SEQUENTIAL TIME-HISTORY ANALYSIS OF BUILDING STRUCTURES UNDER EARTHQUAKE AND TSUNAMI LOADS

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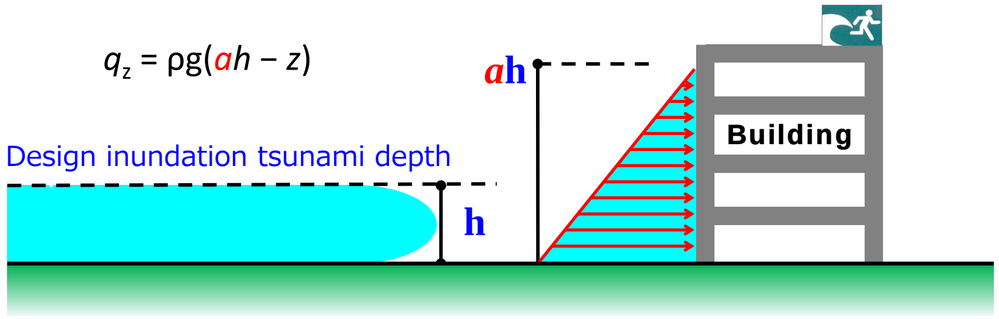
0. Outline

Time-history model of tsunami wave was developed based on SPH analysis. Sequential EQ and tsunami non-linear time-history response analysis reveals that: (1) Froude number (*Fr*) affects the vertical distribution of the tsunami pressure to building structure.
(2) Structural damage by earthquake load affects the maximum displacement of building structure due to tsunami load.

1. Conventional Guideline in JAPAN after 2011

Interim Guidelines on Str. Requirements for Tsunami Evacuation Bldg. (MLIT)

$q_z = \rho g(ah - z)$



a → value larger than reconnaissance results for safety

q_z	: design tsunami press. (kN/m²)	
a	: water depth coefficient	
ρ	: mass/unit vol. of water (t/m³)	
g	: gravity acceleration (m/s²)	
h	: design inundation depth (m)	
z	: distance above G.L. (m)	

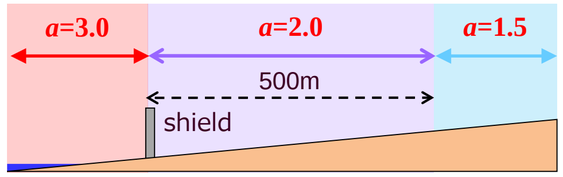


Fig.1 MLIT (in JAPAN) Guideline focused on the Equivalent Hydro-static Pressure

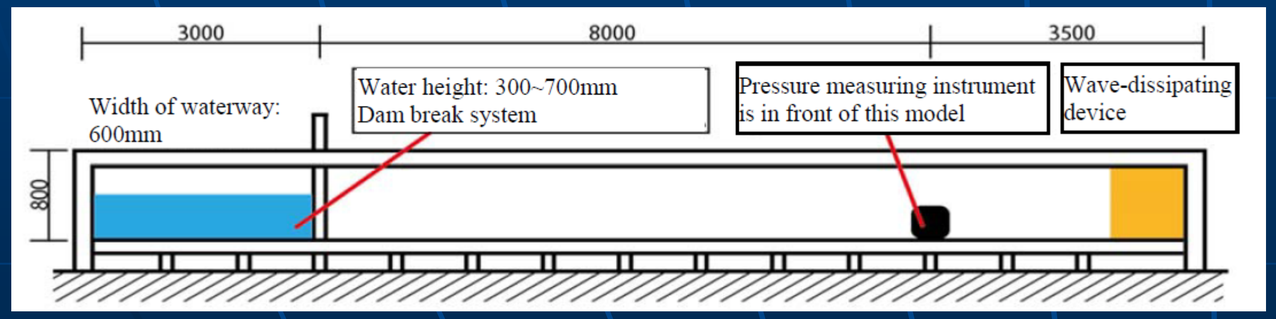
2. Real Tsunami Load is Different from Hydrologic Model

https://www.youtube.com/watch?v=SR2kOR2Ihf0

Can it be converted to equivalent hydro-static pressure?

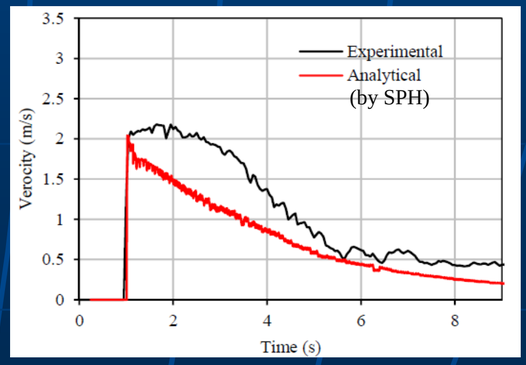
Fig.2 Real Tsunami Video tell us a Complexity of Fluid Pressure

3. Verification of Fluid Analysis with SPH Method

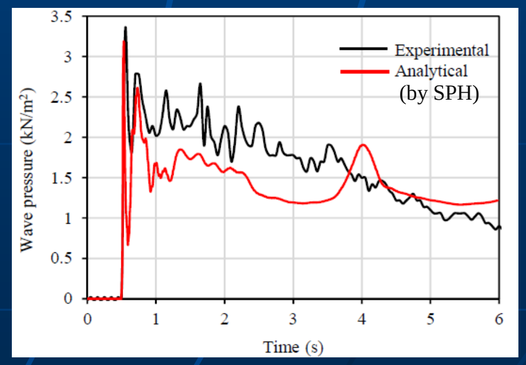


Scaled dam break test (carried out in Akita Pref. Univ. by Prof. Obata)

Fig.3 Overview of Hydraulic Experimental System



(a) Fluid velocity



(b) Wave pressure

Fig.4 Verification of SPH Analysis / almost Approximated with Experimental Results

4. Vertical Distribution Profile of Tsunami Pressure

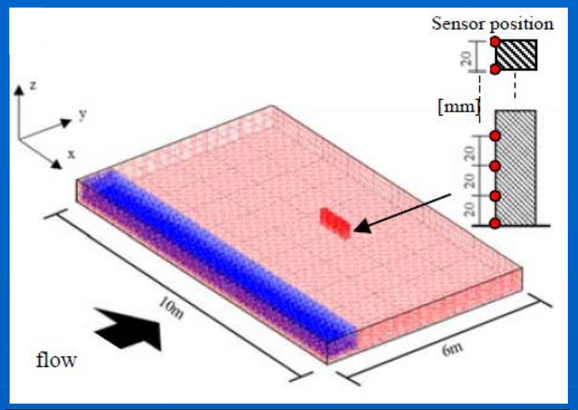


Fig.5 Analytical Model (SPH method)

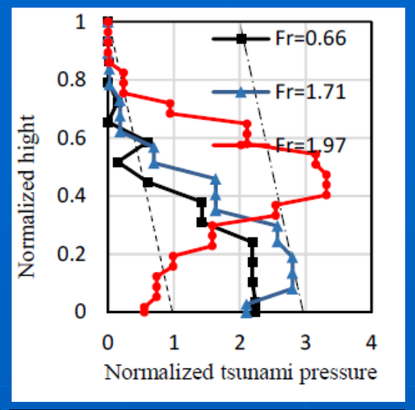


Fig.6 Analytical Results

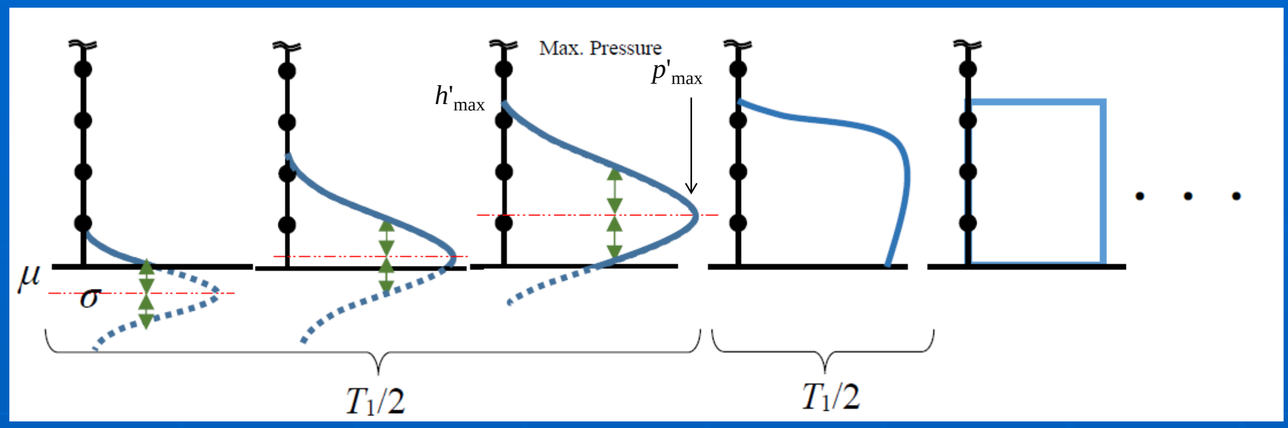


Fig.7 Vertical Distribution Profile Model of Tsunami Pressure

5. Time-history Model

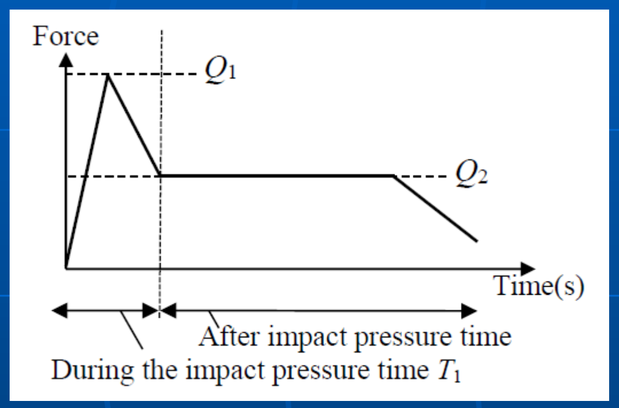


Fig.8 Maximum Tsunami Pressure Model

■Previous Time-history model for Tsunami pressure (Suzuki et. al, 2015)

	Surge pressure $0 \le t \le T_1$	~~Transition period~~	After impact pressure $T_1 < t$
-	$Q_1 = \rho g(\alpha h - z)$	-	$Q_2 = \frac{1}{2}\rho \cdot C_D \cdot u^2$

■New Time-history model for Tsunami pressure (2018)

	Surge pressure $0 \le t \le T_1/2$	Transition period $T_1/2 \le t \le T_1$	After impact pressure $T_1 < t$
$Fr > 1$	$Q_1 = p'(h',t) \cdot \rho g h'_{max}$	$Q_m = (1-\beta) \times Q_1 + \beta \times Q_2$ where, $\left(\beta = \frac{t - T_1/2}{T_1/2}\right)$	$Q_2 = \frac{1}{2}\rho \cdot C_D \cdot u^2$
$Fr \le 1$	$Q_1 = \rho g(h'_{max} - h')$		

C_D :drag coefficient, u: tsunami velocity (m/s)

$$p'(h',t) = p_{max}(t) \times \exp\left(-\frac{\{h' - \mu(t)\}^2}{2\sigma(t)^2}\right) \quad (h' \le 0.5)$$

$$p_{max}(t) \times \exp\left(-\frac{\{h' - \mu(t)\}^2}{2\sigma(t)^2}\right) \times 2(1-h') \quad (h' > 0.5)$$

$$p_{max}(t) = -\frac{4 \times 0.913\exp(0.655F_r)}{T_1^2} \times \left(t - \frac{T_1}{2}\right)^2 + 0.913\exp(0.655F_r)$$

$$\mu(t) = \frac{2\{1 - 8.0 \times 10^{-5}\exp(4.4F_r)\}}{T_1} t + \{2 \times 8.0 \times 10^{-5}\exp(4.4F_r) - 1\}$$

Table.1-2 Time-history model of Tsunami Pressure (Table.1 Previous / Table.2 New (considering the Vertical Profile Time-history) Model)

6. EQ and Tsunami Sequential Non-linear Time-history Analysis

Case	Froude Number F_r	Max. inundation height h(m)	Impact pressure time T_1(s)
Case1	0.66	0.22	0.31
Case3	1.90	0.32	0.23

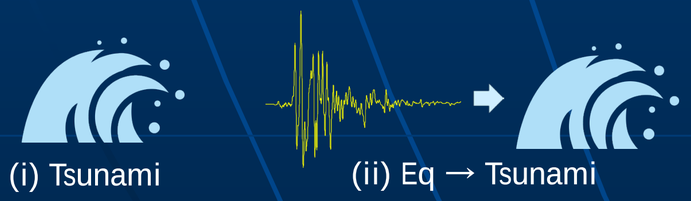
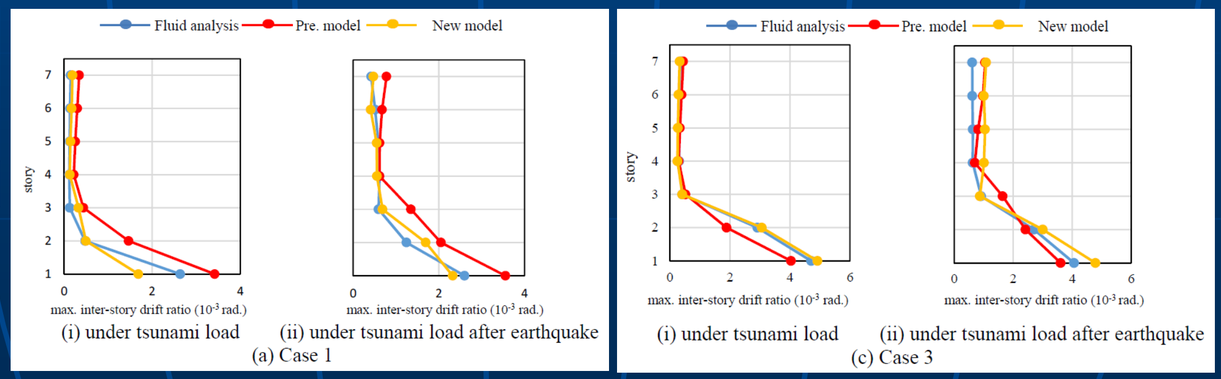


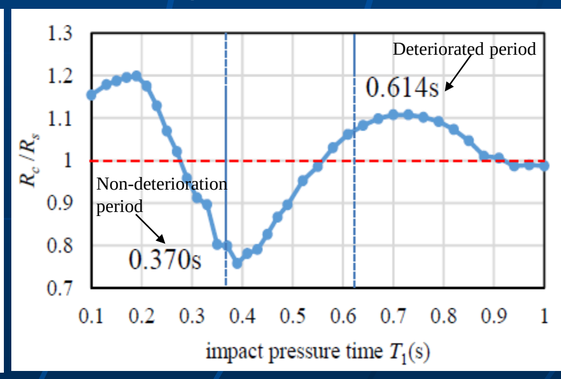
Fig.9 Parameters for Non-linear Time-history Analysis



New model approximates the result of fluid analysis rather than previous model. (Especially in the Case 1)

Fig.10 Results of Non-linear Time-history Analysis

Rc: Max. Disp. under Eq and Tsunami
Rs: Max. Disp. under Tsunami load



Natural period after EQ affects the max. disp. under tsunami load

Fig.11 Influence of EQ damage