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Published by Elsevier Science Ltd 1996
Paper No. 638. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

THE RESISTANCE EARIHQUAKE DESIGN OF THE-SUPER HIGH-RISE RC BULDING STRUCTURE IN CHINA

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ABSTRACT

This paper comprebensive discusses main foundation, Optmigation of the structural system, structural analysis and structural resistance earthquake checking about the resistance earthquake design of the super high-rise RC building structure in China, controduces the experiences and points out the existent problems.

KEYWORDS

Super high-rise; reinforcement concrete; building structure; resistance earthquake design.

GENERAL DESCRIPTION

The super high-rise building in this paper means the building in excess of the suitable maximum height in《The regulation of RC high-rise building structure design and construction》JGJ3-91. When defense intensity is 6, 7, 8 degree, frame-shear, frame tube should be 130m, 120m and 100m. When the height of building exceesed the regulation, Its design should rely on reliable foundaton and adopt effecting measures.

Up to now, the high-rise over 10 floors building in China are 10000 in number and 100 million m^2 in area. Among them there are 95 buildings over 100m in height and 88 buildings of RC structure. The high-rise building over 10 million m^2 will be built annually in China. At present, finished or under design and construction, there are 60 buildings over 150m in height, of which 30 buildings are over 200m in height and 6 buildings over 300m. The tallest building under construction is Diwang Mansion in Shenzhen, 68 floors and 384m in height. Another one is Jinmao Mansion is Shanghai, 88 floors and 360m in height. The two building are RC internal tube, four side are steel frame, coulum are steel at internal still concreteor type-steel concrete. Zhangtian Mansion in Guangzhou, 88 floors and 322. 5m, it is RC tube-in-tube structure. The above-mentioned three building have the seismic defense of intensity 7. The office building of 868 Engineering in Haikou, 68 floors and 260m in height, it is RC structure, has the seimic defense of intensity 8(Men et al., 1995). The discussing resistance earthquake design of RC super high-rise structure is important in engineering and has a better economic benefit.

THE MAIN FOUNDATION OF THE RESISTANCE EARTHQUAKE DESIGN

The Design Earthquake Motion Parameter

Regulated in national standard《The Resistance Earthquake Design Code of Building》GBJ11-89, resistance earthquake defense intensity will be seicsmic intensity of foundation of the resistance earthquake defense. In generally, the seismic basic intensity is determined by《The Seimic Intensity Zoning Map of China (1990)》(1 : 400 millien). The Intensity Zoning Map used probabilistic analysis method of seismic hazard, the map gived adop time area limit and probabilistic level. Intensity value illustrates in zoning map are Intensity ralue at 10% excellence probability at 50-year in generally site condition. Seismic basic intensity, contrasting design basic sesimic acceleration value, 0. 1g in degree 7 , 0. 2g in degree 8 , 0. 4g in degree 9 , 0. 8g in degree 10 . According to the advanced experiences of some coutries . seismic intensity zoning will be replaced by earthquake acceleration plain (EPA) and EPV, EPD. (Hu, 1988)

Super high-rise building structure which need time-history analysis should have earthquake safety appraisement of the engineering site and the effect of the condition on ground mation should be ffully considered. Give seismic acceleration value, curve of accelaration and curve of response spectrum of design of major, medium and minor seismic probability, make most main foundation of resistance earthquake design.

Building Sorting Type According to Its Importance

According to the building which has effect on society and may lead up to heavy loss in national economy, if it is damaged by earthquake, the building sorting A, B, C and D type, also may call "Building Resistance Earthquake Denfense Grade Standard ". The building of type B means "the building of vital engineering in state main resistance earthquake cities", as regulated in GBJ11-89, "the building that has great effect on society and may lead up to heavy loss in national economy, if it is damaged by earthquake and needs rcorering quickly to keep its continuous function", or "the building that must maintain its normal use and meet the needs of rescue in calamities when earthquake happens, or has large number of people in it, or is of other qreate importance". According to the above principles, the super high-rise buildings may be sorted as type B, such as International Mansion with 63 floors in Guangdong, overseas trade building, 5-star hotels, monetary buildings, and commercial and office mansion with over 50000m^2 area. (GBJ11-89, 1989)

Building Site and Ground Condition

In China, the super high—rise building are constructed concentratal in Shenzhen, Shanghai, Guangzhou, Beijing, Haikou and so on. In Beijing. Guangzhou, Shenzhen, Haikou, building site and ground condition is bad, Shanghai with soft soil, Tiangjin with Liquefaction soil, Qingdao as well as Changching with hills.

In GBJ11—89, Site are sorted about resistance earthquake advantage, bad and hazard three types plat. The zonation of site plat types reflects the effects of secsmic geololgy, topography, landborms on seismic damage. According to experiences of site plat zonation in Qingdao, should be differentiate fault fracture zone and slip fracture zone, before one on resistance earquake bad, after one are no (Men et al. , 1995).

The site type determines feature period value T_g, by site soil type (soil layer shear wave speed) and site covering soil thickness. should be point to engineering building site type did not concern and type of foundation. The resistance earthquake design of super high-rise building structure may referring to ISO 3010, site effect on structure damage, it is appropriate to raise the defense standard. In the case of lower limit value Vsm and upper limit dov, for example, Vsm is 145 m/s and dov is 75m, and sit type is between Ⅱ and Ⅳ , it is suggested that this site type should be sorted as type Ⅲ , according to the practial situation to ensure the resistance earthquake reliability of super high-rise building. In GBJ11-89, it is regulated that building used resistance earthquake construction measurements, may be decreased one degree when site is type Ⅰ . In Qingdao, Chengqing etc. city, resistanc earthquake design of super high-rise building may better site condition, decreased engneering cost.

Structure Type

Super high-rise RC building structure in China there are two type, the first type are frame-shear wall and frame-tube, another type are tube-in-tube and funded tube.

Different structural type suit diferent maximurn height, value of limit heigh-width ratio, maxinterspace of expansion joint, minimum width of earthquake proof joint, value of limit deformation and grade of resistance earthquak. Different structural types are different in its pressure and deformation function. The tube structure has diffrent shear lagging feature and the zonation of its structure type has extension effect and can not be ambiguous (JGJ3-91, 1991).

Resistance Earthquake Grade of Super High-Rise RC Structure

According to above-mentioned foundation—defense intensity, importance type of building, plat and site type, structure type and building height detemined resistance earthquake grade of super high-rise RC structure. According to JGJ3-91 regulate super high-rise building should be taken into B type building account in resistance earthquake, at type I site, its resistance earthquak grade, frame-shear, frame-tube structure in degree 6, degree 7 and degree 9 is class 3, class 2, class 1, about do not I type site, in degree 6 is class 2, degree 7 and degree 8 is class1. Also, resistance earinquake grade of frame and shear wall in many number super high-rise RC huilding structure is class1. The coefficient of regulation of internal force on it' s mumber duclity required are most larg, in ratio of shear span of a beam, in ratio of normal compressive of coulum, requiremant of closed stirrup at the end of beam and coulum should be most strict.

Earthquake Simulation Vibrationtable Test

In order to know the structural resistance earthquake behavior, especially behavior of structral deformation under major earthquake, and compare with resuets of structural analysis, it is necessary to take the test of earthquake simulation vibrationtable for super high-rise building and it is feasible because of a earthquake simulation vibratontable test loot $ 20000～30000, such as International Manson with 63 floors in Guangzhou, Xianchang Mansion in Shenzhen etc (Fang et al., 1990).

THE OPTIMIZATION OF STRUCTURAL PLAN

Deformation Joint

It is shown by high-rise strueture design experiences and related research in home and abroad that setting joint in high-rise building with complex shape is of larger disadvantagc and avoid joint, the measures should be taken in architecture design, structural calculation and construction.

When earthquake happened in Tangsha, the seismic damage was not reduced in the high-rise buildings with earthquake proof joints in Beijing, Tiangin, Tangshan area. Because of the unproperly set joints the seismic damage was even worse. Shown by the seismic damage in Mexico, America and Japan, the earthquake proof joint can not surely reduce the damage. The experiences of these countries are not to set earth quake proof joint. In the high-rise buildings of complex shaps in China, the typical engineerings without earthquake proof joints are Great wall Hotel in Beijing, Huaqiao Hotel in Shenzhan, Kunlun Hotel in Beijing. By full analysis and discussion it is considered proper not to set earthquake proof joint in Bailemen Hotel in Shanghai and Chengban Hotel in Chengdu (ZHU et al., 1989).

Vertial Structural System

In the resistance earthquake design of the super high-rise RC building structure, it is requlated in code that the resistance earthquake behavior of whole structure should be ensured and the whole structure has sufficient bearing capacity, rigity and ductility. in existing design of RC high-ris structure, generally, it is surplus rigdity and insuficient ductility. The elastic displacment angle is generally small than 1/2000, the relative angles and apex displacement angles are between 1/4000 and 1/5000. Most column is short column ($Hco/hc \leqslant 4$), some of them is exytremeby-short celumn ($Hco/hc < 3$) The height of section of some frame beam and the connecting heam of shear wall are larger and hardly ensure structural ductility (Men et al. 1995).

Most RC high-rise structure have rigidity layers in their equipment layers (refugc layers) by increasing size of section of floor member and in creasing rigidity. This contradicts the basic requirement of the even chang of vertical rigidity of resistance earthquake structure, and in creases self-weight and materials and does not benefit resistance earthquake.

Floor structure

In 1980y, in Beijing, build-up board of shape-steel-concrete was used in most buildings. the prestressing board without binding are used in large scale after being used in International Mansion in Guangdong. It is the engineering of most floors that the prestressing board without binding in world. After, prestressing board without binding are used in Telecommunication Building in Fuzhou (25 floors, height 157. 0m), Ocean Shipping Center in Shenzhen (total building area 176 thousand m^2). No-binding prestressing board can lower floor height and increase usahle area of several floors and has significant economic benefit. In this case the floor horizontal rigidity decreases some what and this should be taken into account in the whole structure calculation.

Foundation Plan

In 1980y in Beijing the founiondat of most high-rise strutures were box foundation and few or pile-box pile-mat or mat foundaton. In Shanghai, Guangzhou, Shenzhen etc. most foundation are pile, some are pile-mat and few are pile-box or mat foundaton. According to the engineering experiences of Shangcheng Main Building, Jingan-Hiltan Hotel and Mingpai Mansion in Shanghai pile-mat foundation is suitable. According to the experience of International Trade Center Jing-guang Center, Jingcheng Mansion in Beijing, Zhongtian Mansion in Guangzhou and International Mansion in Guangdong mat foundation or mat-strip (frame-tube with strip foundation) is suitable in Beijing, Guangzhou, Qingdao etc. The pile foundation is suitable in Shenzhen and Haikou, pile cap and substratum for waterproofing are easy to form pile-mat foundation(Men et al. m 1995).

High-Strength Concrete and Steel-Concrete composite member

In the low floors of super high-ris RC building structure cross section of column are 2. 2×2. 2m. They are form short column or extremely short column and of low ductility and can not ensure reinforement yielding prior to concrete crushing. High-strength concrete and steel-concrete composite member has been generally used to reduce the cross section of wall and column, increase usable floor area of building and meet the needs of wall and column axial pressure ratio and bearing capability.

According to overseas experiences, high-strength concrete can be used. The typical example is Wuchan Man sion in Liaoning, which the C80 concrete core column of steel tube was taken for its frame-shear structure. Steel-tube conerete were used in the low floors of building, such as, Shangzhu Mansion in Huizhou and Post Bureau Mansion in Quanzhou. While type-steel-concrete was used in Wenjin Guangchang Mansion in Shenzhen. These experiences are worth spreading.

Index of Technology and Economy

The structural plan should be determined by general analysis and comparison of tech-economy including deformation joint, vertial structural systeme, floor structure, foundation plan and high-strength concrete and steel-concrete composite member are used etc.

According to the requirement of bearing capability, elastic displacement, elastic-plastic displacement, ductility and related construction, compression thickness in m^2 and steel consumption can be compared. According to the statistical analysis of finished building in over 30 floor buildings conerete consumption of 72% of the buiedings is 0. 4～0. 6m and steel consumption is 0. 40～0. 70 10N/m^2. The conversion thickness of Hainan Waijing Mansion is 0. 78m under ground part, 0. 42m above ground, steel consumption 1. 02 KN under ground and 0. 65 KN above ground and has a better economic index (Hu et al. m 1992).

STRUCTURAL ANALYSIS

The Model of Structural Analysis

Calculation structural mechanics creates condition for the exact calculation of complex high-rise structure, especially in space structue dynamic analysis under wind load and earthguake ground motion. Previous plate, stastic, linear and simplified calculation method is replaced by special, dynamic, nonlinear and exact calculation

method. The mechanical model of high-rise space structure has developed from rigidity floor hypothesis and wall-calumn space coordination to three-dimension special model of elastic floor, column as bar unit, wall as plate unit, from calculation analysis of structural common effect-inclouding axial force, bending moment, shear force, torsional moment and deformation to temperature stress analysis. In general, the development of super high-rise building of China requires to analyze practical pressure and deformation of structure by the method of calculation structure mechanics and the mechanical model according with practical structure. At present, The above structure analysis programs has applied in engeering design (Men et al., 1992).

The Method of Structural Analysis

In compression with ISO3010 and resistance earthquake code of Japan, the resistance earthquake effect regulated in China code is on the low side, it should be taken into accound when modify code in the future.

The basic method of horizontal earthquake effect for high-rise RC structure is response spectrum of virbration pattern decomposition The resistance earthquake analysis of super high-rise RC structure should be taken into accound in two points. The first, adopt the response spectrum of structure long period. There is special regulation in Shanghai about this, The second, the structure of torsion. Adopt response spectrum of virbration pattern oftorsion coupling connection and calculated by method of two-orthogonal horizontal move and a turning angle (CQC).

The analysis for super high-rise RC structure should be adopted time-history analysis mathod. The purpose is as follow. The first, the result by elastic time-history analysis method could compared with result by analysis method of response spectrum of virbration pattern decomposition. The final result according with practical condition could be confirmed and reinforced of member cross section sould set up. The second, adopting elastic-plastic time-history analysis method could be undstanded member yield or failure older, failure type, failure extent. Could be checked structural ductility and avoiding structural collapse in case of major earthquake and could be compared with result by test of earthquake simulation vibrationtable, could be find out property of structural resistance earthquake. At present, the program for elastic-plastic time-history analysis is adopted for the plate structure model. Qinghua university analyzei structure of Changfugong Hotel in Beijing by program TAMS, Hunan university analysis engneering of Hunan Xiangtan International Mansion by NDCAD, the institute of Architectural Resarch in China analyzed engineering of in Wu Yi garden Mansion in Xiamen. It supplies some exepriences for elastic-plastic analysis of super-high-rise structure. These experiences are worth spreading.

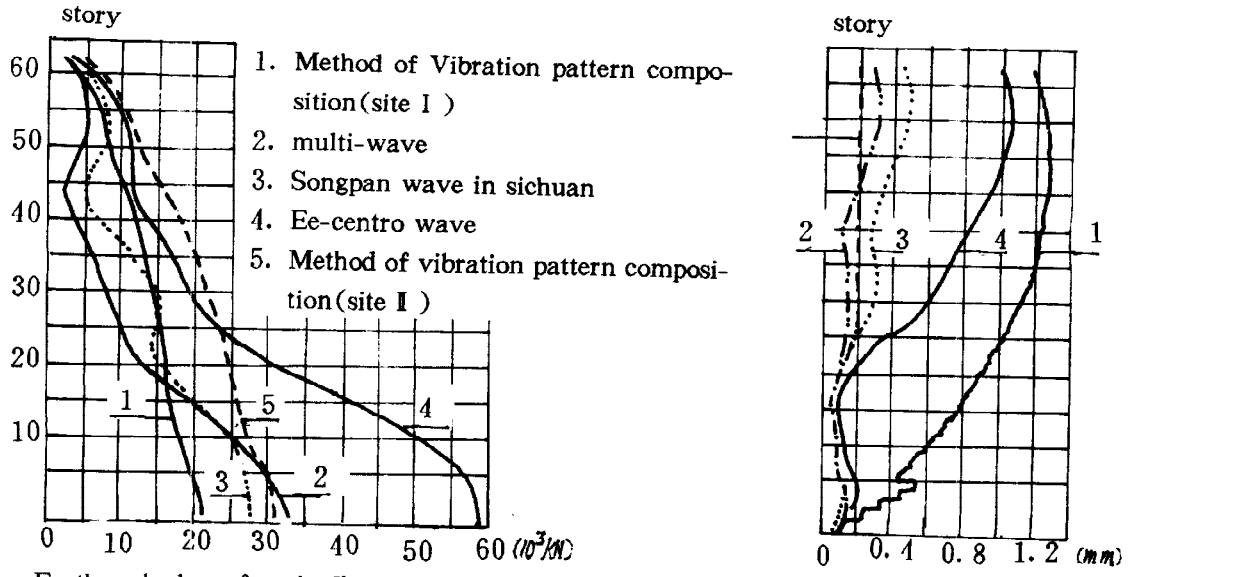
The direction Earthquake shear force in floor, relative displacment of stories in International Mansion in Guangdao with 63 floors is illustrated in Fig. 1. This engineering was analyzed by program TBSA and TBDYNA (Rong et al., 1991). The earthquake shear force in floor, elastic desplacement, elastic-plastic displacem ent of the Zhongtian Mansion in Guangzhou 80 floors main building is illustrated in Fig. 2. This engineering was analyzed by program ETABS-plus.

CHECKING OF STRUCTURAL RESISTANCE EARTHQUAKE

The Regulation of Internal Force by Reguirement of Structural Ductility

The resistance earthquake grade of most super high-rise RC building structure is class 1 or class 2. The code adopt in regulate internal force of across section of member for ensure structural cuctility. It will be realizated strong column and soft beam of frame structure and strong shear and soft curve of beam and column of frame structure and connecting beam of shear wall and stronging area of shear wall, in order to avoid brittle shear failure. Regulated design value of moment of end of frame codumn, class 1 is 1.5, class 2 is 1.25. In order to avoid column hinging, associated with large interstory sway, introduces problems of instability, which in turn may jeopardize the grarity load-carrying capacity of the structure, form structural collapse. For example strong column and soft beam of frame structure, method of regulation of intrnal force of member, design value of moment of frame column should be had follow requirement:

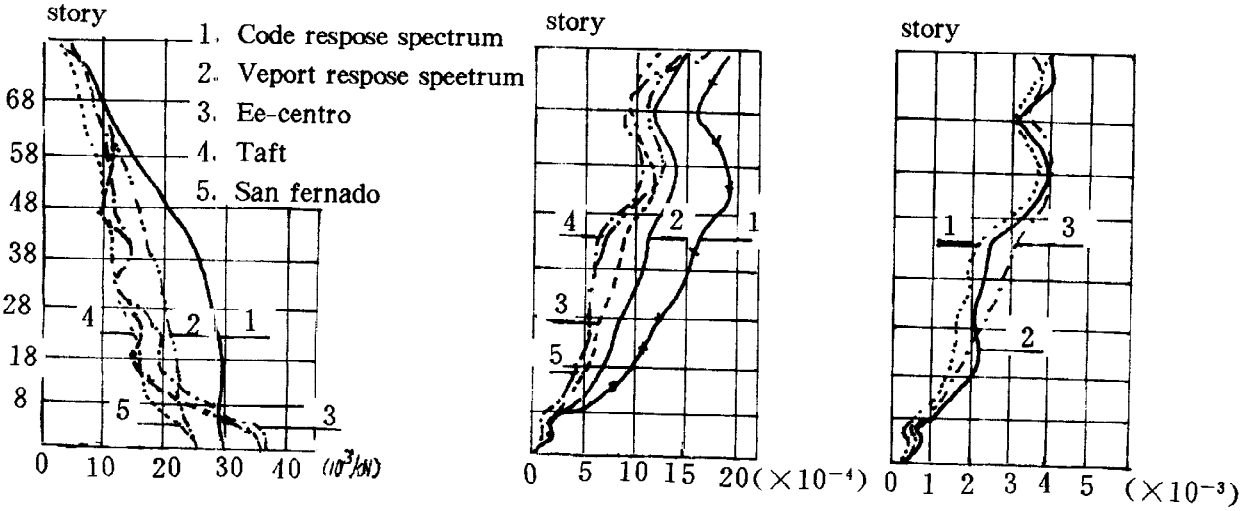
frame class 1
$$\sum M_C = 1.1 \sum M_{bua} \quad (1)$$
or
$$\sum M_C = 1.1 \lambda j \sum M_b = \eta_M \sum M_b \quad (2)$$
frame class 2
$$\sum M_C = 1.1 \sum M_b \quad (3)$$
frame class 3 and class 4
$$\sum M_C = 1.0 \sum M_b \quad (4)$$



a. Earthquak shear forc in floor

b. relative dis placement of stories

Fig. 1 The X direetion Earthquake shear force in floor, relative displacement of stories in International mansion in Guangdao.



a. Earthquake shear force

b. Elastic displacement

c. elasti-platic displacement

Fig. 2 The Earthquake shear force in floor, elastic displacement, elastic-plastic displacement of the Zhongtian Mansion in Guangzhou.

in equation, λ_j——practical setting coefficient, may be adopt 1. 1 time of ratio of practical tension reinforcement total area and area of calculating reinforce ment, increace coefficient monent of colum end $\eta_M = 1.1\lambda_j$. Anather mark in equation see GBJ11—89.

Strutural Elastic-plastic Displarcement Checking

On the super high-rise RC building structure, coording to code take into member section bearing capacity checking, According to structural "mechanism controlling heory", (Men et al., 1994) the controlling structural failure state and failure level should have some elastic-peastic deformation to from absorbing energy mechanism to meeting durablity requirement and meet the requirement of repairable under medium earthquake and no callapse under major earthquake. considering the structure to be a middle froquency structure before yielding and conforms to the principle of "absorbing energy equally", after yielding it becomes a flexible structure and conforms to the principle of equak displacement. About Frame shear wall structure, the limit relative angle of stories are $\frac{1}{100}\sim\frac{1}{150}$ under medium earthquake, limit relative angle of stories are $\frac{1}{60}\sim\frac{1}{100}$ under major earth-

quake.

CONCLUSION

The main foundation of the Resistance earthquak design of super high-rise RC structure in China are the design earthquake motion parameter, building sorting type according to its importance, building site and ground condition, structure type and earthquak simulation vibrationtable test etc.

The optimization of structural plan should be considerde to deformation joint, vertial structural system, floor structure, Foundation plan and index of technology and econemy etc.

The structural analysis should value the model of structural analysis and method of elastic-plastic time-history analysis.

The checking of structural resistance earthquake should be considered to the regulation of internal force by requirement of structure ductility and structural ductility and the checking of structure no collapse under major earthquake.

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