# Standard Reference Earthquake Parameters

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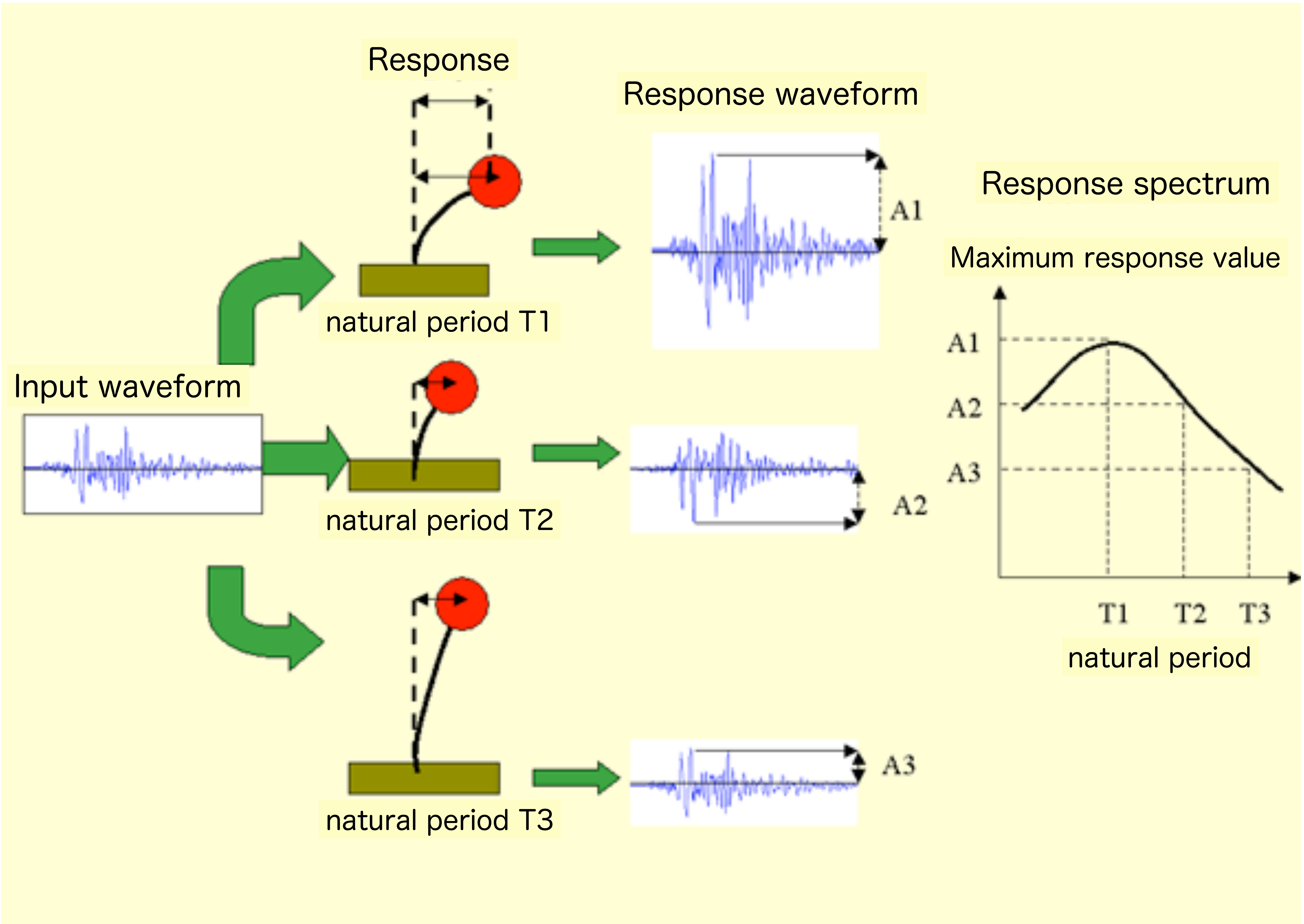
# Response Spectrum of Earthquake

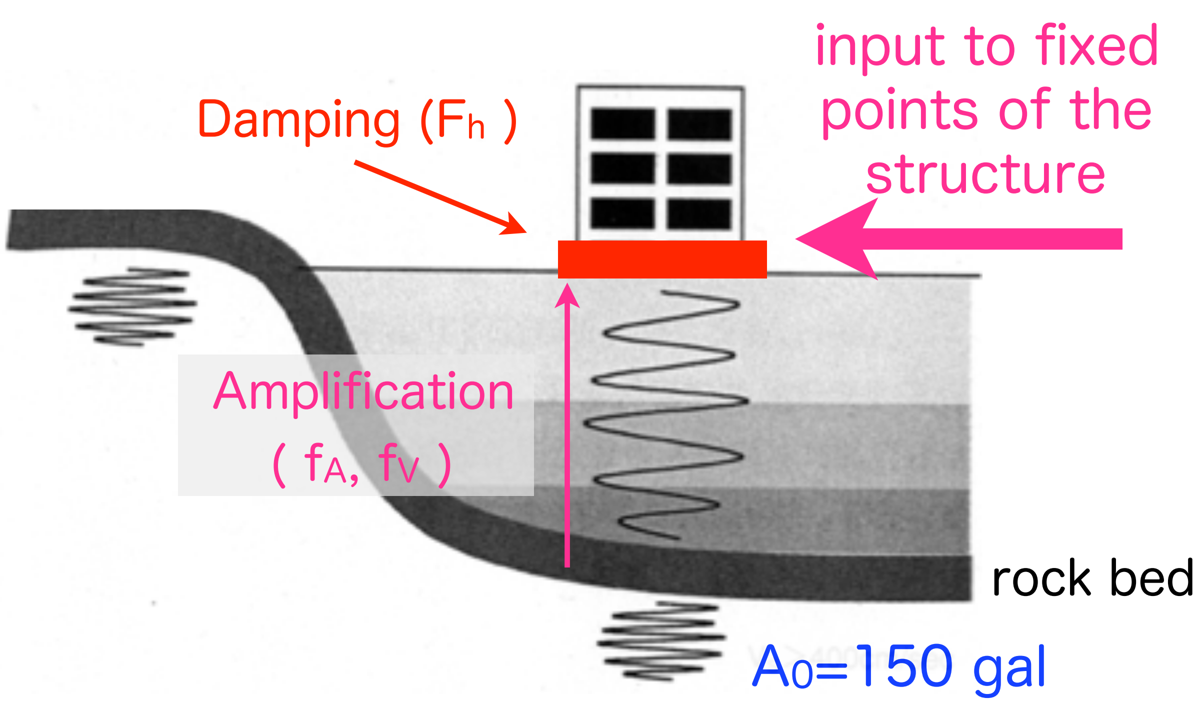
## for dynamic ground motion analysis of the structure

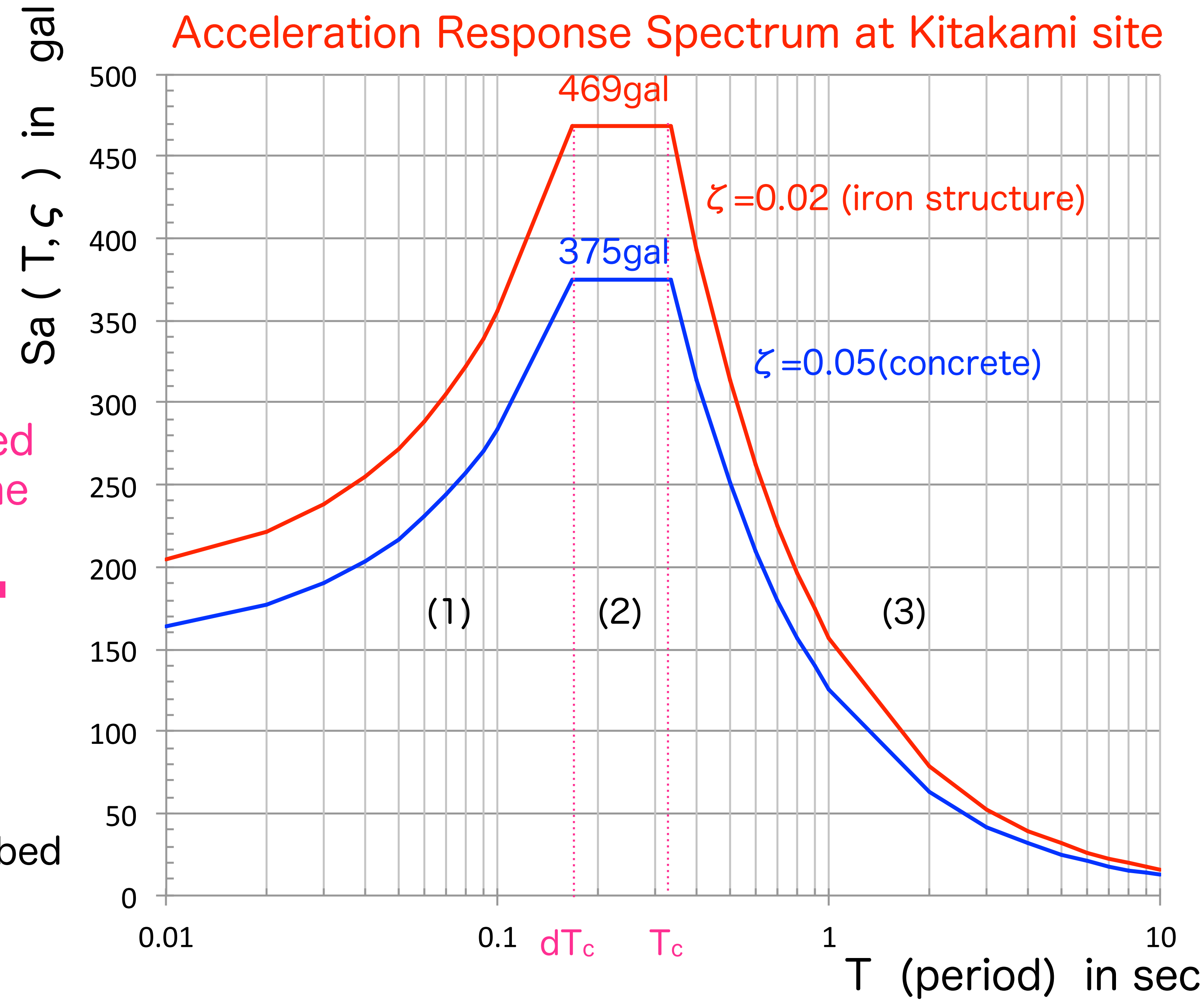


# Seismic Analysis with the class-1 geology (hard soil)

following the guideline of construction loads by Architectural Institute of Japan, also ISO3010

## Kitakami is a site with hard soil.




$$(1)\ 0 \le T \le dT_c \quad : \quad S_a = \left(1 + \frac{f_A - 1}{d}\frac{T}{T_c}\right) F_h G_A R_A A_0$$

$$(2)\ dT_c \le T \le T_c \quad : \quad S_a = f_A F_h G_A R_A A_0$$

$$(3)\ T_c \le T \quad : \quad S_a = \frac{2\pi f_V F_h G_V R_V V_0}{T}$$

(constant velocity spectrum)

$$T_c = \frac{2\pi f_V G_V R_V V_0}{f_A G_A R_A A_0} = 0.33\text{sec}$$

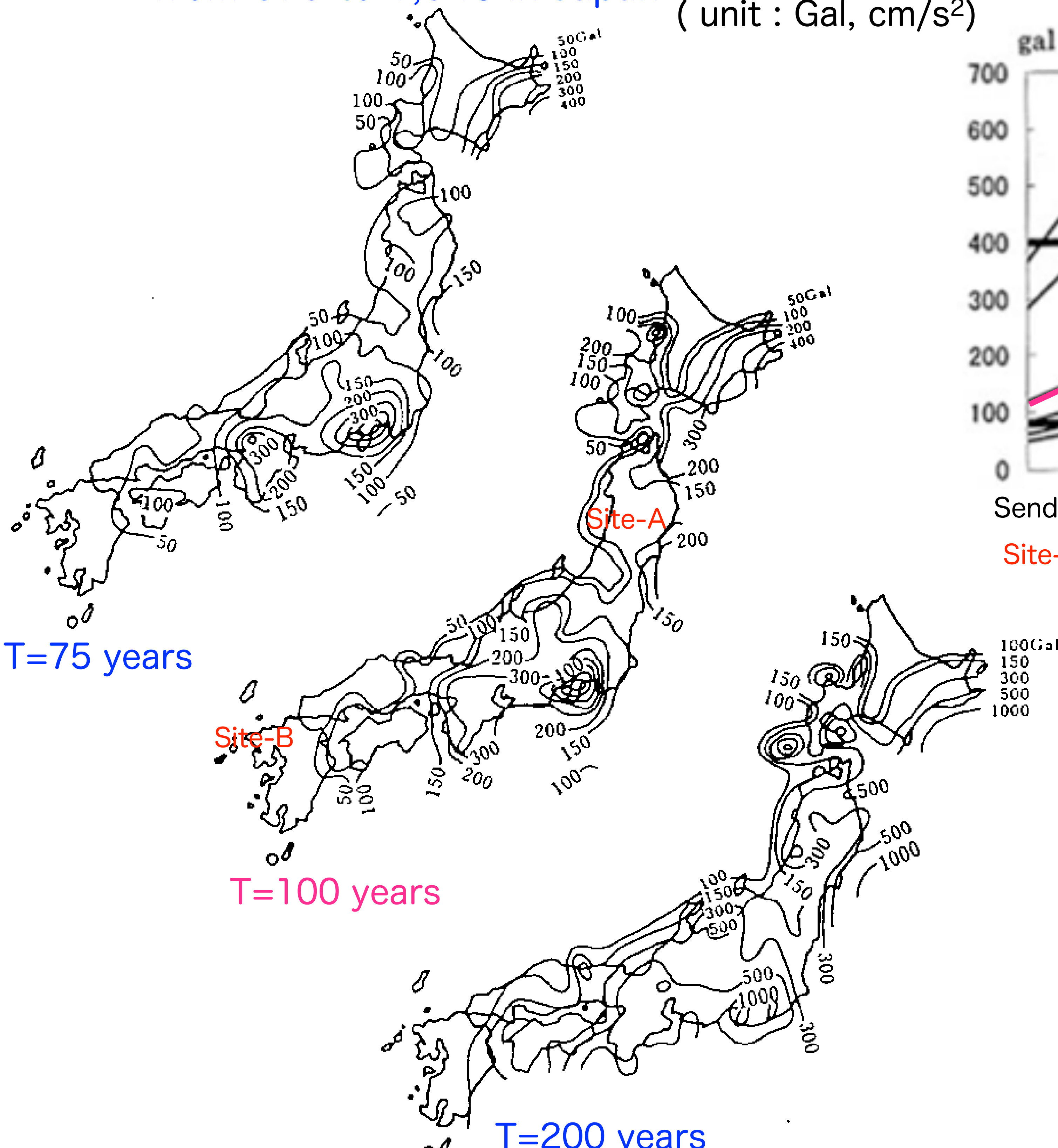
$$dT_c = 0.17\text{sec for } d = 0.5$$

$$\text{Frequency:} f = \frac{1}{T} \quad \text{Displacement:} x(f,\zeta) = \frac{S_a(T,\zeta)}{(2\pi f)^2}$$

# Seismic Hazard Map in Japan : Maximum acceleration (gal) in recurrence intervals (T) of earthquake

Kawasumi map : based on earthquakes from 679 to 1,948 in Japan

( unit : Gal, cm/s$^2$)

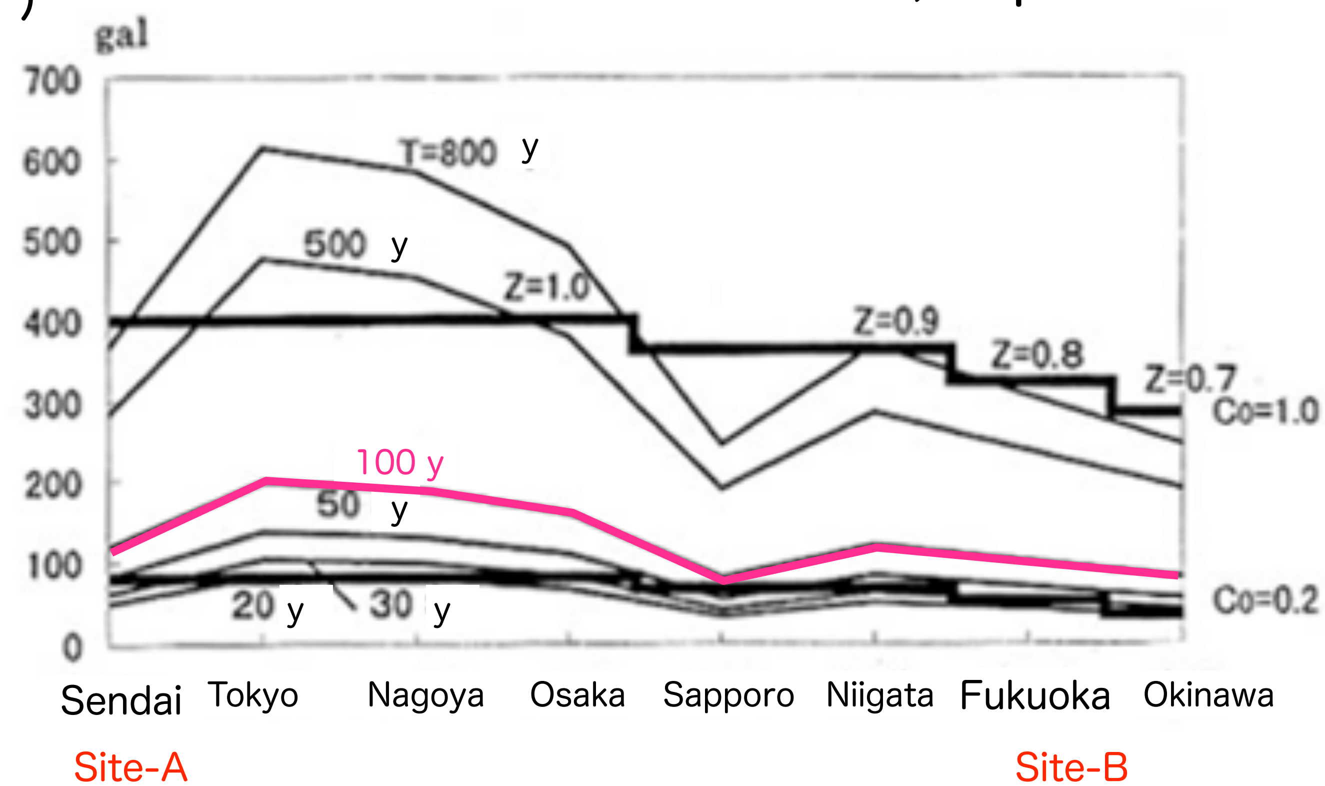



T=75 years

T=100 years

T=200 years

Max. acceleration in cities, Japan



# Site-dependent parameters in seismic analysis for hard soil

$A_0$ (150 at Kitakami site ): Basic maximum acceleration of ground motion

$V_0$ ($A_0$/15 hard) : Basic maximum velocity of ground motion

$R_A$ (1.0 hard): conversion coefficient of recurrence intervals (std:100y) of the maximum acceleration

$R_v$ (1.0 hard) : conversion coefficient of recurrence intervals (std:100y) of the maximum velocity

$G_A$ (1.0 hard): site-dependent (ground type) correction factor of the maximum acceleration

$G_v$ (1.0 hard): site-dependent (ground type) correction factor of the maximum velocity

$F_h$ (1.25/1.0 hard): Correction factor by damping, $1.5/(1+10\varsigma)$ with $\varsigma$=0.02/0.05 for steel/concrete

$f_A$ (2.5 hard): ratio of $G_A R_A A_0$ of $S_a(T,\varsigma)$ in $dT_c<T<T_c$ , amplification factor

$f_v$ (2.0 hard): ratio of $G_v R_v V_0$ of the velocity spectrum $S_v(T, \varsigma)= S_a(T, \varsigma)T/2\pi$ in $T_c<T$, amplification factor

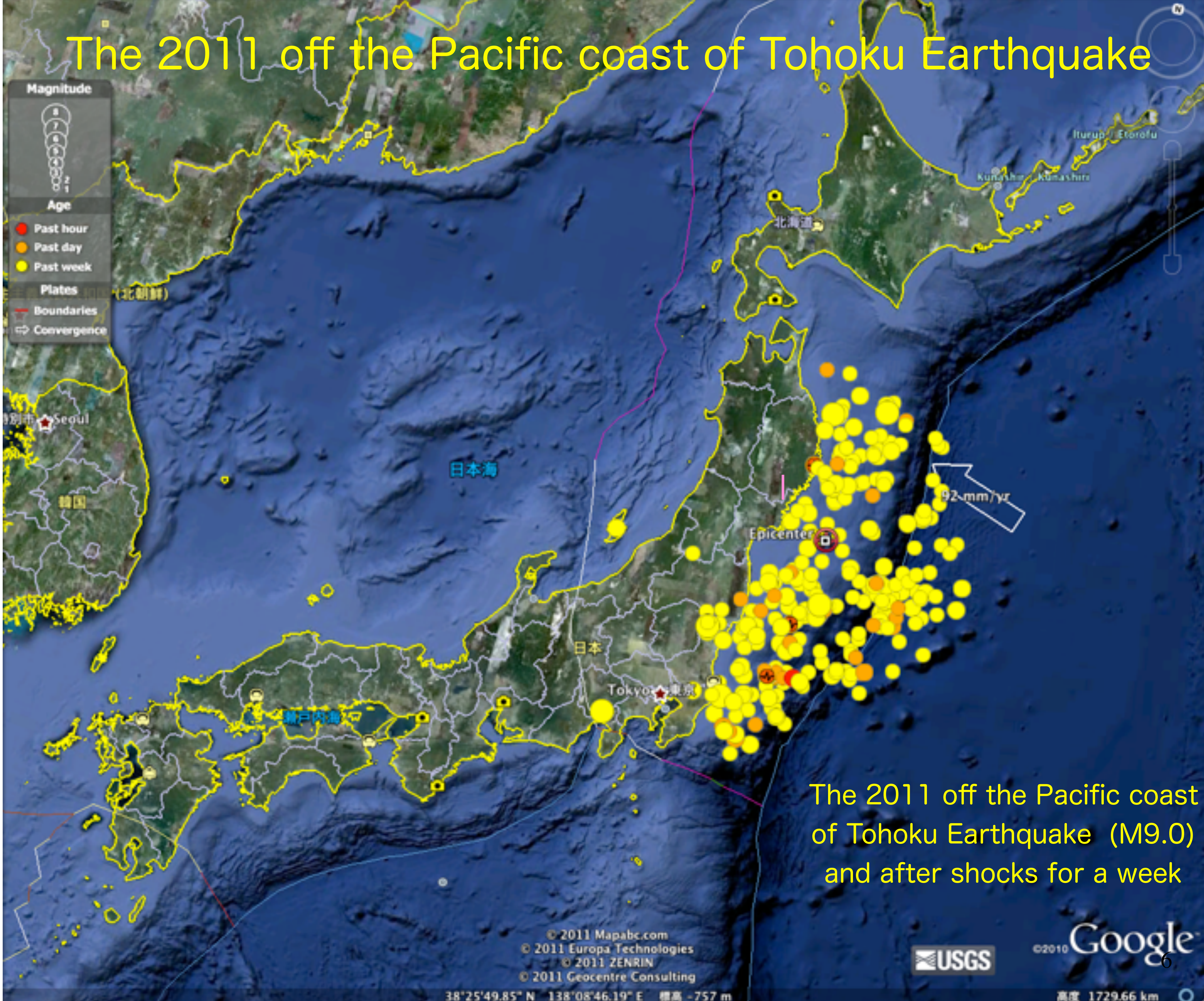
d (0.5 hard): $dT_c/T_c$, ratio of lower bound of period ($dT_c$) relative to the upper one ($T_c$=0.33sec hard) in the constant $S_a(T,\varsigma)$

## Natural vibration analysis of structures

Calculation of natural frequencies, own natural periods, natural angular frequencies, natural vibration modes, impulse constants, effective masses then,

Estimation of maximum displacement, maximum response acceleration, and maximum stress to be reviewed if it is less than the allowable stress.

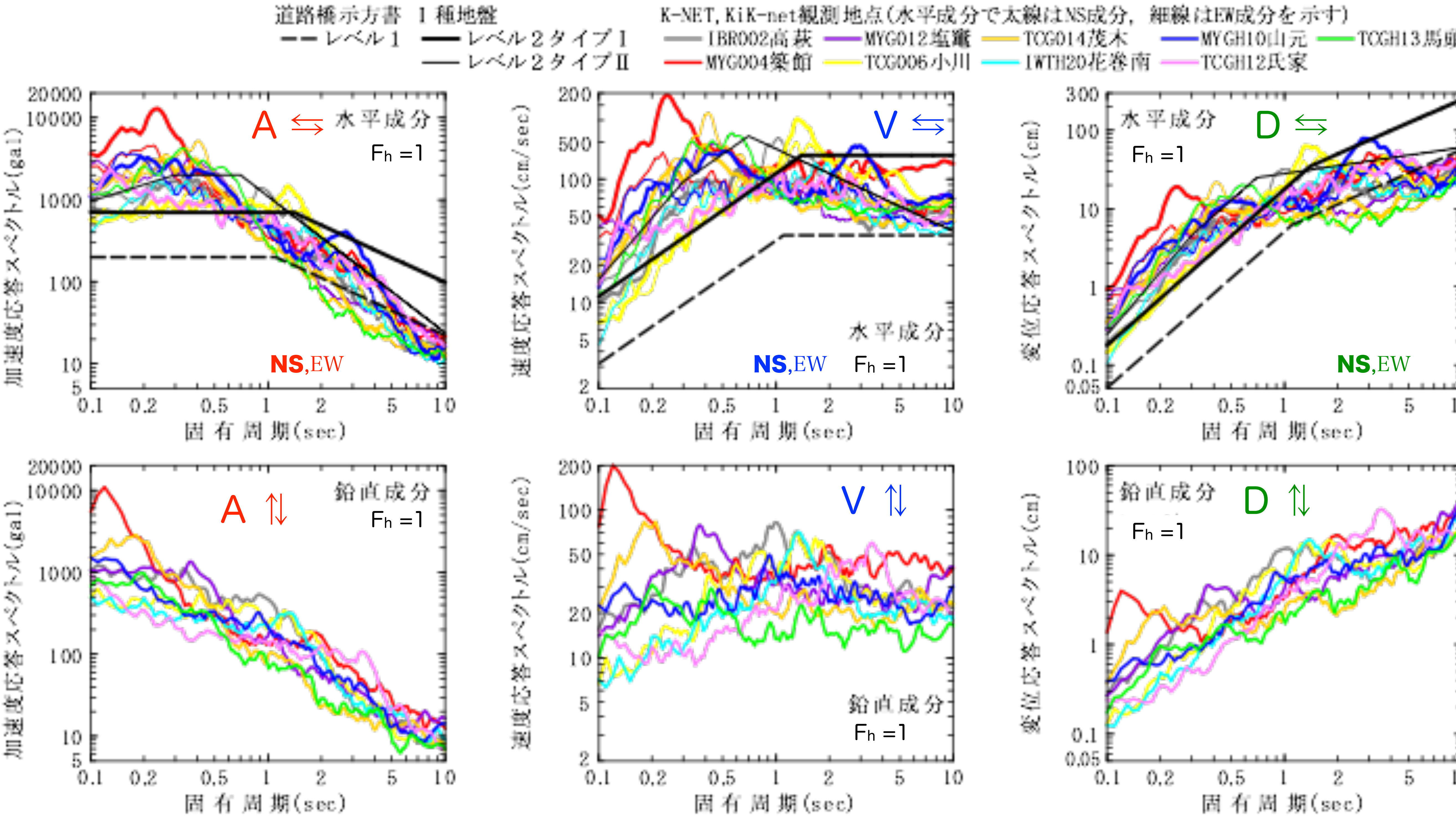
# The 2011 off the Pacific coast of Tohoku Earthquake




The 2011 off the Pacific coast of Tohoku Earthquake (M9.0) and after shocks for a week

# Acceleration/Velocity/Displacement Response Spectrum

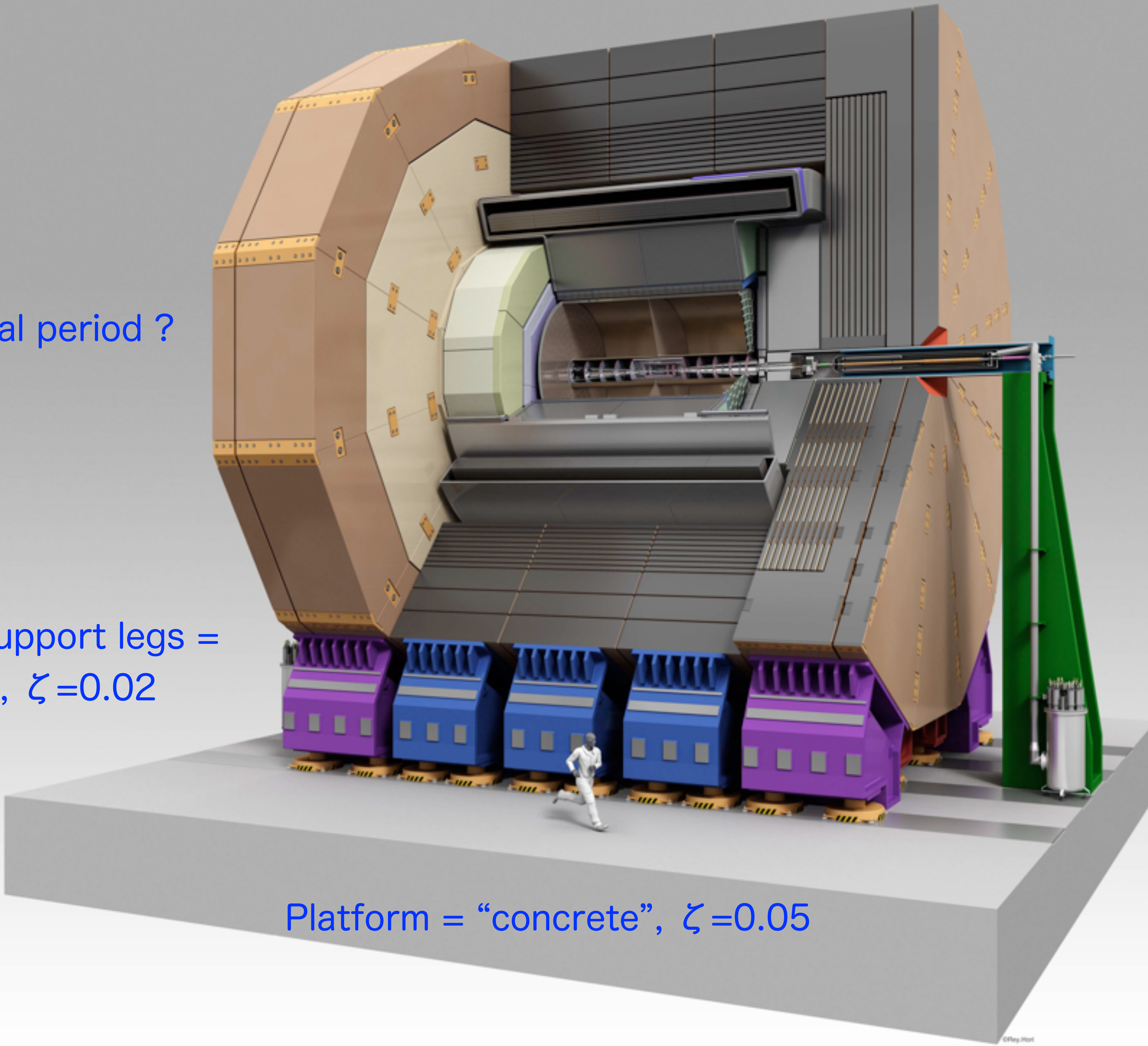
2011.3.11 M9.0 24 km in depth




(1) 加速度応答スペクトル　(2) 速度応答スペクトル　(3) 変位応答スペクトル

Acceleration : shear force　Velocity : kinetic energy　Displacement : strain

Natural period ?



ILD support legs =
“iron”, $\zeta$=0.02

Platform = “concrete”, $\zeta$=0.05

# Material Strength and Allowable stress

| | Material | | Steel | Aluminum | Stainless |
|---|---|---|---|---|---|
| | | | SS400 | AC4C－T5 | SUS304 |
| Material strength | Tensile ($\sigma_U$) | N/mm2 (=MPa) | 400 | 137 | 520 |
| | Yield ($\sigma_y$) | N/mm2 | 205 | 108 | 205 |
| | F -1 | F-1= $\sigma_y$ | 205 | 108 | 205 |
| | F-2 | F-2=0.7*$\sigma_u$ | 280 | 96 | 364 |
| | F | Smaller value | 205 | 108 | 205 |
| Material Allowable Stress | Allowable stress(MPa) | | | | |
| | Tension | ft=F/1.5 | 137 | 72 | 137 |
| | Shearing | fs=F/(1.5√3) | 79 | 42 | 79 |
| | Bending | fb=F/1.3 | 158 | 83 | 158 |
| with individual safety factors | Hertz stress | fp=F/1.1 | 186 | 98 | 186 |
| | Bolt(Tension) | ft=F/2 | 103 | 54 | 103 |
| | Bolt(Shear) | fs=F/(1.5√3) | 79 | 42 | 79 |
| | Bolt(Hertz) | fp=1.25F | 256 | 135 | 256 |
| | Roller | fp=1.9F | 390 | 205 | 390 |
| | Welding(PT) | fs=F/(1.5√3) | 79 | 42 | 79 |
| | Welding(No PT) | fs=0.45F/(1.5√3) | 36 | 19 | 36 |
| | | | 237@Bend | | |
| | Earthquake | (Above)x1.5 | (=158x1.5) | | |

H. Yamaoka, “Magnet seismic analysis”, 10 July, 2007, KEK

# Summary/recommendation on seismic studies for the Kitakami site

1. Earthquake protection should follow AIJ and ISO3010;

   uses analysis with the response spectrum

2. Earthquake model at Kitakami site :

   150 gal (100 years) as the earthquake representative $A_0$
   , where flat period between 0.17 to 0.34sec ( $dT_c$ - $T_c$)
   , using the damping coefficient $\zeta$=0.05 (0.02) for concrete (iron) base structure

3. For ILD earthquake protection

   - Natural periods of the structure and each sub-detectors
   - Nothing should exceed the material allowable stress
   - Minimum gaps should be enough for the natural vibrations
   - Isolation must be carefully designed on the platform

# Appendix

# ISO3010

# International Standard
# Based for Design of Structures - Seismic Actions on Structures

## ISO3010 2001

## International Organization for Standardization

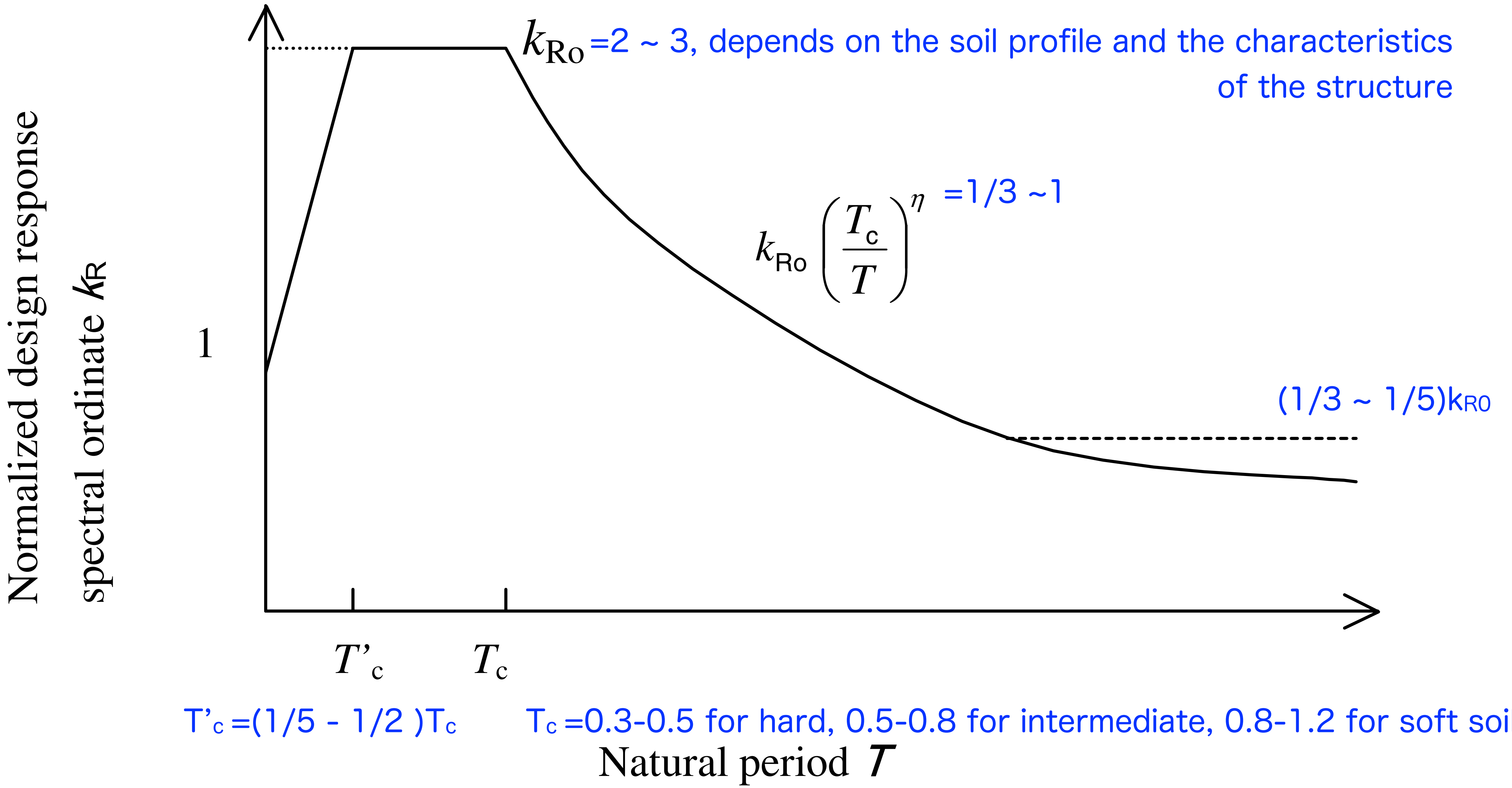
a) (ultimate limit state: ULS) The structure should not collapse nor experience other similar forms of structural failure due to severe earthquake ground motions that could occur at the site .

b) (serviceability limit state: SLS) The structure should withstand moderate earthquake ground motions which may be expected to occur at the site during the service life of the structure with damage within accepted limits.

In both cases, the seismic force can be the maximum acceleration of earthquakes in the recurrence intervals of 100 years, but the response force of ULS is larger 5 times than the SLS, or ULS for 500years and SLS for 20years.

The ISO 3010 is expected to be used as a raw material for new national regulations or as a guideline for revising existing national regulations.

# Normalized design response spectrum by maximum ground acceleration




At each level of the structure such as a skyscraper, the forces are defined by;

ULS :design lateral seismic force, $F_{E,u,i} = \gamma_E \, k_Z \, k_{E,u} \, k_D \, k_R \, k_{F,i} \, \Sigma^{j=n}_{j=i} F_{G,j}$ , summing loads upper levels from i to n

SLS :design lateral seismic force, $F_{E,s,i} = \gamma_E \, k_Z \, k_{E,s} \, k_R \, k_{F,i} \, \Sigma^{j=n}_{j=i} F_{G,j}$ , $k_Z$ = seismic hazard zoning factor

**Table 1 – Example 1 for load factors $\gamma_{E,u}$ and $\gamma_{E,s}$ and representative values $k_{E,u}$ and $k_{E,s}$ (where $k_{E,u} \neq k_{E,s}$)**

| LIMIT STATE | DEGREE OF IMPORTANCE | $\gamma_{E,u}$ or $\gamma_{E,s}$ | $k_{E,u}$ or $k_{E,s}$ | Return period for $k_{E,u}$ or $k_{E,s}$ |
|---|---|---|---|---|
| Ultimate | a) High | 1.5 – 2.0 | 0.4 | 500 years |
| | b) Normal | 1.0 | | |
| | c) Low | 0.4 – 0.8 | | |
| Serviceability | a) High | 1.5 – 3.0 | 0.08 | 20 years |
| | b) Normal | 1.0 | | |
| | c) Low | 0.4 – 0.8 | | |

**Table 2 – Example 2 for load factors $\gamma_{E,u}$ and $\gamma_{E,s}$ and representative value $k_E$**

| LIMIT STATE | DEGREE OF IMPORTANCE | $\gamma_{E,u}$ or $\gamma_{E,s}$ | $k_E = k_{E,u} = k_{E,s}$ | Return period for $k_E$ |
|---|---|---|---|---|
| Ultimate | a) High | 3.0 – 4.0 | 0.2 | 100 years |
| | b) Normal | 2.0 | | |
| | c) Low | 0.8 – 1.6 | | |
| Serviceability | a) High | 0.6 – 1.2 | | |
| | b) Normal | 0.4 | | |
| | c) Low | 0.16 – 0.32 | | |

ULS : structural factor $k_D$ =1/5 - 1/3 for systems with excellent ductility

$k_D$ =1/3 - 1/2 for systems with medium ductility

$k_D$ =1/2 - 1 for systems with poor ductility