PDEM Analysis System——Instruction

(2018-01-16, International Joint Research Center for Engineering Reliability and Stochastic Mechanics)

Contents

1 Installation and startup

The Software "PDEM analysis system V3.0" is developed based on Windows operating system. Users should ensure that the operating system version is at least Windows XP. (For XP users, if encountering the problem of missing dynamic link library, please contact us via chenjb@tongji.edu.cn).

The PDEM analysis system V3.0 can be used without installation. After downloading and unzipping the zipped package we provide, double-click the executable file PDEM.exe to start the PDEM analysis system V3.0 as shown in Figure 1.1. (Tips: It is not recommended that users delete or modify the compressed files. If users want to add shortcuts to desktop or start screens, right-click the PDEM.exe and make the corresponding operations.)

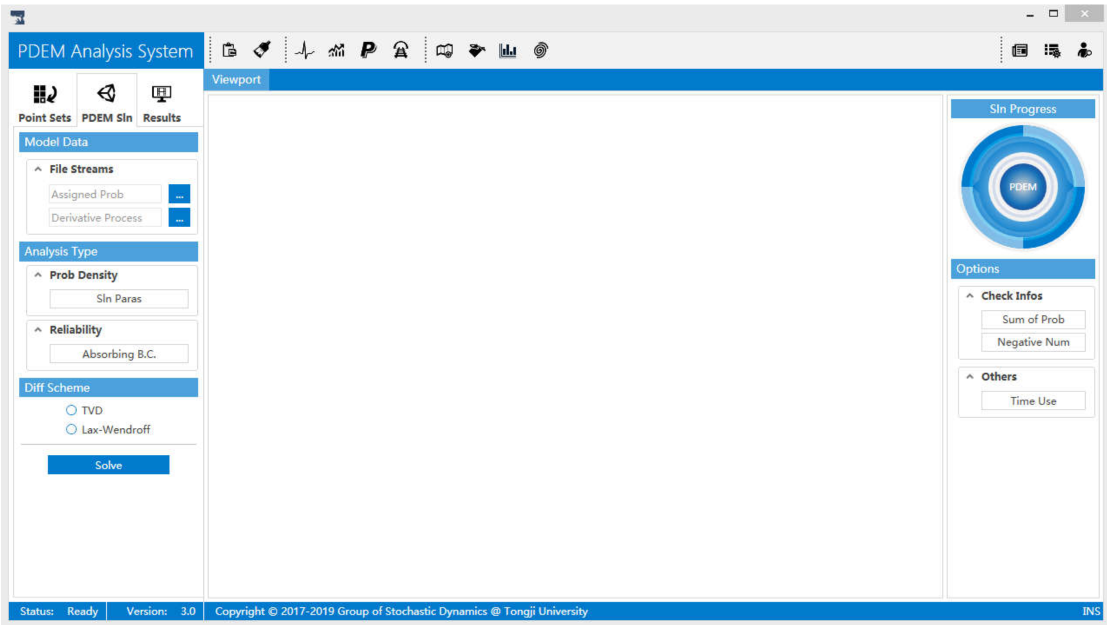


Figure1.1 Startup interface of the PDEM analysis system

As shown in the menu bar on the left of Figure 1.1, the PDEM analysis system V3.0 mainly consists of three modules: Point selection module (Point Sets), the solution of PDEM module (PDEM Sln) and the results visualization modules (Results).

- The function of the Point Sets module is to select the points according to the dimension of the basic random vector and to output the values and the assigned probability of the representative set for deterministic analysis.
- The PDEM Sln module can be used to simulate the probability density evolution in order to get the mean value, standard deviation, probability density function of the response of interest and the

reliability of structures by solving the generalized density evolution equation based on the results of deterministic analysis.

- All these results can be displayed in the Results visualization module.

The following chapter contains a specific example demonstrating the input and operation process of the PDEM analysis system V3.0.

2 Input and operation

2.1 Data format for the Point selection module and deterministic analysis

This section introduces the data preparation for solving PDEM, including the point selection in probability-assigned space and the deterministic analysis. The former is the foundation of the latter. There are two issues to be emphasized:

- **About the point selection**: If the user has generated a set of discrete representative points and the corresponding assigned probabilities, the point selection module can be skipped. It is recommended to use the point set generated based on minimizing the GF-discrepancy. At present, if all the basic random variables obey normal distribution, the software provides the coordinates and assigned probabilities of the rotated quasi-symmetric point set generated based on minimizing the GF-discrepancy. For theoretical bases, refer to: "Chen JB, Zhang SH. Improving point selection in cubature by a new discrepancy. SIAM Journal on Scientific Computing, 2013, 35(5): A2121-A2149". The software which generates the optimal representative point set based on the minimization of GF-discrepancy for more general distributions is still under development and will be released in an updated version. For the theoretical bases and implementation steps for the point selections related to general distributions, refer to: "Chen Jianbing, Zhang Shenghan. Probability density evolution analysis of nonlinear response structures with non-uniform random parameters. Chinese Journal of Theoretical and Applied Mechanics, 2014, 46(1): 136-144 (in Chinese)" and "Chen JB, Yang JY, Li J. A GF-discrepancy for point selection in stochastic seismic response analysis of structures with uncertain parameters. Structural Safety, 2016, March, 59: 20-31".
- **About the deterministic analysis**: The software does not provide numerical

analysis solver for deterministic dynamic analysis, therefore the users need to employ commercial finite element software or self-compiled solver to carry out structural analysis, and then the time histories of physical quantities of interest should be prepared in textual form (.txt) in the required data format (see Section 2.1.2 for details) before performing the PDEM module. It is worth noting that the data prepared for the physical quantity should be ”speed” if the probabilistic information of the “displacement” is of interest. Here “displacement” and “speed” should be understood in a wide sense, i.e. “displacement” can be any physical quantity of interest and “speed” is the corresponding “first-order time derivative process.”

2.1.1 Point selection module

Switch the left menu of this analysis system to the Point Sets module as shown in Figure 2.1. At present, the current software provides point sets only for random variables which obey normal distribution and the dimension is limited to $[3, 24]$. Point sets for more general situations will be introduced soon. It should be noted that each dimension is a standard normal distribution with zero mean and unity standard deviation. Users can simply make a transform for general normal distributions.

The specific operation of the point selection module is as follows: Enter the desired dimension in the text dialog N_Dim as shown in Figure 2.1. Click the button Select to get the selected point data (as shown in Figure 2.2). Click the two buttons under Save Files respectively to output the coordinate and the assigned probability of the point set. The specific data format is shown in Figure 2.3. It should be noted that users should select the folder when saving the coordinate data.

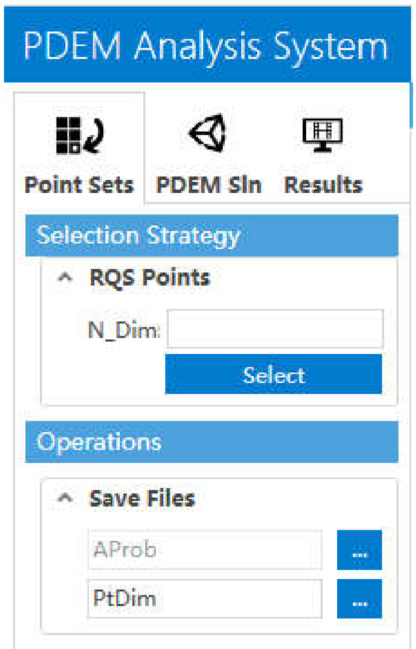


Figure 2.1 Point selection module

AProb	PtDim1	PtDim2	PtDim3	PtDim4	PtDim5	PtDim6
0.0330579000	0.1361420000	-0.2685390000	-0.1589880000	1.0005700000	0.2439300000	-1.564460
0.0330579000	0.1540400000	-0.0996069000	-0.0293058000	0.1613800000	-0.0716864000	-0.277705
0.0330579000	-1.3502200000	0.5386500000	-0.0844697000	0.4478970000	1.2331100000	-0.407740
0.0330579000	0.7828650000	0.9301120000	-0.5496290000	1.4269700000	0.4723280000	0.518331
0.0330579000	-0.7065680000	0.6833280000	-0.9796690000	-1.0149800000	0.6810360000	0.234693
0.0330579000	0.3192100000	-1.5607800000	-0.9263410000	0.2586890000	0.9547760000	0.908244
0.0330579000	1.2579500000	0.3871840000	1.0392600000	-0.7386500000	1.4258100000	-0.172343
0.0330579000	0.4336100000	1.0965400000	-0.4970880000	0.1502340000	-0.5100020000	0.646280
0.0330579000	0.8063350000	0.0862582000	-1.4211300000	-0.7554310000	-0.1525420000	-1.101380
0.0330579000	-0.1361420000	0.2685390000	0.1589880000	-1.0005700000	-0.2439300000	1.564460
0.0330579000	-0.1540400000	0.0996069000	0.0293058000	-0.1613800000	0.0716864000	0.277705
0.0330579000	1.3502200000	-0.5386500000	0.0844697000	-0.4478970000	-1.2331100000	0.407740
0.0330579000	-0.7828650000	-0.9301120000	0.5496290000	-1.4269700000	-0.4723280000	-0.518331
0.0330579000	0.7065680000	-0.6833280000	0.9796690000	1.0149800000	-0.6810360000	-0.234693
0.0330579000	-0.3192100000	1.5607800000	0.9263410000	-0.2586890000	-0.9547760000	-0.908244
0.0330579000	-1.2579500000	-0.3871840000	-1.0392600000	0.7386500000	-1.4258100000	0.172343
0.0330579000	-0.4336100000	-1.0965400000	0.4970880000	-0.1502340000	0.5100020000	-0.646280
0.0330579000	-0.8063350000	-0.0862582000	1.4211300000	0.7554310000	0.1525420000	1.101380
0.0031637400	-0.9799750000	-0.9584760000	1.9282200000	-0.5006800000	-2.2860200000	0.650026
0.0031637400	-2.1132000000	-0.7762000000	1.6366200000	1.2203200000	-0.7836380000	-1.755230
0.0031637400	0.0024852200	-0.2512250000	1.1706700000	2.0944700000	-1.5203100000	-0.468339

Figure 2.2 Point data of the 9-dimensional basic random vector (normal distribution)

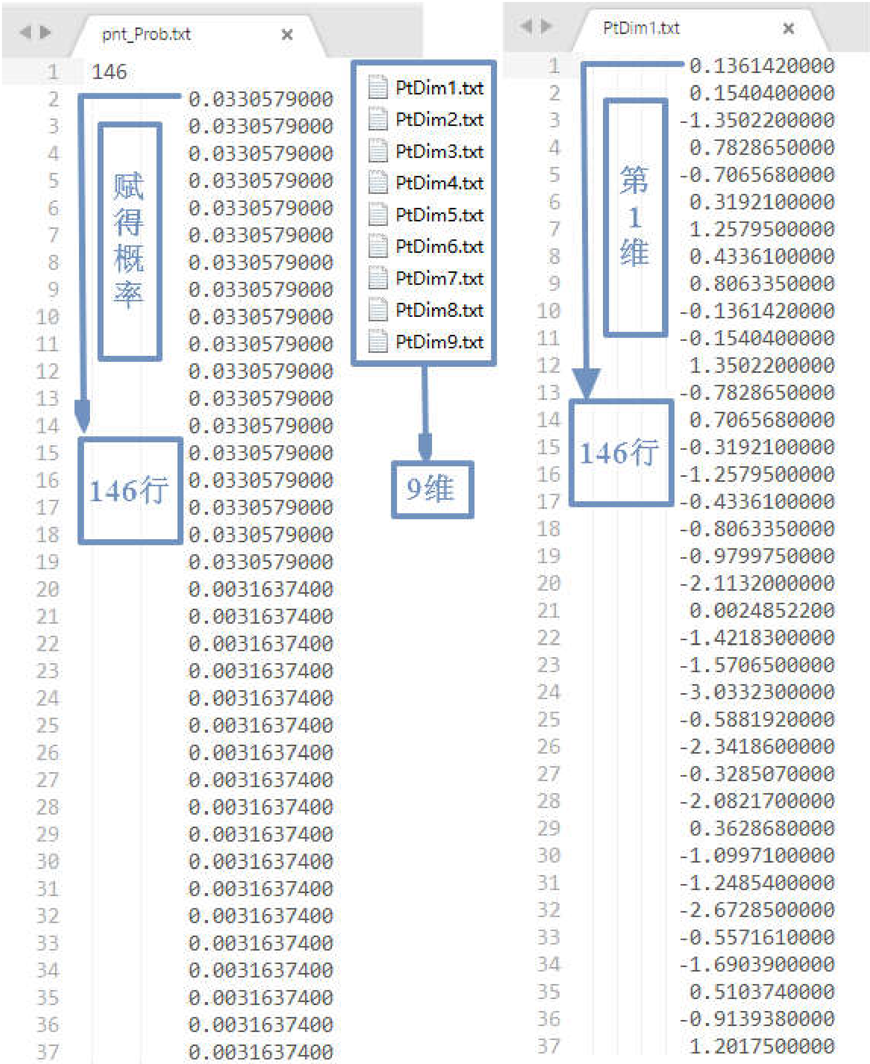


Figure 2.3 Output data format of the 9-dimensional basic random vector (normal distribution)

2.1.2 Data format of the deterministic analysis results

After the deterministic analyses, users should output and save the results of "speed" of the physical quantity of interest as a text format (.txt). The filenames must be marked with Arabic numerals such as W ***.txt as shown in the Demo folder (There are 192 representative time histories corresponding to 192 discrete representative points, each of the time history having 1024 time steps with interval of 0.02) where "***" is an Arabic numeral and corresponds with the assigned probability file "pnt_Prob.txt", as shown in Figure 2.4.

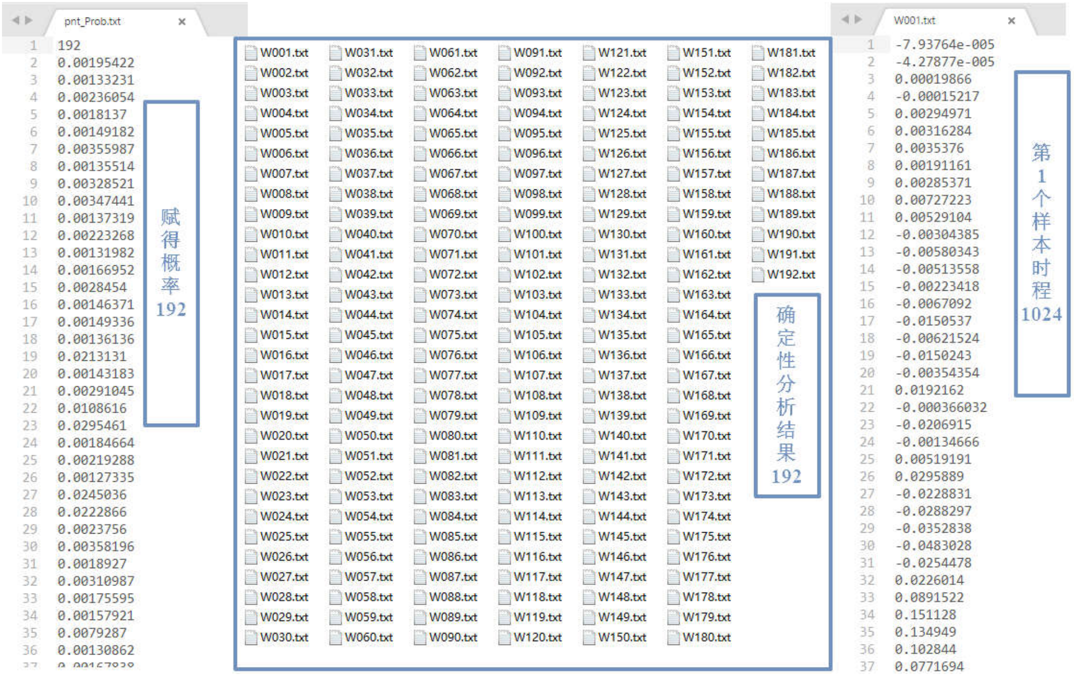


Figure 2.4 Data format of deterministic analysis results

2.2 PDEM solution and visualization of results

Once the data is ready, the user can carry out PDEM solution. This section includes two parts, PDEM solution and visualization of results. The followings describe the specific operation.

2.2.1 Input of PDEM

Switch the left menu of the software to the “PDEM Sln” module as shown in Figure 2.5. In this section, the work need to be done includes:

(1) Import the files of the assigned probability and the deterministic analyses result.

(2) Input the parameters of PDEM and the reliability threshold.

(3) Select the scheme of the finite difference method and carry out PDEM solution.

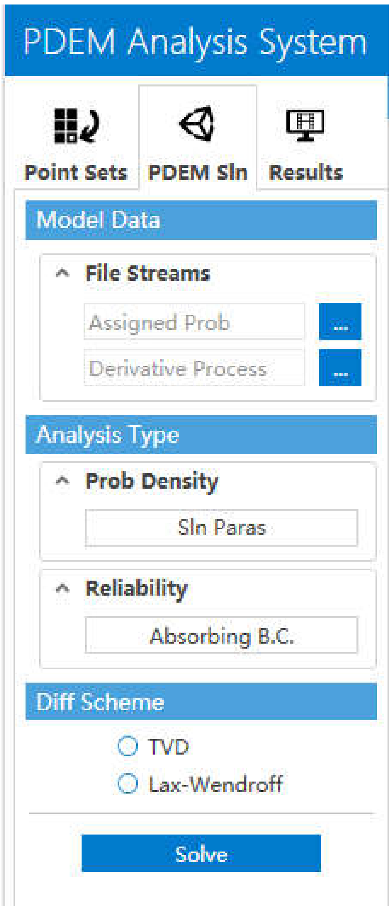


Figure 2.5 PDEM solution module

- (1) **File Input**: Click the file input button (light blue, with "…" box) in "File Streams" under "Model Data" menu, select the assigned probability file and the deterministic analyses result file (The Shift key can be used for multiple-choice). If the message box as shown in Figure 2.6 pops up, it indicates that the import is successful (in the example, the results display after successfully reading the data provided in the Demo folder).

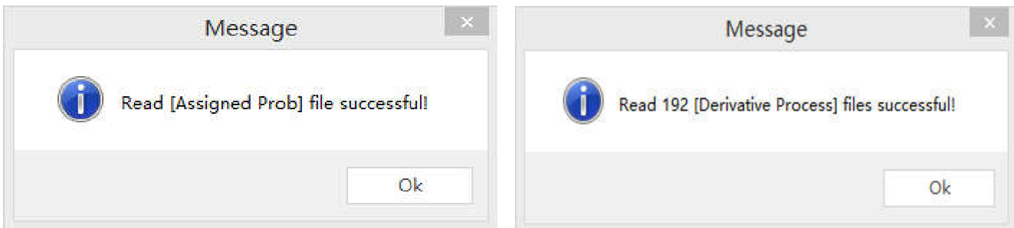


Figure 2.6 Prompt box of successful import

- (2) **Parameters and reliability threshold input**: Click the "Sln Paras" button under the menu "Analysis Type" to pop up the dialog shown in Figure 2.7. Therein
  - Num-Step of Smps and Time-Step of Smps correspond to the time

length and time interval in deterministic analyses (i.e. the duration and the time interval of the deterministic analysis data);

- Ratio of Time-Sln is the ratio of difference solving steps to 2000. This value is a positive integer (⩾1), and usually ⩽10. When using the Lax-Wendroff scheme, the software automatically adjusts it to 1 regardless of the value entered. When the TVD scheme is selected, the time interval should not be greater than that of the Lax-Wendroff scheme, so Ratio of Time-Sln should be ⩾1. Let a be the value, the time interval of the TVD difference format is 1/a of the parameter "Time-Step of Sln" to be introduced below. However, the time interval of the result output data is still "Time-Step of Sln" to avoid oversized data. For the same reason, the number of output steps is fixed at 2000;
- Time-Step of Sln is the nominal step interval (This value should not be greater than the step interval used in deterministic analysis). As mentioned above, the real time step interval is Time-Step of Sln divided by Ratio of Time-Sln.
- Mesh-Step of Adj is the grid ratio adjustment factor for differential solving(It is usually taken as 0.95).
- Number of Bound is the grid computing range used in PDEM analysis.(It is recommended to be taken as 100. If all the probability density at the same time sums to some value less than 1, the Number of Bound should be expanded)
- Spc-Step of Check is the probability check step (Any value can be entered).
- If all the procedures mentioned above are completed, click the Apply button to submit the solution data.
- In addition, for the dynamic reliability analysis of first-passage failure, click the Absorbing B.C button, a dialog box pops up (As shown in Figure 2.8), then users can enter the appropriate threshold according to the actual situation, click the Apply button to submit the reliability threshold data. (As for the theoretical bases for dynamic reliability analysis of first-passage failure based on the absorption boundary conditions with PDEM, please refer to "Li J, Chen JB. Stochastic Dynamics of Structures. John Wiley & Sons, 2009, Chapter 8." and "Chen JB, Li J. Dynamic response and reliability analysis of nonlinear stochastic structures. Probabilistic Engineering Mechanics, 2005, 20(1):

33-44”). The dynamic reliability analysis of first-passage failure can also be calculated by using the principle of extreme value distribution and equivalent extreme-value event. However, these contents are not yet included in the software and will be released in a future update. For more information, please refer to “Li J, Chen JB. Stochastic Dynamics of Structures. John Wiley & Sons, 2009, Chapter 8.”, “Chen JB, Li J. The extreme value distribution and dynamic reliability analysis of nonlinear structures with uncertain parameters. Structural Safety, 2007, 29(2): 77-93”和“Li J, Chen JB, Fan WL. The equivalent extreme-value event and evaluation of the structural system reliability. Structural Safety, 2007, 29(2): 112-131”。

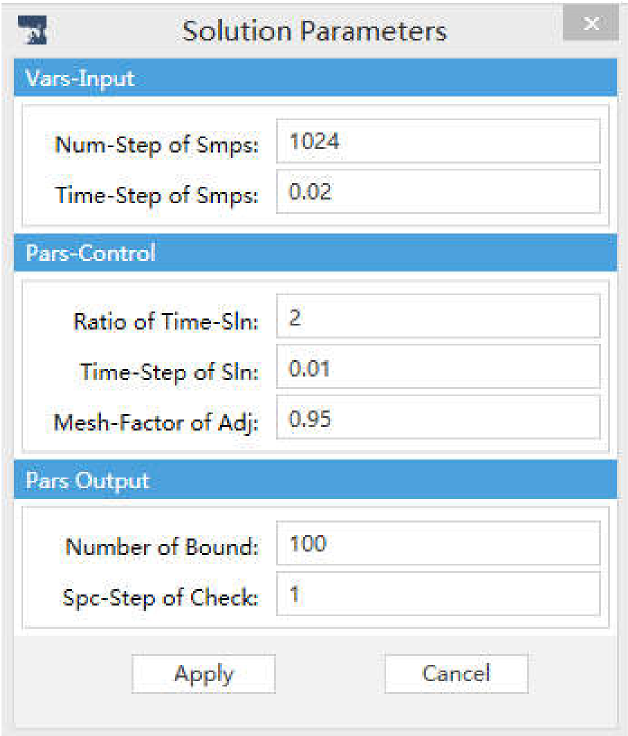


Figure 2.7 Input dialog of PDEM parameters

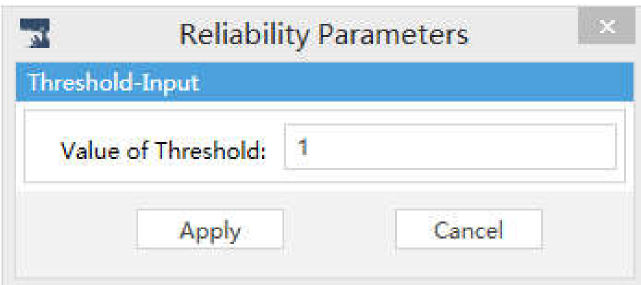
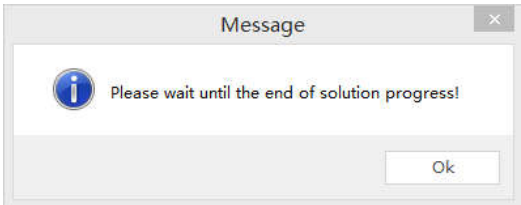


Figure 2.8 Input dialog of reliability threshold

- **(3) Differential scheme selection and solution：** After selecting the difference scheme (TVD or Lax-Wendroff) in the menu block “Diff Scheme”, click the “Solve” button to submit the solution. The circular progress bar (As shown in Figure 2.9a) on the right side of the system will start to scroll and the dialog box shown in Figure 2.9b will pop up. After the solution is completed, the circular progress bar will stop scrolling. At this time, the user can enter the result visualization module. It should be noted that the TVD scheme should be used when structural reliability analysis is required. Both Lax-Wendroff scheme and TVD scheme can be used when only probability density evolution analysis is required where users should set the Absorbing B.C to a large value.

(a) Round progress bar



(b) Prompt dialog box

Figure 2.9 Prompt information of the solution process

2.2.2 Visualization of results

Switch the left menu of this software to the “Results” module as shown in Figure 2.10. This section provides the following features:

(1) Visualization of digital features such as mean value and standard deviation;

(2) Visualization of the probability density curve (probability density curves at any time can be chosen optionally) and surface;

(3) Visualization of dynamic reliability curve.

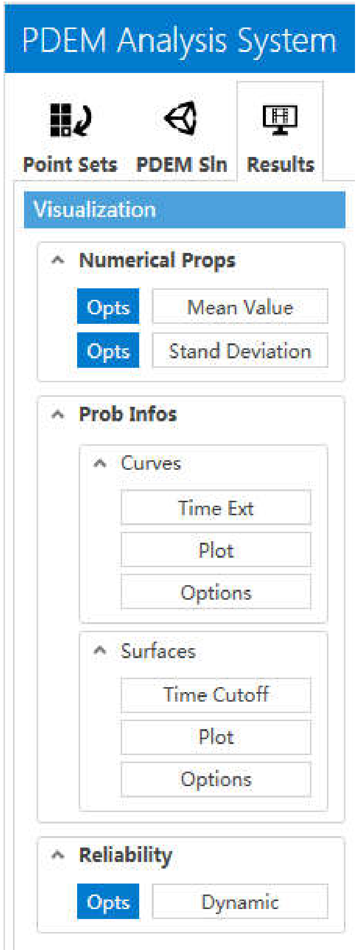


Figure 2.10 Results visualization module

- (1) **Visualization of digital features**: Click the Mean Value button in the menu block Numerical Props to display the mean value result. Click "Stand Deviation" to display the standard deviation result, as shown in Figure 2.11 and 2.12. To modify the title and coordinates, click the Opts button to bring up the dialog box and make the appropriate modification.

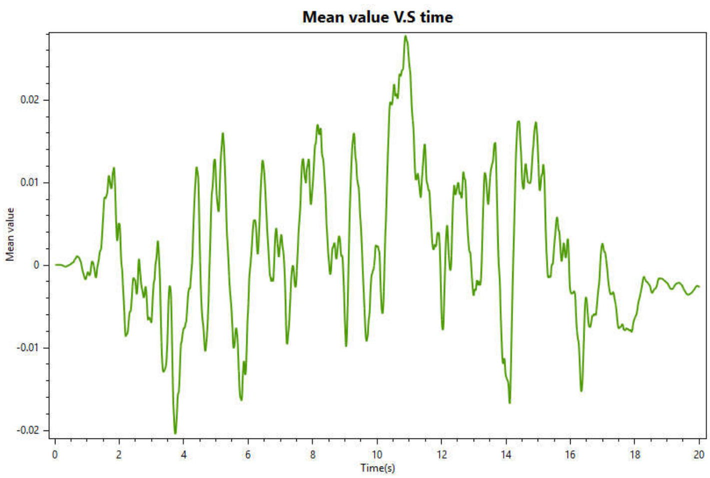


Figure 2.11 Mean value

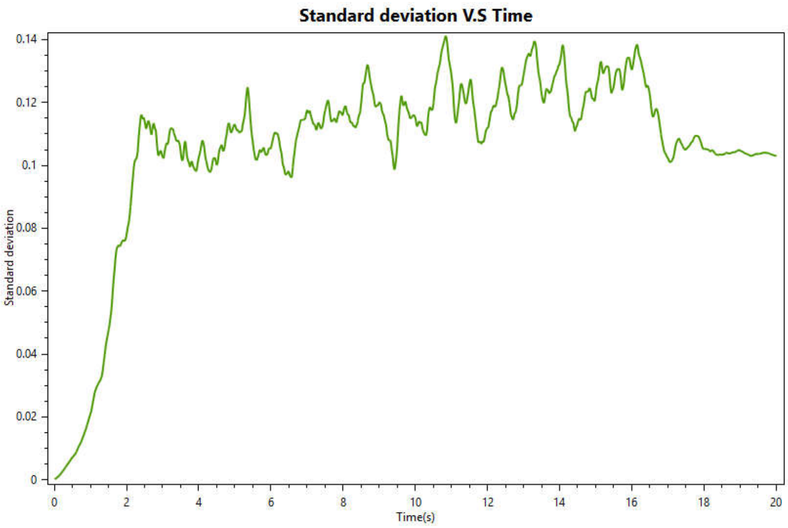


Figure 2.12 Standard deviation

- **(2) Visualization of the probability density curves and surface:** Click the Time Ext button in the menu block Prob Infos Curves to pop up the extraction dialog box, then input several time points of concern, for example 1s, 2s, 3s, 4s were extracted here, Click the Plot button after Apply to draw the probability density curve of the selected moment (As shown in Figure 2.13). Click the Time Cutoff button in the menu block Prob Infos Surfaces to pop up the extraction dialog box, enter the beginning and end of the interception period(for example, 10 and 11 are entered here which means the interception period is[10s,11s]). Due to the huge probability surface data, users should not enter too large time interval). Click the Plot button after Apply to draw the probability density evolution surface of the interception period (as shown in Figure 2.14). In addition, the user can also click the button in the toolbar  to draw different forms of surface (As shown in Figure 2.14 (A-D)). If the user needs to modify the title and coordinates, click the Options button and make the corresponding modification in the pop-up dialog box.

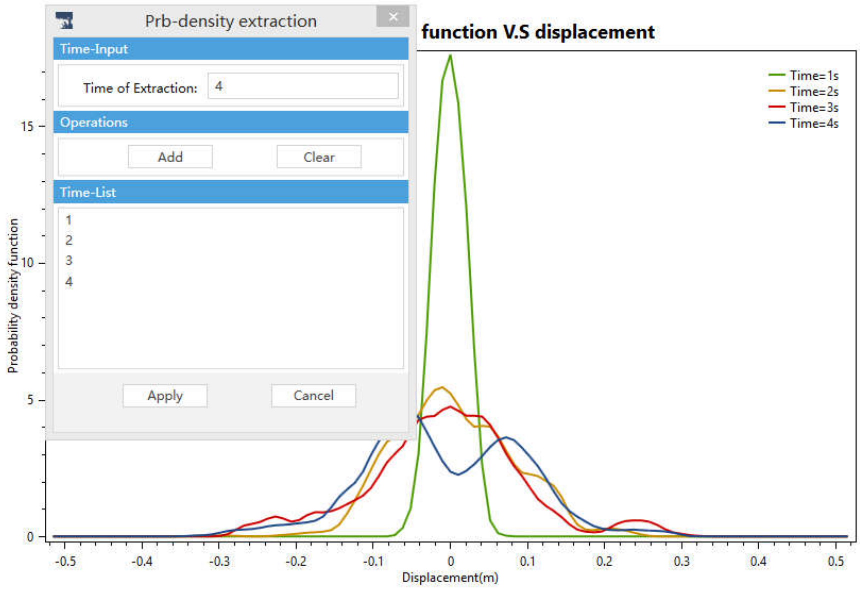


Figure 2.13 Extraction of probability density curve

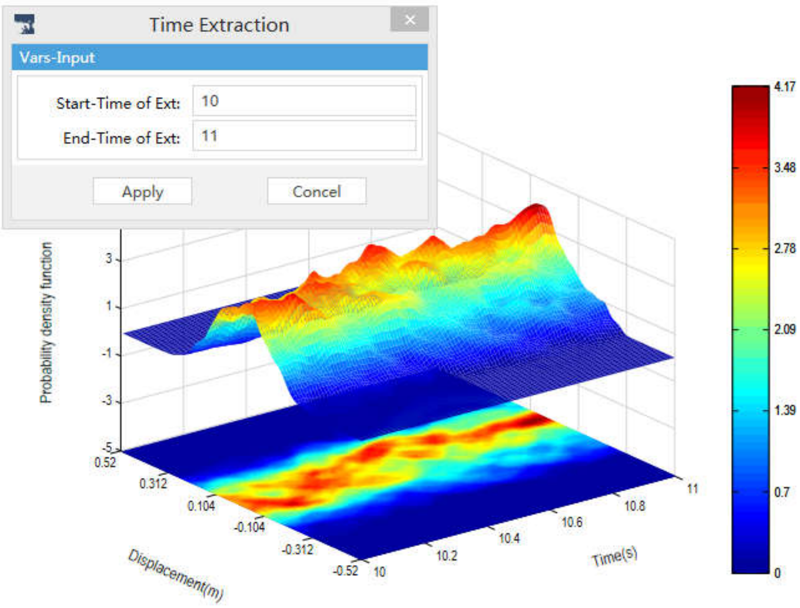
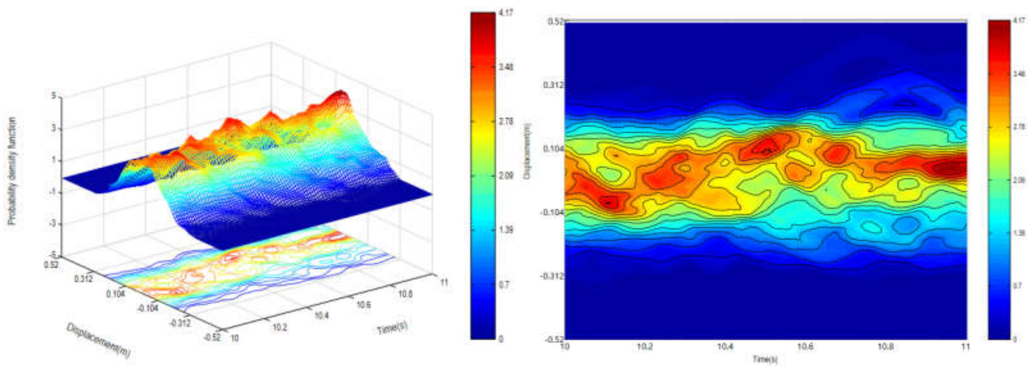
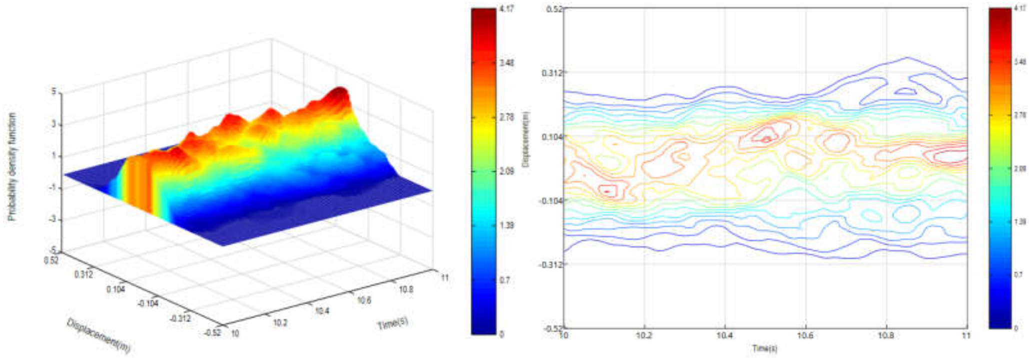


Figure 2.14 Extraction of probability density surface



(a) (b)



(c) (d)

Figure 2.15 Other expression of probability density surface

- **(3) Visualization of dynamic reliability curve:** In the menu block Reliability, click the Dynamic button to display the dynamic reliability curve (As shown in Figure 2.16). The reliability is 1 here due to the larger threshold of reliability entered before.

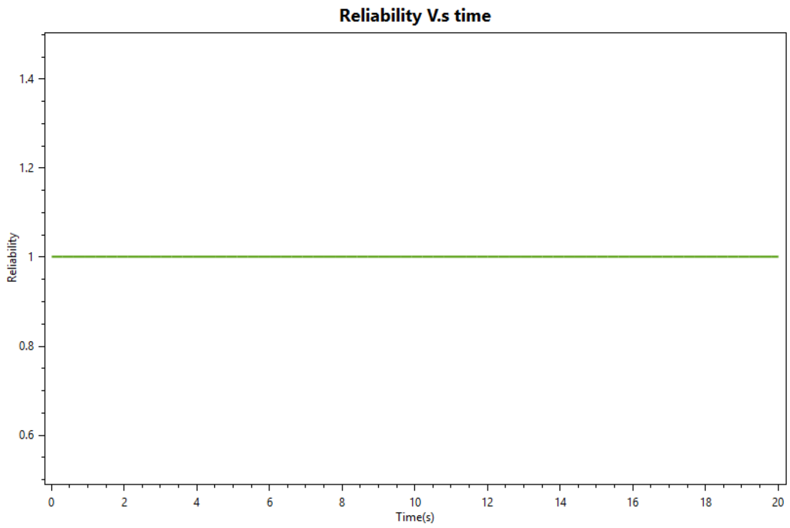


Figure 2.16 Visualization of dynamic reliability

3 Other instruction of the software

(1) The copyright of this software belongs to the International Joint Research Center for Engineering Reliability and Stochastic Mechanics of Tongji University.

(2) This software is not responsible for the analysis results obtained by this software.

(3) The contact of this software is Jianbing Chen, the programmer of this software is Guangda Lu. This instruction was prepared by Guangda Lu in Chinese, and translated by Jianpeng Chan. This software was first released in January 2018.

(4) If you have any questions or suggestions, please contact (chenjb@tongji.edu.cn) for our further improvement.