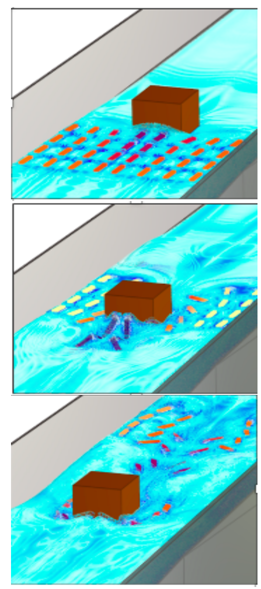
Hydro-UQ Application Summary (V3.1.0)

Hydro-UQ is a free, open-source 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 simulates 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 or the Material Point Method, and (iii) structural-geotechnical response of the built environment in OpenSees. Both deterministic and probabilistic simulations are supported. In probabilistic simulations, random variables can represent uncertainties in the hazard, the structural model, and the numerical solver. These uncertainties are automatically propagated through the simulation to arrive at a probabilistic description of structural response. Probabilistic results may lead into sensitivity analysis, surrogate model training, and more. To accelerate and democratize high-fidelity 3D CFD, Hydro-UQ sends intensive workflows to supercomputers for users with a free DesignSafe account.

USE CASES

Virtual Wave Flume Simulation



Hydro-UQ'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. 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, still 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 custom inputs. 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. Receive uncertainty quantified engineering demands for modelled structures (e.g., local pressure fluctuations on façades, integrated story loads, building-story 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

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. Hydro-UQ's versatile workflow computes transient water loads for any building geometry and water exposure condition. For complex structures, Hydro-UQ imports OpenSees models with either a Tcl or Python script. Capture randomness in the structural model parameters using popular distributions (Normal, Lognormal, Beta, Uniform, Weibull, Gumbel). Specify the response quantities, i.e., engineering demand parameters (EDPs), to record, or use presets for typical hazard scenarios.

CURRENT CAPABLITIES

Water Event Selection: Hydro-UQ provides multiple paths for water-borne hazard generation:
- Generate integrated loads and point pressures by creating and running a CFD model on DesignSafe.
- Model 3D, validated debris with elastic / elasto-plastic materials both near- and on-shore using MPM.
- Couple GeoClaw, a shallow-water solver vetted for tsunamis / surges, to OpenFOAM via the GUI.
- Define and adjust prebuilt digital twin wave-makers (1D / 2D pistons, pumps, pressure head release).
- 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.
- Generate shear column models automatically from basic building information in OpenSees.

Response Simulation: Defines analysis options for the numerical simulation, e.g., time integration strategy, convergence criteria, and damping options. Select a modeling tool to perform the simulation and collect the requested or preset 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 enable you to leverage the following techniques to strengthen 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

- Generative AI: Debris generation from both text (“a big school bus”) and image prompts. (Jul 2024)
- Multi-Model Response: Support multi-model approaches for building response simulation. (Jul 2024)
- Digital Twins IV, V: Capture loading with quantified uncertainty at a structural apparatus component granularity. OSU Directional Wave Basin. (Aug 2024), VI: Hannover Large Wave Flume (Nov 2024)
- Hydrodynamic Database Creation: Employ results from multiple numerical methods (e.g. MPM, FVM), experiments, and real-world events from the DesignSafe Data Depot. (Sep 2024)
- Multi-fidelity Monte Carlo: Routines to utilize lower cost computational models along with higher fidelity models to reduce computational time while preserving accuracy. (Oct 2024)
- Surrogate Impact and Damming Load for Debris: Surrogate models to predict the structural response during multi-debris impacts and damming for various debris-field parameters. (Oct 2024)
- Structural Component Damage and Building Collapse: Physics-based 3D damage, validated by experiments, which extends to full collapse with debris generation/advection/deposition. (Dec 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/.

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