Tsunami Risk Assessment of Nuclear Power Plants in Taiwan

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Outline

- Verification of Tsunami Model
- Workflow of Tsunami Simulation
- Far-field Tsunami Simulations
- Near-field Tsunami Simulations
- ECW 3D simulations

SEC-HY21
Verification of Tsunami Model

Verification of Tsunami model

- Follow the "Model Evaluation Standards" of NOAA(National Oceanic and Atmospheric Administration) 「STANDARDS, CRITERIA, AND PROCEDURES FOR NOAA EVALUATION OF TSUNAMI NUMERICAL MODELS」。

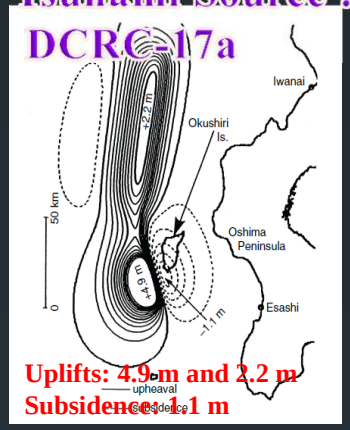
1. Analytical Benchmarking
   - AB-1: Single wave on a simple beach
     a. Solitary wave evolution and runup
     b. N-wave runup
     c. Boundary value problem
     d. Initial value problem
   - AB-2: Solitary wave on composite beach
   - ★ AB-3: Subaerial landslide on simple beach
2. Laboratory Benchmarking
   - ★ LB-1: Solitary wave on a simple beach
   - ★ LB-2: Solitary wave on a composite beach
   - ★ LB-3: Solitary wave on a conical island
   - ★ LB-4: Tsunami runup onto a complex three-dimensional beach; Monai Valley
   - ★ LB-5: Tsunami generation and runup due to three-dimensional landslide
3. Field Benchmarking
   - ★ FB-1: Okushiri Island
   - FB-2: Rat Islands tsunami

★ Used in verification of SEC-HY21

Verification of Tsunami Model

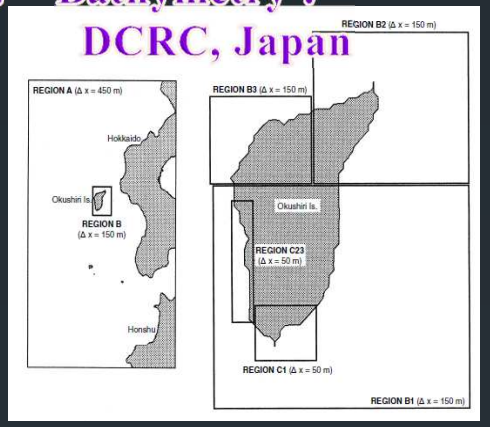
Okushiri Island

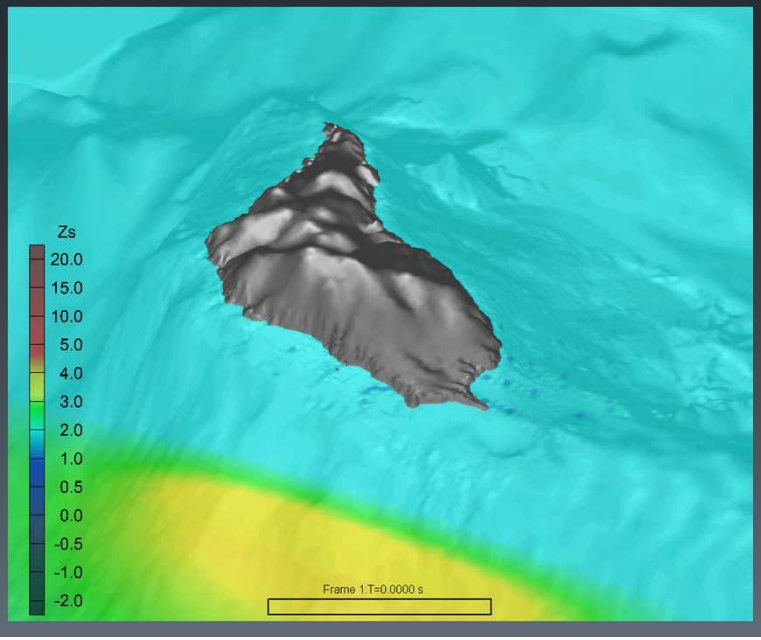
Tsunami Source : DCRC-17a

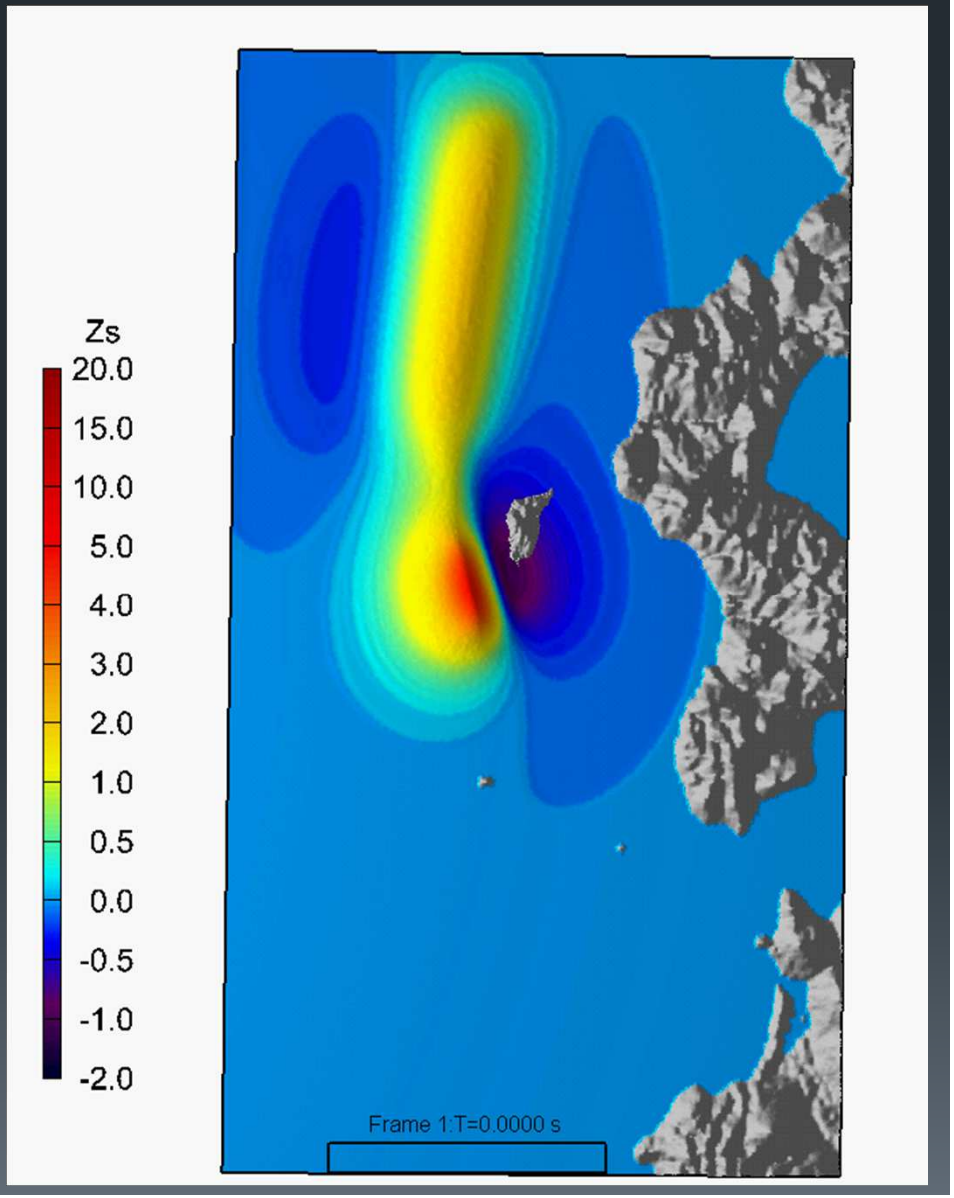


Uplifts: 4.9 m and 2.2 m
Subsidence: 1 m

Bathymetry : DCRC, Japan



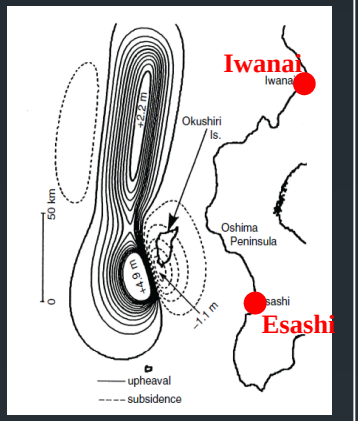


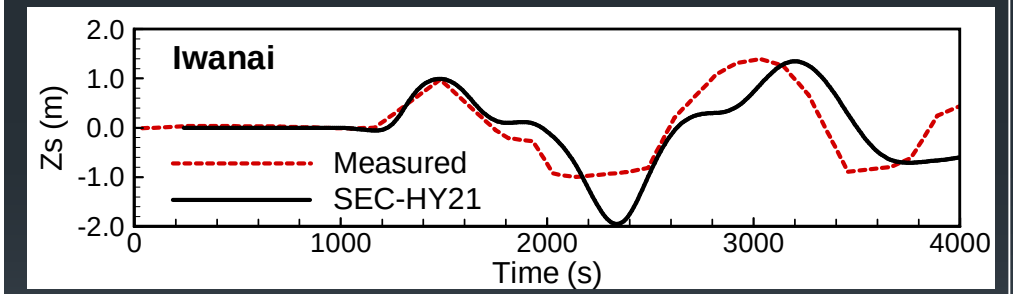


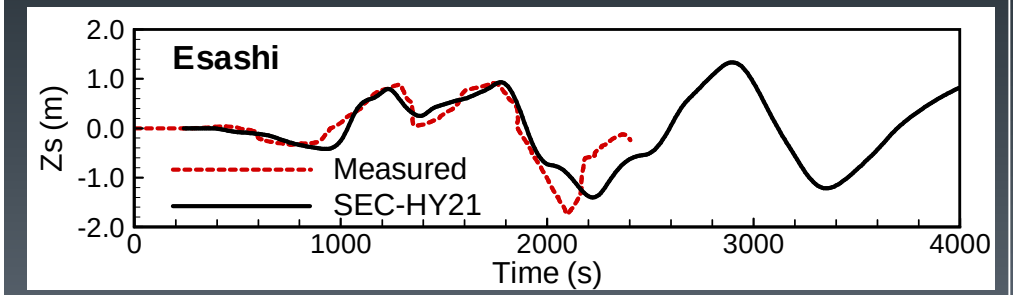
Verification of Tsunami model

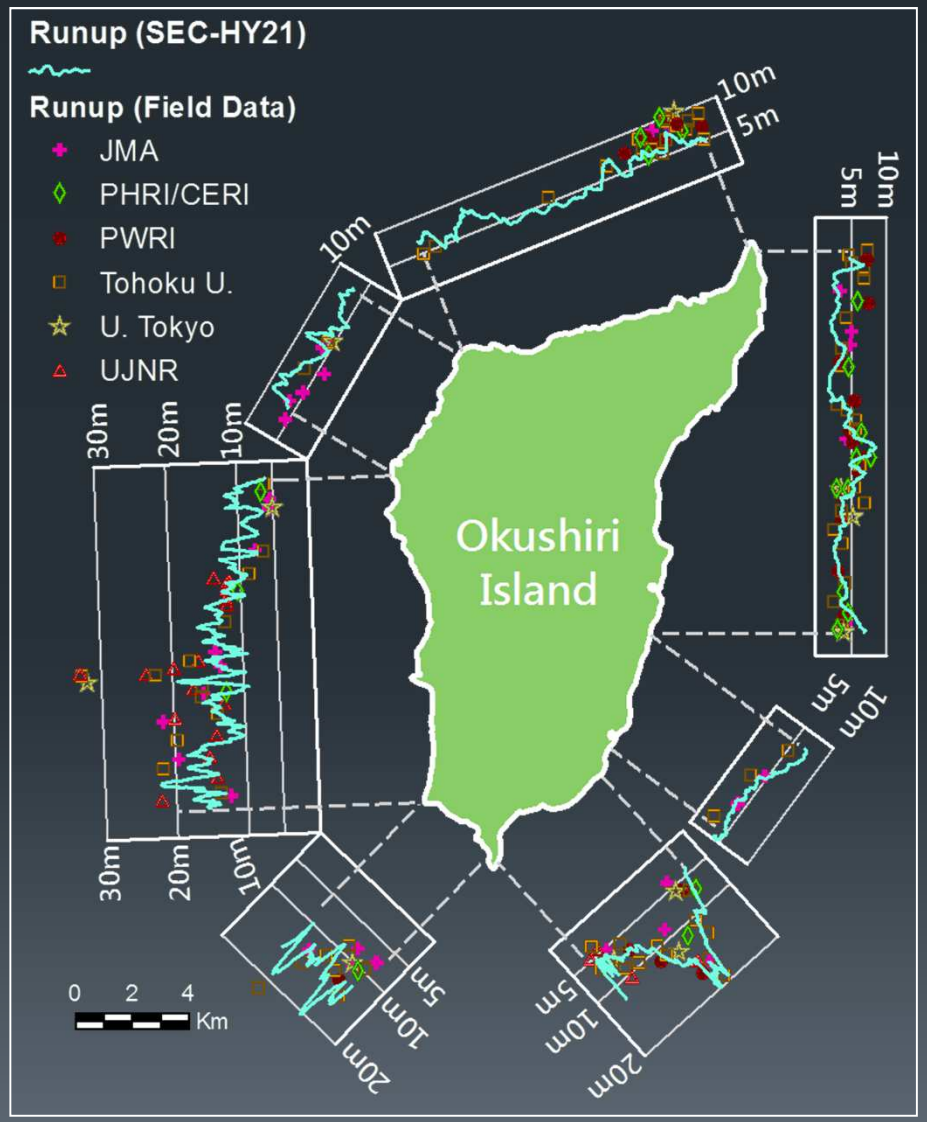
Okushiri Island

Computed and measured water level at two tidal stations



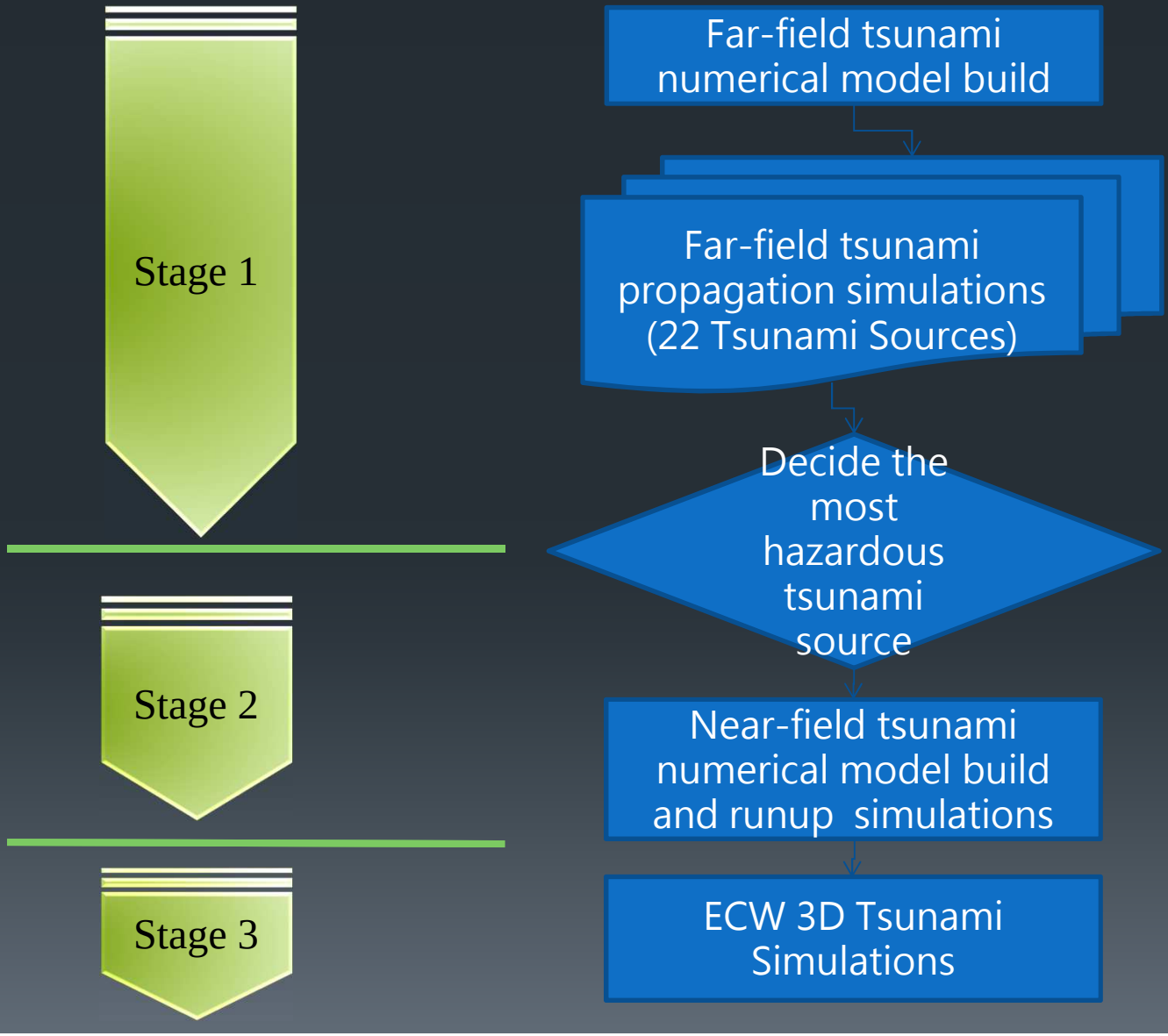






Workflow of Tsunami Simulation

Workflow of Tsunami Simulation



Far-field Tsunami Simulations

Tsunami Sources

Possible damaging tsunami sources near Taiwan are determined by the National Science Council in 2011

Fault parameters

	L(km)	W(km)	Mw	D(m)	Strike	Dip	Cx (Long.) Fault plane center	Cy (Lat.) Fault plane center
trench_segment-01	151.87	50.0	8.14	5.21	-66.24	45	122.4453	23.4230
trench_segment-02	169.96	50.0	8.21	5.65	340.76	20	120.1508	20.5729
trench_segment-03	236.53	50.0	8.35	6.63	35.35	20	119.8625	19.2219
trench_segment-04	478.16	50.0	8.62	9.05	2.40	20	119.1192	15.9716
trench_segment-05	127.08	50.0	8.04	4.64	313.05	25	119.7737	12.9093
trench_segment-06	368.56	50.0	8.52	8.07	328.39	67	125.2201	14.3301
trench_segment-07	724.69	50.0	8.77	10.76	347.60	57	127.1703	9.5541
trench_segment-08	626.89	50.0	8.72	10.15	44.92	58	137.4050	9.1923
trench_segment-09	464.67	50.0	8.61	8.95	74.32	58	142.7773	11.1794
trench_segment-10	707.36	50.0	8.76	10.63	24.43	58	146.5129	14.3385
trench_segment-11	531.21	50.0	8.66	9.48	-9.68	58	147.2804	19.4987
trench_segment-12	717.63	50.0	8.76	10.63	-42.10	62	144.8181	23.7578
trench_segment-13	568.98	50.0	8.68	9.70	-4.11	32	142.6213	27.7950
trench_segment-14	542.80	50.0	8.67	9.59	-10.97	43	142.0009	32.2760
trench_segment-15	708.80	50.0	8.76	10.63	-115.81	10	135.3682	32.0531
trench_segment-16	533.78	50.0	8.66	9.48	-154.62	45	131.1535	29.0373
trench_segment-17	544.01	50.0	8.67	9.59	-134.98	45	128.0292	25.1642
trench_segment-18	311.86	50.0	8.46	7.53	-95.13	45	124.5803	23.1398
T19	Hengchun-1 + Hengchun-2 + Hengchun-3							
T20	Shanjiao-1							
T21	Shanjiao-2							
T22	Shanjiao-1 + Shanjiao-2							

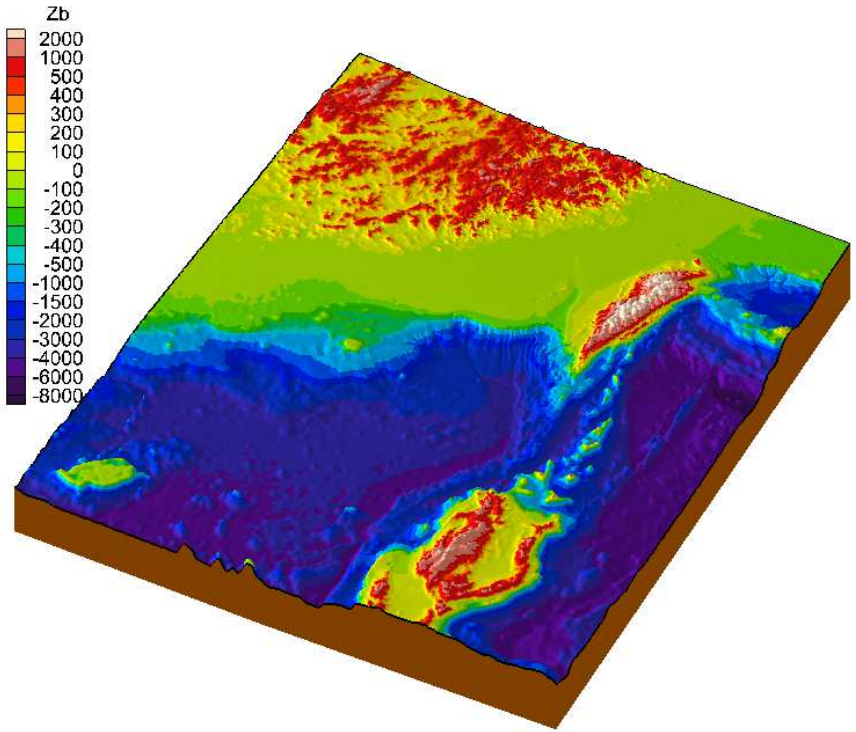
L & W *: fault length and width*
Mw *: moment magnitude of earthquake*
D *: slip amount*
Strike *: strike direction*
Dip*: dip angle*
Rake angle of each source is 90 degree

Fault parameters (cont.)

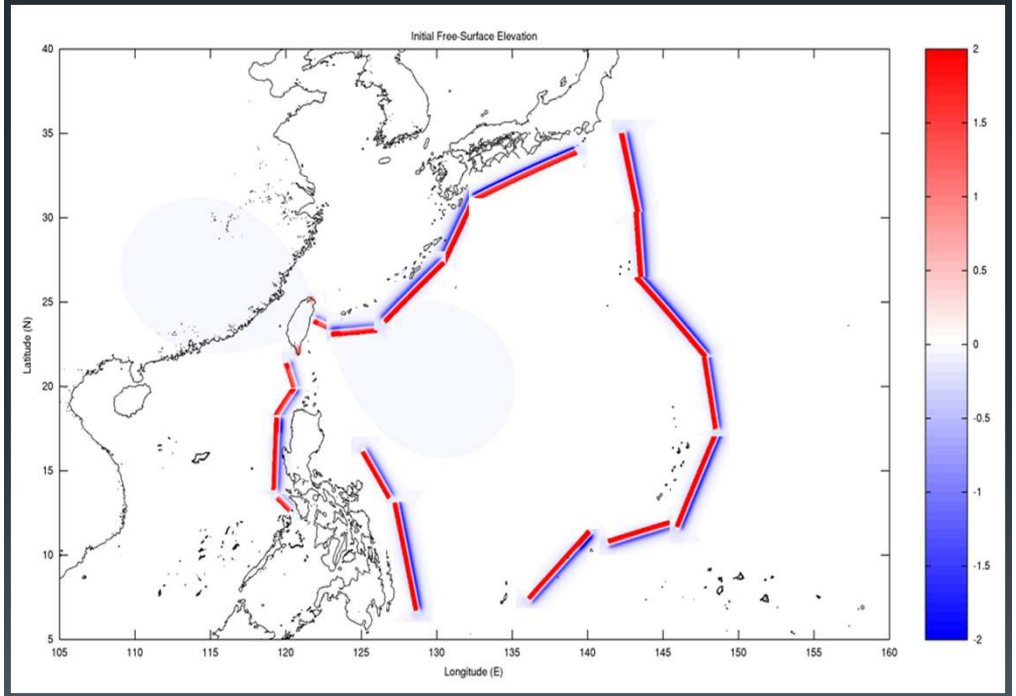
	L(km)	W(km)	Mw	D(m)	Strike	Dip	Cx (Lon) Fault plane center	Cy (Lat) Fault plane center
Shanjiao-1	50	50	7.5	2.49	54	55	121.6076	25.2289
Shanjiao-2	37	37	7.15	1.67	25	55	121.4355	25.1811
Hengchun-1	26	26	6.83	1.15	340	60	120.6660	22.1970
Hengchun-2	16	16	6.41	0.71	340	60	120.7355	22.0250
Hengchun-3	21	21	6.64	0.93	324	60	120.8180	21.8800

Far-field Tsunami Simulations

Numerical Model

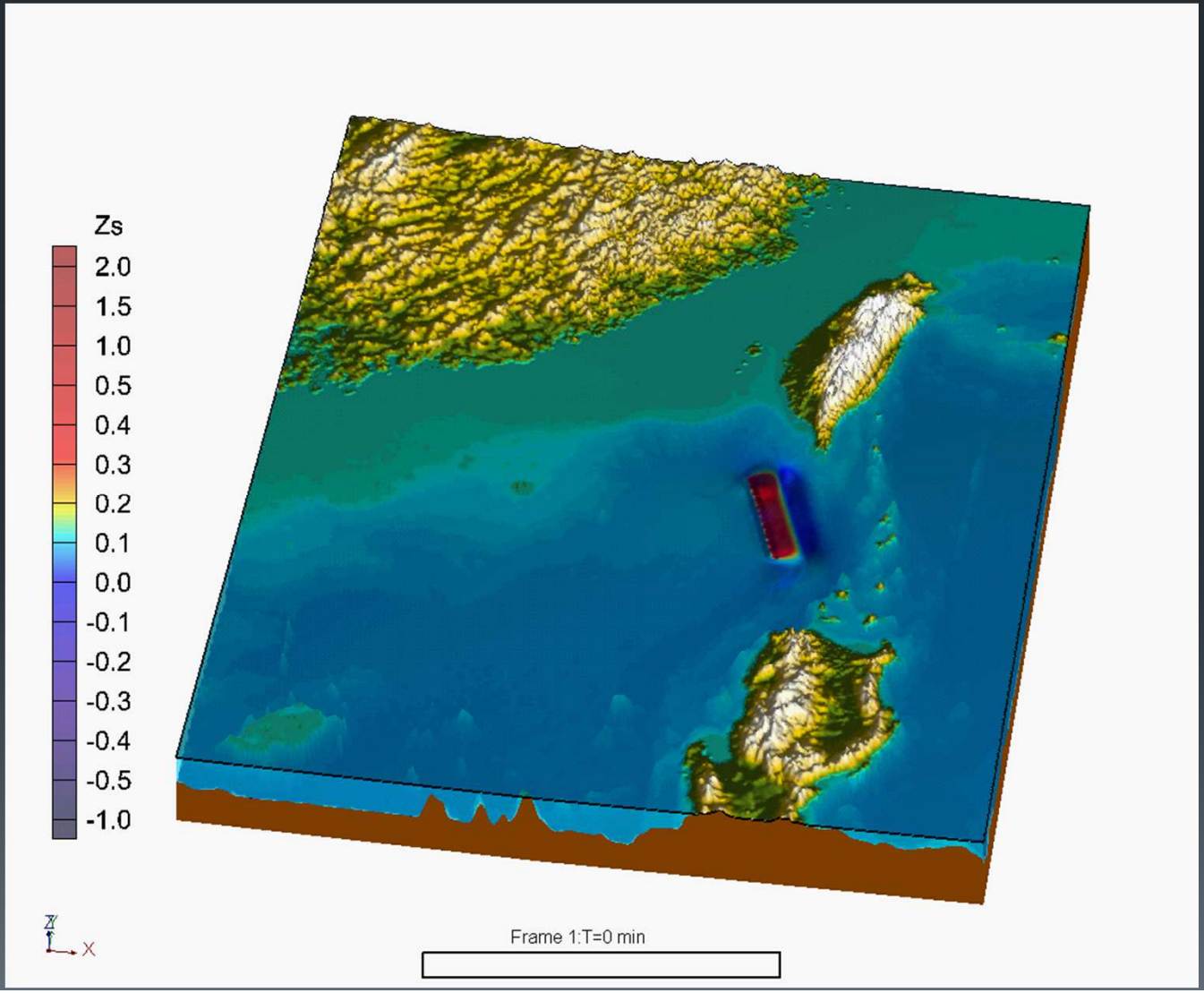


Tsunami sources



Far-field Tsunami Simulations

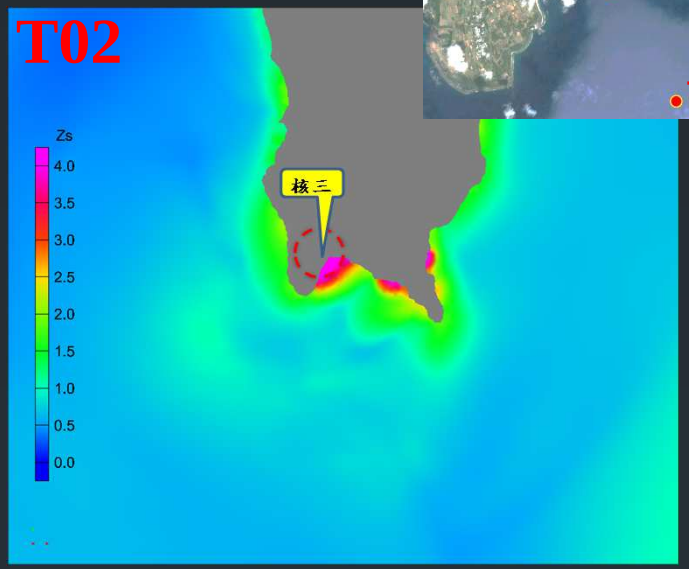
Tsunami propagation animation : T02

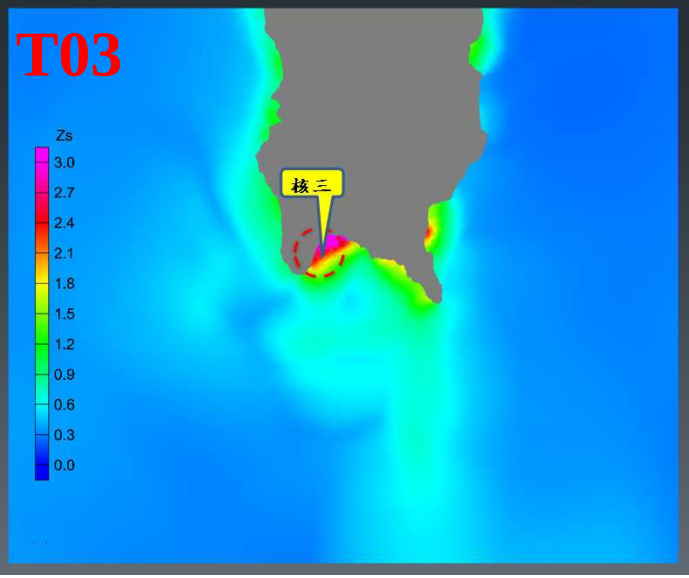


Far-field Tsunami Simulations

Nuclear Power Plant no. 3

No.	Offshore water depth 20m Max Water Surface(m)	Offshore water depth 50m Max Water Surface(m)	Offshore water depth 100m Max Water Surface(m)
T01	0.87	0.67	0.42
T02	4.06	2.70	1.09
T03	2.93	1.71	0.65
T04	1.40	1.06	0.51
T05	0.08	0.06	0.06
T06	0.19	0.15	0.11
T07	0.19	0.14	0.08
T08	1.21	0.77	0.49
T09	0.24	0.17	0.09
T10	0.74	0.52	0.24
T11	0.43	0.23	0.14
T12	0.33	0.20	0.11
T13	0.17	0.15	0.12
T14	0.04	0.03	0.03
T15	0.01	0.01	0.01
T16	0.02	0.02	0.02
T17	0.27	0.20	0.13
T18	0.79	0.50	0.29
T19	1.52	1.38	0.91
T20	0.01	0.01	0.01
T21	0.03	0.03	0.02
T22	0.02	0.02	0.02



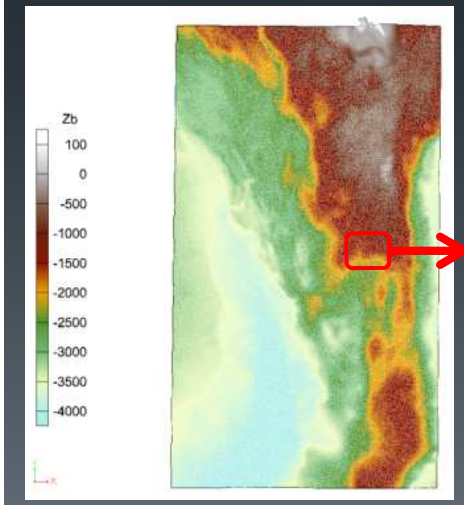


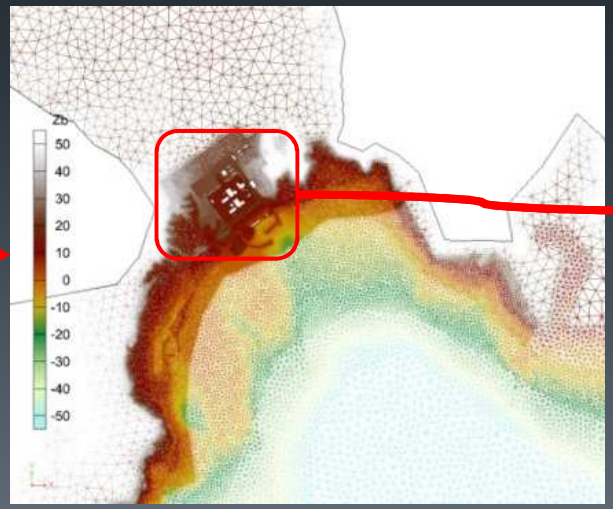
Near-field Tsunami Simulations
-Nuclear Power Plant no.3 for example

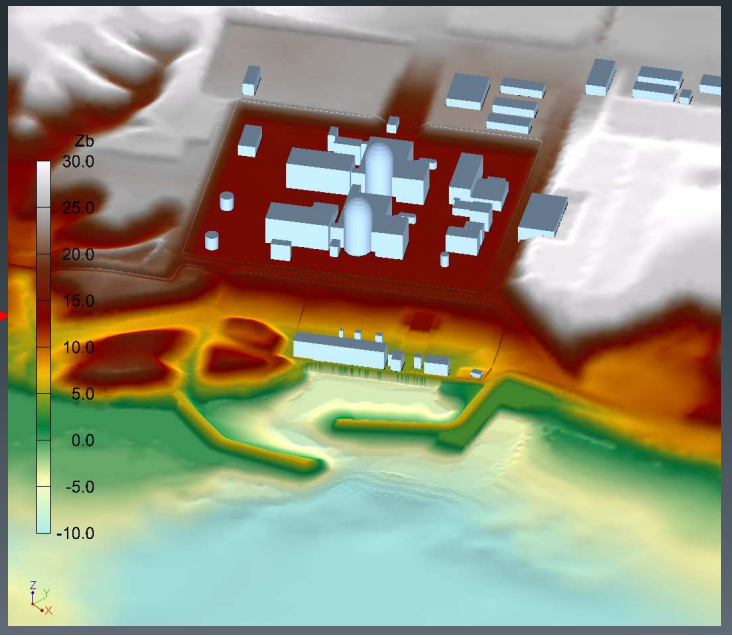
Near-field Tsunami Simulations

- Location of Nuclear Power Plant 3 in Taiwan

- Use unstructured mesh, cell size follows the standards recommended by U.S. Nuclear Regulatory Commission.



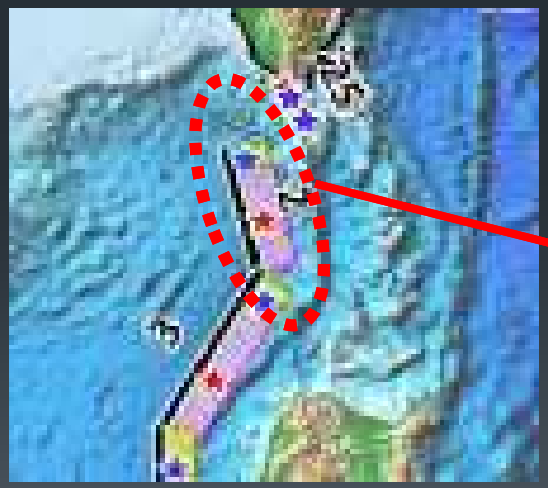




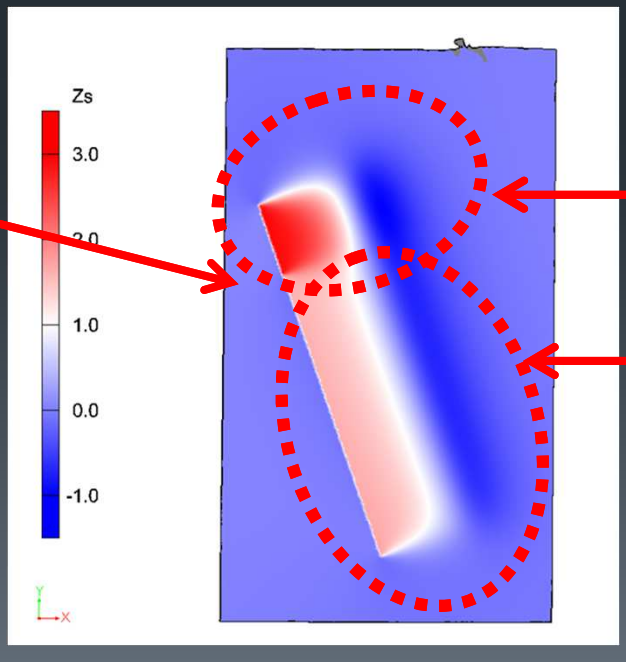
Near-field Tsunami Simulations

- Parameters for Elastic Fault Plane Model : T02

	Strike	Dip	Length (km)	Width (km)	Slip (m)	Epicenter (Latitude)	Epicenter (Longitude)	Slip (degree)	focal Depth
trench_segment-2_NonAsperity	340.7619	20	135.97	50.00	4.94375	20.42875	120.205	90	8.5505
trench_segment-2_Asperity	340.7619	20	33.99	50.00	8.475	21.14951	119.936	90	8.5505



Tsunami Initial Water Stage



Asperity

Non-Asperity

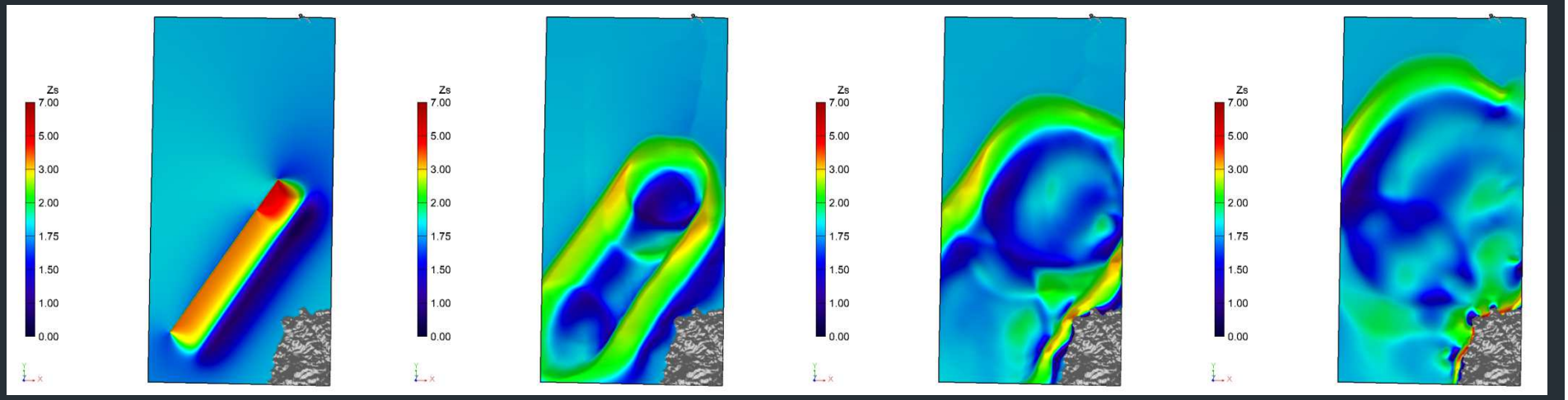
Near-field Tsunami Simulations

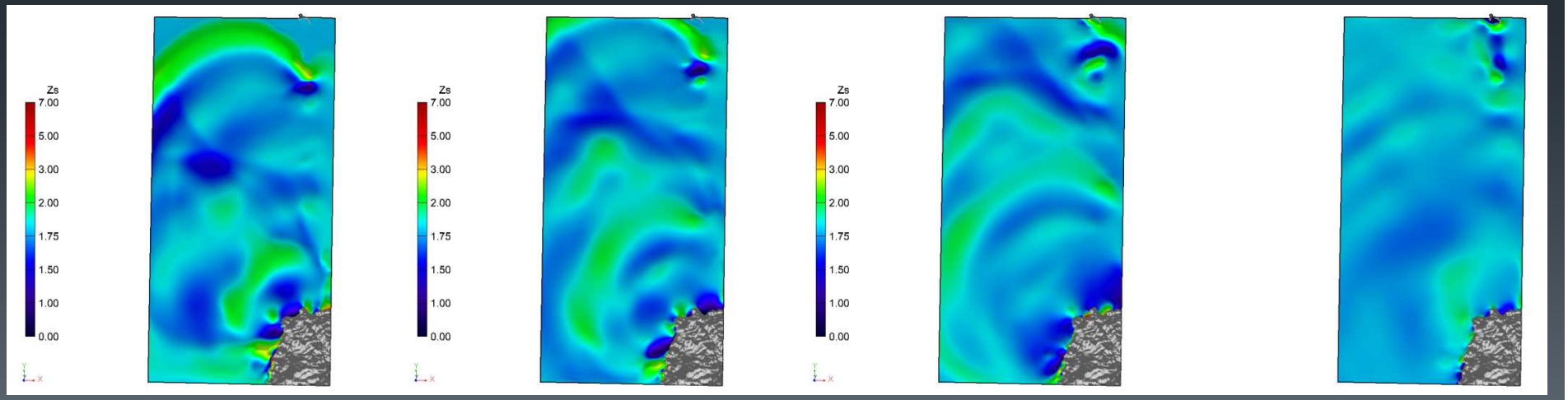
- **Numerical Parameters**
  - **Sea water level**
    - High water Level : +1.801m (HWOST + Return period 200 years Storm surge deviation)
    - Low water Level : -0.572m (LWOST)
    - Average water Level : +0.000m
  - **Boundary condition**
    - Non-reflective boundary
  - **Bed roughness**
    - Sea area
      1. Water depth > 20m : n = 0.0
      2. Water depth from 1 to 10m : n = 0.028~0.012
    - Land area :
      n=0.045
  - **Computational time interval**
    - CFL(Courant-Friedrichs-Lewy) = 0.5
  - **Initial tsunami waveform**
    - Okada method (1985)

HWOST : mean High Water level Of Spring Tide
LWOST : mean High Water level Of Spring Tide
n : Manning's n

Near-field Tsunami Simulations

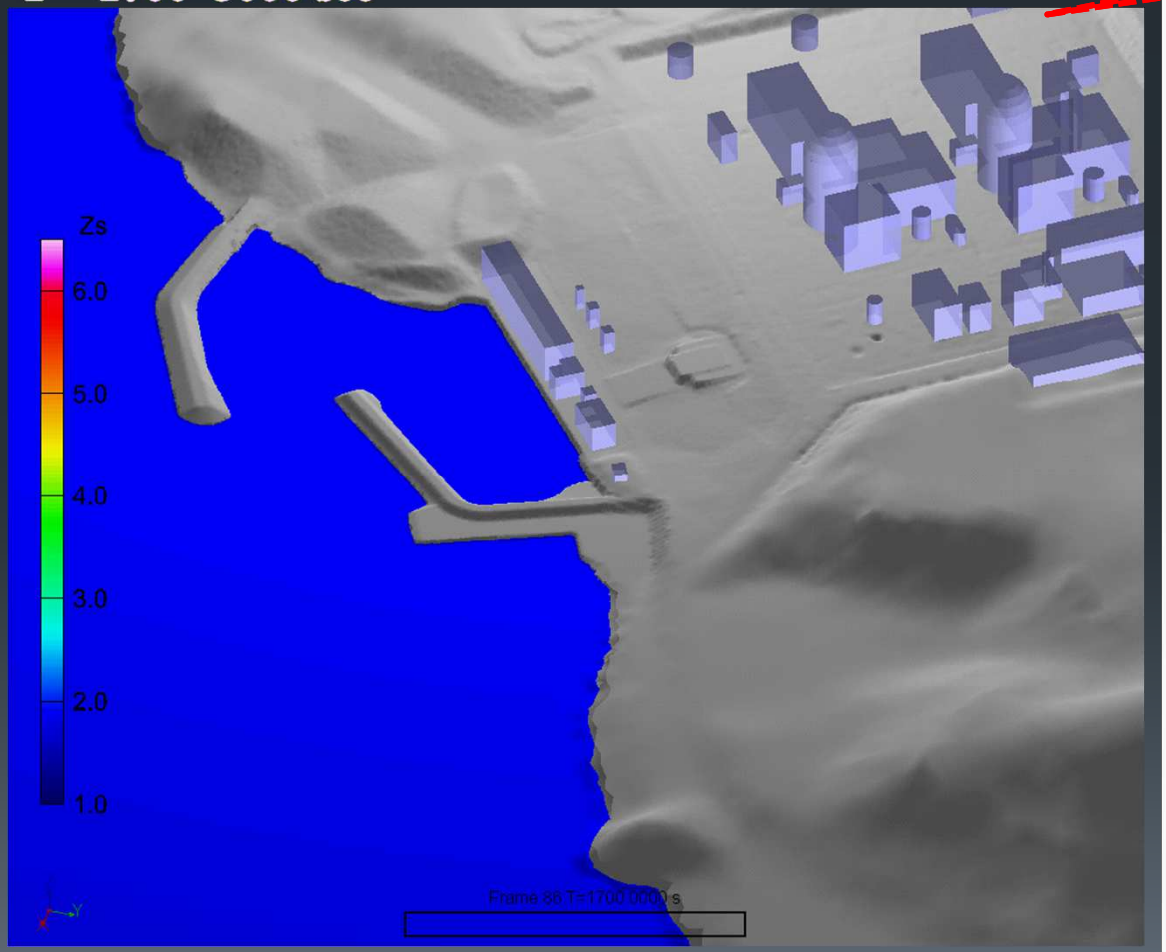
- Tsunami propagation：T03, H.W.L.(+1.801m)

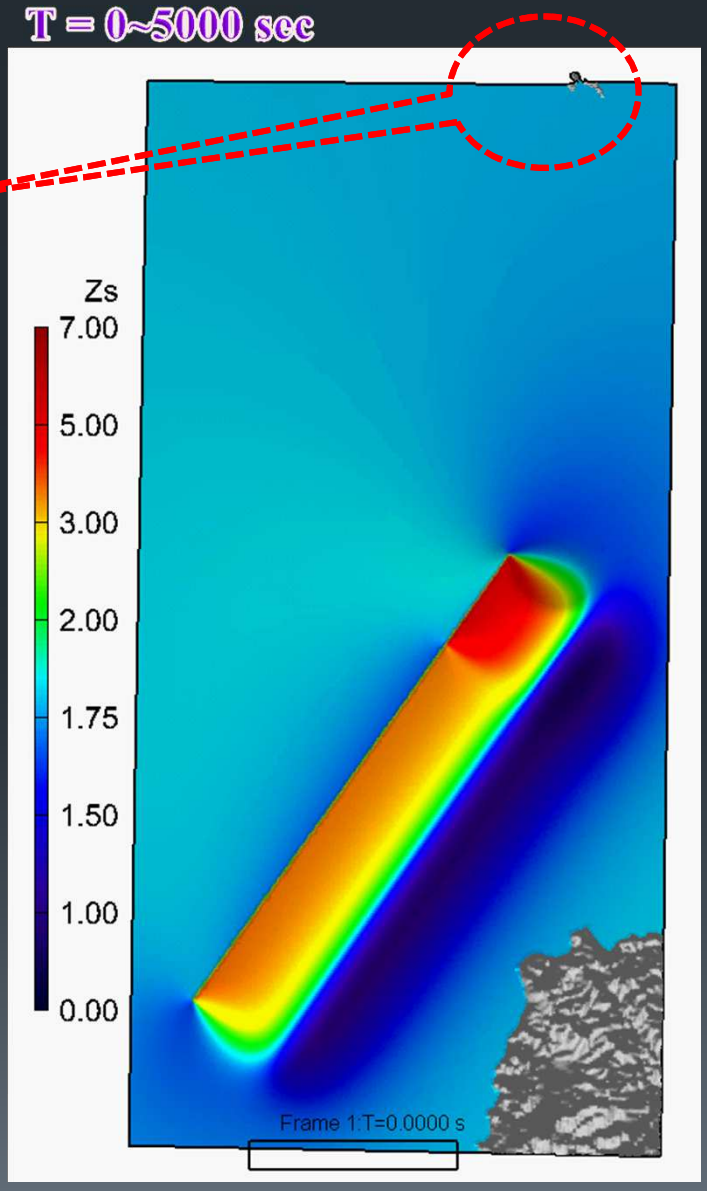




Near-field Tsunami Simulations

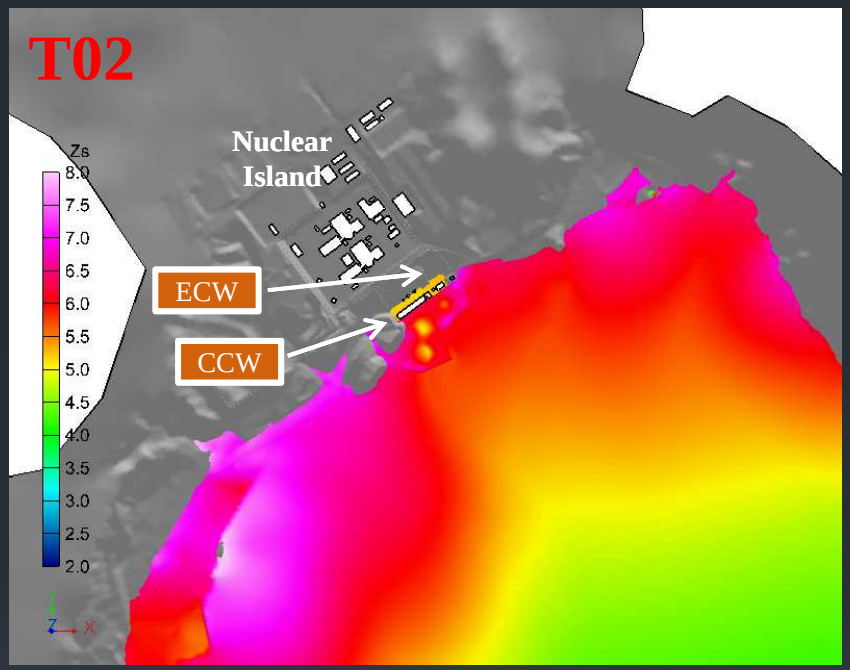
- Tsunami propagation & Runup Animation

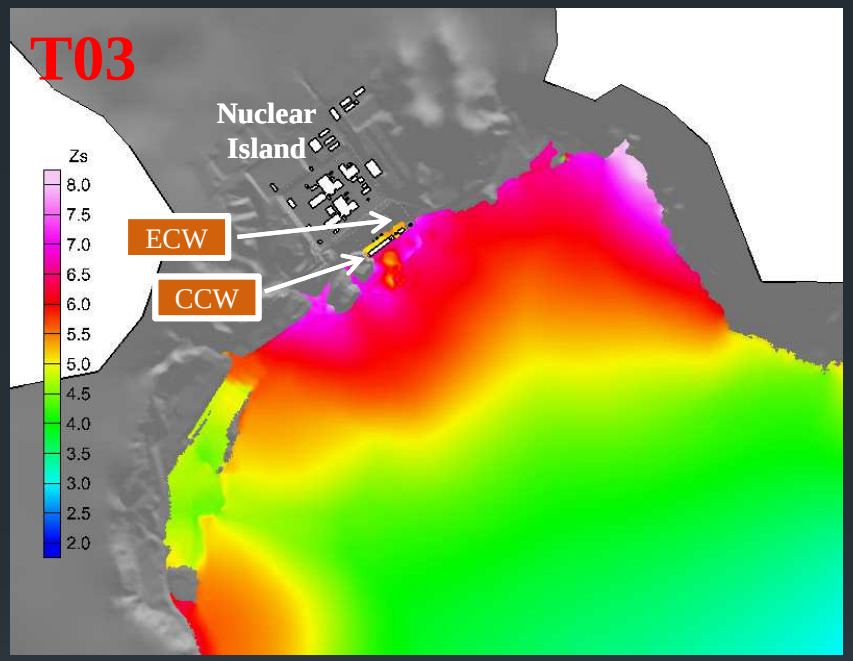




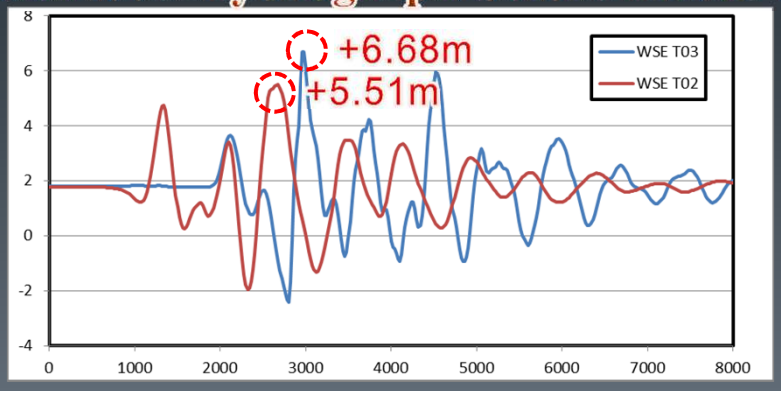
Near-field Tsunami Simulations

- Tsunami simulation result : max. runup





Water level hydrograph before intake of ECW



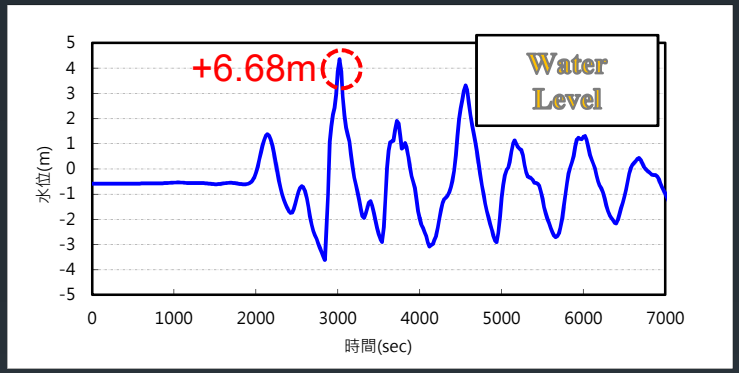
Select T03 to run ECW 3D simulation

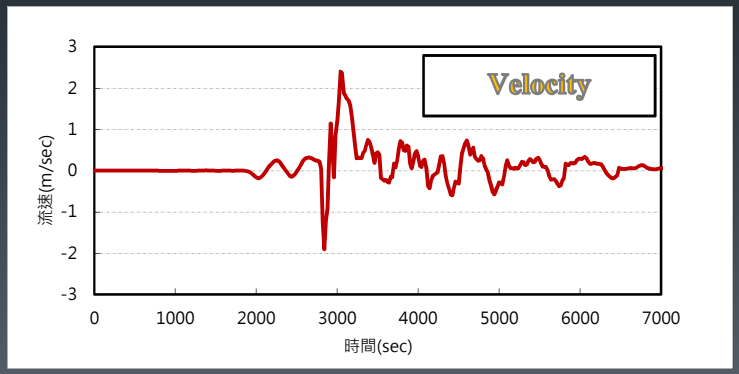
Near-field Tsunami Simulations

- Max. Runup and Rundown

Max. Run-up

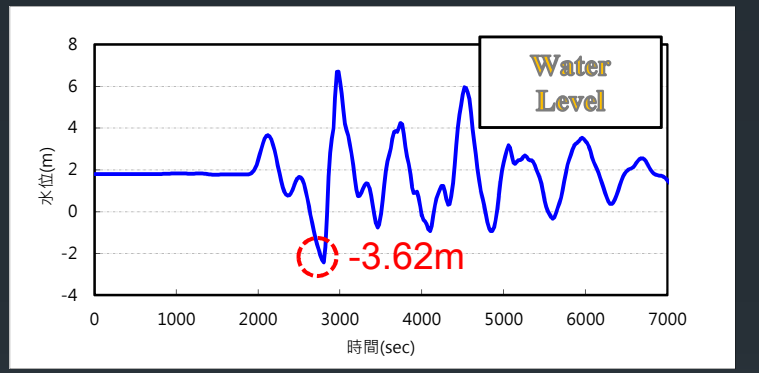
Tsunami：T03; H.W.L (+1.801m)

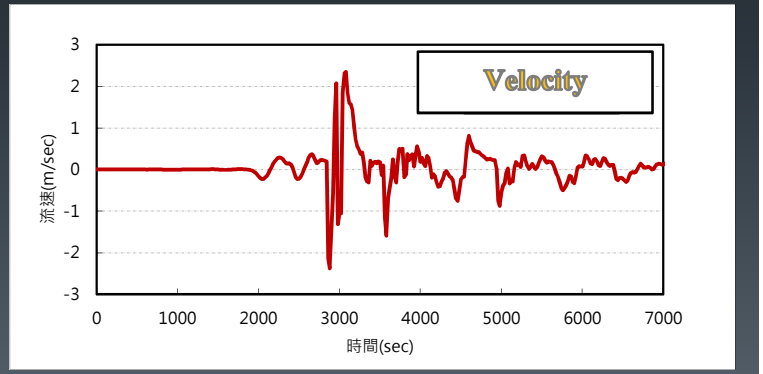




Max. Run-down

Tsunami：T03; L.W.L (-0.572m)

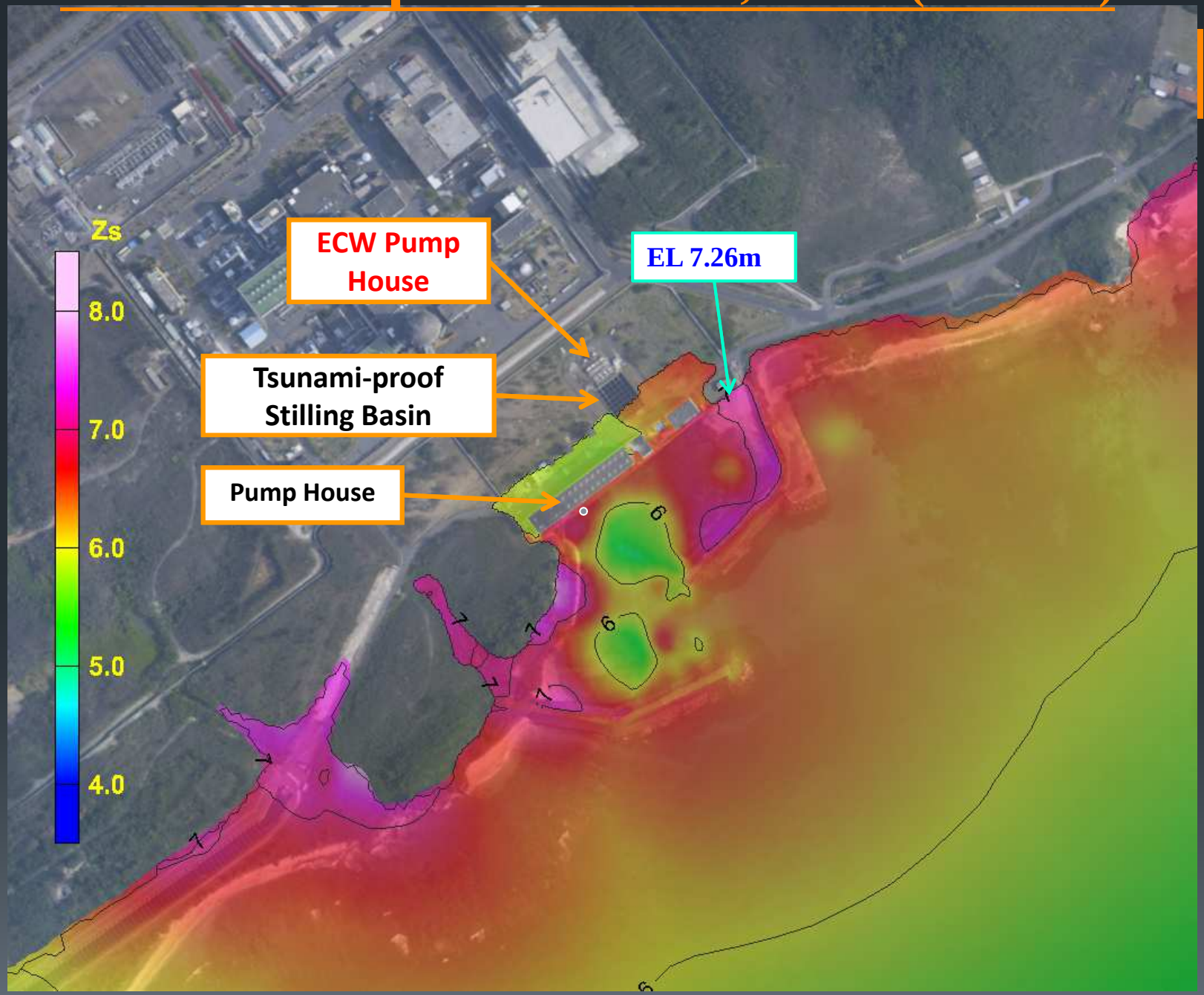




ECW 3D simulations

-Maanshan Nuclear Power Plant for example

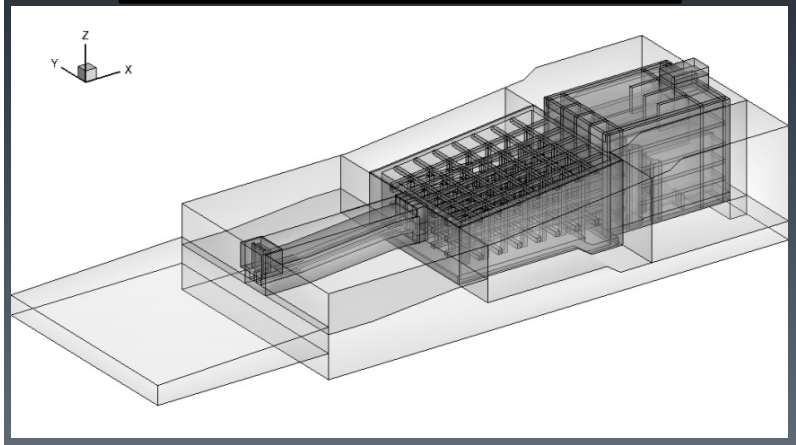
Max. Run-up: Tsunami T03, H.W.L (+1.801m)



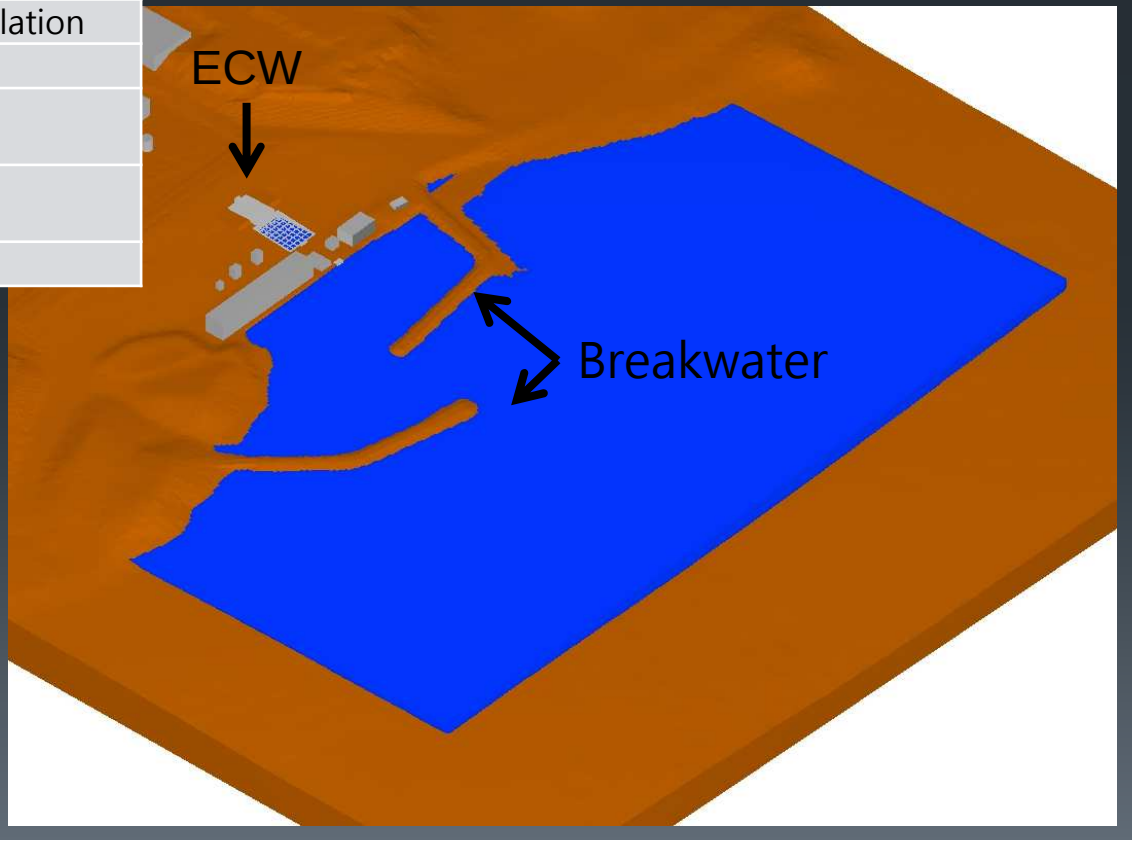
ECW 3D simulations

Control Equation	3-D Navier-Stokes Equations
Turbulence Model	RNG (Renormalized Group Model)
Mesh Size	Intake and Intake Pool: 0.5mx0.5mx0.5m Pump room： 0.25mx0.25mx0.25m Cells number ：300 millions
Input	Simulation result of 2D simulation
Initial water level	E.L. = -0.69m
Roughness of structure	1 mm
Free surface Process	VOF method
Equations Solver	GMRES Solver

Numerical Model of ECW

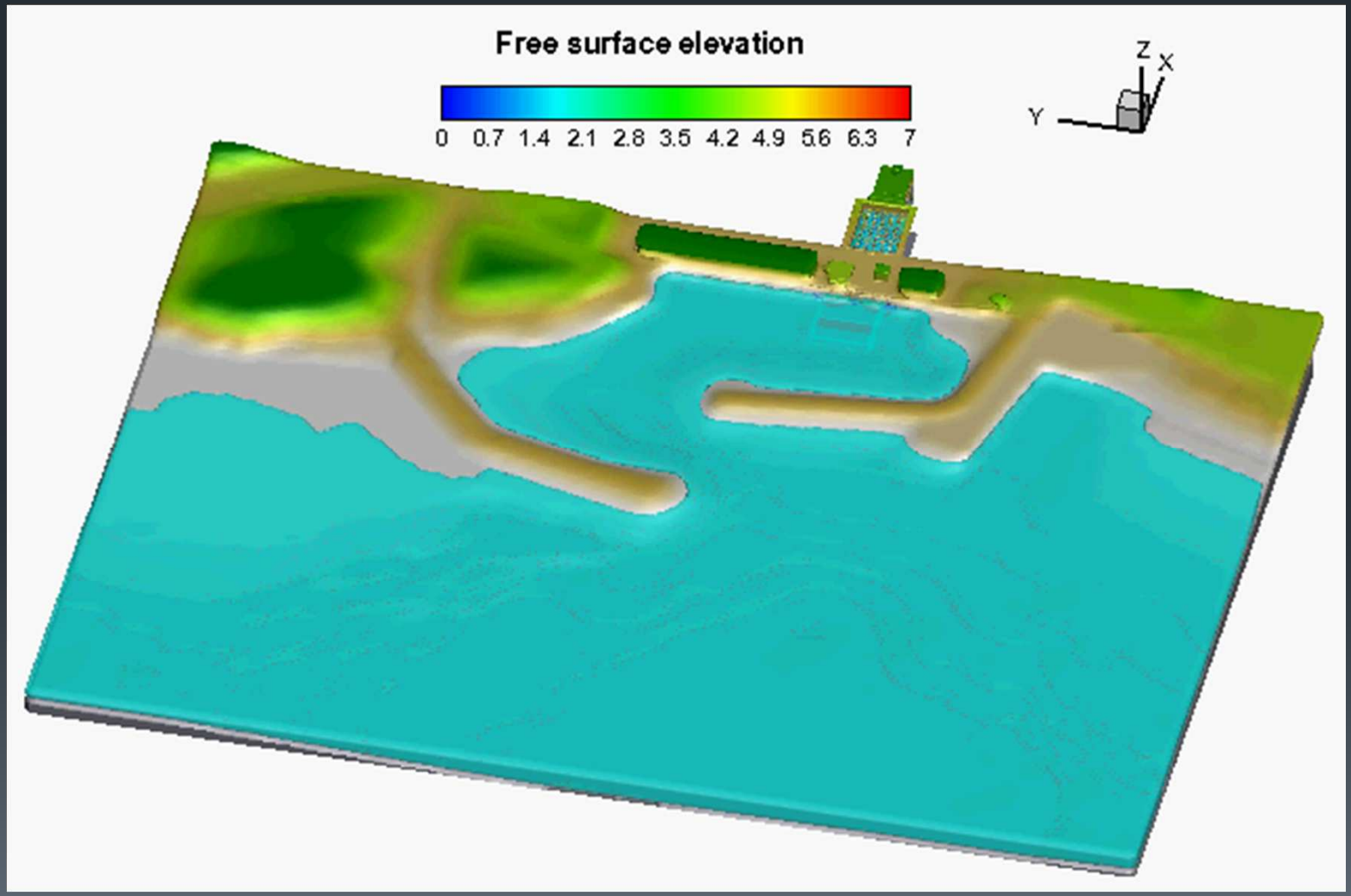


Numerical Model for 3D Simulation

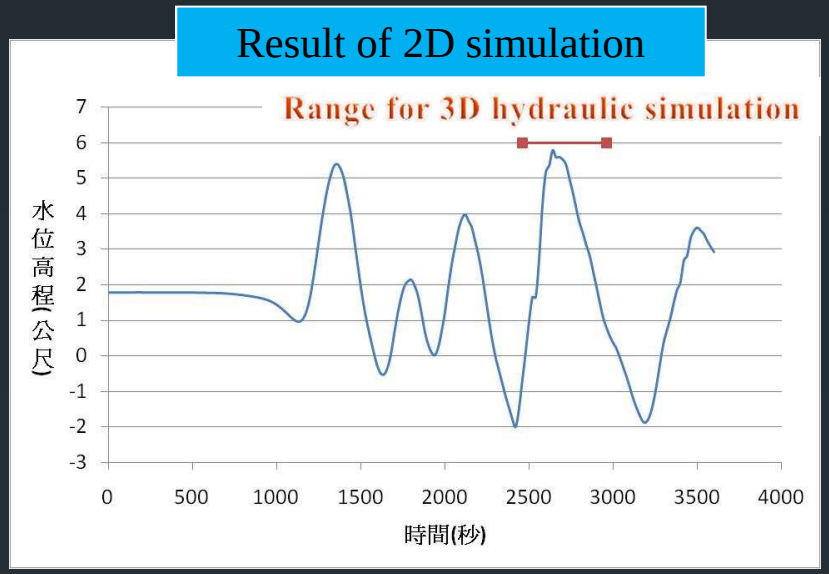


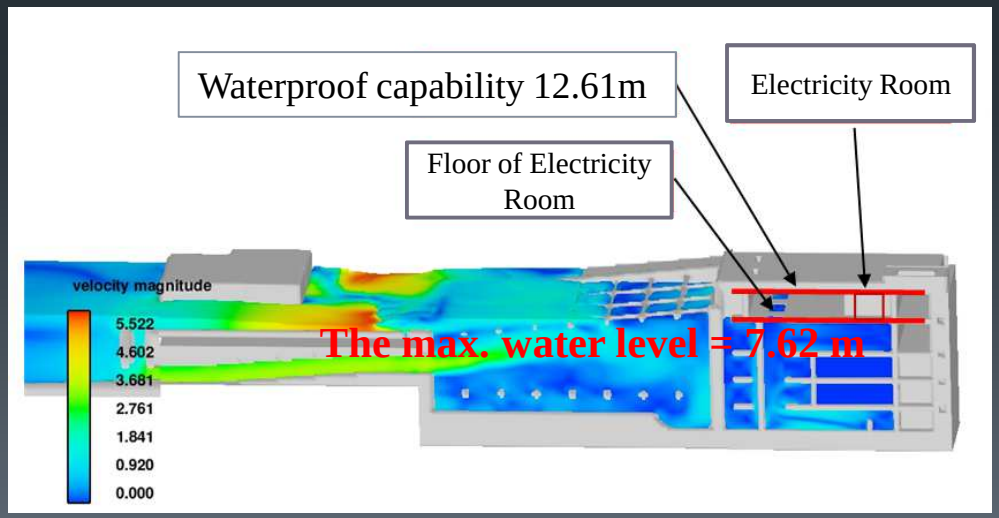
ECW 3D simulations

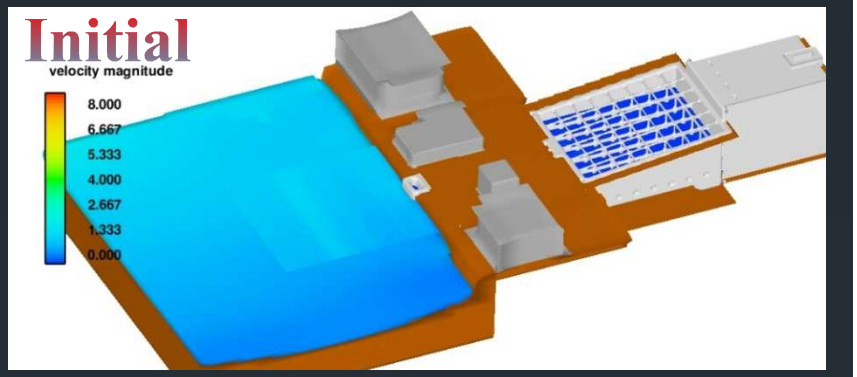
- ECW Tsunami simulation

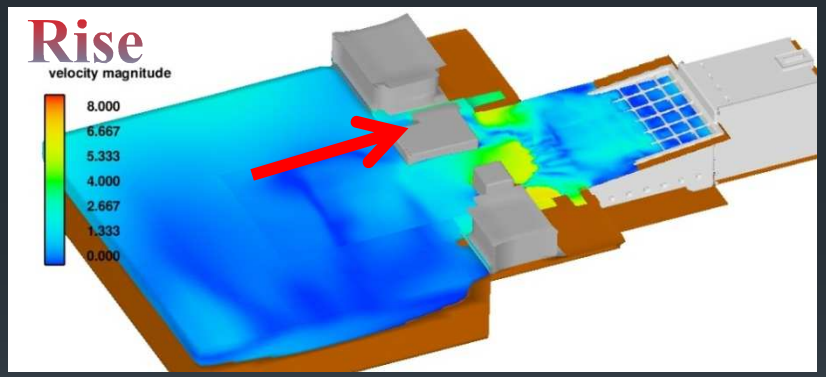


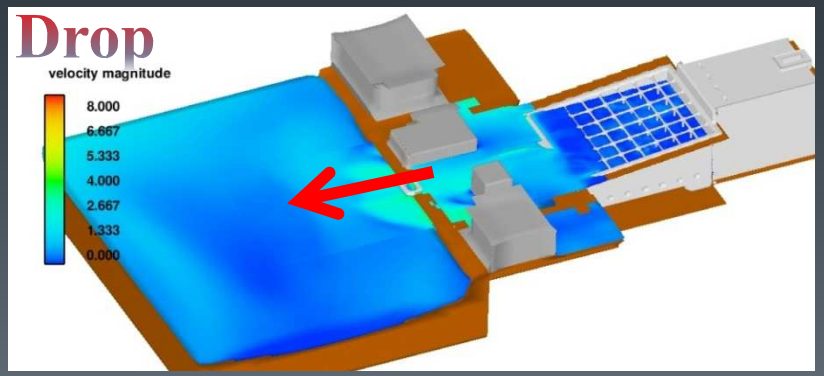
ECW 3D simulations(Max. Run-up)





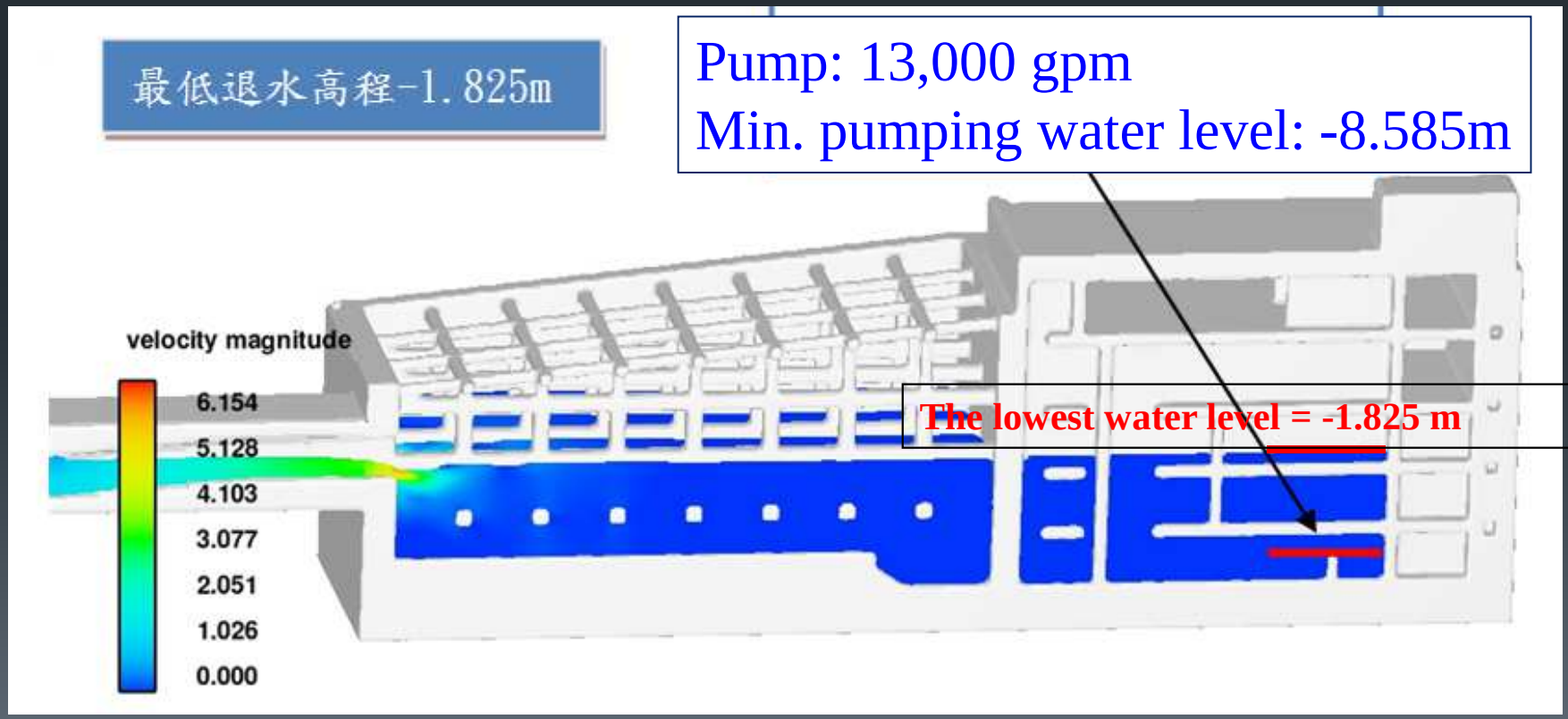






ECW 3D simulations(Max. Run-down)

- The lowest water level in pump pit of ECW house is -1.825 m, which is higher than the min. water level -8.585 m for pumping.
- **The pumping capability of ECW will not be affected by tsunami run-down.**



Near-field Tsunami Simulations
-Chin Shan Nuclear Power Plant

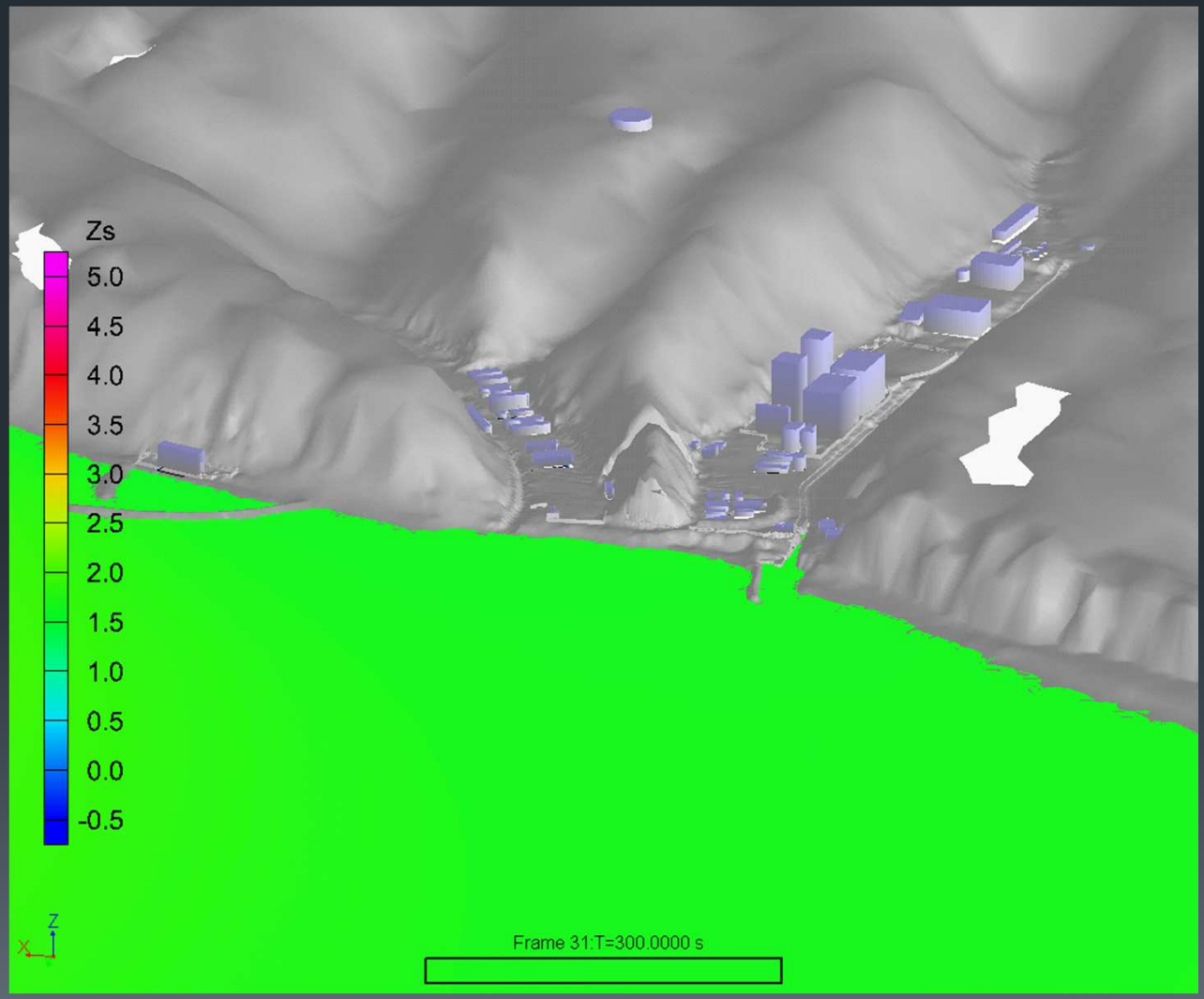
Near-field Tsunami Simulations

- **Numerical Parameters**
  - **Sea water level**
    - High water Level : +1.925m (HWOST + Return period 200 years Storm surge deviation)
    - Low water Level : -0.785m (LWOST)
    - Average water Level : +0.000m
  - **Boundary condition**
    - Non-reflective boundary
  - **Bed roughness**
    - Sea area
      1. Water depth > 20m : n = 0.0
      2. Water depth from 1 to 10m : n = 0.028~0.012
    - Land area :
      n=0.045
  - **Computational time interval**
    - CFL(Courant-Friedrichs-Lewy) = 0.5
  - **Initial tsunami waveform**
    - Okada method (1985)

HWOST : mean High Water level Of Spring Tide
LWOST : mean High Water level Of Spring Tide
n : Manning's n

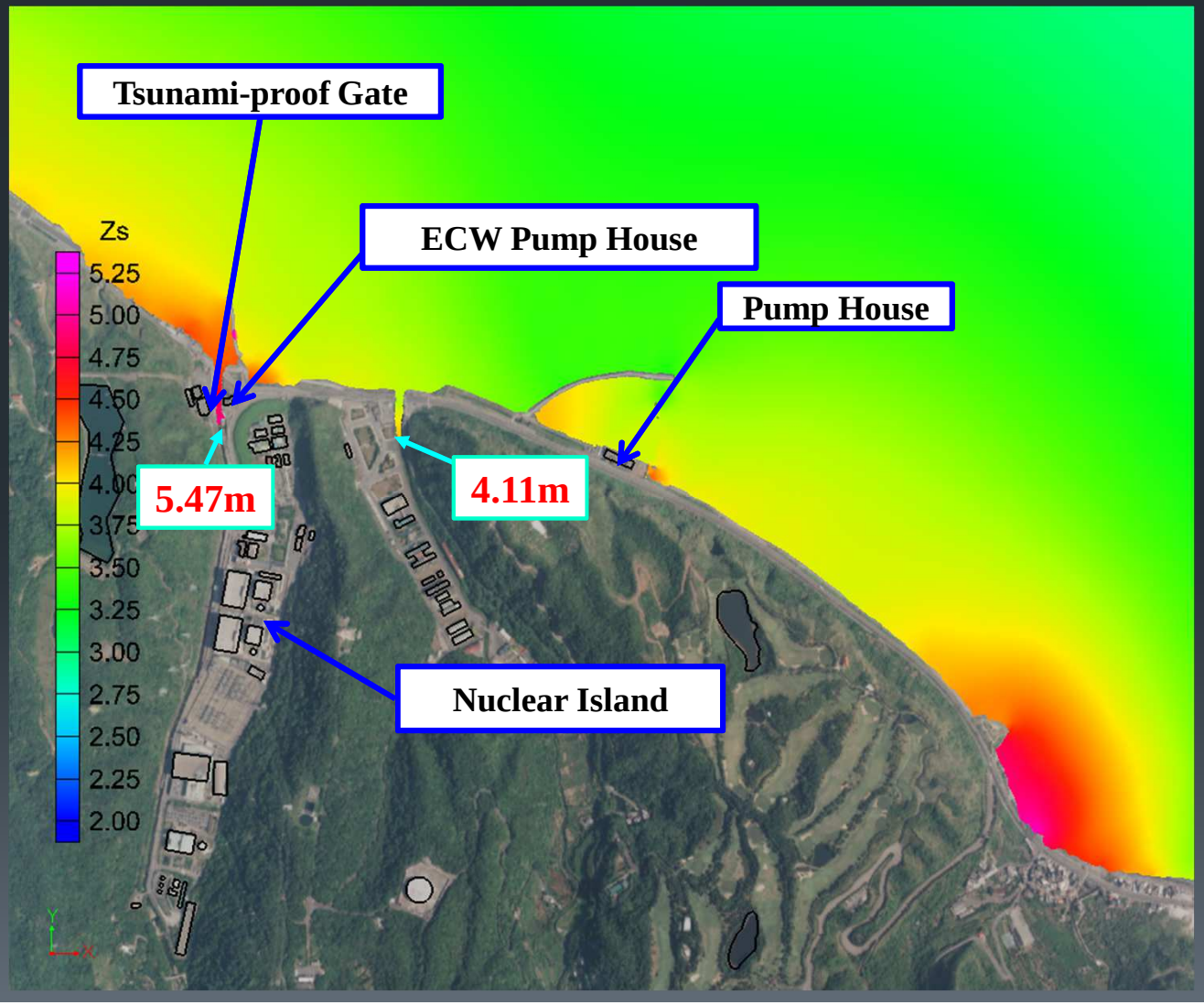
Near-field Tsunami Simulations

- Tsunami propagation : T20, H.W.L.(+1.925m)



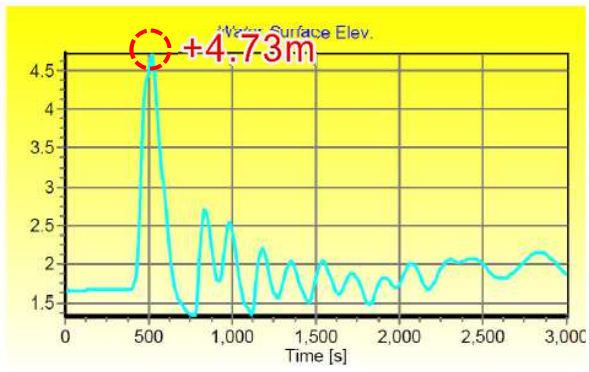
Near-field Tsunami Simulations

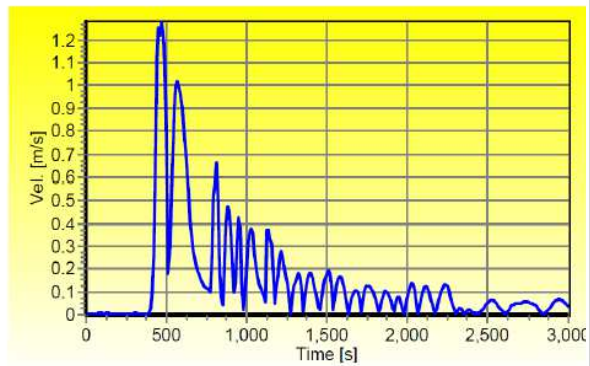
- Max. Runup : T20, H.W.L.(+1.925m)



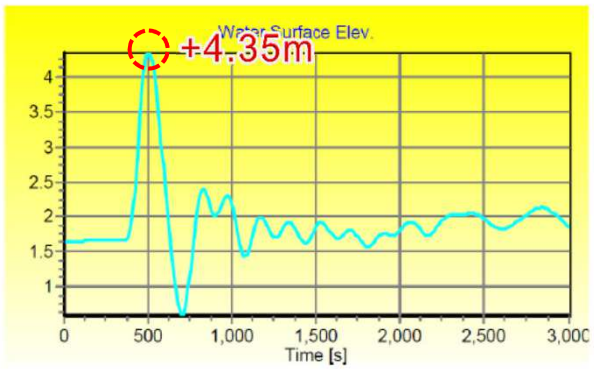
Near-field Tsunami Simulations

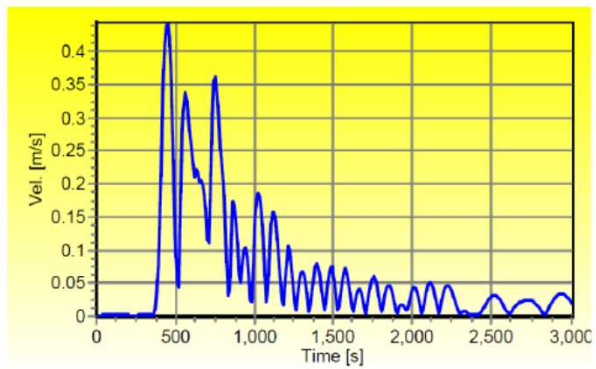
- Max. Runup : T20, H.W.L.(+1.925m)



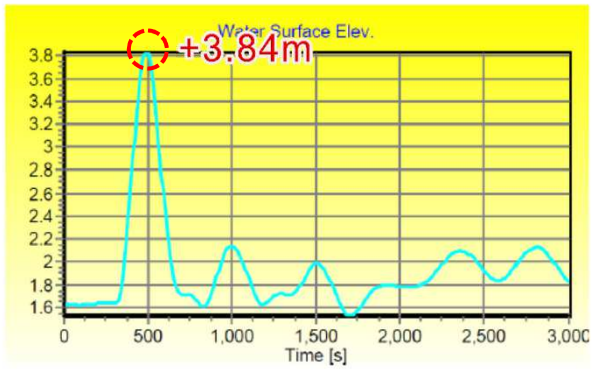


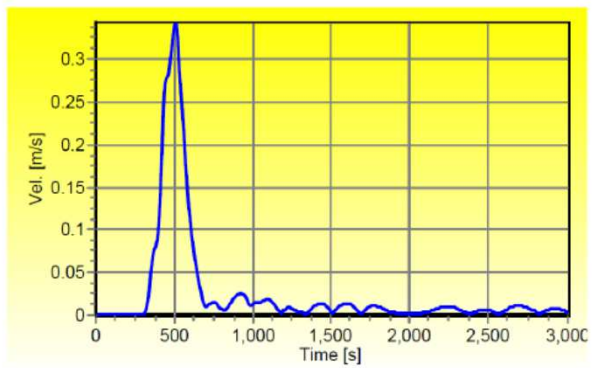
Gate





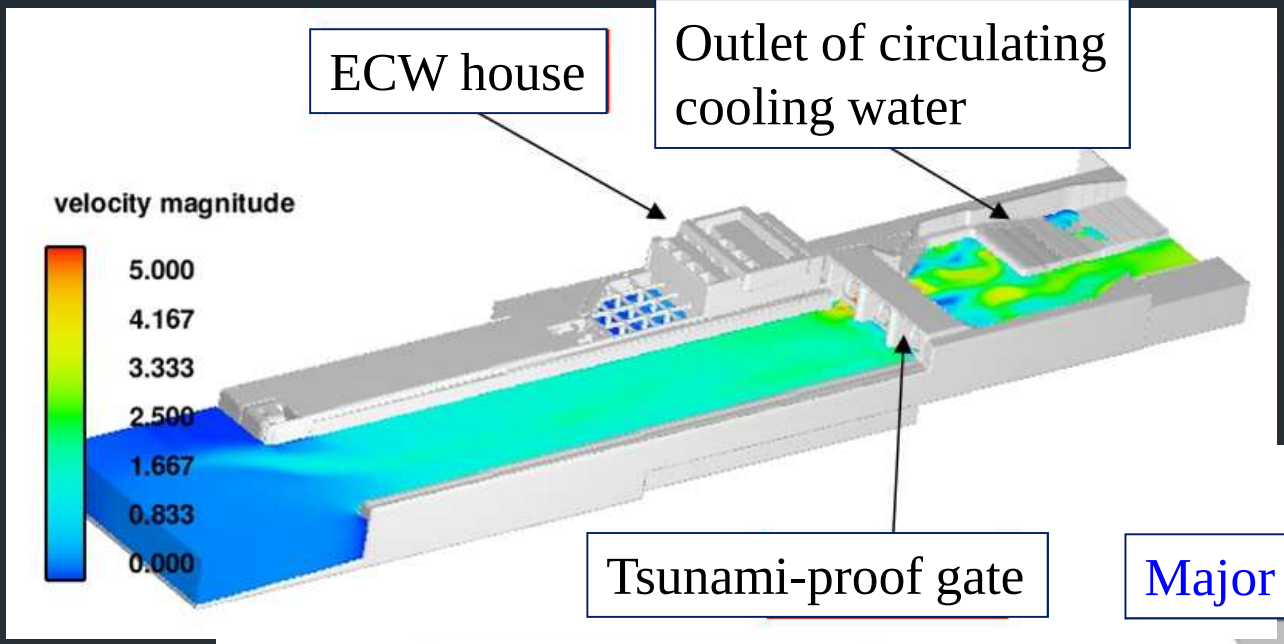
Intake of ECW

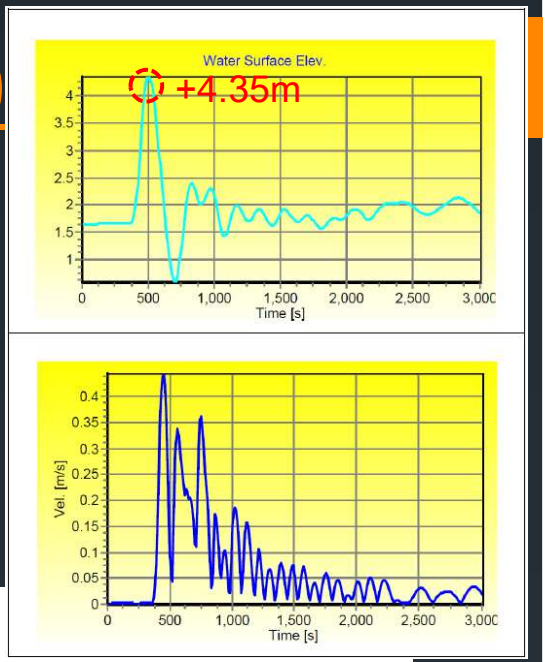


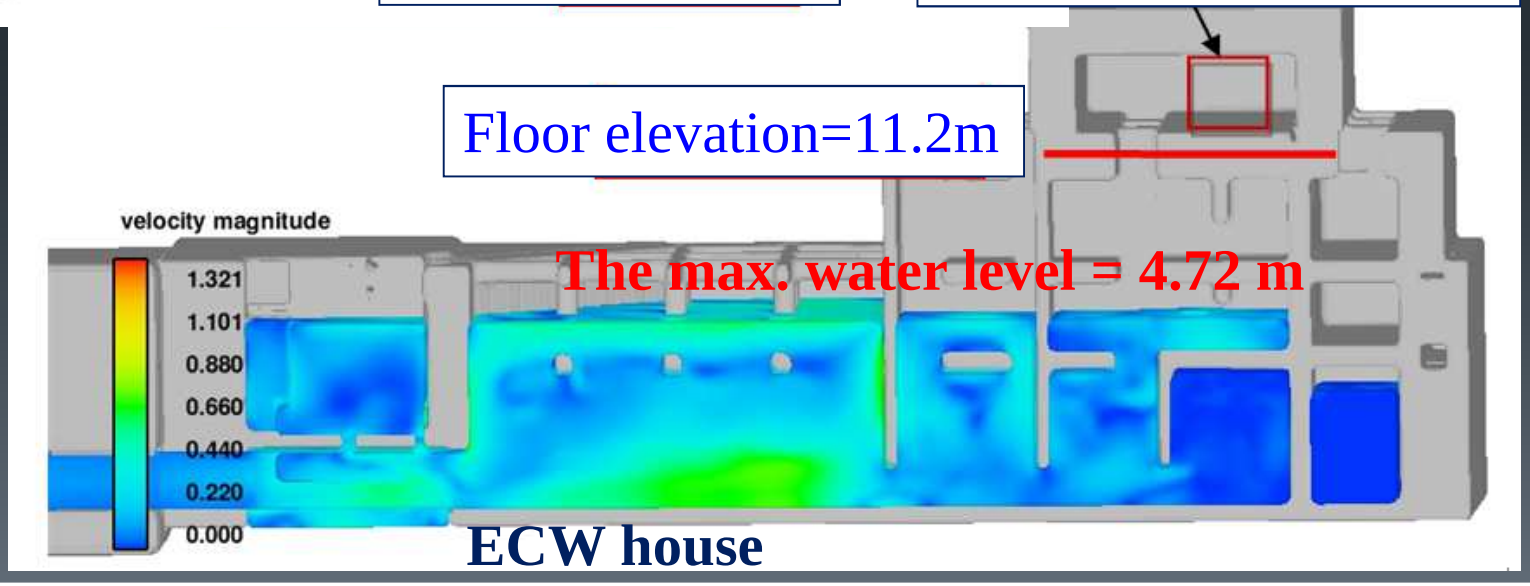


Pump House

ECW 3D simulations(Max. Run-up)

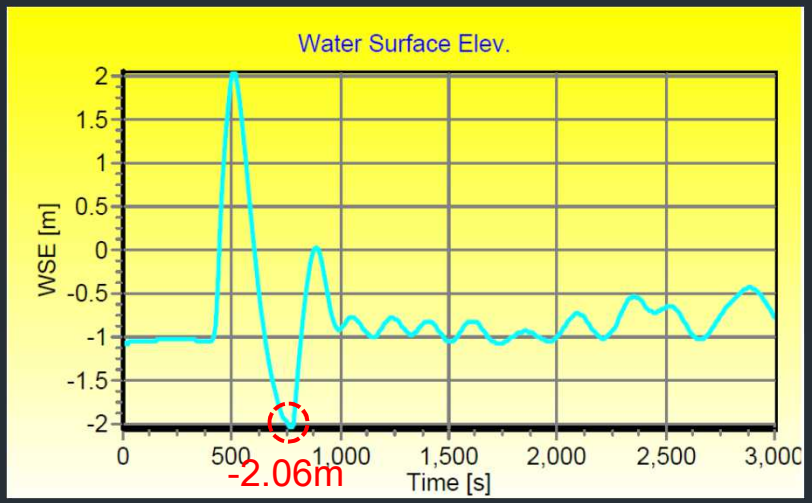


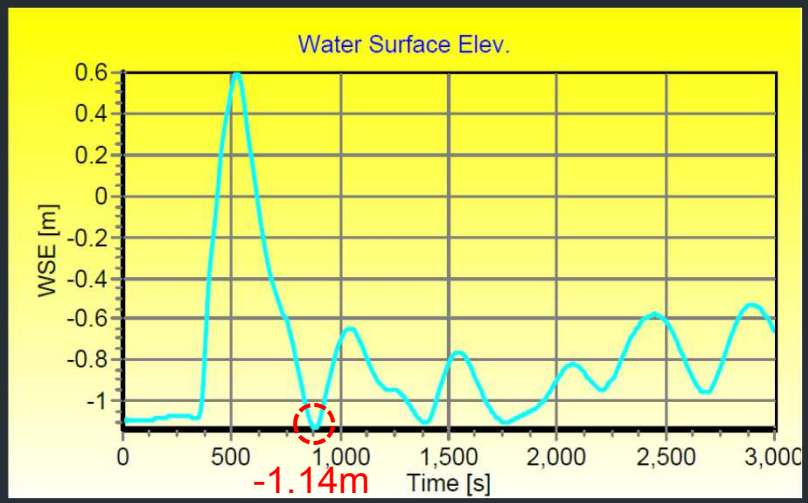


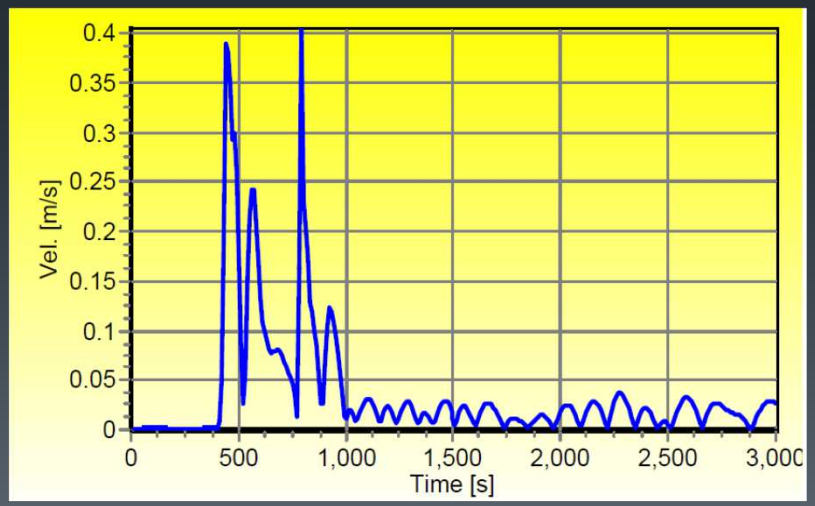


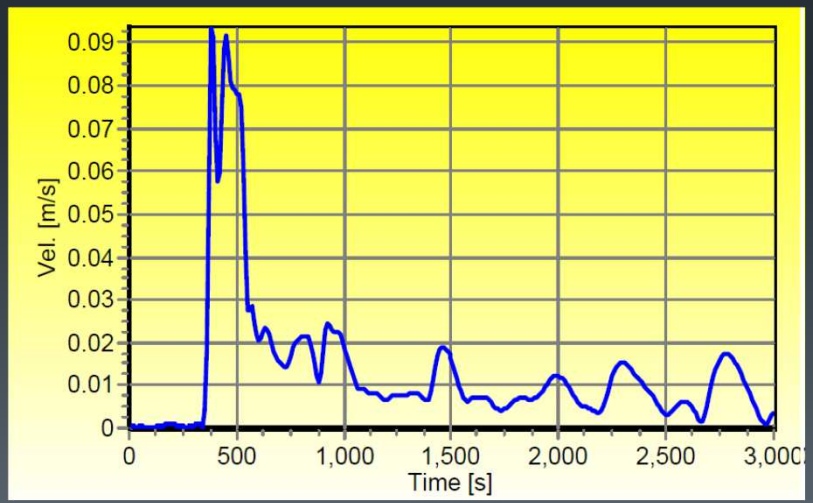
Near-field Tsunami Simulations

- Max. Rundown : T20, L.W.L.(-0.785m)







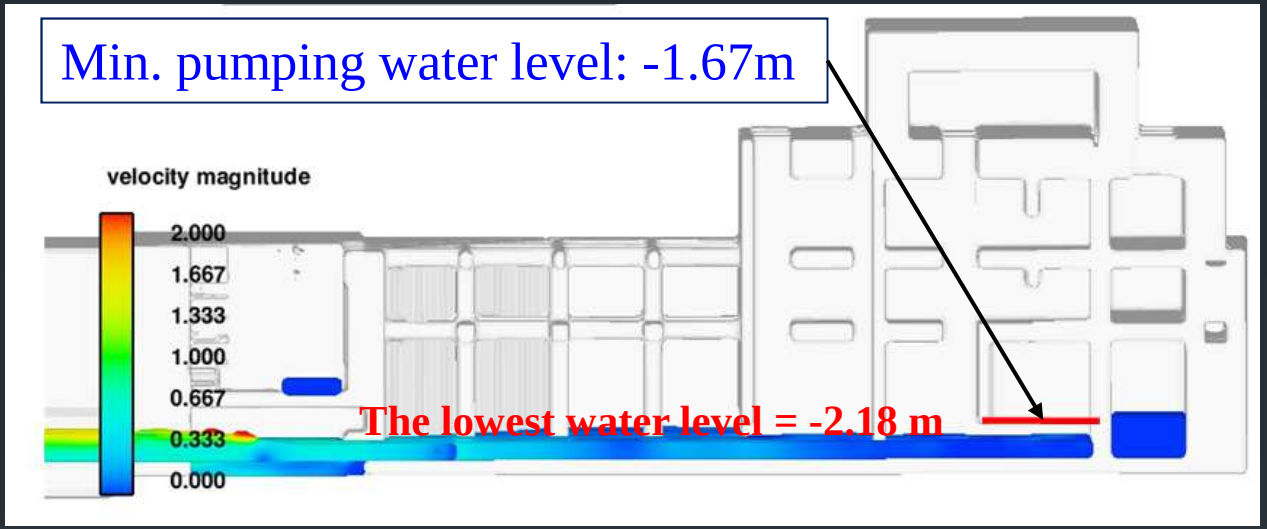


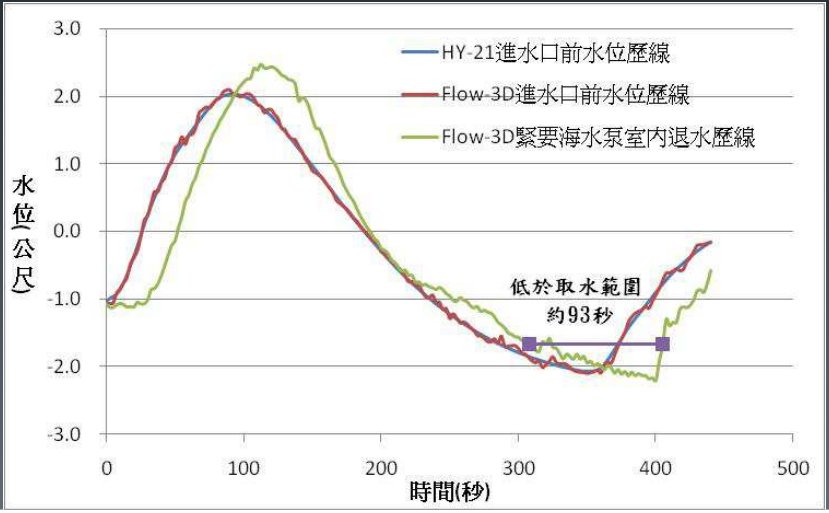
Intake of ECW

Pump House

ECW 3D simulations(Max. Run-down)

- **The lowest water level is -2.18 m during tsunami run-down, which is lower than the min. pumping water level -1.67m.**





- **The pumping capability will be affected by tsunami rundown in 93 seconds.**

Near-field Tsunami Simulations -Kuosheng Nuclear Power Plant

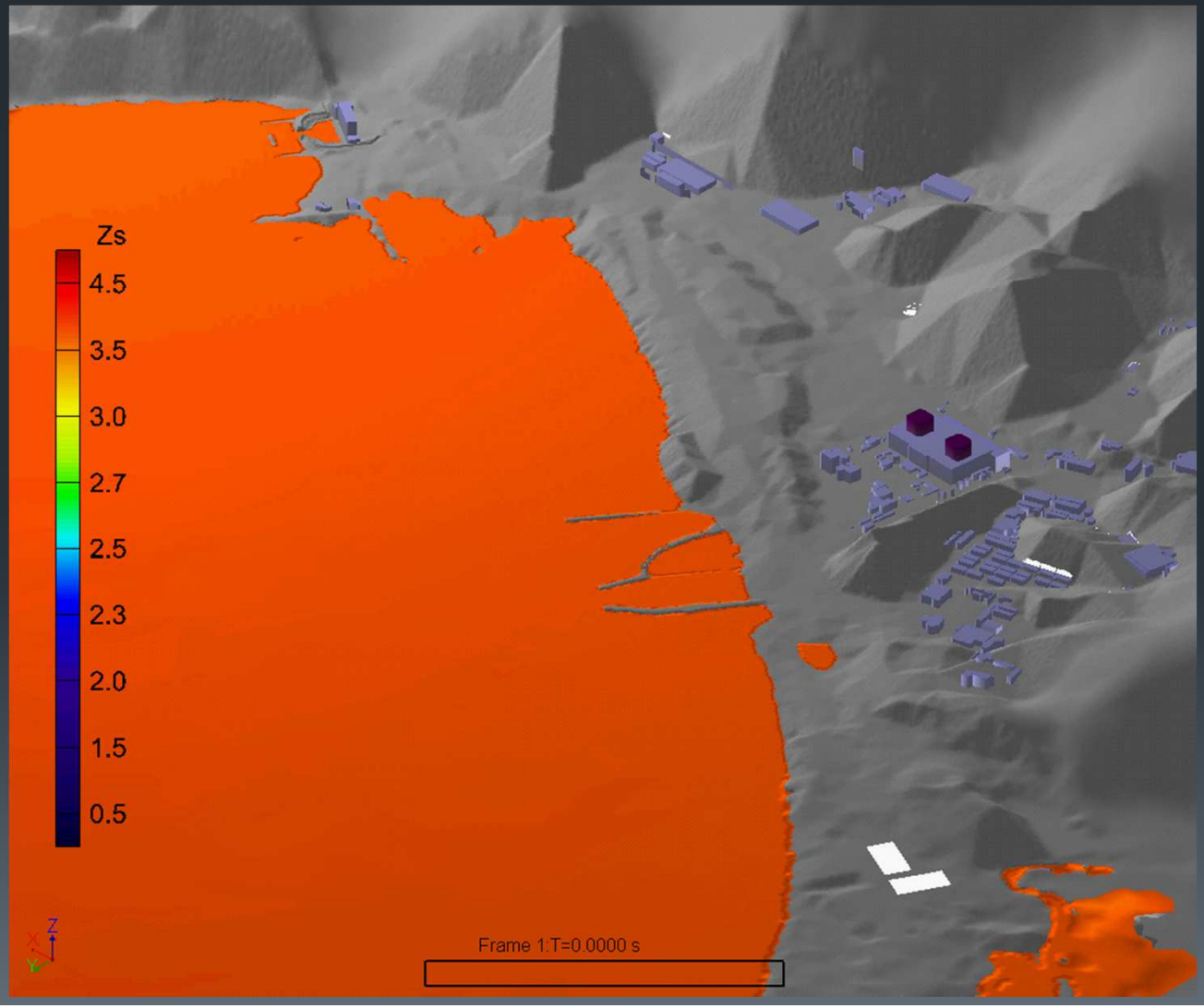
Near-field Tsunami Simulations

- **Numerical Parameters**
  - **Sea water level**
    - High water Level : +2.458m (HWOST + Return period 200 years Storm surge deviation)
    - Low water Level : -0.967m (LWOST)
    - Average water Level : +0.000m
  - **Boundary condition**
    - Non-reflective boundary
  - **Bed roughness**
    - Sea area
      1. Water depth > 20m : n = 0.0
      2. Water depth from 1 to 10m : n = 0.028~0.012
    - Land area :
      n=0.045
  - **Computational time interval**
    - CFL(Courant-Friedrichs-Lewy) = 0.5
  - **Initial tsunami waveform**
    - Okada method (1985)

HWOST : mean High Water level Of Spring Tide
LWOST : mean High Water level Of Spring Tide
n : Manning's n

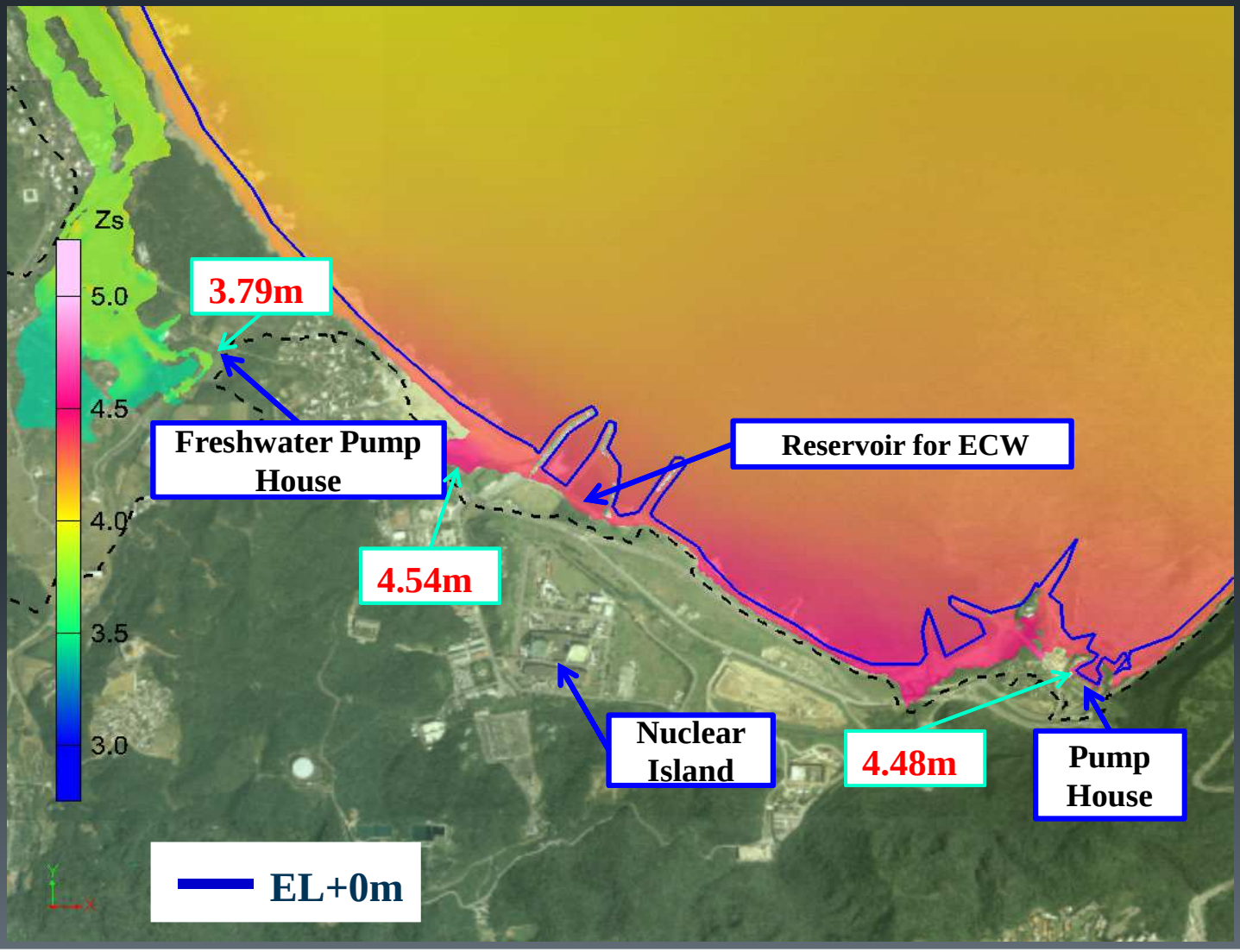
Near-field Tsunami Simulations

- Tsunami propagation : T20, H.W.L.(+2.458m)



Near-field Tsunami Simulations

- Max. Runup : T20, H.W.L.(+2.458m)

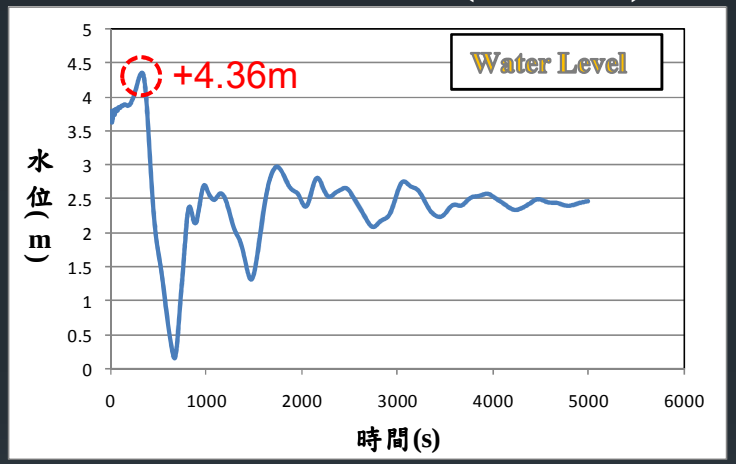


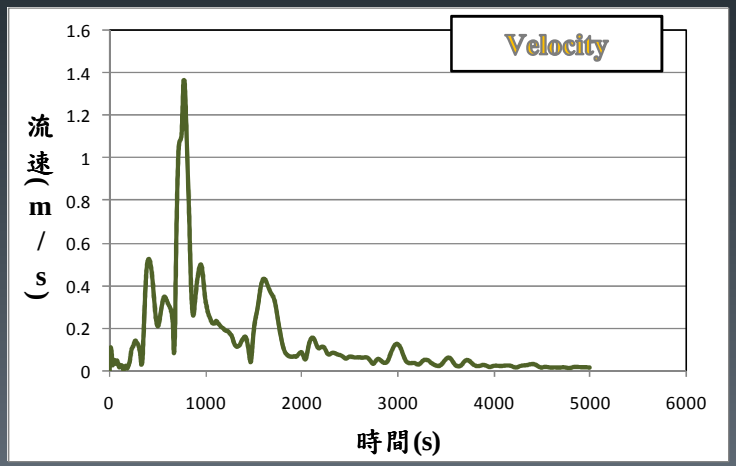
Near-field Tsunami Simulations

- Max. Run-up and Run-down

Max. Run-up

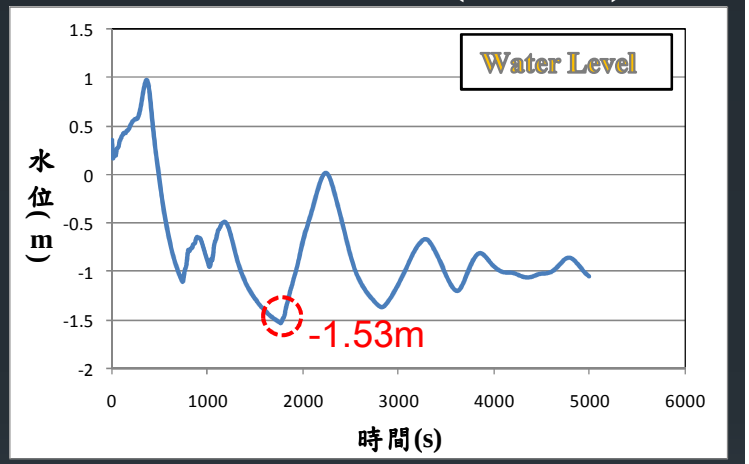
Tsunami：T20; H.W.L (+2.458m)

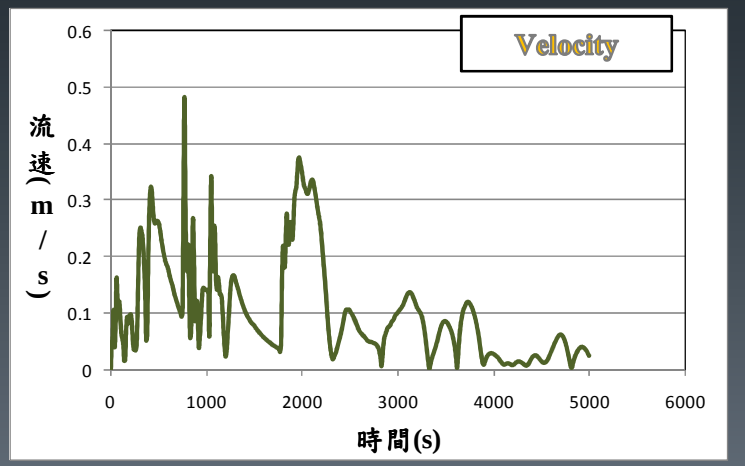




Max. Run-down

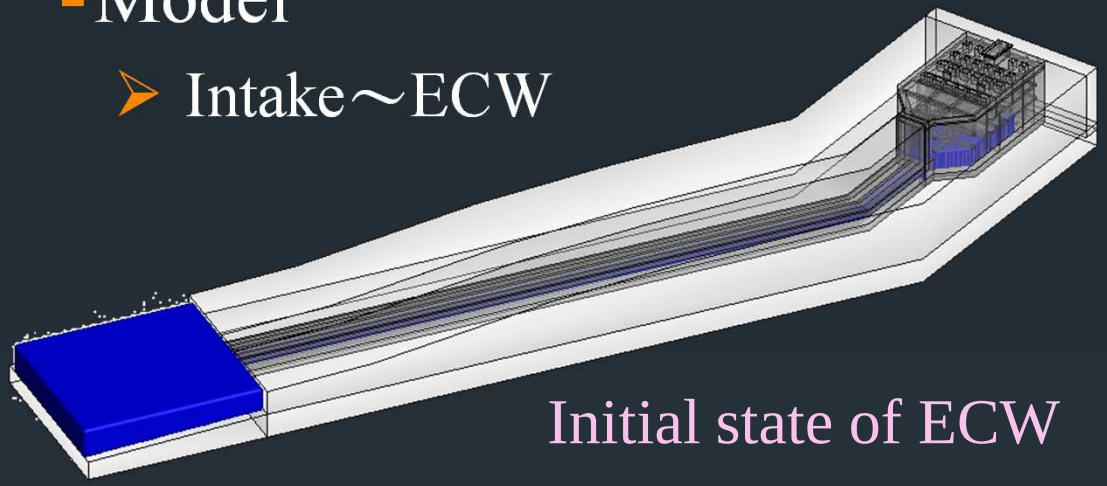
Tsunami：T22; L.W.L (-0.967m)





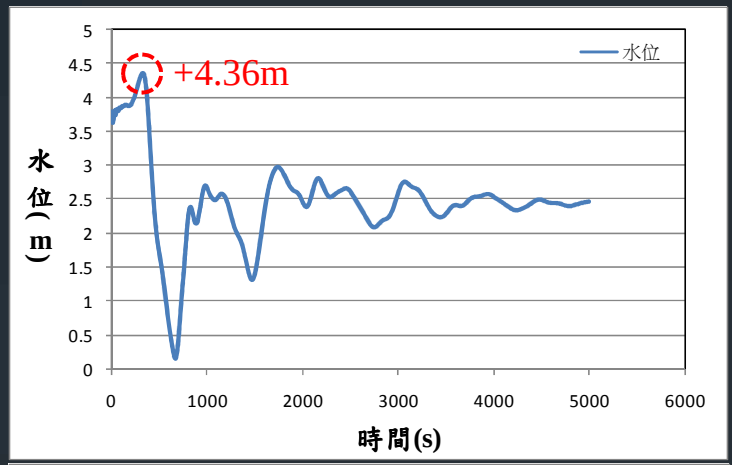
ECW 3D simulations

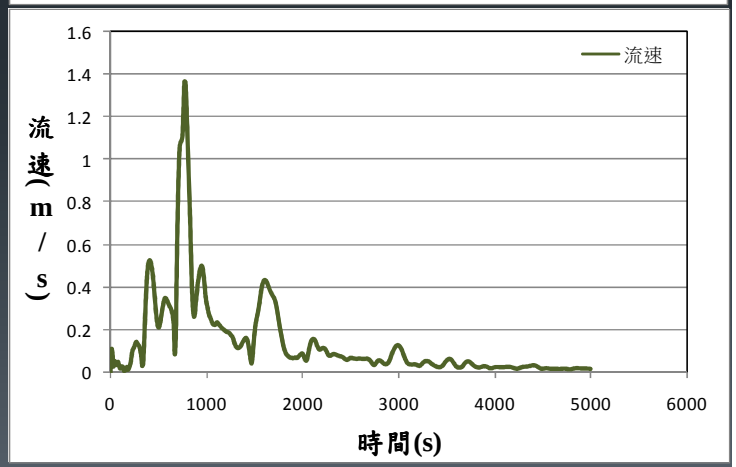
- Model
  - Intake～ECW



Initial state of ECW

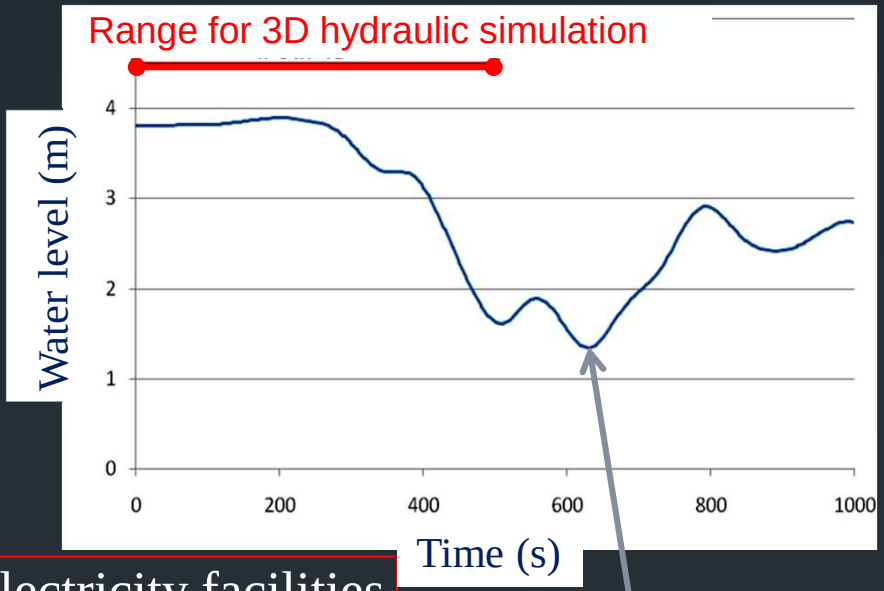
- Tide conditions
  - High-tide-level for the simulation of tsunami run-up.
  - Low-tide-level for the simulation of tsunami run-down.

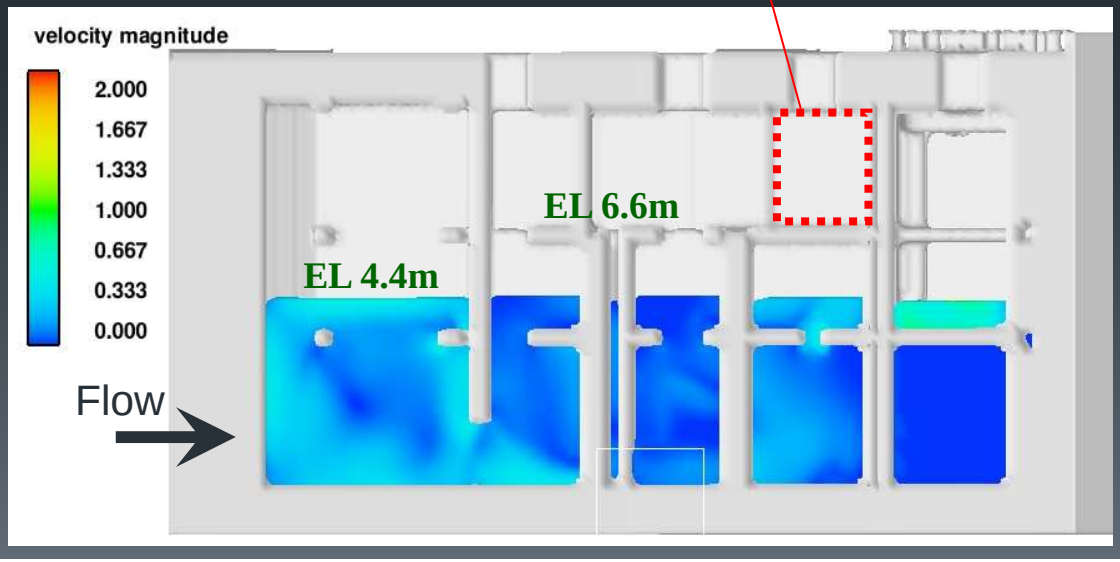




ECW 3D simulations(Max. Run-up)

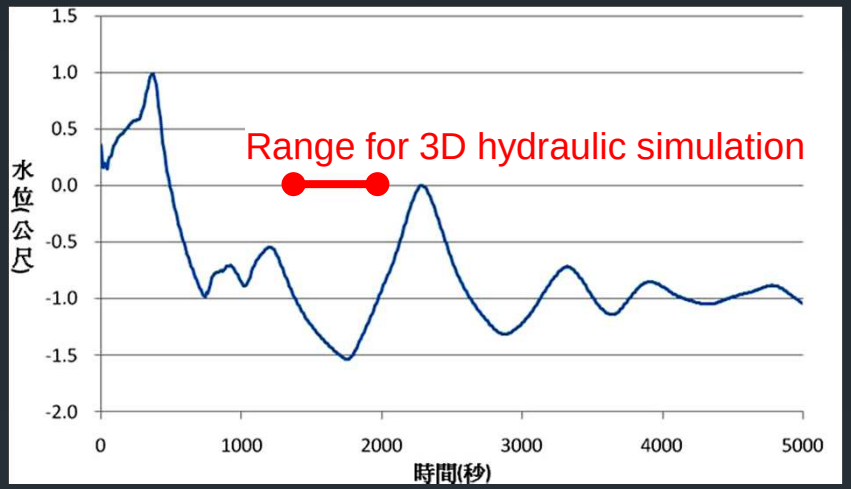
- Max. water level in the ECW house is EL 4.4m which is lower than the floor elevation 6.6m which main electricity facilities was installed.
- The pumping capability of ECW will not be affected by tsunami run-up.



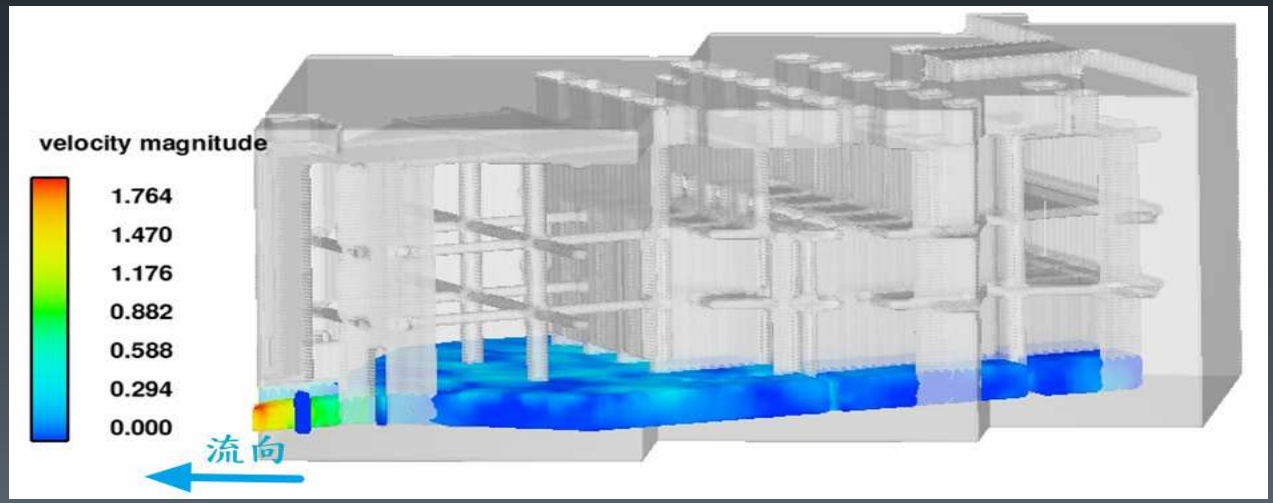


ECW 3D simulations(Max. Run-down)

- **The lowest water level in the ECW is EL -1.68m, which is higher than the min. pumping water level (EL -1.83m).**
- **The pumping capability will not be affected during tsunami run-down.**



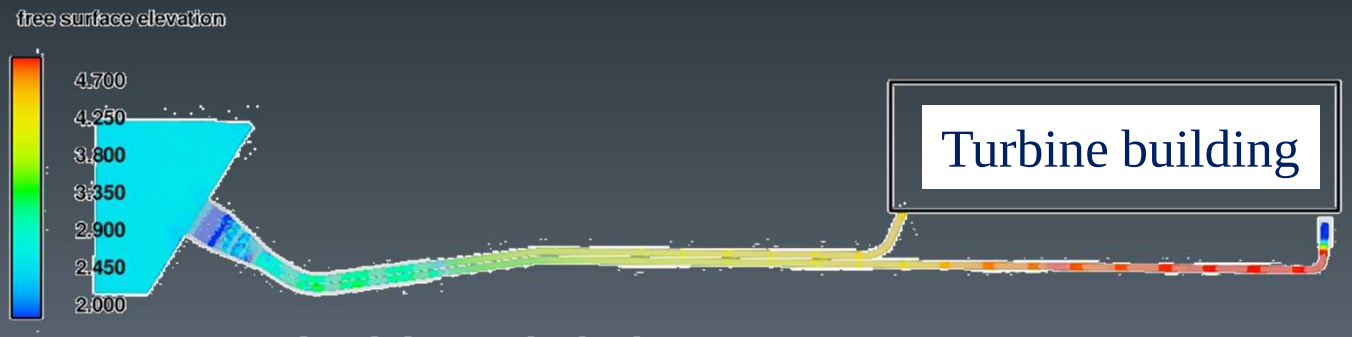
Water level (from: HY-21)



3D simulation model of ECW

3D-hydraulic Analysis for Outlet Conduit of CCW

- Model ：outlet conduit～turbine building (TB)
  - The system is running on min. required cooling water (Q=9500GPM) .
- Result of analysis
  - Max. run-up water elevation : EL 4.71m。
  - Max. water head is EL 4.34m, simulated by 3D hydraulic model, which is lower than the lowest point (EL 8.95m) of TB.
  - The pumping capability of CCW will not be affected by tsunami run-up.



Water level during the highest tsunami run-up

Near-field Tsunami Simulations -Lungmen Nuclear Power Plant

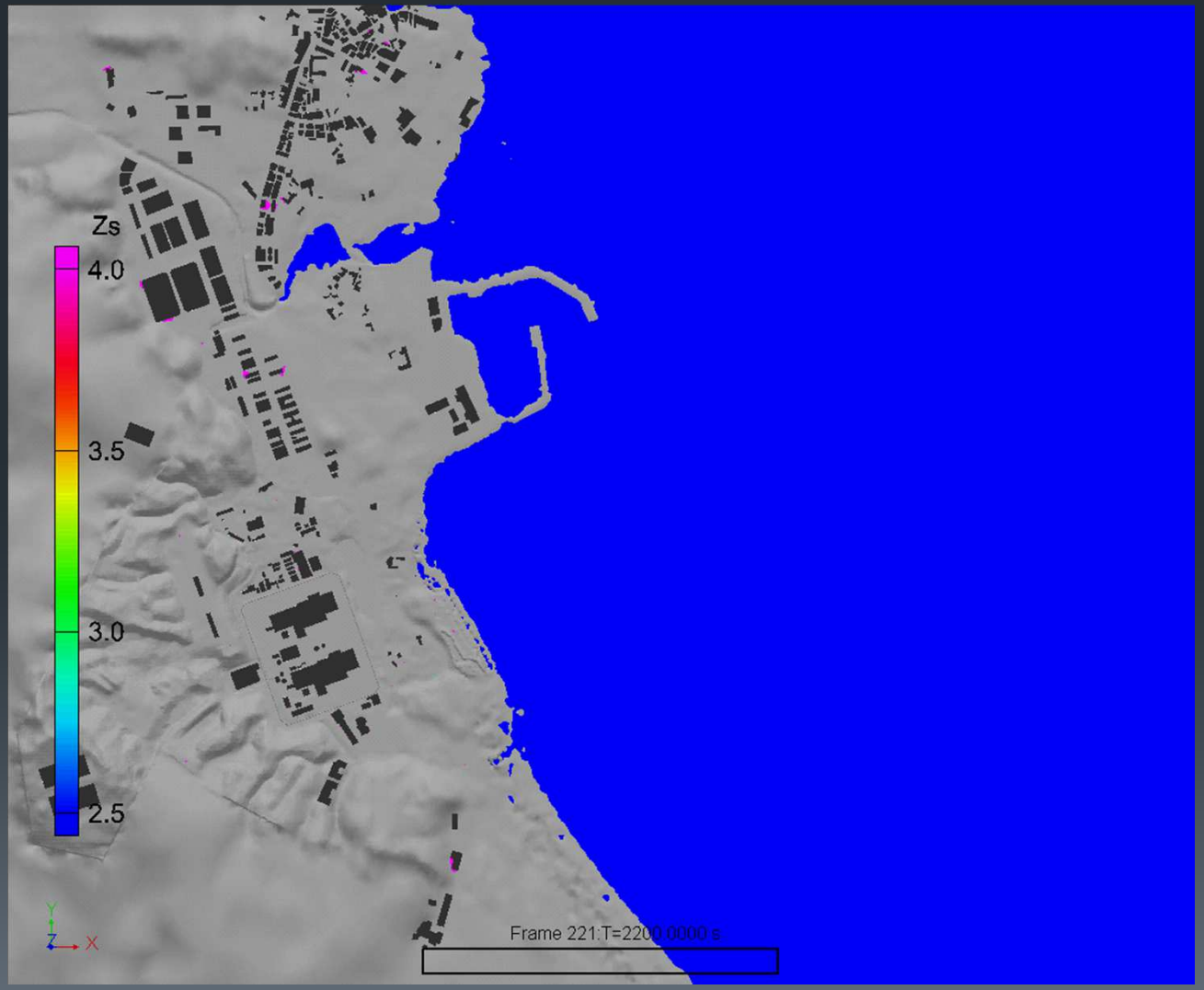
Near-field Tsunami Simulations

- **Numerical Parameters**
  - **Sea water level**
    - High water Level : +2.333m (HWOST + Return period 200 years Storm surge deviation)
    - Low water Level : -0.573m (LWOST)
    - Average water Level : +0.000m
  - **Boundary condition**
    - Non-reflective boundary
  - **Bed roughness**
    - Sea area
      1. Water depth > 20m : n = 0.0
      2. Water depth from 1 to 10m : n = 0.028~0.012
    - Land area :
      n=0.045
  - **Computational time interval**
    - CFL(Courant-Friedrichs-Lewy) = 0.5
  - **Initial tsunami waveform**
    - Okada method (1985)

HWOST : mean High Water level Of Spring Tide
LWOST : mean High Water level Of Spring Tide
n : Manning's n

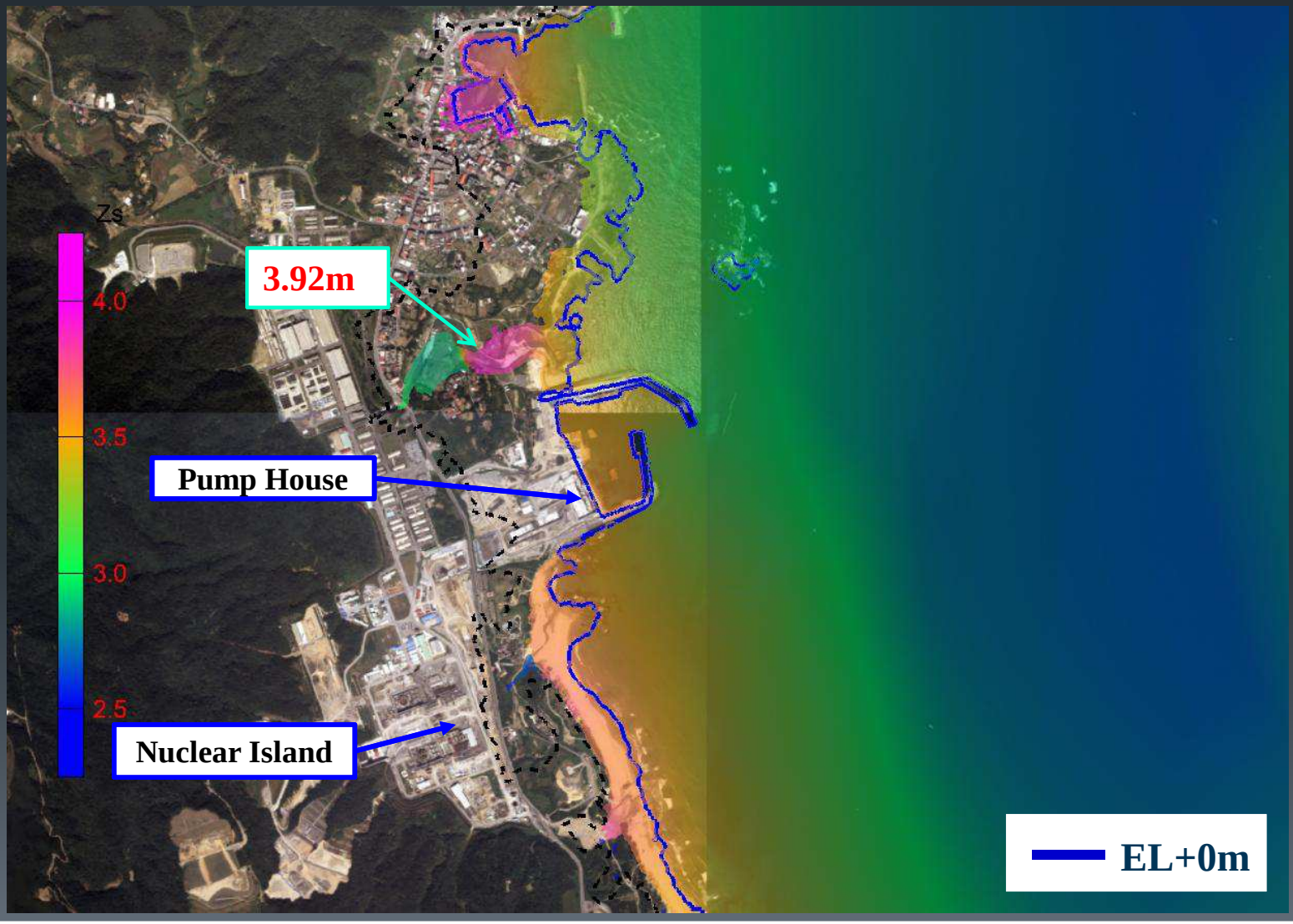
Near-field Tsunami Simulations

- Tsunami propagation : T18, H.W.L.(+2.333m)



Near-field Tsunami Simulations

- Max. Runup : T18, H.W.L.(+2.333m)

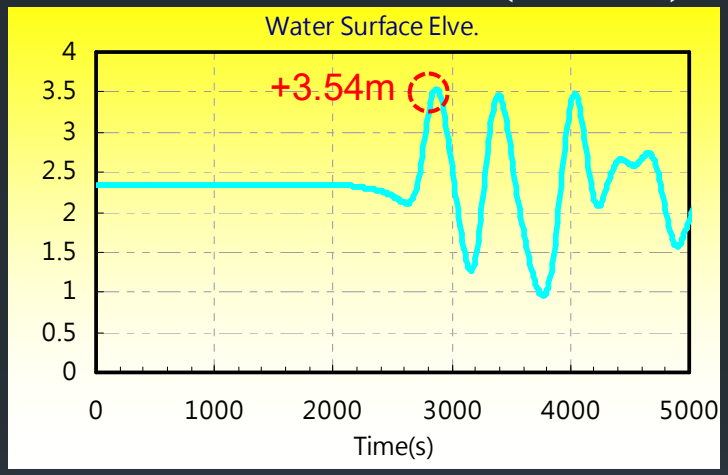


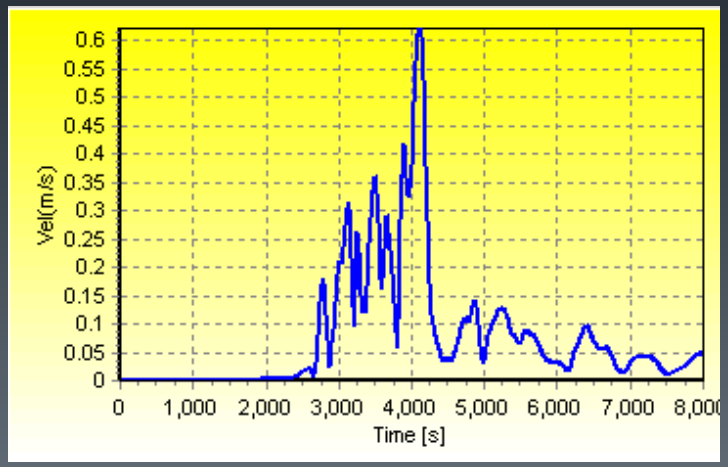
Near-field Tsunami Simulations

- Max. Run-up and Run-down

Max. Run-up

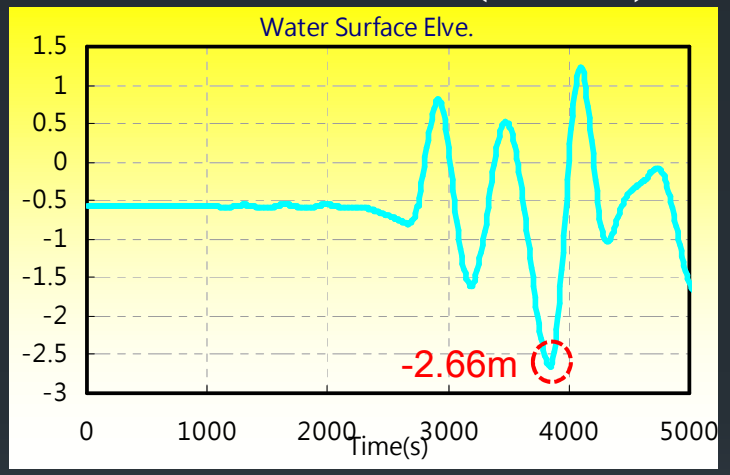
Tsunami：T18; H.W.L (+2.333m)

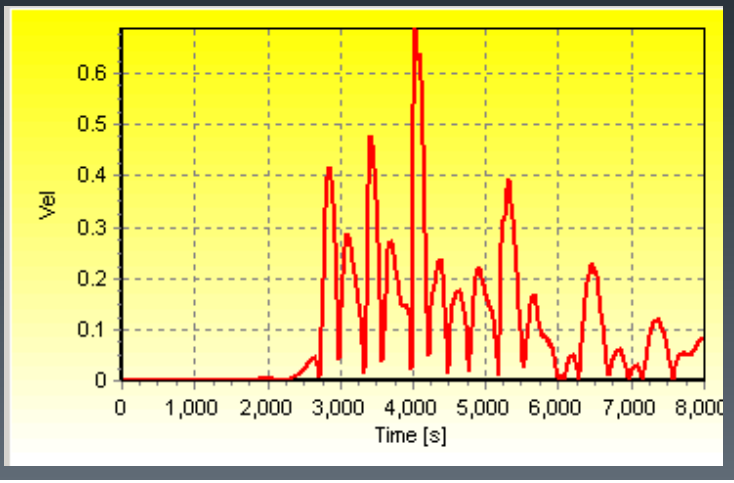




Max. Run-down

Tsunami：T18; L.W.L (-0.573m)





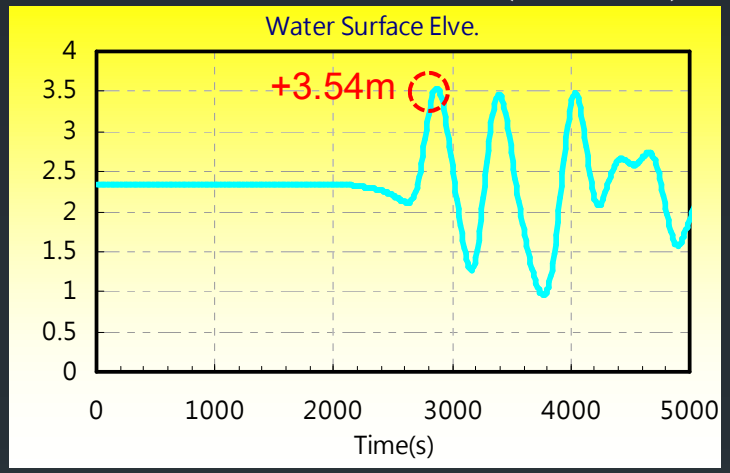
Reactor Building Service Water Pump House (RBSWPH)

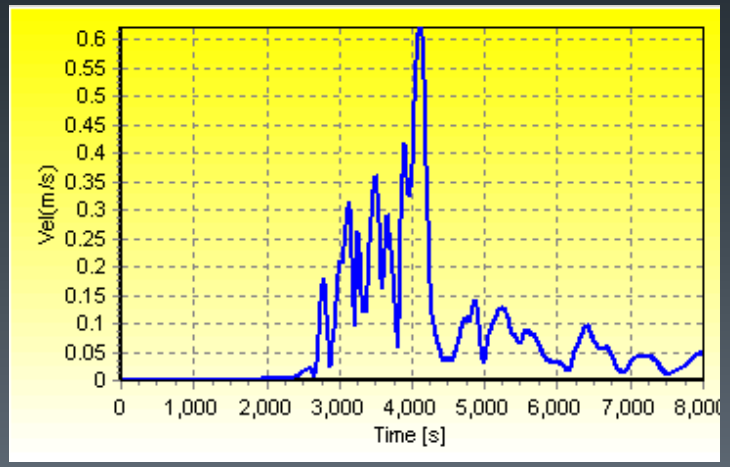
The max. water elevation in the RBSWPH is 3.54 m, which is lower than the ground elevation of 5.0 m and also lower than the floor elevation of 5.3 m with nuclear power safety-related equipment.

The Water Pump House will not be affected by the tsunami run-up.

Max. Run-up

Tsunami：T18; H.W.L (+2.333m)





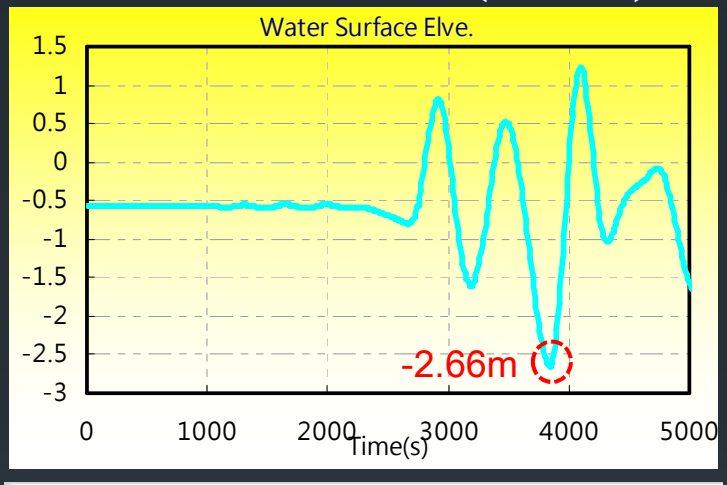
Influences by Tsunami Run-down

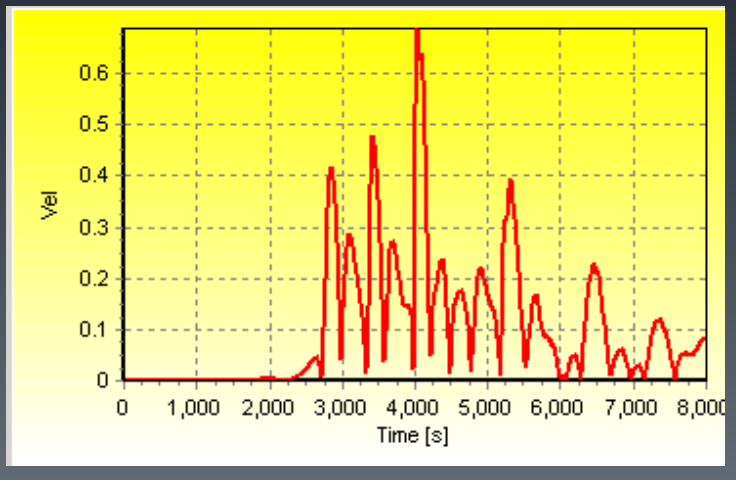
The Water Pump House has a stilling basin with the storage capacity of 14,210 m^3 sea water which will provide two generators for 30 minutes cooling requirement.

The water pump function of RBSWPH will not be affected by the tsunami run-down.

Max. Run-down

Tsunami：T18; L.W.L (-0.573m)





THANKS FOR YOUR ATTENTION