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Original Article

Effect of Seismic Conditions in Architectural Design of Buildings

[1] Yousef Zandi,[2] Roza Naziri,and [3]R. Hamedani

[1] Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran

[2] Department of Architectural Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran

[3] Project Manager and Technical Adviser of Hormozgan Cement Company, Iran

Email: ZANDI@IAUT.AC.IR

ABSTRACT

The following factors affect and are affected by the design of the building. It is important that the design team understands these factors and deal with them prudently in the design phase. Objects and buildings have a center of mass, a point by which the object (building) can be balanced without rotation occurring. If the mass is uniformly distributed then the geometric center of the floor and the center of mass may coincide. Uneven mass distribution will position the center of mass outside of the geometric center causing "torsion" generating stress concentrations. A certain amount of torsion is unavoidable in every building design. Symmetrical arrangement of masses, however, will result in balanced stiffness against either direction and keep torsion within a manageable range. It is believed that following the recommendations presented in this paper will lead to more reliable seismic behavior of these buildings, and consequently their functionality during and after the earthquake, which is the main concern about these buildings from the "seismic risk mitigation" point of view. In the case of some special buildings it is felt that more work is needed, and close cooperation of architects and structural engineers is very essential for these studies and researches to be successful. Thinking of more earthquake resistant configurations in general and safer internal design for specific buildings are also matters, which are still under study.

Keywords: *Architectural Seismic Design, Regular Configuration buildings, Important Buildings, Damping, Terminals, Irregular Configuration buildings.*

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INTRODUCTION

Earthquakes are the shaking, rolling, or sudden shock of the earth's surface. Basically, the Earth's crust consists of a series of "plates" floating over the interior, continually moving (at 2 to 130 millimeters per year), spreading from the center, sinking at the edges, and being regenerated. Friction caused by plates colliding, extending, or sub ducting (one plate slides under the other) builds up stresses that, when released, causes an earthquake to radiate through the crust in a complex wave motion, producing ground failure (in the form of surface faulting [a split in the ground], landslides, liquefaction, or subsidence), or tsunami. This, in turn, can cause anywhere from minor damage to total devastation of the built environment near where the earthquake occurred.

It is well known that the architectural form of a building has a great role in its seismic vulnerability. Furthermore, past earthquakes have shown that architectural detailing has a great role in the extent of damage to people and properties inside and outside the buildings. Special buildings, including public gathering centers such as department stores, terminals, amusement centers, as well as hospitals, fire stations, and also other rescue and relief centers, educational centers, police stations, and other government important buildings, particularly those which place decision-making authorities for crisis management, are all categorized as highly important buildings in all seismic design codes. Many of these building have specific architectural design depending on their assigned function, which is quite different from ordinary buildings. Additionally, the specific function of these kinds of buildings requires some particular equipment and facilities, which are not usually used in ordinary buildings. Finally, the contents of these buildings and the setting of the contents are usually very different from common residential and commercial buildings. However, in spite of the existence of several publications with regard to so-called "earthquake resistant architecture", most of these publication deals with general considerations, applicable mainly to ordinary buildings, and only few of them address the cases required for the aforementioned special buildings. Furthermore, the first publications, addressing this issue, are usually concern about the general features or some nonstructural elements of some group of special buildings, [1-5].

There are also some reports on the operation of hospitals and public schools in San Fernando (1971), Morgan Hill (1984), and San Salvador (1986) earthquakes, and a few Italian quakes, including Friuli (1976), Irpinia (1980), and Abruzzo (1984) earthquakes, [6-9], which mention the total collapse of some hospitals and significant disruption of local health services, causing evacuation of many major hospitals. These experiences and similar events lead to the issuance of FEMA 150 publication on the seismic consideration for health care facilities in 1988, [10]. Accordingly, some modifications were done on the old versions of standards for some of special buildings, particularly public centers, [11], which emphasized more and more on the compatibility of architectural and structural designs.

One of the first documents on special buildings, which was aimed directly at an architectural body, was published in California in mid 90s, and was with regard to schools as some of them have received extensive damages in 1994 Northridge earthquake, [12]. It is mentioned in this publication that portable buildings and nonstructural components have made two major categories of damages to school buildings. In late 90's ATC published some requirements on performance of nonstructural components [13], which can be considered as the first issue of its type. Recently, some researchers have worked on architectural remodeling of existing hospitals, [14], which has discussed basically on medical-architectural schemes. Finally, a paper has been published on the "theory of the architectural design of buildings in seismic areas", [15], but it deals, mainly, with making architectural and structural designs compatible in the case of ordinary buildings, and does not address the case of special buildings.

This paper presents some specific seismic considerations to be regarded in the architectural design of special buildings. Public buildings, rescue and relief centers and government important building are all discussed. Special attention is paid to some of the special buildings like transportation terminals, particularly those belonging to airports, which have very great roles in aid-receiving process from other countries or states in the case of a destructive earthquake. This point is much more important in developing countries, which usually need more help in catastrophic events. It is believed that following the recommendations presented in this paper will lead to more reliable seismic behavior of these buildings, and consequently their functionality during and after the earthquake, which is the main concern about these buildings from the "seismic risk mitigation" point of view[1].

The paper at first expresses various reasons by which each of the special buildings is categorized in the highly important buildings. Then it tries to discuss in brief on the basic architectural features of each group of these buildings individually, and clarifies the 'adverse interaction' of these features, if any, with the structural.

[1]The main body of this paper is based on a new course proposed to and taught at Cornell University, USA, by the author in 2002 Spring semester under the title of "Earthquake Considerations in Architectural and Urban Design".

seismic design of the building. Particular attention is paid to the nonstructural elements, and more specifically, the architectural detailing, which are the main cause of injuries and damage to people and properties in those buildings, which have been designed for earthquake structurally, but not architecturally.

CLASSIFICATION AND IMPORTANCE OF SPECIAL BUILDINGS

Generally speaking, special buildings can be classified in five main categories. These include:

1- Public Buildings
2- Rescue and Relief Centers
3- Government's and Government-Related Buildings
4- High rise Buildings
5-Industrial Buildings Of these five categories, the first three ones are considered in this paper.

High rise buildings, particularly those of more than 20 stories, have some special rules for their architectural as well as structural design, [16], and need a separate discussion for their seismic resistant architectural design, which can not be dealt with in this paper. In the case of industrial buildings, the role of architectural design is not dominant and therefore, they have been excluded from the discussion in this paper. In the following parts of the paper at first the subcategories of each of the first three aforementioned categories are introduced and their importance is discussed, and then the points which should be regarded in their architectural design, are explained.

Public Buildings

Public buildings, namely those which place a great number of people in some or many occasions during their life time, and therefore, are considered as the important buildings**,** have the general following features:

1- They place a great number of people when in use.
2- They usually place lots of materials and goods, some of which being necessary, particularly after the earthquake.
3- Many of them can be used, if remain intact after the earthquake, as shelters for the stricken people.

Various types of this category and their specific reason(s) of importance are:

Schools, Colleges and Universities (Educational Environments); School buildings are important since: a) kids are the community human asset for the future, b) kids can not save themselves as adults, and c) any harm to a kid can affect several families. In the case of colleges and universities it can be said that any harm to the knowledgeable people and the facilities is a threat to the country stability and development.

Important Office Buildings and Banks; They are supposed to keep the important documents, which their loss can result in several social right problems, followed by many claims.

Libraries and Museums; In addition to the attendance of several people, they are supposed to keep the information sources and national heritage. The existence of tourists from other countries in museums can create some very critical human right and foreign affaires problems for the host country if they get injured.

Malls and Department Stores; Beside the attendance of several people, they contain lots of materials and goods, some of which maybe much necessary after the earthquake.

Hotels and Guest Houses; In addition to the problem of the existence of tourists from other countries, these buildings can be the best shelters for stricken people after the earthquake.

Transportation Terminals; Beside the attendance of several people, they can be also be good shelters for stricken people after the earthquake. Furthermore, in the case of airport terminals they can be considered as the main gate for receiving the aids from other states or country in the case of a big earthquake in the important cities of the country.

Cinemas and Amphitheaters; In addition to the attendance of several people, and the human value of the theater actors, these spaces can be also very good shelters for stricken people after the earthquake.

Worship Places (Mosques, Churches, …) and Shrines; Besides the attendance of several people, these buildings can be also very good shelters for stricken people after the earthquake, and a good center for managing the volunteers as well.

Restaurants and Indoor Play Stations; In addition to the attendance of several people, particularly kids, they can be very good places for sheltering and taking care of kids after the event.

Gymnasiums and Sport Centers; Beside the attendance of several people, particularly young ones, and the national value of the sportsmen and sportswomen, these buildings can be also very good shelters for stricken people after the earthquake, as well as good center for managing the volunteers.

Rescue and Relief Centers

These buildings are considered as the most important ones by most codes. These buildings are very important since in addition to their normal daily duties, they should provide the stricken people with the required helps and services as well. These centers and their specific importance reason(s) are as follow:

Hospitals; these centers should be able to receive several probable casualties as emergency cases in addition to their normal services.

Fire Stations; These stations should be able to fight with several post earthquake fires at the same time in various parts of the city.

Police Departments; Police forces should be able to control the city situation as well as the city transportation system to keep it passable for rescue and relief teams. They should be also capable of guarding the left properties of the people who have had to leave their places because of the event.
Mass Media Centers; These centers should be able to keep the people informed about the condition of various parts of the stricken area. This is very important from the mental situation of the people in the area, which itself has a great role in the crisis mitigation and management. Regarding these facts, these centers should have the highest chance of remaining quite intact, even after the big earthquakes. Otherwise, it will not be possible to perform any successful emergency management activity in the stricken area.

Government's and Government-Related Buildings

In addition to police departments, which were mentioned in the previous section, there are many other buildings that are basically used and managed and by the government employees or by the people whose jobs are in very close relation with the government. Most of these buildings, including the presidential and ministries buildings as well as embassies, which are among the most important buildings, can be classified as important offices having the same general architectural design. In the following subcategories those buildings which have some functions other than or more than office works, are included. These buildings and their importance reason(s) are as follow:
Crisis Management Headquarters and Bureaus; These buildings are important since they place the authorities who are responsible for crisis management and keeping control on the activities of the rescue and relief teams, lifeline systems representatives, as well as police forces. Obviously, any damage to these kinds of buildings can disturb or even stop the rescue and relief activities.
Parliament or Congress Buildings; It is obvious that the political stability of the country will be threatened if a great number of representatives, in various occupancy levels, get injured/killed at the same time, or if the important documents get lost.
Lifeline Authorities Headquarters; The importance of lifeline systems is implied by their name. In fact, any damage to the lifeline headquarters can result in the delay or even total failure of the emergency reaction of rescue and relief teams.
Courts; In addition of the existence of a great number of people, these buildings place several important documents, which if get damaged or lost, can result in conflicts between the engaged people.
Jails!; If crime-related prisoners get released because of the damage to the jail building and lack of guards' control they, at least some of them, will find new opportunities to do some more crimes as there may be many properties left in the damaged buildings, belonging to either public or private or government, and some stricken people, who have lost their shelters and may have not been reached yet by the rescue and relief teams.
Army Centers; In addition to the human resource problem some of army buildings have great importance for the security of the whole nation. There are some other important buildings, which cannot be categorized as a
Specific type of government centers, but their importance is not less than other government buildings. For example, the Coroners' Office and Archive Building, which contain several important people and documents, are in fact individual buildings, which may be considered as special offices. Furthermore, some of the aforementioned government buildings can be used as the victims' camps in the aftermath of big earthquakes. This feature is also another aspect of the importance of these buildings.

Desired Architectural Features of Special Buildings

There are some principal rules in seismic design of all buildings, which if followed will make the seismic behavior of the building more reliable. Of these, some are related to the building configuration or its architectural form. These include simplicity and symmetry, regularity in plan and elevation, having a proper aspect ratio, and being not very long or large in plan. There are also some recommendations about the architectural details and building attachments, which can help the building proper seismic design. In the case of special buildings, under discussion, some more recommendations or rules can be added to the aforementioned ones. These proposed rules can be classified in the following two main categories:

- General Rules
- Building-Specific Rules Each of these two categories includes some recommendations with regard to the building configuration and some others with regard to the nonstructural

elements. In the following sections these rules are explained briefly.

General Rules

Regarding the high importance of special buildings, as expressed in the previous sections, it seems reasonable to prevent them from the earthquake damage by every possible provision. In recent years a tendency has been created in structural designers to use passive and active controls as a seismic remedy for important buildings. But it is notable that control technology, is not available easily and with a reasonable cost in many seismic parts of the world, and furthermore, even in the case of base-isolated or actively-controlled buildings the improper architectural design can decrease the efficiency of the system to a great extent. Additionally, using the control techniques is very expensive or even impossible for some of special buildings, mainly because of their specific architecture. Big malls and large cinemas are good examples in this regard. Therefore, following some general rules, as follow, in the architectural design is basically very helpful.

1. Avoiding, as much as possible, the complex configuration both in plan and in elevation – This is a recommendation for all buildings, but for special buildings it is more vital.
2. Using the plan shapes which are dividable to simple, and preferably, symmetrical geometric forms – This will make it possible to use easily some seismic joints to have a complicated form made up of some simple and structurally independent parts, and will make the structural seismic design of the building more doable and reliable.
3. Extensive use of seismic joints – This feature in combination with the previous one will give to the whole building a more reliable seismic behavior. There are several details for architectural covering of seismic joints, of which one or some can be used for any specific building depending on its other architectural features.
4. Using the lightweight structural materials as much as possible – Obviously, the seismic forces acting on the building will decrease as its weight decreases, and therefore it will have more chance to remain intact against earthquake.
5. In the cases of need to very large buildings, use of horizontal expansion rather than vertical – This feature will decrease generally the seismic forces and consequently the seismic design problems, and will make more reliable access to various parts of the building when rescue and relief actions are necessity.
6. Making minimum the total volume of architectural nonstructural elements – This will give more chance of health to residents of the building.
7. Avoiding the use of heavy materials for the architectural nonstructural elements

This will decrease the chance of these elements to get damaged due to high seismic accelerations, and to be harmful for the residents when they possibly fall down.

BUILDING-SPECIFIC RULES

Regarding the great variety of special buildings, in addition to the general rules expressed in the previous section, there are some additional recommendations for every specific type of these buildings, which if followed, make them safer against earthquake. It is not possible here, because of lack of space, to go through all this recommendation for all types of special buildings discussed in the paper. So, as some samples, recommendations with regard to hospitals, as important buildings for rescue and relief activities, and department stores as one of the most frequent ones of public buildings are explained here.

Generally speaking, hospitals, located in seismic areas, should be able to give extensive emergency services, much more than hospitals in other areas. Therefore, in seismic regions the emergency section of hospitals should be larger and more equipped, and its accessibility should be very high. The architectural nonstructural elements in hospitals in seismic should be designed with more care to be minimum firstly, and to be as much lighter as possible and be quite secure, so that they cannot threat patients at all. Even the internal design of these hospitals' facilities and accommodations should be compatible with the seismic safety rules.

Department stores, which are occupied with people of every kind during their work hours, should have some special architectural features in seismic regions. The main feature is seismically safe goods areas, which is basically an internal design matter. The second important feature is safe passage areas in the case of a seismic event. It is much safer to avoid high racks, particularly when they are supposed to place heavy goods, and all racks should be secured against falling or moving to sides. The passage areas should be wide enough to let the threatened people, in the case of a seismic event, to reach the safer areas. The number of exits should be as many as possible. Finally, the architectural nonstructural elements, particularly around entrance and exit areas, should be designed to be quite safe seismically.

Accordingly, some other architectural features can be expressed for other types of special buildings in seismic areas, and there is no more space here in this paper to go through them. The author is presently developing some teaching materials for students of Architecture, in which more detailed discussion on these matters can be found.

CONCLUSIONS

Despite the existence of several publications with regard to so-called "earthquake resistant architecture", most of these publication deals with general considerations, applicable mainly to ordinary buildings, and only few of them address the case of aforementioned special buildings. Many of these building have specific architectural design depending on their assigned function, which is quite different from ordinary buildings. This paper presents some specific seismic considerations to be regarded in the architectural design of special buildings. Special attention is paid to some of special buildings like terminals, particularly those belonging to airports, which have very great roles in aid-receiving process from other countries or states in the case of a destructive earthquake. This point is much more important in developing countries, which usually need more help in catastrophic events. It is believed that following the recommendations presented in this paper will lead to more reliable seismic behavior of these buildings, and consequently their functionality during and after the earthquake, which is the main concern about these buildings from the "seismic risk mitigation" point of view.

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