# Design seismic motions and wind loads for 1000 m high, 1000 year use building

# Design Seismic Motions and Wind Loads for 1000 m High, 1000 Year Use Building

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## Summary

Construction of 1,000-meter-high hyper buildings for 1,000-year use having a total floor area of 10 million square meters in Japan requires studies on structural safety against earthquakes and winds. In this study, flowcharts for checking the structural safety of hyper buildings taking into consideration their characteristics, namely height and service life, were proposed, through comparison with typical flowcharts for high-rise buildings. Target performance and methods for determining design values of seismic and wind loads were also studied. This paper presents the basic concepts thus developed, along with a list of subjects of further study.

## 1. Introduction

Starting in 1995, a group of organizations including the Ministry of Construction, the Building Center of Japan, general contractors, and design firms conducted a two-year joint study as a step toward the realization of the scheme for hyper buildings, which are 1,000 m high and have a service life of 1,000 years and a total floor area of 10 million square meters. The study covered 13 fields of research, and the subject of design ground motions and wind loads was adopted as one of them.
Needless to say, a 1,000m-high building for 1,000-year use requires a more comprehensive structural safety evaluation than a conventional 300m-high 100-year-or-so-useful-life high-rise building does.
In this study, considering the construction of hyper buildings in Japan, methods for evaluating their structural performance and target structural performance are proposed. An example of calculation of a measure of safety common to seismic loads and wind loads is also presented. Finally, the basic concepts of seismic- and wind-resistant design and flowcharts for the proposed design procedures are presented.

## 2. Basic concept of structural safety

### 2.1 Image of a hyper building

Structural safety of a hyper building is considered for its three major components: main structure, secondary structure, and infrastructure. The main structure is the part of the hyper building that is supposed to remain unchanged in performance throughout the service life of the building. The secondary structure is any structure inside the main structure that may be changed, often more than once during the service life of the building, depending on performance requirements. The infrastructure is the part of the building that supports the circulation of people, vehicles, energy, and the like and computer-based control functions and is therefore subject to change depending on the performance needs of the time.

### 2.2 Flowchart for structural performance evaluation

Structural performance evaluation of hyper buildings requires a life-cycle approach because the construction period and service life of hyper buildings are longer than those of conventional high-rise buildings.
A flowchart for a life-cycle structural performance evaluation of hyper buildings against ground motions and wind loads is shown in Fig. 1.

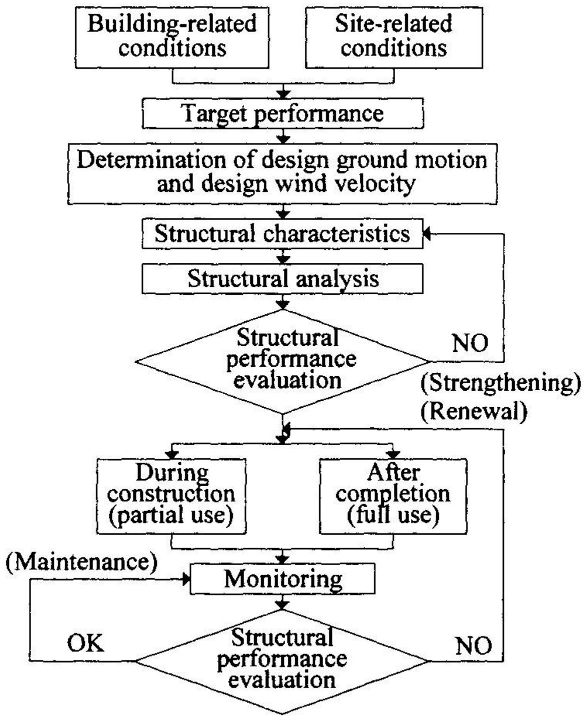


*Fig.1 Flowchart for life-cycle structural performance evaluation of a hyper building*

### 2.3 Target performance

The target performance of a hyper building is its ability to remain safe, restorable, and functional against natural and artificial phenomena that can occur during the assumed service life of 1,000 years. From the engineering point of view, it is considered reasonable to determine load conditions needed for structural design by statistically treating data on past natural and artificial phenomena and estimating phenomena which can take place in future. Specific target performance of each component of a hyper building for the three purposes that the building must fulfill is shown in Table 1.

*Table 1 Definitions of target performance of hyper building by key word*

| Load category | | L | P | F |
|---|---|---|---|---|
| Key word | | Safety | Restorability | Functionality |
| Purpose | | Protect life | Protect property | Maintain functions |
| Target performance | General | The structure neither collapses nor undergoes lifethretening damage under the maximum load expected during the service life of the main structure. | The secondary structure undergoes only minor damage under the maximum load expected during the service life of secondary structure. | The building is able to maintain its functions without making users feel uncomfortable under loads expected about once in several years |
| | Main Structure | The main structure behaves,for the most part,elastically under loads expected two or more times during the service life of the main structre. | The main structure responds elastically. | Attainment of habitability goals |
| | Secondary Structure | The secondary structure neither collapses nor undergoes life-thretening damage. | Mostly elastic response<br>Minor repairs | Attainment of habitability goals |
| | Infra-structure | Rescue and evacuation are possible. | Easy restoration | Normal traffic, communications,etc. |

## 2.4 Calculation of design load based on optimum reliability and checks of structural safety

### *1) Optimum reliability index*

Using Kanda's method,[1] the optimum reliability index $\beta_{OPT}$ is calculated from the equation

$$\beta_{OPT} = -\alpha_Q V_Q + \sqrt{(\alpha_Q V_Q)^2 + 2\ln(\frac{g}{\sqrt{2\pi}\kappa\alpha_Q V_Q})}$$

where $\alpha_Q$ : separation factor
$V_Q$ : coefficient of variation of load effect
$g$ : normalized failure cost
$\kappa$ : normalized cost ratio

The design load $X_D$ can be given as

$$X_D = \exp(\alpha_Q \beta_{OPT})\mu_{QT}$$

where $\mu_{QT}$ is the mean value of maximum loads per T years.
In this study, $\alpha_Q$=0.85, $g$=2, and $\kappa$=0.05[2] are assumed for both seismic loads and wind loads.

### *2) Seismic load*

The means of maximum values per 50, 100, and 1,000 years for ground surface velocity in Tokyo and Osaka were calculated, using Kanda's distribution parameters. The design ground motion velocity $V_D$ based on the optimum reliability index was then calculated accordingly.
The mean $\mu_{QT}$ of the maximum values per T years of ground surface velocity and the optimum design ground motion velocity $V_D$ for each site are shown in Table 2.

### *3) Wind load*

The Gumbel distribution parameters for the annual maximum wind velocity at each site were calculated on the basis of Nakahara et al. (1984).[3] Then, the mean of the maximum values of the basic wind velocity (ground roughness category II for open space such as rural district, 10 m above ground surface) and the coefficient of variation at each site were calculated. For the evaluation of optimum reliability, dynamic pressure, which can be regarded as the load effect, was used, and the optimum design value was converted to a basic design wind velocity.
The coefficient of variation of the basic wind velocity was assumed to be

$$V_Q = \sqrt{(V_V^2 + 0.2^2)}$$ [4]

using the coefficient of variation, $V_V$, of the maximum value per T years.
The mean $\mu_{QT}$ of the maximum values per T years of ground surface velocity and the optimum design basic wind velocity $U_D$ at each site are shown in Table 3. Since no upper limit is imposed on load values as in the case of seismic loads, the design load increases as the service period becomes longer.

### *4) Checks of structural safety*

The probability of exceedance during the service period for each component is established, and structural safety is checked accordingly.

*Table2 Mean of maximum values per T years of ground surface velocity and optimum design ground motion velocity (unit:cm/s)*

| T \ Site | 50 | | 100 | | 1000 | |
|---|---|---|---|---|---|---|
| | $\mu_{QT}$ | $V_D$ | $\mu_{QT}$ | $V_D$ | $\mu_{QT}$ | $V_D$ |
| Tokyo | 14.8 | 41.3 | 17.8 | 44.6 | 21.9 | 50.6 |
| Osaka | 11.2 | 52.6 | 16.5 | 69.9 | 45.9 | 135.5 |

*Table3 Mean of maximum values per T years of basic wind velocity and optimum design wind velocity (unit:m/s)*

| T \ Site | 50 | | 100 | | 1000 | |
|---|---|---|---|---|---|---|
| | $\mu_{QT}$ | $U_D$ | $\mu_{QT}$ | $U_D$ | $\mu_{QT}$ | $U_D$ |
| Tokyo | 40.5 | 65.0 | 43.4 | 69.1 | 52.7 | 82.8 |
| Osaka | 46.7 | 76.9 | 50.8 | 82.7 | 64.4 | 102.5 |

## 3. Design ground motion

Because of the height and service life of hyper buildings which far exceed conventional ones considered for current seismic design practices, a study was undertaken for the development of a flowchart for the seismic design of a hyper building. The flowchart thus developed is shown in Fig. 2.(The steps common to seismic design and wind-resistant design are omitted, and only the steps between C and D in Fig.4 is shown)

The most important technical consideration in seismic design is how to determine the design ground motion. Therefore, various design input ground motions specified or proposed by laws, academic societies, or other institutions[5], and studies on source processes were examined, and a framework for the evaluation and determination of design ground motion was developed (Fig. 3).

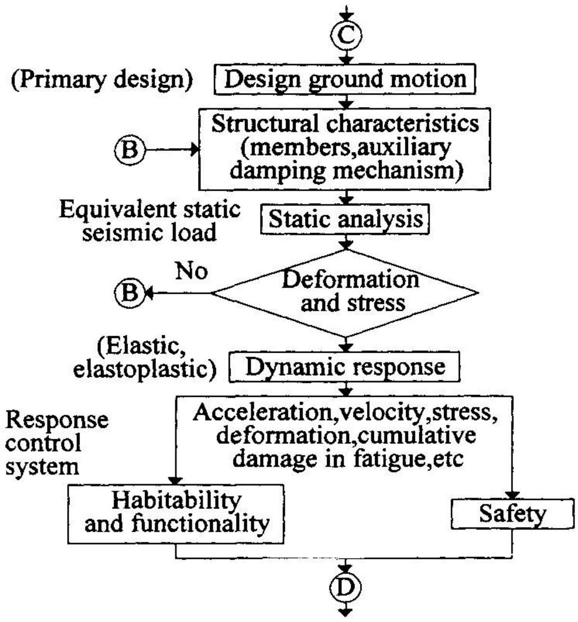


*Fig.2 Flowchart for seismic design (part)*

| Site Investigation | | |
|---|---|---|
| Seismological condition | Ground condition | Earthquake observation |
| Historical earthquake<br>Active fault<br>Seismo-tectonic structure | Bedrock<br>Sedimentary basin<br>Surface geology / topografy | Array observation |

| Characteristics of hyper building |
|---|
| Importance<br>Size (1000m, period 20sec. )<br>Service period (1000years )<br>Design criteria classification |

| Design criteria | | |
|---|---|---|
| Category L | Category P | Category F |
| Protection of life | Protection of property | Maintenance of functions(daily)<br>Normal traffic and communication |

| Selection of study earthquake<br>( a simplified method to be used for estimation of ground motion at the time of selection) | | |
|---|---|---|
| Historical earthquakes | Active faults | Seismo-tectonic structure |

| Evaluation of ground motion | |
|---|---|
| Method 1 : Theoretical method<br>Method 2 : Emperical method<br>Method 3 : Semiemperical method | Method 4 : Hybrid method<br>Method 5 : Other method |

| Determination of design ground motion | | |
|---|---|---|
| Evaluation of ground motion characteristics | Determination of time history | Comparison with lower-limit ground motion for safety |
| Maximum amplitude<br>Response spectrum<br>Duration time<br>Nonstationary chracteristics | Two or more time histories obtained by different methods<br>Selection of representative one from two or more time histories<br>Simulated ground motion compatible with two or more time histories | Definition of lower-limit ground motion for safety |

*Fig.3 Framework for evaluation and determination of design ground motion*

## 4. Design wind loads

The proposed wind-resistant design procedure (Fig. 4) differs greatly from that for conventional high-rise buildings in the following aspects:

a) The method of determining the design wind velocity through estimation using a typhoon simulation model[6] is also applicable.
b) Wind observation[7,8] at altitudes of more than 1,000 m using doppler radar or doppler sodar is necessary.
c) In order to protect life, inelastic response analysis[9] is carried out as part of the studies conducted for the prevention of collapse.
d) Additional damping mechanisms are adopted wherever appropriate.
e) Checking fatigue damage[10] is essential.
f) The importance of maintenance not only during but also after construction is shown.

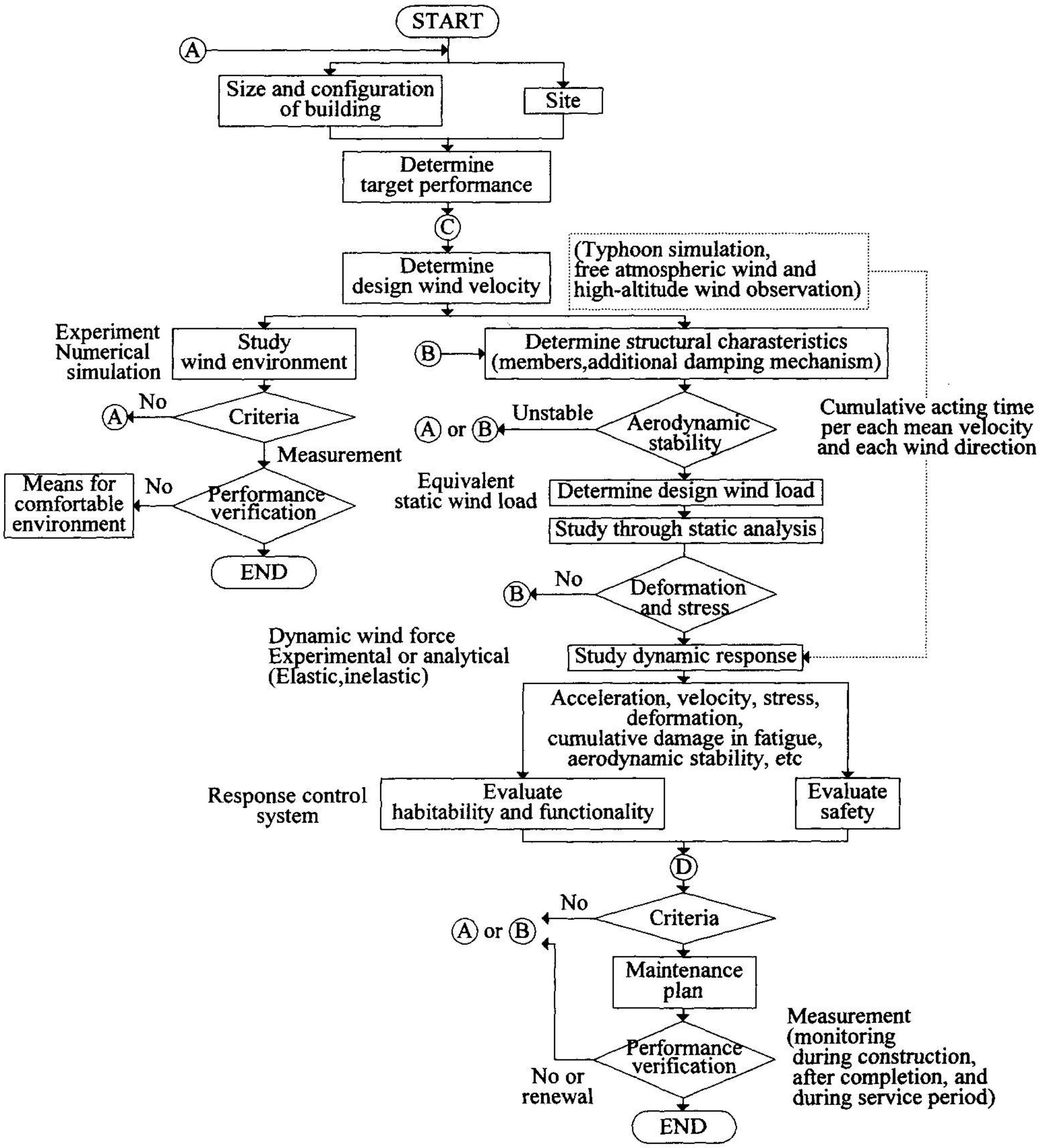


*Fig. 4 Flowchart for wind-redistant design*

## 5. Conclusions

In this paper, basic concepts of what should be done to ensure the structural safety of hyper buildings against earthquakes and winds have been presented. As a result of this study, a number of subjects of further study have been identified. Among them are as follows,

*1) Subjects concerning structural safety*

(1) Risk level determination by use of such techniques as risk management
(2) Design recurrence interval and criteria
(3) Variations among analysis models

*2) Subjects concerning design ground motion*

(1) Synthesizing of broad-band (period: 0.1 to 20 second) design ground motions
(2) Zoning of predominant periods of ground based on past studies of velocity structure and on observation records of long-period strong ground motions
(3) Seismological conditions at the construction site and the determination of ground investigation areas
(4) Variations of factors affecting the maximum ground motion

*3) Subjects concerning with wind-resistant design*

(1) Development of wind-resistant design methods which consider elastoplasticity of structural members
(2) Development of more accurate typhoon simulation methods
(3) Observation of high-altitude winds

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