process and coordination on performance. PhD dissertation,MIT, 1995.
13. Lewlyn L.R. Rodrigues, N. Dharmaraj, B.R. Shrinivasa, Rao. System dynamics approach for change management in new product development. Management Research News, 2006, 29 (8), pp. 512–523.
14. S. Han, P. Love, F. Peña-Mora. A system dynamics model for assessing the impacts of design errors in construction projects. Mathematical and Computer Modelling, 2013, 57, pp. 2044-2053.

Fuzzy Assessment of Quakeproof Property in Stadium Buildings

Huang Li

Department of Physical Education, Hohai University, Nanjing 210098, China

Corresponding author is Huang Li

Abstract
Stadium buildings are important population-intensive buildings where various social activities are held frequently. The quakeproof property of stadium buildings directly concerns safety and image of social people and the cities. This research takes sports stadium buildings for example, combines architectural characteristics and quakeproof requirements of sports stadium and introduces fuzzy assessment theory. Deep analysis is carried out from the site environment, foundation, major structure, building materials and components which influence quakeproof property. On this basis, this paper proposes a set of scientific comprehensive assessment index system, and applies fuzzy comprehensive assessment to construct quakeproof property assessment model of sports stadium. Meanwhile, based on case study of Wukesong Stadium, this paper verifies feasibility of this assessment system. The research shows that this method has certain reference significance for quakeproof property assessment of similar stadiums.
Keywords: STADIUM BUILDINGS, QUAKEPROOF, FUZZY COMPREHENSIVE ASSESSMENT

1. Introduction

Compared with other natural hazards, earthquake imposes the most serious destructive effect on human society and it is most sudden [1]. At present, early warning technique is still not developed. Human beings can only depend on passive prevention methods such as enhancing quakeproof property of buildings. For some important buildings such as sports stadium and station, there is corresponding quakeproof design which can resist certain intensity of earthwork. To visually reflect quakeproof property of buildings, architectural engineering standard also sets corresponding quake-proof grade, and specifies corresponding specifications. Due to functional attribute of stadiums, quakeproof grade of sports stadiums has high requirements, and quakeproof assessment process is more rigorous. Thus, many scholars study architectural quakeproof problems. B. Li and H.M. Zhang present a building earthquake disaster simulation system. The system can estimate the destruction of buildings by different earthquakes, and analyze the quake-proof ability of different buildings[2]. Sun Zifa systematically expounded quakeproof design and problems of Olympic stadiums according to seismic intensity area where Beijing is located, and pointed out concrete quakeproof measures[3]. Dong Guozhen et al. mainly studied the important functions of sports on earthquake prevention and disaster reduction from physiology and psychology, and explained the important significance of sports stadium on improving quakeproof grade[4]. Chen Gang analyzed economic effects of seismic isolation technology on quake resistance from the perspective of engineering economy, and studied its development prospect in quake-proof building application[5]. Su Ting set forth technical principles of seismic isolation system and energy dissipation design and indicated the importance and practical significance of such new techniques through comprehensive analysis of development course of structural quakeproof and seismic dissipation technology of Chinese housing buildings[6]. Zhao Xiaojie et al. applied PKPM and Midas software to carry out elastic analysis of different types of earthquake for the structure of a sports stadium in Taicang. On this basis, they put forward corresponding reinforcement design scheme to achieve the quakeproof goal[7]. Huang Zhen et al. analyzed quakeproof property of Wutaishan Stadium in Nanjing, gave quakeproof capacity evaluation value of this stadium by combining structure features of this stadium and offered basis for continuous transformation and reinforcement[8]. It thus can be seen that current researches on quakeproof property involve various aspects of architectural quake resistance, ranging from quakeproof technology and quakeproof t design philosophy to quakeproof assessment. But, there is short of individual research aiming at characteristic buildings, and there are too many similar researches. Based on predecessors' researches, this paper takes stadium for example and creatively proposes a set of quakeproof property evaluation index system specially evaluating such buildings and verifies it, in the hope of offering reference for implementing quakeproof planning and reducing disaster losses.

2. Theoretical basis

In September 2012, Adobe Company released Adobe Audition v5.0 version of Audition. Because this version is a part of Adobe Creative Suite software package, this version is also called Adobe Audition CS6 [8]. In this paper, Adobe Audition CS6 version is used to handle relevant audio files.

Earthquake destruction principle is that, destruction results in rapid energy release in geologic structure change and seismic wave with certain vibration frequency forms. When vibration frequency of buildings is close to master vibration frequency of earthquake, horizontal and longitudinal acting force will destroy buildings[9]. The destruction forms include three types: 1. structural destruction. In such case, supporting walls of buildings will fracture, which will affect overall structure; 2. gravity load destruction. It mainly refers to destruction to the walls, pillars and beams of buildings so that bearing capacity is insufficient and buildings collapse; 3. foundation failure destruction. This is because the foundation of building has no quakeproof reinforcement treatment. In the earthquake, buildings sink and tilt[10].

Accordingly, in terms of quakeproof design of buildings, it is necessary to cut down the influence of natural vibration, enhance strength and reduce destruction of earthquake. Generally, quakeproof intensity reference value of buildings is set to the seismic intensity whose probability of occurrence is 10% within 50 years[11]. According to the purpose of buildings, quakeproof is classified into four types: A, B, C and D. It is required to prevent rare and frequent earthquakes and achieve the basic goal of "no damage in small earthquake, no repair in medium earthquake and no collapse in serious earthquake" [12].

In view of architectural characteristics and quakeproof demand of stadiums, this paper applies fuzzy comprehensive assessment to evaluate and analyze quakeproof property. Fuzzy comprehensive assessment, based on the principle of fuzzy mathematics, applies maximum membership degree and fuzzy transformation principle to achieve quantitative assessment of complex and multiple factors. It is applicable to the assessment objects with many influence factors and fuzzy relations. Through setting fuzzy set, this method expands the amount of assessment information, comprehensively reflects hierarchy and objectivity of assessment objects, accurately divides the membership degree and gains assessment results. According to this method, this paper will construct stadium quakeproof property assessment index system.

3. Construction of quakeproof property assessment system

As one category of key buildings, quakeproof property requirement of stadiums is higher than that of common civil buildings. Overall assessment of quakeproof property of stadiums involves complex factors, and many uncertain fuzzy factors exist. Thus, this paper will first combine fuzzy comprehensive assessment method to establish stadium quakeproof property assessment index system and form factor set in comprehensive assessment. Then, in combination of experts' opinions, evaluation and calculation are carried out, and the membership degree is differentiated from the perspective of the influence of each factor on quakeproof property. Thus, the judgment matrix is gained. Next, the weight of each index is figured out according to characteristic value method. Finally, stadium quakeproof property assessment model is confirmed.

3.1. Construction of assessment index system

In view of its public attribute, stadium generally adopts corresponding quakeproof design, and the difference lies in different quakeproof intensity. How to subdivide intensity grade? A set of scientific, comprehensive and objective assessment indexes is needed. According to architectural quakeproof design and property requirements, stadium quakeproof property assessment should include architectural structure, building materials and foundation structure etc. The main assessment index system is shown in Table 1.

It is known Form Table 1 that, there are many factors influencing stadium quakeproof property, including geological environment and load distribution of peripheral area. If peripheral load is excessive and distributed densely, peripheral foundation settlement will be affected, thus leading to subsidence and deformation. Meanwhile, the following factors will impose serious impacts on stadium quakeproof property: poor foundation of stadium, foundation liquidation failure, settlement deformation, irrational design of major structure, poor vertical and lateral deformation property, disqualified building material rigidity and intensity, layout defect of quakeproof equipment and common equipment. For example, to enhance quakeproof intensity of materials, stadium design usually adopts specific xxx. In order to further differentiate the influence of various indexes on the whole, judgment matrix and index weight are constructed in combination of experts' opinions.

3.2. Construction of judgment matrix and index weight

In line with fuzzy comprehensive assessment theory, after assessment index system is confirmed (i.e. factor set is set up), judgment matrix should be constructed to analyze the influence of single index on overall property. The basic steps are as follows: establish judge met set V= (v1, v2 v3, …, vm); each element vi represents all kinds of possible total assessment result. Fuzzy comprehensive assessment aims to gain the optimal assessment result from judgment set based on considering all influence factors.

Secondly, we assume $x_{ij}^{(k)}$ is the membership degree of the jth comment according to the ith factor of assessment object considered by the kth expert. If tem-mark system is adopted, overall membership degree can be figured out:

$$r_{ij} = \frac{\sum_{k=1}^{n} x_{ij}^{(k)}}{10N} \tag{1}$$

Judgment matrix R is gained as follows:

$$R = \left(r_{ij}\right)_{n\times m} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{m} \end{bmatrix} \quad r_{ij} \in [0,1] \tag{2}$$

Finally, characteristic value method is used to establish weight set A. For the elements in R, they multiply according to the line and m power is conducted to gain geometric mean of elements in each

Table 1. Stadium quakeproof property assessment index system

Target layer	Criterion layer	Index layer	Attribute
Stadium quakeproof property	Stadium quakeproof property area	Peripheral load distribution	Qualitative
	Stadium foundation	Underground water distribution	Qualitative
		Geology stability	Quantitative
	Stadium structure	Graphic design	Qualitative
		Façade modeling	Qualitative
		Wall bearing capacity	Quantitative
		Beam column bearing capacity	Quantitative
		Structural distortion capacity	Quantitative
	Building materials	Material rigidity and intensity	Quantitative
		Material quakeproof property	Qualitative
	Accessory equipment	Energy dissipation equipment	Quantitative
		Common equipment	Quantitative

line: $b_i = \left(\prod_{j=1}^{m} r_{ij} \right)^{\frac{1}{m}}$. After normalization processing, weight coefficient w_j of index x_j is $w_j = \frac{b_j}{\sum_{k=2}^{m} b_k}$. If this value passes characteristic root test, w_j is index weight; conversely, it is necessary to continue to adjust judgment matrix until the value passes test. Characteristic root test method is as follows:

$$CR = \frac{CI}{RI}, \quad CI = \frac{(\lambda_{\max} - m)}{m-1}, \quad \lambda_{\max} = \frac{1}{m} \sum_{i=1}^{m} \frac{\sum_{j=1}^{m} r_{ij} \omega_j}{\omega_i} \quad (3)$$

If CR≤0.10, it is considered judgment matrix owns satisfying consistency, and ω_j is weight coefficient of index; RI=(0,0.12,0.15,0.35,0.38,0.45,0.49,0.56, 0.83,1.25,1.39,1.42).

3.3. Confirmation of assessment model

In accordance with stadium quakeproof property requirements and fuzzy comprehensive assessment theory, when weight set and judgment matrix of assessment index system are known, corresponding comprehensive assessment model can be gained through fuzzy transformation.

$$B_i = \omega_i \circ R_i^T = (b_{i1}, b_{i2}, ..., b_{in}) \quad (4)$$

Where, ω_i is weight set; R_i is judgment matrix; b_{ij} is the membership degree of assessment object when the ith factor influences the whole; ∘ is a composition operator, and common composition operators include factors deciding operator M(∨, ∧), main factor highlighting factor M(∨, •), weighted average operator M(+,•) and geometric mean operator M (•, -) . Considering stadium quakeproof property is jointly decided by the site, main structure and building materials. Thus, in Formula (4), composition operator ∘ is weighted average operator M(+, •). This operator takes into account of effects of all factors, and reserves all information of single-factor assessment. Besides, it is well applied in engineering construction assessment. So, this operator is adopted for fuzzy transformation. In addition, in combination of building quakeproof grade classification GB 50223, membership degree of assessment model is set to four intervals (0.6-0.9) which correspond to 6-9 quakeproof grades. Through arithmetic treatment of sequential value of the assessment model, specific corresponding intervals are divided to visually and overall reflect stadium quakeproof property.

4. Example verification

“Wukesong” Stadium was the basketball stadium of 2008 Beijing Olympic Games. As one of iconic stadiums, it has undertaken all kinds of large-scale and medium-scale sports events, vocal concerts and exhibitions except basketball competition in Olympic Games. It belongs to a comprehensive stadium with complete functions. Its building design and quakeproof property are superior to other transformed and expanded stadiums. Like Bird's Nest and the Water Cube, its design quakeproof intensity is Grade 8, and its service life is 100 years. This means within the service life, the stadium can still ensure stable structure and functions within Grade 8 earthquake interference. It owns excellent quakeproof property.

To verify the feasibility of stadium assessment model, quakeproof property of this stadium is overall evaluated as per 2008 version of Code for Seismic Design of Buildings (GB50011-2001) and in combination of quakeproof design of Wukesong Stadium. In accordance with evaluation index system, this paper first analyzes regional environmental conditions of Wukesong Stadium. Wukesong Stadium is located at the intersection of Haidian, Fengtai and Shijingshan in Beijing and can accommodate about 18000 people. Its overall covered area is about 350000m2, and it is located on the main traffic artery. All kinds of supporting facilities are complete. This means peripheral load of the stadium is heavy. Seeing from seismic belt distribution, it is located in heavy Grade 6 area. Its congenital conditions have no advantage, so quakeproof property should be enhanced. Secondly, seeing from main structure of Wukesong Stadium, central structure is 10m lower than the ground. The competition layer and interlayer are on the first and second floors above the ground. The stadium presents bowl-shaped structure, and the external façade presents a façade. To reach Grade 8 quakeproof effect, this stadium adopts cast-in-place reinforced concrete framework - shear wall structure below the two floors under the ground. Framework - shear wall structure system is applied for the wall, framework and beam column of elevator room and pipeline shaft. Meanwhile, both-way orthorhombic truss system is adopted around the space with axis span of 120x120m from the second floor to the roof, and 20 supporting pillars are arranged to form cast-in-place reinforced concrete framework - shear wall structure system, which contributes to enhancing quakeproof property of overall structure. In the aspect of foundation structure, according to the features of natural foundation, strip foundation under pillar, single foundation under column, local raft foundation and strip foundation under wall are adopted, respectively to ensure to adapt different axial force requirements of vertical bearing members. In the design, pressure test is carried out for Wukesong Stadium under three conditions (frequent earthquake, design earthquake and rare earthquake) to make sure 20 steel columns, roof, outrigger of bleachers and steel support at side direction keep elastic state, and meet quakeproof demand. Reference standards of members are shown in Table 2.

Except quakeproof design of the above basic structures, Wukesong Stadium also adopts energy dissipation technology. Viscous dampers and energy dissipation devices are set up in quantity at key structure positions and hysteresis deformation is adopted in order to disperse the impacts of seismic energy on key parts, reach quakeproof effects and reduce earthquake destruction. In combination of the above basic quakeproof information, this stadium applies this index system to carry out relevant evaluation.

Based on stadium quakeproof assessment index system, the judgment set V= (v1, v2, v3, v4, v5) = (stadium area, stadium foundation, stadium structure, building materials, accessory equipment) of judgment matrix is first confirmed. Comprehensive judgment may be made form these five aspects. In combination of evaluation opinions of 10 experts, quakeproof property of Wukesong Stadium is scored according to the five dimensions. The full score is 100. In combination of Formula (1), membership vector r_{ij} attached to judgment V forms.

Thus, judgment matrix is gained according to Formula (2).

$$R=(r_{ij})_{n\times m}=\begin{bmatrix} 0.65 & 0.72 & 0.82 & 0.68 & 0.75 \\ 0.69 & 0.78 & 0.85 & 0.72 & 0.66 \\ 0.72 & 0.70 & 0.88 & 0.73 & 0.71 \\ 0.68 & 0.76 & 0.81 & 0.78 & 0.77 \\ 0.62 & 0.74 & 0.84 & 0.82 & 0.69 \\ 0.71 & 0.75 & 0.83 & 0.79 & 0.72 \\ 0.66 & 0.73 & 0.85 & 0.78 & 0.70 \\ 0.61 & 0.78 & 0.84 & 0.72 & 0.66 \\ 0.65 & 0.73 & 0.81 & 0.76 & 0.81 \\ 0.62 & 0.71 & 0.82 & 0.77 & 0.75 \end{bmatrix}$$

In combination of Formula (2)-(3), weight set of stadium quakeproof property assessment index system is gained as follows:

$$\omega_j=(0.06, 0.14, 0.54, 0.15, 0.11)$$

According to Formula (4), quakeproof property assessment model of Wukesong Stadium is gained as follows:

$$B_i=\omega_i\circ R_i^T=(b_{i1}, b_{i2}, \cdots, b_{in})$$
$$=(0.77, 0.79, 0.80, 0.79, 0.79, 0.79, 0.79, 0.78, 0.78, 0.78)$$

Through arithmetic treatment, comprehensive assessment value of quakeproof property of Wukesong Stadium is gained (0.79). According to membership rules, it is known this assessment value amounts to Grade 8 in quakeproof property. Thus, quakeproof property grade of this stadium indeed reaches Grade

Table 2. Technical specification of building quakeproof design (part)

Member name	Grade 6 Type II building	Grade 7 Type III and Type IV sites	Grade 8	Grade 9
Longitudinal bar of center pillar and center pillar	Total reinforcing bar ≥0.5%	Tiepiece ≥0.2%	Total reinforcing bar ≥0.6%	Total reinforcing bar ≥0.8%
Longitudinal bar of corner pillar	Total reinforcing bar≥0.7%	Tiepiece ≥0.2%	Total reinforcing bar ≥0.8%	Total reinforcing bar ≥1.0%
Stirrup at upper and lower ends of pillar	——	φ6-200	φ6-200	φ8-150
Beam-end stirrup interval	——	Same with non-quakeproof design	200	150
Full-height stirrup of short pillar	——	Same with non-quakeproof design	φ8-150	φ8-100
Section width of pillar	——	Not less than 300mm	300-400mm (type III and Type IV sites)	400mm

*Date source: Code for Seismic Design of Buildings (GB50011-2001) 2008 version

8 from the perspective of fuzzy comprehensive assessment. It can be seen from sequential value that, 10 experts evaluate quakeproof property of the stadium differently from regional position, foundation, main structure, building materials and stadium equipment and even have a large gap in some aspects. For instance, during evaluating quakeproof property of stadium equipment, some experts give the score of only 0.66 (Grade 6); some experts consider it reaches Grade 8. In evaluation items, the experts have relatively consistent opinions on traditional and objective quakeproof indexes such as regional position, foundation, main structure and building materials. This indicates Wukesong Stadium does well in traditional quakeproof technology. However, in terms of application of quakeproof equipment, experts' opinions differ. On the one hand, this is because they do not totally agree on actual effects of quakeproof equipment; on the other hand, this also reflects large development space of new quakeproof technology and certain growth potential. In the future, to enhance quakeproof effects of stadium equipment while improving stadium quakeproof property is an approach worth trying.

5. Conclusions

As an important building in a city, the stadium bearing the mission of enriching people's life is the center of cultural entertainment activities. Once earthquakes and other disasters happen, the stadium may become the shelter of the public or the disaster site. The key lies in stadium quakeproof property. How to evaluate stadium property in earthquake resistance and disaster reduction is especially important. This paper introduces fuzzy comprehensive assessment method and establishes a ser of comprehensive assessment index system from such aspects as geographical environment, stadium structure and non-structural members. Example verification of Wukesong Stadium shows this assessment system points out the quakeproof grade of this stadium is 0.79, and anti-seismic grade is 8. This is consistent with design quakeproof intensity. This indicates this assessment system is feasible in evaluation of similar stadiums. Meanwhile, this assessment system verifies excellent quakeproof property of Olympic venues. In the future, quakeproof technology of large-scale public buildings will have a very wide prospect. It is very significant to boost quakeproof property of stadiums for ensuring people's life safety, social prosperity and stability.

References

1. Q. Miao, D. Popp. Necessity as the mother of invention: Innovative responses to natural disasters. Journal of Environmental Economics and Management, 2014, 68(2), p.p.280-295.
2. G.L. Pang, D.Q. Chen. Huang M. Research on Building Earthquake Disaster Simulation. Advanced Materials Research, 2013, 791, p.p.1228-1231.
3. Z.F. Sun. Olympic venues should consider quakeproof problem. Overview of Disaster Prevention, 2001, 1(1), p.p.29.
4. G.Z. Dong, X.L. Feng. Study on sports function in earthquake prevention and disaster mitigation system. Bulletin of Sport Science & Technology, 2013, 21(12), p.p.147-149.
5. G. Chen. Analysis of economical efficiency of earthquake prevention, disaster reduction and seismic isolation structure. Housing Science, 2011, 12(S1), p.p.38-40.
6. T. Su, Study on earthquake prevention and disaster reduction technology and property in building construction engineering. Sichuan Cement, 2015, 17(2), p.p.334.
7. X.J. Zhang, Q.Y. Huang. Anti-seismic property of ultralimit reinforced concrete frame gymnasium and design suggestion. Journal of Jiamusi University (Natural Science), 2015, 33(3), p.p.387-390.
8. Z. Huang, X.G. Qin, A.Q. Li, et al. Anti-seismic property test and authentication of Nanjing Wutaishan Stadium [J]. Industrial Construction, 2006, 36(5), p.p.102-104+19.
9. T. Belash. Dry Friction Dampers in Quakeproof Structures of Buildings. Procedia Engineering, 2015, 117, p.p.402-408.
10. E. Michel-Kerjan, S. Hochrainer-Stigler, H. Kunreuther, et al. Catastrophe risk models for evaluating disaster risk reduction investments in developing countries. Risk Analysis, 2013, 33(6), p.p.984-999.
11. Y. Feng, X. Xia, Z. Cao, et al. Study on anti-seismic property of cable-supported dome structure of Changzhou Stadium. Architectural Structure, 2010, 40(9), p.p.41-44.
12. W. Cui, J.F. Tian, Y.M. Zhang. Seismic design of shelter buildings based on Design Standard for Emergency Shelter – case study of stadium in a middle school. Journal of North China Coal Medical College (Natural Science), 2014, 36(2), p.p.90-96.