

# LUSAS CUSTOMER SUPPORT NOTE

## **Nonlinear Control Using Manual, Automatic and Mixed Incrementation**

Note Number: **CSN/LUSAS/1034**

Last Updated: **May 2016**

This support note is issued as a guideline only

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The LUSAS logo consists of the word "LUSAS" in a bold, white, sans-serif font, centered within a blue rectangular box that has a light blue gradient at the bottom.

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## Nonlinear Control Using Manual, Automatic and Mixed Incrementation

For software product(s):	Any Plus version.
With product option(s):	Nonlinear

### Description

Linear finite element analysis assumes that all materials are linear elastic in behaviour, there is no lift-off from supports, and that deformations are small enough to not significantly affect the overall behaviour of the structure. If the response of a structure is linear the concept of load superposition will hold true and resultant effects can be found by combining loadcases. The effects of **Loadcase 1** (multiplied by a factor) can simply be added to the effects of **Loadcase 2** (multiplied by a factor) to give the total effect.

A nonlinear structural response, in contrast, does not satisfy the load superposition principle, meaning that the output from a nonlinear structural analysis is not directly proportional to the input. Since the load superposition principle is not satisfied, combinations can no longer be used to obtain resultant effects.

In order to create a resultant effect from multiple loadcases in a nonlinear structure, LUSAS needs to be 'told' that the loading from **Loadcase 1** should be 'remembered' and held constant as the loading from **Loadcase 2** is added. Whether a loading from a loadcase is 'remembered' or 'forgotten' in subsequent loadcases depends on the *Nonlinear controls* and in particular the procedure that is being used.

Incrementation for loadcases in nonlinear modelling problems may be specified in four ways:

- **Manual Incrementation** where the loading data in each load increment is specified separately. The full load is applied in one increment.
- **Automatic Incrementation** where a specified loadcase is factored using fixed or variable increments.
- **Mixed Incrementation** Mixed manual and automatic incrementation.
- **Load Curves** where the variation of one or more sets of loading data is specified as a graph of load factor vs. load increment or time.

## Objectives

To understand the importance of incrementation and effects that Manual-, Automatic- and Mixed-Incrementation uses can have on an analysis.

## Keywords

Nonlinear Control, Incrementation

## Modelling



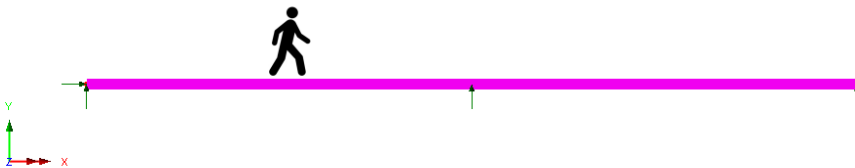
**Note.** The model used is a simple linear beam without any complex nonlinear behaviour. This has been done to allow the example to concentrate on the concepts of how incrementation is used in a nonlinear analysis, and to simplify the learning outcomes of the example, without having to get involved in the complexities of concrete cracking, steel yielding, stage construction analysis, lift/contact or second order large displacement analysis that might be found in a true nonlinear model. However a discussion on a more realistic nonlinear model is included in the concluding remarks.

## Running LUSAS Modeller

For details of how to run LUSAS Modeller see the heading *Running LUSAS Modeller* in the Examples Manual Introduction.



**Note.** This example is written assuming a new LUSAS Modeller session has been started and a basic two span continuous footbridge model has been created.



In the model two loadcases have been created:-



- Loadcase 1 – Self weight of the bridge
- Loadcase 2 – Span 1 pedestrian

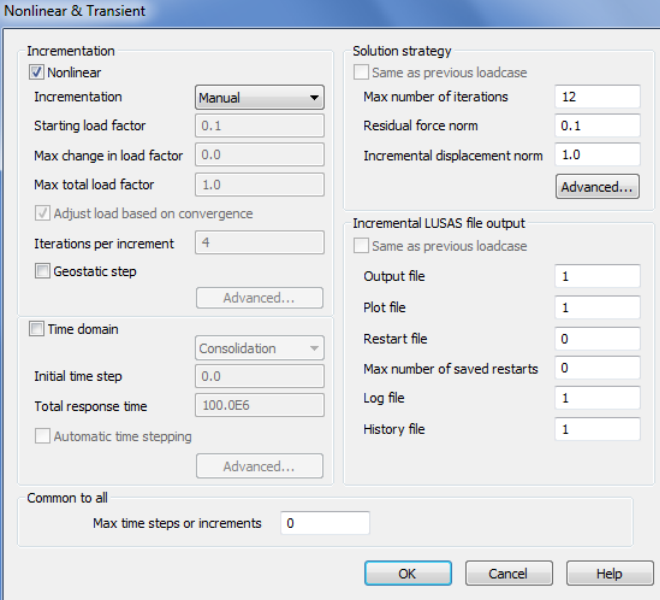
# Manual Load Incrementation

The first analysis of the model will use **Manual** load incrementation on both loadcases.

## Defining loadcase properties

- In the Treeview right-click on **Loadcase 1 – Self weight of the bridge** and, from the **Controls** menu item, select the **Nonlinear & Transient** menu option.
- On the Nonlinear & Transient dialog select the **Nonlinear** option in the top-left hand corner and leave the incrementation type as **Manual**.
- Click **OK** to return to the Modeller working window.

A Nonlinear and Transient object  will be added to the Treeview . Double-clicking on this object will allow any changes to be made to the control properties.



Nonlinear & Transient

Nonlinear

Incrementation: Manual

Starting load factor: 0.1

Max change in load factor: 0.0

Max total load factor: 1.0

Adjust load based on convergence

Iterations per increment: 4

Geostatic step

Time domain

Initial time step: 0.0

Total response time: 100.0E6

Automatic time stepping

Solution strategy

Same as previous loadcase

Max number of iterations: 12

Residual force norm: 0.1

Incremental displacement norm: 1.0

Incremental LUSAS file output

Same as previous loadcase

Output file: 1

Plot file: 1

Restart file: 0

Max number of saved restarts: 0

Log file: 1

History file: 1

Common to all

Max time steps or increments: 0

OK Cancel Help



## Notes.

- This form of load incrementation is the most simple to define but, depending on the degree of nonlinearity experienced by the structure within each load increment, convergence may not be achieved. To obtain convergence in such a case, it is necessary to apply the load gradually over a number of increments. This may be performed using manual incrementation

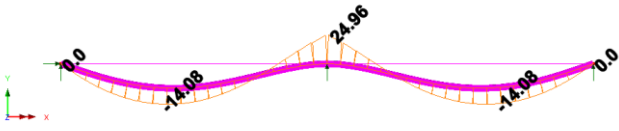
by increasing the number of load cases and adjusting the load levels applied in each. However as this method is tedious, it is easier to use automatic load incrementation which performs the same task automatically.

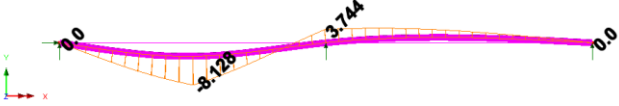
- By specifying **Manual** incrementation for the first loadcase unless changed, all other loadcases will automatically be assumed to be **Manual** incrementation without having to set the properties.

## Running the Analysis



Click the **Solve Now** button and press **OK** to run the analysis using LUSAS Solver and load the results file.

Incrementation type	Loadcase ID	Comments
MANUAL	<p>Loadcase 1 – Self weight of the bridge</p>  <p>Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 1:Dead load, Increment 1  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0184323 at node 33  Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 24.9601 at Gauss point 11 of element 20  Diagram minimum -14.0775 at Gauss point 6 of element 8  Diagram scale: 1: 0.400639</p>	Loadcase 1 is treated as a separate event and the results are shown to the left.

Incrementation type	Loadcase ID	Comments
MANUAL	<p data-bbox="256 281 591 309">Loadcase 2 – Span 1 pedestrian</p>  <p data-bbox="270 482 615 720"> Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 2:Span 1 pedestrian, Increment 2  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0101782 at node 11  Deformation exaggeration: 50.0  Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 3.74402 at Gauss point 11 of element 20  Diagram minimum -8.12799 at Gauss point 11 of element 10  Diagram scale: 1: 1.23032 </p>	<p data-bbox="955 281 1143 552">In Loadcase 2, the loading from the previous Loadcase – Loadcase 1 is forgotten and Loadcase 2 is treated as a separate.</p>



**Note.**



- By specifying **Manual** incrementation for all loadcases, the loading from Loadcase 1 is ‘forgotten’ during Loadcase 2. However the starting condition of Loadcase 2 is the internal stressed state and displacements from the end of Loadcase 1, and for this LUSAS solves for the out of balance equivalent nodal forces (caused by the forgotten loads from Loadcase 1 and the additional load in Loadcase 2). The resulting effect at the end of loadcase 2 is caused by the loading from Loadcase 2 only.

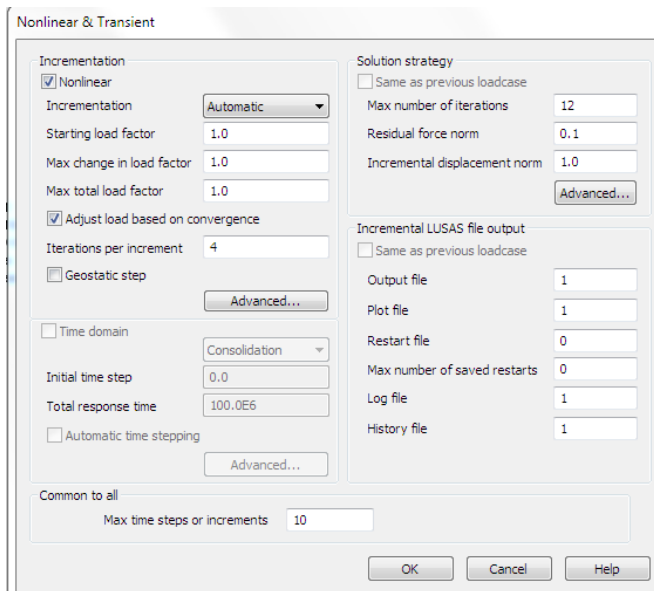
## Automatic Load Incrementation

The second analysis of the model will use **Automatic** load incrementation on both loadcases.

## Defining loadcase properties

- In the Treeview right-click on **Loadcase 1 – Self weight of the bridge** and, from the **Controls** menu item, select the **Nonlinear & Transient** menu option.
- On the Nonlinear & Transient dialog select the **Nonlinear** option in the top-left hand corner and leave the incrementation type as **Automatic**.
- Enter the **Starting load factor** as **1**, the **Max change in load factor** as **1** and **Max total load factor** as **1**.
- Enter the **Max time steps or increments** as **10** to allow extra steps for any possible step reductions.
- **Switch off Auto-Switch to arc length** by pressing the **Advanced** button and change **stiffness ratio to switch to arc-length** from **0.4** as zero.
- Click **OK** to return to the Modeller working window.

A Nonlinear and Transient object  will be added to the Treeview . Double-clicking on this object will allow any changes to be made to the control properties.



Section	Property	Value	
Incrementation	<input checked="" type="checkbox"/> Nonlinear		
	Incrementation	Automatic	
	Starting load factor	1.0	
	Max change in load factor	1.0	
	Max total load factor	1.0	
	<input checked="" type="checkbox"/> Adjust load based on convergence		
Time domain	<input type="checkbox"/> Time domain		
	Initial time step	0.0	
	Total response time	100.0E6	
Solution strategy	<input type="checkbox"/> Same as previous loadcase		
	Max number of iterations	12	
	Residual force norm	0.1	
	Incremental displacement norm	1.0	
	Advanced...		
	Incremental LUSAS file output	<input type="checkbox"/> Same as previous loadcase	
		Output file	1
Plot file		1	
Restart file		0	
Max number of saved restarts		0	
Log file		1	
History file		1	
Common to all	Max time steps or increments	10	

Repeat the above for Loadcase 2 using the same settings.



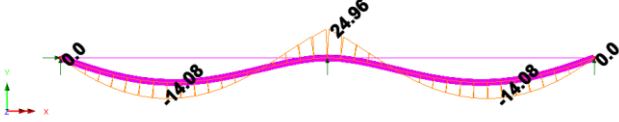
## Notes.

- This form of load incrementation is more involved than manual incrementation but it responds automatically to the solution behaviour, and gives the best possible chance of convergence by the use of step reduction and arc length procedures. In this example the default settings will be used, however more information on Uniform and Variable incrementation can be found in the online help.
- In this case **Automatic** incrementation is set on both loadcases.

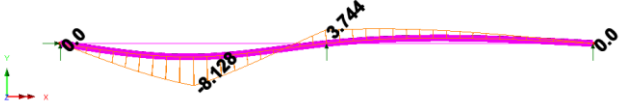
## Running the Analysis



Click the **Solve Now** button and press **OK** to run the analysis using LUSAS Solver and load the results file.

Incrementation type	Loadcase ID	Comments
AUTOMATIC	<p>Loadcase 1 – Self weight of the bridge</p>  <p>Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 1:Dead load, Increment 1 Load Factor = 1.00000  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0184323 at node 33  Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 24.9601 at Gauss point 11 of element 20  Diagram minimum -14.0775 at Gauss point 6 of element 8  Diagram scale: 1: 0.400639</p>	Loadcase 1 is treated as a separate event and the results are shown to the left.



<p>AUTOMATIC</p>	<p>Loadcase 2 – Span 1 pedestrian</p>  <p>Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 2:Span 1 pedestrian, Increment 2 Load Factor = 1.00000  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0101782 at Gauss point 11  Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 3.74402 at Gauss point 11 of element 20  Diagram minimum -8.12799 at Gauss point 11 of element 10  Diagram scale: 1: 1.23032</p>	<p>In Loadcase 2, the loading from the previous Loadcase – Loadcase 1 is forgotten and Loadcase 2 is treated as a separate.</p>
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**Note.**



- ❑ By specifying **Automatic** incrementation for all loadcases, the loading from Loadcase 1 is ‘forgotten’ during Loadcase 2. However the starting condition of Loadcase 2 is the internal stressed state and displacements from the end of Loadcase 1, and for this LUSAS solves for the out of balance equivalent nodal forces (caused by the forgotten loads from Loadcase 1 and the additional load in Loadcase 2). The resulting effect at the end of loadcase 2 is caused by the loading from Loadcase 2 only.

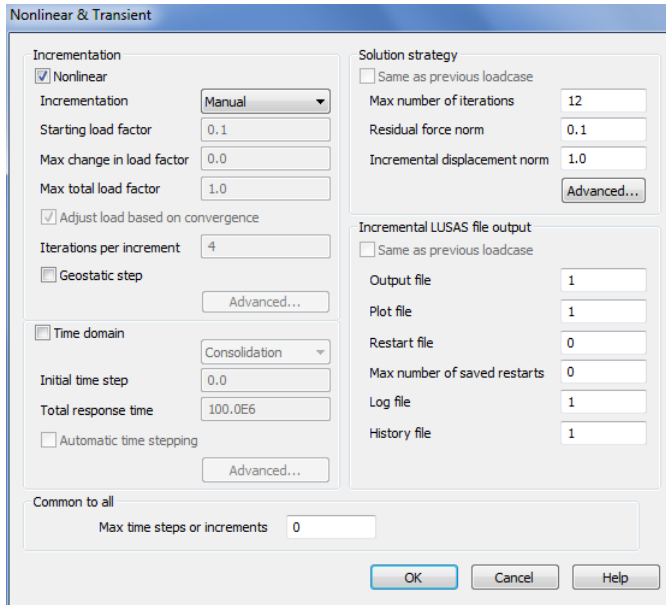
## Mixed Load Incrementation

For the third analysis **Mixed** load incrementation will be used.

### Defining loadcase properties

- In the  Treeview right-click on **Loadcase 1 – Self weight of the bridge** and, from the **Controls** menu item, select the **Nonlinear & Transient** menu option.
- On the Nonlinear & Transient dialog select the **Nonlinear** option in the top-left hand corner and leave the incrementation type as **Manual**.
- Click **OK** to return to the Modeller view window.

A Nonlinear and Transient object  will be added to the  Treeview. Double-clicking on this object will allow any changes to be made to the control properties.



**Nonlinear & Transient**

**Incrementation**

Nonlinear

Incrementation:  (dropdown)

Starting load factor:

Max change in load factor:

Max total load factor:

Adjust load based on convergence

Iterations per increment:

Geostatic step

**Solution strategy**

Same as previous loadcase

Max number of iterations:

Residual force norm:

Incremental displacement norm:

**Incremental LUSAS file output**

Same as previous loadcase

Output file:

Plot file:

Restart file:

Max number of saved restarts:

Log file:

History file:

**Time domain**

Time domain

(dropdown)


Initial time step:

Total response time:

Automatic time stepping

**Common to all**

Max time steps or increments:


- In the  Treeview right-click on **Loadcase 2 – Span 1 pedestrian** and, from the **Controls** menu item, select the **Nonlinear & Transient** menu option.
- On the Nonlinear & Transient dialog select the **Nonlinear** option in the top-left hand corner and leave the incrementation type as **Automatic**.
- Enter the **Starting load factor** as **1**, the **Max change in load factor** as **1** and **Max total load factor** as **1**.
- Enter the **Max time steps or increments** as **100** to allow for any possible step reductions.
- Click **OK** to return to the Modeller view window.

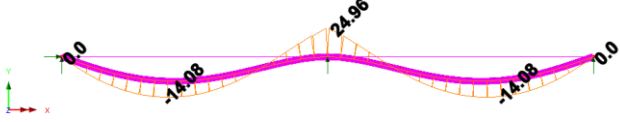
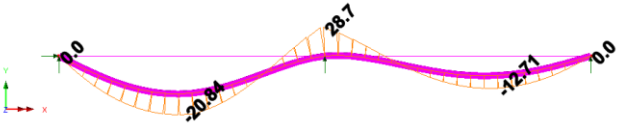
Nonlinear & Transient

<b>Incrementation</b> <input checked="" type="checkbox"/> Nonlinear Incrementation: Automatic Starting load factor: 1.0 Max change in load factor: 1.0 Max total load factor: 1.0 <input checked="" type="checkbox"/> Adjust load based on convergence Iterations per increment: 4 <input type="checkbox"/> Geostatic step <input type="checkbox"/> Time domain Initial time step: 0.0 Total response time: 100.0E6 <input type="checkbox"/> Automatic time stepping Common to all Max time steps or increments: 10		<b>Solution strategy</b> <input type="checkbox"/> Same as previous loadcase Max number of iterations: 12 Residual force norm: 0.1 Incremental displacement norm: 1.0 <b>Incremental LUSAS file output</b> <input type="checkbox"/> Same as previous loadcase Output file: 1 Plot file: 1 Restart file: 0 Max number of saved restarts: 0 Log file: 1 History file: 1	
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OK Cancel Help

## Running the Analysis

 Click the **Solve Now** button and press **OK** to run the analysis using LUSAS Solver and load the results file

Incrementation type	Loadcase ID	Comments
MANUAL	<p>Loadcase 1 – Self weight of the bridge</p>  <p>Scale: 1: 107.94 Zoom: 100.0 Eye: (0.0, 0.0, 1.0) Nonlinear analysis Analysis: Analysis 1 Loadcase: 1: Dead load, Increment 1 Results file: Simple footbridge-Analysis 1.mys Maximum displacement 0.0184323 at node 33 Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam Diagram component: Mz (Units: kN.m) Diagram maximum 24.9601 at Gauss point 11 of element 20 Diagram minimum -14.0775 at Gauss point 6 of element 8 Diagram scale: 1: 0.400639</p>	<p>Loadcase 1 is treated as a separate event and the results are shown to the left.</p>
AUTOMATIC	<p>Loadcase 2 – Span 1 pedestrian</p>  <p>Scale: 1: 107.94 Zoom: 100.0 Eye: (0.0, 0.0, 1.0) Nonlinear analysis Analysis: Analysis 1 Loadcase: 2: Span 1 pedestrian, Increment 2 Load Factor = 1.00000 Results file: Simple footbridge-Analysis 1.mys Maximum displacement 0.0285373 at node 10 Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam Diagram component: Mz (Units: kN.m) Diagram maximum 28.7041 at Gauss point 11 of element 20 Diagram minimum -20.8371 at Gauss point 2 of element 10 Diagram scale: 1: 0.348382</p>	<p>In Loadcase 2, the loading from the previous Loadcase – Loadcase 1 is remembered and held constant during Loadcase 2.</p>



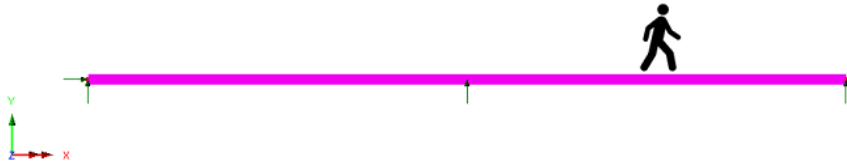
### Note.


- By specifying **Manual** incrementation followed by **Automatic** incrementation, the loading from Loadcase 1 is ‘remembered’ and held constant during Loadcase 2. The starting condition of Loadcase 2 is the internal stressed state and displacements from the end of Loadcase 1, and for this LUSAS solves for the out of balance equivalent nodal forces (caused by the additional load in Loadcase 2). The resulting effect at the

end of loadcase 2 is caused by the incorporation of loading from both Loadcase 1 and Loadcase 2.

### **Loadcase 3 – Span 2 pedestrian**

Let's now add a third loadcase with the pedestrian load in span 2.



- In the  Treeview right-click on **Loadcase 3 – Span 2 pedestrian** and, from the **Controls** menu item, select the **Nonlinear & Transient** menu option.
- On the Nonlinear & Transient dialog select the **Nonlinear** option in the top-left hand corner and leave the incrementation type as **Automatic**.
- Enter the **Starting load factor** as **1**, the **Max change in load factor** as **1** and **Max total load factor** as **1**.
- Enter the **Max time steps or increments** as **10** to allow for any possible step reductions.
- Click **OK** to return to the Modeller view window.

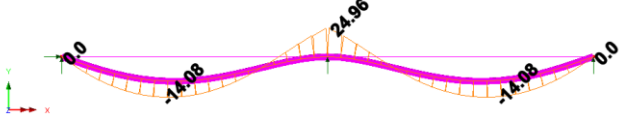
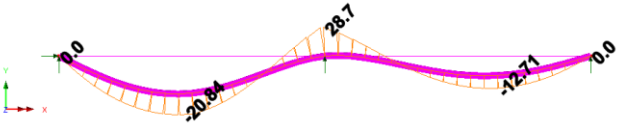
Nonlinear & Transient

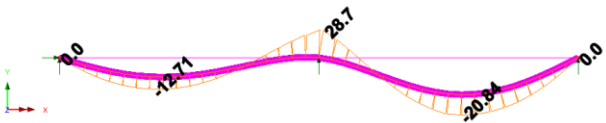
<input checked="" type="checkbox"/> Nonlinear Incrementation: Automatic Starting load factor: 1.0 Max change in load factor: 1.0 Max total load factor: 1.0 <input checked="" type="checkbox"/> Adjust load based on convergence Iterations per increment: 4 <input type="checkbox"/> Geostatic step <input type="checkbox"/> Time domain Initial time step: 0.0 Total response time: 100.0E6 <input type="checkbox"/> Automatic time stepping		Solution strategy <input type="checkbox"/> Same as previous loadcase Max number of iterations: 12 Residual force norm: 0.1 Incremental displacement norm: 1.0 <input type="button" value="Advanced..."/>	
<input type="button" value="Advanced..."/>		Incremental LUSAS file output <input type="checkbox"/> Same as previous loadcase Output file: 1 Plot file: 1 Restart file: 0 Max number of saved restarts: 0 Log file: 1 History file: 1	
Common to all Max time steps or increments: 10			
<input type="button" value="OK"/>		<input type="button" value="Cancel"/>	
<input type="button" value="Help"/>			

## Running the Analysis



Click the **Solve Now** button and press **OK** to run the analysis using LUSAS Solver and load the results file

Incrementation type	Loadcase ID	Comments
MANUAL	<p>Loadcase 1 – Self weight of the bridge</p>  <p>Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 1: Dead load, Increment 1  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0184323 at node 33  Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 24.9601 at Gauss point 11 of element 20  Diagram minimum -14.0775 at Gauss point 6 of element 8  Diagram scale: 1: 0.400639</p>	<p>Loadcase 1 is treated as a separate event and the results are shown to the left.</p>
AUTOMATIC	<p>Loadcase 2 – Span 1 pedestrian</p>  <p>Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 2: Span 1 pedestrian, Increment 2 Load Factor = 1.00000  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0285373 at node 10  Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 28.7041 at Gauss point 11 of element 20  Diagram minimum -20.8371 at Gauss point 2 of element 10  Diagram scale: 1: 0.348382</p>	<p>In Loadcase 2, the loading from the previous Loadcase – Loadcase 1 is remembered and held constant during Loadcase 2.</p>

<p>AUTOMATIC</p>	<p>Loadcase 3 – Span 2 pedestrian</p>  <p>Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 3:Span 2 pedestrain, Increment 3 Load Factor = 1.00000  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0285373 at node 32  Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 28.7041 at Gauss point 11 of element 20  Diagram minimum -20.8371 at Gauss point 10 of element 31  Diagram scale: 1: 0.348382</p>	<p>In Loadcase 3, the loading from the previous Loadcase – Loadcase 2 forgotten but the loading from Loadcase 1 is remembered and held constant during Loadcase 3.</p>
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**Notes.**

- ❑ By specifying **Manual** incrementation (Loadcase 1) followed by two **Automatic** incrementations (one each for Loadcase 2 and Loadcase 3), the loading from Loadcase 1 is ‘remembered’ and held constant during Loadcase 2.
- ❑ The starting condition of Loadcase 2 is the internal stressed state and the displacements from the end of Loadcase 1, and for this LUSAS solves for the out of balance equivalent nodal forces (caused by the additional load in Loadcase 2). The resulting effect at the end of Loadcase 2 is caused by the incorporation of loading from both Loadcase 1 and Loadcase 2.
- ❑ For Loadcase 3 the loading from Loadcase 2 is ‘forgotten’ but the loading from Loadcase 1 is remembered. The starting condition of Loadcase 3 is the internal stressed state and displacements from the end of Loadcase 2, and for this LUSAS solves for the out of balance equivalent nodal forces (caused by the forgotten loads from Loadcase 2 and the additional load in Loadcase 3). The resulting effect at the end of Loadcase 3 is caused by the incorporation of loading from both Loadcase 1 and Loadcase 3.

It is important to understand that Loadcase 3 appears to be loading from Loadcase 1 added to the loading from Loadcase 3, but it is more complex than that. It is really the internal stressed state and displacements from the end of Loadcase 2 with the addition of the out of balance equivalent nodal forces (caused by the forgotten loads from Loadcase 2 and the additional load in Loadcase 3). The consequence of this in relatively stiff or just linear elastic models is that the resulting effect at the end of Loadcase 3 is caused by the incorporation of loading from both Loadcase 1



and Loadcase 3. However if a model had nonlinear materials, then the plastic deformations or material damage in load case 2 is carried over. When there is no nonlinear materials and no significant nonlinear geometric effects in Loadcase 2, then the results in load case 3 will be independent of load case 2.

For large geometric effects (say snap through – see the following pages) It is likely that the resulting effect at the end of Loadcase 3 is not as expected or has convergence difficulties. However, most engineering structures are rigid enough such that the applied loads are not expected to excite a snap through behaviour.

### **Freezing the state of a model**

Finally, an additional Loadcase that will have Manual incrementation will be added in-between the existing Loadcase 2 and Loadcase 3. This new Loadcase 3 will have all the loads from Loadcase 1 and Loadcase 2 reassigned in a single **Manual** load step. This effectively ‘freezes’ the internal stressed state of the model at that point in the analysis, prior to Loadcase 4 being applied and assessed.

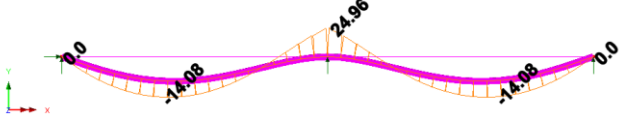
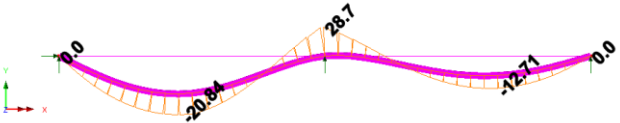
To recap:

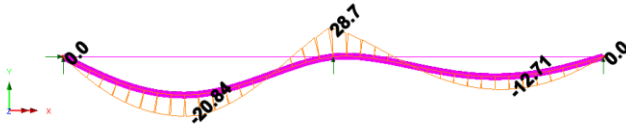
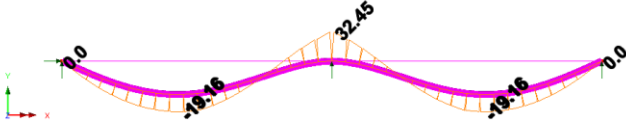
- Loadcase 1 – Self weight of the bridge
- Loadcase 2 – Span 1 pedestrian
- Loadcase 3 – Freeze (reapplying loads from Loadcase1 and Loadcase 2)
- Loadcase 4 – Span 2 pedestrian

## **Running the Analysis**



Click the **Solve Now** button and press **OK** to run the analysis using LUSAS Solver and load the results file

Incrementation type	Loadcase ID	Comments
MANUAL	<p>Loadcase 1 – Self weight of the bridge</p>  <p>Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 1: Dead load, Increment 1  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0184323 at node 33  Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 24.9601 at Gauss point 11 of element 20  Diagram minimum -14.0775 at Gauss point 6 of element 8  Diagram scale: 1: 0.400639</p>	<p>Loadcase 1 is treated as a separate event and the results are shown to the left.</p>
AUTOMATIC	<p>Loadcase 2 – Span 1 pedestrian</p>  <p>Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 2: Span 1 pedestrian, Increment 2 Load Factor = 1.00000  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0285373 at node 10  Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 28.7041 at Gauss point 11 of element 20  Diagram minimum -20.8371 at Gauss point 2 of element 10  Diagram scale: 1: 0.348382</p>	<p>In Loadcase 2, the loading from the previous Loadcase – Loadcase 1 is remembered and held constant during Loadcase 2.</p>

<p>MANUAL</p>	<p>Loadcase 3 – Freeze</p>  <p>Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 3:Freeze, Increment 3  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0285373 at node 10  Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 28.7041 at Gauss point 11 of element 20  Diagram minimum -20.8371 at Gauss point 2 of element 10  Diagram scale: 1: 0.348382</p>	<p>In Loadcase 3, the loading from the Loadcase 1 and Loadcase 2 is reassigned with Manual incrementation.</p>
<p>AUTOMATIC</p>	<p>Loadcase 4 – Span 2 pedestrian</p>  <p>Scale: 1: 107.94  Zoom: 100.0  Eye: (0.0, 0.0, 1.0)  Nonlinear analysis  Analysis: Analysis 1  Loadcase: 4:Span 2 pedestrian, Increment 4 Load Factor = 1.00000  Results file: Simple footbridge-Analysis 1.mys  Maximum displacement 0.0247678 at node 10  Deformation exaggeration: 50.0</p> <p>Diagram entity: Force/Moment - Thick 2D Beam  Diagram component: Mz (Units: kN.m)  Diagram maximum 32.4481 at Gauss point 11 of element 20  Diagram minimum -19.1628 at Gauss point 9 of element 9  Diagram scale: 1: 0.308184</p>	<p>In Loadcase 4, the loading from the previous Loadcase – Loadcase 3 is remembered and held constant during Loadcase 4.</p>



## Notes.

- ❑ By specifying **Manual** incrementation (Loadcase 1) followed by **Automatic** incrementation (loadcase 2), the loading from Loadcase 1 is remembered and held constant during Loadcase 2.
- ❑ The starting condition of loadcase 2 is the internal stressed state and displacements from the end of Loadcase 1 and solver now solves for the out of balance equivalent nodal forces (caused by the additional load in Loadcase 2). The resulting effect at the end of loadcase 2 is caused by the incorporation of loading from both Loadcase 1 and Loadcase 2.
- ❑ For loadcase 3, loads from both Loadcase 1 and Loadcase 2 need to be considered. Currently this requires that the load attributes from Loadcase 1 and Loadcase 2 need to be reassigned into Loadcase 3 (these can be copied and pasted in LUSAS Loadcase tree view). The starting condition of loadcase 3 is the internal stressed state and displacements from the end of Loadcase 2 and solver now solves for the out of balance equivalent nodal forces. Since there is no additional load added in Loadcase 3 there is no out of balance equivalent nodal forces and the solution converges instantaneously. However, having solved Loadcase 3 as a **Manual** incrementation it allows Loadcase 4 to be added such that the internal stressed state is remembered and can be added to.
- ❑ For Loadcase 4, the loading from Loadcase 3 is remembered and held constant during Loadcase 4. The starting condition of loadcase 4 is the internal stressed state and displacements from the end of Loadcase 3 and solver now solves for the out of balance equivalent nodal forces (caused by the additional load in Loadcase 4). The resulting effect at the end of loadcase 4 is caused by the incorporation of loading from both Loadcase 3 and Loadcase 4.

This completes the example.

## Discussion

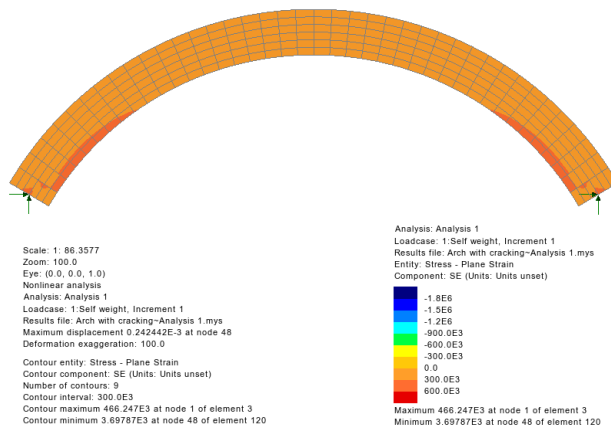
If prescribed displacement or initial stress loading is being used to model settlement, the loading will always be remembered regardless of **Manual** or **Automatic** incrementation, therefore the effect of prescribed displacements will be remembered and will not need to be input again.

If a creep material model is used with transient control (time) only **Manual** incrementation is used but the loading is 'remembered' through the analysis as long as there are no new loads in different load cases.

This worked example is a rather simplistic linear model of a footbridge that shows the effect that the use of **Manual** or **Automatic** incrementation for individual loadcases can have of the resulting effects. In most cases, apart from linear stage construction, the model being considered is likely to include significant nonlinear affects.

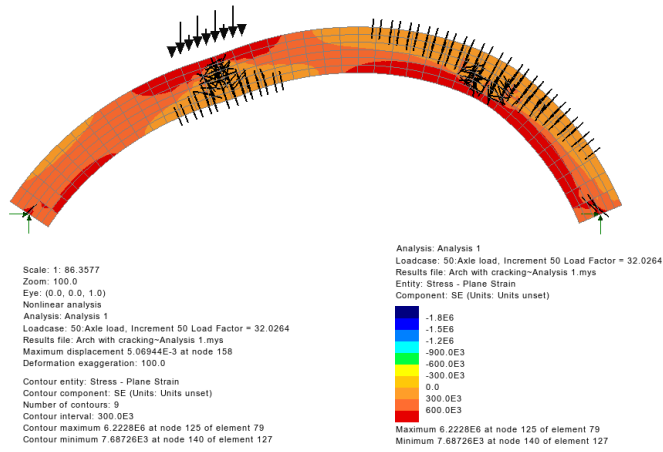
Consider the more complex example below of a masonry arch:

Loadcase 1 is the self weight of the structure and the soil overburden. It has been applied using Manual incrementation.



Loadcase 2 applies a wheel load as a pressure locally to part of the arch and ramps the load intensity up using Automatic incrementation.

- On the Nonlinear & Transient dialog select the **Nonlinear** option in the top-left hand corner and leave the incrementation type as **Automatic**.
- Enter the **Starting load factor** as **1**, the **Max change in load factor** as **1** and **Max total load factor** as **50**.
- Enter the **Max time steps or increments** as **100** to allow for any possible step reductions.



This results in significant nonlinear affects (cracking) of the arch ring. Since the load intensity has been ramped-up using the **Automatic** incrementation, following this Loadcase 2 with further Loadcases using **Automatic** incrementation is likely to cause problems. This is because Loadcase 3 would start with the internal stressed state and displacements from the last increment of Loadcase 2, with its high stress, cracks and highly deformed shape. **It is important to notice that whatever controls that you apply after this stage, the cracked structure will not heal and will not go back to unloaded stage.**

In this case if different wheel positions are required with increasing load intensity from Automatic incrementation it is likely that multiple analyses would be used, one for each wheel position.

Another good example to consider is a simple shallow convex arch.



If sufficient load is applied in Loadcase 1 with **Manual** incrementation, such that the arch snaps through, it will create the concave deformed shape shown below.



If Loadcase 2 is added with **Manual** incrementation the loading from Loadcase 1 is 'forgotten' but the starting condition of this loadcase would be the internal stressed state and displacements at the end of Loadcase 1. Obviously since the arch has snapped through the starting conditions of Loadcase 2 (snapped through shape) will be completely different than that of Loadcase 1. So in this case to get back to the initial starting geometry rather than allowing the loads to be 'forgotten' the second loadcase might be used to reverse the original loading. Following this reversal then additional loading can be added. If such a method is applied, it is essential to check all deformations are zero (or nearly zero) before progressing.

## Conclusion

- If you are using **Manual > Manual > Manual** to simulate a moving load analysis where the load is being considered at different locations across the model it has to be realised that each Loadcase is not starting from the undeformed geometry but is using the internal stressed state and displacements at the end of the previous Loadcase.

For example if a load is moved across the model and at position 1 the load causes any sort of material nonlinearity (say yielding or cracking) when the load is moved to position 2 it will be starting from the damaged structure which was obtained at the end of the previous Loadcase.

This loading sequence for a trying various load positions can also cause problems if a snap through response is achieved (see above).

- If you are using **Manual > Manual > Manual** to simulate a stage construction sequence where the all loads are reassigned in each loadcase. Then the fact that the next Loadcase is using the internal stressed state and displacements from the previous Loadcase will not be a problem as that is what is required.



## Appendix A - Manual vs Automatic decision flow chart

This chart is not applicable to time domain problems or those using load curves, where “manual” incrementation should generally be used

