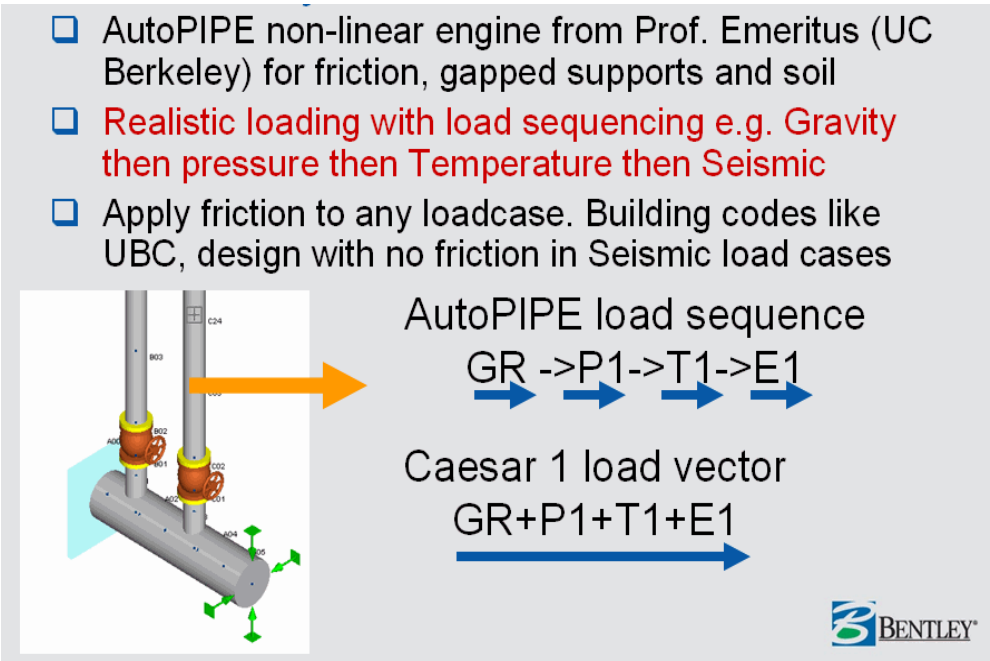
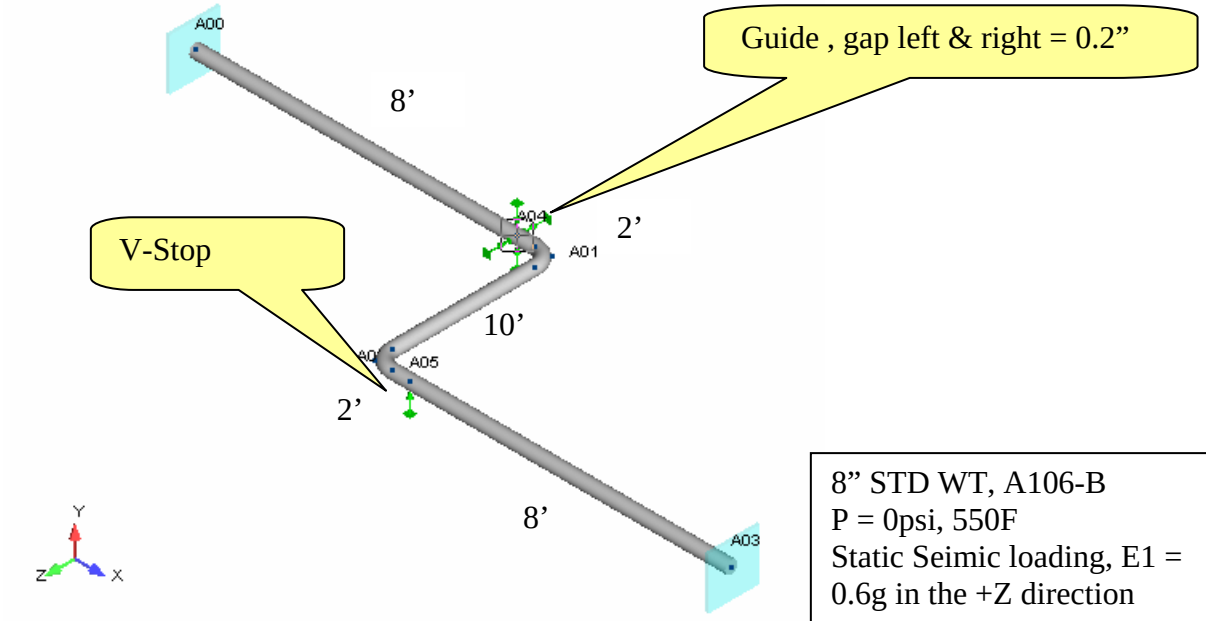
Understanding Non-Linear Load Sequencing

Typical loadings are Deadweight applied then pressure then system heated up. i.e. Gr -> P1 -> T1. Many pipe stress programs lump all these loadings together. AutoPIPE non-linear analysis applies these loadings in a sequence with Gravity always first as expected.

Note: There is no load sequencing for a Linear analysis.



Lets look at Loading Sequencing



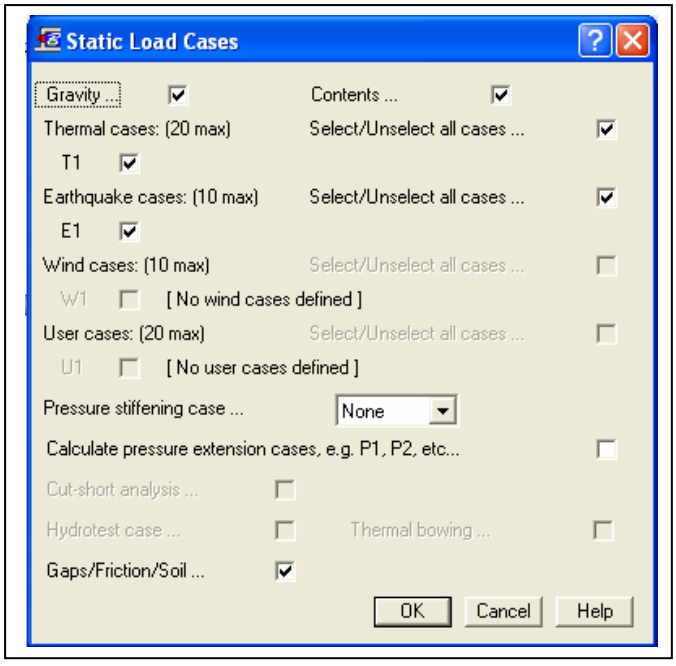
8" STD WT, A106-B
P = 0psi, 550F
Static Seimic loading, E1 = 0.6g in the +Z direction

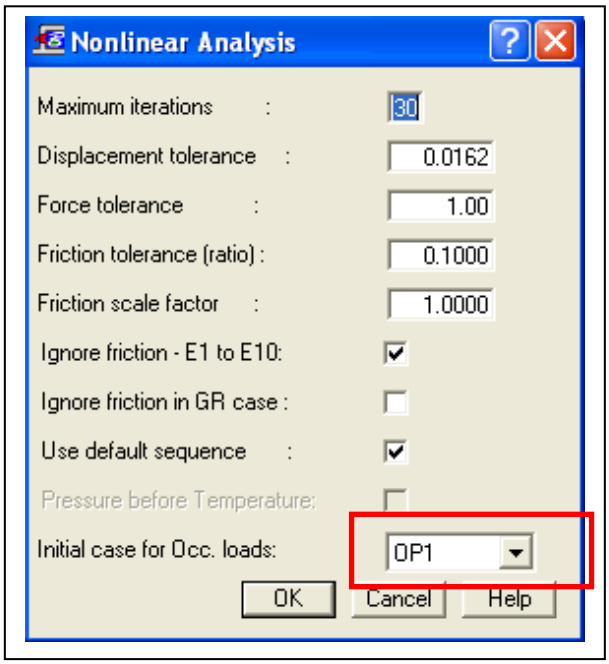
Example 1

No friction, load sequence = OP1 for occasional loads like Seismic, Wind, User etc

OP1 = hot operating condition GR -> T1, since no pressure analysis. So case E1 is applied in the hot condition after Gravity and temperature are applied.

Create User combination: GrE1 = Gr + E1 [This is to illustrate how this combination is inconsistent with the load sequence]





S U P P O R T F O R C E S

(Force - lb , Moment - ft-lb , Tran. - in , Rot. - deg)

Point/ Supp. ID	Connect/ Type	Load Combination	L O C A L Dirn	Force	Deform	G L O B A L Dirn	Force	Deform
Tag No.: <None>								
A04		GR	down	727	0.000	X		0.000
A04 1	Guide		left		0.000	Y	-727	0.000
Stiff	:RIGID		back		0.000	Z		0.000
		T1	down		0.000	X		0.737
			left	232	0.200	Y		0.000
			forw		0.737	Z	-232	-0.200
		E1	down		0.000	X		0.000
			rght	232	0.306	Y		0.000
			forw		0.000	Z	232	0.306
		GT1	down	727	0.000	X		0.737
			left	232	0.200	Y	-727	0.000
			forw		0.737	Z	-232	-0.200

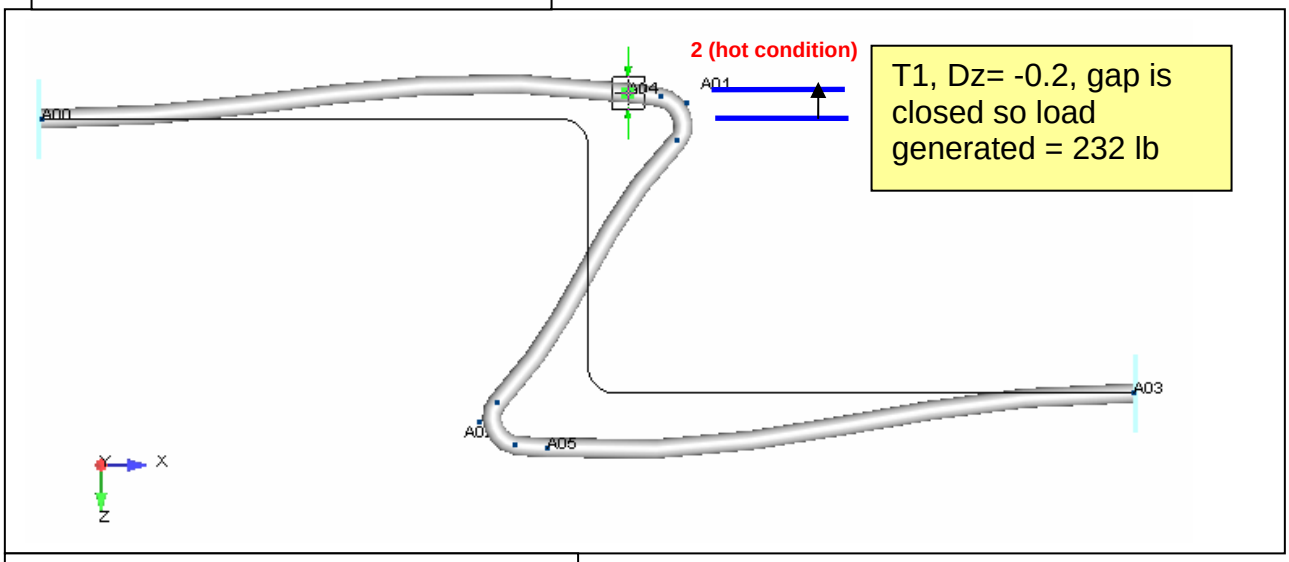
Notice default non-code combination is GT1E1 which is consistent with the load sequence

Notice combined movement =0.106" in +Z direction

GT1E1	down	727	0.000	X		0.737
	rght		0.106	Y	-727	0.000
	forw		0.737	Z		0.106
GRE1	down	727	0.000	X		0.000
	rght	232	0.306	Y	-727	0.000
	forw		0.000	Z	232	0.306

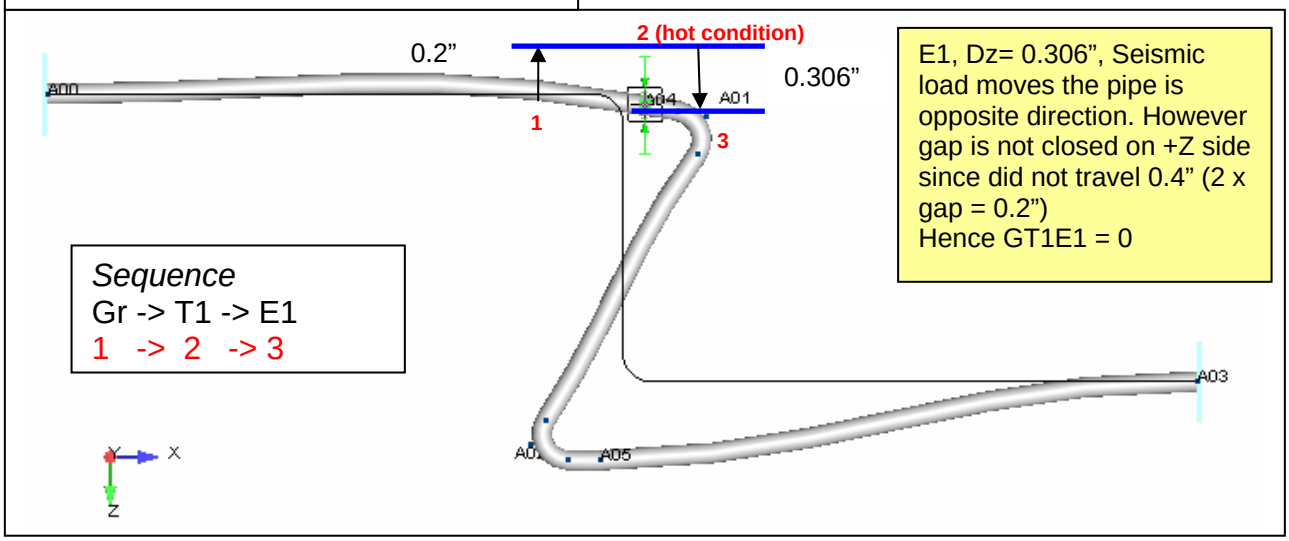
Inconsistent User Combination GrE1

2. Thermal Loading (GT1)



T1, Dz= -0.2, gap is closed so load generated = 232 lb

3. Seismic E1 Loading (GT1E1)



Sequence
Gr -> T1 -> E1
1 -> 2 -> 3

E1, Dz= 0.306", Seismic load moves the pipe is opposite direction. However gap is not closed on +Z side since did not travel 0.4" (2 x gap = 0.2")
Hence GT1E1 = 0

However notice User combination GrE1 = Gr + E1, GrE1 Load at A04 guide, Fz = 232lb. However this does not make sense because the load sequence was Gr then T1 then E1, so this combination GrE1 does not consider movement due to T1. It thinks the E1 is applied after Gravity case which is not correct. If it was for E1, expect Dz = 0.2" instead of 0.306" and gap closed.

Note: Gr -> P1 -> T1 -> E1 gives the same result as Gr -> T1 -> P1 -> E1

Also refer to Analysis Summary

A N A L Y S I S S U M M A R Y

```
Current model revision number : 6

  Static - Date and Time of analysis ..... Apr 16, 2007   9:46 AM
           Model Revision Number ......... 6
           Number of load cases .......... 3
           Load cases analyzed ........... GR  T1  E1
           Gaps/Friction/Soil considered ..... Yes
           Tolerance - Force, Displacement ..... 1.00 lb   0.0162 in
           Friction - Scale Factor, Tolerance .... 1.00   0.10
           Ignore friction for cases E1,E2,E3 .... Yes
           Ignore friction for gravity case ...... No
           Hanger design run ..................... No
           Cut short included .................... No
           Thermal bowing included ............... No
           Include Bourdon rotational effect ..... No
           Pipe radius for Bourdon calculation ... Mean
           Occasional load analysis type ......... Nonlinear
           Non-linear analysis summary file ...... LOADSEQ_1.LOG
           Use default load sequence ............. Yes
           Base load cases for nonlinear analysis
                                                   GR  = None
                                                   T1  = GR
                                                   E1  = T1
```

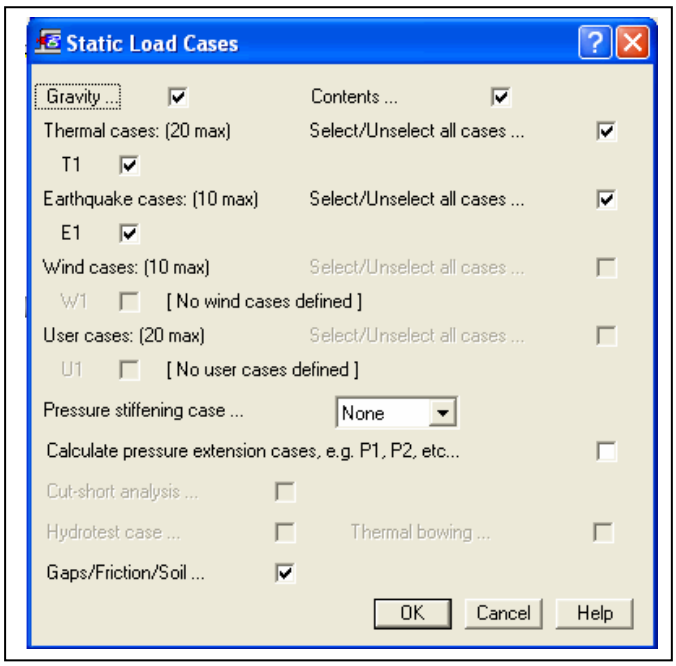
Actual load sequence:

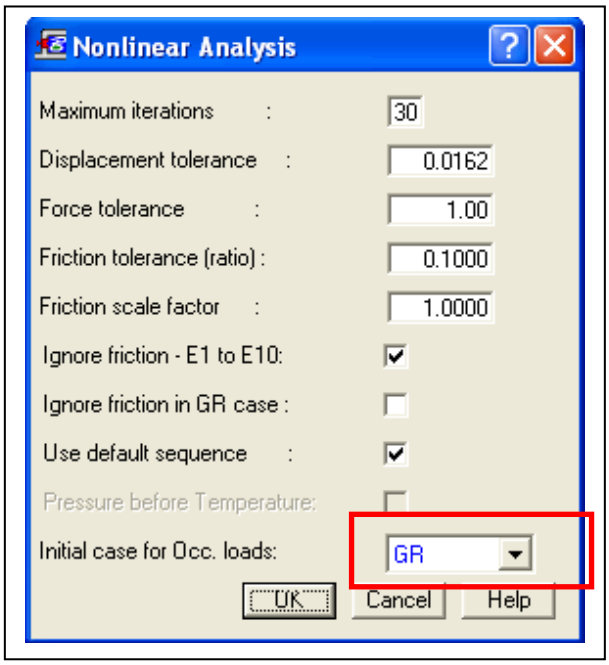
GR -> T1 -> E1

Example 2

No friction, load sequence = GR for occasional loads like Seismic, Wind, User etc

GR = cold operating condition GR -> E1, since no pressure analysis. So case E1 is applied in the cold condition after Gravity so temperature is not considered.





S U P P O R T F O R C E S

(Force - lb , Moment - ft-lb , Tran. - in , Rot. - deg)

Point/ Supp. ID	Connect/ Type	Load Combination	L O C A L Dirn	Force	Deform	G L O B A L Dirn	Force	Deform
Tag No.: <None>								
A04		GR	down	727	0.000	X		0.000
A04 1	Guide		left		0.000	Y	-727	0.000
Stiff	:RIGID		back		0.000	Z		0.000
		T1	down		0.000	X		0.737
			left	232	0.200	Y		0.000
			forw		0.737	Z	-232	-0.200
		E1	down		0.000	X		0.000
			rght	450	0.200	Y		0.000
			forw		0.000	Z	450	0.200
		GT1	down	727	0.000	X		0.737
			left	232	0.200	Y	-727	0.000
			forw		0.737	Z	-232	-0.200
		GE1	down	727	0.000	X		0.000

Notice default non-code combination is GE1 which is consistent with the load sequence
i.e. no temperature case considered

		rght	450	0.200	Y	-727	0.000
		forw		0.000	Z	450	0.200
	GRE1	down	727	0.000	X		0.000
		rght	450	0.200	Y	-727	0.000
		forw		0.000	Z	450	0.200

Notice combined movement =0.2" in +Z direction, i.e. gap distance

Also refer to Analysis Summary

A N A L Y S I S S U M M A R Y

Current model revision number : 6

```
  Static - Date and Time of analysis ..... Apr 16, 2007   9:14 AM
           Model Revision Number ......... 6
           Number of load cases .......... 3
           Load cases analyzed ........... GR  T1  E1
           Gaps/Friction/Soil considered ..... Yes
           Tolerance - Force, Displacement ..... 1.00 lb   0.0162 in
           Friction - Scale Factor, Tolerance .... 1.00   0.10
           Ignore friction for cases E1,E2,E3 .... Yes
           Ignore friction for gravity case ...... No
           Hanger design run ..................... No
           Cut short included .................... No
           Thermal bowing included ............... No
           Include Bourdon rotational effect ..... No
           Pipe radius for Bourdon calculation ... Mean
           Occasional load analysis type ......... Nonlinear
           Non-linear analysis summary file ...... LOADSEQ_1.LOG
           Use default load sequence ............. No
           Base load cases for nonlinear analysis
                                                   GR  = None
                                                   T1  = GR
                                                   E1  = GR
```

Actual load sequence:

GR -> T1
GR -> E1

Summary

	Load Case	SEQ	LOAD	Disp (DZ)	Reaction (Fz)		Remarks
						0.2	
CASE1	OP1 as initial state for E1	A	GR	0.000	0		
	Earthquake during operation	B	GR+T1	-0.200	-232		Gap closes due to T1
	Actual case GT1E1	C	GR+T1+E1	0.106	0		Pipe moves 0.306 inches due to E1, no contact with gap support
						0.306	Displacement due to E1 alone in hot case
	User Cases E1 and GR+E1	C-B	E1	0.306	232		
	obtained by superposition	A+(C-B)	GR+E1	0.306	232		Conflicting results, movement (0.306") > gap(0.2"), smaller reaction and most likely larger stresses due to large displacement
							E1=(GR+T1+E1)-(GR+T1) (linear superposition)
							GE1 estimated by linear superposition
CASE2	GR as initial state for E1	A	GR	0.000	0		
	Earthquake during cold case Actual case GE1	B	GR+E1	0.200	450		Gap closes, Large reaction, smaller disp and stress
							Actual GE1 case
	Bottom line: When support conditions change, superposition leads to inconsistent and less accurate results						

Recommendations

It is recommended to evaluate the maximum support loads and movements by analyzing both GR and OP1 default sequence. Also remember to include + ve and –ve Seismic and wind loadings for 'worst-case' evaluation of occasional loads and stresses.