

# Structure and Materials of Urban Construction for Earthquakes and Fire Disasters Prevention

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**Abstract.** As urbanization becomes a significant factor in modern society, the security of urban constructions are very essential. This study focuses on the safety performance when urban constructions face disasters, especially earthquakes and fires, and analyzed the different structure and material methods. The results show the “chicken wire mesh” system could effectively protect the infilled structure from collapsing during an earthquake in a structural way. Furthermore, changing the ingredient or adding the admixture of concrete can also provide better anti-seismic ability with construction. In the field of fire resistance, thick timber board and ceramic concrete can effectively improve the fire-resistance ability of buildings.

**Keywords:** Urban Construction Safety, Disaster, Structure, Material.

## 1. Introduction

During the history of human beings, disasters are always a menace to the lives and development of mankind. In modern society, urbanization has become a significant factor. As the fundamental construction in cities, buildings provide enough space for human activities in cities. Behaviors of cities are influenced by the number of building structures in a unit area. In order to reach the sustainable development goals, the city with high-density buildings is considered more frequently by city designers which are called “compact cities”. This means more people will live or work in a relatively crowded space and this may cause much more serious losses or damage once the disasters happen.

Earthquakes and fire hazards are two main types of disasters in city buildings. For earthquakes, many famous grievous earthquakes happened in urban make thousands even millions of people get hurt or lose their lives. There is 75% of death in earthquakes are caused by the failure of buildings from 1900 to 1989 which is still a very high percentage. For example, the Wenchuan earthquake happened in Wenchuan County, Sichuan Province on May 12nd, 2008, Dujiangyan is one of the 10 most seriously destroyed areas in this earthquake. There are 3091 people killed and there are 3035 people who are the death of the collapse of buildings which is 98% of the whole number of deaths [1].

Fires happen in living buildings most frequently among all types of city buildings. High hazard probability in high-density population areas may more easily cause more people to get injuries. Taking the fire disasters in Jakarta and Surabaya in Indonesia during the past 7 years as an example, 321 disasters happened in Surabaya while 840 disasters happened in Jakarta every year from 2002 to 2008 [2].

In addition, the sufferers of disasters in cities not only cause the hurt in their bodies but also the psychic problems including depressive disorder, anxiety disorder, posttraumatic stress disorder (PTSD) and sleeping problems [3]. Besides negative effects on human beings, there is also a negative influence on the development of society. Serious and widespread treasure losses and serious community financial problems are two obviously society hazards caused by disasters in the urban area. The consequence caused by urban disasters is complex.

Higher building and population density with several kinds of consequences caused to make it will influence many aspects of human lives or social development and may lead to catastrophic results when the disasters attack urban areas. All these factors show it is valuable and necessary to find out

the methods of how to keep the buildings in urban areas safe when they face disasters. This paper focuses on potential measures to protect buildings in cities from earthquakes and fire disasters by using different construction structures or construction materials and some modern technologies in civil engineering with a conclusion at the end of the article.

## 2. Urban architecture

Urban architecture or constructions refers to all the constructions made by soil, stone, wood, steel, glass, plastic, and other construction materials in urban areas including houses, bridges, and towers. [4]. However, in this article, urban construction mainly refers to residential buildings which provide enough space and specific functions for human activities including houses and departments

As for residential buildings, fire resistance and anti-seismic are important because they directly relate to human lives who live or work in these buildings. Therefore, protecting buildings from earthquakes and fires is always widely considered. Furthermore, frame and material are two important elements of urban buildings and construction. This study mainly focused on several typical and new fire resistance and anti-seismic frame and materials.

## 3. Construction frame protection

Construction frame refers to the structures made by carlings, beams, and columns. It not only supports the construction but also bears the loads caused by earthquakes, winds, or other extra loads. It is a key structure in a building to keep the most basic and most important safety [5]. The frame structures including are analyzed in detail in this study.

### 3.1 Existing problems of infilled wall

Although the wall made of the masonry built with burned clay bricks is one of the most common types of construction frame structures for its low cost. These walls could easily break with inclined fissures and the fissures can continue crazing around columns. After the attack of earthquakes, the damage near headwalls, the walls between windows and the corners of doors and windows become worse than the original situation. If the intensity of the earthquake is hard enough, these walls with fissures are going to collapse (Figure 1). Besides, the lateral deformation caused by shear force may cause the deformation in the lower part of a structure to be bigger than the higher part, this makes the lower part of the infilled wall heavier than the higher part when the earthquake happens. Due to the low shear strength of the infilled wall, the ability to defect the damage caused by deformation is poor. There is no effective tie effect between walls and structures, shear broken is easily happened after the reciprocating deformation during the earthquake [6].



Figure 1. The collapse of an infilled wall during earthquakes

### 3.2 New reinforced structure

A new structure method to reinforce the walls and structures is mentioned to solve the situations infilled walls faced in the earthquake.

The method strengthens the structure by combining the infilled wall with frame structures with extra materials which are meshes or rebars. The basic structure is the ferroconcrete frame filled with brick masonry with no extra protection systems (Figure 2a). And the first strength way is fixing bricks with a network system called “chicken wire mesh” in the diagonal line of a rectangle frame (Figure 2b). Those metal wires are fixed on structure surfaces by the applied force provided by chemical adhesive. The other way is the bricks are riveted with columns on two sides of the frame with steel rebar (Figure 2c).

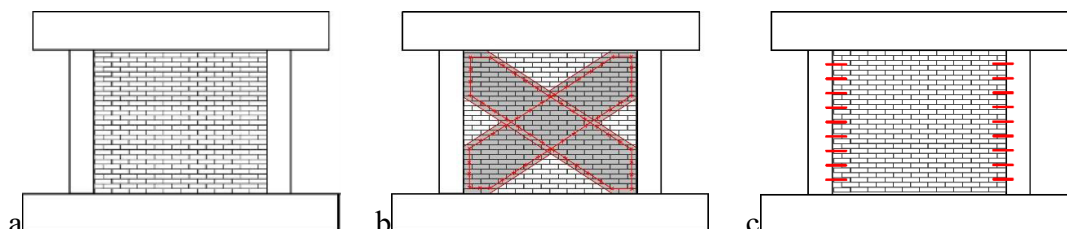


Figure 2. Symbols of ferroconcrete frame filled with bricks. (a) Basic structure; (b) “chicken wire mesh” structure; (c) Structure with two columns fixed on two sides

There are three 25% scale testing specimens are made for earthquake simulation testing in the same condition. For the first protection method, testing results show the specimen with a wire system successful decrease the fissures in filled bricks, slow down the collapse of the structure frame which means this strength method can help the structure stay for a longer time than before in the earthquakes and means more time for the human to escape the buildings before it breaks down. The flexibility of wires helps the structure can defend against the tension stress in the diagonal direction of a rectangle frame effectively and make the fissures only happen in the infilled bricks without the protection of the “chicken wire system”. It shows installing a “chicken wire system” is an effective way to protect construction frames from the damage of earthquakes.

The anchoring to protect the weak parts between infilled bricks and columns also shows a positive influence in the test. Only a few cracks appeared in the joint face of bricks and frames. In the mechanical field, the lateral forces almost keep stable during the simulated tests.

In general, using the wire system to strengthen the infilling bricks can effectively increase the strength of reinforced concrete, especially in the lateral direction and postpone the failure of infilled walls. At the same time, the anchoring between bricks and frame columns improves the connecting strength of the joint face of infilled materials and columns. However, in real situations, both the lateral strength and the interface strength will affect by an earthquake, single protection method is not enough for the safety of infilled masonry brick walls in buildings, it is necessary to combine these two methods to protect the constructions. In other words, it is a simple and safe method to protect the constructions in earthquakes by using both the “chicken wire system” and anchoring in the same infilled walls [7].

## 4. Construction materials protection

Construction materials are common of all materials used in construction projects. The requirements for the scale become larger and the requirements for quantities become higher while the history is going ahead [8]. Rebar, concrete, glass, tile, and painting all belong to construction materials [9]. The study contains the analysis of structural materials like concrete and non-structural materials like painting to find out potential solutions to protect buildings from earthquakes and fires.

### 4.1 Anti-seismic materials

Protecting the urban architecture from the earthquake is a complex project. Only considering the structure influence in the protection is not sufficient for the resistant earthquake. As the basics of construction structures, construction materials are also important to be focused on in the research.

In order to let buildings can survive from an earthquake, construction materials should have enough strength. Although high strength is not directly equal to high anti-seismic ability, it is also important to buildings. Without enough strength, buildings can't be safe even in normal situations. Especially for brittle materials, the bending strength and tension strength are even more important for them. In the other hand, materials should have outstanding durability and safe reliability to defend against different negative influences in different working environments and different mediums to increase the safety and service life of materials.

Unfortunately, as the most widely used construction material since its creation in 1824, concrete is a typical brittle material that is a disadvantage to antiknock requirements, especially in the areas that are often attacked by earthquakes. It is necessary to find out some material methods to improve the properties of concretes or find out some effective materials to replace concretes in buildings in these areas.

There are several methods to improve the seismic performance of cement including controlling the mixing ingredient and using admixtures. Water content is a critical factor that influences the anti-seismic properties of concrete. The workability, strength, and durability are very sensitive to how much water is used in concrete when mixing. For example, when the water and cement ratio decreases from 0.5 to below 0.3 can double the concrete strength. Decreasing the water content may be one possible solution to anti-seismic. Although decreasing water content can strengthen concrete, the brittle characteristics become more obvious when it breaks down while the decreasing of water content. It is negative to the safety of buildings in earthquakes, so multiple protection methods are needed. The polymer can provide a potential option for this problem. Concretes have better performance in the combination of paste and the interface.

Adding polymer can improve the combination of paste and the interface of aggregates and make concretes have better ductility which has been proved by the creation of super-high-strength concrete springs. Polymer fiber is a form to add polymer to concrete. Polymer fiber can effectively increase the anti-crack property in the early age of concrete and also make ductility better. Results of experiments show adding 2% polyvinyl alcohol (PVA) fiber in volume percentage can increase the tensile strain of concrete by 3% to 7% without the loss of strength. In addition, this strengthening method has been used in newly-built large-scale buildings in Japan.

Steel fiber can be another choice for additive material which can improve concretes mechanical properties. Steel fiber can increase the tension, bending, and shearing strength because it can avoid concrete cracking and the extension of cracks. The shock resistance, antifatigue, toughness after cracking, and durability are all better than normal concretes without steel fiber. Therefore, steel fiber concrete is a new type of composite material with good performance in construction, especially in anti-seismic. The potentiation will increase the increasing of the volume content and the length-diameter ratio of those fibers. However, there are also some shortages for adding steel fiber in concretes. Fiber content is limited in construction sites. There will be troubles in using common methods to stir and mold if the content is out of the limitation. For widely used steel fiber concretes, the fiber content is suggested to be 1.0% to 2.0% in volume. Column-beam nodes, columns, pile caps, roof panels, and other structures are all satisfied with the application of steel fibers. Compare with normal reinforced concretes (RC), the ductility of those column-beam nodes in steel fiber concrete frames increases by 57% and load cycles increased by 15%. Using steel fiber concrete to replace some stirrups in the nodes area can not only improves the anti-seismic ability but solves the construction troubles including the high density of rebars.

Although materials' mechanical properties may always be considered as one of the most important fields in anti-seismic, durability is also an important factor that might be ignored. Durability determines how long the concretes can keep good mechanical properties and the service life. If the concretes don't have enough durability, an earthquake within allowable intensity may also cause the failure of the buildings and get more injured or death reports which won't happen if the durability is eligible. Aggregate is an important element to effective the durability of concretes. If the aggregates are basic active or have harmful components used in concretes can not only decrease the durability

and service life but also accelerate the damage in natural disasters such as earthquakes. The investigation for broken down buildings in the Turkey earthquake in 2003 shows the uncorrected use of sea sands with high content of chloride ions accelerates the corrosion of bars in concretes is the main reason for the collapsing of buildings in earthquakes.

On the other hand, cement can also provide many benefits to improve the durability of concrete including reducing the content of tricalcium aluminate whose chemical composition is  $3CaO \cdot Al_2O_3$  and the abbreviation is  $C_3A$ , control the specific surface area and hydration heat reasonably, and decrease the content of chloride ions or alkali. Completely changing the type of cement is also acceptable. Low-heat Portland cement is a kind of cement with low hydration heat, high strength in old age, and have high bending strength. It can solve many concrete problems mentioned before just by changing a different type of cement. It is a good choice for high-strength and high properties concrete in priority projects [10].

## 4.2 Anti-fire materials

Fire safety is always a focus of city construction. Construction materials directly contact occupants in the buildings which means the safety of these materials directly affects the safety of humans in buildings once the fire happens. Therefore, it is important to work on materials safety to ensure the anti-fire properties of constructions and effectively decrease the probability of fire disasters in buildings by using fire protection materials legitimately and scientifically [11].

The requirements for anti-fire materials include mechanical, heat conduction, burning, smoke-producing, and poisonous properties. Mechanical properties require materials can keep their capacity under a high temperature, and cracks and perforations won't appear. For example, although steel won't burn under a high temperature, it will become soft than before and lose its original capacity then causing the collapse of a construction. For heat conduction factors, if construction materials can conduct heat effectively, more construction areas may be destroyed by fires once the temperature is conducted from the fireplace to the space without fires and the temperature reaches the burning point of materials, there will be another fire. Burning properties refer to the combustible degree and velocity of the material. The fire will extend faster if the material can burn fast. Smoke and poisonousness can also make serious injury and death in a fire. Those poison gas released by burning materials are harmful to human beings, so they are also valuable to be considered in anti-fire construction materials [12].

### 4.2.1 Thick wood-based boards

Timber board is one of the widely used materials for the surface of enclosures and grounds. According to the revising of the Japanese construction standard, some timber construction materials or structures are allowable for now. And Japanese government encourages construction companies to use waste wood materials then thick timber board becomes a potential option for reusing products. However, when timber boards are used as fire-resistant construction materials, several quantities are necessary:

- (1) Huge deformation, melting and breaking won't happen under a fire;
- (2) The temperature of the back surface (the surface inside the board) won't increase over the burning point of combustible materials;
- (3) There are no fissures or other damages when an outer fire happens.

These three properties respond the heat conduction and burning factors mentioned before. However, there are few studies about thick timber boards used in construction fire protection while more information about the thin boards within 20mm. Glued board, grained board and medium-density fibril board are tested under the ISO 834-1 standard of anti-fire properties of walls and cone taper calorimeter testing. The results show the plank made by Japanese *Pinus koraiensis*, Japanese *larix gmelina* and dahurian *larix gmelina* glued planks with 28mm thickness and 30mm grained board and medium-density fibril are satisfied with Japanese construction standard for insulation requirement

for 30 minutes protection of outer walls. It also figures out that the insulation properties have a relationship with its density when the thickness of planks are similar [13].

The results of this research are positive to find out an effective anti-fire construction material. Plank is such a normal material in construction and decorations. As the surface of walls, planks will be the first defense line of construction. Its good insulation property can control the temperature of the outer space of a fire room and decrease the spread velocity of flames then provide more time for evacuation and protect the entire structure of buildings. In addition, easily getting raw material is another advantage of fire resistance planks. It brings an economical advantage. Due to these factors mentioned before, timber board is easily widely used in to protect the whole building for every room.

#### 4.2.2 Ceramic concrete

As this study mentioned before, concrete is the most widely used construction material worldwide and plays an important role in construction structures which is the most basic safety element in buildings. Therefore, it is ponderable to focus on the fire resistance ability and find out an effective material method to improve the ability.

Cellular concrete is the concrete with froth which is made by blowing agents with physical methods. It has multiple advantages in construction including light in weight, environment friendly and anti-seismic [14]. Ceramic and mineral are also two common construction materials. The following part analyzes the fire resistance ability of cellular concrete with admixtures of ceramics and minerals. Ceramic used in this concrete is the replacement of river sand as the aggregate in concretes. Some cubic concrete specimens with 150mm side length are made under the standard method. These specimens include the experiment group with ceramic and aluminite powder and the comparison group. Specimens are tested under the temperature of 400, 500, and 600 degrees centigrade to observe its changing and analyze their fire resistance abilities.

In the laboratory, specimens are exposed to set temperature for 60min and test their compressive strength. The result is positive for the study. With the increase in temperature, the compressive strength of specimens is steady. Concretes are destroyed by high temperature, however, concrete with ceramic performs better in the strength test. In further, a high replacement percentage for ceramic provides better fire resistance ability to behave with higher compressive strength after testing (Table 1; Figure 3). The potential explanation for the phenomena is ceramic is produced under a very high temperature which makes it can keep its normal ability at high temperature and this property can help concrete with ceramic aggregate to have good fire resistance ability. In addition, the heat insulation property also is tested in this study. The results show that the experiment group with ceramic to replace sand aggregate in concrete has a conductive coefficient a little bit bigger than the comparison group without ceramic replacement (Table 2) [15]. However, the research from Demirboğa mentioned that the concrete with mineral admixture has a lower conductive than the original concrete without minerals [16]. Whatever, the conductive difference is not huge, there is not an obvious effect on the insulation of concretes with ceramic. This means the fire resistance of concrete will keep stable in construction protection. It is positive to protect buildings from fire in heat conduction way to slow down the fire spread velocity.

In short, the cellular concrete with ceramic aggregate and minerals is satisfied to protect construction structures from fires.

#### 4.2.3 Relationship between material fire resistance ability and construction structure safety in fires

Material is the most basic element in every construction. There is not any construction without satisfied construction materials. Similarly, to keep the safety of construction when a fire happens, construction materials that keep their normal workability are necessary. Therefore, improving the fire resistance of materials is to improve the anti-fire ability of buildings.

Timber boards are usually used on the surface of construction structures. It may be one of the first materials directly face the fire. If these boards can have a good heat insulation ability, the structure inside can stay at a relatively normal temperature longer and no structural failure will happen. On the

other hand, good heat insulation not only can protect the structure but also slow down the increase of temperature inside the building which can retard fire spread and earn more time for evacuation.

Concrete is more important in building safety protection because it directly constitutes the construction structure. If the concrete used in structures especially load-bearing structures has poor anti-fire ability, its workability won't maintain for a long time then the structure failure may happen and finally cause the collapse of the whole building.

In general, the anti-fire ability of construction materials directly affects structure safety and construction safety under fire. Increasing the anti-fire ability of materials is to improve the ability of the structure.

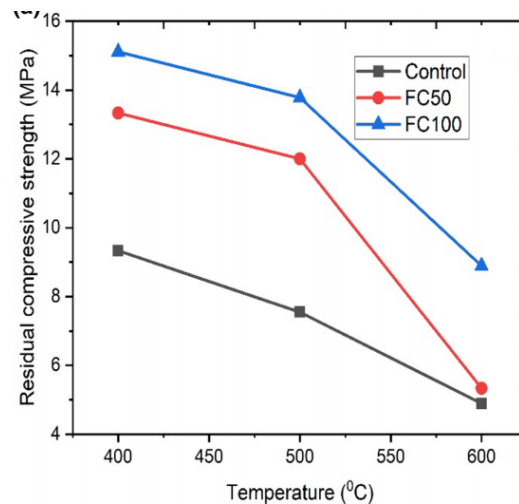


Figure 3. The compressive strength after the test

Table. 1. Concrete Design

Types	Ceramic aggregate (kg/m <sup>3</sup> )	Cement (kg/m <sup>3</sup> )	Sand (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	Aluminum Powder (kg/m <sup>3</sup> )	Super Plasticizers (kg/m <sup>3</sup> )
Comparison	0	400	1800	180	15	10
FC 50	900	400	900	180	15	10
FC 100	1800	400	0	180	15	10

Table. 2. Heat Conductive Coefficient

Types	Amount of heat transfer (Q)	Length (m)	Area (m <sup>2</sup> )	Temperature change (K)	Heat conductive coefficient (W/mk)
Comparison	1900	0.03	0.3	330	0.57
FC 50	1886	0.03	0.3	337	0.6
FC 100	2090	0.03	0.3	353	0.59

## 5. Conclusion

Facing disasters in urban cities, construction safety is widely considered among architecture designers worldwide.

Earthquakes and fires are the two most common types of disasters that happen in city areas and may cause serious amounts of casualties. Therefore, earthquake and fire protection are valuable to be considered. Different measurements can protect buildings in different aspects. As one of the most widely used construction materials, improving concrete properties can not only protect buildings from earthquakes but also fires. Controlling satisfied water content, polymer addition, using steel fiber,

choosing correct aggregates, and reducing the content of tricalcium aluminate in concrete can improve the anti-seismic ability of construction. Replacing river sand aggregate in concrete with ceramic can also improve the anti-fire properties of buildings. On the other hand, using a “chicken wire system” in infilled wall structures can reinforce this structure to defend against the destruction caused by earthquakes. For fire resistance, thick timber board used on the surface of walls can retard the spread of fire to protect the building structure and earn more evacuation time for those people in the buildings.

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