극한 환경 이벤트에 대한 웨트로폴리스 홍수 조사관하고 극한 물 파도 역학

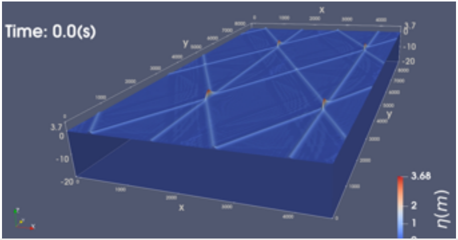
Onno Bokhove/언노 보코베 [et al.], KSCAM 24-08-2024
£€: EU Eagre GA859983

Leeds Institute for Fluid Dynamics, UK

[redacted] December 26 at 5:56pm · Leeds

The clean up crew [redacted] Onno Bokhove

[redacted]



개요

저는 수학하고 통계안에 나의 연구 개요를 줄 거에요:

- 웨트로폴리스 홍수 조사관 (Bokhove et al. (2020, 2024)),
- 극한 물 파도 연구는 새로운 파동 에너지 장치를 영감을 했어요. (e.g., Kadomtsev & Petviashvilli 1970, Benney & Luke 1964, Luke 1967, Kodama (2010, 2018), B. & Kalogirou 2016, Choi et al. (2022,2024), B. et al. (2019,2024)).

개요

홍수에/On floods:

- Goal Wetropolis & legacy of our work.
- Definition flood-mitigation measures.
- Graphical cost-effectiveness tool for design flood (1 : 200years).
- Wetropolis (old & new) statistics return periods rainfall.
- Conclusions.

홍수에/On floods: 웨트로폴리스 홍수 조사관

Inspiration for Wetropolis: Boxing Day 27-12-2015 floods of the River Aire in Leeds

여기는 웨트로폴리스예요: 극한 환경 이벤트에 시각하기

Goal: 반환 기간/연간 초과 확률 시각하기 (요청으로, EA & JBA Trust). `https://www.youtube.com/watch?v=rNgEqWdafKk`

도전/Challenge

- People often classify extreme events by saying: that was an extreme (rainfall or flooding) event with a magnitude corresponding to a return period of 1 : 100 years.
- Then they can be confused to think that such an event does not occur for (approximately) another 100 years.
- For rainfall, that might mean that this extreme rainfall of (say) $50\mathrm{mm/day}$ had a 1 : 100 year return period.
- Wetropolis aims to visualise return periods for the general public.
- To avoid long (say 100 year) average waiting times, we need to shrink time and reduce the rainfall to a small-scale set-up such that viewers can experience return periods of extreme events in $\mathrm{minutes}$.
- Challenge: **what time duration should** wd **have and what is a suitable unit amount** $10r_0$ per wd in a small-scale set-up?

Legacy: 우리의 홍수기 연구는 다음은 유산이 있어요

- **Leeds' public 2017 Flood-Alleviation Scheme II 분석는:** led to graphical flood-mitigation cost-effectiveness tool, laying bare inconsistencies in FASII.
- **웨트로폴리스는 비용 효율성 도구 영감을 했어요:** used in flood cases France & Slovenia
- 도구는 shows that **efficacy of Natural Flood Management** small to minute, e.g. beaver dams, contrary to statements on NFM & beavers by Environment Agency, council & media.
- **REF Impact case study ICS 2021 봐:** Wetropolis & flood-mitigation effectiveness tool for decision-makers. `https://results2021.ref.ac.uk/impact/submissions/1eedb5bd-8f92-4737-a6f0-1e61c997e4f0/impact`

우리는 어떻게 홍수를 완화시킬 수 있어요?

어느 우리의 홍수 완화시키 선택할 수 있어요?

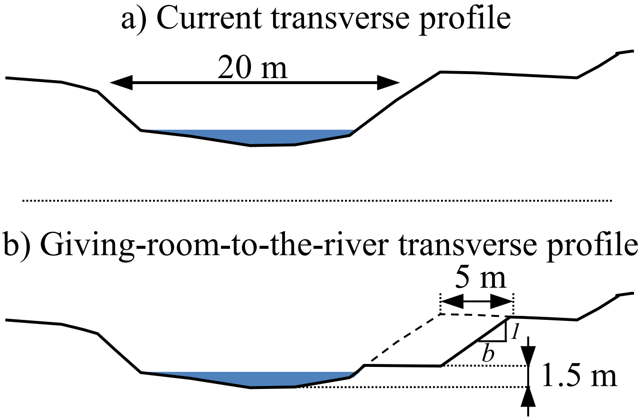
- Higher walls (HW)
- Flood-plain storage (FPS): dynamic using weirs and optimal control (underdeveloped)
- Giving-room-to-the-river (GRR)
- Natural Flood Management (NFM): tree planting, peat land, leaky dams
- Beaver colonies
- Sustainable urban drainage systems (SUDS)
- Dredging
- Resilience?

우리는 어떻게 홍수를 완화시킬 수 있어요?

Higher flood defence walls – HW (2m high proposed in Leeds):

우리는 어떻게 홍수를 완화시킬 수 있어요?

Giving-room-to-the-river – GRR:



우리는 어떻게 홍수를 완화시킬 수 있어요?

Giving-room-to-the-river – GRR, extra channel in River Aire at *Aire River at Kirkstall The Forge* (Leeds):

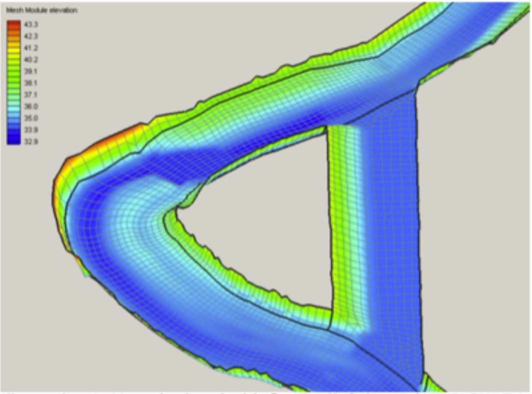


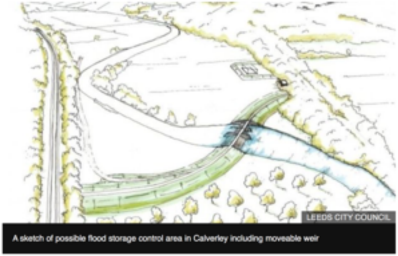
Illustration 1: Meander bend with flood relief channel, TUFLOW FV mesh

우리는 어떻게 홍수를 완화시킬 수 있어요?

Giving-room-to-the-river – GRR, extra channel in River Waal/Rhine Nijmegen (NL):

우리는 어떻게 홍수를 완화시킬 수 있어요?

Flood-plain storage –FPS & dynamic weir control:



우리는 어떻게 홍수를 완화시킬 수 있어요?

Extra storage –FPS active flooding of certain areas (Merwede, Storm Ciara, NL, $20\mathrm{Mm}^3$):

우리는 어떻게 홍수를 완화시킬 수 있어요?

Natural flood management – NFM 1300 leaky dams & trees (public engagement & co-benefits, e.g. carbon sequestration)

Central part of one of the two experimental timber bunds in the River Seven catchment

우리는 어떻게 홍수를 완화시킬 수 있어요? 비버는 안 효과적여요!

Imagine your home is flooded. Lots of beaver colonies then? Extra water storage behind dams: $\sim 1100\mathrm{m}^3 = 1.1\mathrm{M}$litres (or $1/5^{\mathrm{th}}$).

How beavers can help stop homes from flooding

17 Feb 2020 Last updated at 11:08

PA MEDIA

Beavers can play an important role in helping to keep our homes from being flooded.

That's according to scientists at Exeter University, who have carried out a five year study of wild animals living in Devon.

우리는 어떻게 홍수를 완화시킬 수 있어요?

Dredging –Wainfleet Flood Action Group (flood June 2019, 67 homes & lots of farmland flooded):

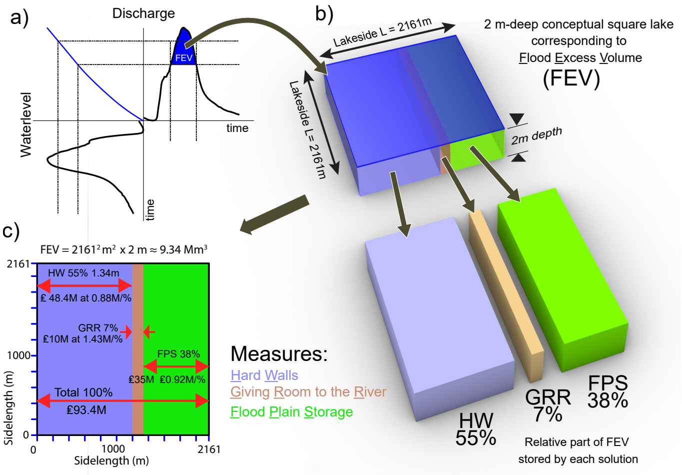
우리는 어떻게 홍수를 완화시킬 수 있어요?

Resilience: raising of new houses now mandatory in Wainfleet:

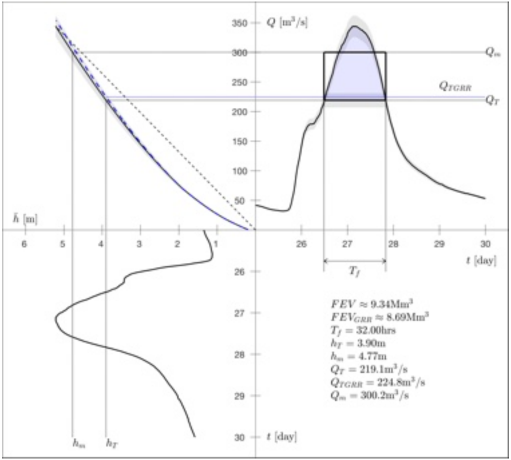
우리는 어떻게 홍수를 완화시킬 수 있어요?

Resilience: responsible flood-plain development (zero-sum or negative volume rule), Rhine valley:

그래픽 비용 효율성 도구

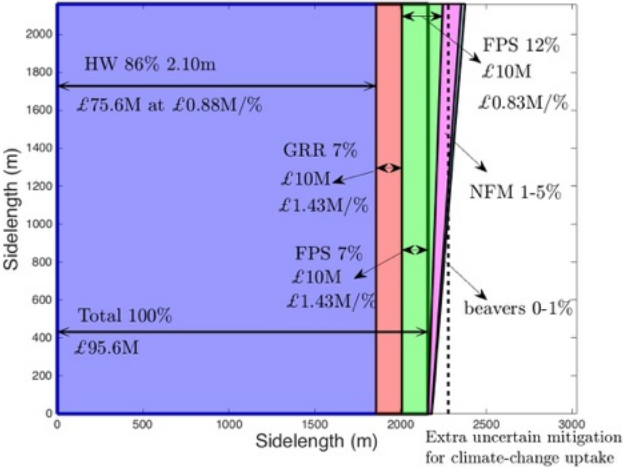

a)
Discharge
FEV
Waterlevel
time
time
b)
Lakeside L = 2161m
Lakeside L= 2161m
2 m-deep conceptual square lake
corresponding to
Flood Excess Volume
(FEV)
2m depth
c)
FEV = 2161² m² x 2 m ≈ 9.34 Mm³
2161
1000
0
HW 55% 1.34m
£ 48.4M at 0.88M/%
GRR 7%
£10M at 1.43M/%
FPS 38%
£35M £0.92M/%
Total 100%
£93.4M
Sidelength (m)
0
1000
2161
Sidelength (m)
Measures:
Hard Walls
Giving Room to the River
Flood Plain Storage
HW
55%
GRR
7%
FPS
38%
Relative part of FEV
stored by each solution

그래픽 비용 효율성 도구: 그래프과 세 사분면

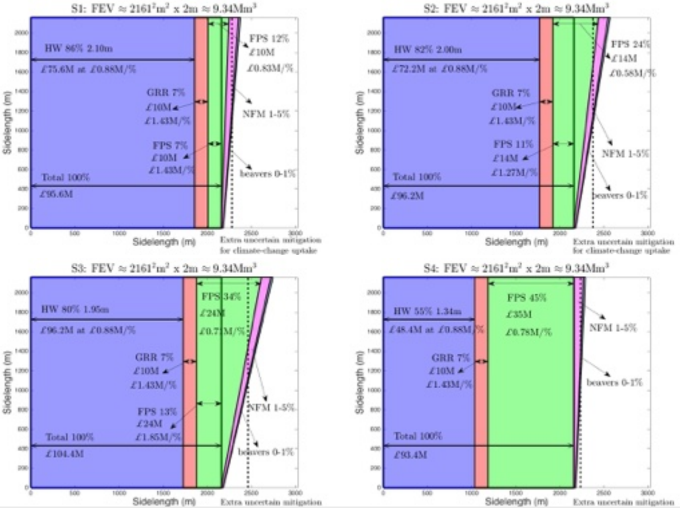


그래픽 비용 효율성 도구: 사각 호수

S1: FEV $\approx 2161^2\text{m}^2 \times 2\text{m} \approx 9.34\text{Mm}^3$

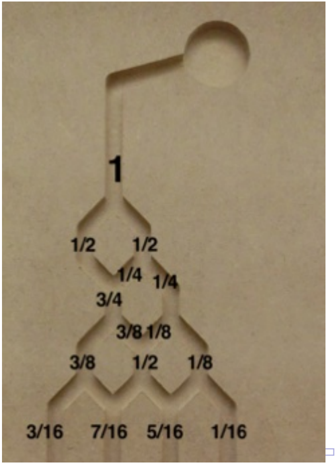


그래픽 비용 효율성 도구: 프레임워크 하고 사각 호수 (1 : 200yrs)



웨트로폴리스의 날씨: 왜곡핸 갈튼 보드

Ball falls through, peak chance at 7/16 & “rare” event at 1/16:



웨트로폴리스의-I 날씨: 왜곡핸 갈튼 보드 두 개

갈튼 보드 두 개: 비의 위치경우 보드 한 개하고 비의 지속 시간경우 보드 한 개:

웨트로폴리스의-I 날씨: 확률과 통계

- X, Q: probabilities p_i rainfall duration/wd versus q_j rain location:
- p_i, q_j with $i, j = 1, 2, 3, 4$ and $\sum p_i = 1, \sum q_j = 1$.
- For old case, $p_1 = q_1 = 3/16, p_2 = q_2 = 7/16, q_3 = p_3 = 5/16, q_4 = p_4 = 1/16$:

Table: Probability matrix $P_{ij} = p_i q_j$ times 256.

	1s p_1	2s p_2	4s p_3	9s p_4
reservoir q_1	9	21	15	3
both q_2	21	49	35	7
moor q_3	15	35	25	5
no rain q_4	3	7	5	1

홍수의 반환 기간: 기하학적 분포

- Rain amount per $T_d = 10\mathrm{s} = 1\mathrm{wd}$ determined by tuning: no to minor flooding for $(1,2,4)$ & $(8,9)$, flooding for 18 units r_0.
- Return period T_r of extreme flooding at $t_n = nT_d$ determined by geometric distribution with here $p_n = (1-p_e)^{n-1}p_e$ where $p_e = P_{24} = q_2 p_4 = 7/256$, s.t.

$$T_r = \mathbb{E}(t_n) = \sum_{n=1}^{\infty} T_d n(1-p_e)^{n-1}p_e = \frac{T_d}{p_e} \approx 365.7\mathrm{s} \approx 6:06\mathrm{min}.$$

- Standard deviation σ_r (thanks to Daan C & Jason F):

$$\begin{aligned}\sigma_r^2 =& \mathbb{E}\left((t_n - \mathbb{E}(t_n))^2\right) = (1-p_e)\frac{T_d^2}{p_e^2}\\ =&(1-p_e)T_r^2 \Longrightarrow \sigma_r = 36.07\mathrm{wd} = 360.7\mathrm{s} \approx 6\mathrm{min}.\end{aligned}$$

슈퍼 홍수과 대규모 홍수: 차수 k의 기하학적 분포

- Two consecutive “2015 Boxing Days” of extreme rainfall WEP $p_e^2 = (7/256)^2$ s.t.

$$T_r^{(2)} \approx \frac{T_d}{p_e^2} = (256/7)^2 \times 10\text{s} \approx 223\text{min} \approx 3:43\text{hr}.$$

Movie “Wetropolis Boxing Day flood” on `https://github.com/obokhove/wetropolis20162020`

- $T_r^{(2)}$ & $\sigma_r^{(2)}$ follow from geometric distribution of order $k=2$ (Viveros & Balakrishnan 1993, Koutras & Eryilmaz 2017):

$$\frac{T_r^{(k)}}{T_d} = \frac{(1-p_e^k)}{(1-p_e)p_e^k}, \quad \frac{\sigma_r^{(k)}}{T_d} = \frac{\sqrt{1-(2k+1)(1-p_e)p_e^k - p_e^{2k+1}}}{(1-p_e)p_e^k}.$$

슈퍼 홍수과 대규모 홍수: 웨트로폴리스-II의 재검토된 디자인

- For floods on two consecutive days with old $p_e = 7/256$:

$$
\begin{aligned}
T_r^{(2)} =& T_d \frac{(1+p_e)}{p_e^2} = 1374\mathrm{wd} = 13740\mathrm{s} = 3.8\mathrm{hr},\\
\sigma_r^{(2)} =& T_d \frac{\sqrt{1-5(1-p_e)p_e^3 - p_e^5}}{(1-p_e)p_e^3} = 3.8\mathrm{hr}.
\end{aligned}
$$

- Long waiting times suggest *redesign*, e.g. take Galton board outcome $p_e = p_2 q_2 = 49/256 \approx 1/5$ for $9\mathrm{s}$ rainfall in moor & reservoir, yielding return periods for $k = 2, 3$-day floodings:

$$
\begin{aligned}
T_r =& 5.2\mathrm{wd} = 52\mathrm{s},\ T_r^{(2)} = 32.5\mathrm{wd} = 5:25\mathrm{min},\\
T_r^{(3)} =& 175\mathrm{wd} = 29:11\mathrm{min}, \sigma_r^{(k)} \approx T_r^{(k)}, k = 1,2,3.
\end{aligned}
$$

다시 찾은 웨트로폴리스-II의 재검토된 날씨

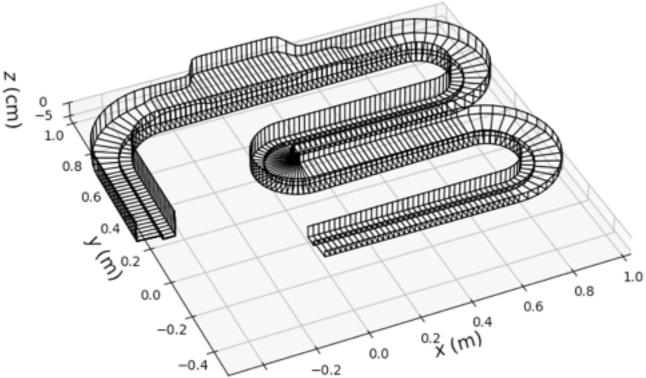
- X, Q: probabilities p_i rainfall duration/wd versus q_j rain location: `https://www.youtube.com/watch?v=g8znktYpxvY`
- p_i, q_j with $i, j = 1, 2, 3, 4$ and $\sum p_i = 1, \sum q_j = 1$.
- For current case, $p_1 = q_1 = 3/16, p_2 = q_2 = 7/16, q_3 = p_3 = 5/16, q_4 = p_4 = 1/16$:

Table: Probability matrix $P_{ij} = p_i q_j$ times 256.

	1s	7s	4s	2s
	p_1	p_2	p_3	p_4
reservoir q_1	9	21	15	3
both q_2	21	49	35	7
moor q_3	15	35	25	5
no rain q_4	3	7	5	1

웨트로폴리스의 수학적 모델

Kinematic river flow in design model fixed wd, r_0; 1D predictive shallow-water river model with ground-water & reservoir dynamics, in progress (PDEs & ODEs: B. et al, HESS, 2020). Bathymetry:



웨트로폴리스 홍수 조사관하고: 미래의 일고 제안하려면

How can a Wetropolis laboratory set-up and a Numerical Wetropolis Prediction model be used to understand:

- risk, extreme weather & flooding probability statistics –revisit spatial-temporal rainfall & change-point analysis;
- rare-event simulations (for events of "intermediate rarity");
- flood control –e.g., reservoirs in Wetropolis;
- data assimilation & parameter estimation –experiment as "truth run"; test (limits of) machine learning;
- Wetropolis World's goal: investigate "classical" PDE & Data Assimilation prediction model with ML predictions.
- Proposal EPSRC-F$^+$ (Korea?): PDE/ML, info-gap theory on decision-making, 1/4 educational-version, board game, workshops.

파도에: 개요

파도에/On waves:

- Introduction via movie bore-soliton-splash.
- Eight-to-ninefold amplification three-soliton interactions.
- Sketch & movie wave-energy device.
- Achievement: model device with one grand variational principle.
- Preliminary optimisations.
- Conclusions.

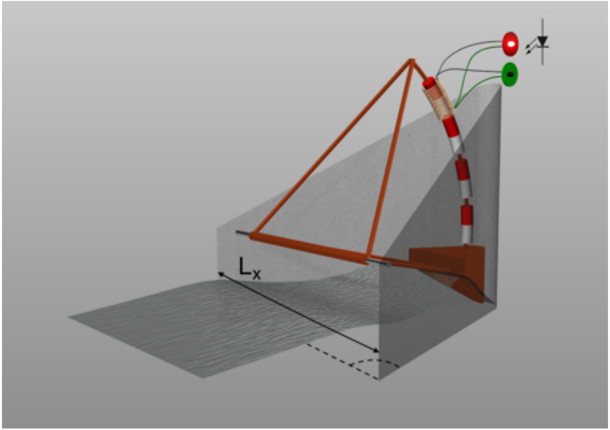
파도에: 모델로 하기 극한의 높은 물 파도

- Origin 2010 *bore-soliton-splash*:
- Definition rogue/extreme waves: $AI = H_r/H_s > 2$.
- Wave-energy device inspired by this amplification in a contraction.

새로운 파동 에너지 장치를 방파제의 수축에 배치했어

Proof of principle/원칙 증명: `https://www.youtube.com/watch?v=SZhe_SOxBWo&t=254s`.

Sketch wave amplification in contraction with angle θ_c:



파동 에너지 장치의 전반적인 수학적 변분 원리

Equations of motion follow from 수학적 변분 원리 (red=waves, blue=buoy, green=EM-generator, <u>coupling</u>):

$$\begin{aligned} 0 =&\delta \int_0^T \int_0^{L_x} \int_{R(t)}^{l_y(x)} \int_0^h -\left(\partial_t\phi + \frac{1}{2}|\nabla\phi|^2\right)\mathrm{d}z - gh\left(\frac{1}{2}h - H_0\right) \\ &\underline{-\frac{1}{2\gamma}\Big(F_+(\gamma(h-h_b)-\lambda)^2-\lambda^2\Big)\mathrm{d}y\mathrm{d}x} \\ &MW\dot{Z} - \frac{1}{2}MW^2 - MgZ + (L_i I - \underline{K(Z)})\dot{Q} - \frac{1}{2}L_i I^2 \mathrm{d}t \qquad (1) \end{aligned}$$

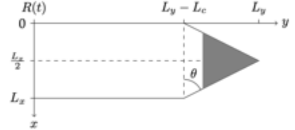
velocity $u = \nabla\phi(x,y,z,t)$, depth $h(x,y,t)$, rest depth H_0, buoy $h_b(Z,x) = Z - K - \tan\theta(L_y - x)$, coupling function $\gamma_m G(Z) = K'(Z)$, buoy mass M, keel height K, buoy coordinate $Z(t)$, buoy velocity $W(t) = \dot{Z}$, charge $Q(t)$, current $I(t) = \dot{Q}$.

모델로 하기: 편미분 방정식/PDEs

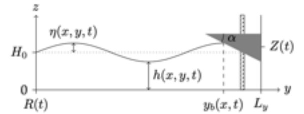
- Potential-flow water-wave dynamics (Laplace equation in interior, kinematic & Bernoulli equations at free surface):

$$\begin{aligned} \delta\phi: &\quad \nabla^2\phi = 0 \quad \text{in} \quad \Omega \\ (\delta\phi)|_{z=h}: &\quad \partial_t h + \nabla\phi\cdot\nabla h = \phi_z \quad \text{at} \quad z = h \\ \delta h: &\quad \partial_t\phi + \frac{1}{2}|\nabla\phi|^2 + g(z - H_0) - \lambda = 0 \quad \text{at} \quad z = h. \end{aligned}$$

- Coupled elliptic Laplace equation to hyperbolic free-surface equations, plus a (Lagrange) **multiplier** λ.



(b) Top view of the tank and buoy, outlining the tank's dimensions and how the buoy fits the shape of the contraction.



(c) Side view at time t, with the buoy constrained to move vertically.

수학적 모델로 하기: 부등식 제약 한 캐 상미분 방정식

- Karush-Kuhn-Tucker inequality conditions satisfied at every space-time x, t-position are:

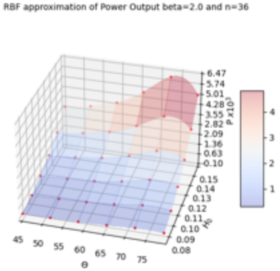
$$\delta\lambda : \lambda = -[\gamma(h-h_b)-\lambda]_+ = -F_+(\gamma(h-h_b)-\lambda)$$
$$\Longrightarrow \underline{h(x,t)-h_b(Z,x) \le 0}, \lambda \le 0, \lambda(h-h_b) = 0.$$

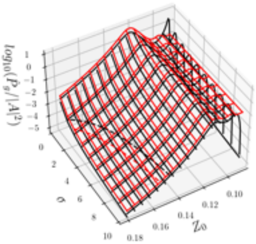
- Add resistance R_i, R_c & Shockley load $V_s(|I|)$ to submodel:

$$\delta W : \quad \dot{Z} = W,$$
$$\delta Z : \quad M\dot{W} = -Mg\underline{-\gamma_m G(Z) I} - \int_0^{L_x}\int_0^{l_y(x)} \lambda \, \mathrm{d}y\mathrm{d}x$$
$$\delta I : \quad \dot{Q} = I,$$
$$\delta Q ; \quad L_i \dot{I} = \underline{\gamma_m G(Z)\dot{Z}} - (R_i + R_c) I - \frac{I}{|I|} V_S(|I|).$$

파동 에너지 장치의 최적화

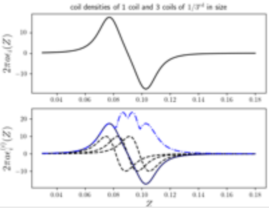
Surrogate modelling geometry angle/rest depth θ_c-H_0 & 1-coil (**black**) vs. 3-coil (red) power P_g (B. et al IEEE2024):

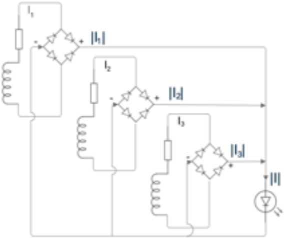




새로운 파동 에너지 장치: 미래의 일

- **Brief overview given** of wave-energy device, based on extreme-wave amplification in a contraction. Showcased modelling with VPs & geometric numerical integrators.
- 미래의 일: optimisation, real-time control using Pontryagin's principle, surrogate modelling & ML.
- Experiment soliton interactions: `https://www.youtube.com/watch?v=cBhr0DnVclU`
- Laboratory realisation under development, for testing of submodels & wave-to-wire models.





감사합니다!

- Knotters, B, Lamb, Poortvliet 2024: How to cope with uncertainty monsters in flood risk management? *Water Prisms*. `https://doi.org/10.1017/wat.2024.4` (Nominated paper.)
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세 솔리톤의 상호작용의 차원 결과

Crossing seas (8 domains combined) `https://www.youtube.com/watch?v=EGhpQ7BM2jA`