Structural Design Requirement on the Tsunami Evacuation Buildings

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Concept of Tsunami Evacuation Buildings

- Evacuation to a high ground is a basic principle when tsunamis occur
- If there is no high ground to evacuate to, a tsunami evacuation building will protect human lives instead of high ground
- Tsunami evacuation buildings should have a reliable structure which is comparable to a high ground

- Tsunami evacuation buildings should be prepared for quick evacuation in coastal area

Design target

1) **Not to collapse**

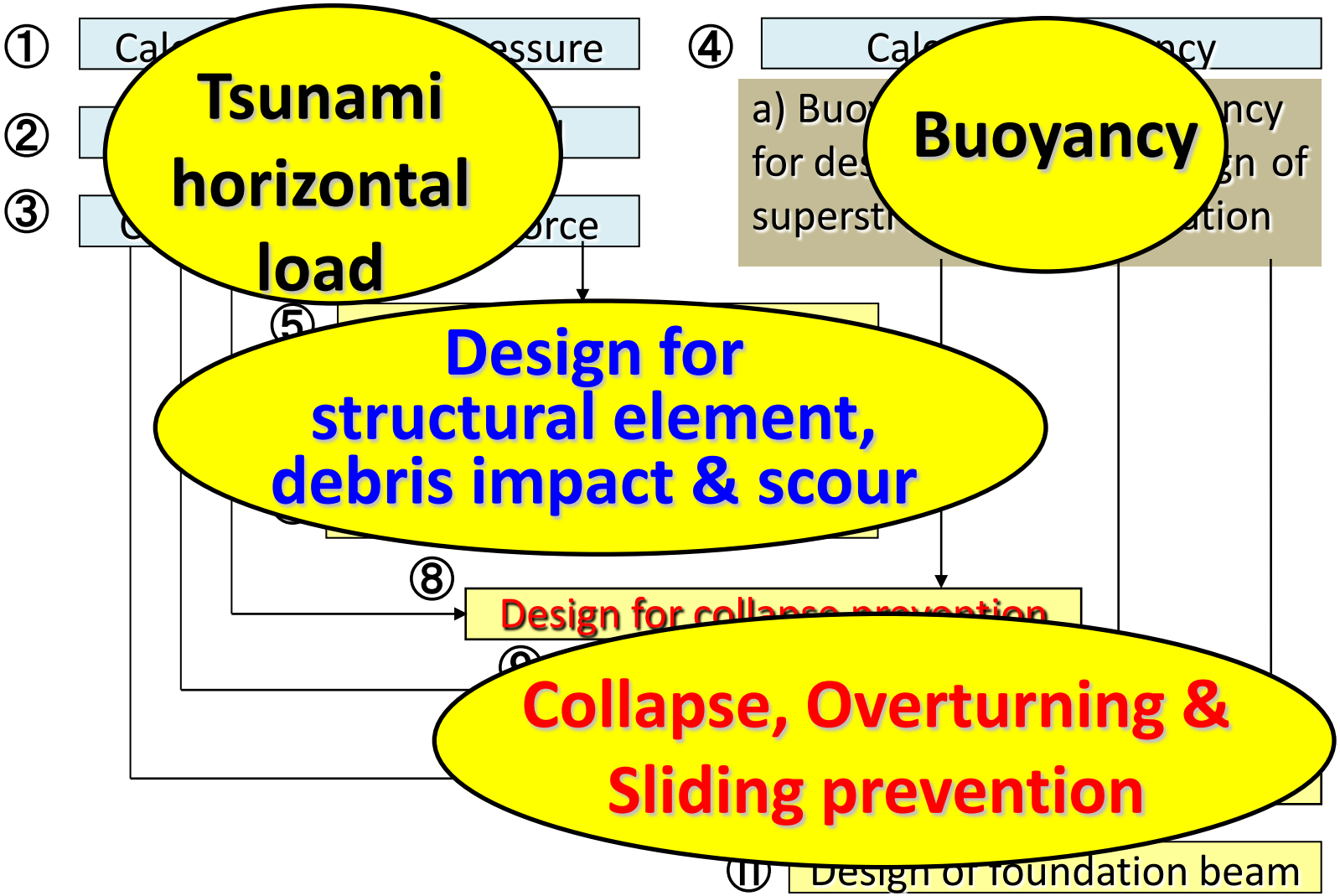
2) **Not to overturn**

3) **Not to slide**

Design items

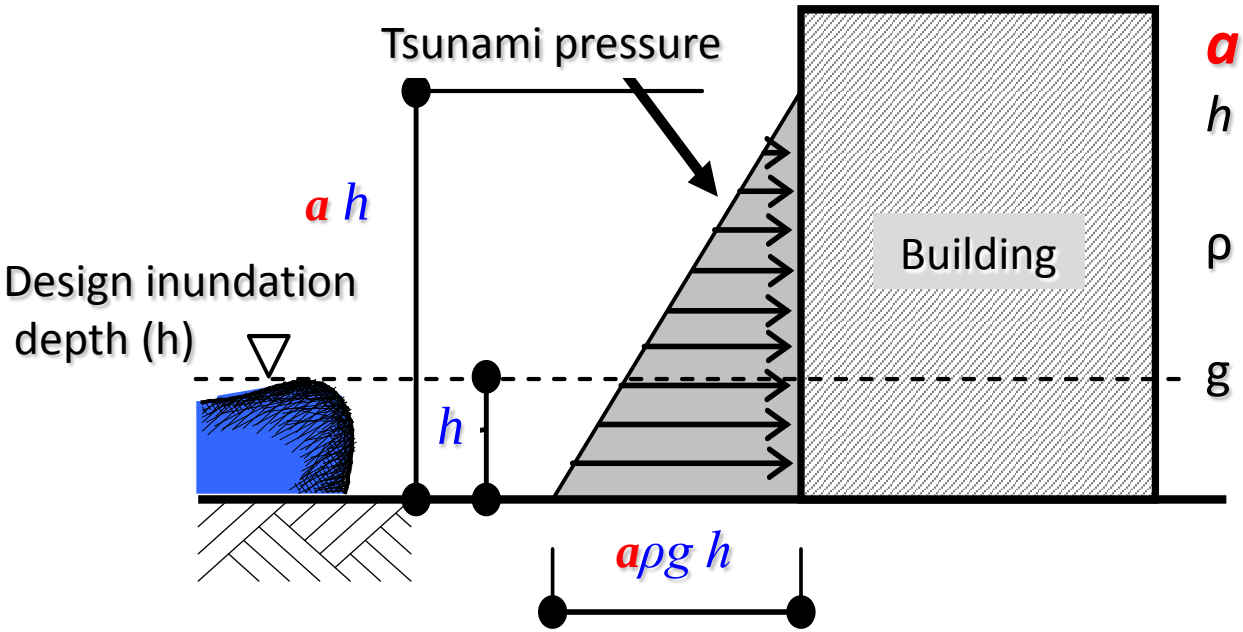
- Design for preventing failure of exterior elements (walls & columns)
- Design for debris impact
- Design for scour

Design flow


①
②
③
④
Tsunami horizontal load
Buoyancy
Design for structural element, debris impact & scour
⑧
Design for collapse prevention
Collapse, Overturning & Sliding prevention
Design of foundation beam

(1) Calculate tsunami pressure

Tsunami pressure is obtained as hydrostatic pressure distribution with height of design inundation depth multiplied by coefficient *a*



a : Coefficient

h : Design inundation depth (m)

ρ : Specific gravity of water (t/m^3)

g : Acceleration of gravity (m/s^2)

	with defense		w/o defense
Distance from sea or river	≧ 500m	＜ 500m	Regardless of distance
a	**1.5**	**2**	**3**

Tsunami Forces by FEMA P646 (2008)

1) Hydrostatic Force $F_h=1/2\rho_s g b h_{max}^2$, (where, $h_{max}=1.3R$)

Japanese proposal

Only information of maximum inundation depth (h_{max}) can be obtained by hazard maps prepared by local governments in Japan as results of numerical simulations using **shallow water long wave eq.**

It is hard to obtain the flow velocity (u) or momentum flux (hu^2) due to uncertainty in the numerical simulations.

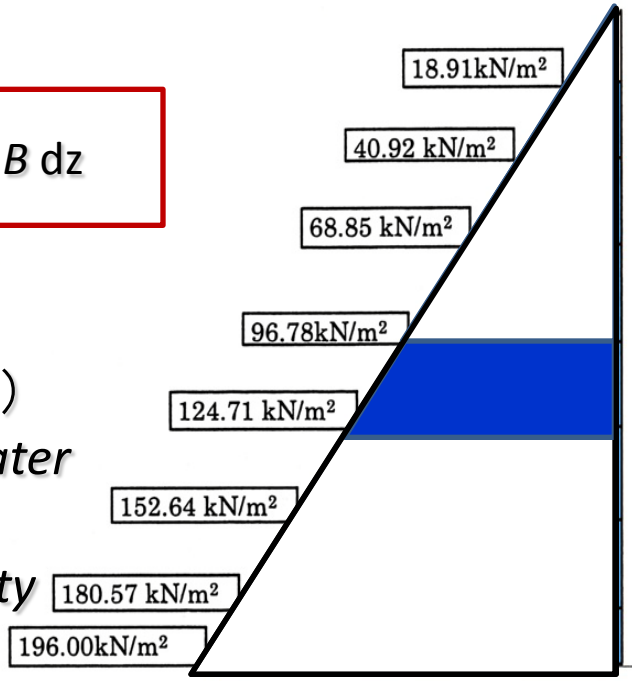
→ Hydrostatic force **including hydrodynamic force is proposed.**

(2) Calculate tsunami load on each floor

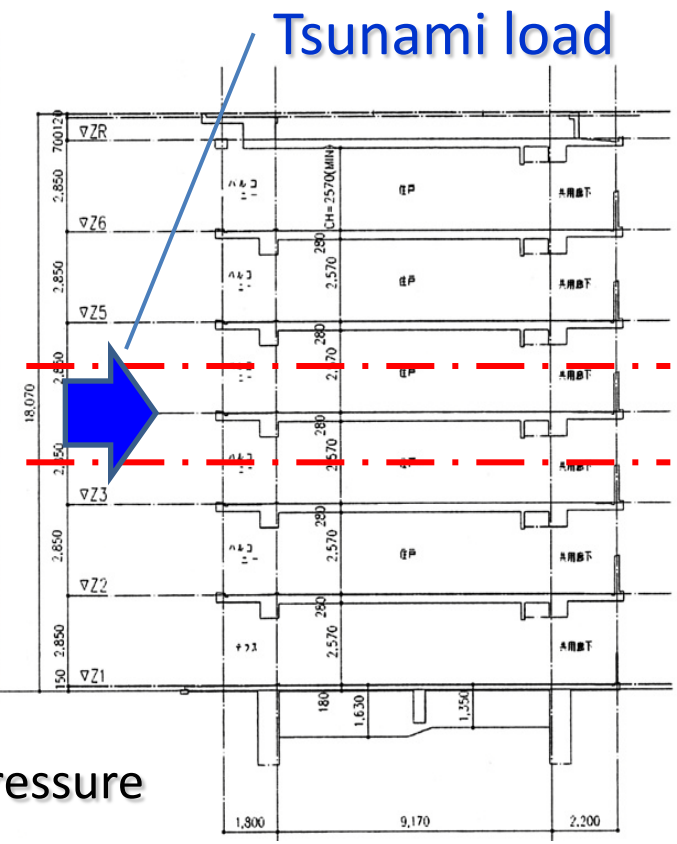
Tsunami load works on each floor will be calculated **by integrating tsunami wave pressure** from the middle of the height of the floor downstairs to the middle of the height of the floor concerned

$$Qz = \rho\, g \int_{z1}^{z2} (ah - z)\, B\, dz$$

Qz : *Tsunami load* (kN)
B : *width of building* (m)
ρ : *Specific gravity of water* (t/m^3)
g : *Acceleration of gravity* (m/s^2)

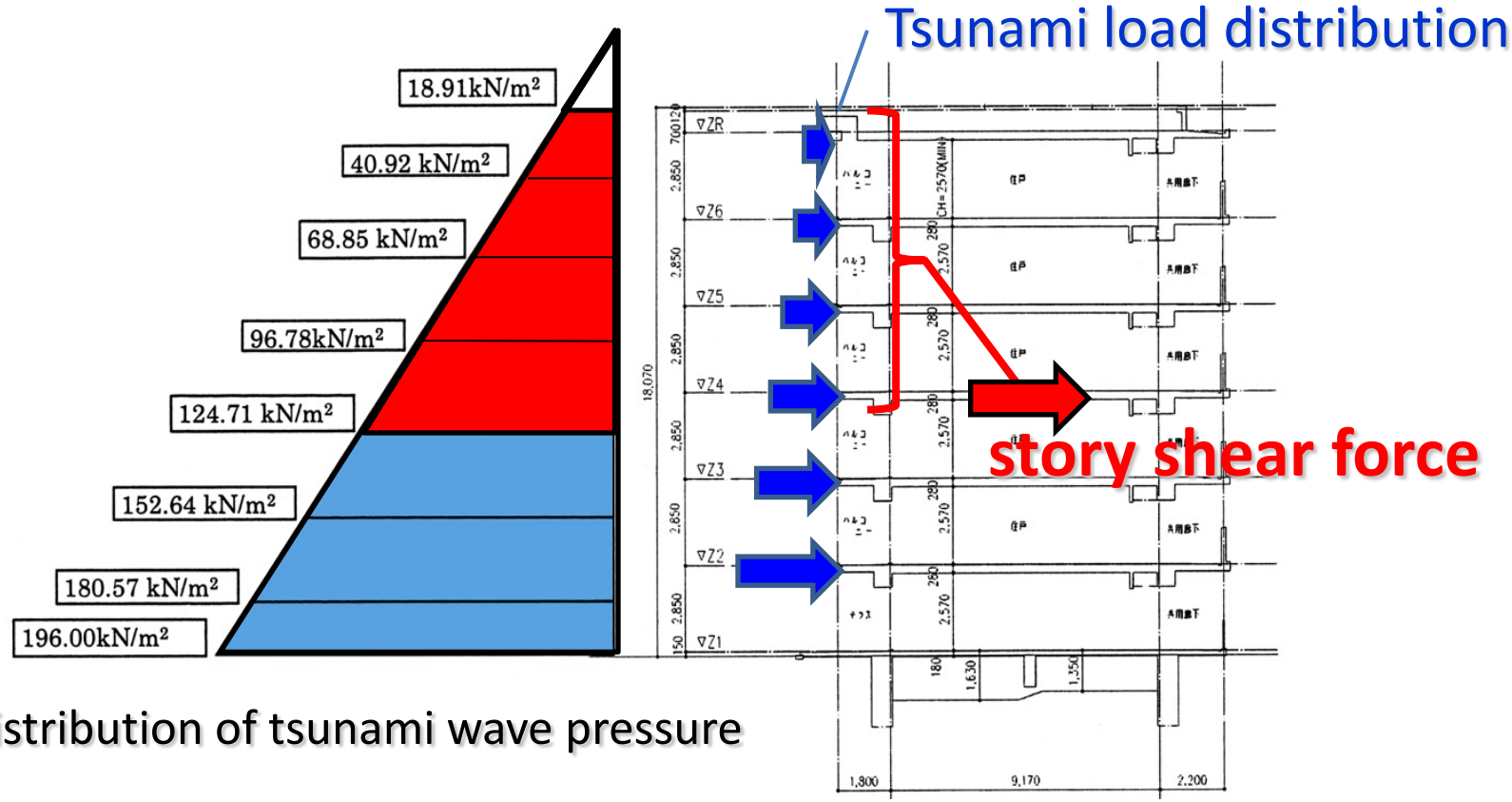


Distribution of tsunami wave pressure



(3) Calculate story shear force

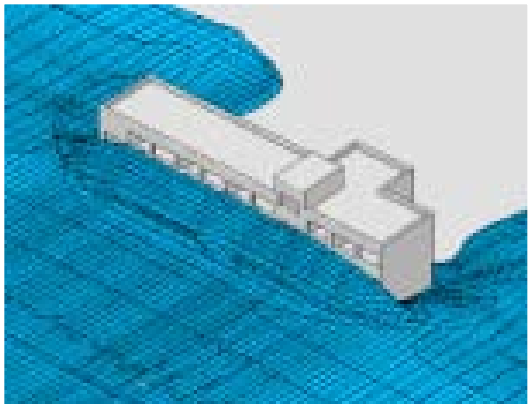
The story shear force should be calculated **by summing up all the tsunami load on all the stories above the concerned floor**

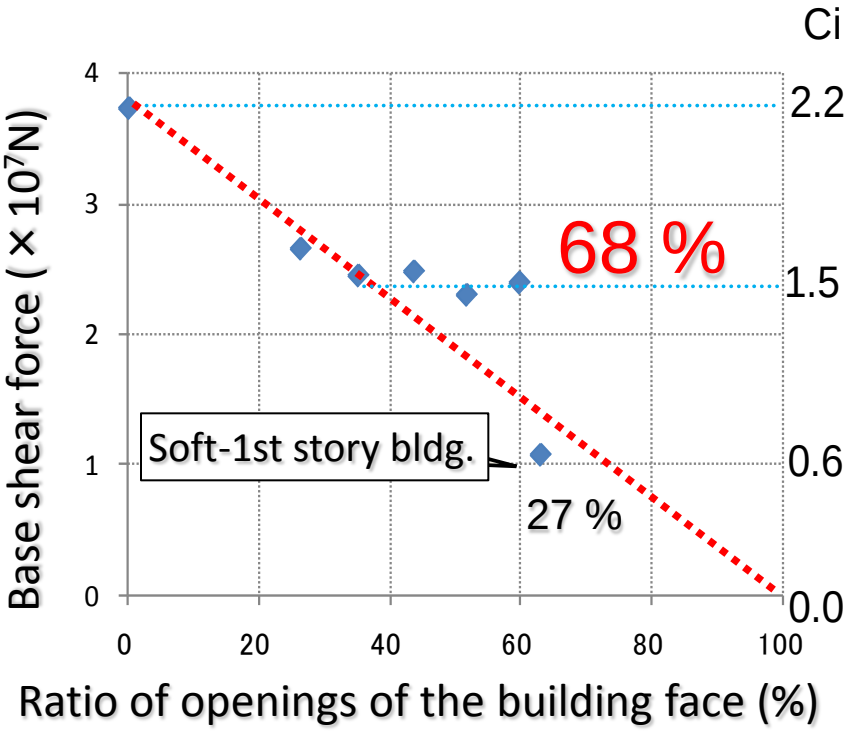


Effect of opening

Tsunami load can **be reduced** based on the ratio of openings

0.7 is lower limit of reduction coefficient of tsunami load based on the results of new numerical simulations





(4) Calculate buoyancy

Buoyant force should be calculated for design of collapse, overturning and sliding prevention

Air remained under the slab of 2nd floor of a 2-story RC-building at the tsunami, which height was more than 15m.

Design of superstructure for collapse prevention

The state "water completely flow into the building from the openings" should be considered to obtain minimum axial force of columns for calculating conservative lateral capacity

Design of piles or foundations for overturning and sliding prevention

The state that no water flow into the building should be considered to obtain minimum axial force of piles or foundation for calculating conservative tensile capacity of piles used for overturning moment and shear capacity of piles or friction of foundation used for sliding resistance

(5) Design of exterior elements

Tsunami load ≦ Ultimate capacity of columns and walls

Failure of columns and walls should be prevented

(6) Design for debris impact

Preventing failure of walls and columns by debris impact is not easy

Gravity loads supporting capacity of each story should be kept even after the failure of exterior column or wall due to debris impact

= Missing Column Strategy for preventing progressive collapse

(7) Design for scouring

Pile foundation is recommended to prevent tilting of superstructures induced by scouring

Mat foundation

Pile

(8) Design for collapse prevention

Story shear force < Story shear capacity

(9) Design for overturning prevention

Axial force of piles < Axial capacity of piles

(10) Design for sliding prevention

Lateral force of piles < Lateral capacity of piles

Base shear required

(In case of RC residential buildings)

C_B: Base shear coefficient in short direction

	Inundation depth		
	5m	10m	15m
***a* = 3.0**	C_B=0.97	C_B=2.83	C_B=4.56
***a* = 2.0**	C_B=0.38	C_B=1.44	C_B=2.42
***a* = 1.5**	C_B=0.3	C_B=0.78	C_B=1.36

◎ : Strength due to seismic design is larger than strength due to tsunami design (except piles and foundations)

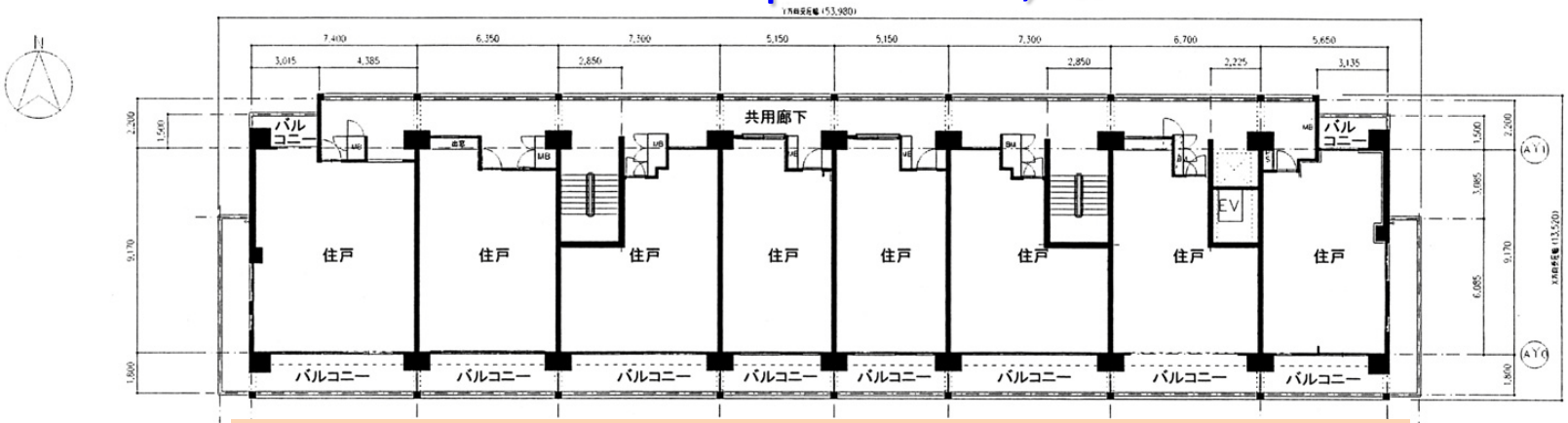
○ : Meeting demand is available by increase of strength (need special consideration for piles and foundations)

△ : Require special consideration for increase of strength of super-structure, piles and foundations

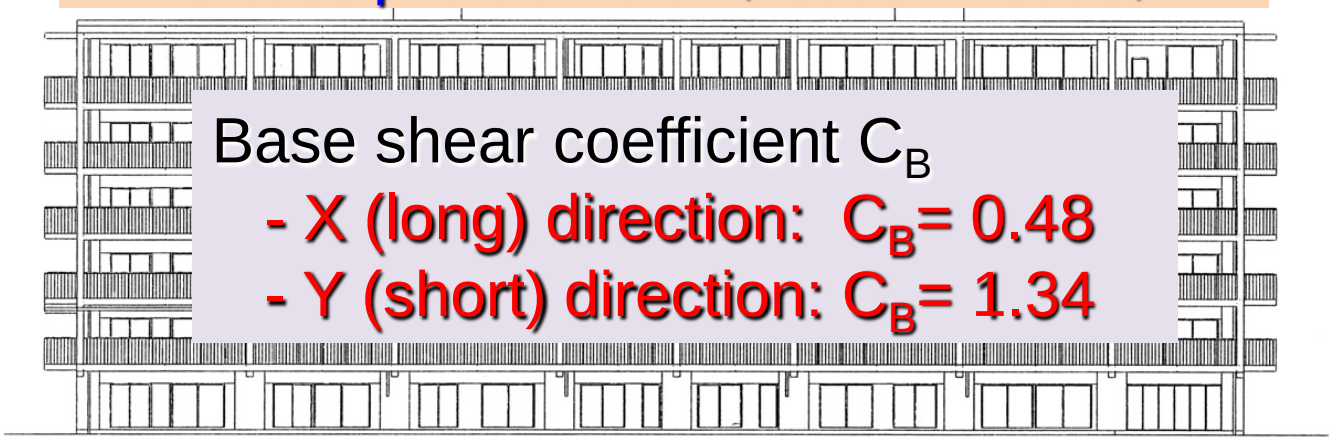
Design example

(Lower 6 stories of 8-story building is used)

Inundation depth = 10m, α = 2.0



- Increase steel bars in columns and beams
- Increase wall thickness（230→350mm）
- Increase pile diameter（1300Φ→1900Φ）



Base shear coefficient C_B

- X (long) direction: C_B= 0.48
- Y (short) direction: C_B= 1.34

South elevation

Result of the design for collapse prevention

Seismic design

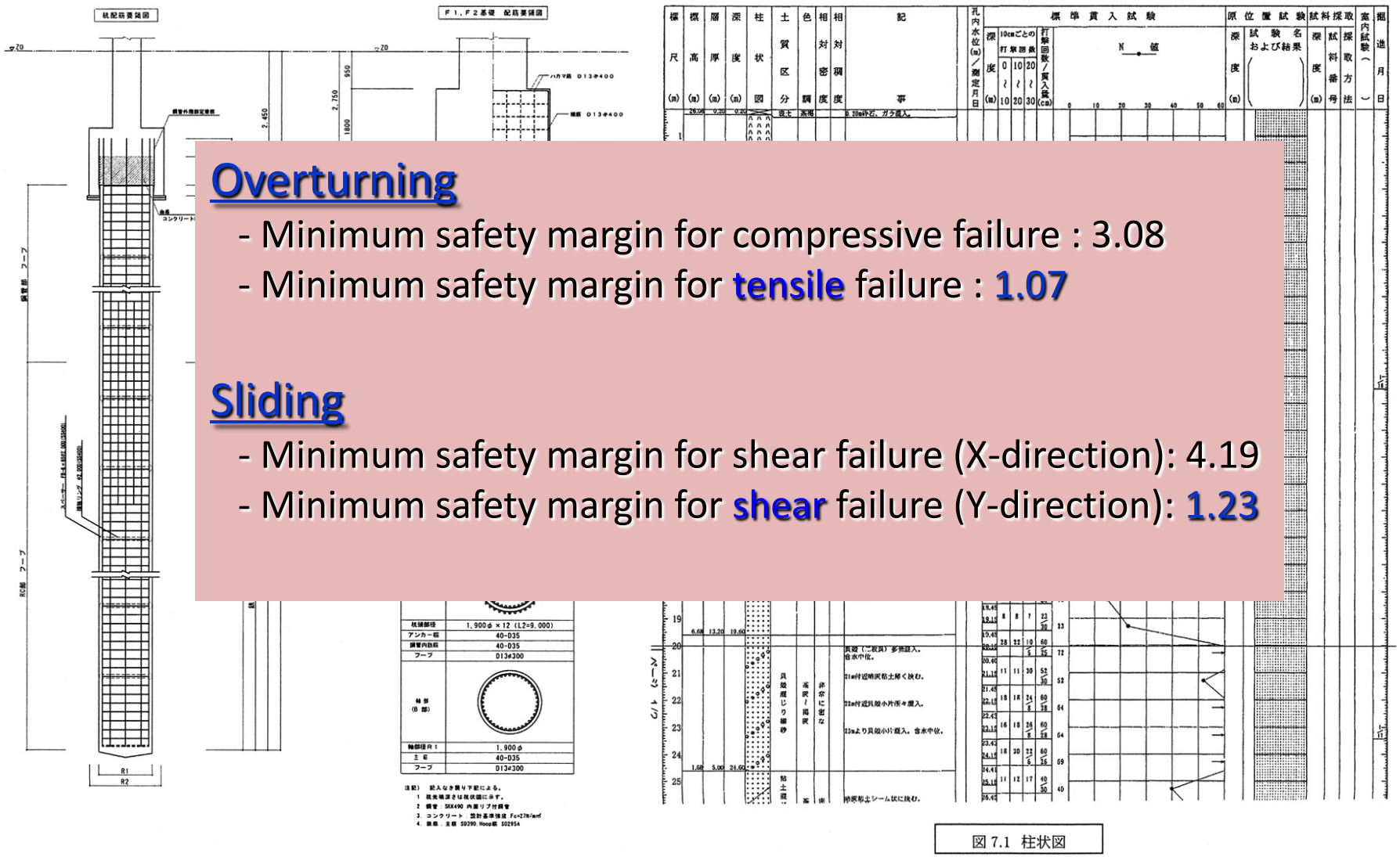
- Safety margin* for lateral capacity (X-direction): 1.60
- Safety margin* for lateral capacity (Y-direction): 2.44

Tsunami design

- Safety margin* for lateral capacity (X-direction): 1.58
- Safety margin* for lateral capacity (Y-direction): 1.06

* Safety margin = Lateral capacity / Demand capacity

Design of piles for overturning & sliding prevention



Overturning

- Minimum safety margin for compressive failure : 3.08
- Minimum safety margin for **tensile** failure : **1.07**

Sliding

- Minimum safety margin for shear failure (X-direction): 4.19
- Minimum safety margin for **shear** failure (Y-direction): **1.23**

Design of tsunami evacuation buildings

Design tsunami force is capable of over seismic force in case inundation depth is larger than 10m

Large lateral capacity of buildings required

- ✓ thick wall, much steel
- ✓ larger & longer piles

→ **available with conventional techniques**

Future tasks

- The design methods are proposed based on the field surveys of the 3.11 tsunami damage to buildings

1)Study on resistance mechanisms based on the hydraulic tests and/or new numerical simulations and **rationalization of the structural design methods**

2)New **technical development** for overturning prevention and/or sliding prevention

3)International cooperation and harmonization with ASCE, AIJ and others **under the umbrella of UJNR!**

Thank you
for your attention
BRI Japan