Why Worry about Earthquake in Regions of Moderate Seismicity: A Case-Study of Hong Kong

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ABSTRACT

This paper reports a part of research work on earthquake resistance consideration in regions of moderate seismicity, which is being carried out in the Department of Civil Engineering, Hong Kong University of Science & Technology. The possible seismic hazard in Hong Kong, which is located in a region of moderate seismicity, is described. A case study is presented to compare the wind and earthquake effects on Hong Kong buildings and to assess whether seismic analysis and design is necessary for building structures. Potential problems of reinforced concrete buildings under earthquake effects in regions of moderate seismicity are discussed.

Key words *: moderate seismicity, seismic hazard, earthquake effect, seismic design, ductility*

1. Introduction

Hong Kong is not located in a region of frequent destructive earthquake activities. Reviews of the data on historical earthquakes within a region about 350 km radius of Hong Kong have been published by GCO of the Hong Kong Government,[4] Pun and Ambraseys,[8] and Lee, et. al.[7] The dada include an assessment of 'observed' and 'fel t' effects of earthquakes going as far back as more than 900 years ago.

Although Hong Kong is not among most seismic active areas, comparable to Los Angeles or Kobe, the earthquake risk is not nil. Destructive earthquakes did occur in southern China and the Southern China sea that have potential of affecting Hong Kong significantly. It has been recorded more than sixty destructive earthquakes in Guangdong Province of China since 1067, and the distribution of major earthquakes in Hong Kong and the vicinities is shown in Fig. 1.

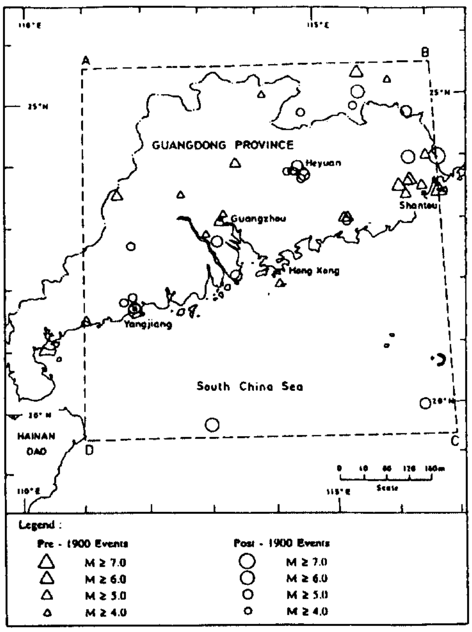

Fig. 1 Major earthquakes in Hong Kong and the vicinities(GCO 1991)

There are sixteen events between M 4.7 and 4.9; thirty-seven events between M 5 and 5.9; nine events between M 6 and 6.9;

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and two events rated larger than M 7. The most significant event was the M 7.4 one occurred in Shantou of Guangdon Province, about 300 km from Hong Kong in 1918. And there were some reports of damaged buildings in Hong Kong. For example, St. Stephen's Girl's College in Hong Kong Island was damaged to such an extent that the school had to be relocated to its present site on Lyttelton Road of Hong Kong. The recent M 7.3 event occurred in the Strait of Taiwan on 16 September 1994 was widely felt in Hong Kong.

2. Seismic hazard of Hong Kong

The up to date study (Lee, et. al.[7]) indicates that Hong Kong has a peak ground acceleration of about 0.1g with a 10% probability of exceedance in 50 years as shown in Fig. 2. Statistically this is equivalent to a return period of 475 years. The study also evaluates the hazard in terms of Chinese seismic intensity (GBJ11-89[3]) and rates Hong Kong is located within an intensity 7 region

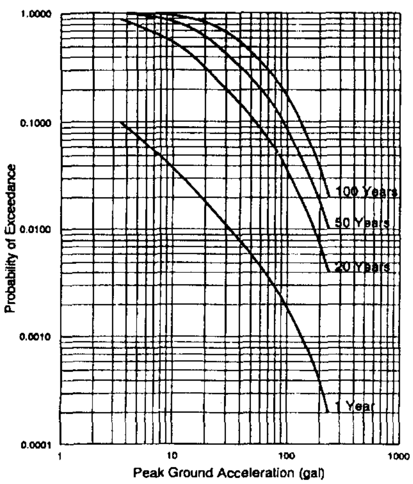


Fig. 2 Probability of exceedance of PGA(Lee, et. al.[7])

as shown in Fig. 3.

Base on these investigations, as can be seen the rate of earthquake activity in the vicinity of Hong Kong is similar to Eastern USA, and the seismic hazard of Hong Kong can be considered to be similar to that in New York state. Both areas would be rated as Zone 2A seismic region according to the zoning in Uniform Building Code (International Conference of Building Officials[5]). Thus, it can be stated that Hong Kong is located in a region of moderate seismicity.

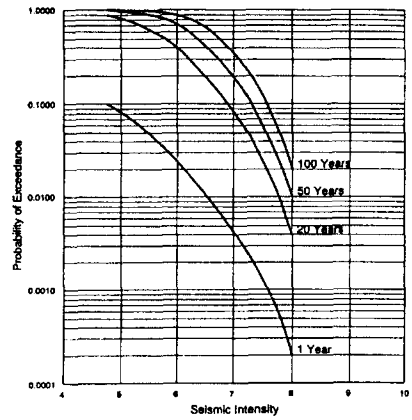


Fig. 3 Probability of exceedance of Seismic Intensity (Lee, et. al.[7])

It has been understood that in regions of high seismicity, the ground motion from a maximum credible earthquake is about double that of a 475-year return period value; while in regions of low seismicity, the ground motion from the maximum credible one can be several times larger than the 475-year return period value is then questionable for use as a design value in regions of low to moderate seismicity in order to maintain the same level of reliability under the maximum credible earthquake.

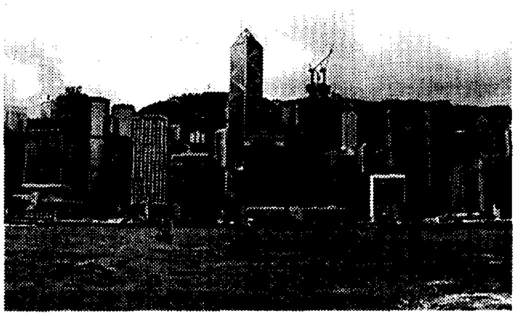
Therefore, it is more reasonable to use values from a return period which is longer than 475 years for design in regions of low to moderate seismicity. Scott, et. al.[9] suggested that the 1000-year return period value may be used in Hong Kong.

3. Current status and needs

At the present time, the earthquake preparedness in Hong Kong is relatively low, similar to many regions of moderate seismicity. However, two aspects may make the Hong Kong situation differ from other regions of moderate seismicity in the world (Tso[10]). First, the earthquake effect is not a major effect traditionally required to be considered in design of buildings and structures. Currently, official earthquake regulations do not exist in Hong Kong for design of civil structures; while structures are normally designed to carry their service loads-dead, imposed and wind loads. Second, the subject of seismic analysis and design is not yet within the standard curriculum in most civil and structural engineers trained in Hong Kong. As a result, there is lack of manpower with enough knowledge to handle the earthquake disaster problems.

Hong Kong is a densely built area, and most of commercial and residential buildings are tall buildings(Fig. 4). Considering the high density of population, which is six millions, and the extensive infrastructure built-up in the region during the past several decades, even if the seismic intensity may be low, the consequence of the earthquake could be enormous. It is the typical case of '*low probability but high consequence*' (Kuang[6]). This has been shown in the earthquake of Newcastle, Australia, in 1991, which is a relatively small earthquake (M = 5.6) but causes about 2.5 billion US dollars of dollars of damage (EEFIT 1991). Therefore, it may be the time for Hong Kong as a highly developed region to seriously consider esrthquake disaster mitigation procedures.

In Hong Kong, buildings and structures are generally required to be designed for wind load, ignoring the effects of earthquake. However, having no earthquake regulations



(a) Commercial buildings

(b) Residential buildings

Fig. 4 Typical commercial and residential buildings of Hong Kong does not imply that the lateral strength of structures in Hong Kong is necessarily low, since the place is along the typhoon path of the Pacific. What is lacking at the moment for the local engineers is the general awareness that a satisfactory design for strong wind does ont mean the design will automatically be satisfactory for earthquakes, even if for a low or moderate earthquake.

What has been missed in the past in Hong Kong is the routine checking that could be performed in some regions of moderate seismicity to show whether the wind effect is in fact the dominant effect. Fig. 5 gives two situations to illustrate this point.

A rectangular building with a high aspect ratio in plan is shown in Fig. 5(a). While the base shear from wind exceeds the base shear from earthquake many times normal to the broad side, the base shears from wind and earthquake can be comparable normal to the narrow side of the building. Fig. 5(b) shows the equivalent wind and earthquake loads acting on the structure, and Fig. 5(c) shows the comparison of the interstorey shear from wind and earthquake for tall buildings. Due to the higher modal effect, it is not uncommon that the interstorey shear at the upper part of the buildings from earthquake exceeds that from wind. Moreover, the seismic design problems in connection with buildings having "soft storey," or located in soft grounds, do not have their counterparts in the wind design.

It is very clear that there are needs to raise the effort of Hong Kong in terms of earthquake disaster mitigation:

1. to identify and classify the situations when the earthquake effect exceeds the wind effect, based on actual Hong Kong structures, and prepare a data base on these strutures for possible retrofit in the

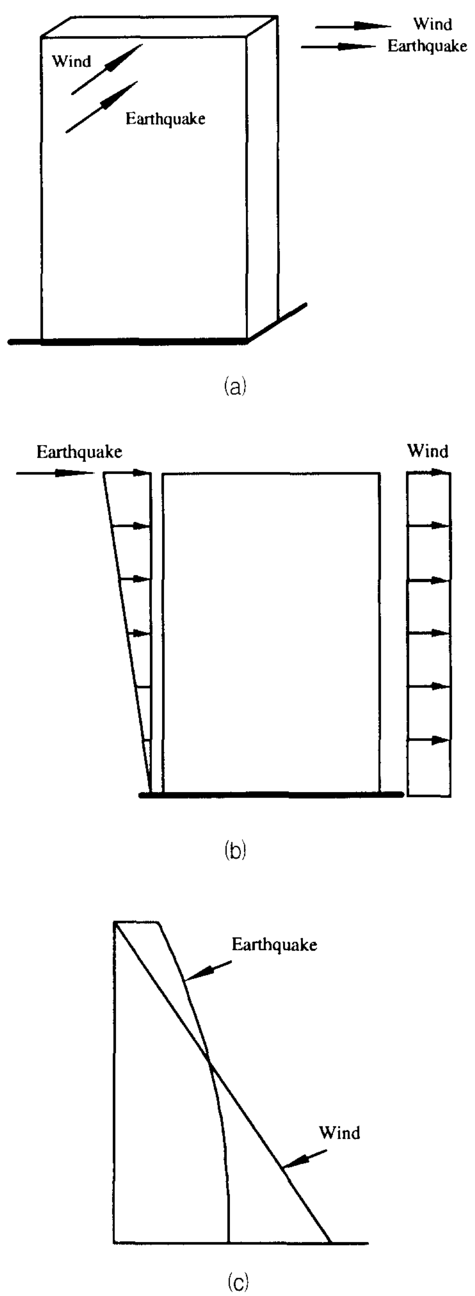


Fig. 5 (a) A rectangular building; (b) Wind and earthquake loads; (c) Interstorey shear future;

2. to evaluate the ductility capacity of Hong Kong buildings, based on currently used design and detailing;
3. to formulate a set of earthquake regulations for new constructions, based on the current practice so that the regulations can be implemented conveniently;
4. to train the current and future crop of engineers to carry out the earthquake regulations in practice;and; and
5. to develop plans and procedures to follow in case of a destructive earthquake to hit the place.

4. Comparison of wind and earthquake effects on buildings

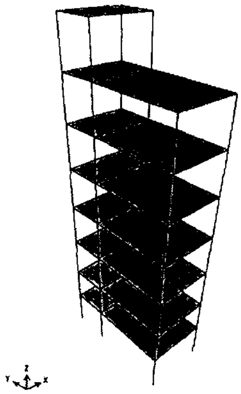
Five samples representative of reinforced concrete buildings are chosen and analysed for comparison of wind and earthquake effects on existing Hong Kong buildings (Kuang[6]), which are classified as from low-rise to high-rise buildings built in different time, and have different structural forms;

- 6-storey framed structure (21m high; 5m × 11m plan size) developed in early 1960's.
- 8-storey frame-shear wall structure (28m high; 10m × 19m plan size) developed in 1960's
- 15-storey frame-core wall structure (44m high, 17m × 22m plan size) developed in 1990's
- 22-storey frame-shear wall structure (75m high; 11m × 16m plan size) developed in 1990's
- 47-storey tube-in-tube structure (155m high; 40m × 40m plan size) developed in 1980's.

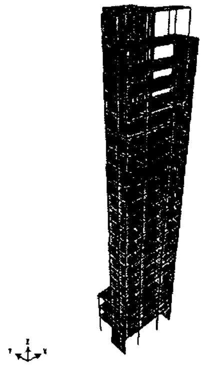
In this study, determination of wind loads on the structures follows the recommendations given by Hong Kong wind code (BDD[1]), while the earthquake forces on the buildings are calculated by 1997 UBC Code and Chinese Code GBJ11-89, respectively. Zone 2A from UBC-97 and the Seismic Intensity 7 from GBJ11-89 are considered the give the peak ground acceleration of 0.15g and 0.1g, respectively. Considering that the ground condition of Hong Kong is mainly hard clay or rock, the soil profile type Sc in UBC-97 and the site category Ⅱ in GBJ11-89 are adopted for analysis. The analysis for site conditions of the soil profile type Se and the site category Ⅳ are also carried out. In the analysis, the reduction factor $R=3.5$ for framed buildings and $R=6.5$ for wall-frames in UBC97, while $R=3$ to 4 in GBJ11-89.

The Computer programme ETABS is employed for the detailed analyses of the sample buildings, and the corresponding 3-D computer models are illustrated in Fig. 6.

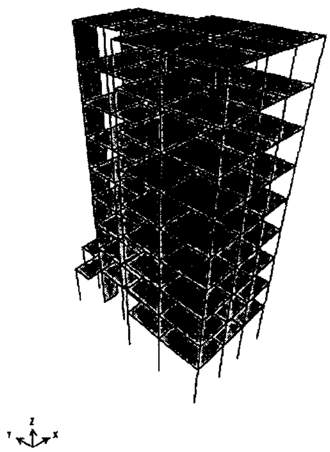
Fig. 7 shows a comparison of interstorey shears along the height of buildings caused by wind and seismic forces. It is seen that for low-rise frames or wall-frame buildings, the interstorey shear of the structures caused by seismic force is larger or much larger than that caused by wind. The seismic force will then lead to a larger overturning moment than that arising from the wind force. It is also been seen that for medium- to high-rise buildings, the interstorey shear at the upper part of the structure from earthquake generally exceeds that from wind.



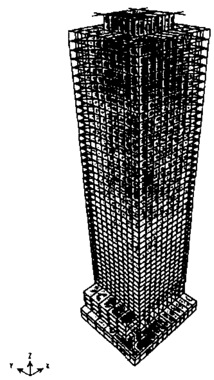
(a) 6-storey rigid-frame structure



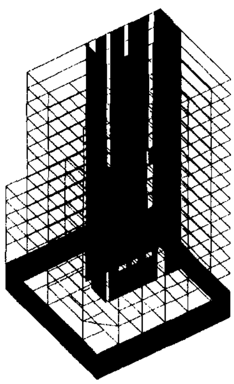
(d) 22-storey frame-wall structure



(b) 8-storey wall-frame structure



(e) 47-storey tube-in-tube structure



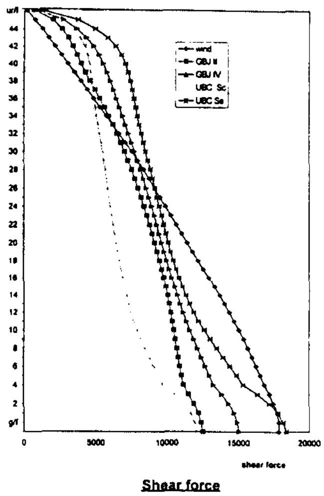
(c) 15-storey frame-core wall structrue

Fig. 6 Computer models for sample buildings

Moreover, the results of analysis have indicated that the lateral deflections of buildings caused by the moderate seismic force are smaller than those caused by wind loading. All structures can meet the deflection and storey drift requirements under the action of moderate earthquakes.

General findings from the analysis can be drawn as follows:

1. For the low-rise buildings, all structures are capable of meeting the deflection and



(e) 47-storey tube-in tube structures (45° -directions)

Fig. 7 Interstorey shear

storey drift requirements under a moderate earthquake. However, the shear and moment capacities demanded for earthquake resistance are significantly more than those for wind. These structures may perform woefully under a moderate earthquake.

2. For the medium-rise to high-rise buildings, all structures are also capable of meeting the deflection and storey drift erquirements under a moderate earthquake. The shear and moment capacities demanded at upper storeys for earthquake resistance are more than those for wind. It means that the upper parts of the structures may perform woefully under a moderate earthquake.
3. The seismic effects are even more pronounced for unequal directional stiffness.

However, the seismic forces specified in design codes are generally lower than the elastic force levels of maximum probable earthquake after introducing a suitable reduction factor, which is normally equal to the overall ductility factor. Structures are then expected to dissipate the earthquake energy inelastically, provuded that they possess a proper level of ductility. Now what has been questioned is whether the ductility capacity of structural elements, such as beams, columns and walls, with non-seismic reinforcement detailing can meet the ductility requirement for a moderate seismic design.

5. Current studies

The investigation of moderate erathquake problems and seismic design of built-up structures in Hong Kong is being carried out by the governmental building agencies and the Hong Kong University of Science and Technology. The goal of the investigation is to examine the feasibility of earthquake regula-tions for Hong Kong. Objectives of the present phase study include following aspects:

1. to assess the adequacy of existing design practice for reinforced concrete buildings of Hong Kong in resisting moderate seismic forces;
2. to recommend appropriate parameters for use at the design and analysis stagea; and
3. to recommend a steel reinforcement detailing techinque suitable for Hong Kong in order to enhance seismic performance of reinforced concrete buildings.

Details of the study include: (a) comparison of wind and earthquake effects on existing Hong Kong buildings using representative building types; (b) determination of the lateral strength and ductility capacity for the existing buildings and structural elements based on the as-built capacity; (c) determination of earthquke ductility demands and ductility capscity inherent in structural concrete members with typical Hong Kong detailing (non-seismic design detailing); (d) experimental investigation and determination of the reduction factors and ductility capacity of building elements considering the as-practised detailing and alternative new detailing approach; and (e) recommendations on the appropriate ductility capacity and reinforcement detailing for Hong Kong buildings and structures in regions of moderate seismicity.

6. Conclusions

Hong Kong is not located in the most seismic active areas in the Asia-Pacific region, but the earthquake risk of the place is not nil. The potential of a moderate seismic event does exist and could affect Hong Kong significantly. A case-study is presented to compare the wind and earthquake effects on Hong Kong buildings, which indicates that the consideration of earthquake resistance is necessary for reinforced concrete buildings in Hong Kong. From the present analysis, it is evident that it should be prudent and reasonable to adopt properly moderate level of seismic reinforcement detailing into building design practice in regions of moderate seismicity.

Considering the high density of population and the extensive infrastructure built-up in Hong Kong during the past three decades, even if the seismic intensity may be low, the consequence of an earthquake could be enormous-low probability but high consequence. Therefore, it may be the time for Hong Kong as a highly developed region, and probably for other regions of moderate seismicity in the world, to examine the feasibility of earthquake regulations and to consider seriously earthquake disaster mitigation procedures.

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