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# VAWS user manual

*Release 2.0*

**Geoscience Australia**

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**CHAPTER  
ONE**

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## **INTRODUCTION**

Vulnerability and Adaptation to Wind Simulation (VAWS) is a software tool that can be used to model the vulnerability of small buildings such as domestic houses and light industrial sheds to wind. The primary use-case of VAWS is the examination of the change in vulnerability afforded by mitigation measures to upgrade a building's resilience to wind hazard.

### **1.1 Background**

Development of VAWS commenced in 2009-2010 in a collaborative project, partly funded by the then Department of Climate Change and energy Efficiency (DCCE), between Geoscience Australia, James Cook University and JDH Consulting [2][7]. The development of the current version was undertaken as part of the Bushfire and Natural Hazard Cooperative Research Centre (BNHCRC) project “Improving the Resilience of Existing Housing to Severe Wind” led by James Cook University.

### **1.2 Overall logic**

The VAWS tool takes a component-based approach to modelling building vulnerability. It is based on the premise that overall building damage is strongly related to the failure of key connections.

The tool generates a building model by randomly selecting parameter values from predetermined probability distributions using a Monte Carlo process. Values include component and connection strengths, external pressure coefficients, shielding coefficients, wind speed profile with height, building orientation, debris damage parameters, and component masses.

Then, for progressive gust wind speed increments, it calculates the forces in all critical connections using influence coefficients, assesses which connections have failed and translates these into a damage scenario and costs the repair. Using the repair cost and the full replacement cost, it calculates a damage index for each wind speed.

For more details, see *Chapter 5*.

### **1.3 Key features**

- Component-based approach:

A house is modelled consisting of a large number of components, and overall damage is estimated based on damage to each of the components.

- Uncertainty captured through a Monte-Carlo process:

Various uncertainties affecting house performance are modelled through a monte-carlo process.

- Inclusion of debris and water ingress induced damages:

In addition to the damage to the connections by wind loads, debris and water ingress induced damages are modelled.

- Internal pressurisation:

Internal pressure coefficients are calculated at each wind speed following the procedures of AS/NZS 1170.2 (Standards Australia, 2011) using the modelled envelope failures to determine envelope permeability.

## 1.4 Key uncertainties

The Monte Carlo process capture a range of variability in both wind loading and component parameters. The parameter values are sampled for each model and kept the same through the wind steps.

- Wind direction

For each house, its orientation with respect to the wind is chosen from the eight cardinal directions either randomly, or by the user.

- Gust wind profile

Variation in the profile of wind speed with height is captured by the random sampling of a profile from a suite of user-provided profiles.

- Pressure coefficients for zones and coverages

Pressure coefficients for different zones of the house surfaces envelope are randomly chosen from a Type III (Weibull) extreme value distribution with specified means for different zones of the house envelope, and specified coefficients of variation for different load effects.

- Construction level (or quality)

Multiple construction levels can be defined with mean and coefficient of variation (CV) factors which will be used to adjust the mean and CV of distribution of connection strength.

- Strength and dead load

Connection strengths and dead loads for generated houses are sampled from lognormal probability distributions.

## 1.5 Caveats and limitations

VAWS has been designed primarily as a tool for assessing vulnerability of houses to wind hazard. The simulation outcomes should be interpreted as vulnerability of a group of similar houses on average, even though an individual house is modelled. In other words, the tool is not capable of predicting performance of an individual house for a specific wind event.

## GETTING STARTED

This chapter provides instructions on how to install and run the code for general users. Also it provides instructions for developers on how to install, test and build the package of the code. These instructions have been tested on *Windows 7*, *Linux*, and *OS 10.11.x* and is expected to work on most of modern operating systems.

### 2.1 Instructions for general users

#### 2.1.1 Installation

The VAWS code currently runs with Python 2.7 with many dependencies. It is recommended to create a Python environment dedicated to the code without disrupting the existing environment. With conda, you can manage environments easily. Instructions below are based on conda, but virutalenv can be used alternatively.

##### 1. Install Miniconda

Download and install Miniconda(<https://conda.io/miniconda.html>) with Python 2.7. This step can be skipped if either Miniconda or Anaconda with Python 2.7 is already installed.

- Windows
  - Double-click the downloaded *Miniconda2-latest-Windows-x86\_64.exe* file.
  - When installation is finished, from the *Start* menu, open the *Anaconda Prompt*.

- Linux
  - In Terminal window, run

```
$ bash Miniconda2-latest-Linux-x86_64.sh
```

- Mac
  - In Terminal window, run

```
$ bash Miniconda2-latest-MacOSX-x86_64.sh
```

##### 2. Create a conda environment.

In the terminal client, enter the following command to create the environment called *vaws\_env*.

```
conda create -n vaws_env python=2.7
```

##### 3. Activate the environment.

In the terminal client, enter the following to activate the environment.

- Windows

```
activate vaws_env
```

- Linux/Mac

```
source activate vaws_env
```

### 4. Install the code from conda channel

In the terminal client, enter the following to install the code.

```
conda install -c crankymax vaws
```

In case you see *PackageNotFoundError: Packages missing in current channels:* then enter the following in the terminal client and try above command again.

```
conda config --add channels conda-forge
```

### 2.1.2 Updating

In case new version of the code is available, you may update the code. The conda environment *vaws\_env* should be activated first as [2.1.1 step 3](#). And then enter the following commands in the terminal to remove the old version and re-install the new version of the code.

```
conda remove vaws
conda install -c crankymax vaws
```

### 2.1.3 Running through GUI

To run the code, the conda environment *vaws\_env* should be activated first as [2.1.1 step 3](#). And then enter the following command in the terminal.

```
vaws
```

The default scenario will be loaded as shown in [Fig. 2.1](#). See [chapter 4](#) for details.

## 2.2 Instructions for developers

The development of the code is tracked using the git version control system. The source code is at <https://github.com/GeoscienceAustralia/vaws>.

### 2.2.1 Installation

#### 1. Get the source code

Source code can be copied by cloning the git repository or downloading the zip file from the git repository.

- If git is installed, run the following command in the terminal

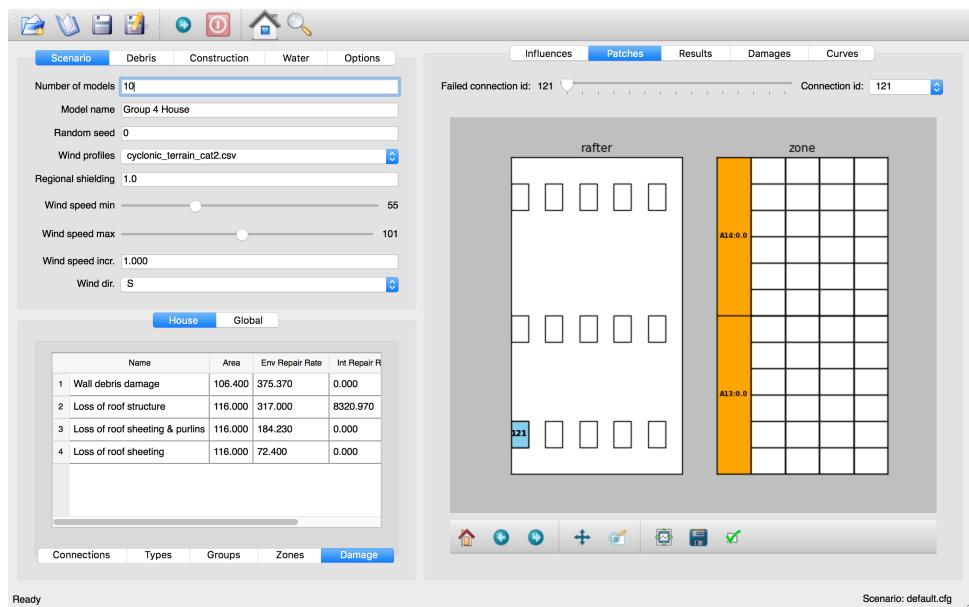


Fig. 2.1: Program main window with default scenario loaded

```
$ git clone git@github.com:GeoscienceAustralia/vaws.git
```

- Otherwise download the zip file (<https://github.com/GeoscienceAustralia/vaws/archive/master.zip>) and then extract it.

This step will create directory called <vaws dir>.

## 2. Create a conda environment.

Make sure either miniconda or anaconda is installed. Otherwise install either Miniconda or Anaconda with Python 2.7 as [2.1.1 step 1](#). Then create the environment called *vaws\_env*. by entering the following command in the terminal.

- Windows

```
cd <vaws dir>
conda env create --name vaws_env --file vaws_win.yml
```

- Linux/Mac

```
cd <vaws dir>
conda env create --name vaws_env --file vaws_env.yml
```

This will create the environment called *vaws\_env*. The *vaws\_env* can be activated as [2.1.1 step 3](#).

## 3. Create GUI

To create the GUI of the code, enter the following commands in the terminal.

- Windows

```
cd <vaws dir>\vaws\gui
build.cmd
```

- Linux/Mac

```
cd <vaws dir>/vaws/gui  
./build.sh
```

#### 4. Run the code

The code can be run in either GUI or CLI mode.

- GUI

```
cd <vaws dir>  
python -m vaws.gui.main # for default scenario  
python -m vaws.gui.main -c <config_file> # for a specific scenario
```

- CLI

```
cd <vaws dir>  
python -m vaws.model.main -c <config_file> # for a specific scenario
```

### 2.2.2 Building the conda package

Steps for the conda package is described below. Please refer to (<https://conda.io/docs/user-guide/tutorials/build-pkgs.html>) for details.

#### 1. Install conda-build and anaconda-client

To build the package, you need to install *conda-build* and *anaconda-client* in the *conda root* environment not the *vaws\_env* environment. And then enter the following in the terminal.

```
conda install conda-build anaconda-client
```

#### 2. Build the package

In the terminal client, enter the following to build the package.

```
cd <vaws dir>/build  
conda-build .
```

At the end of the building, you should see something like below:

```
Updating index at /foo/anaconda2/conda-bld/noarch to make package  
→installable with dependencies  
INFO:conda_build.build:Updating index at /foo/anaconda2/conda-bld/noarch  
→to make package installable with dependencies  
Nothing to test for: /foo/anaconda2/conda-bld/osx-64/vaws-2.0.3-py27_1.  
→tar.bz2  
# Automatic uploading is disabled  
# If you want to upload package(s) to anaconda.org later, type:  
  
anaconda upload /foo/anaconda2/conda-bld/osx-64/vaws-2.0.3-py27_1.tar.bz2  
  
# To have conda build upload to anaconda.org automatically, use  
# $ conda config --set anaconda_upload yes  
  
anaconda_upload is not set. Not uploading wheels: []
```

#### 3. Upload to anaconda channel

In the terminal client, enter the following to upload the package to the channel.

```
anaconda login
anaconda upload <package>
```

### 2.2.3 Testing the code

To test the code, the conda environment *vaws\_env* should be activated first as *2.1.1 step 3*. And then enter the following command in the terminal.

```
nose tests -v vaws
```

You should see something similar to below.

```
test_distribute_damage_by_row (vaws.model.tests.test_simulation_batten.
    ↪TestHouseDamage) ... ok
test_calc (vaws.model.tests.test_stats.MyTestCase) ... ok
test_calc2 (vaws.model.tests.test_stats.MyTestCase) ... ok
test_calc_big_a_b_values (vaws.model.tests.test_stats.MyTestCase) ... ok
test_compute_arithmetic_mean_stdev (vaws.model.tests.test_stats.MyTestCase) ... ok
test_compute_logarithmic_mean_stdev (vaws.model.tests.test_stats.MyTestCase) ... ok
test_gev_calc (vaws.model.tests.test_stats.MyTestCase) ... ok
test_gev_calc2 (vaws.model.tests.test_stats.MyTestCase) ... ok
test_sample_lognormal (vaws.model.tests.test_stats.MyTestCase) ... ok
test_calc_zone_pressures (vaws.model.tests.test_zone.MyTestCase) ... ok
test_get_grid (vaws.model.tests.test_zone.MyTestCase) ... ok
test_is_wall (vaws.model.tests.test_zone.MyTestCase) ... ok
test_str2num (vaws.model.tests.test_zone.MyTestCase) ... ok

-----
Ran 93 tests in 56.053s

OK
```

### 2.2.4 Documentation

The VAWS user manual is generated using the Sphinx documentation tool (<http://www.sphinx-doc.org/en/1.7/>). The source code of the manual is located at the subdirectory called *docs* under *vaws* root directory. Both the *html* and *pdf* versions of the manual can be generated using the commands below:

```
cd <vaws dir>/docs
make html   # for html format
make latexpdf # for pdf format
```

The html version of the manual can be updated to the manual website (<http://geoscienceaustralia.github.io/vaws>) as below. Note that the *<build\_dir>* can be set in the *Makefile* in the *docs* directory.

```
cd <build_dir>/html
git checkout gh-pages
git commit -m <commit_message>
git push origin gh-pages
```

The pdf version of the manual can be accessed at <https://github.com/GeoscienceAustralia/vaws/tree/master/manual.pdf>.



---

**CHAPTER  
THREE**

---

## **INPUT AND OUTPUT**

The input data for a scenario consists of a configuration file and a large number of files located in three different directories. This chapter provides details of input data using the template of default scenario, which can be downloaded from <https://github.com/GeoscienceAustralia/vaws/blob/master/scenarios/default>. The folder structure of the default scenario is shown Listing 3.1, which consists of a configuration file (default.cfg) and input directory with three sub-directories (debris, gust\_envelope\_profiles, and house). The output file named *results.h5* is located in the output directory.

Listing 3.1: Folder structure

```
default
+-- default.cfg
+-- input
    +-- debris
        |   +-- debris.csv
        |
    +-- gust_envelope_profiles
        |   +-- cyclonic_terrain_cat2.csv
        |   +-- cyclonic_terrain_cat2.5.csv
        |   +-- cyclonic_terrain_cat3.csv
        |   +-- non_cyclonic.csv
        |
    +-- house
        +-- house_data.csv
        +-- conn_groups.csv
        +-- conn_types.csv
        +-- connections.csv
        +-- zones.csv
        +-- zones_cpe_mean.csv
        +-- zones_cpe_str_mean.csv
        +-- zones_cpe_eave_mean.csv
        +-- zones_edge.csv
        +-- coverages.csv
        +-- coverage_types.csv
        +-- coverages_cpe.csv
        +-- influences.csv
        +-- influence_patches.csv
        +-- damage_costing_data.csv
        +-- damage_factorings.csv
        +-- water_ingress_costing_data.csv
        +-- footprint.csv
        +-- front_facing_walls.csv
+-- output
    +-- results.h5
```

### 3.1 Configuration file

Each simulation requires a configuration file where basic parameter values for the simulation are provided. The configuration file can be created either by editing the template configuration file using a text editor or through GUI.

The configuration file consists of a number of sections, among which *main* and *options* are mandatory while others are optional. An example configuration file is shown in Listing 3.2.

Listing 3.2: Example configuration file: default.cfg

```
[main]
no_models = 10
model_name = Group 4 House
random_seed = 0
wind_direction = S
wind_speed_min = 55
wind_speed_max = 101
wind_speed_increment = 0.1
wind_profiles = 'cyclonic_terrain_cat2.csv'
regional_shielding_factor = 1.0

[options]
debris = True
differential_shielding = False
water_ingress = True
construction_levels = True
save_heatmaps = True

[debris]
region_name = Capital_city
staggered_sources = False
source_items = 250
boundary_radius = 24.0
building_spacing = 20.0
debris_radius = 200
debris_angle = 45
flight_time_mean = 2.0
flight_time_stddev = 0.8

[construction_levels]
levels = low, medium, high
probabilities = 0.33, 0.34, 0.33
mean_factors = 0.9, 1.0, 1.1
cv_factors = 0.58, 0.58, 0.58

[water_ingress]
thresholds = 0.1, 0.2, 0.5
speed_at_zero_wi = 50.0, 35.0, 0.0, -20.0
speed_at_full_wi = 75.0, 55.0, 40.0, 20.0

[fragility_thresholds]
states = slight, medium, severe, complete
thresholds = 0.02, 0.1, 0.35, 0.9

[heatmap]
vmin = 54.0
vmax = 95.0
vstep = 21.0
```

### 3.1.1 Main section

Parameters of the main section are listed in [Table 3.1](#). In the GUI window, they are displayed in the Scenario tab as box shown in [Fig. 3.1](#).

Table 3.1: Parameters of the main section

| Name                      | Name in GUI        | Description   |
|---------------------------|--------------------|---|
| no_models                 | Number of models   | number of models  |
| model_name                | Model name         | name of model   |
| random_seed               | Random seed        | a number used to initialize a pseudorandom number generator |
| wind_profiles             | Wind profiles      | file name of wind profile                                   |
| regional_shielding_factor | Regional shielding | regional shielding factor (default: 1.0)                    |
| wind_speed_min            | Wind speed min     | minimum wind speed (m/s)                                    |
| wind_speed_max            | Wind speed max     | maximum wind speed (m/s)                                    |
| wind_speed_increment      | Wind speed incr.   | the magnitude of the wind speed increment (m/s)             |
| wind_direction            | Wind dir.          | wind direction (S, SW, W, NW, N, NE, E, SE, or RANDOM)      |

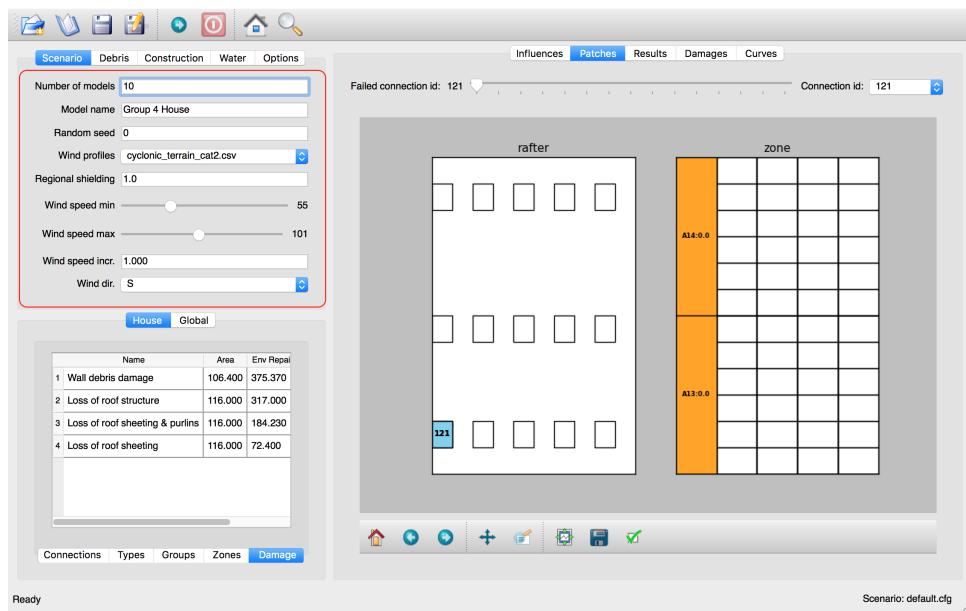


Fig. 3.1: Parameters of main section in the Scenario tab

### 3.1.2 Options section

Parameters of the Options section are listed in [Table 3.2](#). Note that all the parameter values of the option section should be chosen between *True (or 1)* or *False (or 0)*. In the GUI window, they are displayed in the Debris, Water, Construction, and Options tab as listed in the [Table 3.2](#).

Table 3.2: Parameters of options section

| Name                   | Name in GUI  | Description   |
|------------------------|--|---|
| debris                 | 'Enabled' tick box in the Debris tab                 | if True then debris damage will be simulated.               |
| differential_shielding | 'Differential shielding' tick box in the Options tab | if True then differential shielding effect is applied.      |
| water_ingress          | 'Enabled' tick box in the Water tab                  | if True then damage due to water ingress will be simulated. |
| construction_levels    | 'Enabled' tick box in the Construction tab           | if True then construction level will be sampled.            |
| save_heatmaps          | 'Save heatmaps' tick box in the Options tab          | if True then heatmap plot of each model will be saved.      |

### 3.1.3 Debris section

Parameters of the debris section are listed in Table 3.3. Note that debris section is only required if *debris* is set to be *True* in the options. In the GUI window, they are displayed in the Debris tab as box shown in Fig. 3.2.

Table 3.3: Parameters of debris section

| Name               | Name in GUI       | Description  |
|--------------------|-------------------|--|
| region_name        | Region            | one of the region names defined in the Listing 3.3. Each region has different debris source characteristics. |
| building_spacing   | Building spacing  | distance between debris sources (m)  |
| debris_radius      | Radius            | radius (in metre) of debris sources from the modelled house  |
| debris_angle       | Angle             | included angle (in degree) of the sector in which debris sources exist                                       |
| source_items       | Source items      | number of debris items per debris sources  |
| boundary_radius    | Boundary          | radius (in metre) of boundary for debris impact assessment   |
| flight_time_mean   | Flight time mean  | mean flight time of debris items   |
| flight_time_stddev | Flight time std   | standard deviation of flight time of debris items  |
| staggered_sources  | Staggered sources | if True then staggered sources are used. Otherwise, a grid pattern of debris sources are used.               |

### 3.1.4 Construction\_levels section

Parameters of the construction\_levels section are listed in Table 3.4. In the GUI window, they are displayed in the Construction tab as box shown in Fig. 3.3. The parameters are used as shown in (5.1).

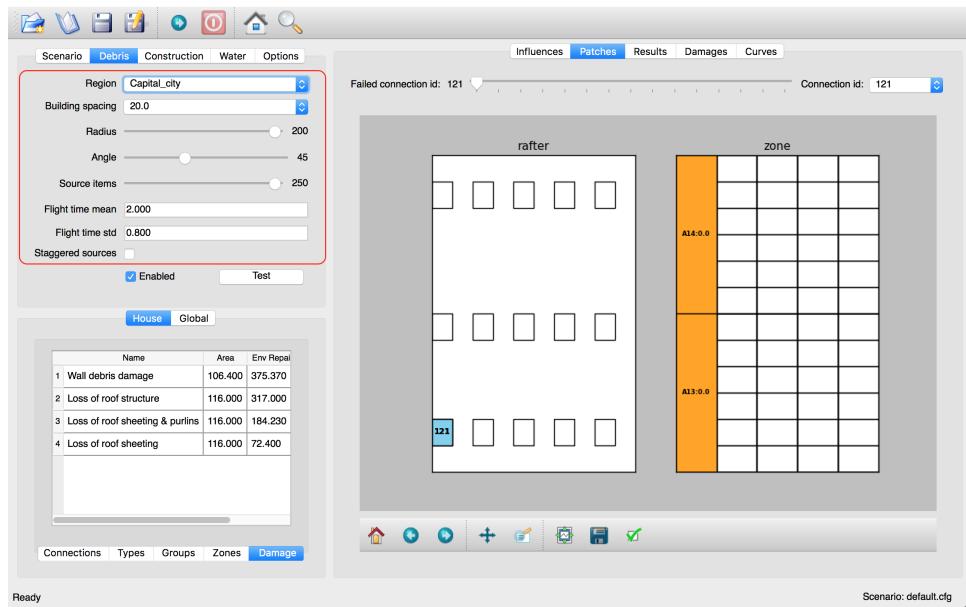


Fig. 3.2: Parameters of debris section in Debris tab

Table 3.4: Parameters of construction\_level section

| Name          | Name in GUI   | Description   |
|---------------|---------------|---|
| levels        | Levels        | comma separated list of construction levels (default: low, medium, high)  |
| probabilities | probabilities | comma separated list of probabilities of a modelled house being of a construction level (default: 0.33, 0.34, 0.33) |
| mean_factors  | Mean factors  | comma separated list of mean factors of construction levels (default: 0.9, 1.0, 1.1)                                |
| cv_factors    | CV factors    | comma separated list of CV factors of construction levels (default: 0.58, 0.58, 0.58)                               |

### 3.1.5 Water\_ingress section

Parameters of the water\_ingress section are listed in Table 3.5. In the GUI window, they are displayed in the Water tab as box shown in Fig. 3.5. The thresholds define a lower limit of envelope damage index above which the relevant water ingress vs wind speed curve is applied. The speeds at 0% water ingress and speeds at 100% water ingress define cumulative normal distribution used to relate percentage water ingress to wind speed as shown in Fig. 3.4.

Table 3.5: Parameters of water\_ingress section

| Name             | Name in GUI       | Description  |
|------------------|-------------------|--|
| thresholds       | DI thresholds     | comma separated list of thresholds of damage indices (default: 0.0, 0.1, 0.2, 0.5)                 |
| speed_at_zero_wi | Speeds at 0% WI   | comma separated list of maximum wind speed at no water ingress (default: 40.0, 35.0, 0.0, -20.0)   |
| speed_at_full_wi | Speeds at 100% WI | comma separated list of minimum wind speed at full water ingress (default: 60.0, 55.0, 40.0, 20.0) |

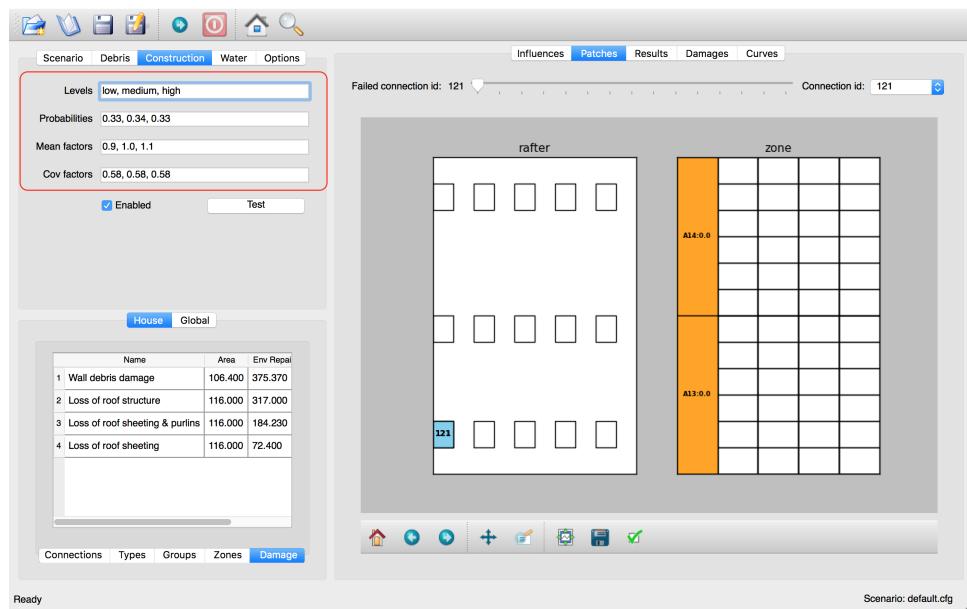


Fig. 3.3: Parameters of construction\_levels section in Construction tab

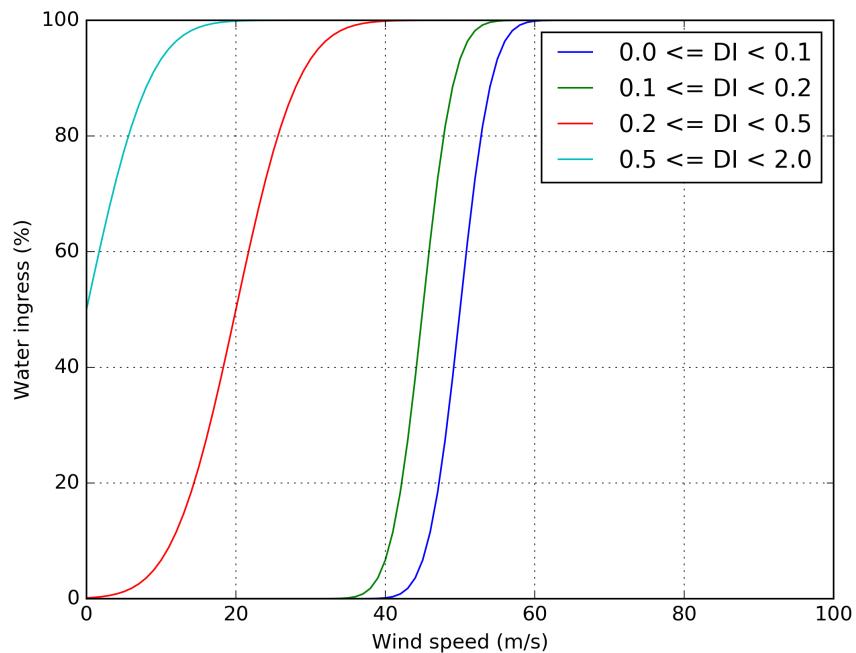


Fig. 3.4: Water ingress vs. wind speed for different ranges of damage index

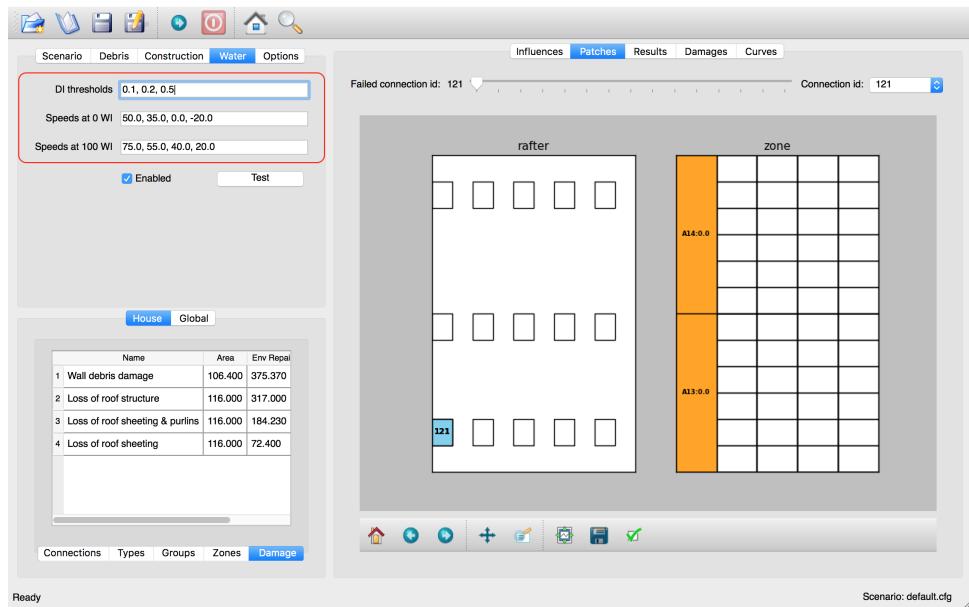


Fig. 3.5: Parameters of water\_ingress section in Water tab

### 3.1.6 Fragility\_thresholds

Parameters of the fragility\_thresholds section are listed in Table 3.6. In the GUI window, they are displayed in the Options tab as box shown in Fig. 3.6. The fragility thresholds are used as shown in (5.21).

Table 3.6: Parameters of fragility\_thresholds section

| Name       | Name in GUI   | Description   |
|------------|---------------|---|
| states     | Damage states | comma separated list of damage states (default: slight, medium, severe, complete) |
| thresholds | Thresholds    | comma separated list of damage states thresholds (default: 0.02, 0.1, 0.35, 0.9)  |

### 3.1.7 Heatmap

Parameters of the heatmap section are listed in Table 3.7. In the GUI window, they are displayed in the Options tab as box shown in Fig. 3.7

Table 3.7: Parameters of heatmap section

| Name  | Name in GUI  | Description                           |
|-------|--------------|---------------------------------------|
| vmin  | Lower limit  | lower limit of wind speed for heatmap |
| vmax  | Upper limit  | upper limit of wind speed for heatmap |
| vstep | No. of steps | number of steps                       |

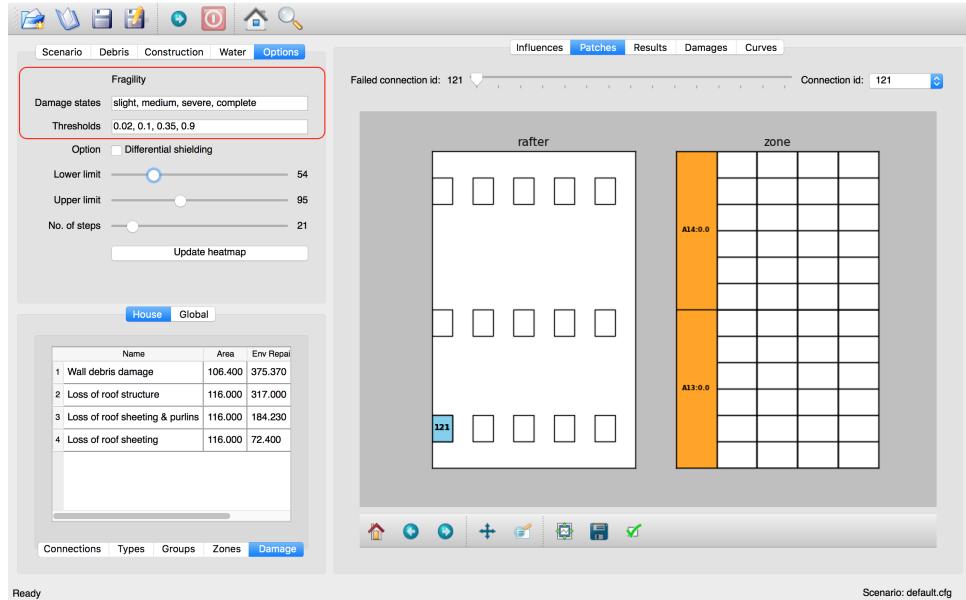


Fig. 3.6: Parameters of fragility\_thresholds section in Options tab

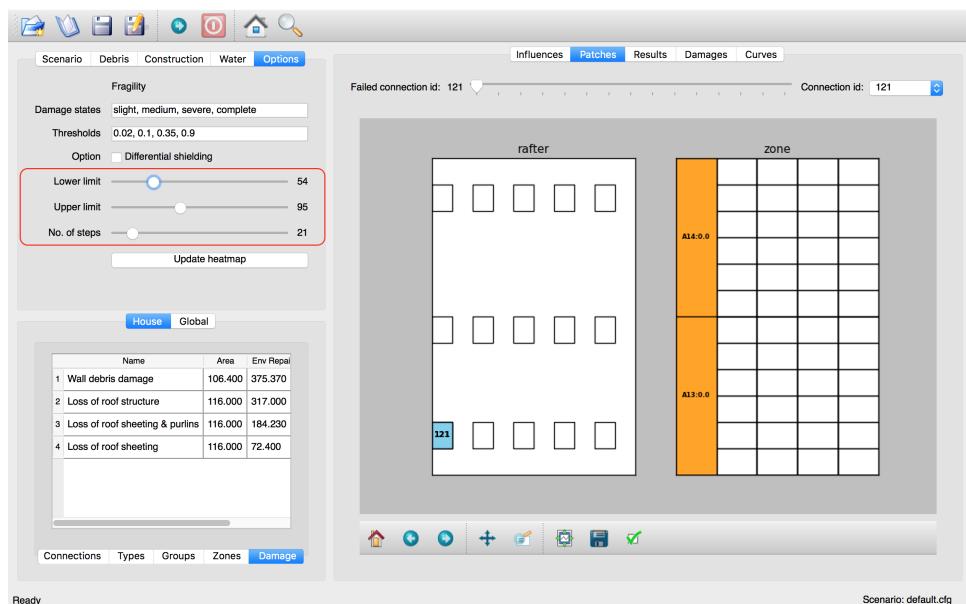


Fig. 3.7: Parameters of heatmap section in Options tab

## 3.2 Input file under *debris* directory

In the debris directory, *debris.csv* is located where parameter values related to windborne debris are defined. Three types of windborne debris are modelled, as listed in [Table 3.8](#), which include *Compact*, *Rod*, and *Sheet*. Parameter values for each debris type needs to be defined by unique region name, and the defined region name should be referenced in the configuration file.

An example *debris.csv* is shown in [Listing 3.3](#), in which debris parameters are defined for both *Capital\_city* and *Tropical\_town*. Note that *Capital\_city* is referenced in the example configuration file [Listing 3.2](#).

[Listing 3.3: Example debris.csv](#)

```
Region_name,Capital_city,Tropical_town
Compact_ratio,20,15
Compact_mass_mean,0.1,0.1
Compact_mass_stddev,0.1,0.1
Compact_frontal_area_mean,0.002,0.002
Compact_frontal_area_stddev,0.001,0.001
Compact_cdav,0.65,0.65
Rod_ratio,30,40
Rod_mass_mean,4,4
Rod_mass_stddev,2,2
Rod_frontal_area_mean,0.1,0.1
Rod_frontal_area_stddev,0.03,0.03
Rod_cdav,0.8,0.8
Sheet_ratio,50,45
Sheet_mass_mean,3,10
Sheet_mass_stddev,0.9,5
Sheet_frontal_area_mean,0.1,1
Sheet_frontal_area_stddev,0.03,0.3
Sheet_cdav,0.9,0.9
```

[Table 3.8: Debris types](#)

| Name    | Examples  |
|---------|---|
| Compact | Loose nails screws, washers, parts of broken tiles, chimney bricks, air conditioner units |
| Rod     | Parts of timber battens, purlins, rafters   |
| Sheet   | Roof cladding (mainly tiles, steel sheet, flashing, solar panels)                         |

The parameter values should be provided for each of the debris types as set out in [Table 3.9](#).

[Table 3.9: Parameters for each debris item](#)

| Name                | Note   |
|---------------------|--|
| ratio               | proportion out of debris in percent          |
| mass_mean           | mean of mass (kg)                            |
| mass_stddev         | standard deviation of mass (kg)              |
| frontal_area_mean   | mean of frontal area ( $m^2$ )               |
| frontal_area_stddev | standard deviation of frontal area ( $m^2$ ) |
| cdav                | average drag coefficient                     |

### 3.3 Input files under *gust\_envelope\_profiles* directory

The gust envelope profiles are defined under *gust\_envelope\_profiles* directory. In the configuration file, file name of the gust envelope profile needs to be referenced as shown in Listing 3.2.

Example files are provided with respect to Australian wind design categories: *cyclonic\_terrain\_cat2.csv*, *cyclonic\_terrain\_cat2.5.csv*, *cyclonic\_terrain\_cat3.csv*, and *non\_cyclonic.csv*, which are recommended in [3].

An example of gust envelope profile is provided in Listing 3.4, and the corresponding plot is shown in Fig. 3.8.

Listing 3.4: Example of *gust\_envelope\_profile*

```
# Terrain Category 2
3,0.908,0.896,0.894,0.933,0.884,0.903,0.886,0.902,0.859,0.927
5,0.995,0.980,0.946,0.986,0.962,1.010,0.978,0.970,0.945,0.990
7,0.994,1.031,1.010,0.986,0.982,0.987,0.959,0.984,0.967,0.998
10,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000
12,1.056,1.025,1.032,1.033,0.998,1.043,0.997,1.008,1.005,1.027
15,1.058,1.059,1.028,1.069,1.048,1.076,1.016,1.027,1.021,1.039
17,1.092,1.059,1.079,1.060,1.042,1.053,1.046,1.045,1.047,1.102
20,1.110,1.103,1.037,1.068,1.088,1.107,1.068,1.106,1.098,1.103
25,1.145,1.151,1.069,1.091,1.089,1.196,1.126,1.113,1.099,1.142
30,1.245,1.188,1.177,1.178,1.192,1.199,1.179,1.165,1.127,1.203
```

The first row is header, and heights (in metre) are listed in the first column. Profile values along the heights are listed from the second column with comma separation. One wind profile (one column) will be randomly selected for each run of the simulation.

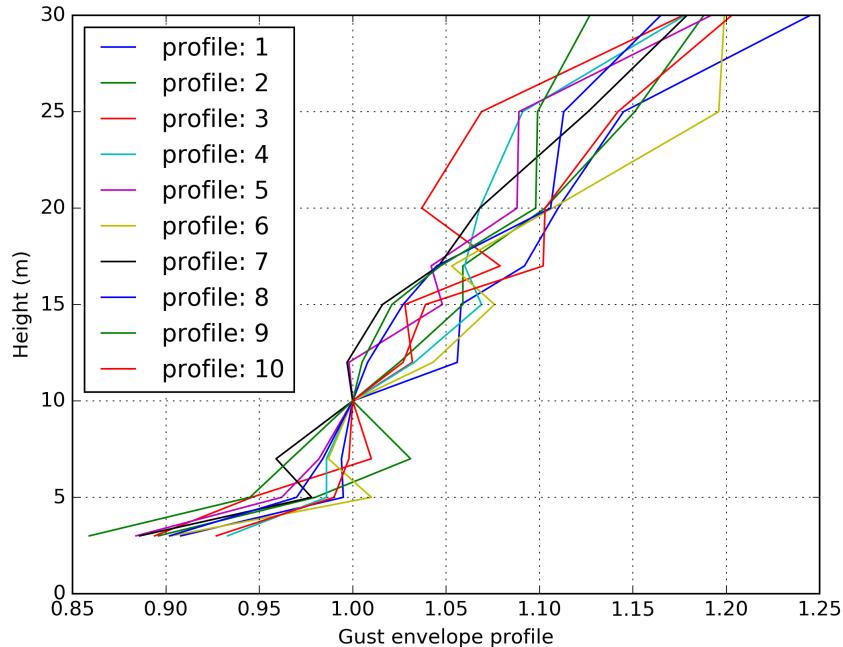


Fig. 3.8: Wind gust envelope profile along height.

## 3.4 Input files under *house* directory

In the house directory, a large number of files are located which are required to set parameter values of the model. The simulation model is assumed to consist of connections and zones. The connections are grouped into a number of connection types, and the connection types are further grouped into connection groups.

### 3.4.1 *house\_data.csv*

This file defines parameter values for the model such as replacement cost and dimensions. An example is shown in [Listing 3.5](#), and description of each of the parameter values are provided in [Table 3.10](#).

[Listing 3.5: Example house\\_data.csv](#)

```
replace_cost,3220.93
height,4.5
length,0.9
width,9.0
cpe_cv,0.0
cpe_k,0.1
cpe_str_cv,0.0
cpe_str_k,0.1
```

[Table 3.10: Parameters in the house\\_data.csv](#)

| Name         | Type  | Description  |
|--------------|-------|--|
| replace_cost | float | replacement cost of the model (\$)   |
| height       | float | height of the model (in metre)   |
| length       | float | length of the model (in metre)   |
| width        | float | width of the model (in metre)  |
| cpe_cv       | float | CV of $C_{pe}$ for cladding elements such as sheeting and batten           |
| cpe_k        | float | shape factor of $C_{pe}$ for cladding elements such as sheeting and batten |
| cpe_str_cv   | float | CV of $C_{pe}$ for structural elements such as rafter                      |
| cpe_str_k    | float | shape factor of $C_{pe}$ for structural elements as rafter                 |

### 3.4.2 *conn\_groups.csv*

The model is assumed to consist of a number of connection groups. This file defines connection groups and parameter values of the each connection group. An example is shown in [Listing 3.6](#), and description of each of the parameter values are provided in [Table 3.11](#).

Listing 3.6: Example conn\_groups.csv

```
group_name,dist_order,dist_dir,damage_scenario,trigger_collapse_at,patch_dist,  
flag_pressure  
sheeting,1,col,Loss of roof sheeting,0.0,1,cpe  
batten,2,row,Loss of roof sheeting & purlins,0.0,1,cpe  
rafter,3,col,Loss of roof structure,0.0,1,cpe_str
```

Table 3.11: Parameters in the conn\_groups.csv

| Name                | Type    | Description   |
|---------------------|---------|---|
| group_name          | string  | name of connections group   |
| dist_order          | integer | order of checking damage  |
| dist_dir            | integer | direction of damage distribution; either ‘col’, ‘row’, or ‘’  |
| damage_scenario     | string  | damage scenario name defined in damage_costing_data.csv   |
| trigger_collapse_at | float   | proportion of damaged connections of the group at which a model is deemed to be collapsed. 0 if ignored |
| patch_dist          | integer | 1 if influence patch is applied when connection is damaged otherwise 0                                  |
| flag_pressure       | string  | type of $C_{pe}$ for pressure calculation; either ‘cpe’ or ‘cpe_str’                                    |

### 3.4.3 conn\_types.csv

A connection group may consists of a number of connection types which have different parameter values for strength, dead load, and costing area. This file defines connection types and parameter values of the each connection type. An example is shown in Listing 3.7, and description of each of the parameter values are provided in Table 3.12.

Listing 3.7: Example conn\_types.csv

```
type_name,strength_mean,strength_std,dead_load_mean,dead_load_std,group_name,
costing_area
sheetinggable,1.54,0.16334,0.02025,0.0246,sheeting,0.405
sheetingeave,4.62,0.28292,0.02025,0.0246,sheeting,0.405
sheetingcorner,2.31,0.2,0.01013,0.0246,sheeting,0.225
sheeting,2.695,0.21608,0.0405,0.0246,sheeting,0.81
batten,3.6,1.26,0.089,0.0708,batten,0.81
battenend,3.6,1.26,0.089,0.0708,batten,0.405
batteneave,3.6,1.26,0.089,0.0708,batten,0.405
battencorner,3.6,1.26,0.089,0.0708,batten,0.225
endraftertopplate,19.5,5.85,0.84,0.063,rafter,1.238
endrafterridge,16.5,4.95,1.8,0.135,rafter,1.665
collarraftertopplate,19.5,5.85,1.68,0.126,rafter,1.845
collarrafterridge,16.5,4.95,1.13,0.08475,rafter,1.26
collarraftercollar,2.4,0.48,3.95,0.29625,rafter,1.665
plainraftertopplate,19.5,5.85,1.68,0.126,rafter,2.475
plainrafterridge,16.5,4.95,3.6,0.27,rafter,3.33
weakbatten,3.6,1.26,0.089,0.0708,batten,0.81
```

Table 3.12: Parameters in the conn\_types.csv

| Name           | Type   | Description                     |
|----------------|--------|---------------------------------|
| type_name      | string | name of connection type         |
| strength_mean  | float  | mean strength (kN)              |
| strength_std   | float  | standard deviation of strength  |
| dead_load_mean | float  | mean dead load (kN)             |
| dead_load_std  | float  | standard deviation of dead load |
| group_name     | string | name of connections group       |
| costing_area   | float  | costing area (m <sup>2</sup> )  |

#### 3.4.4 connections.csv

This file defines connections and parameter values of the each connection. An example is shown in Listing 3.8, and description of each of the parameter values are provided in Table 3.13.

Listing 3.8: Example connections.csv

```
conn_name,type_name,zone_loc,section,coords
1,sheetingcorner,A1,1,0,0,0.2,0,0.2,0.5,0,0.5
2,sheetinggable,A2,1,0,0.5,0.2,0.5,0.2,1,0,1
3,sheetinggable,A3,1,0,1,0.2,1,0.2,1.5,0,1.5
4,sheetinggable,A4,1,0,1.5,0.2,1.5,0.2,2,0,2
5,sheetinggable,A5,1,0,2,0.2,2,0.2,2.5,0,2.5
```

Table 3.13: Parameters in the connections.csv

| Name      | Type    | Description   |
|-----------|---------|---|
| conn_name | string  | name of connection  |
| type_name | string  | name of connection type   |
| zone_loc  | integer | zone name corresponding to connection location  |
| section   | integer | index of section in which damage distribution occurs  |
| coords    | float   | comma separated values of x, y coordinates for plotting purpose. e.g., 4 sets for a rectangular shape, 3 sets for a triangular shape. |

### 3.4.5 zones.csv

This file defines zones and parameter values of the each zone. An example is shown in Listing 3.9, and description of each of the parameter values are provided in Table 3.14.

Listing 3.9: Example zones.csv

```
name,area,cpi_alpha,wall_dir,coords,  
A1,0.2025,0,0,0,0.2,0,0.2,0.5,0,0.5  
A2,0.405,0.5,0,0,0.5,0.2,0.5,0.2,1,0,1  
A3,0.405,1,0,0,1,0.2,1,0.2,1.5,0,1.5  
A4,0.405,1,0,0,1.5,0.2,1.5,0.2,2,0,2  
A5,0.405,1,0,0,2,0.2,2,0.2,2.5,0,2.5
```

Table 3.14: Parameters in the zones.csv

| Name      | Type   | Description   |
|-----------|--------|---|
| name      | string | name of zone  |
| area      | float  | area of zone ( $\text{m}^2$ )   |
| cpi_alpha | float  | proportion of the zone's area to which internal pressure is applied   |
| coords    | float  | comma separated list of x, y coordinates for plotting purpose. e.g., 4 sets for a rectangular shape, 3 sets for a triangular shape. |

### 3.4.6 zones\_cpe\_mean.csv

This file defines mean cladding  $C_{pe}$  of each zone with regard to the eight wind directions. An example is shown in Listing 3.10, and description of each of the parameter values are provided in Table 3.15.

Listing 3.10: Example zones\_cpe\_mean.csv

```
name,S,SW,W,NW,N,NE,E,SE
A1,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2
A2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2
A3,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2
A4,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2
A5,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2
A6,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2,-1.2
A7,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5
A8,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5
A9,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5
A10,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5
A11,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5
A12,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5,-0.5
A13,0,0,0,0,0,0,0,0
A14,0,0,0,0,0,0,0,0
```

Table 3.15: Parameters in the zones\_cpe\_mean.csv

| Name | Type    | Description  |
|------|---------|--|
| name | string  | name of zones  |
| S    | float   | mean cladding $C_{pe}$ value in South direction      |
| SW   | float   | mean cladding $C_{pe}$ value in South West direction |
| W    | integer | mean cladding $C_{pe}$ value in West direction       |
| NW   | float   | mean cladding $C_{pe}$ value in North East direction |
| N    | float   | mean cladding $C_{pe}$ value in North direction      |
| NE   | float   | mean cladding $C_{pe}$ value in North East direction |
| E    | integer | mean cladding $C_{pe}$ value in East direction       |
| SE   | float   | mean cladding $C_{pe}$ value in South East direction |

### 3.4.7 zones\_cpe\_str\_mean.csv

Like zones\_cpe\_mean.csv, mean  $C_{pe}$  values for zones associated with structural component (e.g., rafter) need to be provided in zones\_cpe\_str\_mean.csv. An example is shown in Listing 3.11.

Listing 3.11: Example zones\_cpe\_str\_mean.csv

```
name,S,SW,W,NW,N,NE,E,SE
A1,0,0,0,0,0,0,0,0
A2,0,0,0,0,0,0,0,0
A3,0,0,0,0,0,0,0,0
A4,0,0,0,0,0,0,0,0
A5,0,0,0,0,0,0,0,0
A6,0,0,0,0,0,0,0,0
A7,0,0,0,0,0,0,0,0
A8,0,0,0,0,0,0,0,0
A9,0,0,0,0,0,0,0,0
A10,0,0,0,0,0,0,0,0
A11,0,0,0,0,0,0,0,0
A12,0,0,0,0,0,0,0,0
A13,-1,-1,-1,-1,-1,-1,-1,-1
A14,-0.4,-0.4,-0.4,-0.4,-0.4,-0.4,-0.4,-0.4
```

### 3.4.8 zones\_cpe\_eave\_mean.csv

Like zones\_cpe\_mean.csv, mean  $C_{pe}$  values for zones at eave need to be provided in zones\_cpe\_eave\_mean.csv. An example is shown in Listing 3.12.

Listing 3.12: Example zones\_cpe\_eave\_mean.csv

```
name,S,SW,W,NW,N,NE,E,SE
A1,0.7,0.7,0.7,0.7,0.7,0.7,0.7,0.7
A2,0.35,0.35,0.35,0.35,0.35,0.35,0.35,0.35
A3,0,0,0,0,0,0,0,0
A4,0,0,0,0,0,0,0,0
A5,0,0,0,0,0,0,0,0
A6,0,0,0,0,0,0,0,0
A7,0,0,0,0,0,0,0,0
A8,0,0,0,0,0,0,0,0
A9,0,0,0,0,0,0,0,0
A10,0,0,0,0,0,0,0,0
A11,-0.1,-0.1,-0.1,-0.1,-0.1,-0.1,-0.1,-0.1
A12,-0.2,-0.2,-0.2,-0.2,-0.2,-0.2,-0.2,-0.2
A13,0.07,0.07,0.07,0.07,0.07,0.07,0.07,0.07
A14,-0.02,-0.02,-0.02,-0.02,-0.02,-0.02,-0.02,-0.02
```

### 3.4.9 zones\_edge.csv

In zones\_edge.csv, for each of the eight direction, 1 is provided for zone within the region of a roof edge, otherwise 0. Zones in the edge region are considered to be subjected to differential shielding if enabled by user. An example is shown in Listing 3.13.

Listing 3.13: Example zones\_edge.csv

```
name,S,SW,W,NW,N,NE,E,SE
A1,1,1,1,0,0,0,0,0
A2,1,1,1,0,0,0,0,0
A3,1,1,1,0,0,0,0,0
A4,0,1,0,0,0,0,0,0
A5,0,1,0,0,0,0,0,0
A6,0,1,0,0,0,0,0,0
```

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```
A7,0,0,0,1,0,0,0,0
A8,0,0,0,1,0,0,0,0
A9,0,0,0,1,0,0,0,0
A10,0,0,1,1,1,0,0,0
A11,0,0,1,1,1,0,0,0
A12,0,0,1,1,1,0,0,0
A13,1,1,1,0,0,0,0,0
A14,0,0,1,1,1,0,0,0
```

### 3.4.10 coverages.csv

This file defines coverages making up the wall part of the envelope of the model. An example is shown in Listing 3.14, and description of each of the parameter values are provided in Table 3.16. The wall name is defined in Listing 3.23. Coverages are assessed for debris impact damage and failure by direct wind pressure. The area of coverage is used in the calculation of  $C_{pi}$ .

Listing 3.14: Example coverages.csv

```
name,description,wall_name,area,coverage_type
1,window,1,3.6,Glass_annealed_6mm
2,door,1,1.8,Timber_door
3,window,1,1.89,Glass_annealed_6mm
4,window,1,1.89,Glass_annealed_6mm
```

Table 3.16: Parameters in the coverages.csv

| Name          | Type    | Description           |
|---------------|---------|-----------------------|
| name          | integer | coverage index        |
| description   | string  | description           |
| wall_name     | integer | wall name             |
| area          | float   | area ( $m^2$ )        |
| coverage_type | string  | name of coverage type |

### 3.4.11 coverage\_types.csv

This file defines types of coverages referenced in the Listing 3.14. An example is shown in Listing 3.15, and description of each of the parameter values are provided in Table 3.17.

Listing 3.15: Example coverage\_types.csv

```
name,failure_momentum_mean,failure_momentum_std,failure_strength_in_mean,failure_
→strength_in_std,failure_strength_out_mean,failure_strength_out_std
Glass_annealed_6mm,0.05,0.0,100,0.0,-100,0.0
Timber_door,142.2,28.44,100,0.0,-100,0.0
```

Table 3.17: Parameters in the coverage\_types.csv

| Name                      | Type   | Description  |
|---------------------------|--------|--|
| name                      | string | name of coverage type  |
| failure_momentum_mean     | float  | mean failure momentum ( $\text{kg} \cdot \text{m/s}$ ) for debris impact                 |
| failure_momentum_std      | float  | standard deviation of failure momentum   |
| failure_strength_in_mean  | float  | mean failure strength inward direction (positive) for failure due to wind pressure (kN)  |
| failure_strength_in_std   | float  | standard deviation of failure strength inward direction                                  |
| failure_strength_out_mean | float  | mean failure strength outward direction (negative) for failure due to wind pressure (kN) |
| failure_strength_out_std  | float  | standard deviation of failure strength outward direction                                 |

### 3.4.12 coverages\_cpe.csv

Like zones\_cpe\_mean.csv, mean  $C_{pe}$  values for coverages are provided in coverages\_cpe.csv. An example is shown in Listing 3.16.

Listing 3.16: Example coverages\_cpe.csv

```
ID,S,SW,W,NW,N,NE,E,SE
1,2.4,2.4,2.4,2.4,2.4,2.4,2.4,2.4
2,1.69,1.69,1.69,1.69,1.69,1.69,1.69,1.69
3,-1.14,-1.14,-1.14,-1.14,-1.14,-1.14,-1.14,-1.14
4,-1.45,-1.45,-1.45,-1.45,-1.45,-1.45,-1.45,-1.45
5,0.9,0.9,0.9,0.9,0.9,0.9,0.9,0.9
6,-0.55,-0.55,-0.55,-0.55,-0.55,-0.55,-0.55,-0.55
```

### 3.4.13 influences.csv

This file defines influence coefficients relating a connection with either another connection(s) or zone(s). The wind load acting on a connection can be computed as the sum of the product of influence coefficient and either wind load on zone or load on another connection. An example is shown in Listing 3.17, and description of each of the parameter values are provided in Table 3.18. In this example, connection 1 is related to the zone A1 with coefficient 1.0, and connection 61 is related to the connection 1 with coefficient 1.0. Similarly, connection 121 is related to the zone A13 with coefficient 0.81 and the zone A14 with coefficient 0.19.

Listing 3.17: Example influences.csv

```
Connection,Zone,Coefficient
1,A1,1.0
2,A2,1.0
61,1,1
62,2,1
63,3,1
121,A13,0.81,A14,0.19
```

Table 3.18: Parameters in the influences.csv

| Name        | Description  |
|-------------|--|
| Connection  | name of connection   |
| Zone        | name of either zone or connection associated with the Connection |
| Coefficient | coefficient value  |

### 3.4.14 influence\_patches.csv

This file defines influence coefficients of connections when associated connection is failed. An example is shown in [Listing 3.18](#), and description of each of the parameter values are provided in [Table 3.19](#). In the example, when connection 121 is failed, influence coefficients of connection 121, 122, 123 are re-defined.

Listing 3.18: Example influence\_patches.csv

```
Damaged connection,Connection,Zone,Coefficient
121,121,A13,0,A14,0
121,122,A13,1,A14,0
121,123,A13,1,A14,1
122,121,A13,1,A14,0
122,122,A13,0,A14,0
122,123,A13,0,A14,1
```

Table 3.19: Parameters in the influence\_patches.csv

| Name               | Description  |
|--------------------|--|
| Damaged Connection | name of damaged connection   |
| Connection         | name of connection for which the influence coefficients are to be updated      |
| Zone               | name of either zone or connection associated with the connection to be updated |
| Coefficient        | new influence coefficient value  |

### 3.4.15 damage\_costing\_data.csv

This file defines damage scenarios referenced in [Listing 3.6](#). An example is shown in [Listing 3.19](#), and description of each of the parameter values are provided in [Table 3.20](#). The damage cost for each damage scenario  $C$  is calculated as

$$C = x \times (A \times C_{\text{env}} \times R_{\text{env}} + C_{\text{int}} \times R_{\text{int}}) \quad (3.1)$$

where  $x$ : proportion of damaged area ( $0 \leq x \leq 1$ ),  $A$ : surface area,  $C_{\text{env}}$ : costing function for envelope,  $R_{\text{env}}$ : repair rate for envelope,  $C_{\text{int}}$ : costing function for internal, and  $R_{\text{int}}$ : repair rate for internal. Two

types of costing functions are defined as:

$$\begin{aligned} f_1 &= c_1 \times x^2 + c_2 \times x + c_3 \\ f_2 &= c_1 \times x^{c_2} \end{aligned} \quad (3.2)$$

Listing 3.19: Example damage\_costing\_data.csv

```
name,surface_area,envelope_repair_rate,envelope_factor_formula_type,envelope_
↳coeff1,envelope_coeff2,envelope_coeff3,internal_repair_rate,internal_factor_
↳formula_type,internal_coeff1,internal_coeff2,internal_coeff3,water_ingress_order
Loss of roof sheeting,116,72.4,1,0.3105,-0.8943,1.6015,0,1,0,0,0,6
Loss of roof sheeting & purlins,116,184.23,1,0.3105,-0.8943,1.6015,0,1,0,0,0,7
Loss of roof structure,116,317,1,0.3105,-0.8943,1.6015,8320.97,1,-0.4902,1.4896,0,
↳0036,3
```

Table 3.20: Parameters in the damage\_costing\_data.csv

| Name                         | Description  |
|------------------------------|--|
| name                         | name of damage scenario                            |
| surface_area                 | surface area ( $\text{m}^2$ )                      |
| envelope_repair_rate         | repair rate for envelope damage(\$/ $\text{m}^2$ ) |
| envelope_factor_formula_type | type index of costing function for envelope        |
| envelope_coeff1              | $c_1$ in costing function for envelope             |
| envelope_coeff2              | $c_2$ in costing function for envelope             |
| envelope_coeff3              | $c_3$ in costing function for envelope             |
| internal_repair_rate         | repair rate for internal damage (\$)               |
| internal_factor_formula_type | type index of costing function for internal        |
| internal_coeff1              | $c_1$ in costing function for internal             |
| internal_coeff2              | $c_2$ in costing function for internal             |
| internal_coeff3              | $c_3$ in costing function for internal             |
| water_ingress_order          | order in applying cost induced by water ingress    |

### 3.4.16 damage\_factorings.csv

This file defines a hierarchy of costings, where each row has a parent and child connection type group. When costing the parent group, all child costings will be factored out of the parent. This mechanism avoids double counting of repair costs. An example is shown in Listing 3.20.

Listing 3.20: Example damage\_factorings.csv

```
ParentGroup,FactorByGroup
batten,rafter
sheeting,rafter
sheeting,batten
```

### 3.4.17 water\_ingress\_costing\_data.csv

This file contains costing information of damage induced by water ingress for various scenarios of structural damage. Each row contains coefficients that are used by costing functions. An example is shown in Listing 3.21, and description of each of the parameter values are provided in Table 3.21. The

water ingress cost  $WC$  is calculated as

$$WC = B \times C(x) \quad (3.3)$$

where  $x$ : envelope damage index prior to water ingress ( $0 \leq x \leq 1$ ),  $B$ : base cost, and  $C$ : costing function. Like the damage costing functions, two types of costing functions are defined as (3.2).

**Listing 3.21:** Example water\_ingress\_costing\_data.csv

```
name,water_ingress,base_cost,formula_type,coeff1,coeff2,coeff3
Loss of roof sheeting,0,0,1,0,0,1
Loss of roof sheeting,5,2989.97,1,0,0,1
Loss of roof sheeting,18,10763.89,1,0,0,1
Loss of roof sheeting,37,22125.78,1,0,0,1
Loss of roof sheeting,67,40065.59,1,0,0,1
Loss of roof sheeting,100,59799.39,1,0,0,1
```

**Table 3.21:** Parameters in the water\_ingress\_costing\_data.csv

| Name          | Description                    |
|---------------|--------------------------------|
| name          | name of damage scenario        |
| water_ingress | water ingress in percent       |
| base_cost     | base cost $B$                  |
| formula_type  | type index of costing function |
| coeff1        | $c_1$ in costing function      |
| coeff2        | $c_2$ in costing function      |
| coeff3        | $c_3$ in costing function      |

### 3.4.18 footprint.csv

This file contains information about footprint of the model. Each row contains x and y coordinates of the vertices of the footprint. An example is shown in Listing 3.22.

**Listing 3.22:** Example footprint.csv

```
footprint_coord
-6.5, 4.0
6.5, 4.0
6.5, -4.0
-6.5, -4.0
```

### 3.4.19 front\_facing\_walls.csv

This file contains wall information with respect to the eight wind direction. Each row contains wall name(s) for a wind direction. An example is shown in Listing 3.23.

**Listing 3.23:** Example front\_facing\_walls.csv

```
wind_dir,wall_name
S,1
SW,1,3
W,3
NW,3,5
```

(continues on next page)

(continued from previous page)

|          |
|----------|
| N, 5     |
| NE, 5, 7 |
| E, 7     |
| SE, 1, 7 |

## 3.5 output file

After simulation output file named *results.h5* is created, which is in HDF5 format. Its content can be accessed via Python or HDF Viewer. Table 3.22 lists attributes in the output file. Note that time invariant attribute is one whose value is set when the model is created, and is kept the same over the range of wind speeds.

Table 3.22: Attributes saved in the output file

| Attribute                 | Description   | Note                            |
|---------------------------|---|---------------------------------|
| profile_index             | wind profile index  | per model (time invariant)      |
| wind_dir_index            | wind direction index  | per model (time invariant)      |
| construction_level        | construction quality level                                      | per model (time invariant)      |
| terrain_height_multiplier | terrain height multiplier                                       | per model (time invariant)      |
| shielding_multiplier      | shielding multiplier  | per model (time invariant)      |
| mean_factor               | mean factor of construction quality                             | per model (time invariant)      |
| cv_factor                 | cv factor of construction quality                               | per model (time invariant)      |
| qz                        | free stream wind pressure                                       | per model                       |
| cpi                       | internal pressure coefficient                                   | per model                       |
| collapse                  | 1 if model collapse otherwise 0                                 | per model                       |
| di                        | damage index  | per model                       |
| di_except_water           | damage index except water ingress induced damage                | per model                       |
| repair_cost               | repair cost   | per model                       |
| water_ingress_cost        | repair cost induced by water ingress                            | per model                       |
| window_breached_by_debris | 1 if any window breached by debris otherwise 0                  | per model                       |
| no_items                  | total number of generated debris items                          | per debris model                |
| no_impacts                | total number of debris impacts                                  | per debris model                |
| damaged_area              | total damaged area by debris impact                             | per debris model                |
| damaged_area              | total damaged area by group                                     | per group                       |
| damaged                   | 1 if connection is damaged otherwise 0                          | per connection                  |
| capacity                  | wind speed at which damage occurred                             | per connection                  |
| load                      | wind load   | per connection                  |
| strength                  | strength  | per connection (time invariant) |
| dead load                 | dead load   | per connection (time invariant) |
| pressure_cpe              | wind pressure for zone component related to sheeting and batten | per zone                        |

Continued on next page

Table 3.22 – continued from previous page

| Attribute         | Description   | Note                          |
|-------------------|---|-------------------------------|
| pressure_cpe_str  | wind pressure for zone component related to rafter                              | per zone                      |
| cpe               | external pressure coefficient for zone component related to sheeting and batten | per zone (time invariant)     |
| cpe_str           | external pressure coefficient for zone component related to rafter              | per zone (time invariant)     |
| cpe_eave          | external pressure coefficient for zone component related to eave                | per zone (time invariant)     |
| strength_negative | strength in one direction   | per coverage (time invariant) |
| strength_positive | strength in the other direction   | per coverage (time invariant) |
| load              | wind load   | per coverage                  |
| breached          | 1 if coverage is damaged otherwise 0  | per coverage                  |
| breached_area     | cumulative area breached by debris  | per coverage                  |
| capacity          | wind speed at which breach occurred   | per coverage                  |

Fig. 3.9 shows the structure of the results when opened in the HDFView, a visual tool for browsing HDF5 files. There are 8 groups consisting of connection, coverage, debris, fragility, group, house, vulnerability, and zone. Fig. 3.10 shows a list of sub-groups under the connection: capacity, damaged, dead\_load, load, and strength. Fig. 3.11 shows a dataset of capacity of the selected connection.

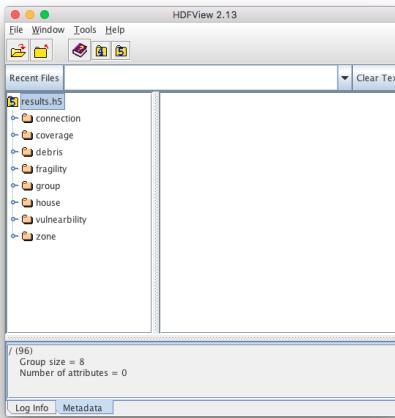


Fig. 3.9: Structures of output in the HDFView

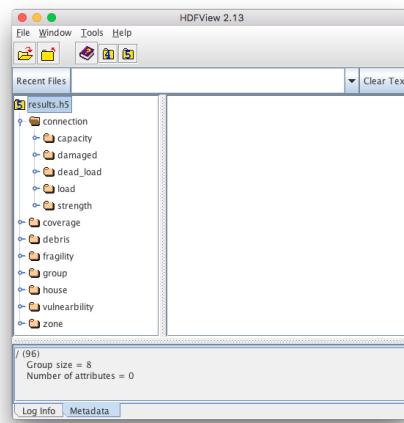


Fig. 3.10: Attributes under connection tab in the HDFView

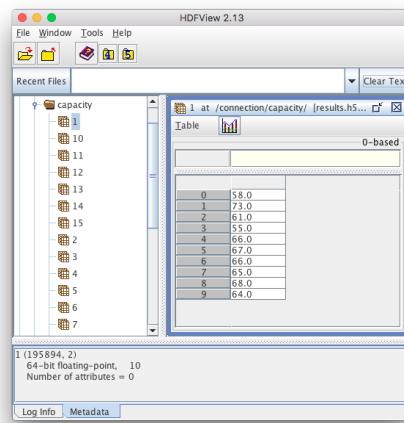


Fig. 3.11: Values of capacity of the selected connection in the HDFView

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# CHAPTER FOUR

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## USE OF THE GUI

This chapter provides an overview of the GUI and instructions on how to run simulations using the GUI.

### 4.1 Structure

The main window is logically separated into distinct areas of functionality as shown as Fig. 4.1.

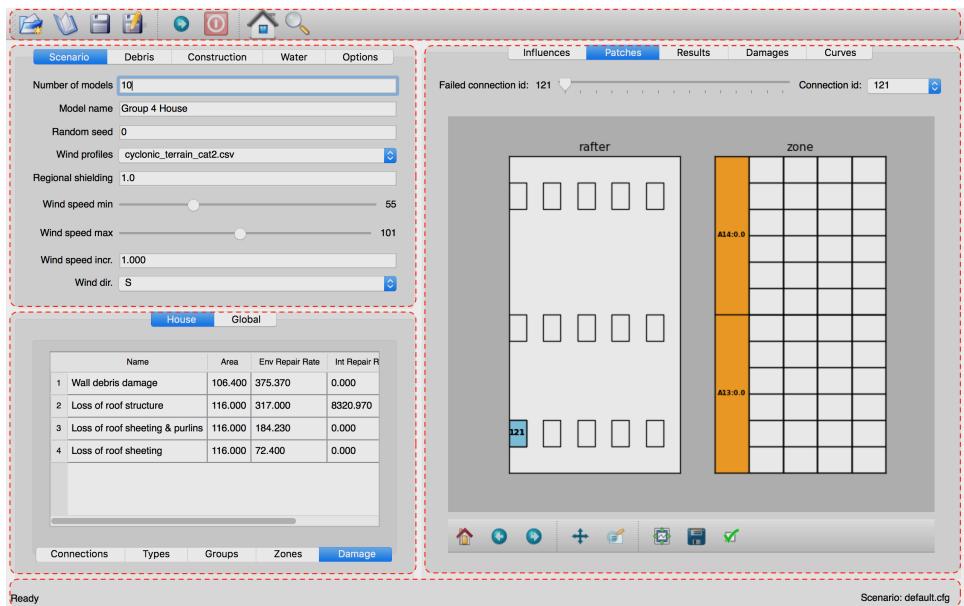


Fig. 4.1: Program main window consisting of five areas by functionality as shown as dotted box

#### 4.1.1 Top

At the top of the main window, tool bar with buttons is located. The file menu and action corresponding to each of the buttons is set out in the Table 4.1.

Table 4.1: Buttons in the toolbar

| Button | Menu                  | Action  |
|--------|-----------------------|---|
|        | File -> New           | Create a new scenario with default setting                  |
|        | File -> Open Scenario | Open an existing configuration file                         |
|        | File -> Save          | Save current scenario                                       |
|        | File -> Save As       | Save current scenario to a new configuration file           |
|        | Simulator -> Run      | Run the scenario  |
|        | Simulator -> Stop     | Stop the simulation when in progress                        |
|        | Model -> House Info   | Show the current house information including wall coverages |

#### 4.1.2 Top left

The top left panel contains simulation settings across five tabs: Scenario, Debris, Construction, Water, and Options, where parameter values for a simulation can be set. The details of each of the tab can be found in [3.1](#).

There are three test button across the tabs.

The Test button in the Debris tab demonstrates debris generation function at a selected wind speed. Once the wind speed is determined, then a window showing debris traces from sources are displayed as shown as [Fig. 4.2](#). The vulnerability curve used in the test function is selected from the curves shown in [Fig. 4.3](#), whereas other parameter values can be changed through the GUI.

Table 4.2: Parameter values for vulnerability curves ([4.2](#)) used in the debris test

| name          | $\alpha$ | $\beta$ |
|---------------|----------|---------|
| Capital_city  | 0.1585   | 3.8909  |
| Tropical_town | 0.1030   | 4.1825  |

The Test button in the Construction tab shows distribution of connection strength of the selected connection type. Example of sampled strength of batten type is shown in [Fig. 4.4](#).

The Test button in the Water tab shows relationship between percentage of water ingress and wind speed for a range of damage index as shown in [Fig. 4.5](#).

#### 4.1.3 Bottom left

The bottom left panel contains data browser of house and global data. This panel contains two tabs at the top: House and Global. The House tab has five tabs at the bottom: Connections, Types, Groups, Zones, and Damage, as shown in [Fig. 4.6](#). [Table 4.3](#) sets out corresponding input file and section for each of the tabs.

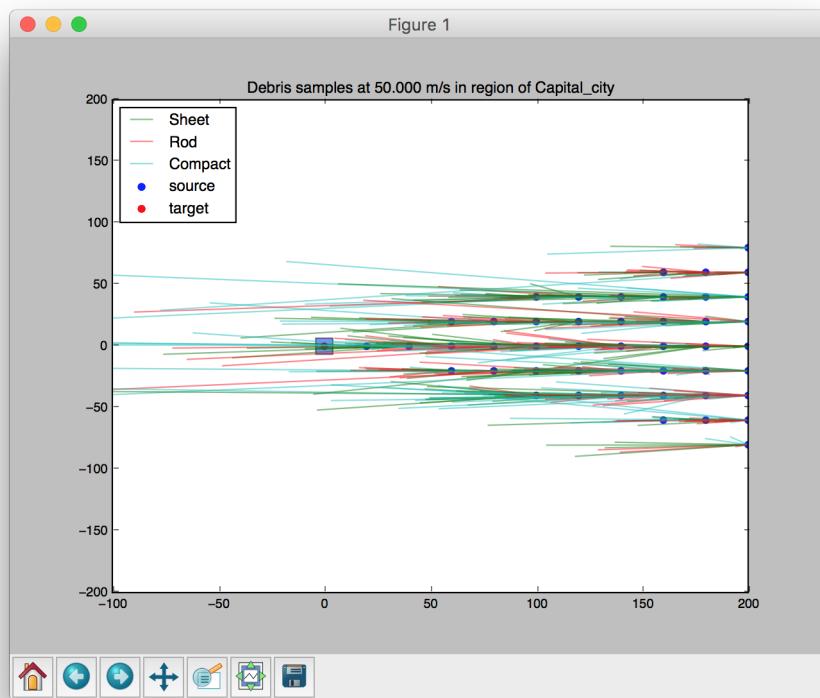


Fig. 4.2: Test of debris generation function: debris generated at 50 m/s in region of Capcital\_city

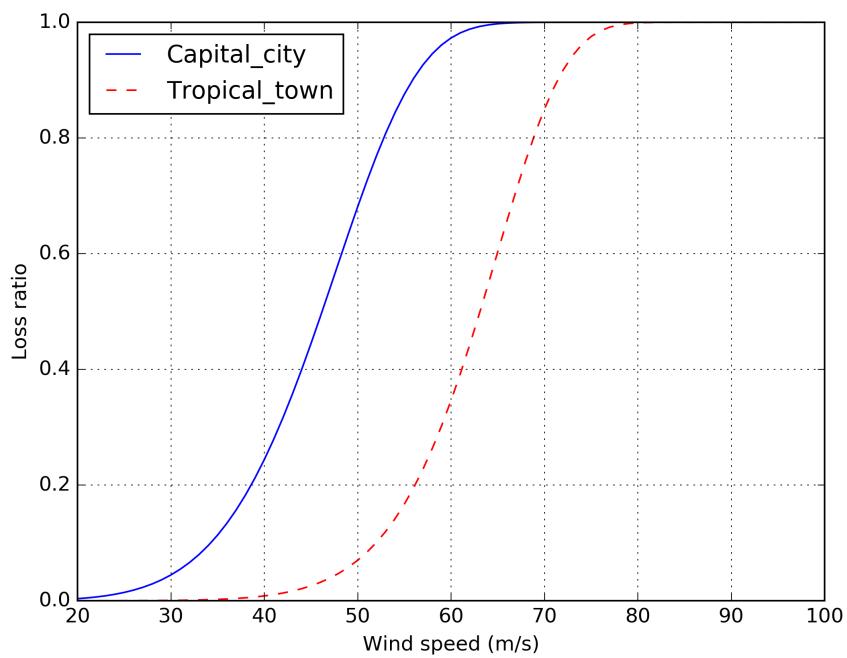


Fig. 4.3: Vulnerability curves implemented in the debris test function using the parameter values listed in Table 4.2.

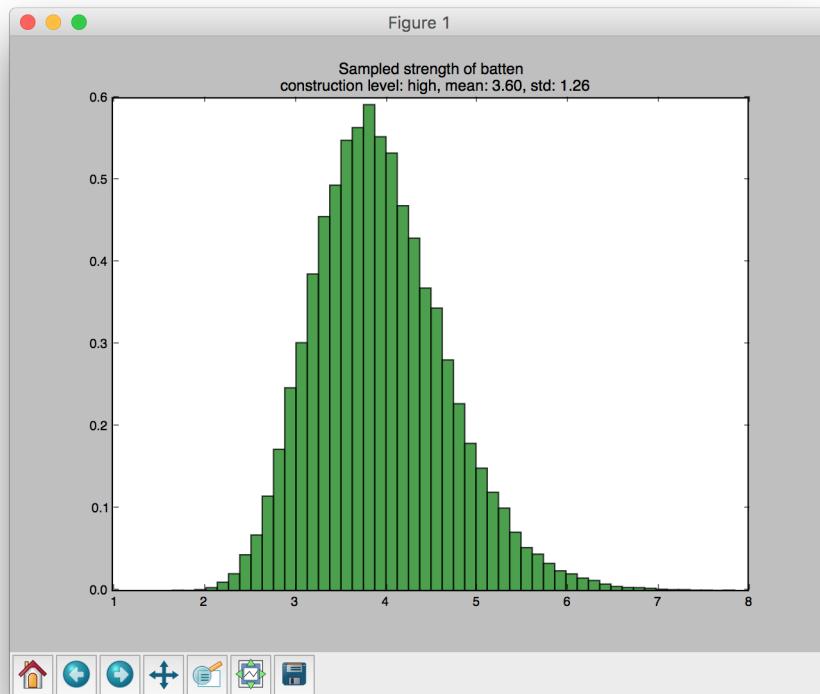


Fig. 4.4: Distribution of sampled strength of the selected connection type

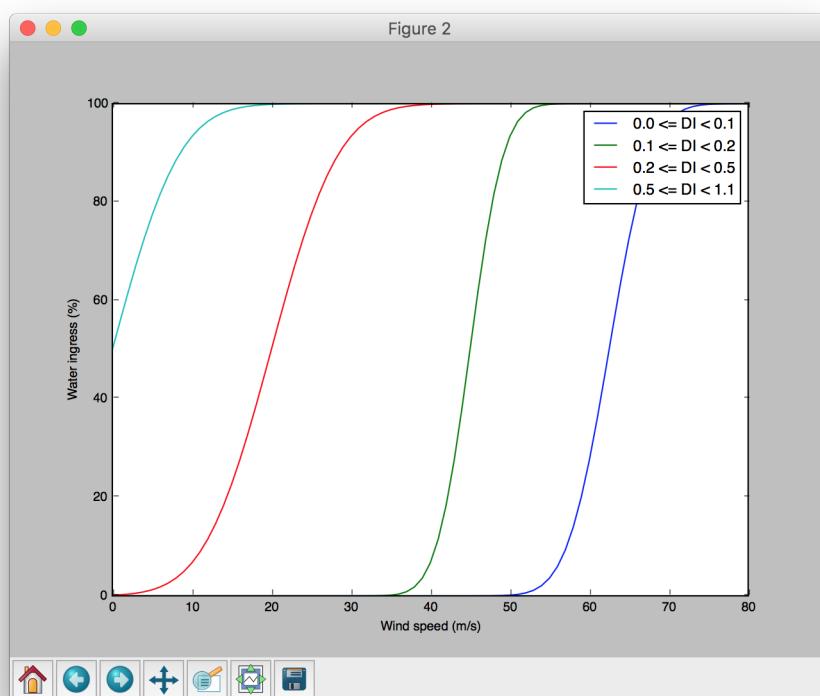


Fig. 4.5: Relationship between percentage of water ingress and wind speed

Table 4.3: House data

| Tab name    | Input file              | Section  |
|-------------|-------------------------|--|
| Connections | connections.csv         | <a href="#">3.4.4 connections.csv</a>          |
| Types       | conn_types.csv          | <a href="#">3.4.3 conn_types.csv</a>           |
| Groups      | conn_groups.csv         | <a href="#">3.4.2 conn_groups.csv</a>          |
| Zones       | zones.csv               | <a href="#">3.4.5 zones.csv</a>                |
| Damage      | damage_costing_data.csv | <a href="#">3.4.15 damage_costing_data.csv</a> |

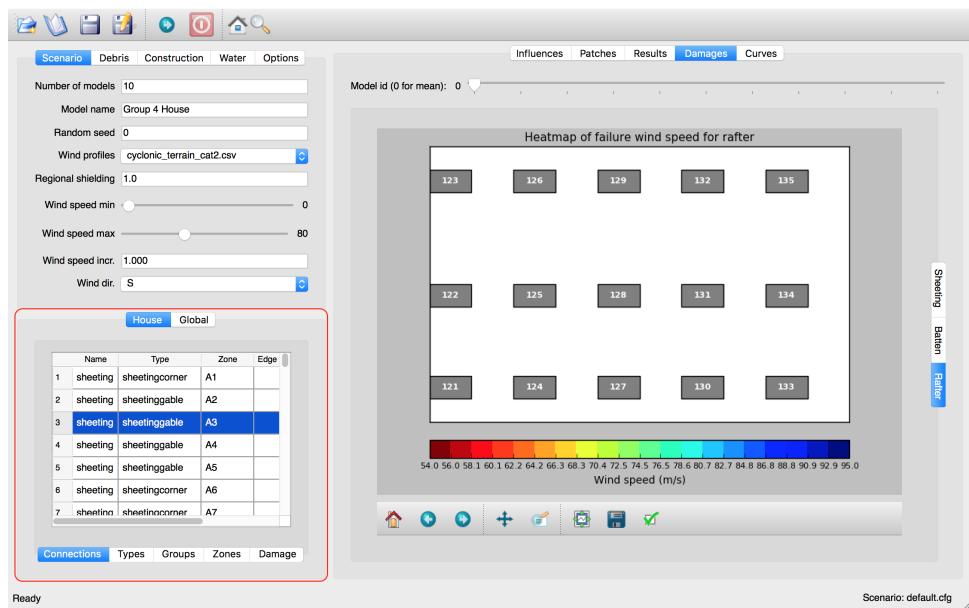


Fig. 4.6: House data tab showing connections information

The Global tab has two tabs at the bottom: Boundary Profile and Debris, as shown in Fig. 4.7. In the Boundary Profile tab, gust envelope profiles of selected wind profiles is displayed. Details about the gust envelope profiles can be found in 3.3. In the Debris tab, parameter values for debris model listed in the debris.csv (3.1.3) is displayed. Note that the contents of both tabs are to be changed dynamically upon different selection of wind profile file (Wind Profiles) and debris region (Region).

#### 4.1.4 Bottom right

The bottom right panel shows input data of influence coefficients and simulation results. This panel consists of five tabs: Influences, Patches, Results, Damages, and Curves, among which Results, Damages, and Curves are empty until a simulation is completed.

##### Influences tab

Once connection id is set by the slider at the top, then the selected connection (coloured in skyblue) and its associated either zone or connection (coloured in orange) with influence coefficient are shown as Fig. 4.8.

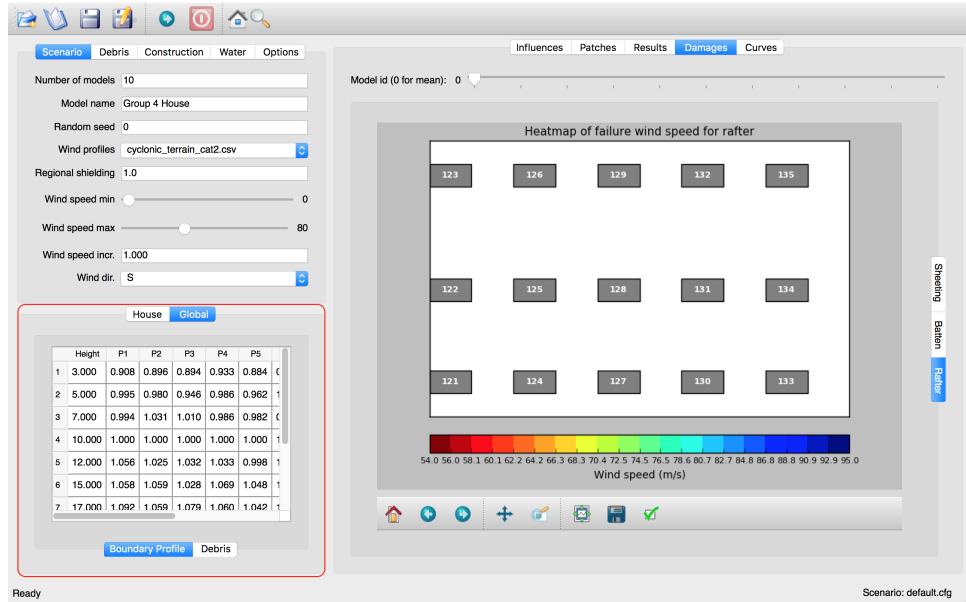


Fig. 4.7: Global data tab showing boundary profiles information

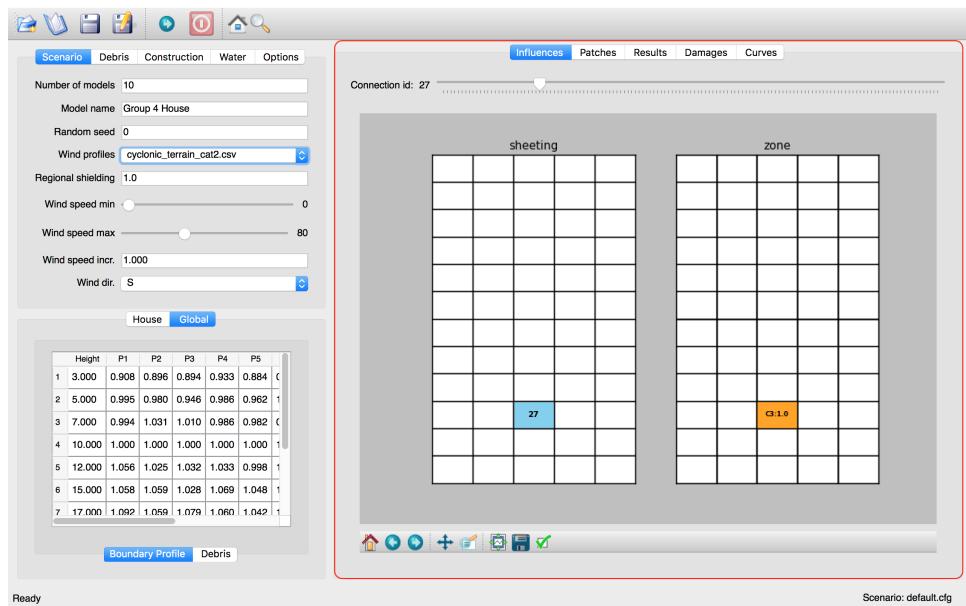


Fig. 4.8: Display of influence coefficient of connection id 27, which is 1.0 with Zone C3.

## Patches tab

The Patches tab shows the influence coefficient of connection when associated connection is failed. Once failed connection (coloured in gray) and connection id (coloured in skyblue) are set, then associated either zone or connection (coloured in orange) with influence coefficient is shown as Fig. 4.9.

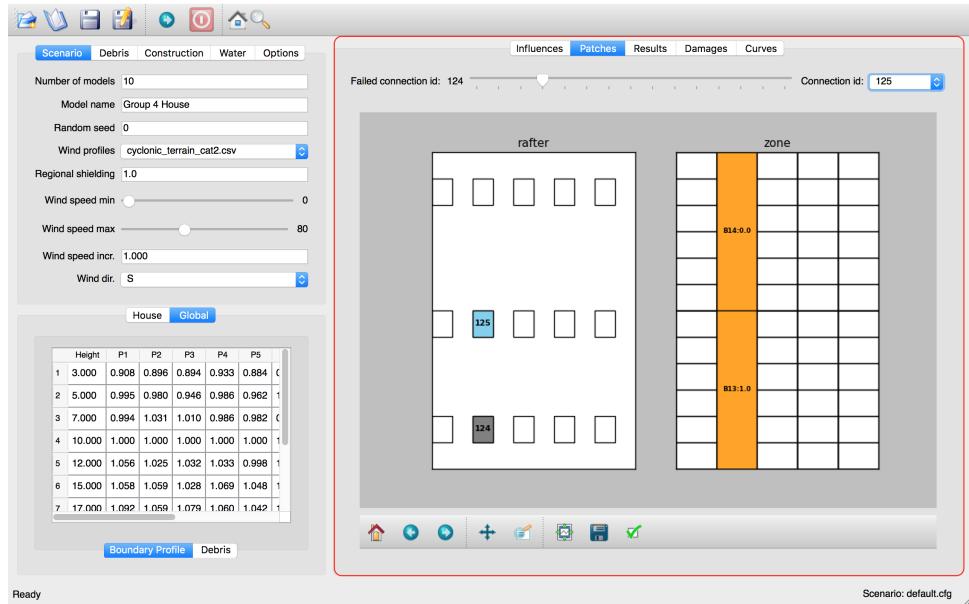


Fig. 4.9: Display of influence coefficient of connection 125 when connection 124 is failed.

## Results tab

The Results tab shows the results of simulation in four sub-windows: Zones, Connections, Type Strengths, and Type Damage.

The Zones window shows sampled Cpe values for each of the zones for each realisation of the simulation models as shown as Fig. 4.10. The first string at the *House* column refers to model index, and the string before and after slash refer to wind direction and construction quality level, respectively.

Likewise, the Connections window shows the results of each connections such as sampled strength and dead load as shown as Fig. 4.11.

The Type Strengths window show distribution of connection strength by connection type as shown as Fig. 4.12.

The Type Damage window shows distribution of speeds at which connection fails by connection type as shown as Fig. 4.13.

## Damages tab

The Damages tab shows heatmap by connection type group such as Sheeting, Batten, and Rafter as shown in Fig. 4.14. The heatmap averaged across models is shown by default, and heatmap for individual model can be displayed by moving the slide at the top.

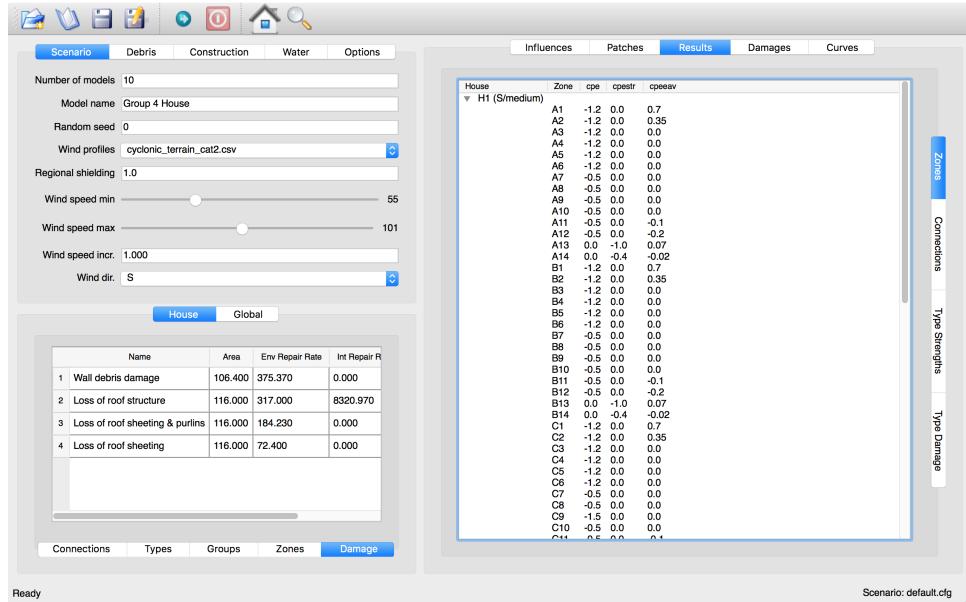


Fig. 4.10: Display of Cpe values for each zone

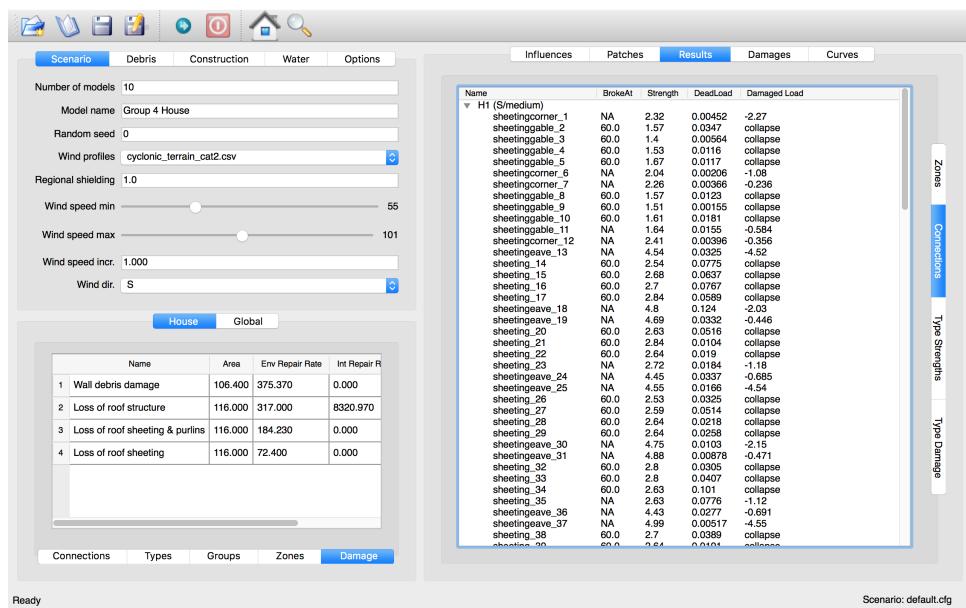


Fig. 4.11: Display of strength, dead load, and failure wind speed for each connection

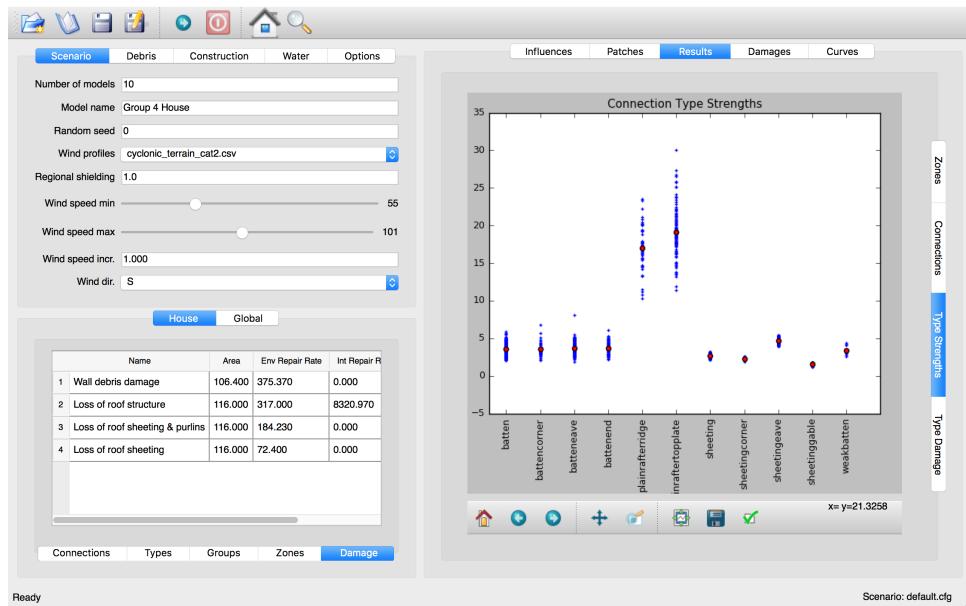


Fig. 4.12: Display of distribution of sampled connection strength by connection type

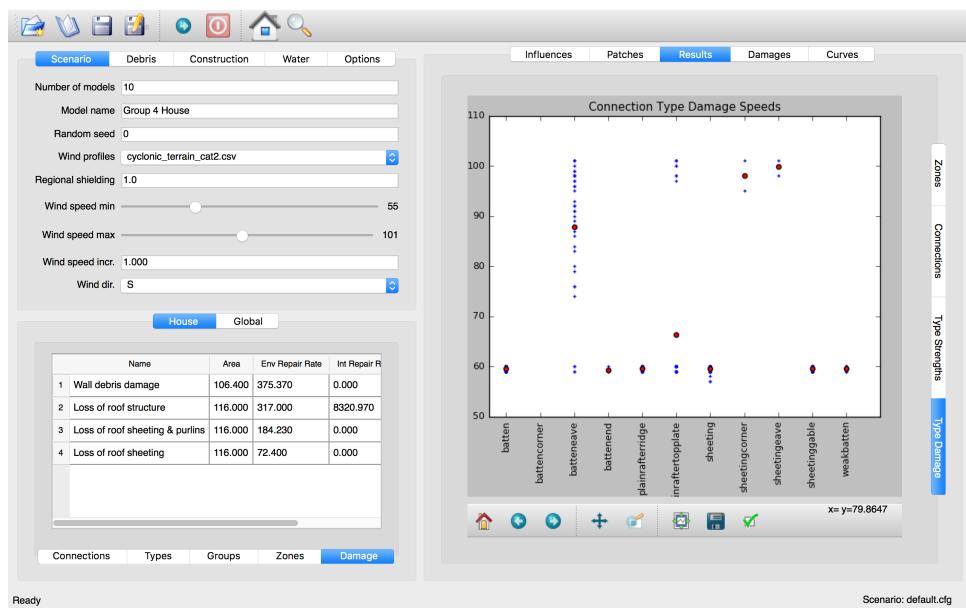


Fig. 4.13: Display of distribution of failure wind speed by connection type

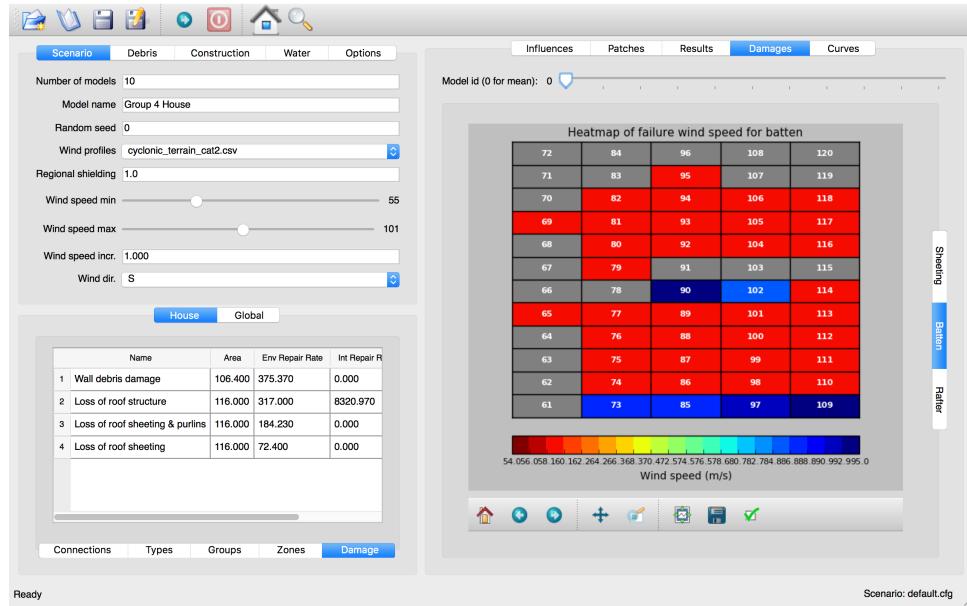


Fig. 4.14: Heatmap of failure wind speed averaged across models for batten group

## Curves tab

The Curves tab shows curves in four sub-windows: Vulnerability, Fragility, Water Ingress, and Debris. The Vulnerability window shows a scatter plot of damage indices at each wind speed along with two fitted vulnerability curves, one of which is cumulative lognormal distribution function as (4.1) and the other one is cumulative Weibull distribution as (4.2). The estimated parameter values are displayed at the top.

$$F_X(x; m, \sigma) = \Phi\left(\frac{\ln(x/m)}{\sigma}\right) \quad (4.1)$$

where  $\Phi$ : the cumulative distribution function of the standard normal distribution,  $m$ : median, and  $\sigma$ : logarithmic standard deviation.

$$F(x; \alpha, \beta) = 1 - \exp\left[-\left(\frac{x}{e^\beta}\right)^{\frac{1}{\alpha}}\right] \quad (4.2)$$

An example plot is shown in Fig. 4.15.

The Fragility window shows fragility curves for discrete damage states, which are fitted to cumulative lognormal distribution function, as shown in Fig. 4.16.

The Water Ingress window shows a scatter plot of the costing associated with water ingress along wind speed, as shown in Fig. 4.17.

The Debris window shows 1) number of generated debris items, 2) number of impacted debris items, and 3) proportion of models breached by debris along the range of wind speed, as shown in Fig. 4.18.

### 4.1.5 Bottom

At the bottom of the main window, configuration file name and status of current simulation are displayed as shown in Fig. 4.19.

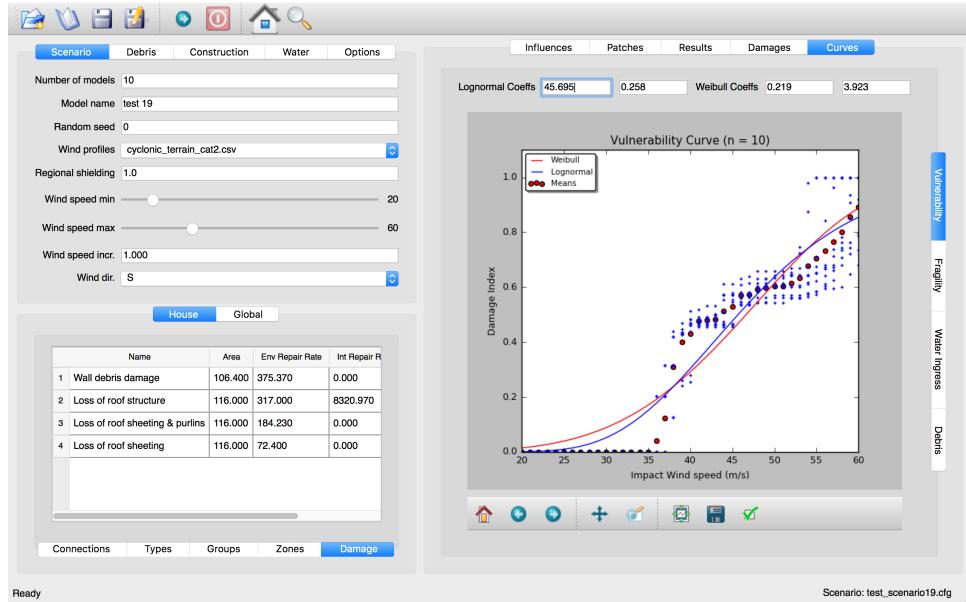


Fig. 4.15: Plot in the Vulnerability window

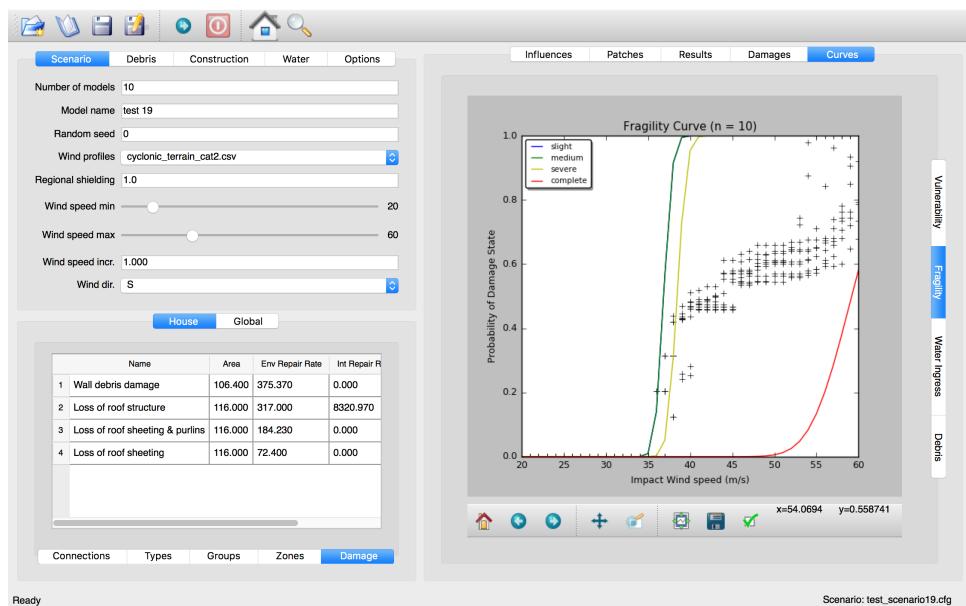


Fig. 4.16: Plot in the Fragility window

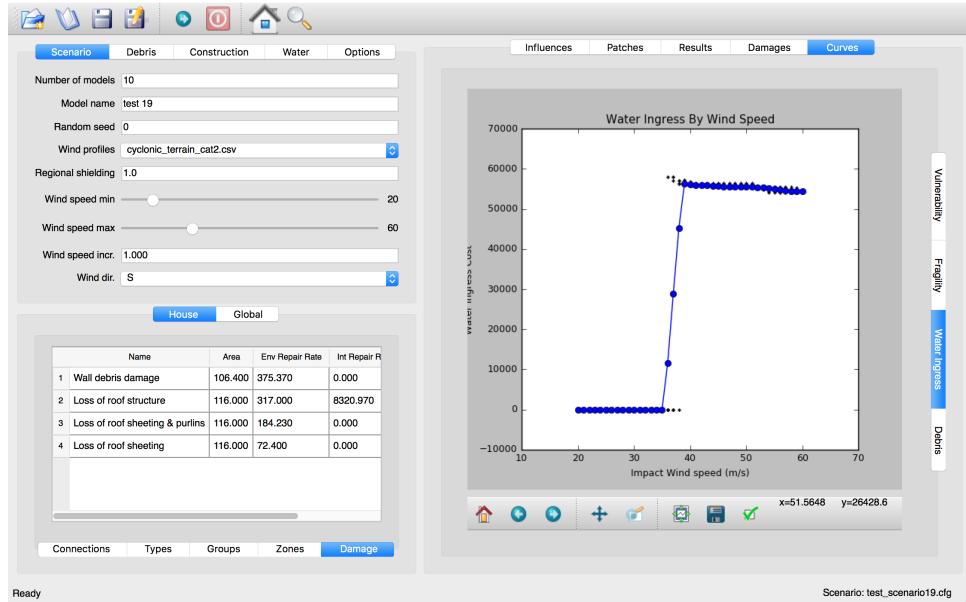


Fig. 4.17: Plot in the Water Ingress window

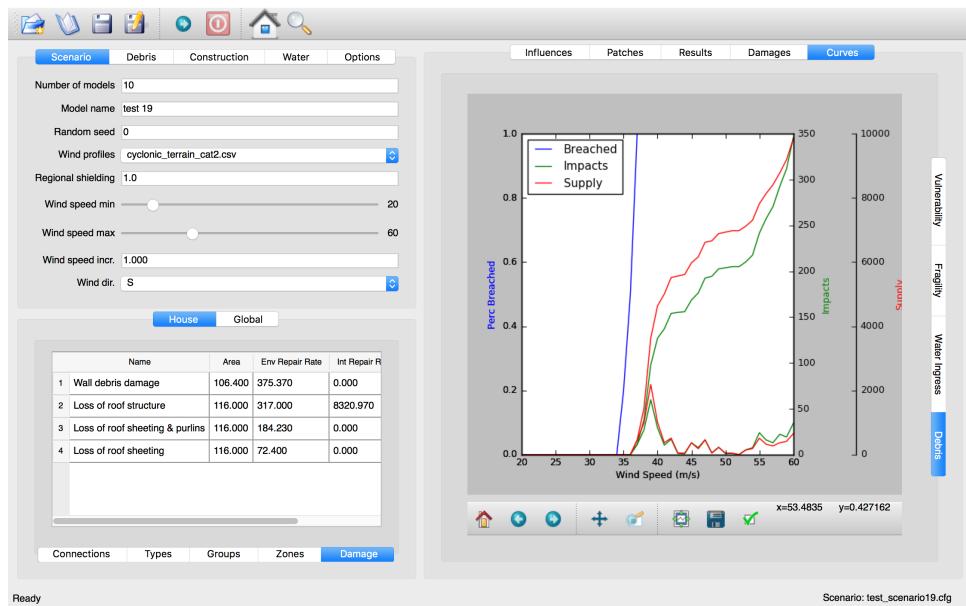


Fig. 4.18: Plot in the Debris window

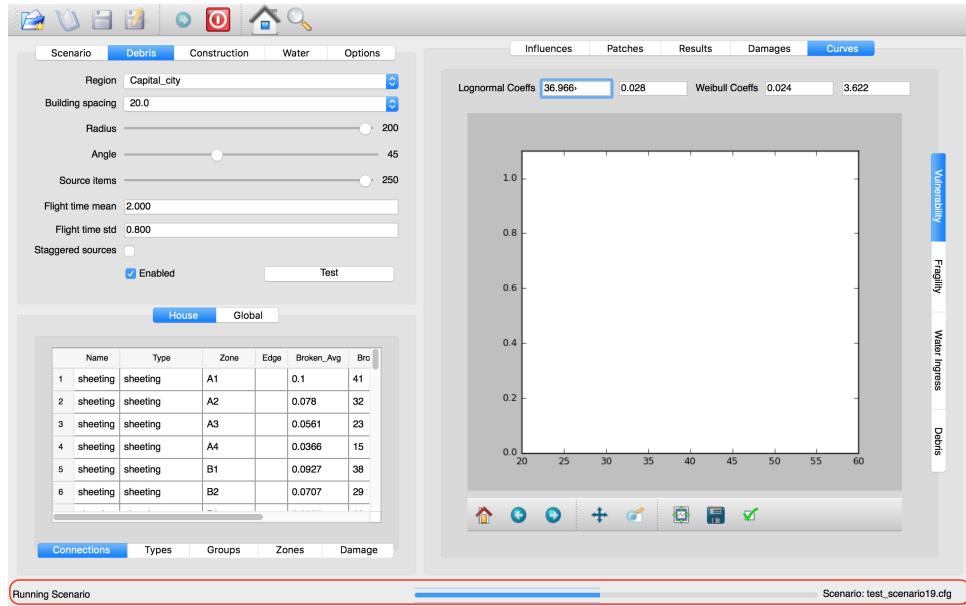


Fig. 4.19: Display of configuration file and status of simulation

## 4.2 Running simulations

The simulation can be run by either 1) creating a new scenario or 2) loading a saved scenario.

### 4.2.1 Creating a new scenario

User can create a new scenario by clicking the *New* button, as shown in Table 4.1. The new scenario comes with a set of input files as an template. Once all the setting are set, then user can save the configuration file to a folder where the template input files will be saved. User need to make changes to each of the input files as required.

### 4.2.2 Loading a saved scenario

User can load a saved scenario file (e.g., default.cfg). A collection of input files should be located in the directory with the folder structure described in Listing 3.1. User may make some changes on the settings through GUI. Once all the settings are set, then simulation can be run by clicking the *Run* button, as shown in Table 4.1. Once the simulation is completed, user can either exit the program or save the current setting to a different scenario, as shown in Fig. 4.20.

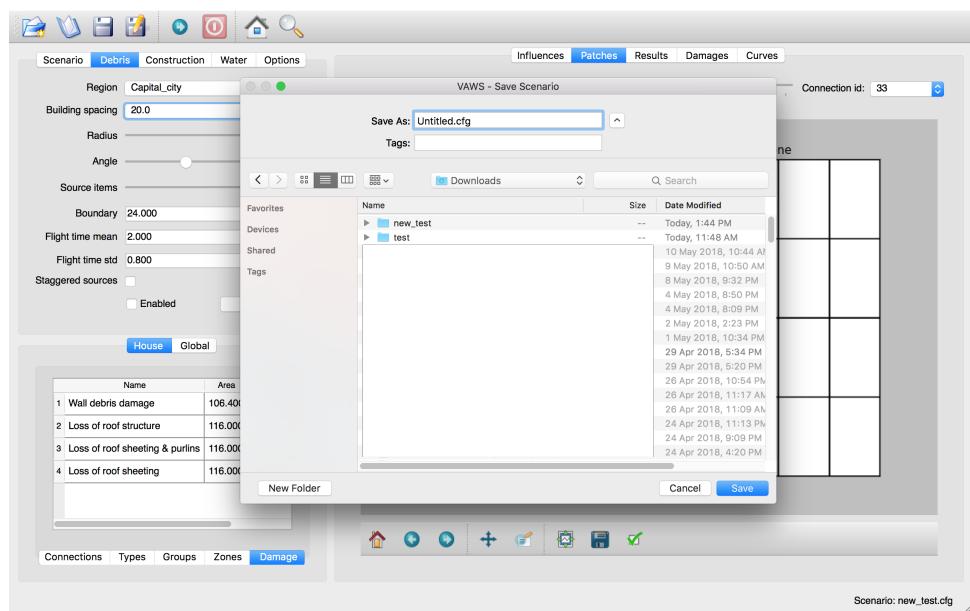


Fig. 4.20: Save as a new scenario

## PROGRAM LOGIC

This chapter describes the logic of the program.

### 5.1 Overall logic

The program is built around the following high level sequence:

1. Create a group of models
  - For each model
    - *sample wind direction*
    - *sample construction quality level*
    - *sample wind profile*
    - *set terrain height multiplier*
    - *set shielding multiplier*
    - *set up coverages*
    - *set up connections*
    - *set up zones*
    - *set up debris model*
2. Calculate damage indices of the models over a range of wind speeds
  - For each wind speed
    - simulate damage for each model
      - \* *compute free stream wind pressure*
      - \* *compute zone pressures*
      - \* *compute coverage load and check damage*
      - \* *compute connection loads*
      - \* *check damage of each connection by connection group*
      - \* *update influence by connection group*
      - \* *check model collapse*
      - \* *run debris model and update Cpi*

- \* *compute damage index*
  - *compute damage index increment*
3. *Fit fragility and vulnerability curves and save outputs*

## 5.2 Detailed logic

Detailed description of the logic is explained in the following sections by module.

### 5.2.1 Main module

#### **compute damage index increment (`compute_damage_increment()`)**

The increment of mean damage index for the group of models is computed. If the computed increment is less than zero, then zero value is returned.

#### **fit fragility and vulnerability curves and save outputs (`save_results_to_files()`)**

Based on the simulation results, fragility (see [fit fragility](#)) and vulnerability curves (see [fit vulnerability](#)) are fitted. The output file *results.h5* is also created, and the values of the selected attributes are saved. See [output file](#) for the list of attributes.

### 5.2.2 House module

#### **sample wind direction (`House.set_wind_dir_index()`)**

The wind direction is set up at the time of model creation, and kept constant during the simulation over a range of wind speeds. If *wind\_direction* (Table 3.1) is ‘RANDOM’, then wind direction is randomly sampled among the eight directions.

#### **sample construction quality level (`House.set_construction_level()`)**

A set of mean and coefficient of variation (CV) factors for connection strength is defined for each construction quality level with likelihood as listed in Table 3.4. Construction level for each model is determined from a random sampling, and the corresponding mean and CV factors are later multiplied to arithmetic mean and standard deviation of connection strength as (5.1):

$$\begin{aligned}\mu_{adj} &= \mu \times f_\mu \\ \sigma_{adj} &= \sigma \times f_\mu \times f_{cv}\end{aligned}\tag{5.1}$$

where  $\mu_{adj}$  and  $\sigma_{adj}$ : adjusted mean and standard deviation of connection strength reflecting construction quality level, respectively,  $\mu$  and  $\sigma$ : mean and standard deviation of connection strength,  $f_\mu$  and  $f_{cv}$ : mean and CV factors for connection strength.

### **sample wind profile (`House.set_profile_index()`)**

A set of gust envelope wind profiles is read from *wind\_profiles* (Table 3.1). Note that each profile is a normalized profile whose value is normalized to 1 at 10 metres height. An example profile is shown in Fig. 3.8. One profile is randomly chosen for each model and kept constant during the simulation over a range of wind speeds.

### **set terrain height multiplier (`House.set_terrain_height_multiplier()`)**

The terrain height multiplier ( $M_{z,cat}$ ) value at the model height is calculated by the interpolation using the selected wind profile over height.

### **set shielding multiplier (`House.set_shielding_multiplier()`)**

The shielding multiplier ( $M_s$ ) value is determined based on the location. If the value of *regional\_shielding\_factor* is less or equal to 0.85, which means that the model is located in Australian urban areas, then  $M_s$  value is sampled based on the proportion of each type of shielding listed in Table 5.1. Otherwise,  $M_s$  value is set to be 1.0, which corresponds to *No shielding*. The proportion of shielding type is adopted following the recommendation in [3].

Table 5.1: Proportion of shielding type

| Type              | $M_s$ value | Proportion |
|-------------------|-------------|------------|
| Full shielding    | 0.85        | 63%        |
| Partial shielding | 0.95        | 15%        |
| No shielding      | 1.0         | 22%        |

### **set up coverages (`House.set_coverages()`)**

The coverages make up the wall part of the envelope of the model. Two failure mechanism are implemented: 1) failure by wind load and 2) failure by windborne debris.

A set of coverage components (*Coverage*) is defined using the information provided in the input files of *coverages.csv*, *coverage\_types.csv* and *coverages\_cpe.csv*. The  $C_{pe}$  and strength values for each coverage component are sampled when it is defined. The windward direction for each coverage component is assigned from among *windward*, *leeward*, *side1*, or *side2*, which is used in determining the windward direction of dominant opening due to coverage failure.

### **set up zones (`House.set_zones()`)**

A set of zone components (*Zone*) is defined using the information provided in the input files of *zones.csv*, *zones\_cpe\_mean.csv*, *zones\_cpe\_str\_mean.csv*, *zones\_cpe\_eave\_mean.csv*, and *zones\_edges.csv*. The  $C_{pe}$  value for each zone component is sampled when it is defined.

### **set up connections (`House.set_connections()`)**

A set of connection components (*Connection*) is defined using the information provided in the input files of *conn\_groups.csv*, *conn\_types.csv*, *connections.csv*, *influences.csv*, and *influence\_patches.csv*.

The strength and dead load values for each connection component are sampled and influence and influence patch for each connection are also defined with reference to either zone or another connection components.

A set of connection type group (`ConnectionTypeGroup`) is also defined, and reference is created to relate a connection component to a connection type group. A connection type group is further divided into sub-group by section in order to represent load distribution area within the same group. For instance roof sheetings on a hip roof are divided into a number of sheeting sub-groups to represent areas divided by roof ridge lines.

### **set up debris model (`House.set_debris()`)**

A debris damage model is set up by referencing the wind direction and coverages of the model. Once the wind direction of the model is assigned to the debris model, the footprint for debris impact is created by rotating the model footprint with regard to the wind direction as set out in [Table 5.2](#) (`Debris.footprint`). Note that all the debris sources are assumed to be located in the East of the model when debris impact to the model is simulated.

Table 5.2: Rotation angle by wind direction

| Wind direction | Rotation angle (deg) |
|----------------|----------------------|
| S or N         | 90                   |
| SW or NE       | 45                   |
| E or W         | 0                    |
| SE or NW       | -45                  |

Also walls and coverage components subject to debris impact are selected based on the wind direction (`Debris.front_facing_walls`). The boundary for debris impact assessment is also defined with the radius of boundary (`Debris.boundary`)

### **calculate free stream wind pressure (`House.compute_qz()`)**

The free stream wind pressure,  $q_z$  is calculated as (5.2):

$$q_z = \frac{1}{2} \times \rho_{air} \times (V \times M_{z,cat} \times M_s)^2 \times 1.0e-3 \quad (5.2)$$

where  $\rho_{air}$ : air density ( $=1.2 \text{ kg/m}^3$ ),  $V$ : 3-sec gust wind speed at 10m height,  $M_{z,cat}$ : terrain-height multiplier,  $M_s$ : shielding multiplier. Note that  $1.0e-3$  is multiplied to convert the unit of the wind pressure from Pa to kPa.

### **check model collapse (`House.check_collapse()`)**

The model is deemed to be collapsed if the proportion of damaged components out of the total components is greater than the value of `trigger_collapse_at`, which is listed in [Table 3.11](#), for any group with non-zero value of `trigger_collapse_at`.

### **run debris model and update $C_{pi}$ (`House.check_internal_pressurisation()`)**

If the value of `debris` is *True* (see [Table 3.2](#)), then debris impact to the model is simulated. See [Debris module](#) for more details.

The internal pressure coefficient,  $C_{pi}$  is determined based on [Table 5.3](#) and [Table 5.4](#) depending on the existence of dominant opening by either coverage failure or debris breach, which are revised from Tables 5.1(A) and 5.1(B) of AS/NZS 1170.2:2011 [\[1\]](#), respectively.

Table 5.3:  $C_{pi}$  for buildings without dominant openings

| Condition  | $C_{pi}$ |
|--|----------|
| All walls equally breached                       | -0.3     |
| Two or three windward walls equally breached     | 0.2      |
| Two or three non-windward walls equally breached | -0.3     |

Table 5.4:  $C_{pi}$  for buildings with dominant openings

| Ratio of dominant opening to total open area ( $r$ ) | Dominant opening on windward wall | Dominant opening on leeward wall | Dominant opening on side wall |
|--|-----------------------------------|----------------------------------|-------------------------------|
| $r < 0.5$  | -0.3                              | -0.3                             | -0.3                          |
| $0.5 \leq r < 1.5$                                   | 0.2                               | -0.3                             | -0.3                          |
| $1.5 \leq r < 2.5$                                   | $0.7 C_{pe}$                      | $C_{pe}$                         | $C_{pe}$                      |
| $2.5 \leq r < 6.0$                                   | $0.85 C_{pe}$                     | $C_{pe}$                         | $C_{pe}$                      |
| $r \geq 6.0$   | $C_{pe}$                          | $C_{pe}$                         | $C_{pe}$                      |

### compute damage index (`House.compute_damage_index()`)

The damage index is calculated over the following steps:

1. calculate sum of damaged area by connection group (`House.compute_area_by_group()`)
2. Apply damage factoring (`House.apply_damage_factoring()`)
3. Calculate sum of damaged area by damage scenario (`House.compute_area_by_scenario()`)

A damage scenario is assigned to each connection type group as explained in [3.4.2](#).

4. calculate total damage cost and damage index prior to water ingress ( $DI_p$ ) as [\(5.3\)](#):

$$DI_p = \frac{\sum_{i=1}^S C_i}{R} \quad (5.3)$$

where  $S$ : number of damage scenario,  $C_i$ : damage cost for  $i$  th damage scenario, and  $R$ : total replacement cost.

5. Calculate cost by water ingress damage,  $C_{wi}$  if required as explained in [damage due to water ingress](#).
6. calculate damage index as [\(5.4\)](#):

$$DI = \frac{\sum_{i=1}^S C_i + C_{wi}}{R} \quad (5.4)$$

### 5.2.3 Zone module (Zone)

#### sample Cpe (Zone.sample\_cpe())

The external pressure coefficient,  $C_{pe}$  is used in computing zone pressures, and is sampled from Type III extreme value distribution (`stats.sample_gev()`) which has the cumulative distribution function and probability density as (5.5) and (5.6), respectively.

$$F(s; k) = \exp(-(1 - ks)^{1/k}) \quad (5.5)$$

$$f(s; a, k) = \frac{1}{a} (1 - ks)^{1/k-1} \exp(-(1 - ks)^{1/k}) \quad (5.6)$$

where  $s = (x - u)/a$ ,  $u$ : location factor ( $\in \text{IR}$ ),  $a$ : scale factor ( $> 0$ ), and  $k$ : shape factor ( $k \neq 0$ ).

The mean and standard deviation are calculated as (5.7):

$$\begin{aligned} E(X) &= u + \frac{a}{k} [1 - \Gamma(1 + k)] \\ \text{SD}(X) &= \frac{a}{k} \sqrt{\Gamma(1 + 2k) - \Gamma^2(1 + k)} \end{aligned} \quad (5.7)$$

The  $u$  and  $a$  can be estimated given  $c_v (= \frac{SD}{E})$  and  $k$  values as (5.8):

$$\begin{aligned} a &= E \frac{c_v}{B} \\ u &= E - a \times A \end{aligned} \quad (5.8)$$

where  $A = (1/k) [1 - \Gamma(1 + k)]$  and  $B = (1/k) \sqrt{\Gamma(1 + 2k) - \Gamma^2(1 + k)}$ .

#### calculate zone pressure (Zone.calc\_zone\_pressure())

Two kinds of zone pressure,  $p_z$  for zone component related to sheeting and batten and  $p_{z,str}$  for zone component related to rafter, are computed as (5.9):

$$\begin{aligned} p_z &= q_z \times (C_{pe} - C_{pi,\alpha} \times C_{pi}) \times D_s \\ p_{z,str} &= q_z \times (C_{pe,str} - C_{pi,\alpha} \times C_{pi} - C_{pe,eave}) \times D_s \end{aligned} \quad (5.9)$$

where  $q_z$ : free stream wind pressure,  $C_{pe}$ : external pressure coefficient,  $C_{pi}$ : internal pressure coefficient,  $C_{pi,\alpha}$ : proportion of the zone's area to which internal pressure is applied,  $C_{pe,str}$ : external pressure coefficient for zone component related to rafter,  $C_{pe,eave}$ : external pressure coefficient for zone component related to eave, and  $D_s$ : differential shielding. The value of differential shielding is determined as explained in *set differential shielding*.

#### set differential shielding (Zone.differential\_shielding)

If the value of *differential\_shielding* (see Table 3.2) is *True*, then differential shielding effect is considered in calculating zone pressure. Based on the recommendations from [3], adjustment for shielding multiplier is made as follows:

- For outer suburban situations and country towns (*building\_spacing=40m*), adjust  $M_s$  to 1.0 except for the leading edges of upwind roofs
- For inner suburban buildings (*building\_spacing=20m*) with full shielding ( $M_s=0.85$ ), adjust  $M_s$  to 0.7 for the leading edges of upwind roofs

- For inner suburban buildings (*building\_spacing* =20m) with partial shielding ( $M_s=0.95$ ), adjust  $M_s$  to 0.8 for the leading edges of upwind roofs
- Otherwise, no adjustment is made.

## 5.2.4 Coverage module (Coverage)

### calculate coverage load and check damage (Coverage.check\_damage())

The load applied for each of coverages are calculated as (5.10):

$$L = 0.9 \times q_z \times (C_{pe} - C_{pi}) \times A \quad (5.10)$$

where  $q_z$ : free stream wind pressure,  $C_{pe}$ : external pressure coefficient,  $C_{pi}$ : internal pressure coefficient, and  $A$ : area.

If the calculated load exceeds either positive or negative strength, which represents strength in either direction, then it is deemed to be damaged.

## 5.2.5 Connection module (Connection and ConnectionTypeGroup)

### calculate connection load (Connection.compute\_load())

The load applied for each of connections are calculated as (5.11):

$$L_i = D_i + \sum_{j=1}^{N_z} (I_{ji} \times A_j \times P_j) + \sum_{j=1}^{N_c} (I_{ji} \times L_j) \quad (5.11)$$

where  $L_i$ : applied load for  $i$  th connection,  $D_i$ : dead load of  $i$  th connection,  $N_z$ : number of zones associated with the  $i$  th connection,  $N_c$ : number of connections associated with the  $i$  th connection,  $A_j$ : area of  $j$  th zone,  $P_j$ : wind pressure on  $j$  th zone,  $I_{ji}$ : influence coefficient from  $j$  th either zone or connection to  $i$  th connection.

### check connection damage by connection type group (ConnectionTypeGroup.check\_damage())

Damage of each connection is checked by connection type group. If the load applied for a connection is less than the negative value of its strength, then the connection is considered damaged. Then damage grid of the connection type group (ConnectionTypeGroup.damage\_grid) is updated with the index of the damaged connection, which is later used in updating influence of intact components (ConnectionTypeGroup.update\_influence()).

### update influence by connection group (ConnectionTypeGroup.update\_influence())

The influence coefficient is used to associate one connection with another either zone or connection with regard to load distribution. For instance, if connection 1 has influences of connection 2 and 3 with coefficient 0.5 and 0.5, respectively, then the load on connection 1 is equal to the sum of 0.5 times load on connection 2 and 0.5 times load on connection 3, as shown in (5.11).

Once a connection is damaged, then load on the damaged connection needs to be distributed to other intact connections accordingly, which means that influence set of the connections needs to be updated.

Two types of influence update are implemented:

1. update influence coefficients of the next intact connections for the distribution of load on the damaged connection

Given the damage of connection of either sheeting and batten connection type group, the influence coefficient will be distributed evenly to the next intact connections of the same type to the distribution direction (*dist\_dir* listed in [Table 3.11](#)). Note that *patch\_dist* of both sheeting and batten connection group are set to *False*. If both the next connections, which are left and right if *dist\_dir* is ‘row’ or above and below if ‘col’, of the damaged connection are intact, then the half of the load is distributed to the each of next intact connection. Otherwise, the full load of the damaged connection is distributed to the intact connection.

2. replace the existing influence set with new one, when *patch\_distribution* is set to 1 (`ConnectionTypeGroup.update_influence_by_patch()`)

Unlike sheeting and batten, a connection of rafter group fails, then influence set of each connection associated with the failed connection are replaced with a new set of influence, which is termed “patch”. In the current implementation, the patch is defined for a single failed connection. Thus the failure order of the connections may make difference in the resulting influences as shown in [Table 5.5](#).

[Table 5.5: Example of how patch works](#)

| Failed connection | Connection | Patch (connection: influence coeff.) |
|-------------------|------------|--------------------------------------|
| 1                 | 3          | 1:0.0, 2:0.5, 3:0.5                  |
| 2                 | 3          | 1:0.5, 2:0.0, 3:1.0                  |
| 1 and then 2      | 3          | 1:0.0, 2:0.0, 3:1.0                  |
| 2 and then 1      | 3          | 1:0.0, 2:0.0, 3:0.5                  |

## 5.2.6 Debris module ([Debris](#))

The methodology of modelling damage from wind-borne debris implemented in the code is described in [\[4\]/\[6\]](#). The debris damage module consists of four parts: 1) debris source generation, 2) debris generation, 3) debris trajectory, and 4) debris impact.

### debris source generation

The debris sources are generated by calling `Debris.create_sources()`, which requires a number of parameters as shown in the [Fig. 5.1](#).

Depending on the value of *staggered\_sources*, different layout of debris sources can be generated as shown in [Fig. 5.2](#) and [Fig. 5.3](#).

### debris generation

The mean number of debris items to be generated ( $N_{mean}$ ) is calculated by (5.12).

$$N_{mean} = \text{nint} (\Delta DI \times N_{items}) \quad (5.12)$$

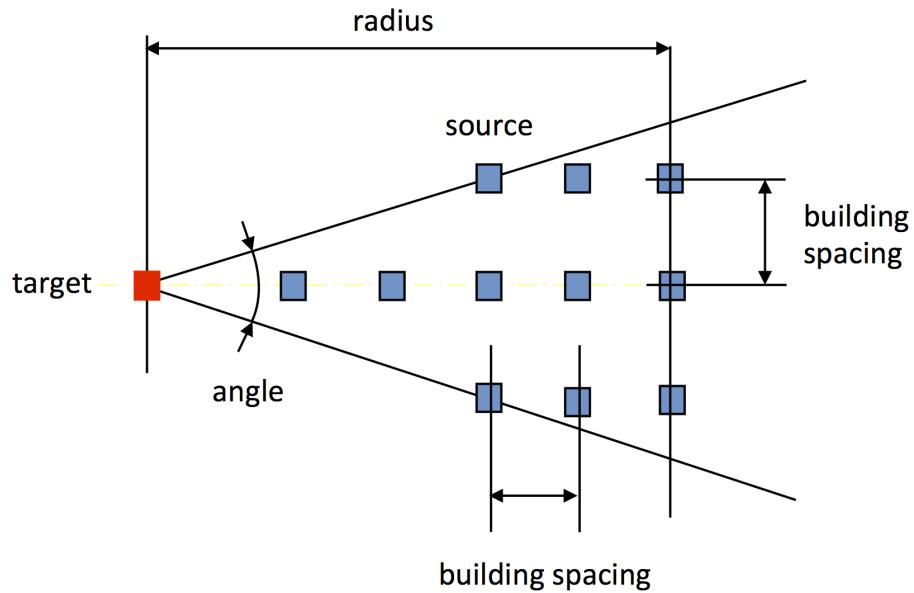


Fig. 5.1: Distribution of debris sources with parameters

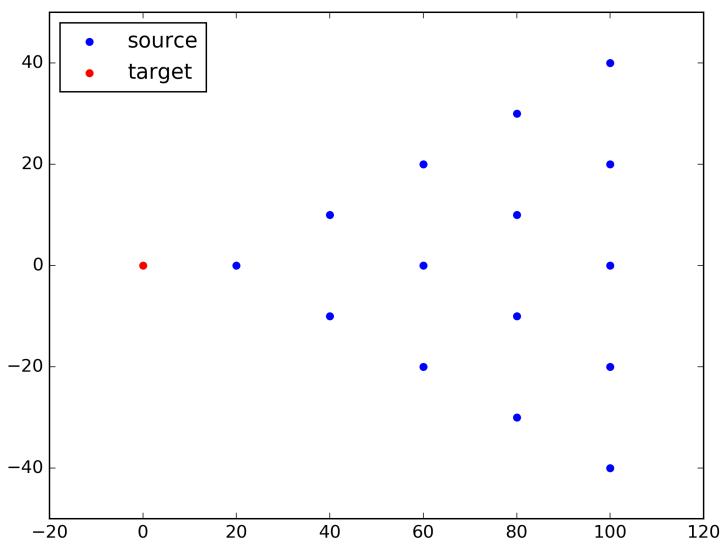


Fig. 5.2: Distribution of debris sources generated with debris\_radius = 100.0 (m), debris\_angle = 45.0 (deg), debris\_space = 20.0 (m), and staggered\_sources = *True*.

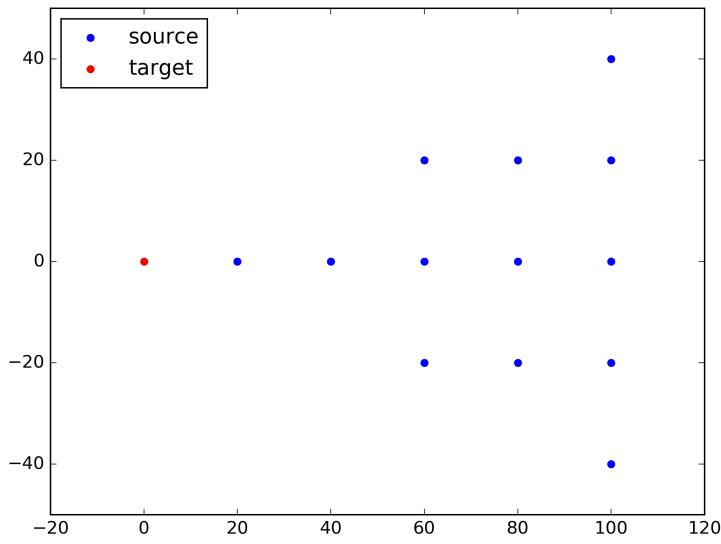


Fig. 5.3: Distribution of debris sources generated with `debris_radius = 100.0` (m), `debris_angle = 45.0` (deg), `debris_space = 20.0` (m), and `staggered_sources = False`.

where  $N_{items}$ : number of debris items per source defined in 3.1.3,  $\Delta DI$ : increment in damage index from previous wind step, and `nint`: nearest integer function.

The number of generated debris items is assumed to follow the Poisson distribution with parameter  $\lambda = N_{mean}$ . For each debris source, the number of generated debris items is randomly sampled from the distribution, and debris type is randomly chosen as many as number of items with probability proportional to the ratio of each type defined in Table 3.9. The debris types are provided in the section of 3.2 `debris.csv`.

## debris trajectory

For each generated debris item, mass, frontal area, and flight time are sampled from the lognormal distribution with parameter values provided in 3.1.3 and 3.2. The flight distance is calculated based on the methodology presented in the Appendix of [5]. Note that the original fifth polynomial functions are replaced with quadratic one with the coefficients as listed in Table 5.6. The computed flight distance by debris type using the fifth and quadratic polynomials is shown in Fig. 5.4.

Table 5.6: Coefficients of quadratic function for flight distance computation by debris type

| Debris type | Linear coeff. | Quadratic coeff. |
|-------------|---------------|------------------|
| Compact     | 0.011         | 0.2060           |
| Rod         | 0.2376        | 0.0723           |
| Sheet       | 0.3456        | 0.072            |

The probability distribution of point of landing of the debris in a horizontal plane is assumed to follow a bivariate normal distribution as (5.13).

$$f_{x,y} = \frac{1}{2\pi\sigma_x\sigma_y} \exp \left[ -\frac{(x-d)^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2} \right] \quad (5.13)$$

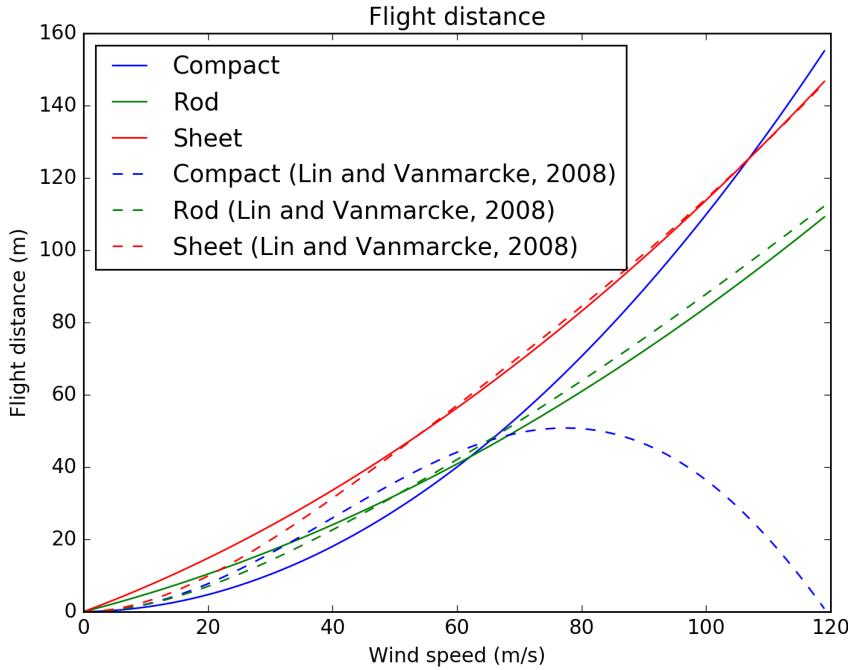


Fig. 5.4: Flight distance of debris item

where  $x$  and  $y$  are the coordinates of the landing position of the debris,  $\sigma_x$  and  $\sigma_y$ : standard deviation for the coordinates of the landing position, and  $d$ : expected flight distance. The value of  $\sigma_x$  and  $\sigma_y$  are set to be  $d/3$  and  $d/12$ , respectively.

Either if the landing point is within the footprint of the model or if the line linking the source to the landing point intersects with the footprint of the model and the landing point is within the boundary, then it is assumed that an impact has occurred. The criteria of debris impact is illustrated in the Fig. 5.5 where blue line represents debris trajectory with impact while red line represents one without impact.

Following Lin and Vanmarcke 2008, the ratio of horizontal velocity of the windborne debris object to the wind gust velocity is modelled as a random variable with a Beta distribution as (5.14).

$$\frac{u_m}{V_s} \sim Beta(\alpha, \beta) \quad (5.14)$$

where  $u_m$ : the horizontal velocity of the debris object,  $V_s$ : the local (gust) wind speed,  $\alpha$  and  $\beta$  are two parameters of the Beta distribution and estimated as (5.15).

$$\begin{aligned} \alpha &= E \times \nu \\ \beta &= \nu \times (1 - E) \end{aligned} \quad (5.15)$$

where  $E$ : the expected value and  $\nu = \alpha + \beta$ .

The expected value ( $E$ ) and the parameter ( $\nu$ ) are assumed to be as (5.16).

$$\begin{aligned} E &= 1 - \exp(-b\sqrt{x}) \\ \nu &= \max\left[\frac{1}{E}, \frac{1}{1-E}\right] + 3.0 \end{aligned} \quad (5.16)$$

where  $x$ : the flight distance,  $b$ : a dimensional parameter calculated as (5.17). If  $E$  is 1, then  $\alpha$  and  $\beta$  are assigned with 3.996 and 0.004, respectively.

$$b = \sqrt{\frac{\rho_a C_{D,av} A}{m}} \quad (5.17)$$

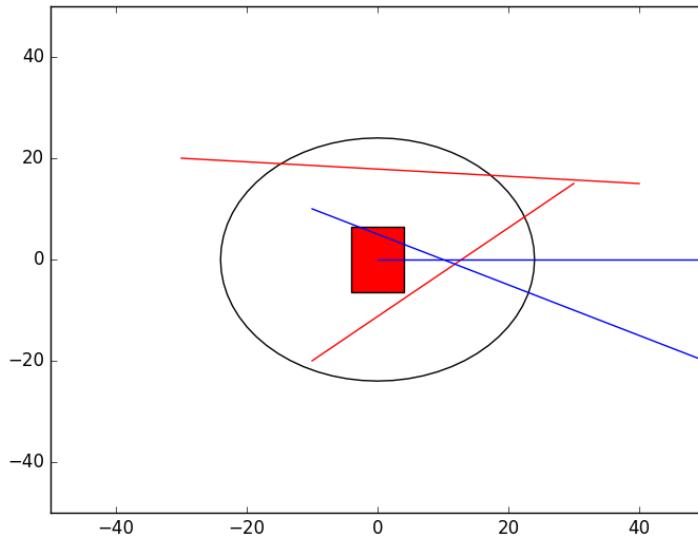


Fig. 5.5: Graphical presentation of debris impact criteria

where  $\rho_a$ : the air density,  $C_{D,av}$ : an average drag coefficient,  $A$ : the frontal area, and  $m$ : the mass of the object.

The momentum  $\xi$  is calculated using the sampled value of the ratio,  $\frac{u_m}{V_s}$  as (5.18).

$$\xi = \left( \frac{u_m}{V_s} \right) \times m \times V_s \quad (5.18)$$

## debris impact

Based on the methodology presented in HAZUS and Lin and Vanmacke (2008), the number of impact  $N$  is assumed to follow a Poisson distribution as (5.19).

$$\begin{aligned} N &\sim \text{Pois}(\lambda) \\ \lambda &= N_v \cdot q \cdot F_\xi(\xi > \xi_d) \end{aligned} \quad (5.19)$$

where  $N_v$ : number of impacts at a single wind speed,  $q$ : proportion of coverage area out of the total area of envelope,  $F_\xi$ : the cumulative distribution of momentum, and  $\xi_d$ : threshold of momentum or energy for damage of the material of the coverage.

The probability of damage can be calculated based on the Poisson distribution as (5.20).

$$P_D = 1 - P(N = 0) = 1 - \exp[-\lambda] \quad (5.20)$$

$q$  and  $F_\xi(\xi > \xi_d)$  are estimated for each coverage. If the material of the coverage is glass, then  $P_D$  is computed and compared against a random value sampled from unit uniform distribution to determine whether the coverage is damaged or not. For coverage with non-glass material, a random value of number of impact is sampled from the Poisson distribution with  $\lambda$ , and damaged coverage area is then computed assuming that the area requiring repairs due to debris impact is 1.

## 5.2.7 damage\_costing module (Costing)

### damage due to water ingress

The damage cost induced by water ingress is estimated over the following three steps:

1. estimate amount of water ingress (`compute_water_ingress_given_damage()`)

The amount of water ingress is estimated based on the relationship between water ingress and wind speed, which is listed in [Table 3.5](#). The estimated damage index prior to water ingress is used to choose the right curve as shown in [Fig. 3.4](#).

2. determine damage scenario (`House.determine_scenario_for_water_ingress_costing()`)

The damage scenario for water ingress is determined based on the order of damage scenario as listed in [Table 3.20](#). One damage scenario is selected by the order among the damage scenarios with which damage area of connection associated is greater than zero. When the damage index is zero (or no connection damage yet), then damage scenario of ‘WI only’ is used.

3. calculate cost for water ingress damage (`House.compute_water_ingress_cost()`)

The cost for water ingress damage is estimated using the data provided in [3.4.17](#). The example plot for the scenario of *loss of roof sheeting* is shown in [Fig. 5.6](#). The cost for water ingress damage is estimated using the curve for water ingress closest to the estimated amount of water ingress.

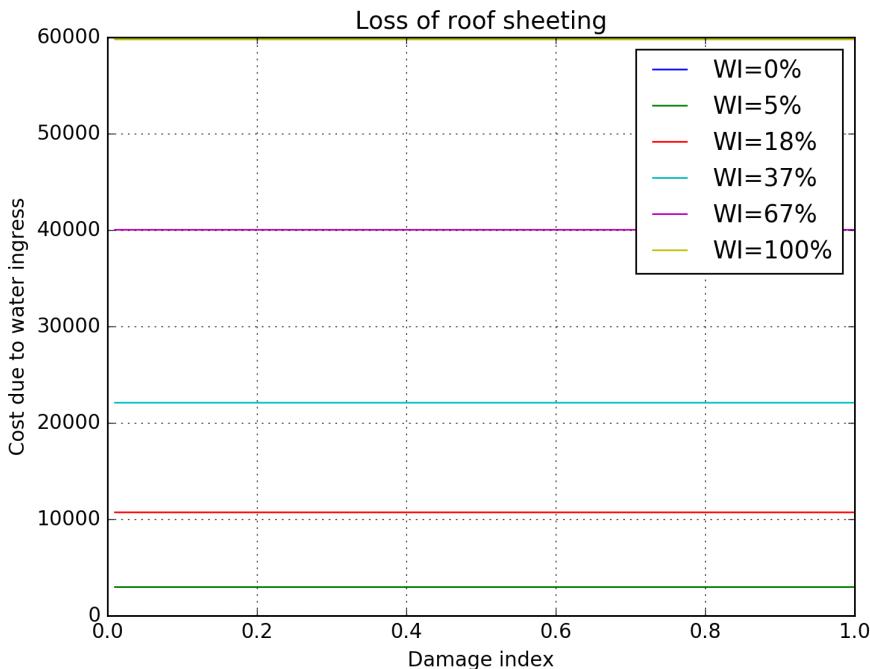


Fig. 5.6: Relationship between cost due to water ingress damage and damage index

## 5.2.8 Curve module

**fit fragility (curve.fit\_fragility\_curves())**

The probability of exceeding a damage state  $ds$  at a wind speed  $x$  is calculated as (5.21):

$$P(DS \geq ds|x) = \frac{\sum_{i=1}^N [DI_{i|x} \geq t_{ds}]}{N} \quad (5.21)$$

where  $N$ : number of models,  $DI_{i|x}$ : damage index of  $i$  th model at the wind speed  $x$ , and  $t_{ds}$ : threshold for damage state  $ds$ .

Then for each damage state, a curve of cumulative lognormal distribution (4.1) is fitted to the computed probabilities of exceeding the damage state.

**fit vulnerability (curve.fit\_vulnerability\_curve())**

Two types of curves are used to fit the results of damage indices of models: a cumulative lognormal distribution ((4.1), `curve.vulnerability_lognormal()`) and Weibull distribution ((4.2), `curve.vulnerability_weibull()`).

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CHAPTER  
SIX

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GLOSSARY

**connection** models a physical structural connection that will bear a simulated load and when broken cause load to be distributed and generate damage outcomes.

**connection type** a collection of connections sharing the same strength and dead load statistical characteristics and costing area

**coverage** a component making up the wall part of the envelope of the model

$C_{pe}$  external pressure coefficient

$C_{pi}$  internal pressure coefficient

$C_{pi,\alpha}$

proportion of the zone's area to which internal pressure is applied

**CV** coefficient of variation, the ratio of the standard deviation to the mean

**damage index** The total cost of repairing the building fabric of a group of buildings exposed to severe natural hazard divided by the total cost of fully rebuilding the same assets in the existing locality to current local building regulations.

**differential shielding** incremental adjustments to be applied to envelope surface pressures to account for different degrees of shielding between envelope surfaces on a single shielded structure.

**fragility, fragility function, fragility curve** Fragility describes the probability of discrete damage states for a specific hazard. Fragility function or curve is referred to a damage model which describes the likelihood of a building of a particular type being damaged to a defined degree for a given level of natural hazard exposure.

**influence coefficient** coefficient relating a connection to either zone or connection with regard to load distribution

$M_s$  shielding multiplier. This multiplier represents the reduction in peak 3-second gust velocity at a given height and terrain, caused by the presence of buildings and other obstructions upwind of the site of interest.

$M_{z,cat}$  terrain height multiplier

**patch** a set of revised influence coefficients for a connection

$q_z$  free stream wind pressure

**vulnerability, vulnerability function, vulnerability curve** A damage model, or curve, which describes the average severity of physical economic loss to a group of build-

ings of a particular type in terms of a damage index with increasing natural hazard exposure.

**zone** an area of building enveloped on which wind pressure acts. Zone is linked with connection with influence coefficient so the wind pressure is transformed to wind load on a connection.

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