A BRIEF DESCRIPTION OF ASEISMIC DESIGN

CODE FOR INDUSTRIAL AND CIVIL BUILDINGS

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SYNOPSIS

This paper presents the main contents of the current aseismic design code for industrial and civil buildings in China, including the general principles, regulations concerning the selection of construction site and earthquake resistance of foundation, the evaluation of earthquake loading and some aseismic measures for various types of structures.

INTRODUCTION

In China, a good part of the territory is found to be highly seismic. About one third of the territory belongs to seismic area of earthquake intensity grade 7 or higher. According to his_torical records of about three thousand years, almost all provinces have experienced earthquakes of Richter magnitude 6 or greater. In addition, the sources of destructive earthquake were often quite shallow thus causing severe damage.

Since 1966, eight major destructive earthquakes have occurred on the continental part of China as shown in Table 1. Various technical lessons were learned from these recent earthquakes.

In this country, scientific research work on earthquake engineering has begun in the fifties, and in the sixties, a draft of design code for building design in seismic region was first studied and compiled by the Institute of Engineering Mechanics, which was formerly accepted by designers as reference for aseismic design.

As the result of a concerted effort by scientific research, design, construction units and eductational institutes, the first (tentative) aseismic design code for industrial and civil buildings was compiled and issued in 1974. A revised edition of this code was issued in 1978, which is the current code for aseismic building design. The code consists of chapters on:1) general principles;2) construction site and foundation;3) earthquake leadings and check of the aseismic strength of a structure;4) the aseismic measures of various types of structures. The code is established on the basis of information from past severe earthquakes, of experiences from scientific research, of design practice and of economic considerations. Some of the contents of

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the code are as follows:

GENERAL PRINCIPLES

Earthquake intensity

In the code, the earthquake risk of an area is estimated in terms of "basic intensity", while the aseismic designs are made on the basis of design intensity.

By basic intensity is meant the maximum seismic intensity most probable in a region within one hundred years hereafter for normal site conditions. It can be seen from this definition that the basic intensity is based on long term earthquake predictions. Earthquake intensity is graduated into 12 grades according to the Chinese intensity scale. The maximum acceleration of the ground motion to be taken for design calculations corresponding to earthquake intensity is 0.1g for grade 7, 0.2g for grade 8 and 0.4g for grade 9. The basic intensity is given on the seismic zoning map of China, which has been compiled and issued by State Seismological Bureau.

The design intensity is decided by adjusting the basic intensity in conformance with the importance of the building. In general, the design intensity of building is equal to the basic intensity. For exceedingly important buildings, the design intensity may be one grade higher than the basic intensity. For less important buildings, the design intensity may be lower than the basic intensity.

Importance of a building is classified according to their political and economical significance, the consequence of accompanying hazards as well as the requirements for the exigencies when earthquake should occur. In case of buildings for which the design intensity is to be taken one grade higher, it is necessary to report to the authorized government department for appoval.

The code specifies that aseismic design measures for buildings are needed for a design intensity of grade 7 or higher. In regions where the basic intensity is of grade 6, no aseismic measure is required except that the shape and layout plan of the building should be simple, homogeneous, symmetric; and unnecessary decoration, especially those which are apt to collapse during earthquake should be avoided; and good quality of construction should be warranted.

Design philosophy

The philosophy of aseismic design is to ensure the security of human lives and important equipments, while a certain degree of damage to the buildings are permissible so long as they are serviceable without repairing or with ordinary repairing during

earthquakes of the design intensity.

CONSTRUCTION SITE AND FOUNDATION

Selection of site

Experiences from the past destructive earthquakes show that site conditions have great effect on the earthquake damage to buildings. Hence the code specifies that with the aids of topographical and geological surveys decision should be made to the construction site as whether it is favorable, unfavorable or dangerous in regards to the earthquake resistance of buildings. Select as much as possible those sites that are favorable to construction and avoid the unfavorable site. Construction on dangerous site is not suggested.

Site conditions unfavorable to earthquake resistance are: soft soil, strip shaped ribs, dominant mountain spurs, non-rock scarps, river banks, old river beds, hidden swamps, creeks, ditches, valleys and places of partial cutting and partial filling etc.

Sites that are dangerous for buildings are: the neighbourhood of causative faults and site liable to have landslide, landslip or excessive settlement during earthquake.

These regulations are all qualitative, no quantitative index is given in the code.

Earthquake Resistance of Foundation

From the experience of destructuve earthquakes it can be seen that majority of ordinary building foundations possess reservation of aseismic capacity, and are not liable to be damaged during earthquakes, thereby no special aseismic measure is necessary, and the allowable bearing capacity of foundations under earthquake load may be raised by 25-70% depending on the nature of the soil, but no raising is allowed for soft clay.

Experiences from several destructive earthquakes further indicate that the following types of foundations are liable to suffer damages:

(1) Saturated loose sand foundation —— Due to liquefaction of saturated sand during earthquakes, the foundation is vitiated.

(2) Soft clay foundation —— The superstructure is damaged due to additional settlement and uneven settlement during earthquake.

(3) Excessively non-uniform foundation —— Additional and uneven settlements and slides occured during earthquakes

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lead to the damage of superstructure.

In the code, methods of discrimination of above mentioned three kinds of foundations and measures for their treatment are defined

For discriminating whether liquefaction of sand will occur at a site during earthquake, the standard penetrating test is recommended. In areas of intensities grade 7-9 standard penetrating tests have been performed for liquified and unliquified sand layers with a depth of 2-4 meters (averaging 3 meters) and a ground water depth of 2 meters. The critical number of blows for liquefaction has been found as follows:.

earthquake intensity	Critical number of blows by the standard penetrating test ($\bar{N}'$)
7	6
8	10
9	16

For conditions where the depth to sand layer and ground water level are other than those mentioned above, the code defines that within a range of 15 meters below the ground surface, saturated sand layers shall become liquified, when the number of blows for standard penetration $N_{63.5}$ is smaller than the value N'

$$N' = \bar{N}' [1 + 0.125(d_s - 3) - 0.05(d_w - 2)] \qquad (1)$$

where d_s is the depth to sand layer, and d_w the depth to the ground water level.

Liquefaction may take place in saturated sand with clay grains. The code specifies that if grains of diameters greater than 0.05 mm amount to more than 40% of the total weight, the possibility of liquefaction must be ascertained by testing.

In case of soft clay foundations, the code specifies a critical bearing capacity, below which the situation might be regarded as dangerous and appropriate aseismic measures are required.

According to tests on soft clay foundations in past earthquake sites, it is found that the relationship between the critical bearing capacity and the earthquake intensity is as follows:

Earthquake intensity	Possible bearing capacity
7	8 ton/meter^2
8	10 "
9	12 "

For foundations on excessively nonuniform soils such as the case of old river beds, hidden ditches or pits, places of partial cutting and partial filling etc., consideration of aseismic meas ures are required by the code.

EVALUATION OF EARTHQUAKE LOADINGS

In the code the aseismic design of a structure is based on linear elastic dynamic analysis. Since it is realized that during a destructuve earthquake, the structure may enter the plastic stage, consideration must be given to such situation in the evaluation of earthquake loading of a structure.

Two approaches of evaluation of earthquake loadings are recommended by the code, viz:

(i) Equivalent lateral force procedure;

(ii) Modal analysis procedure.

Approach (i) is recommended as the fundamental procedure, while approach (ii) is to be used only for irregular structures or those structures to which approach (i) is unapplicable.

Equivalent lateral force procedure

(a) For building of shear-beam type and with comparatively even distribution of mass and stiffness, the base shear of the structure is calculated according to:

$$Q_o = C \alpha_1 W \qquad (2)$$

and the horizontal earthquake loading corresponding to a mass point i at a height H_i of the structure is given by:

$$P_i = \frac{W_i H_i}{\sum_k^n W_k H_k} \qquad (3)$$

where W is the total weight of the structure, while W_i and W_k are the weights concentrated at points i and k whose hights are H_i and H_k respectively.

(b) For isolated chimney or similar slender flexible structure, the base moment of the structure:

$$M_o = C\alpha_1 W\bar{H} \qquad (4)$$

the base shear of the structure:

$$Q_o = v C\alpha_1 W \qquad (5)$$

The distribution of earthquake shear force and bending moment along the hight of the structure is given in Table 2. Where $\bar{H}$ is the hight of the center of gravity of the structure, and is

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given in Table 3.

Approach (a) is quite well known.

The shear force and bending moment distribution of approach (b) are based on the modal analysis of a number of reinforced concrete chimneys of hight 80-150 meters and brick chimneys of hight 20-50 meters. The first three vibration modes are taken and the shear force and bending moment in various sections at different hights of the structure are obtained by the square root of the sum of the squares rule (SRSS).

In the modal analysis, the periods and mode shapes of vibration are simplified in view of the following two conditions, which are found to be true in practice.

(i) The statistics of a number of results of calculation show that the periods T_1, T_2, T_3 of the first, second and third mode of vibration of chimneys bear the relation:

$$T_1 \cong 4.2\ T_2 \qquad\qquad T_1 \cong 9.6\ T_3$$

(ii) Generally peaking, the mass and stiffness distributions of the chimneys along the hight are roughly the same, hence their mode shapes are also roughly similar. Therefore, the average shape obtained from the calculated mode shapes of a limited number of chimneys may be considered as a good representative of the mode shape of any chimney.

Formulae (4) and (5) are the base moment and the base shear of the equivalent single-degree-of-freedom system with weight W and period T_1.

Design response spectra

The factor α specified by the code as a family of site dependent elastic response spectra, is the production of the maximum ground acceleration in terms of gravity and dynamic amplified factor of ground motion.

Based on the ground motion data in China and abroad, design response spectra for 5 per cent damping are given for 3 categories of site conditions, as shown in Fig. 1.

$\alpha_{max.}$, which denotes the maximum value of α , is given in Tab. 4,

α_l is value of α for the fundamental period T_1 of the structure.

The period T of the structure may be determined either by dynamic analysis or by field measurements on similar structures. Approximate formulae may be used. For multistory reinforced concrete frames with shear walls or solid masonry infill walls,

$$T = 0.22 + 0.035\, H/\sqrt[3]{B}$$

H is height, in meters, and B is length of frame, in meters.

Structural influence factor C

In formula (2) the product $\alpha_1 W$ is the lateral force of the equivalent (in comparison with the actual structure) SDOF system, responding elastically. According to the design philosophy of the code, the actual structure may subject to some degree of damage (crack or plastic deformation) during a strong earthquake. Consequently, a combined correction factor C is used in formula (2). This factor is essentially emperical (chosen by judgement). It covers the following factors:

(i) The ductility of the structure. For reinforced concrete structures, the ductility value is to be taken as 4-6.

(ii) The diversity factor of equivalent SDOF system from the MDOF system. This diversity factor varies in a certain range with the fundamental period as well as design spectra. According to the results of calculation made on various types of buildings, the diversity factor for single storey plant buildings is unity, for multi-storey brick buildings is 0.8 in average and for multi-storey reinforced concrete frame buildings is 0.9 in average. For chimneys the diversity factor various comparatively widely and is especially taken care of by another factor ν, leaving factor C unaffected.

(iii) The damping factor. It is considered to be 1-1.5.

(iv) Data provided by past earthquakes. Besides the factor discussed above, there are still many other factors affecting the aseismic capability of a building, which we are unable to know distinctly at present. For example, the aseismic capability of non-structural components, and the stability after the structure has been fractured. Such factors are collectively presented in the actual behaviour of the buildings during an earthquake. Therfore, in the code, the factor C for some types of buildings (single storey plant building, multi-storey brick building and brick chimney) is chosen partially out of the consideration of the data provided by the past earthquakes. For multi-storey brick buildings, if consideration is limited to its low ductility, a very high value of C must be chosen, which makes the design difficult. To obtain the proper value of C, the actual capability of resisting lateral force of multi-storey brick buildings and the corresponding earthquake loading were estimated, based on data from numerous buildings damaged or undamaged in a number of past earthquakes.

The value of coefficient C suggested by the code for various types of structures of different construction materials are given in Tab. 6.

ASEISMIC MEASURES

The main purpose of the aseismic measures is to strengthen the weak phases of the building, to enhance the integrity and the ductility of the structure, to prevent local failure or collapse in all.

The following are the essential aseismic measures for some kinds of buildings:

Brickwork buildings

Brickwork buildings are generally of 3-5 storey (in cities), with load-bearing walls and precast or cast in place concrete floor or wooden floor. The load-bearing wall is usually 24-49 cm thick, laid with mortar of cement, slaked lime and sand.

The code permits to construct brickwork buildings in the seismic zones of grade 7, 8 and 9, on the condition that the following aseismic measures are taken in the design.

The total hight of an unreinforced brickwork building is to be limited: not to exceed 19 meters in earthquake intensity grade 7, 13 meters in 8 and 10 meters in 9. For hospitals and schools, this limit can be lowered. In case this limit has to be exceeded, reinforced concrete columns must be used at the joint of interior and exterior walls. The function of the reinforced concrete columns is to restrict the brickwall so as not to collapse even after earthquake damage.

It is required to strengthen the junctions of inner and outer walls, such as by providing reinforcing steel bars, in order to prevent the outer wall from collapse outward during an earthquake.

Reinforced concrete beams along the periphery of the exterior wall are required, at appropriate different floor levels, and provision must be made to strengthen the connection between the precast reinforced concrete slabs so as to ensure the integrity of the building and to prevent the slabs from falling off.

Reinforced concrete frame building

In a reinforced frame structure earthquake damages occur most possibly in the vicinity of the joints of beams and column. The code emphasizes the importance in ensuring the ductility of the joints by increasing the number of stirrups in beams and columns within a definite range around the joint, so that a confined concrete is formed, especially within the joint.

The brittle fracture of a frame column is most dangerous. Therefore the code requires that the ductility of the column must be ensured, the spacing between the stirrups is to be limited and the steel ratio of the columns is specified. During an earthquake the lateral deformation of a frame structure is excessive, incurring damage to interior finish. Although this is not structural damage, yet it vitiates the usefulness of the building quite severely. Hence the code requires such deformation to be rendered to the minimum, by the use of aseismic walls or aseismic braces which undertake the lateral forces. Appropriate measure is to be taken to prevent the infill wall from falling down during an earthquake.

Single storey industrial plant constructions

Single storey industrial plant constructions are generally precast reinforced concrete structures. Such structures are assembled from precast roof slabs, trusses or beams, columns, etc. The integrity and stability of such assembled structure is of vital significance to earthquake resistance. Therefore, the code lays stress on enhancing the reliability of the joints and reinforcing the bracing system, so that stable spacial system is formed. For this reason, attention is called for to take the follwing measures in design and construction work:

The connection between the roof slabs and the trusses must be reliable. They must be firmly welded. Steel bars must be placed in the crevices between the slabs, which are then filled with mortar of cement, so as to increase the integrity of the assembled roof.

The joint between the truss and the column is a vital location. It must be ductile so that it would not fall off under the impact of the earthquake.

The complete system of longitudinal, lateral and vertical bracing is required to ensure even distribution of earthquake loadings.

Attention is to be paid to the integrity of the curtain walls and its connection with the main structure. Such connection must not only be strong enough but also be sufficiently ductile.

Brick chimneys

Brick chimneys are structures most liable to damage or collapse in case of earthquakes; damages might be found even in the case of a seismic intensity of grade 6; the upper half portion of a brick chimney is often damaged or led to collapse in case of grade 7-8. Such chimney may even break at its lower portion and collapse in case of grade 9.
Brick chimneys are therefore required by the code to have steel rinforcement in their upper half portion for design intensity of grade 7-8 and all over the whole hight for design intensity of grade 9.

FINAL REMARKS

The compilation and revision of the code was done under the auspices of the Chinese Academy of Building Research in coordination with a number of units concerned.

In the code, the scientific achievements and suggestions from the following main participants have been adopted:

Institie of Engineering Mechanics; Beijing Architectural Design Institute; North-Western Architectural Design Institute; The General Institute and 1st Institute of Plant Design, The 1st Ministry of Machine Buildings; The General Research Institute of Building and Construction, MMI; Department of Geotechnical Exploration , The Beijing Municipal Bureau of City planning; Sichuan Provincial Building Research Institute; Harbin Civil Engineering Institute; and others.

Mention must be made of Prof. Liu Hui-hsien for his important contribution to the development of the code.

The code is approved by the State Capital Construction Commission, China.

REFERENCE

I.   The Aseismic Design Code For Industrial and Civil Buildings (TJ 11-78), Beijing,1979.

Table 1. Recent destructive earthquakes occurred on
the continental part of China

No	Earthquake	Date	Epicenter	Magnitude	Intensity
I	Xingtai (province Hebei)	8th Mar. 1966	37° 21' N 114° 55' E	6.8	9
		22nd Mar.1966	37° 30' N 115° 05' E	6.7	9
		22nd Mar.1966	37° 32' N 115° 03' E	7.2	10
2	Tonghai (Province Yunnan)	5th Jan. 1970	24° 12' N 102° 41' E	7.7	10
3	Luhuo (Province Sichuan)	6th Feb. 1973	31° 30' N 100° 24' E	7.9	9 - 10
4	Daguan (Province Yunnan)	5th Nov. 1974	28° 12' N 104° 06' E	7.1	9
5	Haicheng (Province Liaoning)	4th Feb. 1975	40° 42' N 123° 0' E	7.3	9
6	Longling (Province Yunnan)	29th May 1976	24° 24' N 98° 42' E	7.5	9
		29th May 1976	24° 24' N 98° 48' E	7.6	9
7	Tangshan (Province Hebei)	28th July 1976	39° 24' N 118° 06' E	7.8	11
		28th July 1976	39° 42' N 118° 48' E	7.1	9
8	Songpan (Province Sichuan)	16th Aug.1976	32° 42' N 104° 06' E	7.2	9
		23nd Aug,1976	32° 30' N 104° 12' E	7.2	9

Table 2. Distribution of lateral loading of Chimney

Schematic shetch of structure	Distribution of bending moment	distribution of shear force
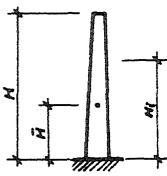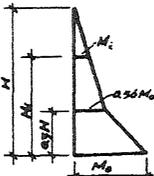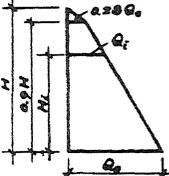
Table 3. Factor v

Category of site	T_1 (sec.)							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	v							
I	0.83	1.26	1.00	0.39	0.77	0.70	0.65	0.61
II	0.65	1.03	1.26	1.07	0.96	0.89	0.80	0.74
III	0.55	0.62	0.74	0.90	1.08	1.23	1.26	1.16

Table 4. Value of α max.

Design intensity	7	8	9
α max.	0.23	0.45	0.90

Table 5. Category of site

Cetegory of site	Description of soil profile
I	Stable bed-rock
II	Ordinary stable soil other than those belong to categories I and III.
III	Saturated loose sand, mud and muddy soil, hydraulic-fill soil and other soft and loose manually back-filled soils.

Table 6. Structural influence factor C

Types of structures	C

Frame structure
    steel
    reinforced concrete
	
	0.25
	0.30

Frame with aseismic wall or aseismic brace	 0.30-0.35
Shear wall	0.35-0.40
Unreinforced masonry	0.45

Single storey plant structures
    steel
    reinforced concrete
    brick
	
	0.30
	0.35
	0.40

Chimneys, and tall slender structures
    steel
    reinforced concrete
    brick
	
	0.35
	0.40
	0.50

Timber structures	0.25

Site category I $\alpha = 0.2\alpha_{max}/T$

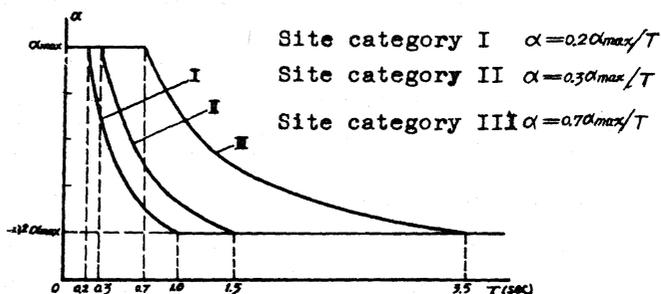Site category II $\alpha = 0.30\alpha_{max}/T$

Site category III $\alpha = 0.70\alpha_{max}/T$

Fig. 1. Design Response Spectre