

Evaluation of Disaster Prevention and Sheltering Index of Stadiums Based on Combination of Normal and Disaster time

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Abstract. Urban disaster Shelters play a vital role in dealing with all kinds of major disasters in cities. As an important part of the modern city disaster prevention and refuge, the sport stadiums based on combination of normal time and disaster time have the unique advantage of emergency refuge and can play an irreplaceable role in other disaster prevention shelters. In normal times, the stadiums play sports entertainment functions, and can be converted into disaster prevention shelters when disasters occur. In this paper, by establishing the evaluation index system of the disaster prevention and shelter in stadiums, the AHP is used to analyse the potential of disaster prevention and refuge in several different types of stadiums, and then comprehensively evaluates the disaster prevention and evacuation capabilities of stadiums.

1. Introduction

In recent years, disasters have occurred frequently. From the Indian Ocean earthquake, the Indonesian tsunami and the Wenchuan earthquake to the 2011 earthquake off the Pacific coast of Tōhoku and the frequent floods in southern China, the successive disasters caused the victims to be homeless and displaced [1]. With the global climate warming and environmental deterioration, the frequency of all kinds of disasters is on the rise [2]. In large cities, due to the intensive building, the serious lack of disaster prevention and refuge space, when disaster occurs, it is easily prone to cause secondary disasters. And the construction of disaster prevention and shelters in China is still in its infancy. Therefore, there is an urgent demand to improve the city's disaster prevention and evacuation system to improve disaster prevention and evacuation capabilities in evacuation sites.

During the 2008 Wenchuan earthquake, the Jiuzhou Stadium was urgently requisitioned as a refuge for the victims of Mianyang City and surrounding areas and the Mianyang Earthquake Command Center. It accommodated 30,000 homeless people and provided temporary housing for the victims [3]. The stadium based on the combination of normal and disaster time is a multi-functional complex. In normal times, sports and entertainment activities are held to play the normal function of stadiums, and when there are sudden disasters such as earthquakes or fires, the emergency plan for disaster prevention is activated, and stadiums are transformed into the disaster prevention and refuge places [4]. Wan Beilei began to comprehensively assess the vulnerability of the disaster prevention index by refining it into 21 indicators [5]. The Inter-American Development Bank established four risk management indicators, such as disaster deficit index, local disaster index, general vulnerability index and risk management index, to evaluate the risk of disasters in the Americas [6].

Therefore, fully excavating and exerting the disaster prevention and asylum function of stadiums, considering the combination of normal and disaster time and strengthening the disaster prevention and refuge function of stadiums will help the construction of the whole urban disaster prevention and



refuge system. The evaluation index system of disaster prevention and refuge is established for stadiums based on the combination of normal and disaster time. The analytic hierarchy process (AHP) is used to analyse the potential of disaster prevention and refuge in several different types of stadiums, and then the disaster prevention and refuge ability of the stadiums based on the combination of normal and disaster time is evaluated comprehensively.

2. Evaluation index system for disaster prevention and asylum in stadiums

The stadiums, based on the combination of normal and disaster time, fully take into account the normal functions of stadiums and disaster prevention and asylum ability. The stadiums have a high construction standard, strong disaster prevention capability, good safety performance, complete supporting facilities, large area and internal space, open external space, low buildings around, convenient transportation, and high idle rate. When a major disaster occurs, the surrounding residents can quickly reach the stadium and use it as a temporary shelter for temporary evacuation of evacuees and centralized rescue. Compared to other temporary shelters such as exhibition halls, theaters, etc., the stadium has the advantages of high idle rate, completes supporting facilities, etc., and is more conducive to exerting its disaster prevention and evacuation capabilities. It is an ideal place for disaster prevention and refuge.

According to China's current regulations, "Standard for Urban Earthquake Disaster Prevention Planning" (GB 50413-2007), "Earthquake emergency refuge sites and supporting facilities" (GB 21734-2008), "Code for Design of Disaster Prevention Shelters" (GB 51143-2015) Relevant stipulations have been made on the construction of shelters [7-9]. The planning and construction of shelters should meet the safety requirements for geological environment, natural environment, artificial environment, earthquake resistance, fire prevention, etc. As a refuge site for disaster victims, shelters should consider various factors when selecting indicators that can evaluate the effectiveness of shelters. In this paper, the following indexes are selected to evaluate the performance of disaster prevention and asylum for stadiums with the combination of normal and disaster time, including: (1) the safety of the refuge site itself; (2) the effective area of the refuge site; (3) the accessibility of the refuge place; (4) the rationality of the setting of the disaster prevention identification; and (5) the completeness of emergency equipment. According to the regulations of China and the situation of disaster prevention and asylum in the stadiums, 9 characteristic indexes can be selected in the above 5 basic contents to evaluate the disaster prevention and asylum ability of the stadium as a refuge place, and the corresponding evaluation index system structure diagram is shown in figure 1.

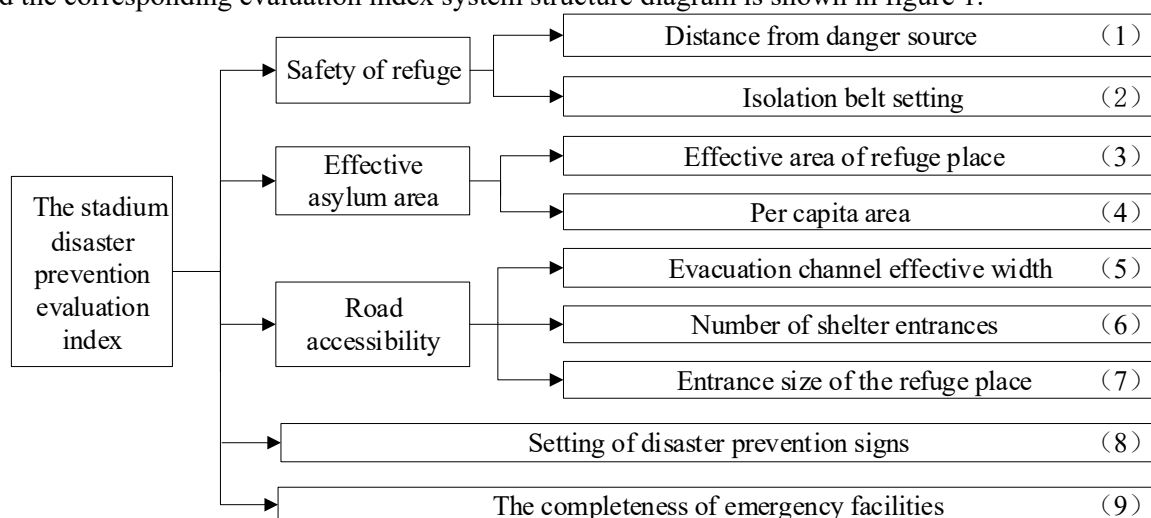


Figure 1. Evaluation index system for disaster prevention and asylum in stadiums

2.1. Safety in refuge

Indicator 1: Distance from the source of dangers - Refuge land should avoid the storage points of flammable and explosive dangerous materials, severe pollution sources, and other areas prone to secondary disasters. The distance from major secondary fires or explosion hazards such as flammable and explosive factories, gas supply plants and gas storage stations, etc. shall not be less than 1000m to ensure the safety of the refuge. The minimum distance from the source of the hazards should be taken in the evaluation.

Indicator 2: Segregation zone settings - segregated safety belts should be provided between the evacuation blocks, with fire prevention facilities, fire protection equipment, fire exits, safe passages. No more than 30 meters of fire safety belt should be installed between the emergency functional area and the surrounding secondary inflammable buildings. Fire isolation zones should be provided when there are fire or explosion hazards.

2.2. Effective asylum area

Indicator 3: Effective area of evacuation shelters - In order to ensure that evacuation sites meet the certain activities of the victims and the rescue sites after the disaster, the effective area of the refuge and the per capita effective asylum area should be selected as the evaluation index.

Indicator 4: Per capita area occupied by shelters - per capita effective refuge area for fixed shelters and evacuation sites is not less than 2m², and the per capita effective refuge area of emergency shelter is not less than 1m². Per capita effective evacuation area of refuge floor (middle) in high-rise buildings is not less than 0.2m². The per capita effective evacuation area is determined by the number of refuge and the effective area of refuge. The refuge capacity of the stadium is 0.4 to 64 thousand people, and the service radius should be 2~3km. It can be reached within about 1 hour on foot. The actual service radius of the stadium refuge can be calculated by the following formulas.

$$\text{Refuge service radius:} \quad R = t \times v \times \beta \quad (1)$$

$$\text{Refuge Area Service Area:} \quad S = \pi \times R^2 \quad (2)$$

$$\text{The size of the shelter:} \quad S = D \times S_1 / S_2 \quad (3)$$

In the formulas, t means the walking time, v expresses the walking speed (0.85 to 1.2 m/s), β indicates the bending coefficient of the evacuation road (0.65), D represents the average density of the refuge population, S_1 means the area of the refuge, S_2 indicates the area of the per capita asylum.

2.3. Road Accessibility

Indicator 5: Number of refuge entrances and exits - Emergency evacuation sites should have more than two evacuation routes and entrances and exits that communicate with the outside world. The greater the number of entrances and exits would be, the better the community's connectivity with the outside world would be.

Indicator 6: Effective width of evacuation passages - The effective width of the evacuation passage should not be less than 4m, and the effective width of the main evacuation passage of the fixed evacuation site should not be less than 7m.

Indicator 7: The size of the entrances and exits of the evacuation shelters – the stipulations in the draft of the " Design Criteria for Emergency Refuge Sites " provides the total width of the entrance and exit of the refuge and the width of the road within the sites, as shown in table 1. According to different types of evacuation sites for entrance size, it's required that the total width of all entrances and exits used for the evacuation of evacuees should be not less than 10m/ ten thousand people.

Table1. The lower limit of the total width of the entrance and exit of the refuge site (m/million people)

| Refuge period | urgent | temporary | short term | Mid-term | long term |
|---------------|--------|-----------|------------|----------|-----------|
| width | 10.0 | 10.0 | 10.0 | 8.3 | 6.7 |

2.4. The completeness of the infrastructure

Indicator 8: Integrity of infrastructure - the shelter should have certain functional facilities. According to the relevant stipulations of China's "Earthquake emergency shelter sites and supporting facilities" (GB21734-2008), regular emergency shelters should have at least 9 items basic functional facilities, including: emergency shelter facilities, medical aid and sanitation facilities, emergency water supply facilities, emergency power supply facilities, emergency sewage systems, emergency toilets, emergency garbage storage facilities, emergency passages, and emergency signs. If conditions are available, 3 general facilities, including emergency fire-fighting facilities, emergency material storage facilities, emergency command and management facilities, and 5 comprehensive facilities including emergency parking lots, emergency apron, emergency bathing facilities, emergency ventilation facilities and emergency functions, should be added. The establishment of infrastructure can be evaluated in the form of grading and 80 is defined as a satisfactory value, as shown in table 2.

Table 2. Evaluation of completeness of infrastructure

| Completeness of infrastructure | Scores |
|--------------------------------|------------|
| Basically complete | 100 — 80 |
| good | 79 — 60 |
| poor | 60 or less |

2.5. Refuge Site Marking Settings

Indicator 9: Marking settings of refuge places – the construction of disaster prevention shelter should plan and set up guiding sign boards, and draw the distribution maps and internal zoning maps of the responsibility areas. The main roads and intersections around the site should be provided with the indication signs. All kinds of supporting facilities can also be evaluated in the form of scoring, and the score is 80 divided into satisfactory value, as shown in table 3.

Table 3. The evaluation table of refuge's marks setting

| Refuge place sign setting | scores |
|---------------------------|------------|
| Clear and reasonable | 100 — 80 |
| good | 79 — 60 |
| poor | 60 or less |

3. Comprehensive evaluation of evacuation sites investigated

Based on the above 9 evaluation Indicators, the specified values of each index are taken as satisfactory values, and then the values of the various measurement indexes of the five stadiums under investigation are respectively converted into dimensionless relative numbers, and the degree of satisfaction of each index is calculated. The weight of the index system of the disaster prevention and refuge place is determined by the analytic hierarchy process. The most unfavorable disaster prevention and evacuation site is obtained by horizontally comparing the total evaluation scores of different stadiums. The formulas can be expressed as:

$$d_{ij} = \frac{x_{ij}}{x_i^{(h)}} \quad (4)$$

$$y_j = \left(\prod_{i=1}^p d_{ij}^{\omega_i} \right)^{\frac{1}{\sum_{i=1}^p \omega_i}} \quad (5)$$

In the formulas, d_{ij} is the relative satisfaction of the index i ($i=1, 2, 3, \dots, 9$) of the j th unit (1 is basically satisfactory, less than 1 is not satisfied); x_{ij} is the index value of index i of the j ($j=1, 2, 3, \dots, n$)

participants; $x_i^{(h)}$ is the satisfaction value of item i ; y_i is the total efficiency score; p is the number of selected indexes; ω_i is the weight of item i index.

According to the selected evaluation system, each index of A, B, C, D, E stadiums for disaster prevention and evacuation was evaluated item by item, and the evaluation is shown in table 4. The satisfaction value of each indicator takes the specified value of each indicator.

Table 4. Evaluation of various efficacy scores

| Index | Satisfactory value x_i^h | Relative satisfaction d_{ij} | | | | |
|---|----------------------------|--------------------------------|------|------|------|------|
| | | A | B | C | D | E |
| X ₁ -- Distance from danger source (m) | 1000 | 2.00 | 2.50 | 1.50 | 1.50 | 2.00 |
| X ₂ -- Isolation belt setting | 30 | 1.20 | 1.50 | 1.00 | 1.20 | 1.40 |
| X ₃ -- Effective area of refuge place (m ²) | 2000 | 2.00 | 1.30 | 1.20 | 1.50 | 1.50 |
| X ₄ -- Per capita (m ²) | 2 | 1.27 | 0.74 | 0.45 | 0.65 | 1.07 |
| X ₅ -- Evacuation channel effective width (m) | 4 | 0.80 | 0.50 | 1.0 | 0.50 | 0.80 |
| X ₆ -- Number of entrance of | 2 | 4.50 | 4.00 | 3.00 | 4.00 | 4.50 |
| X ₇ -- Refuge place entrance size (m/ ten thousand people) | 10 | 0.80 | 0.80 | 1.20 | 0.60 | 0.70 |
| X ₈ -- Disaster prevention sign settings | 80 | 0.81 | 1.1 | 0.38 | 0.63 | 1.13 |
| X ₉ -- The completeness of emergency facilities | 80 | 1.08 | 0.96 | 0.50 | 0.96 | 1.13 |

The weight ω_i of each index is determined by the adjacent index comparison method. In the first example of the form, through the comparison of the importance of both x_1 and x_2 by experts, the importance of x_1 is taken as the unit 1, and we obtain and unify the degree of importance of x_2 relative to x_1 , that is the value of g_1 ; Then the importance of x_2 is the unit 1. and the degree of importance of x_3 relative to x_2 is obtained and unified, that is the value of g_2 , and so on, to get the total value of $g_1 \sim g_9$. According to the formula (6), the weight ω_i' of each index is calculated, and normalized weight ω_i of each index is normalized, as shown in table 5.

Table 5. Comparison Method Index Weight Table

| Indicator a | Reference indicator b | Relative importance $a/b=g_i$ | Weights ω_i' | Normalized weights ω_i |
|--|--|-------------------------------|---------------------|-------------------------------|
| X ₁ -- Distance from danger source | X ₁ -- Distance from danger source | 1 | 1 | 0.12 |
| X ₂ -- Isolation belt setting | X ₁ -- Distance from danger source | 0.5 | 0.5 | 0.06 |
| X ₃ -- Effective area of refuge place | X ₂ -- Isolation belt setting | 1.5 | 0.75 | 0.09 |
| X ₄ -- Per capita area | X ₃ -- Effective area of refuge place | 1 | 0.75 | 0.09 |
| X ₅ -- Evacuation channel effective width | X ₄ -- Per capita area | 1.2 | 0.9 | 0.1 |
| X ₆ -- Entrance number of refuge places | X ₅ -- Evacuation channel effective | 1.2 | 1.08 | 0.13 |

| | | | | |
|--|--|-----|--------|------|
| X ₇ -- Refuge place main entrance size | X ₆ -- Entrance number of refuge places | 1 | 1.08 | 0.13 |
| X ₈ -- Setting of disaster prevention signs | X ₇ -- Refuge place main entrance size | 1.3 | 1.404 | 0.16 |
| X ₉ -- The completeness of emergency facilities | X ₈ -- Setting of disaster prevention | 0.7 | 0.9828 | 0.12 |

From the distribution of weights, it can be seen that the evaluation index of stadium refuge place from high to low is the following: the setting of the surrounding disaster prevention signs, the number of evacuation entrances and the size of the main entrance, the distance from the refuge to the dangerous source and the complete degree of emergency setting, the effective width of the evacuation passages, the effective area of the evacuation site and the per capita occupied area, and the setting of the isolation zone. From table 4, table 5 and formula (5), the total efficacy scores for each stadium are shown in table 6:

Table 6. Total efficacy scores of sport stadiums

| stadiums | A | B | C | D | E |
|----------------------------|------|------|--------|-------|------|
| Total efficacy score y_i | 1.35 | 1.25 | 0.9247 | 1.023 | 1.36 |

According to the calculation, it can be seen that the order of the advantages and disadvantages of stadiums' refuge from good to bad is E, A, B, D, C. E stadium has the best conditions for disaster prevention and evacuation, and C stadium has the lowest scores, it is urgent to strengthen the reconstruction of the emergency equipment, the disaster prevention mark setting and the effective per capita area of the refuge. The common problem of stadiums' construction is unreasonable for the setting of disaster prevention signs, which is not good to evacuate quickly in the emergency situations.

4. Conclusions

According to the relevant rules and regulations, combined with the actual situation of disaster prevention and asylum in the stadium, from the inherent characteristics of the refuge place, by considering the safety of the refuge site, the effective area, the accessibility, the setting of the identification of disaster prevention and the completion of the emergency equipment, the 9 typical indicators are selected, and a practical evaluation index system for evaluating the effectiveness of disaster prevention and asylum in stadiums is established. The evaluation system is used to evaluate and compare the comprehensive performance of 5 stadiums. The conclusions are as follows:

(1) In the calculation of index weights, the AHP method can effectively avoid the complex comparison and coordination of non-evaluation benchmarks, achieve better weight distribution, and further make a comprehensive evaluation of the disaster prevention and asylum ability.

(2) It can be seen from the distribution of indicators' weights obtained from experts' discussions that the most concern for the construction of stadiums' refuge is the setting of perimeter disaster prevention signs, followed by the accessibility of evacuation entrances and major roads. These two indicators can ensure that residents reach the shelter in time as soon as the disaster occurs.

(3) Using the evaluation system to evaluate the 5 stadiums, it can be concluded that the order of the stadium's strengths and weaknesses is from good to poor is E, A, B, D, and C. The score of C stadium is the lowest, and there is an urgent need to strengthen the reconstruction of emergency facilities, the design of disaster prevention signs, and the effective per capita area of shelters.

(4) Through field surveys, the problem of various stadiums is concentrated on the irrational setting of disaster prevention signs, which will hinder the safety and asylum of residents in the disaster.

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