Responses of concrete vertical walls to tsunami wave pressures and debris impact

Civil Engineering Research Laboratory
Central Research Institute of Electric Power Industry
(CRIEPI)

Naoto Kihara, Hideki Kaida
Atsushi Shibayama, and Yoshinori Miyagawa

36th International Conference on Coastal Engineering 2018
Baltimore, Maryland

August 1, 2018

CRIEPI
Central Research Institute of Electric Power Industry

ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018

Table of contents

1. Introduction
2. Experiment
3. Characteristics of wall response to wave pressure
4. Characteristics of wall response to both wave pressure and debris collision
5. Summary

Introduction

- Fragility assessments and designs of infrastructures against tsunamis are composed of evaluations of tsunami impacts and structures' responses to the tsunami impacts.

- Evaluation methods of structures' responses to tsunami impacts should be selected by considering <u>the types of structures, tsunami impacts, and damage mode</u>.

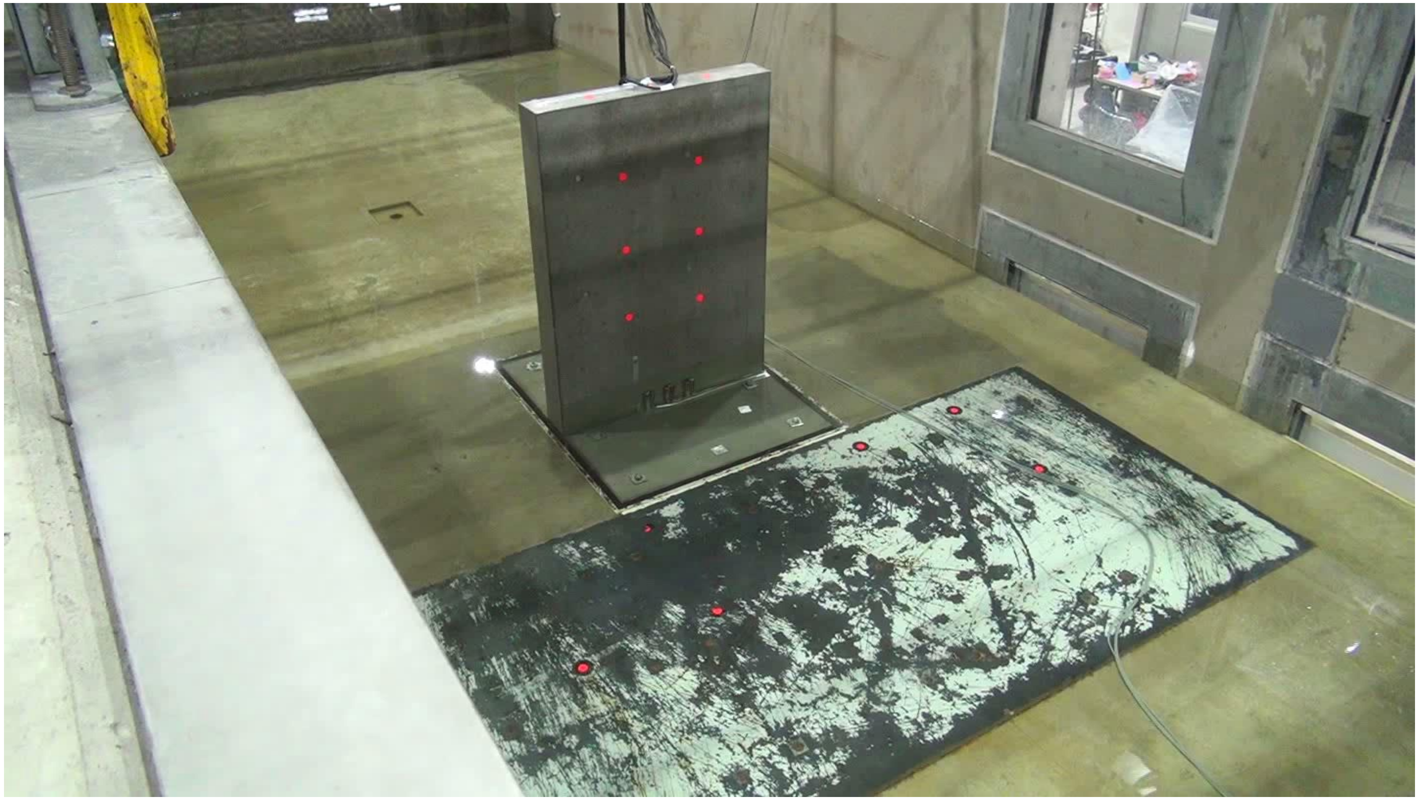
- In this study, we carry out experiments on the responses of concrete and reinforced concrete (RC) vertical walls to tsunami wave pressure and debris collision.
  - For investigation of characteristics of the responses of concrete and RC walls to tsunami impacts.
  - For enrichment of experimental data that is useful for V & V of evaluation methods.

Tokyo Electric Power Company, Inc. "Fukushima Nuclear Accident Analysis Report"

1. Introduction
2. Experiment
3. Characteristics of wall response to wave pressure
4. Characteristics of wall response to both wave pressure and debris collision
5. Summary

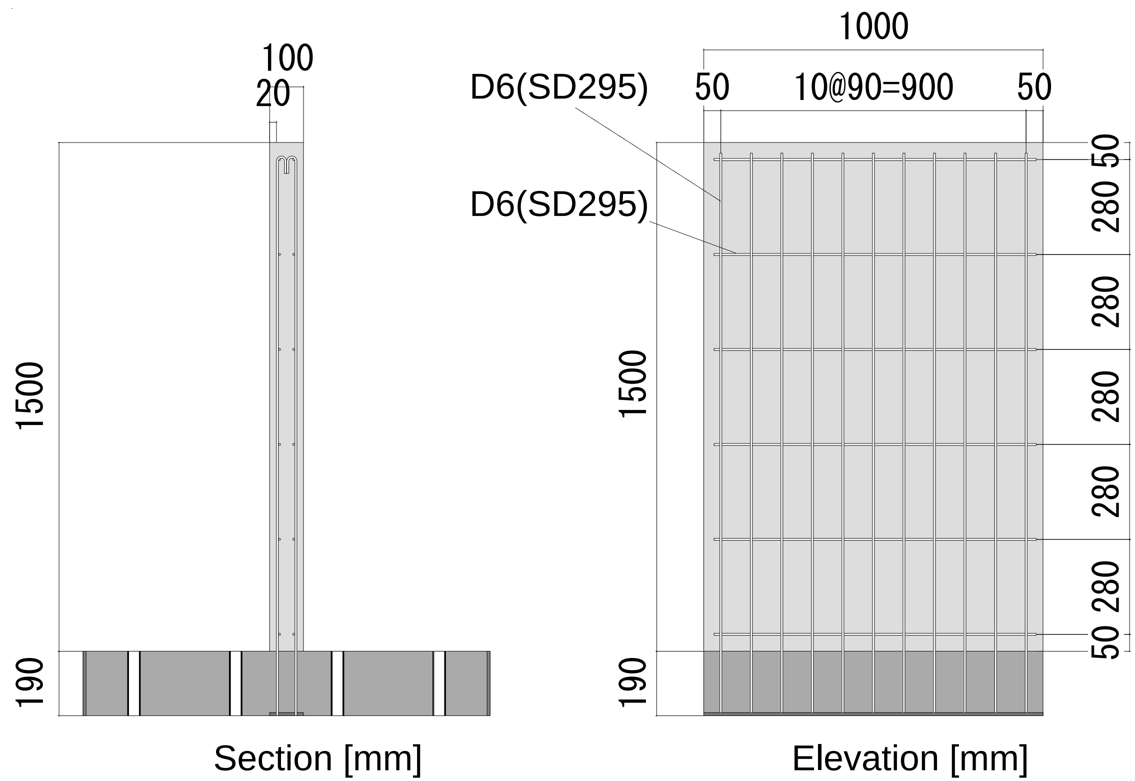
Experiments on wall responses to tsunami impact

Experiments on response of wall
- to tsunami wave pressure
- to both tsunami wave pressure and debris collision



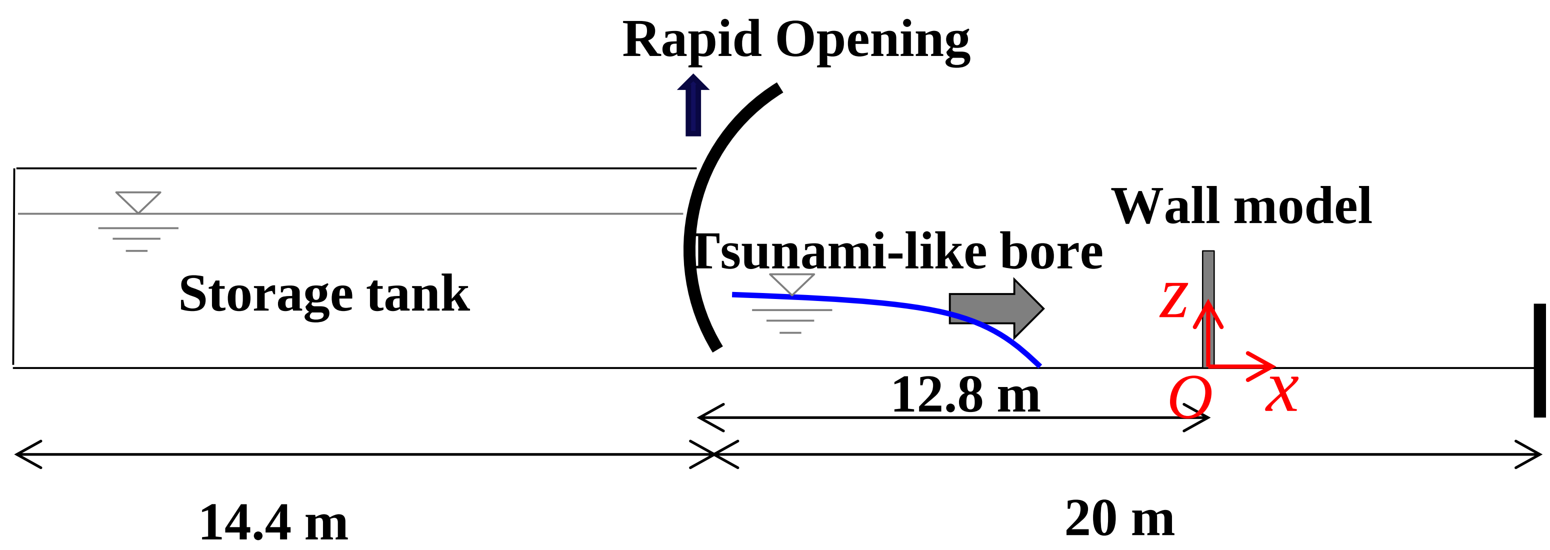
Specification of wall models

- Concrete wall
  - Height: 1.5 m
  - Width: 1.0 m
  - Thickness:
    - 0.05 m (**N50**)
    - 0.1 m (**N100**)
    - 0.15 m (**N150**)
- RC wall (**RC100**)
  - Height: 1.5 m
  - Width: 1.0 m
  - Thickness: 0.10 m



Concrete Strength	Reinforcement ratio
45.7 MPa	0.35 %

Flow Type



Flow type	Initial water depth in the test section [m]	Initial water depth in the storage tank [m]
Type 1	0	1.3
Type 2	0	1.7
Type 3	0.3	2.0

Specification of debris model

1. Shape
   - ✓ Column
2. Size
   - ✓ Diameter: 0.51 m
   - ✓ Height: 0.4 m
3. Mass
   - ✓ 48 kg
4. Surface material
   1. Polyethylene foam
   2. Steel

Experiment cases

Wall	Flow type	Debris
N50	Type 1	None
	Type 2	None
N100	Type 3	None
		Polyethylene
		Steel
N150	Type 3	None
		Polyethylene
		Steel
RC100	Type 3	None
		Polyethylene
		Steel

CRIEPI Central Research Institute of Electric Power Industry

Experiment cases

Wall	Flow type	Debris
N50	Type 1	None
	Type 2	None
N100	Type 3	None
		Polyethylene
		Steel
N150	Type 3	None
		Polyethylene
		Steel
RC100	Type 3	None
		Polyethylene
		Steel

Measurement items

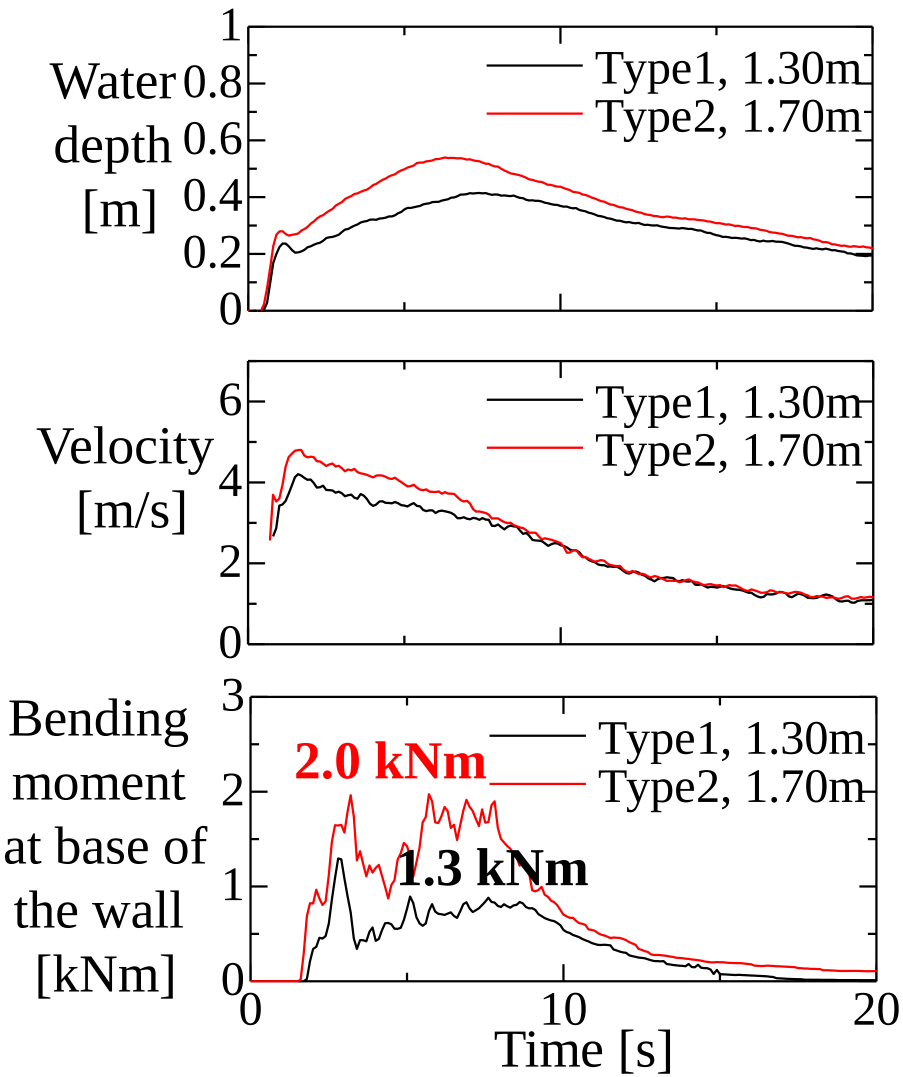
- **Pressure**
  - Center line of the upstream face of the wall
  - z = 0.01, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.49 m
- **Concrete strain**
  - z = 0.039, 0.09, 0.18, 0.27, 0.36, 0.64, 0.92 m
- **Reinforcement strain**
  - z = -0.1, 0, 0.09, 0.18, 0.27, 0.36, 0.64, 0.92, 1.2 m
- **Acceleration of wall**
  - z = 1.5 m
- **Water depth**
  - x = -7.6, -5.4, -2.7 m
- **Velocity (ADV)**
  - x = -5.4 m

1. Introduction
2. Experiment
3. **Characteristics of wall response to wave pressure**
4. Characteristics of wall response to both wave pressure and debris collision
5. Summary

(1) N50 CASES

Wall	Flow type	Debris
N50	Type 1	None
	Type 2	None

Comparison of two cases of N50 (None debris cases)



Wall	Flow type	Maximum bending moment	Damage
N50	Type 1	**1.3 kNm**	**None**
	Type 2	**2.0 kNm**	**Collapse**

Harmonic

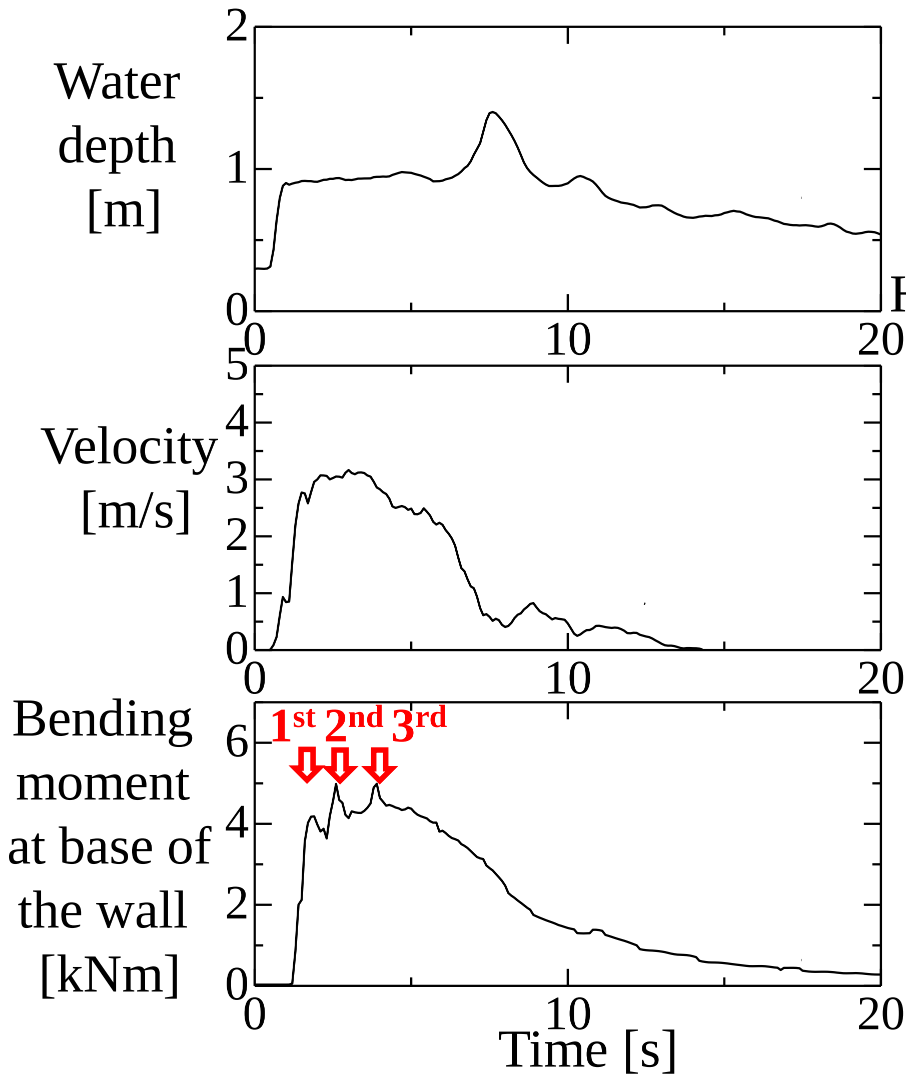
$$M_{cr} = f_r Z = \mathbf{1.5}\ \mathrm{kNm}$$

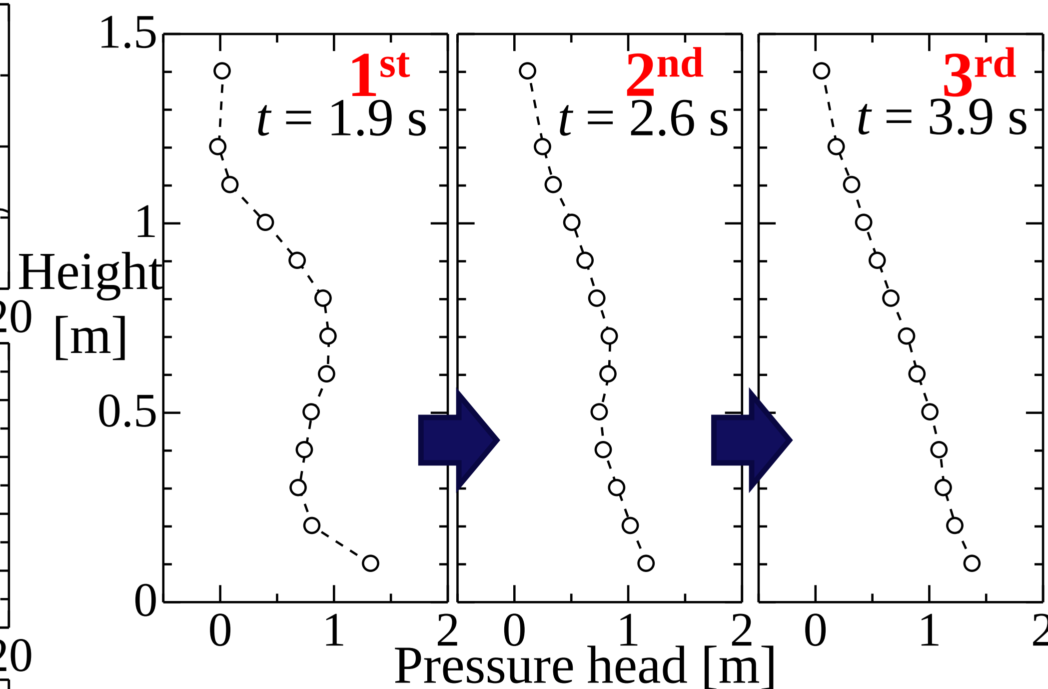
M_{cr}: Cracking moment [kNm]
f_r : Flexural strength of concrete [N/mm^2]
Z : Sectional coefficient [mm^3]

(2) N100, N150, AND RC100 CASES

Wall	Flow type	Debris
N100	Type 3	None
		Polyethylene
		Steel
N150	Type 3	None
		Polyethylene
		Steel
RC100	Type 3	None
		Polyethylene
		Steel

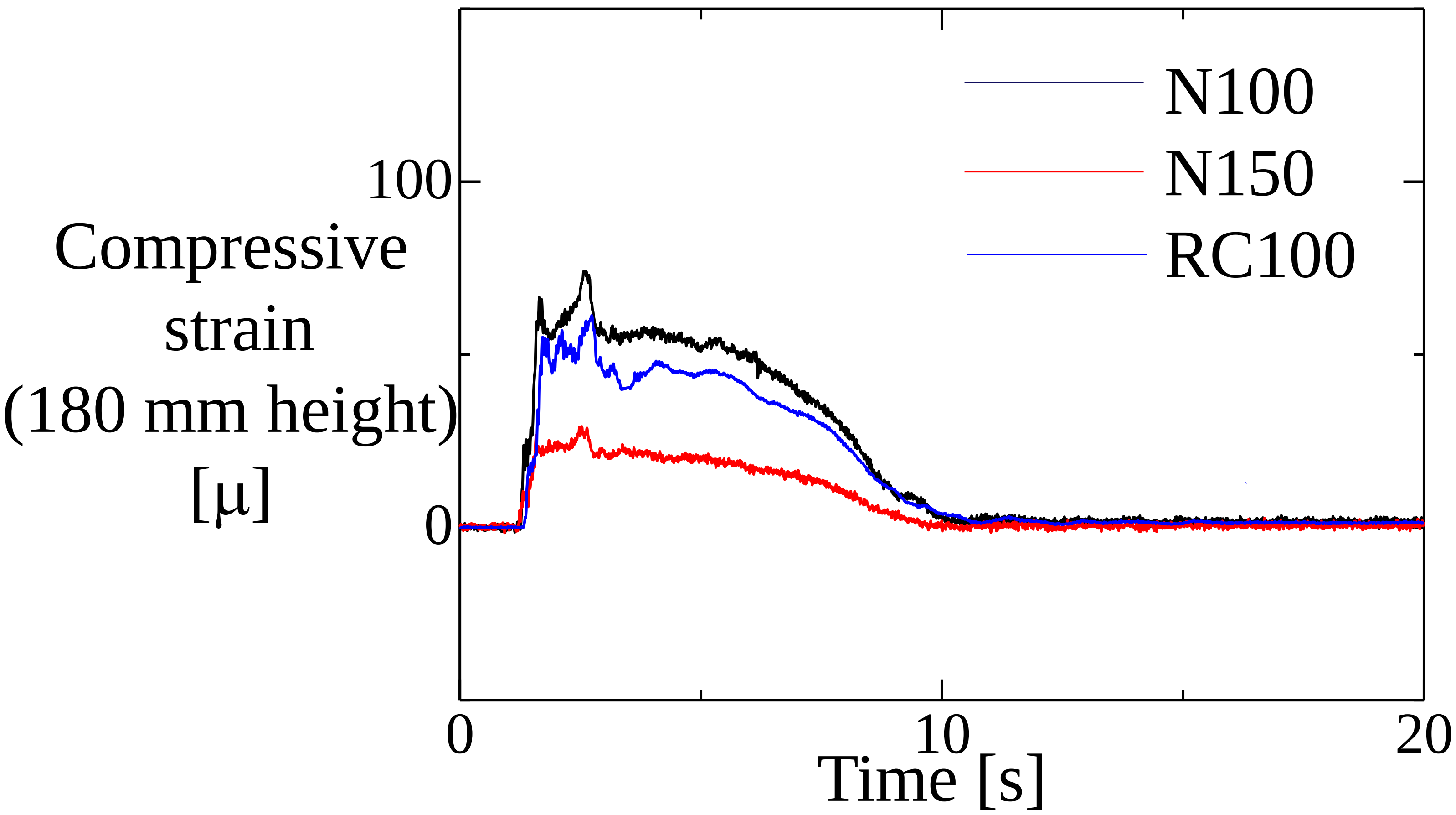
Wave profiles and pressure of Type 3





Flow type	Maximum bending moment at the base of the wall [kNm]
Type 3	5.2

Surface compressive strain at 180 mm height



1. Introduction
2. Experiment
3. Characteristics of wall response to wave pressure
4. **Characteristics of wall response to both wave pressure and debris collision**
5. Summary

Damages of walls

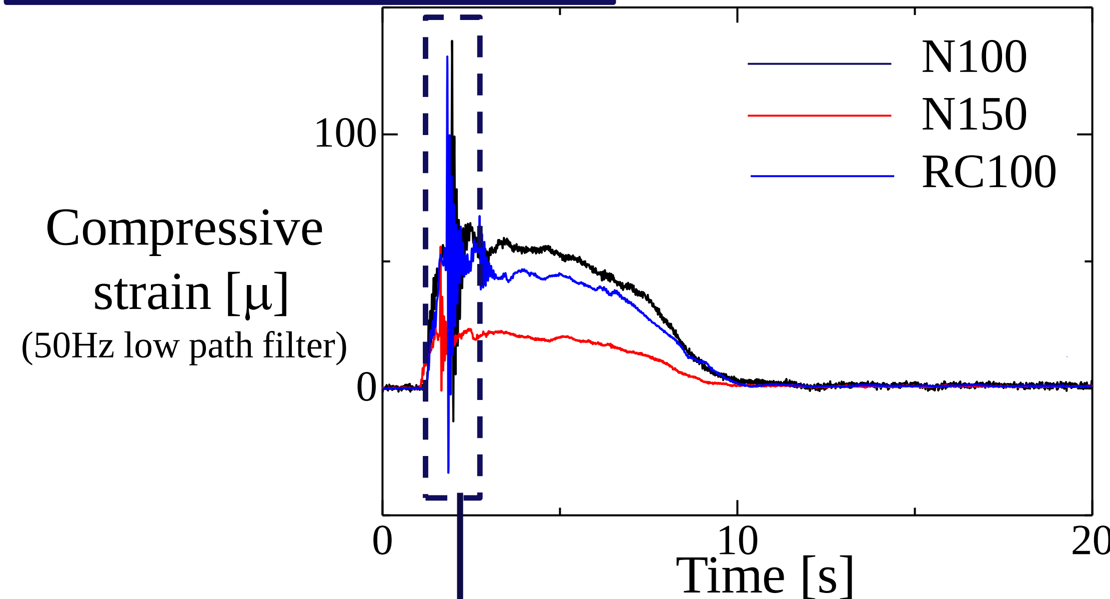
Wall type	Debris type	Damage of wall
N100	None	None
	Polyethylene	None
	Steel	Collapse
N150	None	None
	Polyethylene	None
	Steel	Crack
RC100	None	None
	Polyethylene	None
	Steel	Crack

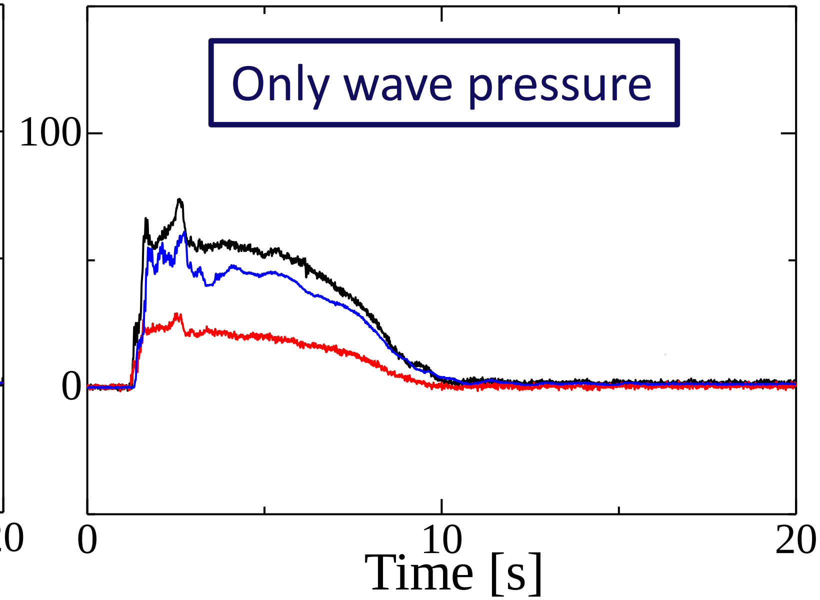
Collision speed : 0.5 m/s – 2 m/s

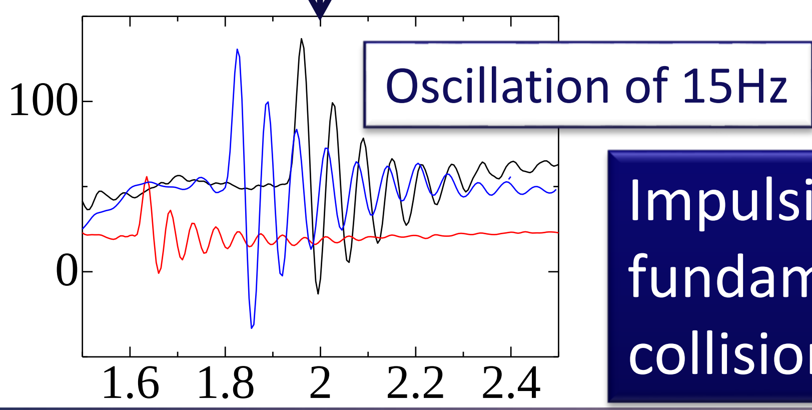
For the cases with steel debris, flexural cracks and failure at the base were observed.

Surface compressive strain at 180 mm height

Polyethylene foam



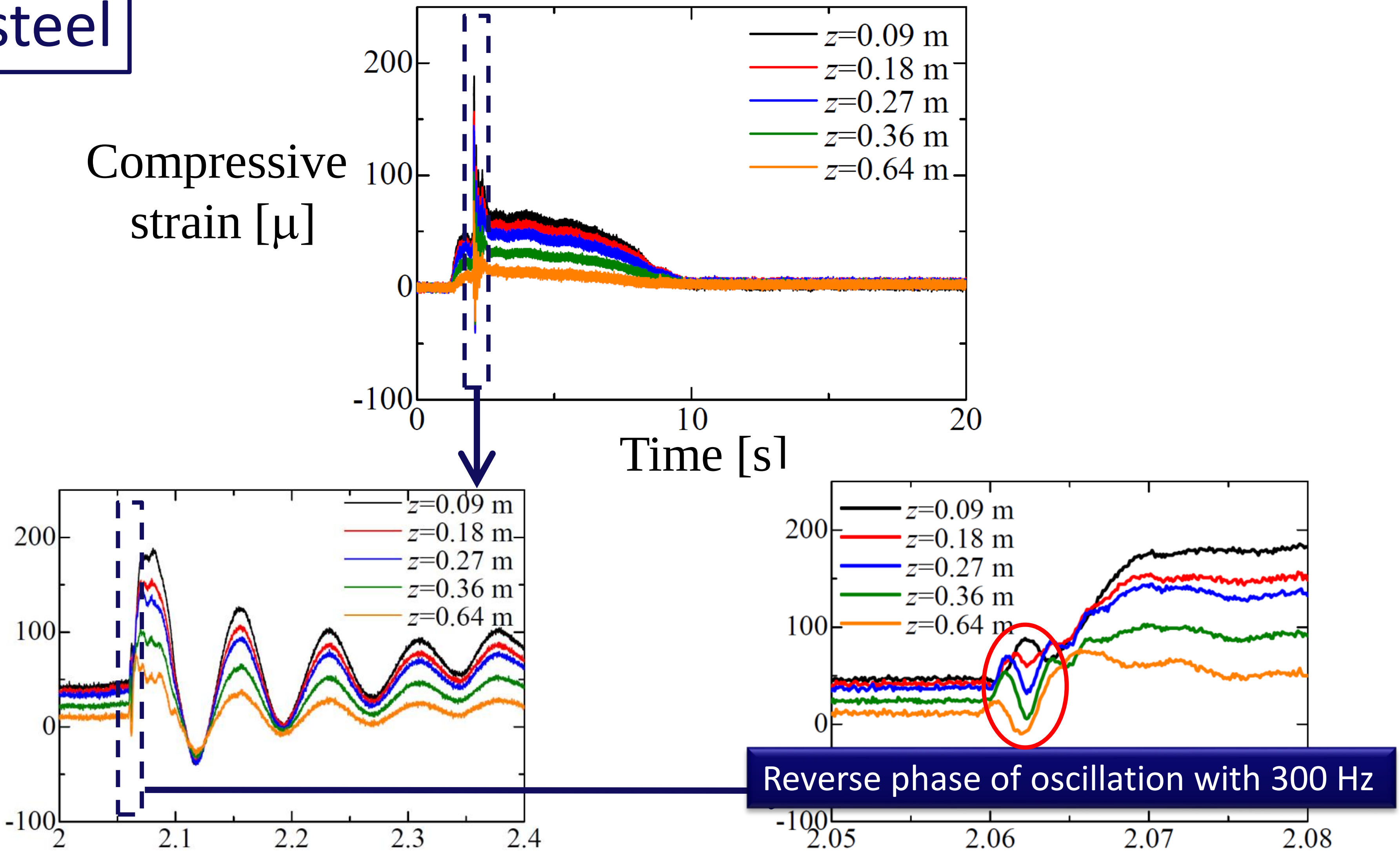




Impulsive oscillations with the fundamental mode just after the debris collision were observed.

Surface compressive strain of RC100

steel



1. Introduction
2. Experiment
3. Characteristics of wall response to wave pressure
4. Characteristics of wall response to both wave pressure and debris collision
5. Summary

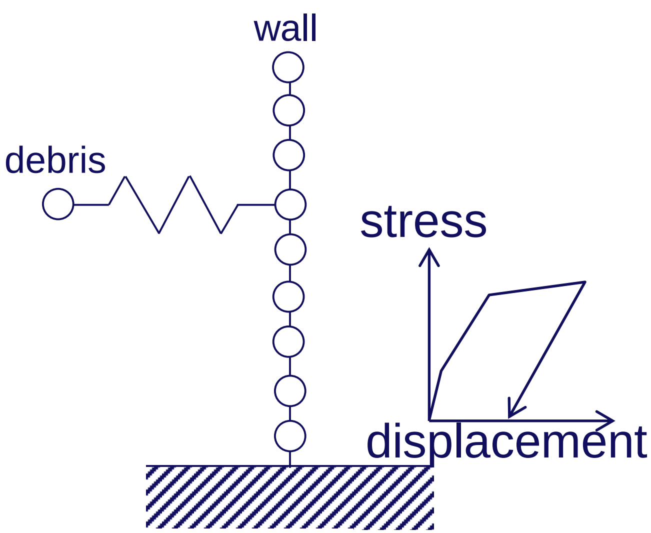
Summary

- Large-scale experiments on the responses of concrete/RC vertical walls to tsunami wave pressure and debris collision were carried out.

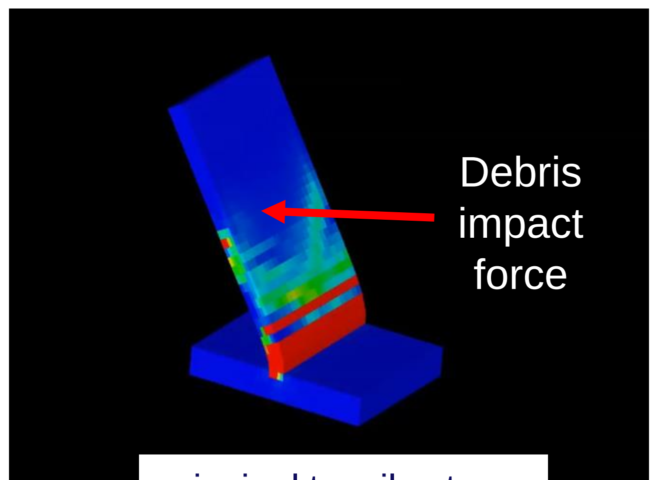
- Major results are as follows
  - "Only tsunami wave pressure" cases
    - Flexural failures at the bases of the walls were observed.
    - The capacity for the flexural failure of concrete wall may be able to be evaluated by its cracking moment.
  - "Both tsunami wave pressure and debris impact" cases
    - Flexural cracks and failures at the bases of walls were observed.
    - impulsive oscillations just after the debris collision whose frequency depended on the material of debris were observed.

Summary

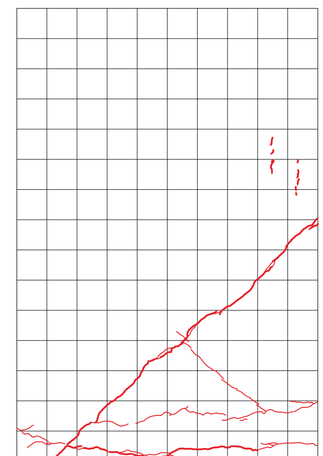
- Evaluation of wall response to both tsunami wave pressure and debris collision.
  - All of the cases shown in this study, flexural failures at the bases of walls were observed, and for those cases beam model can be used for the wall response evaluation.
  - For the other case, oblique flexural failures was observed, and for such a case, application of FEM is appropriate.



Beam model



principal tensile stress solved by FEM



Trace of crack (experiment)

Shibayama, Miyagawa, Kihara and Kaida, Response characteristics and nonlinear Finite Element Analysis of RC walls subjected to tsunami wave pressure and driftage collision force, *Proc., Int. J. Offshore and Polar Eng.*, 2018. (in revision)