VGOSWEC Analytical Sizing

**Inputs**

**Parameterization**

**Hydrodynamic Coefficients**

**Power Estimation**

Power estimates can be obtained based on two methods: (1) an unconstrained case in which the maximum pitch amplitude is not limited and power is estimated based on a constant PTO restoring coefficient; or (2) a constrained case in which the maximum pitch amplitude is limited to a maximum value defined by the user and PTO coefficients are defined based on the principle of complex conjugate control [1]. Both methods rely on the Haskind relation to obtain the pitch wave-excitation torque [2]:



Where is the wave group velocity,



The Haskind relation is valid for bodies with a vertical axis of symmetry, such as a spar or sphere, for which the excitation force is independent of the angle of incidence. Gomes et al. (2015) argue a bottom-hinge converter may be treated as an asymmetrical point absorber if the device width is small compared to the wavelength, hence providing validation for the use of the Haskind relation [3].

*Unconstrained Case:* If no limits are placed on the pitch amplitude of the VGOSWEC, the time-averaged power, per wave-amplitude squared, absorbed by an ideal PTO unit is determined by:



Where the coefficient is defined as,



The PTO damping coefficient for this case is then related to the wave radiation damping by,



*Constrained Case:* In this case, the pitch amplitude is limited to a defined value and the time averaged power is maximized by employing PTO coefficients based on complex conjugate control (reactive),



Where represents the ratio of constrained-to-optimal pitch angular velocity,



The PTO coefficients are then set to the following:





*Capture Width:* One possible metric to evaluate the power production for a given set of device parameters is the capture width:



Where is the device width and is the time-averaged wave power per unit crest-width:



**ACE Metric**

The ACE metric is a more comprehensive method for evaluating the techno-economic viability of a wave energy converter device which incorporates estimates of both power production and structural costs [4]:



Where is the average climate capture width, a modified capture width which consists of a weighted average of absorbed power for  sea states at a geographic location  divided by the incident wave energy flux:



Where is the scaling factor for the sea states and locations defined in the ACE metric methodology publication by Driscoll et al. (2018).

denotes the characteristic capital expenditure, a first-order estimate of structure costs based on a summation of the cost of structural materials for each material used in the device design. This estimate is based on the manufactured material cost per unit mass, , and the total mass of each material, :



*Estimation of ACCW:* Average climate capture width estimates are currently obtained for the unconstrained power estimation case only. As the metric is based on  sea states defined by their peak period and significant wave heights, it is necessary to incorporate a wave energy spectrum. In its most basic form, the energy spectrum is a superposition of the of energy components of each wave that contributes to an irregular sea state:



As a given spectrum is typically defined per water specific gravity (in units of m2/(rad/s)), the following relation can be defined between the spectrum and wave amplitude,



Here, the Bretschneider Spectrum is elected for use,



Where is the modal frequency and is the significant wave height.

The expression presented in can be used in conjunction with the time-averaged power per wave-amplitude squared to obtain the time-averaged device power, which is done by integrating the expression over the range of input frequencies:



Since , , and  are computed at each defined frequency step, this is expression is integrated numerically:



*Estimation of CCE:* The characteristic capital expenditure is calculated based solely on the material mass of the device and foundation. Here, the device is assumed to be primarily composed of structural steel while the foundation is assumed to be reinforced concrete:



Or if a mass ratio  of structure to sea water is used,



Where is the density of sea water.

Similarly, the mass of the foundation, assumed to be a cylinder, is estimated as:



Here the height of the foundation is simply the difference between the water depth  and the device height . The diameter is parameterized such that the ratio of the volume of the device to the volume of the structure remains constant:





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**Foundation Load**

**Hydrodynamic Efficiency**

*Wave kinetic energy:* The average kinetic energy carried in a wave, per unit surface area, is:



[Dean and Dalrymple p.97, eq. 4.73]

Evaluating at the generic bounds *x*1 , *x*2 and *z*1, *z*2 yields:





Which is then evaluated at the bounds,



½ in theta\_dot

Time-averaged integration of energy, NOT over wavelength

*Wave kinetic energy:* The time-averaged kinetic wave energy across a plane at position *x*, per unit surface area, is:



[Dean and Dalrymple p.97, eq. 4.73]

Evaluating at the generic bounds *t*1 , *t*2 and *z*1, *z*2 yields:





The pressure beneath a progressive wave is:

 (D&D p83)









Evaluate for a flap with *c* = 0.5 m (dist from seabed) and *w* = 0.5 m:



With,



Maximum occurs at *x*=0, *t*=0:





If we neglect the hydrostatic term, as it is balanced on both sides) and only consider the dynamic term, the resulting force is:



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[1] N. Tom, Y.-H. Yu, and A. Wright, “Balancing the Power-to-Load Ratio for a Novel Variable Geometry Wave Energy Converter with Nonideal Power Take-Off in Regular Waves,” p. 11, 2017.

[2] J. N. Newman, “The Exciting Forces on Fixed Bodies in Waves,” *J. Ship Res. Soc. Nav. Archit. Mar. Eng.*, vol. 6, no. 4, Dec. 1962.

[3] R. P. F. Gomes, M. F. P. Lopes, J. C. C. Henriques, L. M. C. Gato, and A. F. O. Falcão, “The dynamics and power extraction of bottom-hinged plate wave energy converters in regular and irregular waves,” *Ocean Eng.*, vol. 96, pp. 86–99, Mar. 2015, doi: 10.1016/j.oceaneng.2014.12.024.

[4] F. R. Driscoll *et al.*, “Methodology to Calculate the ACE and HPQ Metrics Used in the Wave Energy Prize,” NREL/TP--5000-70592, 1426063, Mar. 2018. doi: 10.2172/1426063.

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