Earthquake risk and damage assessment for airport transportation system

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Abstract. Taking airport transportation system as the main research object, this paper studies the potential danger and direct economic loss of earthquake. Based on the structural response and damage characteristics of airport transportation system under earthquake action, the framework and theoretical model of HAZUS disaster assessment and direct economic loss developed by FMEA are introduced. This paper focuses on the application of vulnerability curve and capacity curve in airport transportation system risk assessment and economic loss assessment. Taking an airport terminal suffering from a magnitude 8 earthquake as an example, the potential damage degree, probability and direct economic loss of the earthquake are quantitatively calculated, and the property loss is given, thus explaining the importance of the seismic risk assessment framework and method to the safety assessment of China.

1. Introduction
The urban transportation system contains many subsystems, among which the airport transportation system, as the bridgehead of air lifeline, is the main channel of long-distance personnel and cargo transportation, and because the airport has the characteristics of personnel gathering, expensive equipment and facilities, once the earthquake occurs, the consequences are unimaginable. At home and abroad in recent years, there are many earthquake accident happened to the airport transportation system, such as the earthquake in the northern Philippines, clark airport more severely damaged, Turkey earthquake airport passenger plane was forced to transfer, to the earthquake in yushu airport runway is impaired, the plane can't normal landing, and so on, thus the earthquake is dangerous for the airport transportation system[1].

The seismic risk analysis system is more mature abroad. As early as 1970, the United States passed legislation requiring earthquake risk assessment in earthquake-prone areas. Analysis of the lifeline system also began in the 1970s. For example, Giocel et al. conducted seismic response analysis and vulnerability assessment of soil structure interaction in the eastern United States. Bhargava et al. conducted 3D finite element modeling for the Indian water storage system COSMOS/M, and assessed its vulnerability based on a large number of nonlinear earthquakes. Through modeling, the analysis was more accurate. In 1995, Tanaka conducted vulnerability assessment on the highway system, assuming that the vulnerability curve was in the form of two-parameter normal distribution, and
verified by using a large amount of data[2][3]. Based on the achievements of a large number of researchers, HAZUS is a single column module of the lifeline system, making the analysis system more complete. The formation of seismic risk analysis system in China is relatively late. The first analysis of earthquake vulnerability was in the 1980s. Yang Yucheng et al. made a more systematic analysis of the vulnerability of houses. Subsequently, Gao Xiaowang, Zhong Yishu et al. began to calculate the failure probability of structures under different earthquake intensification with data. In recent years, Cheng Xiaoping et al. proposed to use neural network model to analyze earthquake vulnerability. For the analysis of lifeline system, the first one is the seismic vulnerability analysis of reinforced concrete bridge structure jointly conducted by Professor Liu Jingbo of Tsinghua University and Professor Huang Hongmou of the United States[4]. For China, there are many analyses on Bridges and highways, but weak analyses on other lifeline systems, and no specific targeted analysis system has been generated. Most of them refer to relevant risk analysis methods abroad.

At home and abroad, there are only unilateral studies on lifeline vulnerability, disaster prevention and loss calculation, which lack a systematic assessment framework, leading to a lack of theories and methods to summarize the current risk assessment system. In contrast, THE analysis of HAZUS is more comprehensive, including risk assessment and loss assessment, and can be divided into several modules. By using this risk analysis method, direct economic losses can be obtained through the probability of occurrence of disaster and unilateral risk or loss assessment can be avoided. Through the risk analysis of the airport earthquake damage, the vulnerable links can be grasped more effectively and the losses of relevant departments can be transferred, which is of great significance to the disaster prevention of the airport system.

2. Introduction to airport transportation system

The airport system consists of six main parts. The details are described below: Airport Control Tower (commonly constructed of reinforced concrete); Airport Terminal (made of structural steel or reinforced concrete); Airport Car Park Structure (with all building type options enabled); Airport fuel facilities [including buildings, storage tanks (above ground storage tanks are steel structures, underground storage tanks are mostly concrete wall structures) and anchored, unanchored or buried types]; Airport maintenance and hangar facilities (made of structural steel or reinforced concrete); Airport runway; Helipad facilities[5].

3. Risk assessment process

3.1. The damage function form of the airport system

Damage function mainly includes vulnerability curve and capability curve [6].

The seismic loss prediction steps are as follows: the response spectrum of the earthquake is converted into demand spectrum; the capability curve and demand spectrum are plotted in the same cartesian coordinate system; the intersection point of the two curves is the performance point. For the peak ground displacement of the disaster-bearing body, the probability of different damage degrees of buildings is obtained by looking up the vulnerability curve according to the displacement.

(1) Vulnerability curve

The vulnerability curve indicates the cumulative probability of a disaster-bearing body reaching or exceeding a certain degree of damage at a given ground shock intensity.

Given spectral displacement $S_d$ (or other parameters), the conditional probability of DS in or over a specific damage state is defined by the function, as shown in Formula (1):

$$P(d | S_a) = \phi\left(\frac{1}{\beta_a} \ln\left(\frac{S_a}{S_{d, \sigma}}\right)\right)$$

In the formula: $d_s$ is the degree of damage; $S_d$ is peak ground displacement;$S_d$ is the median value of peak ground acceleration sustained by the disaster-bearing body when it reaches the damage degree $d_s$; $\beta_a$ is the standard deviation of natural logarithm of $S_d$; $\phi$ is the standard normally distributed cumulative function.
(2) Capability curve

The capability curve describes the relationship between spectral acceleration $S_a$ and spectral displacement $S_d$, as shown in Figure 1, the bearing capacity curve consists of three control points, namely, design bearing capacity $(D_d, A_d)$, yield bearing capacity $(D_y, A_y)$ and ultimate bearing capacity $(D_u, A_u)$. The design bearing capacity represents the seismic design code requirements, the yield bearing capacity is the conservative estimate of the bearing capacity of the disaster body considering the redundant design and the stress strength of the material. The ultimate bearing capacity reflects the maximum bearing capacity of the damaged structure or member or the limit state of deformation which is not suitable for continuous bearing[7].

![Image of capability curve](image.png)

It is generally believed that the structure changes linearly before reaching the control point of the yield bearing capacity, so the bearing capacity curve can be determined by calculating the yield bearing capacity and ultimate bearing capacity. The calculation of the two is shown in formula (2):

$$
A_y = \frac{C_y \gamma}{\alpha}; \quad D_y = 9.8 \cdot A_y T_e; \quad A_u = \lambda A_y; \quad D_u = \lambda \mu D_y
$$

(2)

In the formula: $C_s$ design strength coefficient; $T_e$ structure in elastic state time, seconds; $\alpha$ the self-weight coefficient of the structure is in the static elastic-plastic mode; $\gamma$ the structural strength excess coefficient of yield bearing capacity relative to design bearing capacity; $\lambda$ the coefficient of structural strength over lambda ultimate carrying capacity relative to yield carrying capacity; $\mu$ ductility factor.

(3) Demand spectrum

Demand spectrum is obtained by using effective damping to reduce the seismic response spectrum with a damping ratio of 0.05[8]. The peak response at the intersection of the capability curve and the demand curve is a parameter used together with the brittle curve to estimate the probability of damage state.

### 3.2. Direct economic loss to the airport system

Direct economic loss is an evaluation method combining damage status. In the past, damage assessment studies have generally limited the consideration of damage to the cost of repair and replacement of building materials. HAZUS is dedicated to providing direct economic loss methods for urban lifelines, as follows.

The calculation of direct economic losses is based on:

1) Probability of being in a certain damage state $P[D_s \geq D_S]$
2) Replacement value of components
3) The damage ratio (DRi) for each damage state (dsi).

The calculation formula of composite damage rate is as follows:

$$
DR_c = \sum_{i=2}^{5} DR_i * P[dsi]
$$

(3)

In the formula, $P[dsi]$ is the probability of being in damage state i, 1, 2, 3, 4, 5 correspond to no damage state, slight, medium, extensive and complete. There is no loss associated with damage state 1, so the sum is from $i = 2$ to 5; $DR_i$ is the damage rate: part of the replacement cost. The rate of component damage is determined based on the damage status[9]. $DR_c$ is the composite damage ratio.
The economic loss is assessed by multiplying the composite damage ratio (DRc) by the replacement value.

Replacement values for individual building system components are determined by building materials. The fuel system is determined based on whether it is anchored or buried underground[10].

4. The example analysis
Taking the structural damage of terminal 3 of an airport in the epicenter area of a magnitude 8 earthquake as an example, the seismic risk analysis was carried out. The airport, located in Shandong province, was built in 2000. The specific setting conditions of the research area are as follows: The terminal is a steel-concrete structure with four floors and a height of 3.6m. The THREE-DIMENSIONAL model is shown in Figure 2. The seismic intensity is 8 degrees, the seismic acceleration value is 0.3g, the maximum horizontal seismic impact coefficient of frequent earthquakes is 0.24, the maximum characteristic period is 0.4s, the maximum horizontal earthquake impact coefficient of rare earthquakes is 1.2, the characteristic period is 0.5s, the periodic reduction coefficient is 0.85, and the damping ratio is 0.05[11].

Fig2. Three-dimensional diagram of terminal building.

4.1. Vulnerability curve analysis
The median Sa, ds and standard deviation βds of the vulnerability curve of airport terminals based on PGA are shown in Table 3. According to the above formula (1), the vulnerability curve of airport terminals is obtained, as shown in FIG.3.

| Type          | Degree of damage | The median value | The standard deviation |
|---------------|------------------|------------------|------------------------|
| Terminal (PGA)| Slight           | 0.14             | 0.64                   |
|               | Medium           | 0.26             | 0.64                   |
|               | Serious          | 0.62             | 0.64                   |
|               | Completely       | 1.43             | 0.64                   |

4.2. Ability curve determination
According to the survey, the total height of the airport terminal is about 35.9 meters, and the overall structure is steel mixed structure. Therefore, it is defined as a medium high-rise with S1L steel structure, so the parameters of the capability curve can be determined, Cs=0.050, Te=1.08, α1=0.80, γ=1.25, λ=3.00, μ=4.0[12]. According to formula (2), Dy=0.89, Ay=0.078, Du=10.65, Au=0.234. The capability curve can be determined according to the coordinates of two points, as shown in Green line in FIG. 4.
4.3. Determination of performance points and damage probability

According to the above terminal and earthquake-related parameters, the capacity curve and demand spectrum of terminal were plotted in the same cartesian coordinate system using PUSH_OVER to obtain the performance points, as shown in Figure 4 (abscissa Sd, ordinate Sa). It can be seen from the figure that the ground peak acceleration corresponding to the performance point is 0.484g, and the ground peak displacement is 0.086m.

According to the ground peak acceleration determined by the performance point and the vulnerability curve, the probability of the terminal being in slight damage is 76%, the probability of medium damage is 43%, the probability of severe damage is 21%, and the probability of complete damage is 3%.

4.4. Direct economic loss calculation

Damage rate DRi can be determined according to Table 4. In this paper, the best damage rate is selected to calculate. Because the terminal structure is S1L steel structure, its replacement value is $8 million.

| Damage status       | Best estimate of damage rate | Damage rate floating range |
|---------------------|------------------------------|---------------------------|
| Slight              | 0.10                         | 0.01-0.15                 |
| Medium              | 0.40                         | 0.15-0.40                 |
| Serious             | 0.80                         | 0.40-0.80                 |
| Completely destroyed| 1.00                         | 0.80-1.00                 |

Calculation of damage probability:
P1 = 1-76% = 24%; P2 = 76%-43% = 33%; P3 = 43%-21% = 22%; P4 = 21%-3% = 18%; P5 = 3%.

Compound damage rate: DRe = 33%*0.10 + 22%*0.40 + 18%*0.80 + 3%*1 = 0.295

Direct economic loss = $8 million * 0.295 = $2.36 million.

4.5. Risk analysis recommendations

Based on the above risk analysis results, the following risk analysis suggestions can be proposed:

(1) There is a high possibility that the loss of the building is at or above the medium level. After investigation, it may be caused by the improper use and maintenance of the building. Therefore, it is necessary to reinforce the roof, beam and column and other key parts to prevent the system from being threatened in a strong earthquake.

(2) Set up multi-seismic defense lines. Since the earthquake has a certain duration, and may be the reciprocating effect of the earthquake, and the reciprocating effect of the earthquake is the main cause of the serious damage to the structure. It is an important measure to increase the seismic capacity of the structure to properly deal with the relationship between strength and weakness of components and make them form multiple lines of defense.
5. Conclusion and Prospect

1) the conclusion

In this paper, the airport transportation system is selected as the research object, and the vulnerability assessment model based on the seismic vulnerability assessment method of aircraft transportation system is established by using the capability demand spectrum method, and the risk analysis is carried out. Through the analysis result, the direct economic analysis method is used to analyze the economic loss. This method can directly apply the risk assessment data to the loss assessment and make full use of the data.

The conclusion is as follows: when the risk is a magnitude 8 earthquake risk, the risk analysis of the airport terminal based on the vibration parameters shows that the probability of no loss of the terminal is 24%, slight damage is 33%, moderate damage is 22%, serious damage is 18%, and complete damage is 3%. Direct economic losses were estimated at $2.36 million.

Through the software simulation, the risk prediction of airport transportation system can be carried out and a reference of risk management can be provided to relevant managers. This research can not only effectively identify the seismic thin links of the airport transportation system and improve the underwriting related matters, but also help the airport to recognize its own shortcomings and improve, and reduce the loss caused by the earthquake from the source, which has practical significance.

(2) expectation

In this paper, only one method is used to analyze the vulnerability curve, which is lack of comparative test. The conclusion may have errors and cannot be corrected.

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References

[1] DU W. (2012)Study on emergency rescue System of catastrophe type Events. Henan: Henan University of Science and Technology
[2] Stuary F, Thomas J. (2010)Parcel-scale Earthquake Loss Estimation with HAZUS: A Case Study in Salt Lake County, Utah. Carto-graphy and Geographic Information Science, 37: 17-29.
[3] Jonathan W. (2012)HAZUS-MH earthquake modeling in the central USA. ORIGINAL PAPER, 63: 1055-1081.
[4] LV Dg, YU Xh. (2013)Probabilistic seismic risk Theory Research based on seismic vulnerability Analytic function. Journal of Architectural Structure, 34: 41-48.
[5] Mulii-hazard Loss Estimation Methodology E-earthquake Models[R]. FEMA, 2003.
[6] YU Xh, LV Dg. (2016)Earthquake vulnerability analysis of hazus-compatible reinforced concrete frame structure. Engineering Mechanics, 33: 152-160.
[7] HAN M, LI Sj. (2010)Seismic vulnerability Analysis of frame shear wall Structure based on capability Spectrum Method. Journal of Civil Engineering, 43: 108-112.
[8] LI Yme, LI Zy, YANG By. (2017)Seismic vulnerability Analysis of Steel Frame Structure based on performance. Journal of Seismic and Reinforcement Engineering, 39: 55-60.
[9] YANG Ya, LI L. (2016)Comparative Study on Economic Evaluation Models of Earthquake Disasters in China and Foreign countries. Journal of Resources and Environmental Science, Wuhan University, 7: 27-31.
[10] ZUO z. (2012)Research on the Potential Risk Assessment Method of large storage Tank based on ground motion parameters. China Science and Technology of Work Safety, 8: 41-46.
[11] JReza D, Amir, Mahmoud, et al. (2017)New Design for Creating Safe Places to Reduce Earthquake Loss and the Best Way to Rescue and Relief People. Geological Journal, 8: 913-924.
[12] Hazus® Estimated Annualized Earthquake Losses for the United States[R]. FEMAP-366, 2017.