SERA Hazard Analysis Toolbox
Application: SHAPE_ver1 – Seismic HAzard Parameters Evaluation

*Current Version: **ver1.0**, last updated **09/2019**, compatible with Matlab version 2017b or later*

APPLICATION DESCRIPTION

OVERVIEW:

"SHAPE_ver1" Application performs time-dependent Seismic Hazard Analysis (SHA), taking into account the activity rate and the magnitude distribution of seismicity for selected time windows. The hazard parameters estimated are:

1) The Mean Return Period (MRP) of a given magnitude, M, which is defined as the average elapsed time between the occurrence of consecutive events of M and

2) The Exceedance Probability (EPR) of a given magnitude, M, within a given time period of length, T, which is defined as the probability of an earthquake of M to occur during T.

These hazard parameters are estimated for different time windows which are constructed upon User's particular specifications. 4 different magnitude distribution models can be chosen:

- **GRU**, for Unbounded Gutenberg-Richter law
- **GRT**, for Upper bounded (truncated) Gutenberg-Richter law
- **NPU**, for Unbounded non-parametric Kernel estimate
- **NPT**, for Upper bounded (truncated) non-parametric Kernel estimate

The input files must be in ASCII format (e.g. *.txt). Please see "Input Data Requirement Specification" section below for details on input Data format.

The application is a standalone version performed within a series of steps which allows a high interactivity level with the User. This version supports a GUI in order to allow the User interactively select the options and parameter values needed for the calculations.

PACKAGE:

The SHAPE_ver1 package includes the following material (Fig. 0):

- **3 Matlab Scripts**
  - **SHAPE_ver1**: This is the main application script that the User must launch to perform the analysis. All the other scripts and functions included into this and the other directories are auxiliary and run within SHAPE_ver1.
  - Zplo: This is an auxiliary script called by SHAPE_ver1 to create and save the output figure.
  - Zsave_output: This is an auxiliary script called by SHAPE_ver1 to create the and save the output results.
- **6 Directories**
  - **CATALOGS:** Seismic data directory (*see INPUT section below*)
  - **PRODUCTION_DATA:** Production data directory (*see INPUT section below*)
  - **TIME_WINDOWS:** Directory with files to define time windows (*see INPUT section below*)
  - **OUTPUTS_SHA:** Directory where the output data, figures and reports will be stored (this is automatically generated by SHAPE_ver1)
  - **SSH:** Directory with source size distribution functions and function for calculating seismic hazard parameters, called by SHAPE_ver1.

- **Filtering:** Directory with functions and scripts called by SHAPE_ver1 for data filtering.

- **1 pdf document** – READ_ME_SHAPE_ver1.pdf (user guide)

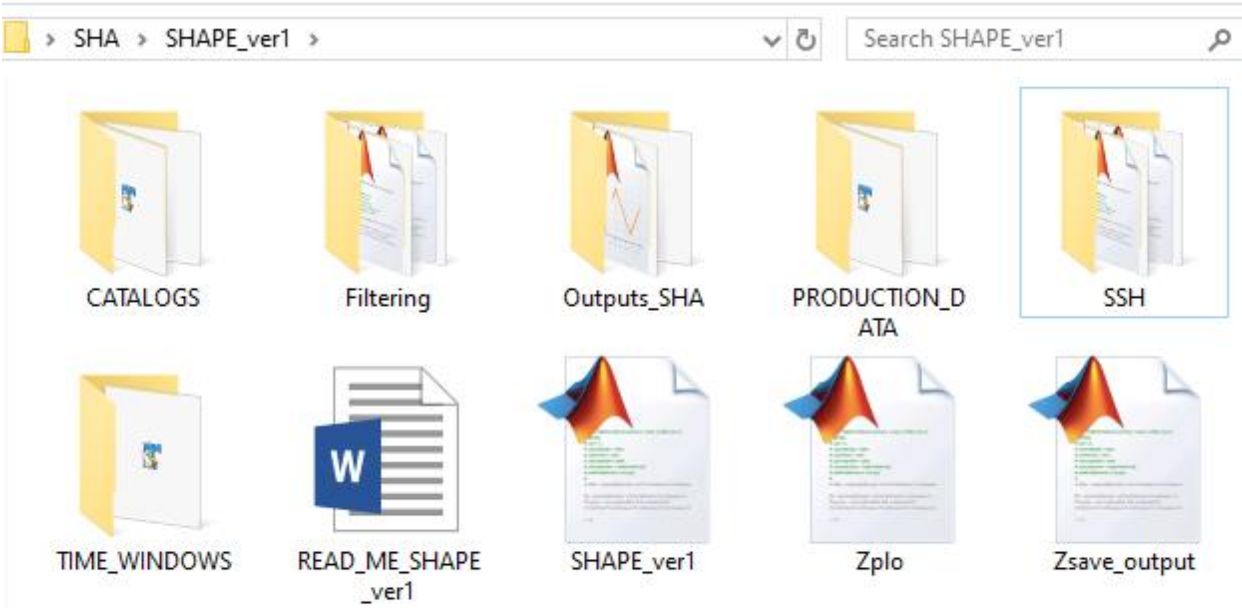

Fig. 0. Material included within SHAPE_ver1

INPUT:

The input files, options and parameter values are set by the User through a GUI in a step-by-step interactive implementation process.

For the application performance 3 Input Directories must be available (one mandatory, two optional). Sample data files must be located in these directories in appropriate format. An Output directory where the results are stored is created as well after running the 'SHAPE_ver1' Application:

- INPUT DIRECTORY – "CATALOGS" [*Mandatory*]: This directory must be named after "CATALOGS" and it must contain
  - Seismic catalogs in ASCII format (e.g. "ST2_SEIS_Data.txt").
  - Files with the description of the Fields of the corresponding seismic catalog, also in ASCII format (e.g. "ST2_SEIS_Fields.txt")
- INPUT DIRECTORY – "PRODUCTION_DATA" [*Optional*]: This directory must be named after "PRODUCTION_DATA" and must contain
  - Files with production data in ASCII format (e.g. "ST2_PROD_Data.txt")
  - Files with the description of the Fields of the corresponding production data, also in ASCII format (e.g. "ST2_PROD_Fields.txt")
- INPUT DIRECTORY – "TIME_WINDOWS" [*Optional*]:]: This directory must be named after "TIME_WINDOWS" and must contain
  - Files with two columns, the first of which corresponds to the time windows starting time and the second column corresponds to the time windows' ending time. Their format must be matlab time format (e.g. "ST2_test_timewindows.txt").

- OUTPUT DIRECTORY – "Outputs_SHA": This is the directory where the output data, figures and reports will be stored (Automatically generated by the Application).

INPUT DATA Requirements Specification: There is no difference in Catalog/Production Data format, therefore the DATA and FIELD files generic formats are only specified here (See also Figures 1 and 2 below and refer to the sample data included in the package within the corresponding directories):

✓ **SEISMIC CATALOG/PRODUCTION *DATA* File**: The **Data** files must be in ASCII format (e.g. ST2_SEIS_Data.txt). The data must be stored in columns, such that each column contains the values of a specified parameter. All records must be in numerical format, no strings are allowed (with the exception of 'NaN' values, which are acceptable). The minimum number of columns is **7** - 6 date/time columns plus one magnitude column (or production parameter observation). The first 6 columns must correspond to the occurrence time of the seismic events (or production data observation time), such that (see Fig. 1a and Fig. 2a):

Column 1: **Year** (*integer*)
Column 2: **Month** (*integer*)
Column 3: **Day** (*integer*)
Column 4: **Hour** (*integer*)
Column 5: **Minute** (*integer*)
Column 6: **Second** (*double*)

Note that SHAPE_ver1 provides the option of filtering data according to the origin time of the events. There is no upper limit on the number of columns. The rest of the columns may correspond to any other seismic parameter (e.g. depth, a moment tensor component, rms error, fault plane strike etc) – or equivalently, production parameter (e.g. water level, volume of extracted gas etc). Only magnitude and time columns are considered for the analysis. However, data filtering according to epicentral location (in either geographical or Cartesian coordinates) and depth distribution of the events is possible. The Production Data parameters are only used to facilitate visual inspection of input parameters and results and they do not take part in the calculations.

✓ **SEISMIC CATALOG/PRODUCTION *FIELDS* File**: The **Fields** files must be stored separately from the **Data**, in ASCII format as well (e.g. ST2_SEIS_Fields.txt). The specified Fields must be typed in a row, separated by space intervals (one or more spaces). Note that no commas, tabs or any other delimiters are allowed (see Fig. 1b and Fig. 2b). The first Field must be 'Time' (for Catalog) or 'Date' (for Production) and it corresponds to the 6 first columns of the Data file (see "*seismic catalog/production data file*" above). The remaining number of the specified fields must be equal to the number of the remaining columns in the Data file. For example, if the ***Data*** file has 10 columns (6 for time and 4 for other parameters, including at least one magnitude), the ***Fields*** file must have 5 columns (the first to be 'Time' and the rest corresponding to each one of the 4 remaining parameters, respectively). NOTE: be aware that the last character of the string line in the text file CANNOT be space or line! Make sure that the file ends with a character (letter or number).

Magnitude Fields: The Application provides the option of filtering data for Completeness Magnitude. In doing so, one or more Magnitude fields must be identified. SHAPE_ver1 supports the following names for Magnitude Scales (case sensitive): 'ML' , 'Mw' , 'Ms' , 'mb' , 'Md' and 'M'. If the User wishes to specify a different magnitude scale (other than the first 5 stated above), he/she may name it after 'M' (general case). Please make sure that the corresponding Magnitude column fields have one of the aforementioned names.

a TG_SEIS_Data.txt

```
2007  12  10  10  27 50.00 2.261   514922   4298613  2218   14  44   97  38.83619300000 122.82807000000 2.2
2007  12  14   2  13 55.00 2.270   514865   4298893  2546  223  37   44  38.83871900000 122.82872200000 2.5
2007  12  16  23  42 43.00 1.712   514874   4298841  2382  153  82  164  38.83824700000 122.82861300000 2.3
2007  12  19  12  17 16.00 2.414   514774   4298429  1703  218  53   56  38.83453900000 122.82977600000 1.7
2007  12  31  11  54 14.00 1.631   514800   4298819  2055  343  27  135  38.83805400000 122.82947700000 2.0
2008   1   1  11  19 40.00 1.901   514912   4298900  2249  353  35   61  38.83877900000 122.82817400000 2.2
2008   1   7  11   6 43.00 2.486   514831   4299037  2711  262  32   83  38.84001100000 122.82910500000 2.7
2008   1  20  21  23  2.00 1.568   514895   4298839  2373  115  82  177  38.83823100000 122.82837700000 2.3
2008   1  21  10  53 45.00 1.802   514883   4298898  2258   74  39   83  38.83875900000 122.82851900000 2.2
2008   2   2   8  47  2.00 1.937   514931   4298790  2625  289  51  124  38.83778600000 122.82796400000 2.6
2008   2  12  18  56  9.00 1.478   515115   4299119  2102  140  71  148  38.84075000000 122.82583200000 2.1
2008   2  12  19   6 14.00 2.162   515146   4299128  2125   86  42  111  38.84083000000 122.82548400000 2.1
2008   2  18  23  24  0.00 1.928   514852   4299100  2540   55  34   79  38.84058500000 122.82886500000 2.5
2008   2  22   6  14 24.00 1.568   514955   4299102  2057  173  47   83  38.84060200000 122.82768200000 2.0
2008   2  22  14  41 16.00 1.919   515154   4299101  2556    9  42   93  38.84059000000 122.82539100000 2.5
2008   3   3  23  12 28.00 2.261   514840   4298968  2511  354  28  144  38.83939500000 122.82900300000 2.5
```

b TG_SEIS_Fields.txt

```
Time  Mw  X  Y  Depth  StrikeA  DipA  RakeA  Long Lat  Elevation  M0  R  delta_sigma
```

Fig. 1. Example of a Seismic Data File (a) and the corresponding Seismic Data Fields File (b).

a ST2_PROD_Data.txt

```
2013 08 23 00 00 00   139.89
2013 08 24 00 00 00   140.04
2013 08 25 00 00 00   140.32
2013 08 26 00 00 00   140.44
2013 08 27 00 00 00   140.34
2013 08 28 00 00 00   140.29
2013 08 29 00 00 00   140.42
2013 08 30 00 00 00   140.34
2013 08 31 00 00 00   140.21
2013 09 01 00 00 00    140.2
2013 09 02 00 00 00    140.3
2013 09 03 00 00 00   140.22
2013 09 04 00 00 00   140.16
```

b ST2_PROD_Fields.txt

```
Date Water_Level
```

Fig. 2. Example of a Production Data File (a) and the corresponding Production Data Fields File (b).

<u>Epicentral Coordinates Fields</u>: SHAPE_ver1 also provides the option of filtering data according to the epicentral location of the events. The program supports both geographical as well as Cartesian coordinates (in any local system, in meters). The corresponding Fields for Latitude and Longitude must be specified in the Field File as “Lat” and “Long”, respectively. Equivalently, the corresponding Fields for the horizontal components of the Cartesian coordinate system must be specified as “X” and “Y” (see Fig. 1).

<u>Depth Field</u>: SHAPE_ver1 also provides the option of filtering data according to the depth distribution of the events. For this reason, the corresponding Field in the Fields File must be specified as “Depth”.

TIME WINDOWS File: This file is optional and can only be used when “Windows Creation Mode”: ‘Files’ is selected (see next section). The **<u>Time Windows</u>** files must be in ASCII format (e.g. ST2_test_timewindows.txt). The data must be stored in 2 columns, such that each column contains the values of a specified parameter: 1st column – the starting point of each time window, 2nd column – the ending point of each time window. The file format must be matlab time (Fig. 2b).

```
test_time_windows.txt

        733388.930241936          733736.185887097
        733736.185887097           734054.28266129
         734054.28266129          734409.490725806
        734409.490725806          734621.555241936
        734621.555241936           734907.84233871
         734907.84233871          735355.828629032
        735355.828629032          735586.448790323
        735586.448790323          735843.577016129
```

Fig. 2b. Example of a Time Windows file.

RUNNING THE PROGRAM:

After launching "SHAPE_ver1" the Application runs at the following sequence of steps:

STEP 1. MODE Selection: A message appears in the screen showing the 2 available modes and the corresponding numbers (codes of the modes). The mode is selected by the User after typing a number (numerical input) and pressing 'enter'. The available modes are: "1" for Seismic Data only, and "2" for both Seismic and Production Data.

Parameter	**Variable**	**Input**	**Type**	**Format**	**Range**	**Default**
Mode	Mode1	Type in Screen	Scalar	Integer	1 or 2	-

STEP 2. DATA Selection: Depending on the MODE selection (STEP 1), the User is requested here to select dataset(s) and data field files, parameters from each dataset(s), as follows for each MODE:

For MODE 1 and MODE 2

Parameter	**Variable**	**Input**	**Type**	**Format**	**Comments**
Seismic Catalog Data File		Select from pop-up window	ASCII file	Please see *"Input Data Requirements Specification"* section above	Only one can be selected
Seismic Catalog Fields File					Only one can be selected

Additional Input for MODE 2

Parameter	**Variable**	**Input**	**Type**	**Format**	**Comments**
Production Data File		Select from pop-up window	ASCII file	Please see *"Input Data Requirements Specification"* section above	Only one can be selected
Production Fields File					Only one can be selected
Fields from Production dataset			Vector(s)	variable	Only one can be selected

STEP 3. Magnitude Scale Selection: The User is requested to select one of the magnitude scales available in the uploaded catalog (See 'Magnitude Fields' in the "INPUT Data" section above).

Parameter	**Variable**	**Input**	**Type**	**Format**	**Comments**
Magnitude Scale	Mtype	Select from pop-up window	String	String	Only one can be selected

<u>STEP 4.</u> Data Filtering: Before proceeding to Seismic Hazard Analysis the User is given the option to filter the data according to the following filters (See also Fig. 4). The filtering process is done interactively, in an iterative way, such that the same way of filtering can be performed many times, as long as the User selects 'Yes' in "Data Filtering" dialog box (Fig. 3):

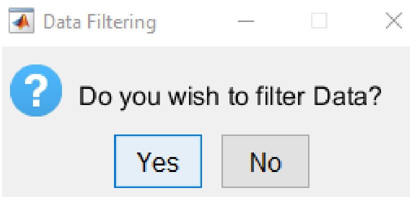

Fig. 3. Filtering Data Dialog Box.

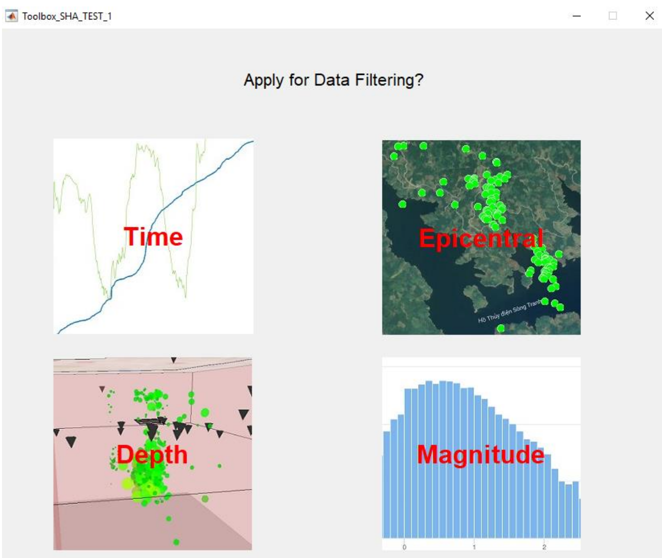

Fig. 4. Filtering Options.

There are 4 different filters that can be applied (each one more than once), which the User can access by clicking on the corresponding buttons (Time, Epicentral, Depth, Magnitude) shown in Fig. 4:

- **Time Filtering:** The User is requested to select a starting and an ending time point from the seismic activity plot, to constrain the period of analysis between these two points. If production data have been uploaded (see Step 2) then the corresponding time-series of the production parameter is plotted as well (Fig. 5). After the filter has been applied, a message appears in the screen showing the remaining number of events after the filtering and the System requests from the User for further data filtering (Fig. 3).

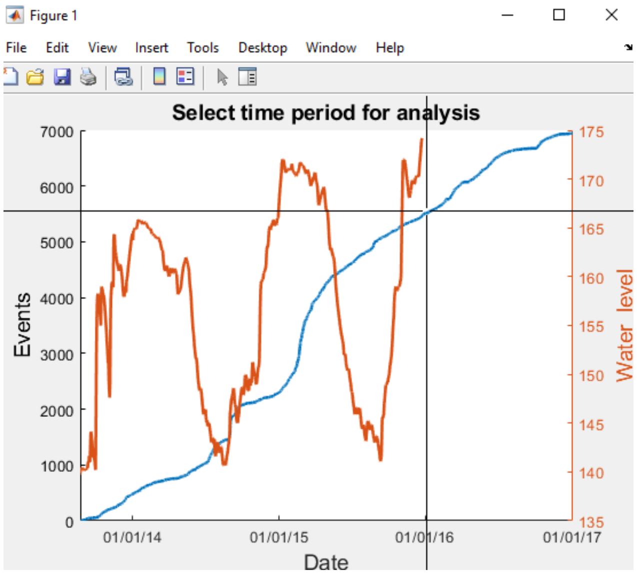

Fig. 5. Interactive Time Filtering.

- **Depth Filtering:** The User can inspect the vertical distribution of the events from a figure like the one shown in Fig. 6. In the left frame, the histogram of events for specified depth range is shown. The User can change the number of bins by typing a number in the box which lies on the right of the 'Enter number of bins' textbox. Then the User may click on the 'Update Histogram' button to update the figure. On the right frame the vertical distribution of the seismic events are shown. Once the User decides, he/she may click on the "Proceed" button in order to set the desirable depth values (Fig. 7). After the filter has been applied, a message appears in the screen showing the remaining number of events after the filtering and the System requests from the User for further data filtering (Fig. 3).

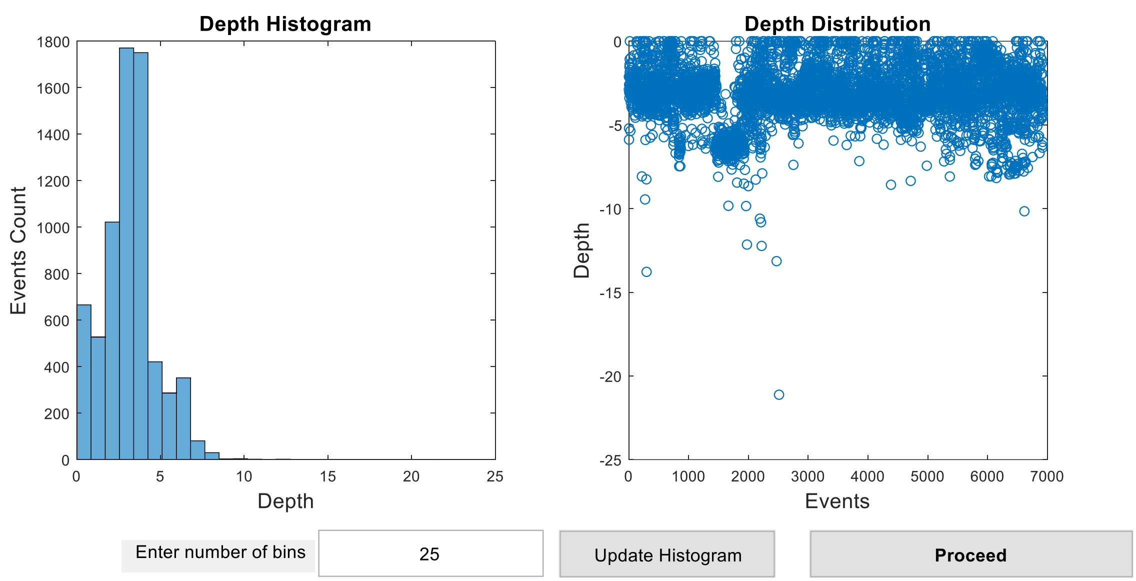

Fig. 6. Interactive Depth Filtering.

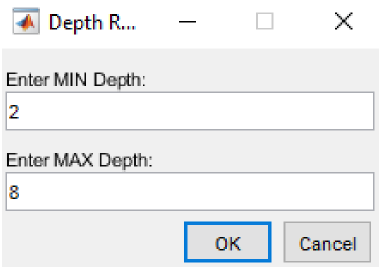

Fig. 7. Depth Range Selection.

- **Mc Filtering:** The User is here requested to graphically chose the minimum magnitude threshold, corresponding to the catalog completeness level, by clicking at a point on a plot similar to this shown in Fig. 8. After the filter has been applied, a message appears in the screen showing the selected Mc and the remaining number of events after the filtering and the System requests from the User for further data filtering (Fig. 3).

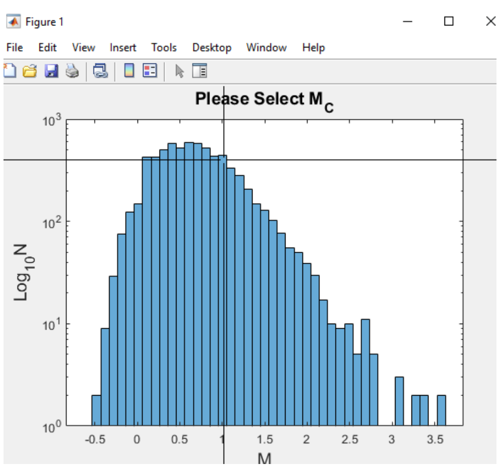

Fig. 8. Interactive Magnitude Filtering.

- **Epicentral Filtering:** Epicentral filtering can be applied in either geographical or Cartesian coordinates, if they are available (Fig. 9). Once the Users clicks on one of the two coordinate systems. Then, the User is provided two additional option, to constrain a polygonal or a circular area (Fig. 10).
  If the 'Polygon' is selected, the User subsequently clicks on the plot (Fig. 11) to define the edges of the polygon (Double-click to close the polygon). Next, the User can use the mouse to re-adjust the polygon position and the location of its edges. When the area has been decided, the User has to press 'enter' in order to proceed to data filtering.

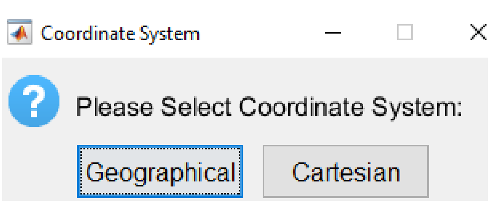

Fig. 9. Select Coordinate System.

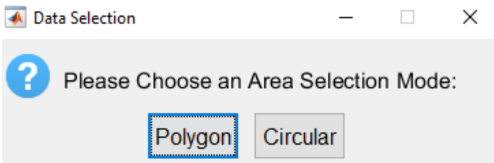

Fig. 10 Area Selection Mode.

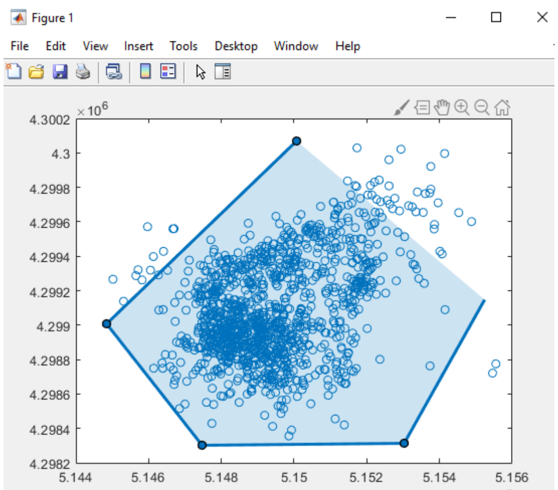

Fig 11. Polygonal Area Selection Mode.

If the ‘Circular’ is selected, the User clicks on a point in the plot (Fig. 12) to define center of the circle, and drags the mouse to set the radius. Next, the User can use the mouse to re-adjust the circle’s position and the diameter. When the area has been decided, the User has to press ‘enter’ in order to proceed to data filtering.

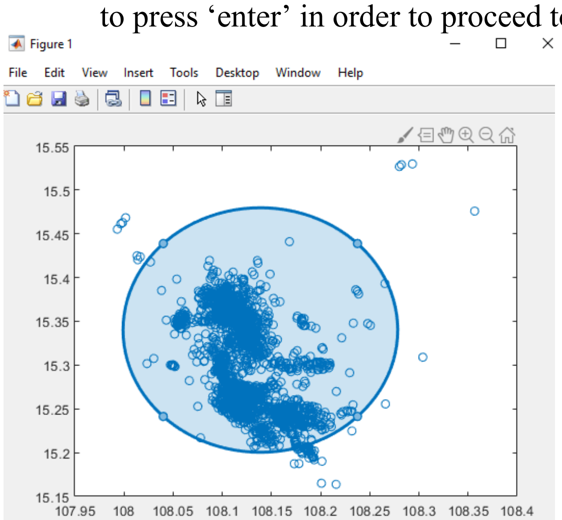

Fig. 12. Circular Area Selection Mode.

After the filter has been applied, a message appears in the screen showing the remaining number of events after the filtering and the System requests from the User for further data filtering (Fig. 3). If the User clicks on ‘No’, then no further data filtering applied and the system proceeds to Seismic Hazard Analysis.

STEP 5. **Time Windows Generation:** In this step the data in divided according to time windows defined by the User, by means of 4 different modes. 'Time', 'Events', 'Graphical' and 'File' (Fig. 13). If 'Time' mode is selected the User has to define the window size (in days) and the window step (in days), by typing values in the corresponding fields in a pop-up window which appears in the screen (Fig. 14 left frame). If 'Events' mode is selected the User has to define the window size (in events) and the window step (in days), by typing values in the corresponding fields in a pop-up window which appears in the screen (Fig. 14 right frame). Alternatively, the User can select 'graphical', for graphical selection of subsequent points from a plot (Fig. 15). The first point corresponds to the starting point of the first period, the next point corresponds to the ending points of the first period and at the same time to the starting point of the next period etc. To define the ending point of the last period, the User has to press 'Enter'. Finally, if 'File' is selected, the User is requested to select a file containing the starting and ending points of time windows, which is located in the "TIME_WINDOWS" directory (Fig. 16).

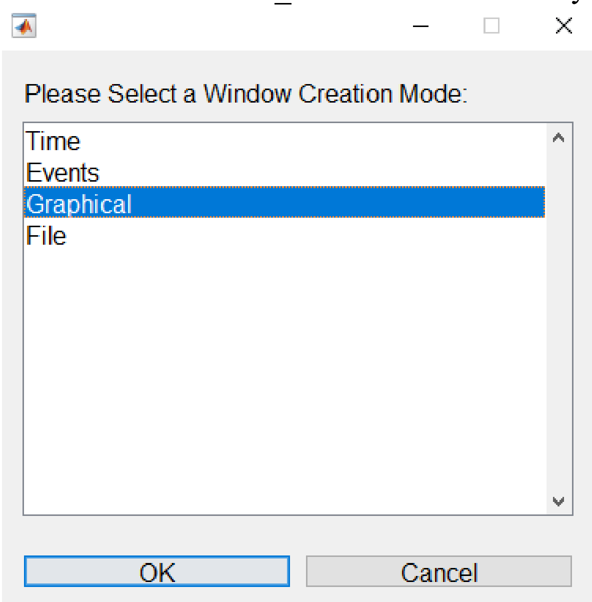

Fig. 13. Time Windows Generation Mode Selection.

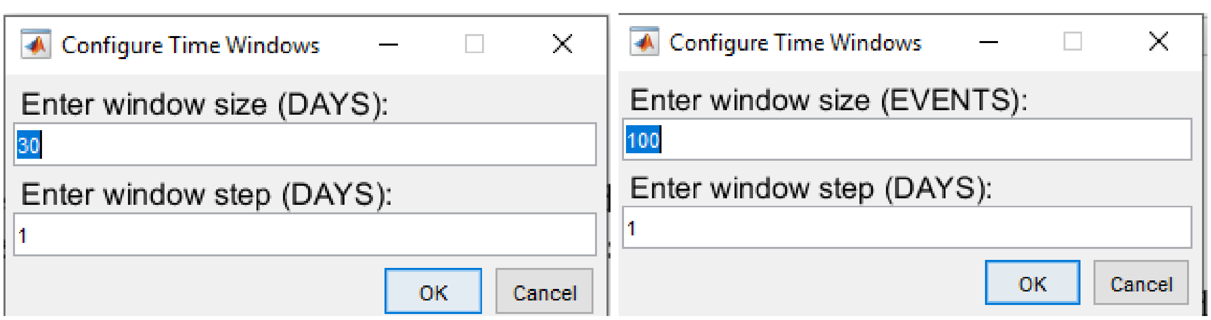

Fig. 14. Parameters Set for Time Windows Generation.

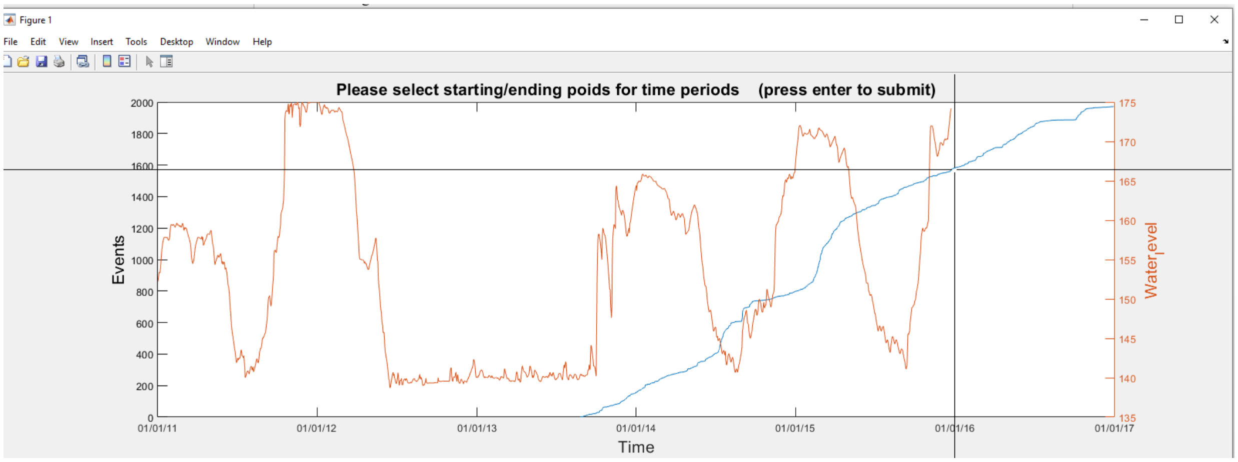

Fig. 15. Graphical Selection of Time-Windows.

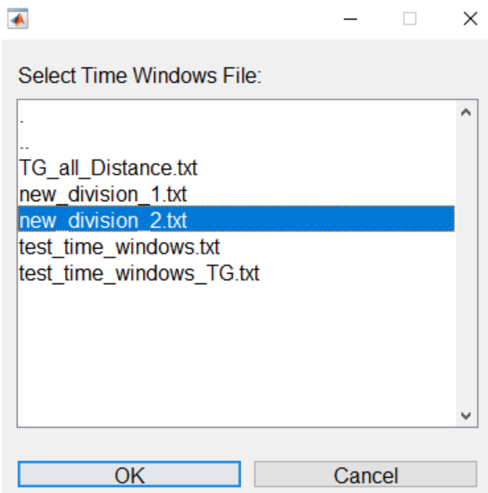

Fig. 16. Selection of Time-Windows from a file.

<u>STEP 6.</u> SHA (Seismic Hazard Assessment) Parameters Selection: The User selects from subsequent pop-up windows the parameters required for data handling within SHAPE_ver1.

Parameter	Variable	Input	Type	Format	Possible Values	Default
Magnitude Distribution Model	Method	Select from pop-up window	String	String	'GRU', 'GRT', 'NPU', 'NPT'*	**-**
Time Unit	Tunit		String	String	'Day', 'Month', 'Year'	**-**
Magnitude	MaG		Scalar	Double	real	**Equal to catalog maximum**
Period	PLength		Scalar	Double	Positive	**30**
Maximum Magnitude+	Mmax		Double *(or string as default)*		Greater or equal to the maximum magnitude in the catalog	**'adaptive'**

*GRU: Gutenberg-Richter unbounded, GRT: Gutenberg-Richter truncated, NPU: non-parametric unbounded, NPT: non-parametric truncated

+For the special case of the truncated magnitude distributions (GRT and NPT), the maximum magnitude must also be set. This magnitude corresponds to the maximum possible magnitude given the dimensions of the area and/or seismicity history. The default value is ‘adaptive’, meaning that the Mmax is estimated by the Kijko-Sellevoll formula, individually for each one of the selected time windows. Alternatively, the User may set a specific (constant) value for Mmax applied to the entire study area.

STEP 7. OUTPUTS: after the analysis is performed by the System, the following output results are produced and stored in the directory ”Outputs_SHA”.

Structure “**SHA.mat**” containing fields with outputs from ‘SHAPE_ver1.m’ script as well as the corresponding input values. The structure has as many cells as the number of time windows generated. These fields are the following:

Field	Type	Format	Parameter/comments
Time	Vector	Double	Origin times of the events included in each time window
M	Vector	Double	Magnitudes of the events included in each time window
Mmin	Scalar	Double	Minimum magnitude threshold
eps	Scalar	Double	Magnitude round-off interval
lambd	Scalar	Double	Mean activity rate
lambd_err	Logical	0, 1	Events number sufficiency: if lambd_err=0, all parameters are estimated, if lambd_err=1 all outputs are set as NaN.
unit	String	String	Time unit
method	String	String	Magnitude distribution model selected among ‘GRU’, ’GRT’, ’NPU’ and ’NPT’
b[1]	Scalar	Double	b-value of the Gutenberg-Richter law
h[2]	Scalar	Double	Kernel smoothing factor
xx[2]	Vector	Double	Background sample for the non-parametric kernel estimators of magnitudes
ambd[2]	Vector	Double	Weighting factors for the adaptive kernel
ierr[2]	Scalar	0, 1, 2	h convergence indicator: ierr=0: process converged, ierr=1: multiple zeros found, ierr=2: no zeros found.
Mmax[3]	Scalar	Double	Upper limit of the magnitude (truncated) distribution
err[3]	Logical	0,1	Mmax convergence indicator: err=0: convergence, err=1: no convergence

[1] Applies only when “**method**” is set to “**GRU**” or “**GRT**”
[2] Applies only when “**method**” is set to “**NPU**” or “**NPT**”
[3] Applies only when “**method**” is set to “**GRT**” or “**NPT**”

Note that the User is requested to change the default output filename of the structure (Fig. 17), after closing the output figures (see below).

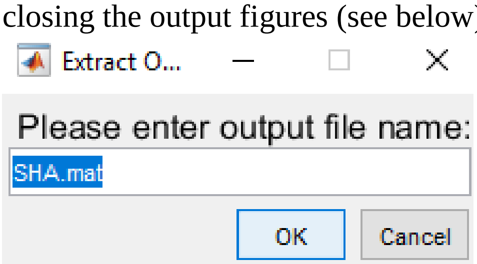

Fig. 17. Dialog box for setting output structure name

Report: ‘REPORT_Hazard_Analysis.txt’ is generated and stored (by the auxiliary script “Zsave_output.m”, called by SHAPE_ver2), including a summary of the input parameters and data considered, as well as the results obtained from the analysis.

FIGURE SHA.mat/SHA.jpeg: An output figure is generated by the auxiliary script “Zplot.m” called by SHAPE_ver2 (see also Fig. 18 and Fig. 19 below). The figure has three frames:

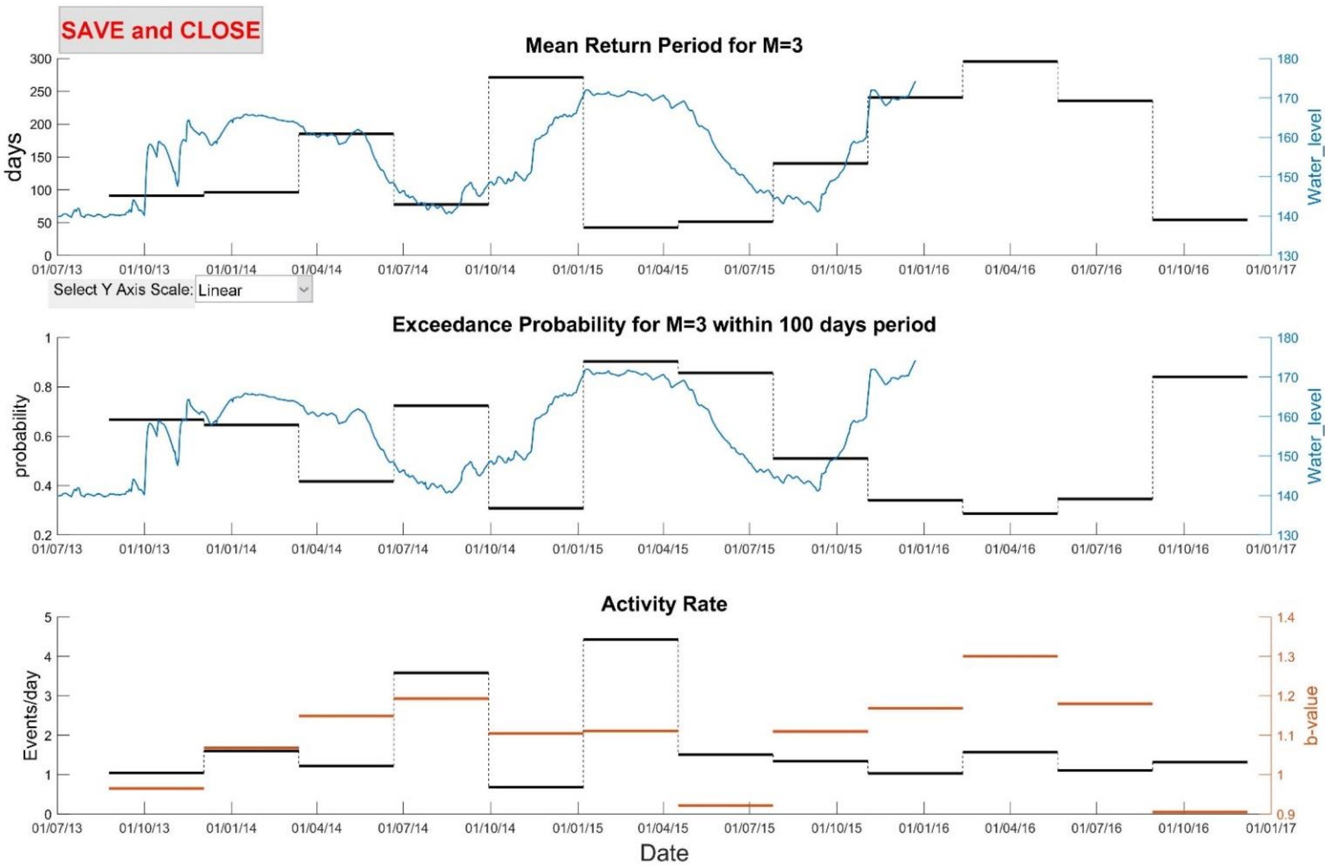

Fig. 18. Output figure for non-overlapping windows and Production Data plotted (GRU selected).

The upper frame demonstrates MRP for the selected target magnitude (Fig. 18 and Fig. 19). In the left axis the selected unit is shown. Optionally, if Production Data are loaded, they are plotted as well (right axis, Fig. 19). The left y-axis can be switched from linear to log scale and vice versa.

The middle frame demonstrates EPR for the selected target magnitude and period duration (Fig. 18 and Fig. 19). Optionally, if Production Data are loaded, they are plotted as well (right axis, Fig. 18).

The lower frame shows the mean activity rate in events/unit selected. In the right axis, the b-values are plotted if ‘GRU’ or ‘GRT’ method is selected (Fig. 18). Alternatively, the mean magnitude for each dataset is plotted (right axis) if method is set to ‘NPU’ or ‘NPT’ (Fig. 19).

In all three frames there are 2 plotting types. If the time windows are not overlapping, the resulted plot looks like Fig 18 (horizontal lines). Otherwise, if time windows overlap with each other, the resulting plot looks like Fig. 19 (Circular points). Click on the ‘SAVE and CLOSE’ button to save the figure in .mat and .jpeg formats.

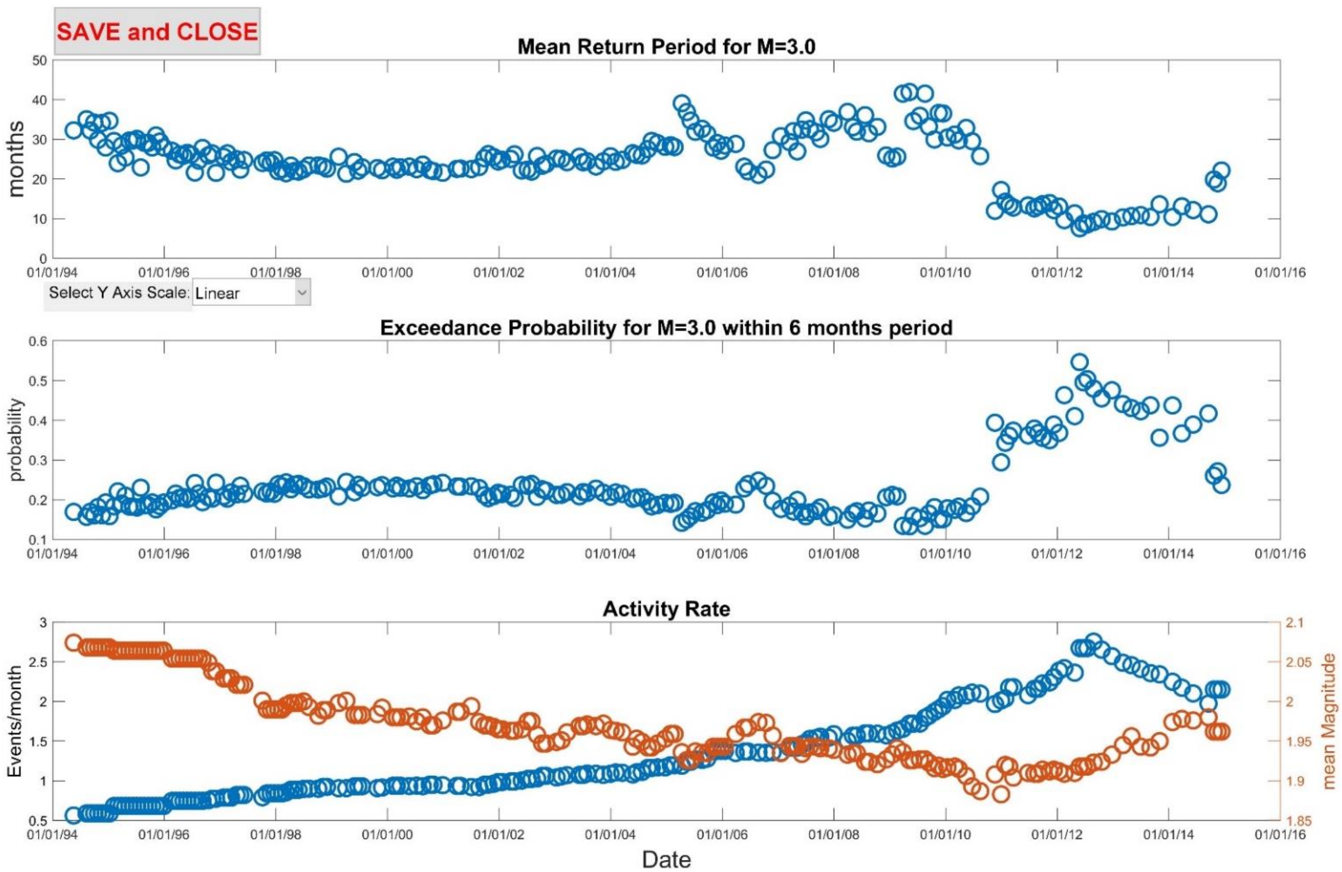

Fig. 19. Output figure for overlapping windows without Production Data plotted (NPU selected).

<u>Appendix:</u> Parameter Values Tutorial

Although this application can be evenly used tectonic seismicity case studies, it has been developed to mainly apply for anthropogenic seismicity episodes. Therefore, the default parameter values are adjusted rather to induced than to natural seismicity. By setting the appropriate parameter values and units, the application can be equivalently implemented for any seismic hazard analysis. The following table presents examples of typical (yet, not exclusive) values set for anthropogenic as well as for tectonic seismicity case studies.

Parameter	Anthropogenic SHA	Tectonic SHA
Magnitude Distribution Model	Non-parametric kernel	Gutenberg-Richter law
Time Unit	Days to months	Years
Maximum Magnitudes	Depending on technology, Usually M_{max}< 4.0	Depending on the seismic zone, can be as high as M_{max}~9.5
Target Magnitudes for EP and MRP	Depending on technology, 2<M<5	Depending on the seismic zone, M>5.0
Target time period for EP	1 day to 1 week	10-50 years
NOTE: This table does NOT show the observed range, it just provides some typical values for comparison between anthropogenic and tectonic seismicity. Please consult relevant reference to adapt proper values for specific case studies.		