Tsunami Risk Assessment of Nuclear Power Plants in Taiwan

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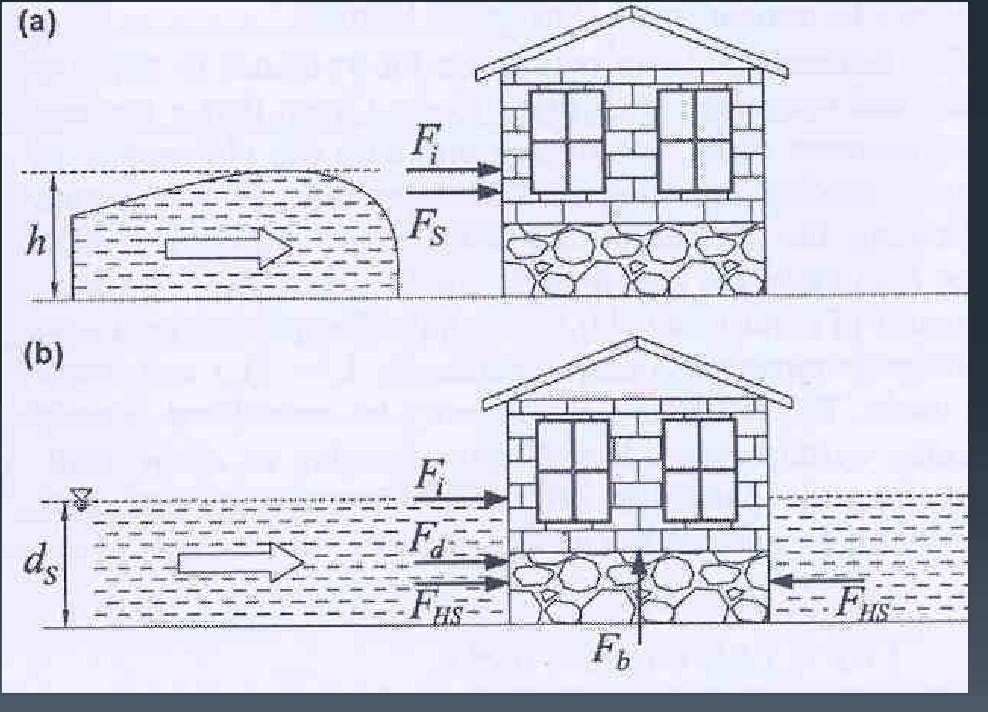
Risk Assessment of Nuclear Power Plants under Tsunami Attack

- **PURPOSE :**
- **To assess the influence of pump/electric facilities in the pump house for emergent cooling water (ECW) during tsunami run-up.**
- **To assess the pumping function for the ECW during tsunami drawdown.**
- **To check the stability/stress of structures under tsunami attack.**

Structural Analysis Method

- The tsunami forces applied to structures were calculated using the information of inundation area, water depth and velocity obtained from the numerical simulation with HY-21.



- **(surge force)**

$$F_s = \frac{1}{2}\rho g h^2 b + \frac{1}{2} C_D \rho u^2 h b$$

(debris impact force)

$$F_i = m \frac{u}{\Delta t}$$

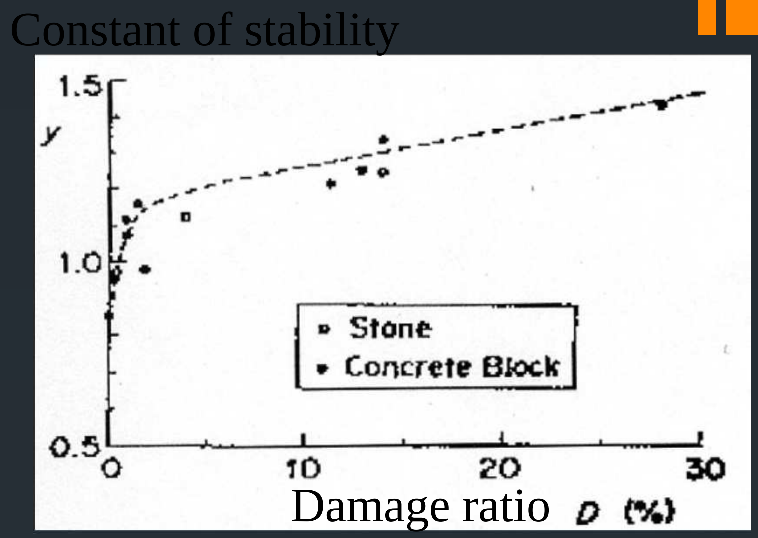
(drag force)

$$F_d = \frac{1}{2}\rho C_D A u^2$$

(**hydrostatic** force)

$$F_{HS} = \frac{1}{2}\rho g \left(h + \frac{u_p^2}{2g}\right)^2$$

- The stability of jetty/dike
- Most of jetties/dikes were constructed from rocks or concrete blocks.
- We checked the stability of rock/concrete block using CERC formula, presented by Hitachi (1994).



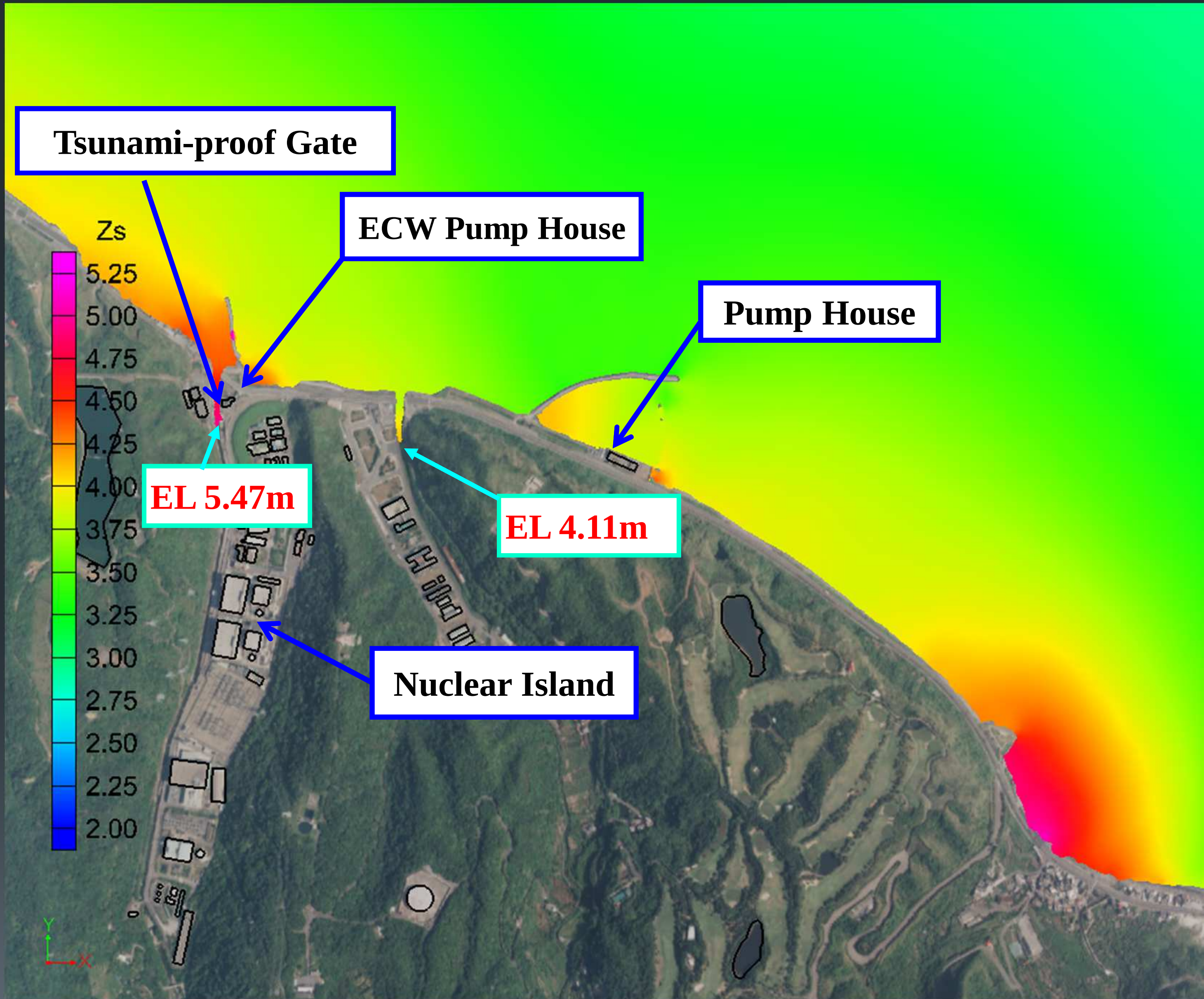
- CERC formula：

$$W = \frac{\pi \rho_s U_d^6}{48 y^6 g^3 (\rho_s / \rho_w - 1)^3 (\cos\alpha - \sin\alpha)^3}$$

- W：Min. weight of block (t)
- Ud：velocity (m/sec)
- ρs：density of block (t/m3)
- ρw：density of sea water (t/m3)
- y：constant of stability
- (when damage ratio=10%，y=1.2)
- g：gravity (9.8 m/sec2)
- α：slop (°)

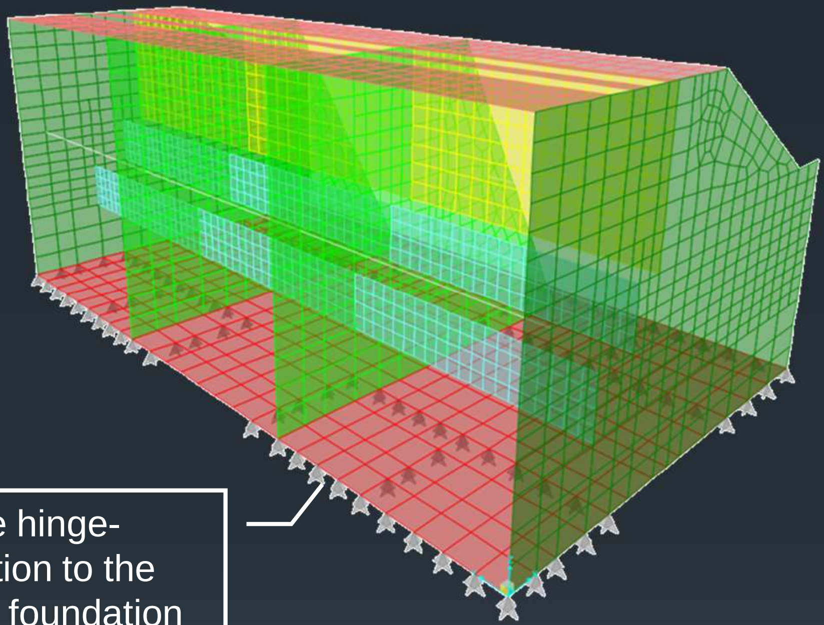
Chin Shan Nuclear Power Plant

Chin Shan NPP



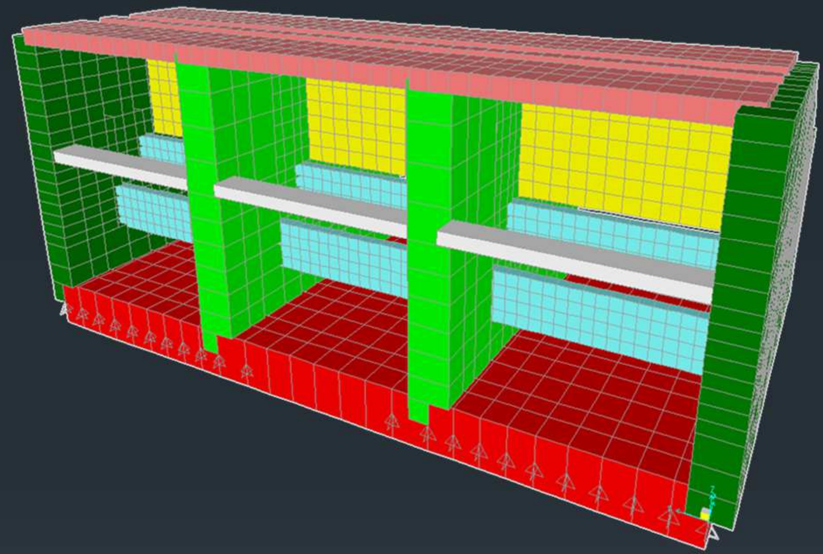
Chin Shan NPP

Structural Analysis for tsunami-proof Gate Structure



Assume hinge-connection to the caisson foundation

Analysis model



Real model

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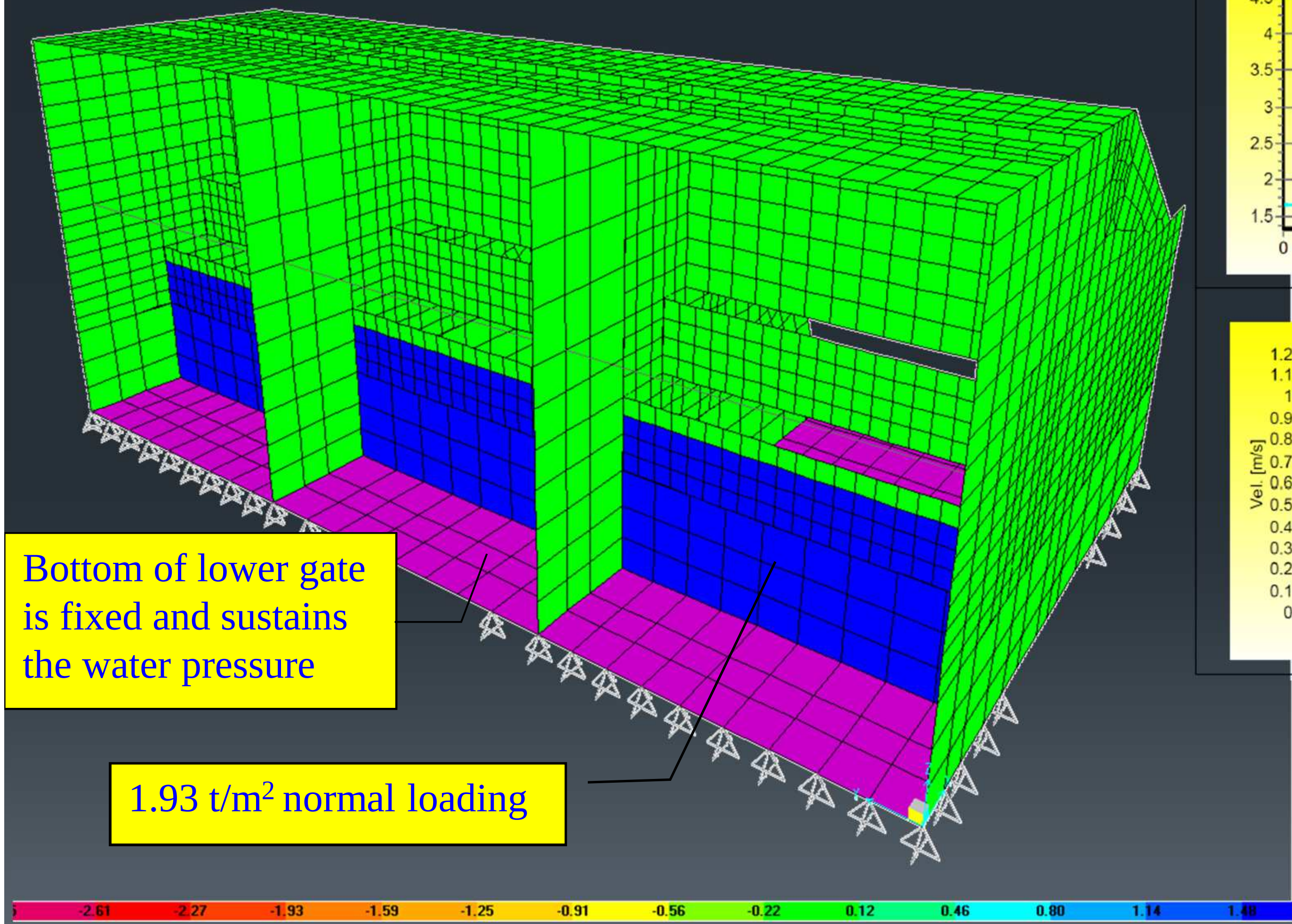
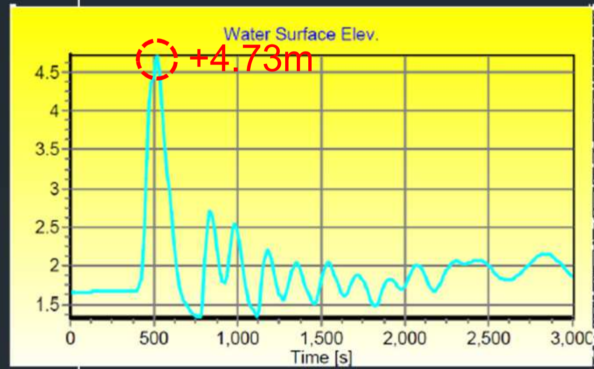
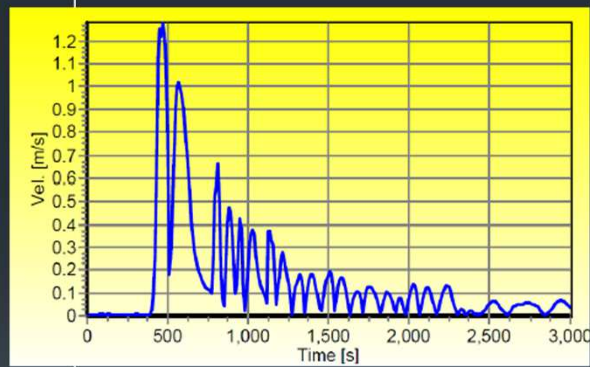
Distribution of tsunami surge forces



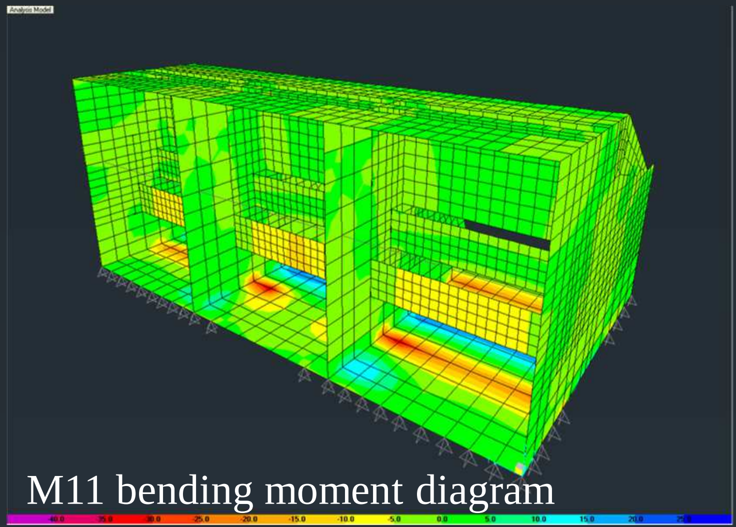
Bottom of lower gate is fixed and sustains the water pressure

1.93 t/m^2 normal loading

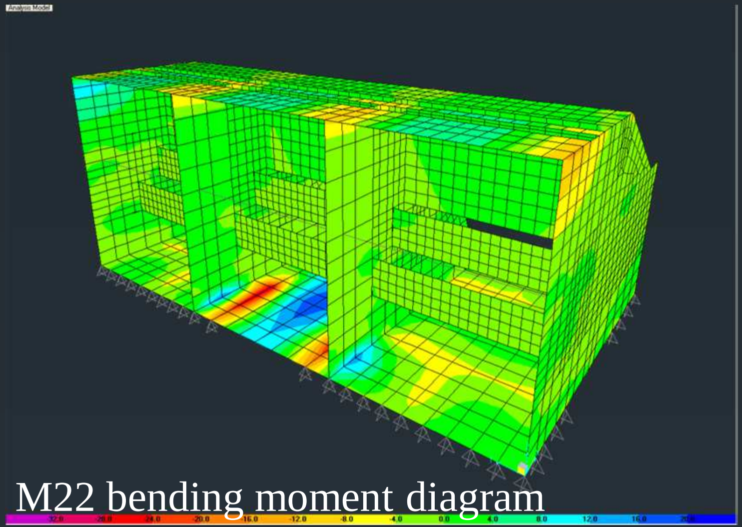




Result of Analysis



M11 bending moment diagram



M22 bending moment diagram

- The max. bending moment is 43.7 t-m in bottom slab. The required reinforcement is about 21 cm^2/m, which is far less than the design reinforcement 33 cm^2/m (#8@15cm).
- The computed stresses in the piers are smaller than the allowable stress. The stability of the piers is also satisfied.

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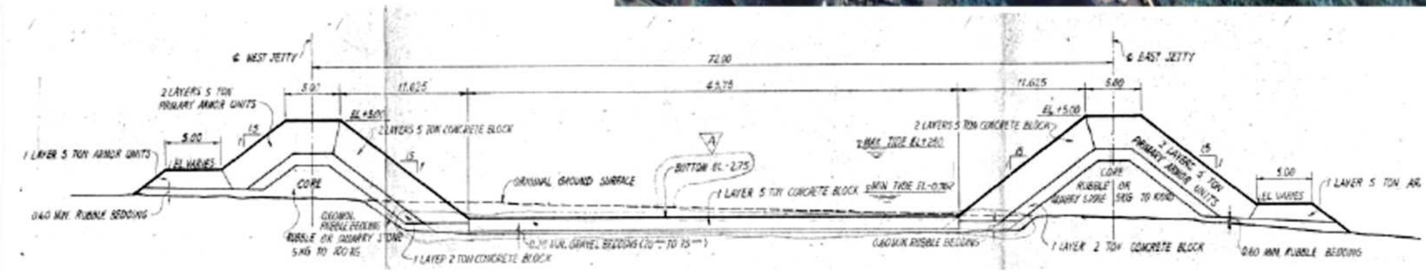
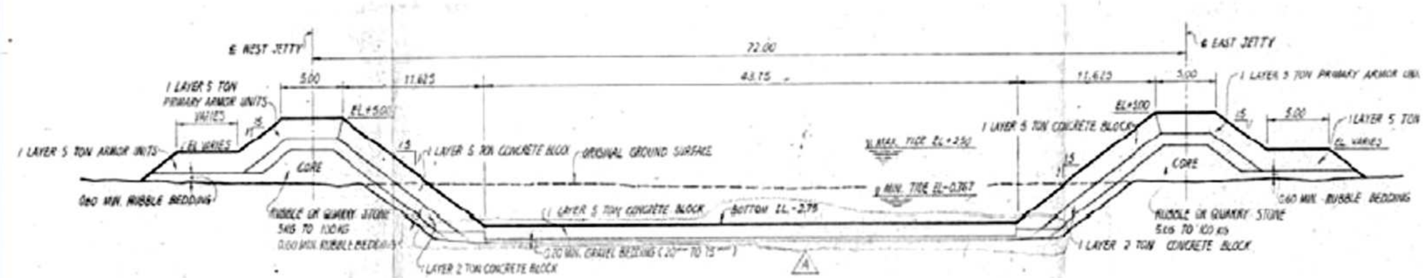
Stability analysis of Jetty/Dike

Cross section of jetty nearby CCW outlet conduit



Deep water section



Shallow water section

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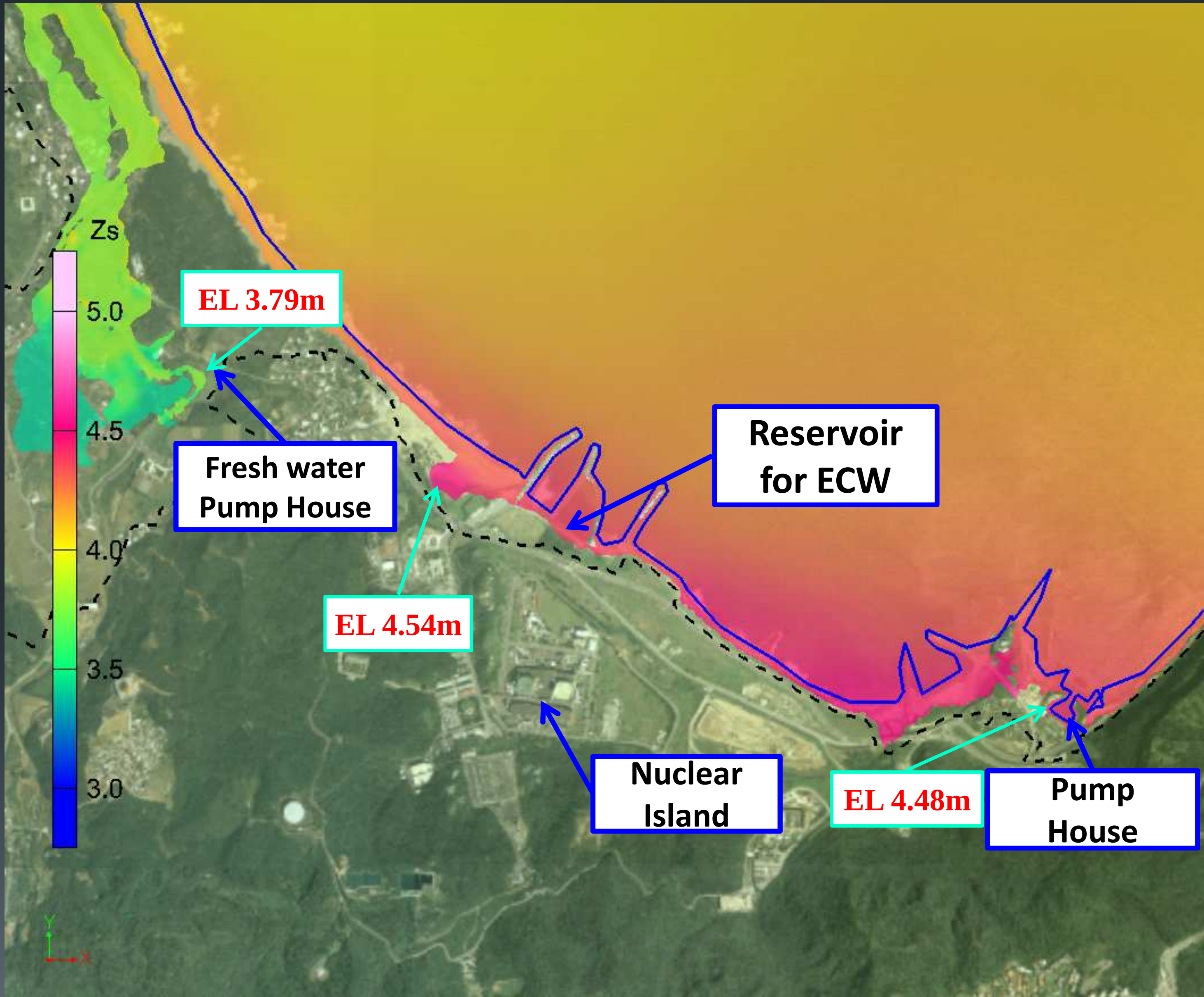
Result of Analysis

Nuclear Power Plant No.1	Water Depth (m)	Elevation of Dike Crest (m)	Slope (surface block weight)		Water Depth (m)		Check
			Interior Slope	Exterior Slope	Allowable	Simulation	
East Dike for Intake	Shallow Section	EL.+5.0	1/1.5(5t)	1/2(5t)	6.94	3.9	o.k.
	Deep Section	EL.+5.0	1/1.5(10t)	1/2(10t)	7.45	3.5	o.k.
West Dike for Intake	Shallow Section	EL.+5.0	1/1.5(5t)	1/2(5t)	6.94	3.5	o.k.
	Deep Section	EL.+5.0	1/1.5(10t)	1/2(10t)	7.45	3.3	o.k.
East Dike for Outlet	Shallow Section	EL.+5.0	1/1.5(5t)	1/2(5t)	6.94	4.5	o.k.
	Deep Section	EL.+5.0	1/1.5(10t)	1/2(10t)	7.45	3.9	o.k.
West Dike for Outlet	Shallow Section	EL.+5.0	1/1.5(5t)	1/2(5t)	6.94	4.3	o.k.
	Deep Section	EL.+5.0	1/1.5(10t)	1/2(10t)	7.45	4.2	o.k.

Kuosheng Nuclear Power Plant

Kuosheng NPP

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



Stability Analysis of Dikes

The analysis was performed by using CERC formula to check the stability of concrete blocks under tsunami attack.

Kuosheng NPP

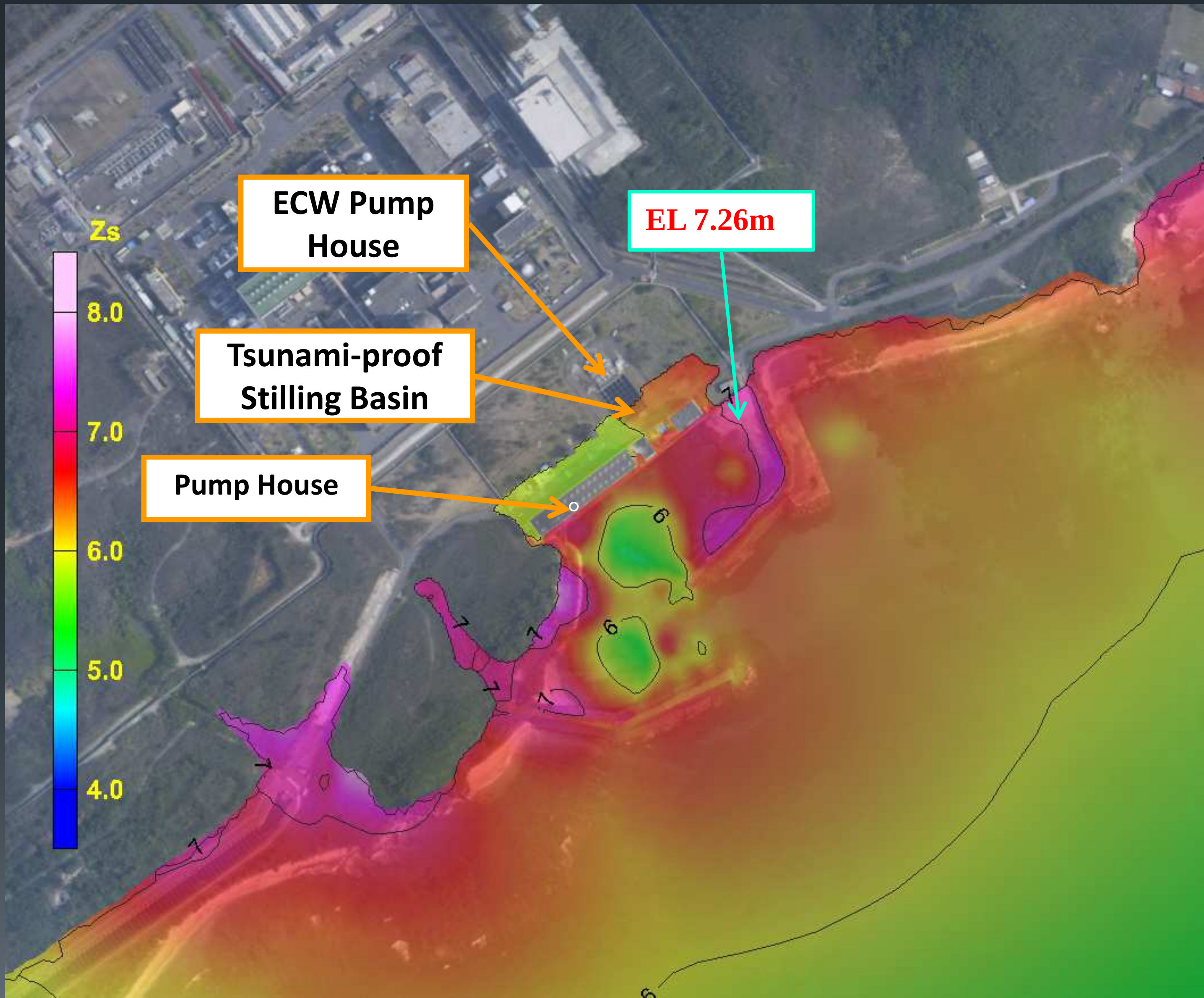
Result of Analysis

Nuclear Power Plant No.1	Water Depth (m)	Elevation of Dike Crest (m)	Slope (surface block weight)		Water Depth (m)		Check
			Interior Slope	Exterior Slope	Allowable	Simulation	
East Dike for Intake	Shallow Section	EL.+4.5	1/1.3 (5t)	1/1.5 (5t)	4.78	4.4	o.k.
	Deep Section	EL.+3.5	1/1.3 (5t)	1/1.5 (5t)	4.78	4.4	o.k.
West Dike for Intake	Shallow Section	EL.+5.0	1/1.5 (10t)	1/2 (10t)	7.45	4.3	o.k.
	Deep Section	EL.+5.0	1/1.5 (15t)	1/2 (15t)	7.81	4.2	o.k.
East Dike for Outlet	Shallow Section	EL.+5.0	1/1.5 (10t)	1/2 (10t)	7.45	4.3	o.k.
	Deep Section	EL.+5.0	1/1.5 (10t)	1/2 (10t)	7.45	4.3	o.k.
West Dike for Outlet	Shallow Section	EL.3.5~5.0	1/1.5 (5t)	1/2 (5t)	5.44~6.94	4.3	o.k.
	Deep Section	EL.+5.0	1/1.5 (10t)	1/2 (10t)	7.45	4.2	o.k.

Maanshan Nuclear Power Plant

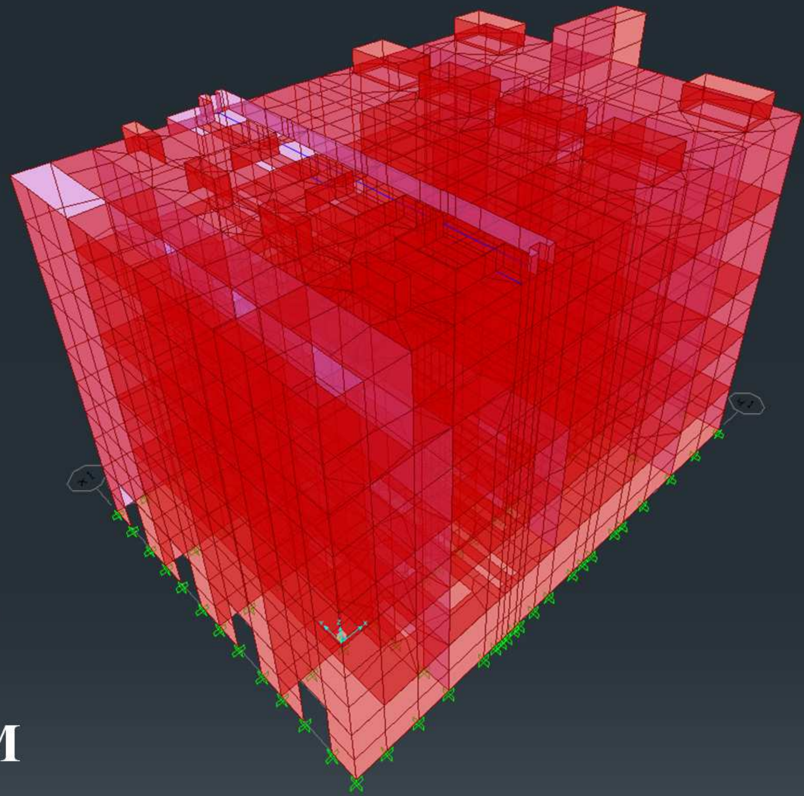
Maanshan NPP

Max. Runup: H.W.L (+1.801m)



Structural Analysis of ECW House

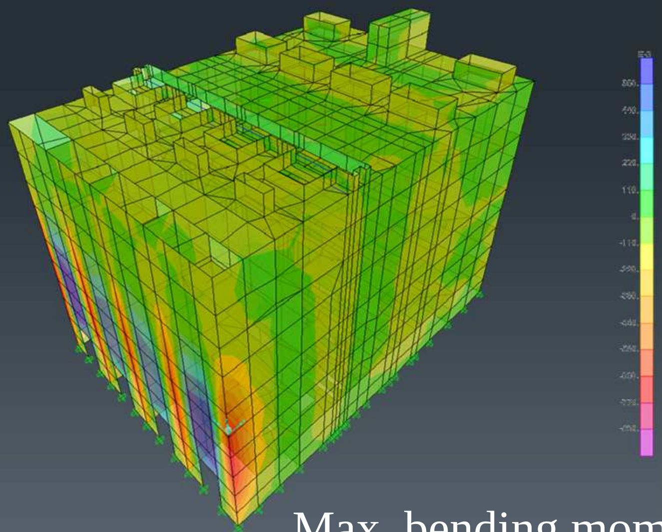
- ECW is a RC structure. (length=35.10m. Width=24.70m. height=25.20m).
- Interior max. surge pressure of ECW house is 0.37 t/m^2 with water level 4.65m and velocity 0.48m/sec.
- Use SAP 2000 program built a FEM model to analyze structural safety.



Maanshan NPP

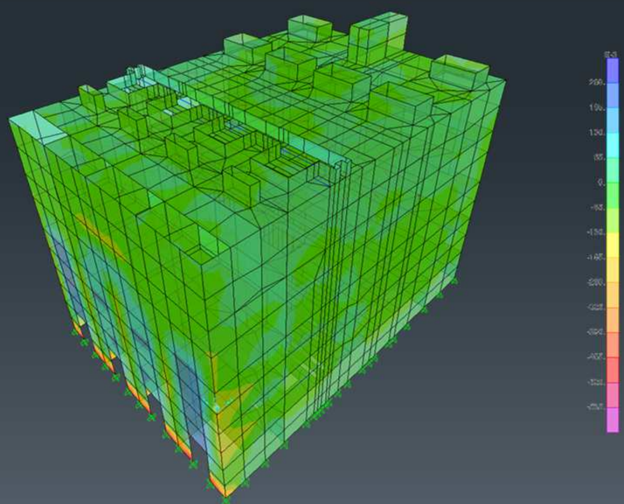
Result of Analysis

- The thickness of interior wall in ECW house is 0.91m. And min. design reinforcement is double layers #8@25.4cm, allowable bending moment is 27.38 t-m。
- The thickness of outer wall in ECW house is 1.22m. And min design reinforcement is double layers #10@25.4cm, allowable bending moment is 58.49 t-m。
- The ratio of bending moment caused by tsunami and design moment is 0 .96/27.38*100% = 3.5%. Not significant.
- The ECW house will be survived under the tsunami attack.



Max. bending moment =0.96 t-m

Max bending moment (horizontal)

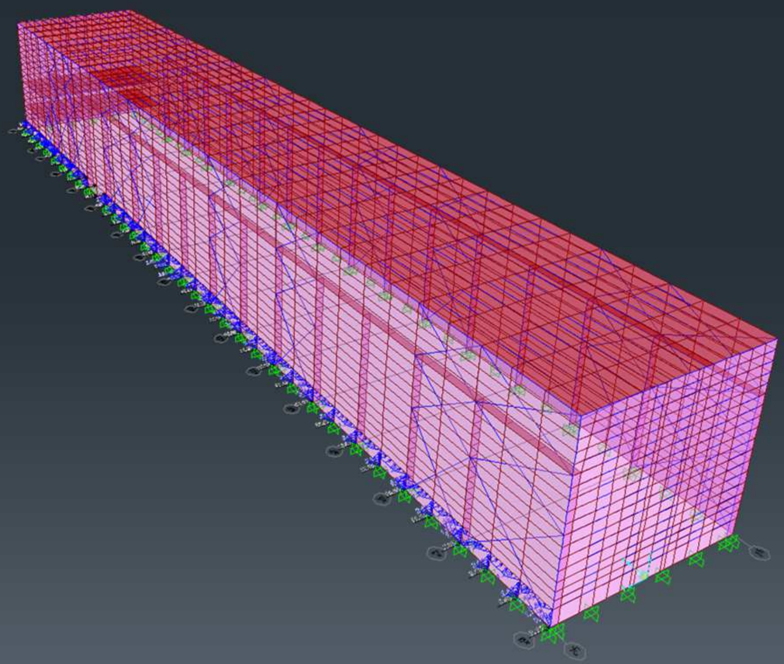


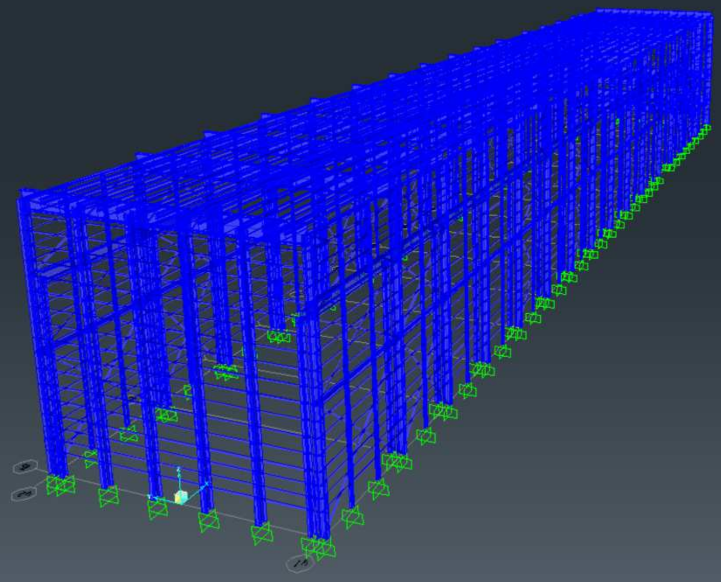
Max. bending moment =0.62 t-m

Max bending moment (vertical)

Structural Analysis of CCW building

- The simulated tsunami wave level outside of the CCW building is in EL. 6.33 m and with velocity 3.19 m/s. The max surge force is 2.04 t/m2 applied to the lower portion, 1.83 m, of the building.
- Built a SAP 2000 FEM model to analyze structural safety.
- Assume windows and covered steel plate are not affected by tsunami.

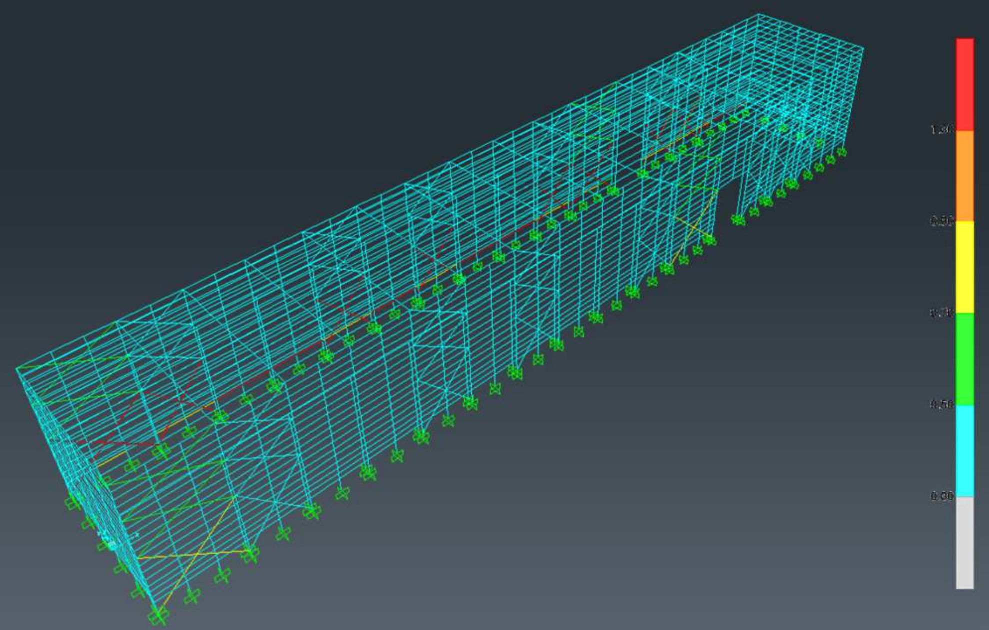




Maanshan NPP

Result of Analysis

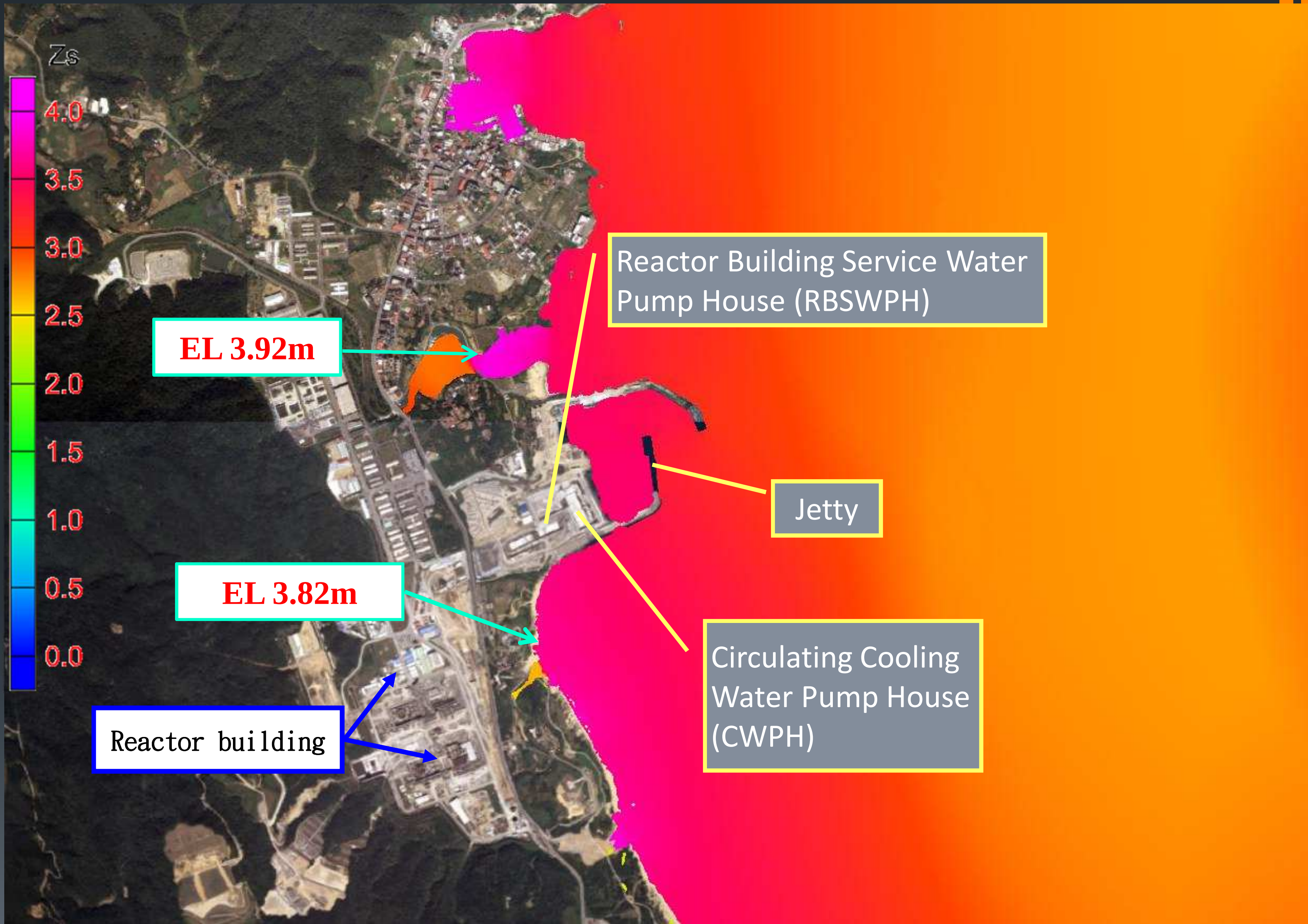
- The stresses of beams and columns of the CCW building are lower than the allowable stresses, but the braces will be yielded under tsunami attack.
- The equipment will be inundated and the structure may be damaged during tsunami attack.
- CCW system is not a part of the nuclear cooling system, the failure will not induce a nuclear accident.



Lungmen Nuclear Power Plant

Lungmen NPP

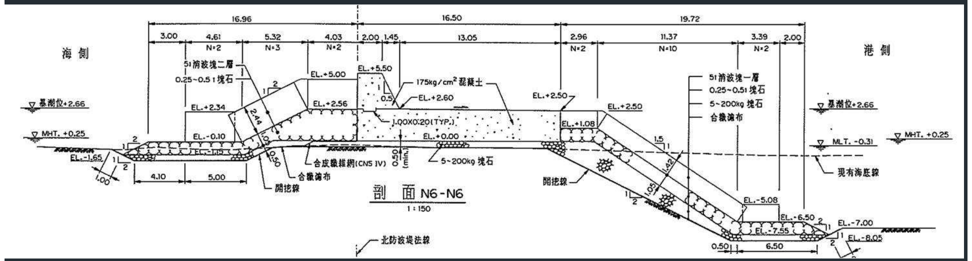
Max. Runup: H.W.L (+2.333m)



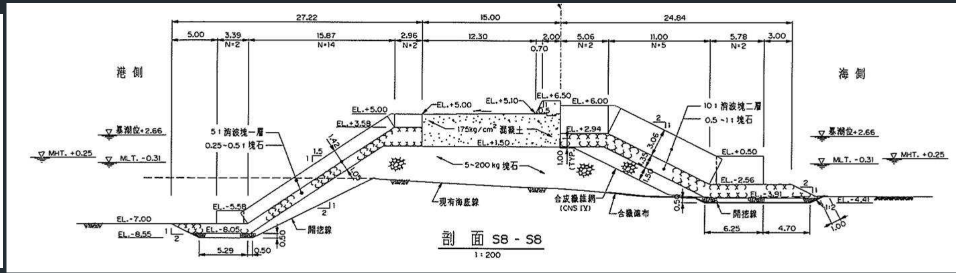
Lungmen NPP

Stability Analysis of Jetties

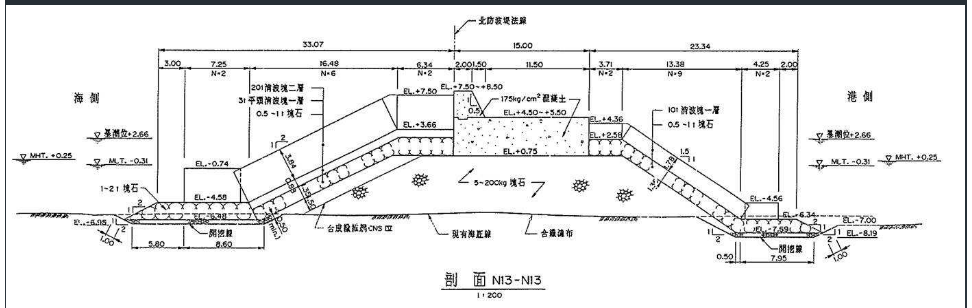
North jetty in shallow water section



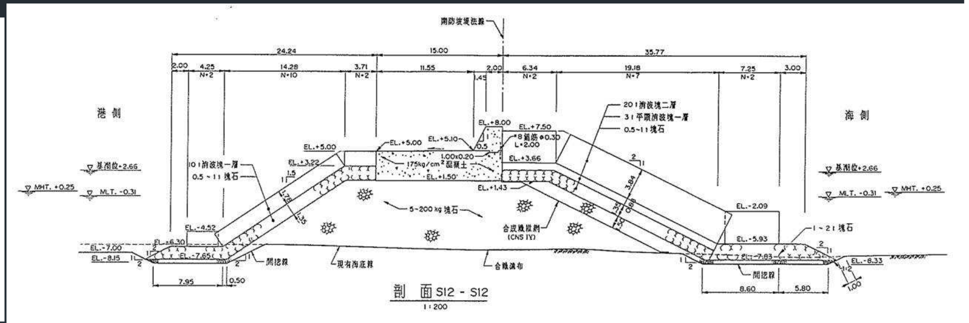
South jetty in shallow water section



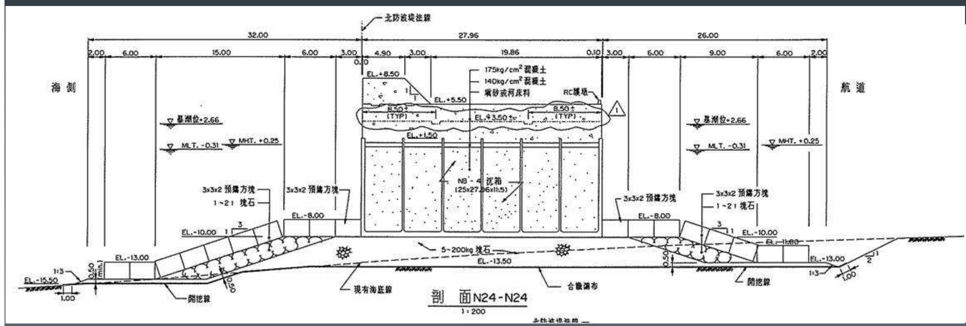
North jetty in deep water section



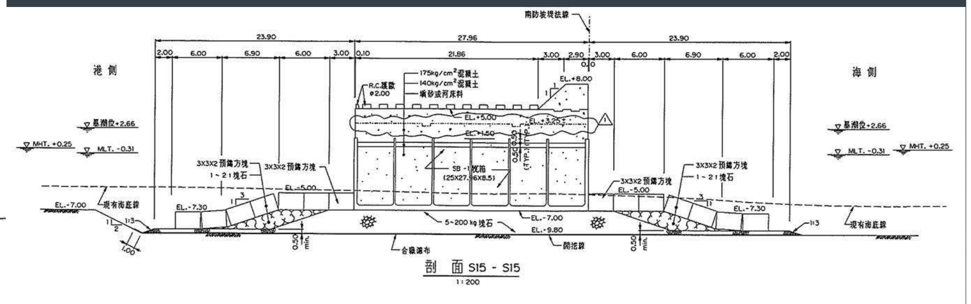
South jetty in deep water section



North jetty in caisson section



South jetty in caisson section



Lungmen NPP

Result of Analysis

Nuclear Power Plant No.1	Water Depth (m)	Elevation of Dike Crest (m)	Slope (surface block weight)		Water Depth (m)		Check
			Interior Slope	Exterior Slope	Allowable	Simulation	
North Jetty for Intake	Shallow Section	EL.+5.5	1/1.5 (5t)	1/2 (5t)	7.44	3.4	o.k.
	Deep Section	EL.+7.5	1/1.5 (10t)	1/2 (15~20t)	9.95	3.2	o.k.
	Caisson Section	EL +8.5			12.6	3.1	o.k.
South Jetty for Intake	Shallow Section	EL.5.5~6.5	1/1.5 (5t)	1/2 (5~10t)	7.44~8.44	3.4	o.k.
	Deep Section	EL.7.5~8.5	1/1.5 (10t)	1/2 (15~20t)	9.95~10.45	3.3	o.k.
	Caisson Section	EL +8.0			8.9	3.3	o.k.

The jetties will survive from the tsunami attack .

Lungmen NPP

Circulating Cooling Water Pump House (CWPH)

- The max. water elevation in the CCW is 3.82 m, which is lower than the elevation of pumping equipment floor of 5.0 m.
- The pumping capability of the CCW will not be affected by the tsunami.

Lungmen NPP

Reactor Building Service Water Pump House (RBSWPH)

- **The max. water elevation in the RBSWPH is 3.82 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 RBSWPH will not be affected by the tsunami.**

Lungmen NPP

Influences by Tsunami Drawdown

- A stilling basin with the capacity of 14,210 m^3 sea water can provide the cooling requirement of two generator units for 30 minutes.
- The water pump function of RBSWPH will not be influenced by the tsunami drawdown.