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The State of the Art and Science of Coastal Engineering

Jetty Design Using Dual Life-Cycle And Physical Modeling Approach

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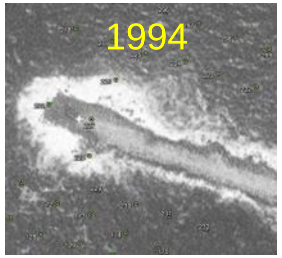
Outline

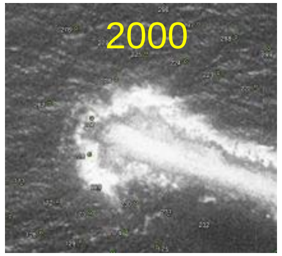
- Introduction
- Modeling approach
- Waves and water levels
- Initial stone sizing
- Physical model
- Life cycle approach
- Conclusions

Introduction

- The advantages of risk-based methodologies over traditional deterministic analyses in coastal design have been well established.
- Nevertheless, probabilistic approaches are often not applied consistently in coastal design.
- A probabilistic design approach using life-cycle analysis and physical modeling is applied for Coos Bay.
- Effects of uncertainties associated with forcing, structural, and stability equations parameters are considered.
- Coastal hazard data sources are now readily available that can facilitate the implementation of these methods.

Coos Bay Jetties
Oregon, U.S.A.





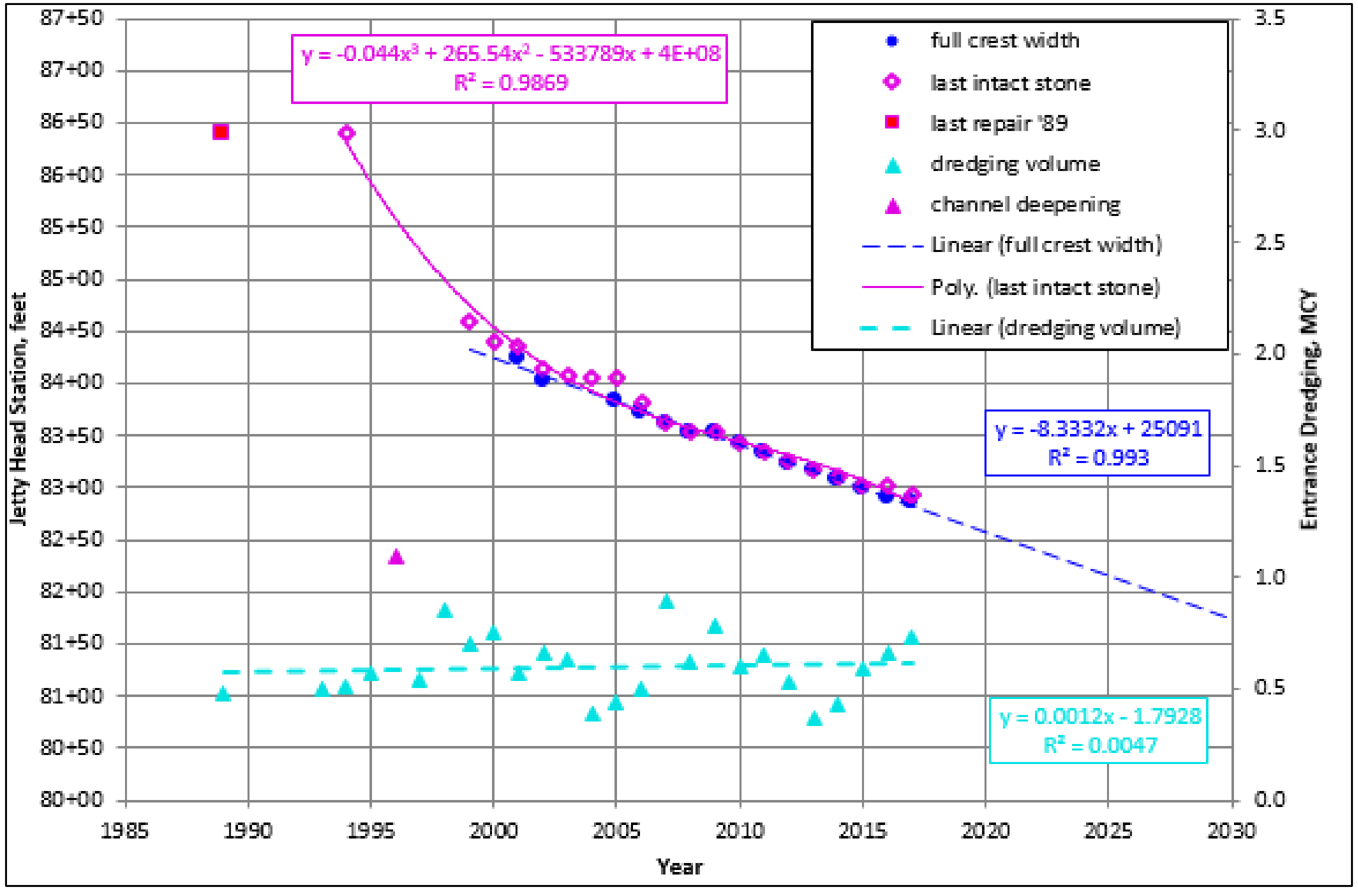
North Jetty Head Recession

Authorized length: 9,600 ft (2,926 m)

Last head repair: Year 1989, Sta. 86+40
27.5 US tons, 165 pcf specific weight

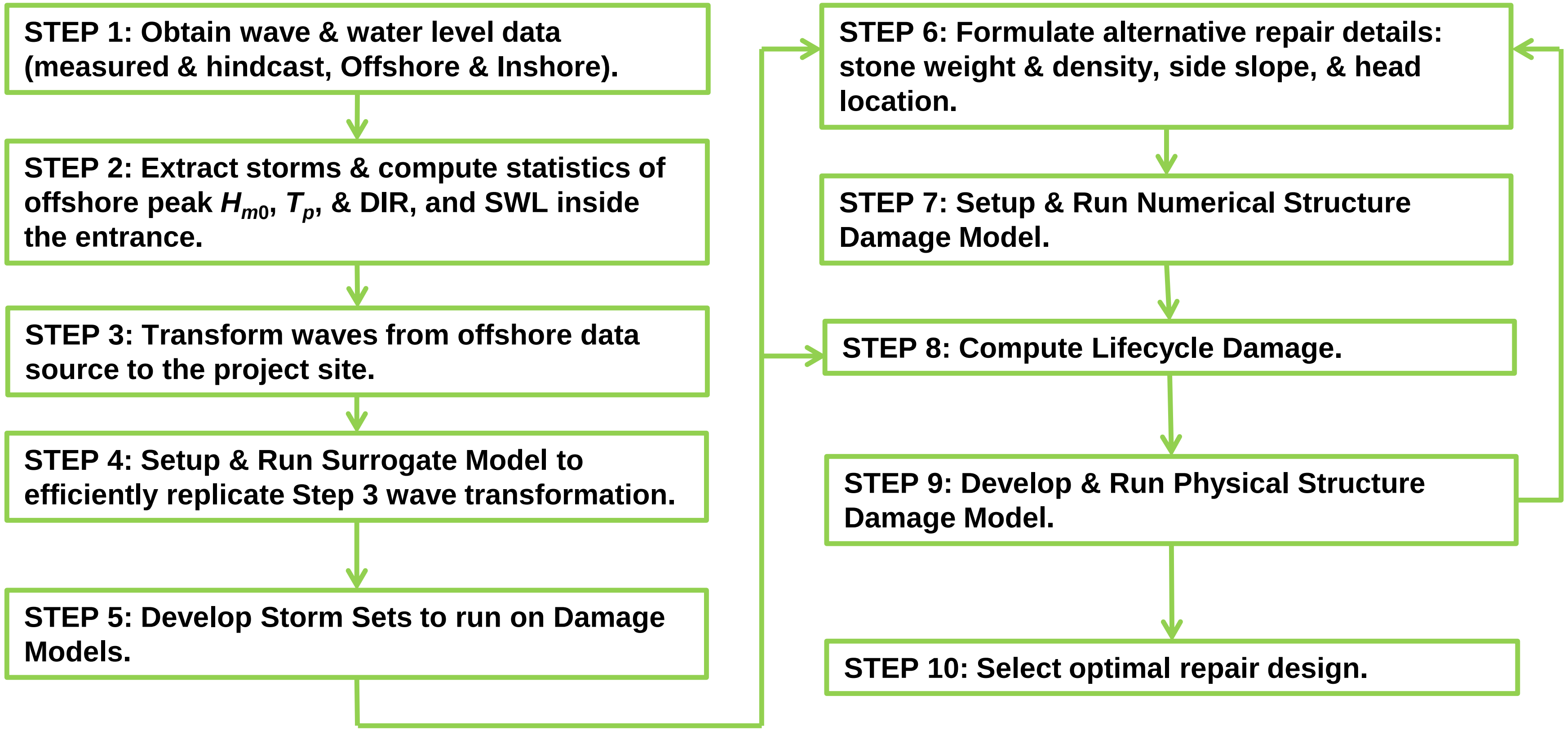
Existing configuration: 1:2 slope,
25 ft (7.62 m) crest elevation [MLLW],
30 ft (9.14 m) crest width.

Current head location: Sta. 82+73
Receded 367 feet since 1989.



Coos Bay Step-Wise Modeling Process

And Validation Methods



STEP 1: Obtain wave & water level data (measured & hindcast, Offshore & Inshore).

STEP 2: Extract storms & compute statistics of offshore peak H_{m0}, T_p, & DIR, and SWL inside the entrance.

STEP 3: Transform waves from offshore data source to the project site.

STEP 4: Setup & Run Surrogate Model to efficiently replicate Step 3 wave transformation.

STEP 5: Develop Storm Sets to run on Damage Models.

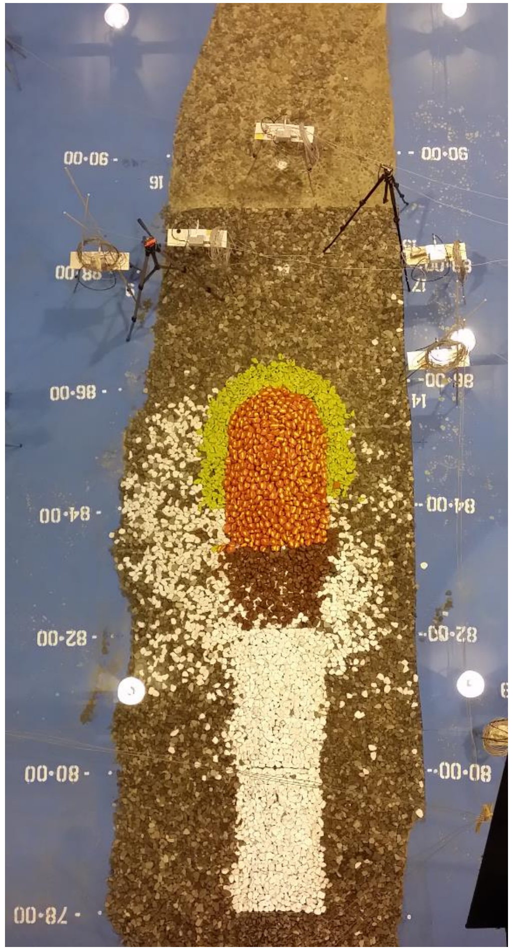
STEP 6: Formulate alternative repair details: stone weight & density, side slope, & head location.

STEP 7: Setup & Run Numerical Structure Damage Model.

STEP 8: Compute Lifecycle Damage.

STEP 9: Develop & Run Physical Structure Damage Model.

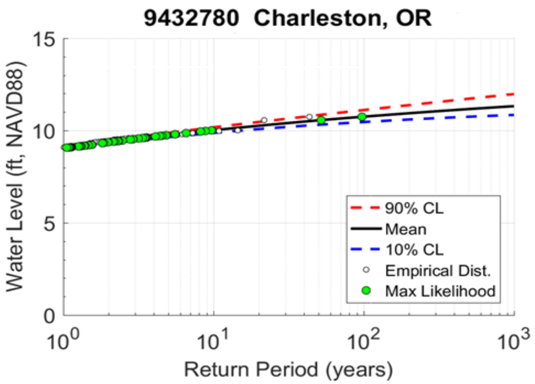
STEP 10: Select optimal repair design.

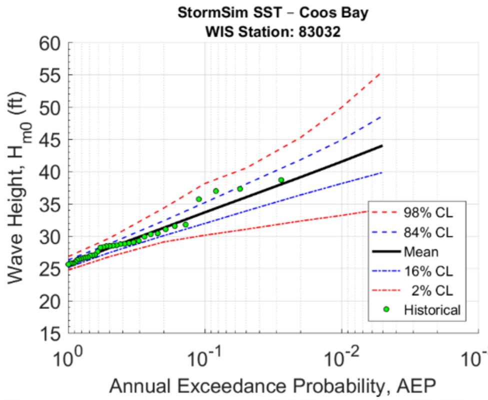


Waves and water levels: data sources and storm extraction (Steps 1-2)

- Offshore wave data
  - Buoys: 46029 Columbia River Bar, 46050 Newport, 46229 Umpqua Offshore, and 46015 Port Orford
  - USACE Wave Information Studies: **station 83032**
- Water levels: NOAA station 9432780 Charleston, OR

- Peaks-over-threshold of WIS 83032
  - 154 events (36-yr record)
  - 4.3 storms/yr
- Extremal analysis (Nadal-Caraballo and Melby 2012)
  - Detrend WL data, POT – Q-Q Optimization, GPD, Bootstrapping





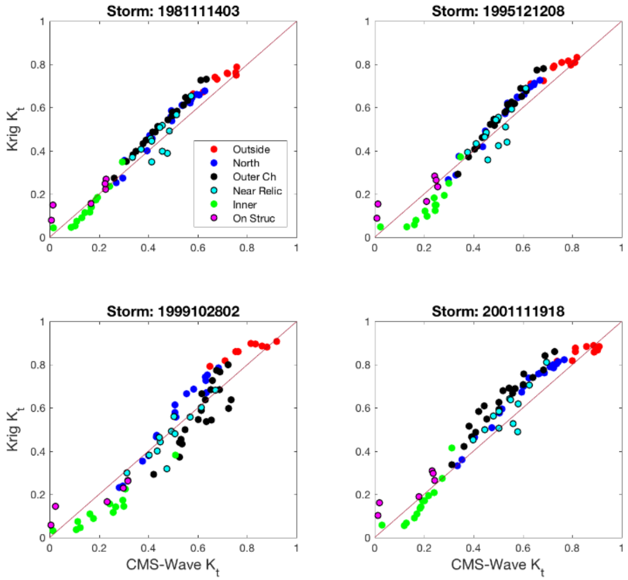
Waves and water levels: wave transformation and surrogate model (Steps 2-5)

- Wave transformation to the nearshore was performed using CMS-Wave steady-state 2D spectral wave model (Lin et al. 2011, 2008).
- Model runs
  - 4,320 offshore incident wave combinations
  - Top 20 historical storms (by offshore H_{m0})

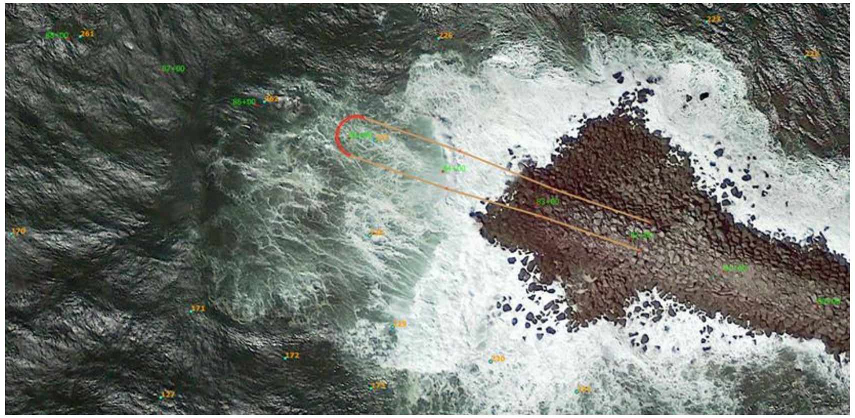
Offshore Wave Forcing Parameters	Values
Significant Height (m)	1, 3, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15
Peak Period (sec)	8, 10, 12, 14, 16, 18, 20, 22
Mean direction (deg)	220, 250, 280, 310, 340
Water Level, MSL (m)	-1.5, -1, -0.5, 0, 0.5, 1, 1.5, 2, 2.5

- Kriging surrogate model (Jia et al. 2016).
  - Allows wave transformation within the Monte Carlo simulation storm sampling.
  - Compute hazard at save point locations in model domain.

$$K_t = \frac{H_{m0\_i}}{H_{m0\_o}}$$



Initial stone sizing (Steps 6-7)



- Seaside armor stability: Maximum momentum flux, Melby and Hughes (2003)

$$D_{n50} = h a_m \left(\frac{S}{K_S \sqrt{N_z}}\right)^{-0.2} \left(\frac{(M_F/\gamma_w h^2)_{max}}{\Delta}\right)^{1/2}$$

$$a_m = \frac{1}{K_{m1} P^{0.18} \sqrt{cot\theta}} \quad s_m \geq s_{mc}$$

$$a_m = \frac{s_m^{P/3}}{K_{m2} P^{0.18} (cot\theta)^{0.5-P}} \quad s_m < s_{mc}$$

$$s_{mc} = -0.0035 cot\theta + 0.028$$

- Stable armor size based on return period wave conditions and water level conditions
- Return period conditions were based on the joint probability distributions of forcing parameters.

Configuration	Crest Elevation (ft) (NAVD88)	Structure Slope (cot θ)	Specific gravity	SP 261 Depth (NAVD 88)
1	24.5	2	2.578	18.83
2	24.5	2.5	2.578	18.83
3	24.5	3	2.578	18.83
4	24.5	2	2.734	18.83
5	24.5	2.5	2.734	18.83
6	24.5	3	2.734	18.83

Configuration	Return Period							
	5	10	25	50	75	100	200	500
	Median stone weights (Tons)							
1	35	37	39	40	41	41	42	44
2	25	26	28	29	29	30	30	31
3	19	20	21	22	23	23	23	24
4	32	34	36	37	38	38	39	40
5	23	24	26	27	27	27	28	29
6	18	19	20	20	21	21	22	22

Life-Cycle Analysis (Step 8)

- Seaside damage progression (Melby and Kobayashi 2011):

$$\bar{S}(t_n) = 0.5 + 1.3\sqrt{N_{ze} + (N_z)_n}(a_m N_m)_n^5 \quad \text{for } n = 1, S(t_1) > 0.2$$

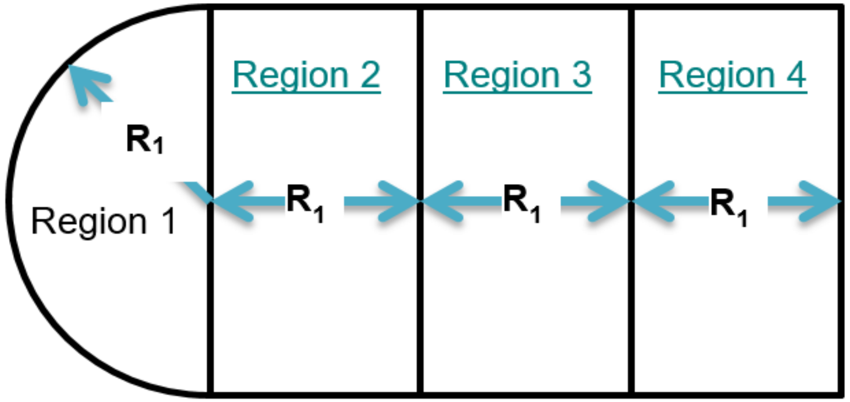
$$\bar{S}(t_n) = 1.0\sqrt{N_{ze} + (N_z)_n}(a_m N_m)_n^5 \quad \text{for } n > 1$$

$$(N_z)_n = \frac{t_n - t_{n-1}}{(T_m)_n}$$

$$N_{ze} = \left(\frac{\bar{S}(t_{n-1})}{(a_m N_m)_n^5}\right)^2$$

- Validated (Melby 2018, Panchang and Kaihatu, Ed.) momentum flux equation for jetty data (Pratt et al. 2004)

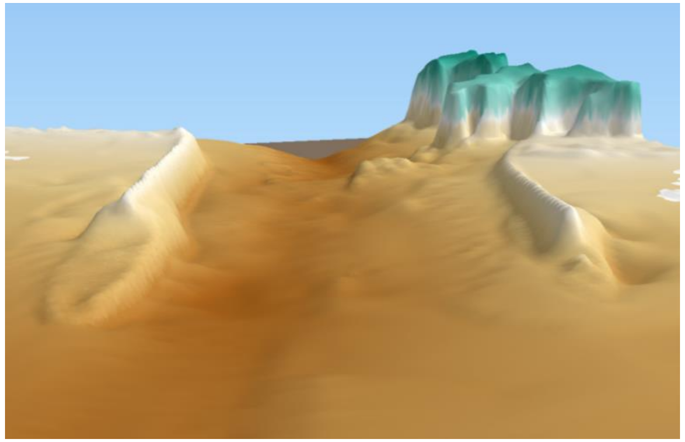
- Forcing scenarios evaluated:
  - Sequence of historical storms over WIS 36-year record.
  - Monte Carlo sampling of historical storms with random tide for a 50-year design life.

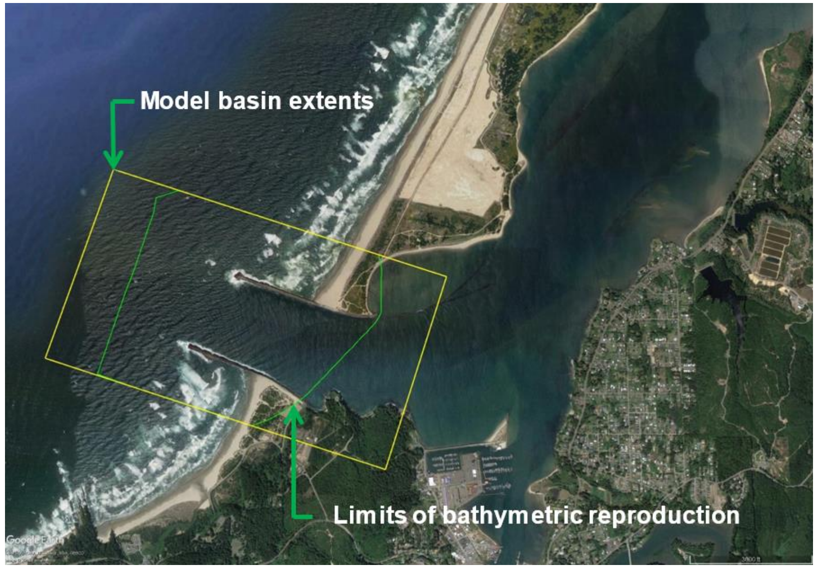


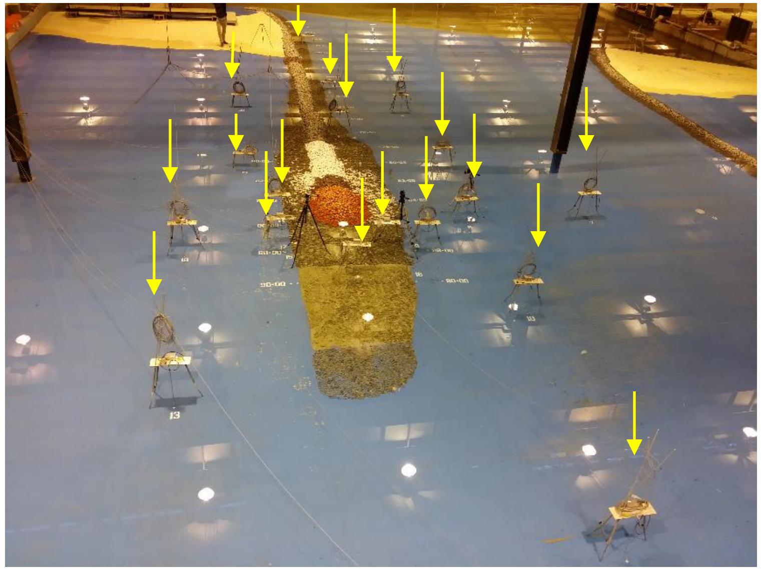
Physical Model (Step 9)
Experimental Setup

Coos Bay Physical Model:

- 1:55 scale
- 92-ft by 100-ft basin
- Directional spectral wave generator
- 20 Wave gages



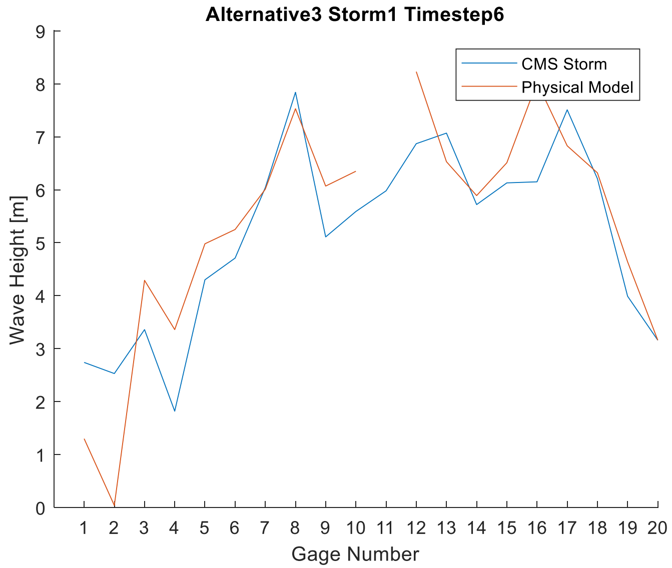




Physical model wave forcing

Modeled historical storms:

Storm Name	Date of Storm Peak	Wave Height H_{m0} (ft)	Power Index P (ft^2-hr)	Wave Period T_p (sec.)	Time Steps in Model
Storm 1	Jan 4-6, 2008	38.7	46371	19.5	6
Storm 2	Oct 28-29, 1999	37.1	36888	19.5	8
Storm 3	Dec 13-16, 2006	28.9	64250	14.7	20



Wave parameter inputs for physical model for Storm 1:

Prototype Selected Conditions for Storm 1 @ Save Point 340						
	T1	T2	T3	T4	T5	T6
Wave Dir,deg	265	268	273	276	278	278
Wave Period, sec	12.5	12.5	14.3	16.7	16.7	16.7
Wave Height, ft	13.98	15.26	25.20	28.41	28.77	28.54
Water Level, ft [NAVD88]	2.27	2.27	4.89	7.39	7.39	5.94
	The duration of each time step (T1, T2,….T10) was 2.5 hr prototype					

Design Wave:

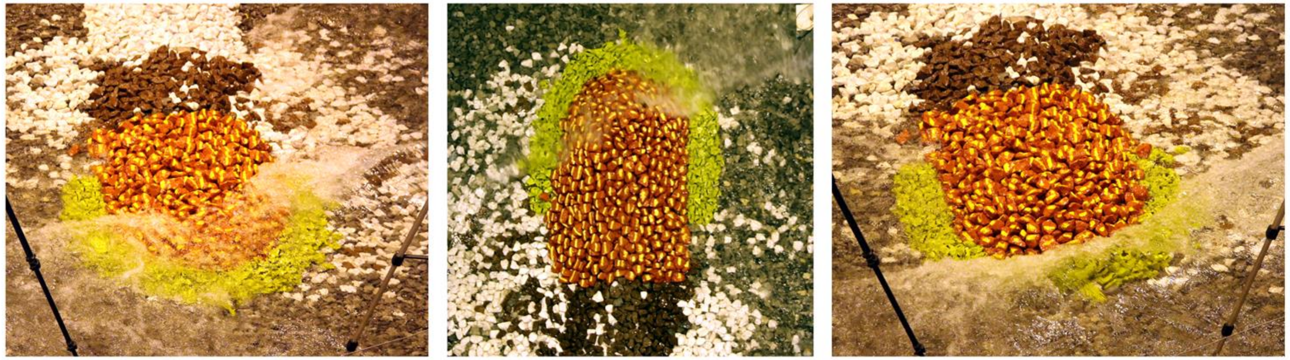
Design Wave	Prototype
θ, deg	283
T_p, sec	20
H_{m0}, ft (SP 347)	35.1
SWL, ft – NAVD88	10.68
Time steps	6

Physical model experiments

Structure Parameters	All alternatives
W_{50} (US Tons)	37
Specific weight (pcf)	175
Slope	1V:2H
Crest width (ft)	40
Crest height (ft, NAVD88)	24.5

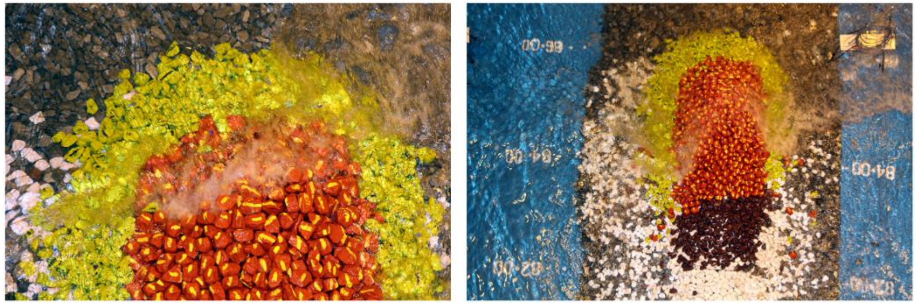
	Alternative 1	Alternative 2	Alternative 3
Storms	S1, S2, S3	S1,S2,DW	S1,S2,DW
Toe berm W_{50} Specific weight top elevation	25 ton 192 pcf -4 ft NAVD88	1 jetty stone high and 3 stone wide apron	25 ton 192 pcf 4 ft NAVD88

A1



A2

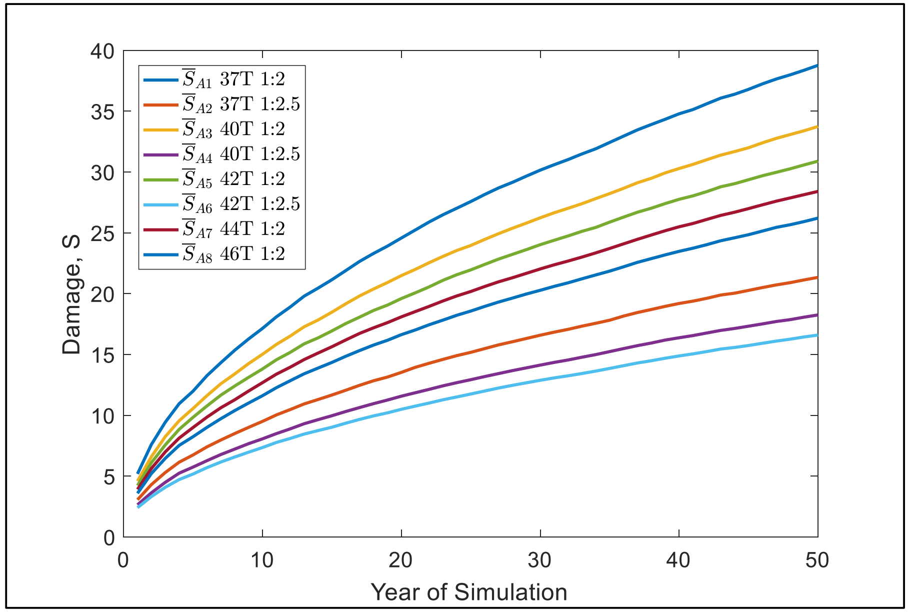
A3



Design Optimization (Step 10)

- Physical model damage was well predicted for alternatives 1 and 3 for the main armor (Difference in *S* less than 2)
- The K_m coefficients were revised for Alternative 2 to better capture the observed damage

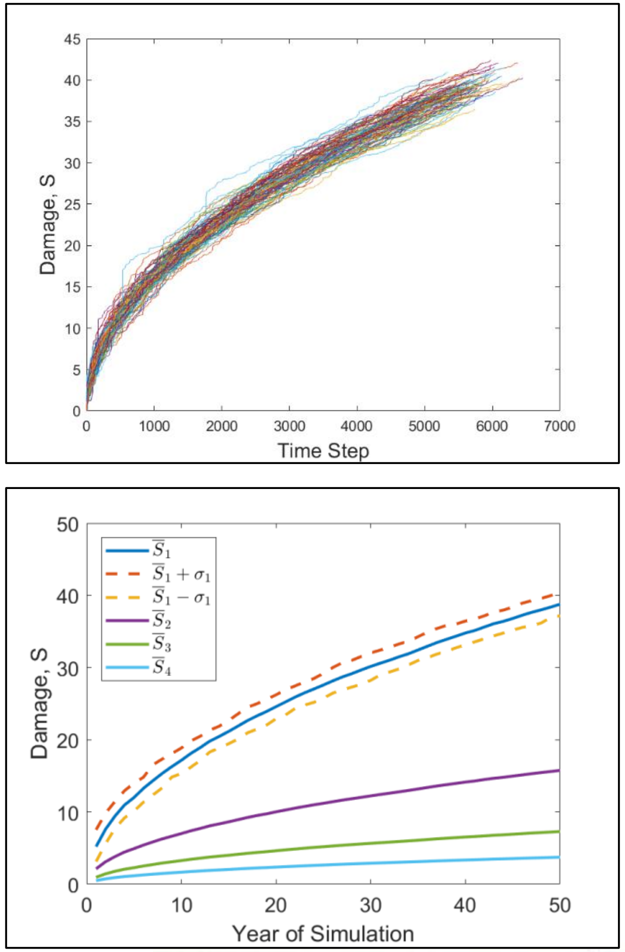
Damage, S for Alternative 2				
Predicted	9.5	5.7	2.6	1.2
Measured	9.5	5.4	5.4	1.2
Damage, S for Alternative 3				
Predicted	4.2	1.6	0.7	0.4
Measured	4.2	3.6	2.4	0.0



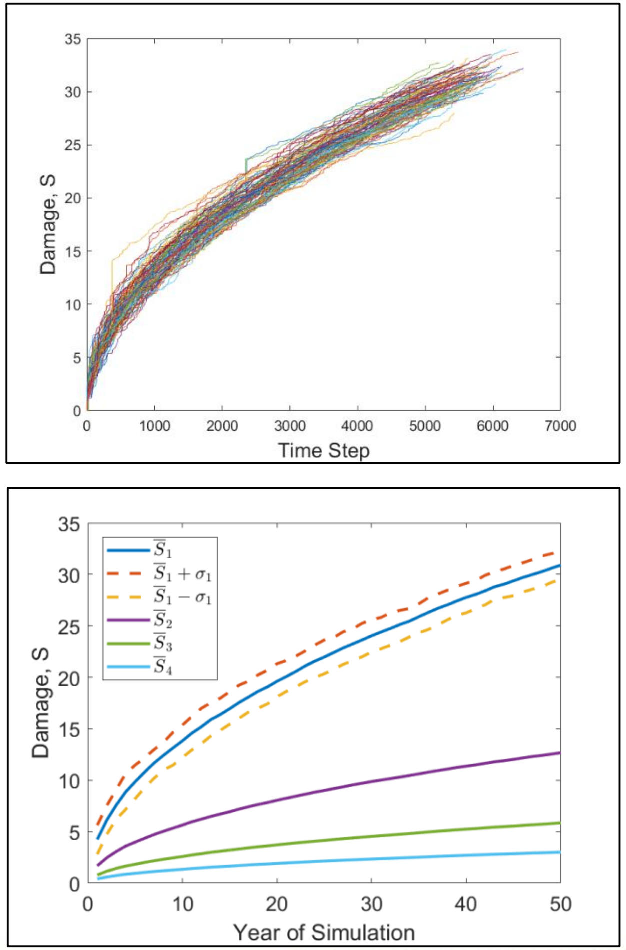
Armor Alt	Armor Weight W50	Structure Slope cot a	Mean Ultimate Damage S for Region 1	Mean Ultimate Damage S for Region 2	Mean Ultimate Damage S for Region 3	Mean Ultimate Damage S for Region 4
A1	37	2	37	15	7	4
A2	37	2.5	21	9	4	2
A3	40	2	33	14	6	4
A4	40	2.5	18	8	4	2
A5	42	2	30	12	6	3
A6	42	2.5	16	7	4	2
A7	44	2	26	11	6	3
A8	46	2	25	10	5	3

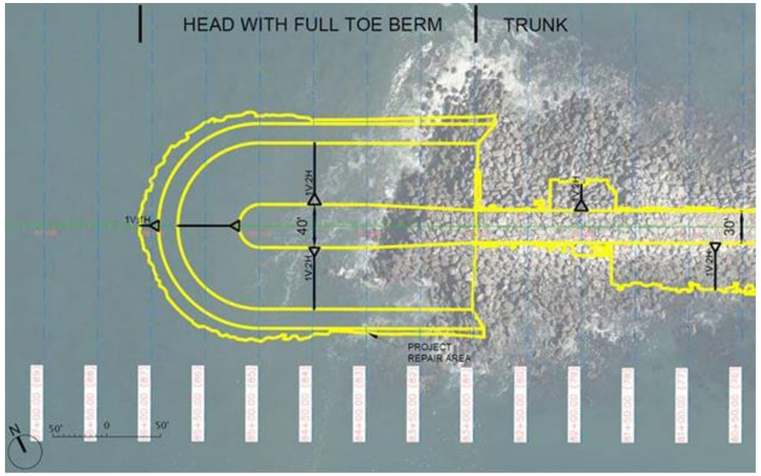
Design Optimization

Armor alternative A1: W_{50}=37 t, cot α=2, γ_r=175 pcf and a toe berm configuration



Armor alternative A5: W_{50}=42 t, cot α=2, γ_r=175 pcf and a toe berm configuration





Conclusion

- Advantages of life cycle modeling:
  - Quantification of damage accumulation over the design life.
  - Quantification of uncertainty.
  - Assessment impact of sea level change on damage.
  - Can be used to assess risk.
- Use of a single design event with an armor stability equation may not be conservative.
- Surrogate model enables expedient wave transformation during analysis.
- The benefits of physical modeling included toe berm assessment and validation of damage model to site conditions.
- Physical model demonstrated that toe berm reduces damage to the structure.

Thank you!

Sea Level Change Example