, so it is a moderate thunderstorm area. Lightning density (N_g) reflects lightning strokes occurring in a square kilometre in a year (strokes/ $\text{km}^2 \cdot \text{a}$). For instance, lightning density of Jiangsu in 2013-2020 is shown in Figure 1. We could see that such cities as Suqian, Huaian, Yangzhou and Zhenjiang have values of N_g with a maximum of 15.9 strokes/ $\text{km}^2 \cdot \text{a}$. Lightning density (N_g) and thunderstorm days (T) jointly contribute to dangerousness of lightning disasters of ancient buildings.

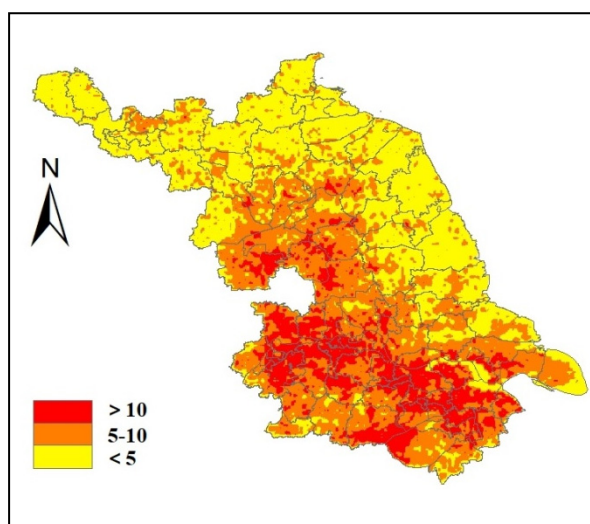


Figure 1. Lightning density of Jiangsu in 2013-2020

Meanwhile, Chinese traditional architecture shared a preference of mountains and waters in terms of location. Earth electrical resistivity tends to fluctuate sharply in those areas. This leads to higher probability of lightning discharges.

A majority of China's ancient buildings were made of wood, which was quite flammable. Fire accidents could be triggered by lightning disasters. On the other hand, whether the building's administrator takes fine lightning protection measures has a significant impact on lightning vulnerability of the ancient building. The measures include lightning receiver and surge protection device (SPD) installation, regular inspection of lightning devices and lightning warning service.

To sum up, the lightning disaster risk of an ancient building (A2) is determined by dangerousness of lightning activities (B3), vulnerability of ancient buildings (B4) as well as their surrounding environment (B5). The factor B3 includes two sub factors: thunderstorm days (C6) and lightning density (C7). The factor B4 is affected by the following three sub-factors: building material (C8), lightning protection measures (C9) and lightning surveillance and warning ability (C10).

2.2.3 Flood

Flood disasters happen frequently in China, imposing great threat to ancient buildings. According to meteorology, the rain with precipitation over 50mm in 24 hours is defined as “rainstorm”. Regions along Changjiang River suffer a lot from rainstorms and floods, which are introduced by typhoon and monsoon front.

Immersion in flood would accelerate corruption of building materials. Besides, secondary disasters like dike breach, debris flow and landslides could be more destructive for the ancient buildings. On one hand, drainage system of those buildings tends to be deficient because of their construction technology and topography features (many of them were in low-lying areas). On the other hand, compared to modern concrete buildings, ancient buildings are often built with wood or tiles, which are much weaker in structural strength and more vulnerable to flood disasters.

To sum up, the flood disaster risk of an ancient building (A3) is determined by dangerousness of flood (B6), flood resistance of ancient buildings (B7) and landform (B8). The factor B6 includes two sub-factors, which are annual precipitation (C12) and rainstorm days (C13). The factor B7 mainly reflects drainage system of the building (C14).

2.2.4 Snow

Snow is not a major threat to modern architecture. But for ancient buildings with roofs made of colored glaze or tiles, accumulated snow can be unsustainable. When snow built on the roof, it may collapse. Meanwhile, many traditional Chinese buildings are sloping. The snow and ice on the roof could damage the roof, even the side wall of the building.

So, the snow disaster risk of an ancient building (A4) is determined by dangerousness of snow (B9) and roof structure of the building (B10). The factor B9 includes three sub-factors, which are snow depth (C16) annual snow days (C17) and low temperature days (C18). The factor B10 includes roof form (C19) and material of roof and walls(C20).

3. Risk Assessment

3.1 Method and Steps

The Analytic Hierarchy Process (AHP) is a structured technique for dealing with complex decisions. Rather than prescribing a "correct" decision, the AHP helps the decision makers find the one that best suits their needs and their understanding of the problem. It provides a series of options for decision-makers, who could get the finest answer through weight comparison of those options. Procedures of AHP method are listed as below [10].

3.1.1 Establishment of Judgment Matrix

Judgment matrix is the basis of quantifying the importance of each index. It reflects the decision-maker's understanding of the relative importance of each index. Scale of 1-9 is used to compare each index in pairs to determine the relative importance of each index and the corresponding ratio, as is shown in Table 2.

Table 2. Comparison in pairs

Scale	Meaning
$a_{ij}=1$	A_i and A_j are equally important
$a_{ij}=3$	A_i is a bit more important than A_j
$a_{ij}=5$	A_i is apparently more important than A_j
$a_{ij}=7$	A_i is much more important than A_j
$a_{ij}=9$	A_i is dominant over A_j
$a_{ij}=2, 4, 6, 8$	Between the scales above
Reciprocal	$a_{ji}=1/a_{ij}$

From the process above we could get judgment matrix A as:

$$A = (a_{ij})_{n \times n} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

3.1.2 Calculation of Relative Weight

By calculating the maximum eigenvalue of the judgment matrix A and the corresponding eigenvector W, the relative weight coefficients of each index in the same level are obtained.

3.1.3 Consistency Check

Check the consistency of the judgments using such three indexes: coincidence indicator, average random consistency index and consistent ratio.

3.1.4 Calculation of Synthetic Weight

Based on the relative weight of all levels calculated in Step 3, the combined weight of the lowest level index relative to the overall target in the hierarchical structure model is further calculated. This step is carried out from the bottom to the top layer.

3.2 Model and Results

3.2.1 Model Establishment

Table 3. Hierarchical model of meteorological disasters

Target layer	The first-grade factors	The second-grade factors	The third-grade factors		
Meteorology disaster assessment of ancient buildings	A1 Wind disaster	B1 Dangerousness of wind	C1 Wind classification		
			C2 Wind velocity grade		
			C3 Occurrence		
	A2 Lightning disaster	B2 Wind-resistance of building	B3 Dangerousness of lightning	C4 Building structure and material	
				C5 Topography features	
		B4 Vulnerability of building	B5 Surrounding environment	C6 Thunderstorm days	
				C7 Lightning density	
		A3 Flood disaster	B6 Dangerousness of flood	B7 Flood resistance of building	C8 Building material
					B8 Landform
	C10 Lightning warning ability				
	A4 Snow disaster	B9 Dangerousness of snow	B10 Roof structure	C11 Surrounding environment	
				C12 Annual precipitation	
		C13 Rainstorm days	C14 Drainage system		
			C15 Landform		
				C16 Annual snow depth	
			C17 Annual snow days		
			C18 Annual low temperature days		
			C19 Roof form		
			C20 Material of roof and walls		

The model of meteorological disaster assessment of ancient buildings has three layers. The first-grade layers consist of four major disaster categories: wind disaster, flood disaster, lightning disaster and snow disaster. The second-grade layers are measuring indexes indicating attributes of the first-grade factors. The third-grade layers are used to further illustrate the second-grade factors. This model includes one target layer, four first-grade factors, ten second-grade factors and twenty third-grade indexes.

3.2.2 Calculation Result

Synthesis weights of risk factors were calculated and consistency checked in Table 4.

Table 4. Synthesis weights of each factor

3rd grade factors	2nd grade factors	Wind disaster	Lightning disaster	Flood disaster	Snow disaster
	Weight				
Wind classification		0.032			
Wind velocity grade		0.073			
Wind occurrence		0.041			
Building structure and material		0.056			
Topography features		0.018			
Thunderstorm days			0.073		
Lightning density			0.102		
Building material			0.066		
Lightning protection measures			0.073		
Lightning warning ability			0.028		
Surrounding environment			0.041		
Annual precipitation				0.091	
Rainstorm days				0.073	
Drainage system				0.073	
Landform				0.073	
Annual snow depth					0.01
Annual snow days					0.01
Annual low temperature days					0.01
Roof form					0.028
Material of roof and walls					0.032

4. Conclusion

This work firstly identified the four major categories of meteorological risk of ancient buildings as strong wind, lightning, flood and snow disasters. Secondly, we analysed impact weights of different factors by Analytic Hierarchy Process (AHP) and come to conclusions as below:

1) Comparison of synthesis weights of first-grade factors showed that lightning disasters have largest threat on ancient buildings. Its weight is the highest of 0.383, followed by that of flood and wind disasters with weight of 0.31 and 0.22 respectively. Snow disasters have the smallest weight of 0.09.

2) Flood disasters, wind disasters and snow disasters of ancient buildings are mainly affected by natural factors and innate characteristics of the buildings themselves, while lightning protection measures have significant influence on vulnerability of ancient buildings and on lightning disaster risks. So, it is quite meaningful to improve lightning protection projects and service.

3) All the mentioned factors such as architectural structure, building types and environment should be taken into consideration in protection of ancient buildings against meteorological disasters. Specific protection strategies are then implemented according to weights of different factors.

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