CUSTOMER SUPPORT NOTE

Nonlinear and Transient Control Settings
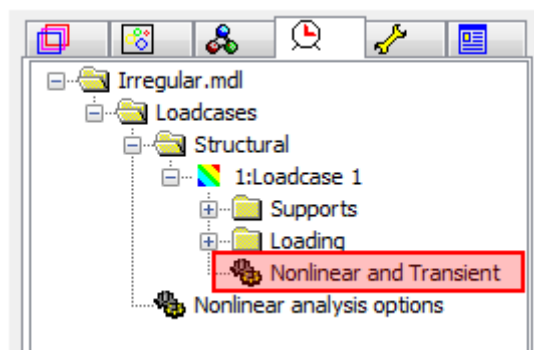
This support note is issued as a guideline only.

Performing a nonlinear or transient analysis in LUSAS requires setting the relevant settings in Nonlinear and Transient Settings in LUSAS Modeller. This document explains these settings.

The following dialog shows the Nonlinear and Transient settings. Each numbered item will be briefly explained.
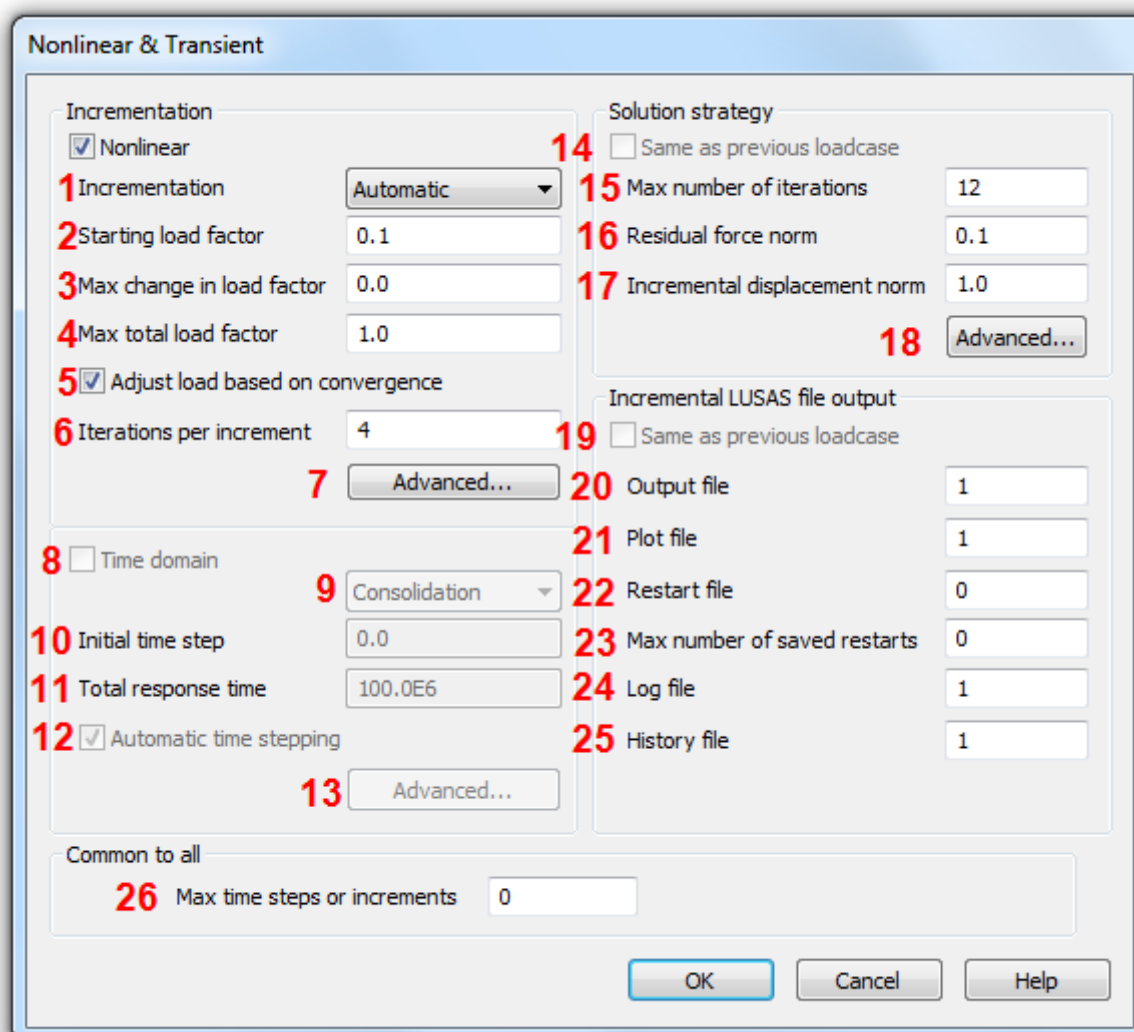
1.   **Incrementation**. The options are *Manual* or *Automatic*. Manual incrementation will attempt to achieve results for load factor of 1 in a single load increment. If convergence

fails, the analysis will stop as reducing the load level is not allowed in Manual setting. Selecting Automatic incrementation will enable the input of the incrementation parameters (entries 2-7). Automatic incrementation will start at the load factor specified in box 2, and will increase the loading until the load factor reaches the number specified in box 4. The maximum single loadstep is limited to the value entered in box 3.

2. **Starting Load Factor**. The load factor at the first increment of the loadcase. If the first increment fails to converge, step reductions will take place.

3. **Max Change in Load Factor**. This is the maximum change in load factor between one increment and the next. The default value (0) means no limit.

4. **Max Total Load Factor.** The loadcase will run up to this load factor and then stop. If the load factor of the last increment exceeds this value, it may be because an 'Arc Length' solution has been used. See item 7 for more details on this.

5. **Adjust Load Based on Convergence**. If this box is ticked, the load steps will automatically be varied (increased or reduced) to try and ensure efficient convergence. The target number of iterations in an increment is the value input in box 6.

6. **Iterations per Increment**. This is the target number of iterations per increment when box 5 is ticked. For example, if a value of 4 was entered, and an increment converged in 8 iterations, the next load step would be reduced. If the increment converged in 2 iterations, the next load step would be increased. The default value of 4 is suitable for most analyses. The maximum number of iterations in an increment is set in box 15. When this limit is hit, step reduction will take place.

7. **Advanced Incrementation Controls.**

7.1. **Stiffness Ratio to Switch to Arc Length**. This is the value of parameter CSTIF (this can be checked in the Solver window or log / output file) at which an Arc Length solution is invoked. CSTIF is effectively a measure of the stiffness of the structure as a proportion of the initial stiffness.

The default value of 0.4 is usually appropriate, but if you find that Automatic loadcase load factors are going higher than the input 'max total load factor' this is probably a result of the Arc Length solution. A value of 0 can be input to disable Arc Length.

7.2. **Arc Length Control**. This section allows you to control the type of Arc Length control used. It is rarely necessary to edit these parameters so do not do so without consulting LUSAS Support. When Arc Length is required we suggest using the automatic switch to arc length with a setting of 0.4 in box 7.1.

7.3. **Terminate on Value of Limiting Variable**. Tick this box if you want to terminate the analysis at a given deflection. See 7.4 to 7.6 for further details.

7.4. **Point Number**. This is the number of the point which will determine when the model has deflected enough to terminate the analysis. For example, for a simply supported beam the number of a point at midspan might be used.

7.5. **Variable Type**. The options are U, V, W, THX, THY, THZ.
U, V and W correspond to the X, Y and Z directions.

7.6. **Value**. The value of deflection of the point in box 7.4 which will terminate the analysis. Input in the model units of distance (e.g. metres) or radians for rotations.

7.7. **Allow Step Reduction**. Ticking this box will allow Automatic incrementation to automatically reduce the size of a load step if there is a convergence failure. This should usually be left ticked.

7.8. **Maximum Step**. This is the maximum number of step reductions which will take place.

7.9. **Load Reduction Factor**. The factor by which a load step will be reduced if an increment fails to converge. For example, if a load step with value of 32 failed to converge, the default Load Reduction Factor of 0.5 would then attempt a reduced load increase of 16, then 8, 4, 2 and 1 before a final attempt to increase the load step once (to 64, see 7.10) is attempted. Convergence failure is declared if the last attempt fails to converge.

Reducing the value in 7.9 sometimes help convergence in analyses where large load steps have been occurring but it is necessary to suddenly reduce them, for example in materially nonlinear analyses where the structure suddenly goes from elastic to plastic.

7.10. **Load Increase Factor**. If the load reduction steps have failed to help the increment converge, a single load step increase is attempted. Occasionally, increasing the load step can help rather than hinder convergence and this is a final check before the solution stops.

8.   **Time Domain**. If a time-stepped (transient) rather than load-stepped analysis is required (say for dynamics or creep) you should tick this box.

9.   The options for transient analysis are **Consolidation** (for 2-phase soil material models), **Viscous** (for creep analysis), **Implicit Dynamics** and **Explicit Dynamics**.

10.   **Initial Time Step**. The size of the first time step, in the model units (except in the case of CEB-FIP creep analysis where units of days are used to prevent exceedingly high numbers being required).

11. **Total Response Time**. The total time that the transient analysis will run to. If multiple transient loadcases are used the total time including previous loadcases must be input.

12. **Automatic time stepping**. This will adjust the time steps to maintain stability. Ticking it will active button 13.

13. **Advanced Time Stepping Parameters**.
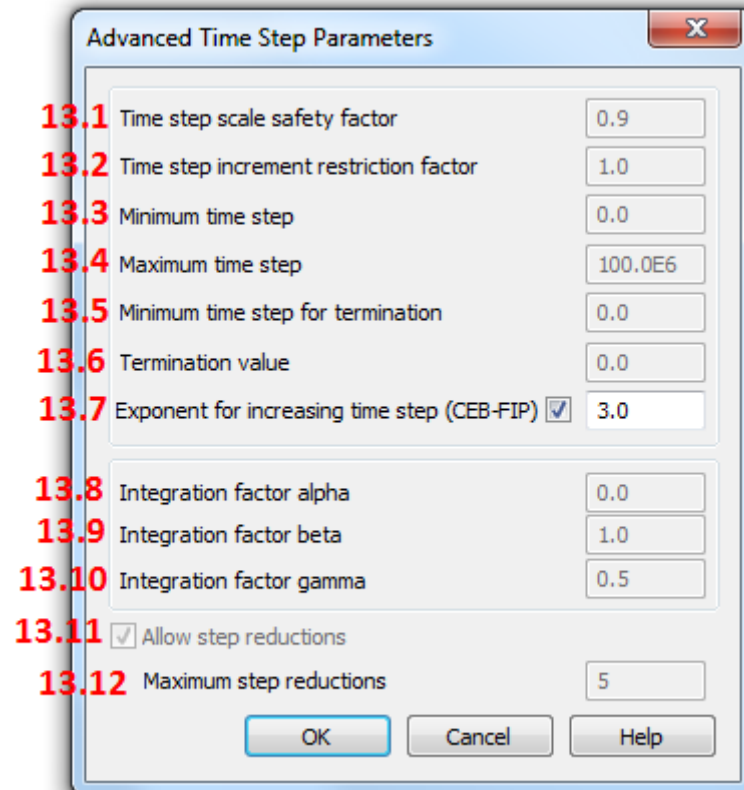
13.1. **Time Step Scale Safety Factor**. Applies to explicit dynamic analysis only. The scale factor for computing the time step for explicit dynamic analyses (default = 0.9 for 3D and 2/3 for 2D).

13.2. **Time Step Increment Restriction Factor**. Increment restriction factor for dynamic analyses (default = 1.0 for explicit analysis, 10.0 for implicit analysis). Note that stability conditions must be taken into account when setting this value. The default value may lead to instability in some cases and large values should be avoided. See LUSAS Theory Manual 1 section 2.4 for detailed information about dynamic analysis formulation.

13.3. **Minimum Time Step**. The smallest permitted time step.

13.4. **Maximum Time Step**. The largest permitted time step. Note that stability conditions must be taken into account when setting this value since solution instability may occur with large time steps. See LUSAS Theory Manual 1 section 2.4 for detailed information about dynamic analysis formulation.

13.5. **Minimum Time Step for Termination**. Minimum time step for dynamic analyses (default = 0.0). Note that stability conditions must be taken into account when setting this value since solution instability may occur with large time steps. See

LUSAS Theory Manual 1 section 2.4 for detailed information about dynamic analysis formulation.

13.6. **Termination Value**. Used only for Viscous analyses. Value to terminate analysis relating the current displacement increment to the displacement increment directly following a new control data section. Incremental displacement on current step divided by incremental displacement norm on first step should be less than this input. This setting could stop the analysis if undue and large deformations are obtained in a new Viscous Control load case. It is suggested to leave the setting as the default value.

13.7. **Exponent for Increasing Time Step**. Only for use with the concrete creep CEB-FIP model. Because the range of time can be so large with this type of analysis (e.g. 1 day to 120 years) an exponential time step growth can be used to avoid an excessive number of steps.

13.8. **Integration Factor Alpha**. See below

13.9. **Integration Factor Beta**. See below

13.10. **Integration Factor Gamma**. See below

the above values are used to specify the time integration factor.

Implicit dynamics (Hilber-Hughes integration scheme)
alpha Integration factor (default = 0).
beta Integration factor (default = 1/4).
gamma Integration factor (default = 1/2).
Note: For an unconditionally stable, second order accurate scheme, **alpha** must lie between the limits:

$$-\frac{1}{3} \le a \le 0$$

and **beta** and **gamma** are defined as:

$$\beta = \frac{(1-\alpha)^2}{4}, \qquad \gamma = \frac{1-2\alpha}{2}$$

Setting **alpha** to zero reduces the algorithm to the Newmark method.

Explicit dynamics
alpha Integration factor = 0
beta Integration factor = 0
gamma Integration factor = ½
Note: For an explicit dynamic analysis the above integration factors are mandatory. Only explicit dynamics elements may be used with the explicit dynamics constants.

13.11. **Allow Step Reductions**. Allow time step reductions in the event of a convergence failure in a transient analysis.

13.12. **Maximum Step Reductions**. The maximum number of time step reductions permitted in a transient analysis.

14. **Same as Previous Loadcase**. In an analysis with multiple loadcases, ticking this box will set all of the "Solution Strategy" parameters the same as those in the previous loadcase. Untick this box if you want to specify different parameters.

15. **Max number of Iterations**. The number of iterations that an increment is given to converge before a step reduction takes place. In Manual nonlinear control (see box 1) the analysis will terminate if no convergence is achieved after trying the given number of iterations in box 12.

16. **Residual Force Norm**. A measure of convergence which compares the residual forces with the external forces (including reactions) as a percentage. The default value of 0.1 is usually appropriate. In models with prescribed displacement loading this measure of convergence is not appropriate and should be set to 0 (i.e. ignore). This is most useful for materially nonlinear problems.

17. **Incremental Displacement Norm**. A measure of convergence which uses iterative displacement. The limit for the sum of the squares of the iterative displacements as a percentage of the sum of the squares of the incremental displacements. Only translational degrees of freedom are considered by default but all degrees of freedom can be included by specifying the LUSAS option number 187.

18. **Advanced Solution Strategy Parameters.**
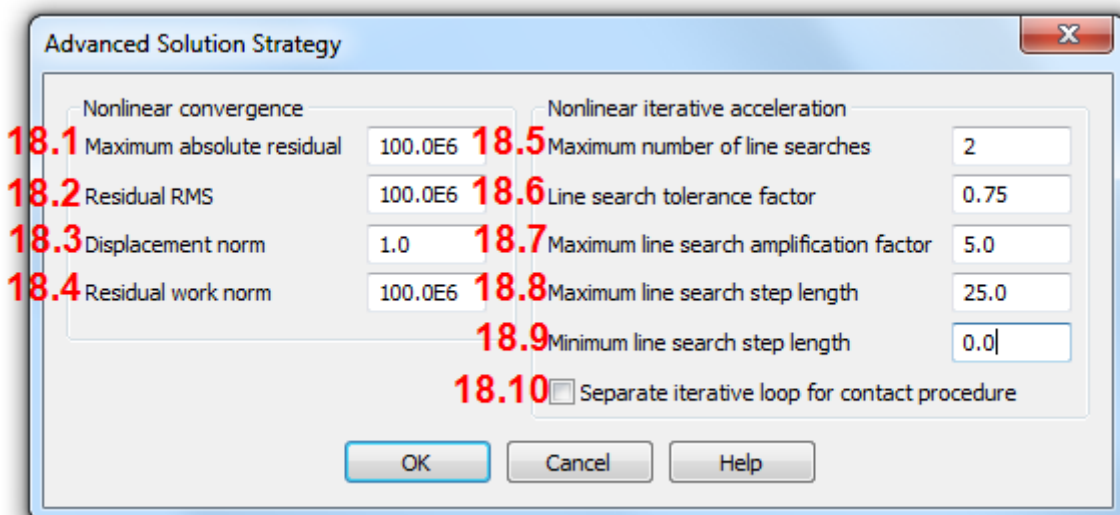
18.1. **Maximum Absolute Residual**. The limit for the maximum absolute value of any nodal residual. This input depends upon the units being used. It is a strict criteria and for some problems, especially those involving plasticity, it may be very difficult to reduce locally large residuals and obtain convergence. However, in sensitive geometrically nonlinear problems near bifurcation points, it can sometimes be necessary to ensure that large residuals are completely eliminated. This parameter has a default value of a large number (i.e. ignore the criterion). See Theory Manual 1 section 2.3.2.3. for further information.

18.2. **Residual RMS**. The limit for the square root of the mean value of the squares of all residuals. This is generally more applicable than the maximum absolute residual, but is still dependent upon the units being used.

18.3. **Displacement Norm**. The limit for the sum of the squares of the iterative displacements as a percentage of the sum of the squares of the total displacements. By default, only translational degrees of freedom are considered but all degrees of freedom can be included by specifying the LUSAS option number 187. This input is a very useful measure for checking convergence.

18.4. **Residual Work Norm**. The limit for the work done by the residuals acting on the iterative displacements as a percentage of the work done by the loads on iteration zero of the increment. See Solver Manual chapter 3 for further information. This value is normally set to a large number.

18.5. **Maximum Number of Line Searches**. See Theory Manual 1 section 2.3.2.2.

18.6. **Line Search Tolerance Factor**. Suggested to leave it as default.

18.7. **Maximum Line Search Amplification Factor**. Suggested to leave it as default.

18.8. **Maximum Line Search Step Length**. Suggested to leave it as default.

18.9. **Minimum Line Search Step Length**. Suggested to leave it as default.

18.10. **Separate Iterative Loop for Contact Procedure**. Ticking this can help convergence in analyses which contain contact as well as nonlinear materials. However the solution time will increase due to having more iterations.

19. **Same as Previous Loadcase**. If ticked, all the "incremental LUSAS file output" controls will be set to the same as the previous loadcase.

20. **Output File**. The increment with which loadcase results are reported in the text output file. For example, a value of five would mean every fifth loadcase will be included in the output file.

21. **Plot File**. The increment with which loadcase results are reported in the plot file (i.e. the results). For example, a value of five would mean results from every fifth loadcase (i.e. 5,10,15,...) are included in the plot file. Useful in transient analyses where there might be thousands of time steps, in which case specifying a value here would decrease the number of loadcases shown in Modeller and decrease the size of the results *.mys file.

22. **Restart File**. The increment with which restart files are created. For example, a value of five would create a restart file after every fifth loadcase (i.e. 5,10,15,...). Restart files enable an analysis to be continued from a certain point rather than restarted from the beginning. Restart analysis is very useful in analyses which have long run times. If needed, contact LUSAS support for further details about restart analysis.

23. **Max Number of Saved Restarts**. The number of restart files which are kept. For example, a value of one would only keep the last restart file leading to a sampler restart (*.rst) file.

24. **Log file** The increment with which incremental results are reported in the text *.log file. For example, a value of five would mean every fifth loadcase will be included in the log file.

25. **History file** The increment with which incremental results are reported in the history (*.his) file. For example, a value of five would mean every fifth loadcase will be included in the history file. This option allows you to access selected results via the text history

file. You can open the created 'HIS' file and explore it if needed or use it in Graph Wizard.

History files are useful for getting selected results while the mys file stays small. The procedure is as follows.

a) In Dynamic controls set the Incremental plot file output (box 21) to a large number and the history file (box 25) to 1.

b) Add target nodes or elements to the "Selection Memory" by selecting them and then Right click > Selection Memory > Set.

c) File > LUSAS Data File > Advanced and use the following settings press   OK and then Save
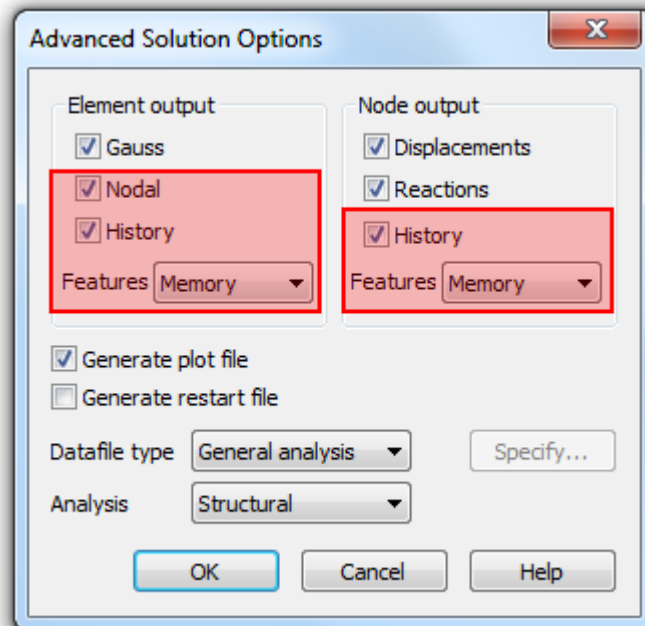
After solving the analysis, in Utilities > Graph Wizard use History files as shown below and Select the history file.
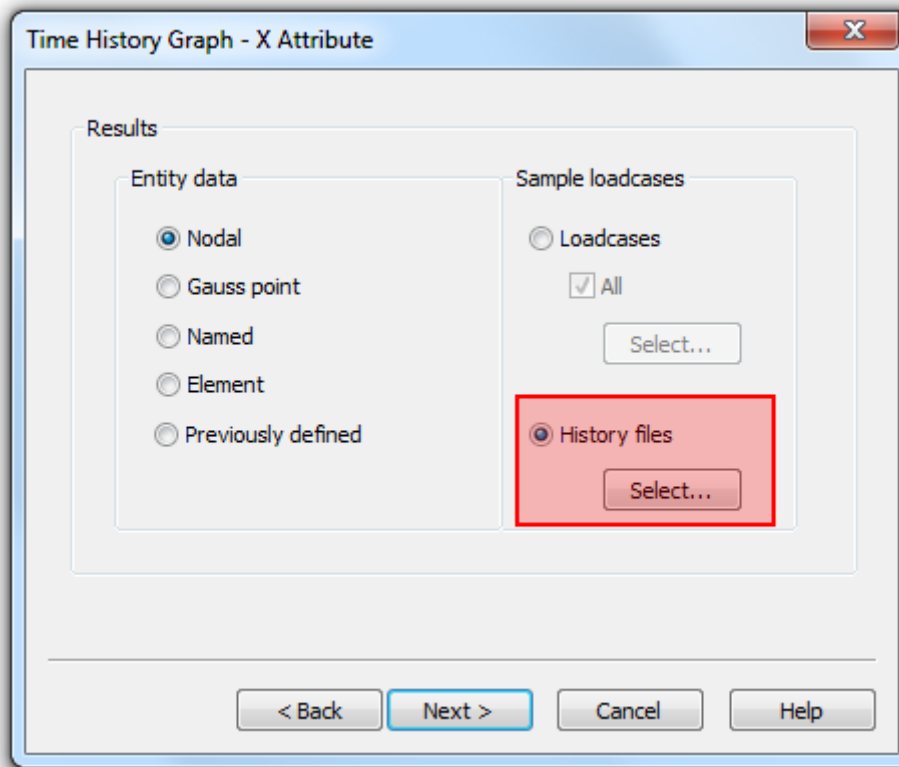
26. **Max Time Steps or Increments**. The number of increments or time steps after which the analysis will terminate, if it has not already been stopped by reaching the load factor specified in box 3 or the total time specified in box 11.

For more information see LUSAS User Area:

http://www.lusas.com/protected/theory/Nonlinear_Dialog_Details.html

(Password protected – request a password from support@lusas.com)