# THE COASTAL STORM IMPULSE (COSI) PARAMETER FOR QUANTIFICATION OF FRAGILITY CURVES IN COASTAL DESIGN

D.R. Basco[1]

**Paper Topic :** Coastal risks and management, including climate changes

## 1. Fragility Curves, Risk, and Resiliency

Fragility curves are functions that describe the probability of failure that is dependent on the “load” (i.e. force) over the full range of the “loads” to which the coastal system might be exposed. (Schultz, Gouldby, Simm, and Wibowo, 2010). These authors discuss four methods (judgemental, empirical, analytical (models) and hybrid combinations) to develop fragility curves. How to define the “load” for coastal systems is not discussed. Herein, we define the “load” as the coastal storm.

The probability of failure is the convolution of the probability of exceedance for the hazard (i.e. coastal storm) and the probability of coastal system damage from the hazard (Kamphuis, 2010). Coastal risk is then simply the summation of the probability of failure times all the consequences (economic (structural, functional), loss of life, environmental, etc.) over the full range of coastal storms.

Resilience is the ability of a system to maintain and recover its structural and functional performance following a disturbance. (Schultz, McKay, and Hales, 2011). The “disturbance” is the short-term excess of forces (i.e., the load or coastal storm) acting on the coastal system components and processes that may impair the system function. These authors discuss three types of resilience (ecological, engineering, community) for coastal systems; focus on engineering resilience; and cite the Saffir-Simpson wind speed scale for hurricanes as an example of a coastal storm disturbance scale. If the level of disturbance (coastal storm) exceeds a critical level, both the level of performance impairment and the duration of performance impairment may exceed management objectives for the resilience of the coastal system.

Clearly, fragility curves are needed to quantify risk and hence resilience in coastal systems design. The intensity of the “load” or “disturbance”, i.e. the severity of the coastal storm must be quantified to develop fragility curves. Excess water levels (storm surge), wave conditions (height, period, direction) and storm duration all contribute to the intensity of a coastal storm. How to combine these three factors has long been a concern of coastal scientists and engineers.

## 2. The Coastal Storm Impulse (COSI) Parameter

A new, coastal storm strength parameter was first introduced by Basco and Klentzman (2006) with subsequent statistical analysis (Basco et al. 2008) and application to understand onshore/offshore sediment transport processes (Basco and Walker, 2010). The Coastal Storm Impulse (COSI) parameter is based on the conservation of linear, horizontal momentum to combine elevated water levels (storm surge) and storm wave conditions in the nearshore zone. The momentum is then integrated over storm duration to determine the storm impulse on the coast. In effect, the storm’s momentum approaching the coastline is changed by the coastal land mass (bathymetry, topography, man’s infrastructure) to develop this impulse ( Newton’s 2$^{nd}$ Law, “Impulse equals the change in momentum”). These efforts cited above all employed (1) the maximum, nonlinear wave momentum flux following Hughes (2004) and (2) the storm surge hydrograph to calculate the storm surge momentum and is herein called the “original” COSI method.

[1]Old Dominion University, dbasco@odu.edu

Analysis of 249 coastal storms over a 10 year period (1994-2003) of measured data at the Corps of Engineers, Field Research Facility (FRF), Duck, NC showed the need to modify the original method to (1) use the mean, nonlinear wave momentum flux, and (2) use only the spikes in storm surge when elevated water levels are above the mean high water level of the tide. This "modified" COSI method is the subject of ongoing research ( Mahmoudpour, 2012, PhD dissertation, in progress). Figure 1 displays the results for Hurricane IRENE (Aug 25-28, 2011) using data from the FRF. The wave momentum (green, 49%) balances the surge momentum (blue, 51%) for this modified method. The total momentum (red) integrated to about 630,000 N-Hrs/m. (The "original" COSI method was too heavily skewed toward wave momentum (90%) and the total was 10 times larger). We now feel confident that this modified COSI parameter captures the true, combined total strength of each coastal storm as one number for a fixed location at the coast. Figure 2 displays the results for Hurricane ISABEL (Sep 15-20, 2003) with duration 3 times longer and 3 times more total momentum . The paper will present full details of the modified method.

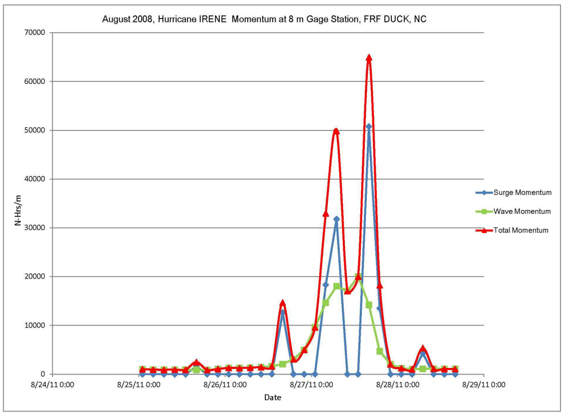


Figure 1. Plot showing Aug 2011 Hurricane IRENE (Momentum at 8 m water depth, FRF, Duck, NC)

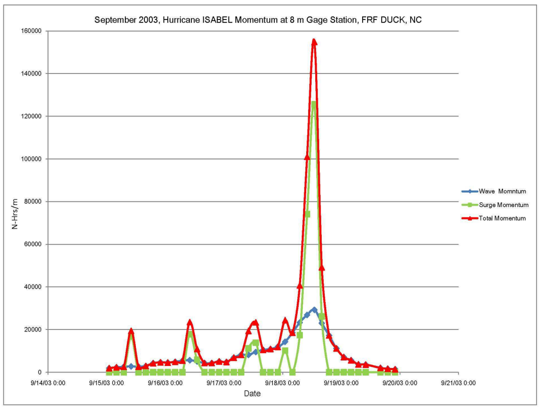


Figure 2. Plot showing Sep 2003 Hurricane ISABEL (Momentum at 8 m water depth, FRF, Duck, NC)

## 3. Applications of the COSI Parameter in Coastal Engineering

Whenever and wherever all three storm intensity parameters (water levels, waves and storm duration) are important, the COSI parameter (modified) can be used to develop fragility curves for use in quantifying risk and resilience. For example, in rubble-mound structures design, "damage" curves can be modified as a function of the COSI parameter and not just wave heights above the design wave height. In vertical seawall design, the wave run up and overtopping rates depend on both storm water level and wave conditions so that the COSI parameter is better suited to develop a fragility curve for design. In beach nourishment design, study is underway (Pezza, 2012, Dr.Engng, in progress) for use of fragility curves with the COSI parameter to replace the Monte Carlo method in the Beach-fx model (Gravens, Males, and Moser, 2007). This paper will present the results of this effort.

A second application is to develop a Coastal Storm Strength Index (for water levels, waves and duration) for the media and general public that is NOT a wind speed scale (Saffir-Simpson) and holds for both tropical and extra-tropical storms.

A third application is to develop numerical models to calculate the COSI storm intensity in time as the storm moves toward the coast.

The long term goal is to understand and quantify the "evolution" of resilience (Schultz, McKay, and Hales, 2012) associated with potential, accelerated sea-level rise rates. Use of the COSI parameter to quantify fragility curves is the first step.

## 4. References

Basco, D.R. and C. Klentzman (2006): "On the Classifications of Coastal Storms Using Principles of Momentum Conservation", Proceedings, ICCE 2006 (San Diego), ASCE, NY, Vol. 2, 1407-1419.

Basco, D.R., N. Mahmoudpour and C. Klentzman (2008): "Statistical Analysis of the Coastal Storm Impulse (COSI) Scale at the Corps of Engineers, FRF, Duck NC", Proceedings, ICCE 2008 (Hamburg), ASCE, NY, Vol. 6, 4134-4142

Basco, D.R. and R.A. Walker (2010) "Under What Conditions Do Coastal Storm Events Produce Onshore Sediment Transport", Proceedings, ICCE 2010 (Shanghai), ASCE, NY, Vol.

Gravens, M.B., Males, R.M., and D.A. Moser (2007) " Beach-fx: Monte Carlo Life-Cycle Simulation Model for Estimating Shore Protectioin Project Evolution and Cost Benefit Analyses", Shore & Beach, Vol 75, No. 1, 12-19.

Hughes, S. A. (2004) " Wave Momentum Flux Parameter: A Descriptor for Nearshore Waves", Coastal Engineering, Vol 51 1067-1084

Schultz, M.T., S. K. McKay, and L. Z. Hales (2011) "The Quantification and Evolution of Resilience in Integrated Coastal Systems, ERDC-TR-11-XX (Draft), Vicksburg, MS, US Army Corps of Engineers.

Schultz, M.T., B.P. Gouldby, J.D. Simm, and J.L. Wibowo (2010) "Beyond the Factor of Safety: Developing Fragility Curves to Characterize System Reliability, ERDC-SR-10-1, Vicksburg, MS, US Army Corps of Engineers