This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

LIQUEFACT

Assessment and mitigation of liquefaction potential across Europe: a holistic approach to protect structures/infrastructure for improved resilience to earthquake-induced liquefaction disasters

H2020-DRA-2015

GA no. 700748

DELIVERABLE D6.6

LIQUEFACT Software – Technical Manual and Application

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DOCUMENT REVISION HISTORY

Date	Version	Editor	Comments	Status
10/03/2018	01	Abdelghani Meslem	Final Draft	Draft

GLOSSARY

Acronym	Description
EILDs	Earthquake-Induced Liquefaction Disaster
LSN	Liquefaction Severity Number
LPI	Liquefaction Potential Index
LP	Liquefaction Probability

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CONTENTS

SUMMARY

This document provides step-by-step guidelines on how to use the LIQUEFACT software, a toolbox for liquefaction mitigation planning and decision support able to estimate and predict the likely consequences of earthquake-induced liquefaction damage (EILD) at local and regional level. The software can provide civil engineers and relevant stakeholders with guidance in making informed assessments on the feasibility and cost-benefit of applying certain liquefaction mitigation techniques for a given earthquake-induced liquefaction threat. The concept of the software process consists of three main independent protocols: Protocol for Hazard Analysis, Protocol for Risk Analysis, and Protocol for Mitigation Analysis. The document is divided into three main parts: Part-1 provides detailed description on the different types of analysis that users can implemented, and type and format of input data required for each case of selected analysis type. Part-2: describes the processing settings that users are required to define depending on the user's objectives and target goal of analysis. Part-3 provides detailed description on the different analysis outcomes and results that users can obtain form each case of selected analysis type, and interpretation of the results. And final part, Part-4, that provides the technical description and theoretical background of all the methodologies, procedures and approaches that have been incorporated in the LIQUEFACT software for the liquefaction hazard, risk and mitigation assessment.

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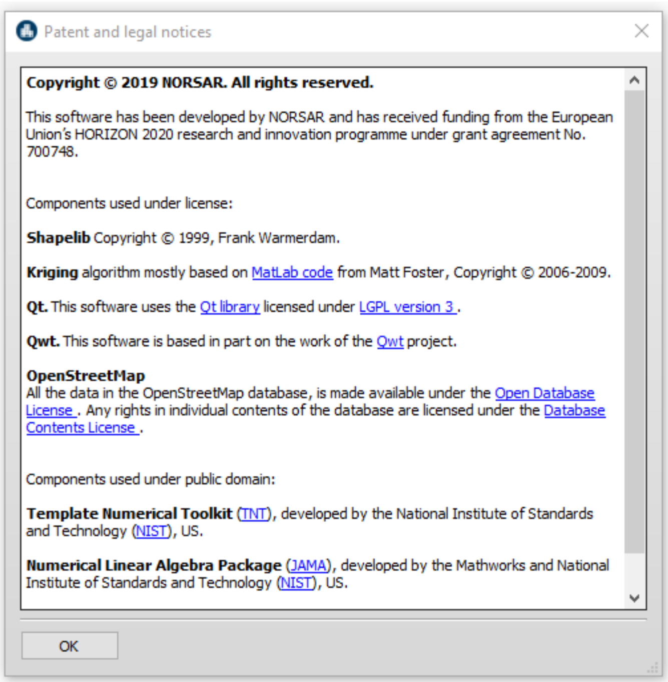
LIQUEFACT Software
Technical Manual and Application

1 LIQUEFACT SOFTWARE

LIQUEFACT software, is a toolbox for liquefaction mitigation planning and decision support, able to estimate and predict the likely consequences of earthquake-induced liquefaction damage (EILD) at local and regional level. The software can provide civil engineers and relevant stakeholders with guidance in making informed assessments on the feasibility and cost-benefit of applying certain liquefaction mitigation techniques for a given earthquake-induced liquefaction threat.

1.1 Credit references

LIQUEFACT software has been developed by NORSAR and has received funding from the European Union's HORIZON 2020 research and innovation programme under grant agreement No. 700748. Credit references can be found in "*About*" under menu Help, and by clicking on "Patent and legal notices".



1.2 Disclaimer

By using the software, the user understands, accepts responsibility for, and agrees to the following conditions and limitations:

- LIQUEFACT software is provided for guidance only. Design decisions should not, under any condition, be based on the software alone.

- Results of the LIQUEFACT software should be critically reviewed by an experienced engineer with sufficient expertise and an understanding of the underlying assumptions and limitations of the software.
- The validity of the results cannot be guaranteed as correct and the mitigation framework results provided in the software should be independently cross-checked.
- This software is offered as is, without warranty or promise of support of any kind either expressed or implied.

1.3 Software Processing Concept

Earthquake-induced liquefaction damage assessment is a multi-process analysis that requires different types and forms of input data related to geology and seismology of the site, geotechnical data, and structure-foundation system characteristics of the asset under risk. To this end, the LIQUEFACT software has been designed in a way that EILD assessment is conducted at three independent protocol of analysis to provide more flexibility to the end-user's requirements with respect to the level of analysis to be implemented and type of input data that are available (see Figure 1).

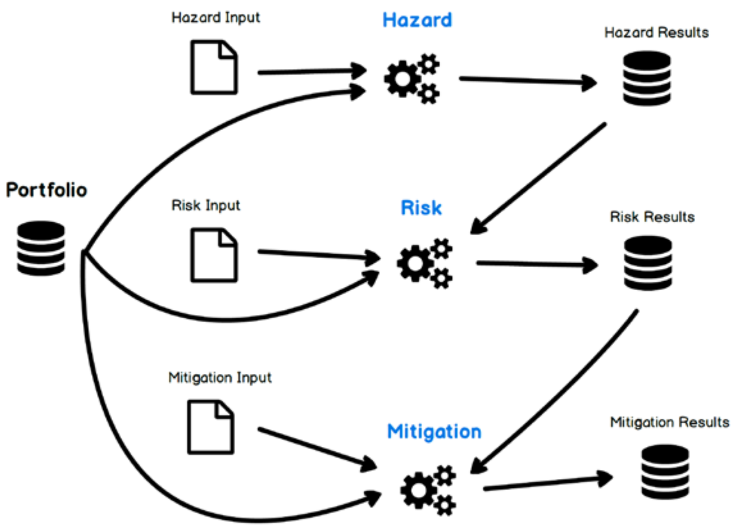


Figure 1. Protocol analysis processes in the LIQUEFACT software

The three-independent protocol of analysis implemented in the LIQUEFACT software are: the protocol for liquefaction hazard analysis, the protocol for risk analysis, and the protocol for mitigation analysis. At the stage of liquefaction hazard, the end-user can conduct qualitative analyses to identify how likely an asset (e.g. individual building/CI asset, portfolio of buildings/distributed infrastructure assets, etc.) is susceptible to liquefaction. If the end-user wants to conduct a risk analysis as well, which is aimed to estimate the level of impact of the potential liquefaction threat on the asset and evaluate the performance, then a quantitative analysis of the liquefaction potential is required (in order to evaluate quantitatively the level of the threat) followed by structural response and damage analysis, and performance evaluation. For the Mitigation Analysis, the end-user can develop a customized mitigation framework based on the outcome of the risk analysis.

1.4 Graphical User Interface

A robust graphic user interface (GUI) has been designed to provide a user-friendly environment for preparing the input information for the LIQUEFACT software. All processes will be handled through this GUI. The main window of the GUI is divided into three parts:

- *Module Selection*: Pre-Processing Module (for data input and configurations), Processing (run and analysis), Results viewer;
- *Analysis Parameters Settings*: Type of Analysis and geographical region, Hazard data input, Risk data input and Mitigation data input;
- *Input & Output*: Portfolio database handling; Liquefaction hazard model, seismic hazard model, risk modelling (vulnerability models and economic and business activity data), portfolio data and mitigation data.

The main Graphic User Interface is used also for work on the database. Filtering and selection options are available for various parameters. Adding, removing and changing information is also done under this GUI.

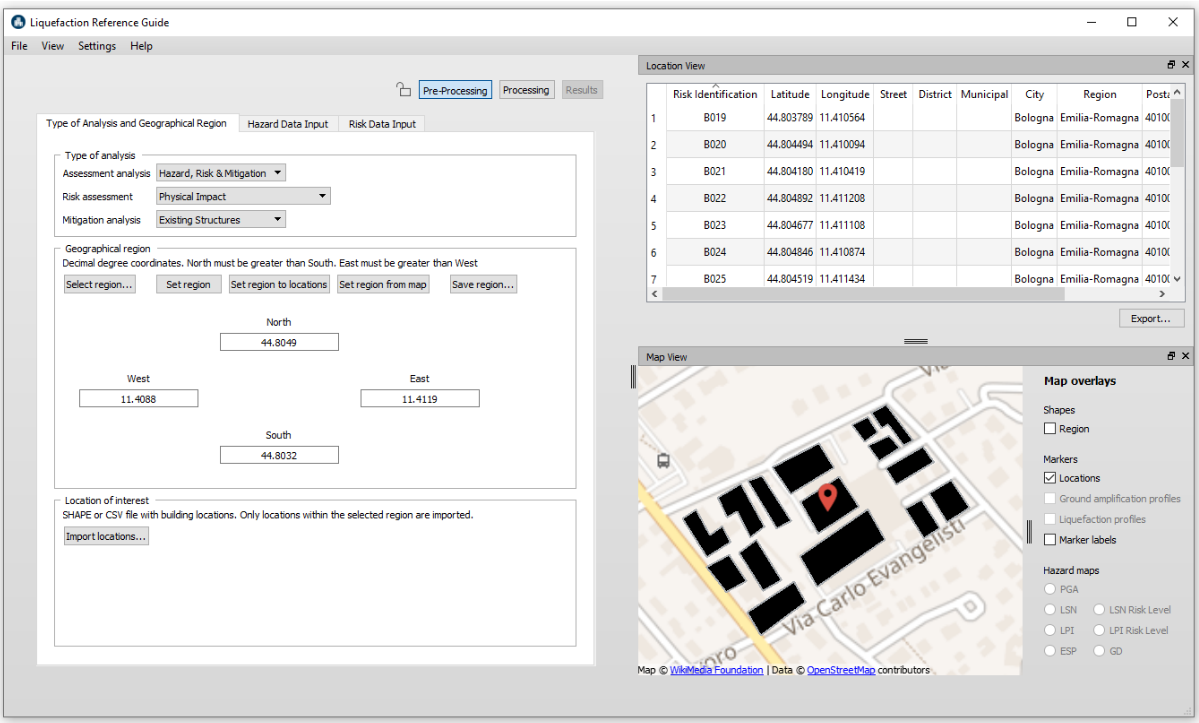


Figure 2. LIQUEFACT Software - graphical user interface

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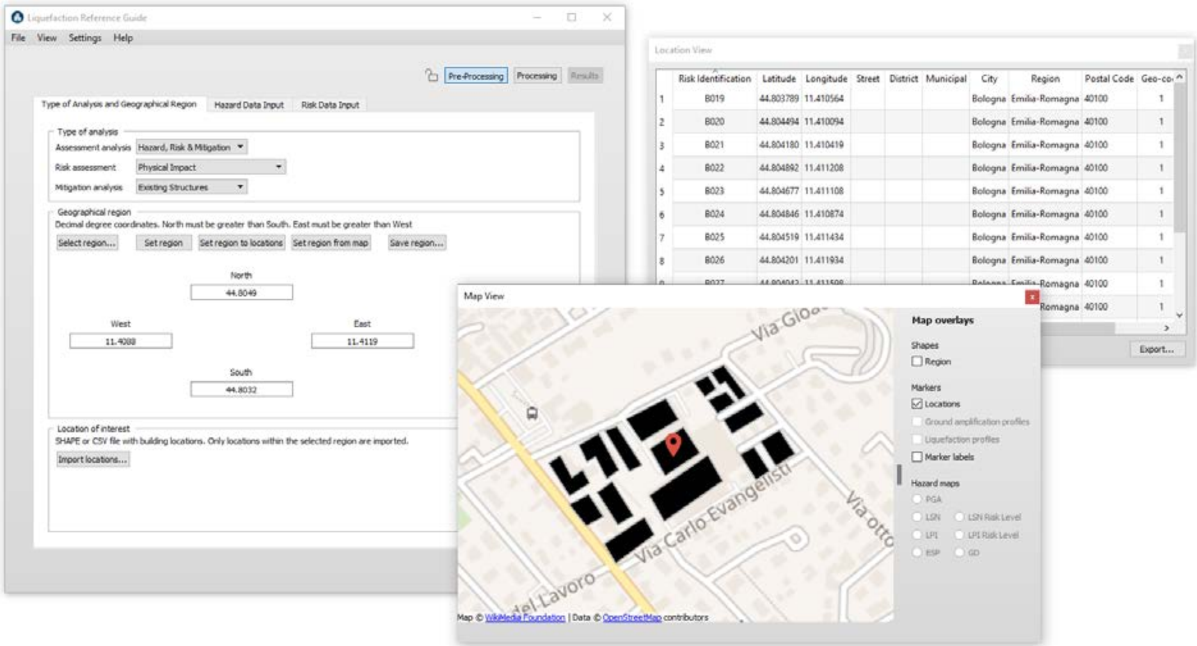

Figure 3. LIQUEFACT Software - alternative selection of graphical user interface

The main menu, at the top of the software window, is the command menu of the software consisting of the following drop-down menus: File, View, Settings, and Help

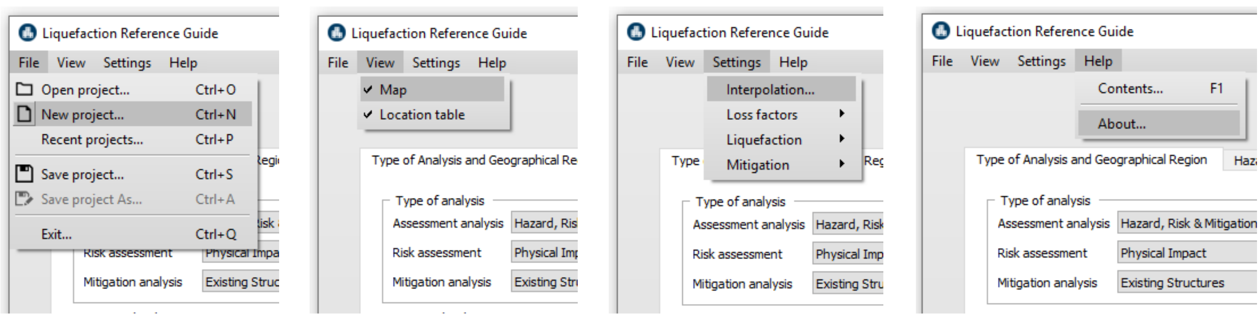

Figure 4. Overview of the command menu of the LIQUEFACT Software

1.5 GIS Interactive Mapping System

The LIQUEFACT software uses Geographic Information Systems (GIS) technology, allowing users to visualize the spatial relationships between various geographic assets or resources for the specific hazard being modelled, a crucial function in the planning process. Open Street Map (Bennet 2010) has been embedded in the Qt for the LIQUEFACT map module, providing the following features:

1. view individual buildings;
2. view street names and other labels;

3. allowing the overlay of input data (e.g. data on buildings, liquefaction profiles and ground shaking maps) on the LIQUEFACT map;
4. Hide/show overlays of various types;
5. obtain a street address from a location (latitude, longitude);
6. obtain a location (latitude, longitude) from a street address;
7. Click on markers (building, liquefaction profile, …);
8. Zoom in and out, and translate the map;
9. Specify geographical region; and many more features….

1.6 File Import/Export

Import of data into the LIQUEFACT software will be based on as tab-separated CSV files, unformatted TXT files or SHAPE files (ESRI defined formats) that will be converted to SQLite database files in the project (through a database management system). Results can be exported as SHAPE or CSV by selecting SHAPE or CSV in the file type pulldown menu in the Export dialog. SHAPE files can be exported as points or polygons. The database and result files in various formats will be stored in a project directory.

1.7 System Requirements and Installation

LIQUEFACT software works on the following operating systems: Windows 10, Windows 8, Windows 7 or Windows Vista (32-bit and 64-bit);

The installation of the LIQUEFACT software can be done through the following steps:

1. LIQUEFACT software can be downloaded from:

   http://www.norsar.no/seismology/engineering/LIQUEFACT
2. Save the application on your computer and run the installation.
3. From the drop-down menu, click the OK button, and then click the Next button to proceed with the installation

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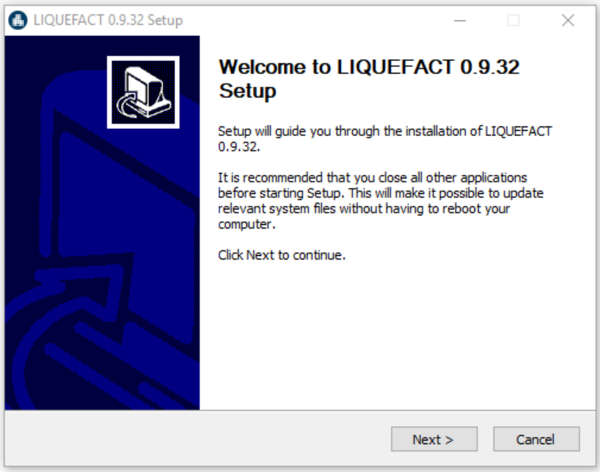
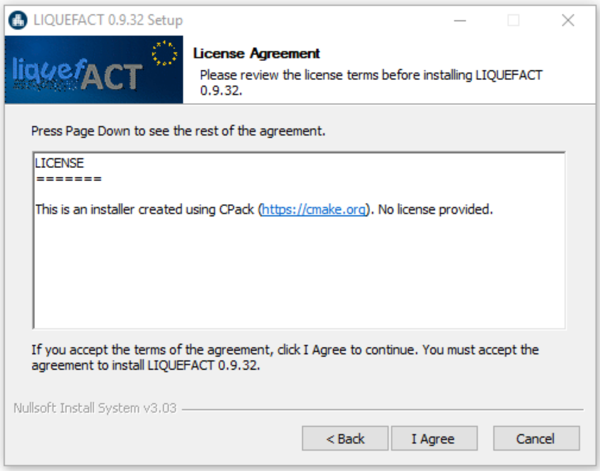
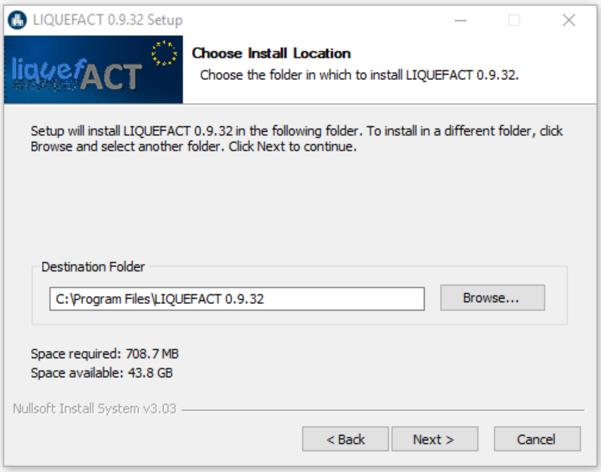


4. The License Agreement appears on the screen. Please, read it carefully and accept the terms by checking the box



5. On the next request to select the destination folder, click the Next button again to install to the 'default' folder or click the Browse button to install to a different one.



6. Click the Install button and wait until the software is installed.

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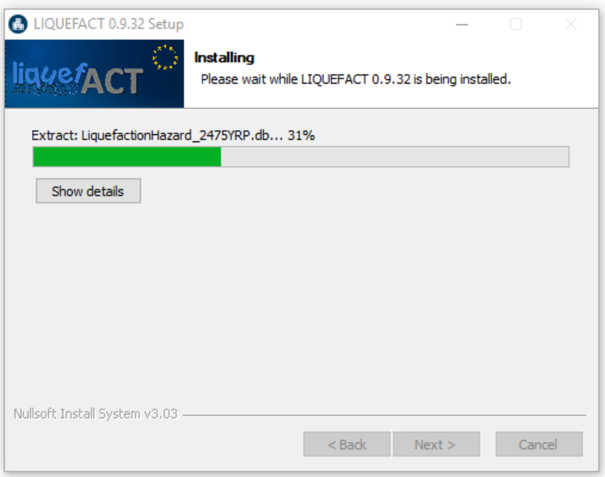
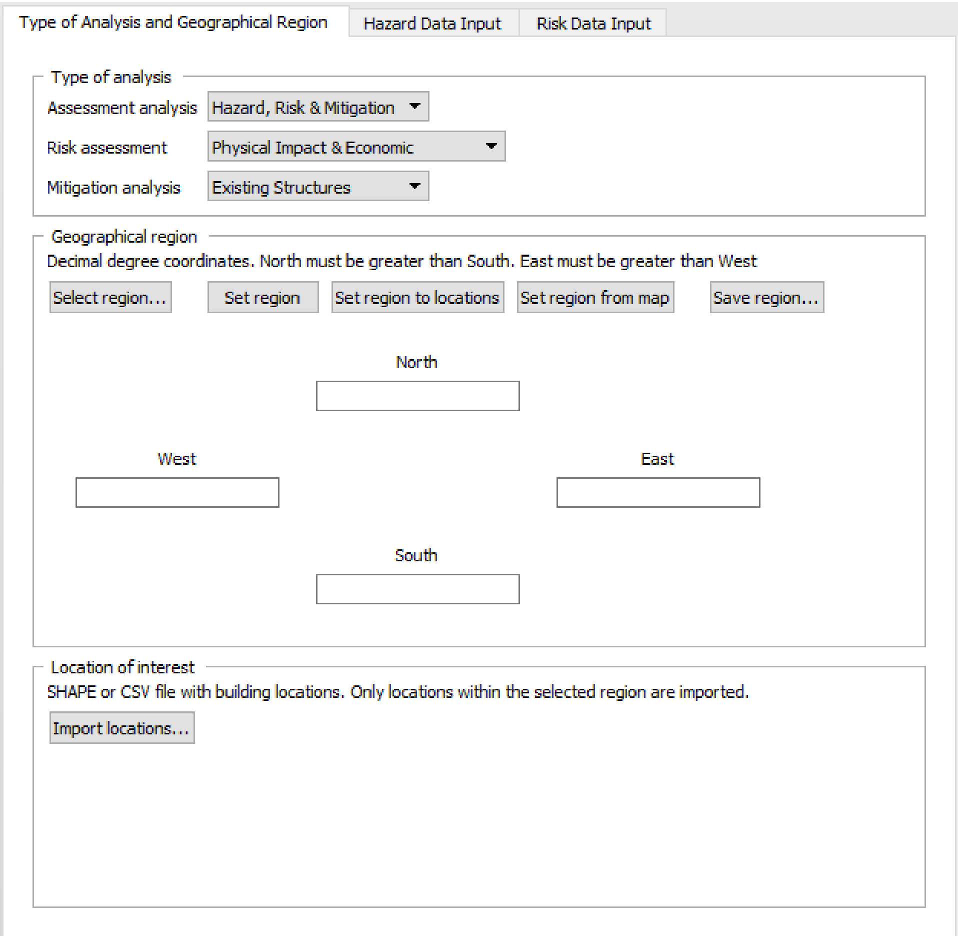


7. At the end of the procedure, click Finish to exit the wizard.

2 SOFTWARE DATA INPUT

LIQUEFACT Software consists of three protocols: Liquefaction Hazard Analysis Protocol, Risk Analysis Protocol, and Mitigation Analysis Protocol. Each protocol consists of an Input and a Results Module.



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2.1 Type and Level of Analysis

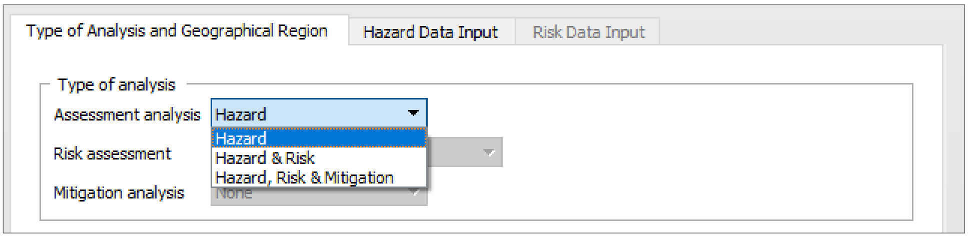
As first step to be implemented in the LIQUEFACT software, is the definition of the objective and level of analysis to be carried out. This can be done by defining the followings:

- Type and level of analysis;
- Geographical region; and
- Location of interest.

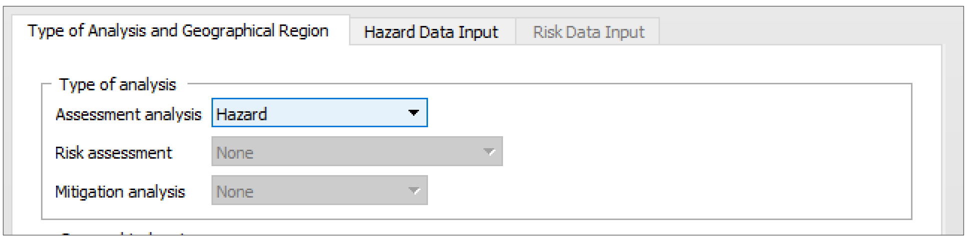
2.1.1 Type and Level of Analysis

Considering the software processing concept aspect described above, the LIQUEFACT software is designed and developed to provide options and alternatives of analysis processing, offering more flexibility to end-users with respect to how detailed the input data are, the availability of the data, and what type of assessment and result the end-users want to obtain. Assessment analysis can be defined using one of the three options:

- Hazard
- Hazard and Risk
- Hazard, Risk and Mitigation



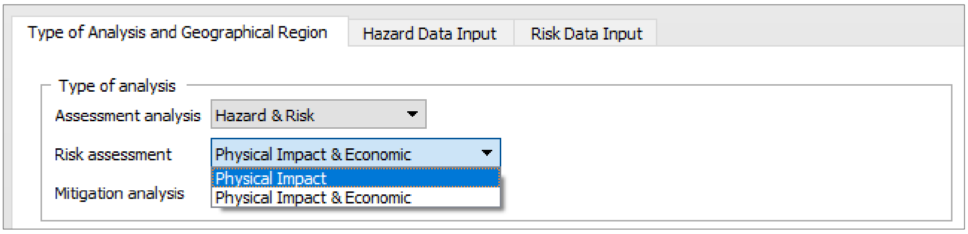
Assessment analysis: Hazard: For Hazard assessment analysis, users will be required to import data related to hazard condition only. This level of assessment allows the evaluation of liquefaction susceptibility for a given susceptible category at specified level of ground shaking intensity. In addition, end-users can estimate the liquefaction threat on a given built/infrastructure asset, where different approaches can be used in order to correlate the liquefaction-induced ground deformation with the asset response/damage.



Assessment analysis: Hazard and Risk. Risk Assessment and Risk Data Input are activated, and end-users will be required to provide input data related to hazard and risk. In addition to the evaluation of liquefaction susceptibility and then level of liquefaction threat, this level of analysis allows the assessment of level of impact of the EILD event on the built asset (building/infrastructure).

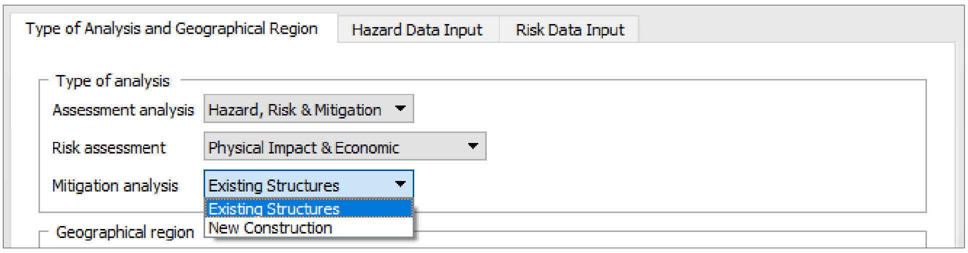
In the section ***Risk Assessment*** end-users will be required to defined level of impact to be assessed:

- *Physical impact*: for the computation of damage. End-users will be required to provide vulnerability models and portfolio data with structural characteristics-related information
- *Physical impact & Economic*: for damage and economic loss computation. In addition to vulnerability models and portfolio data with structural characteristics-related information, end-users will also be required to provide economic and business activity data.



Assessment analysis: Hazard, Risk and Mitigation. Mitigation analysis and Mitigation Data Input are activated, and end-users will be required to provide input data related to hazard, risk and mitigation. In addition to the evaluation of level of impact of the EILD event on the built asset (building/infrastructure), this level of analysis allows the development of mitigation framework in terms of soil improvements, cost and prioritize the mitigation measures.

In the section ***Mitigation analysis*** end-users will be required to defined if at the selected locations of interest there are assets, i.e. *Existing Structures* or *New Construction* (free field), an important factor for the development of mitigation framework.



2.1.2 Geographical Region

In this section end-users will be required to select and set the region of study. After selection, the region can be set using the following options:

Set region	after providing manually the decimal degree coordinates
Set region to locations	this option is used after the import of locations (section location of interest), and then the decimal degree coordinates will automatically be computed by the software.
Set region from map	this is the easiest option and is used after the import of locations (section location of interest). The users can zoom their preference area to be studied and then click on "Set region from map". The decimal degree coordinates will automatically be computed by the software.

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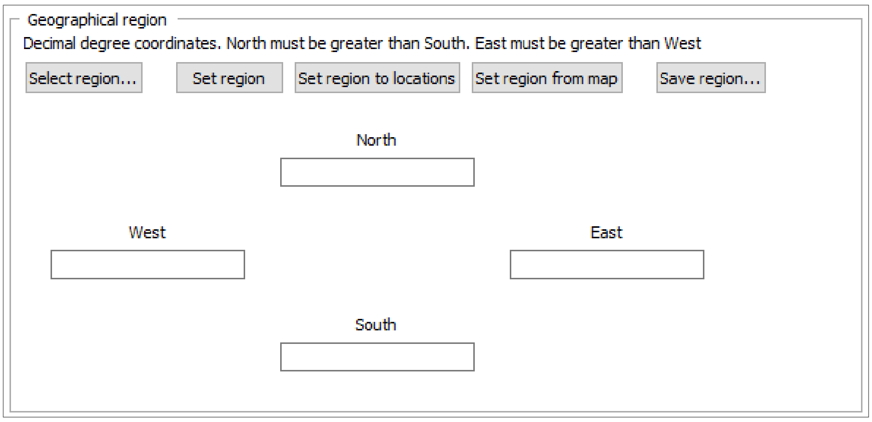
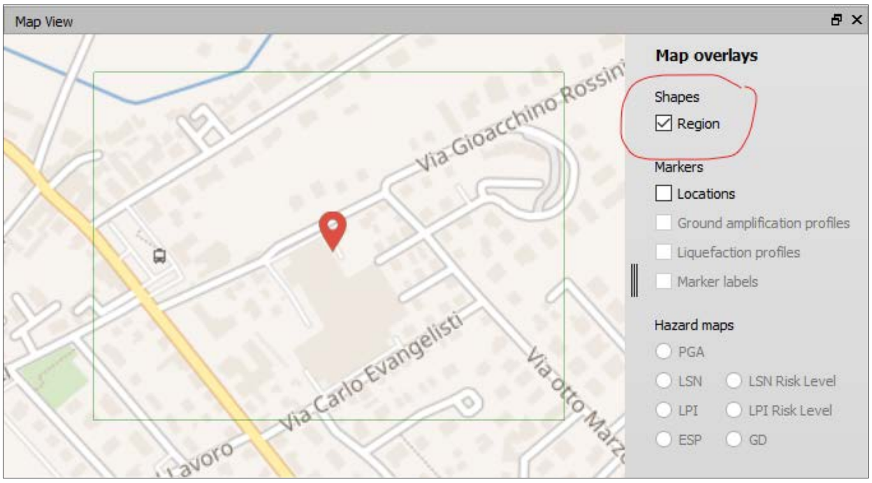


The rectangle displayed in green color represents the selected region of study



2.1.3 Location of Interest

Providing locations of interest is mandatory for all type and level analyses. These locations can represent existing assets (buildings, infrastructures) or free filed sites where future asset will be built on. Table below illustrates the list of input parameters that define *LOCATION* of interest.

Data Input	*Description*	*NOTE*
Risk Identification	*Code identification to be assigned to each individual asset or a given site*	*Mandatory*
LOCATION		
Latitude	*Latitude in decimal degree*	*Mandatory*
Longitude	*Longitude in decimal degree*	*Mandatory*
Street	*Street*	*Nonmandatory*
District	*District*	*Nonmandatory*
Municipal	*Municipal*	*Nonmandatory*
Region	*Region*	*Nonmandatory*
Postal Code	*Postal code*	*Nonmandatory*
Geo-code	*represent the geounit to be used in computation of Mean Loss Ratio*	*Mandatory*

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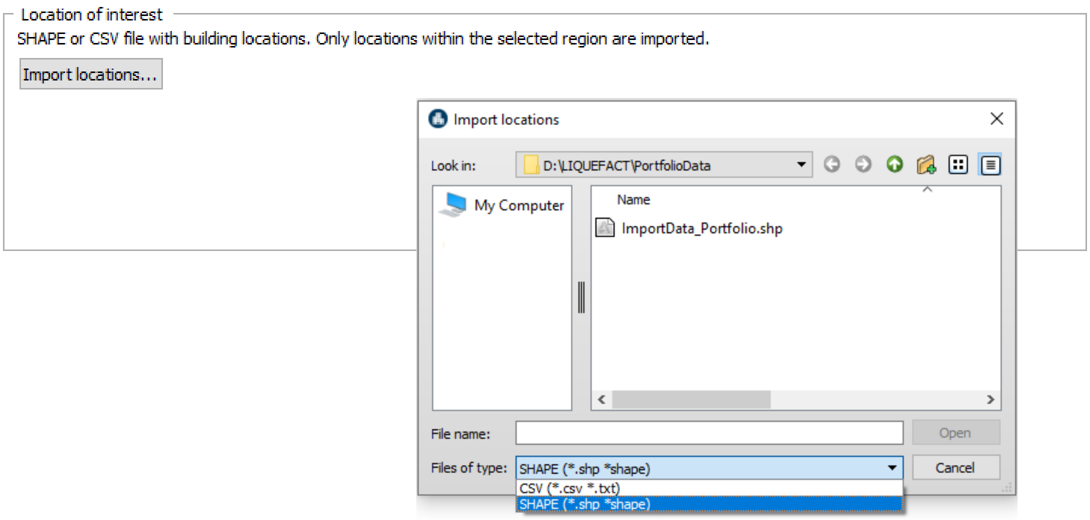
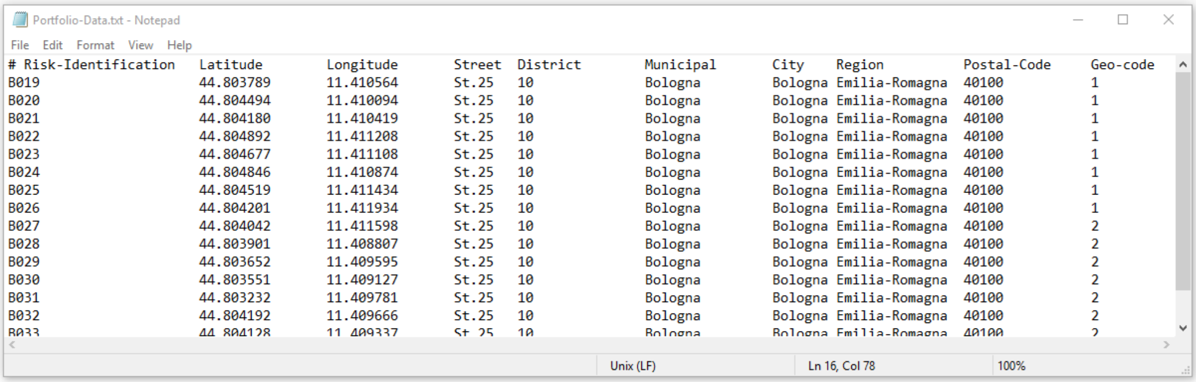
Users can import asset (building/infrastructure) locations as tab-separated CSV, unformatted TXT or SHAPE files (ESRI defined formats). CSV and TXT files are always imported as points, and SHAPE files can be important as points or polygons.



Example of CSV/TXT file for building locations that can be imported in the LIQUEFACT software



Portfolio-Data.txt - Notepad

# Risk-Identification	Latitude	Longitude	Street	District	Municipal	City	Region	Postal-Code	Geo-code
B019	44.803789	11.410564	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	1
B020	44.804494	11.410094	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	1
B021	44.804180	11.410419	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	1
B022	44.804892	11.411208	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	1
B023	44.804677	11.411108	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	1
B024	44.804846	11.410874	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	1
B025	44.804519	11.411434	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	1
B026	44.804201	11.411934	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	1
B027	44.804042	11.411598	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	2
B028	44.803901	11.408807	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	2
B029	44.803652	11.409595	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	2
B030	44.803551	11.409127	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	2
B031	44.803232	11.409781	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	2
B032	44.804192	11.409666	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	2
B033	44.804128	11.409337	St.25	10	Bologna	Bologna	Emilia-Romagna	40100	2

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Building locations and map view, imported from CSV/TXT file

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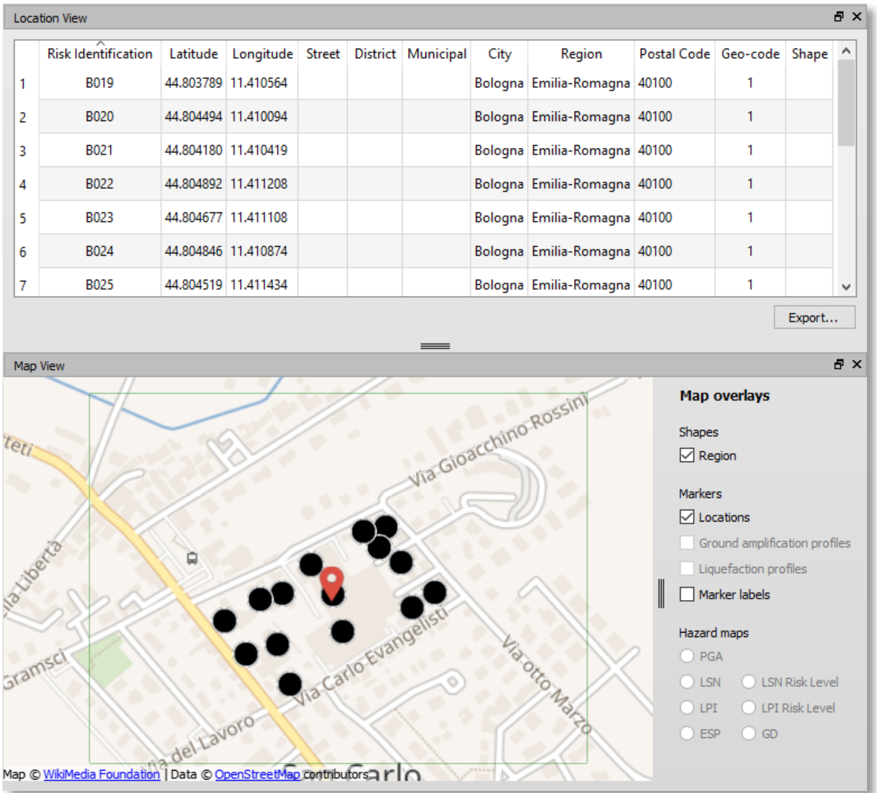

Location View

	Risk Identification	Latitude	Longitude	Street	District	Municipal	City	Region	Postal Code	Geo-code	Shape
1	B019	44.803789	11.410564				Bologna	Emilia-Romagna	40100	1	
2	B020	44.804494	11.410094				Bologna	Emilia-Romagna	40100	1	
3	B021	44.804180	11.410419				Bologna	Emilia-Romagna	40100	1	
4	B022	44.804892	11.411208				Bologna	Emilia-Romagna	40100	1	
5	B023	44.804677	11.411108				Bologna	Emilia-Romagna	40100	1	
6	B024	44.804846	11.410874				Bologna	Emilia-Romagna	40100	1	
7	B025	44.804519	11.411434				Bologna	Emilia-Romagna	40100	1	

Example of SHAPE file for building locations that can be imported in the LIQUEFACT software

FID	Shape	ID	Latitude	Longitude	Street	District	Municipal	City	Region	PostalCode	Geo-Code
0	Polygon	B019	44.803789	11.410564	Via Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	1
1	Polygon	B020	44.804494	11.410094	Via Gioacchino Rossini	D01	Bologna	Bologna	Emilia-Romagna	40100	1
2	Polygon	B021	44.80418	11.410419	Via Paolo EvangelisaVia Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	1
3	Polygon	B022	44.804892	11.411208	Via 8 Marzo	D01	Bologna	Bologna	Emilia-Romagna	40100	2
4	Polygon	B023	44.804677	11.411108	Via 8 Marzo	D01	Bologna	Bologna	Emilia-Romagna	40100	2
5	Polygon	B024	44.804846	11.410874	Via Gioacchino Rossini	D01	Bologna	Bologna	Emilia-Romagna	40100	2
6	Polygon	B025	44.804519	11.411434	Via 8 Marzo	D01	Bologna	Bologna	Emilia-Romagna	40100	2
7	Polygon	B026	44.804201	11.411934	Via Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	2
8	Polygon	B027	44.804042	11.411598	Via Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	2
9	Polygon	B028	44.803901	11.408807	Via Risorgimento	D01	Bologna	Bologna	Emilia-Romagna	40100	1
10	Polygon	B029	44.803652	11.409595	Via Risorgimento	D01	Bologna	Bologna	Emilia-Romagna	40100	1
11	Polygon	B030	44.803551	11.409127	Via Risorgimento	D01	Bologna	Bologna	Emilia-Romagna	40100	1
12	Polygon	B031	44.803232	11.409781	Via Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	1
13	Polygon	B032	44.804192	11.409666	Via Gioacchino Rossini	D01	Bologna	Bologna	Emilia-Romagna	40100	1
14	Polygon	B033	44.804128	11.409337	Via Gioacchino Rossini	D01	Bologna	Bologna	Emilia-Romagna	40100	1

Building locations and map view, imported from SHAPE file

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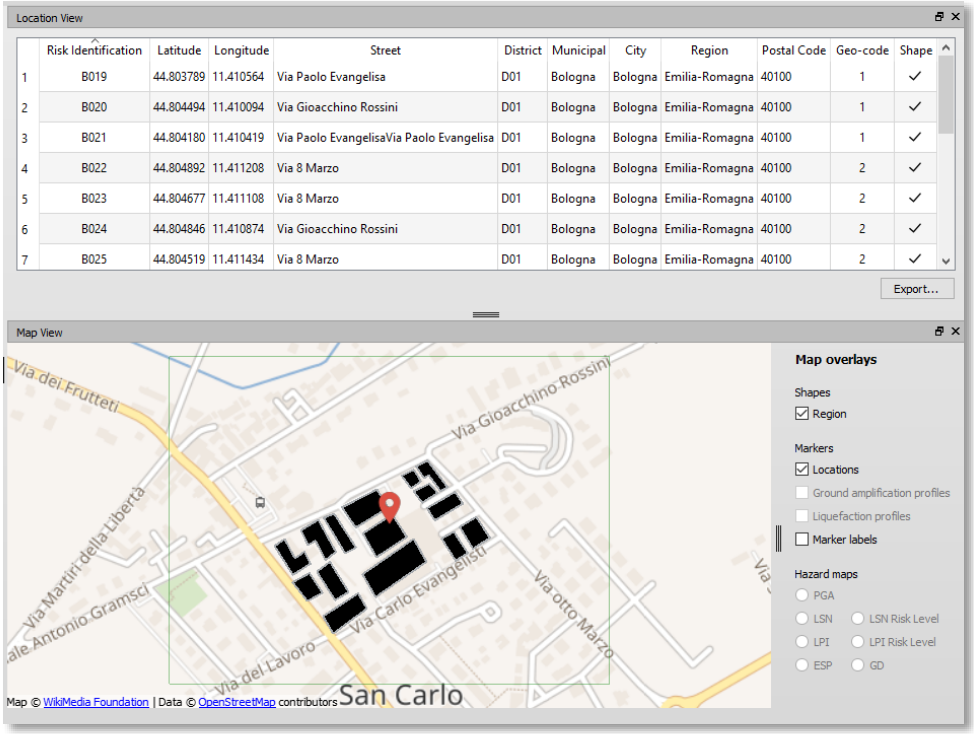
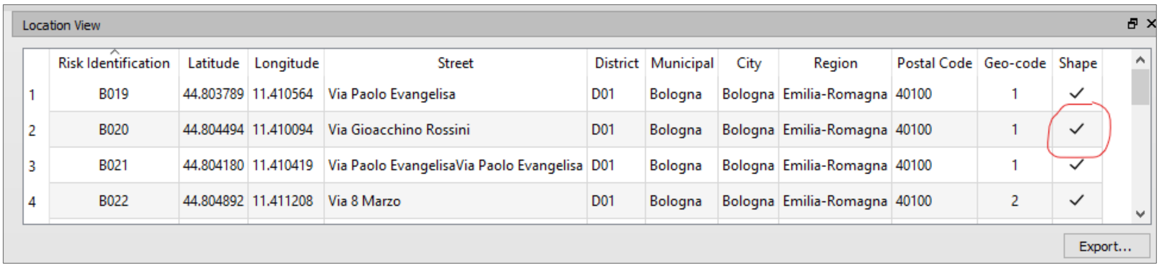


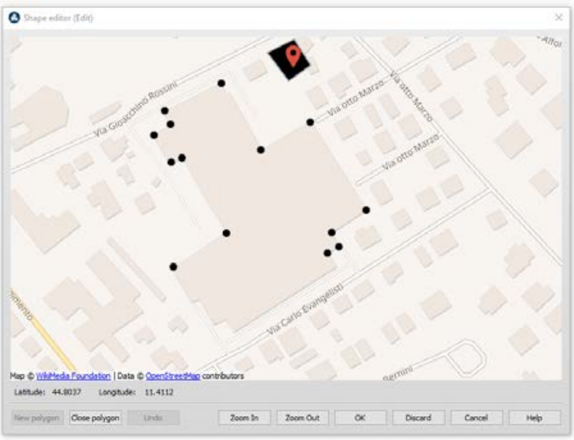
	Risk Identification	Latitude	Longitude	Street	District	Municipal	City	Region	Postal Code	Geo-code	Shape
1	B019	44.803789	11.410564	Via Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	1	✓
2	B020	44.804494	11.410094	Via Gioacchino Rossini	D01	Bologna	Bologna	Emilia-Romagna	40100	1	✓
3	B021	44.804180	11.410419	Via Paolo EvangelisaVia Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	1	✓
4	B022	44.804892	11.411208	Via 8 Marzo	D01	Bologna	Bologna	Emilia-Romagna	40100	2	✓
5	B023	44.804677	11.411108	Via 8 Marzo	D01	Bologna	Bologna	Emilia-Romagna	40100	2	✓
6	B024	44.804846	11.410874	Via Gioacchino Rossini	D01	Bologna	Bologna	Emilia-Romagna	40100	2	✓
7	B025	44.804519	11.411434	Via 8 Marzo	D01	Bologna	Bologna	Emilia-Romagna	40100	2	✓

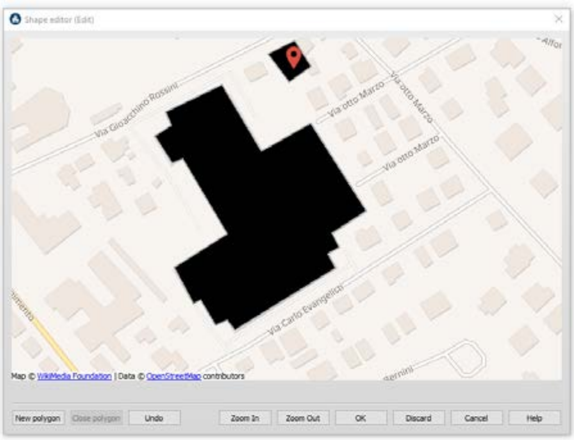
All imported data (CSV, TXT or SHAPE) can be edited and modified in the LIQUEFACT software. Below is an example of creating a polygon editing the original version of the SHAPE file that was imported in the software. Double Click on "SHAPE" selected in Red to modify or edit a polygon.



	Risk Identification	Latitude	Longitude	Street	District	Municipal	City	Region	Postal Code	Geo-code	Shape
1	B019	44.803789	11.410564	Via Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	1	✓
2	B020	44.804494	11.410094	Via Gioacchino Rossini	D01	Bologna	Bologna	Emilia-Romagna	40100	1	✓
3	B021	44.804180	11.410419	Via Paolo EvangelisaVia Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	1	✓
4	B022	44.804892	11.411208	Via 8 Marzo	D01	Bologna	Bologna	Emilia-Romagna	40100	2	✓

By Clicking on "*New polygon*" button to add or modify an existing polygon.

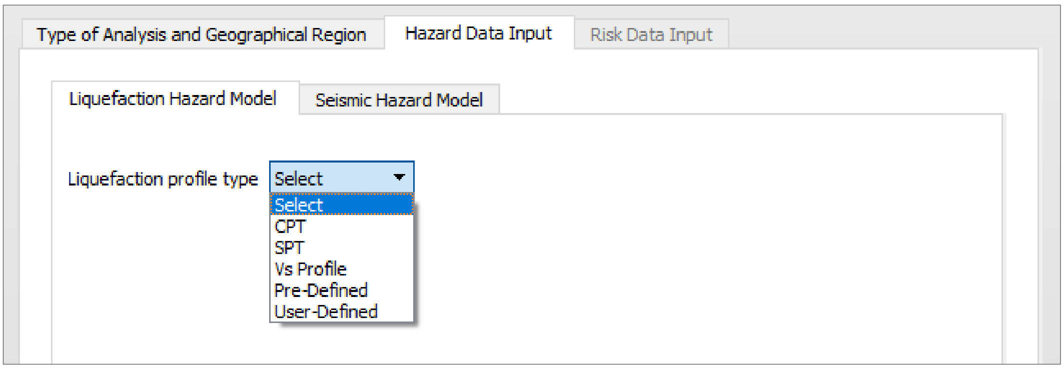




This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

2.2 Hazard Data Input

LIQUEFACT software incorporates alternatives of methodologies providing users with flexibility in conducting analysis depending on how detailed the available input data are and type of result the users want to obtain. In general, the incorporated methodologies of liquefaction hazard assessment are based on two approaches: ***Quantitative*** approach (based on detailed geotechnical soil profiles data such as *CPT*, *SPT* and *Vs Profile*) and ***Qualitative*** approach (based on pre-defined liquefaction hazard classification maps that can be used through *User-Defined* and *Pre-Defined*).



2.2.1 Liquefaction Hazard Model for Quantitative Assessment

The concept of the quantitative approach incorporated in the LIQUEFACT software consists of number of analyses to be carried out in two main sequences:

- *Step-1: Liquefaction Triggering Analysis*: to estimate the tendency of developing liquefaction under a given seismic input. The analysis implies the calculation of a liquefaction safety factor (FSL) obtained by dividing the Cyclic Resistance Ratio (CRR) producing liquefaction with the Cyclic Stress Ratio (CSR) induced by the earthquake. Then, seismic liquefaction is triggered in a susceptible soil when the seismic demand (expressed as CSR) exceeds the resistance of such soils (expressed as CRR).
- *Step-2: Liquefaction-induced Surficial Manifestations*: implies to evaluate the effects at the ground level. At this stage analyses are conducted in free field conditions, neglecting the presence of buildings or infrastructures and their possible interaction with the subsoil, and thus liquefaction severity indicators such as Liquefaction Severity Number (LSN), Liquefaction Probability Index (LPI) and Liquefaction Probability (LP), and free-field settlement are adopted to broadly quantify the severity of liquefaction.

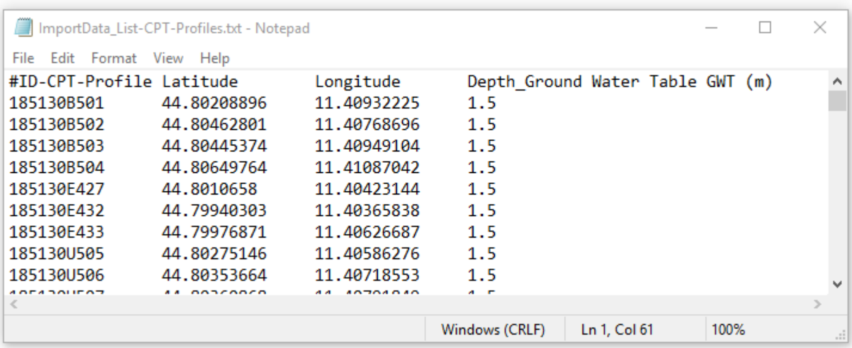
For the computation of liquefaction triggering and liquefaction-induced surficial manifestations, different methods can be used depending on what type of soil profiles data are available: *CPT*-based soil profiles, *SPT* or *Vs*-based soil profiles. Note that results of liquefaction hazard from this level of analysis (i.e. quantitative assessment) can be used to correlate the measured intensities with the asset response in Risk Analysis.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

2.2.1.1 Import Data Type: Cone Penetration Tests (CPT)

LIQUEFACT software incorporates the Boulanger and Idriss (2014) procedure to evaluate the Factor of Safety against liquefaction at each depth of a soil profile using CPT data. For the implementation, CPT data should be imported as following:

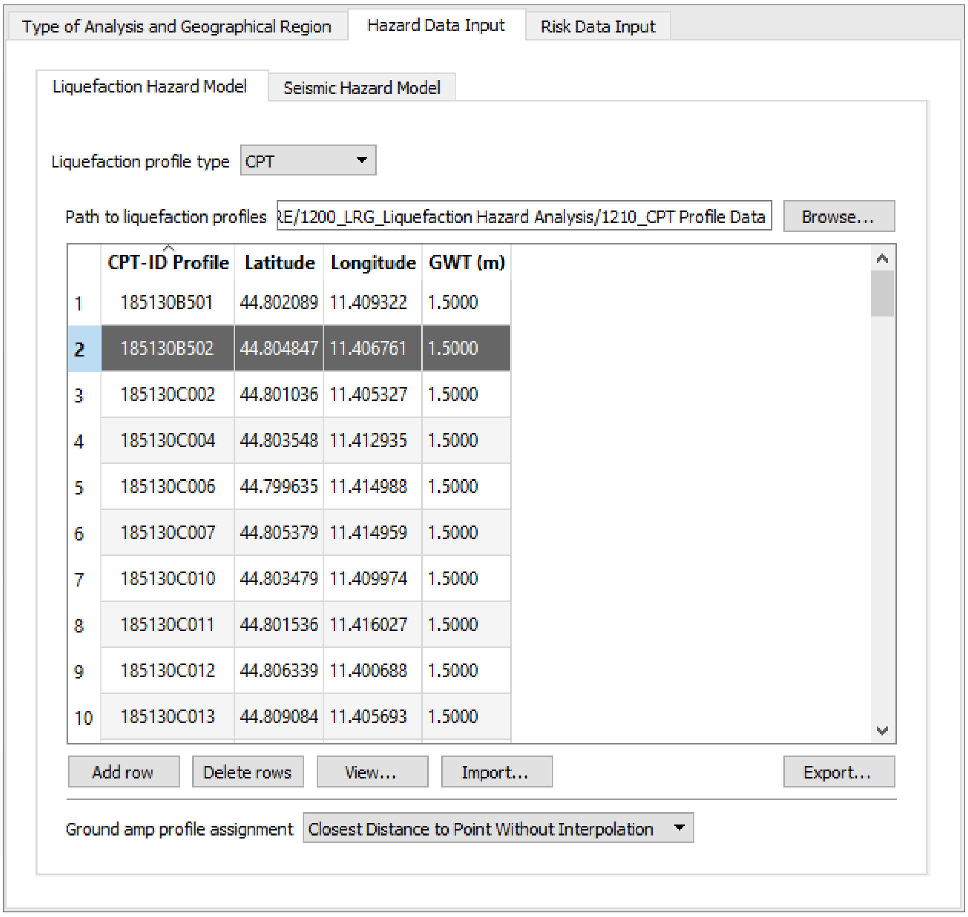
1. Click the *Import* button to import the file with list of the CPT profiles: *ID of CPT Profile*, *Latitude*, *Longitude*, and *Depth to Ground Water Table GWT* (in meter unit). The file can be imported as tab-separated CSV or unformatted TXT.


ImportData_List-CPT-Profiles.txt - Notepad
File Edit Format View Help

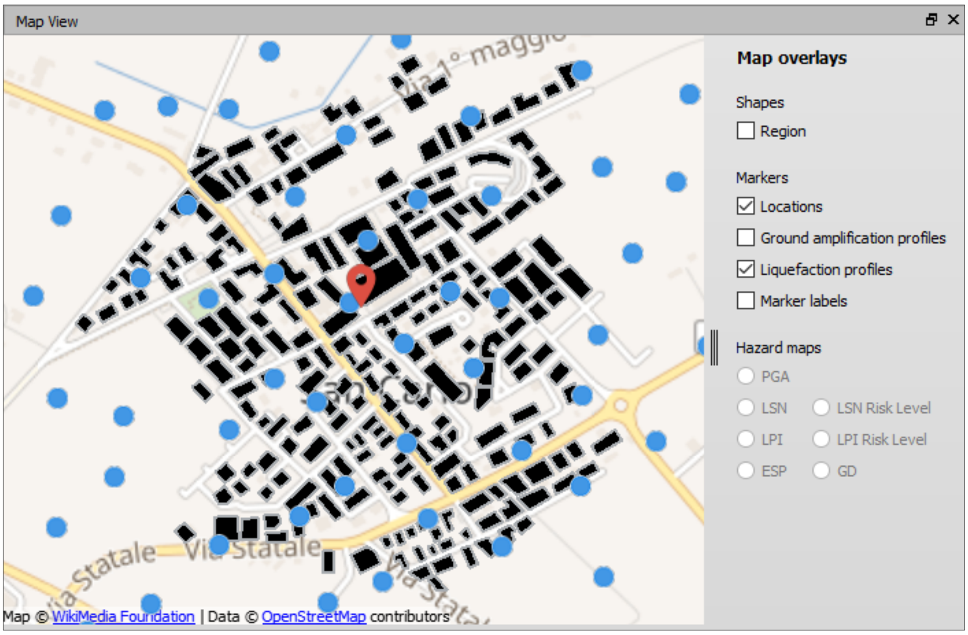
#ID-CPT-Profile	Latitude	Longitude	Depth_Ground Water Table GWT (m)
185130B501	44.80208896	11.40932225	1.5
185130B502	44.80462801	11.40768696	1.5
185130B503	44.80445374	11.40949104	1.5
185130B504	44.80649764	11.41087042	1.5
185130E427	44.8010658	11.40423144	1.5
185130E432	44.79940303	11.40365838	1.5
185130E433	44.79976871	11.40626687	1.5
185130U505	44.80275146	11.40586276	1.5
185130U506	44.80353664	11.40718553	1.5

Windows (CRLF) Ln 1, Col 61 100%

The imported list of CPT profile file can be modified or updated by double click on any selected row representing a given CPT profile. It is also possible to Add or Delete any row/profile.

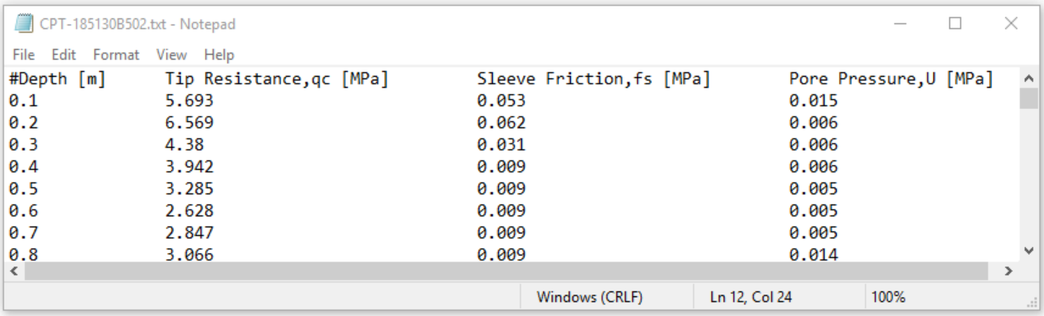


The locations of CPT profiles can be viewed in the GIS platform of the LIQUEFACT software ***Map View*** by ticking the box "*Liquefact profiles*".



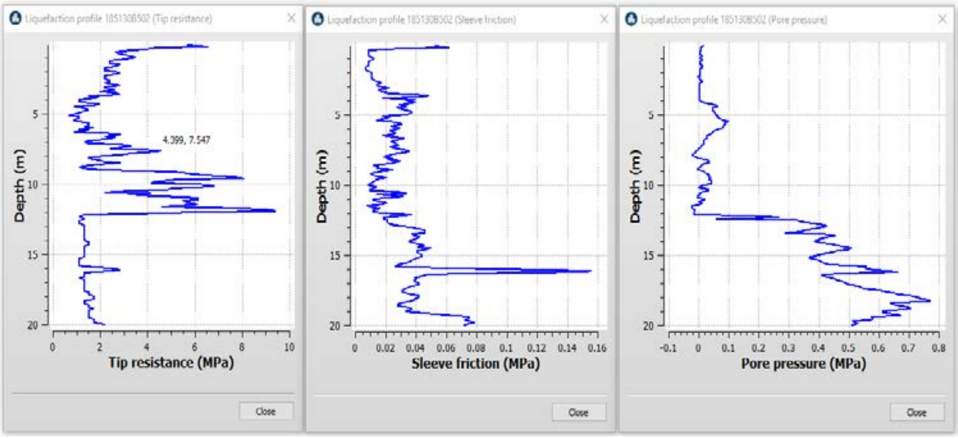
2. Then Click the Browse button to define the path to the folder where CPT profiles are located. The CPT profiles must be created as separate files in format of tab-separated CSV or unformatted TXT files. Each CPT profile file contains: *Depth [in m]*, *Tip Resistance qc [in MPa]*, *Sleeve Friction fs [in MPa]*, and *Pore Pressure U [in MPa]*.

   The *View* button allows to view the three plots of a selected CPT profile: *CPT Tip Resistance, Sleeve Friction*, and *Pore Pressure*.


CPT-185130B502.txt - Notepad
File Edit Format View Help

#Depth [m]	Tip Resistance,qc [MPa]	Sleeve Friction,fs [MPa]	Pore Pressure,U [MPa]
0.1	5.693	0.053	0.015
0.2	6.569	0.062	0.006
0.3	4.38	0.031	0.006
0.4	3.942	0.009	0.006
0.5	3.285	0.009	0.005
0.6	2.628	0.009	0.005
0.7	2.847	0.009	0.005
0.8	3.066	0.009	0.014

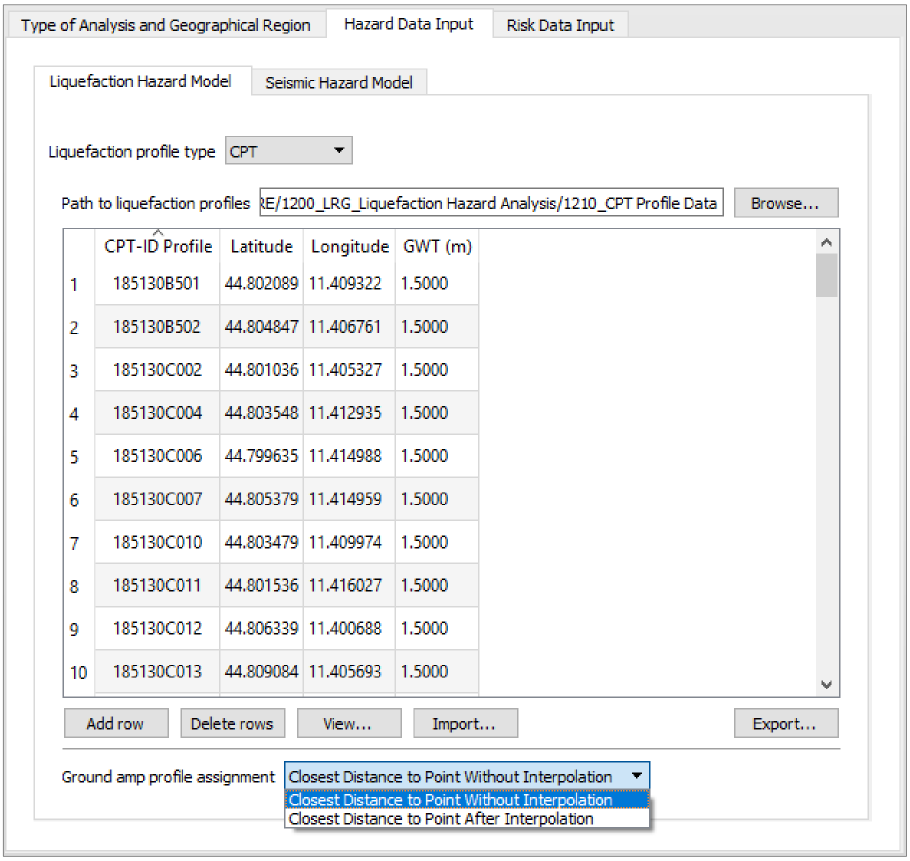
Windows (CRLF) Ln 12, Col 24 100%

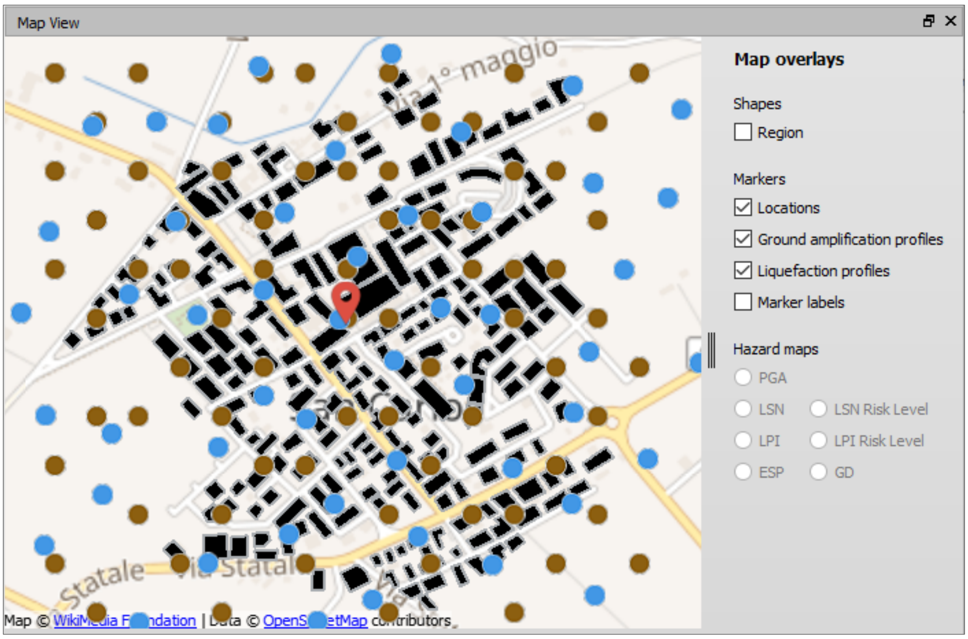


3. At the section *Ground amp profile assignment*, users can define how seismic actions (peak ground accelerations PGAs) resulted from ground amplification profiles will be assigned to the CPT profiles for the computation of liquefaction severity indicators. Users will have to choose one of the following options:

   Closest Distance to Point Without Interpolation: the assigned value of PGA is directly resulted from the closest ground amplification profile at the location of a given CPT profile or the closed to it.

   Closest Distance to Point After Interpolation. the assigned value of PGA is directly resulted from interpolation, at the location of a given CPT profile.





2.2.1.2 Import Data Type: Standard Penetration Tests (SPT)

LIQUEFACT software incorporates the Boulanger and Idriss (2014) procedure to evaluate the Factor of Safety against liquefaction at each depth of a soil profile using CPT data. For the implementation, CPT data should be imported as following:

1. Click the <u>*Import*</u> button to import the file with list of the SPT profiles: *ID of SPT Profile*, *Latitude*, *Longitude*, and *Depth to Ground Water Table GWT* (in meter unit). The file can be imported as tab-separated CSV or unformatted TXT.

ImportData_SPT.txt - Notepad

#ID-SPT-Profile	Latitude	Longitude	Depth_Ground Water Table GWT [m]
SPT-001	59,958507	11,039507	0,5
SPT-002	59,958675	11,052391	0,8
SPT-003	59,956712	11,053313	1
SPT-004	59,956477	11,043931	0,8
SPT-005	59,955118	11,039575	4
SPT-006	59,955999	11,049108	1,5
SPT-007	59,955672	11,049845	3,5
SPT-008	59,952946	11,049158	0,8

Windows (CRLF) Ln 1, Col 62 100%

The imported list of SPT profile file can be modified or updated by double click on any selected row representing a given SPT profile. It is also possible to Add or Delete any row/profile.

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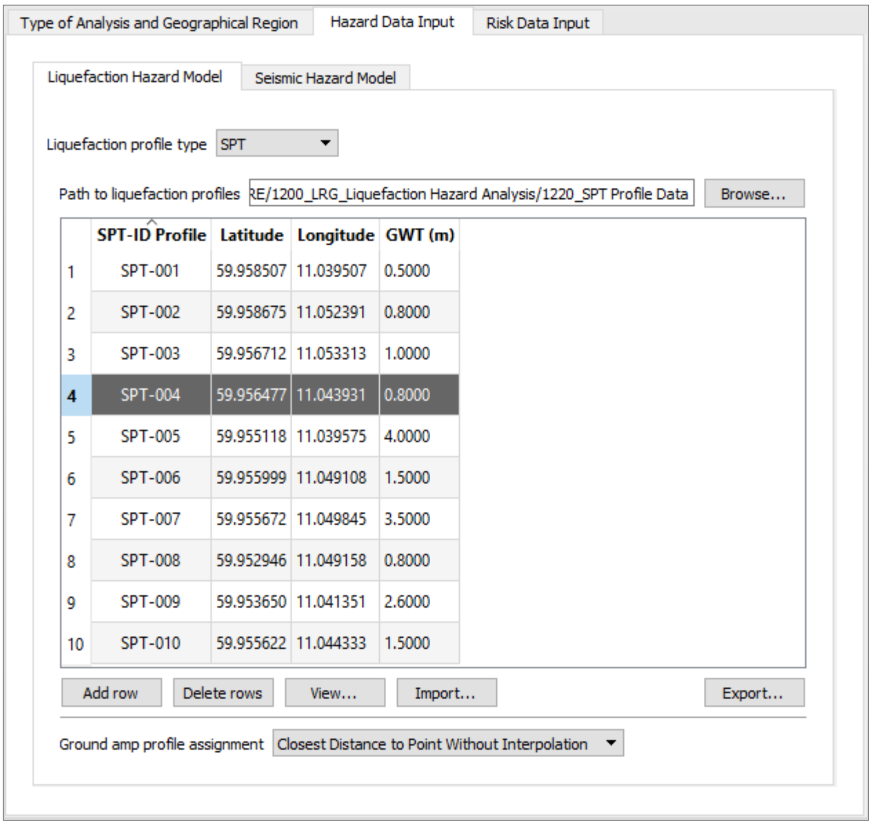
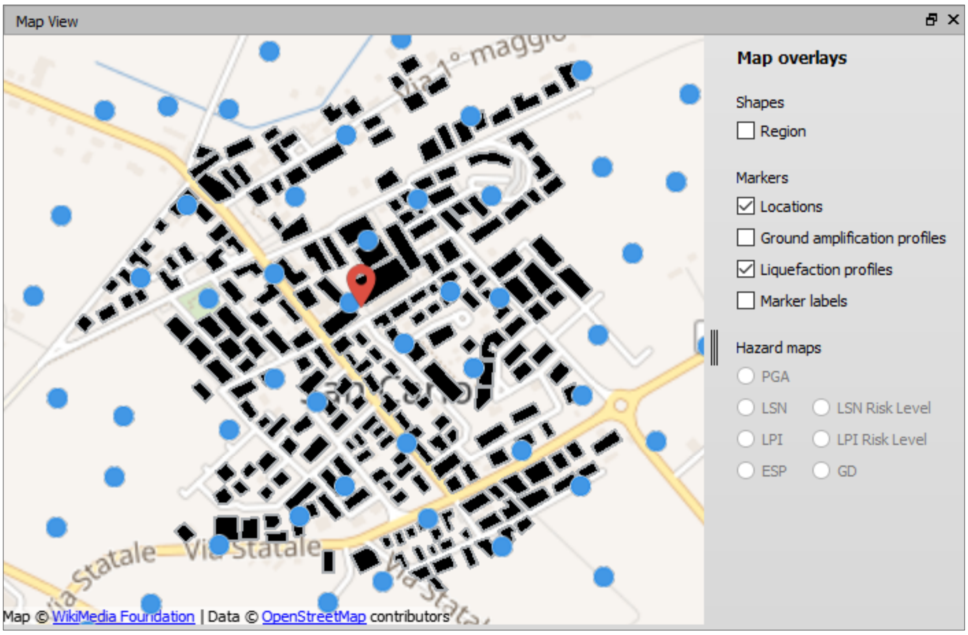


	SPT-ID Profile	Latitude	Longitude	GWT (m)
1	SPT-001	59.958507	11.039507	0.5000
2	SPT-002	59.958675	11.052391	0.8000
3	SPT-003	59.956712	11.053313	1.0000
4	SPT-004	59.956477	11.043931	0.8000
5	SPT-005	59.955118	11.039575	4.0000
6	SPT-006	59.955999	11.049108	1.5000
7	SPT-007	59.955672	11.049845	3.5000
8	SPT-008	59.952946	11.049158	0.8000
9	SPT-009	59.953650	11.041351	2.6000
10	SPT-010	59.955622	11.044333	1.5000

The locations of SPT profiles can be viewed in the GIS platform of the LIQUEFACT software ***Map View*** by ticking the box "*<u>Liquefact profiles</u>*".



2. Then Click the *<u>Browse</u>* button to define the path to the folder where SPT profiles are located. The SPT profiles must be created as separate files in format of tab-separated CSV or

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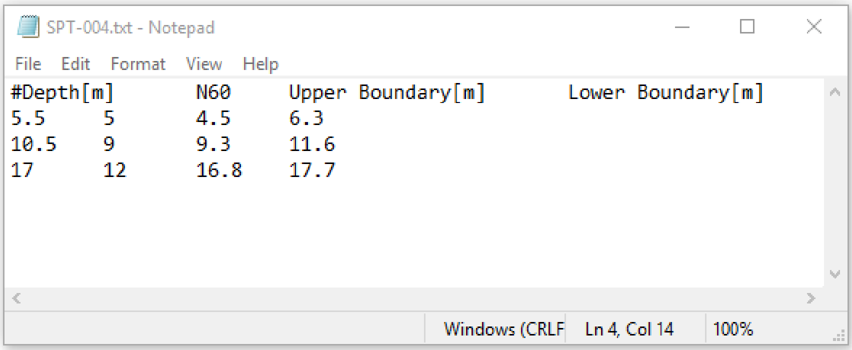
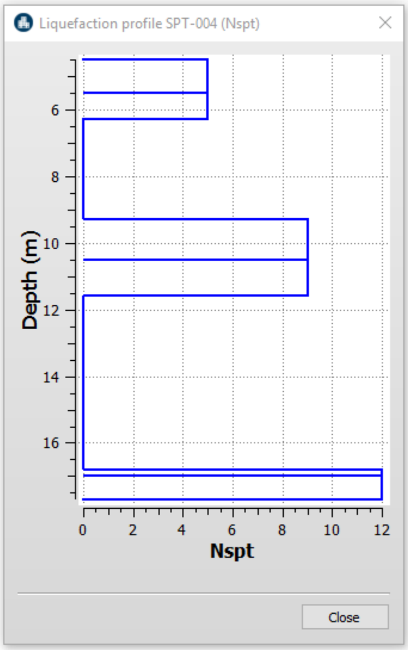
unformatted TXT files. Each SPT profile file contains: *Depth [in m]*, *N_{SPT}*, *Upper Boundary [in m]*, and *Lower Boundary [in m]*.

The *View* button allows to view the plot of a selected SPT profile.


SPT-004.txt - Notepad
File Edit Format View Help

#Depth[m]	N60	Upper Boundary[m]	Lower Boundary[m]
5.5	5	4.5	6.3
10.5	9	9.3	11.6
17	12	16.8	17.7

Windows (CRLF Ln 4, Col 14 100%



3. At the section *Ground amp profile assignment*, users can define how seismic actions (peak ground accelerations PGAs) resulted from ground amplification profiles will be assigned to the SPT profiles for computation of liquefaction severity indicators. Users will have to choose one of the following options:

   Closest Distance to Point Without Interpolation: the assigned value of PGA is directly resulted from the closest ground amplification profile at the location of a given SPT profile or the closed to it.

   Closest Distance to Point After Interpolation. the assigned value of PGA is directly resulted from interpolation, at the location of a given SPT profile.

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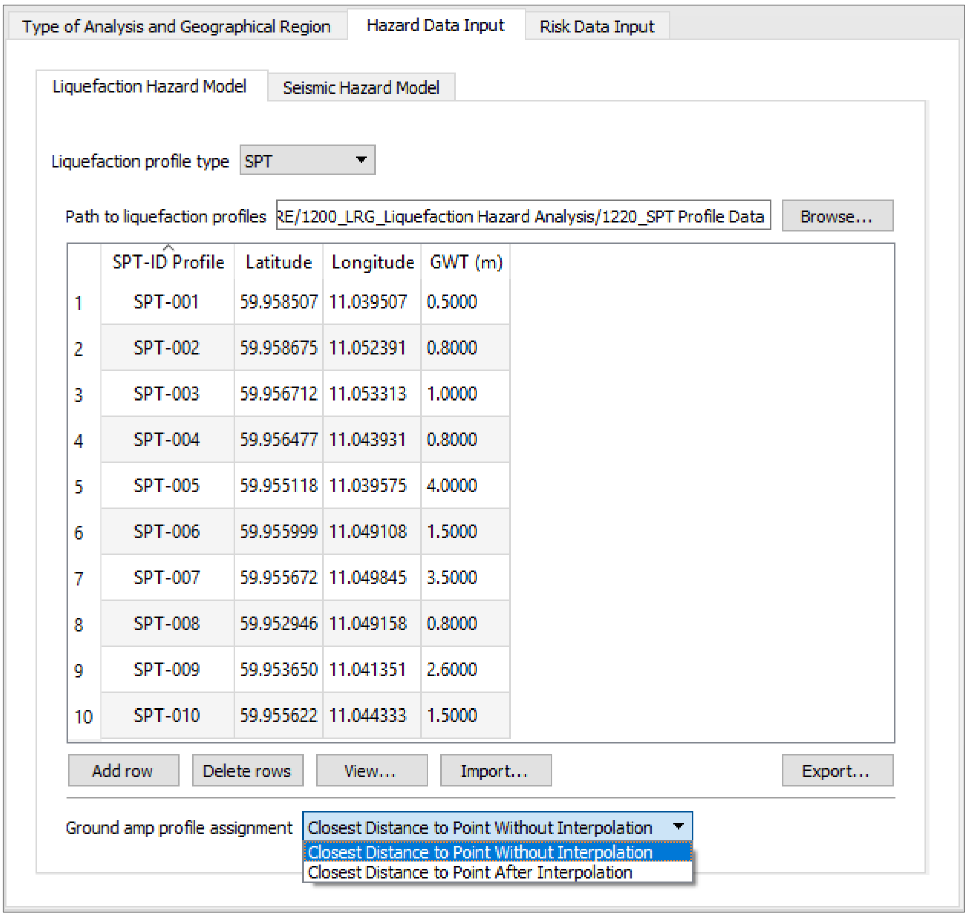
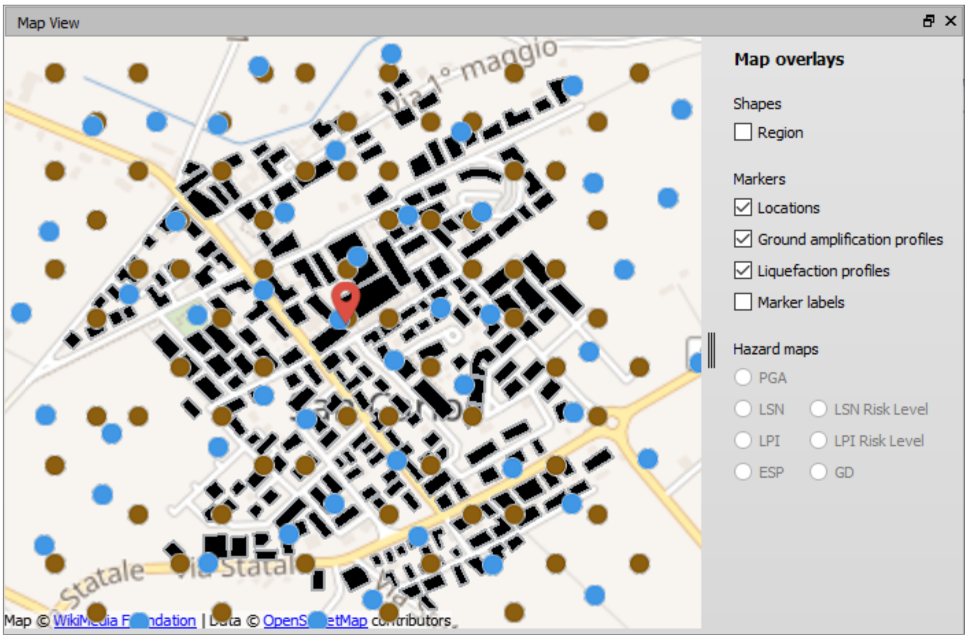


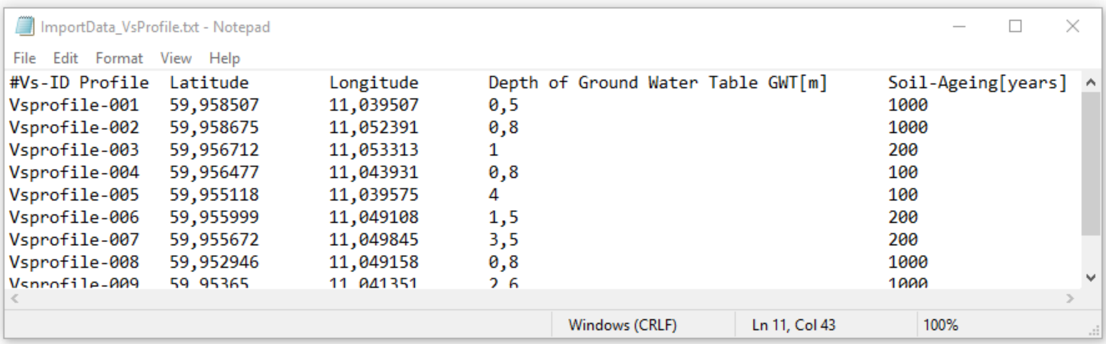


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

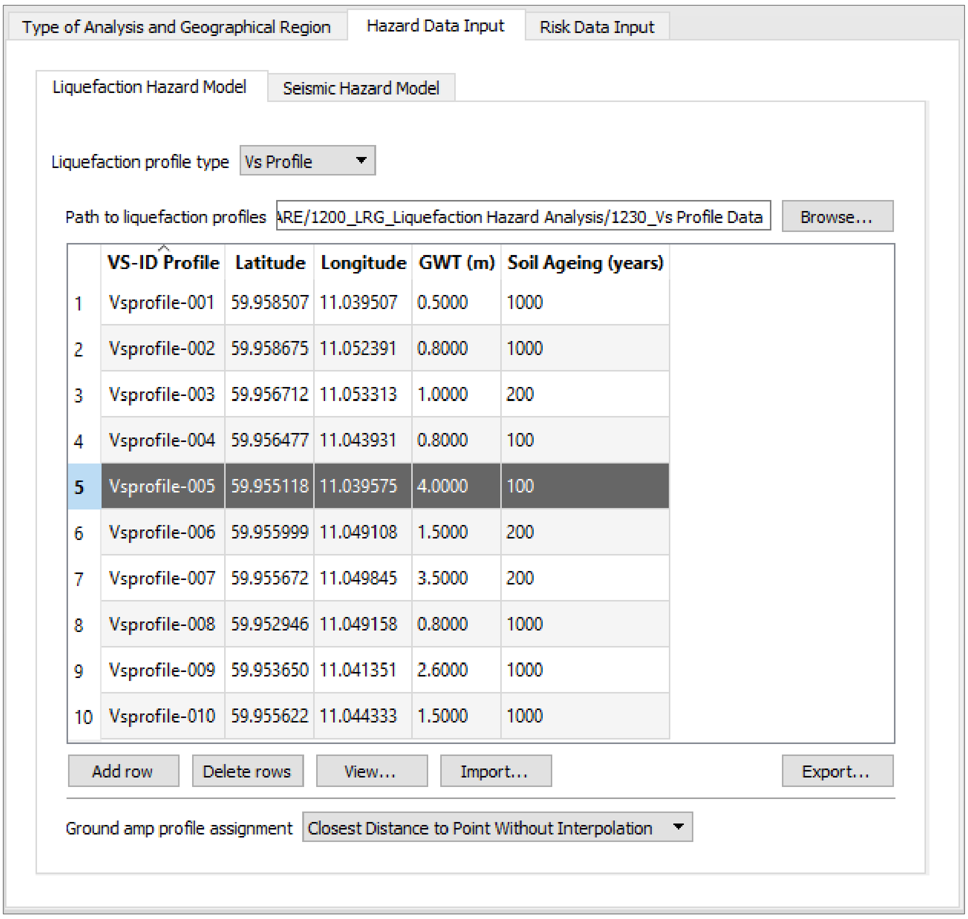
2.2.1.3 Import Data Type: Vs-Profile

LIQUEFACT software incorporates the Boulanger and Idriss (2014) procedure to evaluate the Factor of Safety against liquefaction at each depth of a soil profile using Vs data. For the implementation, Vs data should be imported as following:

1. Click the *<u>Import</u>* button to import the file with list of the Vs profiles: *ID of Vs Profile*, *Latitude*, *Longitude*, *Depth to Ground Water Table GWT* (in meter unit) and *Soil-Ageing* (in year). The file can be imported as tab-separated CSV or unformatted TXT.

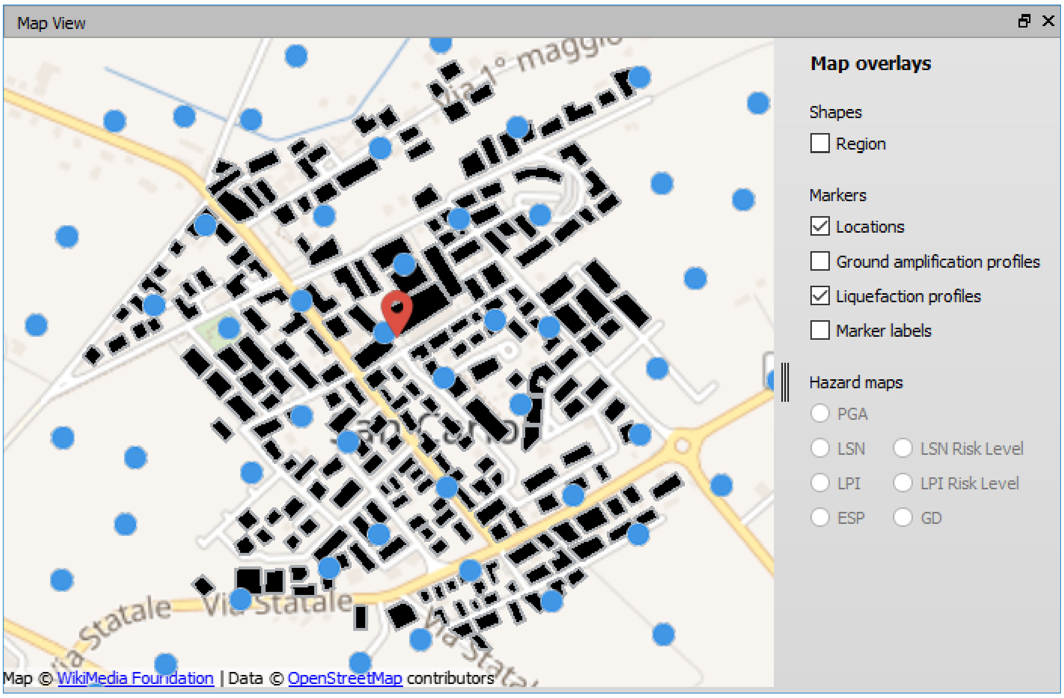


The imported list of Vs profile file can be modified or updated by double click on any selected row representing a given Vs profile. It is also possible to Add or Delete any row/profile.



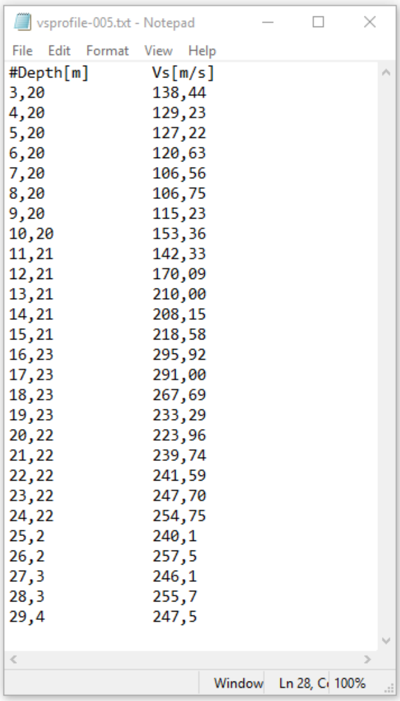
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

The locations of Vs profiles can be viewed in the GIS platform of the LIQUEFACT software ***Map View*** by ticking the box "*Liquefact profiles*".



2. Then Click the *Browse* button to define the path to the folder where Vs profiles are located. The VS profiles must be created as separate files in format of tab-separated CSV or unformatted TXT files. Each V_S profile file contains: *Depth [in m]* and shear velocity *Vs [in m/s]*.

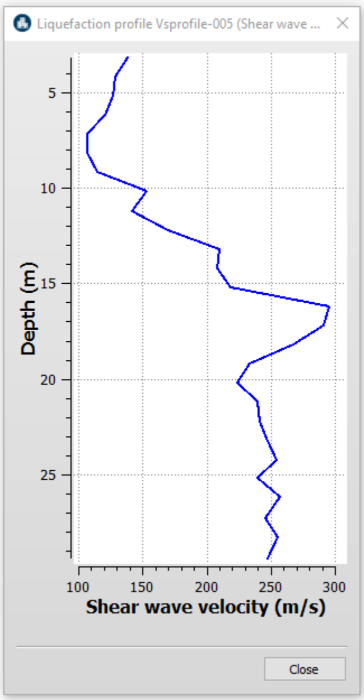
   The *View* button allows to view the plot of a selected Vs profile.


vsprofile-005.txt - Notepad

File Edit Format View Help

#Depth[m]	Vs[m/s]
3,20	138,44
4,20	129,23
5,20	127,22
6,20	120,63
7,20	106,56
8,20	106,75
9,20	115,23
10,20	153,36
11,21	142,33
12,21	170,09
13,21	210,00
14,21	208,15
15,21	218,58
16,23	295,92
17,23	291,00
18,23	267,69
19,23	233,29
20,22	223,96
21,22	239,74
22,22	241,59
23,22	247,70
24,22	254,75
25,2	240,1
26,2	257,5
27,3	246,1
28,3	255,7
29,4	247,5

Window Ln 28, C 100%

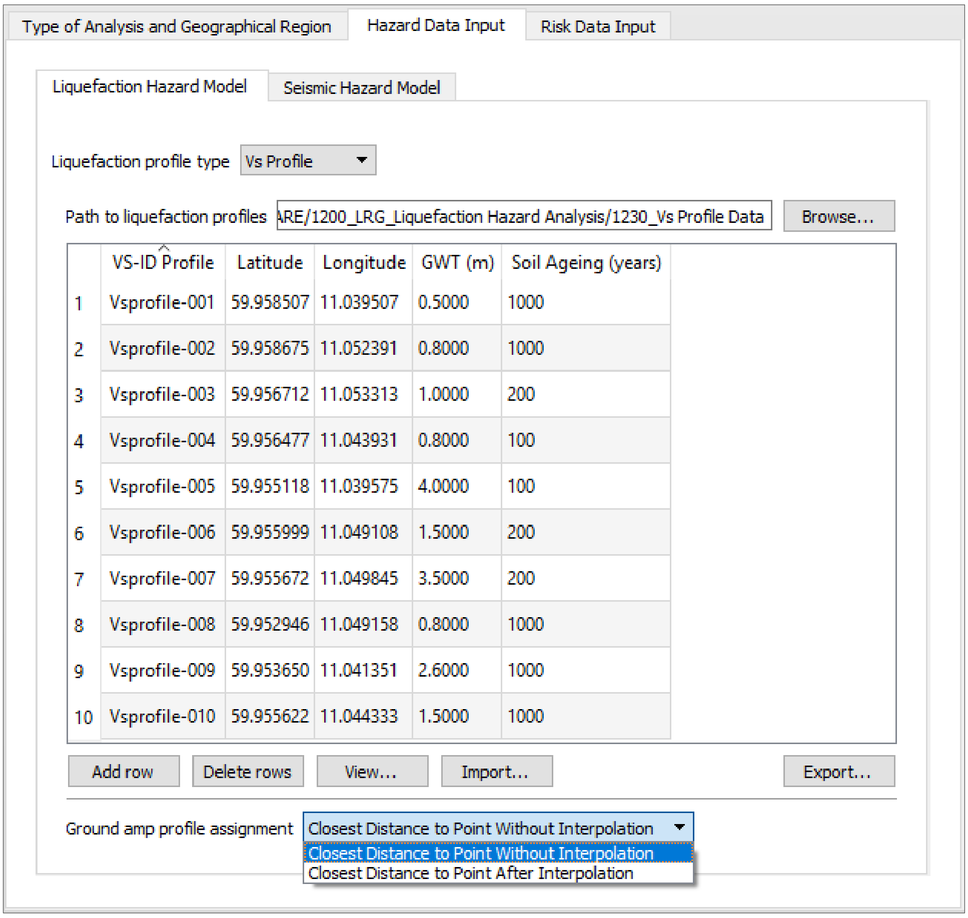


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

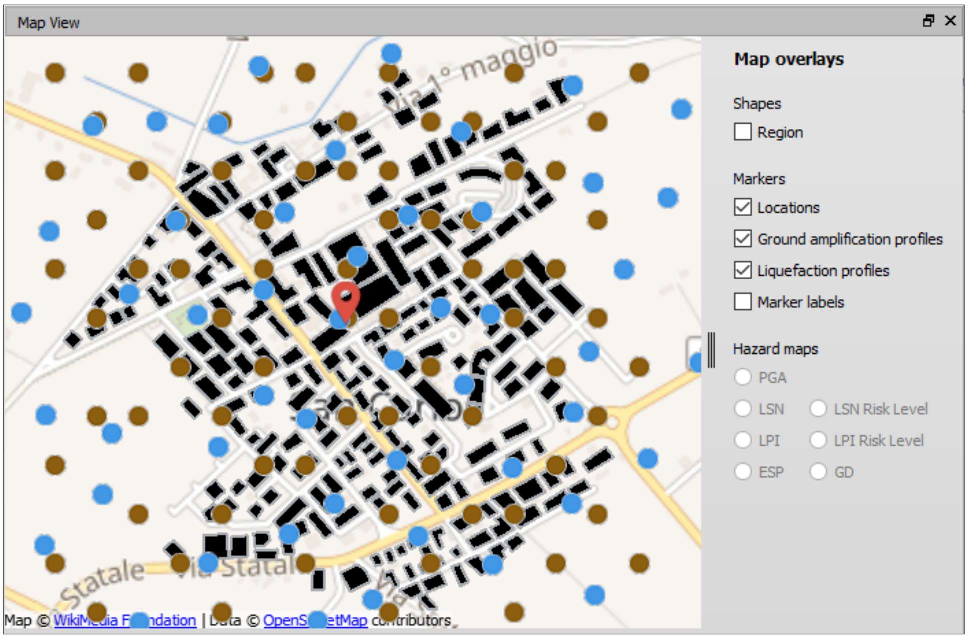
3. At the section *Ground amp profile assignment*, users can define how seismic actions (peak ground accelerations PGAs) resulted from ground amplification profiles will be assigned to the Vs profiles for computation of liquefaction severity indicators. Users will have to choose one of the following options:

   Closest Distance to Point Without Interpolation: the assigned value of PGA is directly resulted from the closest ground amplification profile at the location of a given VS profile or the closed to it.

   Closest Distance to Point After Interpolation. the assigned value of PGA is directly resulted from interpolation, at the location of a given Vs profile.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

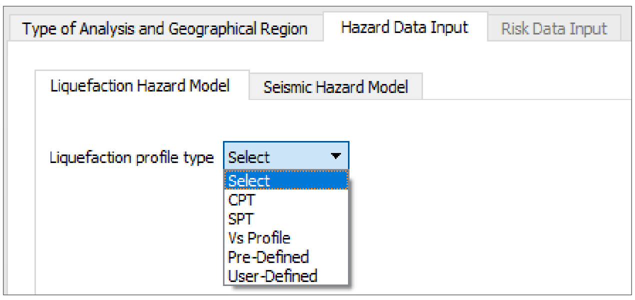


2.2.2 Liquefaction Hazard Model for Qualitative Assessment

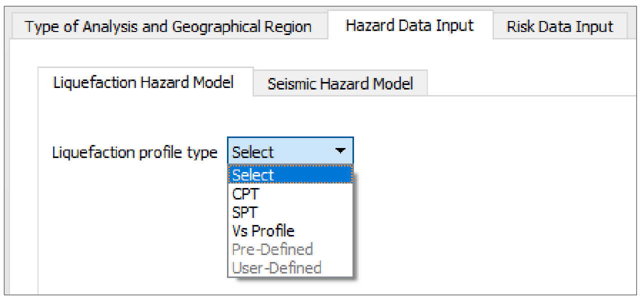
The concept of the qualitative approach, incorporated in the LIQUEFACT software, is based on using used-supplied or pre-defined liquefaction hazard map with qualitative classification labels representing levels of hazard. This process can be conducted through two options:

- *User-Defined*: is based on user-supplied microzonation or macrozonation liquefaction hazard maps generated for local or regional level for a specific study.
- *Pre-Defined*: is based on using the European liquefaction macrozonation maps, provided for different return periods, and which are embedded in the LIQUEFACT software.

Note that *User-Defined* and *Pre-Defined* in the module of *Liquefaction Hazard Model* are activated only if the selected type of *Assessment Analysis* (in the protocol Type of Analysis and Geographical Region) is *Hazard*.



When the selected level of *Assessment Analysis* is *Hazard*, then *User-Defined* and *Pre-Defined* in the module of *Liquefaction Hazard Model* are activated



When the selected level of *Assessment Analysis* is *Hazard & Risk* or *Hazard, Risk & Mitigation*, then *User-Defined* and *Pre-Defined* in the module of *Liquefaction Hazard Model* are not activated

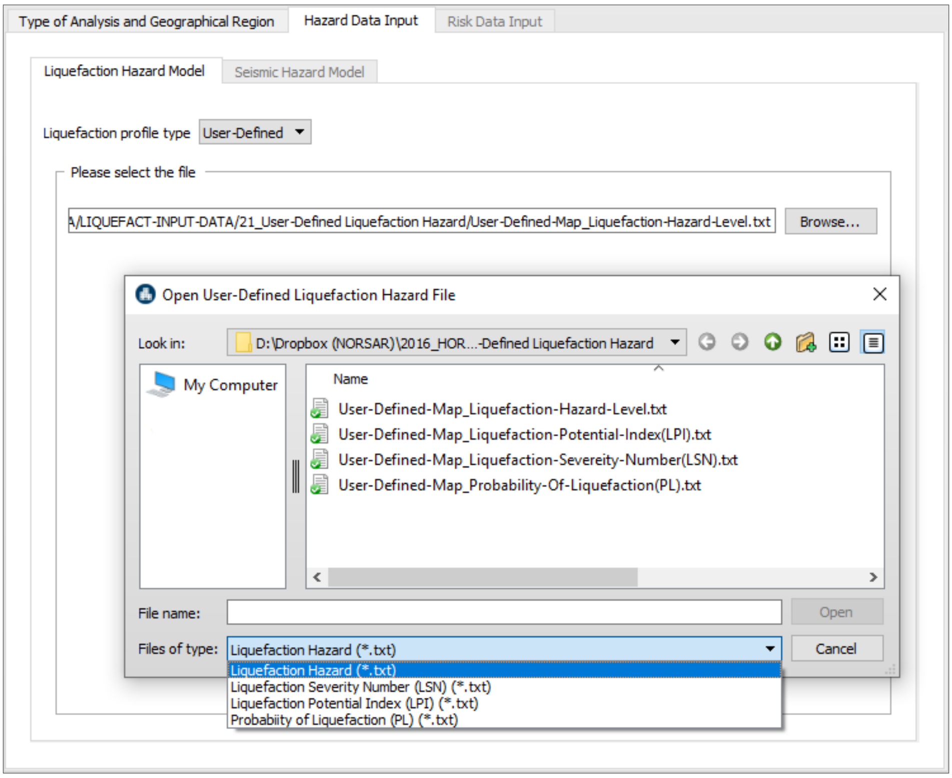
2.2.2.1 *User-Defined Liquefaction Hazard*

User-supplied qualitative liquefaction hazard maps can be in terms of the following liquefaction severity indicators: Liquefaction Susceptibility, Liquefaction Potential Index (LPI), Liquefaction Severity Number (LSN), and Probability of Liquefaction (PL).

NOTE: In the LIQUEFACT software, when user-supplied liquefaction hazard maps are used through the selection of *User-Defined* option, location-specific levels of liquefaction hazard are not interpolated, and closest location-specific to a given asset is assigned for the evaluation of liquefaction risk.

2.2.2.1.1 User-Supplied Liquefaction Hazard Map

To import map in terms of Liquefaction Hazard indicator: user is first required to select "*Liquefaction Hazard*" at section *Files of type*, and then import the map file from the folder where is located.



In user-supplied maps in terms of Liquefaction Hazard indicator, three qualitative levels of hazard classification are used for range labels: Non-susceptible, No Liquefaction, and Liquefaction. Below is an example of user-supplied liquefaction hazard map in terms of susceptibility and which can be imported as unformatted TXT file.

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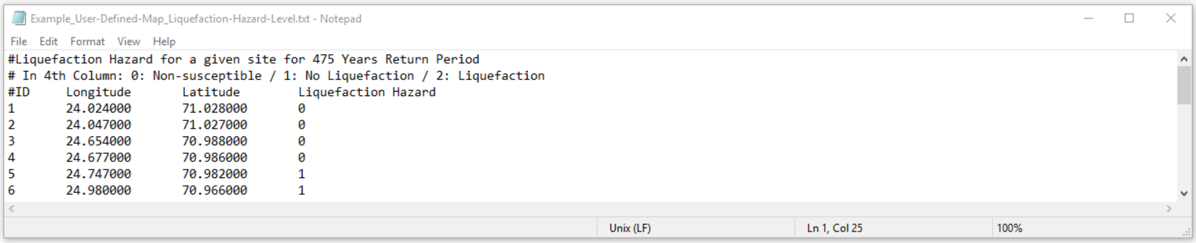
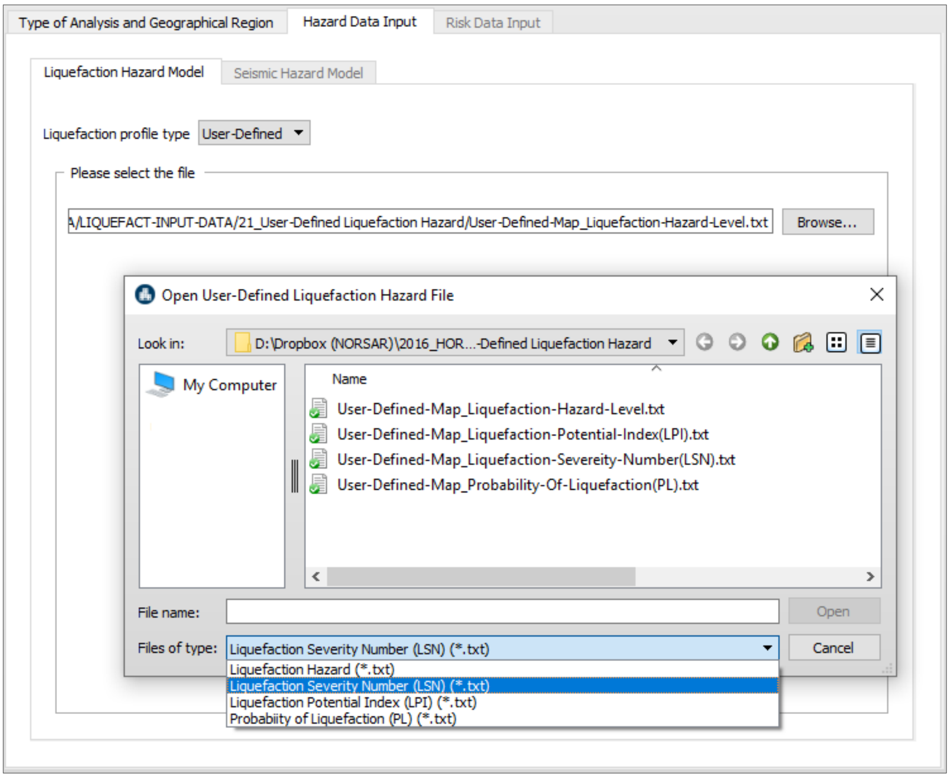


```
#Liquefaction Hazard for a given site for 475 Years Return Period
# In 4th Column: 0: Non-susceptible / 1: No Liquefaction / 2: Liquefaction
#ID     Longitude       Latitude        Liquefaction Hazard
1       24.024000       71.028000       0
2       24.047000       71.027000       0
3       24.654000       70.988000       0
4       24.677000       70.986000       0
5       24.747000       70.982000       1
6       24.980000       70.966000       1
```

2.2.2.1.2 User-Supplied Liquefaction Severity Number (LSN) Map

To import map in terms of Liquefaction Severity Number (LSN) indicator: user is first required to select "*Liquefaction Hazard*" at section *Files of type*, and then import the map file from the folder where is located.



In user-supplied maps in terms of LSN indicator, five qualitative levels of hazard classification are used for range labels: Non-Liquefaction Risk, Low Liquefaction Risk, Moderate Liquefaction Risk, High Liquefaction Risk, and Very High Liquefaction Risk. Below is an example of user-supplied liquefaction hazard map in terms of LSN and which can be imported as unformatted TXT file.

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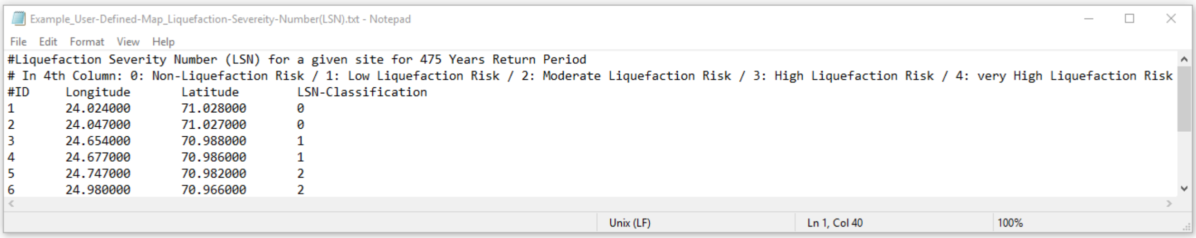
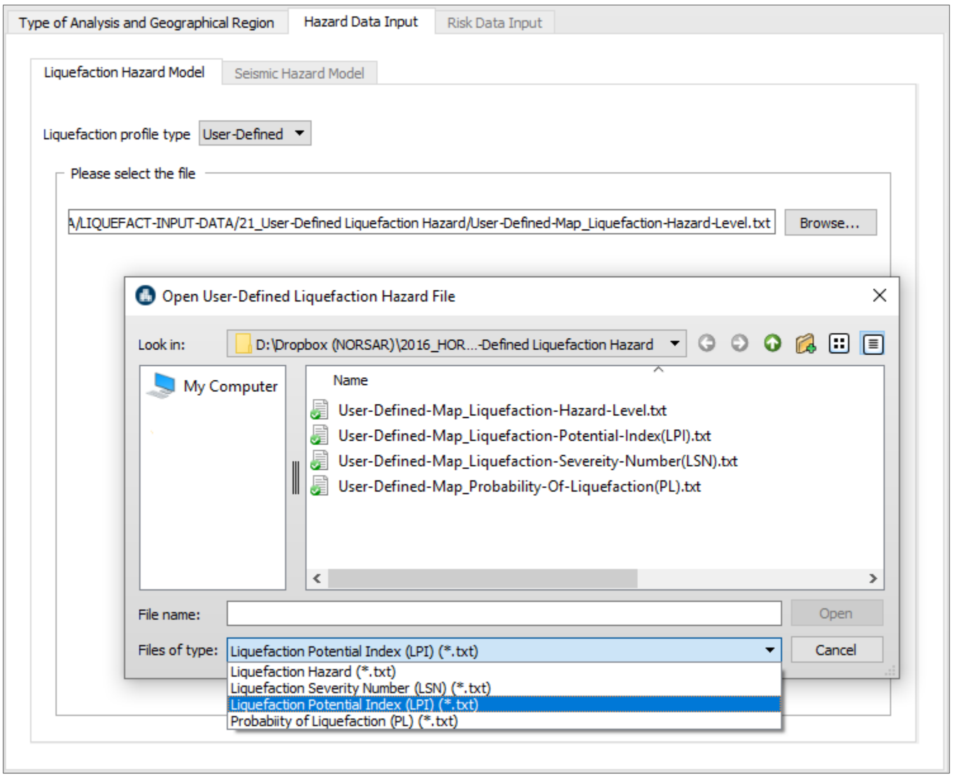


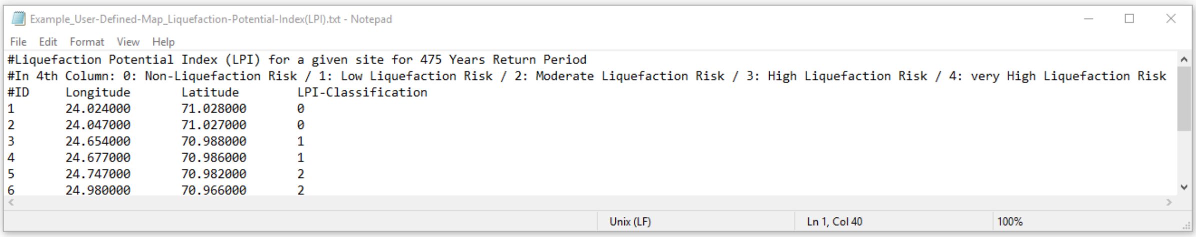
2.2.2.1.3 User-Supplied Liquefaction Potential Index (LPI) Map

To import map in terms of Liquefaction Potential Index (LPI) indicator: user is first required to select "*Liquefaction Hazard*" at section *Files of type*, and then import the map file from the folder where is located.



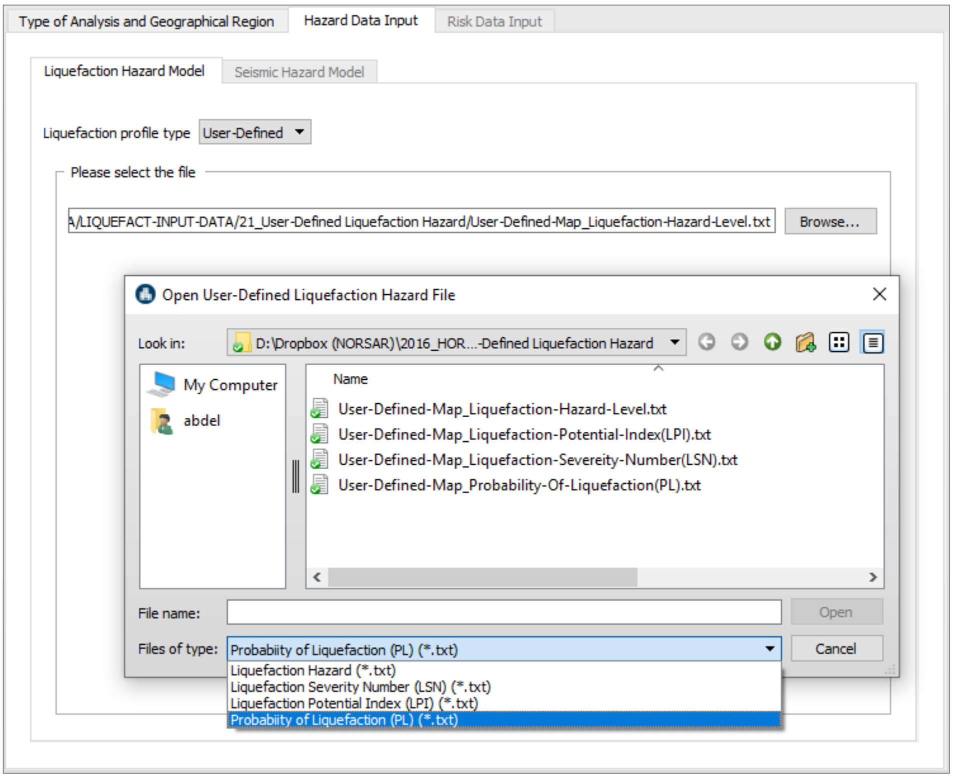
In user-supplied maps in terms of LPI indicator, five qualitative levels of hazard classification are used for range labels: Non-Liquefaction Risk, Low Liquefaction Risk, Moderate Liquefaction Risk, High Liquefaction Risk, and Very High Liquefaction Risk. Below is an example of user-supplied liquefaction hazard map in terms of LPI and which can be imported as unformatted TXT file.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748



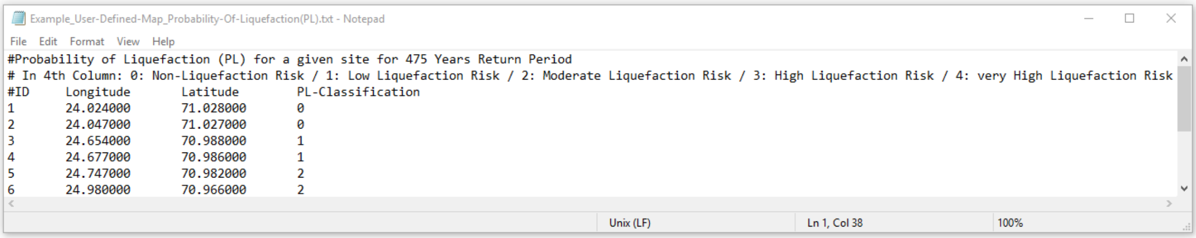
2.2.2.1.4 User-Supplied Probability of Liquefaction (PL) Map

To import map in terms of Probability of Liquefaction (PL) indicator: user is first required to select "*Liquefaction Hazard*" at section *Files of type*, and then import the map file from the folder where is located.



In user-supplied maps in terms of PL indicator, five qualitative levels of hazard classification are used for range labels: Non-Liquefaction Risk, Low Liquefaction Risk, Moderate Liquefaction Risk, High Liquefaction Risk, and Very High Liquefaction Risk. Below is an example of user-supplied liquefaction hazard map in terms of PL and which can be imported as unformatted TXT file.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

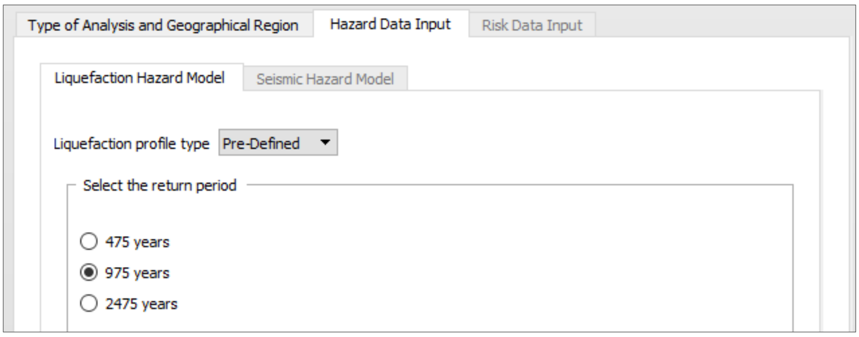

Example_User-Defined-Map_Probability-Of-Liquefaction(PL).txt - Notepad

```
#Probability of Liquefaction (PL) for a given site for 475 Years Return Period
# In 4th Column: 0: Non-Liquefaction Risk / 1: Low Liquefaction Risk / 2: Moderate Liquefaction Risk / 3: High Liquefaction Risk / 4: very High Liquefaction Risk
#ID	Longitude	Latitude	PL-Classification
1	24.024000	71.028000	0
2	24.047000	71.027000	0
3	24.654000	70.988000	1
4	24.677000	70.986000	1
5	24.747000	70.982000	2
6	24.980000	70.966000	2
```

2.2.2.2 Pre-Defined Liquefaction Hazard

The concept of "Pre-Defined" for liquefaction hazard consists of using the embedded Geo-referenced macrozonation liquefaction hazard maps covering the European territory (Carlo et al 2018). Note that this type of analysis is recommended only if users want to conduct liquefaction hazard analysis at continental or large region-scale level. The macrozonation maps are characterized by a return period of 475, 975 and 2475 years, and use three qualitative levels of hazard classification for range labels: *Non-susceptible*, *No Liquefaction*, and *Liquefaction*.

NOTE: In the LIQUEFACT software, when user-supplied liquefaction hazard maps are used through the selection of *Pre-Defined* option, location-specific levels of liquefaction hazard are not interpolated, and closest location-specific to a given asset is assigned for the evaluation of liquefaction risk.



2.2.3 Seismic Hazard Model

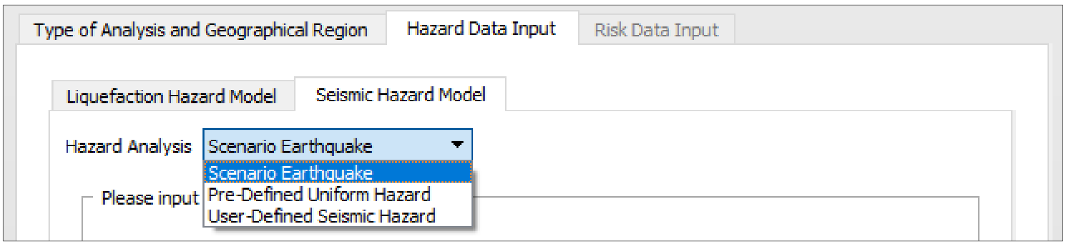
A key point in liquefaction hazard assessment is the provision of seismic ground motion, in general, generated and integrated in the form of contour maps and location-specific seismic demands. In the LIQUEFACT software, input data related to earthquake hazard is required only if quantitative liquefaction assessment is carried-out. When *User-Defined* or *Pre-Defined* in the *Liquefact Hazard Model* module are selected, the module of *Seismic Hazard Model* is not activated as no information related to earthquake is needed.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

2.2.3.1 Seismic Hazard Analysis

In the LIQUEFACT software, the spatial distribution of ground motion can be determined using one of the following methods or sources:

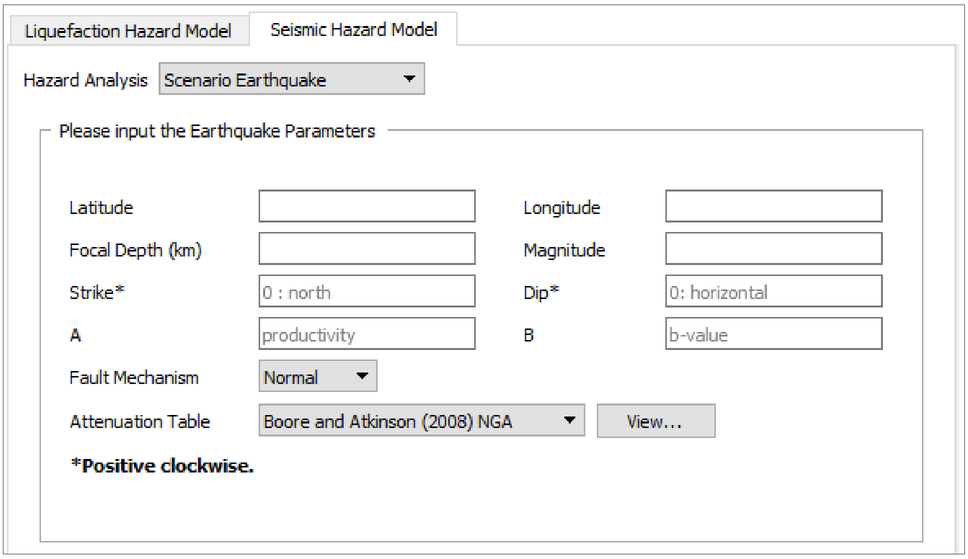
- Scenario Earthquake (repeat of any potential earthquake event);
- Pre-Defined Uniform Hazard map (probabilistic ground motion maps e.g. Share.eu);
- User-Defined Seismic Hazard map (can be based on probabilistic or deterministic ground motion analysis).



2.2.3.1.1 Scenario Earthquake

A scenario earthquake can be either an historic earthquake or a hypothetical earthquake and can be defined using a set of parameters. The software assumes a simple rectangular rupture plane where the size of the rectangle is decided by the earthquake magnitude through the Wells and Coppersmith (1994) relations.

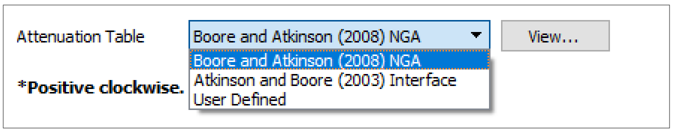
The earthquake source parameters can be defined using the screen that comes up once Scenario Earthquake option is selected from the Seismic Hazard Pull-down Menu and the Seismic Hazard Tab is selected.

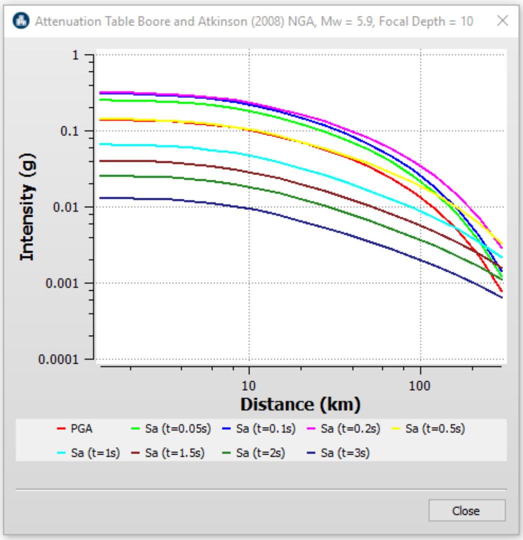


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

These earthquake parameters are:

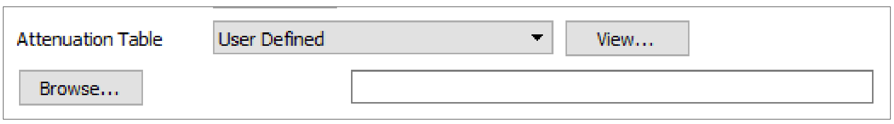
Latitude and Longitude	Latitude and Longitude of the epicenter of the scenario earthquake in degrees (defined using decimals). Note: In case of large ruptures this should be given as the center point of the presumed rupture rectangle.
Focal Depth	Focal depth in km. The depth corresponds to the depth at the longitude/latitude given above.
Magnitude	Magnitude of the scenario earthquake
Strike	Fault orientation in degrees from North.
Dip	Dip angle in degrees from the horizontal plane.
Attenuation relationships	Attenuation relationships (also called Ground Motion Prediction Equations - GMPE) are used to calculate ground shaking demand for rock sites. The attenuation models embedded in the LIQUEFACT software represents response spectral acceleration ordinates, Sa(T), at 5% elastic damping. The values of the spectral acceleration are in m/s2. The influence of any earthquake is set to zero for distances exceeding 300 km.





User-Defined Attenuation Tables

Introducing your own attenuation model is possible and easy. The format of attenuation model follows the one described below and is imported as an unformatted text file (e.g. from WordPad). The example shows the first of 9 blocks (9 periods are used; values of the periods are in blue color). Each block specifies ground shaking prediction (in yellow color) computed for 10 magnitude (rows corresponding to Mw of 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0 and 9.5) and 20 predefined distances (in green color). [texts in red are just for comments].



Periods	9	one block for each period (shown in blue color)
Depth	All	indicating that the relation is independent of depth
Distance-type	2	indicating that distance type is Epicentral (see table below for other type of distances)
Sigma	0.56	sigma of the GMPE model to be used for computation of annual frequency of exceedance

Distances	1.00E+00	1.35E+00	1.82E+00	2.46E+00	3.32E+00	4.49E+00	6.06E+00	8.18E+00	1.10E+01	1.49E+01	2.01E+01	2.72E+01	3.67E+01	4.95E+01	6.69E+01	9.03E+01	1.22E+02	1.65E+02	2.22E+02	3.00E+02	
1.00E-03																					
1.73E+00	1.17E+00	1.12E+00	1.04E+00	9.44E-01	8.31E-01	7.11E-01	5.96E-01	4.89E-01	3.94E-01	3.12E-01	2.41E-01	1.81E-01	1.30E-01	8.91E-02	5.68E-02	3.30E-02	1.69E-02	7.25E-03	2.47E-03	for Mw=5.0
2.40E+00	1.30E+00	1.28E+00	1.24E+00	1.18E+00	1.10E+00	9.87E-01	8.64E-01	7.36E-01	6.11E-01	4.96E-01	3.92E-01	3.00E-01	2.21E-01	1.54E-01	1.00E-01	5.91E-02	3.08E-02	1.35E-02	4.68E-03	for Mw=5.5
3.16E+00	1.37E+00	1.36E+00	1.34E+00	1.32E+00	1.28E+00	1.21E+00	1.12E+00	1.00E+00	8.72E-01	7.33E-01	5.97E-01	4.69E-01	3.53E-01	2.51E-01	1.67E-01	1.01E-01	5.33E-02	2.38E-02	8.41E-03	for Mw=6.0
3.96E+00	1.38E+00	1.38E+00	1.38E+00	1.37E+00	1.35E+00	1.32E+00	1.28E+00	1.20E+00	1.11E+00	9.79E-01	8.34E-01	6.80E-01	5.28E-01	3.86E-01	2.62E-01	1.61E-01	8.74E-02	3.98E-02	1.43E-02	for Mw=6.5
4.42E+00	1.25E+00	1.25E+00	1.25E+00	1.25E+00	1.24E+00	1.23E+00	1.21E+00	1.18E+00	1.14E+00	1.06E+00	9.55E-01	8.22E-01	6.69E-01	5.09E-01	3.58E-01	2.27E-01	1.26E-01	5.86E-02	2.16E-02	for Mw=7.0
4.56E+00	1.01E+00	1.01E+00	1.01E+00	1.01E+00	1.01E+00	1.00E+00	9.97E-01	9.86E-01	9.68E-01	9.37E-01	8.86E-01	8.09E-01	7.01E-01	5.68E-01	4.21E-01	2.80E-01	1.61E-01	7.78E-02	2.95E-02	for Mw=7.5
4.70E+00	7.25E-01	7.25E-01	7.25E-01	7.25E-01	7.24E-01	7.23E-01	7.21E-01	7.18E-01	7.12E-01	7.01E-01	6.81E-01	6.49E-01	5.97E-01	5.19E-01	4.17E-01	2.99E-01	1.85E-01	9.48E-02	3.78E-02	for Mw=8.0
4.85E+00	4.01E-01	4.01E-01	4.01E-01	4.01E-01	4.00E-01	4.00E-01	4.00E-01	3.99E-01	3.97E-01	3.94E-01	3.88E-01	3.79E-01	3.62E-01	3.34E-01	2.91E-01	2.31E-01	1.60E-01	9.13E-02	4.03E-02	for Mw=8.5
5.00E+00	1.31E-01	1.31E-01	1.31E-01	1.31E-01	1.31E-01	1.31E-01	1.31E-01	1.31E-01	1.30E-01	1.30E-01	1.29E-01	1.27E-01	1.24E-01	1.19E-01	1.09E-01	9.51E-02	7.47E-02	4.99E-02	2.62E-02	for Mw=9.0
5.16E+00	1.58E-02	1.58E-02	1.58E-02	1.58E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.56E-02	1.55E-02	1.53E-02	1.49E-02	1.43E-02	1.32E-02	1.14E-02	8.86E-03	5.73E-03	for Mw=9.5
5.00E-02																					
3.54E+00	2.32E+00	2.21E+00	2.05E+00	1.85E+00	1.61E+00	1.36E+00	1.12E+00	9.10E-01	7.23E-01	5.64E-01	4.29E-01	3.17E-01	2.25E-01	1.52E-01	9.53E-02	5.45E-02	2.74E-02	1.16E-02	3.90E-03	for Mw=5.0
4.79E+00	2.49E+00	2.44E+00	2.36E+00	2.23E+00	2.06E+00	1.84E+00	1.60E+00	1.35E+00	1.11E+00	8.87E-01	6.92E-01	5.23E-01	3.79E-01	2.61E-01	1.67E-01	9.77E-02	5.02E-02	2.17E-02	7.43E-03	for Mw=5.5
5.99E+00	2.44E+00	2.42E+00	2.39E+00	2.34E+00	2.26E+00	2.14E+00	1.97E+00	1.76E+00	1.51E+00	1.26E+00	1.02E+00	7.89E-01	5.87E-01	4.13E-01	2.71E-01	1.62E-01	8.47E-02	3.74E-02	1.31E-02	for Mw=6.0
6.92E+00	2.26E+00	2.25E+00	2.24E+00	2.22E+00	2.20E+00	2.15E+00	2.07E+00	1.95E+00	1.78E+00	1.57E+00	1.33E+00	1.07E+00	8.25E-01	5.98E-01	4.02E-01	2.45E-01	1.32E-01	5.93E-02	2.12E-02	for Mw=6.5

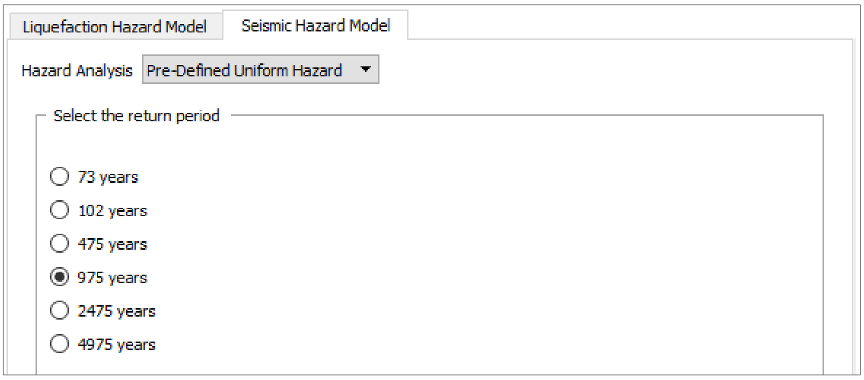
Type of distance to be used for the attenuation table (see Provision of Seismic Demand)

Value	Distance Type
1	for (or blank) Focal
2	for Epicentral
3	for Joyner and Boore
4	for Closest to rupture area (Rrup)

2.2.3.1.2 Pre-Defined Seismic Uniform Hazard

The SHARE project probabilistic seismic hazard contour maps for Euro-Mediterranean Region has been embedded in the LIQUEFACT software, to be used as basis to ground shaking in Pre-Defined Uniform Hazard type analysis. The SHARE maps were produced for different return periods: 73 years (50% in 50 years), 102 years (39% in 50 years), 475 years (10% in 50 years), 975 years (5% in 50 years), 2475 years (2% in 50 years), 4975 years (1% in 50 years). The hazard values are referenced to a rock velocity of $V_{S,30}$ = 800 m/s at 30 m depth. SHARE models earthquakes as finite ruptures and includes all events with magnitudes MW≥4.5 in the computation of hazard values. SHARE introduces an innovative weighting scheme that reflects the importance of the input data sets considering their time horizon, thus emphasizing the geologic knowledge for products with longer time horizons and seismological data for shorter ones.

Incorporation of SHARE hazard maps in the LIQUEFACT software

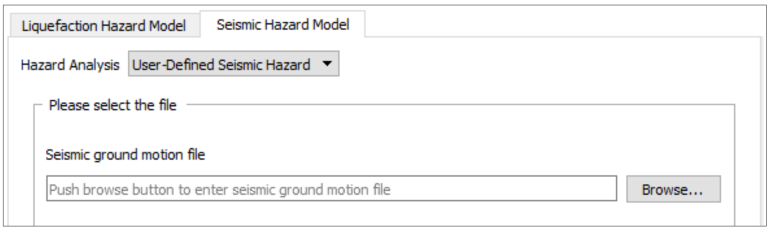


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

In the LIQUEFACT software, when ground motion is based on the pre-defined hazard map, location-specific values of ground shaking demands are interpolated between PGA or spectral acceleration contours.

2.2.3.1.3 User-Defined Seismic Hazard

User-supplied PGA and spectral acceleration contour maps, e.g. resulted from a specific local or regional seismic response analysis, may also be used. In this case, the user must provide all contour maps in a pre-defined digital CSV, unformatted TXT or SHAPE file and a specific format as illustrated in Table below: a file with 14 columns including: ID, Longitude, Latitude, PGA, Sa(T=0.10s), Sa(T=0.15s), Sa(T=0.20s), Sa(T=0.25s), Sa(T=0.30s), Sa(T=0.50s), Sa(T=0.75s), Sa(T=1.00s), Sa(T=2.00s), Sa(T=3.00s), Sa(T=4.00s)]. All the values of PGA and spectral acceleration must be in [g] unit. The user-supplied hazard maps can be generated for rock site class condition or with including soil amplification.



Example of User-Supplied Ground Motion Parameters for a specific region, generated for 475 Years Return Period (10% in 50 years)

# ID	Longitude	Latitude	PGA[g]	Sa(T=0.10s)[g]	Sa(T=0.15s)[g]	Sa(T=0.20s)[g]	Sa(T=0.25s)[g]	Sa(T=0.30s)[g]	Sa(T=0.50s)[g]	Sa(T=0.75s)[g]	Sa(T=1.00s)[g]	Sa(T=2.00s)[g]	Sa(T=3.00s)[g]	Sa(T=4.00s)[g]
1	5.182134	59.9	0.085089	0.191032	0.197592	0.186229	0.158021	0.136942	0.078021	0.047766	0.032759	0.011382	0.004508	0.002388
2	26.482134	63.4	0.004324	0.012001	0.013011	0.013093	0.011202	0.009674	0.005249	0.002941	0.001921	0.000937	0.000901	0.000905
3	24.482134	59.2	0.018039	0.04895	0.050919	0.050172	0.043283	0.037249	0.021894	0.012977	0.008893	0.002714	0.000902	0.0009
4	38.082134	39.2	0.192157	0.420152	0.454613	0.409887	0.3779	0.346666	0.233683	0.172791	0.12924	0.067278	0.048176	0.031169
5	19.382134	65.8	0.005734	0.014947	0.016497	0.016498	0.01396	0.012418	0.006783	0.003899	0.002596	0.000913	0.0009	0.000905
6	30.682134	65	0.009605	0.02673	0.028209	0.027507	0.023593	0.020385	0.011248	0.006424	0.004184	0.001207	0.000902	0.000902
7	23.182134	62.9	0.003514	0.009531	0.010578	0.010746	0.009104	0.007991	0.004268	0.002422	0.001602	0.000932	0.000902	0.000904
8	22.382134	50.5	0.018513	0.043666	0.048242	0.047676	0.042521	0.037382	0.02316	0.015046	0.010262	0.003713	0.001884	0.000914
9	14.382134	36.5	0.094162	0.199499	0.22003	0.202276	0.187579	0.170083	0.106751	0.072661	0.051912	0.02355	0.015128	0.008142
10	29.582134	45	0.07564	0.159991	0.170155	0.161404	0.142743	0.134295	0.094509	0.062557	0.044919	0.018004	0.009658	0.003721
11	-21.61787	62.7	0.067937	0.131042	0.152307	0.155848	0.150978	0.141428	0.101899	0.081894	0.061291	0.030521	0.022545	0.01309
12	-23.71787	64.4	0.163816	0.366356	0.381414	0.354818	0.319045	0.279772	0.186452	0.132528	0.096412	0.04713	0.031904	0.018621
13	16.482134	46.7	0.07059	0.152713	0.169925	0.158087	0.141243	0.129766	0.081599	0.056201	0.039323	0.017174	0.011102	0.005845
14	16.982134	50.6	0.030479	0.070876	0.073818	0.070435	0.06102	0.052235	0.030042	0.018069	0.012193	0.003948	0.001752	0.0009

Note that in the LIQUEFACT software when ground motion is based on user-supplied maps, location-specific values of ground shaking demands are interpolated between PGA or spectral acceleration contours.

2.2.3.2 Ground Amplification (Response Spectrum)

The values of ground shaking demand obtained from the different methodologies/options described above are in general computed for rock condition, and which then amplified by factors based on local soil conditions. This can be done using one of the following alternatives:

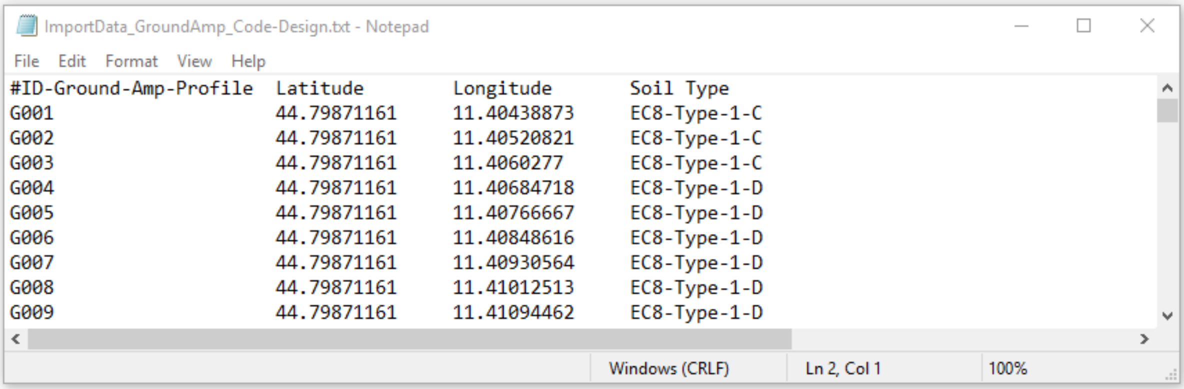
- Use of response spectrum ***Code-Design***: where Eurocode-8 spectrum types are incorporated in the LIQUEFACT software.
- Use of **Site-Specific** option which requires Vs profiles supplied by the user.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

2.2.3.2.1 Code-Design

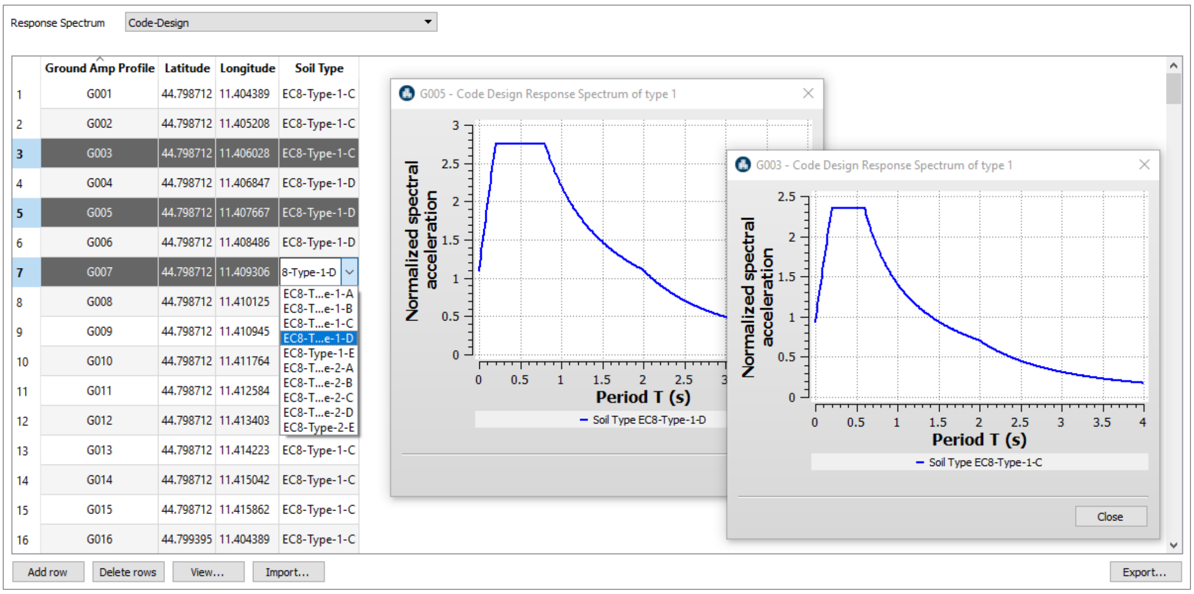
Two different types of design spectra are provided within Eurocode 8 (CEN, 2004). This is mainly done in order to account for the differing level of seismic hazard in Europe and the different earthquake types susceptible to occur. In case that earthquakes with a surface-wave magnitude Ms > 5.5 are expected, it is suggested to use Spectrum Type 1, else (Ms ≤ 5.5) Type 2. The question which spectrum type to choose for a specific region should be based upon "*(...) the magnitude of earthquakes that are actually expected to occur rather than conservative upper limits defined for the purpose of probabilistic hazard assessment*".

Below is an example of user-supplied data for soil classification in terms of EC8 code design and which can be imported as tab-separated CSV files, unformatted TXT files or SHAPE files (ESRI defined formats).

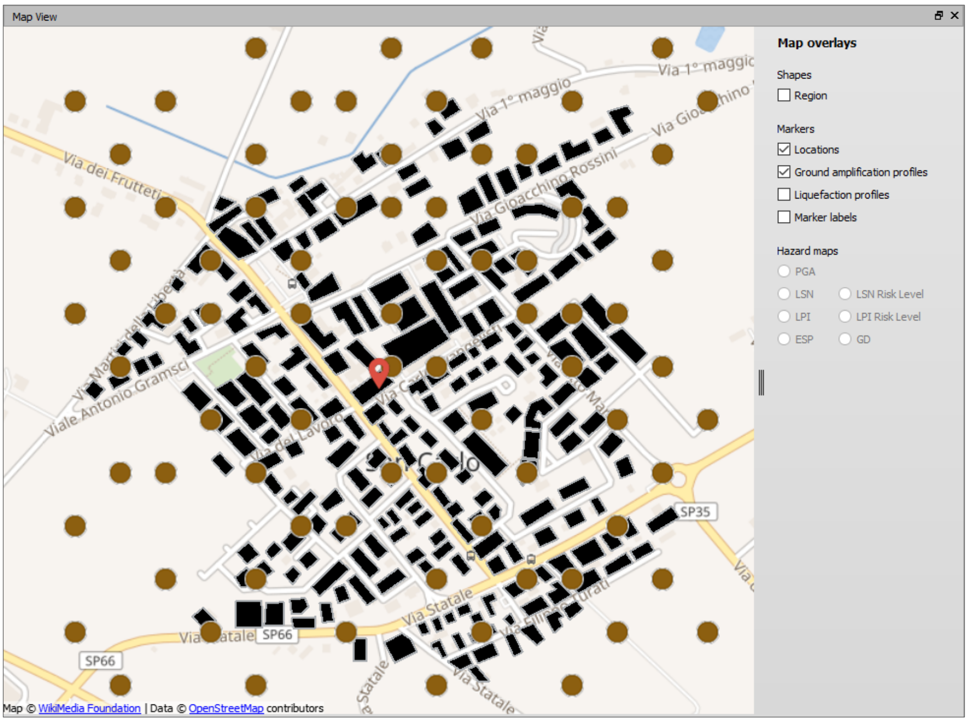


#ID-Ground-Amp-Profile	Latitude	Longitude	Soil Type
G001	44.79871161	11.40438873	EC8-Type-1-C
G002	44.79871161	11.40520821	EC8-Type-1-C
G003	44.79871161	11.4060277	EC8-Type-1-C
G004	44.79871161	11.40684718	EC8-Type-1-D
G005	44.79871161	11.40766667	EC8-Type-1-D
G006	44.79871161	11.40848616	EC8-Type-1-D
G007	44.79871161	11.40930564	EC8-Type-1-D
G008	44.79871161	11.41012513	EC8-Type-1-D
G009	44.79871161	11.41094462	EC8-Type-1-D

The imported ground amplification profiles data can be edited and modified in the software, and the location of the profiles can also be viewed on the GIS platform of the LIQUEFACT software.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748



NOTE: In case that user-supplied maps already include soil amplification, then in Response Spectrum section Soil Type to be defined as class A (i.e. *EC8-Type-1-A* or *EC8-Type-2-A*) referencing rock site condition. This means that the user-supplied ground motion values will not be amplified again (it will simply be multiplied by 1).

2.2.3.2.2 Site-Specific

- In the case of Scenario Earthquake, LIQUEFACT software is using the embedded attenuation relationships to compute the corresponding ground motion estimates using average shear-wave velocity $V_{S,30}$ in order to amplify the ground motion. This $V_{S,30}$ value is user-supplied as input data.
- In the case of Pre-Defined or User-Defined Seismic Hazard (where ground motion map for rock site condition is already computed in terms of PGA values and full spectral acceleration contours), the ground motion is amplified using the soil amplification factors provided by IBC-2006 (ICC, 2006) by assigning a $V_{S,30}$ value that agrees with the soil type.

Below is an example of user-supplied data for soil classification in terms of $V_{S,30}$ values and which can be imported as tab-separated CSV files, unformatted TXT files or SHAPE files (ESRI defined formats).

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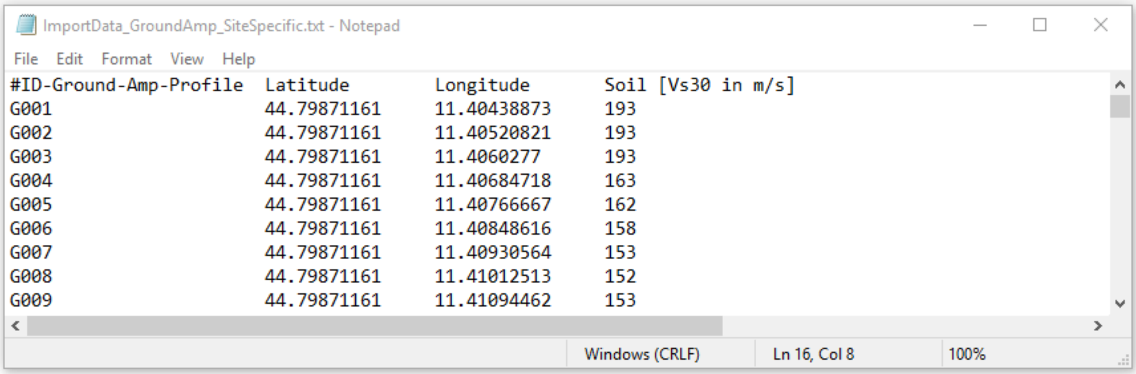
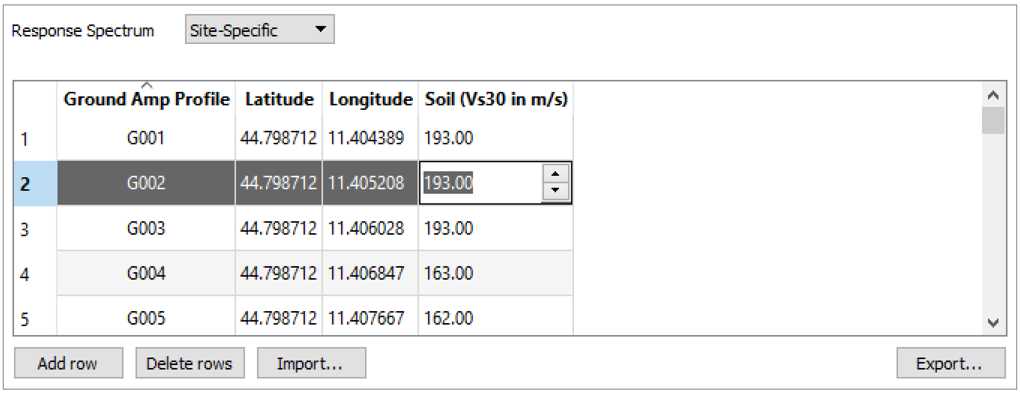


ImportData_GroundAmp_SiteSpecific.txt - Notepad

#ID-Ground-Amp-Profile	Latitude	Longitude	Soil [Vs30 in m/s]
G001	44.79871161	11.40438873	193
G002	44.79871161	11.40520821	193
G003	44.79871161	11.4060277	193
G004	44.79871161	11.40684718	163
G005	44.79871161	11.40766667	162
G006	44.79871161	11.40848616	158
G007	44.79871161	11.40930564	153
G008	44.79871161	11.41012513	152
G009	44.79871161	11.41094462	153

The imported ground amplification profiles data can be edited and modified in the software, and the location of the profiles can also be viewed on the GIS platform of the LIQUEFACT software.



Response Spectrum: Site-Specific

	Ground Amp Profile	Latitude	Longitude	Soil (Vs30 in m/s)
1	G001	44.798712	11.404389	193.00
2	G002	44.798712	11.405208	193.00
3	G003	44.798712	11.406028	193.00
4	G004	44.798712	11.406847	163.00
5	G005	44.798712	11.407667	162.00

NOTE:

- The imported ground amplification profiles data can be edited and modified in the software.
- In case that user-supplied maps already include soil amplification, then in Response Spectrum section values of velocity $V_{S,30}$ >800m/s, referencing rock site condition, to be assigned for soil.

This means that the user-supplied ground motion values will not be amplified again (it will simply be multiplied by 1).

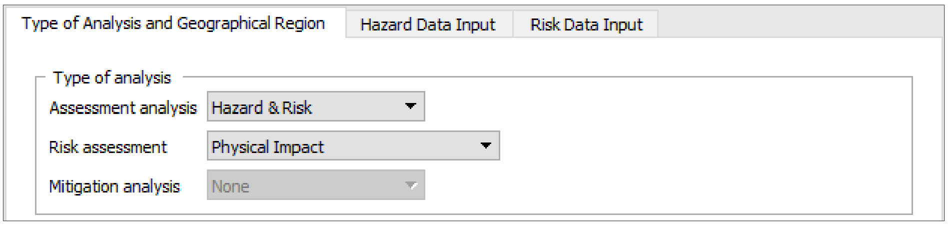
2.3 Risk Data Input

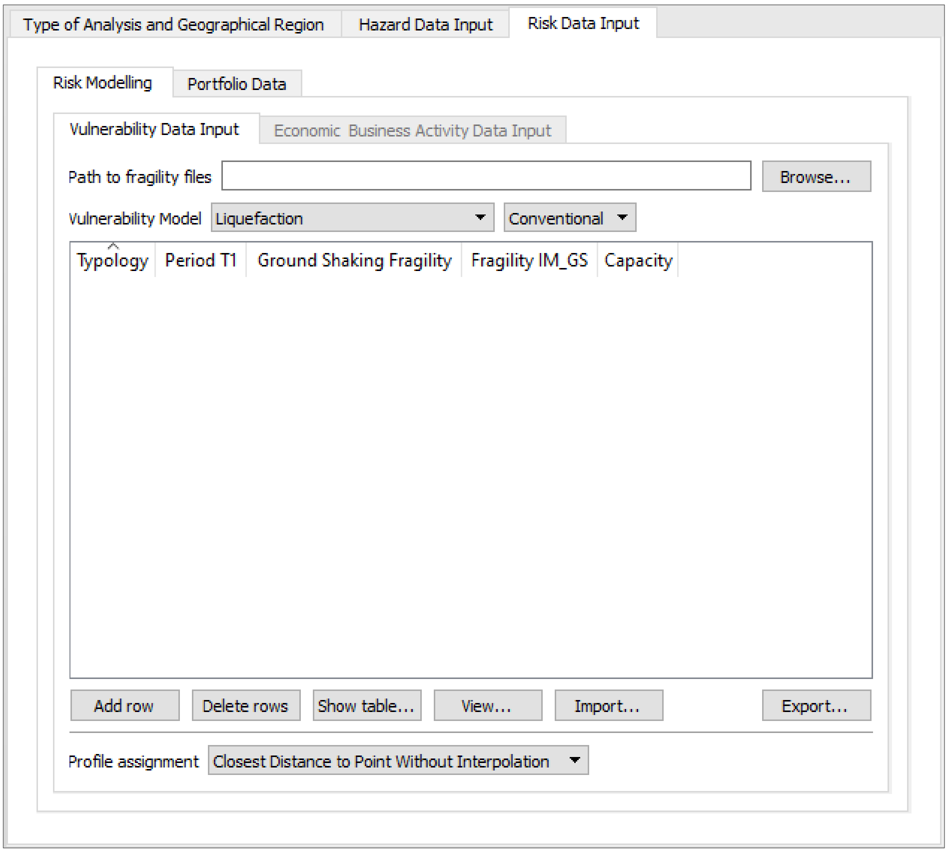
For Risk Analysis, depending on what level of analysis is chosen and output is requested, different numbers of input files should be imported. Two categories of data are to be provided: input data for ***Risk Modelling*** and input data for ***Assets Modelling*** (Portfolio Data).

2.3.1 Risk Modelling

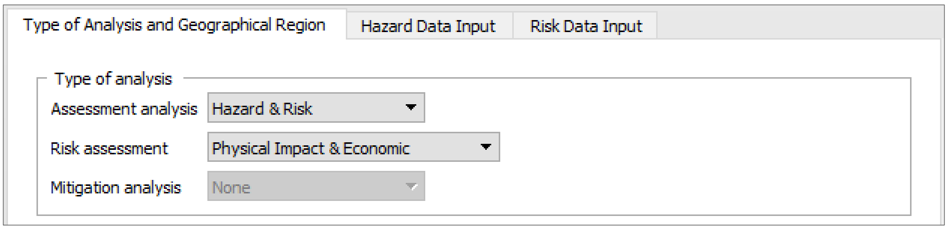
In the section ***Risk Assessment*** (in Module ***Type of Analysis and Geographical Region***):

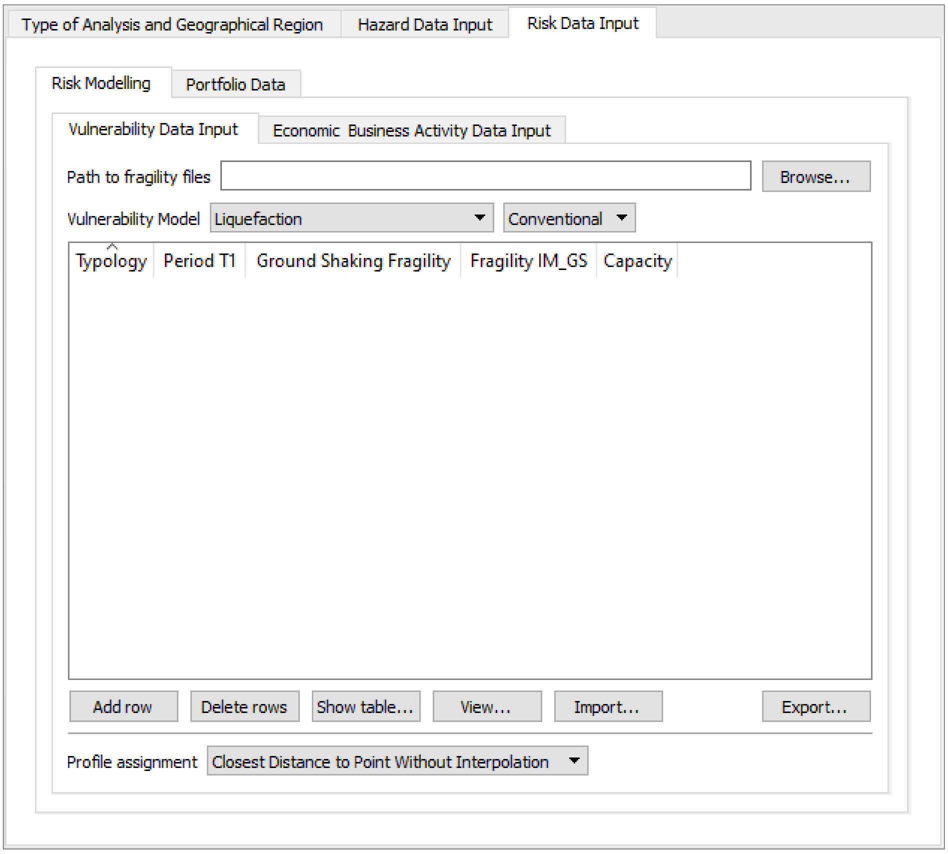
1. If *Physical impact* is selected: then in ***Risk Modelling*** only *Vulnerability Data Input* module is activated, and users will be required to import vulnerability models and portfolio data with structural characteristics-related information.





2. If *Physical impact & Economic* is selected: in ***Risk Modelling*** both *Vulnerability Data Input* and *Economic & Business Activity Data Input* are activated. In this case, users will also be required to import economic and business activity input data, in addition to the vulnerability models and portfolio data with structural characteristics-related information.





2.3.1.1 Vulnerability Data Input

In this module user is required to define the followings:

1. Vulnerability model to be used for the computation of damage and loss ratio on asset/assets (buildings or infrastructures). The software incorporates options to define vulnerability model that will be used for risk analysis:

   - *Liquefaction*: where user-supplied liquefaction fragility models are to be imported.
   - *Ground Shaking and Liquefaction*: where user-supplied ground shaking fragility models are imported in addition to liquefaction fragility models.

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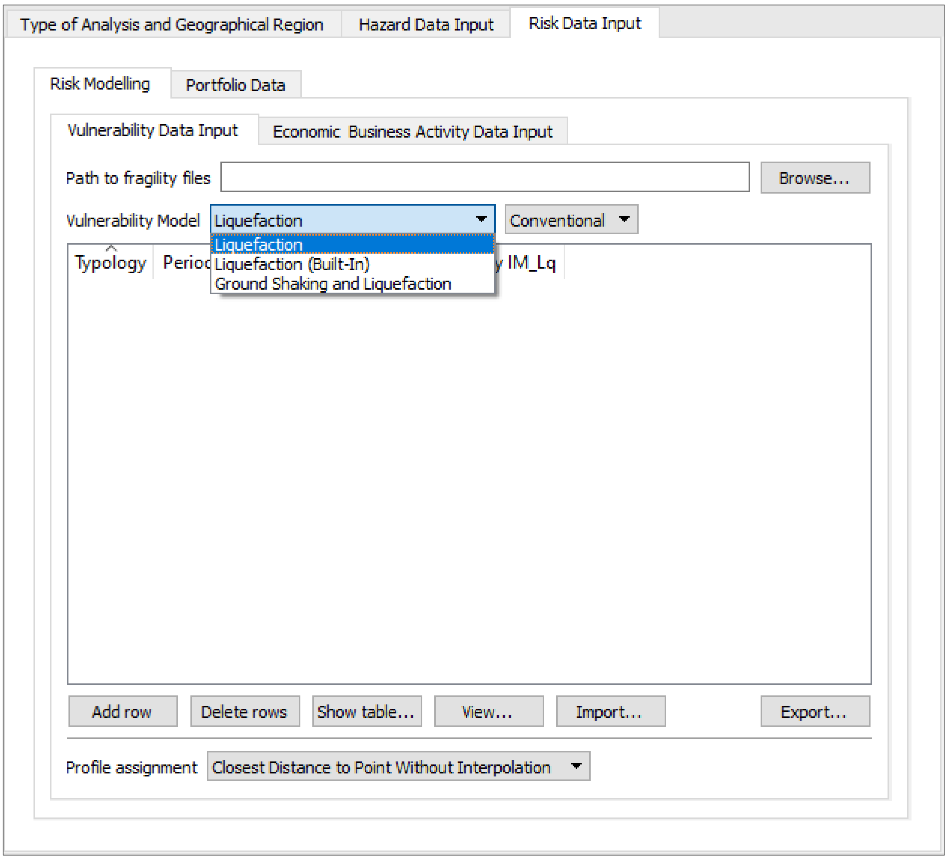
- *Liquefaction (Built-in)*: to make use of the pre-defined fragility models embedded in the software.



2. Select method of Loss Analysis to be implemented for the computation of damage and loss ratio.
3. Path to the fragility files that will be used for the computation of damage and loss ratio.
4. Definition how liquefaction demand will be assigned (through *Profile assignment*) to a given asset for the computation of damage and loss ratio.

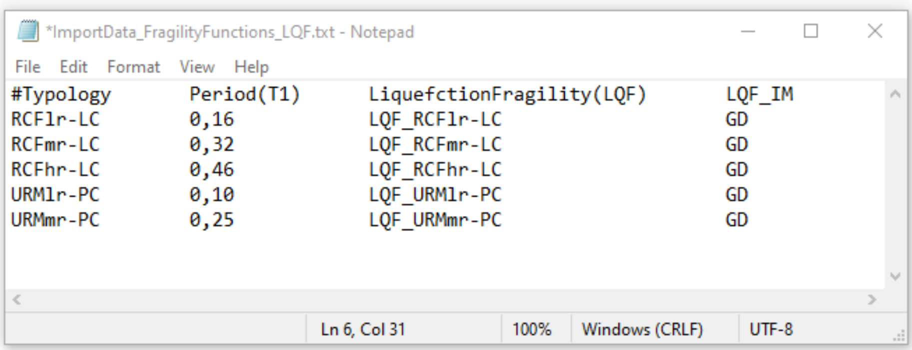
2.3.1.1.1 Liquefaction Vulnerability Model

For the implementation of *Liquefaction* vulnerability analysis, user-supplied *List of Liquefaction Fragility* models should be imported as following:

1. Click the *Import* button to import the file with list of the Liquefaction fragility models. The file can be imported as tab-separated CSV or unformatted TXT, containing the following information:
   - *Typology*: code-name of a given material and structural system typology of the structure/infrastructure;
   - *Period(T1)*: fundamental periods of the structures/infrastructures [in sec];
   - *LiquefactionFragility*: file names of liquefaction fragility models

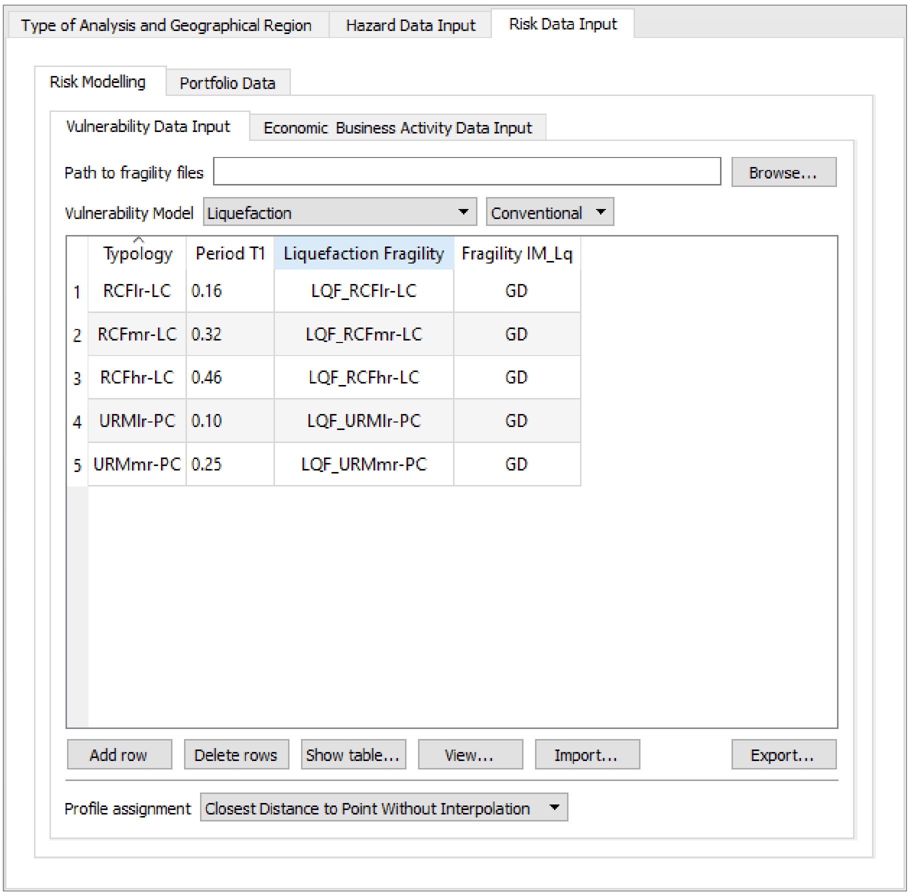
- *LQF_IM*: intensity measure of the liquefaction models (it can be PGA, Sa, LSN, Differential Settlement -GD).

Example of *List of Liquefaction Fragility models* file imported as CSV/TXT


*ImportData_FragilityFunctions_LQF.txt - Notepad
File Edit Format View Help

#Typology	Period(T1)	LiquefctionFragility(LQF)	LQF_IM
RCFlr-LC	0,16	LQF_RCFlr-LC	GD
RCFmr-LC	0,32	LQF_RCFmr-LC	GD
RCFhr-LC	0,46	LQF_RCFhr-LC	GD
URMlr-PC	0,10	LQF_URMlr-PC	GD
URMmr-PC	0,25	LQF_URMmr-PC	GD

Ln 6, Col 31 100% Windows (CRLF) UTF-8



The imported list of Liquefaction fragility models can be modified or updated by double click on any selected row representing a given liquefaction fragility model. It is also possible to Add or Delete any row/model. After any editing, the list of fragility models file can be exported and saved as tab-separated CSV by clicking on <u>*Export*</u> button.

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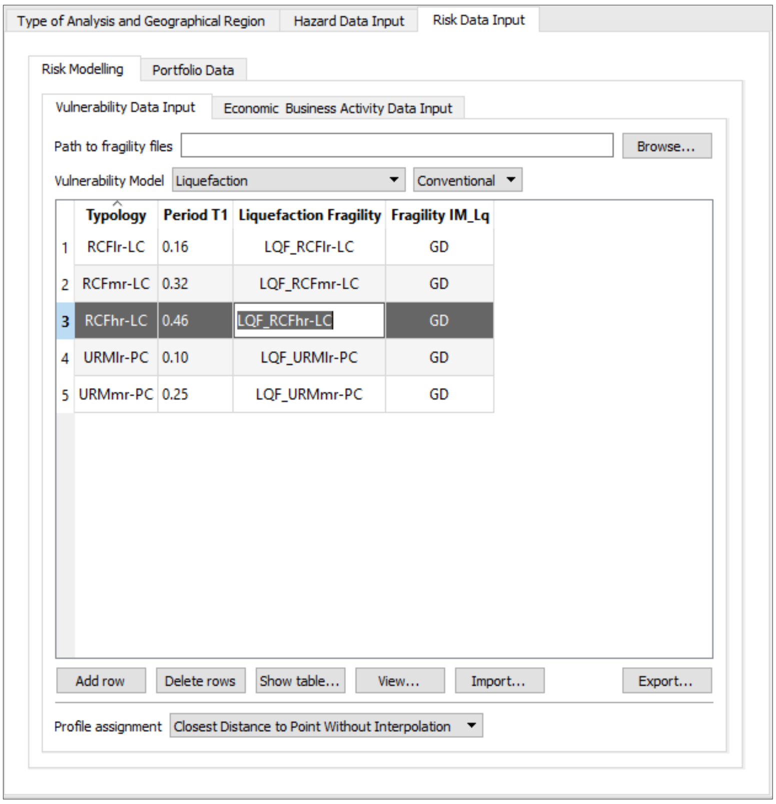
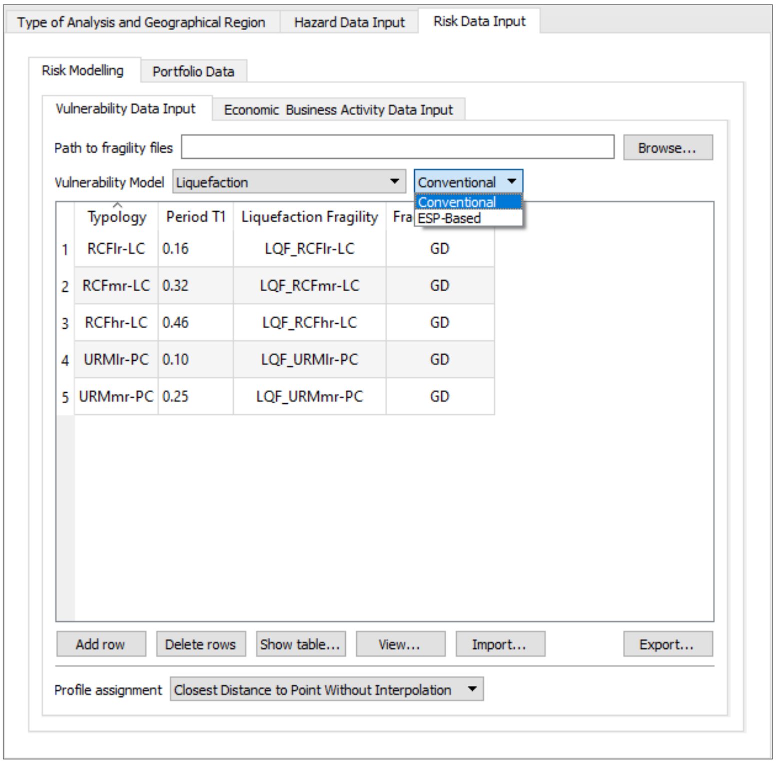


2. Select which method of *Loss Analysis* to be implemented: LIQUEFACT software incorporates two procedures for the computation of physical damage and loss ratio for a given liquefaction demand: *Conventional* procedure or *ESP-based* (Equivalent Soil Profile based) method.



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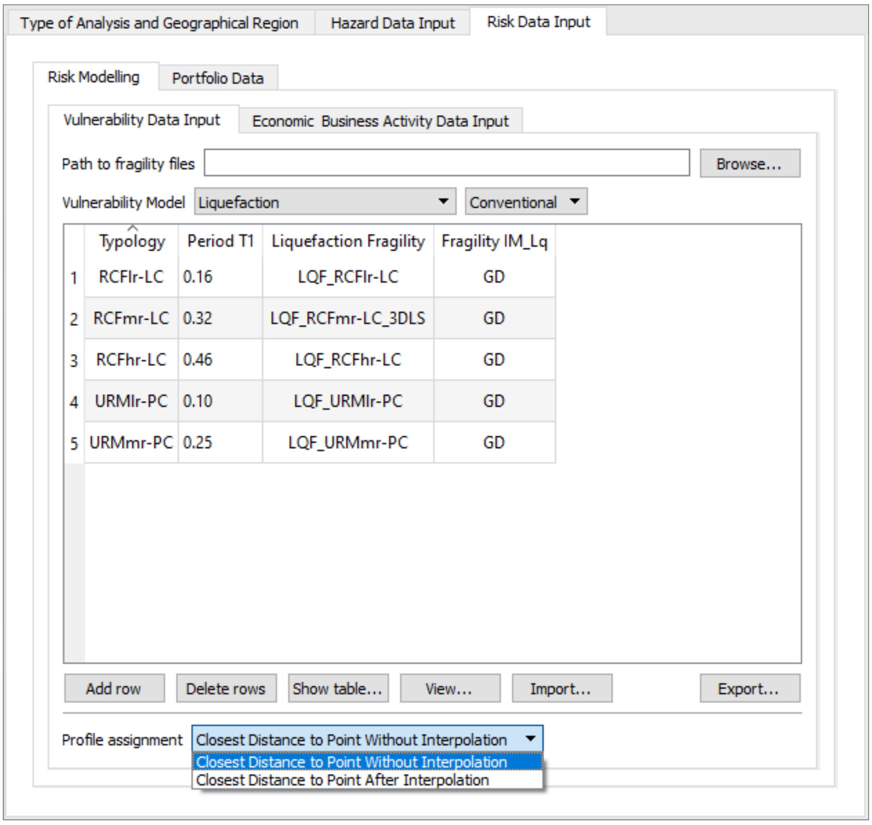
3. At the section *Profile assignment*, users can define how liquefaction severity indicators resulted from liquefaction profiles will be assigned to the assets (buildings, infrastructures) for the computation of liquefaction demand, the associated damage and loss ratio. Users will have to choose one of the following options:

   Closest Distance to Point Without Interpolation: the assigned value of liquefaction severity indicator is directly resulted from the closest liquefaction profile at the location of a given asset or the closed to it.

   Closest Distance to Point After Interpolation: the assigned value of liquefaction severity indicator is directly resulted from interpolation, at the location of a given asset.



2.3.1.1.2 Ground Shaking and Liquefaction Vulnerability Model

By selecting this option, the software will implement loss analysis as following: 1) computation of damage and loss ratio considering liquefaction hazard (in combination with ground shaking); 2) computation of damage and loss ratio considering ground shaking hazard only. Having results from these different analyses will allow the comparison and an extra cross-checking of the results.

For the implementation of *Ground Shaking and Liquefaction* vulnerability analysis, user-supplied *List of Liquefaction Fragility* models should be imported as following:

1. Click the *Import* button to import the file with list of the fragility models. The file can be imported as tab-separated CSV or unformatted TXT, containing the following information:

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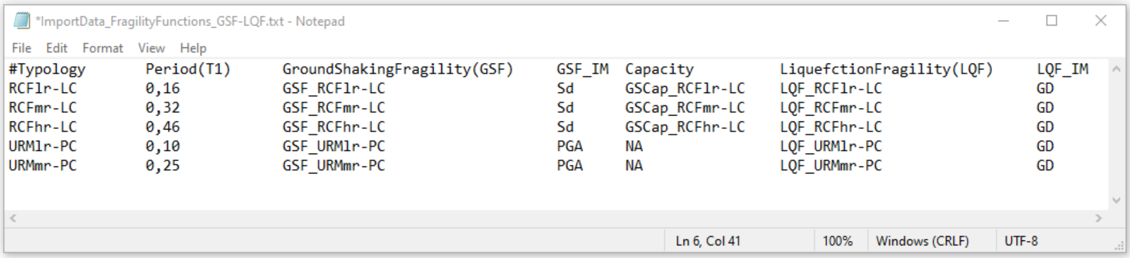
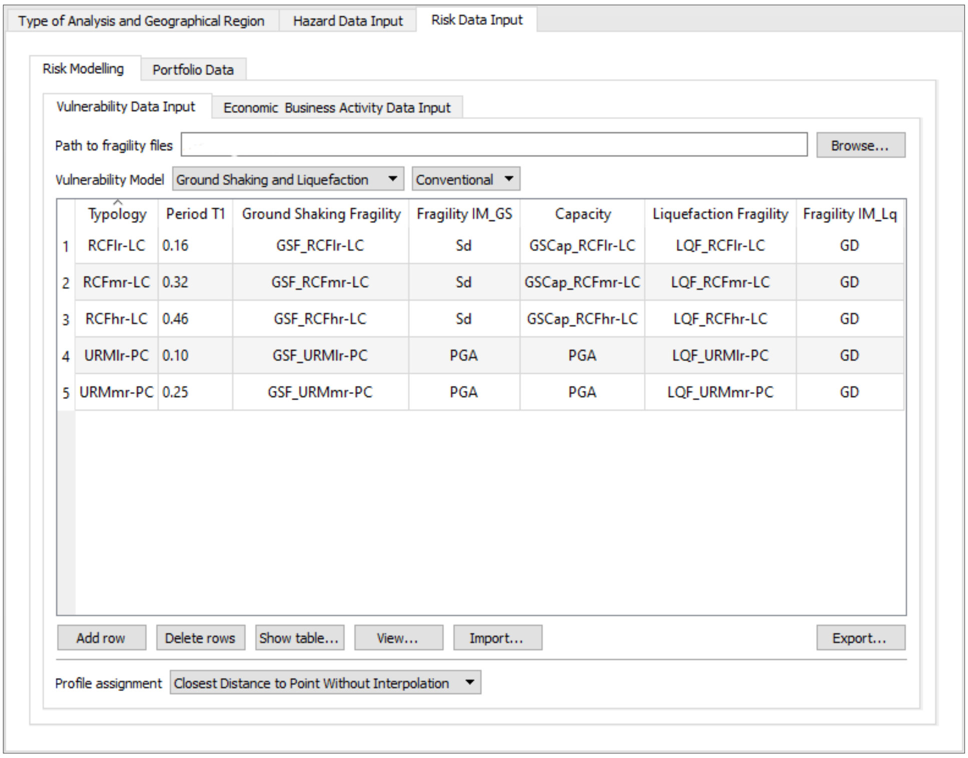
- *Typology*: code-name of a given material and structural system typology of the structure or infrastructure;
- *Period(T1)*: fundamental periods of the structures/infrastructures [in sec];
- *GroundShakingFragility*: file names of ground shaking fragility models
- *GSF_IM*: intensity measure of the ground shaking models (it can be PGA, Sa, LSN, Differential Settlement -GD).
- *Capacity*: file names of capacity curves [in meter] and is required to be defined only if ground shaking fragility curves are based on Spectral Displacement (Sd) intensity measure. If not than just write NA.
- *LiquefactionFragility*: file names of liquefaction fragility models
- *LQF_IM*: intensity measure of the liquefaction models (it can be PGA, Sa, LSN, Differential Settlement -GD).

Example of imported List of Ground Shaking and Liquefaction Fragility models:



#Typology	Period(T1)	GroundShakingFragility(GSF)	GSF_IM	Capacity	LiquefctionFragility(LQF)	LQF_IM
RCF1r-LC	0,16	GSF_RCF1r-LC	Sd	GSCap_RCF1r-LC	LQF_RCF1r-LC	GD
RCFmr-LC	0,32	GSF_RCFmr-LC	Sd	GSCap_RCFmr-LC	LQF_RCFmr-LC	GD
RCFhr-LC	0,46	GSF_RCFhr-LC	Sd	GSCap_RCFhr-LC	LQF_RCFhr-LC	GD
URM1r-PC	0,10	GSF_URM1r-PC	PGA	NA	LQF_URM1r-PC	GD
URMmr-PC	0,25	GSF_URMmr-PC	PGA	NA	LQF_URMmr-PC	GD



The imported list of Ground Shaking Liquefaction fragility models can be modified or updated by double click on any selected row representing a given liquefaction fragility model. It is also

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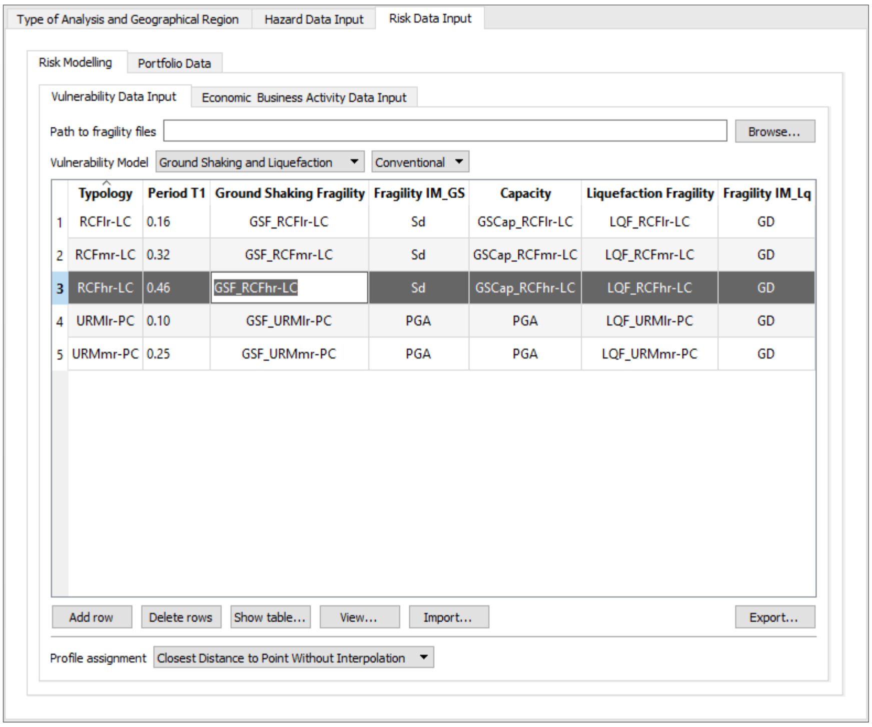
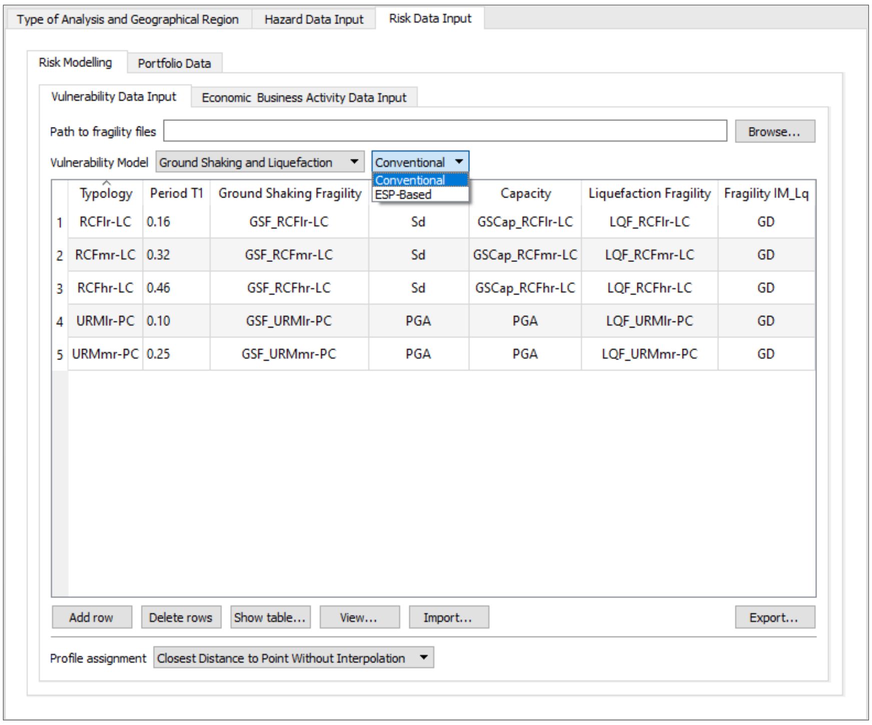
possible to Add or Delete any row/model. After any editing, the list of fragility models file can be exported and saved as tab-separated CSV by clicking on *Export* button.



2. Select which method of *Loss Analysis* to be implemented: LIQUEFACT software incorporates two procedures for the computation of physical damage and loss ratio for a given liquefaction demand: *Conventional* procedure or *ESP-based* (Equivalent Soil Profile based) method.



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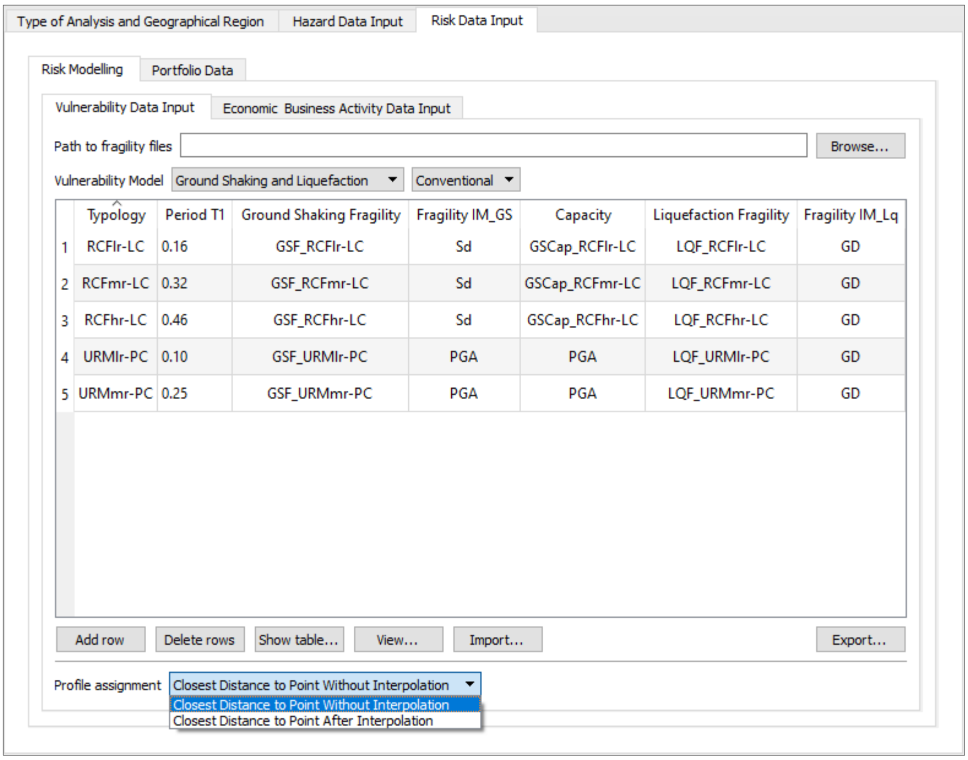
3. At the section *Profile assignment*, users can define how seismic load indicator (PGA, Sa, Sd) resulted from ground amplification profiles and liquefaction severity indicators (PGA, Sa, LSN, GD) resulted from liquefaction profiles will be assigned to the assets (buildings, infrastructures) for the computation of seismic demand and liquefaction demand, the associated damage and loss ratio. Users will have to choose one of the following options:

   Closest Distance to Point Without Interpolation: the assigned value of seismic load indicator and liquefaction severity indicator are directly resulted from the closest ground amplification profile and liquefaction profile at the location of a given asset or the closed to it.

   Closest Distance to Point After Interpolation: the assigned value of seismic load indicator and liquefaction severity indicator are directly resulted from interpolation, at the location of a given asset.



2.3.1.1.3 Fragility Models

In the LIQUEFACT software, Liquefaction and Ground Shaking Fragility models are assumed to take the form of a lognormal cumulative distribution function having a median value and logarithmic standard deviation, or dispersion.

$$P[ds|IM] = \Phi \cdot \left[\frac{1}{\beta_{ds}} \cdot ln\left(\frac{IM}{\overline{IM}_{ds}}\right)\right]$$

$\overline{IM}_{ds}$, is the median value of intensity measure at which the building reaches the threshold of damage state ds; β_{ds}, is the standard deviation of the natural logarithm of intensity measure for damage state ds; $\Phi()$ is the standard normal cumulative distribution function.

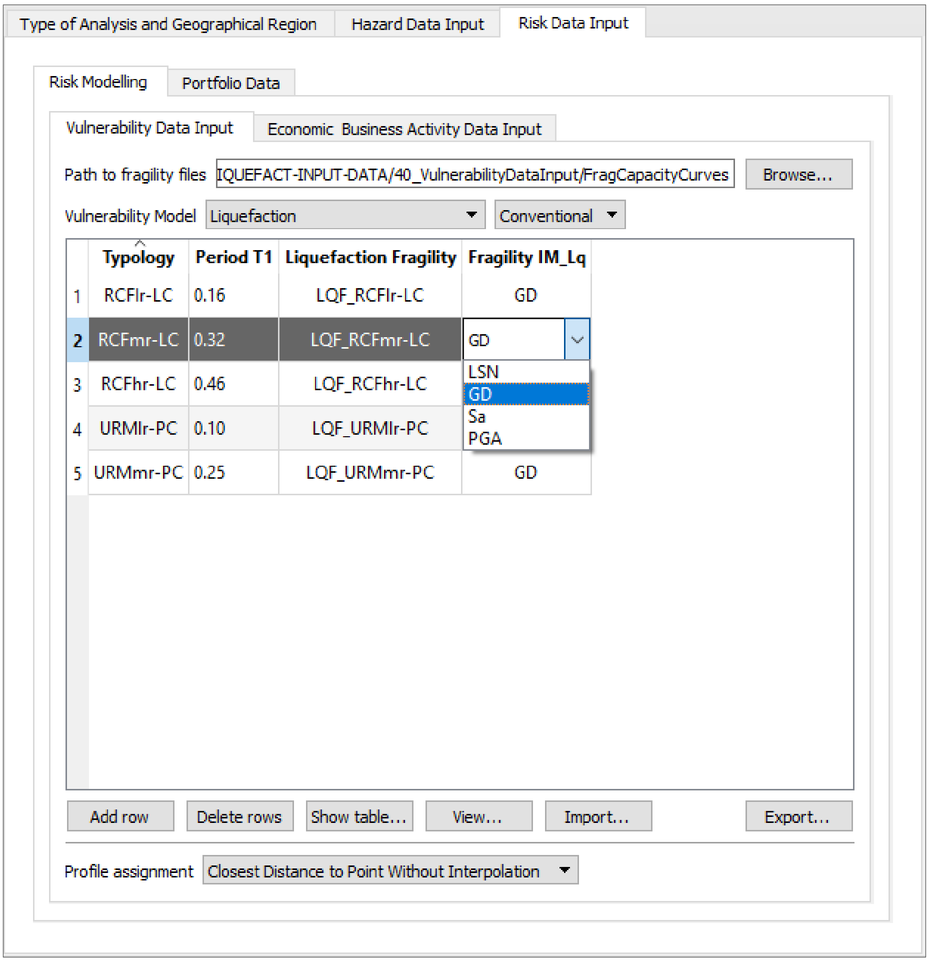
2.3.1.1.3.1 Intensity Measures for Fragility Models

LIQUEFACT software provides options in terms of intensity measures that can be used for user-supplied liquefaction and ground shaking fragility models.

2.3.1.1.3.1.1 Intensity Measures for Liquefaction Fragility Models

For Liquefaction Fragility Model, the following intensity measures can be used as engineering demand parameters for both, *Conventional* and *ESP-based* damage and loss analysis:

- Spectral Acceleration (Sa), where *Median* values must be provided in [g] unit.
- Peak Ground Acceleration (PGA), where *Median* values must be provided in [g] unit.
- Ground Deformation - Settlement (GD), where *Median* values must be provided in [g] unit.
- Liquefaction Severity Number (LSN).

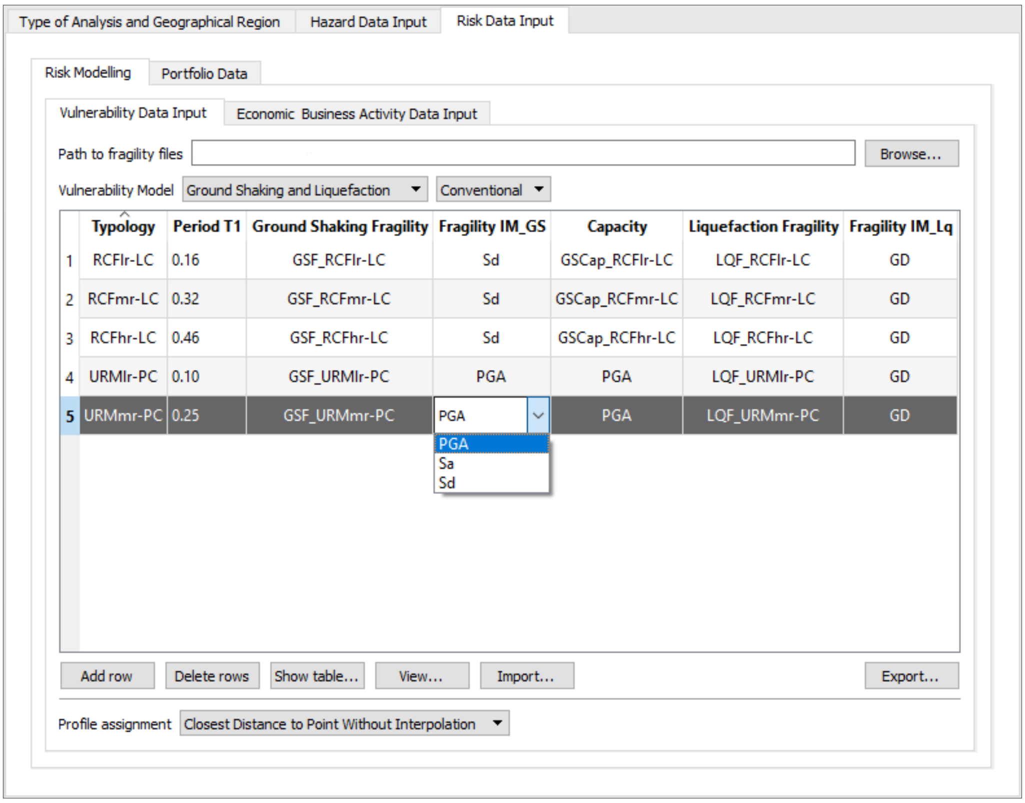


2.3.1.1.3.1.2 Intensity Measures for Ground Shaking Fragility Models

For Ground Shaking Fragility Model, the following intensity measures can be used as engineering demand parameters for damage and loss analysis:

- Peak Ground Acceleration (PGA), where *Median* values must be provided in [g] unit.

- Spectral Acceleration (Sa), where *Median* values must be provided in [g] unit.
- Spectral Displacement (Sd), where *Median* values must be provided in meter unit [m].



2.3.1.1.3.2 Liquefaction Fragility Models

The type and format of user-supplied liquefaction models to be imported depend on the type of loss analysis procedure users wish to implement: *Conventional* procedure or *Equivalent Soil Profile (ESP)* based procedure.

2.3.1.1.3.2.1 Liquefaction Fragility Models for ESP-based method

In the Equivalent Soil Profile (ESP)-based procedure, a given typology (building or infrastructure) is represented by 22 ESP classes that are developed based on the thickness level of liquefiable layer, the depth to the liquefiable layer, the level of strength of the liquefiable layer.

Concept of the 22 classes of Equivalent Soil Profile (ESP)

ESP classes	Soil Resistance	Thickness of Liquefiable Layer	Thickness of Crust Layer
WLS	Weak	Large	Shallow
WLM	Weak	Large	Mid
WLD	Weak	Large	Deep
WMS	Weak	Midsize	Shallow
WMM	Weak	Midsize	Mid
WMD	Weak	Midsize	Deep
WTS	Weak	Thin	Shallow
WTM	Weak	Thin	Mid
WTD	Weak	Thin	Deep

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MLS	Midium	Large	Shallow
MLM	Midium	Large	Mid
MLD	Midium	Large	Deep
MMS	Midium	Midsize	Shallow
MMM	Midium	Midsize	Mid
MMD	Midium	Midsize	Deep
MTS	Midium	Thin	Shallow
MTM	Midium	Thin	Mid
MTD	Midium	Thin	Deep
SLX	Strong	Large	
SMX	Strong	Midsize	
STX	Strong	Thin	
RXX	Resist		

ESP-based Liquefaction Fragility model for a given typology is a combination of fragility functions representing: *Intersotrey Drift of the Superstructure*, *Residual*, *Collapse*, *Foundation Titling*. The ESP-based liquefaction fragility functions must be created as separate files in format of tab-separated CSV.

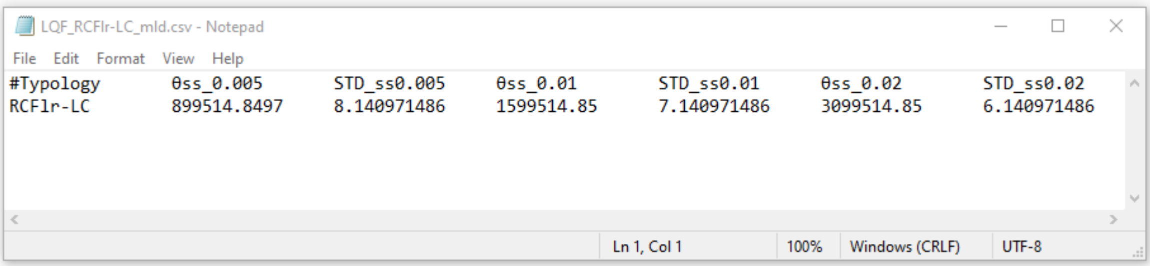
1. ***IntersotryDrift*** Liquefaction Fragility:

To be defined for 22 ESP classes, and containing the followings:

- Code-name (Typology) as defined in the List of Liquefaction Fragility files.
- Median value of intensity measure at which the typology reaches a given threshold of damage state. The median value can be in terms of *PGA* in g unit, *Sa* in g unit, *Differential Settlement (GD)* in meter unit, or in LSN.
- Standard Deviation of the natural logarithm of intensity measure for a given damage state.

Regarding the definition of damage thresholds, the software considers three *Damage Limit States* for the superstructure Interstory Drift liquefaction fragility. The following definition is recommended: *Structural DS1* for limit of 0.005% ($\theta_{ss,0.005}$), *Structural DS2* for limit of 0.01% ($\theta_{ss,0.01}$), and *Structural DS3* for limit of 0.02% ($\theta_{ss,0.02}$).

Example of user-supplied *IntersotryDrift Liquefaction Fragility functions* for ***MLD*** *class* (one of the 22 classes) in terms of *Spectral Acceleration Sa.* Each damage limit state is represented by a *Median* value (in g unit) and *Standard Deviation* value. (MUST be imported as tab-separated CSV file).



#Typology	θss_0.005	STD_ss0.005	θss_0.01	STD_ss0.01	θss_0.02	STD_ss0.02
RCF1r-LC	899514.8497	8.140971486	1599514.85	7.140971486	3099514.85	6.140971486

2. ***Residual*** Liquefaction Fragility:

To be defined for 22 ESP classes, and containing the followings:

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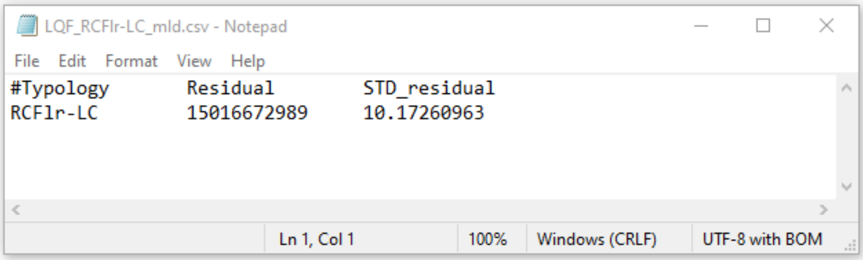
- Code-name (Typology) as defined in the List of Liquefaction Fragility files.
- Median value of intensity measure at which the typology reaches a given threshold of damage state. The median value can be in terms of *PGA* in g unit, *Sa* in g unit, *Differential Settlement (GD)* in meter unit, or in LSN.
- Standard Deviation of the natural logarithm of intensity measure for a given damage state.

Regarding the definition of damage thresholds, the software considers one *Damage Limit State*: *Residual Interstory Drift*, which represents large residual interstory drift that exceeded the repairable limit of 0.005% (Sullivan et al. 2012).

Example of user-supplied *Residual Liquefaction Fragility functions* for ***MLD*** *class* (one of the 22 classes) in terms of *Spectral Acceleration Sa.* The damage limit state is represented by a *Median* value (in g unit) and *Standard Deviation* value. (MUST be imported as tab-separated CSV file).




```
#Typology	Residual	STD_residual
RCFlr-LC	15016672989	10.17260963
```

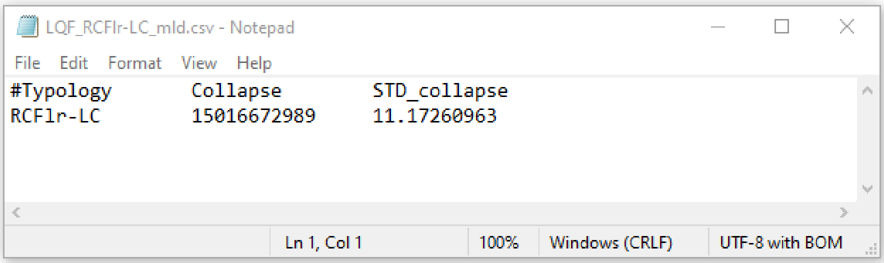
3. ***Collapse*** Liquefaction Fragility:

To be defined for 22 ESP classes, and containing the followings:

- Code-name (Typology) as defined in the List of Liquefaction Fragility files.
- Median value of intensity measure at which the typology reaches a given threshold of damage state. The median value can be in terms of *PGA* in g unit, *Sa* in g unit, *Differential Settlement (GD)* in meter unit, or in LSN.
- Standard Deviation of the natural logarithm of intensity measure for a given damage state.

Regarding the definition of damage thresholds, the software considers one *Damage Limit State* which is *Collapse*.

Example of user-supplied *Collapse Liquefaction Fragility functions* for ***MLD*** *class* (one of the 22 classes) in terms of *Spectral Acceleration Sa.* The damage limit state is represented by a *Median* value (in g unit) and *Standard Deviation* value. (MUST be imported as tab-separated CSV file).




```
#Typology	Collapse	STD_collapse
RCFlr-LC	15016672989	11.17260963
```

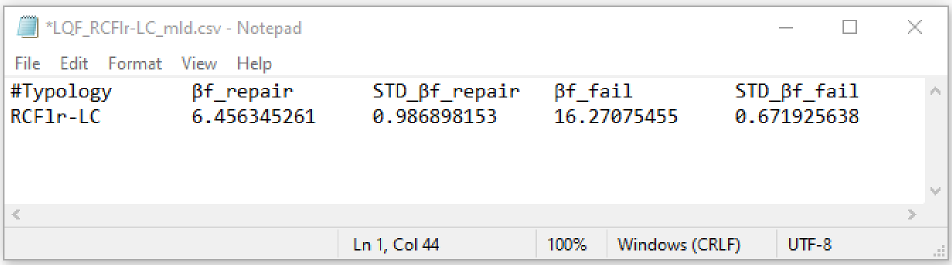
4. ***Foundation Titling*** Liquefaction Fragility:

To be defined for 22 ESP classes, and containing the followings:

- Code-name (Typology) as defined in the List of Liquefaction Fragility files.
- Median value of intensity measure at which the typology reaches a given threshold of damage state. The median value can be in terms of *PGA* in g unit, *Sa* in g unit, *Differential Settlement (GD)* in meter unit, or in LSN.
- Standard Deviation of the natural logarithm of intensity measure for a given damage state.

Regarding the definition of damage thresholds, the software considers two *Damage Limit States* for the foundation performance response under liquefaction hazard. The following definition is recommended: *Limit for repair of foundation*, and *Limit for failure of foundation*.

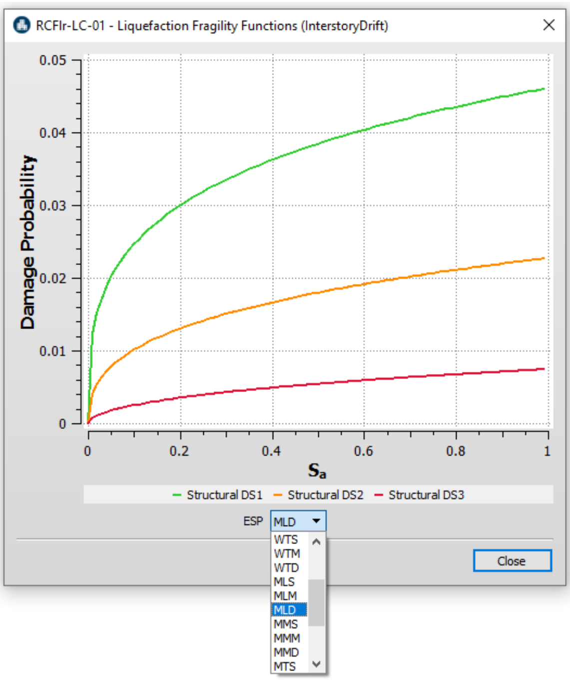
Example of user-supplied *Foundation Titling Liquefaction Fragility functions* for ***MLD*** *class* (one of the 22 classes) in terms of *Spectral Acceleration Sa.* Each damage limit state is represented by a *Median* value (in g unit) and *Standard Deviation* value. (MUST be imported as tab-separated CSV file).

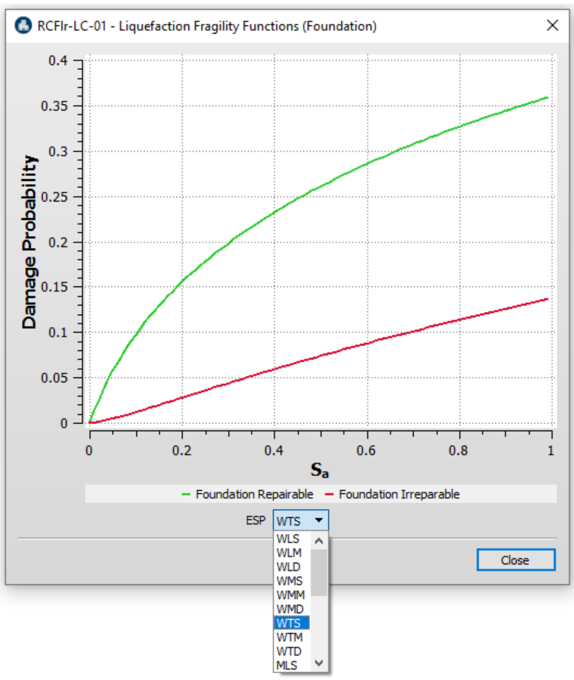

*LQF_RCFlr-LC_mld.csv - Notepad
File Edit Format View Help

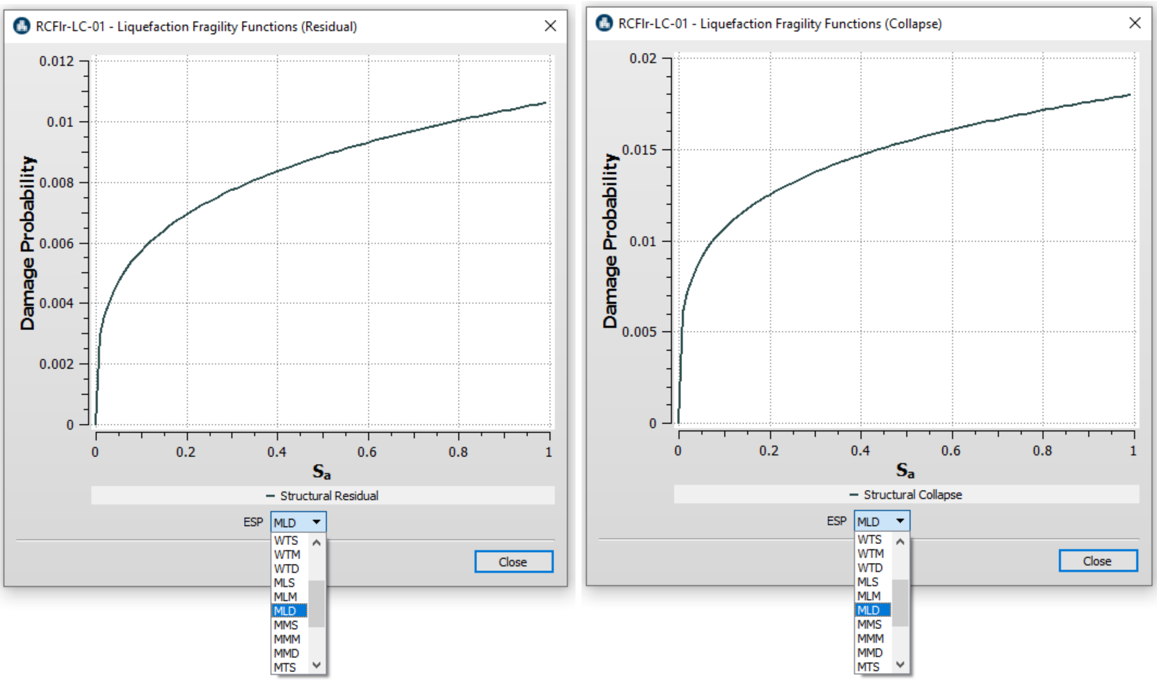
#Typology	βf_repair	STD_βf_repair	βf_fail	STD_βf_fail
RCF1r-LC	6.456345261	0.986898153	16.27075455	0.671925638

Ln 1, Col 44 | 100% | Windows (CRLF) | UTF-8

Below are examples of *InterstoreyDrift* liquefaction fragility curves, *Foundation Titling* liquefaction fragility curves, *Residual* liquefaction fragility curves, and Collapse liquefaction fragility curves, espectively, generated for the 22 ESP classes.







2.3.1.1.3.2.2 *Liquefaction Fragility Models for Conventional method*

In the conventional procedure, a given typology (building or infrastructure) is represented by a single liquefaction fragility model which is developed as result of a combined structural system- soil profile.

Liquefaction fragility models for each typology must be created as separate files, in format of tab-separated CSV file containing:

- Code-name (Typology) as defined in the List of Liquefaction Fragility files.
- Median value of intensity measure at which the typology reaches a given threshold of damage state. The median value can be in terms of *PGA* in g unit, *Sa* in g unit, *Differential Settlement (GD)* in meter unit, or in LSN.
- Standard Deviation of the natural logarithm of intensity measure for a given damage state.

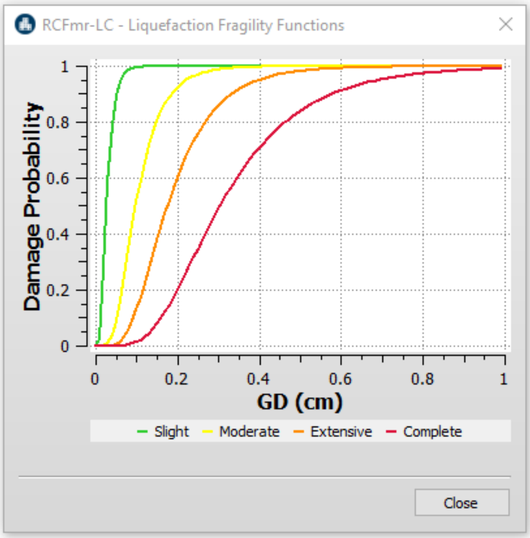
Regarding the definition of damage thresholds, options are providing regarding the *Number of Damage Limit States* that can be used in for user-supplied *Liquefaction Fragility* models. The software incorporates the following definitions for the fragility models:

- *Four Damage Limit States*: *Slight Damage*, *Moderate Damage*, *Extensive Damage* and *Complete Damage*
- *Three Damage Limit States*: *Damage Limitation*, *Significant Damage*, and *Near Collapse.*
- *Two Damage Limit States*: *Minor Damage*, and *Complete Damage*
- *One Damage Limit State*: *Collapse*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

Example user-supplied Liquefaction Fragility model (MUST be imported as tab-separated CSV file) in terms of *Differential Settlement (GD)* and four damage limit states: *Slight Damage*, *Moderate Damage*, *Extensive Damage* and *Complete Damage*. Each damage limit state is represented by a *Median* value (here are in meter unit) and *Standard Deviation* value.

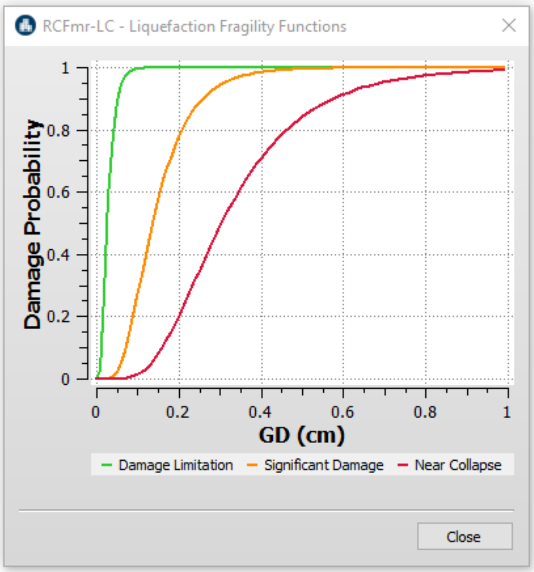
```
*LQF_RCFmr-LC.csv - Notepad
File  Edit  Format  View  Help
# Liquefaction Fragility Functions
# Reference:                    Fotopoulou et al (2018). Vulnerability assessment of low-code reinforced concrete
# Typology:                     Reinforced concrete frames system. Mid-rise. Low-code
# Intensity Measure:            Differential Settlement (m)
# Number of Damage Limit States:4
#
#
#Typology       SlightDamage    STD_SD  ModerateDamage  STD_MD  ExtensiveDamage STD_ED  CompleteDamage  STD_CD
RCFmr-LC        0.027           0.5     0.098           0.5     0.176           0.5     0.305           0.5
Ln 9, Col 50    100%    Windows (CRLF)    ANSI
```



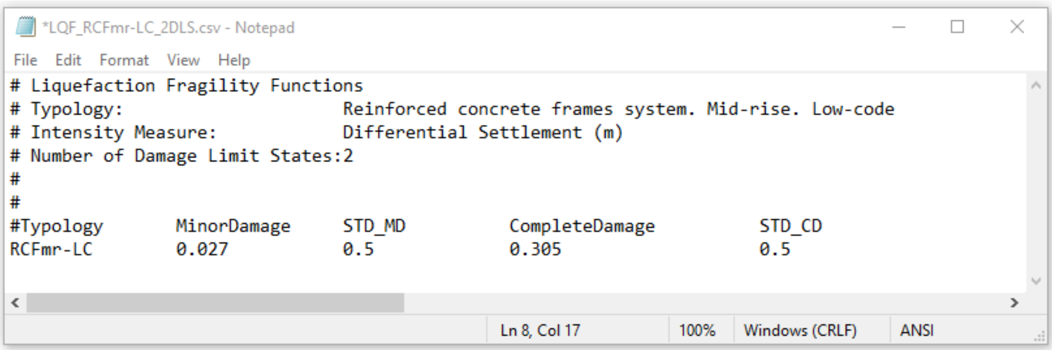
Example user-supplied Liquefaction Fragility model (MUST be imported as tab-separated CSV file) in terms of *Differential Settlement (GD)* and three damage limit states: *Damage Limitation*, *Significant Damage*, and *Near Collapse*. Each damage limit state is represented by a *Median* value (here are in meter unit) and *Standard Deviation* value.

```
*LQF_RCFmr-LC_3DLS.csv - Notepad
File  Edit  Format  View  Help
# Liquefaction Fragility Functions
# Typology:                     Reinforced concrete frames system. Mid-rise. Low-code
# Intensity Measure:            Differential Settlement (m)
# Number of Damage Limit States:3
#
#
#Typology       DamageLimitation        STD_DL          SignificantDamage       STD_SD          NearCollapse    STD_NC
RCFmr-LC        0.027                   0.5             0.137                   0.5             0.305           0.5
Ln 8, Col 36    100%    Windows (CRLF)    ANSI
```

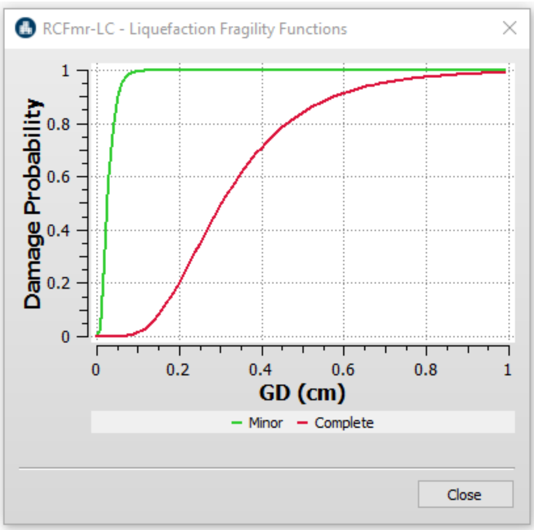
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748



Example user-supplied Liquefaction Fragility model (MUST be imported as tab-separated CSV file) in terms of *Differential Settlement (GD)* and two damage limit states: *Minor Damage*, and *Complete Damage*. Each damage limit state is represented by a *Median* value (here are in meter unit) and *Standard Deviation* value.

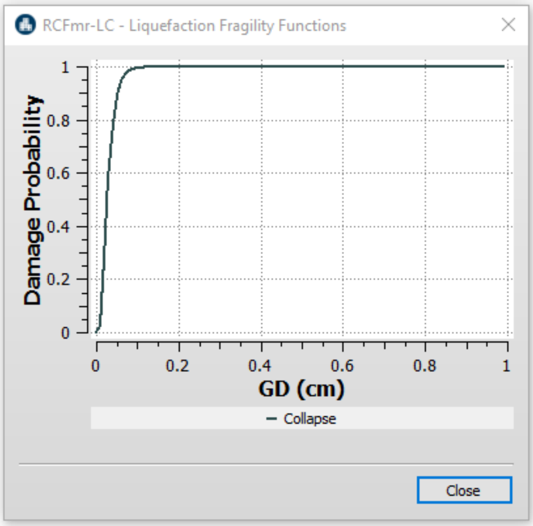


```
# Liquefaction Fragility Functions
# Typology:               Reinforced concrete frames system. Mid-rise. Low-code
# Intensity Measure:      Differential Settlement (m)
# Number of Damage Limit States:2
#
#
#Typology    MinorDamage    STD_MD    CompleteDamage    STD_CD
RCFmr-LC     0.027          0.5       0.305             0.5
```

Example user-supplied Liquefaction Fragility model (MUST be imported as tab-separated CSV file) in terms of *Differential Settlement (GD)* and one damage limit state: *Collapse*. The damage limit state is represented by a *Median* value (here are in meter unit) and *Standard Deviation* value.

```
*LQF_RCFmr-LC_1DLS.csv - Notepad
# Liquefaction Fragility Functions
# Typology:                Reinforced concrete frames system. Mid-rise. Low-code
# Intensity Measure:       Differential Settlement (m)
# Number of Damage Limit States:1
#
#
#Typology        CollapseDamage   STD_CD
RCFmr-LC         0.027            0.5
```



2.3.1.1.3.3 Ground Shaking Fragility Models

For ground shaking, a given typology (building or infrastructure) is represented by a single fragility model which is developed as result of structural performance analysis under ground shaking intensities.

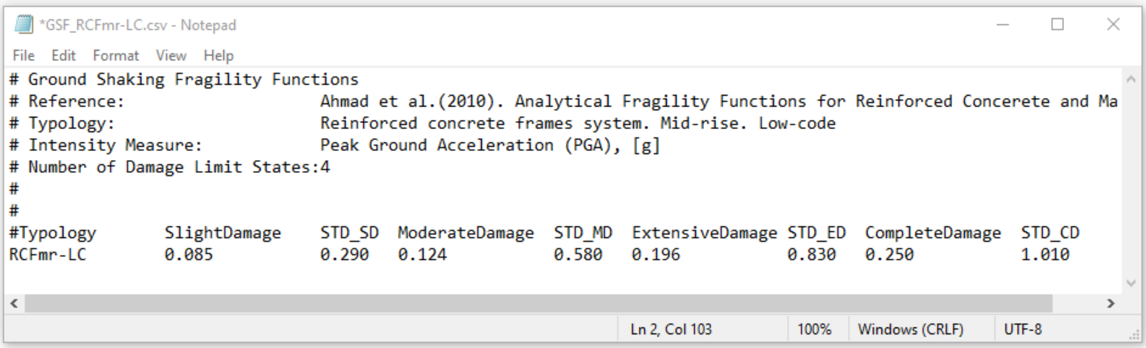
Ground Shaking fragility models for each typology must be created as separate files, in format of tab-separated CSV file containing:

- Code-name (Typology) as defined in the List of Ground Shaking Fragility files.
- Median value of intensity measure at which the typology reaches a given threshold of damage state. The median value can be in terms of *PGA* in g unit, *Sa* in g unit, or *Sd* in meter unit.
- Standard Deviation of the natural logarithm of intensity measure for a given damage state.

Regarding the definition of damage thresholds, options are providing regarding the *Number of Damage Limit States* that can be used in for user-supplied *Ground Shaking Fragility* models. The software incorporates the following definitions for the fragility models:

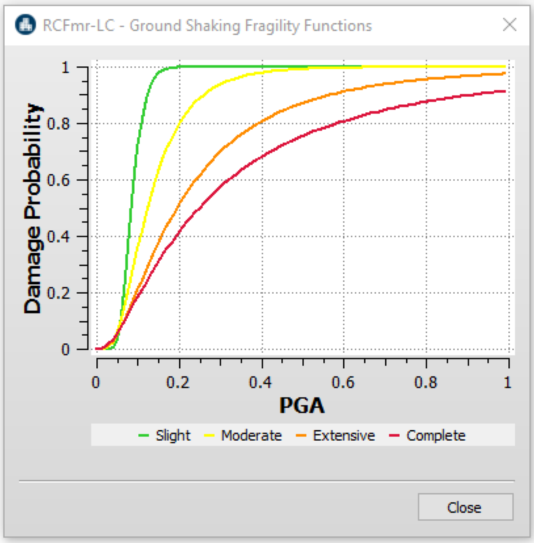
- *Four Damage Limit States*: *Slight Damage*, *Moderate Damage*, *Extensive Damage* and *Complete Damage*
- *Three Damage Limit States*: *Damage Limitation*, *Significant Damage*, and *Near Collapse.*
- *Two Damage Limit States*: *Minor Damage*, and *Complete Damage*
- *One Damage Limit State*: *Collapse*

Example user-supplied Ground Shaking Fragility model (MUST be imported as tab-separated CSV file) in terms of *Peak Ground Acceleration (PGA)* and four damage limit states: *Slight Damage*, *Moderate Damage*, *Extensive Damage* and *Complete Damage*. Each damage limit state is represented by a *Median* value (here are in g unit) and *Standard Deviation* value.

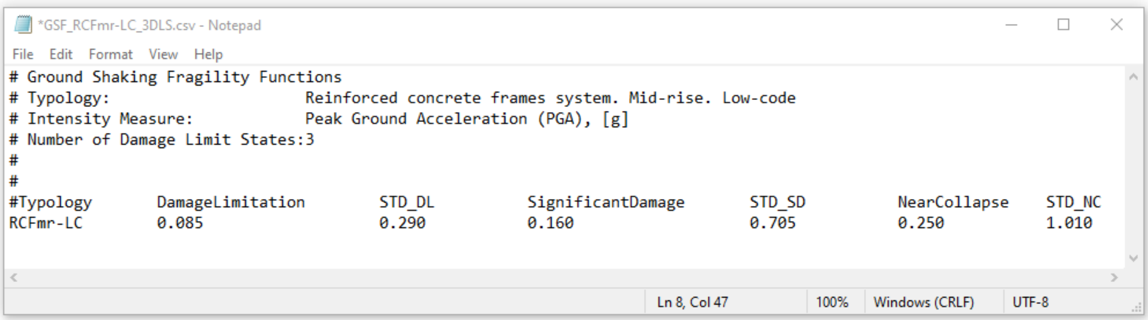

*GSF_RCFmr-LC.csv - Notepad
File Edit Format View Help

```
# Ground Shaking Fragility Functions
# Reference:                    Ahmad et al.(2010). Analytical Fragility Functions for Reinforced Concerete and Ma
# Typology:                     Reinforced concrete frames system. Mid-rise. Low-code
# Intensity Measure:            Peak Ground Acceleration (PGA), [g]
# Number of Damage Limit States:4
#
#
#Typology       SlightDamage    STD_SD  ModerateDamage  STD_MD  ExtensiveDamage STD_ED  CompleteDamage  STD_CD
RCFmr-LC        0.085           0.290   0.124           0.580   0.196           0.830   0.250           1.010
```

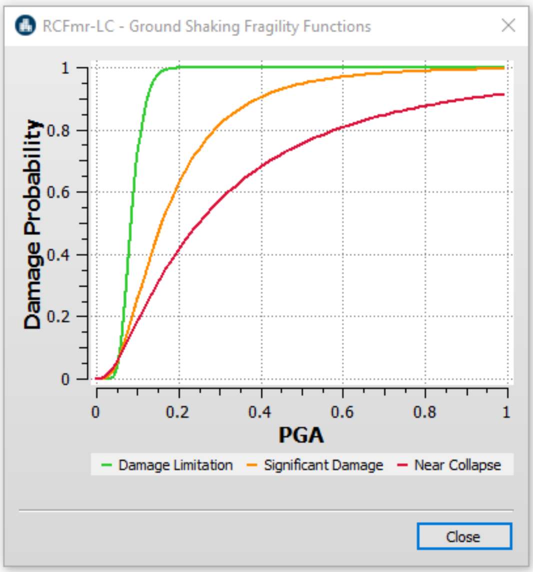
Ln 2, Col 103 100% Windows (CRLF) UTF-8



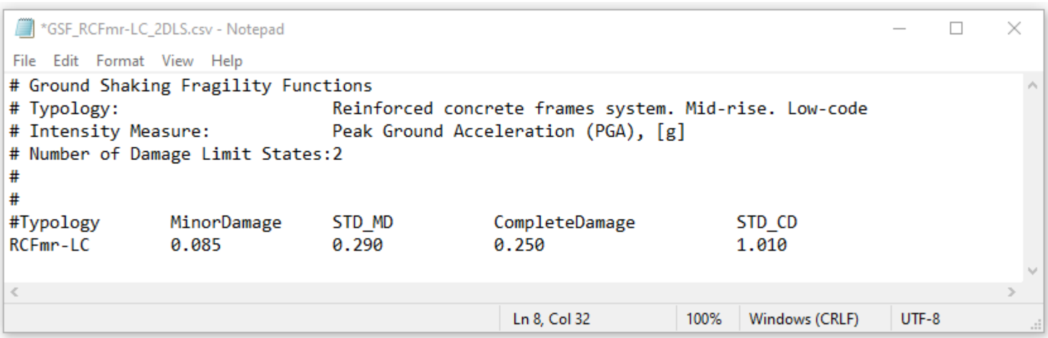
Example user-supplied Ground Shaking Fragility model (MUST be imported as tab-separated CSV file) in terms of *Peak Ground Acceleration (PGA)* and three damage limit states: *Damage Limitation*, *Significant Damage*, and *Near Collapse*. Each damage limit state is represented by a *Median* value (here are in meter unit) and *Standard Deviation* value.



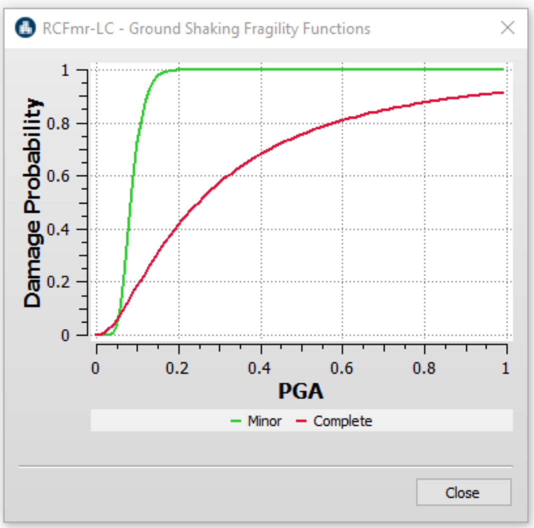
```
*GSF_RCFmr-LC_3DLS.csv - Notepad
File  Edit  Format  View  Help
# Ground Shaking Fragility Functions
# Typology:                 Reinforced concrete frames system. Mid-rise. Low-code
# Intensity Measure:        Peak Ground Acceleration (PGA), [g]
# Number of Damage Limit States:3
#
#
#Typology       DamageLimitation        STD_DL          SignificantDamage       STD_SD          NearCollapse    STD_NC
RCFmr-LC        0.085                   0.290           0.160                   0.705           0.250           1.010
Ln 8, Col 47    100%    Windows (CRLF)    UTF-8
```



Example user-supplied Ground Shaking Fragility model (MUST be imported as tab-separated CSV file) in terms of *Peak Ground Acceleration (PGA)* and two damage limit states: *Minor Damage*, and *Complete Damage*. Each damage limit state is represented by a *Median* value (here are in g unit) and *Standard Deviation* value.

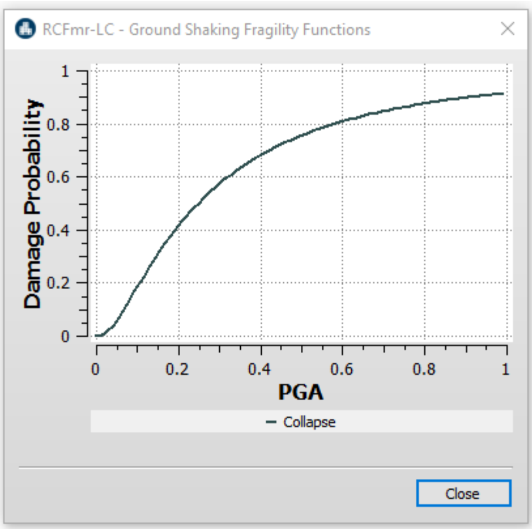


```
*GSF_RCFmr-LC_2DLS.csv - Notepad
File  Edit  Format  View  Help
# Ground Shaking Fragility Functions
# Typology:                 Reinforced concrete frames system. Mid-rise. Low-code
# Intensity Measure:        Peak Ground Acceleration (PGA), [g]
# Number of Damage Limit States:2
#
#
#Typology       MinorDamage     STD_MD          CompleteDamage          STD_CD
RCFmr-LC        0.085           0.290           0.250                   1.010
Ln 8, Col 32    100%    Windows (CRLF)    UTF-8
```



Example user-supplied Ground Shaking Fragility model (MUST be imported as tab-separated CSV file) in terms of *Peak Ground Acceleration (PGA)* and one damage limit state: *Collapse*. The damage limit state is represented by a *Median* value (here are in g unit) and *Standard Deviation* value.

```
*GSF_RCFmr-LC_1DLS.csv - Notepad
File  Edit  Format  View  Help
# Ground Shaking Fragility Functions
# Typology:                       Reinforced concrete frames system. Mid-rise. Low-code
# Intensity Measure:              Peak Ground Acceleration (PGA), [g]
# Number of Damage Limit States:1
#
#
#Typology        CollapseDamage   STD_CD
RCFmr-LC         0.250            1.010
Ln 4, Col 34    100%    Windows (CRLF)    UTF-8
```



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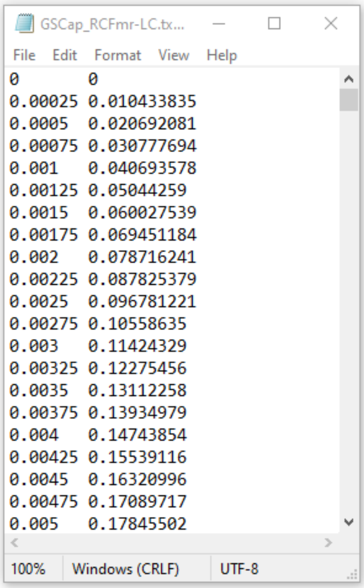
2.3.1.1.3.3.1 Capacity Curves

In case of user-supplied Ground Shaking Fragility models are function of Spectral Displacement (Sd), then users are required to also import *Capacity Curve Model* file associated to each *Ground Shaking Fragility Model* representing a given typology.

Capacity Curve model for each typology must be created and imported as separate unformatted TXT file, containing the following information:

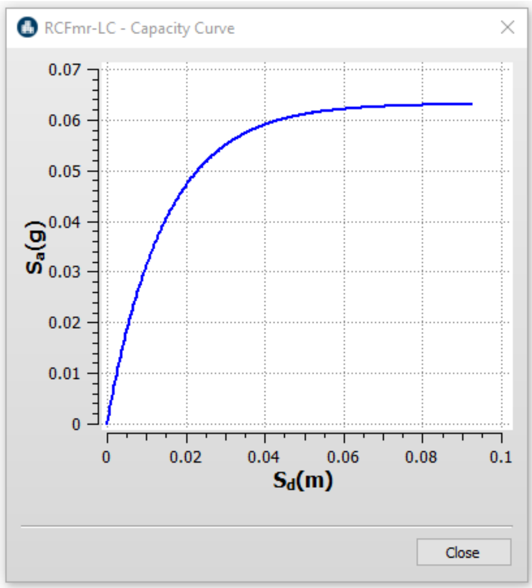
- 1st column represents *Spectral Displacement* S_d *in [m]*;
- 2nd column represents *Spectral Acceleration* S_a *in [g]Period(T1)*.

Example of *Capacity Curve model* to be imported as unformatted TXT file


GSCap_RCFmr-LC.tx...
File Edit Format View Help

```
0       0
0.00025 0.010433835
0.0005  0.020692081
0.00075 0.030777694
0.001   0.040693578
0.00125 0.05044259
0.0015  0.060027539
0.00175 0.069451184
0.002   0.078716241
0.00225 0.087825379
0.0025  0.096781221
0.00275 0.10558635
0.003   0.11424329
0.00325 0.12275456
0.0035  0.13112258
0.00375 0.13934979
0.004   0.14743854
0.00425 0.15539116
0.0045  0.16320996
0.00475 0.17089717
0.005   0.17845502
```

100% Windows (CRLF) UTF-8



2.3.1.1.4 Path to Fragility Models Folders

For user-supplied fragility models, a specific path must be defined to import the models for the computation of damage and loss.

2.3.1.1.4.1 Path to ESP-based Liquefaction Fragility Models Folders

1. Click the *Browse* button to define the path to the ***FragCapacityCurves*** folder where all sub-folders of *Liquefaction Fragility* files must be stored and organized depending on *type of loss analysis* (i.e. ESP-based analysis) and type of *Intensity Measure* of the *Liquefaction Fragility Models*.

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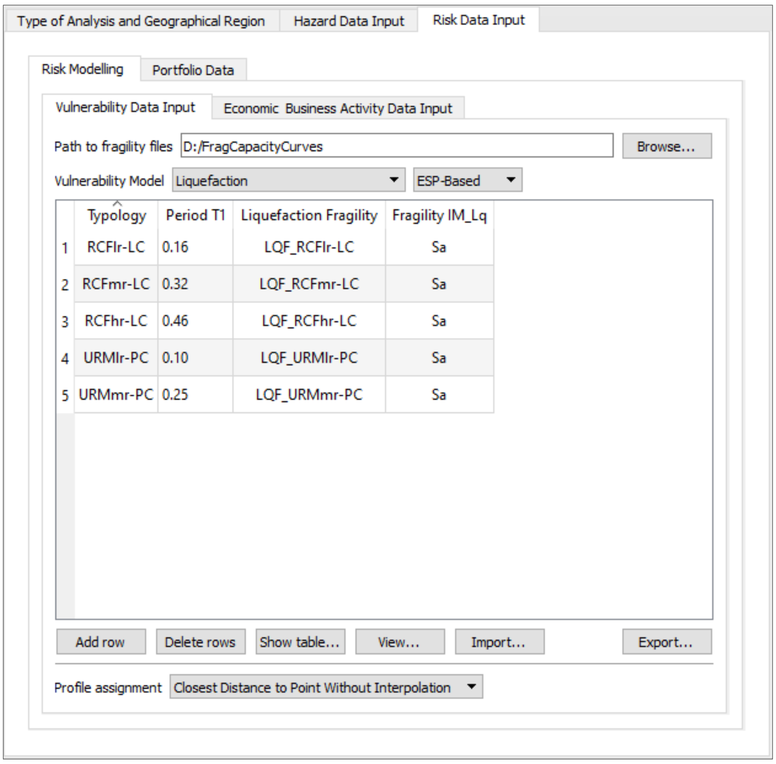

NOTE that the folder name "***FragCapacityCurves***" cannot be changed.

2. The fragility models must be created as separate files in format of tab-separated CSV files. Starting from *FragCapacityCurves* folder and depending on type of intensity measure used (Sa, PGA, GD, or LSN), the software automatically takes the following pre-defined paths to import the ESP-based liquefaction fragility:

   1.1. ESP-based fragility functions in terms of Spectral Acceleration (Sa).

   NOTE: folders with names in *Italic* style must be named as they are.

   2.1.1. *Interstorey Drift* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

   *FragCapacityCurves**Liquefaction**ESP**Sa**InterstoryDrift*\\LQF_RCFlr-LC

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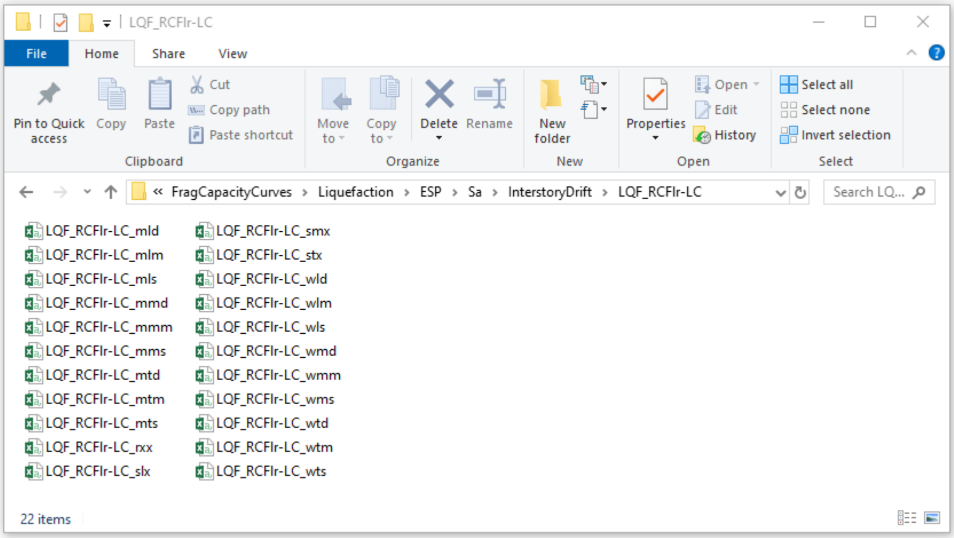
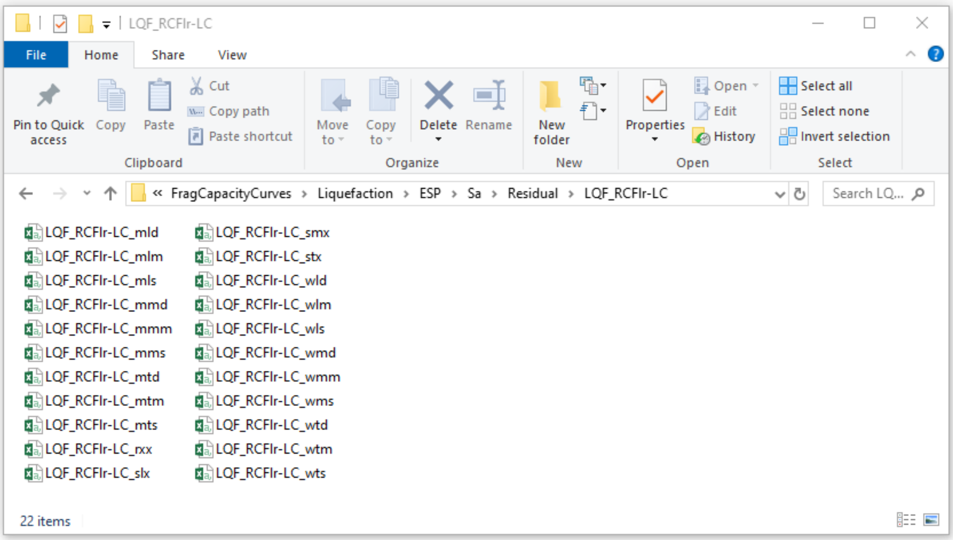


2.1.2. *Residual* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**Sa**Residual*\LQF_RCFlr-LC



2.1.3. *Collapse* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**Sa**Collapse*\LQF_RCFlr-LC

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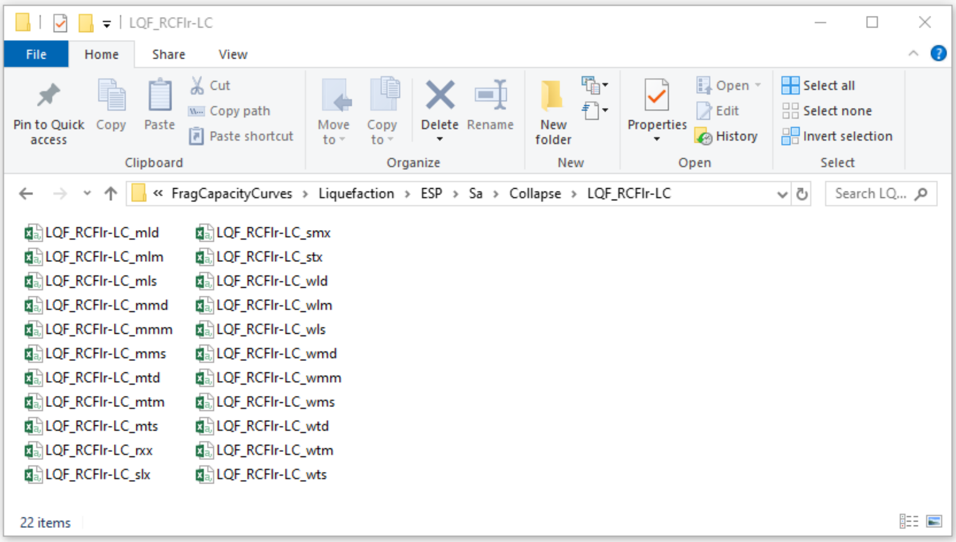
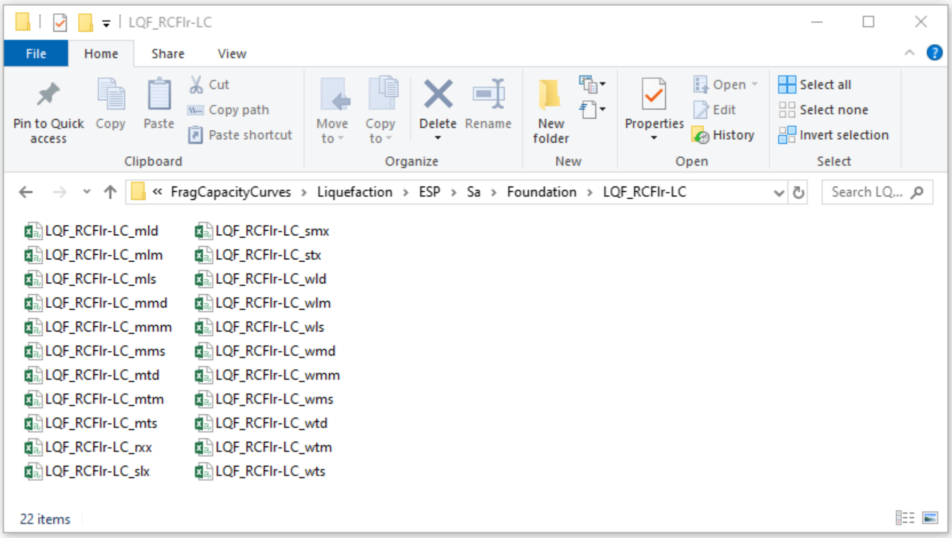


2.1.4. *Foundation Titling* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**Sa**Foundation*\LQF_RCFlr-LC



2.2. ESP-based fragility functions in terms of Peak Ground Acceleration (PGA)

NOTE: folders with names in *Italic* style must be named as they are

2.2.1. *Interstorey Drift* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**PGA**InterstoryDrift*\LQF_RCFlr-LC

2.2.2. *Residual* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**PGA**Residual*\\LQF_RCFlr-LC

2.2.3. *Collapse* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**PGA**Collapse*\\LQF_RCFlr-LC

2.2.4. *Foundation Titling* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**PGA**Foundation*\\LQF_RCFlr-LC

2.3. ESP-based fragility functions in terms of <u>Differential Settlement (GD)</u>

NOTE: folders with names in *Italic* style must be named as they are

2.3.1. *Interstorey Drift* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**GD**InterstoryDrift*\\LQF_RCFlr-LC

2.3.2. *Residual* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**GD**Residual*\\LQF_RCFlr-LC

2.3.3. *Collapse* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**GD**Collapse*\\LQF_RCFlr-LC

2.3.4. *Foundation Titling* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**GD**Foundation*\\LQF_RCFlr-LC

2.4. ESP-based fragility functions in terms of <u>Liquefaction Severity Number (LSN)</u>

NOTE: folders with names in *Italic* style must be named as they are

2.4.1. *Interstorey Drift* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**LSN**InterstoryDrift*\\LQF_RCFlr-LC

2.4.2. *Residual* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**LSN**Residual*\\LQF_RCFlr-LC

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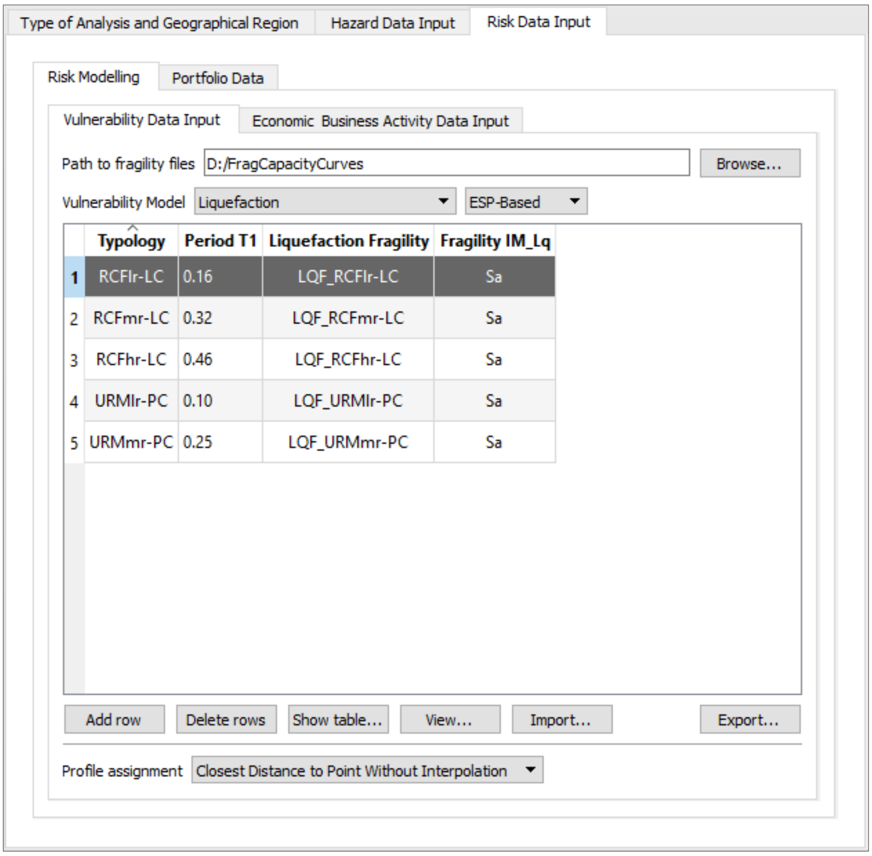
2.4.3. *Collapse* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**LSN**Collapse*\LQF_RCFlr-LC

2.4.4. *Foundation Titling* liquefaction fragility functions for the 22 classes are automatically imported from the following path:

*FragCapacityCurves**Liquefaction**ESP**LSN**Foundation*\LQF_RCFlr-LC



3. Once the ESP-based liquefaction fragility functions are stored in the pre-defined paths as described above, detailed information on each fragility model can be viewed from this table. Manually select the fragility model from the list of the model, click on the *View* button to view the plot of fragility curves, and the *Show* table button to display the table with the fragility curves parameters.

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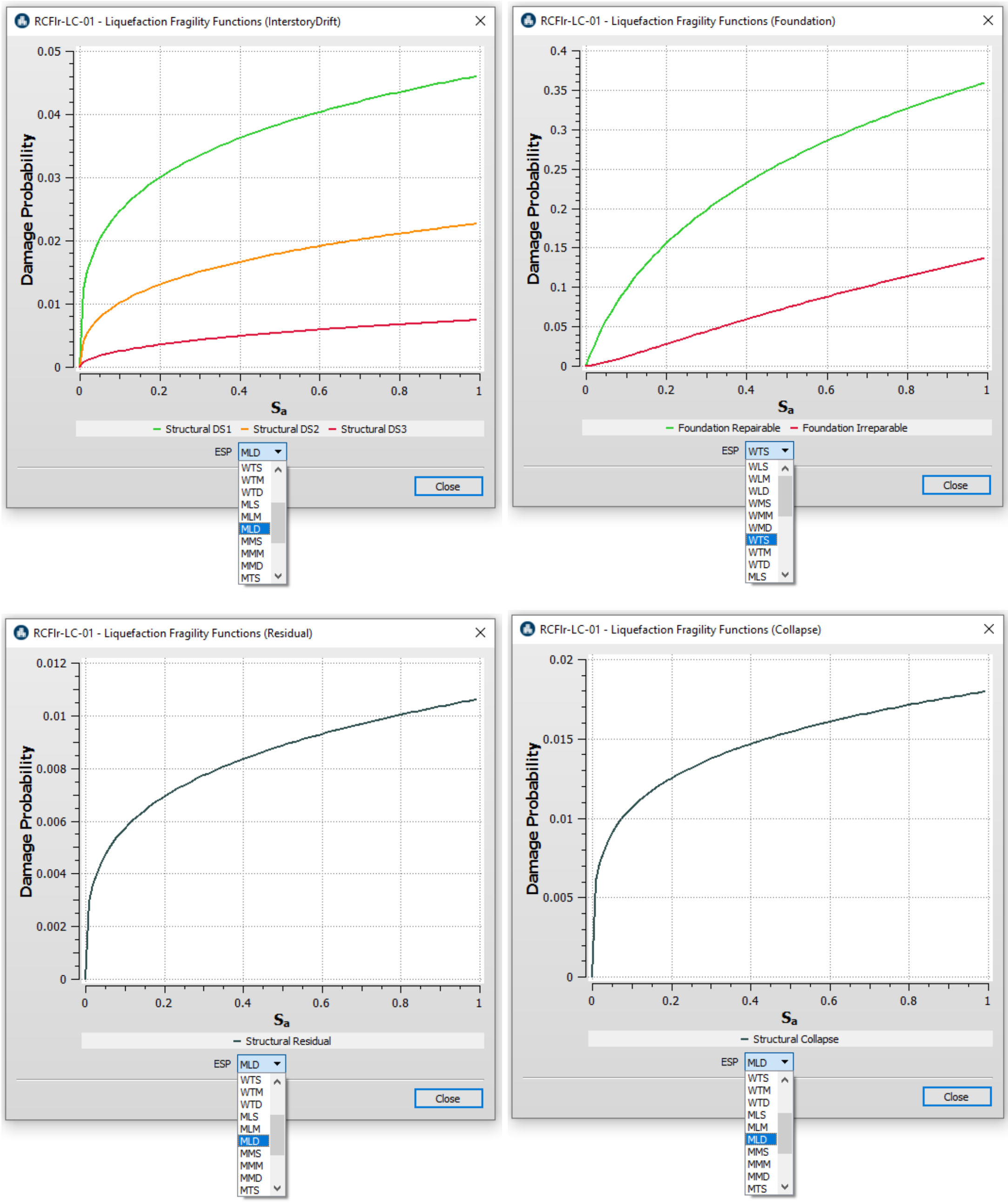
Viewing ESP-based liquefaction fragility models



2.3.1.1.4.2 Path to Conventional-based Liquefaction Fragility Models Folders

1. Click the *Browse* button to define the path to the ***FragCapacityCurves*** folder where all sub-folders of *Liquefaction Fragility* files must be stored and organized depending on *type of loss analysis* (i.e. conventional-based analysis) and type of *Intensity Measure* of the *Liquefaction Fragility Models*.

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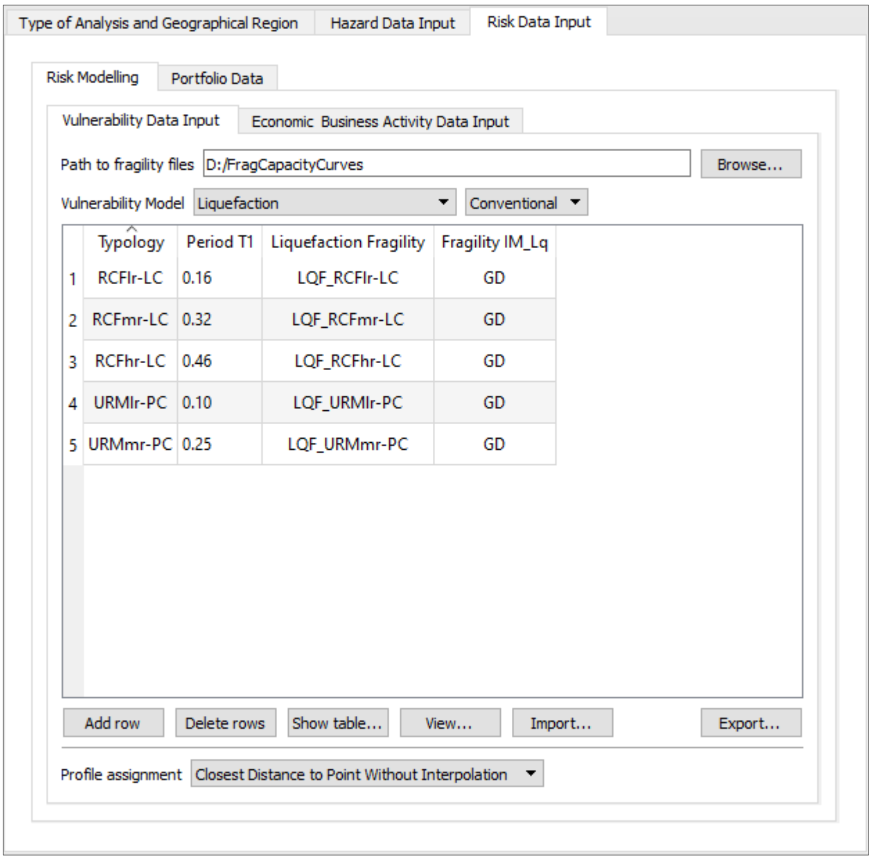


NOTE that the folder name "***FragCapacityCurves***" cannot be changed.

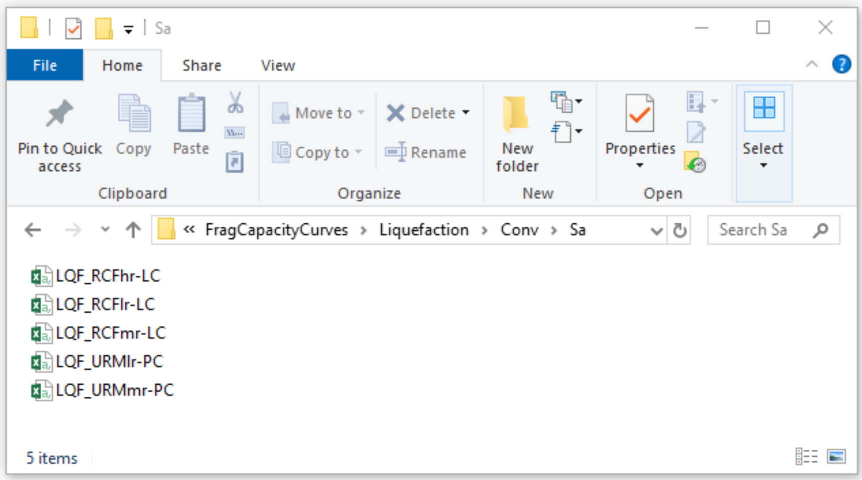
2. The fragility models must be created as separate files in format of tab-separated CSV files. Starting from *FragCapacityCurves* folder and depending on type of intensity measure used (Sa, PGA, GD, or LSN), the software automatically takes the following pre-defined paths to import the Conventional-based liquefaction fragility functions:

   NOTE: folders with names in *Italic* style must be named as they are.

   1.2. Conventional-based fragility functions in terms of Spectral Acceleration (Sa).

   Sa-based Conventional liquefaction fragility functions are automatically imported from the following path:

   *FragCapacityCurves**Liquefaction**Conv**Sa*



2.1. Conventional-based fragility functions in terms of <u>Peak Ground Acceleration (PGA)</u>

PGA-based Conventional liquefaction fragility functions are automatically imported from the following path:

FragCapacityCurves\Liquefaction\Conv\PGA

2.2. Conventional-based fragility functions in terms of <u>Differential Settlement (GD)</u>

GD-based Conventional liquefaction fragility functions are automatically imported from the following path:

FragCapacityCurves\Liquefaction\Conv\GD

2.3. Conventional-based fragility functions in terms of <u>Liquefaction Severity Number (LSN)</u>

LSN-based Conventional liquefaction fragility functions are automatically imported from the following path:

FragCapacityCurves\Liquefaction\Conv\LSN

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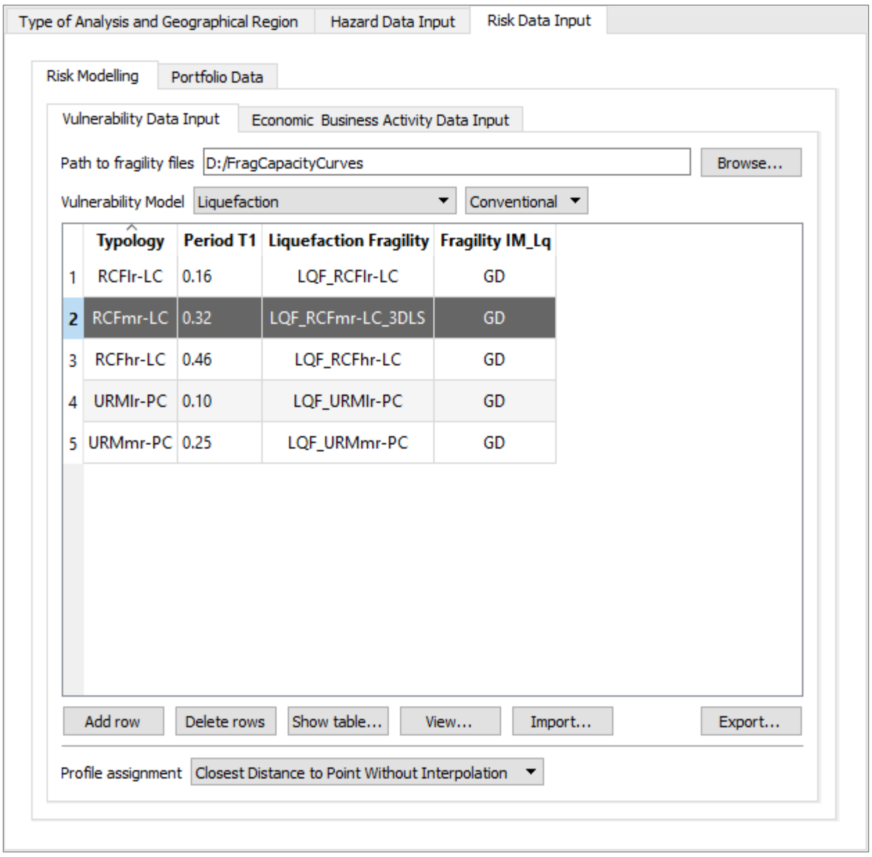
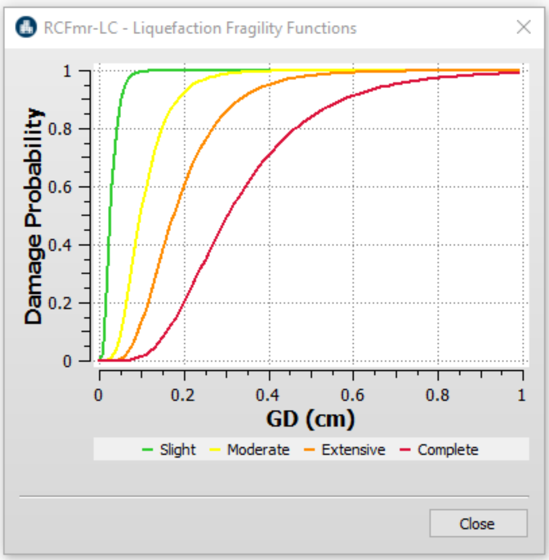
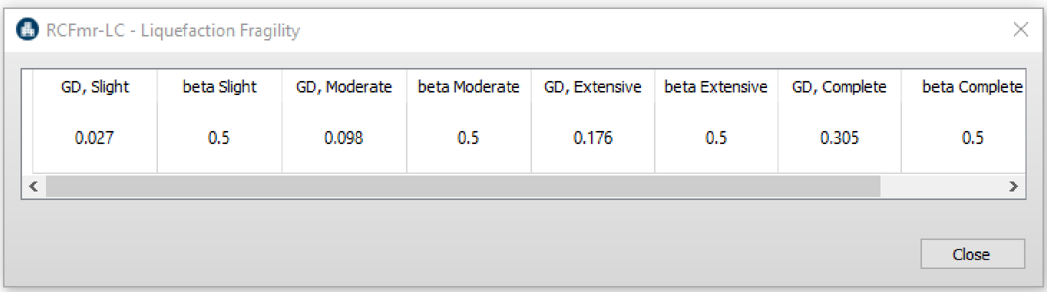


3. Once the Conventional-based liquefaction fragility functions are stored in the pre-defined paths as described above, detailed information on each fragility model can be viewed from this table. Manually select the fragility model from the list of the model, click on the *View* button to view the plot of fragility curves, and the *Show* table button to display the table with the fragility curves parameters.

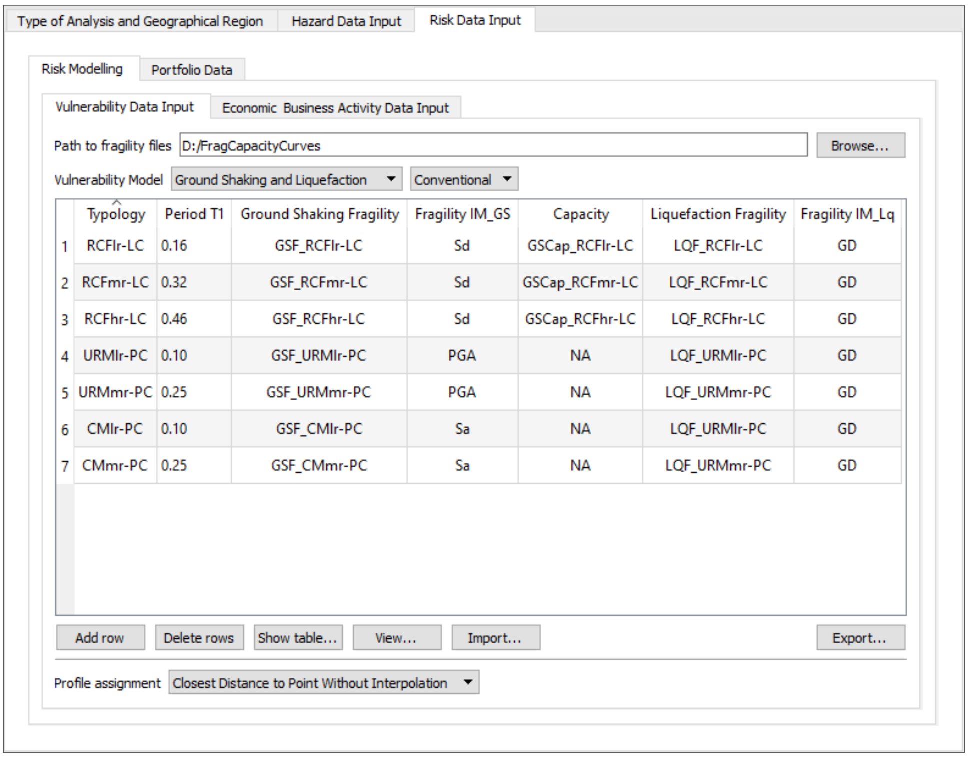
Viewing *Conventional-based* liquefaction fragility models





2.3.1.1.4.3 Path to Ground Shaking Fragility Models Folders

1. Ground Shaking Fragility models are used only when *Ground Shaking and Liquefaction Analysis* is to be implemented by user. Hence, when clicking the *Browse* button to define the path to the ***FragCapacityCurves*** folder where all sub-folders of *Liquefaction Fragility* files to be stored, this automatically also applies for *Ground Shaking Fragility* files.



NOTE that the folder name "***FragCapacityCurves***" cannot be changed.

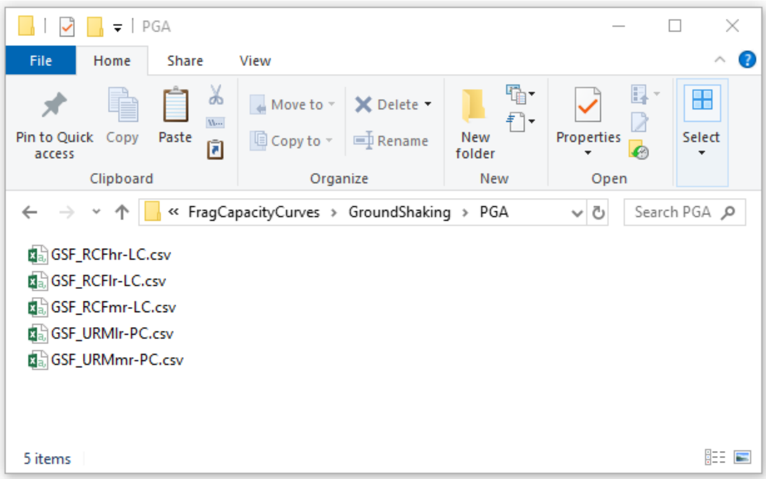
2. The fragility models must be created as separate files in format of tab-separated CSV files. Starting from *FragCapacityCurves* folder and depending on type of intensity measure used (PGA, Sa, or Sd), the software automatically takes the following pre-defined paths to import the Ground Shaking fragility functions:

   NOTE: folders with names in *Italic* style must be named as they are.

1.3. Ground shaking fragility functions in terms of Peak Ground Acceleration (PGA).

PGA-based Ground Shaking fragility functions are automatically imported from the following path:

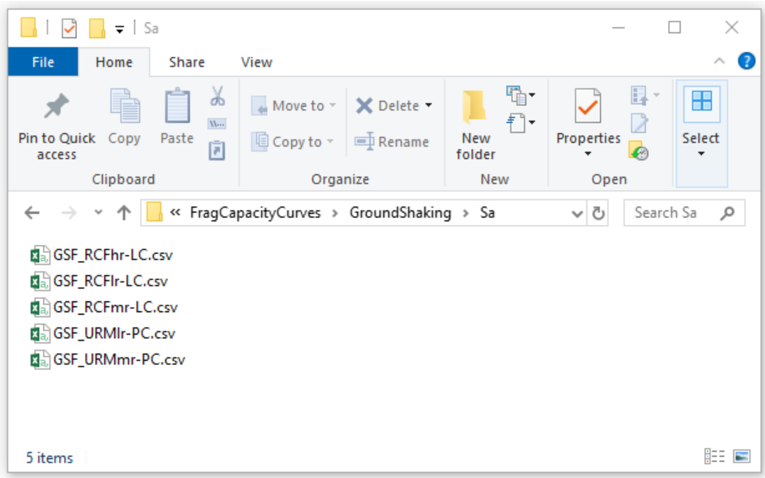
FragCapacityCurves\GroundShaking\PGA



2.1. Ground shaking fragility functions in terms of Spectral Acceleration (Sa)

Sa-based Ground Shaking fragility functions are automatically imported from the following path:

FragCapacityCurves\GroundShaking\Sa



2.2. Ground shaking fragility functions in terms of Spectral Displacement (Sd)

When Sd-based ground shaking fragility functions are used, it is also required to import the associated Capacity Curves

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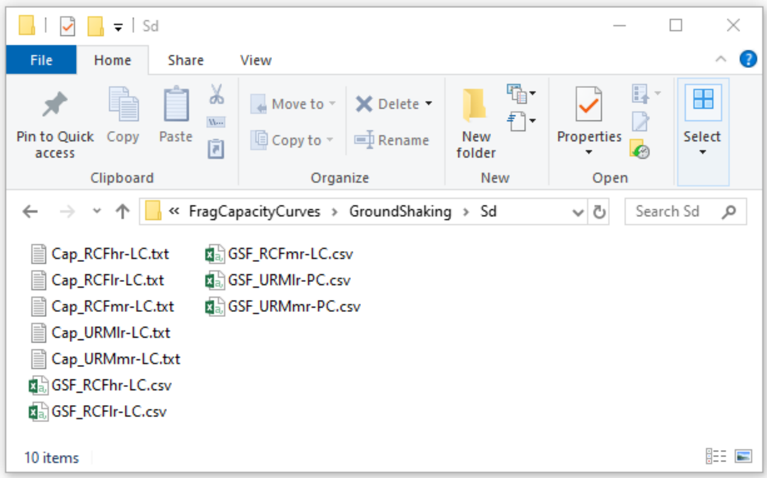
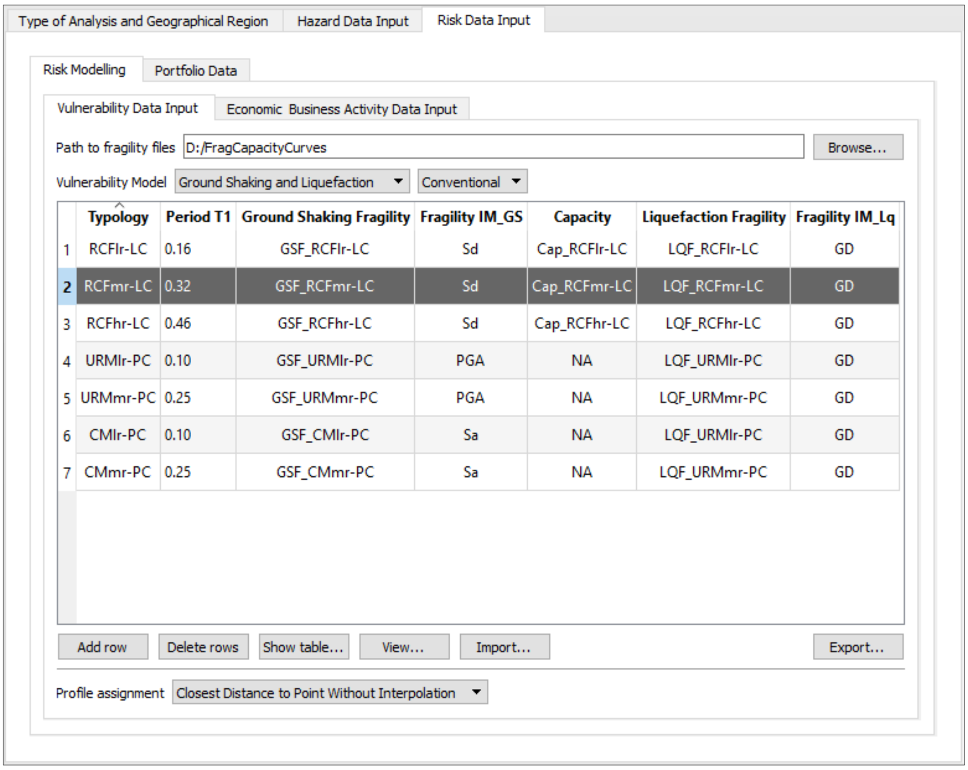
Sd-based Ground Shaking fragility functions are automatically imported from the following path:

FragCapacityCurves\GroundShaking\Sd





3. Once the Ground Shaking fragility functions and Capacity Curves are stored in the pre-defined paths as described above, detailed information on each Fragility model and Capacity Curve can be viewed from this table. Manually select the fragility and capacity model from the list of the model, click on the *View* button to view the plot of fragility and capacity curves, and the *Show* table button to display the table with the fragility and capacity curves parameters.

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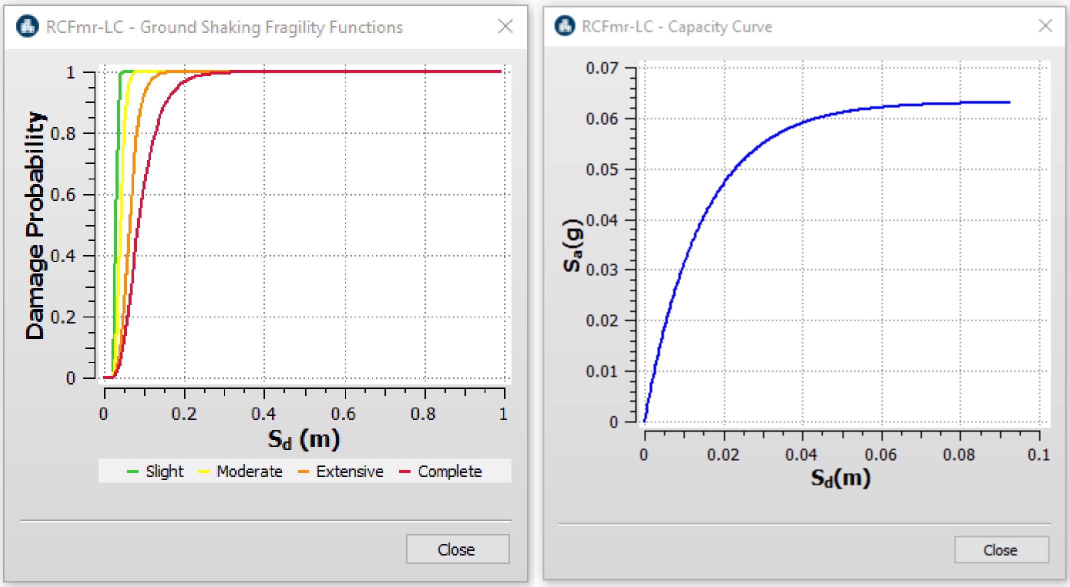
Viewing *Ground Shaking* fragility and *Capacity* models



RCFmr-LC - Ground Shaking Fragility

Sd, Slight	beta Slight	Sd, Moderate	beta Moderate	Sd, Extensive	beta Extensive	Sd, Complete	beta Complete
0.03	0.12	0.041	0.22	0.063	0.32	0.086	0.46

Close

2.3.1.1.5 Built-In Liquefaction Vulnerability Model

To use the pre-defined fragility models embedded in the software:

4. Select *Liquefaction (Built-In)* option
5. Select which method of *Loss Analysis* to be implemented: LIQUEFACT software incorporates two procedures for the computation of physical damage and loss ratio for a given liquefaction demand: *Conventional* procedure or *ESP-based* (Equivalent Soil Profile based) method.

Note that in this case the *Path to fragility files* is disactivated as it is not required

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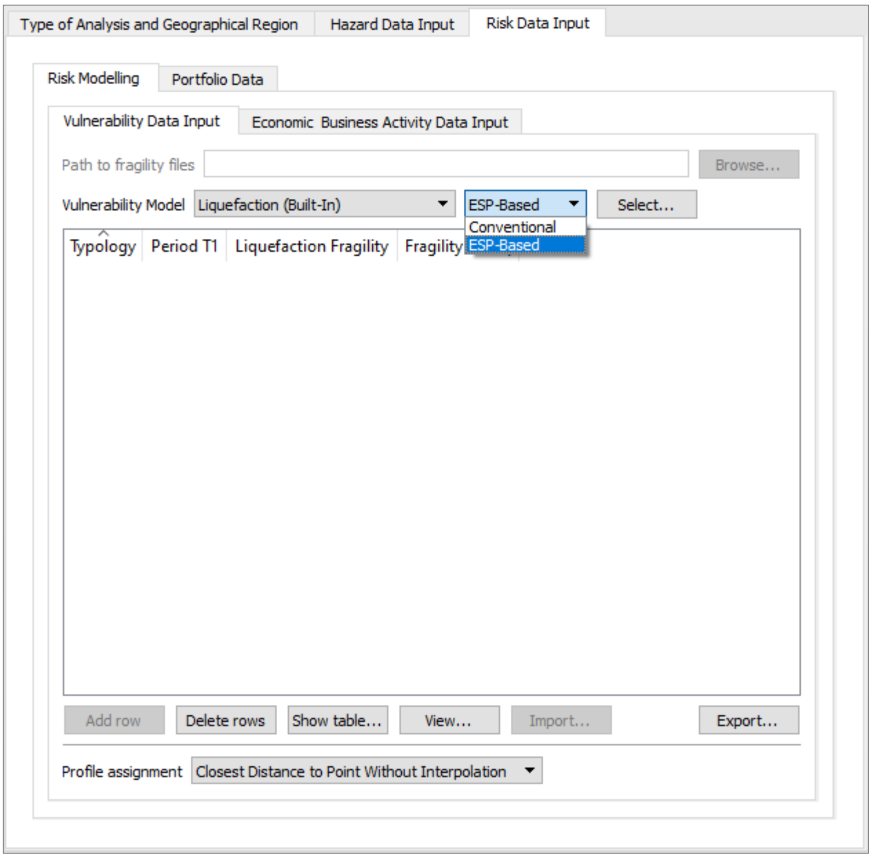
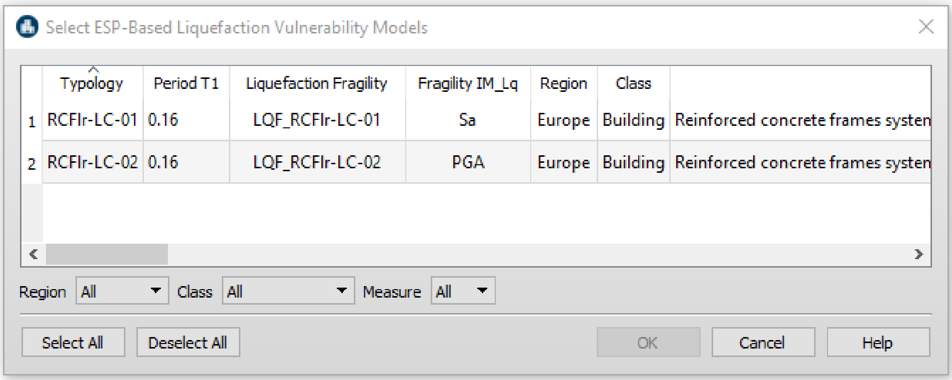


6. By clicking on *Select* button the table below will be displayed showing all the fragility models available in the Built-In system.

Built-in ESP-based Liquefaction Fragility Models

Example of Built-in fragility models for *ESP-based* loss analysis method



Detailed description on each built-in fragility model can be viewed by manually select and double click, the table below will be displayed.

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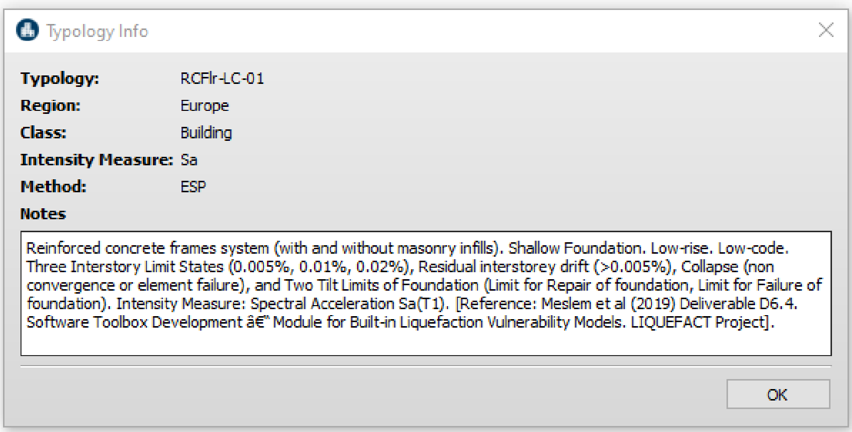
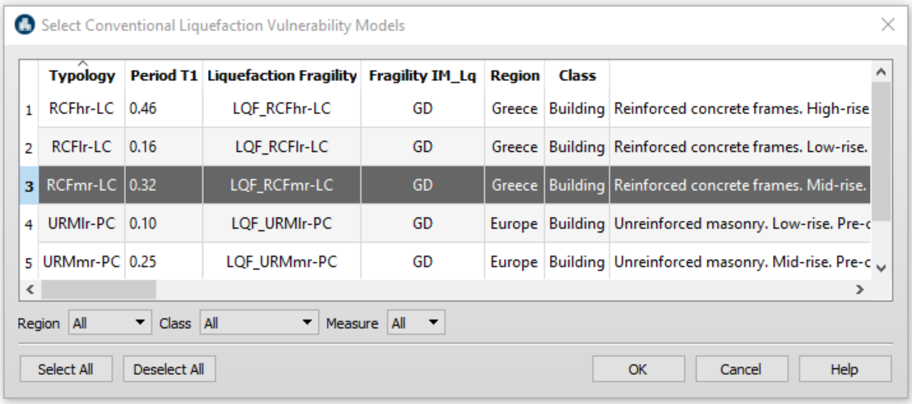
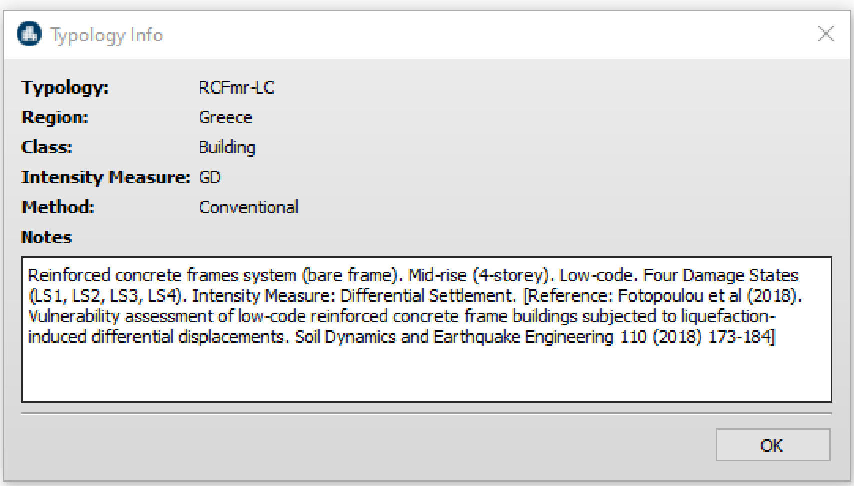


__Built-in Conventional-based Liquefaction Fragility Models__

Example of Built-in fragility models for *__Conventional-based__* loss analysis method



Detailed description on each built-in fragility model can be viewed by manually select and double click, the table below will be displayed.



The built-in system contains a filter for a quick search and selection of available fragility models in terms of "*__Region__*", "*__Class__*" and "*__Intensity Measure__*".

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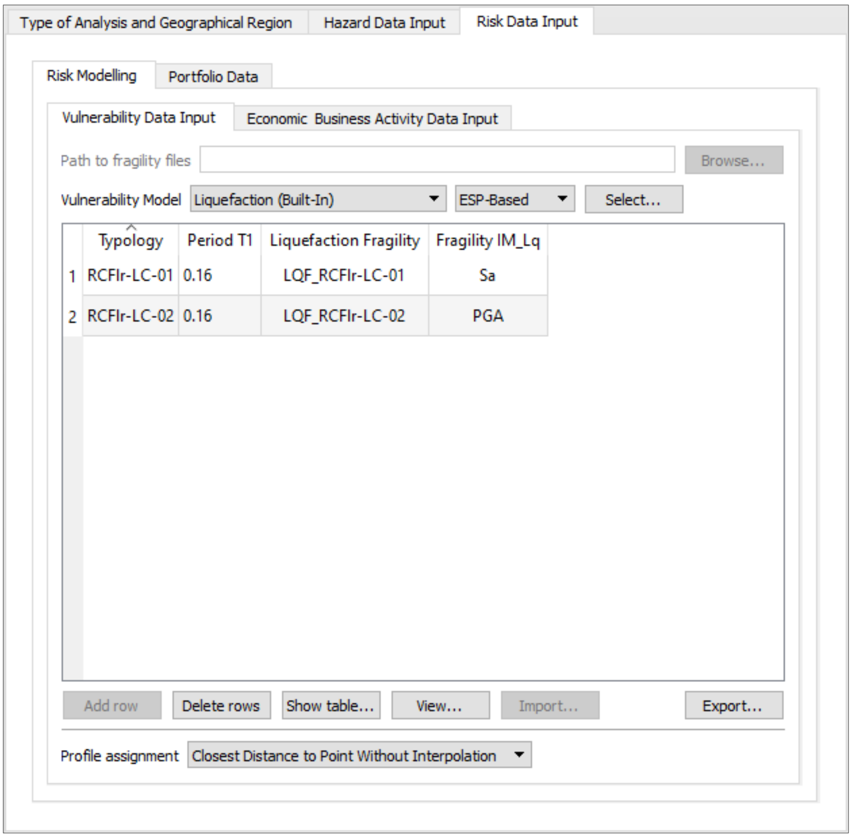
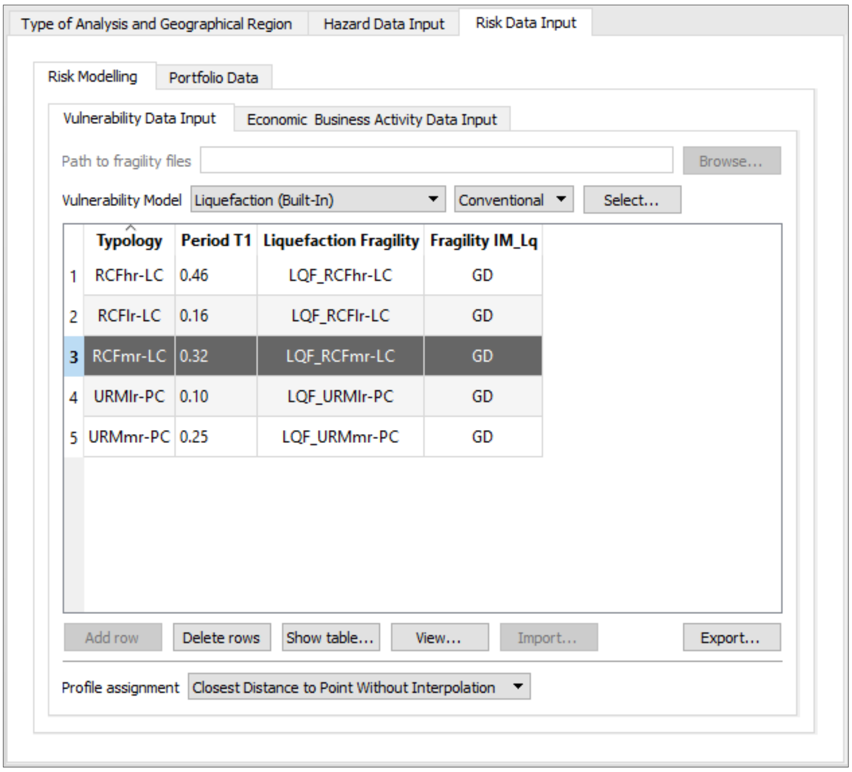
7. Select manually the fragility models to be used or click on *__Select All__* button you wish to select all the models available.





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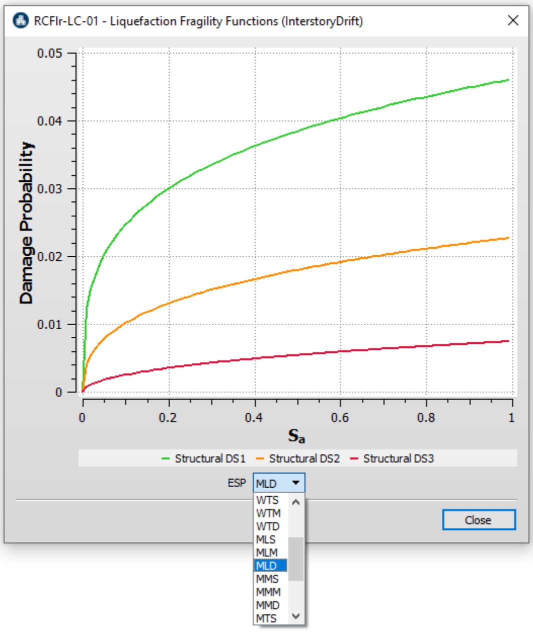
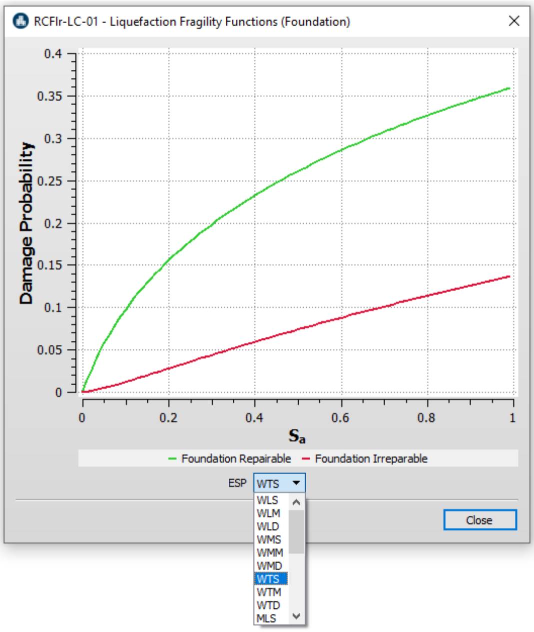
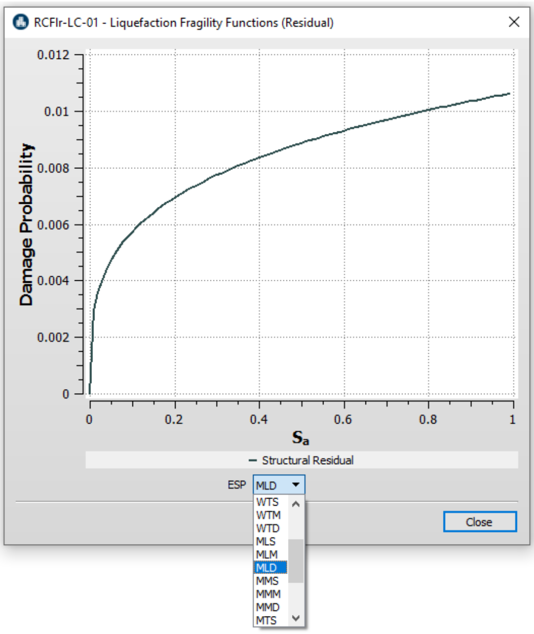
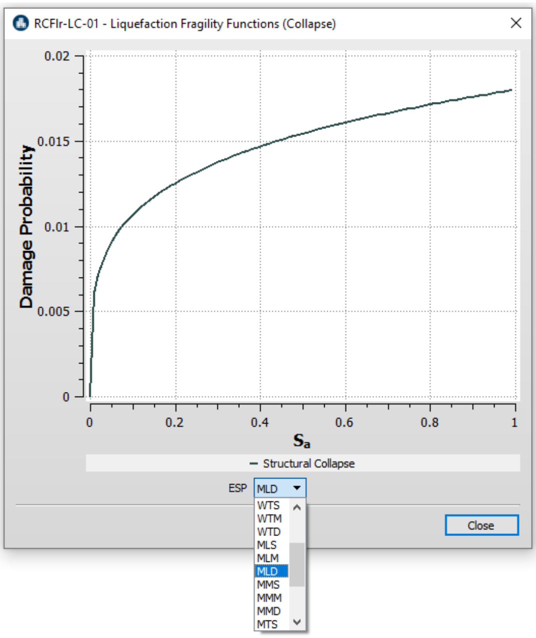
8. From this table, detailed description on each built-in fragility model can also be viewed by manually select and double click, the table below will be displayed. In addition, fragility curves can be plotted by clicking on *View* button.

Viewing built-in *ESP-based* liquefaction fragility models









Viewing built-in *Conventional-based* liquefaction fragility models

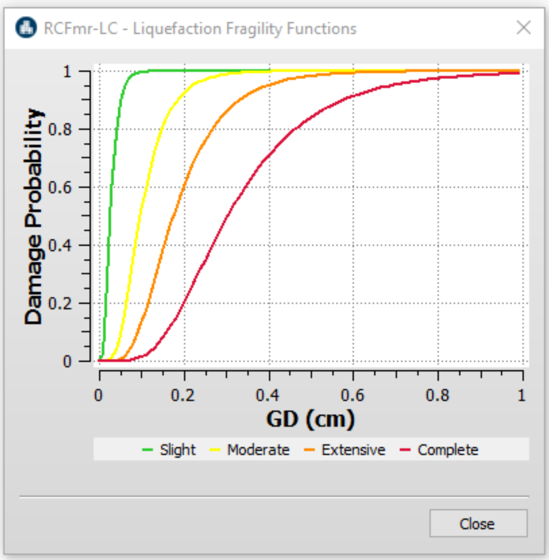


Table showing the functions of fragility model displayed by clicking on Show table button.

RCFmr-LC - Liquefaction Fragility

GD, Slight	beta Slight	GD, Moderate	beta Moderate	GD, Extensive	beta Extensive	GD, Complete	beta Complete
0.027	0.5	0.098	0.5	0.176	0.5	0.305	0.5

Close

9. At the section *Profile assignment*, users can define how liquefaction severity indicators (PGA, Sa, LSN, GD) resulted from liquefaction profiles will be assigned to the assets (buildings, infrastructures) for the computation of liquefaction demand, the associated damage and loss ratio. Users will have to choose one of the following options:

   Closest Distance to Point Without Interpolation: the assigned value of liquefaction severity indicator is directly resulted from the closest liquefaction profile at the location of a given asset or the closed to it.

   Closest Distance to Point After Interpolation: the assigned value of liquefaction severity indicator is directly resulted from interpolation, at the location of a given asset.

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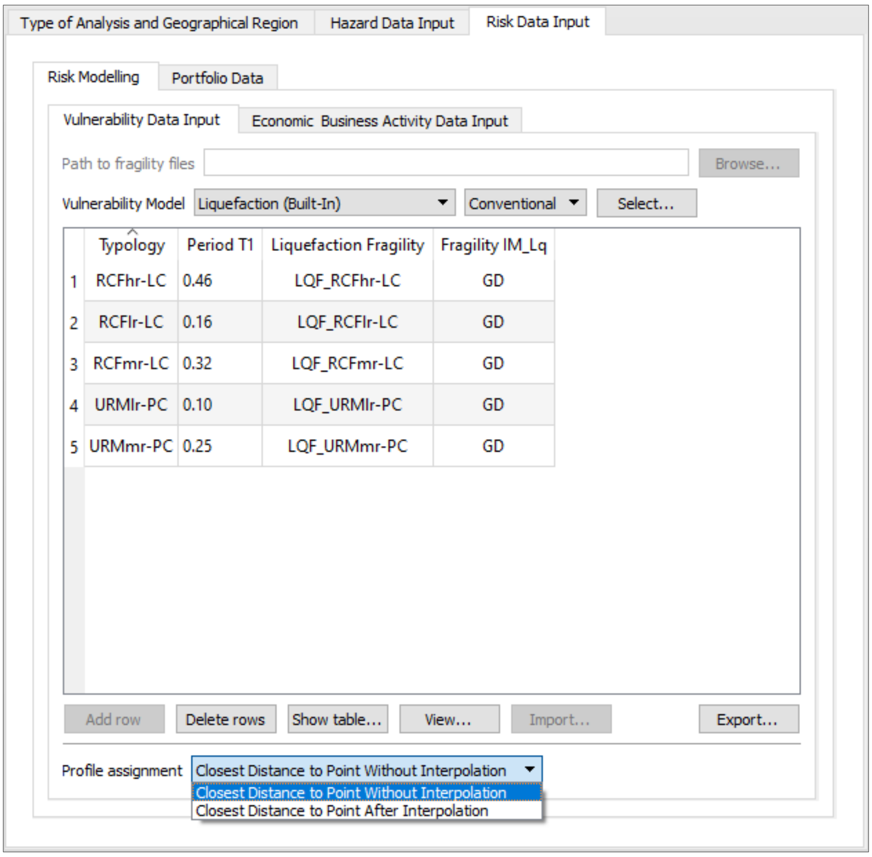


2.3.1.2 Economic & Business Activity Data Input

The module for Economic Loss Analysis is activated only when user select "*Physical impact & Economic*" in the *Type of Analysis* Section. In this case, the user is required to import economic and business activity input data, and which can be categorize into two groups: *Owner* Economic and Business Activity data, and *Insurance* Economic and Business Activity data.

- *Owner* Economic and Business Activity data are shown in the module "*Economical Model*" of the software and used for the computation of *Owner Economic Loss* in terms of direct loss asset loss (due to physical impact), contents loss and business interruption loss.

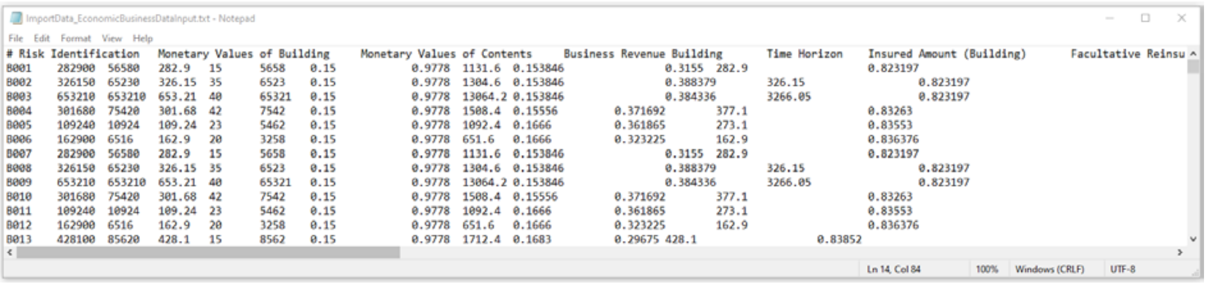
- *Insurance* Economic and Business Activity data are shown in the module: "*Policy*" (for asset insurance loss computation), "*Contents*" (for contents insurance loss computation), and "*Business Interruption*" (for business interruption insurance loss computation)

List of the Economic and Business Activity Data input

Data Input	*Description*	*NOTE*
Risk Identification	*Code identification to be assigned to each individual asset*	*Mandatory*
ECONOMICAL MODEL (for Owner Loss computation)		

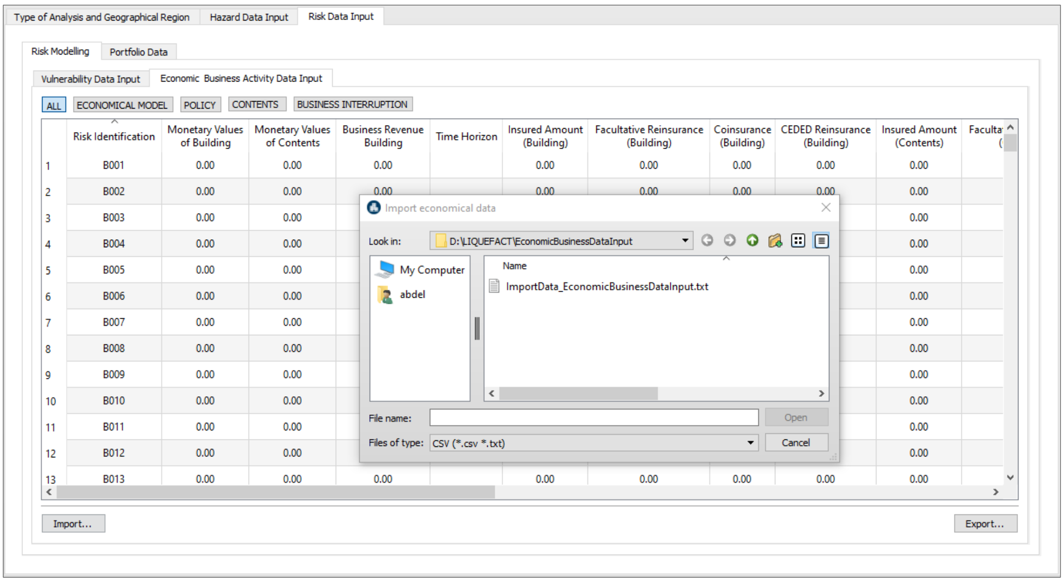
Monetary Values of Building	If no value is assigned than the building owner loss will not be computed.	
Monetary Values of Contents	If no value is assigned than the content owner loss will not be computed	
Business Revenue Building	If no value is assigned than the business loss will not be computed	
Time Horizon	Mandatory for Cost-Benefit computation if Mitigation Analysis in selected	
POLICY (for Building Insurance Loss computation)		
Insured Amount (Building)	*If no value is assigned than the building insurance loss will not be computed.*	
Facultative Reinsurance (Building)	*If no value is assigned, will not be considered in the computation*	
Coinsurance (Building)	*If no value is assigned, will not be considered in the computation*	
CEDED Reinsurance (Building)	*If no value is assigned, will not be considered in the computation*	
CONTENTS (for Contents Insurance Loss computation)		
Insured Amount (Contents)	*If no value is assigned than the content insurance loss will not be computed*	
Facultative Reinsurance (Contents)	*If no value is assigned, will not be considered in the computation*	
Coinsurance (Contents)	*If no value is assigned, will not be considered in the computation*	
CEDED Reinsurance (Contents)	*If no value is assigned, will not be considered in the computation*	
BUSINESS INTERRUPTION (for Business Insurance computation)		
Insured Amount (Business Interruption)	*If no value is assigned than the business interruption insurance loss will not be computed*	
Facultative Reinsurance (Business Interruption)	*If no value is assigned, will not be considered in the computation*	
Coinsurance (Business Interruption)	*If no value is assigned, will not be considered in the computation*	
CEDED Reinsurance (Business Interruption)	*If no value is assigned, will not be considered in the computation*	

The Economic and Business Activity Data input is imported as tab-separated CSV or unformatted TXT files. Here is an example of CSV/TXT file that can be imported in the LIQUEFACT software.

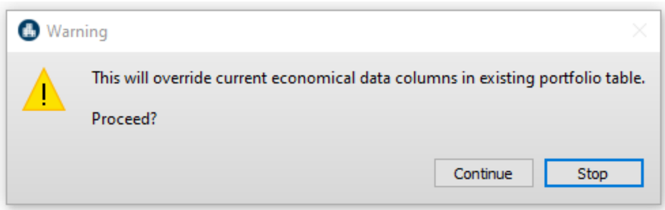

```
# Risk Identification	Monetary Values of Building	Monetary Values of Contents	Business Revenue Building	Time Horizon	Insured Amount (Building)	Facultative Reinsu
B001	282900	56580	282.9	15	5658	0.15	0.9778	1131.6	0.153846	0.3155	282.9		0.823197
B002	326150	65230	326.15	35	6523	0.15	0.9778	1304.6	0.153846	0.388379	326.15	0.823197
B003	653210	653210	653.21	40	65321	0.15	0.9778	13064.2	0.153846	0.384336	3266.05	0.823197
B004	301680	75420	301.68	42	7542	0.15	0.9778	1508.4	0.15556	0.371692	377.1	0.83263
B005	109240	10924	109.24	23	5462	0.15	0.9778	1092.4	0.1666	0.361865	273.1	0.83553
B006	162900	6516	162.9	20	3258	0.15	0.9778	651.6	0.1666	0.323225	162.9	0.836376
B007	282900	56580	282.9	15	5658	0.15	0.9778	1131.6	0.153846	0.3155	282.9		0.823197
B008	326150	65230	326.15	35	6523	0.15	0.9778	1304.6	0.153846	0.388379	326.15	0.823197
B009	653210	653210	653.21	40	65321	0.15	0.9778	13064.2	0.153846	0.384336	3266.05	0.823197
B010	301680	75420	301.68	42	7542	0.15	0.9778	1508.4	0.15556	0.371692	377.1	0.83263
B011	109240	10924	109.24	23	5462	0.15	0.9778	1092.4	0.1666	0.361865	273.1	0.83553
B012	162900	6516	162.9	20	3258	0.15	0.9778	651.6	0.1666	0.323225	162.9	0.836376
B013	428100	85620	428.1	15	8562	0.15	0.9778	1712.4	0.1683	0.29675	428.1	0.83852
```


Import Economic and Business Activity Data input

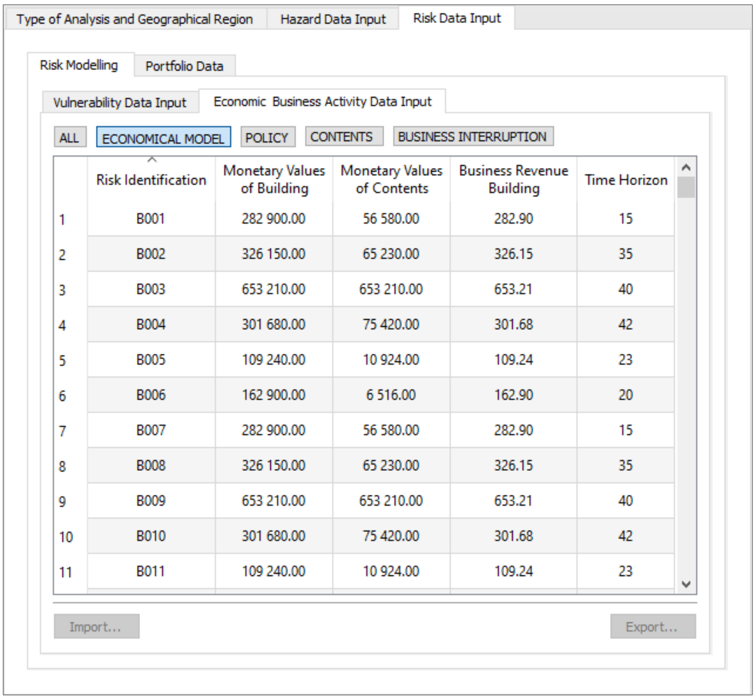
In the Section *Economic Business Activity Data input* and by clicking on the module *ALL* the economic and business data can be imported by clicking on the *Import* button.



This warning message will show-up, and by clicking on *Continue* button the economic data will be imported



The Owner Economic Data can be viewed by clicking on the module *ECONOMICAL MODEL*. Will be used for the computation of owner loss in terms of *Asset*, *Content*, and *Business Revenue*.



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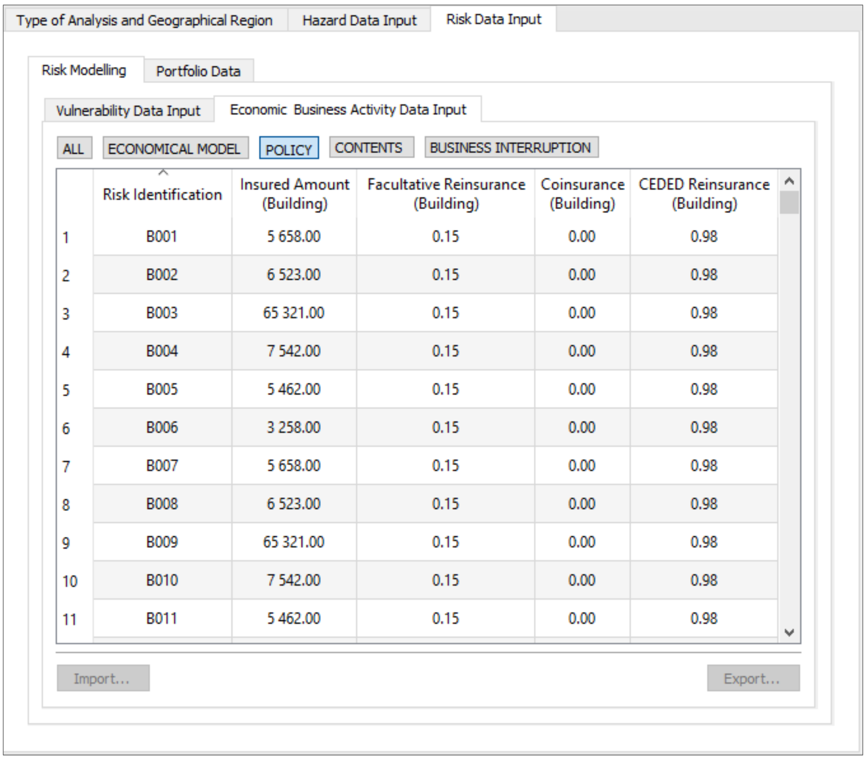
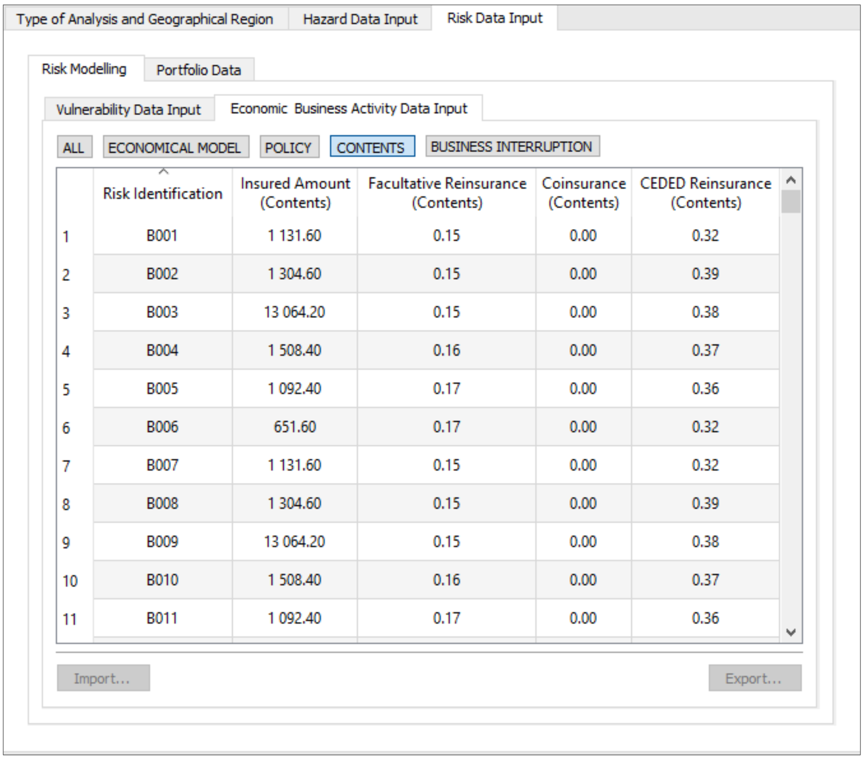
The Asset (building/infrastructure) Insurance Data can be viewed by clicking on the module <u>*POLICY*</u>. Will be used for the computation of *Asset Insurance Loss*.



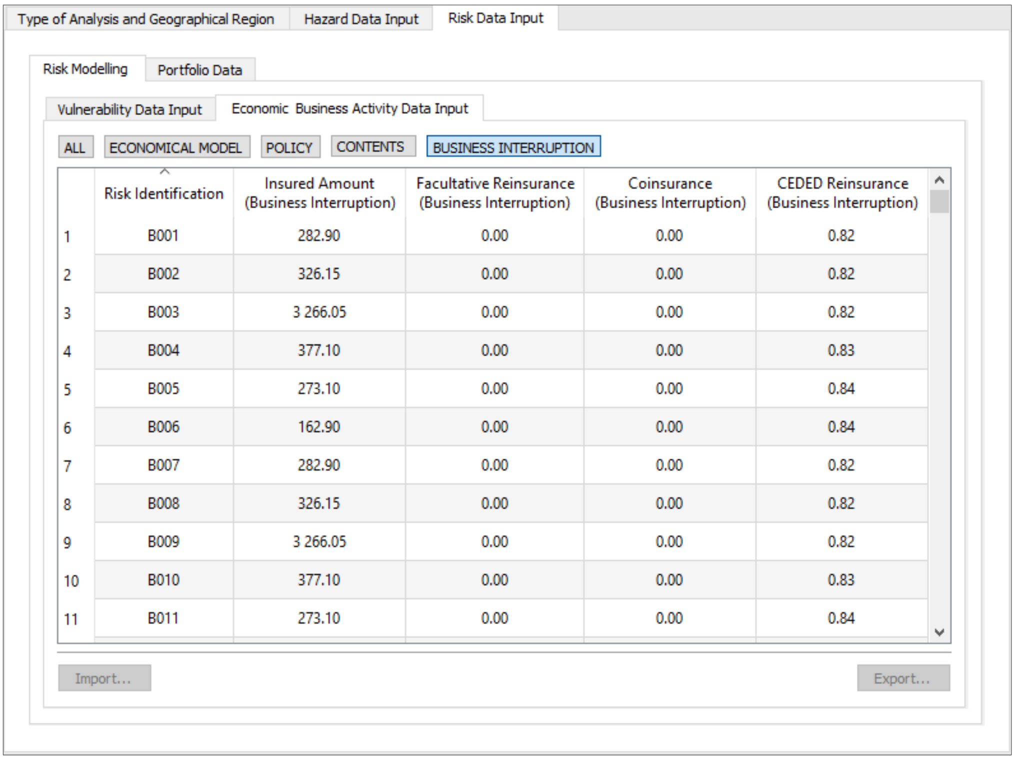
	Risk Identification	Insured Amount (Building)	Facultative Reinsurance (Building)	Coinsurance (Building)	CEDED Reinsurance (Building)
1	B001	5 658.00	0.15	0.00	0.98
2	B002	6 523.00	0.15	0.00	0.98
3	B003	65 321.00	0.15	0.00	0.98
4	B004	7 542.00	0.15	0.00	0.98
5	B005	5 462.00	0.15	0.00	0.98
6	B006	3 258.00	0.15	0.00	0.98
7	B007	5 658.00	0.15	0.00	0.98
8	B008	6 523.00	0.15	0.00	0.98
9	B009	65 321.00	0.15	0.00	0.98
10	B010	7 542.00	0.15	0.00	0.98
11	B011	5 462.00	0.15	0.00	0.98

The Contents Insurance Data can be viewed by clicking on the module <u>*CONTENTS*</u>. Will be used for the computation of *Contents Insurance Loss*.



	Risk Identification	Insured Amount (Contents)	Facultative Reinsurance (Contents)	Coinsurance (Contents)	CEDED Reinsurance (Contents)
1	B001	1 131.60	0.15	0.00	0.32
2	B002	1 304.60	0.15	0.00	0.39
3	B003	13 064.20	0.15	0.00	0.38
4	B004	1 508.40	0.16	0.00	0.37
5	B005	1 092.40	0.17	0.00	0.36
6	B006	651.60	0.17	0.00	0.32
7	B007	1 131.60	0.15	0.00	0.32
8	B008	1 304.60	0.15	0.00	0.39
9	B009	13 064.20	0.15	0.00	0.38
10	B010	1 508.40	0.16	0.00	0.37
11	B011	1 092.40	0.17	0.00	0.36

The *Business Interruption Insurance Data* can be viewed by clicking on the module *BUSINESS INTERRUPTION*. Will be used for the computation of *Business Interruption Insurance Loss*.



	Risk Identification	Insured Amount (Business Interruption)	Facultative Reinsurance (Business Interruption)	Coinsurance (Business Interruption)	CEDED Reinsurance (Business Interruption)
1	B001	282.90	0.00	0.00	0.82
2	B002	326.15	0.00	0.00	0.82
3	B003	3 266.05	0.00	0.00	0.82
4	B004	377.10	0.00	0.00	0.83
5	B005	273.10	0.00	0.00	0.84
6	B006	162.90	0.00	0.00	0.84
7	B007	282.90	0.00	0.00	0.82
8	B008	326.15	0.00	0.00	0.82
9	B009	3 266.05	0.00	0.00	0.82
10	B010	377.10	0.00	0.00	0.83
11	B011	273.10	0.00	0.00	0.84

The imported data can be modified by double click on any cell, and later can also be exported by clicking on the *Export* button from the *ALL* module.

2.3.2 Assets Modelling (STRUCTURE Portfolio Data)

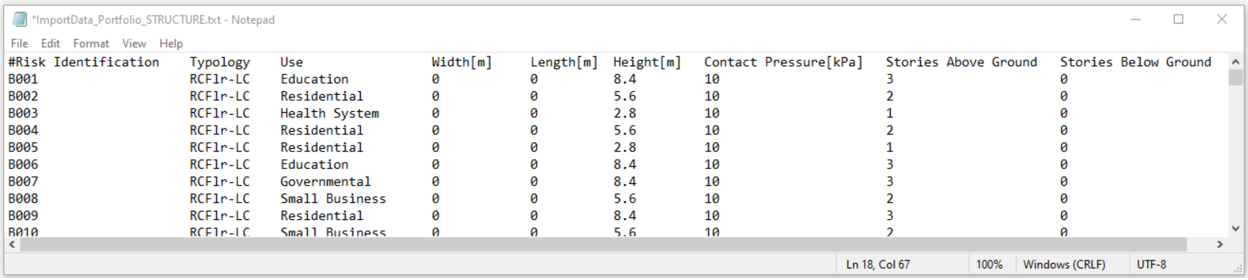
For *Risk Analysis*, user is required to import the assets (buildings/infrastructures) *SRUCTURE* details. Table below illustrates the

Table below illustrates the list of input parameters that define asset STRUCTURE in the Portfolio Data section.

Data Input	*Description*	*NOTE*
Risk Identification	*Code identification to be assigned to each individual asset*	*Mandatory*
STRUCTURE		
Typology	*Typology representing a given structural class*	*Mandatory*
Use	*Occupancy type*	*Nonmandatory*
Width	*Width of each given asset, in meter unit*	*Mandatory*
Length	*Length of each given asset, in meter unit*	*Mandatory*
Height	*Height of each given asset, in meter unit*	*Nonmandatory*
Contact Pressure	*Contact pressure for each asset, in kPa unit*	*Mandatory*
Stories Above Ground	*Number of storeys above ground surface*	*Mandatory*

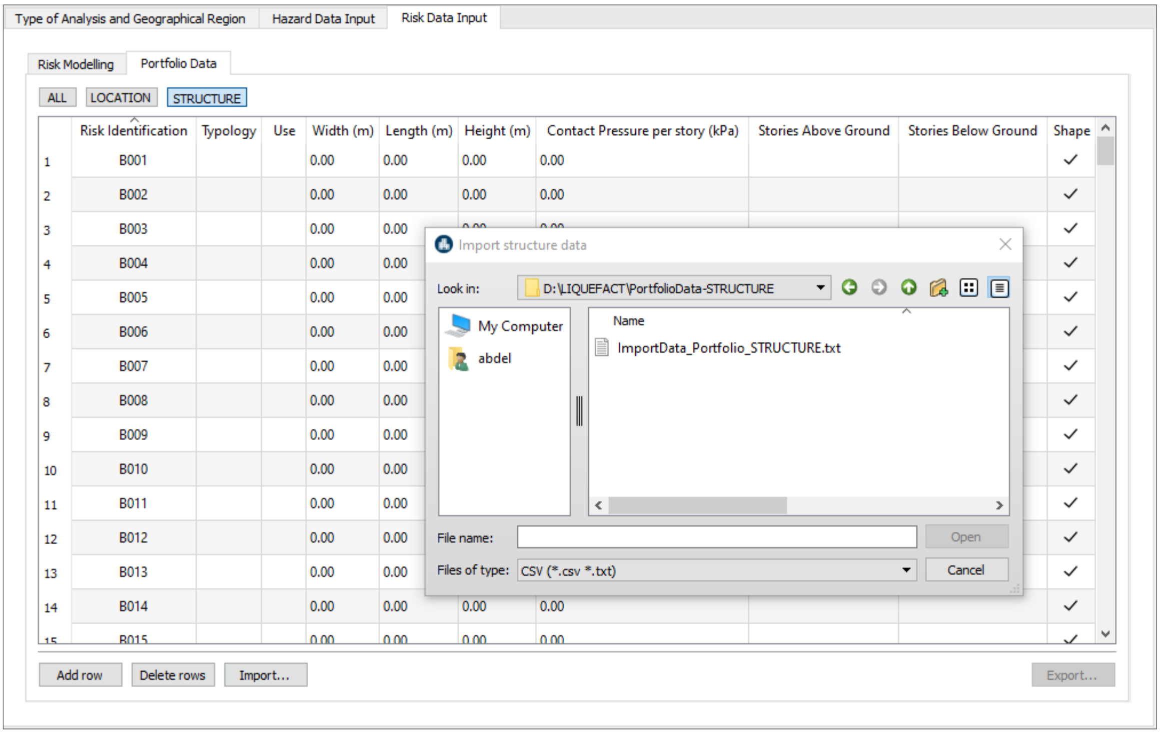
Stories Below Ground	*Number of storeys below ground surface*	*Mandatory*

The Portfolio STRUCTURE data is imported as tab-separated CSV or unformatted TXT files. Here is an example of CSV/TXT file for asset *STRUCTURE* that can be imported in the LIQUEFACT software.

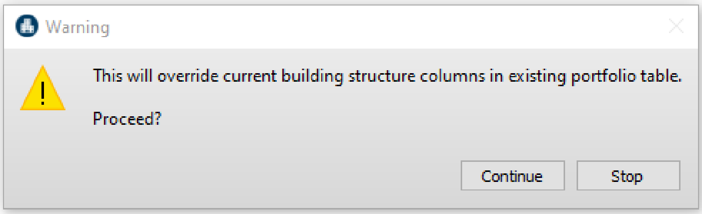


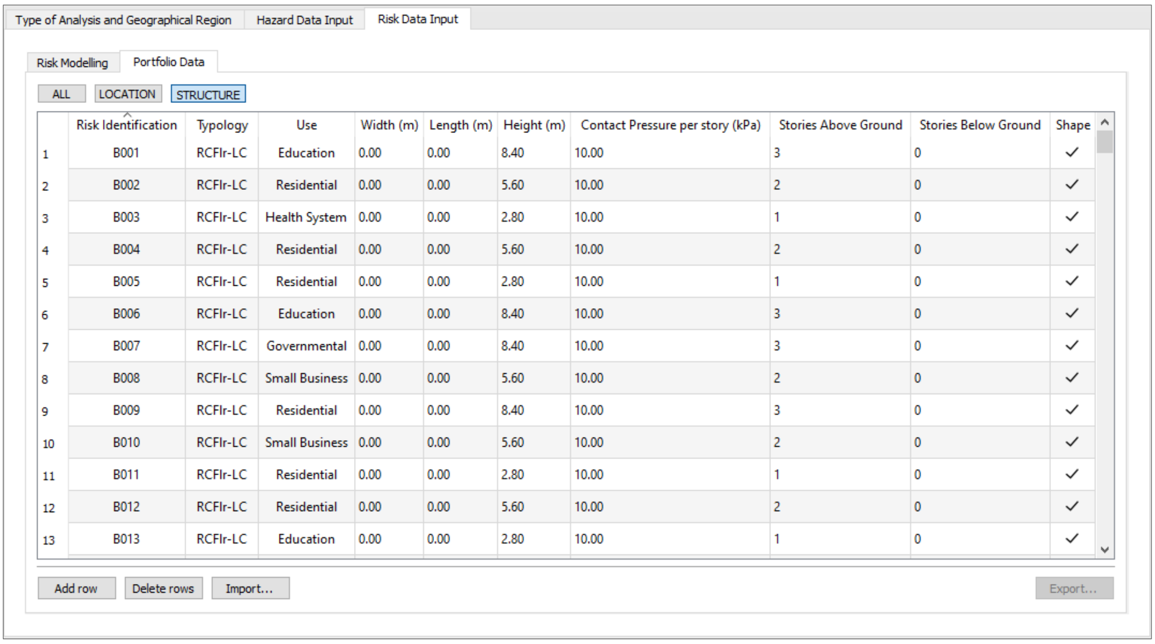
Import Portfolio STRUCTURE Data

In the Section *Portfolio Data* and by clicking on the module *STRUCTURE* the structure details of the assets can be imported by clicking on the *Import* button.



This warning message will show-up, and by clicking on *Continue* button the STRUCTURE related data will be imported

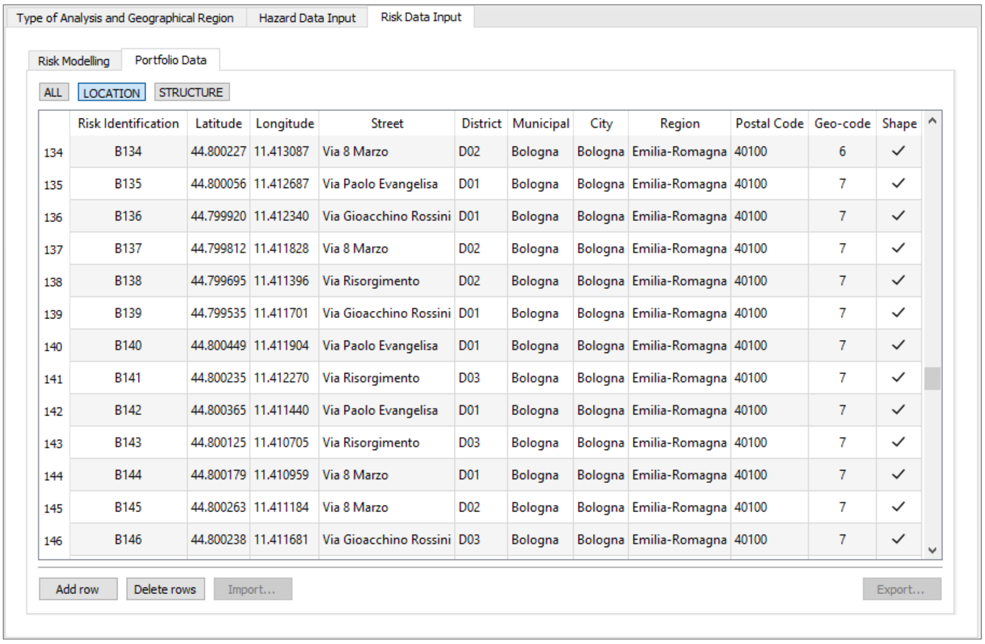




	Risk Identification	Typology	Use	Width (m)	Length (m)	Height (m)	Contact Pressure per story (kPa)	Stories Above Ground	Stories Below Ground	Shape
1	B001	RCFlr-LC	Education	0.00	0.00	8.40	10.00	3	0	✓
2	B002	RCFlr-LC	Residential	0.00	0.00	5.60	10.00	2	0	✓
3	B003	RCFlr-LC	Health System	0.00	0.00	2.80	10.00	1	0	✓
4	B004	RCFlr-LC	Residential	0.00	0.00	5.60	10.00	2	0	✓
5	B005	RCFlr-LC	Residential	0.00	0.00	2.80	10.00	1	0	✓
6	B006	RCFlr-LC	Education	0.00	0.00	8.40	10.00	3	0	✓
7	B007	RCFlr-LC	Governmental	0.00	0.00	8.40	10.00	3	0	✓
8	B008	RCFlr-LC	Small Business	0.00	0.00	5.60	10.00	2	0	✓
9	B009	RCFlr-LC	Residential	0.00	0.00	8.40	10.00	3	0	✓
10	B010	RCFlr-LC	Small Business	0.00	0.00	5.60	10.00	2	0	✓
11	B011	RCFlr-LC	Residential	0.00	0.00	2.80	10.00	1	0	✓
12	B012	RCFlr-LC	Residential	0.00	0.00	5.60	10.00	2	0	✓
13	B013	RCFlr-LC	Education	0.00	0.00	2.80	10.00	1	0	✓

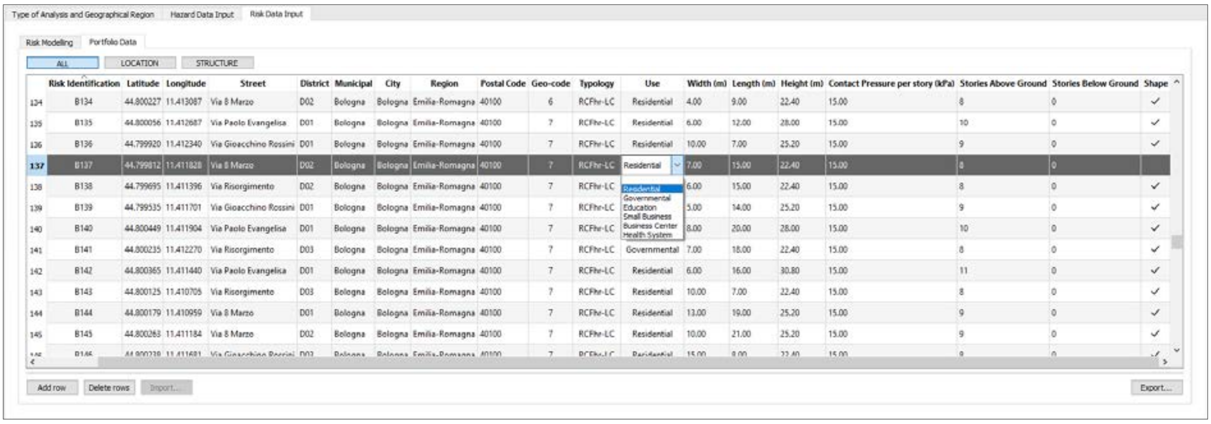
Note that the software will combine the <u>STRUCTURE</u> data with the already imported <u>*LOCATION*</u> (imported from section Type and Level of Analysis) and presented all together in the *Portfolio Data* section.

The assets LOCATION data can be viewed by clicking on the module <u>*LOCATION*</u>.

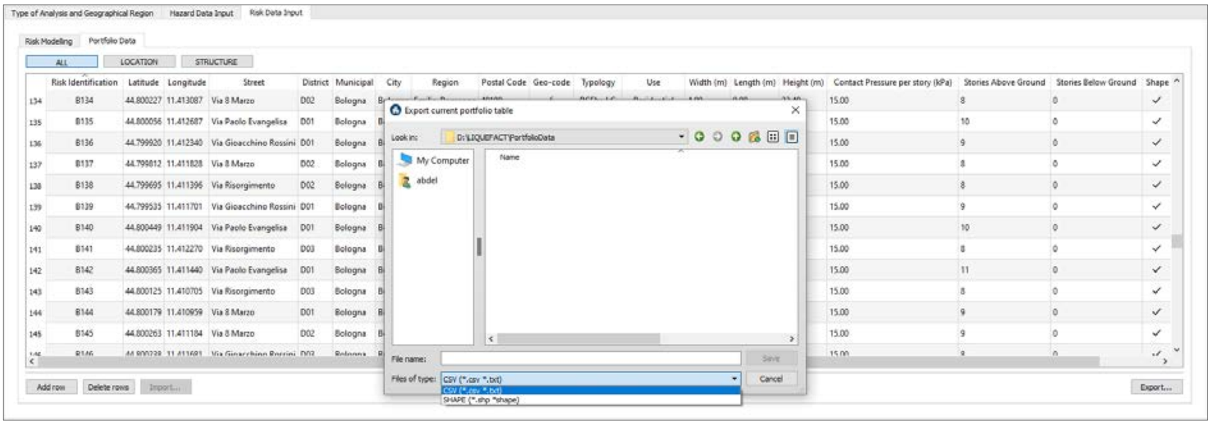


	Risk Identification	Latitude	Longitude	Street	District	Municipal	City	Region	Postal Code	Geo-code	Shape
134	B134	44.800227	11.413087	Via 8 Marzo	D02	Bologna	Bologna	Emilia-Romagna	40100	6	✓
135	B135	44.800056	11.412687	Via Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	7	✓
136	B136	44.799920	11.412340	Via Gioacchino Rossini	D01	Bologna	Bologna	Emilia-Romagna	40100	7	✓
137	B137	44.799812	11.411828	Via 8 Marzo	D02	Bologna	Bologna	Emilia-Romagna	40100	7	✓
138	B138	44.799695	11.411396	Via Risorgimento	D02	Bologna	Bologna	Emilia-Romagna	40100	7	✓
139	B139	44.799535	11.411701	Via Gioacchino Rossini	D01	Bologna	Bologna	Emilia-Romagna	40100	7	✓
140	B140	44.800449	11.411904	Via Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	7	✓
141	B141	44.800235	11.412270	Via Risorgimento	D03	Bologna	Bologna	Emilia-Romagna	40100	7	✓
142	B142	44.800365	11.411440	Via Paolo Evangelisa	D01	Bologna	Bologna	Emilia-Romagna	40100	7	✓
143	B143	44.800125	11.410705	Via Risorgimento	D03	Bologna	Bologna	Emilia-Romagna	40100	7	✓
144	B144	44.800179	11.410959	Via 8 Marzo	D01	Bologna	Bologna	Emilia-Romagna	40100	7	✓
145	B145	44.800263	11.411184	Via 8 Marzo	D02	Bologna	Bologna	Emilia-Romagna	40100	7	✓
146	B146	44.800238	11.411681	Via Gioacchino Rossini	D03	Bologna	Bologna	Emilia-Romagna	40100	7	✓

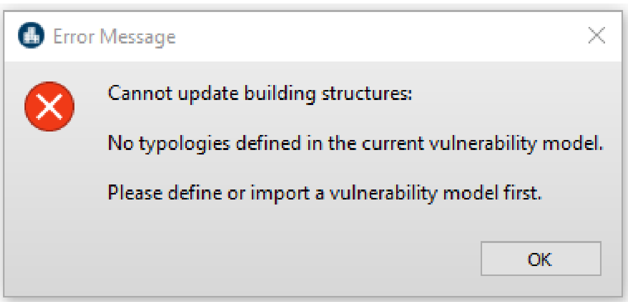
Example viewing the combined LOCATION and STRCUTURE data in the LIQUEFACT software by clicking on the module *ALL*.



All imported LOCATION and STRUCTURE in the Profile Data can be edited and modified in the LIQUEFACT software, by clicking on Add row, Delete rows. Also, in the *ALL* module the combined assets data can be exported by clicking on the *Export* button. The combined Portfolio data can be imported as tab-separated CSV, unformatted TXT or SHAPE files (ESRI defined formats).



NOTE: the STRUCTURE Portfolio Data should be imported after Vulnerability Model is already imported and defined in the software. In case STRUCTURE Portfolio Data is imported first, *Error Message* will display regarding the undefined TYPOLOGY parameter.



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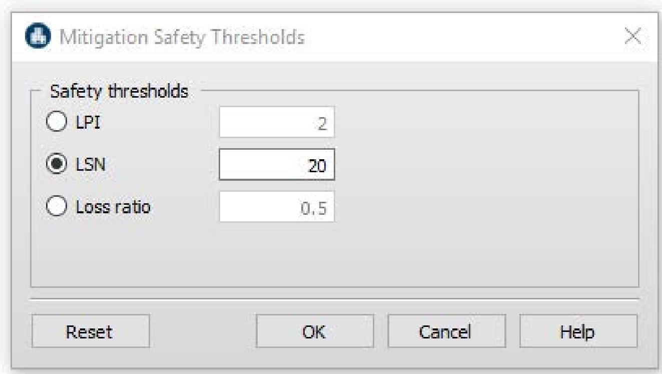
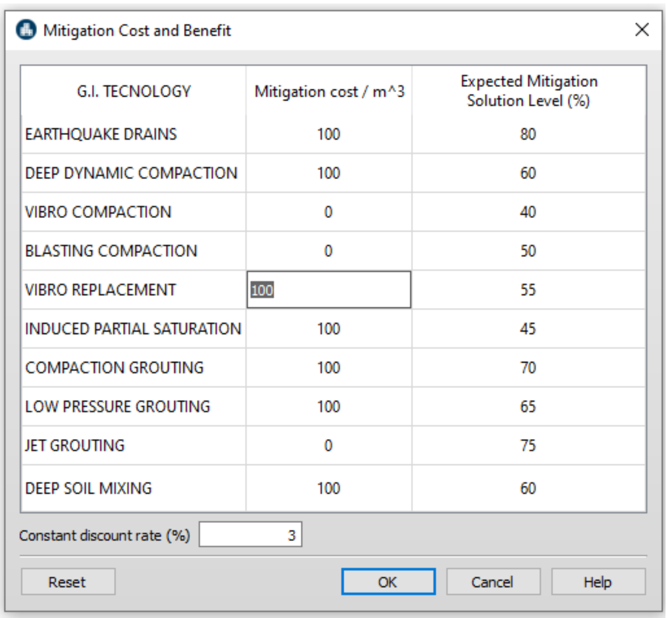
2.4 Mitigation Input Data

For Mitigation analysis, one of the steps required to be implemented by users is to define the target factor and associated value for which a given asset/assets will be selected to undergo mitigation analysis based on the result of hazard and risk analysis. This can be implemented in *Settings > Mitigation > Safety Thresholds*.



From *Settings > Mitigation > Cost and Benefit*, users are required to provide input regarding mitigation technology cost and level of efficiency of each technology that will be considered for mitigation assessment and cost-benefit analysis.

More Details are provided in section *Processing Settings*, however, it is highly important to note that information provided in this section of Mitigation is very critical, and results of mitigation analysis are sensitive to the input data. It is highly recommended that entered information are provided and reviewed by an experienced local engineer with sufficient knowledge and expertise.



Once mitigation settings are completed, and by clicking on *Processing* button *Disclaimer message* will be displayed describing conditions of using the Mitigation Analysis System, that is incorporated in the software.

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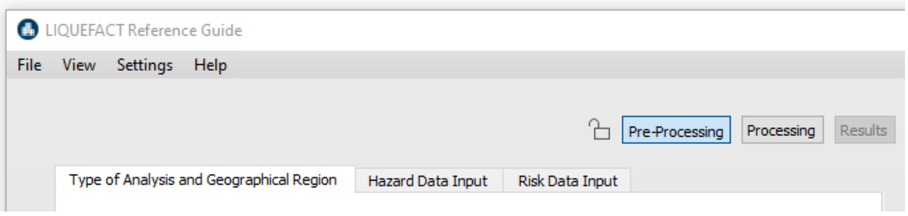
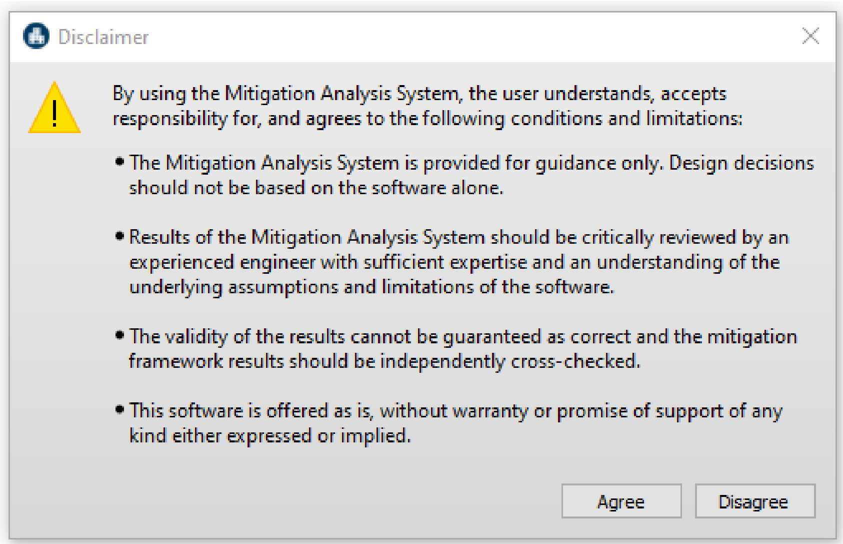
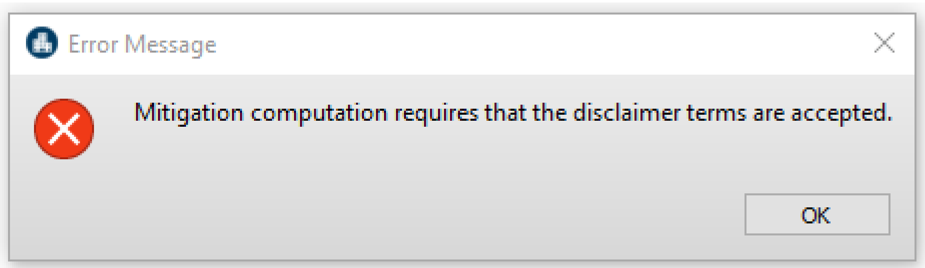


The Disclaimer message asks users to *Agree* or *Disagree* to the conditions.



If users do not accept the conditions by clicking on *Disagree* button the software will not run the analysis, showing the following *Error message*.



If users accept the conditions by clicking on *Agree* button the software starts the analysis processing.

During the analysis processing, more precisely, when the part related to seismic and liquefaction hazard are completed and level of loss of performance and functionality of individual building/infrastructure assets has been established, users will be directed to develop a customized mitigation measure based on cost-benefit analysis.

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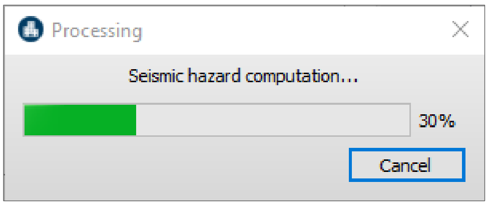
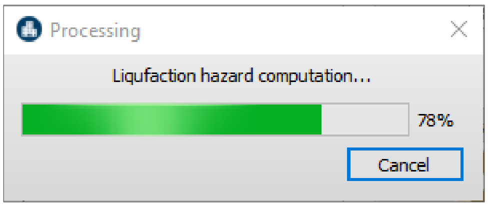
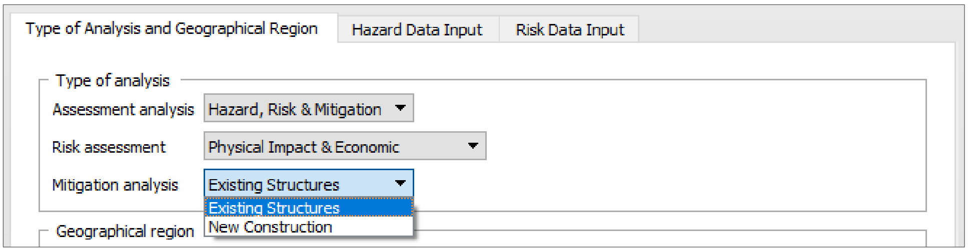




Based on the outcomes of the hazard-risk analysis, a range of mitigation actions are to be identified. In the LIQUEFACT software, 10 types of mitigation technologies are considered and there are all for reducing the hazard level, i.e. for ground improvement mitigation. The mitigation technologies will be ranked according to their impact on improving the assets site ground conditions and on their contribution to improving overall performance of the building/infrastructure assets.

The technologies selection process is based on applicability criteria and score rating considering the most influential factors. The first step in scoring the applicability and eliminate some ground improvement technologies is to define site conditions: if site or location of interest is a free field condition or if there are existing buildings or infrastructures.



Other factors include soil type, stratigraphy, depth of liquefiable zone, size of area to be improved, foundation type, constrains, presence any subsurface obstructions, and environmental compatibility. Table 2 illustrates the list of the factors considered in the system, and they are classified in terms of level of importance to the applicability criteria and weighted accordingly.

Applicability Factors for Ground Improvement Mitigation Technologies	
1. *Site conditions*	1.1) Free field
	1.2) Existing buildings
2. *Soil type*	2.1) Gravel soils
	2.2) Sandy soils
	2.3) Inorganic silts, clays silts of low to medium plasticity
3. *Stratigraphy*	3.1) Soil crust
	3.2) No soil crust
4. *Depth of the treatment zone*	4.1) <3 m
	4.2) 3-12 m
	4.3) 12-18 m
	4.4) 18-25 m
5. *Size of area to be improved*	5.1) Small (<1000 m^2)
	5.2) Medium (1000-5000 m^2)
	5.3) High (>5000 m^2)
6. *Foundation type*	6.1) Shallow foundations
	6.2) Deep foundations
7. *Project constrains*	7.1) Low overhead clearance
	7.2) Adjacent structures

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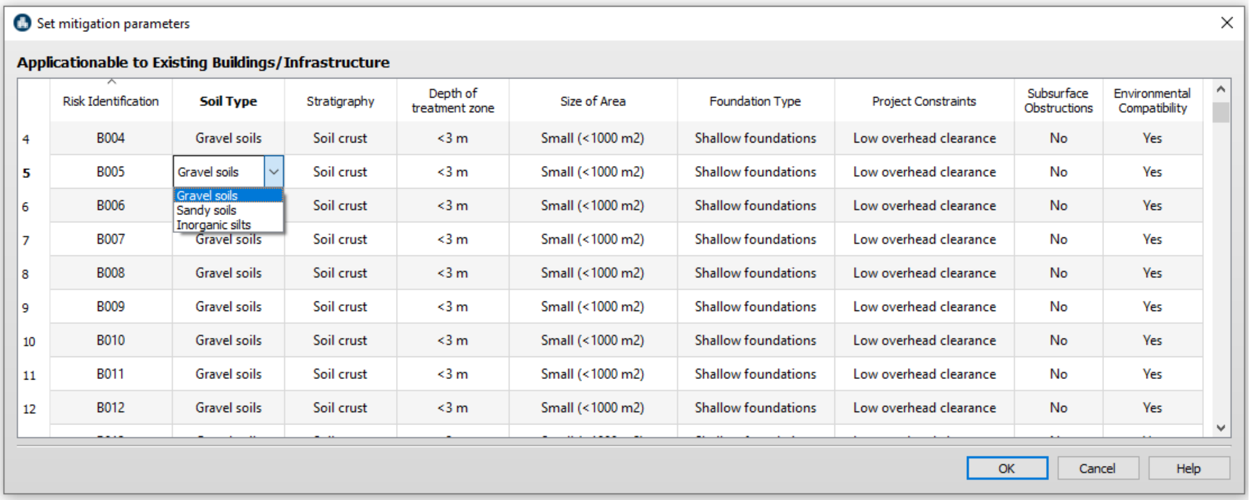
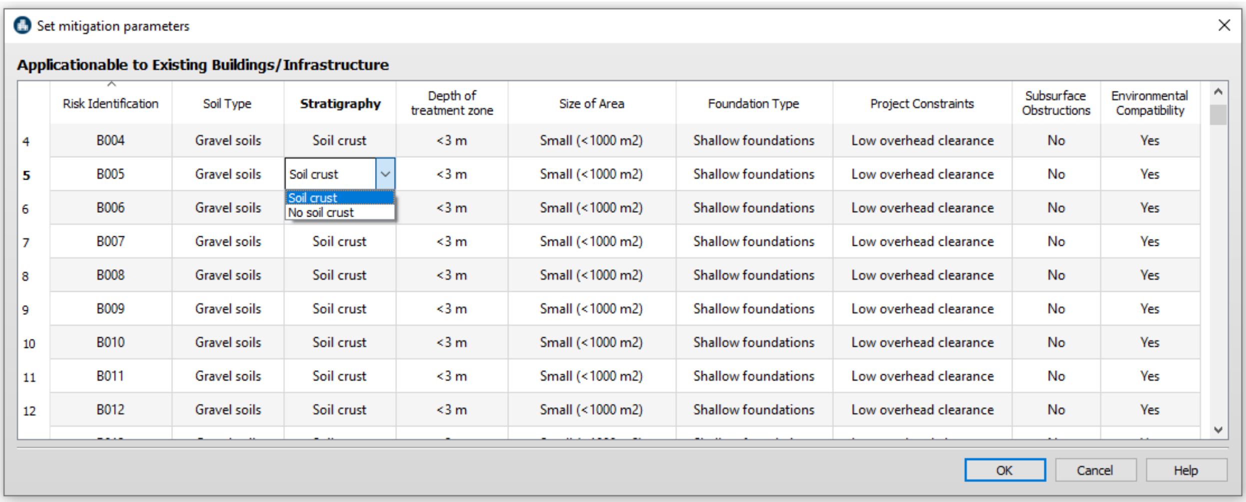
	7.3) Existing utilities
8. *Presence of subsurface obstructions*	
9. *Environmental compatibility*	

Select Soil Type for each building/infrastructure asset



	Risk Identification	Soil Type	Stratigraphy	Depth of treatment zone	Size of Area	Foundation Type	Project Constraints	Subsurface Obstructions	Environmental Compatibility
4	B004	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
5	B005	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
6	B006		Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
7	B007	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
8	B008	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
9	B009	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
10	B010	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
11	B011	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
12	B012	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes

Select Stratigraphy for each building/infrastructure asset



	Risk Identification	Soil Type	Stratigraphy	Depth of treatment zone	Size of Area	Foundation Type	Project Constraints	Subsurface Obstructions	Environmental Compatibility
4	B004	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
5	B005	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
6	B006	Gravel soils		<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
7	B007	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
8	B008	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
9	B009	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
10	B010	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
11	B011	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
12	B012	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes

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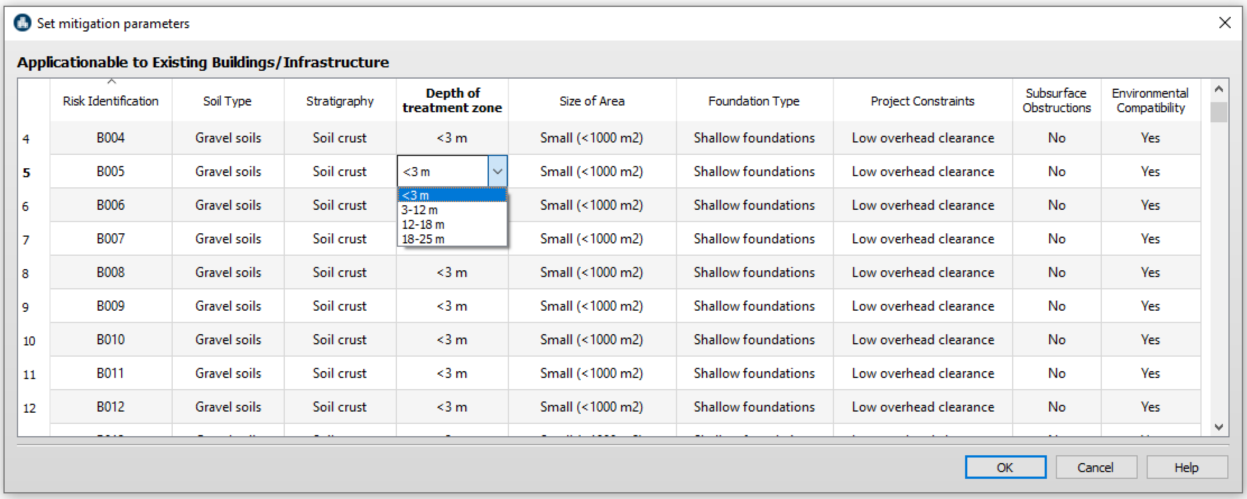
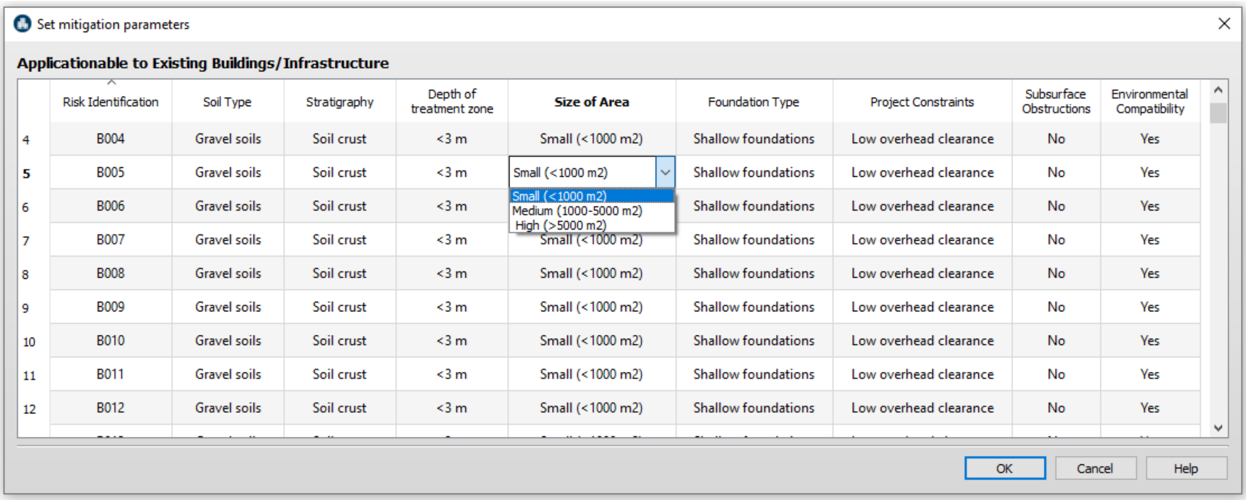
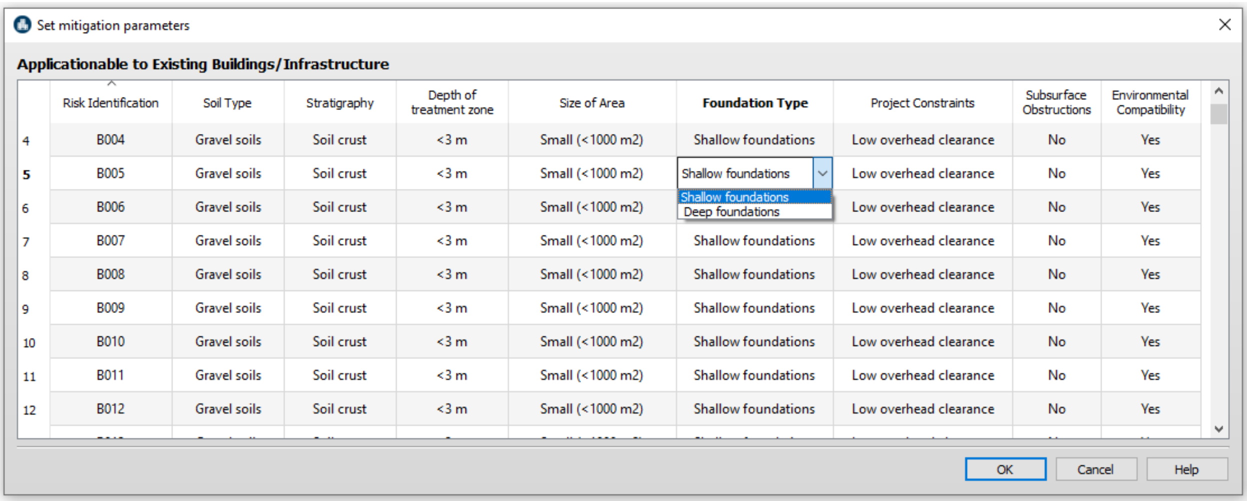
Select Depth of treatment zone for each building/infrastructure asset



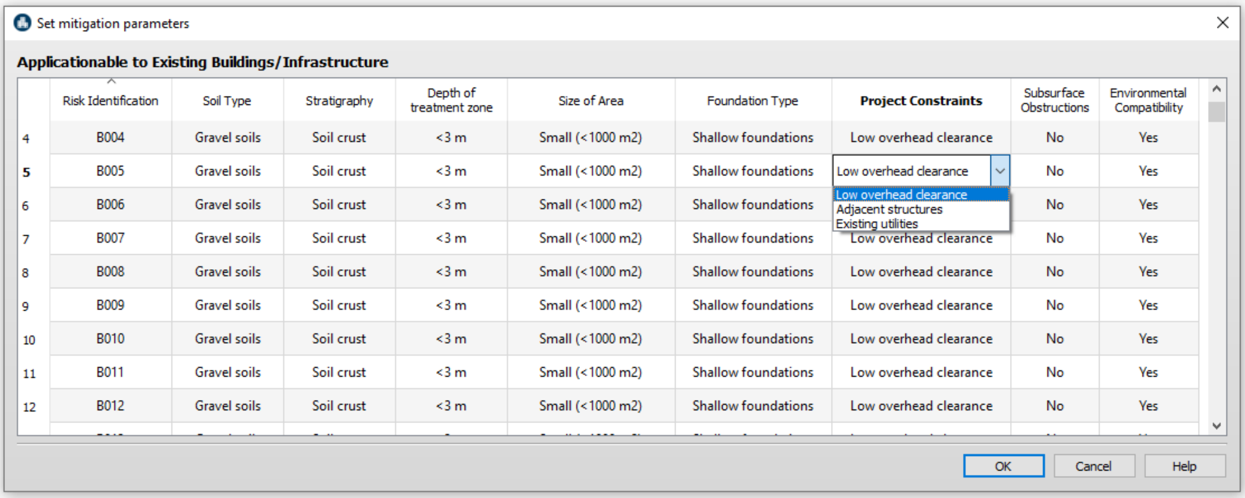
Select Size of Area for each building/infrastructure asset



Select Foundation Type for each building/infrastructure asset

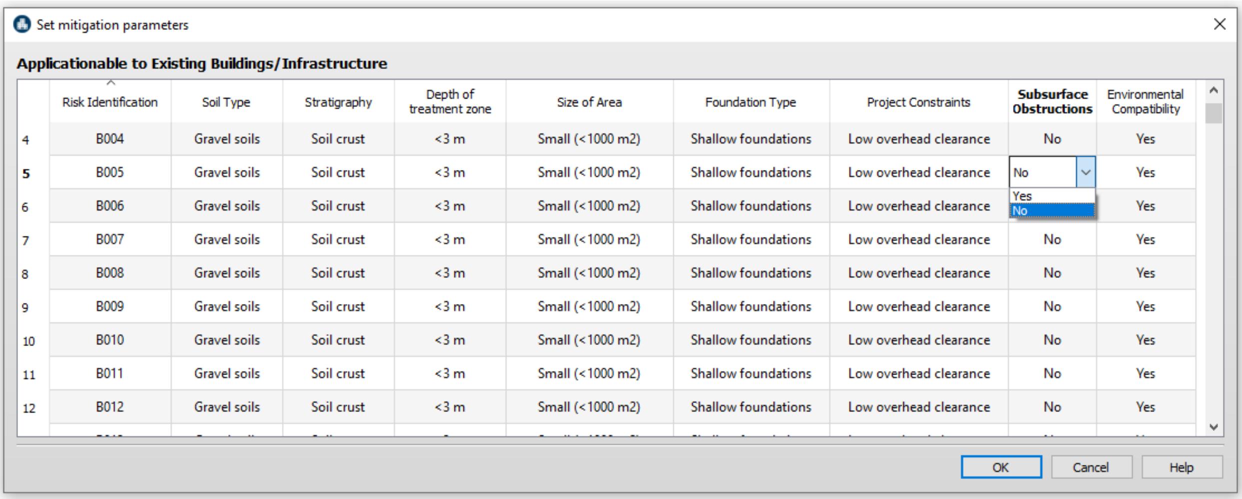


Select Project constraints at the site of each building/infrastructure asset



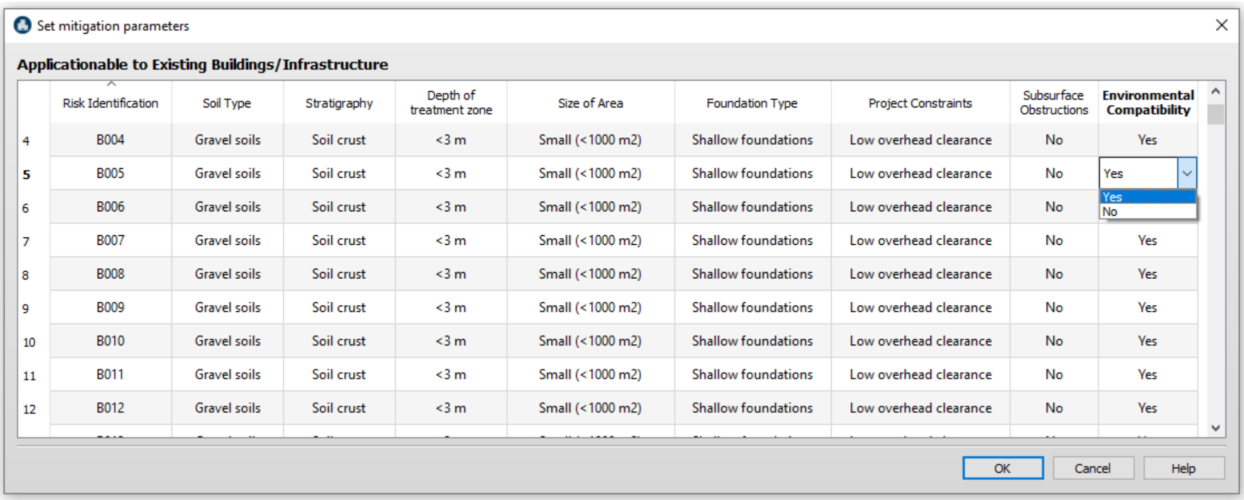
	Risk Identification	Soil Type	Stratigraphy	Depth of treatment zone	Size of Area	Foundation Type	Project Constraints	Subsurface Obstructions	Environmental Compatibility
4	B004	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
5	B005	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
6	B006	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations		No	Yes
7	B007	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
8	B008	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
9	B009	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
10	B010	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
11	B011	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
12	B012	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes

Select subsurface obstructions at the site of each building/infrastructure asset



	Risk Identification	Soil Type	Stratigraphy	Depth of treatment zone	Size of Area	Foundation Type	Project Constraints	Subsurface Obstructions	Environmental Compatibility
4	B004	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
5	B005	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
6	B006	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance		Yes
7	B007	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
8	B008	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
9	B009	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
10	B010	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
11	B011	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
12	B012	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes

Select environmental compatibility at the site of each building/infrastructure asset



	Risk Identification	Soil Type	Stratigraphy	Depth of treatment zone	Size of Area	Foundation Type	Project Constraints	Subsurface Obstructions	Environmental Compatibility
4	B004	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
5	B005	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
6	B006	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	
7	B007	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
8	B008	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
9	B009	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
10	B010	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
11	B011	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes
12	B012	Gravel soils	Soil crust	<3 m	Small (<1000 m2)	Shallow foundations	Low overhead clearance	No	Yes

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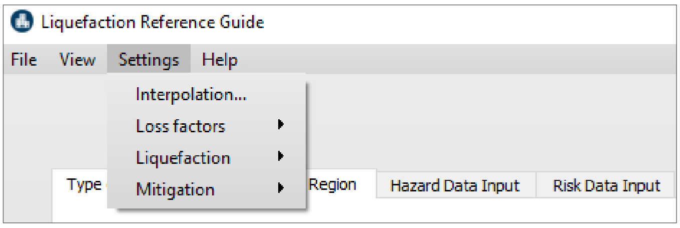
3 PROCESSING SETTINGS

This section describes the processing settings that users are required to define depending on the user's objectives and target goal of analysis. The settings to be defined are related to:

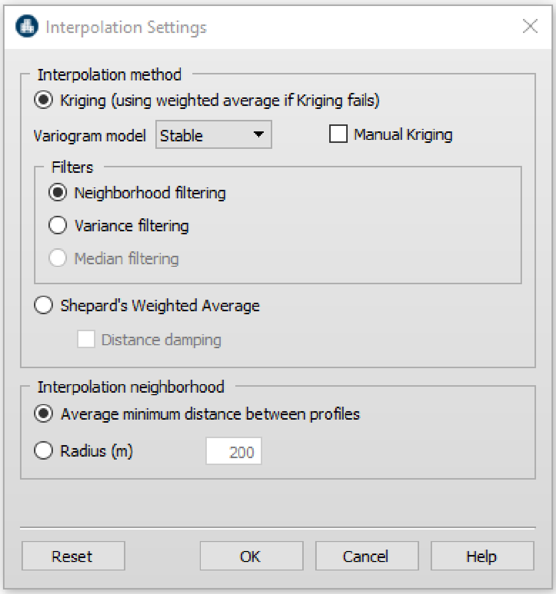
- Interpolation processing to be defined for generating seismic and liquefaction hazard maps
- Loss factors to be defined for the computation of physical and economic loss
- Definition of liquefaction qualitative risk level classification
- Mitigation parameters to be customized to user's case study



3.1 Interpolation Settings

In the LIQUEFACT software, two types of interpolation techniques for generating seismic and liquefaction hazards and the computation of risk: *Geostatistical Interpolation* and *Deterministic Interpolation* procedures.

Interpolation settings incorporated in the LIQUEFACT software.



3.1.1 Geostatistical Interpolation – Kriging Method

For Geostatistical Interpolation, ***Kriging*** method is the procedure that is incorporated in the LIQUEFACT software for generating seismic and liquefaction hazard maps. In this method, options are

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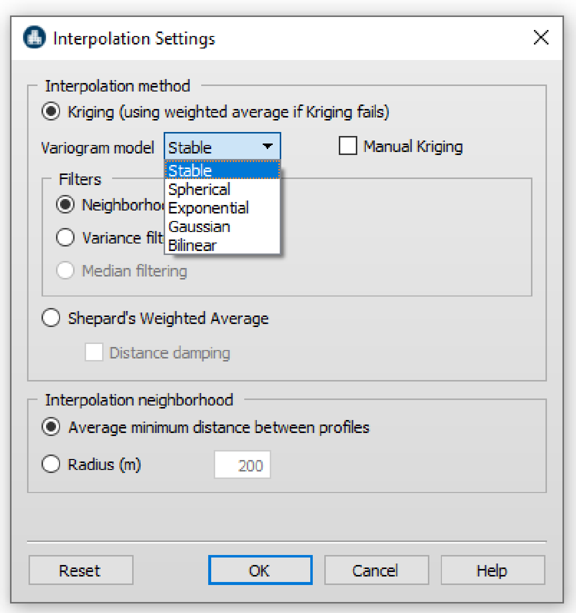
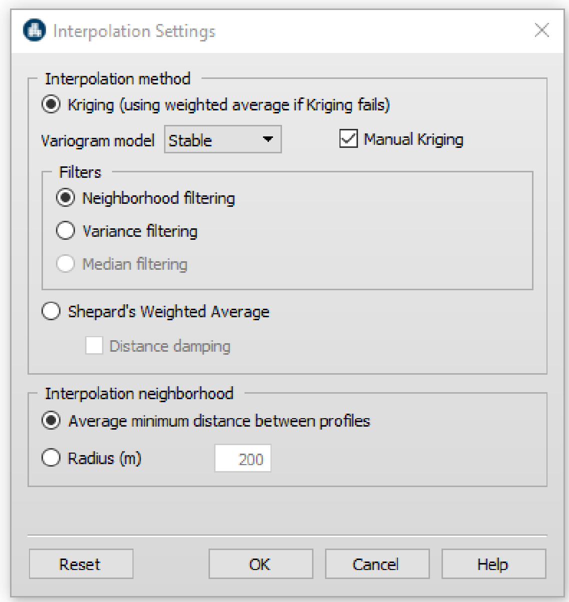
provided for variogram model and users can select between *__Stable__*, *__Spherical__*, *__Exponential__*, *__Gaussian__*, or *__Bilinear__* model. In addition, options for data population filtering is provided.
Note that in case Kriging method fails to interpolate input data, weighted average method of interpolation will be automatically used by the software to generate maps.



Alternatively, user can carry out manual Kriging for the interpolation of the soil and liquefaction input data as shown in the figures below. This can be done by ticking the box "*__Manual Kriging__*".



In this case, use will be required to manually define the Variogram parameters to fit the population variance by defining: the variogram model (Stable, Spherical, Exponential, Gaussian, and Bilinear), Nugget, Sill, Range, Maximum distance, Lag length.

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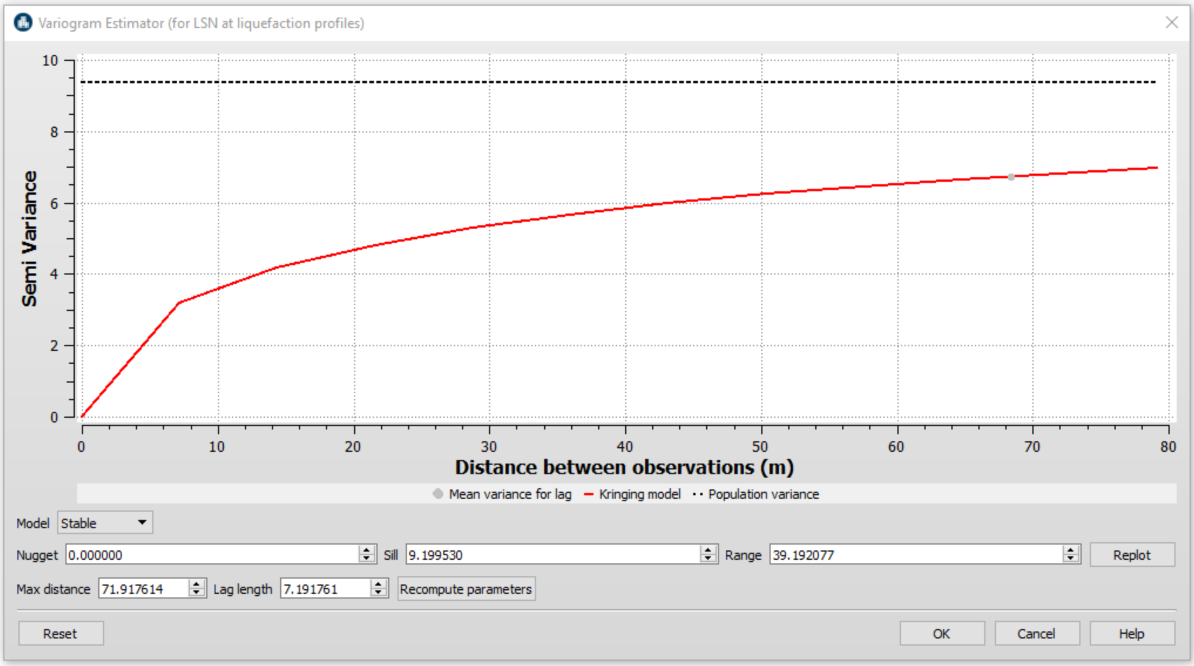
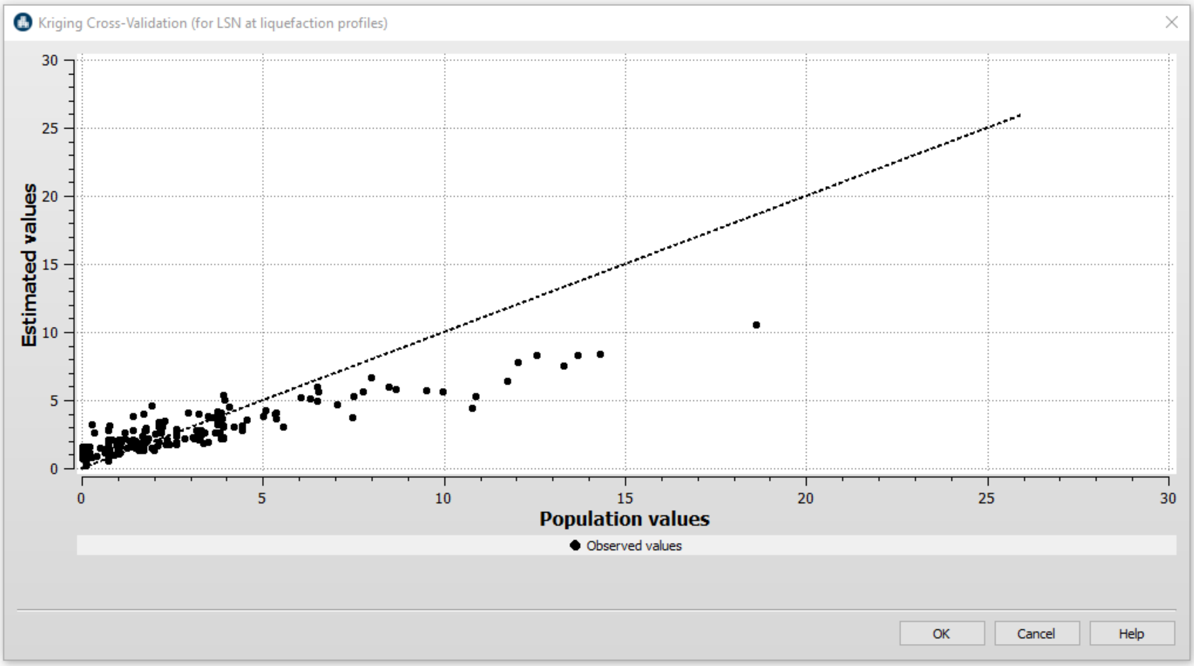


Next, cross-validation graph will be plotted showing result of the choices made manually by the user regarding the selected variogram parameters. The user can use this graph as a guidance cross-checking for a better selection and modelling of the variogram.



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3.1.2 Deterministic Interpolation – Weighted Average Method

For Deterministic Interpolation, ***Shepard's Weighted Average*** is the interpolation technique that is incorporated in the LIQUEFACT software for generating seismic and liquefaction hazard maps.

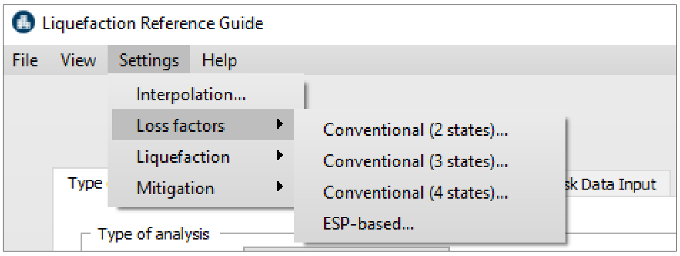
3.1.3 Interpolation Neighborhood

In addition, options for data interpolation neighbourhood between profiles are provided., where user can select between:

- Average minimum distance between the used data profiles, which will be computed automatically by the software.
- User provide manually an estimation of the radius between the data profiles.

3.2 Loss Factors Settings

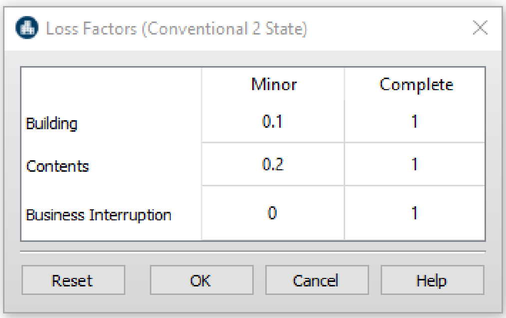
For Risk analysis, one of the steps required to be implemented by users is to define <u>*Loss Factor*</u> to be associated to fragility and selected vulnerability analysis procedure for the computation of losses. Loss factors should be defined for *Building*, *Contents* and *Business Interruption*. In general, the values can be different from country to country and should be estimated by an experienced local engineer. Loss Factors can be defined in <u>*Settings > Mitigation >*</u>.



Note that the software uses default values, but users can edit these values by double click.

3.2.1 Loss Factors for Conventional Vulnerability Analysis

Loss factor for fragility curves with two Damage Limit States.



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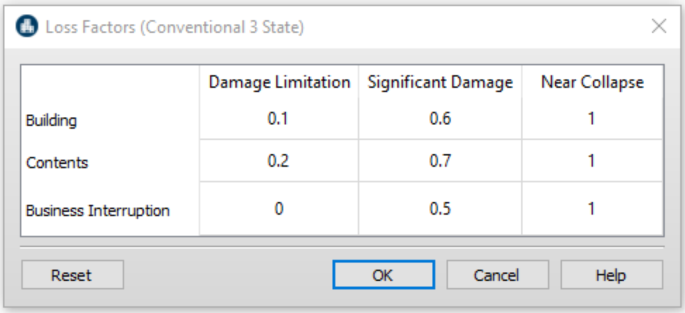
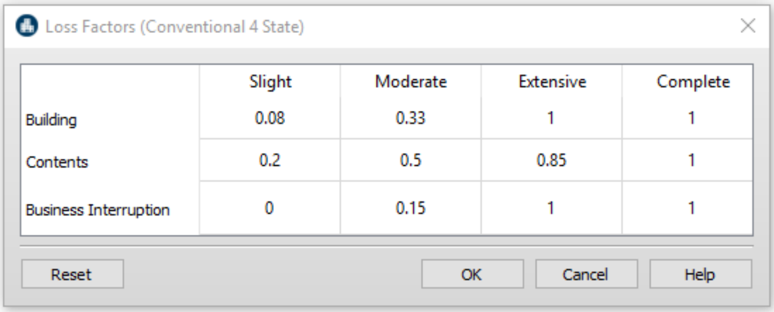
Loss factor for fragility curves with three Damage Limit States.



	Damage Limitation	Significant Damage	Near Collapse
Building	0.1	0.6	1
Contents	0.2	0.7	1
Business Interruption	0	0.5	1

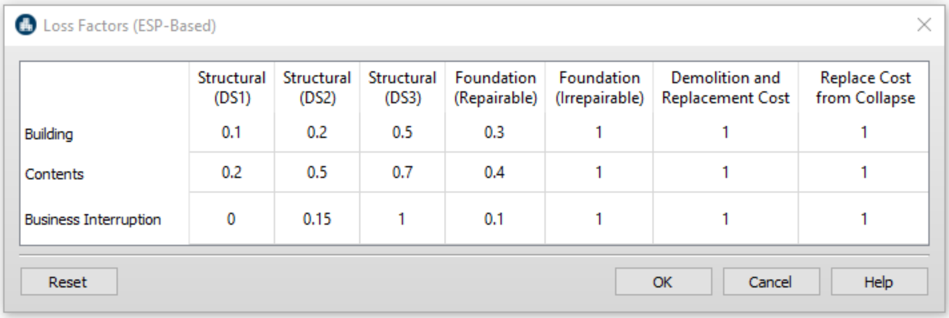
Loss factor for fragility curves with four Damage Limit States.



	Slight	Moderate	Extensive	Complete
Building	0.08	0.33	1	1
Contents	0.2	0.5	0.85	1
Business Interruption	0	0.15	1	1

3.2.2 Loss Factors for ESP-based Vulnerability Analysis

Loss factor for ESP-based fragility curves.



	Structural (DS1)	Structural (DS2)	Structural (DS3)	Foundation (Repairable)	Foundation (Irrepairable)	Demolition and Replacement Cost	Replace Cost from Collapse
Building	0.1	0.2	0.5	0.3	1	1	1
Contents	0.2	0.5	0.7	0.4	1	1	1
Business Interruption	0	0.15	1	0.1	1	1	1

3.3 Liquefaction Risk Levels Definition Settings

In the LIQUEFACT software, the resulted values of liquefaction severity indicator in terms of LPI and LSN are also presented in form of Risk Level Qualitative Classification, in order to help non-technical end-users to easily understand the estimated level of risk of liquefaction-induced ground deformation.

In literature various qualitative-based classification definitions associated with LPI and LSN range values have been introduced in order to quantify the different liquefaction risk level to the ground.

For LPI, the ranges values associated to the different risk level classes are by default mainly adopted and modified from the classes suggested by Iwasaki et al. (1978). However, users can always modify

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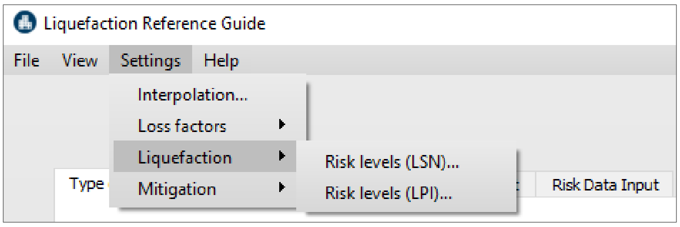
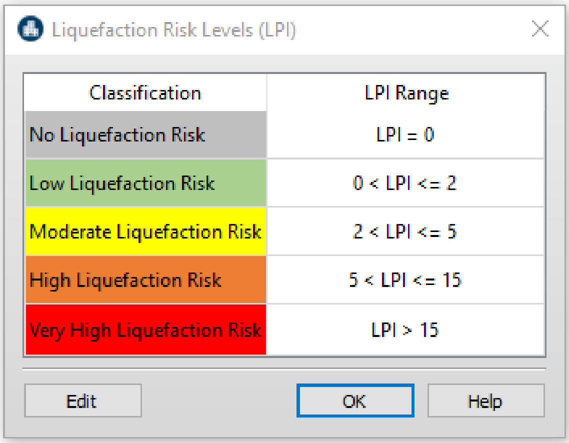
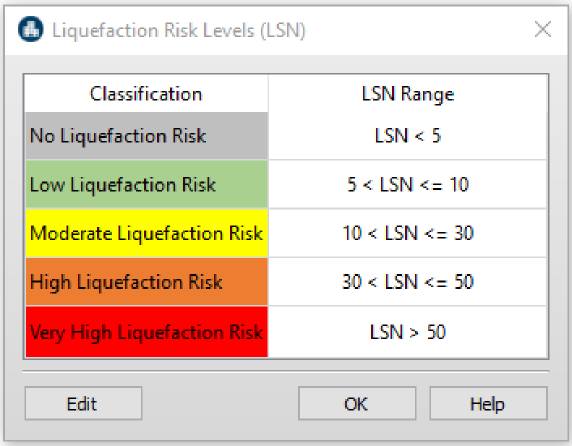
these ranges values, by going from *Settings* to *Liquefaction* and then Risk levels (LPI), and click on *Edit* button to modify the LPI range.

For LSN, the ranges values associated to the different risk level classes are by default mainly adopted and modified from the classes suggested by Tonkin and Taylor (2013). However, users can always modify these ranges values, by going from *Settings* to *Liquefaction* and then Risk levels (LSN), and click on *Edit* button to modify the LSN range.





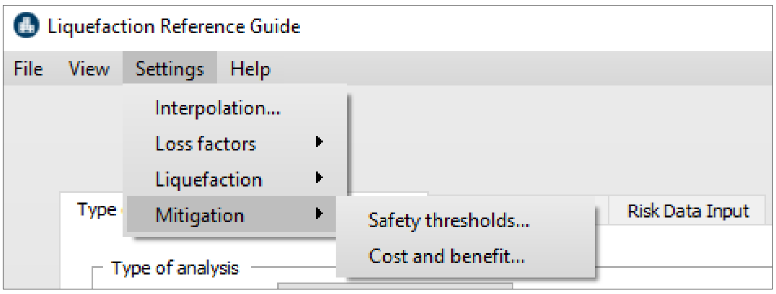
Classification	LPI Range
No Liquefaction Risk	LPI = 0
Low Liquefaction Risk	0 < LPI <= 2
Moderate Liquefaction Risk	2 < LPI <= 5
High Liquefaction Risk	5 < LPI <= 15
Very High Liquefaction Risk	LPI > 15



Classification	LSN Range
No Liquefaction Risk	LSN < 5
Low Liquefaction Risk	5 < LSN <= 10
Moderate Liquefaction Risk	10 < LSN <= 30
High Liquefaction Risk	30 < LSN <= 50
Very High Liquefaction Risk	LSN > 50

3.4 Mitigation Definition Settings

Mitigation definition settings provide users with options on how a given asset/assets is selected to undergo mitigation analysis, and to define the various ground improvement technologies that will be considered for the cost-benefit analysis.



Important to note that information provided in this section of Mitigation is very critical, and results of mitigation analysis are sensitive to the input data. It is highly recommended that the information

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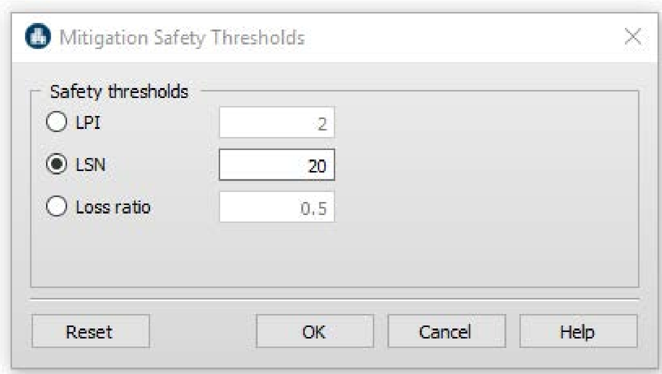
entered in this section is provided and reviewed by an experienced local engineer with sufficient knowledge and expertise.

3.4.1 Mitigation Safety Threshold Settings

This is a very important step where users can define the target factor and the associated value for which a given asset(s) will be selected to undergo mitigation analysis based on the result of hazard and risk analysis. The target factor and the associated value can be in terms of:

- Liquefaction Potential Index
- Liquefaction Severity Number
- Loss Ratio



3.4.2 Mitigation Cost and Benefit Settings

Here users can define which ground improvement technologies that will be considered for Cost-Benefit Analysis.

- In the Section *Mitigation cost/m^3* users can define the local currency cost in m^3 for each technology. Values can be entered by double click on each cell.

  For any given mitigation technology, if the cost is left with zero "0" value then the technology will not be considered in the mitigation analysis

- In the Section *Expected Mitigation Solution Level (%)*: users are required to provide their best estimate for the level of efficiency of a given technology in terms of improving ground condition. If provided, the value must be in percentage (%) and can range from 0% to 100%.

- Constant discount rate (%): is determined from interest rates and adjusted for inflation, and traditionally ranges from 2% to 6%. A default rate value of 3% is used, but users can modify and provide their own value representing the local currency and region.

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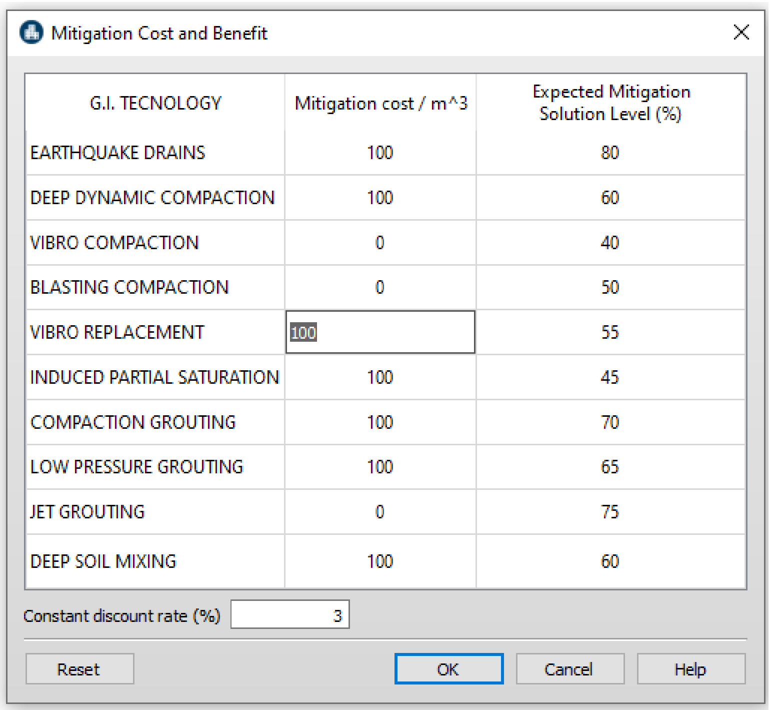
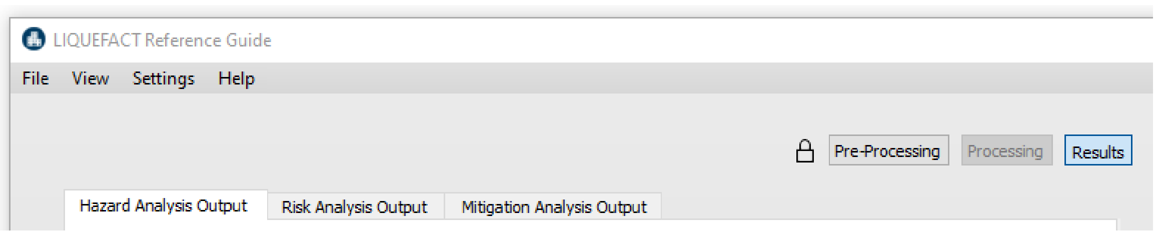


4 SOFTWARE ANALYSIS RESULTS/OUTPUT

This section provides detailed description on the different analysis outcomes and results that users can obtain form each case of selected analysis type, and interpretation of the results.

4.1 Pre-Processing and Results

Once the analysis process is finished, the *Result* button is activated, where all the results of analysis are presented. It is also possible to click *Pre-Processing* button to review the different input data but cannot be changed or modified. If users wish to modify input data than this can be done by clicking on lock icon to unlock the software and make modification/changes in the data input. However, unlocking the software will also clear results (i.e. all analysis results will be lost).



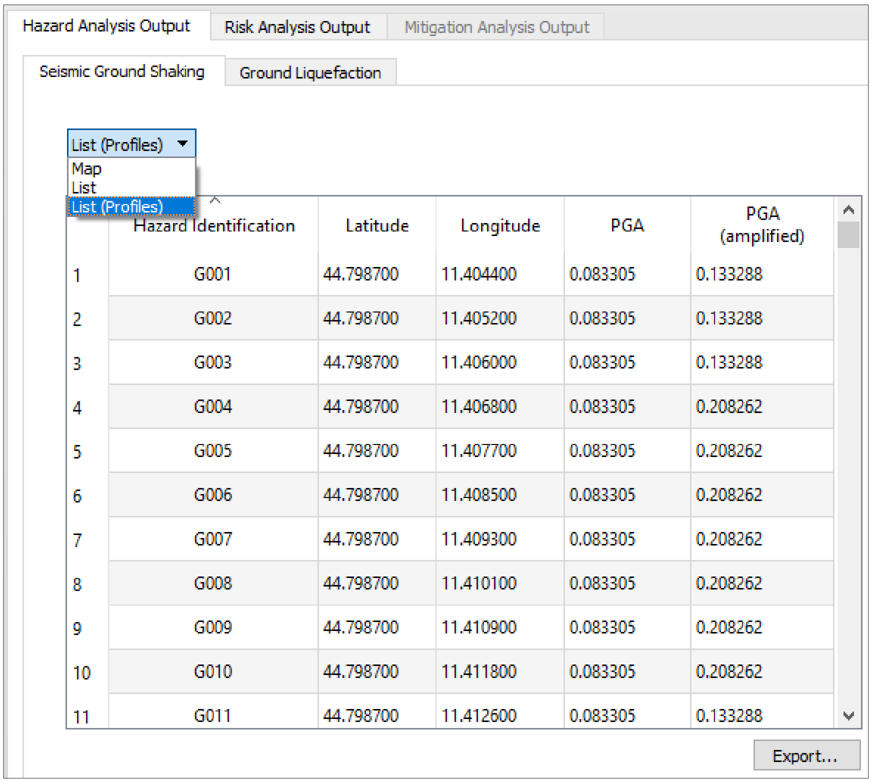
4.2 Hazard Analysis Output

Results of Hazard analysis are presented in terms of GIS-based Seismic Ground Shaking and Liquefaction Risk at the locations of interest. The results are presented as tables and interpolation-based maps.

4.2.1 Seismic Hazard Analysis Output

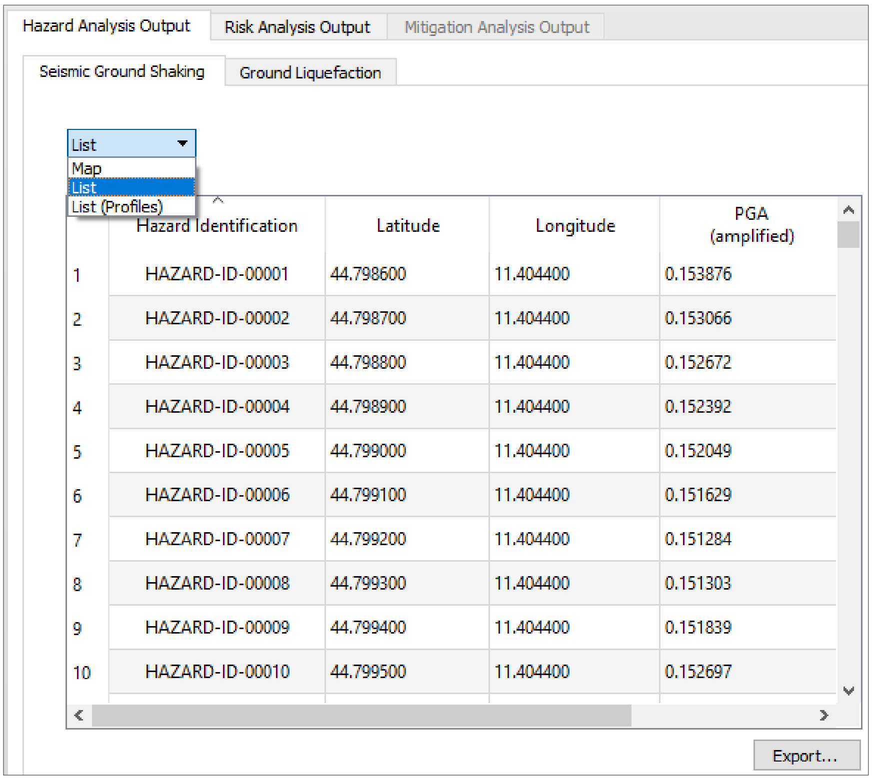
Seismic Hazard Analysis Output Parameters	*Description*
Hazard Identification	Identification number representing each soil profile used in the analysis (when List Profiles is selected) or resulted from interpolation (when List is selected)
PGA	Ground shaking at bedrock
PGA (amplified)	Ground shaking at ground surface

When ***List (Profile)*** is selected, the displayed results represent the outcomes of seismic hazard analysis in terms of peak ground acceleration computed for each soil profile.



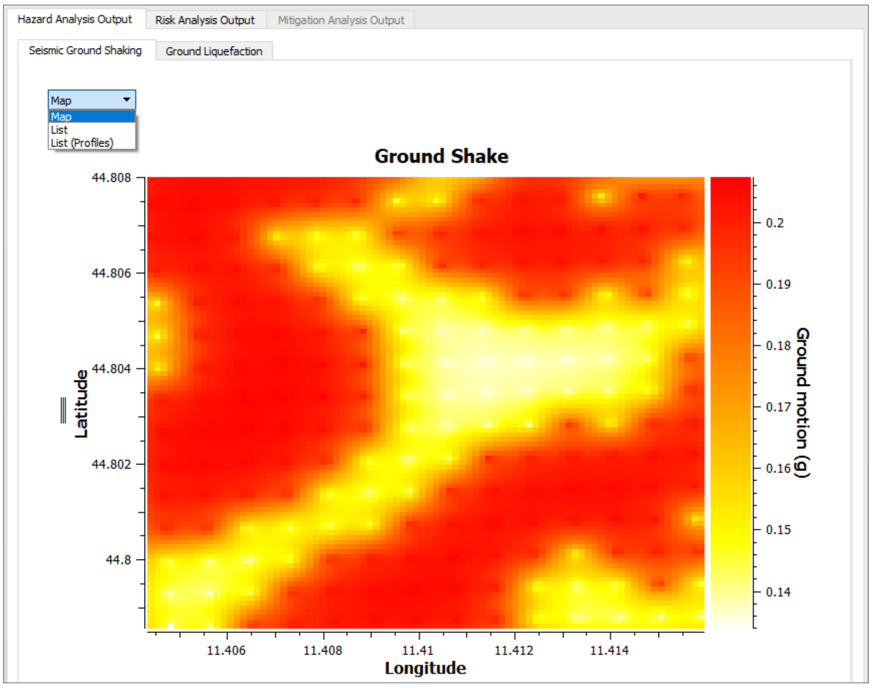
	Hazard Identification	Latitude	Longitude	PGA	PGA (amplified)
1	G001	44.798700	11.404400	0.083305	0.133288
2	G002	44.798700	11.405200	0.083305	0.133288
3	G003	44.798700	11.406000	0.083305	0.133288
4	G004	44.798700	11.406800	0.083305	0.208262
5	G005	44.798700	11.407700	0.083305	0.208262
6	G006	44.798700	11.408500	0.083305	0.208262
7	G007	44.798700	11.409300	0.083305	0.208262
8	G008	44.798700	11.410100	0.083305	0.208262
9	G009	44.798700	11.410900	0.083305	0.208262
10	G010	44.798700	11.411800	0.083305	0.208262
11	G011	44.798700	11.412600	0.083305	0.133288

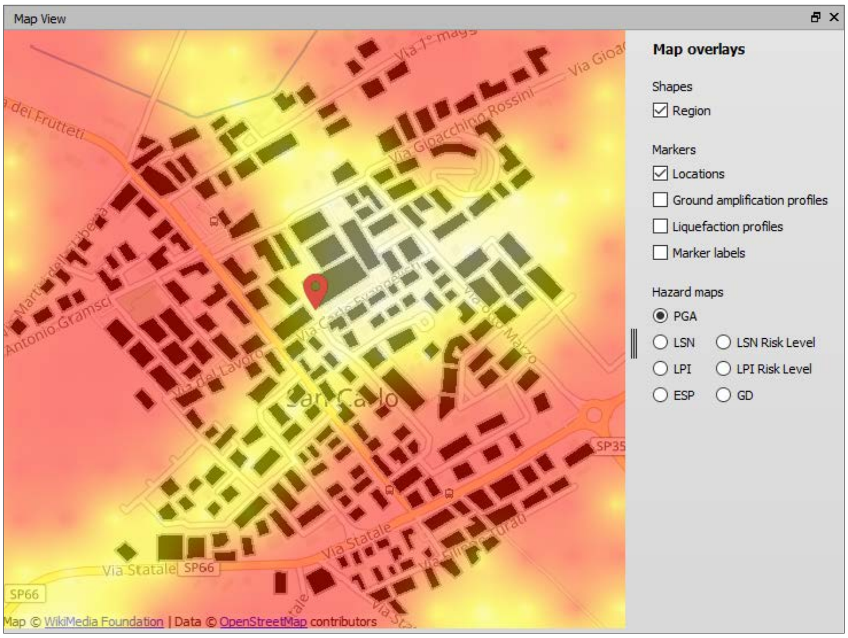
When ***List*** is selected, the displayed results represent the outcomes of seismic hazard analysis in terms of peak ground acceleration (PGA) resulted from the interpolation of the PGA values that were computed for each soil profile.



	Hazard Identification	Latitude	Longitude	PGA (amplified)
1	HAZARD-ID-00001	44.798600	11.404400	0.153876
2	HAZARD-ID-00002	44.798700	11.404400	0.153066
3	HAZARD-ID-00003	44.798800	11.404400	0.152672
4	HAZARD-ID-00004	44.798900	11.404400	0.152392
5	HAZARD-ID-00005	44.799000	11.404400	0.152049
6	HAZARD-ID-00006	44.799100	11.404400	0.151629
7	HAZARD-ID-00007	44.799200	11.404400	0.151284
8	HAZARD-ID-00008	44.799300	11.404400	0.151303
9	HAZARD-ID-00009	44.799400	11.404400	0.151839
10	HAZARD-ID-00010	44.799500	11.404400	0.152697

When ***Map*** is selected, then ground shaking PGA map resulted from the interpolation is displayed.





4.2.2 Quantitative Liquefaction Hazard Analysis Output

Quantitative Liquefaction Hazard Analysis Output Parameters	*Description*
Hazard Identification	Identification number representing each soil profile used in the analysis (when List Profiles is selected) or resulted from interpolation (when List is selected)
PGA (amplified)	Ground shaking at ground surface that was assigned to each liquefaction profile for the computation of liquefaction hazard
PGA Assignment	ID of PGA that was assigned to the liquefaction profile
LPI	Liquefaction Potential Index
Settlement (cm)	Free field settlement in cm unit
LSN	Liquefaction Severity Number
LSN (ESP)	Liquefaction Severity Number estimated from ESP-based method
ESP	Equivalent Soil Profile Class (from the 22 classes)
Liquefaction Risk Level (LPI-based)	Qualitative evaluation of liquefaction risk level based on LPI range values
Liquefaction Risk Level (LSN-based)	Qualitative evaluation of liquefaction risk level based on LSN range values

When ***List (Profile)*** is selected, the displayed results represent the outcomes of liquefaction hazard analysis in terms of multi-liquefaction severity indicators computed for each CPT, SPT or Vs profile.

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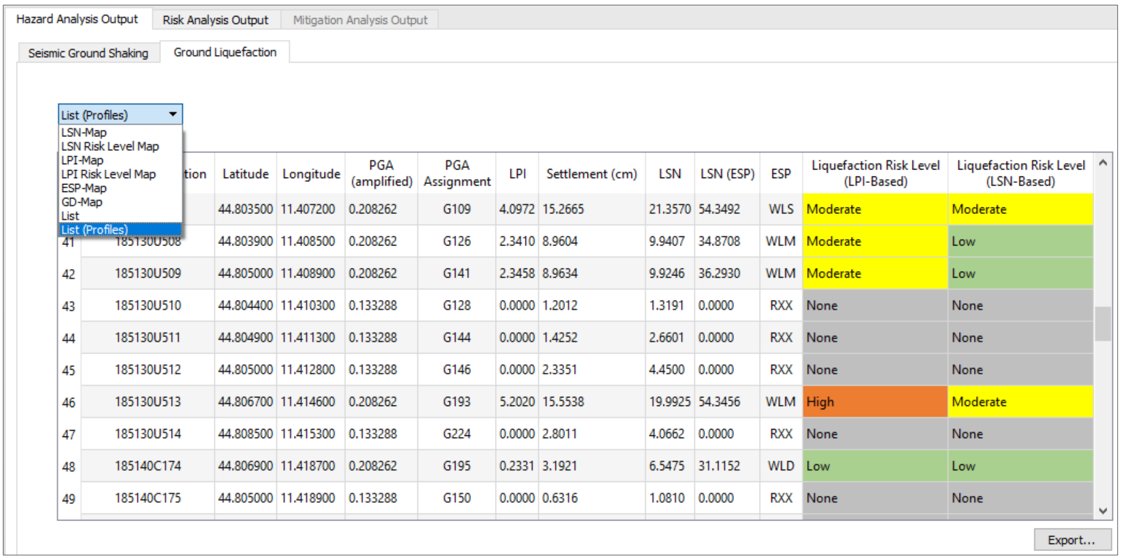
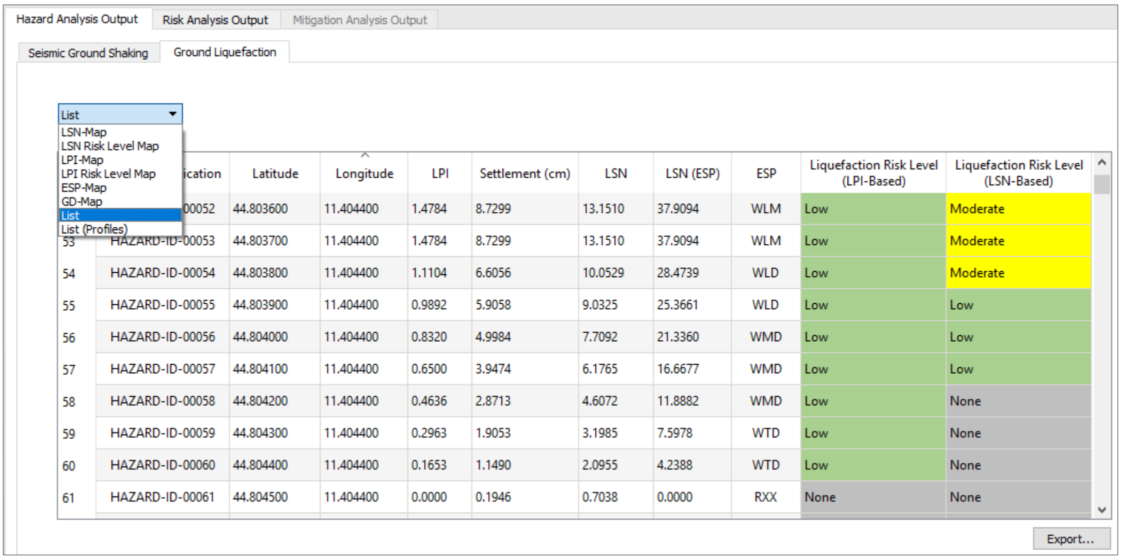


	tion	Latitude	Longitude	PGA (amplified)	PGA Assignment	LPI	Settlement (cm)	LSN	LSN (ESP)	ESP	Liquefaction Risk Level (LPI-Based)	Liquefaction Risk Level (LSN-Based)
		44.803500	11.407200	0.208262	G109	4.0972	15.2665	21.3570	54.3492	WLS	Moderate	Moderate
41	185130U508	44.803900	11.408500	0.208262	G126	2.3410	8.9604	9.9407	34.8708	WLM	Moderate	Low
42	185130U509	44.805000	11.408900	0.208262	G141	2.3458	8.9634	9.9246	36.2930	WLM	Moderate	Low
43	185130U510	44.804400	11.410300	0.133288	G128	0.0000	1.2012	1.3191	0.0000	RXX	None	None
44	185130U511	44.804900	11.411300	0.133288	G144	0.0000	1.4252	2.6601	0.0000	RXX	None	None
45	185130U512	44.805000	11.412800	0.133288	G146	0.0000	2.3351	4.4500	0.0000	RXX	None	None
46	185130U513	44.806700	11.414600	0.208262	G193	5.2020	15.5538	19.9925	54.3456	WLM	High	Moderate
47	185130U514	44.808500	11.415300	0.133288	G224	0.0000	2.8011	4.0662	0.0000	RXX	None	None
48	185140C174	44.806900	11.418700	0.208262	G195	0.2331	3.1921	6.5475	31.1152	WLD	Low	Low
49	185140C175	44.805000	11.418900	0.133288	G150	0.0000	0.6316	1.0810	0.0000	RXX	None	None

When ***List*** is selected, the displayed results represent the outcomes of liquefaction hazard analysis in terms of multi-liquefaction severity indicators resulted from the interpolation of the indicators values that were computed for each CPT, SPT or VS profile.

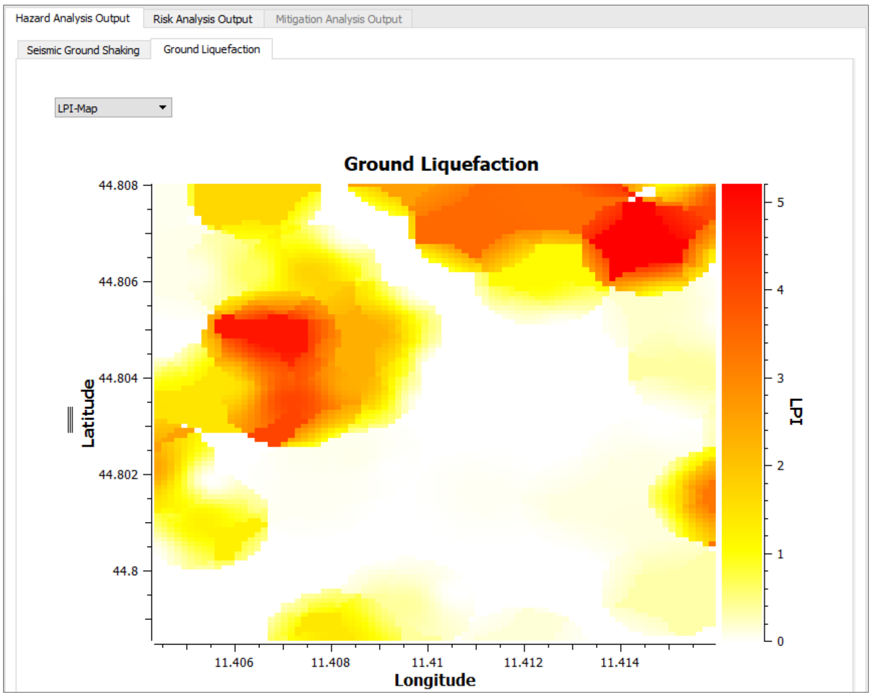


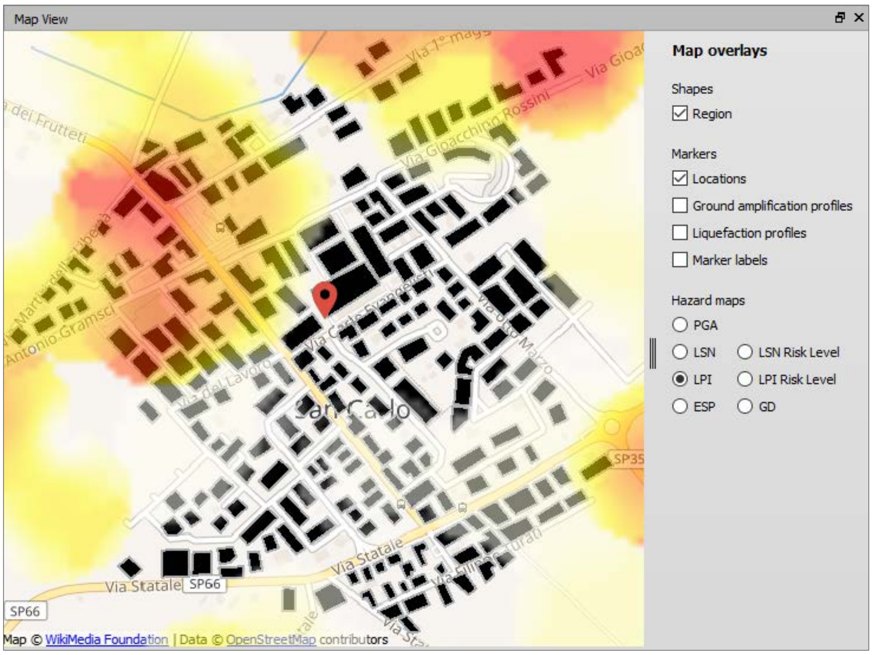
	ication	Latitude	Longitude	LPI	Settlement (cm)	LSN	LSN (ESP)	ESP	Liquefaction Risk Level (LPI-Based)	Liquefaction Risk Level (LSN-Based)
	00052	44.803600	11.404400	1.4784	8.7299	13.1510	37.9094	WLM	Low	Moderate
53	HAZARD-ID-00053	44.803700	11.404400	1.4784	8.7299	13.1510	37.9094	WLM	Low	Moderate
54	HAZARD-ID-00054	44.803800	11.404400	1.1104	6.6056	10.0529	28.4739	WLD	Low	Moderate
55	HAZARD-ID-00055	44.803900	11.404400	0.9892	5.9058	9.0325	25.3661	WLD	Low	Low
56	HAZARD-ID-00056	44.804000	11.404400	0.8320	4.9984	7.7092	21.3360	WMD	Low	Low
57	HAZARD-ID-00057	44.804100	11.404400	0.6500	3.9474	6.1765	16.6677	WMD	Low	Low
58	HAZARD-ID-00058	44.804200	11.404400	0.4636	2.8713	4.6072	11.8882	WMD	Low	None
59	HAZARD-ID-00059	44.804300	11.404400	0.2963	1.9053	3.1985	7.5978	WTD	Low	None
60	HAZARD-ID-00060	44.804400	11.404400	0.1653	1.1490	2.0955	4.2388	WTD	Low	None
61	HAZARD-ID-00061	44.804500	11.404400	0.0000	0.1946	0.7038	0.0000	RXX	None	None

Liquefaction Potential Index LPI

When ***LPI-Map*** is selected, then the Liquefaction Potential Index-based map resulted from the interpolation is displayed.

Example of resulted Liquefaction Severity Indicator maps in terms of Liquefaction Potential Index (LPI), as provided in the LIQUEFACT software.


Hazard Analysis Output
Risk Analysis Output
Mitigation Analysis Output
Seismic Ground Shaking
Ground Liquefaction
LPI-Map
Ground Liquefaction
Latitude
Longitude
LPI
44.808
44.806
44.804
44.802
44.8
11.406
11.408
11.41
11.412
11.414
0
1
2
3
4
5


Map View
Map overlays
Shapes
Region
Markers
Locations
Ground amplification profiles
Liquefaction profiles
Marker labels
Hazard maps
PGA
LSN
LSN Risk Level
LPI
LPI Risk Level
ESP
GD
Via Statale
SP66
SP35
San Carlo
Map © WikiMedia Foundation | Data © OpenStreetMap contributors

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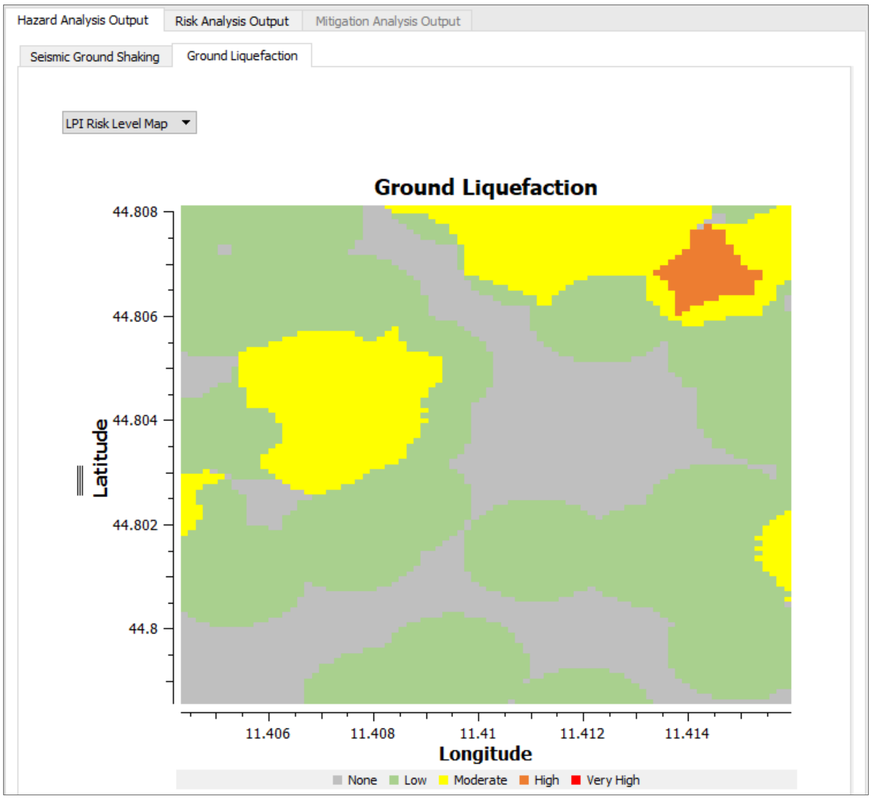
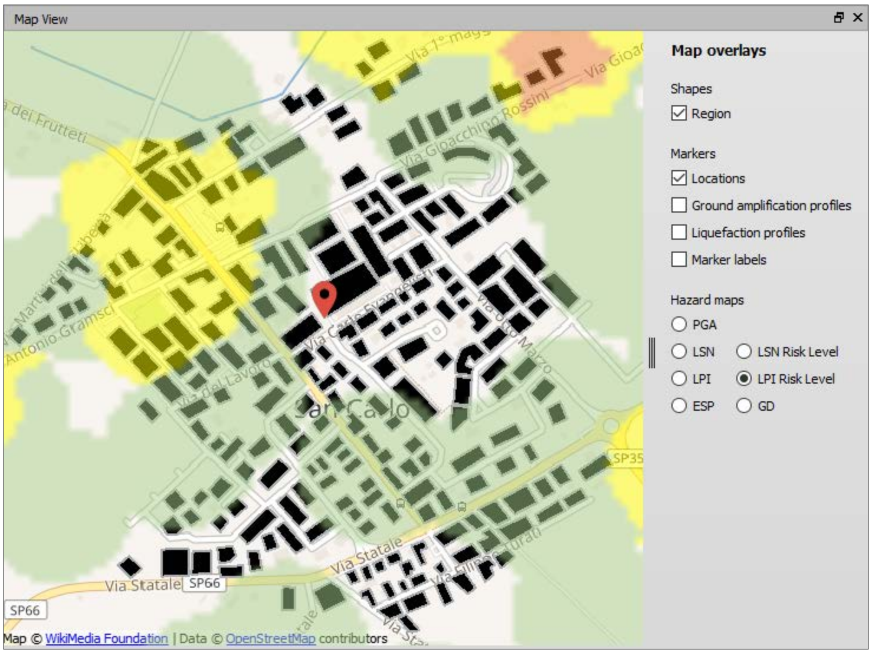
When ***LPI Risk Level Map*** is selected, then the qualitative-based liquefaction risk classification map in terms of Liquefaction Potential Index (LPI), and resulted from the interpolation, is displayed.

Example of resulted LPI Risk level classification maps, as presented in the LIQUEFACT software.

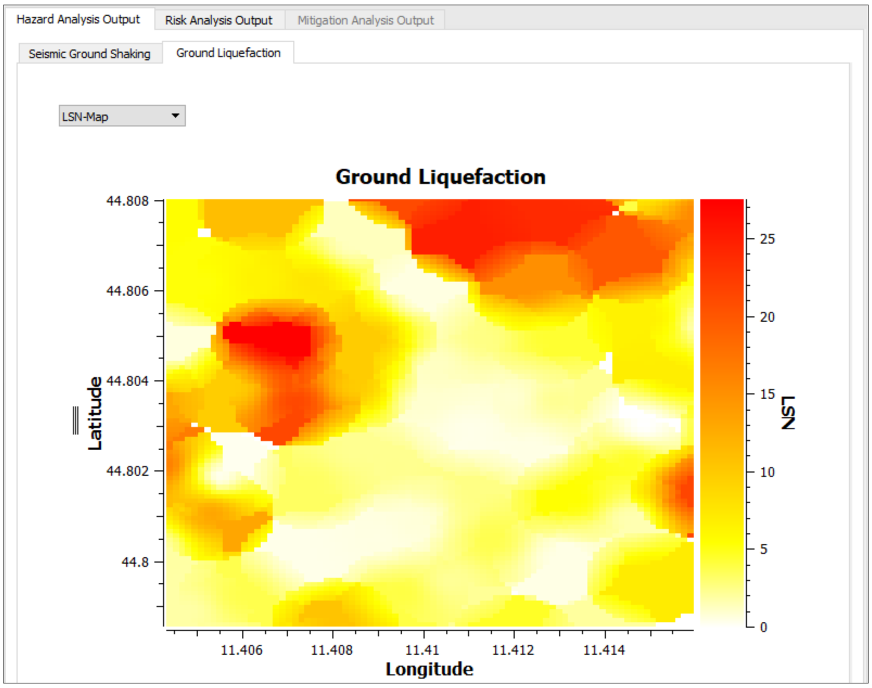


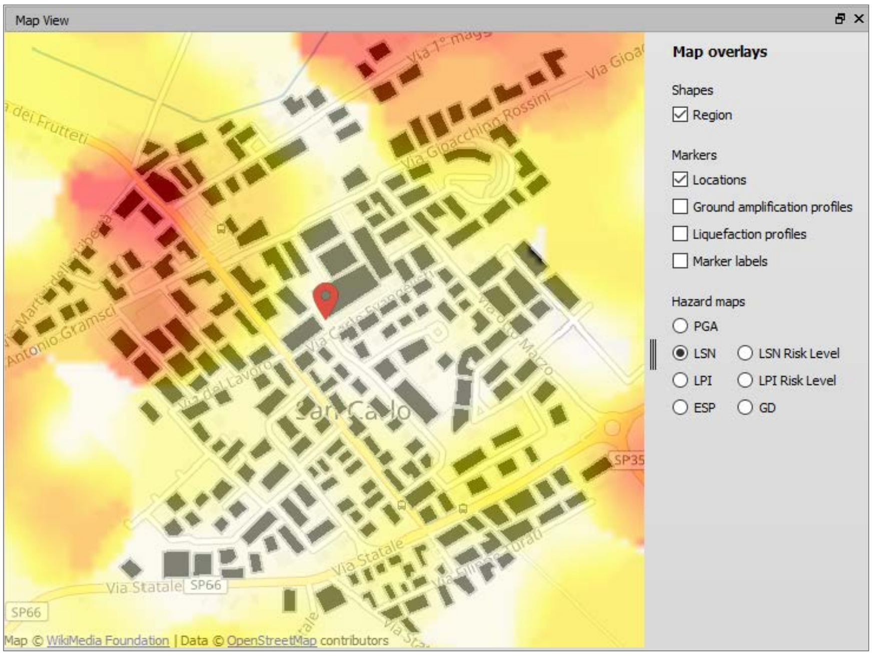


Liquefaction Severity Number LSN

When ***LSN-Map*** is selected, then the Liquefaction Severity Number-based map resulted from the interpolation is displayed.

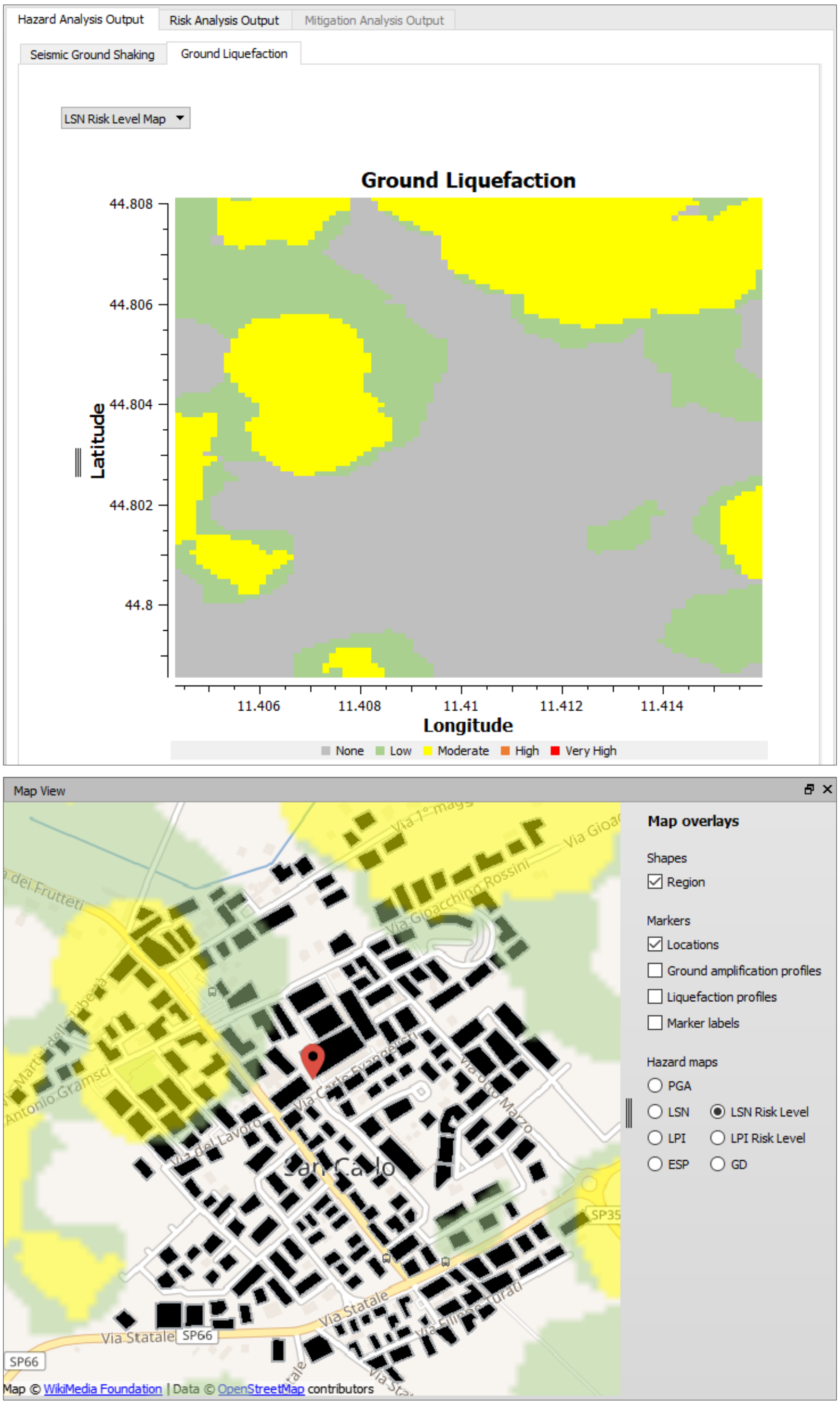
Example of resulted Liquefaction Severity Indicator maps in terms of Liquefaction Severity Number (LSN), as provided in the LIQUEFACT software.





When ***LSN Risk Level Map*** is selected, then the qualitative-based liquefaction risk classification map in terms of Liquefaction Severity Number (LSN), and resulted from the interpolation, is displayed.

Example of resulted LSN Risk level classification maps, as presented in the LIQUEFACT software.



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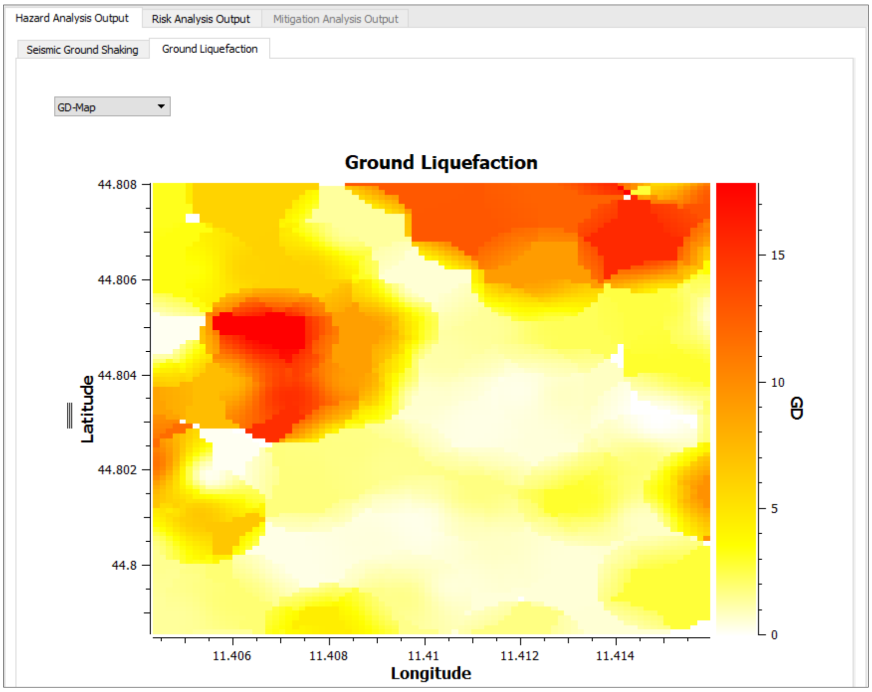
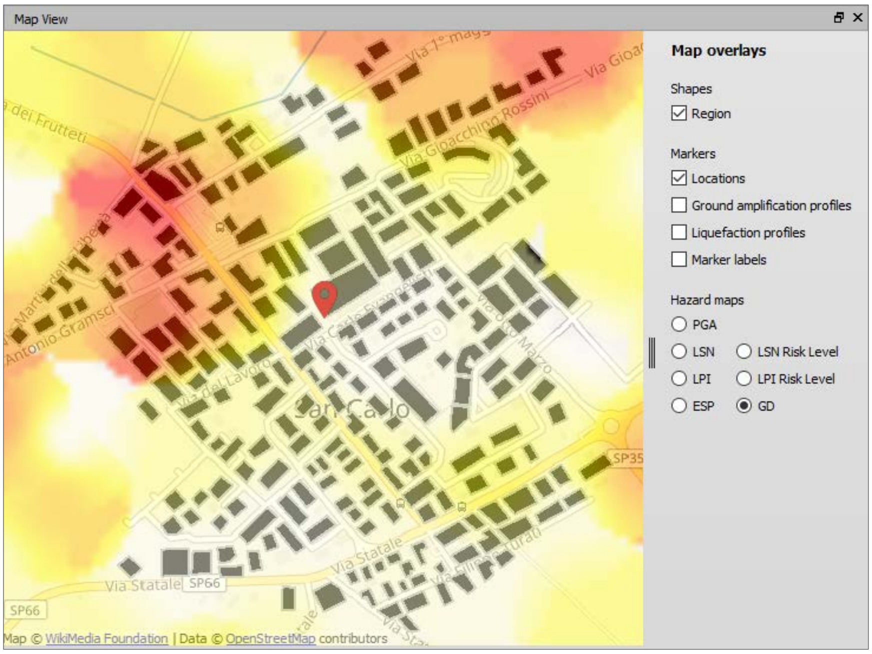
Liquefaction-Induced Ground Settlements

When ***GD-Map*** is selected, then the Ground Deformation Free-Field Settlement -based map resulted from the interpolation is displayed.

Example of resulted Liquefaction Severity Indicator in terms of Ground Deformation Free-Field Settlement, as presented in the LIQUEFACT software.





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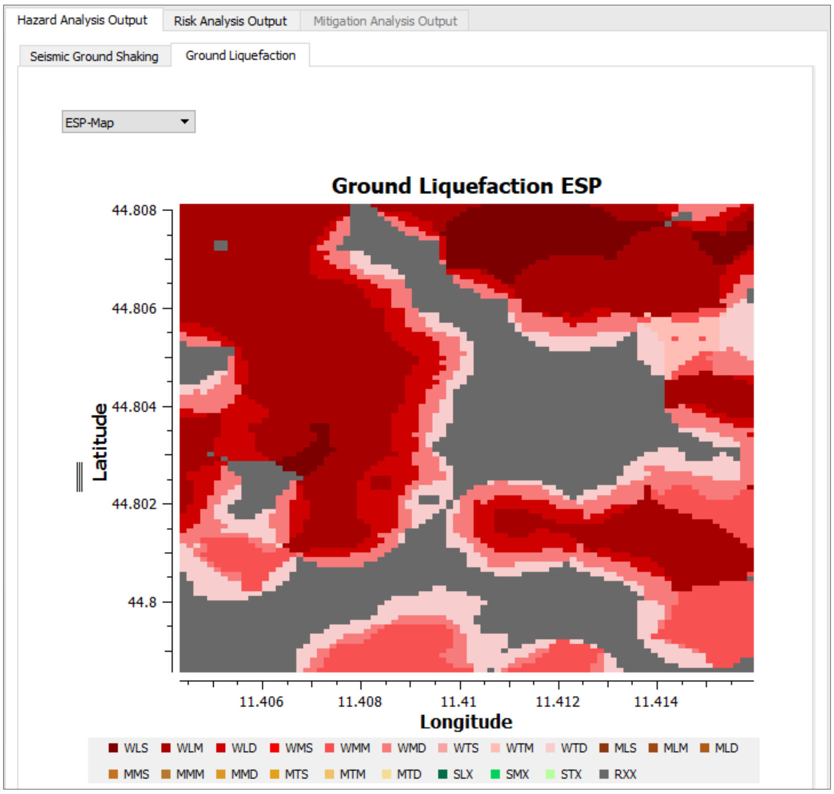
Equivalent Soil Profile (ESP)-based Classification

When ***ESP-Map*** is selected, then the Equivalent Soil Profile-based map resulted from the interpolation is displayed.

Example of resulted Liquefaction Severity Indicator in terms of Equivalent Soil Profile (ESP), as presented in the LIQUEFACT software.

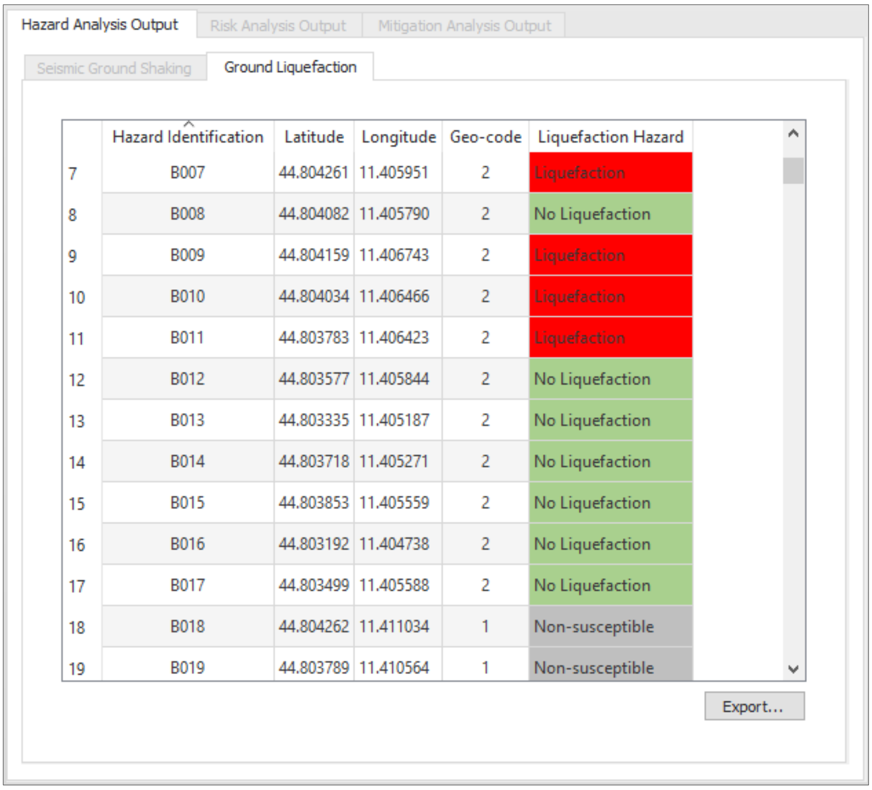


4.2.3 Qualitative Liquefaction Hazard Analysis Output

In the LIQUEFACT software, when user-supplied liquefaction hazard maps are used either through the selection of *User-Defined* or *Pre-Defined* option, location-specific levels of liquefaction hazard are not interpolated, and closest location-specific to a given asset is assigned for the evaluation of liquefaction risk.

4.2.3.1 User-Defined Liquefaction Hazard Output

Example analysis output for user-supplied liquefaction hazard map in terms of Liquefaction Hazard



	Hazard Identification	Latitude	Longitude	Geo-code	Liquefaction Hazard
7	B007	44.804261	11.405951	2	Liquefaction
8	B008	44.804082	11.405790	2	No Liquefaction
9	B009	44.804159	11.406743	2	Liquefaction
10	B010	44.804034	11.406466	2	Liquefaction
11	B011	44.803783	11.406423	2	Liquefaction
12	B012	44.803577	11.405844	2	No Liquefaction
13	B013	44.803335	11.405187	2	No Liquefaction
14	B014	44.803718	11.405271	2	No Liquefaction
15	B015	44.803853	11.405559	2	No Liquefaction
16	B016	44.803192	11.404738	2	No Liquefaction
17	B017	44.803499	11.405588	2	No Liquefaction
18	B018	44.804262	11.411034	1	Non-susceptible
19	B019	44.803789	11.410564	1	Non-susceptible

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

Example analysis output for user-supplied liquefaction hazard map in terms of Liquefaction Potential Index (LPI)

Hazard Analysis Output | Risk Analysis Output | Mitigation Analysis Output

Seismic Ground Shaking | Ground Liquefaction

	Hazard Identification	Latitude	Longitude	Geo-code	Liquefaction Probability Index (LPI)
1	B001	44.804876	11.406691	2	Very High Liquefaction Risk
2	B002	44.804555	11.406245	2	Moderate Liquefaction Risk
3	B003	44.804744	11.407085	2	Very High Liquefaction Risk
4	B004	44.804298	11.407708	2	Moderate Liquefaction Risk
5	B005	44.804456	11.407388	2	Moderate Liquefaction Risk
6	B006	44.804078	11.407326	2	Moderate Liquefaction Risk
7	B007	44.804261	11.405951	2	Moderate Liquefaction Risk
8	B008	44.804082	11.405790	2	Low Liquefaction Risk
9	B009	44.804159	11.406743	2	Moderate Liquefaction Risk
10	B010	44.804034	11.406466	2	Moderate Liquefaction Risk
11	B011	44.803783	11.406423	2	Moderate Liquefaction Risk
12	B012	44.803577	11.405844	2	Low Liquefaction Risk
13	B013	44.803335	11.405187	2	Low Liquefaction Risk

Export...

Example analysis output for user-supplied liquefaction hazard map in terms of Liquefaction Severity Number (LSN)

Hazard Analysis Output | Risk Analysis Output | Mitigation Analysis Output

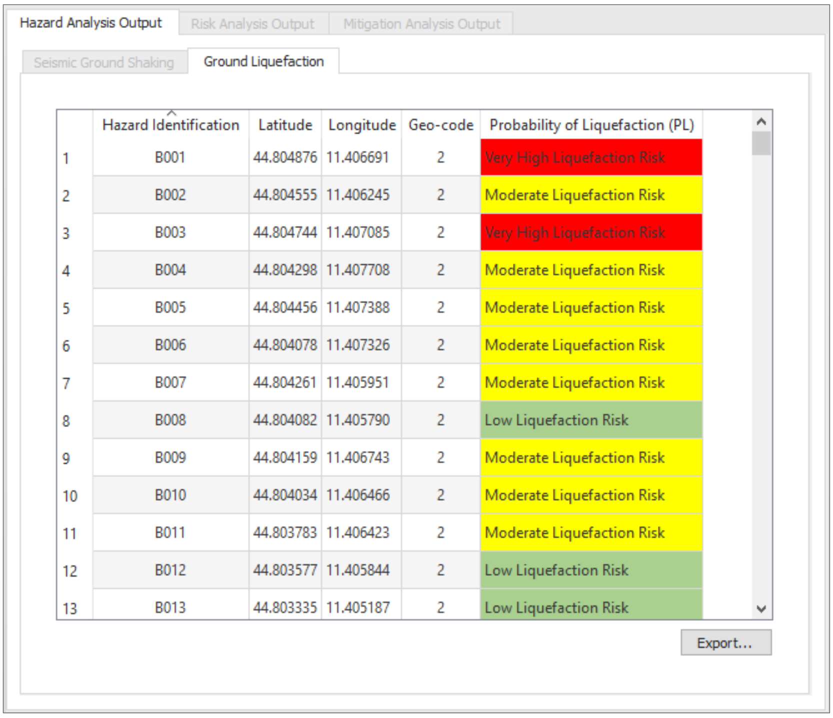
Seismic Ground Shaking | Ground Liquefaction

	Hazard Identification	Latitude	Longitude	Geo-code	Liquefaction Severity Number (LSN)
1	B001	44.804876	11.406691	2	Very High Liquefaction Risk
2	B002	44.804555	11.406245	2	Moderate Liquefaction Risk
3	B003	44.804744	11.407085	2	Very High Liquefaction Risk
4	B004	44.804298	11.407708	2	Moderate Liquefaction Risk
5	B005	44.804456	11.407388	2	Moderate Liquefaction Risk
6	B006	44.804078	11.407326	2	Moderate Liquefaction Risk
7	B007	44.804261	11.405951	2	Moderate Liquefaction Risk
8	B008	44.804082	11.405790	2	Low Liquefaction Risk
9	B009	44.804159	11.406743	2	Moderate Liquefaction Risk
10	B010	44.804034	11.406466	2	Moderate Liquefaction Risk
11	B011	44.803783	11.406423	2	Moderate Liquefaction Risk
12	B012	44.803577	11.405844	2	Low Liquefaction Risk
13	B013	44.803335	11.405187	2	Low Liquefaction Risk

Export...

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

Example analysis output for user-supplied liquefaction hazard map in terms of Probability of Liquefaction (PL)

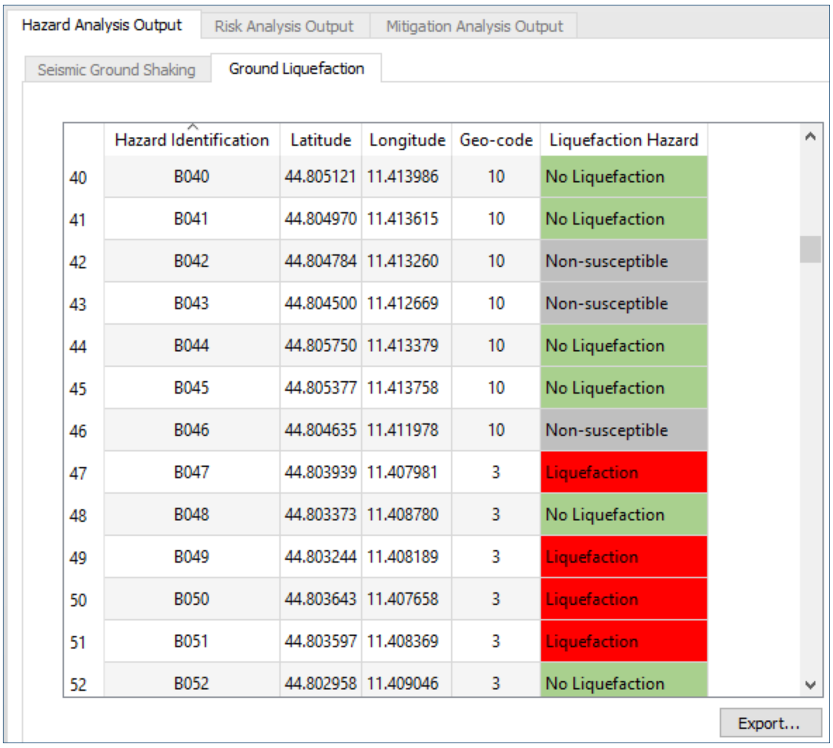


	Hazard Identification	Latitude	Longitude	Geo-code	Probability of Liquefaction (PL)
1	B001	44.804876	11.406691	2	Very High Liquefaction Risk
2	B002	44.804555	11.406245	2	Moderate Liquefaction Risk
3	B003	44.804744	11.407085	2	Very High Liquefaction Risk
4	B004	44.804298	11.407708	2	Moderate Liquefaction Risk
5	B005	44.804456	11.407388	2	Moderate Liquefaction Risk
6	B006	44.804078	11.407326	2	Moderate Liquefaction Risk
7	B007	44.804261	11.405951	2	Moderate Liquefaction Risk
8	B008	44.804082	11.405790	2	Low Liquefaction Risk
9	B009	44.804159	11.406743	2	Moderate Liquefaction Risk
10	B010	44.804034	11.406466	2	Moderate Liquefaction Risk
11	B011	44.803783	11.406423	2	Moderate Liquefaction Risk
12	B012	44.803577	11.405844	2	Low Liquefaction Risk
13	B013	44.803335	11.405187	2	Low Liquefaction Risk

4.2.3.2 Pre-Defined Liquefaction Hazard Output

Example analysis output for a selected return period of pre-defined European macrozonation liquefaction hazard.

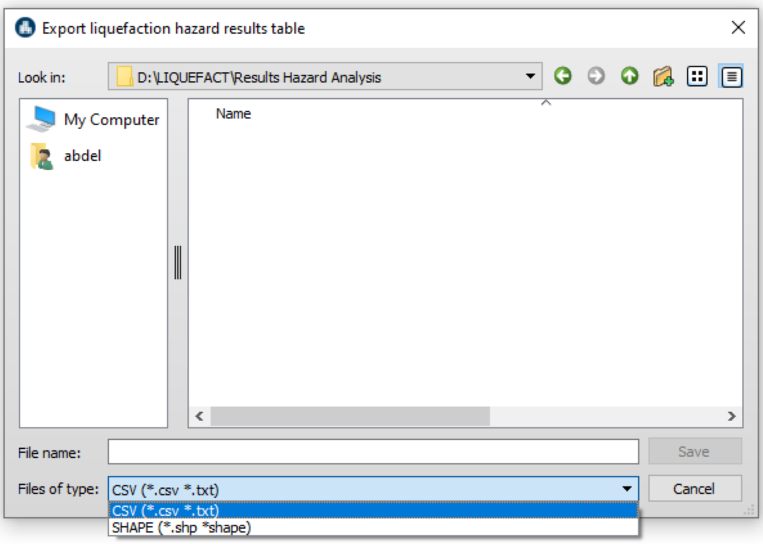
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748



	Hazard Identification	Latitude	Longitude	Geo-code	Liquefaction Hazard
40	B040	44.805121	11.413986	10	No Liquefaction
41	B041	44.804970	11.413615	10	No Liquefaction
42	B042	44.804784	11.413260	10	Non-susceptible
43	B043	44.804500	11.412669	10	Non-susceptible
44	B044	44.805750	11.413379	10	No Liquefaction
45	B045	44.805377	11.413758	10	No Liquefaction
46	B046	44.804635	11.411978	10	Non-susceptible
47	B047	44.803939	11.407981	3	Liquefaction
48	B048	44.803373	11.408780	3	No Liquefaction
49	B049	44.803244	11.408189	3	Liquefaction
50	B050	44.803643	11.407658	3	Liquefaction
51	B051	44.803597	11.408369	3	Liquefaction
52	B052	44.802958	11.409046	3	No Liquefaction

4.2.4 Export Results of Hazard Analysis

All results and output of Hazard Analysis can be exported by clicking on *Export* button. The results can be exported as SHAPE or CSV by selecting SHAPE or CSV in the file type pulldown menu in the Export dialog. SHAPE files can be exported as points or polygons. The database and result files in various formats will be stored in a project directory.



4.3 Risk Analysis Output

Results of Risk analysis are presented in terms of GIS-based owner losses and Insurance losses in terms of physical impact (damage to asset/assets), economic, contents and business interruption losses, due to liquefaction and due to ground shaking.

4.3.1 Ground Liquefaction-related Risk Analysis Output

Risk due to ground liquefaction is computed at individual asset (Risk Identification) as well as at Geo-code level.

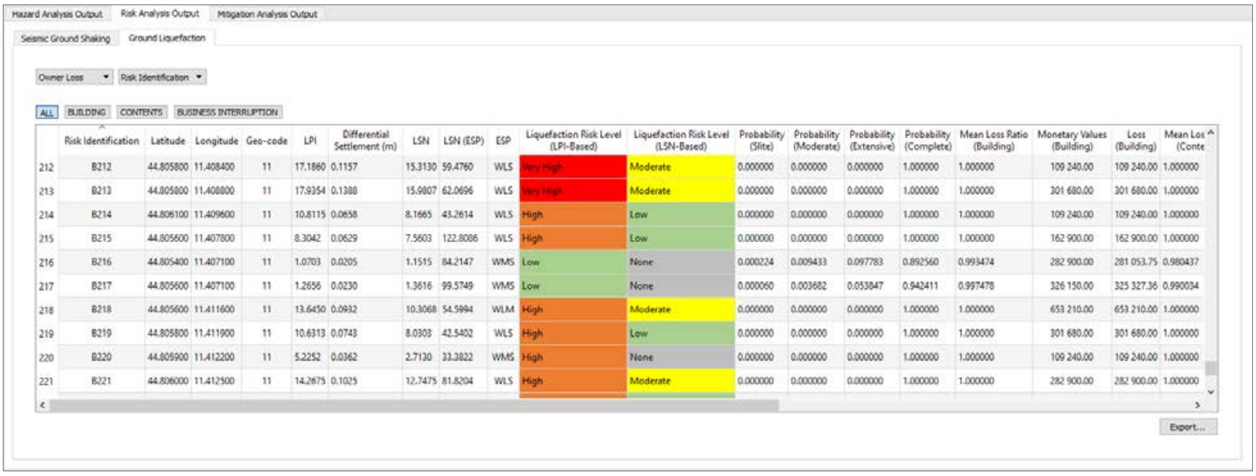
4.3.1.1 Ground Liquefaction related Owner Loss

4.3.1.1.1 Ground Liquefaction related Owner Loss at Asset Level

Ground Liquefaction-related Risk Analysis Output Parameters for Owner Loss at Asset level	*Description*
Risk Identification	Identification number representing each asset (building or infrastructure)
Geo-Code	Geo-code unit where each asset is assigned to.
LPI	LPI computed at the location of the asset
Differential Settlement (m)	Differential settlement of each asset due to ground liquefaction
LSN	LSN computed at the location of the asset
LSN (ESP)	LSN (ESP) computed at the location of the asset
ESP	ESP computed at the location of the asset
Liquefaction Risk Level (LPI-Based)	LPI-based qualitative estimation of liquefaction risk at the location of each asset
Liquefaction Risk Level (LSN-Based)	LSN-based qualitative estimation of liquefaction risk at the location of each asset
Probabilities of Damage	Probabilities of Damage computed for each asset. The number of probabilities depends on the type of fragility curves used in risk analysis: if the fragility was with one, two, three or four Damage Limit States
BUILDING	
Mean Loss Ratio (Building)	Is the mean of building loss ratios of a given number of buildings of same Typology located in same Geo-code.
Monetary Values (Building)	Input Data of monetary value of a given building
Loss (Building)	Is computed as Monetary value (Building) multiplied with the Mean Loss Ratio (Building).
CONTENTS	
Mean Loss Ratio (Contents)	Is the mean of content loss ratios of a given number of buildings of same Typology located in same Geo-code.
Monetary Values (Contents)	Input Data of monetary value of a given content in a given building
Loss (Contents)	Is computed as Monetary value (Contents) multiplied with the Mean Loss Ratio (Contents).
BUSINESS INTERRUPTION	

Mean Loss Ratio (Business Interruption)	Is the mean of content loss ratios of a given number of buildings of same Typology located in same Geo-code.
Business Revenue	Input Data of business revenue of a given building
Loss (Business Interruption)	Is computed as Business revenue multiplied with the Mean Loss Ratio (Business Interruption).

When ***ALL*** is selected, the displayed results represent all the outcomes of ground liquefaction-related Owner Loss at Asset Level



	Risk Identification	Latitude	Longitude	Geo-code	LPI	Differential Settlement (m)	LSN	LSN (ESP)	ESP	Liquefaction Risk Level (LPI-Based)	Liquefaction Risk Level (LSN-Based)	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Building)	Monetary Values (Building)	Loss (Building)	Mean Los (Conte
212	B212	44.805800	11.408400	11	17.1860	0.1157	15.3130	59.4760	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	109 240.00	109 240.00	1.000000
213	B213	44.805800	11.408800	11	17.9354	0.1388	15.9807	62.0696	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	301 680.00	301 680.00	1.000000
214	B214	44.806100	11.409600	11	10.8115	0.0658	8.1665	43.2614	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	109 240.00	109 240.00	1.000000
215	B215	44.805600	11.407800	11	8.3042	0.0629	7.5603	122.8086	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	162 900.00	162 900.00	1.000000
216	B216	44.805400	11.407100	11	1.0703	0.0205	1.1515	84.2147	WMS	Low	None	0.000224	0.009433	0.097783	0.892560	0.993474	282 900.00	281 053.75	0.980437
217	B217	44.805600	11.407100	11	1.2656	0.0230	1.3616	99.5749	WMS	Low	None	0.000060	0.003682	0.053847	0.942411	0.997478	326 150.00	325 327.36	0.990034
218	B218	44.805600	11.411600	11	13.6450	0.0932	10.3068	54.5994	WLM	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	653 210.00	653 210.00	1.000000
219	B219	44.805800	11.411900	11	10.6313	0.0743	8.0303	42.5402	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	301 680.00	301 680.00	1.000000
220	B220	44.805900	11.412200	11	5.2252	0.0362	2.7130	33.3822	WMS	High	None	0.000000	0.000000	0.000000	1.000000	1.000000	109 240.00	109 240.00	1.000000
221	B221	44.806000	11.412500	11	14.2675	0.1025	12.7475	81.8204	WLS	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	282 900.00	282 900.00	1.000000

When ***BUILDING*** is selected, the displayed results represent the ground liquefaction-related Building Owner Loss at Asset Level

	Risk Identification	Latitude	Longitude	Geo-code	LPI	Differential Settlement (m)	LSN	LSN (ESP)	ESP	Liquefaction Risk Level (LPI-Based)	Liquefaction Risk Level (LSN-Based)	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Building)	Monetary Values (Building)	Loss (Building)
212	B212	44.805800	11.408400	11	17.1860	0.1157	15.3130	59.4760	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	109 240.00	109 240.00
213	B213	44.805800	11.408800	11	17.9354	0.1388	15.9807	62.0696	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	301 680.00	301 680.00
214	B214	44.806100	11.409600	11	10.8115	0.0658	8.1665	43.2614	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	109 240.00	109 240.00
215	B215	44.805600	11.407800	11	8.3042	0.0629	7.5603	122.8086	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	162 900.00	162 900.00
216	B216	44.805400	11.407100	11	1.0703	0.0205	1.1515	84.2147	WMS	Low	None	0.000224	0.009433	0.097783	0.892560	0.993474	282 900.00	281 053.75
217	B217	44.805600	11.407100	11	1.2656	0.0230	1.3616	99.5749	WMS	Low	None	0.000060	0.003682	0.053847	0.942411	0.997478	326 150.00	325 327.36
218	B218	44.805600	11.411600	11	13.6450	0.0932	10.3068	54.5994	WLM	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	653 210.00	653 210.00
219	B219	44.805800	11.411900	11	10.6313	0.0743	8.0303	42.5402	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	301 680.00	301 680.00
220	B220	44.805900	11.412200	11	5.2252	0.0362	2.7130	33.3822	WMS	High	None	0.000000	0.000000	0.000000	1.000000	1.000000	109 240.00	109 240.00
221	B221	44.806000	11.412500	11	14.2675	0.1025	12.7475	81.8204	WLS	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	282 900.00	282 900.00
222	B222	44.806100	11.413000	11	10.3904	0.0668	9.2834	59.5863	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	326 150.00	326 150.00

When ***CONTENTS*** is selected, the displayed results represent the ground liquefaction-related Contents Owner Loss at Asset Level

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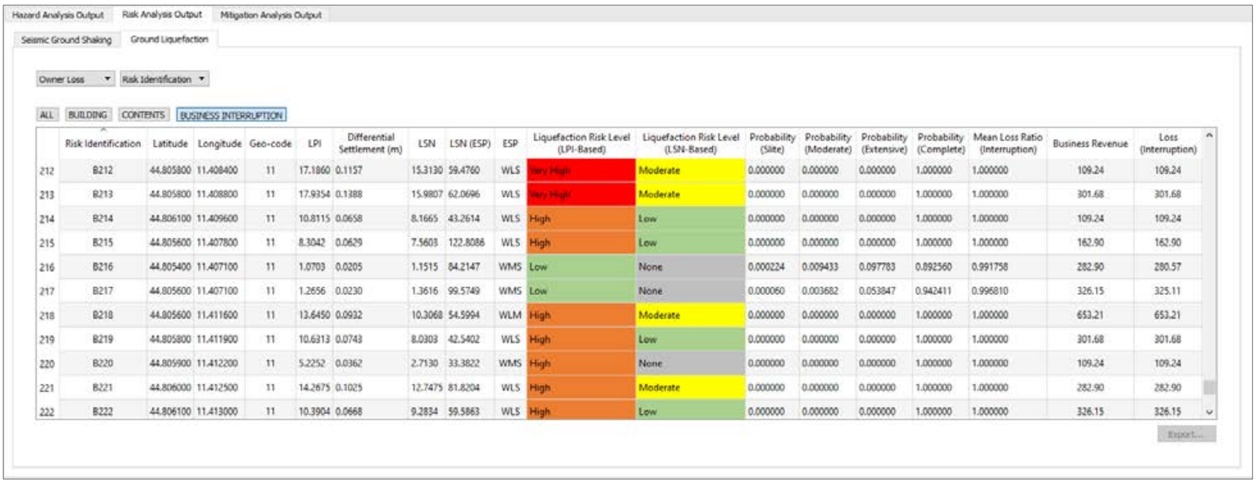
	Risk Identification	Latitude	Longitude	Geo-code	LPI	Differential Settlement (m)	LSN	LSN (ESP)	ESP	Liquefaction Risk Level (LPI-Based)	Liquefaction Risk Level (LSN-Based)	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Contents)	Monetary Values (Contents)	Loss (Contents)
212	B212	44.805800	11.408400	11	17.1860	0.1157	15.3130	59.4760	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	10 924.00	10 924.00
213	B213	44.805800	11.408800	11	17.9354	0.1388	15.9807	62.0696	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	75 420.00	75 420.00
214	B214	44.806100	11.409600	11	10.8115	0.0658	8.1665	43.2614	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	10 924.00	10 924.00
215	B215	44.805600	11.407800	11	8.3042	0.0629	7.5603	122.8086	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	6 516.00	6 516.00
216	B216	44.805400	11.407100	11	1.0703	0.0205	1.1515	84.2147	WMS	Low	None	0.000224	0.009433	0.097783	0.892560	0.980437	56 580.00	55 473.12
217	B217	44.805600	11.407100	11	1.2656	0.0230	1.3616	99.5749	WMS	Low	None	0.000060	0.003682	0.053847	0.942411	0.990034	65 230.00	64 579.91
218	B218	44.805600	11.411600	11	13.6450	0.0932	10.3068	54.5994	WLM	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	653 210.00	653 210.00
219	B219	44.805800	11.411900	11	10.6313	0.0743	8.0303	42.5402	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	75 420.00	75 420.00
220	B220	44.805900	11.412200	11	5.2252	0.0362	2.7130	33.3822	WMS	High	None	0.000000	0.000000	0.000000	1.000000	1.000000	10 924.00	10 924.00
221	B221	44.806000	11.412500	11	14.2675	0.1025	12.7475	81.8204	WLS	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	56 580.00	56 580.00

When ***BUSINESS INTERRUPTION*** is selected, the displayed results represent the ground liquefaction-related Business Interruption Owner Loss at Asset Level



	Risk Identification	Latitude	Longitude	Geo-code	LPI	Differential Settlement (m)	LSN	LSN (ESP)	ESP	Liquefaction Risk Level (LPI-Based)	Liquefaction Risk Level (LSN-Based)	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Interruption)	Business Revenue	Loss (Interruption)
212	B212	44.805800	11.408400	11	17.1860	0.1157	15.3130	59.4760	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	109.24	109.24
213	B213	44.805800	11.408800	11	17.9354	0.1388	15.9807	62.0696	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	301.68	301.68
214	B214	44.806100	11.409600	11	10.8115	0.0658	8.1665	43.2614	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	109.24	109.24
215	B215	44.805600	11.407800	11	8.3042	0.0629	7.5603	122.8086	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	162.90	162.90
216	B216	44.805400	11.407100	11	1.0703	0.0205	1.1515	84.2147	WMS	Low	None	0.000224	0.009433	0.097783	0.892560	0.991758	282.90	280.57
217	B217	44.805600	11.407100	11	1.2656	0.0230	1.3616	99.5749	WMS	Low	None	0.000060	0.003682	0.053847	0.942411	0.996810	326.15	325.11
218	B218	44.805600	11.411600	11	13.6450	0.0932	10.3068	54.5994	WLM	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	653.21	653.21
219	B219	44.805800	11.411900	11	10.6313	0.0743	8.0303	42.5402	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	301.68	301.68
220	B220	44.805900	11.412200	11	5.2252	0.0362	2.7130	33.3822	WMS	High	None	0.000000	0.000000	0.000000	1.000000	1.000000	109.24	109.24
221	B221	44.806000	11.412500	11	14.2675	0.1025	12.7475	81.8204	WLS	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	282.90	282.90
222	B222	44.806100	11.413000	11	10.3904	0.0668	9.2834	59.5863	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	326.15	326.15

4.3.1.1.2 Ground Liquefaction related Owner Loss at Geo-code Level

Ground Liquefaction-related Risk Analysis Output Parameters for Owner Loss at Geo-code level	*Description*
Mean Loss Ratio (Buildings)	Is the mean of loss ratios of all buildings located in a given Geo-code.
Monetary Values (Buildings)	Input Data of total monetary values of all buildings located in a given Geo-code.
Loss (Buildings)	Is computed as Total Monetary value (Buildings) multiplied with the Mean Loss Ratio (Buildings), in a given Geo-code.
Mean Loss Ratio (Contents)	Is the mean of loss ratios of all Contents located in a given Geo-code.
Monetary Values (Contents)	Input Data of total monetary values of all Contents located in a given Geo-code.
Loss (Contents)	Is computed as Total Monetary value (Contents) multiplied with the Mean Loss Ratio (Contents), in a given Geo-code.

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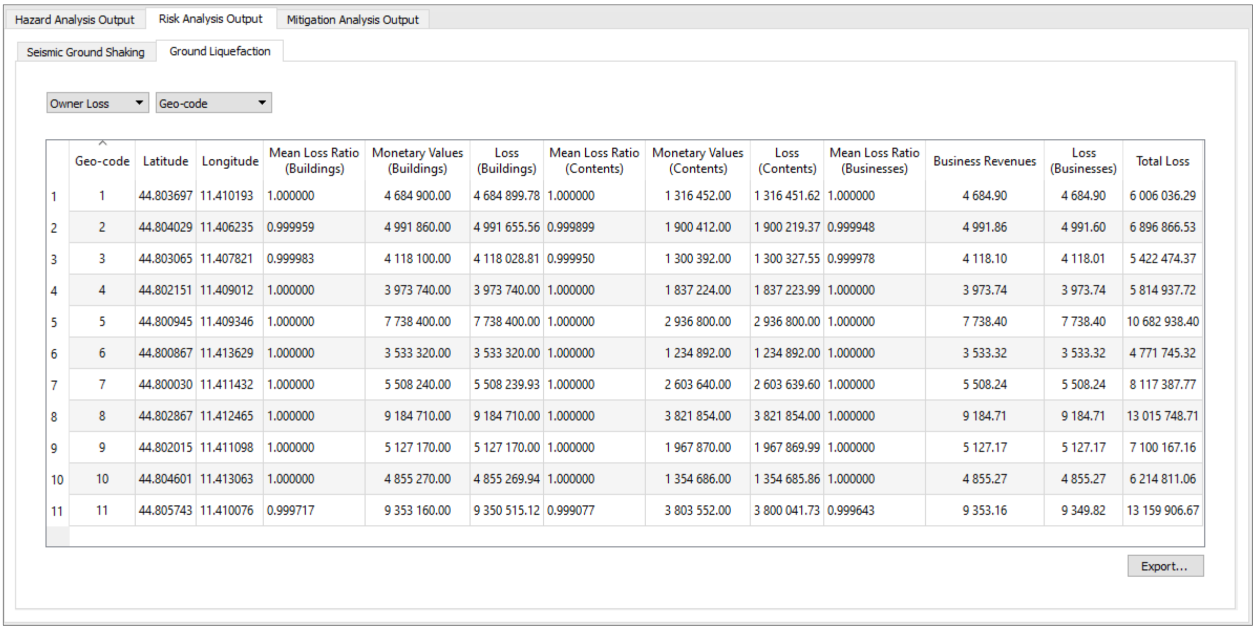
Mean Loss Ratio (Businesses)	Is the mean of loss ratios of all Businesses located in a given Geo-code.
Monetary Values (Businesses)	Input Data of total monetary values of all Businesses located in a given Geo-code.
Loss (Businesses)	Is computed as Total Monetary value (Businesses) multiplied with the Mean Loss Ratio (Businesses), in a given Geo-code.
Total Loss	Total loss in a given Geo-code



	Geo-code	Latitude	Longitude	Mean Loss Ratio (Buildings)	Monetary Values (Buildings)	Loss (Buildings)	Mean Loss Ratio (Contents)	Monetary Values (Contents)	Loss (Contents)	Mean Loss Ratio (Businesses)	Business Revenues	Loss (Businesses)	Total Loss
1	1	44.803697	11.410193	1.000000	4 684 900.00	4 684 899.78	1.000000	1 316 452.00	1 316 451.62	1.000000	4 684.90	4 684.90	6 006 036.29
2	2	44.804029	11.406235	0.999959	4 991 860.00	4 991 655.56	0.999899	1 900 412.00	1 900 219.37	0.999948	4 991.86	4 991.60	6 896 866.53
3	3	44.803065	11.407821	0.999983	4 118 100.00	4 118 028.81	0.999950	1 300 392.00	1 300 327.55	0.999978	4 118.10	4 118.01	5 422 474.37
4	4	44.802151	11.409012	1.000000	3 973 740.00	3 973 740.00	1.000000	1 837 224.00	1 837 223.99	1.000000	3 973.74	3 973.74	5 814 937.72
5	5	44.800945	11.409346	1.000000	7 738 400.00	7 738 400.00	1.000000	2 936 800.00	2 936 800.00	1.000000	7 738.40	7 738.40	10 682 938.40
6	6	44.800867	11.413629	1.000000	3 533 320.00	3 533 320.00	1.000000	1 234 892.00	1 234 892.00	1.000000	3 533.32	3 533.32	4 771 745.32
7	7	44.800030	11.411432	1.000000	5 508 240.00	5 508 239.93	1.000000	2 603 640.00	2 603 639.60	1.000000	5 508.24	5 508.24	8 117 387.77
8	8	44.802867	11.412465	1.000000	9 184 710.00	9 184 710.00	1.000000	3 821 854.00	3 821 854.00	1.000000	9 184.71	9 184.71	13 015 748.71
9	9	44.802015	11.411098	1.000000	5 127 170.00	5 127 170.00	1.000000	1 967 870.00	1 967 869.99	1.000000	5 127.17	5 127.17	7 100 167.16
10	10	44.804601	11.413063	1.000000	4 855 270.00	4 855 269.94	1.000000	1 354 686.00	1 354 685.86	1.000000	4 855.27	4 855.27	6 214 811.06
11	11	44.805743	11.410076	0.999717	9 353 160.00	9 350 515.12	0.999077	3 803 552.00	3 800 041.73	0.999643	9 353.16	9 349.82	13 159 906.67

4.3.1.2 Ground Liquefaction related Insurance Loss

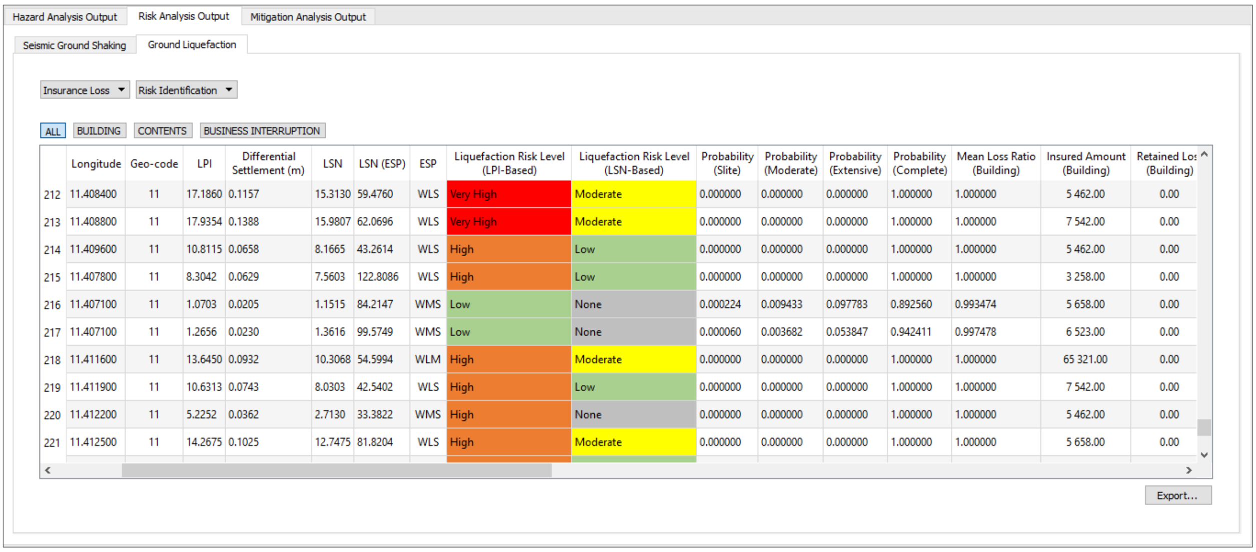
4.3.1.2.1 Ground Liquefaction related Insurance Loss at Asset Level

Ground Liquefaction-related Risk Analysis Output Parameters for Insurance Loss at Asset level	*Description*
Risk Identification	Identification number representing each asset (building or infrastructure)
Geo-Code	Geo-code unit where each asset is assigned to.
LPI	LPI computed at the location of the asset
Differential Settlement (m)	Differential settlement of each asset due to ground liquefaction
LSN	LSN computed at the location of the asset
LSN (ESP)	LSN (ESP) computed at the location of the asset
ESP	ESP computed at the location of the asset
Liquefaction Risk Level (LPI-Based)	LPI-based qualitative estimation of liquefaction risk at the location of each asset
Liquefaction Risk Level (LSN-Based)	LSN-based qualitative estimation of liquefaction risk at the location of each asset

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

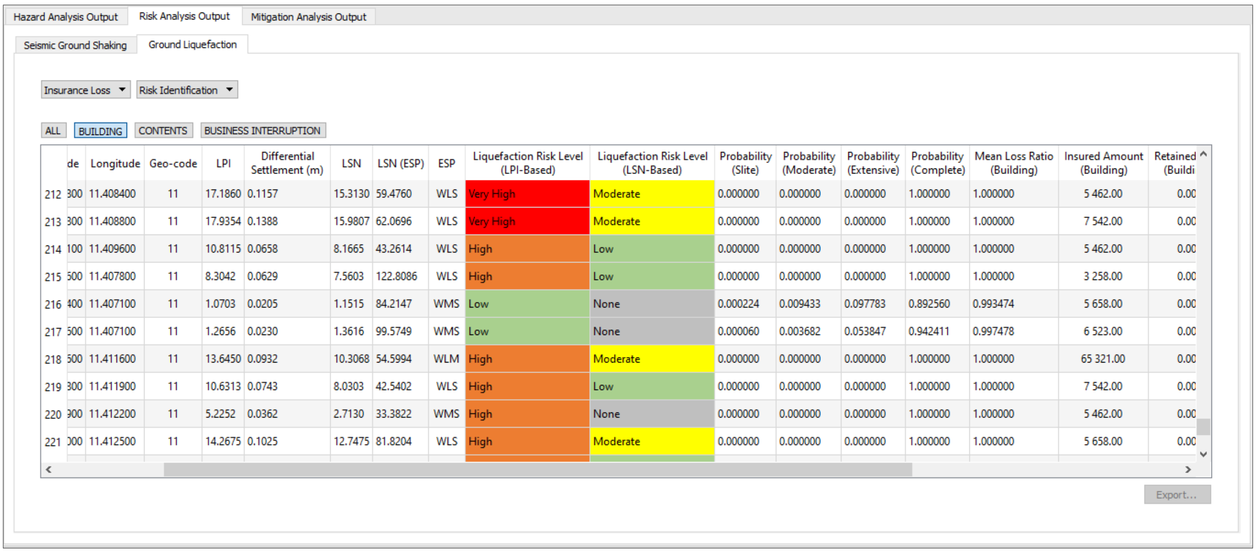
Probabilities of Damage	Probabilities of Damage computed for each asset. The number of probabilities depends on the type of fragility curves used in risk analysis: if the fragility was with one, two, three or four Damage Limit States
BUILDING	
Mean Loss Ratio (Building)	Is the mean of building loss ratios of a given number of buildings of same Typology located in same Geo-code.
Insured Amount (Building)	Input Data of the insured amount for a given building
Retained Loss (Building)	Retained loss of a given building
Facultative Loss (Building)	Facultative loss of a given building
Coinsurance Loss (Building)	Coinsurance loss of a given building
CEDED Loss (Building)	CECED loss of a given building
CONTENTS	
Mean Loss Ratio (Contents)	Is the mean of content loss ratios of a given number of buildings of same Typology located in same Geo-code.
Insured Amount (Contents)	Input Data of the insured amount for contents in a given building
Retained Loss (Contents)	Contents Retained loss of a given building
Facultative Loss (Contents)	Contents Facultative loss of a given building
Coinsurance Loss (Contents)	Contents Coinsurance loss of a given building
CEDED Loss (Building)	Contents CECED loss of a given building
BUSINESS INTERRUPTION	
Mean Loss Ratio (Business Interruption)	Is the mean of business interruption loss ratios of a given number of buildings of same Typology located in same Geo-code.
Insured Amount (Business Interruption)	Input Data of the insured amount for Business Interruption for a given building
Retained Loss (Business Interruption)	Business Interruption Retained loss of a given building
Facultative Loss (Business Interruption)	Business Interruption Facultative loss of a given building
Coinsurance Loss (Business Interruption)	Business Interruption Coinsurance loss of a given building
CEDED Loss (Business Interruption)	Business Interruption CECED loss of a given building

When ***ALL*** is selected, the displayed results represent all the outcomes of ground liquefaction-related Insurance Loss at Asset Level



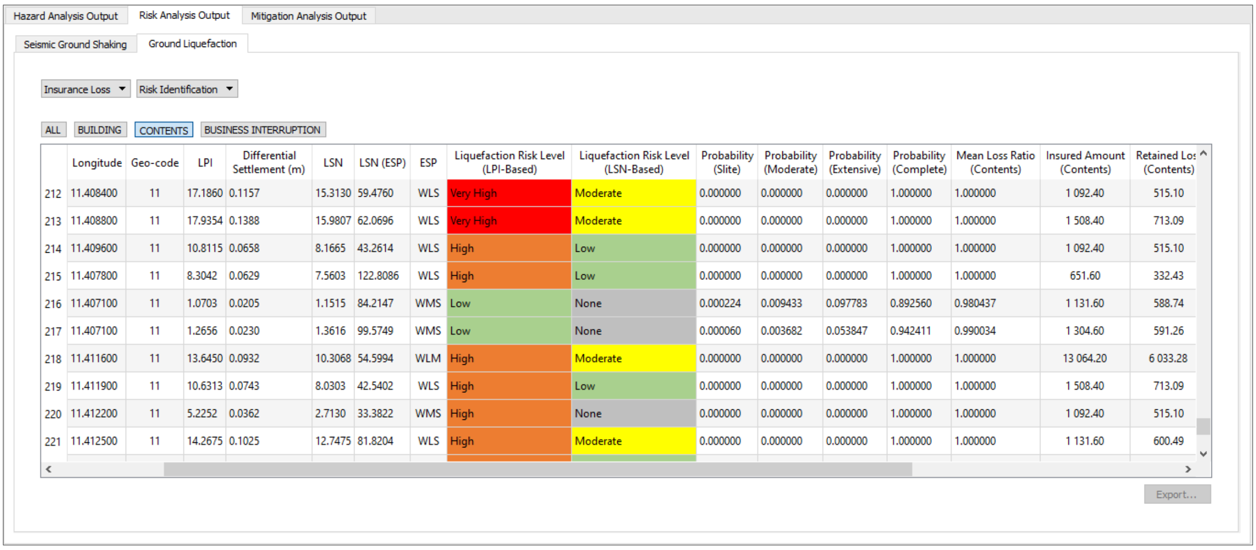
	Longitude	Geo-code	LPI	Differential Settlement (m)	LSN	LSN (ESP)	ESP	Liquefaction Risk Level (LPI-Based)	Liquefaction Risk Level (LSN-Based)	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Building)	Insured Amount (Building)	Retained Los (Building)
212	11.408400	11	17.1860	0.1157	15.3130	59.4760	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	5 462.00	0.00
213	11.408800	11	17.9354	0.1388	15.9807	62.0696	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	7 542.00	0.00
214	11.409600	11	10.8115	0.0658	8.1665	43.2614	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	5 462.00	0.00
215	11.407800	11	8.3042	0.0629	7.5603	122.8086	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	3 258.00	0.00
216	11.407100	11	1.0703	0.0205	1.1515	84.2147	WMS	Low	None	0.000224	0.009433	0.097783	0.892560	0.993474	5 658.00	0.00
217	11.407100	11	1.2656	0.0230	1.3616	99.5749	WMS	Low	None	0.000060	0.003682	0.053847	0.942411	0.997478	6 523.00	0.00
218	11.411600	11	13.6450	0.0932	10.3068	54.5994	WLM	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	65 321.00	0.00
219	11.411900	11	10.6313	0.0743	8.0303	42.5402	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	7 542.00	0.00
220	11.412200	11	5.2252	0.0362	2.7130	33.3822	WMS	High	None	0.000000	0.000000	0.000000	1.000000	1.000000	5 462.00	0.00
221	11.412500	11	14.2675	0.1025	12.7475	81.8204	WLS	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	5 658.00	0.00

When ***BUILDING*** is selected, the displayed results represent the ground liquefaction-related Building Insurance Loss at Asset Level



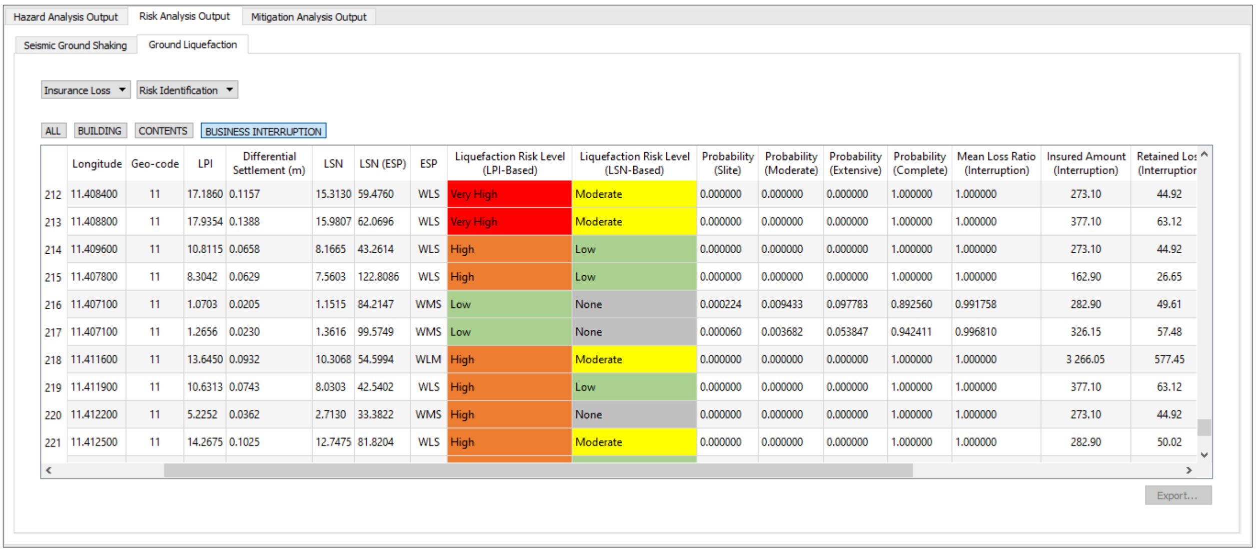
	de	Longitude	Geo-code	LPI	Differential Settlement (m)	LSN	LSN (ESP)	ESP	Liquefaction Risk Level (LPI-Based)	Liquefaction Risk Level (LSN-Based)	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Building)	Insured Amount (Building)	Retained (Buildi
212	300	11.408400	11	17.1860	0.1157	15.3130	59.4760	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	5 462.00	0.00
213	300	11.408800	11	17.9354	0.1388	15.9807	62.0696	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	7 542.00	0.00
214	100	11.409600	11	10.8115	0.0658	8.1665	43.2614	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	5 462.00	0.00
215	500	11.407800	11	8.3042	0.0629	7.5603	122.8086	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	3 258.00	0.00
216	400	11.407100	11	1.0703	0.0205	1.1515	84.2147	WMS	Low	None	0.000224	0.009433	0.097783	0.892560	0.993474	5 658.00	0.00
217	500	11.407100	11	1.2656	0.0230	1.3616	99.5749	WMS	Low	None	0.000060	0.003682	0.053847	0.942411	0.997478	6 523.00	0.00
218	500	11.411600	11	13.6450	0.0932	10.3068	54.5994	WLM	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	65 321.00	0.00
219	300	11.411900	11	10.6313	0.0743	8.0303	42.5402	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	7 542.00	0.00
220	900	11.412200	11	5.2252	0.0362	2.7130	33.3822	WMS	High	None	0.000000	0.000000	0.000000	1.000000	1.000000	5 462.00	0.00
221	000	11.412500	11	14.2675	0.1025	12.7475	81.8204	WLS	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	5 658.00	0.00

When ***CONTENTS*** is selected, the displayed results represent the ground liquefaction-related Contents Insurance Loss at Asset Level



	Longitude	Geo-code	LPI	Differential Settlement (m)	LSN	LSN (ESP)	ESP	Liquefaction Risk Level (LPI-Based)	Liquefaction Risk Level (LSN-Based)	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Contents)	Insured Amount (Contents)	Retained Los (Contents)
212	11.408400	11	17.1860	0.1157	15.3130	59.4760	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	1 092.40	515.10
213	11.408800	11	17.9354	0.1388	15.9807	62.0696	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	1 508.40	713.09
214	11.409600	11	10.8115	0.0658	8.1665	43.2614	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	1 092.40	515.10
215	11.407800	11	8.3042	0.0629	7.5603	122.8086	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	651.60	332.43
216	11.407100	11	1.0703	0.0205	1.1515	84.2147	WMS	Low	None	0.000224	0.009433	0.097783	0.892560	0.980437	1 131.60	588.74
217	11.407100	11	1.2656	0.0230	1.3616	99.5749	WMS	Low	None	0.000060	0.003682	0.053847	0.942411	0.990034	1 304.60	591.26
218	11.411600	11	13.6450	0.0932	10.3068	54.5994	WLM	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	13 064.20	6 033.28
219	11.411900	11	10.6313	0.0743	8.0303	42.5402	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	1 508.40	713.09
220	11.412200	11	5.2252	0.0362	2.7130	33.3822	WMS	High	None	0.000000	0.000000	0.000000	1.000000	1.000000	1 092.40	515.10
221	11.412500	11	14.2675	0.1025	12.7475	81.8204	WLS	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	1 131.60	600.49

When ***BUSINESS INTERRUPTION*** is selected, the displayed results represent the ground liquefaction-related Business Interruption Insurance Loss at Asset Level



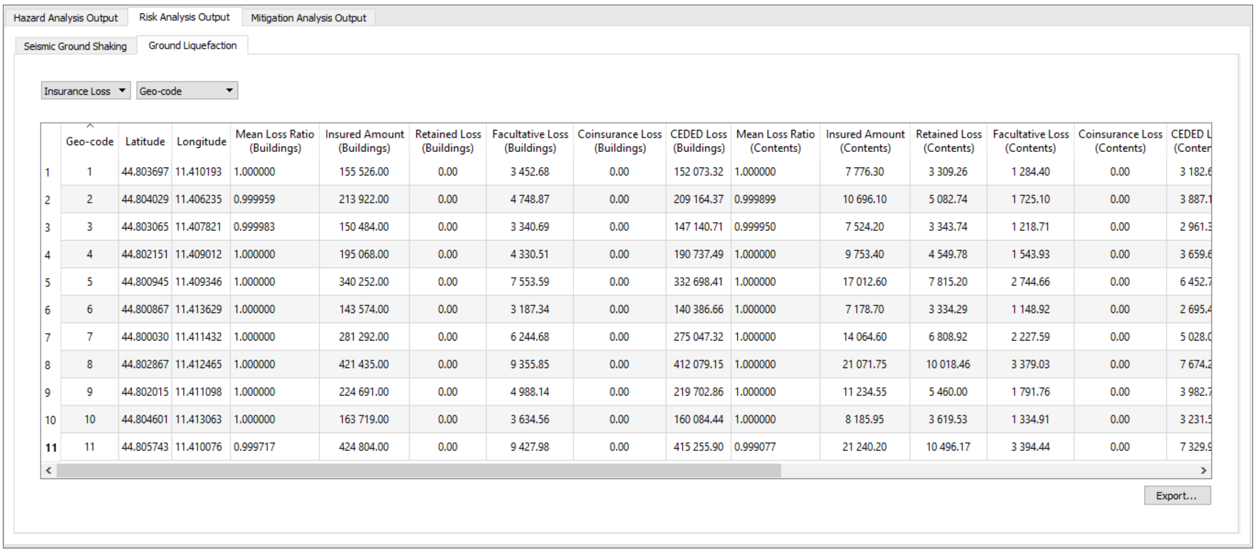
	Longitude	Geo-code	LPI	Differential Settlement (m)	LSN	LSN (ESP)	ESP	Liquefaction Risk Level (LPI-Based)	Liquefaction Risk Level (LSN-Based)	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Interruption)	Insured Amount (Interruption)	Retained Los (Interruptior
212	11.408400	11	17.1860	0.1157	15.3130	59.4760	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	273.10	44.92
213	11.408800	11	17.9354	0.1388	15.9807	62.0696	WLS	Very High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	377.10	63.12
214	11.409600	11	10.8115	0.0658	8.1665	43.2614	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	273.10	44.92
215	11.407800	11	8.3042	0.0629	7.5603	122.8086	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	162.90	26.65
216	11.407100	11	1.0703	0.0205	1.1515	84.2147	WMS	Low	None	0.000224	0.009433	0.097783	0.892560	0.991758	282.90	49.61
217	11.407100	11	1.2656	0.0230	1.3616	99.5749	WMS	Low	None	0.000060	0.003682	0.053847	0.942411	0.996810	326.15	57.48
218	11.411600	11	13.6450	0.0932	10.3068	54.5994	WLM	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	3 266.05	577.45
219	11.411900	11	10.6313	0.0743	8.0303	42.5402	WLS	High	Low	0.000000	0.000000	0.000000	1.000000	1.000000	377.10	63.12
220	11.412200	11	5.2252	0.0362	2.7130	33.3822	WMS	High	None	0.000000	0.000000	0.000000	1.000000	1.000000	273.10	44.92
221	11.412500	11	14.2675	0.1025	12.7475	81.8204	WLS	High	Moderate	0.000000	0.000000	0.000000	1.000000	1.000000	282.90	50.02

4.3.1.2.2 Ground Liquefaction related Insurance Loss at Geo-code Level

Ground Liquefaction-related Risk Analysis Output Parameters for Insurance Loss at Geo-code level	*Description*
Mean Loss Ratio (Buildings)	Is the mean of loss ratios of all buildings located in a given Geo-code.
Insured Amount (Buildings)	Total insured amount for all buildings located in a given Geo-code.
Retained Loss (Buildings)	Total retained Loss considering all buildings located in a given Geo-code.
Facultative Loss (Buildings)	Total facultative Loss considering all buildings located in a given Geo-code.
Coinsurance Loss (Buildings)	Total coinsurance Loss considering all buildings located in a given Geo-code.
CECED Loss (Buildings)	Total CECED Loss considering all buildings located in a given Geo-code.
Insured Amount (Contents)	Total insured amount for all contents of buildings located in a given Geo-code.
Retained Loss (Contents)	Total retained Loss considering all contents of buildings located in a given Geo-code.
Facultative Loss (Contents)	Total facultative Loss considering all contents of buildings located in a given Geo-code.
Coinsurance Loss (Contents)	Total coinsurance Loss considering all contents of buildings located in a given Geo-code.
CECED Loss (Contents)	Total CECED Loss considering all contents of buildings located in a given Geo-code.
Insured Amount (Business Interruption)	Total insured amount for all businesses of buildings located in a given Geo-code.
Retained Loss (Business Interruption)	Total retained Loss considering all businesses of buildings located in a given Geo-code.
Facultative Loss (Business Interruption)	Total facultative Loss considering all businesses of buildings located in a given Geo-code.
Coinsurance Loss (Business Interruption)	Total coinsurance Loss considering all businesses of buildings located in a given Geo-code.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

CECED Loss (Business Interruption)	Total CECED Loss considering all businesses of buildings located in a given Geo-code.
Total Loss	Total insurance loss in a given Geo-code



	Geo-code	Latitude	Longitude	Mean Loss Ratio (Buildings)	Insured Amount (Buildings)	Retained Loss (Buildings)	Facultative Loss (Buildings)	Coinsurance Loss (Buildings)	CEDED Loss (Buildings)	Mean Loss Ratio (Contents)	Insured Amount (Contents)	Retained Loss (Contents)	Facultative Loss (Contents)	Coinsurance Loss (Contents)	CEDED L (Conten
1	1	44.803697	11.410193	1.000000	155 526.00	0.00	3 452.68	0.00	152 073.32	1.000000	7 776.30	3 309.26	1 284.40	0.00	3 182.6
2	2	44.804029	11.406235	0.999959	213 922.00	0.00	4 748.87	0.00	209 164.37	0.999899	10 696.10	5 082.74	1 725.10	0.00	3 887.1
3	3	44.803065	11.407821	0.999983	150 484.00	0.00	3 340.69	0.00	147 140.71	0.999950	7 524.20	3 343.74	1 218.71	0.00	2 961.3
4	4	44.802151	11.409012	1.000000	195 068.00	0.00	4 330.51	0.00	190 737.49	1.000000	9 753.40	4 549.78	1 543.93	0.00	3 659.6
5	5	44.800945	11.409346	1.000000	340 252.00	0.00	7 553.59	0.00	332 698.41	1.000000	17 012.60	7 815.20	2 744.66	0.00	6 452.7
6	6	44.800867	11.413629	1.000000	143 574.00	0.00	3 187.34	0.00	140 386.66	1.000000	7 178.70	3 334.29	1 148.92	0.00	2 695.4
7	7	44.800030	11.411432	1.000000	281 292.00	0.00	6 244.68	0.00	275 047.32	1.000000	14 064.60	6 808.92	2 227.59	0.00	5 028.0
8	8	44.802867	11.412465	1.000000	421 435.00	0.00	9 355.85	0.00	412 079.15	1.000000	21 071.75	10 018.46	3 379.03	0.00	7 674.2
9	9	44.802015	11.411098	1.000000	224 691.00	0.00	4 988.14	0.00	219 702.86	1.000000	11 234.55	5 460.00	1 791.76	0.00	3 982.7
10	10	44.804601	11.413063	1.000000	163 719.00	0.00	3 634.56	0.00	160 084.44	1.000000	8 185.95	3 619.53	1 334.91	0.00	3 231.5
11	11	44.805743	11.410076	0.999717	424 804.00	0.00	9 427.98	0.00	415 255.90	0.999077	21 240.20	10 496.17	3 394.44	0.00	7 329.9

4.3.2 Ground Shaking-related Risk Analysis Output

Risk due to ground shaking only is computed at individual asset (Risk Identification) as well as at Geo-code level.

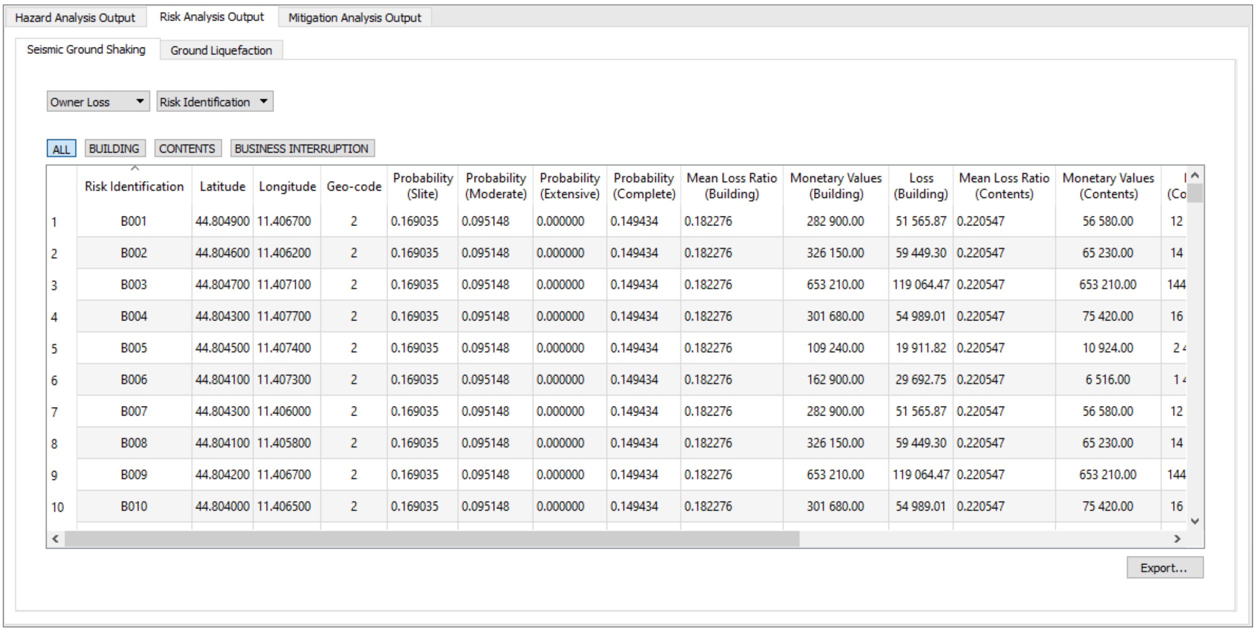
4.3.2.1 Ground Shaking related Owner Loss

4.3.2.1.1 Ground Shaking related Owner Loss at Asset Level

Ground Shaking-related Risk Analysis Output Parameters for Owner Loss at Asset level	*Description*
Risk Identification	Identification number representing each asset (building or infrastructure)
Geo-Code	Geo-code unit where each asset is assigned to.
Probabilities of Damage	Probabilities of Damage computed for each asset. The number of probabilities depends on the type of fragility curves used in risk analysis: if the fragility was with one, two, three or four Damage Limit States
BUILDING	
Mean Loss Ratio (Building)	Is the mean of building loss ratios of a given number of buildings of same Typology located in same Geo-code.
Monetary Values (Building)	Input Data of monetary value of a given building
Loss (Building)	Is computed as Monetary value (Building) multiplied with the Mean Loss Ratio (Building).

CONTENTS	
Mean Loss Ratio (Contents)	Is the mean of content loss ratios of a given number of buildings of same Typology located in same Geo-code.
Monetary Values (Contents)	Input Data of monetary value of a given content in a given building
Loss (Contents)	Is computed as Monetary value (Contents) multiplied with the Mean Loss Ratio (Contents).
BUSINESS INTERRUPTION	
Mean Loss Ratio (Business Interruption)	Is the mean of content loss ratios of a given number of buildings of same Typology located in same Geo-code.
Business Revenue	Input Data of business revenue of a given building
Loss (Business Interruption)	Is computed as Business revenue multiplied with the Mean Loss Ratio (Business Interruption).

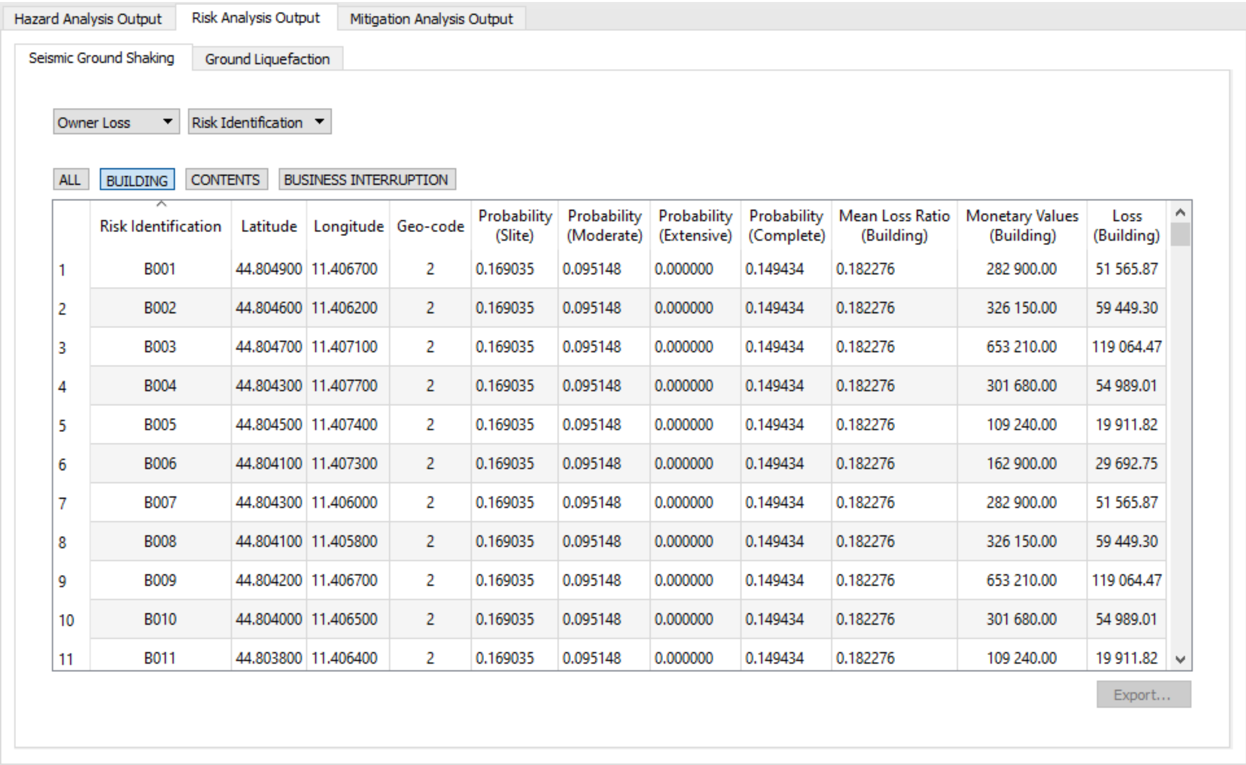
When ***ALL*** is selected, the displayed results represent all the outcomes of ground shaking-related Owner Loss at Asset Level



	Risk Identification	Latitude	Longitude	Geo-code	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Building)	Monetary Values (Building)	Loss (Building)	Mean Loss Ratio (Contents)	Monetary Values (Contents)	(Co
1	B001	44.804900	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.182276	282 900.00	51 565.87	0.220547	56 580.00	12
2	B002	44.804600	11.406200	2	0.169035	0.095148	0.000000	0.149434	0.182276	326 150.00	59 449.30	0.220547	65 230.00	14
3	B003	44.804700	11.407100	2	0.169035	0.095148	0.000000	0.149434	0.182276	653 210.00	119 064.47	0.220547	653 210.00	144
4	B004	44.804300	11.407700	2	0.169035	0.095148	0.000000	0.149434	0.182276	301 680.00	54 989.01	0.220547	75 420.00	16
5	B005	44.804500	11.407400	2	0.169035	0.095148	0.000000	0.149434	0.182276	109 240.00	19 911.82	0.220547	10 924.00	2
6	B006	44.804100	11.407300	2	0.169035	0.095148	0.000000	0.149434	0.182276	162 900.00	29 692.75	0.220547	6 516.00	1
7	B007	44.804300	11.406000	2	0.169035	0.095148	0.000000	0.149434	0.182276	282 900.00	51 565.87	0.220547	56 580.00	12
8	B008	44.804100	11.405800	2	0.169035	0.095148	0.000000	0.149434	0.182276	326 150.00	59 449.30	0.220547	65 230.00	14
9	B009	44.804200	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.182276	653 210.00	119 064.47	0.220547	653 210.00	144
10	B010	44.804000	11.406500	2	0.169035	0.095148	0.000000	0.149434	0.182276	301 680.00	54 989.01	0.220547	75 420.00	16

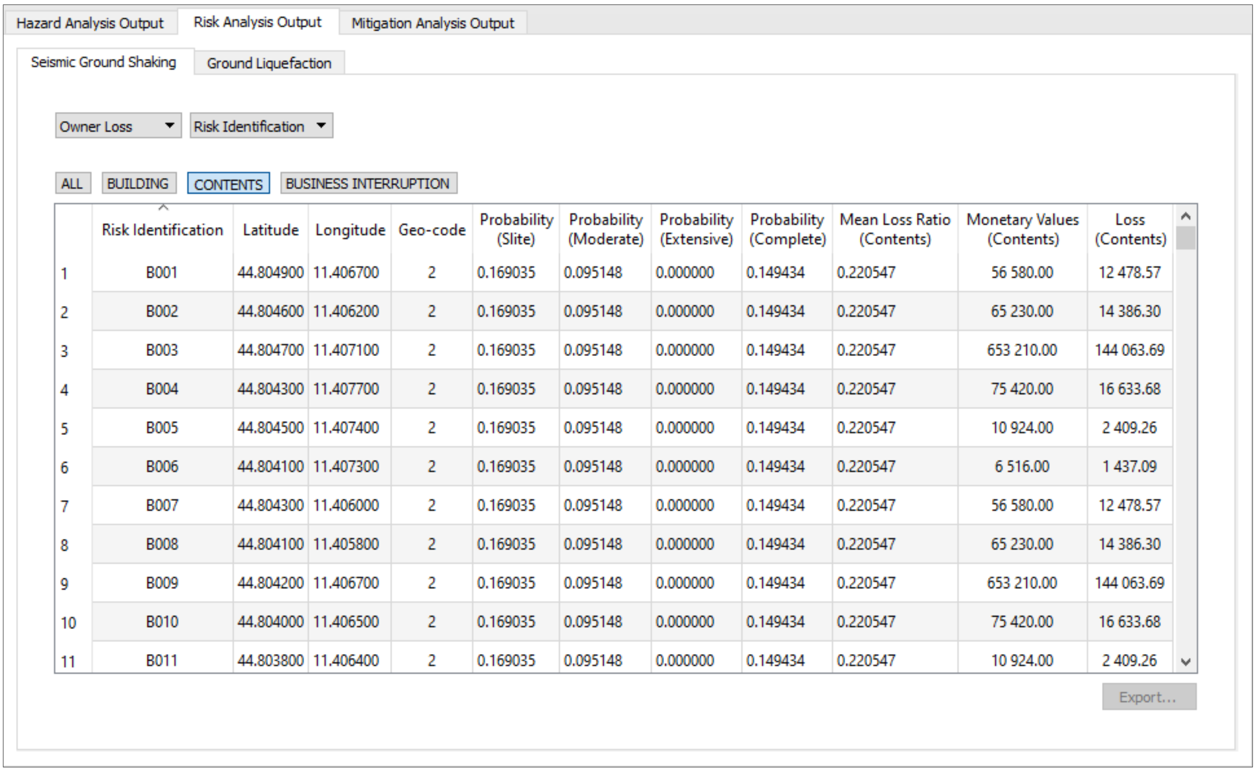
When ***BUILDING*** is selected, the displayed results represent the ground shaking-related Building Owner Loss at Asset Level

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748



	Risk Identification	Latitude	Longitude	Geo-code	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Building)	Monetary Values (Building)	Loss (Building)
1	B001	44.804900	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.182276	282 900.00	51 565.87
2	B002	44.804600	11.406200	2	0.169035	0.095148	0.000000	0.149434	0.182276	326 150.00	59 449.30
3	B003	44.804700	11.407100	2	0.169035	0.095148	0.000000	0.149434	0.182276	653 210.00	119 064.47
4	B004	44.804300	11.407700	2	0.169035	0.095148	0.000000	0.149434	0.182276	301 680.00	54 989.01
5	B005	44.804500	11.407400	2	0.169035	0.095148	0.000000	0.149434	0.182276	109 240.00	19 911.82
6	B006	44.804100	11.407300	2	0.169035	0.095148	0.000000	0.149434	0.182276	162 900.00	29 692.75
7	B007	44.804300	11.406000	2	0.169035	0.095148	0.000000	0.149434	0.182276	282 900.00	51 565.87
8	B008	44.804100	11.405800	2	0.169035	0.095148	0.000000	0.149434	0.182276	326 150.00	59 449.30
9	B009	44.804200	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.182276	653 210.00	119 064.47
10	B010	44.804000	11.406500	2	0.169035	0.095148	0.000000	0.149434	0.182276	301 680.00	54 989.01
11	B011	44.803800	11.406400	2	0.169035	0.095148	0.000000	0.149434	0.182276	109 240.00	19 911.82

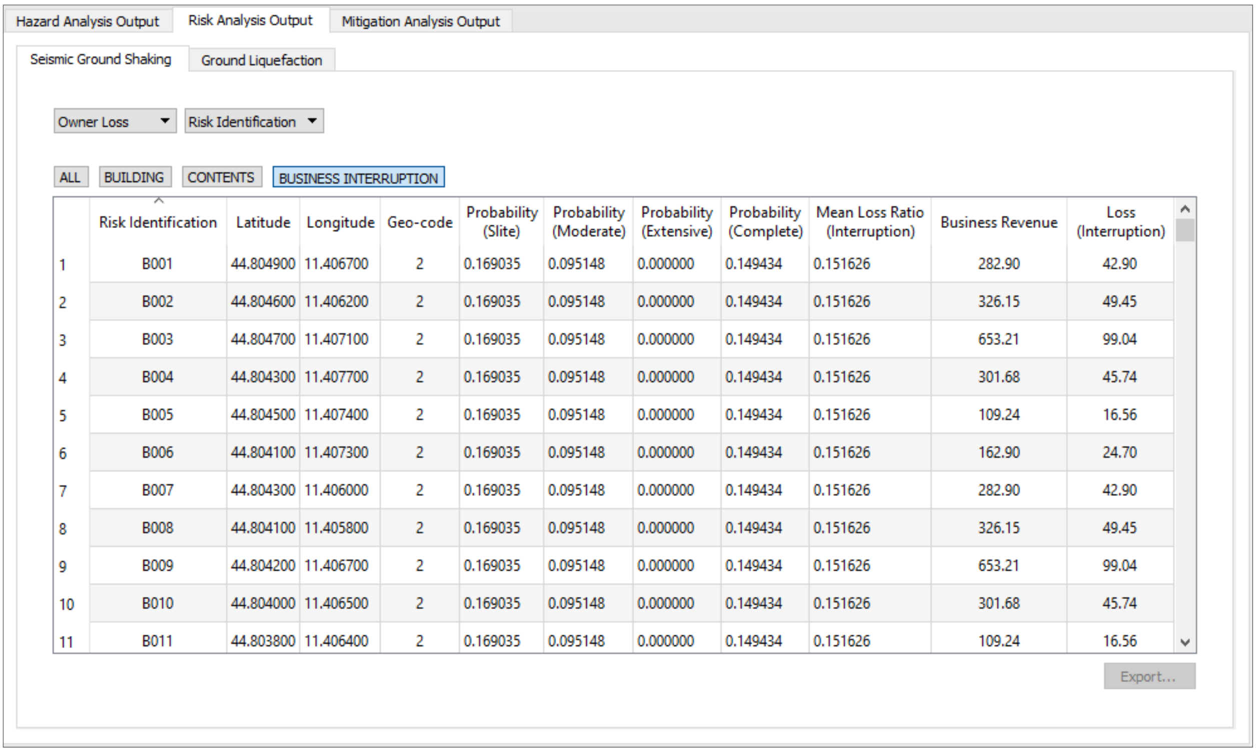
When ***CONTENTS*** is selected, the displayed results represent the ground shaking-related Contents Owner Loss at Asset Level



	Risk Identification	Latitude	Longitude	Geo-code	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Contents)	Monetary Values (Contents)	Loss (Contents)
1	B001	44.804900	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.220547	56 580.00	12 478.57
2	B002	44.804600	11.406200	2	0.169035	0.095148	0.000000	0.149434	0.220547	65 230.00	14 386.30
3	B003	44.804700	11.407100	2	0.169035	0.095148	0.000000	0.149434	0.220547	653 210.00	144 063.69
4	B004	44.804300	11.407700	2	0.169035	0.095148	0.000000	0.149434	0.220547	75 420.00	16 633.68
5	B005	44.804500	11.407400	2	0.169035	0.095148	0.000000	0.149434	0.220547	10 924.00	2 409.26
6	B006	44.804100	11.407300	2	0.169035	0.095148	0.000000	0.149434	0.220547	6 516.00	1 437.09
7	B007	44.804300	11.406000	2	0.169035	0.095148	0.000000	0.149434	0.220547	56 580.00	12 478.57
8	B008	44.804100	11.405800	2	0.169035	0.095148	0.000000	0.149434	0.220547	65 230.00	14 386.30
9	B009	44.804200	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.220547	653 210.00	144 063.69
10	B010	44.804000	11.406500	2	0.169035	0.095148	0.000000	0.149434	0.220547	75 420.00	16 633.68
11	B011	44.803800	11.406400	2	0.169035	0.095148	0.000000	0.149434	0.220547	10 924.00	2 409.26

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

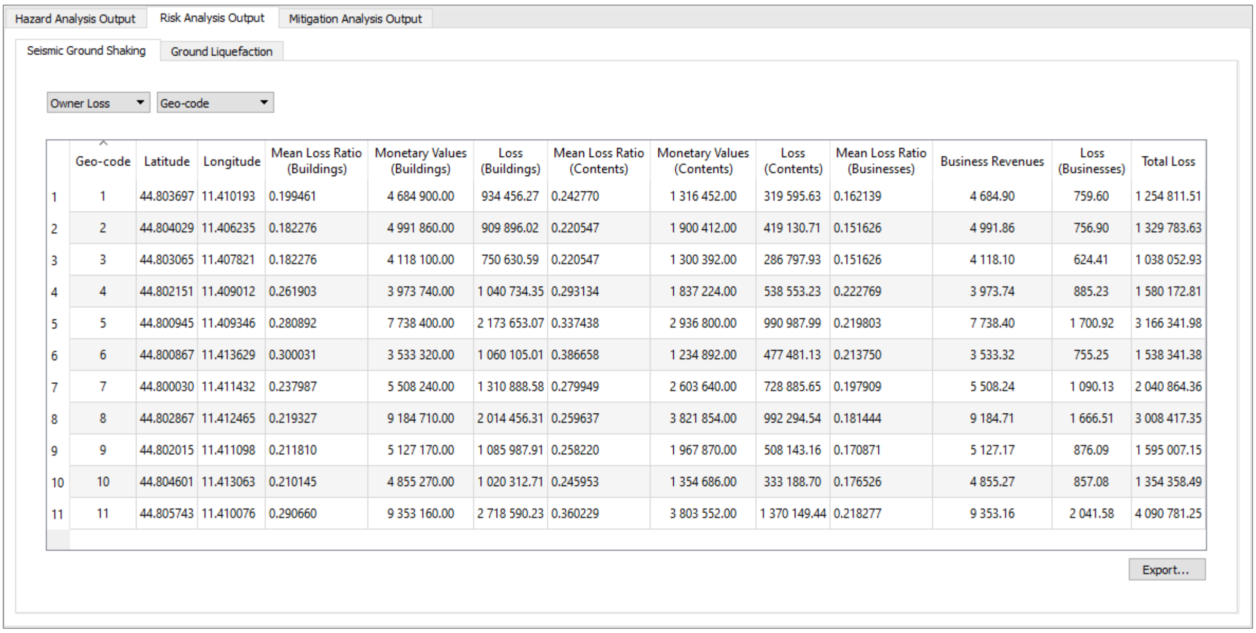
When ***BUSINESS INTERRUPTION*** is selected, the displayed results represent the ground shaking-related Business Interruption Owner Loss at Asset Level



	Risk Identification	Latitude	Longitude	Geo-code	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Interruption)	Business Revenue	Loss (Interruption)
1	B001	44.804900	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.151626	282.90	42.90
2	B002	44.804600	11.406200	2	0.169035	0.095148	0.000000	0.149434	0.151626	326.15	49.45
3	B003	44.804700	11.407100	2	0.169035	0.095148	0.000000	0.149434	0.151626	653.21	99.04
4	B004	44.804300	11.407700	2	0.169035	0.095148	0.000000	0.149434	0.151626	301.68	45.74
5	B005	44.804500	11.407400	2	0.169035	0.095148	0.000000	0.149434	0.151626	109.24	16.56
6	B006	44.804100	11.407300	2	0.169035	0.095148	0.000000	0.149434	0.151626	162.90	24.70
7	B007	44.804300	11.406000	2	0.169035	0.095148	0.000000	0.149434	0.151626	282.90	42.90
8	B008	44.804100	11.405800	2	0.169035	0.095148	0.000000	0.149434	0.151626	326.15	49.45
9	B009	44.804200	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.151626	653.21	99.04
10	B010	44.804000	11.406500	2	0.169035	0.095148	0.000000	0.149434	0.151626	301.68	45.74
11	B011	44.803800	11.406400	2	0.169035	0.095148	0.000000	0.149434	0.151626	109.24	16.56

4.3.2.1.2 Ground Shaking related Owner Loss at Geo-code Level

Ground Shaking-related Risk Analysis Output Parameters for Owner Loss at Geo-code level	*Description*
Mean Loss Ratio (Buildings)	Is the mean of loss ratios of all buildings located in a given Geo-code.
Monetary Values (Buildings)	Input Data of total monetary values of all buildings located in a given Geo-code.
Loss (Buildings)	Is computed as Total Monetary value (Buildings) multiplied with the Mean Loss Ratio (Buildings), in a given Geo-code.
Mean Loss Ratio (Contents)	Is the mean of loss ratios of all Contents located in a given Geo-code.
Monetary Values (Contents)	Input Data of total monetary values of all Contents located in a given Geo-code.
Loss (Contents)	Is computed as Total Monetary value (Contents) multiplied with the Mean Loss Ratio (Contents), in a given Geo-code.
Mean Loss Ratio (Businesses)	Is the mean of loss ratios of all Businesses located in a given Geo-code.
Monetary Values (Businesses)	Input Data of total monetary values of all Businesses located in a given Geo-code.
Loss (Businesses)	Is computed as Total Monetary value (Businesses) multiplied with the Mean Loss Ratio (Businesses), in a given Geo-code.
Total Loss	Total loss in a given Geo-code



	Geo-code	Latitude	Longitude	Mean Loss Ratio (Buildings)	Monetary Values (Buildings)	Loss (Buildings)	Mean Loss Ratio (Contents)	Monetary Values (Contents)	Loss (Contents)	Mean Loss Ratio (Businesses)	Business Revenues	Loss (Businesses)	Total Loss
1	1	44.803697	11.410193	0.199461	4 684 900.00	934 456.27	0.242770	1 316 452.00	319 595.63	0.162139	4 684.90	759.60	1 254 811.51
2	2	44.804029	11.406235	0.182276	4 991 860.00	909 896.02	0.220547	1 900 412.00	419 130.71	0.151626	4 991.86	756.90	1 329 783.63
3	3	44.803065	11.407821	0.182276	4 118 100.00	750 630.59	0.220547	1 300 392.00	286 797.93	0.151626	4 118.10	624.41	1 038 052.93
4	4	44.802151	11.409012	0.261903	3 973 740.00	1 040 734.35	0.293134	1 837 224.00	538 553.23	0.222769	3 973.74	885.23	1 580 172.81
5	5	44.800945	11.409346	0.280892	7 738 400.00	2 173 653.07	0.337438	2 936 800.00	990 987.99	0.219803	7 738.40	1 700.92	3 166 341.98
6	6	44.800867	11.413629	0.300031	3 533 320.00	1 060 105.01	0.386658	1 234 892.00	477 481.13	0.213750	3 533.32	755.25	1 538 341.38
7	7	44.800030	11.411432	0.237987	5 508 240.00	1 310 888.58	0.279949	2 603 640.00	728 885.65	0.197909	5 508.24	1 090.13	2 040 864.36
8	8	44.802867	11.412465	0.219327	9 184 710.00	2 014 456.31	0.259637	3 821 854.00	992 294.54	0.181444	9 184.71	1 666.51	3 008 417.35
9	9	44.802015	11.411098	0.211810	5 127 170.00	1 085 987.91	0.258220	1 967 870.00	508 143.16	0.170871	5 127.17	876.09	1 595 007.15
10	10	44.804601	11.413063	0.210145	4 855 270.00	1 020 312.71	0.245953	1 354 686.00	333 188.70	0.176526	4 855.27	857.08	1 354 358.49
11	11	44.805743	11.410076	0.290660	9 353 160.00	2 718 590.23	0.360229	3 803 552.00	1 370 149.44	0.218277	9 353.16	2 041.58	4 090 781.25

4.3.2.2 Ground Shaking related Insurance Loss

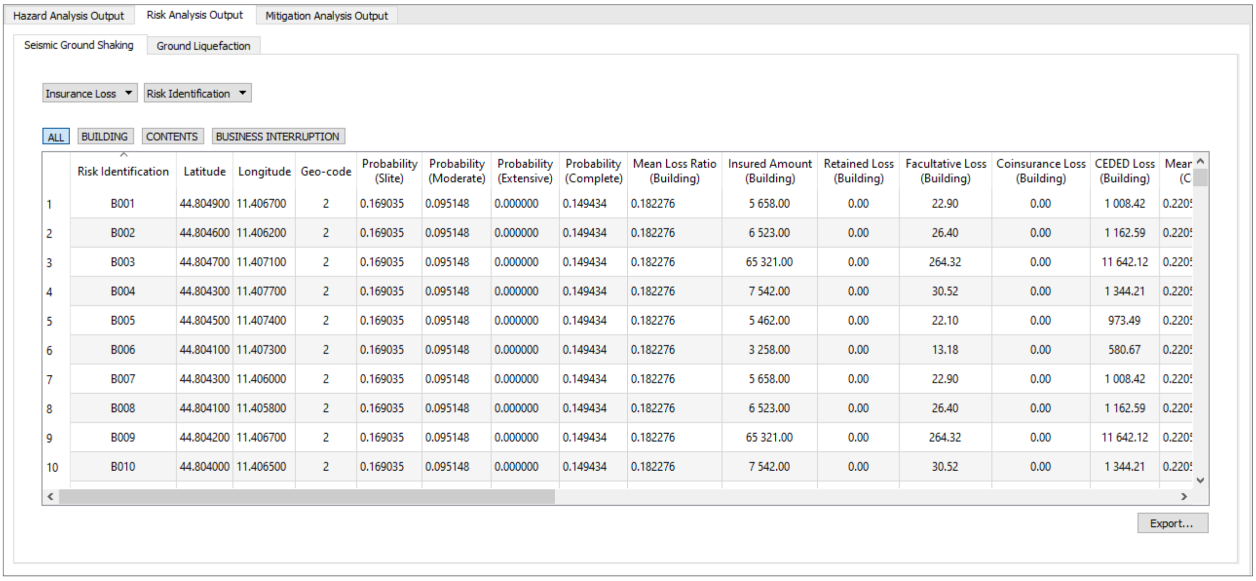
4.3.2.2.1 Ground Shaking related Insurance Loss at Asset Level

Ground Shaking-related Risk Analysis Output Parameters for Insurance Loss at Asset level	*Description*
Risk Identification	Identification number representing each asset (building or infrastructure)
Geo-Code	Geo-code unit where each asset is assigned to.
Probabilities of Damage	Probabilities of Damage computed for each asset. The number of probabilities depends on the type of fragility curves used in risk analysis: if the fragility was with one, two, three or four Damage Limit States
BUILDING	
Mean Loss Ratio (Building)	Is the mean of building loss ratios of a given number of buildings of same Typology located in same Geo-code.
Insured Amount (Building)	Input Data of the insured amount for a given building
Retained Loss (Building)	Retained loss of a given building
Facultative Loss (Building)	Facultative loss of a given building
Coinsurance Loss (Building)	Coinsurance loss of a given building
CEDED Loss (Building)	CECED loss of a given building
CONTENTS	
Mean Loss Ratio (Contents)	Is the mean of content loss ratios of a given number of buildings of same Typology located in same Geo-code.
Insured Amount (Contents)	Input Data of the insured amount for contents in a given building
Retained Loss (Contents)	Contents Retained loss of a given building
Facultative Loss (Contents)	Contents Facultative loss of a given building

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

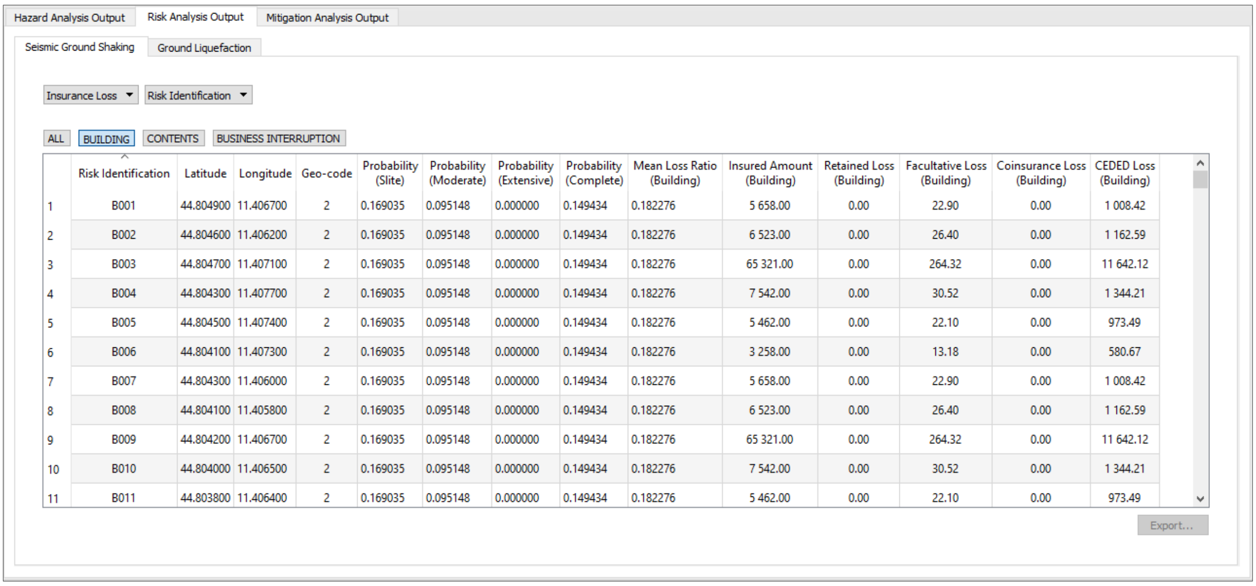
Coinsurance Loss (Contents)	Contents Coinsurance loss of a given building
CEDED Loss (Building)	Contents CECED loss of a given building
BUSINESS INTERRUPTION	
Mean Loss Ratio (Business Interruption)	Is the mean of business interruption loss ratios of a given number of buildings of same Typology located in same Geo-code.
Insured Amount (Business Interruption)	Input Data of the insured amount for Business Interruption for a given building
Retained Loss (Business Interruption)	Business Interruption Retained loss of a given building
Facultative Loss (Business Interruption)	Business Interruption Facultative loss of a given building
Coinsurance Loss (Business Interruption)	Business Interruption Coinsurance loss of a given building
CEDED Loss (Business Interruption)	Business Interruption CECED loss of a given building

When ***ALL*** is selected, the displayed results represent all the outcomes of ground shaking-related Insurance Loss at Asset Level



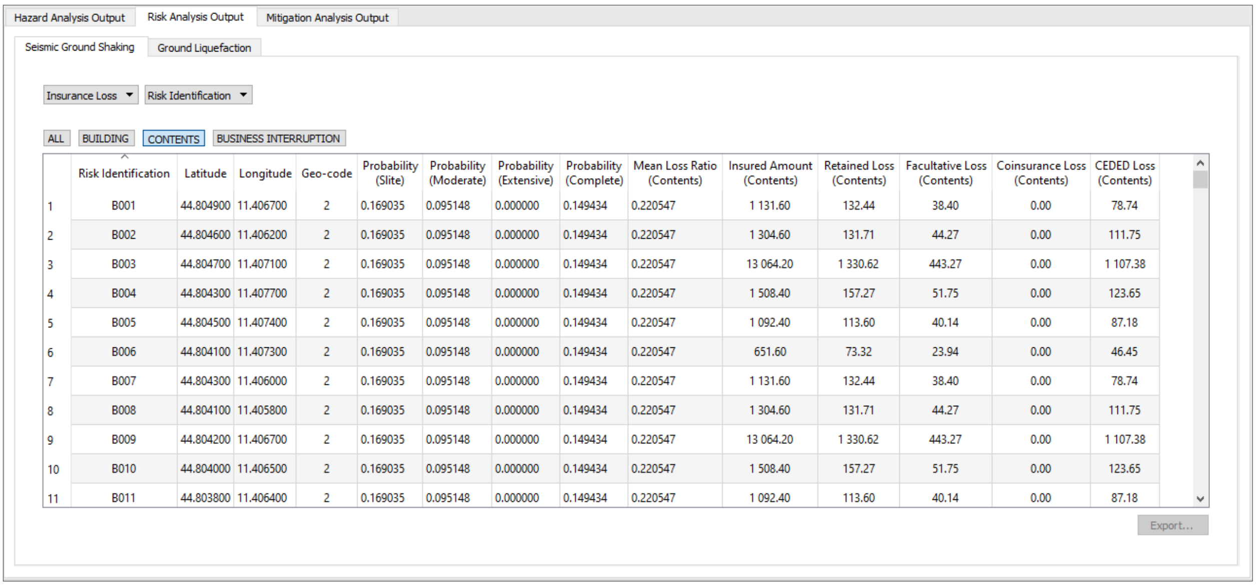
	Risk Identification	Latitude	Longitude	Geo-code	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Building)	Insured Amount (Building)	Retained Loss (Building)	Facultative Loss (Building)	Coinsurance Loss (Building)	CEDED Loss (Building)	Mean (C
1	B001	44.804900	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.182276	5 658.00	0.00	22.90	0.00	1 008.42	0.220
2	B002	44.804600	11.406200	2	0.169035	0.095148	0.000000	0.149434	0.182276	6 523.00	0.00	26.40	0.00	1 162.59	0.220
3	B003	44.804700	11.407100	2	0.169035	0.095148	0.000000	0.149434	0.182276	65 321.00	0.00	264.32	0.00	11 642.12	0.220
4	B004	44.804300	11.407700	2	0.169035	0.095148	0.000000	0.149434	0.182276	7 542.00	0.00	30.52	0.00	1 344.21	0.220
5	B005	44.804500	11.407400	2	0.169035	0.095148	0.000000	0.149434	0.182276	5 462.00	0.00	22.10	0.00	973.49	0.220
6	B006	44.804100	11.407300	2	0.169035	0.095148	0.000000	0.149434	0.182276	3 258.00	0.00	13.18	0.00	580.67	0.220
7	B007	44.804300	11.406000	2	0.169035	0.095148	0.000000	0.149434	0.182276	5 658.00	0.00	22.90	0.00	1 008.42	0.220
8	B008	44.804100	11.405800	2	0.169035	0.095148	0.000000	0.149434	0.182276	6 523.00	0.00	26.40	0.00	1 162.59	0.220
9	B009	44.804200	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.182276	65 321.00	0.00	264.32	0.00	11 642.12	0.220
10	B010	44.804000	11.406500	2	0.169035	0.095148	0.000000	0.149434	0.182276	7 542.00	0.00	30.52	0.00	1 344.21	0.220

When ***BUILDING*** is selected, the displayed results represent the ground shaking-related Building Insurance Loss at Asset Level



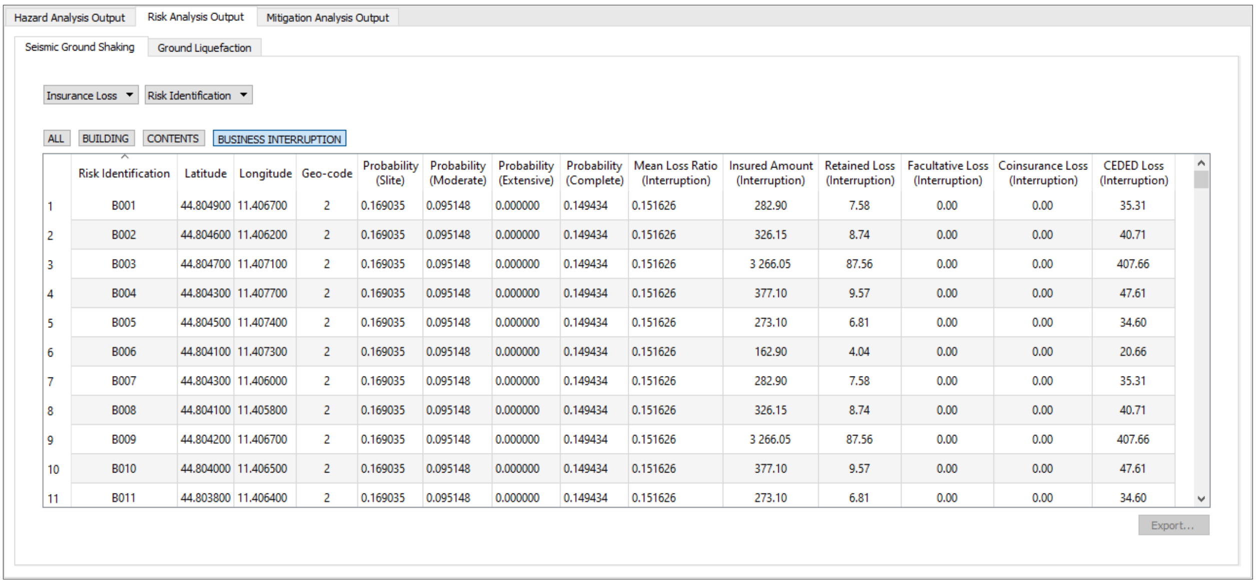
	Risk Identification	Latitude	Longitude	Geo-code	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Building)	Insured Amount (Building)	Retained Loss (Building)	Facultative Loss (Building)	Coinsurance Loss (Building)	CEDED Loss (Building)
1	B001	44.804900	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.182276	5 658.00	0.00	22.90	0.00	1 008.42
2	B002	44.804600	11.406200	2	0.169035	0.095148	0.000000	0.149434	0.182276	6 523.00	0.00	26.40	0.00	1 162.59
3	B003	44.804700	11.407100	2	0.169035	0.095148	0.000000	0.149434	0.182276	65 321.00	0.00	264.32	0.00	11 642.12
4	B004	44.804300	11.407700	2	0.169035	0.095148	0.000000	0.149434	0.182276	7 542.00	0.00	30.52	0.00	1 344.21
5	B005	44.804500	11.407400	2	0.169035	0.095148	0.000000	0.149434	0.182276	5 462.00	0.00	22.10	0.00	973.49
6	B006	44.804100	11.407300	2	0.169035	0.095148	0.000000	0.149434	0.182276	3 258.00	0.00	13.18	0.00	580.67
7	B007	44.804300	11.406000	2	0.169035	0.095148	0.000000	0.149434	0.182276	5 658.00	0.00	22.90	0.00	1 008.42
8	B008	44.804100	11.405800	2	0.169035	0.095148	0.000000	0.149434	0.182276	6 523.00	0.00	26.40	0.00	1 162.59
9	B009	44.804200	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.182276	65 321.00	0.00	264.32	0.00	11 642.12
10	B010	44.804000	11.406500	2	0.169035	0.095148	0.000000	0.149434	0.182276	7 542.00	0.00	30.52	0.00	1 344.21
11	B011	44.803800	11.406400	2	0.169035	0.095148	0.000000	0.149434	0.182276	5 462.00	0.00	22.10	0.00	973.49

When ***CONTENTS*** is selected, the displayed results represent the ground shaking-related Contents Insurance Loss at Asset Level



	Risk Identification	Latitude	Longitude	Geo-code	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Contents)	Insured Amount (Contents)	Retained Loss (Contents)	Facultative Loss (Contents)	Coinsurance Loss (Contents)	CEDED Loss (Contents)
1	B001	44.804900	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.220547	1 131.60	132.44	38.40	0.00	78.74
2	B002	44.804600	11.406200	2	0.169035	0.095148	0.000000	0.149434	0.220547	1 304.60	131.71	44.27	0.00	111.75
3	B003	44.804700	11.407100	2	0.169035	0.095148	0.000000	0.149434	0.220547	13 064.20	1 330.62	443.27	0.00	1 107.38
4	B004	44.804300	11.407700	2	0.169035	0.095148	0.000000	0.149434	0.220547	1 508.40	157.27	51.75	0.00	123.65
5	B005	44.804500	11.407400	2	0.169035	0.095148	0.000000	0.149434	0.220547	1 092.40	113.60	40.14	0.00	87.18
6	B006	44.804100	11.407300	2	0.169035	0.095148	0.000000	0.149434	0.220547	651.60	73.32	23.94	0.00	46.45
7	B007	44.804300	11.406000	2	0.169035	0.095148	0.000000	0.149434	0.220547	1 131.60	132.44	38.40	0.00	78.74
8	B008	44.804100	11.405800	2	0.169035	0.095148	0.000000	0.149434	0.220547	1 304.60	131.71	44.27	0.00	111.75
9	B009	44.804200	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.220547	13 064.20	1 330.62	443.27	0.00	1 107.38
10	B010	44.804000	11.406500	2	0.169035	0.095148	0.000000	0.149434	0.220547	1 508.40	157.27	51.75	0.00	123.65
11	B011	44.803800	11.406400	2	0.169035	0.095148	0.000000	0.149434	0.220547	1 092.40	113.60	40.14	0.00	87.18

When ***BUSINESS INTERRUPTION*** is selected, the displayed results represent the ground shaking-related Business Interruption Insurance Loss at Asset Level



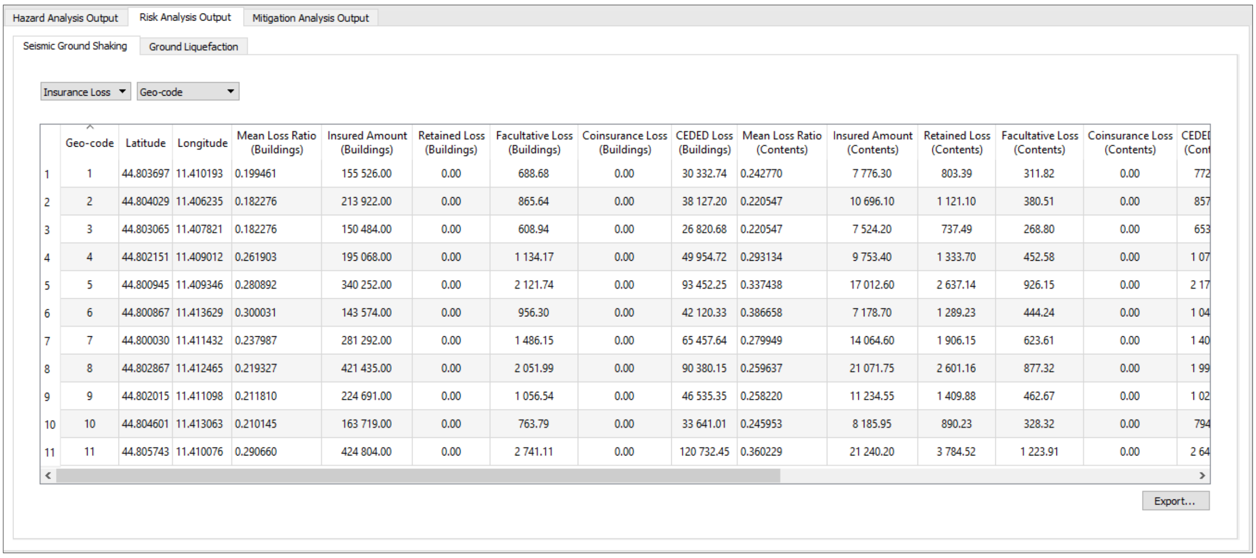
	Risk Identification	Latitude	Longitude	Geo-code	Probability (Slite)	Probability (Moderate)	Probability (Extensive)	Probability (Complete)	Mean Loss Ratio (Interruption)	Insured Amount (Interruption)	Retained Loss (Interruption)	Facultative Loss (Interruption)	Coinsurance Loss (Interruption)	CEDED Loss (Interruption)
1	B001	44.804900	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.151626	282.90	7.58	0.00	0.00	35.31
2	B002	44.804600	11.406200	2	0.169035	0.095148	0.000000	0.149434	0.151626	326.15	8.74	0.00	0.00	40.71
3	B003	44.804700	11.407100	2	0.169035	0.095148	0.000000	0.149434	0.151626	3 266.05	87.56	0.00	0.00	407.66
4	B004	44.804300	11.407700	2	0.169035	0.095148	0.000000	0.149434	0.151626	377.10	9.57	0.00	0.00	47.61
5	B005	44.804500	11.407400	2	0.169035	0.095148	0.000000	0.149434	0.151626	273.10	6.81	0.00	0.00	34.60
6	B006	44.804100	11.407300	2	0.169035	0.095148	0.000000	0.149434	0.151626	162.90	4.04	0.00	0.00	20.66
7	B007	44.804300	11.406000	2	0.169035	0.095148	0.000000	0.149434	0.151626	282.90	7.58	0.00	0.00	35.31
8	B008	44.804100	11.405800	2	0.169035	0.095148	0.000000	0.149434	0.151626	326.15	8.74	0.00	0.00	40.71
9	B009	44.804200	11.406700	2	0.169035	0.095148	0.000000	0.149434	0.151626	3 266.05	87.56	0.00	0.00	407.66
10	B010	44.804000	11.406500	2	0.169035	0.095148	0.000000	0.149434	0.151626	377.10	9.57	0.00	0.00	47.61
11	B011	44.803800	11.406400	2	0.169035	0.095148	0.000000	0.149434	0.151626	273.10	6.81	0.00	0.00	34.60

4.3.2.2.2 Ground Shaking related Insurance Loss at Geo-code Level

Ground Shaking-related Risk Analysis Output Parameters for Insurance Loss at Geo-code level	*Description*
Mean Loss Ratio (Buildings)	Is the mean of loss ratios of all buildings located in a given Geo-code.
Insured Amount (Buildings)	Total insured amount for all buildings located in a given Geo-code.
Retained Loss (Buildings)	Total retained Loss considering all buildings located in a given Geo-code.
Facultative Loss (Buildings)	Total facultative Loss considering all buildings located in a given Geo-code.
Coinsurance Loss (Buildings)	Total coinsurance Loss considering all buildings located in a given Geo-code.
CECED Loss (Buildings)	Total CECED Loss considering all buildings located in a given Geo-code.
Insured Amount (Contents)	Total insured amount for all contents of buildings located in a given Geo-code.
Retained Loss (Contents)	Total retained Loss considering all contents of buildings located in a given Geo-code.
Facultative Loss (Contents)	Total facultative Loss considering all contents of buildings located in a given Geo-code.
Coinsurance Loss (Contents)	Total coinsurance Loss considering all contents of buildings located in a given Geo-code.
CECED Loss (Contents)	Total CECED Loss considering all contents of buildings located in a given Geo-code.
Insured Amount (Business Interruption)	Total insured amount for all businesses of buildings located in a given Geo-code.
Retained Loss (Business Interruption)	Total retained Loss considering all businesses of buildings located in a given Geo-code.
Facultative Loss (Business Interruption)	Total facultative Loss considering all businesses of buildings located in a given Geo-code.
Coinsurance Loss (Business Interruption)	Total coinsurance Loss considering all businesses of buildings located in a given Geo-code.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

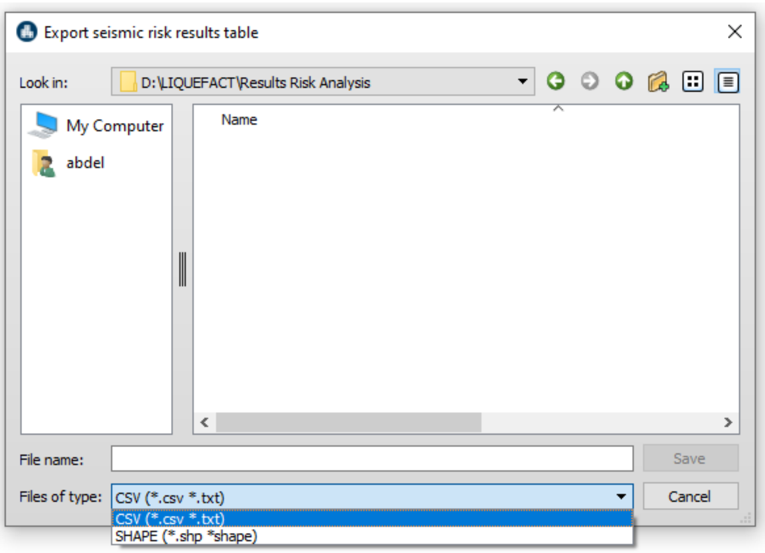
CECED Loss (Business Interruption)	Total CECED Loss considering all businesses of buildings located in a given Geo-code.
Total Loss	Total insurance loss in a given Geo-code



	Geo-code	Latitude	Longitude	Mean Loss Ratio (Buildings)	Insured Amount (Buildings)	Retained Loss (Buildings)	Facultative Loss (Buildings)	Coinsurance Loss (Buildings)	CEDED Loss (Buildings)	Mean Loss Ratio (Contents)	Insured Amount (Contents)	Retained Loss (Contents)	Facultative Loss (Contents)	Coinsurance Loss (Contents)	CEDEI (Cont
1	1	44.803697	11.410193	0.199461	155 526.00	0.00	688.68	0.00	30 332.74	0.242770	7 776.30	803.39	311.82	0.00	772
2	2	44.804029	11.406235	0.182276	213 922.00	0.00	865.64	0.00	38 127.20	0.220547	10 696.10	1 121.10	380.51	0.00	857
3	3	44.803065	11.407821	0.182276	150 484.00	0.00	608.94	0.00	26 820.68	0.220547	7 524.20	737.49	268.80	0.00	653
4	4	44.802151	11.409012	0.261903	195 068.00	0.00	1 134.17	0.00	49 954.72	0.293134	9 753.40	1 333.70	452.58	0.00	1 07
5	5	44.800945	11.409346	0.280892	340 252.00	0.00	2 121.74	0.00	93 452.25	0.337438	17 012.60	2 637.14	926.15	0.00	2 17
6	6	44.800867	11.413629	0.300031	143 574.00	0.00	956.30	0.00	42 120.33	0.386658	7 178.70	1 289.23	444.24	0.00	1 04
7	7	44.800030	11.411432	0.237987	281 292.00	0.00	1 486.15	0.00	65 457.64	0.279949	14 064.60	1 906.15	623.61	0.00	1 40
8	8	44.802867	11.412465	0.219327	421 435.00	0.00	2 051.99	0.00	90 380.15	0.259637	21 071.75	2 601.16	877.32	0.00	1 99
9	9	44.802015	11.411098	0.211810	224 691.00	0.00	1 056.54	0.00	46 535.35	0.258220	11 234.55	1 409.88	462.67	0.00	1 02
10	10	44.804601	11.413063	0.210145	163 719.00	0.00	763.79	0.00	33 641.01	0.245953	8 185.95	890.23	328.32	0.00	794
11	11	44.805743	11.410076	0.290660	424 804.00	0.00	2 741.11	0.00	120 732.45	0.360229	21 240.20	3 784.52	1 223.91	0.00	2 64

4.3.3 Export Results of Risk Analysis

All results and output of Risk Analysis can be exported by clicking on Export button. The results can be exported as SHAPE or CSV by selecting SHAPE or CSV in the file type pulldown menu in the Export dialog. SHAPE files can be exported as points or polygons. The database and result files in various formats will be stored in a project directory.



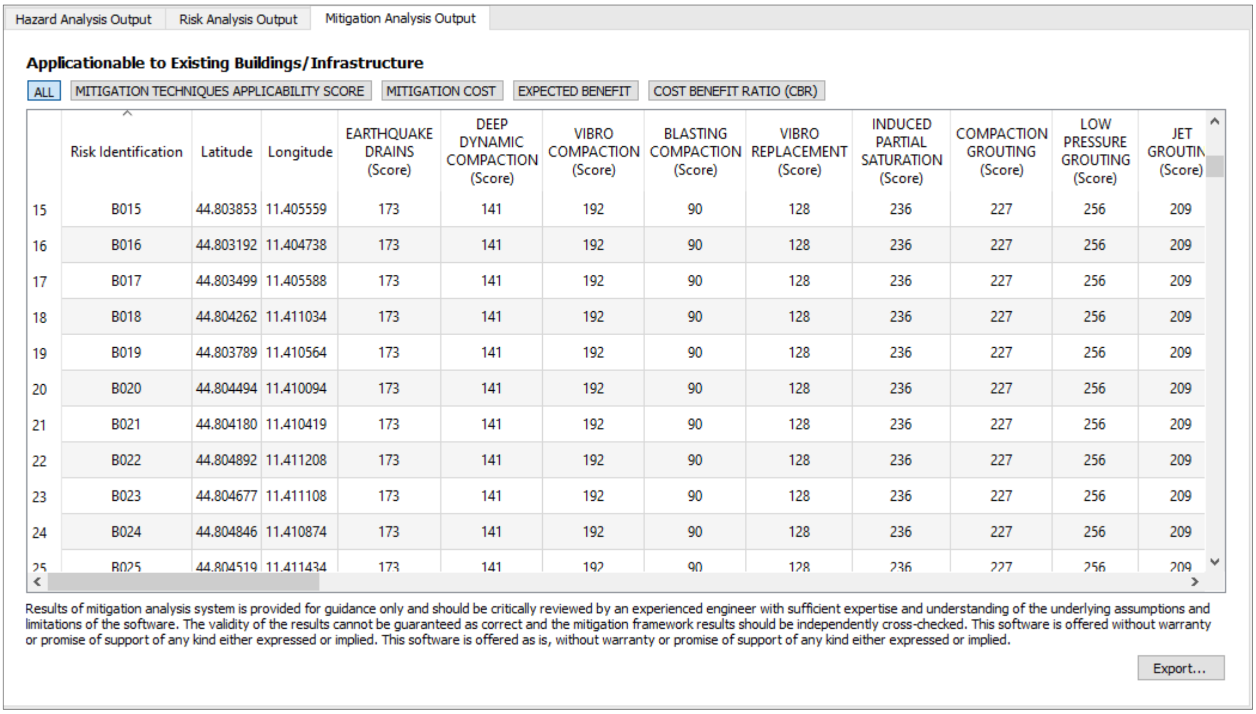
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

4.4 Mitigation Analysis Output

Results of Mitigation analysis are presented in terms applicability score for the incorporated ground improvement liquefaction mitigation techniques and cost-benefit estimation for the application of these different techniques.

Note: here also users are reminded that the results of mitigation analysis are provided just as guidance only and should not be considered for design decision. The results should always be critically reviewed by an experienced local engineer with expertise and understanding of the various assumptions that have been implemented in the development of the Mitigation Analysis System and limitations of the software.

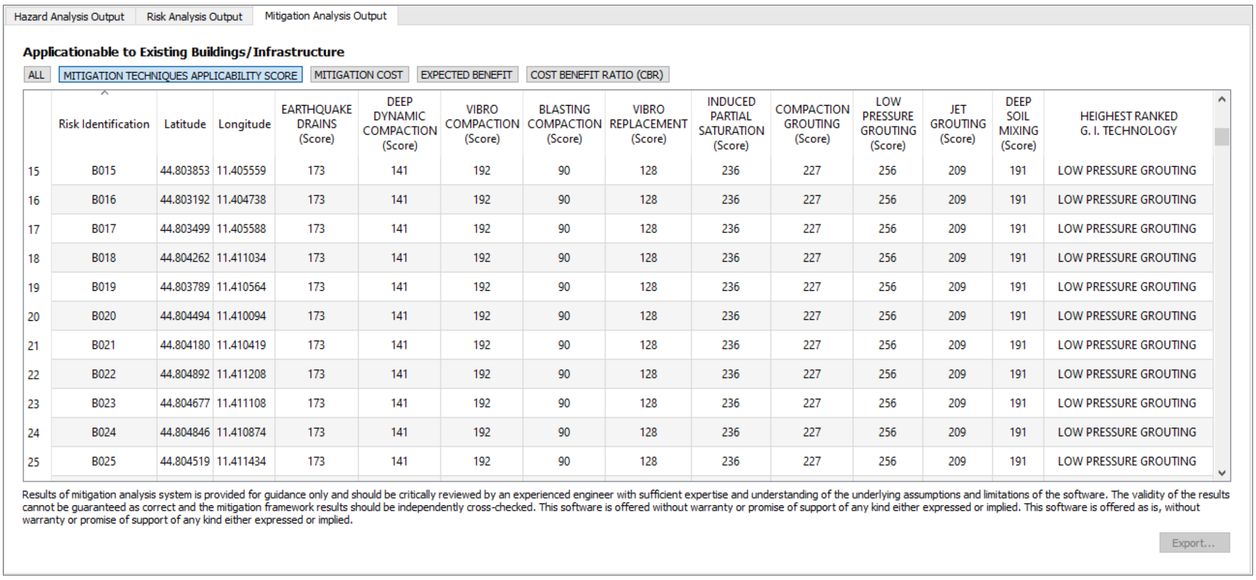
When ***ALL*** is selected, the displayed results represent all the outcomes of mitigation techniques applicability score, mitigation cost, expected benefit, and cost benefit ratio. The results are provided at each Asset Level.



	Risk Identification	Latitude	Longitude	EARTHQUAKE DRAINS (Score)	DEEP DYNAMIC COMPACTION (Score)	VIBRO COMPACTION (Score)	BLASTING COMPACTION (Score)	VIBRO REPLACEMENT (Score)	INDUCED PARTIAL SATURATION (Score)	COMPACTION GROUTING (Score)	LOW PRESSURE GROUTING (Score)	JET GROUTIN (Score)
15	B015	44.803853	11.405559	173	141	192	90	128	236	227	256	209
16	B016	44.803192	11.404738	173	141	192	90	128	236	227	256	209
17	B017	44.803499	11.405588	173	141	192	90	128	236	227	256	209
18	B018	44.804262	11.411034	173	141	192	90	128	236	227	256	209
19	B019	44.803789	11.410564	173	141	192	90	128	236	227	256	209
20	B020	44.804494	11.410094	173	141	192	90	128	236	227	256	209
21	B021	44.804180	11.410419	173	141	192	90	128	236	227	256	209
22	B022	44.804892	11.411208	173	141	192	90	128	236	227	256	209
23	B023	44.804677	11.411108	173	141	192	90	128	236	227	256	209
24	B024	44.804846	11.410874	173	141	192	90	128	236	227	256	209
25	B025	44.804519	11.411434	173	141	192	90	128	236	227	256	209

4.4.1 Mitigation Techniques Applicability Score

When ***MITIGATION TECHNIQUES APPLICABILITY SCORE*** is selected, the displayed results represent the overall applicability score for each of the 10 incorporated ground improvement mitigation techniques estimated for each considered asset (building or infrastructure) selected for mitigation analysis.



Hazard Analysis Output | Risk Analysis Output | Mitigation Analysis Output

Applicationable to Existing Buildings/Infrastructure

ALL | MITIGATION TECHNIQUES APPLICABILITY SCORE | MITIGATION COST | EXPECTED BENEFIT | COST BENEFIT RATIO (CBR)

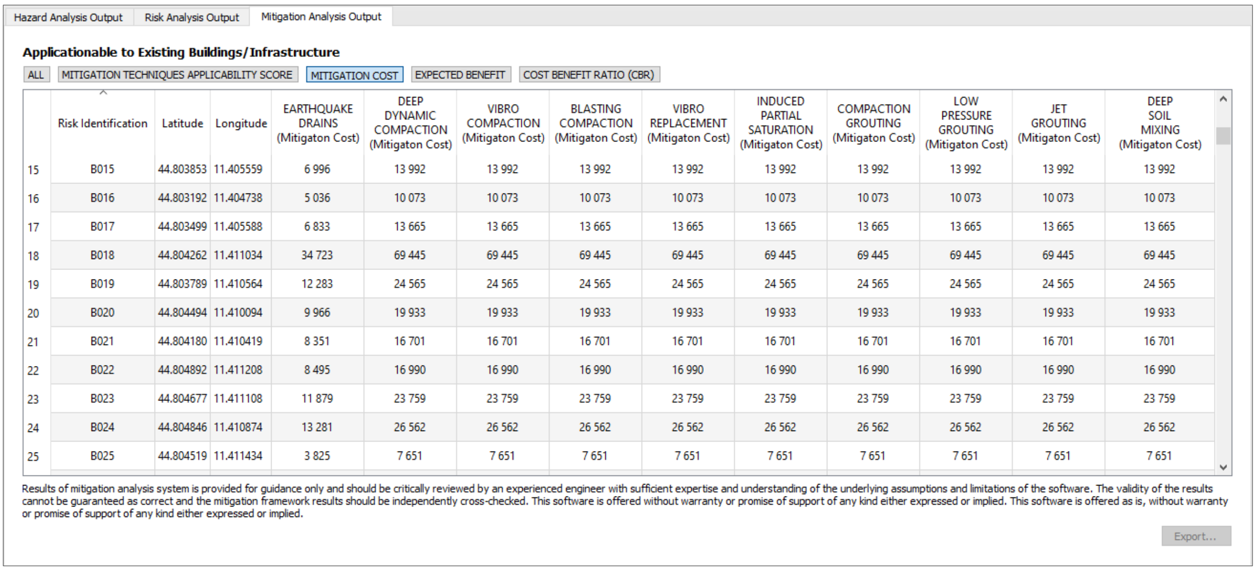
	Risk Identification	Latitude	Longitude	EARTHQUAKE DRAINS (Score)	DEEP DYNAMIC COMPACTION (Score)	VIBRO COMPACTION (Score)	BLASTING COMPACTION (Score)	VIBRO REPLACEMENT (Score)	INDUCED PARTIAL SATURATION (Score)	COMPACTION GROUTING (Score)	LOW PRESSURE GROUTING (Score)	JET GROUTING (Score)	DEEP SOIL MIXING (Score)	HEIGHEST RANKED G. I. TECHNOLOGY
15	B015	44.803853	11.405559	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING
16	B016	44.803192	11.404738	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING
17	B017	44.803499	11.405588	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING
18	B018	44.804262	11.411034	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING
19	B019	44.803789	11.410564	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING
20	B020	44.804494	11.410094	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING
21	B021	44.804180	11.410419	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING
22	B022	44.804892	11.411208	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING
23	B023	44.804677	11.411108	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING
24	B024	44.804846	11.410874	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING
25	B025	44.804519	11.411434	173	141	192	90	128	236	227	256	209	191	LOW PRESSURE GROUTING

Results of mitigation analysis system is provided for guidance only and should be critically reviewed by an experienced engineer with sufficient expertise and understanding of the underlying assumptions and limitations of the software. The validity of the results cannot be guaranteed as correct and the mitigation framework results should be independently cross-checked. This software is offered without warranty or promise of support of any kind either expressed or implied. This software is offered as is, without warranty or promise of support of any kind either expressed or implied.

Export...

4.4.2 Mitigation Cost

When ***MITIGATION COST*** is selected, the displayed results represent the cost for each of the 10 incorporated ground improvement mitigation techniques estimated for each considered asset (building or infrastructure) selected for mitigation analysis.



Hazard Analysis Output | Risk Analysis Output | Mitigation Analysis Output

Applicationable to Existing Buildings/Infrastructure

ALL | MITIGATION TECHNIQUES APPLICABILITY SCORE | MITIGATION COST | EXPECTED BENEFIT | COST BENEFIT RATIO (CBR)

	Risk Identification	Latitude	Longitude	EARTHQUAKE DRAINS (Mitigaton Cost)	DEEP DYNAMIC COMPACTION (Mitigaton Cost)	VIBRO COMPACTION (Mitigaton Cost)	BLASTING COMPACTION (Mitigaton Cost)	VIBRO REPLACEMENT (Mitigaton Cost)	INDUCED PARTIAL SATURATION (Mitigaton Cost)	COMPACTION GROUTING (Mitigaton Cost)	LOW PRESSURE GROUTING (Mitigaton Cost)	JET GROUTING (Mitigaton Cost)	DEEP SOIL MIXING (Mitigaton Cost)
15	B015	44.803853	11.405559	6 996	13 992	13 992	13 992	13 992	13 992	13 992	13 992	13 992	13 992
16	B016	44.803192	11.404738	5 036	10 073	10 073	10 073	10 073	10 073	10 073	10 073	10 073	10 073
17	B017	44.803499	11.405588	6 833	13 665	13 665	13 665	13 665	13 665	13 665	13 665	13 665	13 665
18	B018	44.804262	11.411034	34 723	69 445	69 445	69 445	69 445	69 445	69 445	69 445	69 445	69 445
19	B019	44.803789	11.410564	12 283	24 565	24 565	24 565	24 565	24 565	24 565	24 565	24 565	24 565
20	B020	44.804494	11.410094	9 966	19 933	19 933	19 933	19 933	19 933	19 933	19 933	19 933	19 933
21	B021	44.804180	11.410419	8 351	16 701	16 701	16 701	16 701	16 701	16 701	16 701	16 701	16 701
22	B022	44.804892	11.411208	8 495	16 990	16 990	16 990	16 990	16 990	16 990	16 990	16 990	16 990
23	B023	44.804677	11.411108	11 879	23 759	23 759	23 759	23 759	23 759	23 759	23 759	23 759	23 759
24	B024	44.804846	11.410874	13 281	26 562	26 562	26 562	26 562	26 562	26 562	26 562	26 562	26 562
25	B025	44.804519	11.411434	3 825	7 651	7 651	7 651	7 651	7 651	7 651	7 651	7 651	7 651

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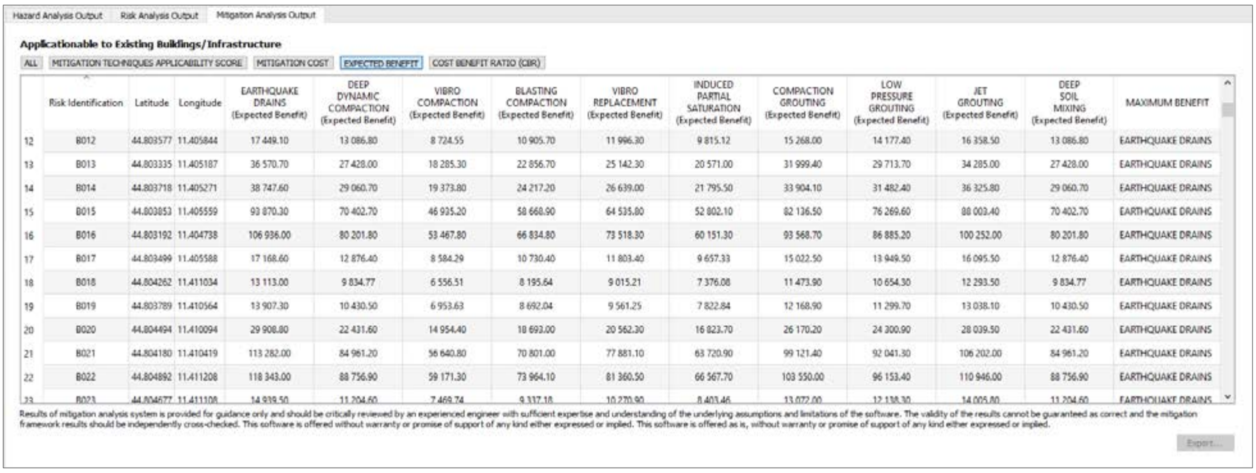
Export...

4.4.3 Expected Benefit

When ***EXPECTED BENEFIT*** is selected, the displayed results represent the expected benefit for each of the 10 incorporated ground improvement mitigation techniques estimated for each considered asset (building or infrastructure) selected for mitigation analysis.



Hazard Analysis Output | Risk Analysis Output | Mitigation Analysis Output

Applicationable to Existing Buildings/Infrastructure

ALL | MITIGATION TECHNIQUES APPLICABILITY SCORE | MITIGATION COST | EXPECTED BENEFIT | COST BENEFIT RATIO (CBR)

	Risk Identification	Latitude	Longitude	EARTHQUAKE DRAINS (Expected Benefit)	DEEP DYNAMIC COMPACTION (Expected Benefit)	VIBRO COMPACTION (Expected Benefit)	BLASTING COMPACTION (Expected Benefit)	VIBRO REPLACEMENT (Expected Benefit)	INDUCED PARTIAL SATURATION (Expected Benefit)	COMPACTION GROUTING (Expected Benefit)	LOW PRESSURE GROUTING (Expected Benefit)	JET GROUTING (Expected Benefit)	DEEP SOIL MIXING (Expected Benefit)	MAXIMUM BENEFIT
12	B012	44.803577	11.405844	17 449.10	13 086.80	8 724.55	10 905.70	11 996.30	9 815.12	15 268.00	14 177.40	16 358.50	13 086.80	EARTHQUAKE DRAINS
13	B013	44.803335	11.405187	36 570.70	27 428.00	18 285.30	22 856.70	25 142.30	20 571.00	31 999.40	29 713.70	34 285.00	27 428.00	EARTHQUAKE DRAINS
14	B014	44.803718	11.405271	38 747.60	29 060.70	19 373.80	24 217.20	26 639.00	21 795.50	33 904.10	31 482.40	36 325.80	29 060.70	EARTHQUAKE DRAINS
15	B015	44.803853	11.405559	93 870.30	70 402.70	46 935.20	58 668.90	64 535.80	52 802.10	82 136.50	76 269.60	88 003.40	70 402.70	EARTHQUAKE DRAINS
16	B016	44.803192	11.404738	106 936.00	80 201.80	53 467.80	66 834.80	73 518.30	60 151.30	93 568.70	86 885.20	100 252.00	80 201.80	EARTHQUAKE DRAINS
17	B017	44.803499	11.405588	17 168.60	12 876.40	8 584.29	10 730.40	11 803.40	9 657.33	15 022.50	13 949.50	16 095.50	12 876.40	EARTHQUAKE DRAINS
18	B018	44.804262	11.411034	13 113.00	9 834.77	6 556.51	8 195.64	9 015.21	7 376.08	11 473.90	10 654.30	12 293.50	9 834.77	EARTHQUAKE DRAINS
19	B019	44.803789	11.410564	13 907.30	10 430.50	6 953.63	8 692.04	9 561.25	7 822.84	12 168.90	11 299.70	13 038.10	10 430.50	EARTHQUAKE DRAINS
20	B020	44.804494	11.410094	29 908.80	22 431.60	14 954.40	18 693.00	20 562.30	16 823.70	26 170.20	24 300.90	28 039.50	22 431.60	EARTHQUAKE DRAINS
21	B021	44.804180	11.410419	113 282.00	84 961.20	56 640.80	70 801.00	77 881.10	63 720.90	99 121.40	92 041.30	106 202.00	84 961.20	EARTHQUAKE DRAINS
22	B022	44.804892	11.411208	118 343.00	88 756.90	59 171.30	73 964.10	81 360.50	66 567.70	103 550.00	96 153.40	110 946.00	88 756.90	EARTHQUAKE DRAINS
23	B023	44.804677	11.411108	14 939.50	11 204.60	7 469.74	9 337.18	10 270.90	8 403.46	13 072.00	12 138.30	14 005.80	11 204.60	EARTHQUAKE DRAINS

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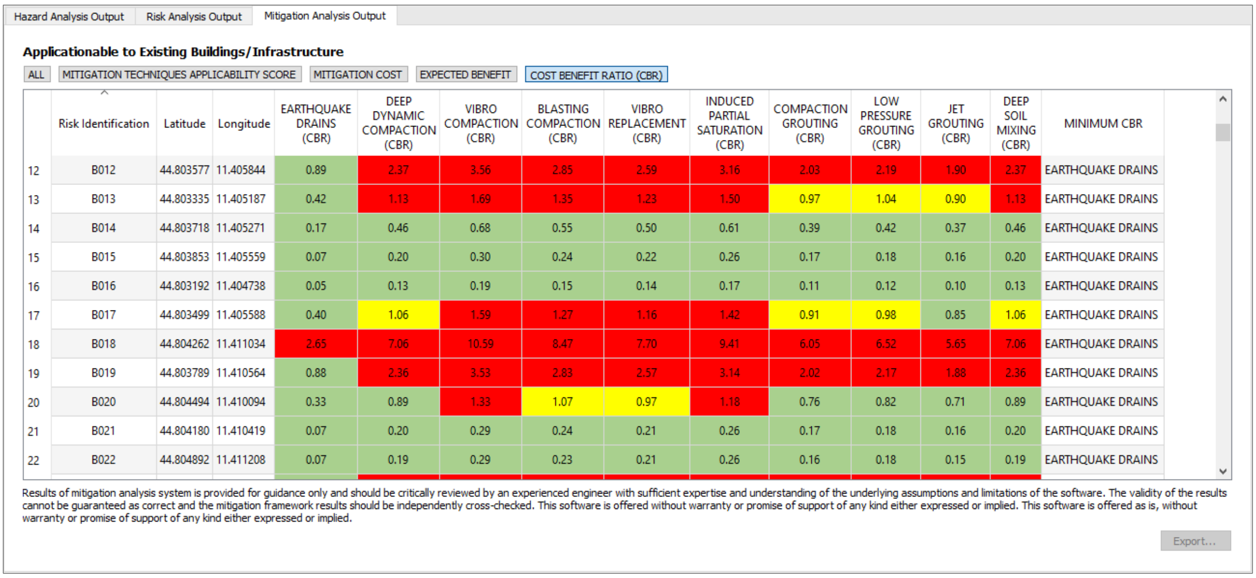
Export...

4.4.4 Cost-Benefit Ratio (CBR)

When ***COST BENEFIT RATIO (CBR)*** is selected, the displayed results represent the cost-benefit ratio for each of the 10 incorporated ground improvement mitigation techniques estimated for each considered asset (building or infrastructure) selected for mitigation analysis.



Hazard Analysis Output | Risk Analysis Output | Mitigation Analysis Output

Applicationable to Existing Buildings/Infrastructure

ALL | MITIGATION TECHNIQUES APPLICABILITY SCORE | MITIGATION COST | EXPECTED BENEFIT | COST BENEFIT RATIO (CBR)

	Risk Identification	Latitude	Longitude	EARTHQUAKE DRAINS (CBR)	DEEP DYNAMIC COMPACTION (CBR)	VIBRO COMPACTION (CBR)	BLASTING COMPACTION (CBR)	VIBRO REPLACEMENT (CBR)	INDUCED PARTIAL SATURATION (CBR)	COMPACTION GROUTING (CBR)	LOW PRESSURE GROUTING (CBR)	JET GROUTING (CBR)	DEEP SOIL MIXING (CBR)	MINIMUM CBR
12	B012	44.803577	11.405844	0.89	2.37	3.56	2.85	2.59	3.16	2.03	2.19	1.90	2.37	EARTHQUAKE DRAINS
13	B013	44.803335	11.405187	0.42	1.13	1.69	1.35	1.23	1.50	0.97	1.04	0.90	1.13	EARTHQUAKE DRAINS
14	B014	44.803718	11.405271	0.17	0.46	0.68	0.55	0.50	0.61	0.39	0.42	0.37	0.46	EARTHQUAKE DRAINS
15	B015	44.803853	11.405559	0.07	0.20	0.30	0.24	0.22	0.26	0.17	0.18	0.16	0.20	EARTHQUAKE DRAINS
16	B016	44.803192	11.404738	0.05	0.13	0.19	0.15	0.14	0.17	0.11	0.12	0.10	0.13	EARTHQUAKE DRAINS
17	B017	44.803499	11.405588	0.40	1.06	1.59	1.27	1.16	1.42	0.91	0.98	0.85	1.06	EARTHQUAKE DRAINS
18	B018	44.804262	11.411034	2.65	7.06	10.59	8.47	7.70	9.41	6.05	6.52	5.65	7.06	EARTHQUAKE DRAINS
19	B019	44.803789	11.410564	0.88	2.36	3.53	2.83	2.57	3.14	2.02	2.17	1.88	2.36	EARTHQUAKE DRAINS
20	B020	44.804494	11.410094	0.33	0.89	1.33	1.07	0.97	1.18	0.76	0.82	0.71	0.89	EARTHQUAKE DRAINS
21	B021	44.804180	11.410419	0.07	0.20	0.29	0.24	0.21	0.26	0.17	0.18	0.16	0.20	EARTHQUAKE DRAINS
22	B022	44.804892	11.411208	0.07	0.19	0.29	0.23	0.21	0.26	0.16	0.18	0.15	0.19	EARTHQUAKE DRAINS

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Export...

By double click on any given individual asset, a table with compiled information summarizing all the mitigation analysis results is displayed.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

Mitigation Result (B017)

G.I. TECNOLOGY	Score	Mitigation cost	Annual Frequency of Damage (%)	Expected Annual Loss Before Mitigation (EALI)	Expected Annual Loss After Mitigation (EALM)	Expected Loss Avoided (EALI - EALM)	Expected Benefit	Cost-Benefit Ratio
EARTHQUAKE DRAINS	173	6 833	0.464764	642.03	128.41	513.62	17 168.60	0.40
DEEP DYNAMIC COMPACTION	141	13 665	0.464764	642.03	256.81	385.22	12 876.40	1.06
VIBRO COMPACTION	192	13 665	0.464764	642.03	385.22	256.81	8 584.29	1.59
BLASTING COMPACTION	90	13 665	0.464764	642.03	321.01	321.01	10 730.40	1.27
VIBRO REPLACEMENT	128	13 665	0.464764	642.03	288.91	353.12	11 803.40	1.16
INDUCED PARTIAL SATURATION	236	13 665	0.464764	642.03	353.12	288.91	9 657.33	1.42
COMPACTION GROUTING	227	13 665	0.464764	642.03	192.61	449.42	15 022.50	0.91
LOW PRESSURE GROUTING	256	13 665	0.464764	642.03	224.71	417.32	13 949.50	0.98
JET GROUTING	209	13 665	0.464764	642.03	160.51	481.52	16 095.50	0.85
DEEP SOIL MIXING	191	13 665	0.464764	642.03	256.81	385.22	12 876.40	1.06

OK Help

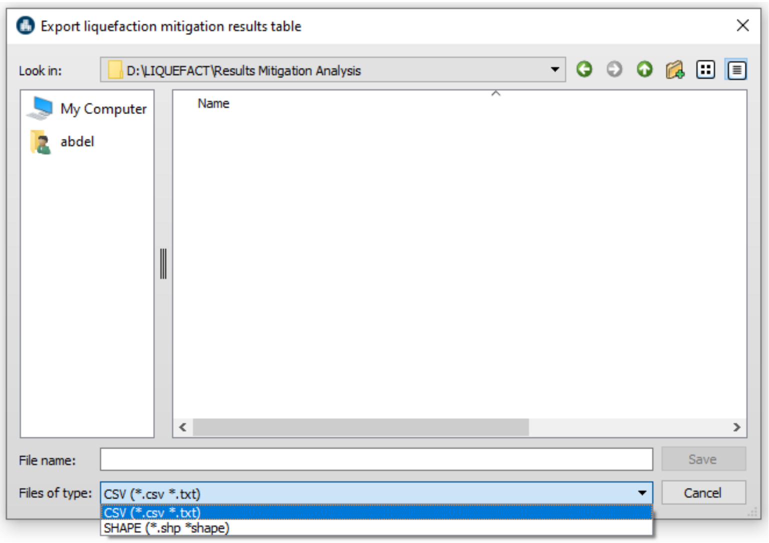
For each of the 10 ground improvement mitigation techniques the following results are provided for each individual asset.

Results of Mitigation Analysis at Asset Level	*Description*
Score	Overall score estimated for each of the 10 ground improvement mitigation techniques for the considered asset
Mitigation cost	Estimated cost of mitigation technique for the considered asset
Annual Frequency of Damage (%)	Estimated annual frequency of damage for the considered asset
Expected Annual Loss Before Mitigation (EALI)	Estimated expected annual loss to the considered asset before the application of the mitigation technique
Expected Annual Loss After Mitigation (EALM)	Estimated (conservative estimation) expected annual loss to the considered asset after the application of the mitigation technique
Expected Loss Avoided	Estimated loss to be avoided if a given technique is applied to the considered asset (EALI – EALM)
Expected Benefit	Estimated expected benefit considering the time horizon of the considered asset
Cost-Benefit Ratio (CBR)	Ratio of Mitigation Cost divided by Expected Benefit, where a given mitigation option is considered favourable if CBR<1

4.4.5 Export Results of Mitigation Analysis

All results and output of Mitigation Analysis can be exported by clicking on Export button. The results can be exported as SHAPE or CSV by selecting SHAPE or CSV in the file type pulldown menu in the Export dialog. SHAPE files can be exported as points or polygons. The database and result files in various formats will be stored in a project directory.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748



5 TECHNICAL DESCRIPTIUON AND BACKGROUND

The following sections provide detailed technical description of the different methodologies and approaches that have been incorporated in the three main protocols of analysis of the LIQUEFACT software: the protocol for liquefaction hazard analysis, the protocol for risk analysis, and the protocol for mitigation analysis.

5.1 Liquefaction Hazard Assessment

The process of liquefaction hazard analysis consists in assessing whether an asset (e.g. individual building/CI asset, portfolio of buildings/distributed infrastructure assets, etc.) is located in a geographical area likely to be affected by an EILD event. The required user-supplied input data are related to liquefaction hazard and seismic hazard modelling.
Methodologies of liquefaction hazard assessment are based on two approaches: *Quantitative* and *Qualitative* based approach.

5.1.1 Quantitative Analysis of Liquefaction Hazard

The concept of the quantitative approach consists of number of analyses to be carried out in two main sequences (Figure 5):

- Step-1 *Liquefaction Triggering Analysis*: to estimate the tendency of developing liquefaction under a given seismic input. The analysis is based on computation of the factor of safety against liquefaction.
- Step-2 *Liquefaction-induced Surficial Manifestations*: implies to evaluate the effects at the ground level, where indicators are adopted to broadly quantify the severity of liquefaction.

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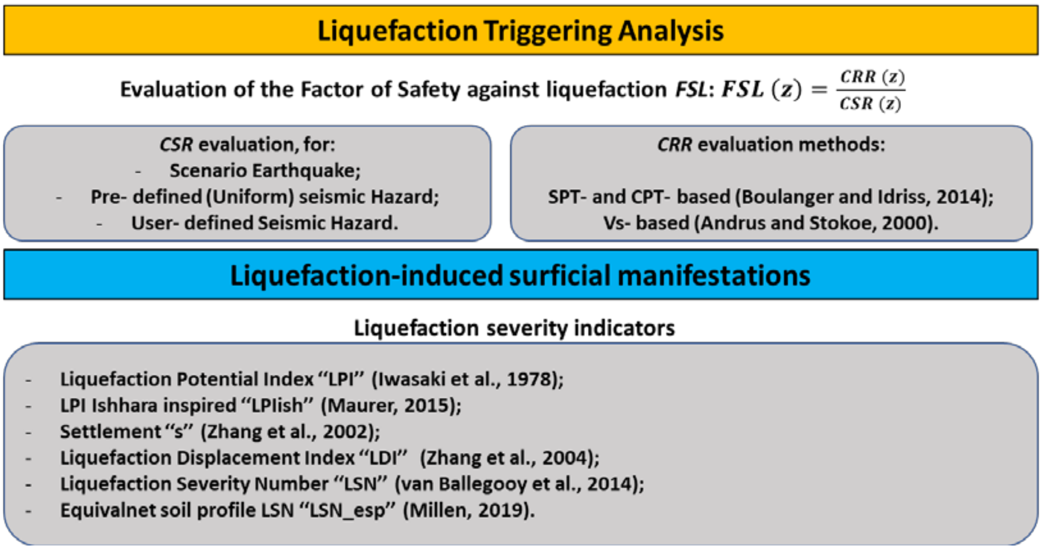

Figure 5. Concept of liquefaction hazard assessment based on quantitative analysis

5.1.1.1 Liquefaction Triggering Analysis

In the LIQUEFACT software, the triggering of liquefaction at a given site can be evaluated by applying Cyclic Stress approach, using user-supplied soil profiles data. This approach implies the calculation of a liquefaction safety factor (FSL) obtained by dividing the Cyclic Resistance Ratio (CRR) producing liquefaction with the Cyclic Stress Ratio (CSR) induced by the earthquake. According to this method, seismic liquefaction is triggered in a susceptible soil when the seismic demand expressed as CSR) exceeds the resistance of such soils (expressed as CRR).

The CRR is a representation of the ability of the soil to resist liquefaction demand and is related to its relative density and Fines Content (FC). It is also recognized that the stress conditions (confining pressure, cyclic shear and initial static shear stresses) play an important role in the liquefaction behaviour of soil, the type of failure mechanism and the mode of development of soil deformation, especially in the case of slopes of sandy deposits.

Site characterization for liquefaction triggering analysis includes collection of information to accurately estimate the values of CRR and earthquake-induced CSR at the site. The goal of a liquefaction triggering analysis is to evaluate whether liquefaction is expected to occur at a site under a given seismic load. An FSL less than 1.0 is generally assumed to indicate that liquefaction is expected to trigger at that depth. The factor of safety against liquefaction, however, does not give insights into the associated uncertainties and variability related to the calculation of CRR and CSR. In practice, a minimum required FSL for design as low as 1.0 has been required when coupled with an extreme ground motion level. Typical minimum values used in practice are between 1.1 and 1.3.

5.1.1.1.1 CPT-based Procedure

One of the most popular CPT-based procedure to evaluate the Factor of Safety against liquefaction at each depth of a soil profile is the Boulanger and Idriss (2014), which is summarized in Figure 6.

Boulanger and Idriss (2014) calculate the CRR from the measured CPT tip resistance, qc, the CPT sleeve friction, fs, and the effective vertical stress, σ'_v, in the soil. These are used to estimate an overburden correction factor, CN, and correct the tip resistance to account for the overburden stress, q_{c1}. The normalized overburden stress, q_{c1N}, is q_{c1} divided by the atmospheric pressure (pa=100 kPa). During the iteration (usually about 3 cycles), q_{c1} is always based on the measured tip resistance, qc, while CN is based on the iteratively updated value for q_{c1N}. A second correction is made for the fines content, FC. With the assumed flat ground or uniform surcharge for the regional-scale analysis, the correction for the effects of an initial static shear stress ratio is Kα=1.

To characterize the soil behaviour type (SBT) and to evaluate the percentage of fines content, FC, the empirical correlations defined by Robertson (2015) are used.

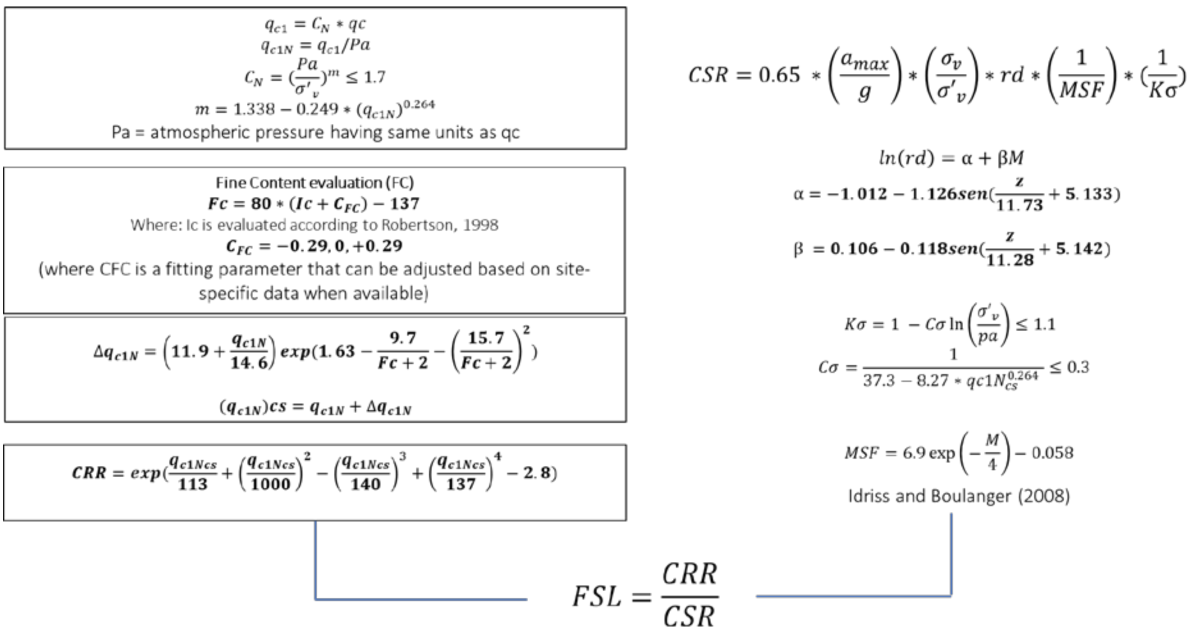

Figure 6. Flowchart of the CPT-based procedure for liquefaction triggering analysis

5.1.1.1.2 SPT-based Procedure

The SPT-based procedure that have been incorporated in the LIQUEFACT software for computation of Factor of Safety against liquefaction at each depth of a soil profile is also the one introduced by Boulanger and Idriss (2014), and which is summarized in Figure 7. The procedure consists on calculating the CRR starting from the number of blows $N1_{60}$, normalized with respect to the atmospheric pressure Pa and increased to account for the fine content.

$$(N_1)_{60cs} = \mathrm{CN} \cdot \mathrm{CE} \cdot \mathrm{CB} \cdot \mathrm{CR} \cdot \mathrm{CS} \cdot \mathrm{N} + \Delta(N_1)_{60}$$

where CN is the correction factor to adjust the blow count to a reference stress of one atmosphere; CE is a correction factor for the kinetic energy of the hammer (i.e. hammer weight and height of fall); CB is a correction factor for the borehole diameter; CR is a rod length correction factor; CS is a correction factor for the configuration of the SPT sampler; N is the recorded blow count; and $\Delta(N1)_{60}$ is the correction factor for the fines content.

There is uncertainty in the computed FS from a stress-based analysis not only because of the uncertainty in the location of the CRR relationship but also because the values of the parameters in the CSR and $(N1)_{60CS}$ equations are not known precisely. In fact, explicit consideration of uncertainty associated with a correction factor may even increase the uncertainty associated with the liquefaction potential assessment. The soil behavior type index Ic, is evaluated with numerous empirical correlations between in-situ tests and geotechnical parameters.

$$(N_1)_{60} = C_N * N_{60}$$

$$C_N = \left(\frac{Pa}{\sigma'_v}\right)^m \leq 1.7$$

$$m = 0.784 - 0.0768 * \sqrt{(N_1)_{60cs}}$$

Fine Content evaluation (FC)

$$Fc = 80 * (Ic + C_{FC}) - 137$$

$$C_{FC} = -0.29, 0, +0.29$$

CFC is a fitting parameter, while Ic is evaluated according to Mayne (2006)

$$Ic = -0.7174 * \ln\left(\frac{Vs^2}{9.81 * z}\right) + 6.3211$$

$$Vs = 100.59 * N_{SPT}^{0.302}$$

Modified after Palmer and Stuart (1957)

$$\Delta(N_1)_{60} = exp\left(1.63 + \frac{9.7}{FC + 0.01} - \left(\frac{15.7}{FC + 0.01}\right)^2\right)$$

$$(N_1)_{60cs} = (N_1)_{60} + \Delta(N_1)_{60}$$

$$CRR = exp\left(\frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 2.8\right)$$

$$CSR = 0.65 * \left(\frac{a_{max}}{g}\right) * \left(\frac{\sigma_v}{\sigma'_v}\right) * rd * \left(\frac{1}{MSF}\right) * \left(\frac{1}{K\sigma}\right)$$

$$ln(rd) = \alpha + \beta M$$

$$\alpha = -1.012 - 1.126 sen\left(\frac{z}{11.73} + 5.133\right)$$

$$\beta = 0.106 - 0.118 sen\left(\frac{z}{11.28} + 5.142\right)$$

$$K\sigma = 1 - C\sigma \ln\left(\frac{\sigma'_v}{pa}\right) \leq 1.1$$

$$C\sigma = \frac{1}{18.9 - 2.55 * (N_1)_{60cs}^{0.5}} \leq 0.3$$

$$MSF = 6.9 \exp\left(-\frac{M}{4}\right) - 0.058$$

Idriss and Boulanger (2008)

$$FSL = \frac{CRR}{CSR}$$

Figure 7. Flowchart of the SPT-based procedure for liquefaction triggering analysis

5.1.1.1.3 Vs-based Procedure

Measuring shear wave velocity (Vs) is another test used to characterize soils in situ. Vs refers to the speed at which a shear wave propagates through the ground. The speed of wave propagation depends on the density of the soil, the directions of wave propagation and particle motion, and the effective stresses in those two directions.

Figure 8 illustrates the flowchart of the VS-based concept for the liquefaction triggering analysis and which is based on the Andrus and Stokoe (2000) procedure for the calculation of CRR. Soil behaviour type index is evaluated based on the procedure proposed by Mayne (2006):

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$$Ic = -0.7174 \cdot \ln[Vs^2 / (9.81 \cdot z)] + 6.3211$$

Then, the fine content FC can be evaluated by appling the following correlation (Robertson and Fear, 1995):

$$FC\ (\%) = 42.4179 \cdot Ic - 54.8574$$

Regarding Factor of Safety, Juang et al. (2005) concluded that the traditional FSL is conservative for calculating CRR, resulting in lower factors of safety and over-prediction of liquefaction occurrence. To account for this, they introduce a multiplication factor of 1.4 to obtain a more realistic estimate of the factor of safety.

$$V_{S1} = Vs \left(\frac{pa}{\sigma'_v}\right)^{0.25}$$

$$V_{S1,csa1} = \frac{V_{S1}}{Ka1}$$

Pa = atmospheric pressure (kPa); σ'v effective vertical stress (kPa).

ka1 is the correction factor accounting for the age of the deposit

Time (years)	Soil aging factor (Ka1)
1	1.09
10	1.01
100	0.94
1 000	0.88
10 000	0.83
100 000	0.78

$$CRR = 0.022 * \left(\frac{V_{S1,csa1}}{100}\right)^2 + 2.8 * \left(\frac{1}{V^*_{S1} - V_{S1,csa1}} - \frac{1}{V^*_{S1}}\right)$$

V^*_{S1} is the limiting upper value of $V_{S1,csa1}$ for cyclic liquefaction occurrence, which varies between 200-215 m/s depending on the fines content of the soil.

$$CSR = 0.65 * \left(\frac{a_{max}}{g}\right) * \left(\frac{\sigma_v}{\sigma'_v}\right) * rd * \left(\frac{1}{MSF}\right) * \left(\frac{1}{K\sigma}\right)$$

$$rd = 1 - 0.00765z \qquad if\ z < 9.2m$$

$$rd = 1.174 - 0.0267z \qquad if\ z \geq 9.2m$$

Liao and Whitman (1986)

$$K\sigma = 1 - C\sigma \ln\left(\frac{\sigma'_v}{pa}\right) \leq 1.1 \qquad C\sigma = \frac{1}{18.9 - 3.1 * \left(\frac{V_{S_1}}{100}\right)^{1.976}} \leq 0.3$$

$$MSF = \left(\frac{Mw}{7.5}\right)^{-2.56}$$

Andrus and Stokoe (1997)

$$FSL = 1.4 * \frac{CRR}{CSR}$$

Juang et al. (2005)

Figure 8. Flowchart of the VS-based procedure for liquefaction triggering analysis

5.1.1.2 Liquefaction-induced Surficial Manifestations

Liquefaction-induced Surficial Manifestations: implies to evaluate the effects at the ground level. At this stage analyses are conducted in free field conditions, neglecting the presence of buildings or infrastructures and their possible interaction with the subsoil, and thus liquefaction severity indicators are adopted to broadly quantify the severity of liquefaction.

5.1.1.2.1 Liquefaction Severity Indicators

Once the Factor of Safety (FSL) has been calculated at each depth, synthetic indicators of the liquefaction severity on the ground (free field) can be evaluated. These integrate the contribution to

the liquefaction of each layers, generally for the first 20 meters of depth, giving a measure of the liquefaction severity on the surface (free field).
In general terms, a liquefaction severity indicator can be defined as the integral of the product between a function of the Factor of Safety against Liquefaction $f_1(FSL)$ and a weight function that emphasizes the severity of liquefaction at a lower depth.

$$INDEX = \int_{zmax} f_1(FSL) * w(z)dz$$

Various liquefaction severity or damage potential indicators were proposed in literature to provide a measure of the liquefaction-induced surficial evidence, based on the cumulative liquefaction response of a soil profile. Table 1 illustrates the most widespread indicators to quantify the damage to the ground by integrating the estimated effects of liquefaction in the first 20 m depth.
The most used of them are: Liquefaction Potential Index "LPI" (Iwasaki et al., 1978); one-dimensional volumetric reconsolidation settlement "S" (Zhang et al., 2002); Liquefaction Severity Number "LSN" (Van Ballegooy et al., 2014).

Table 1 List of liquefaction severity indicators for the quantification of damage to the ground due to liquefaction

Index	Reference	$f_1(FSL)$	w(z)	Z
LPI	Iwasaki et al., 1978	$1 - \text{FSL}$ if FSL < 1 0 if FSL ≥ 1	$10 - 0.5z$	$Z_{min} = 0$ $Z_{max} = 20m$
LSN	van Ballegooy et al., 2014	$\varepsilon_v = \varepsilon_v\ (FSL, q_{C1Ncs})$	$\frac{1000}{z}$	$Z_{min} = 0$ $Z_{max} = 20m$
S	Zhang et al., 2002	$\varepsilon_v = \varepsilon_v\ (FSL, q_{C1Ncs})$	-	$Z_{min} = 0$ $Z_{max} = \max depth$

5.1.1.2.2 Liquefaction Potential Index (LPI)

The Liquefaction Potential Index LPI is the summation of liquefaction severity in each soil layer, which in turn is a function of the Factor of Safety (FSL), weighted by a depth factor that decreases linearly from 10 to 0 over the top 20 m. The LPI value is between 0 (representing no liquefaction expected) and 100 (representing extreme liquefaction effects expected to the ground surface).
By weighting soils to have an increasing influence on LPI as depth decreases, this parameter is able to represent the beneficial effects of an increasing non-liquefied surface layer thickness, or crust. Iwasaki et al. (1978) defined the Liquefaction Potential Index (LPI) of a 20 m deep soil profile as:

$$LPI = \int_0^{20m} F_1(z) \cdot W(z)dz$$

where: $W(z) = 10 - 0.5z$ and $F1(z) = \begin{cases} 1 - \text{FSL} & \text{if FSL} < 1 \\ 0 & \text{if FSL} \geq 1 \end{cases}$

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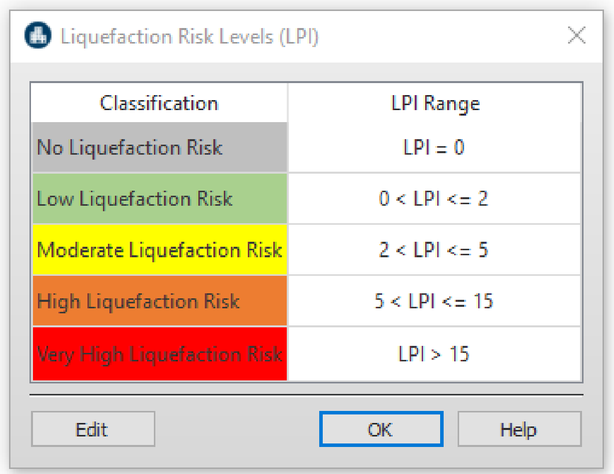
z is the depth below the ground surface in metres; and FSL(z) is the Factor of Safety against Liquefaction.

In literature various qualitative-based classification definitions associated with LPI range values have been introduced in order to quantify the different liquefaction risk level to the ground. In the LIQUEFACT software, the used defaults ranges values associated to the different risk level classes are adopted and modified from the classes suggested by Iwasaki et al. (1978). However, users can always modify and update these ranges values.



Classification	LPI Range
No Liquefaction Risk	LPI = 0
Low Liquefaction Risk	0 < LPI <= 2
Moderate Liquefaction Risk	2 < LPI <= 5
High Liquefaction Risk	5 < LPI <= 15
Very High Liquefaction Risk	LPI > 15

5.1.1.2.3 Liquefaction Severity Number (LSN)

Liquefaction Severity Number was developed as indicator to assess the performance of residential land in Canterbury in future earthquakes and was validated against the residential land damage observed in Canterbury. The LSN depends on the seismic load, depth to groundwater and geological profile (Van Ballegooy et al. 2014). The LSN is defined as:

$$LSN = 1000 \int_{0}^{20m} \frac{\varepsilon_v(z)}{z}\, dz$$

Where: εv (z) is the volumetric densification strain at depth, z, based on Zhang et al. (2002); and z is the depth in metres below the ground surface.
LSN is defined as the summation of the post-liquefaction volumetric reconsolidation strains calculated for each soil layer divided by the depth to the midpoint of that layer. The value of LSN is theoretically between 0 (representing no liquefaction vulnerability) to a very large number (representing extreme liquefaction vulnerability). The hyperbolic depth weighting function (1⁄z) can yield a very large value only when the groundwater table is very close to the ground surface and soil layers immediately below the ground surface liquefy. LSN is an extension of the LPI philosophy. It attempts to quantify the effects of liquefaction and consequent land damage using volumetric strains (adopted in conventional

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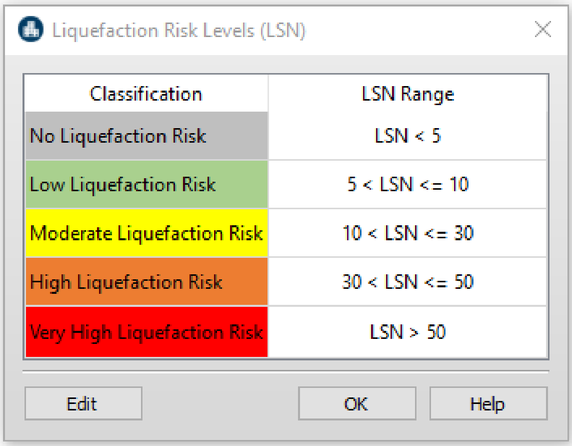
settlement calculations (Zhang et al. 2002). The hyperbolic function gives much greater weight to liquefaction at shallow depths and considers shallow liquefaction (<6 m) to be the key contributor in the overall damage to land and relatively light residential buildings supported on shallow foundations.

In literature various qualitative-based classification definitions associated with LSN range values have been introduced in order to quantify the different liquefaction risk level to the ground. In the LIQUEFACT software, the used defaults ranges values associated to the different risk level classes are adopted and modified from the classes defined by Tonkin and Taylor (2013). However, users can always modify and update these ranges values.



5.1.1.2.4 Liquefaction-Induced Ground Settlements (Free-Field)

Liquefaction-induced ground settlements are essentially vertical deformations of superficial soil layers caused by the densification and compaction of loose granular soils following earthquake loading. Several methods have been proposed to calculate liquefaction-induced ground deformations, including numerical and analytical methods, laboratory modelling and testing, and field-testing-based methods.
The expense and difficulty associated with obtaining and testing high quality samples of loose sandy soils may only be feasible for high-risk projects where the consequences of liquefaction may result in severe damage and large costs. Semi-empirical approaches using data from field tests are likely best suited to provide simple, reliable, and direct methods to estimate liquefaction-induced ground deformations for low to medium-risk projects and also to provide preliminary estimates for higher risk projects. The post-liquefaction volumetric strain can then be estimated using below, that correspond to Figure 9, for every reading in the CPT sounding.

$$S = \sum_{i=1}^{j} \varepsilon_{vi} \cdot \Delta z_i$$

Where: S is the calculated liquefaction-induced ground settlement at the CPT location; ε_{vi} is the post-liquefaction volumetric strain for the soil sublayer i; Δz_i is the thickness of the sublayer i; j is the number of soil sublayers the result should be an appropriate index of potential liquefaction-induced ground settlement at the CPT location due to the design earthquake.

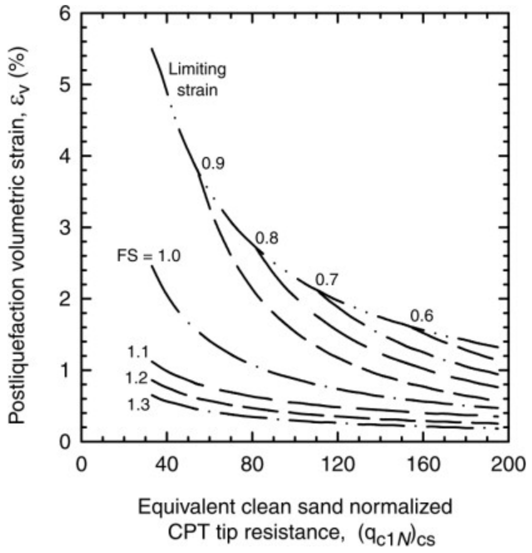


Figure 9. Relationship between post-liquefaction volumetric densification strains, Ɛv, and the normalized CPT tip resistance, qc1N, for selected factors of safety, FS (Zhang et al., 2002)

At each layer, the Factor of Safety (FS) and the normalised tip resistance, q_{c1N}, are used to calculate the post-liquefaction volumetric densification strain, ε_V. These strains are interpolated from the curves proposed by Zhang et al. (2002), except that the CPT tip resistance is corrected to remove the effect of overburden stress using the iterative Idriss and Boulanger (2014) procedure.

The following equations for the relationships plotted in Figure 9 are given by Zhang et al. (2002). Table 2 lists additional constraints that are applied to the volumetric densification calculations using the equations of FS given in Zhang et al. (2002).

$$\text{if FS} \le 0.5, \quad \varepsilon_v = 102(q_{c1N})_{cs}^{-0.82} \quad \text{for } 33 \le (q_{c1N})_{cs} \le 200$$

$$\text{if FS} = 0.6, \quad \varepsilon_v = 102(q_{c1N})_{cs}^{-0.82} \quad \text{for } 33 \le (q_{c1N})_{cs} \le 147$$

$$\text{if FS} = 0.6, \quad \varepsilon_v = 2411(q_{c1N})_{cs}^{-1.45} \quad \text{for } 147 \le (q_{c1N})_{cs} \le 200$$

$$\text{if FS} = 0.7, \quad \varepsilon_v = 102(q_{c1N})_{cs}^{-0.82} \quad \text{for } 33 \le (q_{c1N})_{cs} \le 110$$

$$\text{if FS} = 0.7, \quad \varepsilon_v = 1701(q_{c1N})_{cs}^{-1.42} \quad \text{for } 110 \le (q_{c1N})_{cs} \le 200$$

$$\text{if FS} = 0.8, \quad \varepsilon_v = 102(q_{c1N})_{cs}^{-0.82} \quad \text{for } 33 \le (q_{c1N})_{cs} \le 80$$

$$\text{if FS} = 0.8, \quad \varepsilon_v = 1690(q_{c1N})_{cs}^{-1.46} \quad \text{for } 80 \le (q_{c1N})_{cs} \le 200$$

$$\text{if FS} = 0.9, \quad \varepsilon_v = 102(q_{c1N})_{cs}^{-0.82} \quad \text{for } 33 \le (q_{c1N})_{cs} \le 60$$

$$\text{if FS} = 0.9, \quad \varepsilon_v = 1430(q_{c1N})_{cs}^{-1.48} \quad \text{for } 60 \le (q_{c1N})_{cs} \le 200$$

$$\text{if FS} = 1.0, \quad \varepsilon_v = 64(q_{c1N})_{cs}^{-0.93} \quad \text{for } 33 \le (q_{c1N})_{cs} \le 200$$

$$\text{if FS} = 1.1, \quad \varepsilon_v = 11(q_{c1N})_{cs}^{-0.65} \quad \text{for } 33 \le (q_{c1N})_{cs} \le 200$$

$$\text{if FS} = 1.2, \quad \varepsilon_v = 9.7(q_{c1N})_{cs}^{-0.69} \quad \text{for } 33 \le (q_{c1N})_{cs} \le 200$$
$$\text{if FS} = 1.3, \quad \varepsilon_v = 7.6(q_{c1N})_{cs}^{-0.71} \quad \text{for } 33 \le (q_{c1N})_{cs} \le 200$$
$$\text{if FS} = 2.0, \quad \varepsilon_v = 0.0 \quad \text{for } 33 \le (q_{c1N})_{cs} \le 20$$

Table 2 List of additional constraints that are applied to the volumetric densification calculations using the different equations of FS given in Zhang et al. (2002)

Calculation Issue	Description
Strain equation are only provided for	For q_{c1ncs} < 33, strain is bounded by the limiting value, calculated using q_{c1ncs} = 33
q_{c1} /q_{c1ncs} ≥33	Linear interpolation is used between the published equations
Strain equations are only provided for specific Factors of Safety	Maximum strain = 102 $q_{c1ncs}^{-0.82}$

The Settlement indicator integrates the volumetric densification strains, ε_V, calculated using the Zhang et al. (2002) method, over the total depth of the CPT profile, Z, using:

$$S_{V1,d} = \int_0^Z \varepsilon_v (z) dz$$

Where: εv(z) is the volumetric densification strain at depth, z, based on Zhang et al. (2002); Z is the total depth of the CPT profile; z is the depth in metres below the round surface.

There are always volumetric densification strains when the excess pore pressure rises during shaking, so strains are included for all factors of safety up to FSL = 2.0 (i.e. including non-liquefied layers). Settlements calculated using this method for deeper CPT profiles are typically greater than settlements calculated for shallower CPT profiles. The calculated values are therefore not strictly comparable between CPT profiles.

5.1.1.2.5 Equivalent Soil Profile (ESP)-based Classification

A new hazard-independent liquefaction classification is proposed where the soil profile is defined as an equivalent 3-layered soil profile. The classification consists of only three features, highly influential to the ground behaviour: the depth of the non-liquefying crust, and the thickness and liquefaction resistance of the potentially liquefiable layer. Figure 10 illustrates the general steps for the development of equivalent soil profile (ESP) and evaluation of the level of liquefaction hazard. The concept of this methodology consists of 2 main steps (Viana da Fonseca et al. 2018a):

- Step 1: is about generating 3-layered soil profile, i.e. the equivalent soil profile, from CPT, SPT or Vs data to evaluate the level of liquefaction hazard;
- Step 2 the methodology uses three governing parameters: the depth of the crust (D_{liq}), the thickness of the liquefied layer (H_{liq}) and its liquefaction resistance (CRR_{n15}). Typical ranges of values for each of these variables have been defined, from which 22 different soil profile classes (Table 3) were derived.

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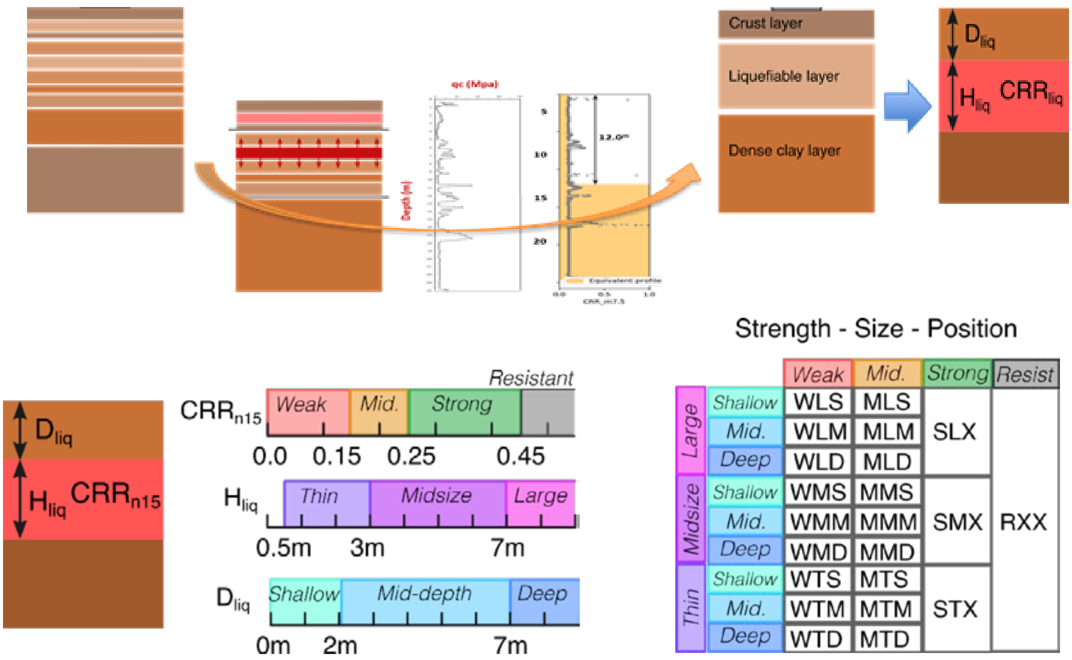

Figure 10. General steps of the development of equivalent soil profile (ESP) and range definition for classification (Viana da Fonseca et al. 2018)

Table 3. Concept and Class of Equivalent Soil Profile (ESP)

Soil Resistance (CRR_{liq})	Liquefiable Layer (H_{liq}) Thickness	Crust Layer (D_{liq}) Thickness	ESP profile
Weak	Large	Shallow	WLS
Weak	Large	Mid	WLM
Weak	Large	Deep	WLD
Weak	Midsize	Shallow	WMS
Weak	Midsize	Mid	WMM
Weak	Midsize	Deep	WMD
Weak	Thin	Shallow	WTS
Weak	Thin	Mid	WTM
Weak	Thin	Deep	WTD
Midium	Large	Shallow	MLS
Midium	Large	Mid	MLM
Midium	Large	Deep	MLD
Midium	Midsize	Shallow	MMS
Midium	Midsize	Mid	MMM
Midium	Midsize	Deep	MMD
Midium	Thin	Shallow	MTS
Midium	Thin	Mid	MTM
Midium	Thin	Deep	MTD
Strong	Large		SLX
Strong	Midsize		SMX
Strong	Thin		STX
Resist			RXX

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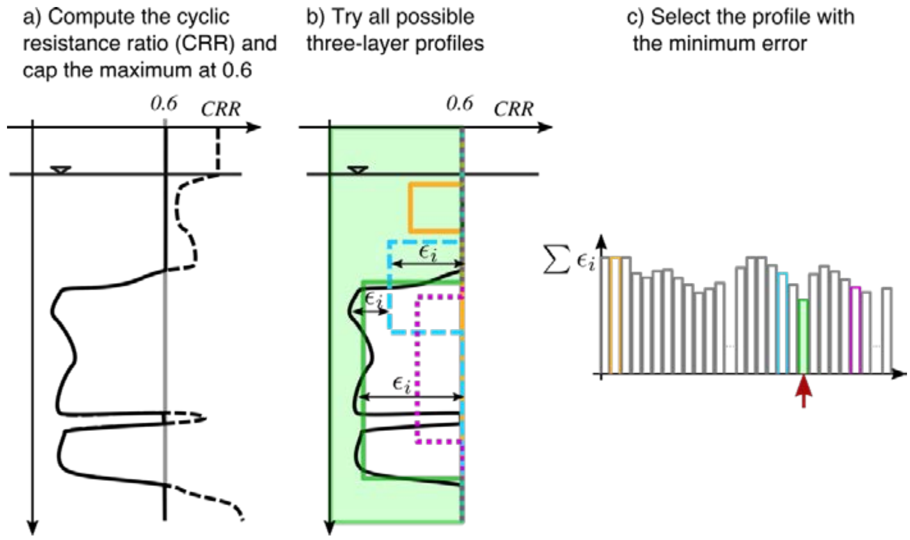


Figure 11. Procedure to implement the CRR-fitted method

The classification of a soil profile can be performed through cyclic element testing to identify key layers, but to allow efficient classification, it is more convenient and reliable to use continuous field data, namely through CPTu results. The procedure can be semi-automated by computing the CRR for a magnitude 7.5 earthquake using a simplified triggering procedure (e.g. Boulanger & Idriss, 2014), and fitting a three-layered profile to the CRR values. The procedure consists of computing every possible three-layered profile so as to minimise the difference between the CRR values of the computed and the equivalent three-layered profiles, as schematically illustrated in Figure 11. The calculation of the error is sensitive to the value set to be the non-liquefying limit of CRR and the maximum depth of the profile. The non-liquefying limit was set to CRR=0.6, as this is a common limit used in simplified procedures (e.g. Youd et al., 2001; Boulanger & Idriss, 2014). Using a higher value means that soil layers with high CRR would generate some error during fitting (Gerace, 2018). The maximum depth was taken as 20 metres, since surficial consequences of liquefaction below such depths are negligible (Maurer et al., 2015). The increment of depths and CRR should be set small enough that they are not influential on the final results. The depth increment was set to 0.1m and the CRR increments were determined by setting the equivalent cone tip resistance for clean sand to range from 0 to 175 kPa in increments of 5kPa to give a CRR range from 0.061 to 0.6.

The implemented algorithm (Figure 11) minimised the normalised difference (equation below), where CRR_{calc} and CRR_{fitted} are the calculated and fitted CRR values, ΔH is the depth increment of the calculated values, $CRR_{non-liq}$ is the non-liquefiable limit and H_{total} is the total height of the profile, capped at the maximum value of 20m.

$$\tilde{\delta} = \frac{\sum (CRR_{calc,i} - CRR_{fitted,i}) \cdot \Delta H}{CRR_{non-liq} \cdot H_{total}}$$

5.1.1.2.6 Equivalent Soil Profile-based Liquefaction Severity Number LSN(ESP)

Graphs showing the correspondence between ESP classes and LSN values were provided (D3.2 of this project) to allow the backward estimate of likely ESPs in a region given a liquefaction severity estimate. In fact, for the investigated profiles, the LSN was computed for four different hazard level representing: low, moderate, high and severe seismicity (PGA values equal to 0.1g, 0.2g, 0.35g, 0.5g and Mw equal to 7.5). By applying the Bayes theorem, the conditional probability of finding each ESP class for a given LSN range was evaluated and plotted for the before mentioned four levels of seismicity. The PGA values from different magnitude events can be converted to an equivalent magnitude 7.5 event using the magnitude scaling factor (Idriss and Boulanger, 2008).

5.1.2 Qualitative Analysis of Liquefaction Hazard

Liquefaction hazard assessment based on qualitative approach is, in general, considered as level-1 step of liquefaction hazard analysis where no detailed geotechnical soil profile data or specific information on the earthquake are required. The concept is based on using hazard map where level of hazard is qualitatively classified using labels ranging such as "*Non-Susceptible*", "*No Liquefaction*" to "*Very High Risk of Liquefaction*", depending on type of liquefaction severity indicator used. The outcomes from this level of assessment provides qualitative evaluation on the level of exposure that asset(s) is/are likely to be susceptible to, and can be employed as guidance for more detailed analysis (quantitative assessment described above).

5.1.2.1 User-Defined Liquefaction Hazard

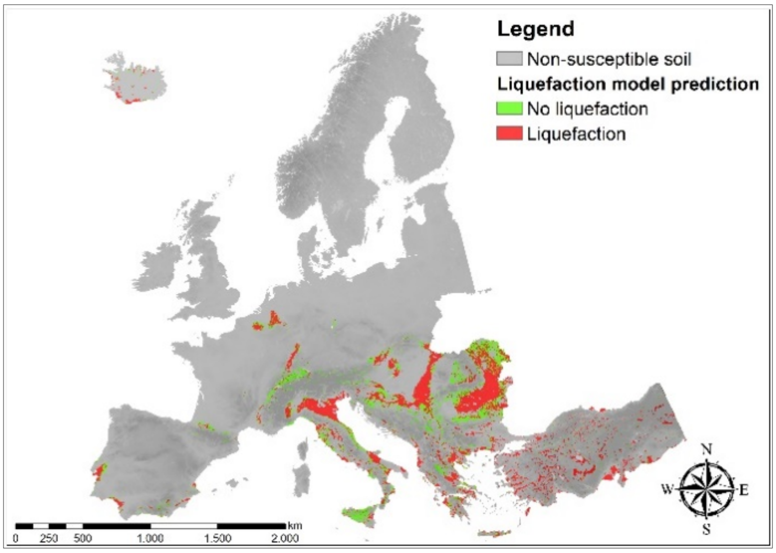
User-supplied qualitative liquefaction hazard maps can be in terms of the following liquefaction severity indicators: Liquefaction Susceptibility, Liquefaction Potential Index (LPI), Liquefaction Severity Number (LSN), and Probability of Liquefaction (PL).

- In user-supplied maps in terms of Liquefaction Hazard indicator, three qualitative levels of hazard classification are used for range labels: Noon-susceptible, No Liquefaction, and Liquefaction.
- For user-supplied maps in terms of LPI, LSN and PL indicators, five qualitative levels of hazard classification are used for range labels: Non-Liquefaction Risk, Low Liquefaction Risk, Moderate Liquefaction Risk, High Liquefaction Risk, and Very High Liquefaction Risk.

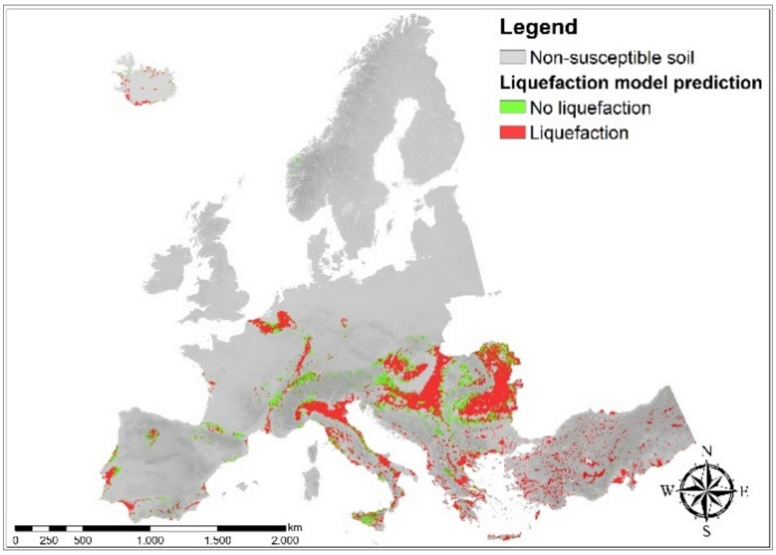
5.1.2.2 Pre-Defined Liquefaction Hazard

At a first glance, zonation of a large territory for liquefaction risk seems an almost impossible task since liquefaction is a phenomenon of soil instability occurring at a very local scale, that is it may or it may not occur at a specific location and depth from the ground surface depending on whether certain conditions of soil susceptibility and severity of ground shaking are met at that particular depth. Thus, the macrozonation of liquefaction hazard at the continental scale is a truly hard facing challenge. Yet, a qualitative representation of the variability of liquefaction potential within a single country is within reach considering the resolution and accuracy of geological and geotechnical information that is currently available in the most developed nations. The availability of a macrozonation map of liquefaction risk of a country can be useful to policy makers and administrators of that country in identifying territories that are potentially at risk of earthquake-induced ground failures. This in turn could motivate the interest in drafting plans for further investigations and in-depth studies in those territories.

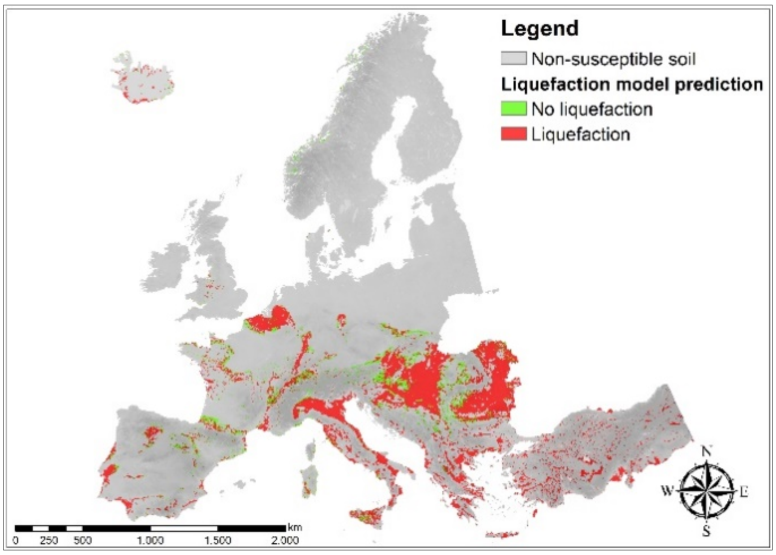
Macrozonation of liquefaction risk of the European territory was addressed in LIQUEFACT project (Carlo et al 2018). Geo-referenced European earthquake-induced soil liquefaction risk maps were built using available datasets at a continental scale on the expected seismic hazard and on the geological, geomorphological, hydrogeological, shallow lithology and digital terrain information. The macrozonation maps were generated for different levels of severity of expected ground shaking, characterized by a return period of 475, 975 and 2475 years, respectively (Figure 12). The maps use three qualitative levels of hazard classification for range labels: Non-susceptible, No Liquefaction, and Liquefaction.



(a) European liquefaction prediction map for 475 years



(b) European liquefaction prediction map for 975 years



(c) European liquefaction prediction map for 2475 years

Figure 12. Macrozonation of liquefaction risk of the European territory (Carlo et al 2018)

5.1.3 Seismic Hazard Analysis

A key point in liquefaction hazard assessment is the provision of seismic ground motion, in general, generated and integrated in the form of contour maps and location-specific seismic demands.

5.1.3.1 Generate seismic ground motion

The spatial distribution of ground motion can be determined using one of the following methods or sources:

- Scenario Earthquake analysis (repeat of any potential earthquake event);
- Pre-Defined Uniform Hazard map (probabilistic ground motion maps e.g. Share.eu);
- User-Defined Seismic Hazard map (can be based on probabilistic or deterministic ground motion analysis).

5.1.3.1.1 Scenario Earthquake Analysis

Deterministic seismic ground motion demands are calculated for user-specified scenario earthquakes. A scenario earthquake can be either an historic earthquake or a hypothetical earthquake and can be defined using a set of the earthquake source parameters. These parameters can be obtained from the available information related to geological, seismotectonic and geotechnical characteristics of the site of interest as well as physical modelling techniques to provide a reliable and robust deterministic basis for hazard and risk analysis.

Scenario earthquake is defined by providing location of the earthquake, depth focal, magnitude, fault orientation, dip angle. Attenuation relationships (also called Ground Motion Prediction Equations - GMPE) are used to calculate ground shaking demand for rock sites. In general, they represent response spectral acceleration ordinates, Sa(T), at 5% elastic damping.

For scenario earthquake analysis, each attenuation table must contain the following information:

Magnitude limits: MINF: Lower limit of magnitude given in the table.
MSUP: Upper limit of magnitude given in the table.
NMAG: Number of magnitudes for which intensity is given.

It is assumed that intensities are given for magnitudes M(K), where M(K)=MINF+(K-1)*DMAG, and DMAG=(MSUP-MINF)/(NMAG-1).

Distance limits: RINF: Lower limit of distance given in the table.
RSUP: Upper limit of distance given in the table.
NRAD: Number of distances for which intensity is given (Integer format).
TYPE: An integer indicating the type of distance used by the attenuation table.

It is assumed that intensities are given for distances R(K), where log(R(K))=log(RINF)+(K-1)*DLRAD, where DLRAD=(log(RSUP)-log(RINF))/(NRAD-1). That is, distances are supposed to be logarithmically spaced.

TYPE represents the type of distance for the selected attenuation model: Focal, Epicentral, Joyner and Boore, Closest to rupture area (Rrup).

For each of the NT different intensity measures, the following blocks of lines: T(J), SLA(J,0)

- T(J): Structural period of j-th spectral ordinate. It is used only for identification purposes and to plot the uniform-hazard spectrum, so in the cases in which structural period has no meaning, it can be just a sequential number.
- SLA(J,0): Standard deviation of the natural logarithm of the j-th measure of intensity. A value of SLA(J,0)<=0 implies that the user will give standard deviations that vary with magnitude. In this case, the corresponding Sigma values, one for each of the NMAG magnitudes has to be given after the table of SA() values.

5.1.3.1.2 Pre-Defined Seismic Uniform Hazard Analysis

The SHARE project probabilistic seismic hazard contour maps for Euro-Mediterranean Region has been embedded in the LIQUEFACT software, to be used as basis to ground shaking in Pre-Defined Uniform Hazard type analysis. The SHARE maps were produced for different return periods: 73 years (50% in 50 years), 102 years (39% in 50 years), 475 years (10% in 50 years), 975 years (5% in 50 years), 2475 years (2% in 50 years), 4975 years (1% in 50 years). An example of SHARE-seismic hazard map is shown in Figure 13, in terms of PGA having 10% exceedance probability in 50 years. The hazard values are referenced to a rock velocity of $V_{S,30}$ = 800 m/s at 30 m depth. SHARE models earthquakes as finite ruptures and includes all events with magnitudes MW≥4.5 in the computation of hazard values. SHARE introduces an innovative weighting scheme that reflects the importance of the input data sets

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considering their time horizon, thus emphasizing the geologic knowledge for products with longer time horizons and seismological data for shorter ones.

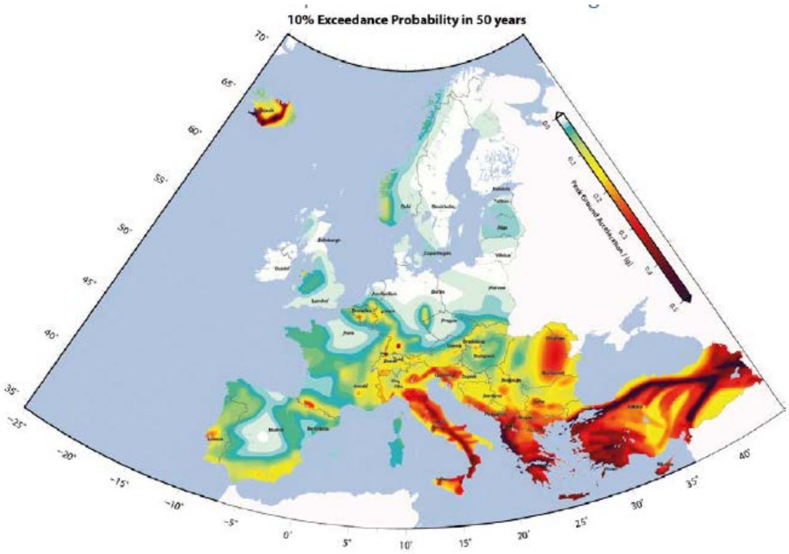

Figure 13. Seismic hazard map depicts the 10% exceedance probability that a peak ground acceleration of a certain fraction of the gravitational acceleration g is observed within the next 50 year

5.1.3.1.3 User-Defined Seismic Hazard Analysis

User-supplied PGA and spectral acceleration contour maps, e.g. resulted from a specific local or regional seismic response analysis, represents another alternative where pre-defined ground shaking maps that were developed for specific location or regional scale.

5.1.3.2 Ground Amplification Analysis

The values of ground shaking demand obtained from the different methodologies/options described above are in general computed for rock condition, and which then amplified by factors based on local soil conditions. This can be done using one of the following alternatives:

- Use of response spectrum ***Code-Design***: where Eurocode-8 spectrum types are incorporated in the LIQUEFACT software.
- Use of **Site-Specific** option which requires Vs profiles supplied by the user.

5.1.3.2.1 Ground Amplification using Code-Design

Two different types of design spectra are provided within Eurocode 8 (CEN, 2004). This is mainly done in order to account for the differing level of seismic hazard in Europe and the different earthquake types susceptible to occur. In case that earthquakes with a surface-wave magnitude $M_s > 5.5$ are expected, it is suggested to use Spectrum Type 1, else ($M_s \leq 5.5$) Type 2. The question which spectrum

type to choose for a specific region should be based upon "*(...) the magnitude of earthquakes that are actually expected to occur rather than conservative upper limits defined for the purpose of probabilistic hazard assessment*".
Both types of the horizontal design spectrum are defined by the following expressions:

$$Sa(T) = a_g \cdot S \cdot [1 + \frac{T}{T_B} \cdot (\eta \cdot 2.5 - 1)] \qquad \text{for } T < T_B$$

$$Sa(T) = a_g \cdot S \cdot \eta \cdot 2.5 \qquad \text{for } T_B < T < T_C$$

$$Sa(T) = a_g \cdot S \cdot \eta \cdot 2.5 \cdot [\frac{T_C}{T}] \qquad \text{for } T_C < T < T_D$$

$$Sa(T) = a_g \cdot S \cdot \eta \cdot 2.5 \cdot [\frac{T_C \cdot T_D}{T^2}] \qquad \text{for } T_D < T < 4.0\ s$$

where:

a_g - design ground acceleration (here: PGA) on soil type A ground,
T_B, T_C - corner periods of the constant spectral acceleration branch (plateau),
T_D - corner period defining the beginning of the constant displacement range,
S - soil amplification factor (see Error! Reference source not found.),
η - damping correction factor (η = 1.00 for 5% viscous damping).

The shape of the design spectrum is thus determined by the corner periods, soil amplification factor, and the level of input ground motion. Both, corner periods (T_B, T_C, and T_D) as well as soil amplification factor S are dependent on 'ground type', which is mainly distinguished by the average shear-wave velocity of the uppermost 30 *m* ($v_{s,30}$) and hence categorized into 5 different soil classes (Table 4). Both, soil amplification factor and corner periods for the different soil classes are given in Error! Reference source not found. and Table 5 for Type 1 and Type 2 design response spectra, respectively. Figure 14 illustrates the corresponding sets of normalized elastic design response spectra.

Table 4 Ground types provided by Eurocode 8 (European Committee for Standardization (CEN, 2004)

Soil Type	Description of Stratigraphic profile	Shear Wave velocity Vs,30 [m/s]
A	Rock or rock-like geological formation, incl. at most 5 m of weaker material at the surface	> 800
B	Deposits of very dense sands, gravel, or very stiff clay (at least several tens of m in thickness) characterized by a gradual increase of mechanical properties with depth	360–800
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of m	180–360
D	Deposits of loose-to-medium cohesion¬less soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil	< 180
E	Soil profile consisting of a surface alluvium layer with vs,30 values of type C or D and thickness H varying between 5–20 m underlain by stiffer material with vs,30 > 800 m/s	n.a.

Table 5 Values of the parameters describing Eurocode 8 – Type 1 spectra (CEN, 2004)

Soil Type	Soil factor S	T_B [sec]	T_C [sec]	T_D [sec]
A	1.00	0.15	0.40	2.00
B	1.20	0.15	0.50	2.00

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

C	1.15	0.20	0.60	2.00
D	1.35	0.20	0.80	2.00
E	1.40	0.15	0.50	2.00

Table 6 Values of the parameters describing Eurocode 8 – Type 2 spectra (CEN, 2004)

Soil Type	Soil factor S	T_B [sec]	T_C [sec]	T_D [sec]
A	1.00	0.05	0.25	1.20
B	1.35	0.05	0.25	1.20
C	1.50	0.10	0.25	1.20
D	1.80	0.10	0.30	1.20
E	1.60	0.05	0.25	1.20

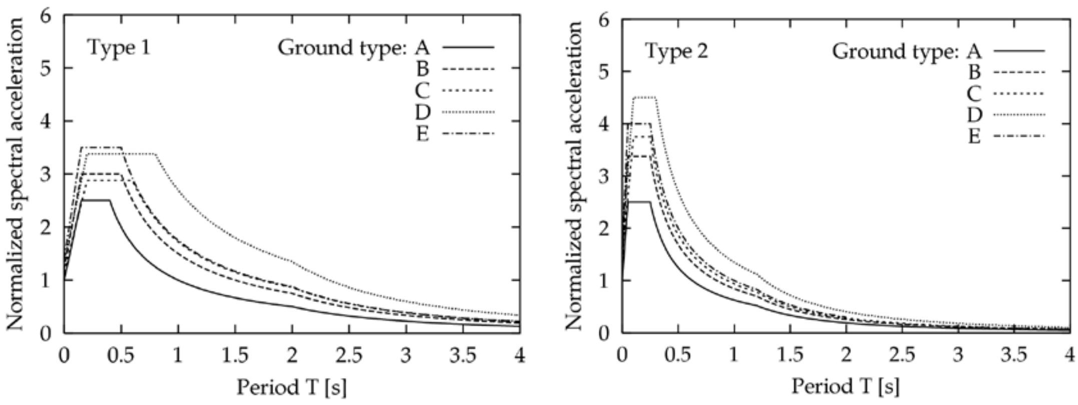

Figure 14. Eurocode-8 elastic design spectra of Type 1 and Type 2

5.1.3.2.2 Ground Amplification using Site-Specific

Site-specific elastic response spectrum can be either derived from a Scenario Earthquake or a Pre-Defined/User-Defined Seismic Hazard. In the case of Scenario Earthquake, LIQUEFACT software is using the embedded attenuation relationships to compute the corresponding ground motion estimates using average shear-wave velocity $V_{S,30}$ in order to amplify the ground motion. This $V_{S,30}$ value is user-supplied as input data. In the of Pre-Defined or User-Defined Seismic Hazard (where ground motion map is already computed in terms of PGA values and full spectral acceleration contours), the ground motion is amplified using the soil amplification factors provided by IBC-2006 (ICC, 2006) by assigning a $V_{S,30}$ value that agrees with the soil type (see Table 7).

Table 7 Site amplification factors modified from IBC-2006 (ICC, 2006)

	Shear-wave velocity $V_{S,30}$ [m/s]			
Spectral Acceleration	**> 800**	**360 – 800**	**180 – 360**	**< 180**
Short-Period Spectral Acceleration [g]	**Short-Period Amplification Factor**			
$\leq$ 0.25	1.0	1.2	1.6	2.5
[0.25, 0.50]	1.0	1.2	1.4	1.7

[0.50, 0.75]	1.0	1.1	1.2	1.2
[0.75, 1.0]	1.0	1.0	1.1	0.9
> 1.0	1.0	1.0	1.0	0.9
1-Second Period Spectral Acceleration [g]	**1-Second Period Amplification Factor**			
≤ 0.1	1.0	1.7	2.4	3.5
[0.1, 0.2]	1.0	1.6	2.0	3.2
[0.2, 0.3]	1.0	1.5	1.8	2.8
[0.3, 0.4]	1.0	1.4	1.6	2.4
> 0.4	1.0	1.3	1.5	2.4

5.1.4 Interpolation and Mapping

In the LIQUEFACT software, two types of interpolation techniques for generating seismic and liquefaction hazards and the computation of risk: *Geostatistical Interpolation* and *Deterministic Interpolation* procedures.

The implemented *Geostatistical Interpolation* is based on ***Kriging*** technique which utilizes the statistical properties of the measured points. Kriging technique quantify the spatial autocorrelation among measured points and account for the spatial configuration of the sample points around the prediction location.

The implemented *Deterministic Interpolation* is based on ***Shepard's Weighted Average*** technique. It creates surfaces from measured points, based on either the extent of similarity (inverse distance weighted) or the degree of smoothing (radial basis functions).

5.2 Risk Assessment

For risk analysis, depending on what level of analysis is chosen and output is requested, different numbers of input files have to be generated:

- Vulnerability analysis and evaluation of physical impact: directly related to vulnerability assessment and computation of damage on buildings/infrastructures
- Economic impact: evaluation of economic impact of the physical damage

5.2.1 Process for Vulnerability Analysis

For vulnerability analysis, alternatives are provided to end-users offering more flexibility in terms of type of vulnerability analysis to be conducted and type and level of details of the input data that can be available, and level of knowledge of the end-users.

5.2.2 Computation of Damage Probabilities

Users is provided with two procedures for the computation of physical damage and mean damage ratio for a given liquefaction demand:

- the newly developed Equivalent Soil Profile (ESP) based procedure,
- the Conventional procedure (which has been widely used.

5.2.2.1 ESP-based procedure

Figure 15 illustrates the general steps of the ESP-based procedure that have been integrated in the software for liquefaction risk analysis. The procedure consists of 3 main steps (Viana da Fonseca et al. 2018a):

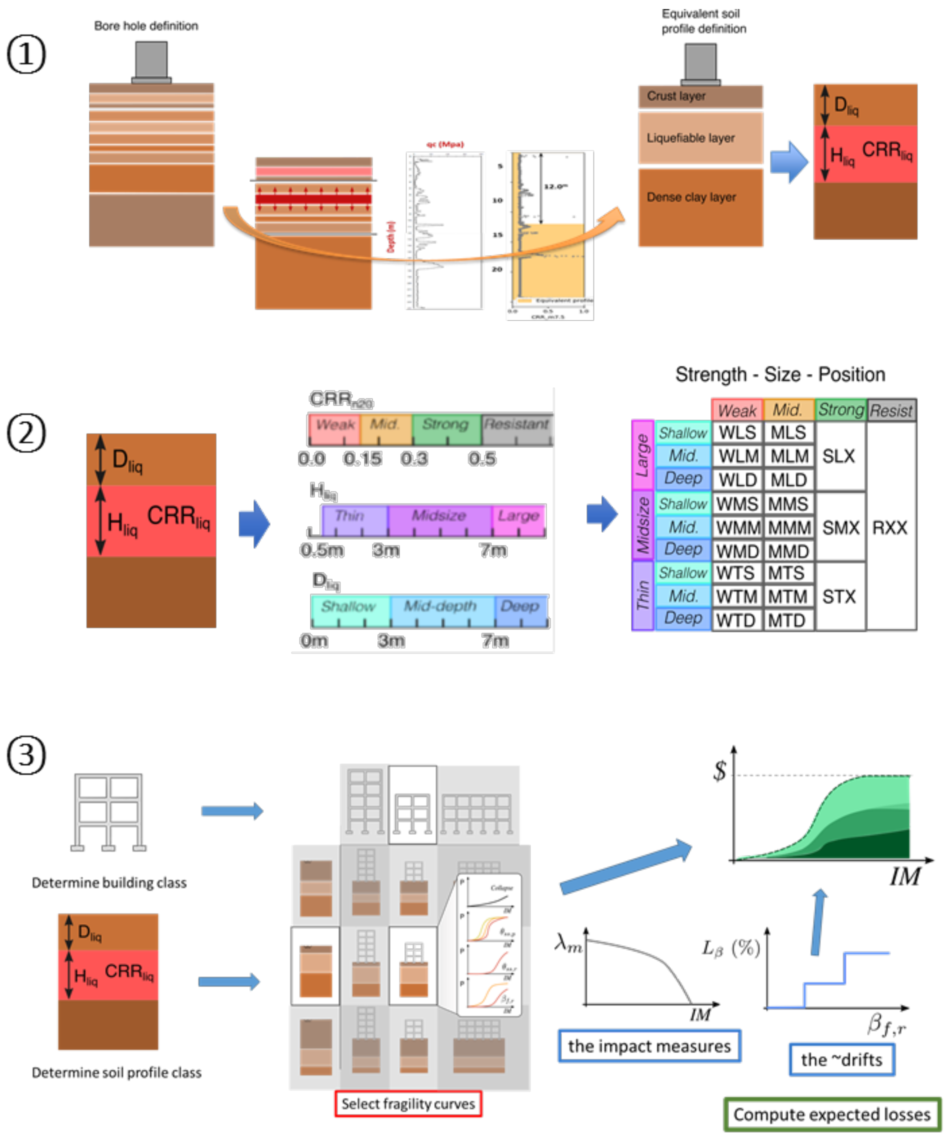

Figure 15. General steps of the ESP-based procedure for the computation of damage and loss (Viana da Fonseca et al. 2018a)

- Step 1: is about generating an equivalent soil profile that will be used for the evaluation of liquefaction risk;

- Step 2 uses of liquefaction soil profile criteria to identify the characteristics of the equivalent soil profile considering parameters of soil strength, thickness of liquefiable layer, depth of the liquefiable layer from the surface; and
- Step 3 combines the selected building/infrastructure in terms of its typology/class with the determined equivalent soil profile class to select the associated fragility curves for the computation of physical impact and the expected losses.

In the Equivalent Soil Profile (ESP)-based procedure vulnerability model assigned to each asset is presented by 22 ESP profiles that have been developed based on the thickness level of liquefiable layer, the depth to the liquefiable layer, the level of strength of the liquefiable layer as illustrated in Table 1. The software then looks up the fragility curves that correspond to equivalent soil profile class and building typology and computes the loss.

Table 8 Concept of the 22 classes of Equivalent Soil Profile (ESP)

ESP classes	Soil Resistance	Thickness of Liquefiable Layer	Thickness of Crust Layer
WLS	Weak	Large	Shallow
WLM	Weak	Large	Mid
WLD	Weak	Large	Deep
WMS	Weak	Midsize	Shallow
WMM	Weak	Midsize	Mid
WMD	Weak	Midsize	Deep
WTS	Weak	Thin	Shallow
WTM	Weak	Thin	Mid
WTD	Weak	Thin	Deep
MLS	Midium	Large	Shallow
MLM	Midium	Large	Mid
MLD	Midium	Large	Deep
MMS	Midium	Midsize	Shallow
MMM	Midium	Midsize	Mid
MMD	Midium	Midsize	Deep
MTS	Midium	Thin	Shallow
MTM	Midium	Thin	Mid
MTD	Midium	Thin	Deep
SLX	Strong	Large	
SMX	Strong	Midsize	
STX	Strong	Thin	
RXX	Resist		

5.2.2.2 Conventional procedure

In the conventional procedure, a given building or infrastructure is represented by a single fragility model which is developed as result of a combined structural system- soil profile.

Regarding the definition of damage thresholds, options are providing regarding the *Number of Damage Limit States* that can be used in for user-supplied *Liquefaction Fragility* models. The software incorporates the following definitions for the fragility models:

- *Four Damage Limit States*: *Slight Damage*, *Moderate Damage*, *Extensive Damage* and *Complete Damage*
- *Three Damage Limit States*: *Damage Limitation*, *Significant Damage*, and *Near Collapse.*
- *Two Damage Limit States*: *Minor Damage*, and *Complete Damage*
- *One Damage Limit State*: *Collapse*

5.2.3 Engineering Demand Parameter

The type of intensity measure for the Engineering Demand Parameter (EDP) will define the procedure for the computation of demand/performance. For liquefaction vulnerability, users are provided with options in defining intensity measure for vulnerability models.

- Spectral Acceleration (Sa)
- Peak Ground Acceleration (PGA)
- Liquefaction Severity Number (LSN)
- Ground Deformation – Differential Settlement (GD)

Similarly, users can define ground shaking vulnerability with options of intensity measures

- Spectral Acceleration (Sa)
- Peak Ground Acceleration (PGA)
- Spectral Displacement (Sd)

5.2.4 Computation of Mean Loss Ratio

Loss Ratio (LR), also called *Damage Ratio*, is defined as the cost ratio (or loss) to the value or cost of new construction for each portfolio entry and insurance type. LR to a specific building or infrastructure from a given liquefaction severity indicator or ground shaking at a given site is computed by the LIQUEFACT software using the HAZUS principles where damage probability is computed in different categories depending on number of Damage Limit States (one, two, three or four Damage Limit States) considered in the selected fragility models. LR in the LIQUEFACT software is used with weights so that it not only reflects damage, but the relative economical loss inflicted.

The weighted LR for each portfolio entry and owner and insurance losses, Building (LR_B), Contents (LR_C) and Business Interruption (LR_I), is computed from the Damage Limit States. Here is example for the case of fragility model with four Damage Limit States:

$$LR_B = B_1P_{Slight} + B_2P_{Moderate} + B_3P_{Extensive} + B_4P_{Complete}$$

$$LR_C = C_1P_{Slight} + C_2P_{Moderate} + C_3P_{Extensive} + C_4P_{Complete}$$

$$LR_I = I_1P_{Slight} + I_2P_{Moderate} + I_3P_{Extensive} + I_4P_{Complete}$$

Where

P_{None} (is Probability of no damage) + P_{Slight} (is Probability of slight damage) + $P_{Moderate}$ (is Probability of moderate damage) + $P_{Extensive}$ (is Probability of extensive damage) + $P_{Complete}$ (is Probability of complete damage) = 1.

The Mean Loss Ratio (MLR) is defined as the ratio of repair costs (or losses) to the total value, and is extensively used as a direct representation of the economic losses and in the insurance industry (e.g. Munich-RE, Swiss-RE).

$$MLR = \frac{\sum_k \sum_j N_j^k LR_j}{N_T}$$

where LR_j is the ratio of the cost for damage state j to the total value, and these values are user changeable. N_T is the total number of buildings (of same typology in a given Geo-code) and N^k_j denotes the number of buildings in damage state j and typology k.

5.3 Liquefaction Mitigation Assessment

Mitigation Analysis System incorporated in the LIQUEFACT software is based on knowledge and processes for ground improvement techniques selection. The mitigation analysis is processed as Score Rating sequences where users can develop mitigation framework customized to their case studies. Note that the system is provided for guidance only and should not be considered as it is for design decisions. Results obtained from the Mitigation Analysis should be independently cross-checked, and critically reviewed by an experienced engineer with sufficient expertise and an understanding of the underlying assumptions and limitations of the software.

5.3.1 Liquefaction Mitigation Techniques

The ground improvement technologies that have been considered in the incorporated mitigation analysis system are the most commonly ground improvement technologies in practice for liquefaction mitigation and are shown in Table 8.

Table 9 List of ground improvement technologies for liquefaction mitigation

Ground improvement technologies for liquefaction mitigation	Earthquake drains
	Deep dynamic compaction
	Vibro-compaction
	Blasting compaction
	Vibro-replacement
	Induced partial saturation
	Compaction grouting

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	Low pressure grouting
	Jet grouting
	Deep soil mixing

5.3.2 Level of Applicability and Score Rating Evaluation

The technology(s) selection process is based on applicability criteria and score rating considering the most influential factors. The first step in scoring the applicability and eliminate some ground improvement technologies is to define site conditions: if site or location of interest is a free field condition or if there are existing buildings or infrastructures. Other involved factors include soil type, stratigraphy, depth of liquefiable zone, size of area to be improved, foundation type, constrains, presence any subsurface obstructions, and environmental compatibility. Table 9 illustrates the list of the factors considered in the system, and they are classified in terms of level of importance to the applicability criteria and weighted accordingly.

Table 10 List of influential factors for ground improvement technologies selection, and classification in terms of level of importance using weighting

Factors	Level of Importance	Weight	Relative Weight (%)
1. Site conditions	Very important	4	18.2
2. Soil type	Very important	4	18.2
3. Stratigraphy	Medium important	2	9.1
4. Depth of the treatment zone	Very important	4	18.2
5. Size of area to be improved	Less important	1	4.5
6. Foundation type	Less important	1	4.5
7. Project constrains	Medium important	2	9.1
8. Presence of subsurface obstructions	Medium important	2	9.1
9. Environmental compatibility	Medium important	2	9.1
		TOTAL	100 %

Table 11 Details on the factors influencing mitigation techniques applicability

Factors	Details
1. *Site conditions*	Free-field or existing structure is one of the major factors that can influence the process of ground mitigation technologies selection, as some technologies could damage structures.
1.1) Free field	
1.2) Existing buildings	
2. *Soil type*	In general, any ground improvement technologies that can effectively improve the shear and compression resistance of liquefiable soil can be used for liquefaction mitigation, but each remedial technology has its own suitable soil type to which it should be applied (if is gravel, sandy or inorganic/clays silts of low to medium plasticity).
2.1) Gravel soils	
2.2) Sandy soils	
2.3) Inorganic silts, clays silts of low to medium plasticity	
3. *Stratigraphy*	Link the suitability of ground improvement technologies to the presence or not of soil crust.
3.1) Soil crust	
3.2) No soil crust	
4. *Depth of the treatment zone*	

4.1) <3 m 4.2) 3-12 m 4.3) 12-18 m 4.4) 18-25 m	The suitability of ground improvement technologies is subject to the specified depth of the liquefiable soil layer. Based on extensive review and several studies the following depths have been determined for the applicability of the various ground improvement technologies.
5. *Size of area to be improved* 5.1) Small (<1000 m^2) 5.2) Medium (1000-5000 m^2) 5.3) High (>5000 m^2)	The suitability of ground improvement technologies is also subject to the size of area to be improved. Some ranges defining the economic size associated to ground improvement technologies have been established based on case studies from literature, suggesting the followings classifications for size area: *Small Area*: indicates an area less than 1000 m2; *Medium Area*: indicates an area between 1000 and 5000 m2; *High Area*: indicates an area more than 5000 m2.
6. *Foundation type* 6.1) Shallow foundations 6.2) Deep foundations	The selection of foundation type allows sorting of technologies based on the usefulness of the ground improvement technology to the specific foundation type.
7. *Project constrains* 7.1) Low overhead clearance 7.2) Adjacent structures 7.3) Existing utilities	The selection of project constrains allows sorting of technologies considering the following cases: •*Low overhead clearance*: means there is no accessibility of the equipment to reach the site. •*Adjacent structures*: means that it may not be possible to use some technologies if there are structures near the site of interest (some technologies could damage the adjacent structures). In a such situation any adjacent buildings and structures must be monitored when using some technologies. •*Existing utilities*: means that a technology may be acceptable if there are some existing utilities, and this could strongly affect the ground improvement operations.
8. *Presence of subsurface obstructions*	Subsurface obstructions such as cobbles, boulders, or construction debris, water bearing sands, organic layers, and very stiff surface deposits can significantly impact type of ground improvement technologies that can be selected.
9. *Environmental compatibility*	Environmental constraints may include: disposal of spoils from a particular ground modification technology, disposal of waste materials encountered on the site, protection of the site from erosion, protection of surface and ground waters from pollution, and the effects of construction vibrations, noise and dust. Some ground improvement technologies such as deep mixing method or grouting methods can improve the in-situ ground by introducing chemicals or contaminates into the soils, which can be a critical environmental issue in some cases.

Tables below illustrates the level of applicability and score rating of ground improvement technologies (for the 10 selected technologies) considering the most influential factors listed in the table above. For each answer to a given factor, weighed score is computed as a value quantified for a given level of applicability multiplied with value quantified for level of importance of the given factor. For example, for an answer of Free-field to the site condition factor, the weighed score value of 55 is the result of 3 (quantified value for level of applicability in free field condition) multiplied with 18.2% (relative weight quantifying level of importance of the factor site condition).

Table 12 Ground improvement technologies applicability and score rating for the factor of *Site Conditions*

Ground Improvement Technologies	Applicability Factors	1. Site conditions	
		1.1) Free field	1.2) Existing buildings

EARTHQUAKE DRAINS	Applicability	Good	Good
		3	3
	Weighed score	55	55
DEEP DYNAMIC COMPACTION	Applicability	Good	Not Applicable
		3	0
	Weighed score	55	0
VIBRO COMPACTION	Applicability	Good	Not Applicable
		3	0
	Weighed score	55	0
BLASTING COMPACTION	Applicability	Good	Not Applicable
		3	0
	Weighed score	55	0
VIBRO REPLACEMENT	Applicability	Good	Not Applicable
		3	0
	Weighed score	55	0
INDUCED PARTIAL SATURATION	Applicability	Good	Good
		3	3
	Weighed score	55	55
COMPACTION GROUTING	Applicability	Good	Good
		3	3
	Weighed score	55	55
LOW PRESSURE GROUTING	Applicability	Good	Good
		3	3
	Weighed score	55	55
JET GROUTING	Applicability	Good	Medium
		3	2
	Weighed score	55	36
DEEP SOIL MIXING	Applicability	Good	Good
		3	3
	Weighed score	55	55

Table 13 Ground improvement technologies applicability and score rating for the factor of *Soil Type*

Ground Improvement Technologies	Applicability Factors	2. Soil Type		
		2.1) Gravel soils	2.2) Sandy soils	2.3) Inorganic silts, clays silts of low to medium plasticity
EARTHQUAKE DRAINS	Applicability	Low	Good	Low
		1	3	1
	Weighed score	18	55	18
DEEP DYNAMIC COMPACTION	Applicability	Medium	Good	Low
		2	3	1
	Weighed score	36	55	18
VIBRO COMPACTION	Applicability	Good	Good	Not Applicable
		3	3	0
	Weighed score	55	55	0
BLASTING COMPACTION	Applicability	Medium	Medium	Not Applicable
		2	2	0
	Weighed score	36	36	0
VIBRO REPLACEMENT	Applicability	Low	Medium	Good
		1	2	3
	Weighed score	18	36	55
INDUCED PARTIAL SATURATION	Applicability	Medium	Good	Low
		2	3	1
	Weighed score	36	55	18
COMPACTION GROUTING	Applicability	Medium	Good	Low

		2	3	1
	Weighed score	36	55	18
LOW PRESSURE GROUTING	Applicability	Good	Good	Not Applicable
		3	3	0
	Weighed score	55	55	0
JET GROUTING	Applicability	Good	Good	Medium
		3	3	2
	Weighed score	55	55	36
DEEP SOIL MIXING	Applicability	Low	Medium	Good
		1	2	3
	Weighed score	18	36	55

Table 14 Ground improvement technologies applicability and score rating for the factor of *Stratigraphy*

Ground Improvement Technologies	Applicability Factors	3. Stratigraphy	
		3.1) Soil crust	3.2) No soil crust
EARTHQUAKE DRAINS	Applicability	Good	Medium
		3	2
	Weighed score	27	18
DEEP DYNAMIC COMPACTION	Applicability	Low	Good
		1	3
	Weighed score	9	27
VIBRO COMPACTION	Applicability	Medium	Good
		2	3
	Weighed score	18	27
BLASTING COMPACTION	Applicability	Low	Good
		1	3
	Weighed score	9	27
VIBRO REPLACEMENT	Applicability	Low	Good
		1	3
	Weighed score	9	27
INDUCED PARTIAL SATURATION	Applicability	Good	Good
		3	3
	Weighed score	27	27
COMPACTION GROUTING	Applicability	Good	Good
		3	3
	Weighed score	27	27
LOW PRESSURE GROUTING	Applicability	Good	Good
		3	3
	Weighed score	27	27
JET GROUTING	Applicability	Good	Good
		3	3
	Weighed score	27	27
DEEP SOIL MIXING	Applicability	Good	Good
		3	3
	Weighed score	27	27

Table 15 Ground improvement technologies applicability and score rating for the factor of *Depth of the treatment zone*

Ground Improvement Technologies	Applicability Factors	4. Depth of the treatment zone			
		4.1) <3 m	4.2) 3-12 m	4.3) 12-18 m	4.4) 18-25 m
EARTHQUAKE DRAINS	Applicability	Low	Good	Good	Good
		1	3	3	3
	Weighed score	18	55	55	55

DEEP DYNAMIC COMPACTION	Applicability	Good	Good	Medium	Low
		3	3	2	1
	Weighed score	55	55	36	18
VIBRO COMPACTION	Applicability	Good	Good	Medium	Low
		3	3	2	1
	Weighed score	55	55	36	18
BLASTING COMPACTION	Applicability	Medium	Good	Medium	Not Applicable
		2	3	2	0
	Weighed score	36	55	36	0
VIBRO REPLACEMENT	Applicability	Good	Good	Medium	Low
		3	3	2	1
	Weighed score	55	55	36	18
INDUCED PARTIAL SATURATION	Applicability	Medium	Good	Good	Good
		2	3	3	3
	Weighed score	36	55	55	55
COMPACTION GROUTING	Applicability	Medium	Good	Good	Low
		2	3	3	1
	Weighed score	36	55	55	18
LOW PRESSURE GROUTING	Applicability	Good	Good	Good	Good
		3	3	3	3
	Weighed score	55	55	55	55
JET GROUTING	Applicability	Medium	Good	Good	Good
		2	3	3	3
	Weighed score	36	55	55	55
DEEP SOIL MIXING	Applicability	Medium	Good	Good	Medium
		2	3	3	2
	Weighed score	36	55	55	36

Table 16 Ground improvement technologies applicability and score rating for the factor of *Size of area to be improved*

Ground Improvement Technologies	Applicability Factors	5. Size of area to be improved		
		5.1) Small (<1000 m2)	5.2) Medium (1000-5000 m2)	5.3) High (>5000 m2)
EARTHQUAKE DRAINS	Applicability	Good	Good	Good
		3	3	3
	Weighed score	14	14	14
DEEP DYNAMIC COMPACTION	Applicability	Good	Good	Good
		3	3	3
	Weighed score	14	14	14
VIBRO COMPACTION	Applicability	Good	Good	Good
		3	3	3
	Weighed score	14	14	14
BLASTING COMPACTION	Applicability	Medium	Medium	Good
		2	2	3
	Weighed score	9	9	14
VIBRO REPLACEMENT	Applicability	Good	Good	Good
		3	3	3
	Weighed score	14	14	14
INDUCED PARTIAL SATURATION	Applicability	Good	Good	Good
		3	3	3
	Weighed score	14	14	14
COMPACTION GROUTING	Applicability	Good	Good	Good
		3	3	3
	Weighed score	14	14	14
LOW PRESSURE GROUTING	Applicability	Good	Good	Good

		3	3	3
	Weighed score	14	14	14
JET GROUTING	Applicability	Good	Good	Good
		3	3	3
	Weighed score	14	14	14
DEEP SOIL MIXING	Applicability	Good	Good	Good
		3	3	3
	Weighed score	14	14	14

Table 17 Ground improvement technologies applicability and score rating for the factor of *Foundation Type*

Ground Improvement Technologies	Applicability Factors	6. Foundation Type	
		6.1) Shallow foundations	6.2) Deep foundations
EARTHQUAKE DRAINS	Applicability	Good	Good
		3	3
	Weighed score	14	14
DEEP DYNAMIC COMPACTION	Applicability	Not Applicable	Not Applicable
		0	0
	Weighed score	0	0
VIBRO COMPACTION	Applicability	Good	Low
		3	1
	Weighed score	14	5
BLASTING COMPACTION	Applicability	Not Applicable	Not Applicable
		0	0
	Weighed score	0	0
VIBRO REPLACEMENT	Applicability	Good	Not Applicable
		3	0
	Weighed score	14	0
INDUCED PARTIAL SATURATION	Applicability	Good	Good
		3	3
	Weighed score	14	14
COMPACTION GROUTING	Applicability	Good	Low
		3	1
	Weighed score	14	5
LOW PRESSURE GROUTING	Applicability	Good	Good
		3	3
	Weighed score	14	14
JET GROUTING	Applicability	Good	Medium
		3	2
	Weighed score	14	9
DEEP SOIL MIXING	Applicability	Good	Good
		3	3
	Weighed score	14	14

Table 18 Ground improvement technologies applicability and score rating for the factor of *Project constrains*

Ground Improvement Technologies	Applicability Factors	7. Project constrains		
		7.1) Low overhead clearance	7.2) Adjacent structures	7.3) Existing utilities
EARTHQUAKE DRAINS	Applicability	Not Applicable	Good	Low
		0	3	1
	Weighed score	0	27	9
DEEP DYNAMIC COMPACTION	Applicability	Not Applicable	Not Applicable	Not Applicable
		0	0	0

	Weighed score	0	0	0
VIBRO COMPACTION	Applicability	Low	Not Applicable	Low
		1	0	1
	Weighed score	9	0	9
BLASTING COMPACTION	Applicability	Not Applicable	Not Applicable	Not Applicable
		0	0	0
	Weighed score	0	0	0
VIBRO REPLACEMENT	Applicability	Low	Not Applicable	Low
		1	0	1
	Weighed score	9	0	9
INDUCED PARTIAL SATURATION	Applicability	Good	Good	Good
		3	3	3
	Weighed score	27	27	27
COMPACTION GROUTING	Applicability	Medium	Good	Medium
		2	3	2
	Weighed score	18	27	18
LOW PRESSURE GROUTING	Applicability	Good	Good	Good
		3	3	3
	Weighed score	27	27	27
JET GROUTING	Applicability	Low	Medium	Low
		1	2	1
	Weighed score	9	18	9
DEEP SOIL MIXING	Applicability	Not Applicable	Good	Medium
		0	3	2
	Weighed score	0	27	18

Table 19 Ground improvement technologies applicability and score rating for the factor of *Presence of subsurface obstructions* and *Environmental compatibility*

Ground Improvement Technologies	Applicability Factors	8. Presence of subsurface obstructions	9. Environmental compatibility
EARTHQUAKE DRAINS	Applicability	Low	Good
		1	3
	Weighed score	9	27
DEEP DYNAMIC COMPACTION	Applicability	Not Applicable	Good
		0	3
	Weighed score	0	27
VIBRO COMPACTION	Applicability	Not Applicable	Good
		0	3
	Weighed score	0	27
BLASTING COMPACTION	Applicability	Not Applicable	Not Applicable
		0	0
	Weighed score	0	0
VIBRO REPLACEMENT	Applicability	Not Applicable	Low
		0	1
	Weighed score	0	9
INDUCED PARTIAL SATURATION	Applicability	Good	Good
		3	3
	Weighed score	27	27
COMPACTION GROUTING	Applicability	Low	Good
		1	3
	Weighed score	9	27
LOW PRESSURE GROUTING	Applicability	Good	Low
		3	1
	Weighed score	27	9

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JET GROUTING	Applicability	Low	Medium
		1	2
	Weighed score	9	18
DEEP SOIL MIXING	Applicability	Medium	Good
		2	3
	Weighed score	18	27

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

Table 20 Concept for the evaluation of overall score rating for selection of mitigation technologies considering the most influential factors of applicability

LEGEND		
APPLICABILITY	Good	3
	Medium	2
	Low	1
	Not applicable	0
WEIGHT	Very important	4
	Important	3
	Medium important	2
	Less important	1
	Not applicable	0

Question		Weight	Relative weight (%)	EARTHQUAKE DRAINS		DEEP DYNAMIC COMPACTION		VIBRO COMPACTION		BLASTING COMPACTION		VIBRO REPLACEMENT		INDUCED PARTIAL SATURATION		COMPACTION GROUTING		LOW PRESSURE GROUTING		JET GROUTING		DEEP SOIL MIXING	
				Applicability	Weighed score	Applicability	Weighed score	Applicability	Weighed score	Applicability	Weighed score	Applicability	Weighed score	Applicability	Weighed score	Applicability	Weighed score	Applicability	Weighed score	Applicability	Weighed score	Applicability	Weighed score
1. Site conditions	1.1) Free field	4	18.2	3	55	3	55	3	55	3	55	3	55	3	55	3	55	3	55	3	55	3	55
	1.2) Existing buildings			3	55	0	0	0	0	0	0	0	0	3	55	3	55	3	55	2	36	3	55
2. Soil type	2.1) Gravel soils	4	18.2	1	18	2	36	3	55	2	36	1	18	2	36	2	36	3	55	3	55	1	18
	2.2) Sandy soils			3	55	3	55	3	55	2	36	2	36	3	55	3	55	3	55	3	55	2	36
	2.3) Inorganic silts, clays silts of low to medium plasticity			1	18	1	18	0	0	0	0	3	55	1	18	1	18	0	0	2	36	3	55
3. Stratigraphy	3.1) Soil crust	2	9.1	3	27	1	9	2	18	1	9	1	9	3	27	3	27	3	27	3	27	3	27
	3.2) No soil crust			2	18	3	27	3	27	3	27	3	27	3	27	3	27	3	27	3	27	3	27
4. Depth of the treatment zone (based on case histories)	4.1) <3 m	4	18.2	1	18	3	55	3	55	2	36	3	55	2	36	2	36	3	55	2	36	2	36
	4.2) 3-12 m			3	55	3	55	3	55	3	55	3	55	3	55	3	55	3	55	3	55	3	55
	4.3) 12-18 m			3	55	2	36	2	36	2	36	2	36	3	55	3	55	3	55	3	55	3	55
	4.4) 18-25 m			3	55	1	18	1	18	0	0	1	18	3	55	1	18	3	55	3	55	2	36
5. Size of area to be improved	5.1) Small (<1000 m^2)	1	4.5	3	14	3	14	3	14	2	9	3	14	3	14	3	14	3	14	3	14	3	14
	5.2) Medium (1000-5000 m^2)			3	14	3	14	3	14	2	9	3	14	3	14	3	14	3	14	3	14	3	14
	5.3) High (>5000 m^2)			3	14	3	14	3	14	3	14	3	14	3	14	3	14	3	14	3	14	3	14
6. Foundation type	6.1) Shallow foundations	1	4.5	3	14	0	0	3	14	0	0	3	14	3	14	3	14	3	14	3	14	3	14
	6.2) Deep foundations			3	14	0	0	1	5	0	0	0	0	3	14	1	5	3	14	2	9	3	14
7. Project constrains	7.1) Low overhead clearance	2	9.1	0	0	0	0	1	9	0	0	1	9	3	27	2	18	3	27	1	9	0	0
	7.2) Adjacent structures			3	27	0	0	0	0	0	0	0	0	3	27	3	27	3	27	2	18	3	27
	7.3) Existing utilities			1	9	0	0	1	9	0	0	1	9	3	27	2	18	3	27	1	9	2	18
8. Presence of subsurface obstructions		2	9.1	1	9	0	0	0	0	0	0	0	0	3	27	1	9	3	27	1	9	2	18
9. Environmental compatibility		2	9.1	3	27	3	27	3	27	0	0	1	9	3	27	3	27	1	9	2	18	3	27
Total			100.0																				

5.3.3 Cost-Benefit Analaysis

5.3.3.1 *Cost-Benefit Ratio (CBR)*

Cost-benefit assessment provides a tool for comparing the costs of a given mitigation strategy to the benefits that can be achieved (Liel and Deierlein 2013). By explicitly quantifying the relationship between mitigation effectiveness and its costs, these assessments facilitate effective decision making for investment in liquefaction risk safety.

$$CBR = \frac{Mitigation\ Cost\ (MC)}{Expected\ benefit\ (EB)}$$

Cost-benefit ratios less than unity indicate favourable conditions where the benefits outweigh the costs

5.3.3.2 *Expected Benefit (EB)*

The *Expected Benefit (EB)* of a given mitigation action over the building's remaining lifespan is given by:

$$EB = (EAL_I - EAL_M) \cdot \sum_{t=1}^{T} (1+r)^t$$

- EAL_I: is the Expected Annual Losses before a mitigation strategy is implemented
- EAL_M: is the Expected Annual Losses after a mitigation strategy is implemented
- r is constant discount rate: is determined from interest rates and adjusted for inflammation, and traditionally ranges from 2% to 6%.
- T: is remaining building life of 50 years

5.3.3.3 *Expected Annual Loss (EAL)*

Expected Annual Loss (EAL) represents the estimated losses, in terms of an average yearly amount, associated with liquefaction mitigation and reducing building vulnerability to liquefaction risk, considering the frequency and severity of possible future earthquake-induced liquefaction represented by the seismic and liquefaction hazard at the site of interest.

EAL is obtained by combining the *Expected Losses* $E[L|im]$ associated with the damage and non-damage states of the building/infrastructure asset, integrated overall ground-motion/liquefaction intensities.

$$EAL = \int_{IM=0}^{\infty} E[L|im] \cdot \lambda_{IM}$$

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