

ForeCoast[®] Rail: Revolutionising Rail Safety in Wales with Advanced Wave Overtopping and Scour Risk Forecasting for Network Rail

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Motivation





AFON WEN SEA WALL DJP 127.09

SEA-STATE AND WEATHER FORECAST

10:50

Fri

No risk

No risk NO ACTION FOR THIS TIDE

23:09

Fri

No risk

11:33

Sat

No risk

23:52

Sat

No risk

12:18

Sun

No risk

00:39

Mon

No risk

13:11

Mon

No risk

01:37

Tue

No risk

Forecast issue date: 24/02/2023

FORECAST DATA

Forecast issue time: 07:05

Forecas

FORECOAST SEA-STATE AND WEATHER FOR

Forecast issue: 24/02/2023 07:05

ABERTOFFD SEA WALL DJP 82.04



AFON WEN SEA WALL DJP 127.09



NEARSHORE	Wave height (m)	0	0	0	0	0	0.14	0	< 0.1	0	NA
	Overtopping (I/s/m)	0	0	0	0	0	0	0	0	0	NA
	Scour (m)	0	0	0	0	0	0	0	0	0	NA
SEA LEVEL	Tide (mAOD)	2.66	2.16	2.16	1.76	1.66	1.36	1.16	0.96	0.76	0.66
	Surge (m)	NA*									
	Correction (m)	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
	Sea level (mAOD)	2.65	2.15	2.15	1.75	1.65	1.35	1.15	0.95	0.75	0.65
~	Wave height (m)	0.80	0.50	0.40	0.40	0.30	0.30	0.30	0.50	0.80	NA
OFFSHORE		wsw	NA								
	Wave period (s)	3	3	3	2	3	3	3	3	6	0
	Wind force	5	4	4	4	3	3	3	3	3	NA
	Wind direction	NNW	NE	NE	ENE	NE	NNE	E	NNE	NNE	NA

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14:23

Tue

No risk

03:01 Wed

No risk



Severn

Legend

: 2024

Asset locations

MET Norway wind forecast location
MET Norway wave forecast location

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* A surge forecast is not yet available for this high tide. Therefore zero surge has been assumed when calculating the expected sea level. The surge and expected sea level for this high tide will be updated within the next forecast.



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NetworkRail consult



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Tools Dashboards Options Help JBA Delft-FEWS Forecasting System (Stand alone) <u>له</u> File X 🛍 🌄 I 🗸 🗁 ForeCoast Rail AFONWEN SEA WALL DJP 127.0798 Forecasts run 🗸 🗁 Wales Route TMM10 MWD (sim) Hs (forecast) Overtopping scour H.forecast priority > 🖿 Sea level forecast Hs (forecast) [1] (m) (s) (degrees) (l/s/m) (m) (m) (-) > 🖿 hindcast wave BCs AFONWEN SEA AFONWEN SEA AFONWEN SEA AFONWEN SEA AFONWEN SEA AFONWEN SEA > indcast wind BCs GMT through Delft-AFONWEN SEA AFONWEN SEA AFONWEN SEA AFONWEN SEA AFONWEN SEA AFONWEN SEA AFONWEN SEA Offshore conditions [1] V Image Nearshore conditions 09-10-2023 09-10-2023 ABERTAFOL SEA WALL DJP 82.0440 09-10-2023 09-10-2023 09-10-2023 09-10-2023 09-10-2023 **FEWS** software 00:00:00 00:00:00 00:00:00 00:00:00 00:00:00 00:00:00 00:00:00 TMM10 [1] AVALANCHE EAST SEA WALL CNH3 229.1338 Mon 09-10-2023 02:18 AVALANCHE VIADUCT NO. 133 CNH3 230.0294 Mon 09-10-2023 02:19 Vave | Tm (s) AVALANCHE WEST SEA WALL CNH3 230.0170 Mon 09-10-2023 02:24 BARMOUTH VIADUCT NORTH SIDE DJP 100.0028 Mon 09-10-2023 02:56 5.0 BARMOUTH VIADUCT SOUTH SIDE DJP 99.0113 Mon 09-10-2023 03:06 BRIWET BRIDGE NORTH APPROACH U SIDE DJP 11 Mon 09-10-2023 03:38 BRIWET BRIDGE SOUTH APPROACH DJP 115.0699 Mon 09-10-2023 04:49 • MWD (sim) [1] BYNEA EMBANKMENT 1 LLA 1.0968 Mon 09-10-2023 05:10 ----BYNEA EMBANKMENT 2 LLA 1.1694 Mon 09-10-2023 05:13 0.27 0.000000 0.24 0.497 6.9 246 CHEPSTOW SEA DEFENCE SOUTH SWM2 141.1496 200 Mon 09-10-2023 07:17 DEGANWY PITCHING LLJ 1.0165 150 Mon 09-10-2023 14:52 . * EERRYSIDE EMBANKMENT SWM2 238 1203 Mon 09-10-2023 14:59 100 -FERRYSIDE ROCK ARMOUR NORTH SWM2 238.166 Mon 09-10-2023 15:23 1.00 -Overtopping [FERRYSIDE ROCK ARMOUR SOUTH SWM2 237,132 Mon 09-10-2023 15:33 0.75 ERIOG CLIEFS DJP 96.0000 Mon 09-10-2023 16:06 FRONGOCH SEA WALL DJP 81.0473 Mon 09-10-2023 17:01 0.50 -GARNSWLLT EMBANKMENT LLA 9.0960 Mon 09-10-2023 17:20 0.25 GATCOMBE SEA WALL SWM2 129.0176 Mon 09-10-2023 17:24 0.24 0.000000 0.746 6.0 245 0.22 GLANDYFI SEA WALL SBA2 79.1430 Mon 09-10-2023 19:36 _____ GOGARTH SEA WALL DJP 80.1221 Mon 09-10-2023 19:40 scour [1] GWENDRAETH FACH SEA DEFENCE SWM2 234.099 Tue 10-10-2023 03:25 GWENDRAETH FAWR SWM2 233.0392 Tue 10-10-2023 03:26 HARLECH SEA WALL DJP 109.0649 0.50 -Tue 10-10-2023 03:34 HOLYWELL EMBANKMENT CNH3 195.1364 Tue 10-10-2023 04:00 0.25 LLANABER SEA WALL DJP 101.1119 Tue 10-10-2023 04:10 0.00 LLANDEILO RIVER DEFENCE VOT 18.0489 Tue 10-10-2023 04:45 LLANDULAS CLAY EMBANKMENT CNH3 216.0517 Tue 10-10-2023 05:38 - H.forecast [1] 3.0 LLANFAIRFECHAN SEA WALL CNH3 230.0484 Tue 10-10-2023 06:00 0.000000 0.10 0.952 0.41 244 2.5 -LLANWRDA 1 VOT 25.1650 Tue 10-10-2023 06:02 2.0 -LLANWRDA 2 VOT 26.0532 Tue 10-10-2023 08:15 1.5 LLWYNGWRIL CLAY CLIFFS DJP 95.1023 Tue 10-10-2023 08:16 LORD VIVIAN'S EMBANKMENT CNH3 192.0660 Tue 10-10-2023 15:44 0.5 LOUGHER EMBANKMENT SWM2 221.1522 Tue 10-10-2023 15:46 2.0 priority [1] LYDNEY ROCK ARMOUR SWM2 132,1510 Tue 10-10-2023 15:54 MOSTYN EMBANKMENT CNH3 197.0616 Tue 10-10-2023 16:22 MOSTYN SEA WALL CNH3 199.0286 -------Tue 10-10-2023 16:32 OLD COLWYN SEA WALL CNH3 217.1390 Tue 10-10-2023 17:07 PENMAENBACH EAST SEA WALL CNH3 226.0330 Tue 10-10-2023 17:48 PENMAENBACH WEST SEA WALL CNH3 226,1641 Tue 10-10-2023 18:06 0.77 4.7 242 0.000000 0.52 1.276 PENMAENMAWR ARMOUR STONE CNH3 227,1207 Mon Mon Tue 10-10-2023 20:26 16-10-2023 23-10-2023 PENMAENMAWR CNH3 227,1676 Tue 10-10-2023 20:31 00:00 00:00 PENMAENMAWR GAS WORKS CNH3 228.0117 Wed 11-10-2023 04:08 ForeCoast_Wales_hindcast: [1] Mon 09-10-2023 00:00:00 GMT Current PIBWRWEN SEA DEFENCE SWM2 243.1705 ForeCoast_Wales_hindcast: [1] Mon 09-10-2023 00:00:00 GMT Current 🛍 Data Display 🗖 🛛 🔍 Map 🌀 Spatial Data Web Browser Current system time: Sat 21-10-2017 00:00 GMT Logs 2 : Forecaster Notes Fay Luxford 13:18:48 GMT 13:18:48 GMT Stand alone -44082, 642965 0.0 MB/s 863 MB

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For each wave model:

- Generated event set of extreme conditions
- Simulated in SWAN
- Used SWAN results to train emulators
- Emulators implemented into Delft-FEWS







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Multi-variate statistics



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SWAN simulations



Event set + everyday high tide conditions

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-0.1

-0.2

0.3

0.4

0.5

0.6

0.7

Modelled Hs(m)

0.8

0.9

SWAN simulation results used to train emulators to predict nearshore wave conditions. Emulators are run in the forecasting system. Emulators shown to have a high level of accuracy.



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Wave overtopping forecasts



Running a wave overtopping Neural Network in Delft-FEWS



Scour forecasts

Currently a simple scour equation, based on forecasted depth of water at the defence toe, wave height and wave period

Infra-gravity waves







EurOtop II recommends an alternative overtopping method for extremely/very shallow foreshore conditions, which involves increasing the wave period $T_{m-1,0}$ from a phase averaged model like SWAN due the presence of infragravity waves and using the empirical formula of Altomare et al. (2016) to calculate wave overtopping. Since EurOtop II was published, Lashley et al (2020) proposed that wave overtopping calculations where infragravity waves play a part could further be improved by also increasing the wave height H_{m0} .



This alternative method is applied when the foreshore is considered as extremely/very shallow

 $\frac{water \; depth_{toe}}{} < 1$ $H_{m0,deep water}$

Altomare, C., Suzuki, T., Chen, X., Verwaest, T. and Kortenhaus, A., 2016. Wave overtopping of sea dikes with very shallow foreshores. Coastal Engineering, 116, pp.236-257, doi: doi.org/10.1016/j.coastaleng.2016.07.002

Lashley, C.H., Zanuttigh, B., Bricker, J.D., Van der Meer, J., Altomare, C., Suzuki, T., Roeber, V. and Oosterlo, P., 2020. Benchmarking of numerical models for wave overtopping at dikes with shallow mildly sloping foreshores: Accuracy versus speed. Environmental Modelling & Software, 130, p.104740



Warning & Alert Thresholds

Still water level and wave overtopping



Validation - hindcast



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- Hindcast of system run from 2016 to 2023
- Preliminary results
- Matched client expectations in terms of assets where there is a known issue and relative frequency
- Preliminary results show some thresholds need updating

	Alerts	Warnings
AFONWEN SEA WALL DJP 127.0798	2	126
AVALANCHE EAST SEA WALL CNH3 229.1338		
	4	0
AVALANCHE VIADUCT NO. 133 CNH3 230.0294		
	4	0
BARMOUTH VIADUCT NORTH SIDE DJP		
100.0028	1	1
BARMOUTH VIADUCT SOUTH SIDE DJP 99.0113		
	2	1
DEGANWY PITCHING LLJ 1.0165	2	0
FERRYSIDE ROCK ARMOUR SOUTH SWM2		
237.1320	1	3
FRONGOCH SEA WALL DJP 81.0473	0	1
GATCOMBE SEA WALL SWM2 129.0176	11	22
GWENDRAETH FACH SEA DEFENCE SWM2		
234.0990	3	21
GWENDRAETH FAWR SWM2 233.0392	6	14
LLANABER SEA WALL DJP 101.1119	0	134
PENMAENMAWR GAS WORKS CNH3 228.0117		
	4	0
PWLL SEA WALL SWM2 226.0473	5	64
St. ISHMAEL SEA WALL SWM2 237.0330	6	0
TYWYN BLOCKSTONE DJP 89.0722	115	325

Validation – Afonwen Sea Wall









Top 10 overtopping events in hindcast

Date	Hs (m)	OT (I/s/m)	Scour (m)	Sea level (mAOD)	Surge	Astro	Rank	Named Storm	
21/10/2017 08:50	1.64	1.64	1.39	3.03	0.68	2.36	-	Storm Brian	(
02/01/2018 20:17	1.73	5.41	0.82	3.72	0.77	2.96	3	Storm	
03/01/2018 08:38	1.54	3.38	1.25	3.45	0.40	3.06	9	Eleanor	-
17/04/2018 08:43	1.7	4.19	1.24	3.41	0.46	2.96	5	NA	
13/01/2020 21:59	1.63	3.74	1.41	3.25	0.60	2.66	7	Storm Brendan	
09/02/2020 07:56	1.93	10.18	1.39	3.47	0.82	2.66	1	Storm Ciara	1
09/02/2020 20:19	1.64	4.47	1.42	3.28	0.53	2.76	4	Storm Clara	
21/08/2020 09:21	1.79	6.78	1.31	3.4	0.55	2.86	2	Storm Ellen	_
15/11/2020 07:44	1.65	2.93	1.04	3.46	0.52	2.96	10	NA	
15/11/2020 20:05	1.42	4.15	1.28	3.34	0.19	3.16	6	NA	
24/11/2022 20:11	1.73	3.6	1.1	3.53	0.68	2.86	8	NA	1

 Storm Ciara client feedback – found paperwork showing the defence had been repaired following this event



What's next?

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Erosion modelling improvements



Example forecasted dune volume loss in Montrose (Scotland)

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Risk at lots of sites is the cumulative effect of multiple storms. Currently working on forecasting systems that can use updated nearshore bathymetry either from observations or modelling as input to subsequent forecasts.

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- Traditional forecasting system built upon fixed thresholding which produces conservative forecasts
- Generated from hindcast and lookup tables

Machine learning for Coastal Hazard Forecasting



- 1. Barriers are critical infrastructure in Orkney
- 2. Understanding, how, when and for how long they may close in storms is key for emergency planning



Dense

Layer

Barrier open ?

Ye

No

Machine learning setup

- Machine learning setup allows for flexible forecasting and can take into local effects
- Able to take into account real-time wind and wave data
- Trained on hindcast data and local data

GRU: 32

GRU: 64



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Wave

Dir

Hs

Τp

Wind Dir

Wind Spd

Neural Network for Anomaly Detection