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A new function for large-span civil buildings

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Abstract

This paper presents in detail Jiuzhou stadium's great functions from temporary settling, relief supplies collecting and medical care to psychological assistance for about 50,000 victims and temporary school for about 2000 primary and secondary students whose classroom buildings just seriously damaged and even collapsed in Wenchuan great earthquake. The reasons of the stadium safely playing such a tremendous role in the battle against the disaster after strong earthquake are discussed. From the case of Jiuzhou stadium, this paper proposes an idea that some future large-span civil buildings should be added a new function as safe-working indoor earthquake victim shelters even under strong earthquake, and their construction are proposed to be legislatively added to official urban and town planning. The functions of this kind of large span buildings and their anti-seismic design standard are also discussed in this paper. The preliminary analysis shows that the cost increase of large-span building with the functions of earthquake shelter may not be much. Their cost could be reduced a lot by careful design and introduction of many high-techniques including vibration reduction and isolation, structural optimization, damping element application and so on.

Keywords: Wenchuan great earthquake, Jiuzhou Stadium, large-span building, indoor earthquake shelters, anti-seismic performance design, urban and town anti-disaster planning

1. Earthquake victim's life in Jiuzhou Stadium after Wenchuan great earthquake

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At 14:28 on May 12, 2008 (Beijing Time), a major earthquake occurred in Wenchuan, Sichuan Province, China. The surface wave magnitude was M_s 8.0. As of August 1, a total of 244 aftershocks with magnitudes more than Ms 4.0 had occurred ,in which 37 aftershocks had magnitudes more than Ms 5.0, and 7 aftershocks were larger than 6.0. The largest one occurred on May 25 with a magnitude of 6.4. Based on the field investigation and the China Seismic Intensity Scale (1999), the Specified intensity and the estimated intensity of some counties around the earthquake epicentre are shown in Table 1.

Table 1 Specified intensity and the estimated intensity around earthquake epicentre

County name	Specified Intensity (degree)	Estimated Intensity (degree)
Wenchuan	7	⩾10
Maoxian	7	⩾10
Beichuan	7	⩾10
Dujiangyan	7	9
Deyang	6	7
Mianyang	6	7
Guangyan	6	7
Chengxian	8	7
Songpan	8	7

This great earthquake killed about 87,000 people and resulted in direct economic losses amounting to 845.1 billion RMB Yuan, of which housing, road, bridge and other infrastructure damages accounted for more than 70%.

From above, we can see the facts as follow: Devastating earthquake may occur at anytime anywhere, even the area whose specified intensity is lower; The most of losses due to major earthquakes were from the civil engineering. Buildings were damaged or destroied and a great number of people lost their housing; A number of aftershocks occured, some of them were very strong and devastating; Earthquake victims dared not go home even their home were still in good condition since aftershock occurred continously, therefore victims faced the greatest diffculty after great earthquake.

During the battle against the disaster after the earthquake, both the victims and the rescuers in Mianyang county, in which there were still seriously affected areas though its estimated intensity only Ⅶ, benefited a lot from a large span building called Jiuzhou Stadium being in good condition after the great earthquake as shown in Fig 1~24. Jiuzhou stadium, with construction area of 24,000m^2 and seating capacity of 6050 and east-west width 87m and north-south span of 165m and building height of 33.07m, was built in 2005. The four north-south spatial steel arch trusses are the main load bearing structure, between which three-dimensional and two-dimensional lateral bracing trusses are placed. Two middle spatial arch trusses intersect near north bearings with supported only in their both ends on the ground. Two edge sptial arch trusses apart from bearings in both ends on the ground are also supported in the two central concrete cylinders respectively served as stair wells.

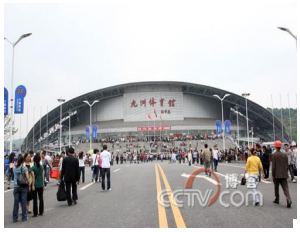

Fig.1 Victims swarmed into Jiuzhou Stadium

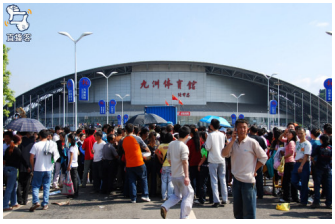

Fig. 2 Victims swarmed into Jiuzhou Stadium

Fig. 3 Temporary Settlement Inside the Stadium

Fig. 4 Victims gathering in the aisle of the stadium

Fig. 5 Relief supplies conveyed to the stadium

Fig.6 Epidemic prevention

Fig.7 Epidemic prevention

Fig.8 Epidemic prevention

Fig.9 Treatment to the wounded

Fig.10 Treatment to the sick

Fig.11 Treatment to the wounded

Fig.12 Registration for the lost family members

Fig.13 Searching for missing Family members

Fig.14 Psychological assistance

Fig.15 Psychological assistance

Fig 16 Tent elementary school

Fig 17 Tent high school

Fig 18 Premier Wen visiting the tent school

Fig 19 Meet the urgent need with electricity vehicle

Fig 20 Victims seeing movie

Fig 21 Victims watching TV

Fig 22 Temporary hair-cutting center

Fig 23 Foreign media in the stadium

Fig 24 CCTV's special performance for disaster victims

From Figures above, we can see the great functions of Jiuzhou stadium after Great Wenchuan Earthquake as summarized as following:

(1) At early 10 Am.of May 13, the first 1600 victim students out of Beichuan Middle School arrived at Jiuzhou Stadium by military vehicles, trucks, agricultural vehicles. Subsequently, a large number of frightened people in disaster areas as flood poured to the stadium in all directions that was called "Noah's Ark" later by them when they were told it was the only safe place they could go to stay at that urgent and hard time(facing aftershocks and bad weather), as shown in Figure 1. Only a few hours later, more than 20,000 victims swarmed into the stadium, in less than three days, the number increased to nearly 35,600, as shown in Fig 1.

(2) On 17th and 18th of May, the victim number plus the 6,000 volunteers reached to the peak of nearly 50,000, as shown in Fig 2~4. It faced great dificulties for a mere 6,050-seat stadium to accommodate a peak of 50,000 people, which is nearly the population of

whole Beichuan county. Disaster-Relief headquarter of Mianyang Goverment immediately set up offices, security groups, aftercare group, logistical support group, material receiving group, health group and epidemic prevention, education and management of student groups, advocacy groups and volunteer groups to deal with the urgent situation of gathering dense large crowd of people in the inside, outside and aisle of that small stadium, and even any of its surrounding open space. All victims had been properly resettled after a short period of time in confusion by the great efforts of the working group of the Disaster-relief Headquarter . From 19th of May, some of the victims were gradually transfered to other safe places to mitigate the risk of secondary disasters. On the 29th of June ,48days late, the last 1400 victims with deep thanksgiving withdrawn from the respected stadium. The varying of the victim number plus volunteers in the stadium is listed in Table 2.

Table 2 Varying of the victim number plus volunteers in the stadium

Date	5, 13	5,14	5,16	5,17	5,18	5,30	6,3	6,26	6,29
Victim number	20938	26262	35600	About 44000	About 44000	20000	8000	1600	1400

(3) From the 14th , food ,water and other necessary material were continuously sent to the stadium by local enterprises and government departments and subsequently by other organizations throughout the country by highway since the stadium happens to be located beside the national highway network still keeping in normal condition after earthquake, as shown in Fig.5. So from the very beginning of resettlement all the affected people gathering in the stadium had got a 24-hour supply of mineral water, bread and instant noodles, etc.

(4) The health group organized doctors and volunteers betimes help a lot of the wounded and sick people of the victims. They rapidly established medical areas, sent the victims seriously injured to local hospitals , gave treatment to the light wounded, as shown in Fig.9~11.

(5) Epidemic prevention group was responsible for the prevention of secondary infectious diseases. They organized some staff from local goverment epidemic prevention departments and volunteers , each carrying a vat of disinfectant, sanitized every corner of the stadium many time a day,as shown in Fig.6~8.

(6) Aftercare group organized the professors and psychologists from Liaoning health department, Applied Psychology Research Center of Sichuan Medical College and other organizations to form psychological relief stations to help a lot victims of the great earthquake disaster, who could not sleep in the evening, stayed restless, and often said ravings, escaping from the psychological shadow,and making them regain their confidence and courage to live by providing the necessary psychological intervention, as shown in Fig.14~15.

(7) After the earthquake, many families lost loved ones. Because of poor communications, they can not contact their family members even all in the Jiuzhou Stadium. Mianyang Labor Unions immediately established the imformation center and registration section

for separated family members as shown in Fig.12, and printed thousands of copies of the registration form for them. A large number of enlightenments of searching missing victims were pasted on bulletin boards urgently set up for victims as shown in Fig.13. From the beginning on the 14th, there were a daily average of more than 2,000 people separated from their loved ones who registed at the registration section. Subsequently, more than 2,000 tracing informations every day at first week, a total of more than 20,000 news articles, had been broadcasted repeatly by radio on the scene.

(8) There were several thousands of students gathering in the stadium after great earthquake. In order to allow them to continue to learn as soon as possible and help them to escape from the psychological shadow as quickly as possible, Mianyang City Education department built temporary schools in two tents with a banner, marked " Mianyang Jiuzhou Stadium Tent School " , hanging between them. More than two thousands students returned to class in the tent school, as shown in Fig. 16~17. Premier Wen, making use of time gap of front-line commanding in the earthquake disaster relief work at the scene and regardless of exhaustion, hurried to visit the affected children in temporary schools in Jiuzhou Stadium and brought them about deep concern from the Central Government and people all over the country as shown in Fig.18.

(9) The logistical support group placed a total of more than 10 televisions for the disaster victims to know the disaster situation and the developments of disaster relieving , feel the warmth from the Central Government, people of all ethnic groups both at home and abroad and even foreign friends, as shown in Fig.20~21.

(10) During the battle against the disaster , the Associated Press, Agence France-Presse, Reuters, Washington Post, The Times and the Asahi Shimbun and other foreign media and the domestic mainstream media more than 500 batches of about 2000 journalists interviewed in the stadium for passing the situation of the disaster and disaster relief to whole world, as shown in Fig.23. Local schools organized volunteer teachers to spend “International Children Day” with victim children on the first of June in Jiuzhou stadium; CCTV "heart to heart" Art Troupe organized a special performance for affected people there in the stadium to inspire them to overcome the terrible disaster on the 29th of June. These activities for achieving the final victory of earthquake relief made a great contribution, as shown in Fig.24.

2. Reasons of the stadium keeping in good working condition during the great Wenchuan earthquake

Why can the Stadium luckily play such a tremendous role in the battle against the disaster after the great earthquake just happened mentioned above?

The first reason is that the local goverment properly deat with the emergency situations. Second is that the stadium happens to be located in highway entrance and its traffic is very convenient. The third, the most important one, is that the stadium had withstood the major earthquake and there is no damage except there are some cracks on the maintenance wall lying in the place of the steel sptial truss going through the wall.

Why can the stadium safely withstand the great earthquake?

The first reason is the well-designed work of the stadium carried out by Beijing Institute of Architectural Design and Research Institute. When they designed the stadium in 2004, some special studies as shown as follow on the stadium structure had been carried out carefully and seriously in addition to the normal design work.

(1) The study on its safty when some accident loadings or actions happen: Two cases had been taken into the consideration. First is the spatial arch trusses could safely work while their arch foot bearing 's supposed displacement occurs. Second is the edge spatial arch trusses could not collapse while its horizontal restrictions on the middle support cylinders be out of work due to the concrete cracking to cause the level stiffness degradation or failure.

(2) The stability analysis. There are 4 load modes (including dead load + live load , dead load +upper half-span live load , dead load +lower half-span live load, dead load +right half-span live load) taken into the consideration. Their corresponding stability coefficients were 8.08, 7.76, 7.20, 8.78 which are all much larger than the code value required.

(3) The special study on the fundation of the spatial trusses. Two middle spatial arch trusses are supported only in their both ends with bearing span of 165m. Two edge sptial arch trusses apart from bearings in both ends are supported in the two central cylinders respectively. After sdudied 4 foundation schemes comparatively, the gravity-type piers concrete foundation were adopted with pre-stressed concrete link between them. The largest thrust is 30168KN, the required area of anti-push is 41.6m^2 , and actual anti-push area is 108m^2 with 2.6 times secure reserves.

(4) Its seismic performance study. Although its Specified intensity is 6 degree according to the national seismic code, its elastic-plastic nonlinear dynamic analysis was carried out with seismic intensity of 8 degree under strong earthquake waves input through x, y, z three directions since its importance.

The second reason is the estimated seismic intensity in Mianyang is 7 degree luckily in the Wenchuan Great Earthquake according to the National Strong Motion Observation Network System of China. If the estimated seismic intensity there had been much more than Ⅷ degree taken in the second phrase of its seismic design, the results above in the stadium would have been so different that no affected people could relied on it as their resettlement during earthquake. Such a situation may occur in the next great earthquake, but also unknown.

3. An idea that some or all future large-span civil buildings should add a new function as safe-working earthquake indoor shelters under major earthquake

As well known,Experiment investigation plays an important role in civil engineering. Is not Wenchuan Great Earthquake a terrible experiment. In the frighten test we must learn a lot for future civil engineering. One of them is to learn from Jiuzhou Stadium. From the case

of Jiuzhou stadium, we propose an idea that some or all future large-span civil buildings may add a new function as safe-working earthquake shelters even under strong earthquake.

The earthquake shelter in the past is just referring to setting up open field spaces or temporary sheds mainly used for temporary escape from the danger. A terrible secondary disaster unfortunately appeared after Haicheng Great Earthquake of Ms 7.3 in Liaoling province occured in Febuary of 1975. Before the earthquake the southerly wind blowed for several days, the temperature rose day by day.On the second to the third of February, the maximum temperature rose to 3-6 ℃, melting snow and ice, but it suddenly turned to north-easterly winds and heavily snowed after the earthquake. The temperature was falling sharply, and reached a minimum temperature of -20 ℃, the maximum was merely -5 ℃. Hot and cold temperature changed together with the majority of people stayed in the temporary earthquake shed without prevention of cold weather caused serious frostbite. In addition, Most of Earthquake sheds was built with inflammable materials, coupled with the heating, cooking and lighting and so on. It resulted in many serious fires. According to statistics, the fire and freeze disaster casualties reached to 8271 people, of which 372 people froze to death, frostbited 6578; and a total of 3142 post-earthquake shed fires caused the death of 341 people, burned 980. Number of casualties in the above-mentioned secondary disasters accounted for 32% of the total number of casualties, the ratio is quite amazing, is a lesson learned.

Comparatively the earthquake shelters presented here are complete indoor shelters, mainly used for victim resettlement for a long time (48 days in Jiuzhou Stadium) after the earthquake. The functions of these large span buildings meantime as earthquake indoor shelters are listed as follow:

(1) The provision of resettlement sites: After earthquake there will be a great number of victims crowding to the nearest large-span building with the function of earthquake shelter. It should immediately start its contingency plan and open its all indoor area for the affected people's resettlement. Besides, temporary tents will also be set up in its surrounding open space for urgent need.

(2) The provision of safe water is by setting up emergency water wells and emergency water tank, storing quantitatively bottled water.

(3) Quantitative food storage is by setting up small granaries in the basement and storing quantitatively emergency instant food.

(4) Emergency energy solution is by equipping small generators and fuel, solar power equipment on roof , walls and in surrounding open area, even by using heat pumps newly developed by Tsinghua University for public need. Meantime small stoves are prepared for group's use in temporary tents

(5) The rescue of the wounded and disease treatment is one of the most important functions. The solution is by setting up temporary emergency hospital equipped with medical facilities and supplies.

(6) Equipped with facilities and equipment for infectious disease control.

(7) Reserves to provide temporary toilets and sanitation.

(8) Equipped with information services facilities and equipment for looking for their relatives and friends.

(9) Equipped with Radios, TV sets and Film machines to impart anti-disaster news and comfort affected people.

(10) Equipped with desks, blackboards and textbooks for temporary schools.

It is impossible for any city to build enough large-span buildings for simple earthquake shelter use, but it is possible for a city or a town to require some large-span buildings being continuously constructed having the function of earthquake shelter. Their construction should be legislatively added to official urban and town planning. Another way to set up earthquak shelters is to have the old built large-span buildings to have the function of earthquake shelters by alteration if possible.

After the above-mentioned long-term building in future, a city or a town, with strong ability to offer the earthquake victim humanity resettlement after great earthquake will appear in front of you.

How many earthquake shelters are needed for a city? Where are earthquake shelters built in a city? These are dependent on the population density and other factors. A new kind of urban planning research on earthquake shelters becomes necessary for cities at a high seismic intensity zone.

4. Preliminary discussion on the seismic performance design of large-span building with earthquake shelter function and its technical and economic indicators

In order to realize the earthquake shelter functions discussed above, the related large-span buildings have to be designed according to a new seismic fortification level much higher than current national seismic code's requirement.

To explore the new seismic fortification level for the large-span building with earthquake shelter functions, the structures of three stadiums using steel spatial trusses with light roof are designed according to different seismic fortification level. They are in 8 degree seismic intensity zone according to the current national seismic code and III field. The technical and economic indicators of their roof structures are listed in table 3.

Take one case in table 3 as an example, the results show that when the seismic fortification level is raised from 8 degree-small earthquake in elastic behavior to 9 degree-major earthquake in elastic behavior, with the PGA increasing from 70 gal to 620 gal (about 8.9 times), the steel weights of roof structures of 60m, 90m and 120 span stadiums are respectively raised from 15.39, 16.62 and 19.50 Kg/m^2 to 19.50, 23.74 and 28.35Kg/m^2 (about 1.26, 1.43 and 1.46 times respectively). its ratio of performance to price achieves about 5.9. If it could be accepted, 9 degree-major earthquake in elastic behavior might be used as the new seismic fortification level of large-span buildings with earthquake shelter function. Further more there appear continuously ways of reducing the costs of these large-span buildings, for example by raising their structural efficiency through vibration reduction and isolation, structural optimization, damping element and joint application and

so on. Just like design and manufacture of automobiles, the large-span building with earthquake shelter function will be continuously updated with development of civil engineering techniques.

Table 3 The technical and economic indicators with different Seismic fortification level

SFL	PGA /gal	MSIC	60W /Kg/m^2	90W /Kg/m^2	120W Kg/m^2
8 degree small earthquake in elastic behavior	70	0.16	15.39	16.62	19.50
8 degree middle earthquake in elastic behavior	200	0.49	15.56	16.80	20.09
8 degree major earthquake in elastic behavior	400	0.9	16.62	19.24	23.47
8.5 degree major earthquake in elastic behavior	510	1.20	18.80	21.27	26.36
9 degree major earthquake in elastic behavior	620	1.40	19.50	23.74	28.35

Note: SFL: Seismic fortification level; PGA: Peak ground acceleration; MSIC: The maximum seismic influence coefficient; 60W: 60m-span steel weight; 90W: 90m-span steel weight; 120W: 120m-span steel weight

Base on the results of preliminary analysis and current national seismic fortification standard in China, the new seismic fortification level for large-span building with earthquake shelter function is suggested in table 4.

According to the new seismic fortification level suggested above, large-span building with earthquake shelter functions built newly should have the standard performances as follow:

(1) Their bearing structures are in elastic working stage under the earthquake action of the new seismic fortification level listed in table 4.

(2) Their displacement ductility coefficients are more than 3.5 (suggested in this paper) and their final failure characteristic is strength failure under stronger earthquake action.

(3) All the connections of non structural elements should not be broken under the earthquake action of the new seismic fortification level listed in table 4.

(4) The ceilings should take flexible materials to prevent falling down and hurting people under strong earthquake.

(5) The performance of their bearing structures should ensure solar power equipment and other necessary equipments related to disaster relief in the normal operation under strong earthquake

Table 4 New seismic fortification level for buildings with earthquake shelter function

SFL	PGA /gal	MSIC	NSFL	PGA /gal	MSIC
Non-earthquake zone	-	-	8 degree small earthquake in elastic behavior	70	0.16
6 degree small earthquake in elastic behavior	-	-	7 degree major earthquake in elastic behavior	200	0.48
7 degree small earthquake in elastic behavior	35	0.08	8 degree major earthquake in elastic behavior	400	0.90
7.5 degree small earthquake in elastic behavior	55	0.12	8.5 degree major earthquake in elastic behavior	510	1.20
8 degree small earthquake in elastic behavior	70	0.16	9 degree major earthquake in elastic behavior	620	1.40
8.5 degree small earthquake in elastic behavior	110	0.24	9.5 degree major earthquake in elastic behavior	848	2.02
9 degree small earthquake in elastic behavior	140	0.32	10 degree major earthquake in elastic behavior	1288	3.08

Note: SFL: Seismic fortification level; NSFL: New Seismic fortification level for buildings with earthquake shelter function; PGA: Peak ground acceleration; MSIC: The maximum seismic influence coefficient according to Code for Seismic Design of Building in China.

5. Conclusion

From the investigation on the situation of victims taking refuge in Jiuzhou Stadium and the preliminary analysis on setting up indoor earthquake shelters in future, the following conclusions can be obtained:

(1) Devastating earthquake may occur at anytime anywhere, even the area whose specified intensity is lower. The most losses were from the civil engineering and a great number of people lost their housing in the great Wenchuan earthquake.

(2) A number of aftershocks occured after the major earthquake. Earthquake victims dared not go home even their homes still were in good condition since aftershock occurred continously, so victims faced the greatest diffculty after great earthquake and needed shelters where they could take refuge for a long time. Jiuzhou stadium happened to play such a role for some victims around it, but there were still a great number of victims in other places who were not lucky enough to have a shelter for their temporary

resettlement. Had they met the terrible weather as victims in Haicheng Great Earthquake, they would have faced the same terrible fate as victims in Haicheng Great Earthquake.

(3) The earthquake victim shelter in the past is just referring to setting up open field spaces for temporarily escaping from danger. In that case terrible secondary disasters may appear. So for modern cities and towns the indoor earthquake victim shelters for the using after major earthquake are very necessary.

(4) With the economic and social development, many cities are fully capable of having large-span public buildings being built more and more to have the function of earthquake shelter. Their construction should be proposed to be legislatively added to official urban and town planning for enhancing the disaster recovery capability of high seismic intensity area after major earthquake.

(5) The cost increase of large-span building with the functions of earthquake shelter may not be much. Their cost could be reduced a lot by careful design and introduction of many high-techniques.

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