PARAMETRIZING DUNE RESILIENCE FROM COLLISION THROUGH INUNDATION

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Numerous studies have identified the protective benefit provided by dunes in shielding upland assets. However, dunes are susceptible to erosion. Breaches, overwash or significant overtopping of a dune are all associated with greater damages to upland infrastructure. Therefore, reliable tools are needed to efficiently assess the likelihood and magnitude of dune erosion during storm events. Existing methods rely on numerical modeling (extensive investment) or insufficiently parameterize the system. To fill this gap, a fragility model using a newly developed dune Engineering Demand Parameter (EDP) was introduced (Janssen and Miller 2022).

Conceptually, the EDP is similar to the Shield's parameter in that it represents the ratio of mobilizing terms to stabilizing terms (Eq. 1). Physically, the EDP is a measure of storm intensity over a dune's resilience (R_f). Storm intensity is characterized by the Peak Erosional Intensity (PEI), derived from the Storm Erosion Index which combines a water levels and wave heights in a physically meaningful way (Miller and Livermont 2008).

$$EDP = \frac{IM}{R_f} \qquad (1)$$

Fragility is modeled using the EDP as an input to a Weibull CDF and fit to an observational dataset (Eq. 2). The return (P) is a probabilistic estimate of a categorical dune response. Damage classification is categorical, based on the percentage of dune volume eroded during a storm (Table 1).

$$P(C|EDP) = 1 - exp\left(\frac{-EDP}{\lambda}\right)^{\kappa} \qquad (2)$$

The dune EDP was developed specifically for forecasting applications (i.e., applications with limited time and data). This necessitated an effort to minimize the number of resilience parameters. Variable reduction was guided by two principles; first, eliminating highly correlated values and secondly, retaining parameters that could obtained easily or from remote sensing (e.g., aerial photos). Dune resilience was quantified by both the dune volume and berm width.

Janssen and Miller tested several forms of the EDP which physically modeled the beach system in terms of shear, moment, and mass-moment of inertia (Table 2). They identified the optimal EDP was dependent on the physical regime the dune was subjected to. In collision regimes, the berm width had greater power, with the EDP taking a similar form to the Erosive Resistance parameter introduced by Judge et al. (2003). However, during extreme storms, with elevated water levels, they noted the effect the berm was attenuated, reducing from a squared to a unity parameter.

Table 1: Damage Classes

Class	Dune Volume Loss (%)	Interpretation
Minimal	< 5%	No quantifiable impact
Moderate	5% to 40%	Visually apparent erosion/scarping
Major	> 40%	Overwash likely; onset of damages upland

Table 2: Select modeled forms of the EDP

Select EDP Forms	Physical Proxy
$\frac{PEI^2}{(Berm\ width^2 + Dune\ vol)}$	Shear
$\frac{PEI^3}{(Berm\ width\ x\ Dune\ vol)}$	Moment
$\frac{PEI^4}{(Berm\ width^2\ x\ Dune\ vol)}$	Simplified Mass-moment of Inertia

This is physically attributed to the berm being inundated and is physically akin to the attenuating effect of submerged breakwaters during elevated water levels. Here, the mandate of easily obtained beach parameters is relaxed, allowing a more thorough analysis of the contributions of the specific and previously neglected beach parameters (e.g., foreshore slope).

A combination of statistical, numerical models and machine learning techniques are applied to test new forms of the EDP throughout Collision, Overwash and Inundation events (Sallenger 2000). The dataset consists of a spatially and temporally diverse observational dataset including 865 profiles distributed over 18 storms (Figure 1).

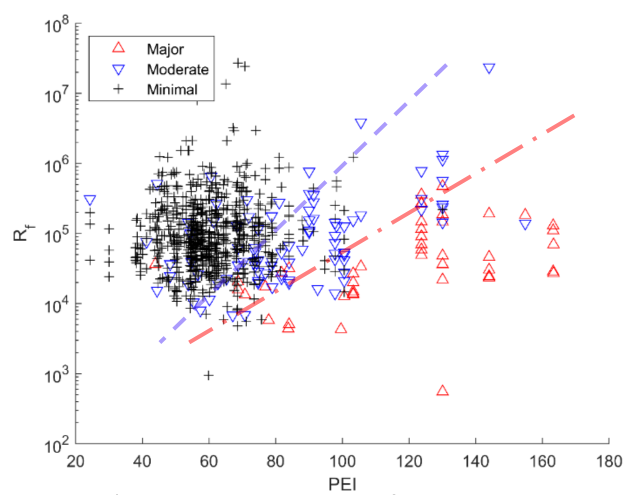

Figure 1 - Individual components of the EDP, storm intensity (x-axis) and dune resilience (y-axis) and observed dune erosion outcomes. Failure planes denoted by horizontal lines.

The objective of the work is twofold. The first is to provide specific guidance as to the where the resilience of a berm and dune system should be modeled as a mass-moment of inertia vs a moment system. The second is if a single form for the EDP can be formulated to model the beach behavior for Collision through Inundation regimes by modification or incorporation of additional and previously neglected parameters necessitated by the operational constraints.

The significance of the physical proxy (e.g., moment, etc.) has implications to optimization of the dune configuration. Consider an analogy between a dune and a beam, with the berm (depth) and dune volume (area) akin to the web and flange, respectively. If the volume of the dune is analogous to the cross-sectional area of steel and an indicator of material cost, then a more efficient geometric shape can potentially imply more cost-effective dunes.

REFERENCES

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