A quick primer for DYANAS (dynamic analysis of single-degree-of freedom systems), a graphical user interface for OpenSees[1]

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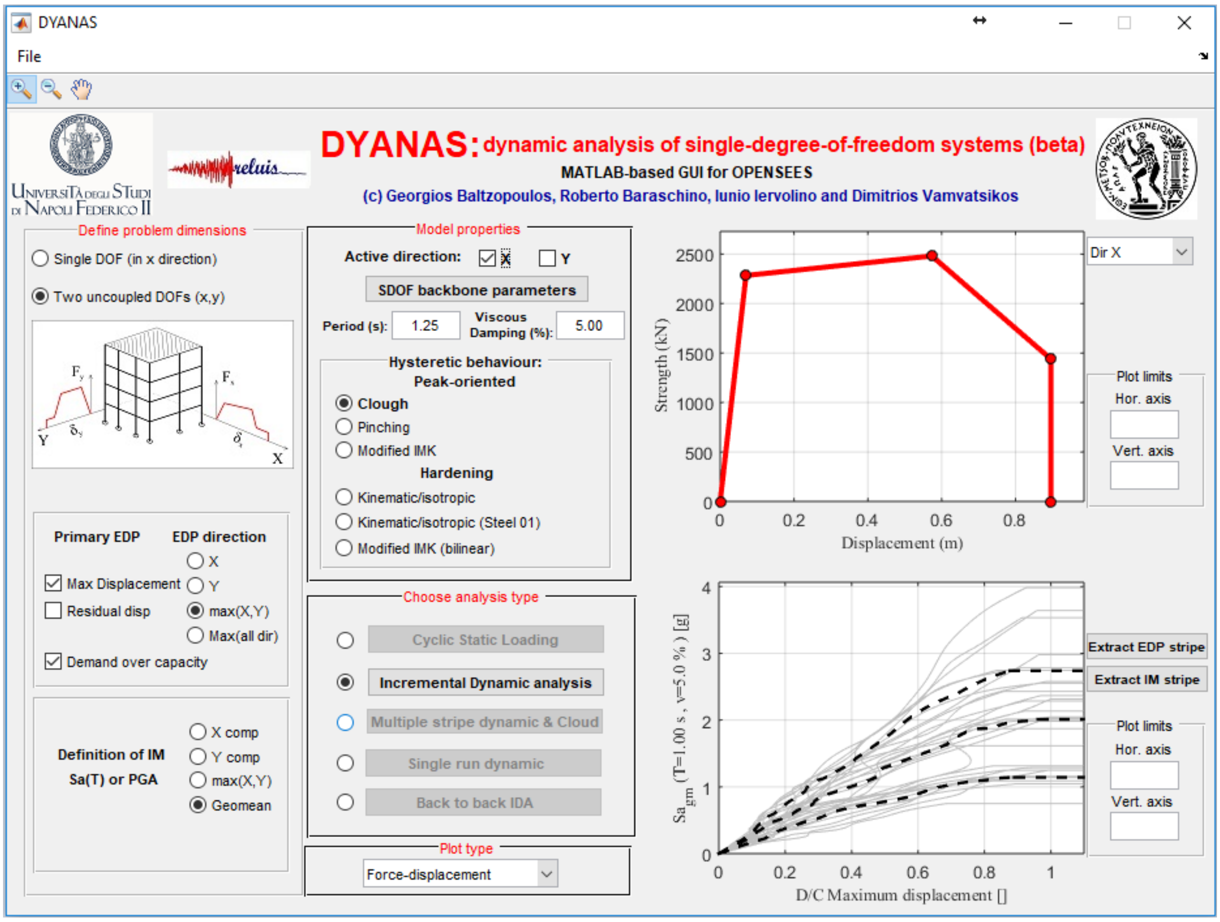

OVERVIEW

DYANAS is a MATHWORKS MATLAB®-based graphical user interface that uses the OpenSees finite element platform to perform nonlinear dynamic analysis of single-degree-of-freedom (SDOF) oscillators. The scope of this open-source software is to serve as a tool for earthquake engineering research. DYANAS is freely distributed and obtainable at http://wpage.unina.it/georgios.baltzopoulos/software/software_page.html with the source code being also available at the GitHub repository https://github.com/georgebaltz/SDOF-OSEES. The main advantages offered by the interface are ease in the definition of the required analysis parameters and corresponding seismic input, efficient execution of the analyses themselves and availability of a suite of convenient, in-built post-processing tools for the management and organization of the structural responses. The types of dynamic analysis frameworks supported are incremental, multiple-stripe and cloud.

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[1] **Based on excerpts from a paper by the same authors titled "Dynamic analysis of single-degree-of-freedom systems (DYANAS): a graphical user interface for OpenSees", submitted to the journal *Advances in Engineering Software*.**

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REQUIREMENTS

- MATHWORKS MATLAB version 2015a or newer installed (including curve fitting toolbox)
- OpenSees version 2.5.0 or newer: executable present in the directory [...]\DYANAS\osees\
- TCL/TK installed

INSTALLATION INSTRUCTIONS

1. Copy (unzip) the DYANAS folder and subfolders to a non-system location on your drive.
2. Go to the directory [...]\DYANAS\osees\ and replace the file "opensees_exe.txt" with the OpenSees executable file "opensees.exe", downloadable from http://opensees.berkeley.edu/.
3. Install tcl/tk according to the instructions found in the OpenSees download page (hint for newer Windows versions: run tcl/tk installer as administrator to be allowed to change the installation directory).
4. Start MATLAB and make the [...]\DYANAS\ directory the working folder.
5. Open "main_GUI.m" in MATLAB and run it.
6. The main DYANAS graphical user interface will appear. MATLAB must remain in the initial working directory of DYANAS for the GUI to be responsive to the user.

GRAPHICAL USER INTERFACE AND SOFTWARE FUNCTIONS

DYANAS is structured around two main pillars: the various MATLAB-coded pre- and post-processing tools that are incorporated into the GUI and the suite of parametric scripts that run directly on the OpenSees platform. Details and parameters for each analysis to run are defined by the user via the MATLAB GUI.Once OpenSees concludes a packet of user-requested analyses, output files are created, that are subsequently parsed by the GUI’s post-processing MATLAB routines for further elaboration of the raw results.

Definition of oscillator characteristics

The first step in any new analysis session is the definition of the system to be analyzed, that may either be an SDOF oscillator or two uncoupled simple oscillators. In the latter case, two separate SDOF systems are defined and analyzed simultaneously, without any interaction occurring between them.

In all cases, the SDOF system definition requires the assignment of dynamic characteristics, such as period of natural vibration T and viscous damping ratio, backbone curve and hysteretic rule. The backbone curve corresponds to a piece-wise linear idealization of the force-displacement response of the system to monotonic loading and is defined by the yield strength and displacement, F_y and δ_y respectively, and up to four parameters for a quadrilinear case, shown in Figure 1.

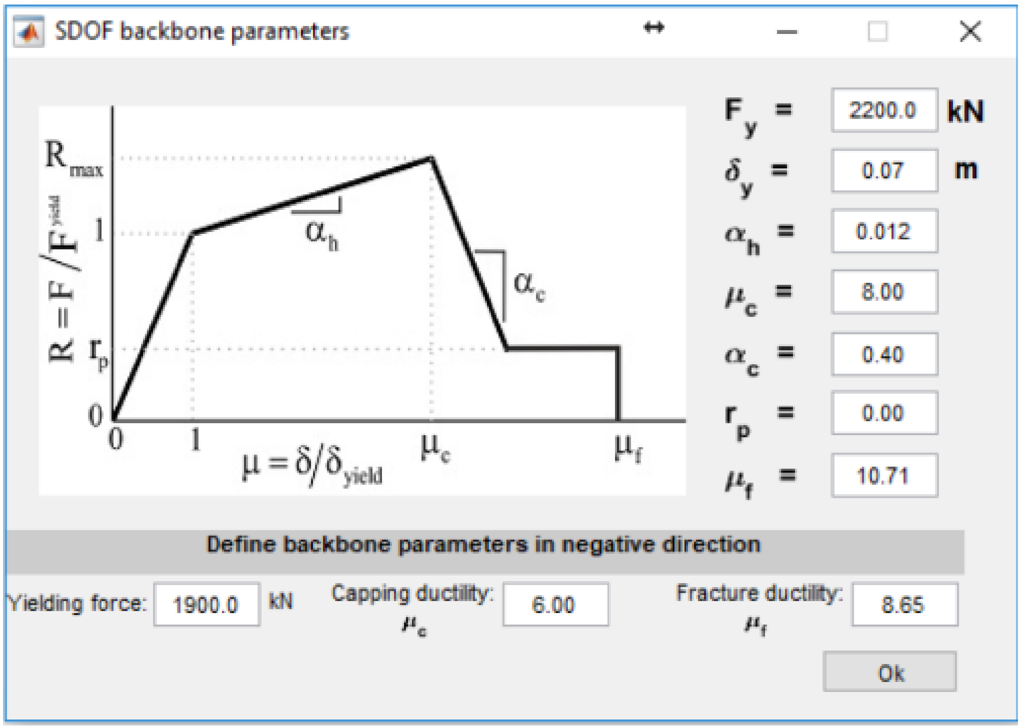

Figure 1 Definition of parameters for the characterization of an SDOF system's piece-wise linear backbone curve

These are the hardening slope α_h (positive ratio of post-yield stiffness to elastic stiffness), the capping-point ductility μ_c (point where loss of strength with increasing deformation begins), the post-capping slope α_c (negative slope corresponding the ratio of the negative post-capping stiffness divided by the initial elastic stiffness), the height of the residual strength plateau r_p (ratio of residual strength divided by yield strength) and the fracture ductility μ_f (point corresponding to sudden, complete loss of strength), with ductility being response displacement normalized by yield displacement, $\mu = \delta/\delta_y$ and strength ratio R as force normalized by yield strength $R = F/F_y$. A sample of the GUI's dialogue windows during the definition of backbone and other properties is provided in Figure 2.

DYANAS allows the definition of asymmetric backbone curves, with μ_c , μ_f and F_y being allowed to differ in the two directions, while maintaining the same elastic stiffness. For the choice of hysteretic constitutive law, several options that have been implemented in OpenSees in the past are available. These are divided into two broad categories of peak-oriented and hardening hysteretic rules; the hysteresis parameter definition windows will typically contain a hyperlink to the corresponding material in the OpenSees online manual. By means of the "quasi-static cyclic" analysis type, the software offers the user a means to visualize the effect of each hysteretic rule on displacement-controlled cyclic loading.

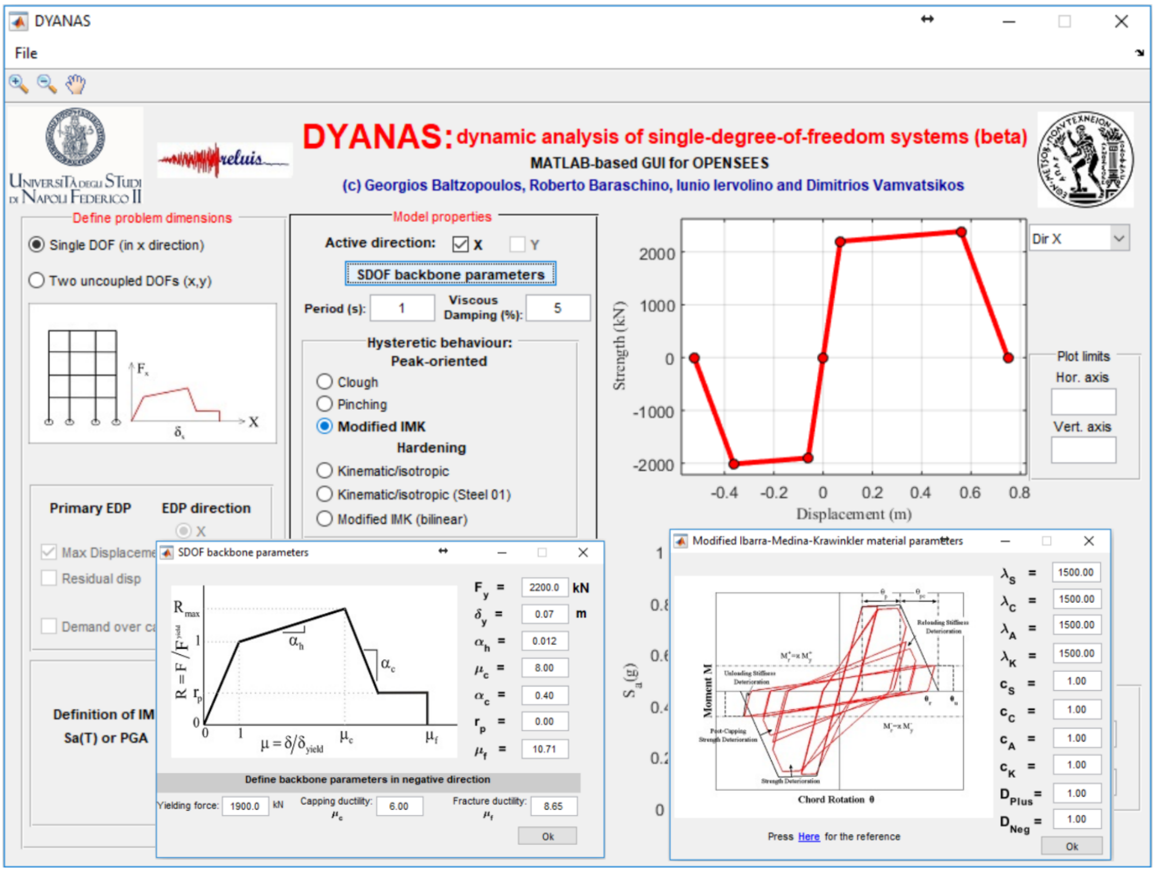

Figure 2 Main GUI window and subsidiary dialogue windows during definition of a SDOF oscillator's dynamic characteristics, backbone curve (asymmetrical in this case) and hysteretic model.

The second preliminary step, prior to proceeding to the analysis, is to select the *engineering demand parameter* (EDP) and seismic *intensity measure* (IM) that will be employed. For such simple structures as these SDOF oscillators, the choice of EDP is limited to the peak transient displacement in either horizontal direction, δ_X and δ_Y, the residual displacements in both directions and the demand over capacity ratio, D/C.

Although the actual choice of IM can be deferred until the analysis definition phase (the default option being $Sa(T)$ at the *X*-direction oscillator's vibration period), in the case of bi-directional ground motion (i.e., definition of two SDOF systems) the user should also determine how that IM is to be calculated: for example, $Sa(T)$ can be taken as the maximum between the values of the two components, $Sa_{\max}(T)$, or as the geometric mean of the two, $Sa_{gm}(T)$.

Definition of seismic input

Seismic input can be defined by selecting sets of ASCII files, each containing a recorded acceleration time-history. The software can parse two standard accelerograms formats, namely the Pacific Earthquake Engineering Research NGA database format (https://ngawest2.berkley.edu) and the Engineering Strong Motion database format (esm.mi.ingv.it). In either case, the necessary information for running the analyses are extracted/computed from the selected files (units, duration, sampling rate, elastic response spectrum) and passed on to the corresponding MATLAB routines, while the actual accelerometric data are written into temporary files suitable for being read by OpenSees. As an alternative to these standard formats, the user may use simple ".txt" ASCII files that contain a single column of acceleration values and will be inquired by the software to provide units and sampling rate.

The software, at this stage, is distributed equipped with two folders that already contain two sets of accelerograms: one is the suite of thirty single-component records used for calibrating the SPO2IDA tool and the other is the twenty-two bidirectional ground motion "far-field" set of FEMA-P695. Both record sets consist of accelerograms recorded on firm soil, predominantly during California events of magnitude six or greater.

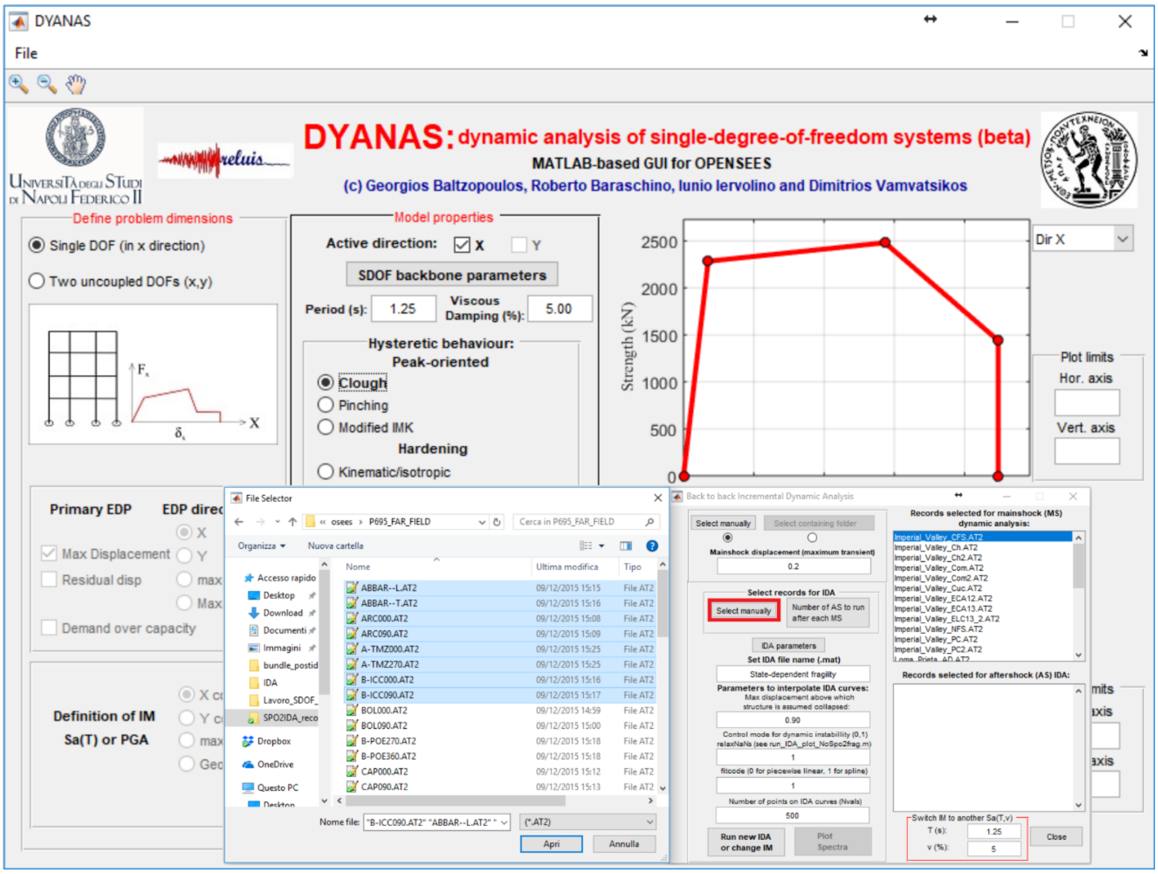

Figure 3 Selection of accelerograms for running back-to-back IDA; the MS record set list has been already filled and the record-selection dialogue window is open for designating the AS set.

For IDA or cloud analysis, a single set of records must be selected by the user, while, in the case of MSA, different sets may be assigned to each predefined IM level (stripe), all containing the same number of records. Cloud analysis in particular, is defined via the MSA control panel, by suspending record scaling, as discussed above. Back-to-back IDA on the other hand, requires two sets of records: the first set, referred to as the MS set, is used to perform a preliminary IDA analysis, that serves to determine the scale factors necessary to induce the predefined EDP value, associated with some structural limit state, across the entire MS record set. During back-to-back IDA, each MS record is followed by an appendix of zero acceleration entries for a duration of five times the elastic period of the system, intended to provide time for the residual velocity at the end of the excitation to be damped down to negligible values.

The second set of accelerograms, referred to as the AS set, is used to run an IDA that always follows one of the MS records (the user is actually free to use the same set to represent both MS and AS if one so desires, or two sets of different size). In other words, each scaled AS record acts on a structure that has already experienced the predefined transient maximum EDP value and has had some time to come to quasi-rest conditions. In Figure 3 the analysis-parameter definition panel for back-to-back IDA is shown, with the AS acceleration-file selection-window open. The user is additionally given the option to define the number of AS IDAs that are going to be run per MS record, ranging from one to the number of records in the AS set. When the number of IDAs requested per MS is less than the number of AS accelerograms defined, a random extraction is performed from among the AS records (independent extractions are performed for each MS record). A final option available to the user for back-to-back IDA, is that one may request that all MS-AS pairs are created so that no AS record is ever used twice, provided that an adequate number of records has been provided.

In the case of bidirectional ground motion, record assignment proceeds as in the single-component-of-motion case, with the difference that all record sets must be even in number, so that they may be divided in two halves and re-assigned to each of the two directions. Pairing of the records follows the ASCII dictionary alphabetical order of the filenames, by assigning any two consecutive records first in the *X* and then the *Y* direction. This is intended to take advantage of the fact that, in most strong ground motion databases, accelerograms recorded by two streams of the same station will be typically saved under filenames differing by only a few characters.

Running IDA and back-to-back IDA

Pressing the “incremental dynamic analysis” or the “back-to-back IDA” buttons will open dedicated GUI windows that allow for the definition of seismic input and analysis options/parameters. The same computational strategy is also followed in the case of back-to-back IDA, with the only difference being in the management/definition of seismic input (discussed above).

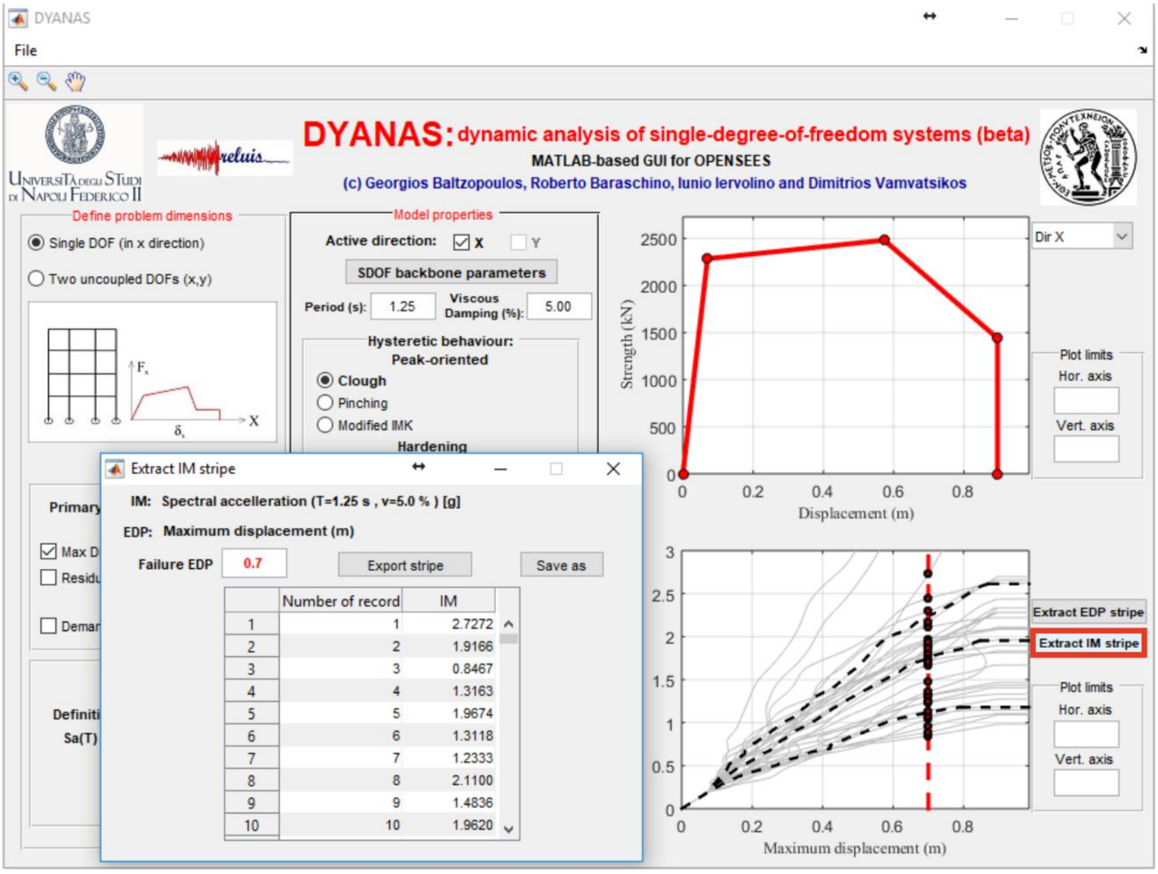

Figure 4 Extraction of an IM stripe from a set of IDA curves. The EDP threshold is defined in the homonymous dialogue window and the intersections with the curves are displayed in the main GUI lower-right window.

At the conclusion of either of these types of analysis (IDA or back-to-back IDA) a set of post-processing options are available to the user: change of IM or EDP, extraction of IM or EDP stripes that can be saved into MATLAB-variable or text file formats and saving the analysis results for later use. Once a set of IDA curves has been obtained, at the conclusion of analysis, change of IM is almost instantaneous.

The post-processing tools of the GUI can provide the extraction of text or MATLAB files containing IDA results organized as either vectors of EDP responses given IM (“EDP stripes”) or IM causing exceedance of a specific EDP value (“IM stripes”). For IM stripe extraction (example provided in Figure 4), the software finds the intersection of each spline-interpolated IDA curve with the vertical line passing through the user-defined EDP threshold; the lowest IM value is returned in the case of non-monotonic IDA curves that intersect the line at more than one point. For EDP stripes, the user defines a vector of desired IM values and the software returns the intersections with the corresponding horizontal lines; for IDA curves that have already flat-lined below a given IM level, the information that the structure has collapsed is returned.

Running multiple-stripe and cloud analysis

To conduct MSA, the user must define all IM levels for which EDP responses are needed beforehand, via the dedicated dialogue window of the GUI (Figure 5), and subsequently assign a set of records to each IM stripe. Each stripe must be assigned a specific IM value and all records in the stripe will be then scaled to match that value (exception to that rule is cloud analysis, see below). In MSA record scaling is completely pre-determined at the start of the analysis (IM level assigned to each stripe) and a different seismic input file has to be read at each single run. Note that, in the case of MSA, a change of IM requires re-running the analysis from scratch, while EDP still can be changed at will after completion of the analysis.

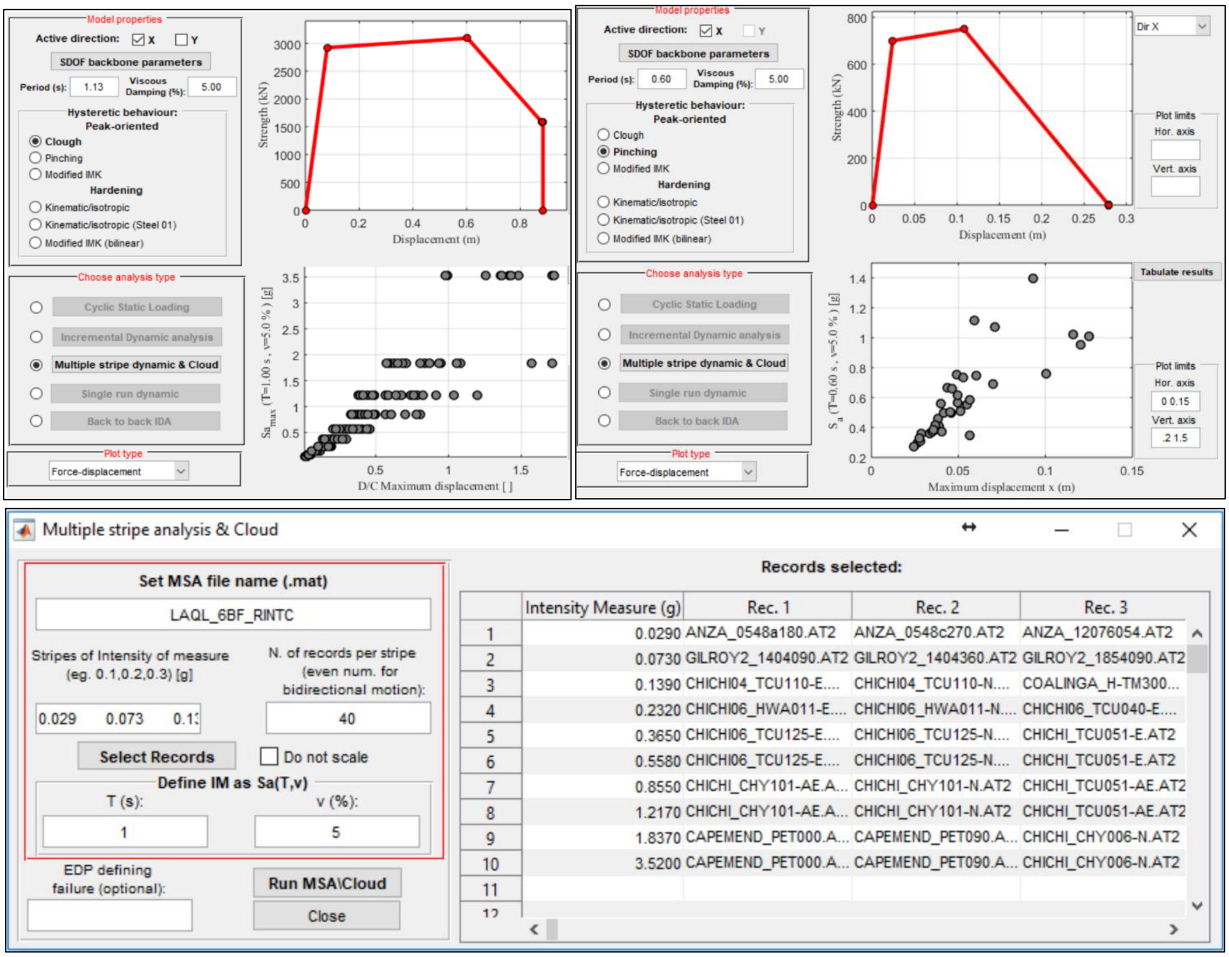

Figure 5 Main GUI window snapshots displaying the results of MSA (upper left panel) and cloud analysis (upper right panel); MSA dialogue window, showing the setting-up of an analysis at ten levels of seismic intensity (lower panel). All records in each stripe will be scaled to match that stripe's predefined IM level, unless the "Do not scale" checkbox is ticked, in which case cloud analysis runs.

In the DYANAS GUI, cloud analysis is also managed via the MSA window, as one may imagine it as a single-record-per-stripe MSA. The user simply has to define a single IM stripe with a nominal intensity value, which is disregarded, and check the "do not scale records" box; in that case the software will realize that could analysis is in order and will display the results accordingly, as shown in Figure 5. For both MSA and cloud analysis, EDP stripes can be exported in text- or MATLAB-file format, reducing to IM-EDP pairs in the latter case.