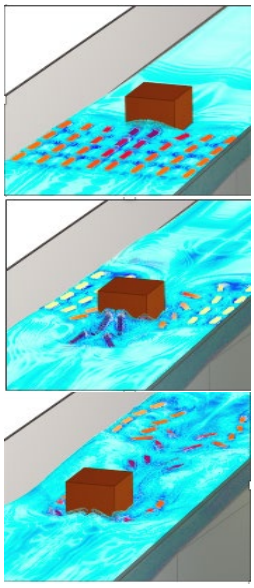
# Hydro-UQ Application Summary (V2.0)

Hydro-UQ is a desktop application that enables the user to analyze the effects of waterborne hazards (i.e., tsunamis and storm surges), including uncertainty characterization, on structures. The application allows users to simulate events at project sites (prototype scale) and in pre-calibrated digital twins of experimental wave flumes (model scale). Hydro-UQ includes three key modules: (i) far-shore wave hazard development via GeoClaw, (ii) near-shore / on-shore wave evolution through computational fluid dynamics (CFD) simulations using OpenFOAM, and (iii) structural-geotechnical response of the built environment. Both deterministic and probabilistic simulations are supported. In probabilistic simulations, random variables can represent uncertainties in the hazard, the structural model, and the numerical simulation solver. These uncertainties are automatically propagated through the simulation to arrive at a probabilistic description of structural response. Probabilistic simulation results can be further processed to perform sensitivity analysis or train surrogate models.

## USE CASES

### Virtual Wave Flume Simulation

HydroUQ's digital twins support and complement physical wave-flume experiments. Pre-built models that replicate relevant geometric and flow characteristics of flume facilities (e.g., Oregon State University's Large Wave Flume) are available. Users can drop-in structural models (rigid, elastic, elasto-plastic) and instrumentation (e.g. wave-gauges, velocimeters, piezometers) for blind studies of future tests, replication of existing studies, and same-day simulation of experiments. Wave flow conditions (e.g., wave-type, period, significant height, direction, standing water level) are fully customizable and generatable with the wave lab facility's mechanisms (pistons, pumps, etc.), far-shore mechanisms (seismic faults via GeoClaw), or user-inputs. Users can adapt digital twins to account for facility specifications that influence experimental conclusions (e.g., bathymetry friction) via simulated sensitivity analysis that are infeasible in physical flumes. Users receive uncertainty quantified engineering demands for their structures (e.g., local pressure fluctuations on façades, integrated story loads, structural component displacements). Similitude laws (e.g., Froude, Reynolds, Cauchy) can be explored with digital scaling, elucidating experiment applicability to real-world hazards.



### Fluid-Structure Interaction Studies

Users can employ two-way, wave-structure interaction via pre-coupled OpenFOAM and OpenSees simulations to observe complex phenomena, ranging from strong wave-surges displacing a building's second-story to subsequent ponding on a concrete ceiling slab nonlinearly amplifying center-span sagging.

### Water Load Generator for Probabilistic Assessment

Water loads on the structure can be generated using CFD models. The CFD events provide a versatile workflow to compute transient water loads for any building geometry and water exposure condition. For structural models, Hydro-UQ can import OpenSees models defined in Tcl or Python. The user can specify which response quantities, i.e., engineering demand parameters (EDPs), to record and random variables in the structural model.

## CURRENT CAPABLITIES

**Water Event Selection:** Users are provided with multiple paths for water borne hazard generation:

- Generate/record integrated loads and point pressure measurements by creating and running a CFD model on DesignSafe.
- Run GeoClaw, a widely used shallow-water solver vetted for tsunamis / storm surges, via the graphical user interface.
- Define and adjust prebuilt, digital twin wave-makers (1D / 2D pistons, pumps, gravity head).
- For advanced users, full authority is provided to input hydrodynamic files from tools of their choice.

**Structural Model:** Defines the structural modeling approach and returns the scripts required to perform the response simulation. One or more models can be assigned to a workflow. Using more than one model allows for benchmarking and epistemic uncertainty analysis. The following options are available:

- Provide your own OpenSees model in Tcl or Python format.
- Provide a Python script that prepares a structural model and performs the response simulation.
- Automatically generate an idealized shear column model in OpenSees from basic building information.

**Response Simulation:** Defines the analysis options that will be used to perform the numerical simulation, e.g., time integration strategy, convergence criteria, and damping options. The user-specified modeling tool is used to perform the simulation and collect the requested response quantities.

**Uncertainty Quantification:** Samples the prescribed random input variables and obtains realizations of the outputs by executing the workflow with each input realization from the generated sample. The underlying UQ engines let you leverage the following techniques in your research:

- Forward propagation: Define a set of random input parameters and perform simulations to obtain a corresponding sample of output parameters and their statistics.
- Sensitivity analysis: Measure the influence of the uncertainty in each input on the uncertainty of outputs.
- Reliability analysis: Algorithms to estimate the probability of exceeding a failure surface.

## UPCOMING CAPABILITIES

- Digital Wave Flume II: An automatically generated CFD model for simulating water loads on an isolated building with arbitrary shape defined by an STL surface. (Sep 2023)
- Ability to use multi-model approaches for building response simulation. (Sep 2023)
- Hydrodynamic database creation employing CFD simulations. (Oct 2023)
- Digital Wave Flume III: CFD model for evaluating water loads on a building with complex surrounding configuration – multiple buildings around it. (Jan 2024)
- Multi-fidelity Monte Carlo routines to utilize lower cost computational models along with higher fidelity models to reduce computational time while preserving accuracy (Jan 2024)
- Surrogate Base Response Estimation for Water: surrogate models for predicting the response of a water-loaded building for several fluid and structural parameters. (Mar 2024)

## MORE INFORMATION

The software application, examples, and information about previous releases can be found in the documentation accessible from the Hydro-UQ website at https://simcenter.designsafe-ci.org/research-tools/hydro-uq/.