Reactor Plant Safety Course FY2010
Winter Course

RPSC-Winter Course L-9

Seismic Design for Reactor Plant

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Preface

Safety of the Reactor Plant Should be guaranteed for conceivable external events in addition to the internal events. Earthquake is usually the most important external event, and provides significant effects in plant design corresponding to the condition.

In the seismic design for the Reactor Plant, all facilities are classified for their importance for safety, and designed for seismic intensity and allowable limit corresponding to the class. In the most of the countries and IAEA the seismic design rules including above items are precisely prescribed.

In this presentation, firstly general idea of earthquake and seismic analysis are explained, then the rules and the practice in Japan are presented. As for plant type, PWR is presumed.

1　Earthquake

1.1 Type of Earthquake

1.1.1 Earthquake at Plate Boundary

1.1.2 Earthquake in Plate Slab

1.1.3 Inland Earthquake

1.2 Intensity of Earthquake

1.2.1 Magnitude of Earthquake

1.2.2 Magnitude and Occurrences

1.2.3 Earthquake Distribution

1.2.4 Plate Boundary

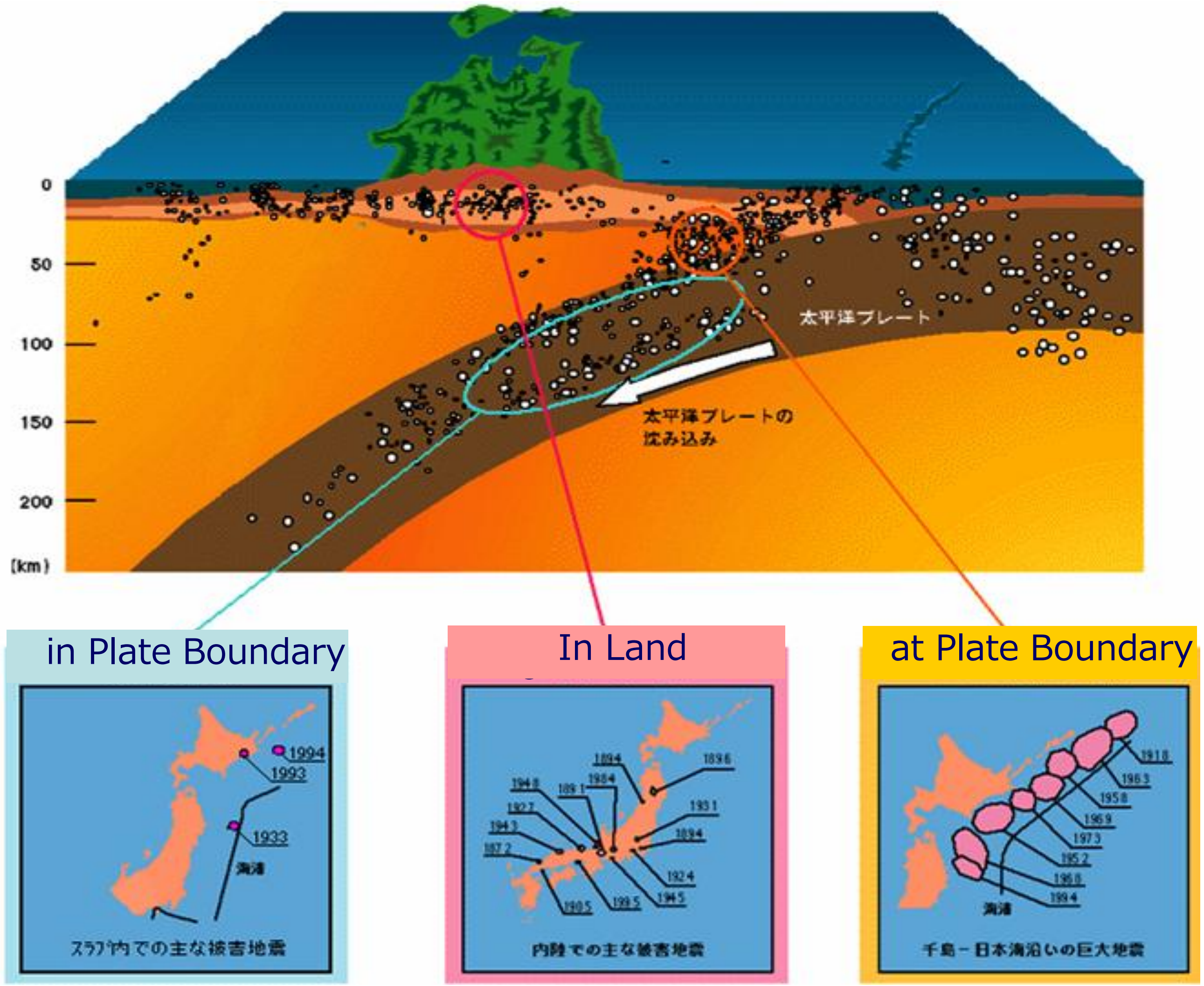
1.2.5 Active Faults in Japan

1.2.6 Magnitude of Earthquake by Fault

1.2.7 Historical Earthquake in Tsuruga Area

1.2.8 Ground Motion and Magnitude

1.1　Type of Earthquake



Distribution of Earthquake in North East Japan

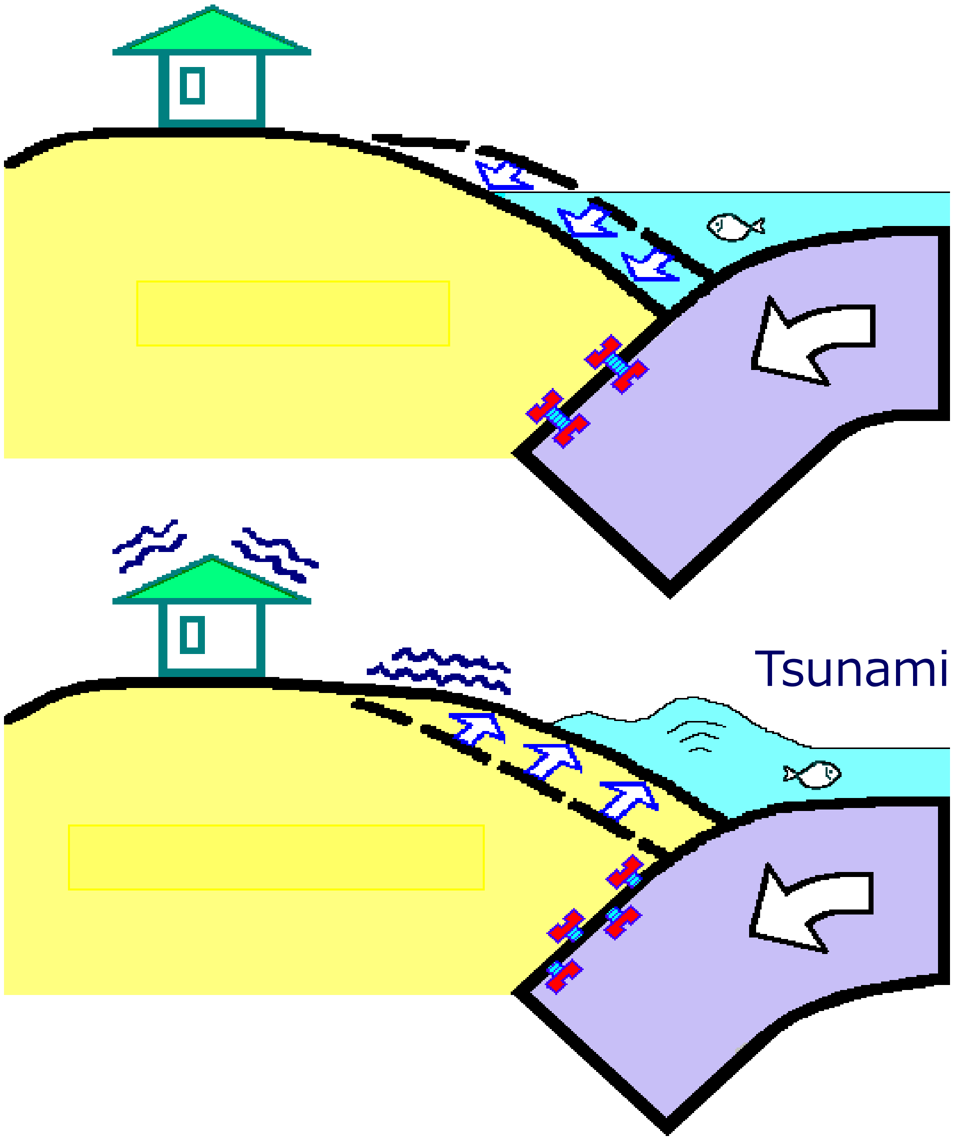
1.1.1 Earthquake at Plate Boundary

1.1.2 Earthquake in Plate Slab

1.1.3 Earthquake in Land

Web 地震調査研究推進本部「地震のメカニズムを探る」より引用

1.1.1 Earthquake at Plate Boundary

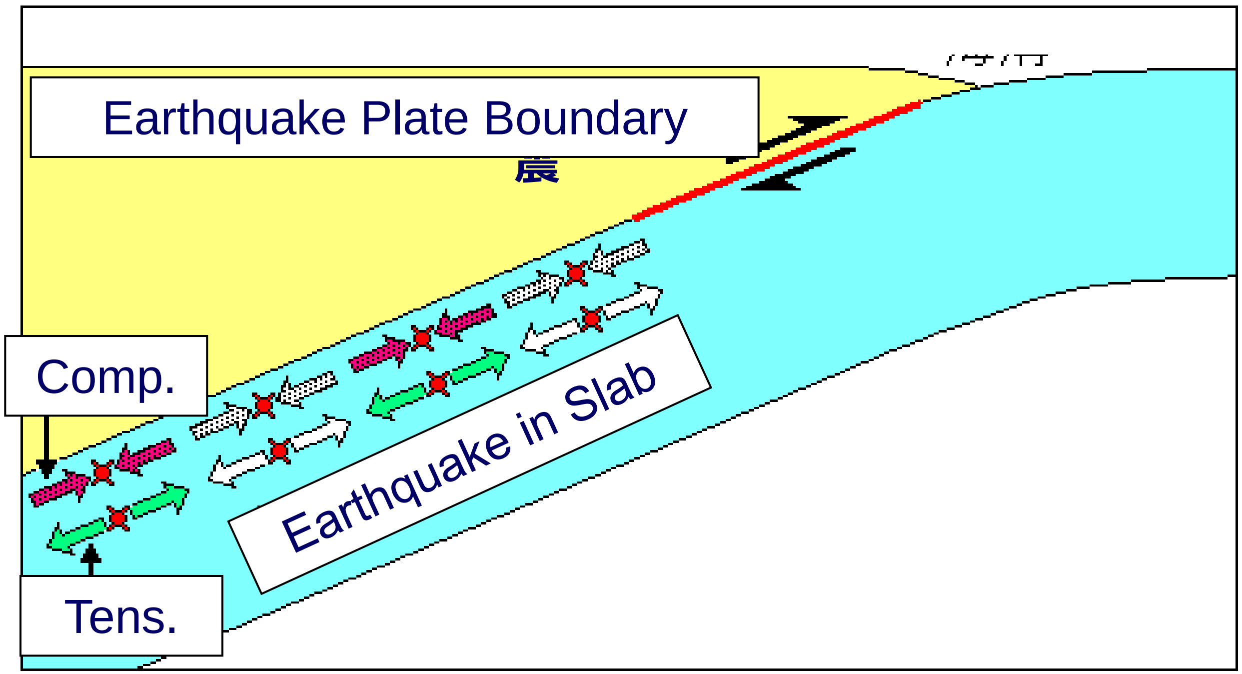


- Ocean Plate Moving beneath Land Plate and Distortion Energy Stored.
- When Distortion Energy over the Limit, Land Plate Springs back, and Large Earthquake Occurs.

Web 防災科学研究所「地震の基礎とその観測」より引用

1.1.2 Earthquake in Plate Slab

- Earthquake by Stress Rupture of Ocean Plate Slab



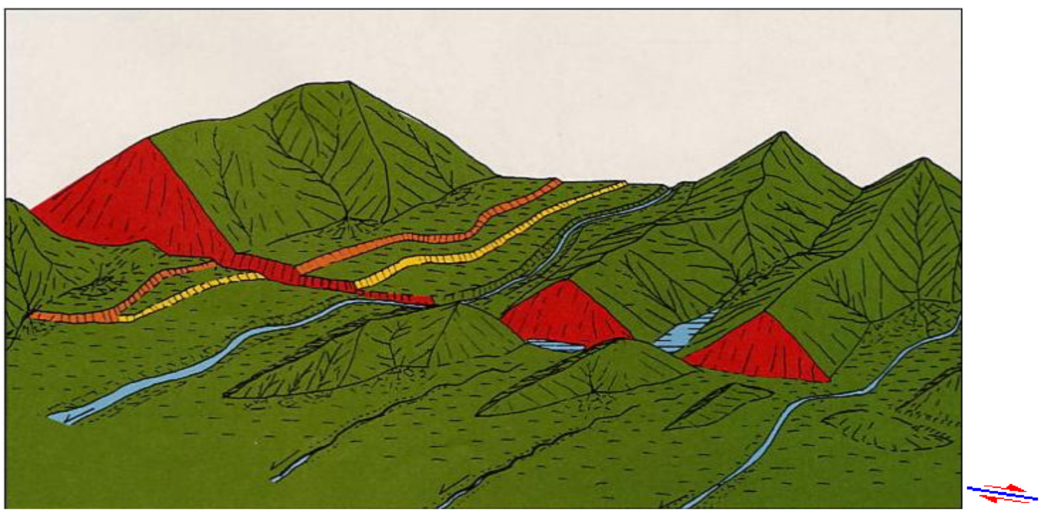
Stress Originated from Compressed Upper Layer and Tensioned Lower Layer

Web 防災科学研究所「地震の基礎とその観測」より引用

1.1.3 Inland Earthquake

Active Fault

That Which Have Frequently Moved during Quaternary Period (before 2 M Year to Now), and Anticipated to Move in Future



Movement

Land Shape by Fault Movement

Classification of Active Fault

Class	Definition	Examples in Japan
A	Ave. Movement per 1,000 Year: 10 m ～1 m	国府津－松田断層(神奈川) 丹那断層(静岡) 富士川断層(静岡) 根尾谷断層(岐阜) 阿寺断層(岐阜) 跡津川断層(岐阜)
B	Ave. Movement per 1,000 Year: 1 m ～10 cm	千屋断層(秋田) 福島断層(福島) 立川断層(東京) 有馬－高槻断層(兵庫) 山崎断層(兵庫)
C	Ave. Movement per 1,000 Year: 10 cm ～1 cm	深溝断層(愛知) 郷村断層(京都) 鳥取断層(鳥取)

新編日本の活断層、活断層研究会編、1991年より引用

1.2.1 Magnitude of Earthquake

"MAGNITUDE" M

⇔ Magnitude of Earthquake

⇔ Released Energy by Earthquake

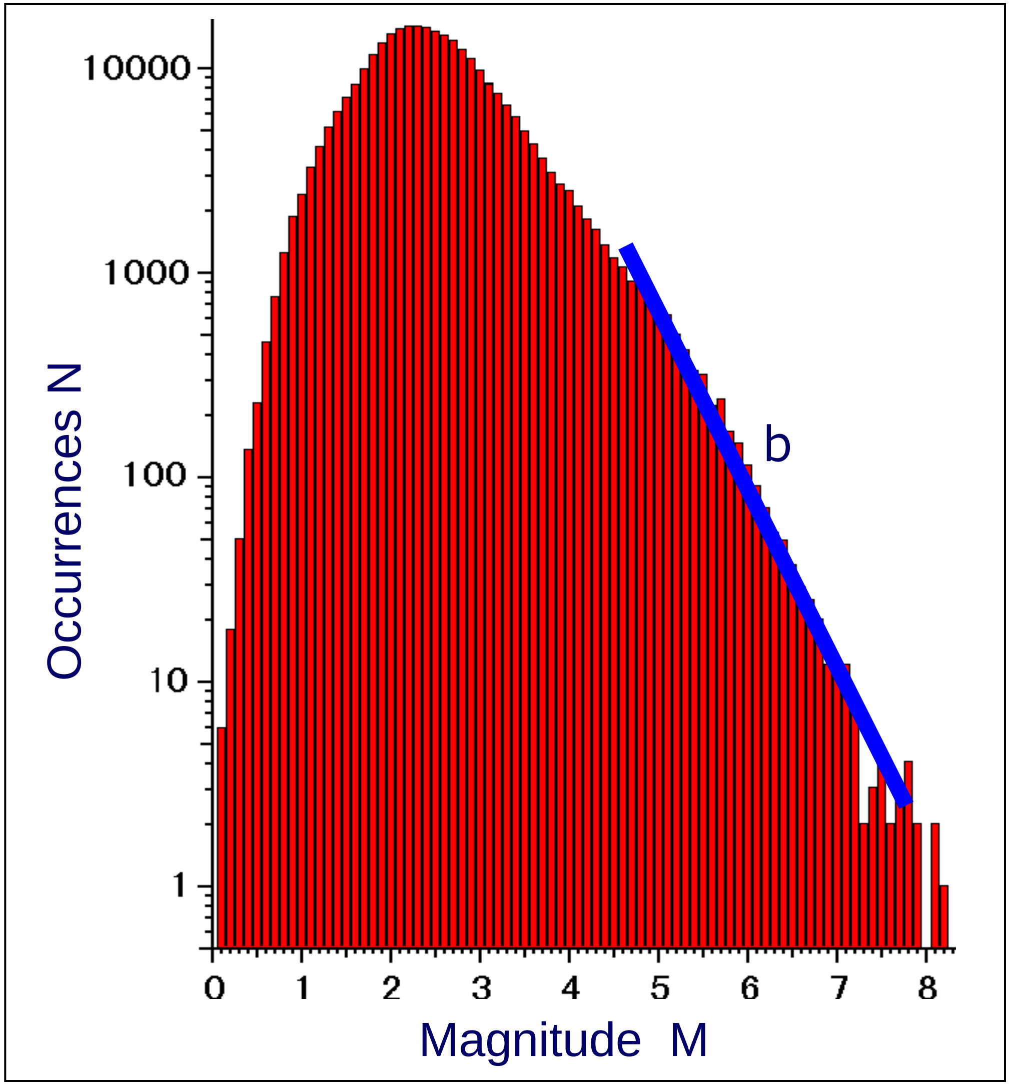
＜Relation between Magnitude M and Energy E ＞

$$\log E = 1.5\,M + 4.8$$

M increases by 1 ⇒ E increases by Factor 32

M increases by 2 ⇒ E increases by Factor 1000

1.2.2 Magnitude and Occurrences



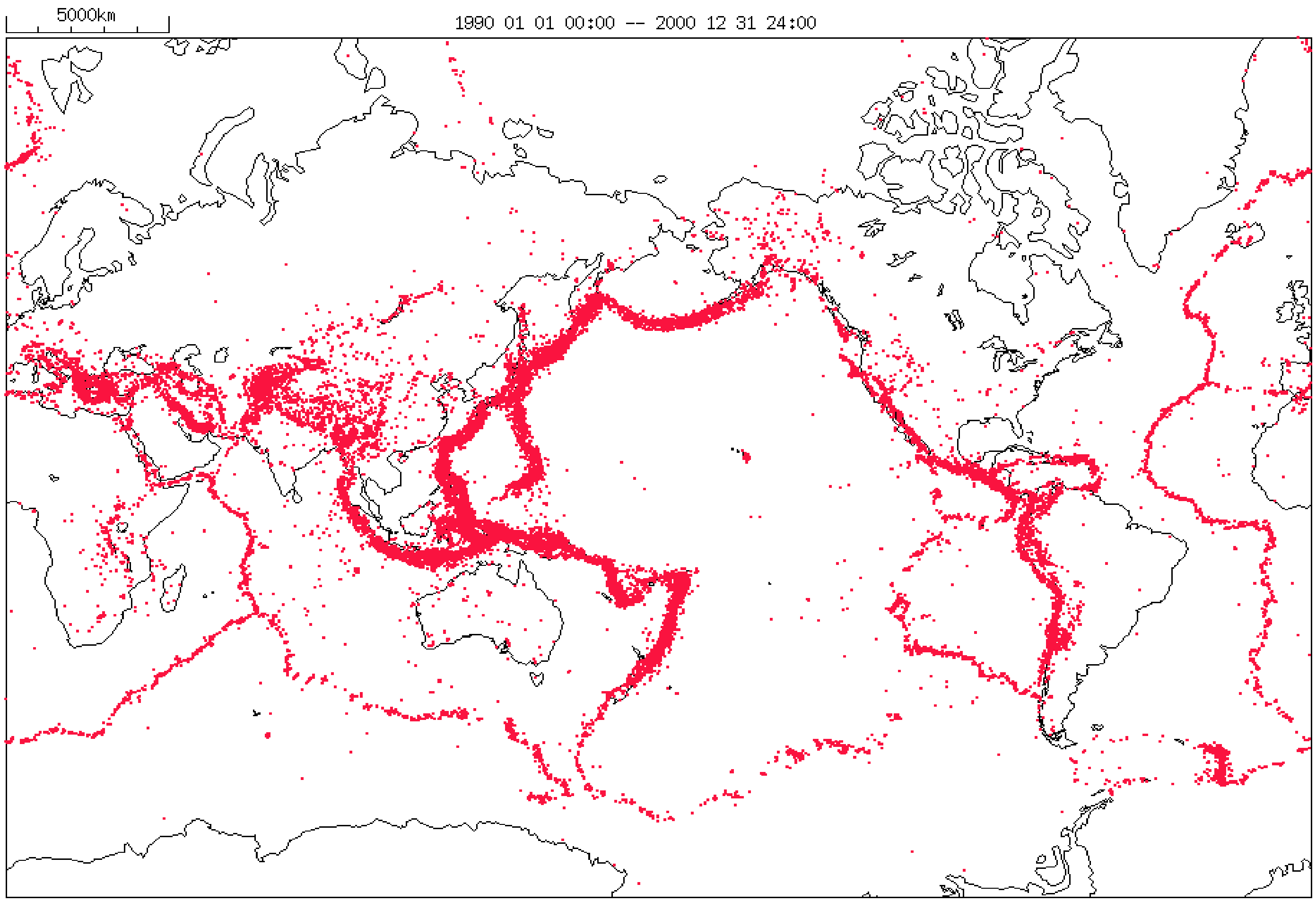
- Relation by Gutenberg and Richiter

  $\log N = a - b \cdot M$ (b=0.9 ～1.0)

- M Decreases by 1 ⇒N Increases by Factor 8～10

Web 防災科学研究所「地震の基礎とその観測」を基に作成

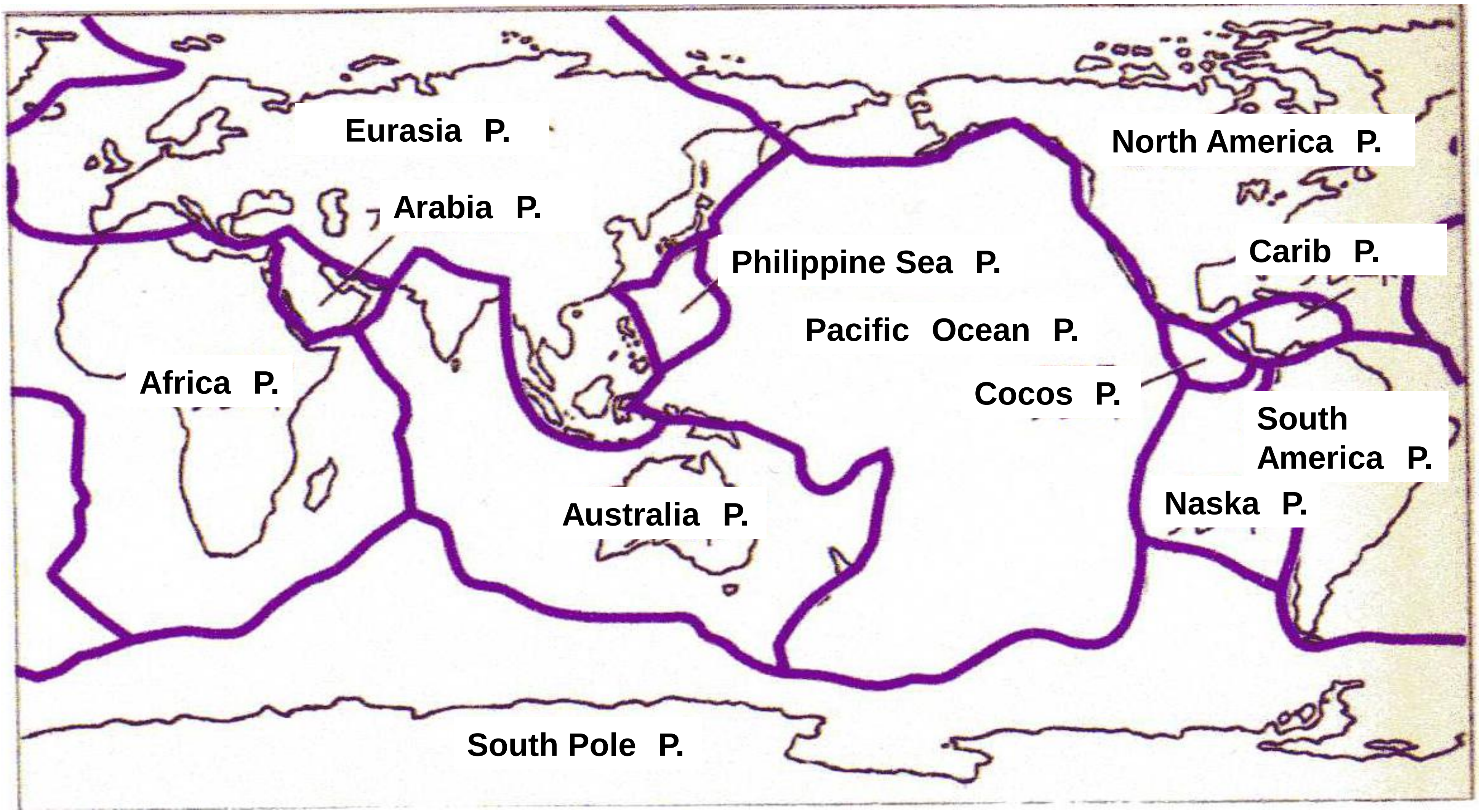
1.2.3 Earthquake Distribution



Earthquake grater than M4 （1961～1967, Depth<100km）

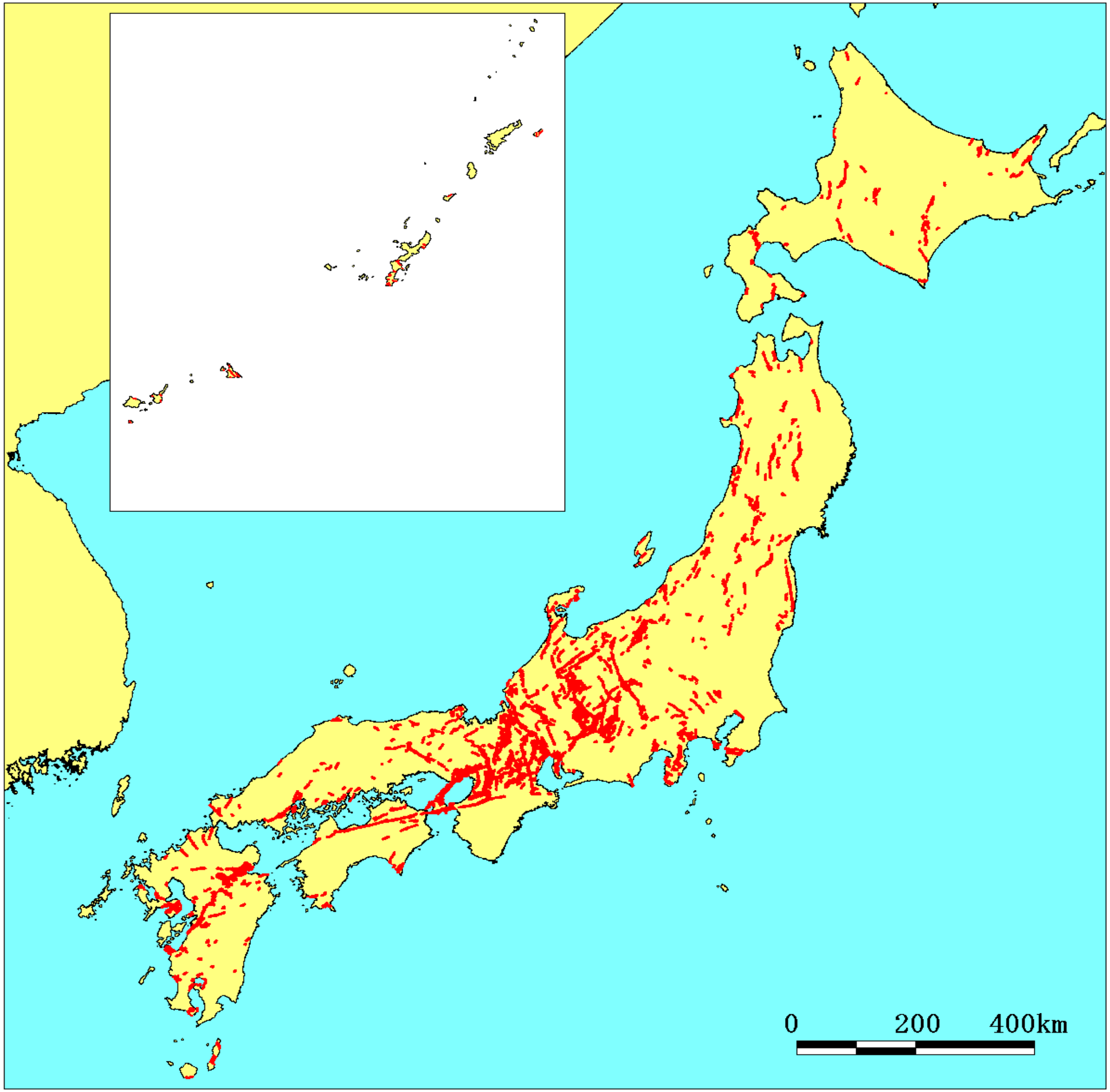
理科年表（東京天文台）より引用

1.2.4 Plate Boundary



理科年表（東京天文台）を基に作成

1.2.5 Active Faults in Japan



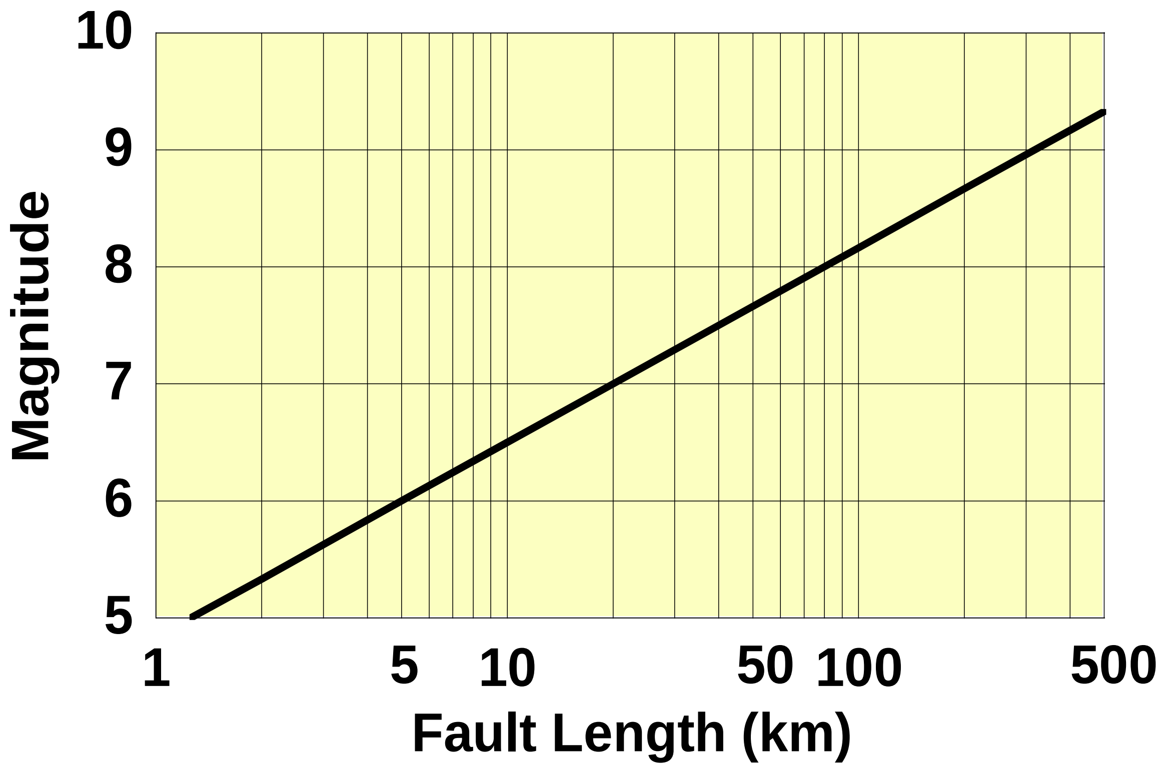
新編　日本の活断層（活断層研究会編、1991）より引用

1.2.6 Magnitude of Earthquake by Fault

$$M = (Log\,L + 2.9)/0.6$$

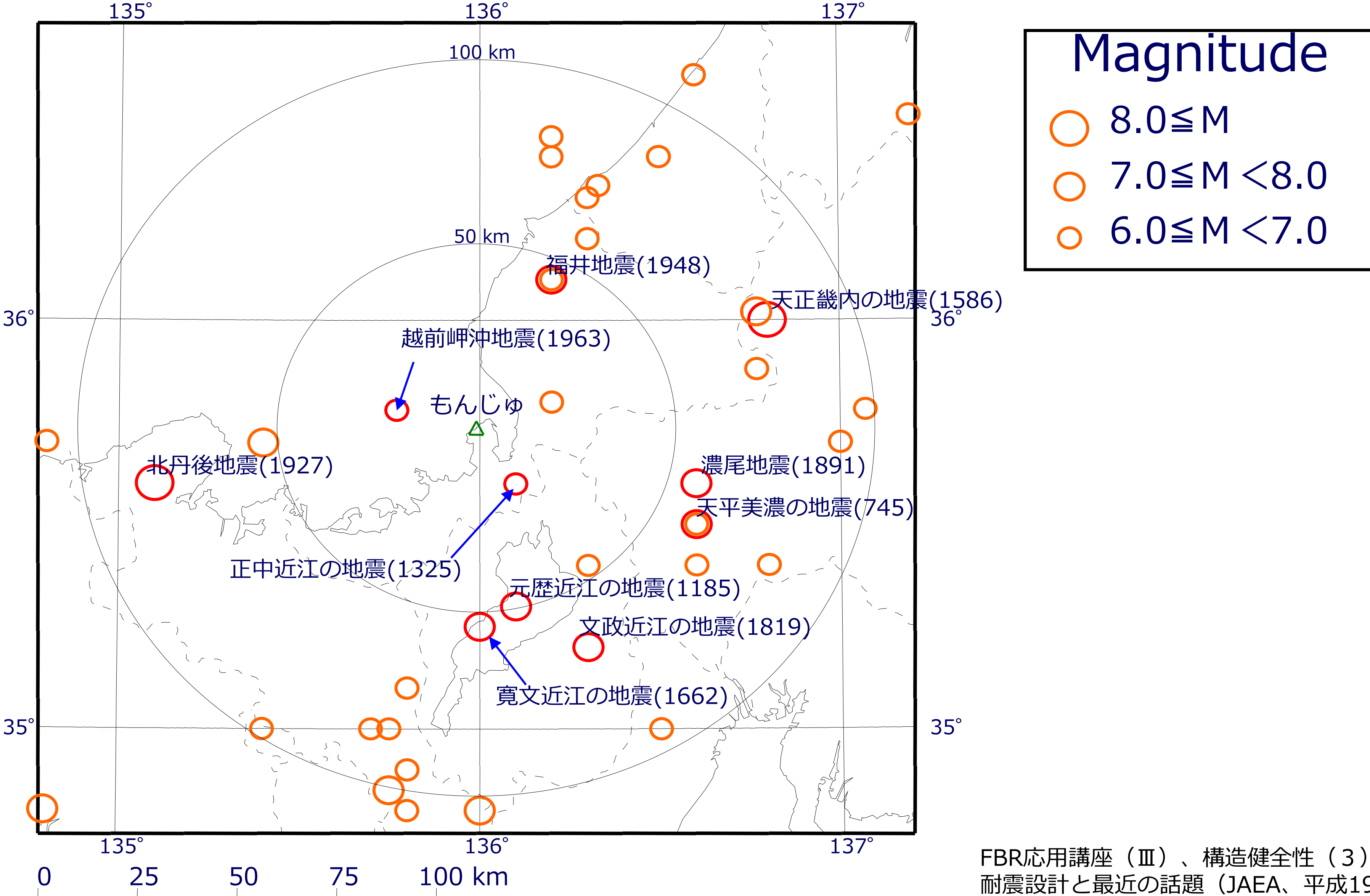
M **: Magnitude of Earthquake**

L : Fault Length (km)



原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

1.2.7 Historical Earthquakes in Tsuruga Area



FBR応用講座（Ⅲ）、構造健全性（3）
耐震設計と最近の話題（JAEA、平成19年10月）より引用

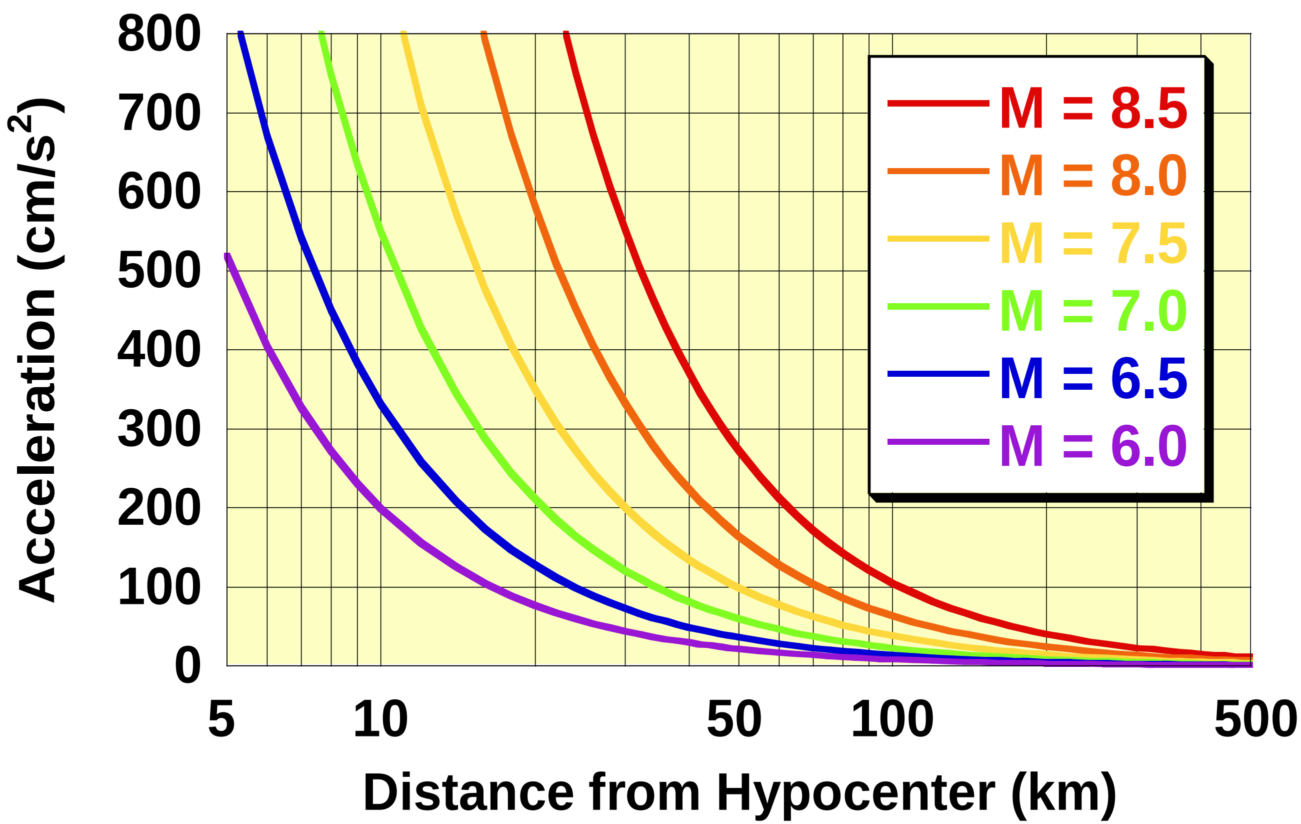
1.2.8 Ground Motion and Magnitude

$$a = 10^{0.440M - 1.38 \log X + 1.04}$$ (Watabe's Formula)

a : Maximum Acceleration (cm/s^2)

M : Magnitude of Earthquake

X : Distance from Hypocenter (km)



原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

2 Seismic Design Method

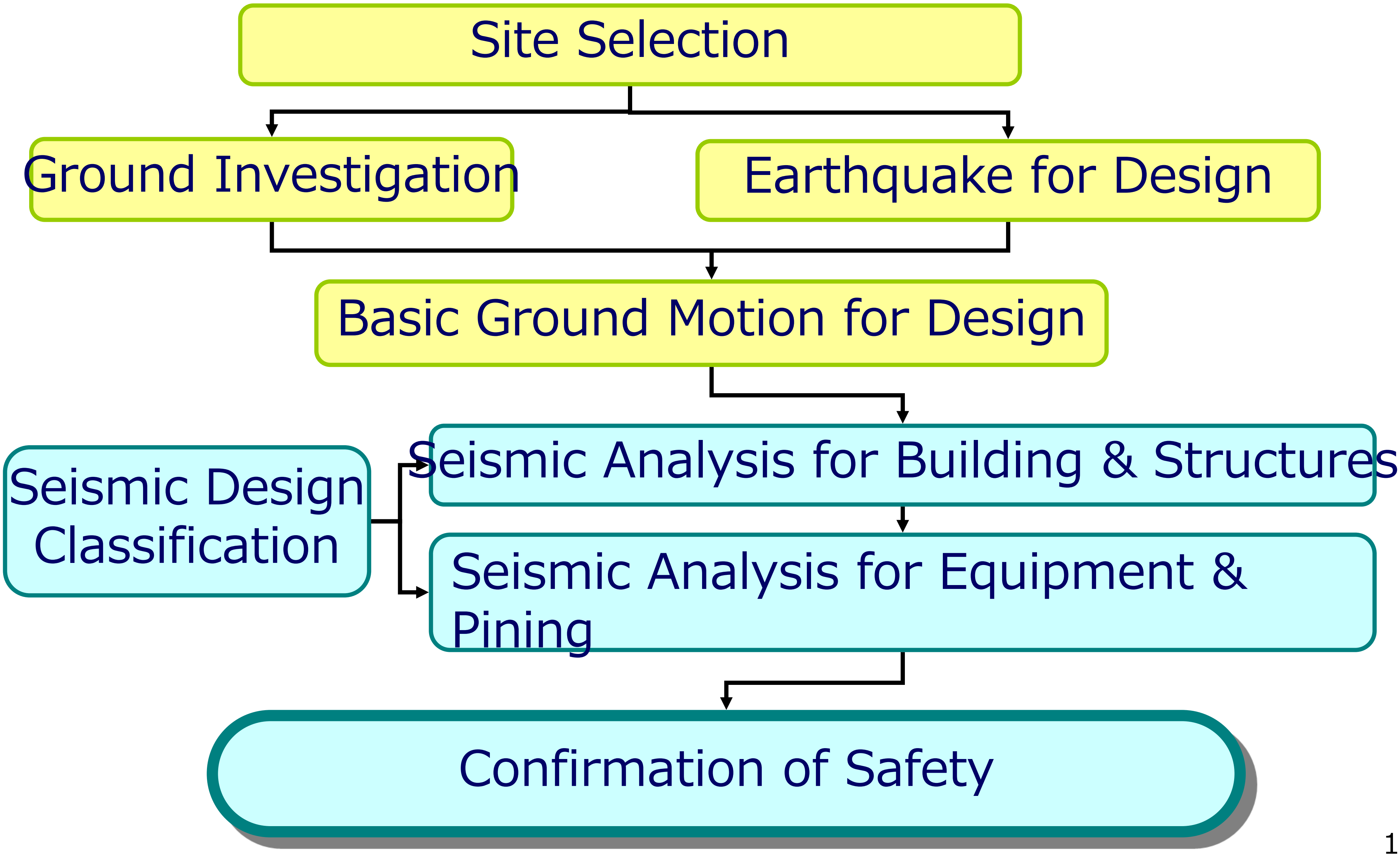
2.1 Flow of Seismic Design

2.2 Feature of Seismic Design for Nuclear Power Plant

2.2.1 Purpose of Seismic Design for Nuclear Power Plant

2.2.2 Principles of Seismic Design for Nuclear Power Plant

2.1 Flow of Seismic Design



2.2.1 Purpose of Seismic Design for NPP

NPP (Nuclear Power Plant) is to be Designed;
against the Design Earthquake which is Conceivable to Occur during Plant Life and has Large Impact on the Plant;
to prevent Loss of Function in Important Facilities for Plant Safety;
to prevent Risk of Excess Radiation Exposure for Public.

原子力百科事典（ATOMICA）、
「原子力発電所の耐震設計」に基づいて作成

2.2.2 Principles of Seismic Design for NPP

1. Detailed Investigation of Plant Site for Historical Earthquake, Active Faults, etc.
2. NPP Shall Be Designed for Conceivable Maximum Earthquake
3. Precise Estimation for Seismic Response of Important Facilities
4. Precise Check for Soundness of Supporting Ground
5. Confirming Safety for Conceivable Tsunami
6. Construction Plant on Ground with Sufficient Stiffness and Supporting Capability
7. Provision for Automatic Reactor Stop against Predetermined Level of Ground Vibration.
8. Aseismic Proof Test Using Shaking Table and/or Vibration

原子力百科事典（ATOMICA）、
「原子力発電所の耐震設計」に基づいて作成

3 Seismic Design Classification

3.1 Definition

3.2 Classification by Function

3.3 Classification of Equipment & Piping

3.4 Classification of Building & Structures

3.1 Seismic Design Classification - Definition

Class	Definition
I	Facilities, which include radioactive material or related to the facilities which include radioactive material, and damage of which may cause release of radioactive material, which are required to protect from such events, which are required for emergency shutdown of rector and are needed to mitigate effects of radioactive material release at the accidents, and effects and influence of which are significant.
II	Facilities, which are the same property as Class I, but effects and influence of which are not significant.
III	Facilities, which are not classified in the above seismic classes, and which are required the same level of safety as general industries.

発電用原子力施設に関する耐震設計審査指針（原子力安全委員会原子力安全基準・指針専門部会：2006年5月19日）を基に作成

3.2 Classification by Function(Class I)

Class	Definition
I	(i) Equipment and piping constituting the "Reactor Coolant Pressure Boundary" (ii)Spent fuel storage facilities (iii)Facilities required to introduce negative reactivity into the core to effect an emergency shut-down and to maintain the core in shut –down state. (iv) Facilities required for the removal of decay heat from the core after reactor shutdown. (v) Facilities required for the removal of decay heat from the core in the event of a failure of the reactor coolant pressure boundaries . (vi) Facilities serving as pressure boundaries which directly prevent the spread of radioactive material in the event of a failure of the reactor coolant pressure boundaries. (vii) Facilities other than those belonging to (vi) which serve to prevent the discharge of radioactive material into the atmosphere after an accident involving radioactive material.

発電用原子力施設に関する耐震設計審査指針（原子力安全委員会原子力安全基準・指針専門部会：2006年5月19日）を基に作成

3.2 Classification by Function(Class II, III)

Class	Definition
II	(i) Facilities physically connected to the reactor pressure boundaries and which contain primary coolant or which may contain reactor coolant. (ii) Facilities containing radioactive waste material excluding those with relatively small quantities of radioactive material or those whose rupture would lead to a considerably lower radioactive dose to the general public than the annual dose permitted at the controlled environs. (iii) Facilities containing radioactive material other than radioactive waste whose rupture might lead to the excessive exposure of the general public and/or plant personnel. (iv) Facilities required to cool spent fuel (v) Facilities other than the those in class I which would prevent the release of radioactive material into the atmosphere in the event of an accident accompanied by the release of radioactive material.
III	(i) Facilities which are not classified as Class I or II.

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3.3 Classification-Equipment & Piping

Class	Facilities
I	(i) Reactor Vessel and other Vessels, Pump, Piping and Valves constituting the "Reactor Coolant Pressure Boundaries" (ii)Spent Fuel Pit (iii)Control Rod Cluster and Drive Mechanisms (iv)Decay Heat Removal System (v)Reactor Containment Vessel and Piping and Valves constituting the "Reactor Containment Pressure Boundaries" (vi) Safety Injection System (vii)Containment Annulus Air Purification System (viii)Reactor Core Structure
II	(i) Waste Disposal System (ii)Spent Fuel pit Cooling System (iii)Turbine System (BWR)
III	(i) Sampling System, Floor Drain System (ii)Turbine System (PWR), Main Generator System

発電用原子力施設に関する耐震設計審査指針（原子力安全委員会
原子力安全基準・指針専門部会：2006年5月19日）を基に作成

3.4 Classification-Building & Structures

Class	Facilities
I	(i) Reactor Containment (Concrete Structure) (ii) Reactor Building (iii)Fuel Building (iv)Control Building (v) Sea Water Intake
II	(i) Waste Disposal Building (ii)Turbine Building(BWR)
III	(i) Turbine Building(PWR)

Note: Classification of Building & Structures Seismic is determined from the equipment which they support .

発電用原子力施設に関する耐震設計審査指針（原子力安全委員会
原子力安全基準・指針専門部会：2006年5月19日）を基に作成

4 Seismic Intensity for Design

4.1 Design Seismic Intensity for Each Class Component

4.2 Design Earthquake Ss and Sd

4.3 Ground Response Spectrum of Earthquake

4.4 Tripper Spectrum Diagram of Earthquake

4.5 Simulated Earthquake Wave

4.1 Design Seismic Intensity for Each Class Component

Class	Design Seismic Intensity
I	Keep safety function for Design Earthquake Ss and Sd (Dynamic) Keep integrity for Design Earthquake Sd (Dynamic) Keep integrity for Static Earthquake force Horizontal : 0.72G (Equipment)or 0.6G(Building) Vertical : 0.3G (Equipment and Building)
II	Keep integrity for Static Earthquake force Horizontal : 0.36G (Equipment)or 0.3G(Building) [For vibratile equipment] Keep integrity for Design Earthquake 1/2 Sd (Dynamic)
III	Keep integrity for Static Earthquake force Horizontal : 0.24G (Equipment)or 0.2G(Building)

Note 1 : Static Earthquake force changes corresponding to characteristics of base rock and building.

Note 2 : For Class II and III Vertical Static Earthquake force is not adopted.

発電用原子力施設に関する耐震設計審査指針（原子力安全委員会
原子力安全基準・指針専門部会：2006年5月19日）を基に作成

4.2 Design Earthquake Ss and Sd

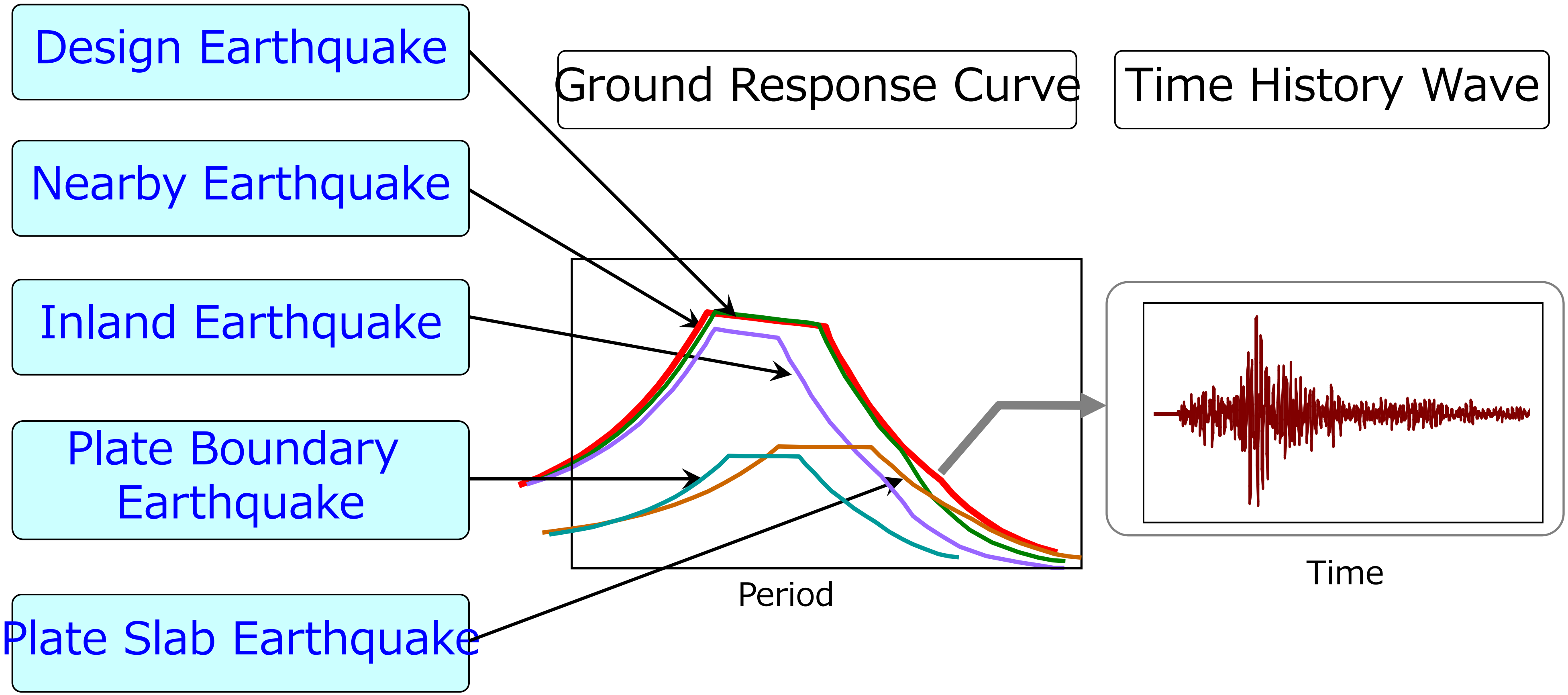
Ss (Basic Design Earthquake)is Determined from following Earthquakes
① Earthquakes which are Specifically Conceivable for each Site
(a) Inland and Incrust Earthquake
(b) Earthquake in Plate Boundary
(c) Earthquake in Plate Slab
② Determined from Conceivable Earthquake not Specific for each Site
Example: Nearby Earthquake of M6.8 at 10km

Sd (Elastic Design Earthquake)is determined as more then 1/2 of Ss

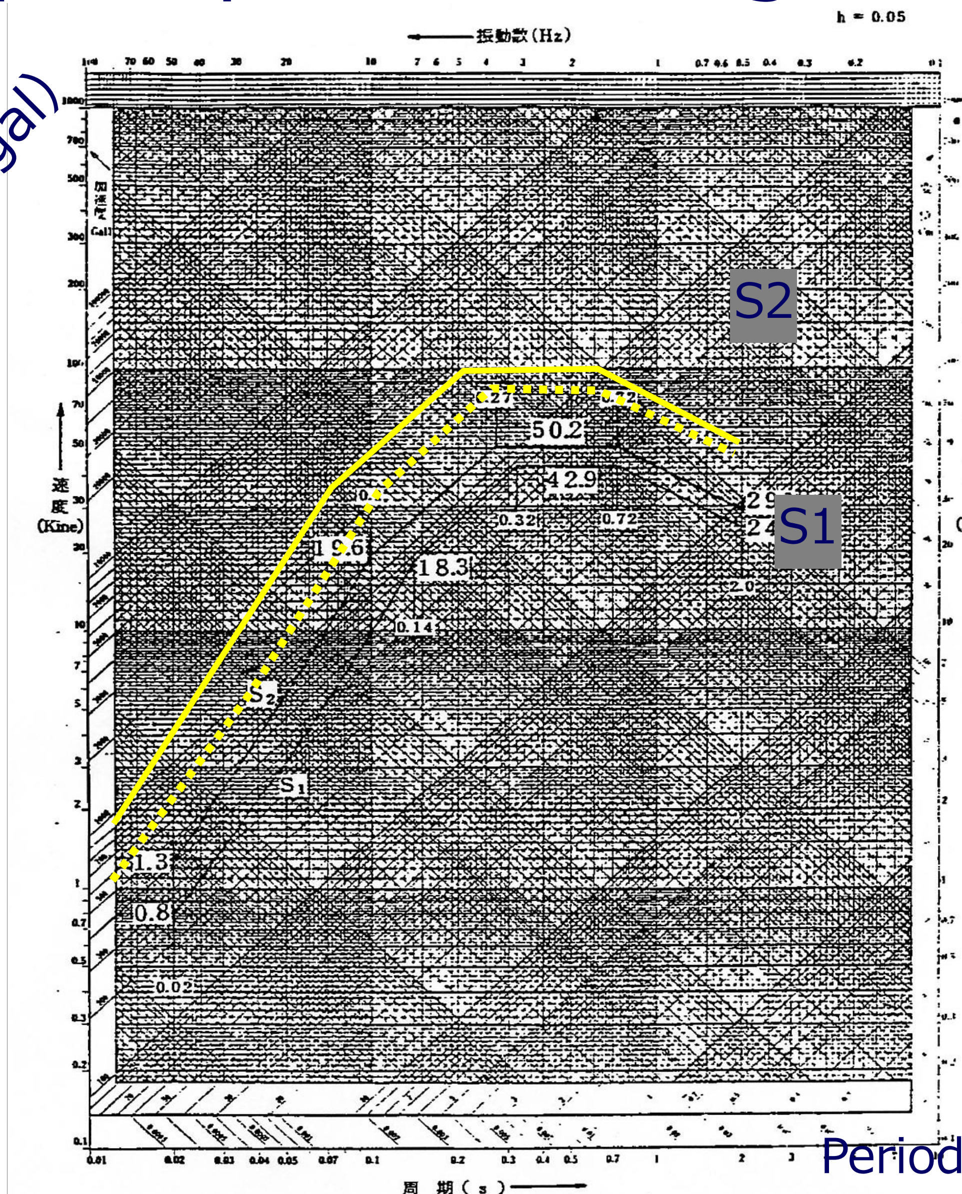
Note ;
(1) Consider Faults not Proved In-active during 80,000～130,000 Year.
(2) Execute Sufficient Investigation of Faults.
(3) Estimate using Response Curve.
(4) Estimate using Fault Model Method.
(5) Estimate Data Scattering for Probabilistic Assessment.

発電用原子力施設に関する耐震設計審査指針（原子力安全委員会 原子力安全基準・指針専門部会：2006年5月19日）を基に作成

4.3 Ground Response Spectrum of Earthquake



4.4 Tripper Spectrum Diagram of Earthquake



第６.３図 基準地震動の応答スペクトル

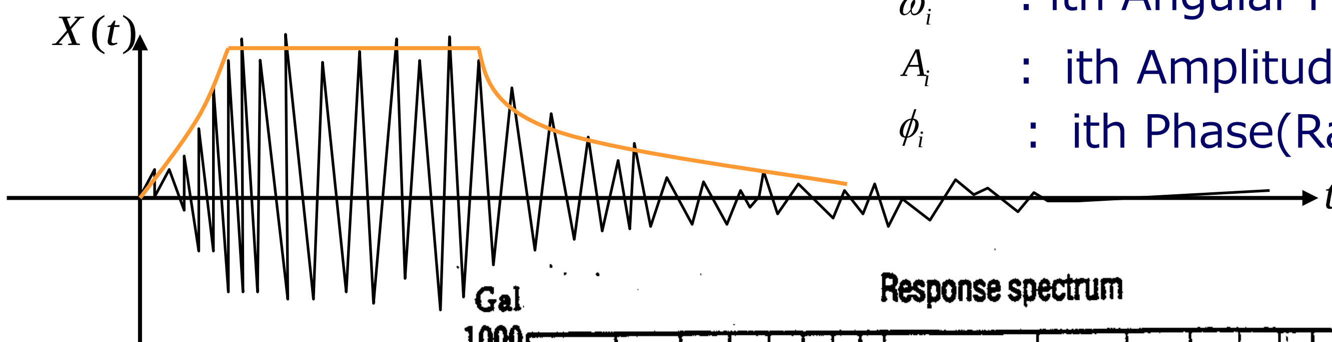
FBR応用講座（Ⅲ）、構造健全性（３） 耐震設計と最近の話題（JAEA、平成19年10月）より引用

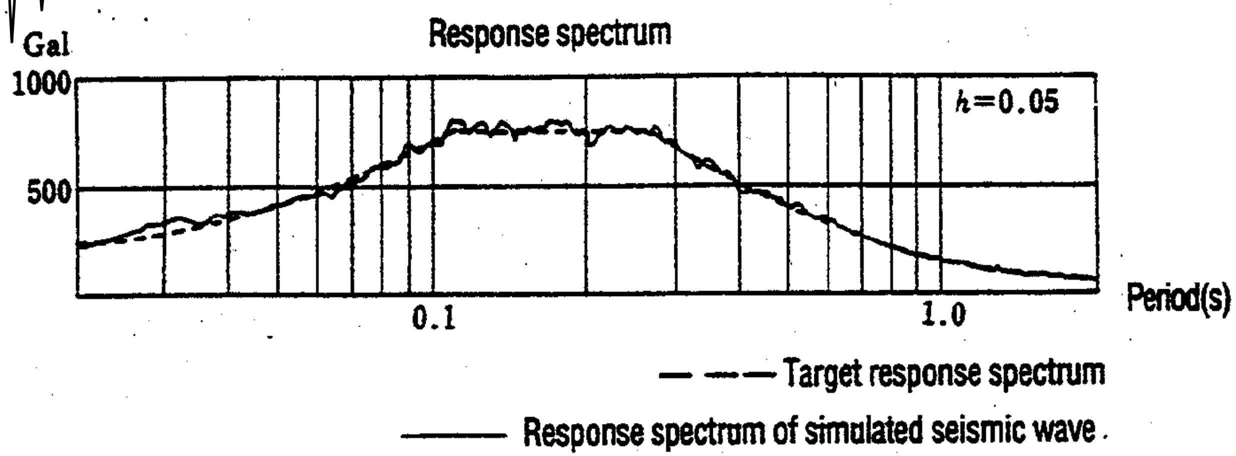
4.5 Simulated Earthquake Wave

Produced as Superposition of Multiple Sine Waves

$$X(t) = E(t)\sum_{i=1}^{N} A_i \sin(\omega_i t + \phi_i)$$

- $X(t)$: Simulated Wave
- $E(t)$: Envelope
- ω_i : ith Angular Frequency
- A_i : ith Amplitude(Random)
- ϕ_i : ith Phase(Random)





Response Spectrum of This Wave is Compared with Target Response Spectrum and Modification is Repeated until Adequate Conformance is Obtained.

原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

5 Seismic Analysis

5.1.1 Seismic Analysis Methods - Procedure

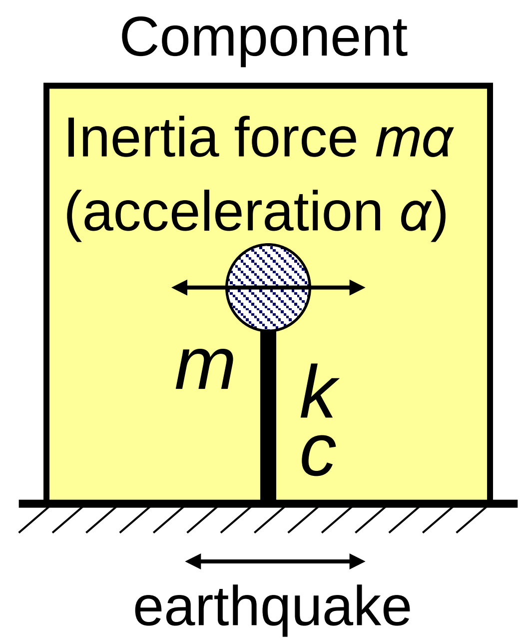
① Prepare Seismic Analysis Model

② Calculate (Maximum) Acceleration of the Component from the Earthquake Motion

③ Calculate (Maximum) Inertia Force of the Component from the Acceleration

④ Calculate (Maximum) Stress of each Part of the Component from the Inertia Force

(Maximum): In Case that only Maximum Value is Necessary



5.1.2 Acceleration Calculation Method

① Time History Method
- Direct Integration

② Modal Time History Method
- Integration for Each Mode

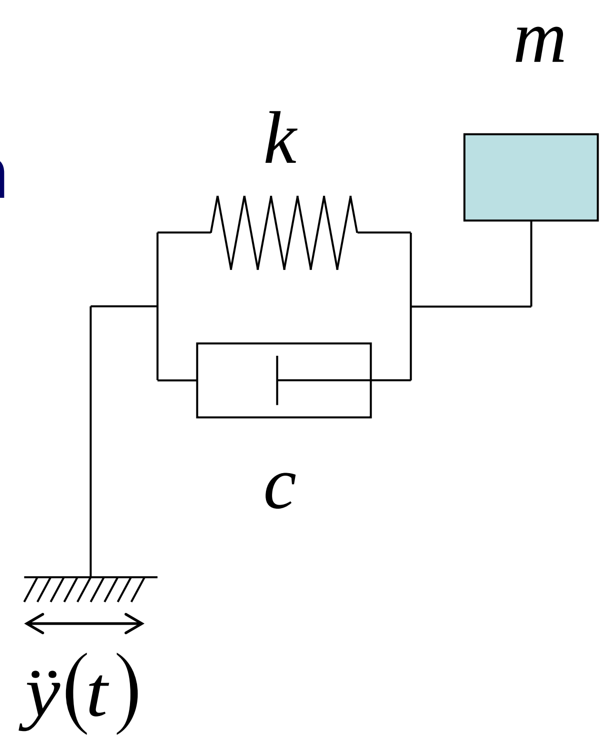
③ Response Curve Method
- Utilization of Response Curve

5.2.1 Single Mass System - Equation

Equation of Motion

$$m\ddot{x} + c\dot{x} + kx = -\ddot{y}(t)$$

x : displacement
$\ddot{y}(t)$: earthquake acceleration
m : mass
c : damping
k : spring constant

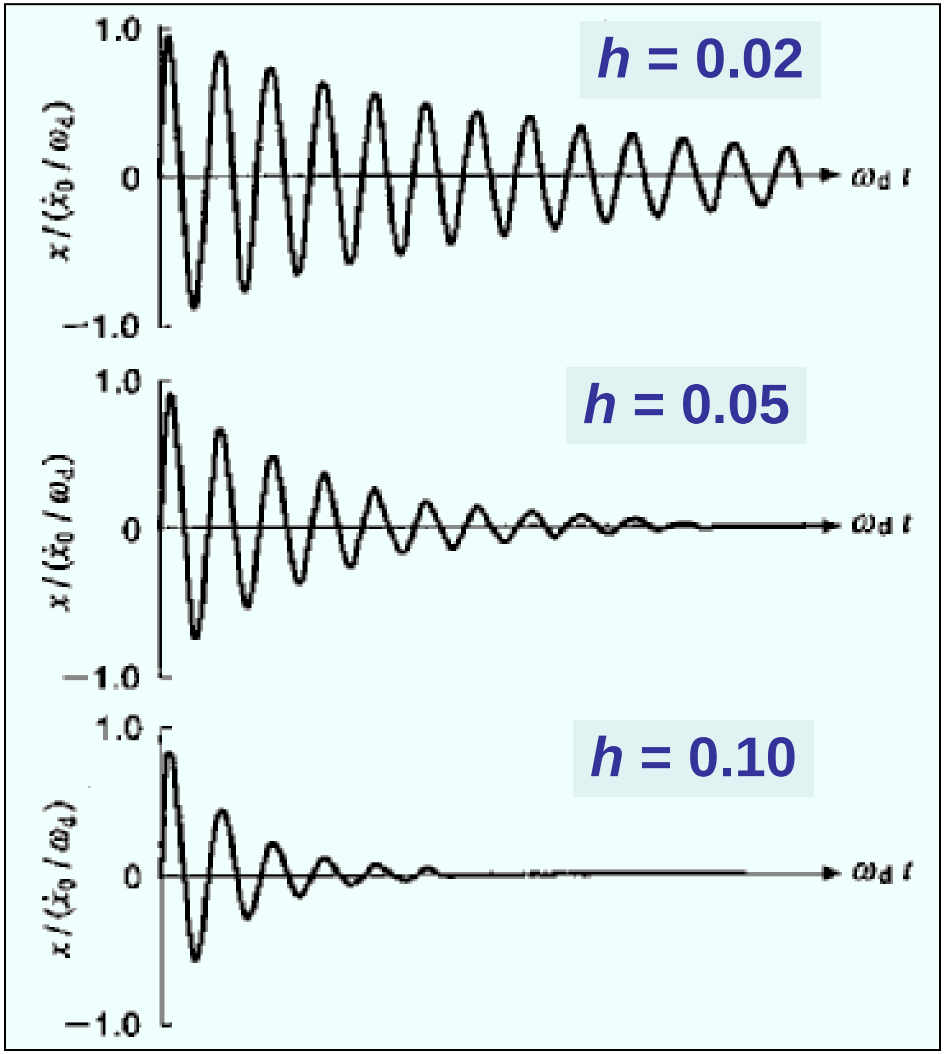


Equation of Free Vibration

$$m\ddot{x} + c\dot{x} + kx = 0$$

$\Rightarrow$ One Natural Frequency

5.2.2 Single Mass System - Damping



Difference of Attenuation of Vibration by Damping Ratio

$h = c / c_0$

h : Damping Ratio

c : Viscous Damping Coefficient

c_0 : Critical Damping Coefficient (Boundary between vibration and Non-vibration)

5.2.3 Single Mass System - Solution

Displacement

$$x(t) = -\frac{1}{\omega_0}\int_0^t \ddot{y}(\tau)\, e^{-h\omega_0(t-\tau)} \sin\omega_0(t-\tau)\, d\tau$$

Velocity

$$\dot{x}(t) = -\int_0^t \ddot{y}(\tau) e^{-h\omega_0(t-\tau)} \left\{ \cos\omega_0(t-\tau) + \tan^{-1}\frac{h}{\sqrt{1-h^2}} \right\} d\tau$$

Acceleration

$$\ddot{x}(t) + \ddot{y}(t) = -\omega_0 \int_0^t \ddot{y}(\tau)\, e^{-h\omega_0(t-\tau)} \sin\omega_0(t-\tau)\, d\tau$$

ω_0 : natural angular frequency

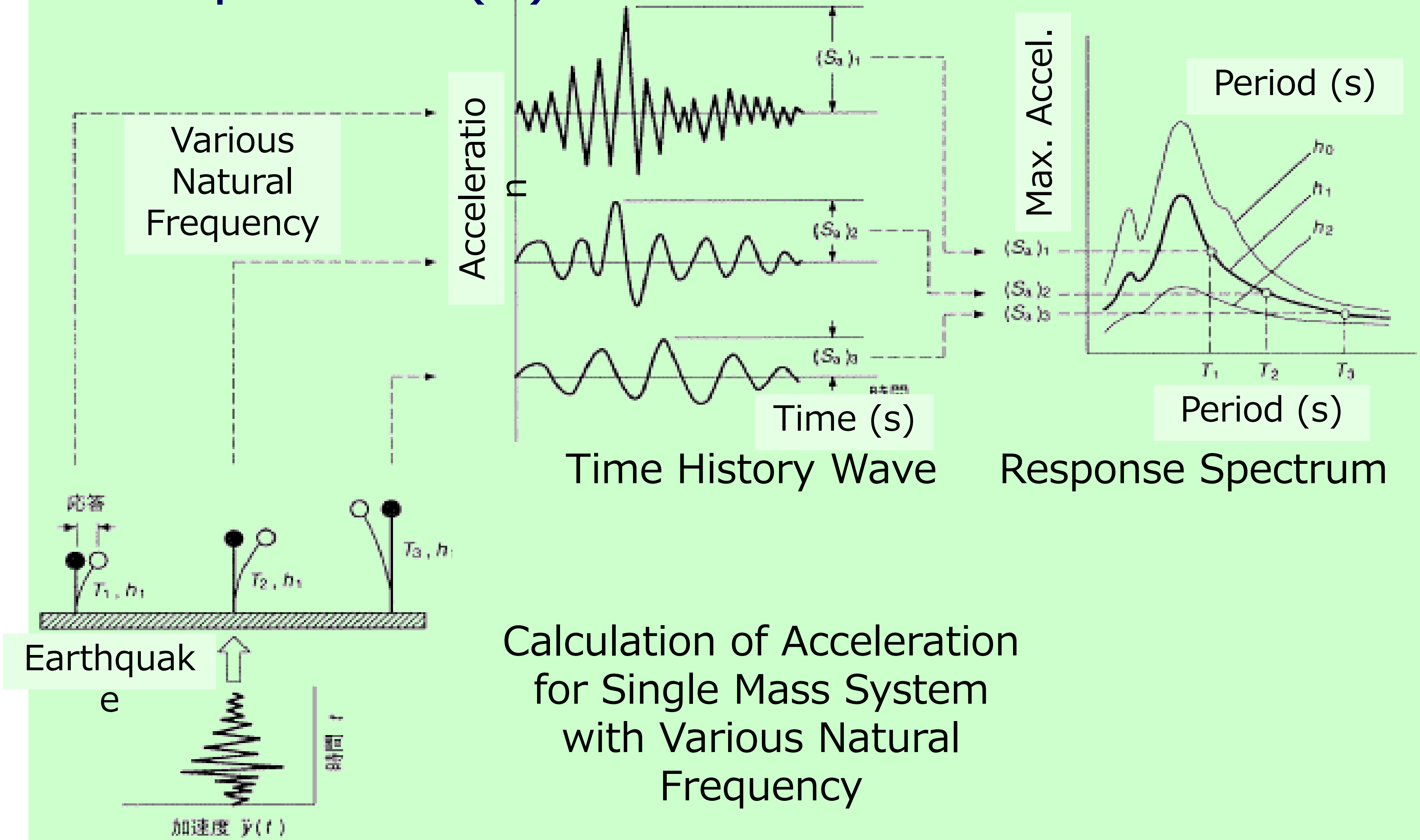
h : damping ratio

$\ddot{y}(t)$: input acceleration

(For $h \ll 1$)

Response Depends on only Natural Frequency and Damping Ratio.

5.2.4 Single Mass System - Response Spectrum(1)

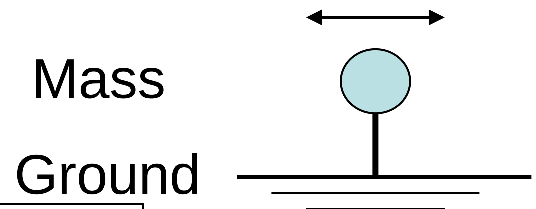


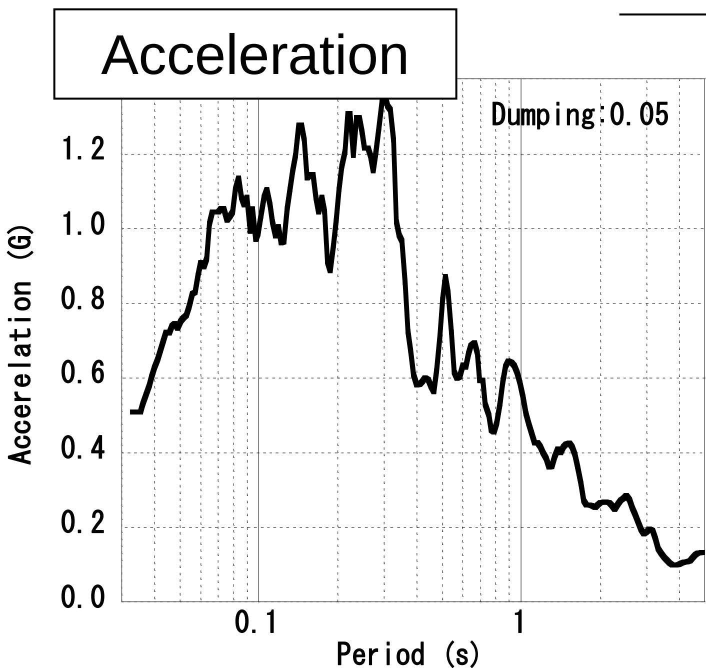
Calculation of Acceleration for Single Mass System with Various Natural Frequency

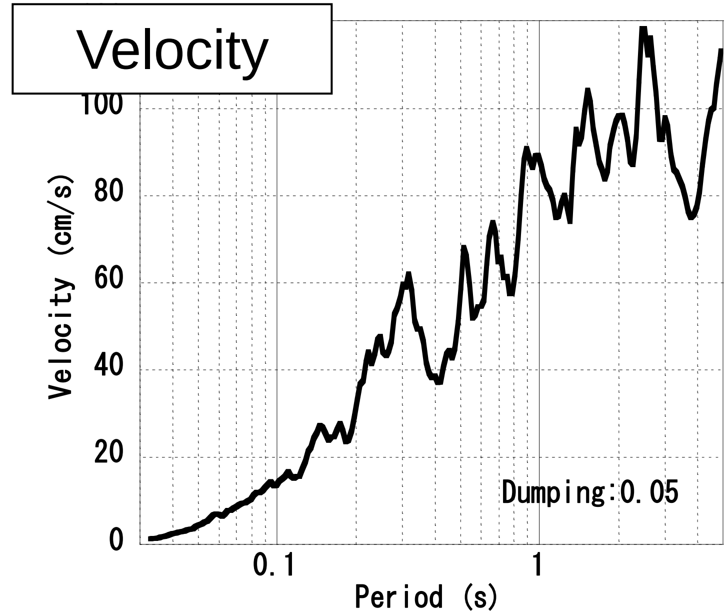
5.2.5 Single Mass System - Response Spectrum(2)

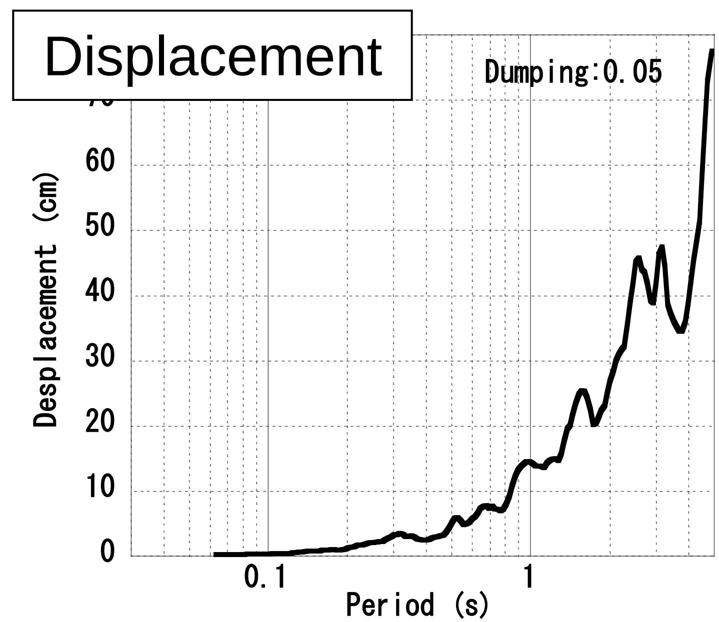
Max. Acceleration, Velocity or Displacement of Mass

Max. Seismic Force = Acceleration Response× Mass





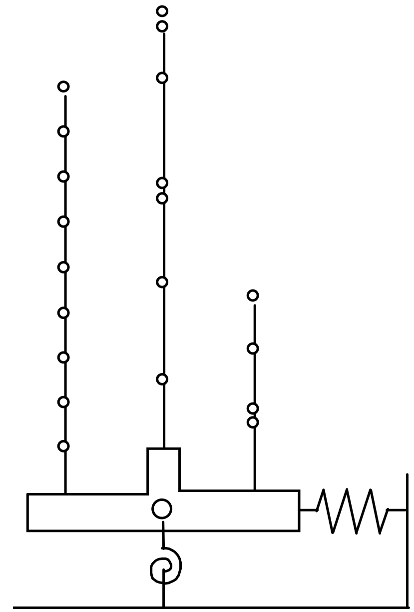




5.3.1 Multi Mass System - Equation

Equation of Motion

$$[m]\{\ddot{x}\}+[c]\{\dot{x}\}+[k]\{x\}=-[m]\{I\}\ddot{y}(t)$$



- $[m]$: mass matrices
- $[c]$: damping matrices
- $[k]$: spring matrices
- $\{x\}$: displacement vector
- $\{I\}$: unit vector
- $\ddot{y}(t)$: earthquake acceleration

Equation of Free Vibration

$$[m]\{\ddot{x}\}+[c]\{\dot{x}\}+[k]\{x\}=0$$

$\Rightarrow$ Natural Frequencies and Vibration Modes for Each Freedom

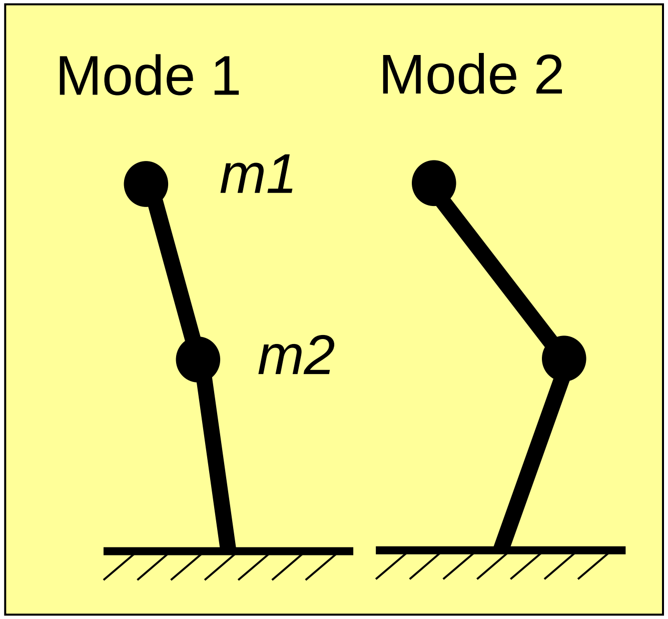
5.3.2 Multi Mass System - Solution

Response Acceleration with Modal Analysis

$$A_i(t) = \sum_{j=1}^{n} X_{ij} \cdot \beta_j \cdot Ma_j(t)$$

$$\beta_j = \sum_{i=1}^{n} m_i X_{ij} \Big/ \sum_{i=1}^{n} m_i X_{ij}^{2}$$

$$(A_i)_{max} = \sqrt{\sum_{j=1}^{n} \left(X_{ij} \cdot \beta_j \cdot Sa_j\right)^2}$$



$A_i(t)$: acceleration of mass i

X_{ij} : mode amplitude of degree j and mass i

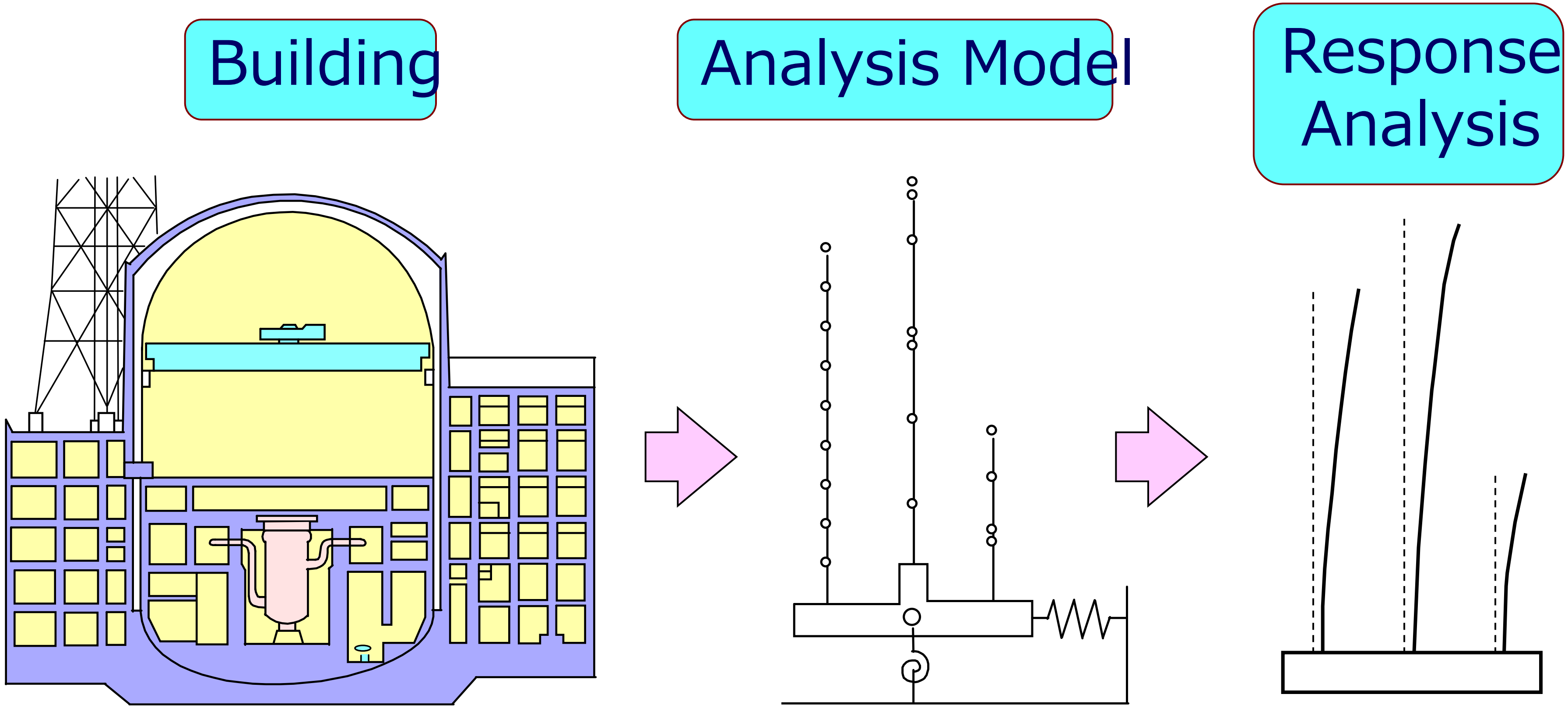
β_j : participation factor

$Ma_j(t)$: response acceleration of mode j

Sa_j : max. response acceleration of mode j

m_i : mass value of mass i

5.4.1 Method for Building & Structures Analysis

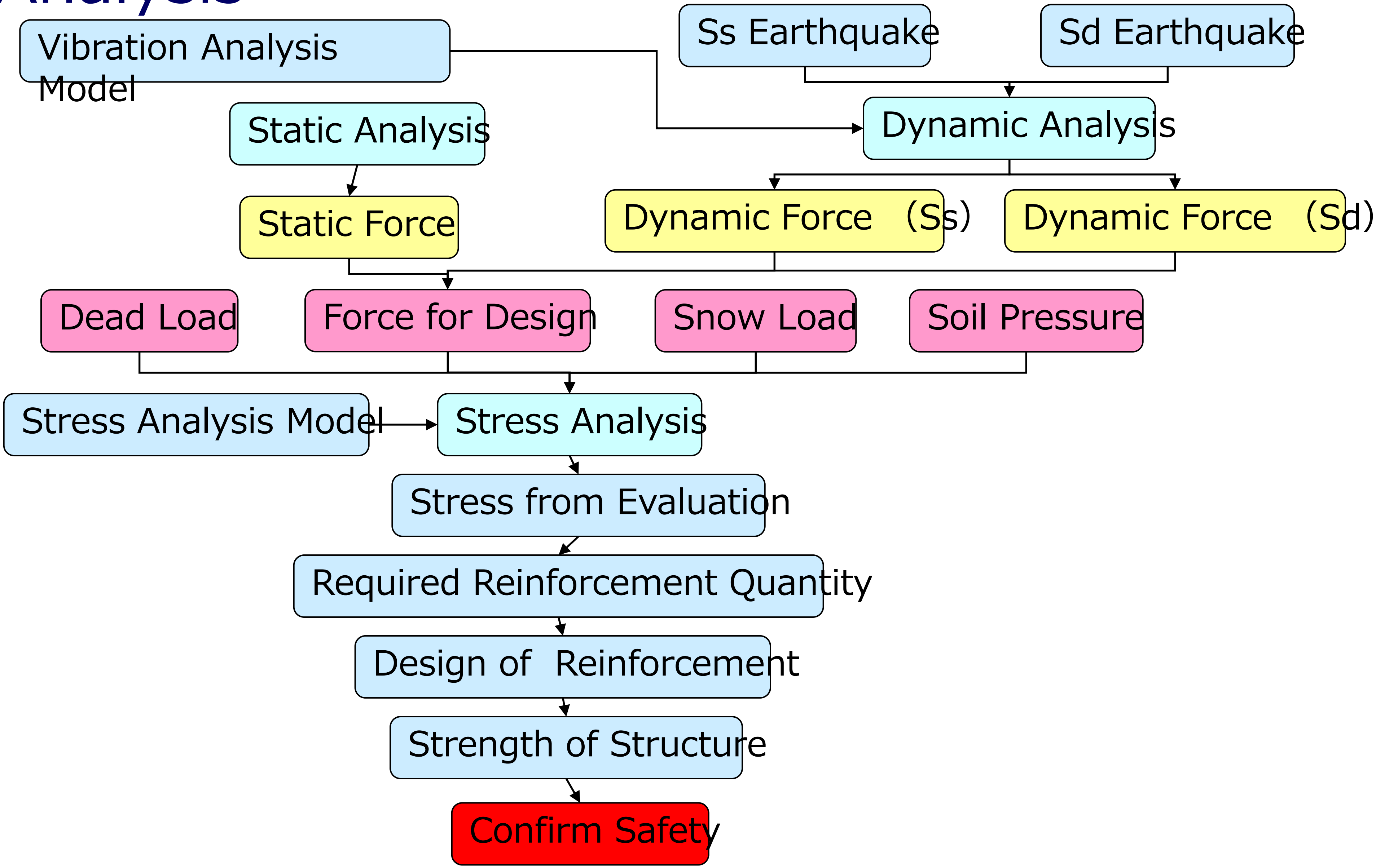


Confirm Safety

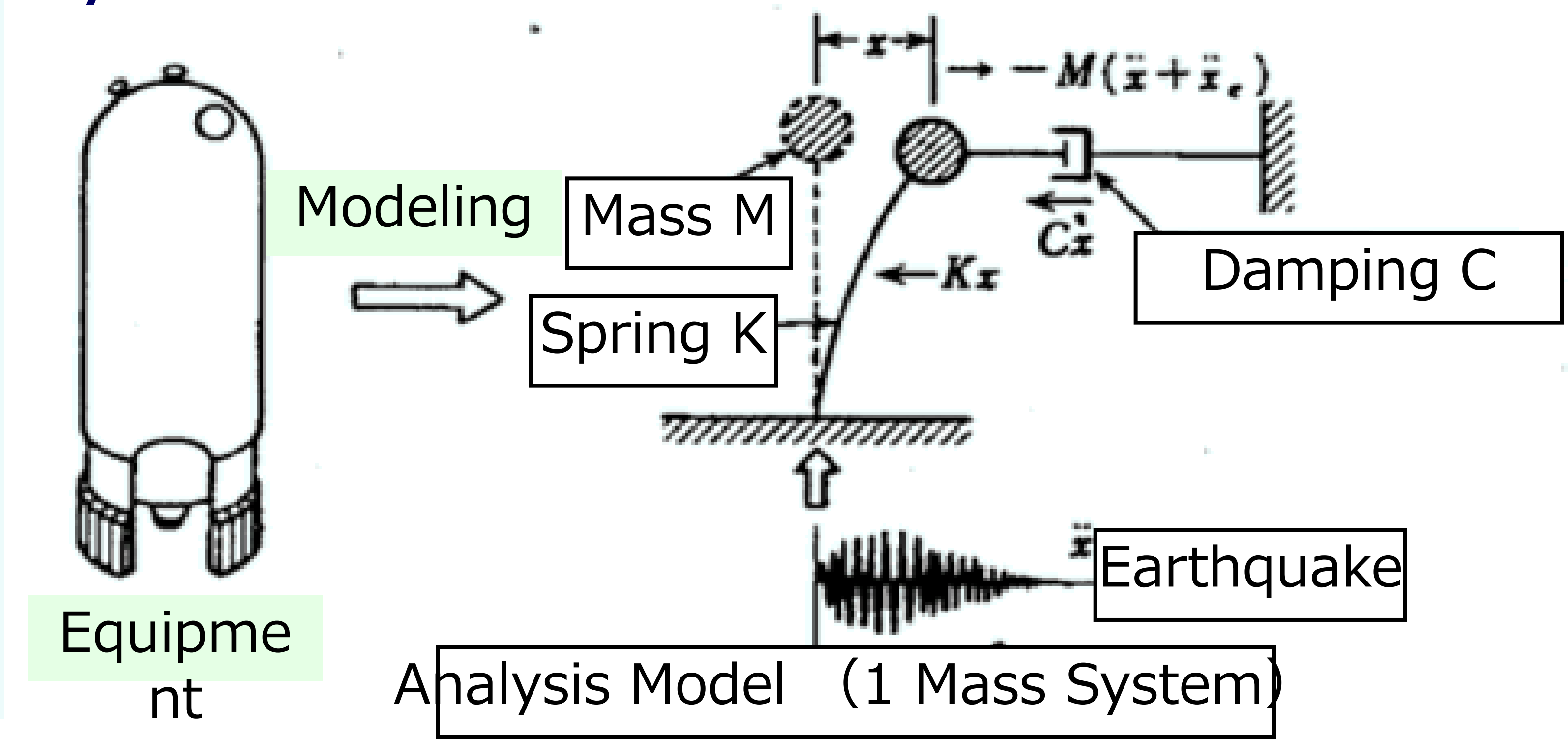
- Stress and Distortion
- Necessary Reinforcement

FBR応用講座（Ⅲ）、構造健全性（3） 耐震設計と最近の話題（JAEA、平成19年10月）より引用

5.4.2 Flowchart for Building & Structures Analysis



5.5.1 Method for Equipment & Piping Analysis

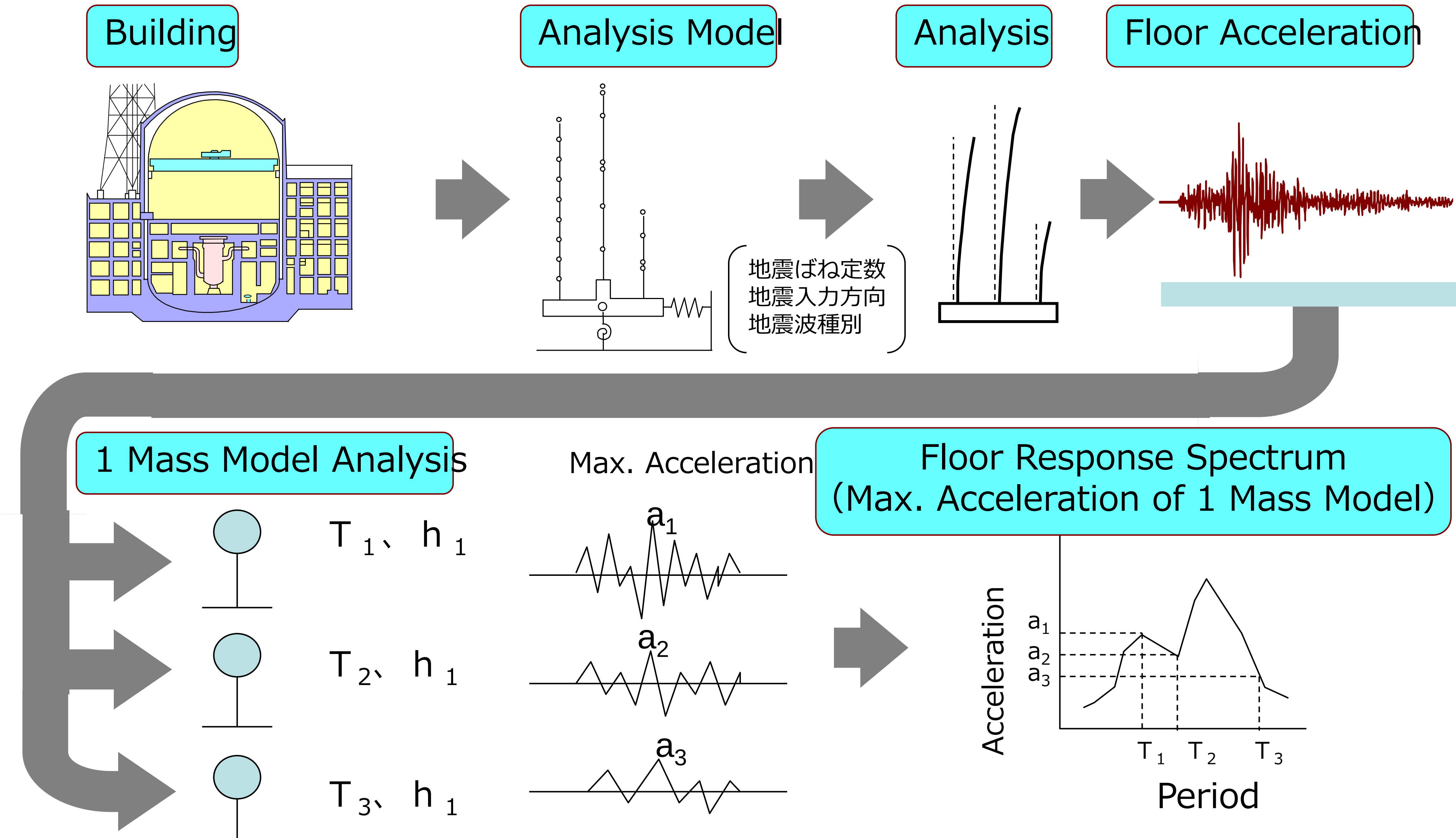


Confirm Safety

- Stress and Distortion
- Necessary Dimensions

FBR応用講座（Ⅲ）、構造健全性（3） 耐震設計と最近の話題（JAEA、平成19年10月）より引用

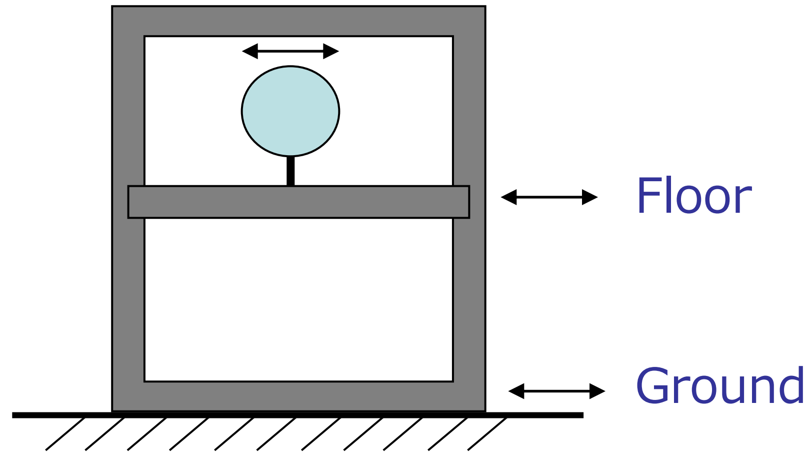
5.5.2 Floor Response Spectrum

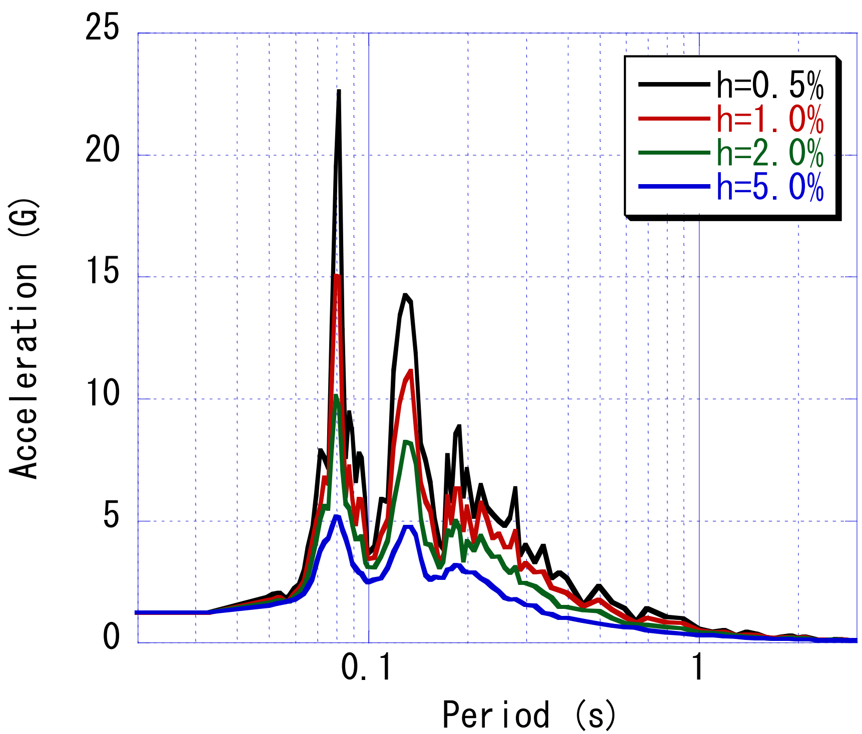


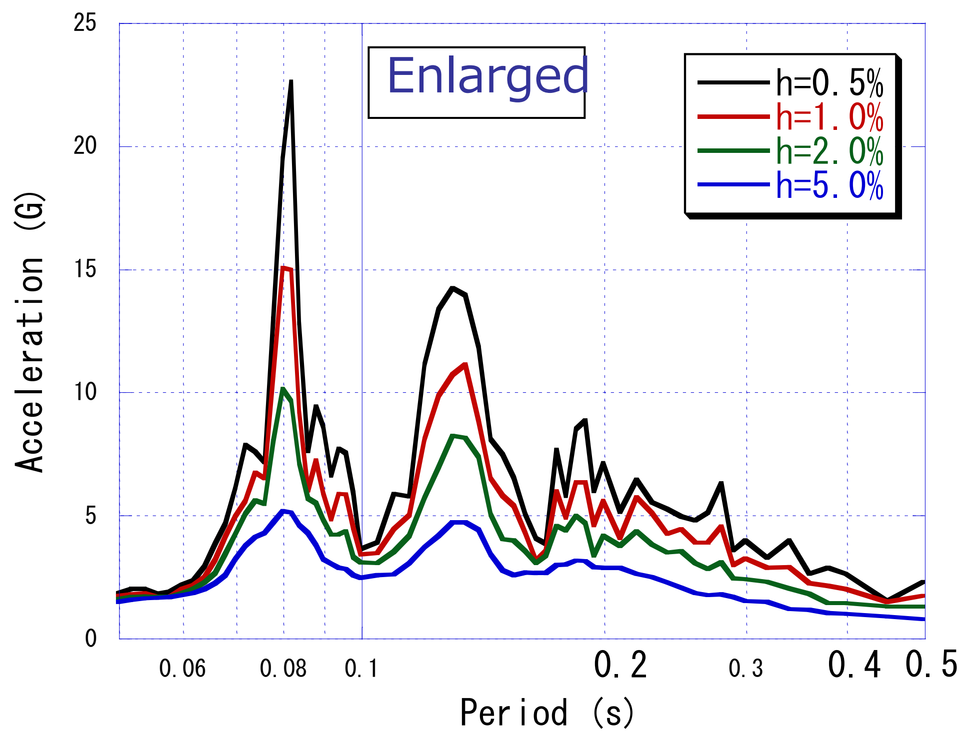
（T ; Natural Period、 h ; Damping, a ; Max. Acceleration）

FBR応用講座（Ⅲ）、構造健全性（3）耐震設計と最近の話題（JAEA、平成19年10月）より引用

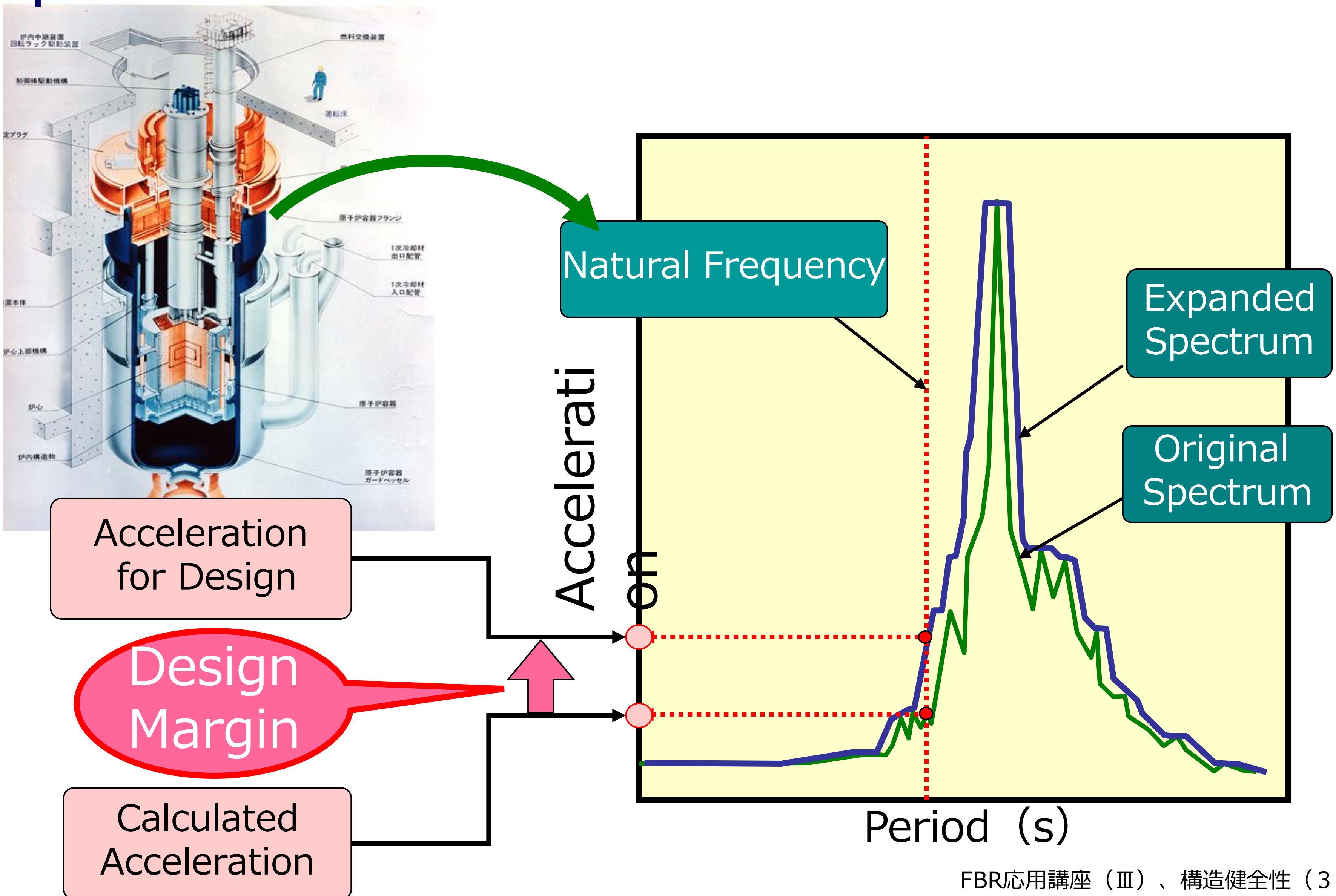
5.5.3 Example of Floor Response Spectrum







5.5.4 Broadening of Floor Response Spectrum



FBR応用講座（Ⅲ）、構造健全性（3）耐震設計と最近の話題（JAEA、平成19年10月）より引用

6 Allowable Limit in Seismic Design

6.1 Combination of Load and Allowable Limit for Equipment & Piping

6.2 Combination of Load and Allowable Limit for Building & Structures

6.3 Allowable Limit of Material

6.1 Combination of Load and Allowable Limit for Equipment & Piping

Class	Combination of Load		Allowable Limit
I	①	Ss Earthquake load and Load under Operating Condition and Load under Transient Condition or Load under Accident Condition	Function of Facility shall be maintained: Excessive deformation, cracking or rupture shall not occur, even in case where a building or a structure supporting the equipment or piping yields.
	②	Sd Earthquake or Static Earthquake load and Load under Operating Condition and Load under Transient Condition	Yield Stress or Equivalent
II III	Static Earthquake Load and Load under Operating Condition and Load under Transient Condition		Yield Stress or Equivalent

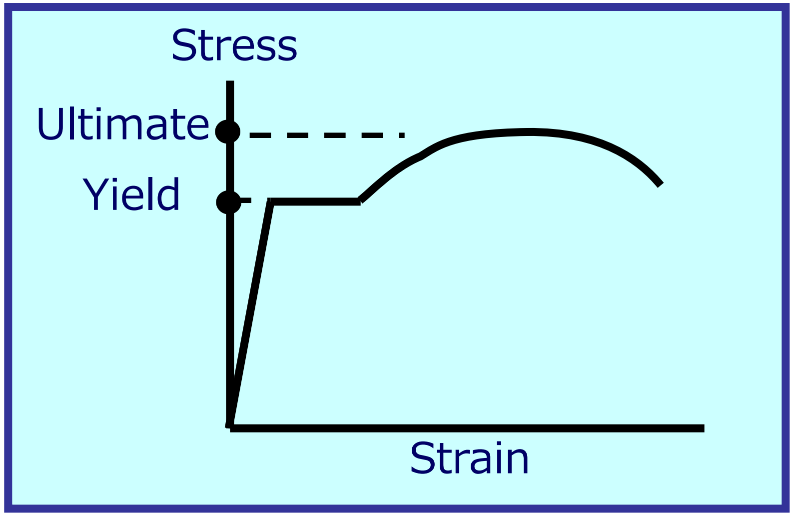
発電用原子力施設に関する耐震設計審査指針（原子力安全委員会 原子力安全基準・指針専門部会：2006年5月19日）を基に作成

6.2 Combination of Load and Allowable Limit for Building & Structures

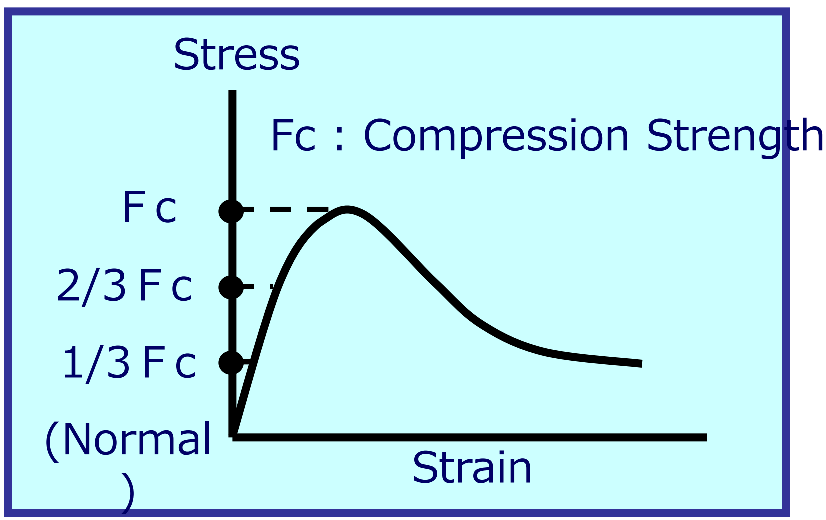
Class		Combination of Load	Allowable Limit
I	①	Ss Earthquake and Normal Load and Load under Operating Condition	Capable of undergoing deformation (Margin of ductility) while Maintaining safety margin to ultimate strength
	②	Sd Earthquake or Static Earthquake load and Normal Load and Load under Operating Condition	Building Code(as Short Term Load) Steel and Reinforcing Bar : Yielding Stress or Equivalent Concrete : 2/3 of Compression Strength
II III		Static Earthquake Load and Load under Operating Condition	Same as ② of Class I

発電用原子力施設に関する耐震設計審査指針（原子力安全委員会
原子力安全基準・指針専門部会：2006年5月19日）を基に作成

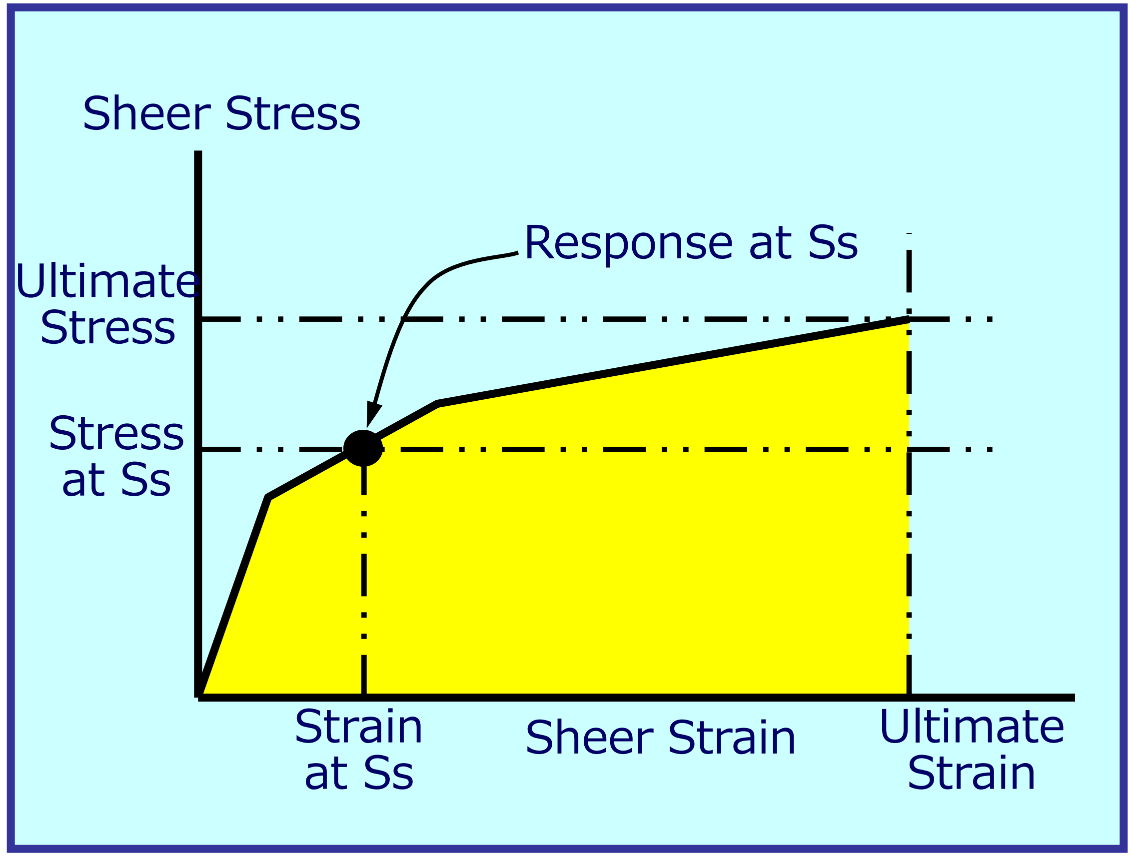
6.3 Allowable Limit of Material



Steel



Concrete

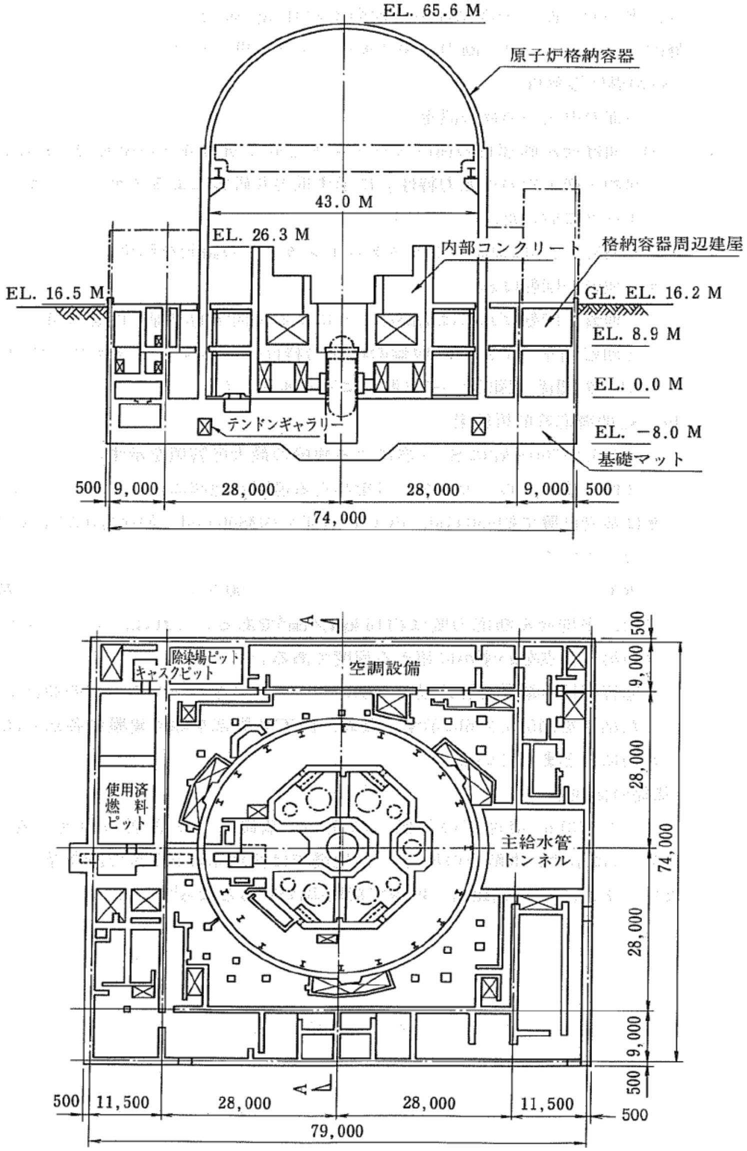


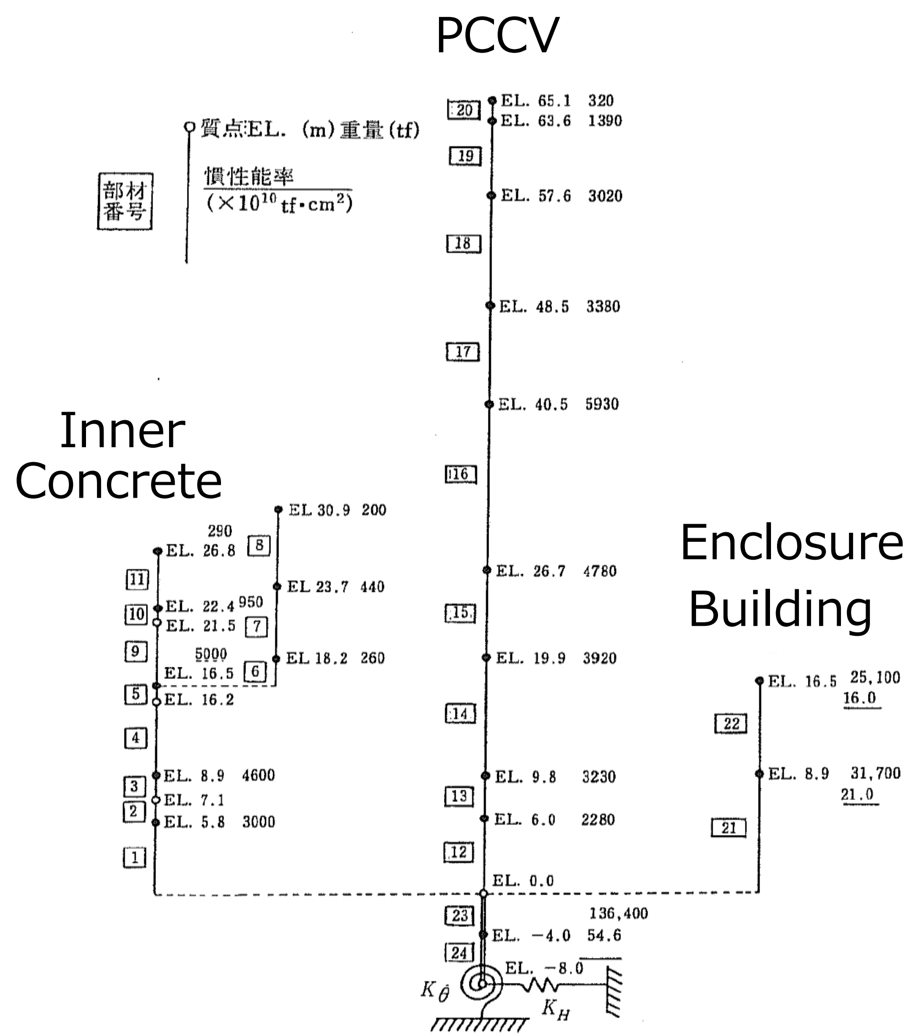
Strain of Concrete Wall

FBR応用講座（Ⅲ）、構造健全性（３）耐震設計と最近の話題（JAEA、平成19年10月）より引用

7 Seismic Design of Actual Plant

7.1.1 Reactor Building （PWR） - Model

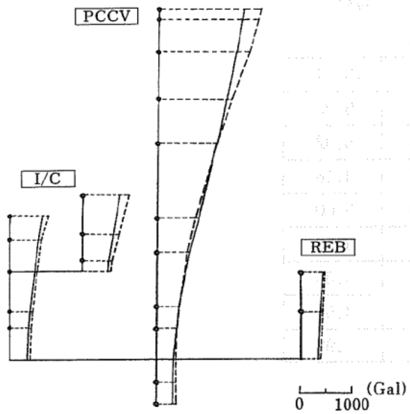




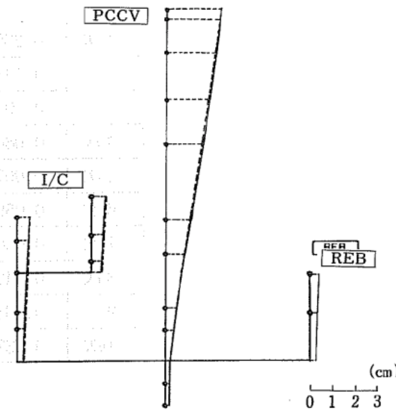
Analysis Model

原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

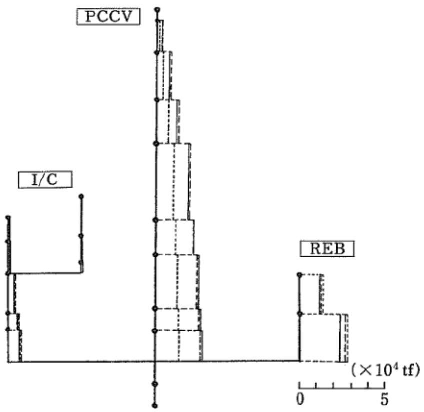
7.1.2 Reactor Building (PWR) - Result of Analysis



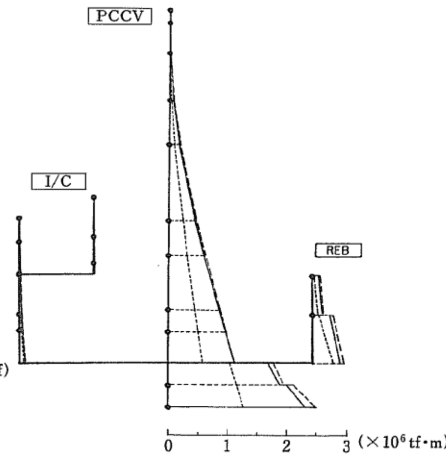
Acceleration



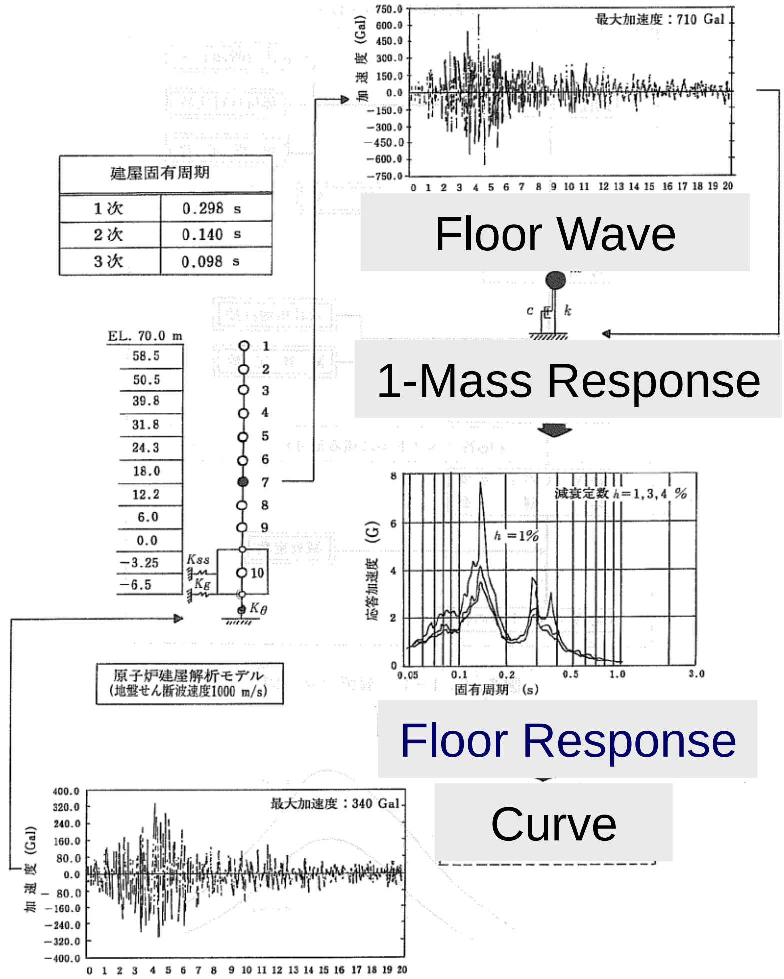
Displacement



Shear Force



Bending Moment



Floor Wave

1-Mass Response

Floor Response Curve

Ground Wave

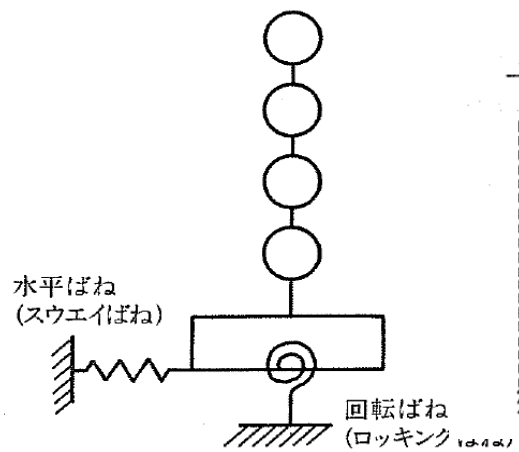
Floor Response Curve
(For Each Floor)

原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

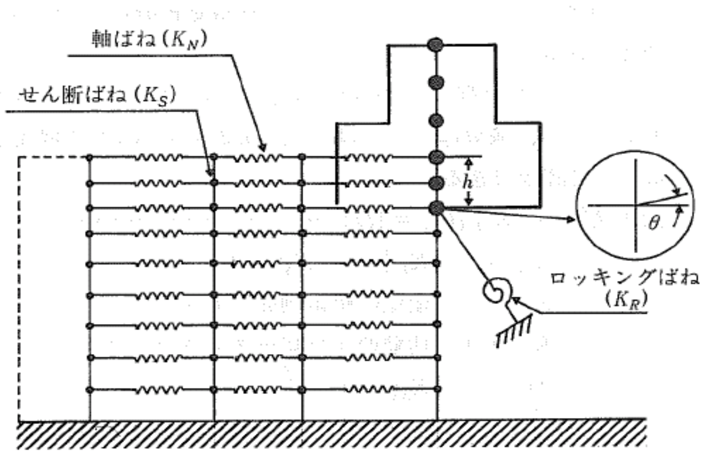
7.1.3 Reactor Building - Soil Structure Interaction

Composite Analysis for Building and Base Rock (Soil)

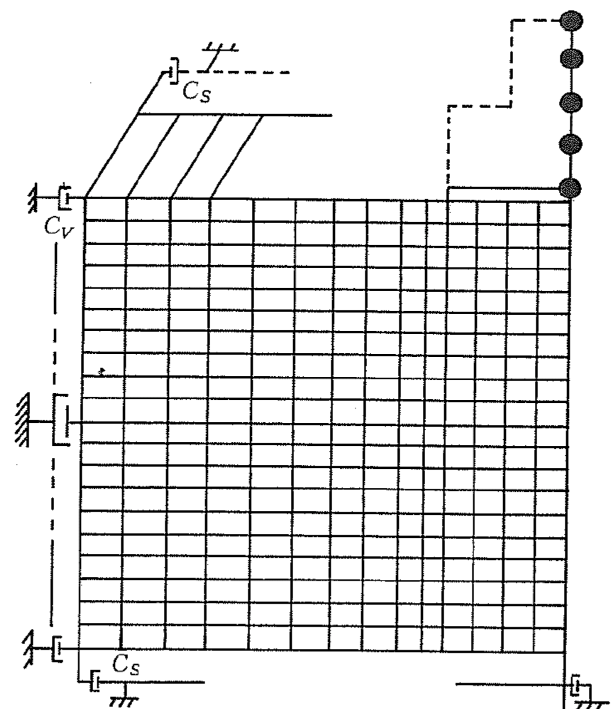
- Rocking of Building
- Correct Response



Sway-Rocking Model



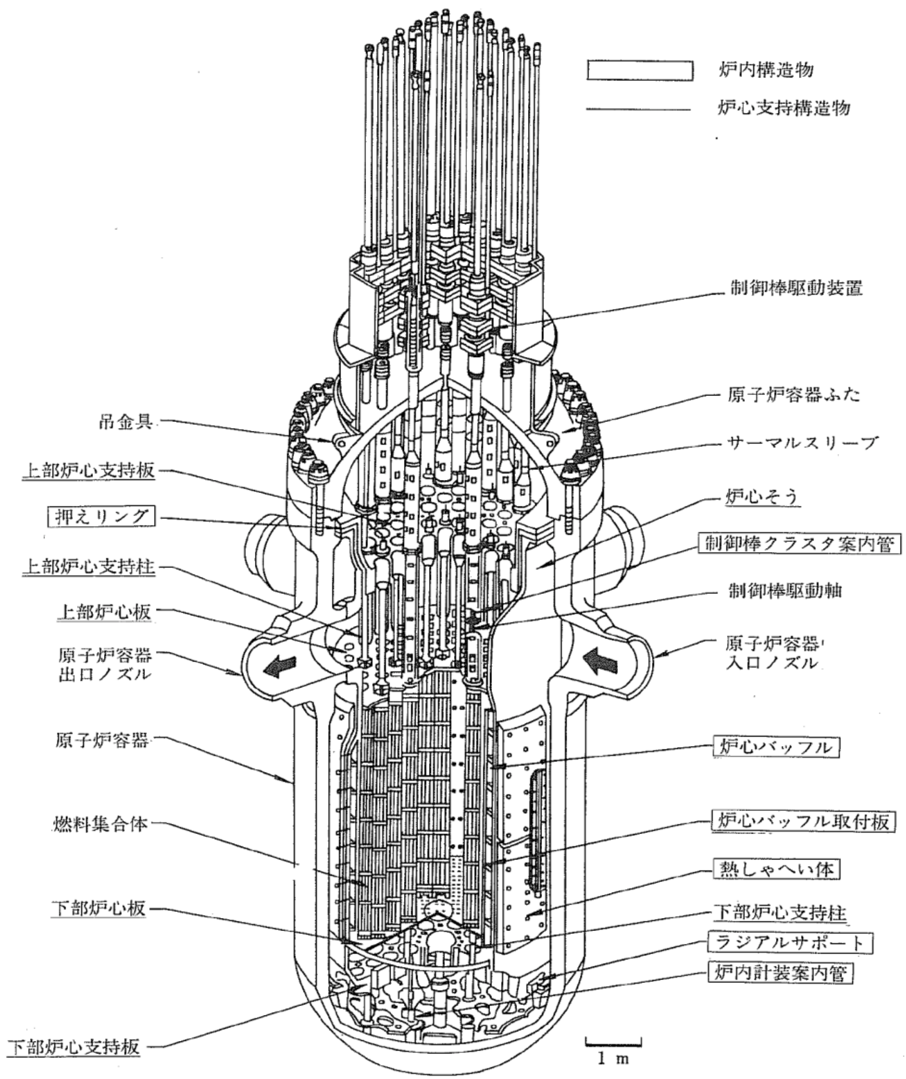
Lattice Model

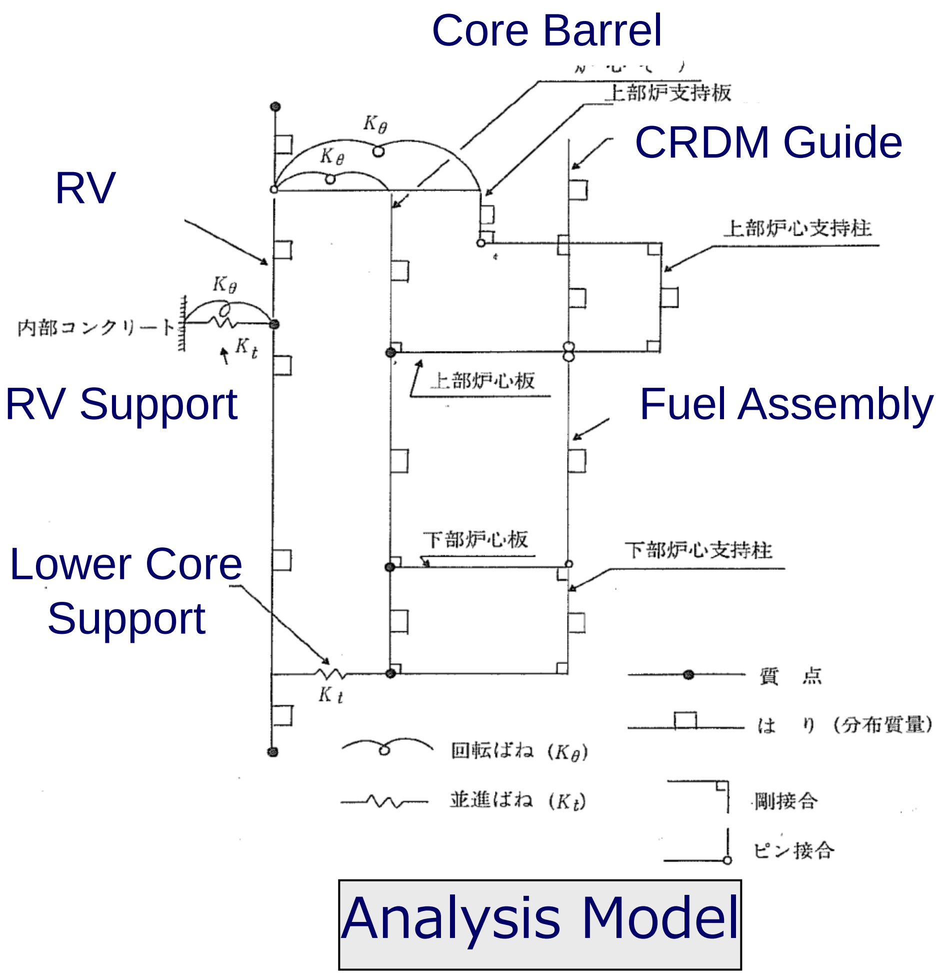


FEM Model

原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

7.2 Reactor Vessel and Core Internal (PWR)

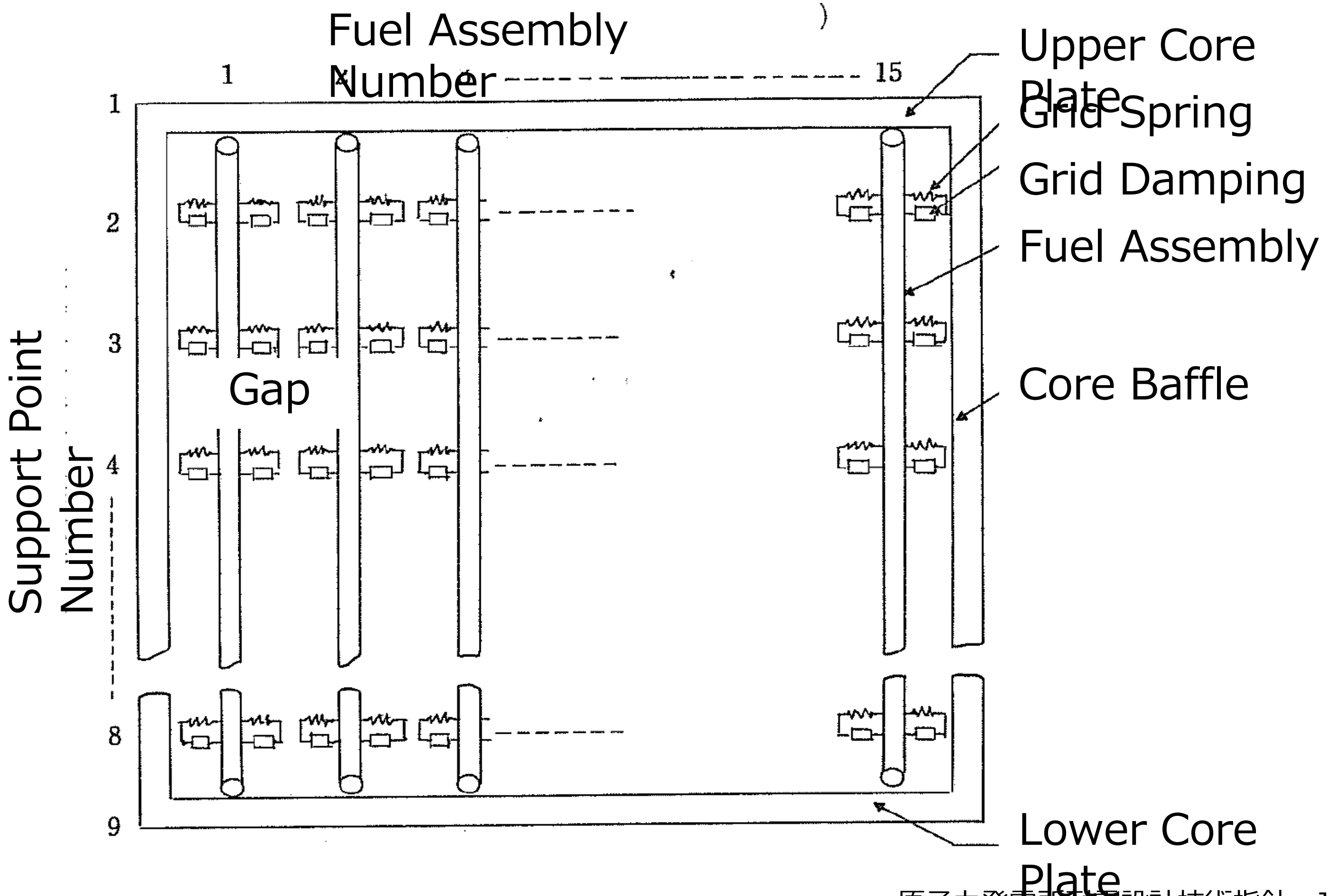




原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

7.3 Fuel Assemblies (PWR)

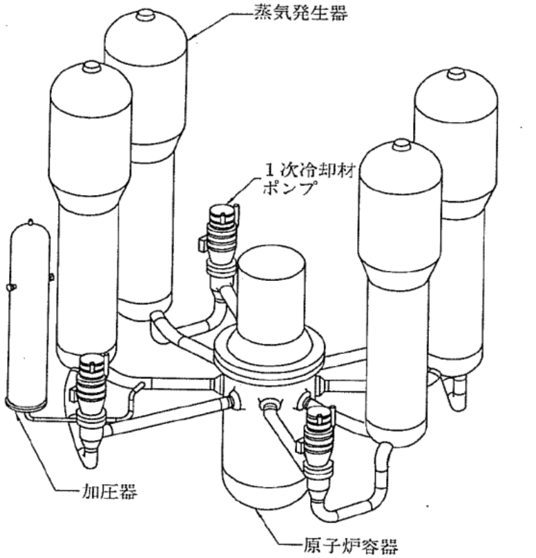
Flexible Elements Adjoined with Springs and Gaps → Nonlinear Analysis Model for Group of Many Elements with Collision

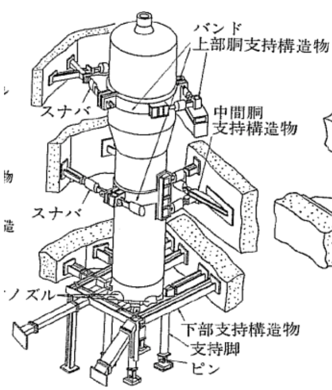


原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

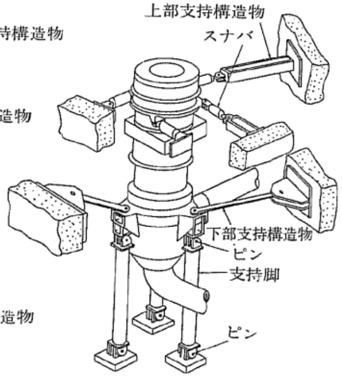
7.4 Reactor Coolant Loop （PWR）

Large Thermal Expansion → Composite Model

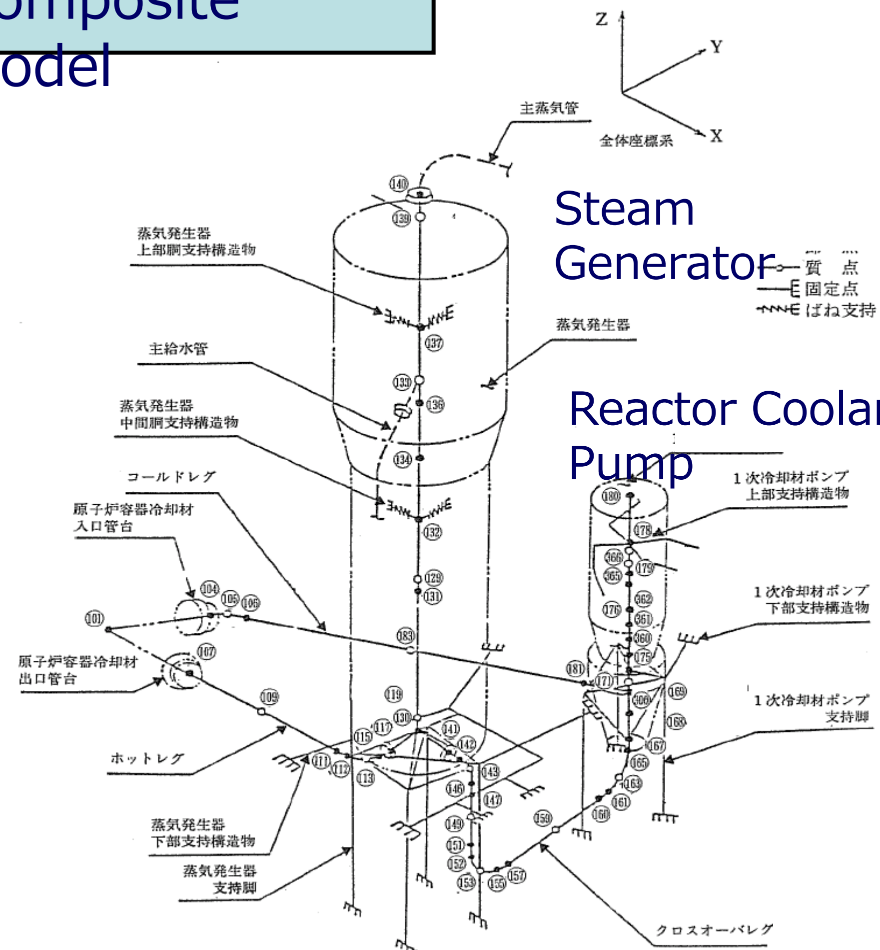




Steam Generator



Reactor Coolant Pump



Steam Generator

Reactor Coolant Pump

Reactor Coolant Pipe

Analysis Model

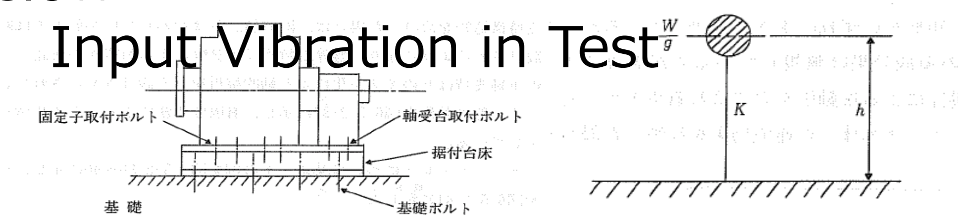
原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

7.5 Dynamic Equipment

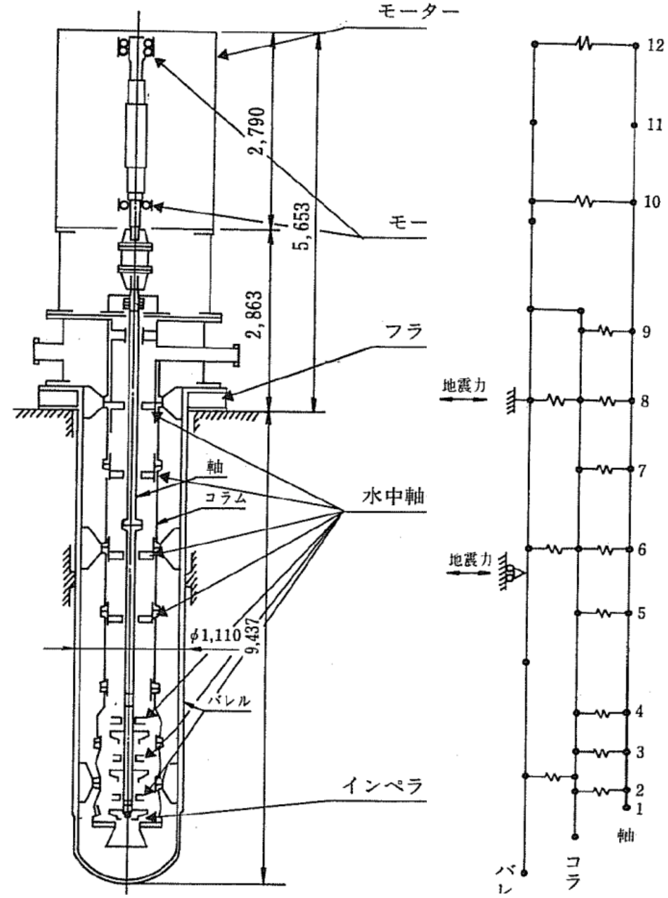
Equipment Required Function
during or after Earthquake
- Control Rod Drive Mechanism
- Pump and Motor (Class I)
- Emergency Diesel Generator
- etc.

↓

- Vibration Tests for Typical Equipment
- Estimation of Actual Input Vibration by Analysis
- Confirmation Actual Input Vibration below Input Vibration in Test



Analysis Model for Rigid Equipment



Analysis Model for Flexible Equipment

原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

7.6.1 Piping - Design Methods

① High Temperature Piping

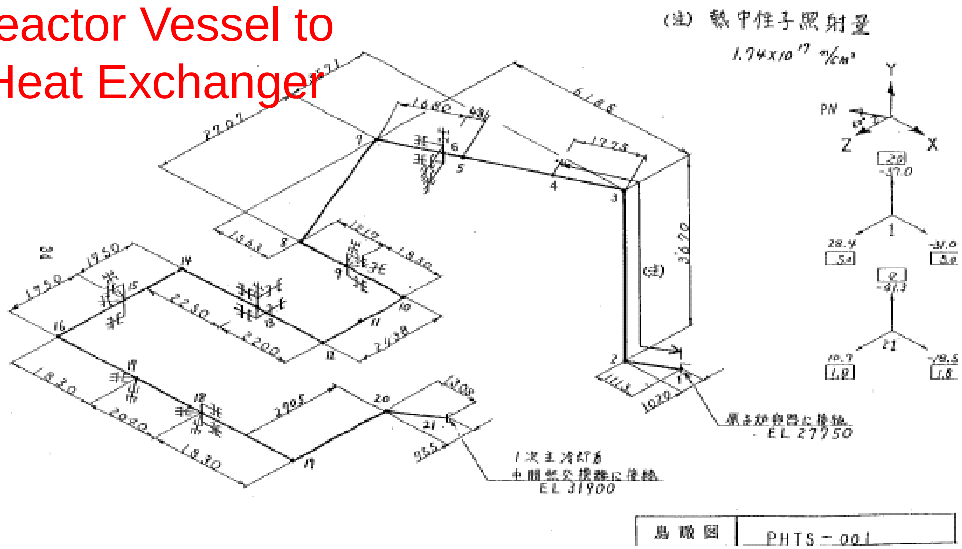
Large Thermal Expansion
⇒ Layout with Piping Flexibility
⇒ Detailed Analysis and
Flexible Support System

② General Piping

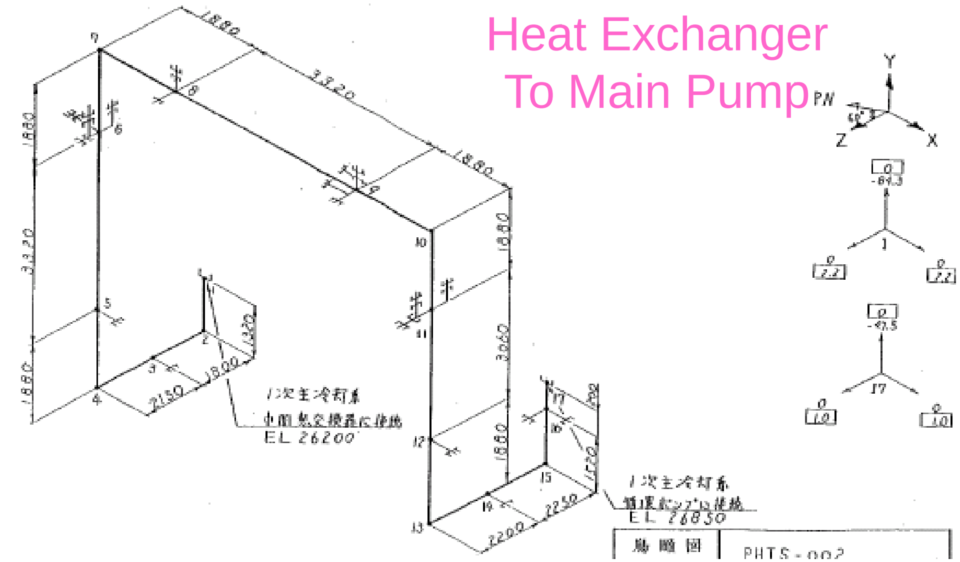
Small Thermal Expansion
⇒ Piping Flexibility not Required
⇒ Rigid Support System with Fixed Support Span
(Support Span is Predetermined Corresponding to
Pipe Size, Floor, Seismic Class)

7.6.2 Hot Piping Analysis Model (FBR)

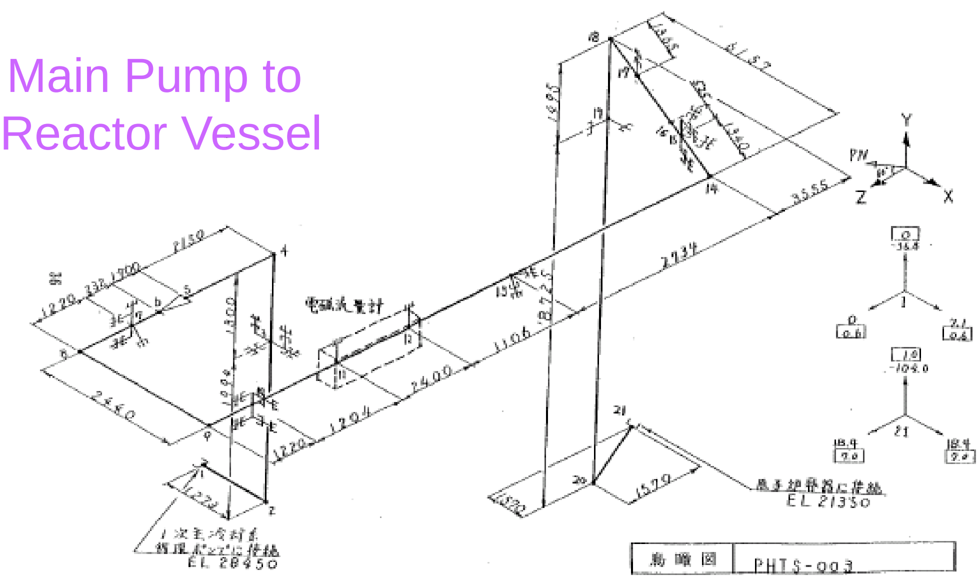
Reactor Vessel to Heat Exchanger

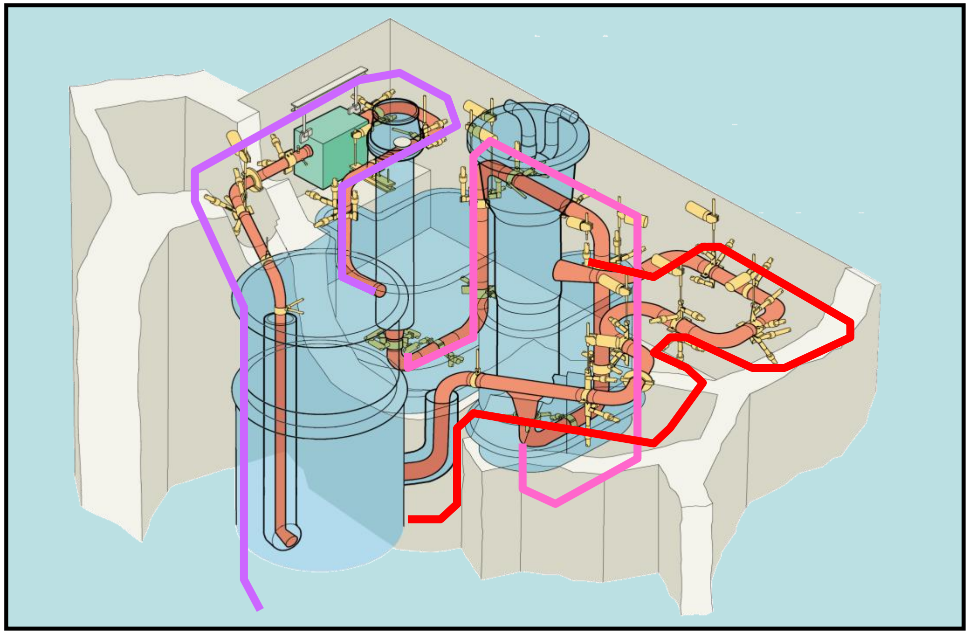


Heat Exchanger To Main Pump



Main Pump to Reactor Vessel



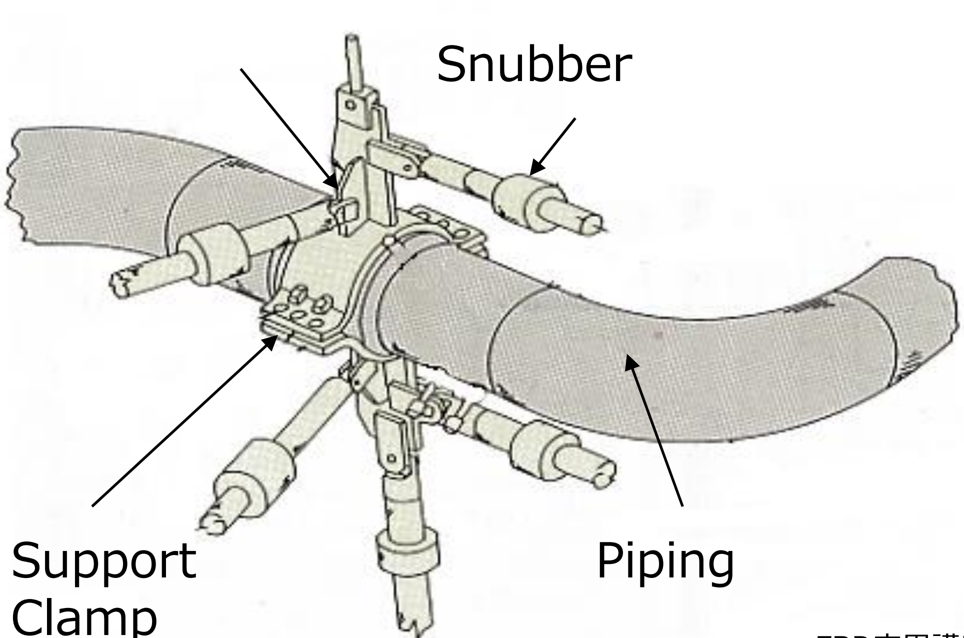


FBR応用講座（Ⅲ）、構造健全性（3）　耐震設計と最近の話題（JAEA、平成19年10月）より引用

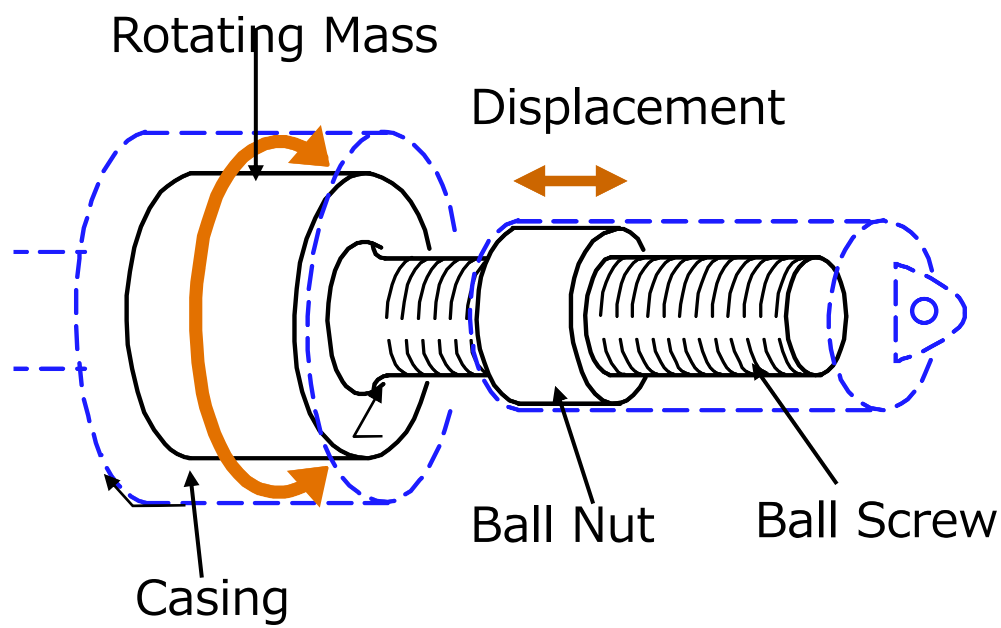
7.6.3 Support for Hot Piping – Mechanical Snubber

- Not Restrain Slow Movement
  by Thermal Expansion
- Restrain Quick Movement
  by Earthquake

- Mechanical Type
- Hydraulic Type

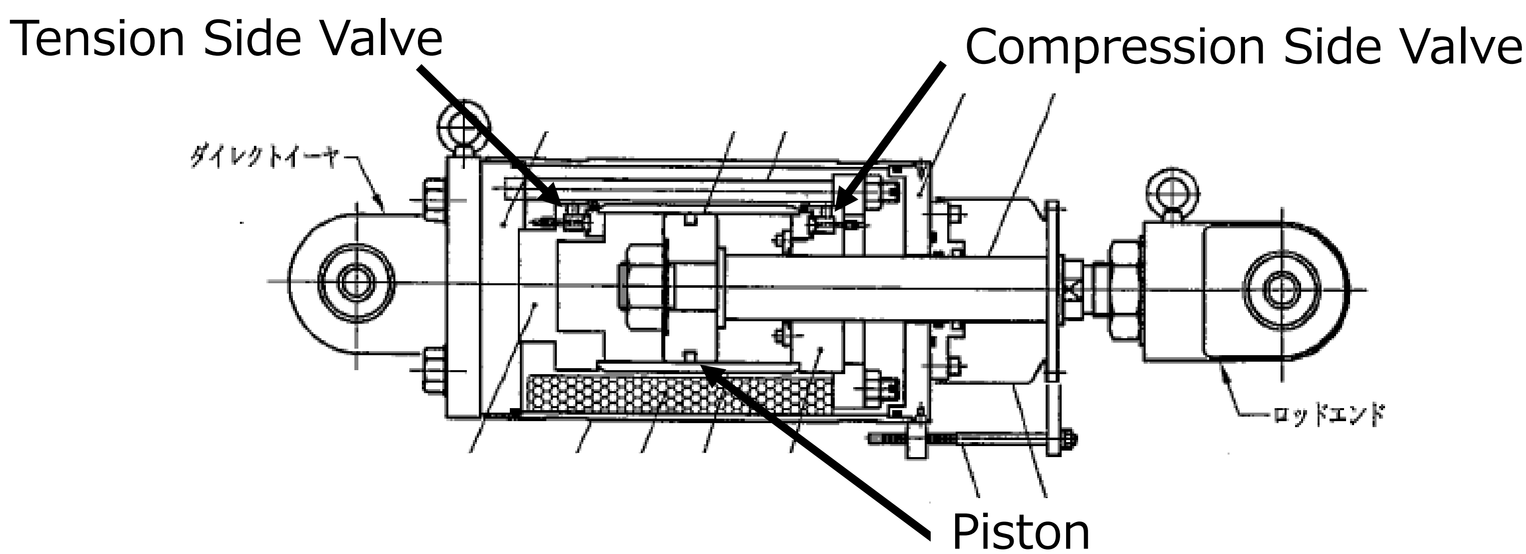


Mechanical Snubber



FBR応用講座（Ⅲ）、構造健全性（３）　耐震設計と最近の話題（JAEA、平成19年10月）より引用

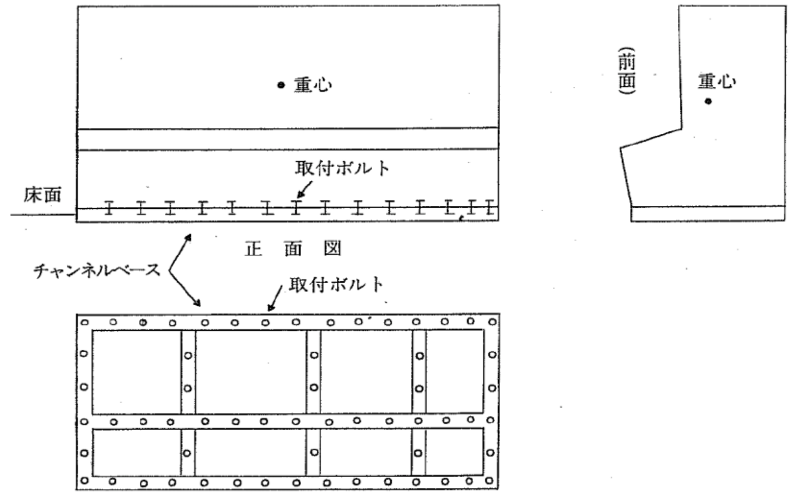
7.6.4 Support for Hot Piping – Hydraulic Snubber



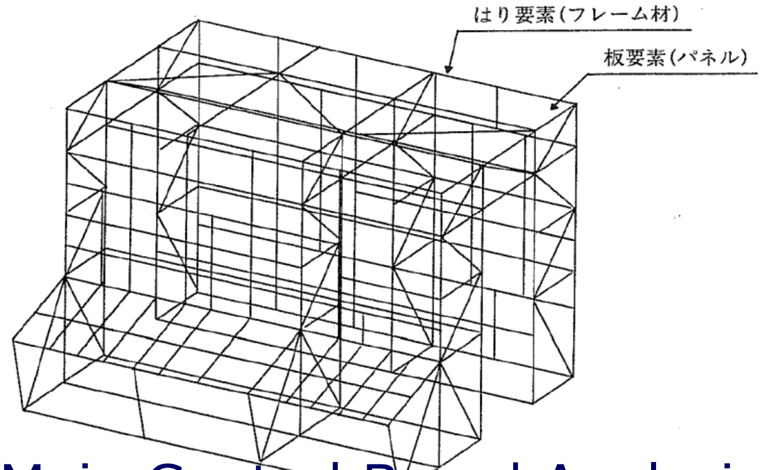
三和テッキ株式会社提供資料を基に作成

7.7 Electrical and Control Element

① Large Boards
 ⇒ Analysis
② Other Boards and Panels
 ⇒ Vibration Test for Each Type
③ Meters and Switches on Boards
 ⇒ Vibration Test for Each Type
④ Cable Trays and Conduits
 ⇒ Determine Suitable Support with Analysis in the Same way as Piping



Main Control Board Structure



Main Control Board Analysis Model

原子力発電所耐震設計技術指針、JEAG4601（日本電気協会　電気技術基準調査委員会、1987）を基に作成

7.8 Overview of Natural Frequency

	Frequency (Hz)	Note
Earthquake	Peak Range From ～3 to ～10	Target for Artificial Wave
Containment (PWR PCCV)	～4	
Reactor Building Inner Concrete (PWR)	～10	
Reactor Building (Seismic Isolation Type)	0.5～2	Reference only. No Actual Plant in Japan
Equipment	> ～20	Exceptions: Large Tank, etc.
Piping	Target >15～30 For All Directions	Depends on Support Design

Note : Frequencies for Horizontal Direction except for Piping

8 Summary – Essential Points in Seismic Design

① Determination of Adequate Design Earthquake
← Precise Investigation for Seismic Activity

② Selection of the Site with Stable and Stiff Ground (Base Rock) ← Precise Investigation for Ground Characteristics

③ Robust Design of Building

④ Comprehensive Design of Component – from Reactor to all Utilities

Note : All Items are Related to the Plant Cost.

Reference

(1) Brookhaven National Laboratory; Technical Guideline for Aseismic Design of Nuclear Power Plant (Translation of JEAG 4601-1987) NUREG/CR-6241(BNL- NUREG-52422)

(2) IAEA Safety Standard Series No. NS-G-1.7 Seismic Design Qualification for Nuclear Power Plants (2003)