FOLLOW-UP OF NEW EARTHQUAKE RESISTANT
REGULATIONS FOR BUILDINGS IN JAPAN

H. Umemura (I)
M. Watabe (II)
Y. Ishiyama (III)
T. Fukuta (IV)
Presenting Author: H. Umemura

1. INTRODUCTION

This paper has been submitted in the hope that researchers and engineers involved to revise of draft the earthquake resistant regulations may make use of our experience introduced herein as the leader or promoters of changing drastically the Japanese national building code for aseismic design.

In the past fifty years, the Japanese national building code for aseismic design had been based upon the statically oriented philosophy, which had resulted the code to have been one of the most obsolete ones in the world. For the purpose of reflecting up to date technology of earthquake engineering into the new national building code, the research and development project led by our Institute had been conducted since 1972 for five years supported hundreds of researchers and engineers from universities and engineering companies. The draft of the code had been proposed in 1977. It took about three years to put this proposed draft of the code into the practical final code, after getting consensus of administrators, practical engineers and researchers, through the committee promoted by authors. The revised New Code was finally enforced in June, 1981.

This paper introduces, first basic concept of the New Code. The post surveys on the situations, problems and impacts to the related communities arised through the implementation of the New Code, are introduced.

The concepts of the New Code have been reflected in the revised or newly issued earthquake resistant regulations or requirements for various related facilities other than building. These regulations are introduced as well.

2. BASIC CONCEPT OF THE NEW CODE

Basic concept and structure of the New Code are introduced here, more in details, refer literature [1].

2.1 Expected Aseismic Capacity

Two basic conditions are required; i) buildings shall withstand elastically against moderate earthquake ground motions which are anticipated to be subjected at the site several times during the use of the buildings and,

---

(I) Professor, Shibaura Institute of Technology
(II) Director, International Institute of Seismology and Earthquake Engineering(IISEE), Building Research Institute, Ministry of Construction
(III) Head, IISEE, Building Research Institute, Ministry of Construction
(IV) Research Staff, IISEE, " , "

ii) shall not collapse nor harm human lives during severe earthquake motions which are anticipated to be subjected at the site less than once during the use of the buildings.

To satisfy the above two conditions dual modes of earthquake resistant designs are in general required. (refer 2.6)

2.2 Lateral Seismic Shear

The lateral seismic shear, Qi of the i-th story above the ground level can be expressed followingly;

$$eQi = eCi \cdot Wi = Z \cdot R_t \cdot Ai \cdot eCo \cdot Wi$$

$$uQi = Ds \cdot Fes \cdot uCi \cdot Wi = Ds \cdot Fes \cdot Z \cdot R_t \cdot Ai \cdot uCo \cdot Wi$$

where, eQi = lateral seismic shear force of the i-th story for moderate earthquake ground motions, and stresses due to this force must be less than yielding stresses of the structural members (for elastic design).

uQi = lateral seismic shear force of the i-th story for severe earthquake ground motions, and the required shear force must be less than ultimate lateral shear strength of the building structure (for ultimate strength design).

Wi = the weight of the building above the i-th story.

eCi = the lateral seismic shear coefficient of the i-th story for elastic design.

uCi = the lateral seismic shear coefficient of the i-th story for ultimate strength design.

eCo = 0.2; the standard base shear coefficient for elastic design.

uCo = 1.0; the standard base shear coefficient for ultimate strength design.

$Z \cdot R_t \cdot Ai \cdot Ds$ and Fes are defined in the subsequent 2.3.

2.3 Various Coefficients

i) Z is the seismic hazard zoning coefficient, the value of which varies between 1.0 and 0.7. Along Pacific Ocean side of Japan Island, there lies the zone of Z equal 1.0.

ii) R_t is the design spectral coefficient, which is determined by the type of subsoil conditions (hard, medium and soft) and fundamental period of the building (T sec.), as illustrated in Fig. 1.

iii) Ai is the lateral shear distribution factor, which is the function of fundamental period of the building (T sec.) and non-dimensionalized weight parameter α_i as shown below and illustrated in Fig. 2.

$$A_i = 1 + \left(\frac{1}{\sqrt{\alpha_i}} - \alpha_i \right) \frac{2T}{1+3T}$$

α_i = Wi/Wn, where Wi is the weight above the i-th story and Wn is the weight above the ground level of the building.

iv) Ds is the structural coefficient only for ultimate strength design representing energy absorptive capacity of the building structure related with ductility and damping for each story. The range of the value is between 0.25 (the most ductile) and 1.0 (non-ductile). Some example is shown in Table 1.

v) Fes is the shape factor only for ultimate strength design determined as follows in each story and direction;
$Fes = Fe \cdot Fs$
where Fe is a function of eccentricity of stiffness Re and Fs is a function of variation of lateral stiffness along the height Rs, both of which are defined in the equations below, in Table 2-a and Table 2-b; $Re = e/r_e$, $Rs = \theta/\bar{\theta}$
where e is the eccentricity of the center of stiffness from the center of mass, r_e the elastic radius, which can be defined as the square root of torsional stiffness divided by the lateral stiffness, θ lateral stiffness which is represented by inverse value of story drift angle and, $\bar{\theta}$ the mean lateral stiffness, which is defined as the arithmetic mean of θ's above the ground level. These values are defined for each story.

vi) Fundamental period T(sec.) can be estimated by an appropriate procedure or by the following equation;
$T = h(0.02 + 0.01 \cdot p)$ (sec.)
h = the height of the building in meter.
p = the ratio of the total height of stories of steel structure portion to the height of the building.

2.4 Lateral Seismic Shear for Underground Etc.

i) The seismic design coefficient of basement K, is determined followingly
$K \geqq 0.1(1-H/40) \cdot Z$
where
H = the depth of the basement in meters and in case the depth is deeper than 20 meters, the value of H is fixed at 20. Z is defined in 2.3, i).

ii) The local seismic design coefficient K, for such as penthouse, parapet, tower and cistern, is 1.0, the value of which however can be reduced to 0.5 in such a case where no harm to human lives is expected. No ultimate strength designs are required for item i) and ii).

2.5 Story Drift Limitation

The drift of each story of the building must be less than 1/200 of story height for elastic design, the value of which can be increased up to 1/120, if the nonstructural members can be proved to be flexible enough at the increased story drift limitation.

2.6 Design Procedures

Some buildings which are not necessarily satisfy ultimate strength design requirements or story drift limitation are specified in i) and ii) below.

i) Design Procedure A requires some details of structural members and those assemblies and elastic design for buildings specified below;

- One of two story wooden buildings not exceeding $500m^2$ in total floor area.
- Buildings not exceeding 20m in height of R.C. or steel encased R.C. structure which satisfy the following formula in each story;

  $25 \cdot \Sigma Aw + 7 \cdot \Sigma Ac + 10 \cdot \Sigma A_c' > Z \cdot Ai \cdot Wi$

  A : horizontal cross-sectional area in cm^2

  Suffix c : R.C. column, $'_c$: steel encased column

  w : wall

  Z, Ai and Wi are defined in 2.2 and 2.3.

ii) Design Procedure B requires Design Procedure A plus story drift limitation for elastic design and eccentricity and stiffness requirements; $Re < 0.15$ and $Rs > 0.6$ refer 2.3, v).
This procedure is for such buildings specified below;

- Steel structure whose increased lateral seismic shear Qb for elastic design is $Qb = (1 + 0.7\beta) \cdot eQi$

  where,

  β = the ratio of the lateral shear for braces to the total lateral seismic shear of the story. The value of $(1+0.7\beta)$ need not exceed more than 1.5.

  eQi = lateral seismic shear for elastic design prescribed in 2.2.
- R.C. or steel encased R.C. structure which satisfy the following formula in each story

  $25 \cdot \Sigma Aw + 7 \cdot \Sigma Ac + 10 \cdot \Sigma A_c' \geqq 0.75 \cdot Z \cdot Ai \cdot Wi$ or

  $18 \cdot \Sigma Aw + 18 \cdot \Sigma Ac \geqq Z \cdot Ai \cdot Wi$

  where Aw, Ac, A_c', Z, Ai and Wi are the same in 2.6, i).

iii) Design Procedure C requires elastic and ultimate strength design and story drift limitations for any types of buildings whose height is less than 60 meters.

iv) Design Procedure D requires time history dynamic analysis for two levels of input earthquake ground motions and the procedure must be reviewed by the special committee appointed by Minister of Construction.

3. FOLLOW-UP OF POST EFFECTS IN VARIOUS ASPECTS

3.1 Design Procedures

The percentage of the number of buildings to the total number of 159 buildings applied by design procedure A, B, C or D (or others) is 39%, 29%, 26% and 6% respectively in some big construction company in the year of 1982, while in terms of the percentage of floor area to the total floor area of 571500 m^2, for design procedure A is 12%, for B, 28%, for C, 50% and for D (or others), 10%.[2] The results of the similar analysis on the number of approval applications to Tokyo Metropolitan Administration Office are tabulated Table 3.[2]

3.2 Inpact of the Cost in Construction and Structural Design

According to the preliminary study on the construction cost influence by the New Code prior to it's enforcement, one to two percent increase of structural construction cost was predicted [3], as compared with the one designed by the previous code which required only elastic static design with the equivalent lateral base shear of the New Code. A professional engineer investigated this cost influence [2], the results of which are indicated in Table 4-a and 4-b. It can be concluded from these tables that for R.C. buildings, almost the same cost with the total structural cost by the previous code may be expected, while for steel encased R.C. structure, a few percent of cost up may have to be considered.

Comparing the required work hour of structural design by the previous code with the one by the New Code, 10~20% up by design procedure B and 50~100% up by design procedure C are reported [2].

3.3 Educational Activities and Questions on the Practical Applications of the New Code to Various Structures

Extensive educational activities have been promoted since a few years prior to enforcement of the New Code, up to present, in order to disseminate the objectives, basic philosophies and practical applications of the New Code approximately 35000 engineers have participated to lectures held by public organizations supported by Ministry of Construction. The specific lectures for administrative engineers have been held in the scope of nation-wide. A set of slides and cassette tape with text book to explain basic concepts of the New Code has been published and the number of the audiences are estimated to be approximately 50,000. For wider and effective dissemination, visual and audio communication means, such as colour slides, cassette and video tapes are recommended.

In spite of these educational activities, various questions concerning the contents and practical applications of the New Code have been asked. Although not all of these questions, answers could be given to, great efforts have been paid to answer the questions. Summary of questions are introduced below.

i) In general; criteria to calculate ultimate lateral shear strength, structural coefficient Ds, criteria to calculate torsional effect, interpretation of Ai, T for buildings on the slope or of twin towers, distribution of seismic shear for the structure in which rigidity of slab can not be expected and explanation of transmission of local lateral seismic shear force to main structure.

ii) On steel structure; design of beam-to-column connection, design of connection of diagonal braces to the frame members, relation between local buckling and width-thickness ratio, interval of lateral bracing and design of column base.

iii) On R.C. structure; effect of slab reinforcing bars to the ultimate bending strength of beam, shear-reinforcing design of column and beam, shear wall with openings, practical design criteria for shear wall, spandrel wall and side-wall.

3.4 Consistency of Various Coefficients in Practical Design

Though extensive trial designs according to the New Code were carried out, prior to the enforcement and most of coefficients have been satisfactorily accepted, some complains on inconsistency of some coefficients have been reported after the enforcement. Coefficient Fe (in terms of eccentricity of stiffness) is complained to be a little too severe by practical structural designers, while coefficient Fs (in terms of variation of lateral stiffness along the height) seems to have been not so effective as was expected. Among coefficients, the best accepted and reported to be well fitting coefficient to the results by dynamic analysis is Ai-lateral shear distribution factor.

In the draft of the New Code, importance factor I was included, however in view of the principle of national code that should provide the lowest allowable potential to the anticipated loading to leave the decision of designers to increase its potential, this factor I was deleted from the New Code. This caused some confusion in designing tall buildings, due to the discrepancy of base shear coefficient among buildings lower than 60 meters designed by design procedure C and higher than 60 meters designed by design procedure D which, in general, requires for larger base shear by reviewers considering importance factor as a high-rise building. In order to solve this problem, additional technical notification is urged to be issued.

4. EARTHQUAKE RESISTANT REGULATIONS FOR THE RELATED FACILITIES

Several earthquake resistant regulations or design manuals were revised or issued in accordance with the New Code. The new earthquake resistant design criteria for foundations and piles, revised regulations on building equipments and facilities, water tank of fiber reinforced plastic, elevators, and chimneys have been issued. Some modifications were also made on Regulatory Guide for Aseismic Design of Nuclear Reactor Facilities. The common trends of these related codes or manuals are; (i) higher lateral seismic shear force in upper part of the building structure than by the previous codes or manuals, (ii) consideration of the effect of story deflection of the building, (iii) dual mode design for two levels of earthquake ground motions with the concept of ductility and ultimate strength.

REFERENCE

[1] International Association for Earthquake Engineering, "Earthquake Resistant Regulations, A World List", 1984. Association for Science Documents Information.

[2] T. Hisatoku, Y. Tagoku, S. Mukasa, S. Aihara, "Trends of the New Code." Journal of Architecture and Building Science, Architectural Institute of Japan. P12, 19, 21, 26, Vol.98, No. 1207, May, 1983.

[3] K. Nakano et al, "On the object postulate for earthquake resistant code." 9th Joint Meeting UJNR Panel on Wind and Seismic Effects, 1977.

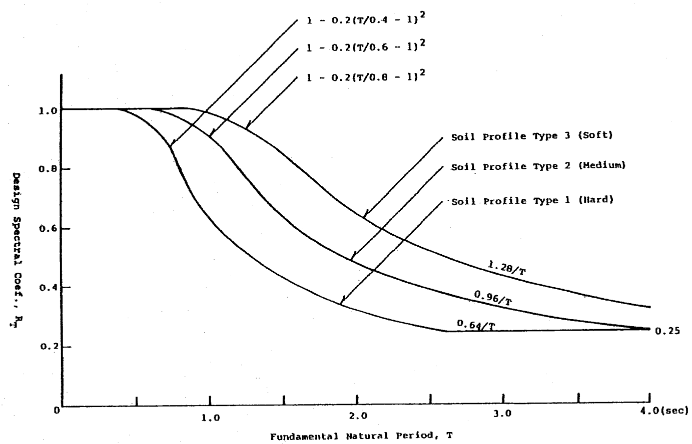

Fig. 1 Design Spectral Coefficient, R_t

Through the precise analysis of the structure, the foundation, the value of R_t can be reduced to 0.75 of the value given by this figure. But the value shall not be less than 0.25.

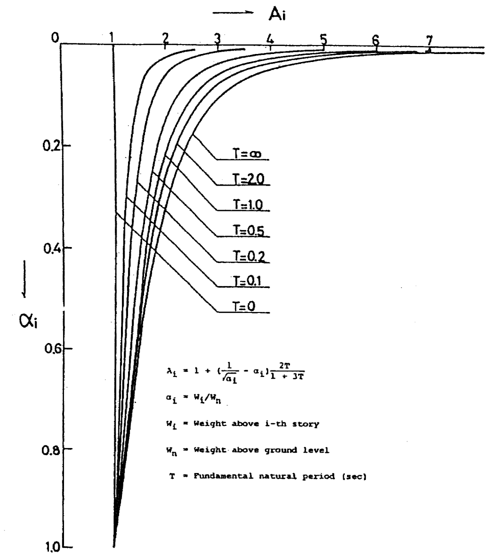

Fig. 2 Lateral Shear Distribution Factor, Ai

Table 1. Example of Ds Value for Steel Structure

Type of Beam-and-Column Component	Moment Frame	Braced Frame: Type of Brace Component A	B: $\beta u \le 0.3$	B: $0.3 < \beta u \le 0.7$	B: $\beta u > 0.7$	C: $\beta u \le 0.3$	C: $0.3 < \beta u \le 0.5$	C: $\beta u > 0.5$
A*	0.25	0.25	0.25	0.3	0.35	0.3	0.35	0.4
B*	0.3	0.3	0.3	0.3	0.35	0.3	0.35	0.4
C*	0.35	0.35	0.35	0.35	0.4	0.35	0.4	0.45
D	0.4	0.4	0.4	0.45	0.5	0.4	0.45	0.5

* : Each beam to column connection should not be ruptured by the full plastic moment of the beam and column. The connections of each brace should not be ruptured by its axial yield strength. And the slenderness ratio of each beam around the weak axis should be less than 170+20n (SS41) or 130+20n (SM50), where n is number of lateral supports in the beam.

** : βu is the ratio of the lateral shear capacity of braces to the total lateral seismic shear capacity of the story.

Table 2-a Coefficient Fe

Re	F_e
less than 0.15	1.0
$0.15 \leqq R_e \leqq 0.3$	linear interpolation
more than 0.3	1.5

Table 2-b Coefficient Fs

R_s	F_s
more than 0.6	1.0
$0.3 \leqq R_s \leqq 0.6$	linear interpolation
less than 0.3	1.5

Table 3. Ratios of Design Procedures

	Ratio (%)	Type of Structure			
		SRC	RC	S	CB
Design Procedure A	29.5	1.0	18.5	8.5	1.5
Design Procedure B	34.7	5.7	15.0	14.0	-
Design Procedure C	33.6	24.8	7.3	1.5	-
Design Procedure D	2.2	0.2	-	2.0	-

SRC:Steel encased reinfored concrete structure
RC:Reinforced concrete structure, S:Steel structure
CB:Concrete block structure

Table 4. Cost Influence by the New Code

a - RC Structure

	Number of Data	C (m^3/m^2)	F (m^2/m^2)	R (ton/m^2)
By Previous Code	17	0.683	4.38	0.094
By New Code	8	0.675	4.28	0.095
By New Code / By Previous Code	-	0.99	0.98	1.01

C : Volum of Concrete, F : Area of forms
R : Weight of reinforcement bar

b - Steel Encased RC Structure

	Number of Data	C (m^3/m^2)	F (m^2/m^2)	R (ton/m^2)	S (ton/m^2)	R + S (ton/m^2)
By Previous Code	54	0.667	4.11	0.079	0.052	0.131
By New Code	16	0.681	4.15	0.081	0.060	0.141
By New Code / By Previous Code	-	1.01	1.01	1.03	1.15	1.08

C : Volum of Concrete F : Area of forms
R : Weight of reinforcement bar S : Weight of steel