Fermilab

PPD/MD/Engineering Analysis Group

Nonlinear Analysis for Nova Structure(v-1)

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Oct 5, 2006

Introduction

Nova detector will be constructed as "block by block" scheme. Each block consists of 1 layers of the PVC extrusion, which will be subjected a 19 psi hydrostatic load and the gravity of the liquid. It is a plastic structure. The creep deformation as the function of the time is a concern. The following analysis is to study this issue based on the several different approaches[1,2,3,5]:

1) Eigen value buckling calculation by using E creep from 1/D curve [4] for 3,5,10 and 20 year (->ΔF).
2) Static non-linear large deflection for E = 20 years value (->ΔF).
3) Time dependent of Non-linear large deflection calculation (->Δt).

The first analysis is very straight forward. It is a linear eigen value extraction __ Euler buckling equation with its E = E creep for a given time. A load factor _ SF is calculated. It indicates that how much additional force, ΔF, is required to collapse the structure. Second calculation is a static non-linear large deflection approach. A structure is given an initial imperfection, e.g. 1" off-set at its top. Then a load is applied to the structure gradually as the structure deforms. The element stiffness matrix is updated during the increment of the loading such that the geometry nonlinearity effect is counted. The structure eventually becomes very unstable as the load increases to a certain point. A small incremental of the load will result a very large or infinite deflection. A critical load, Pcr, is found. SF is calculated as SF=Pcr/Pop. This is considered to be much more accurate than the eigenvalue approach. However, for a simple and well shaped geometry, the first two methods should give a very similar result to find ΔF.

The PVC creep is the time dependent phenomena. To understand its structure stability as the function of time, third calculation is to keep the load as a constant while changing the material property E (t) as function of time. E(t) curve is provided by reference 4. For the asymmetry case with 1" off-set at its top, it is expected that the structure will be lean on one direction. Its magnitude will increase as the creep progress. At some point of time, the deflection of structure gets so large such that the internal bending resistance of structure breaks. It is called as a time dependent buckling which occurs gradually. The time required to accumulate the such deflection is called as critical time t_{cr} .

Result and Discussion

1) First calculation is done by using an eigen value linear buckling with E=Ecreep(3, 5, 10 and 20 year). The result is summarized in Table 1. The boundary condition for the 31 layers block is "top free and bottom fixed" as "free standing case".

Table-1 Calculation result based on the first approach

Year	E creep _1/D (mpsi)	SF
3	0.218	3.1
5	0.195	2.75
10	0.165	2.3
20	0.136	1.859
130*	0.0731	1

* Note: To achieve SF=1, the modulus of E(t) can be found as E (t)= 0.136/1.859 =0.0731 mpsi. Then, the time t, for E reaches 0.0731 mpsi, can be found from E (1/D) vs time curve, as t_{cr} ~130 years.

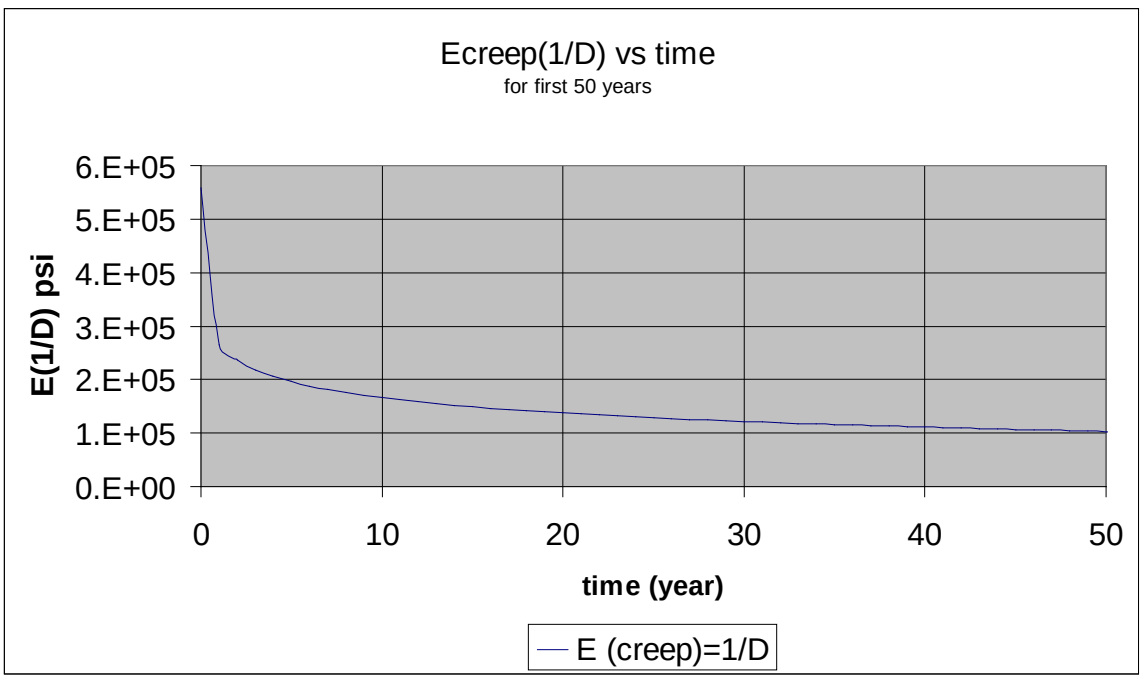

Fig 1The creep modulus as function of time for first 50 year

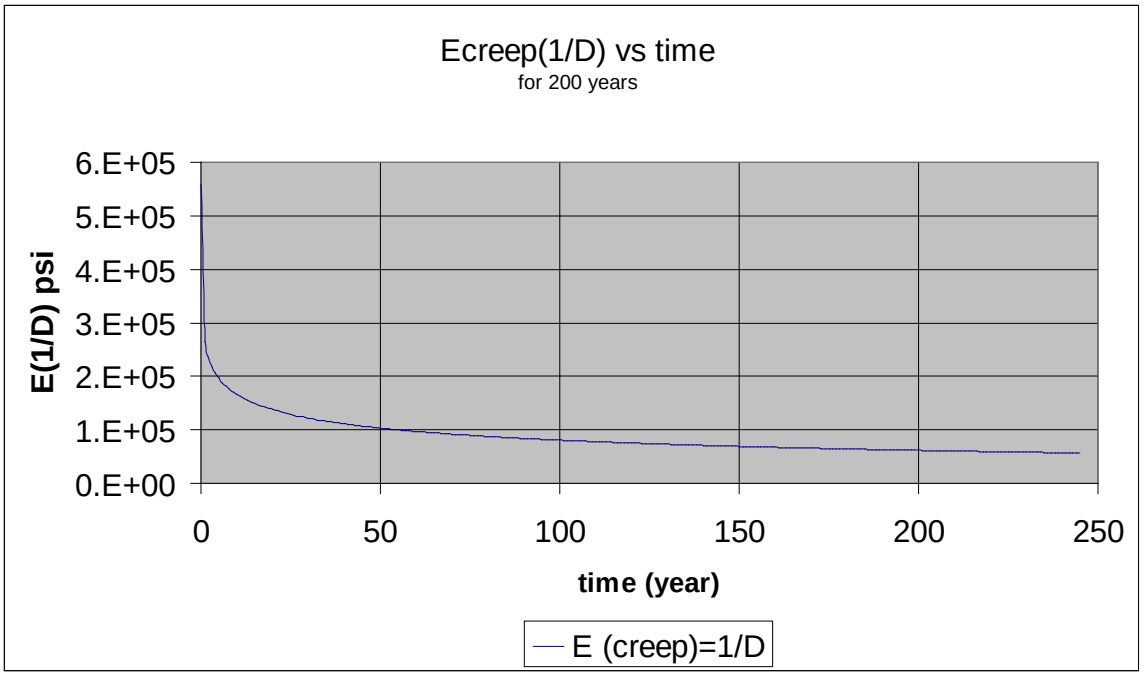

Fig 2 The creep modulus as function of time for 200 year

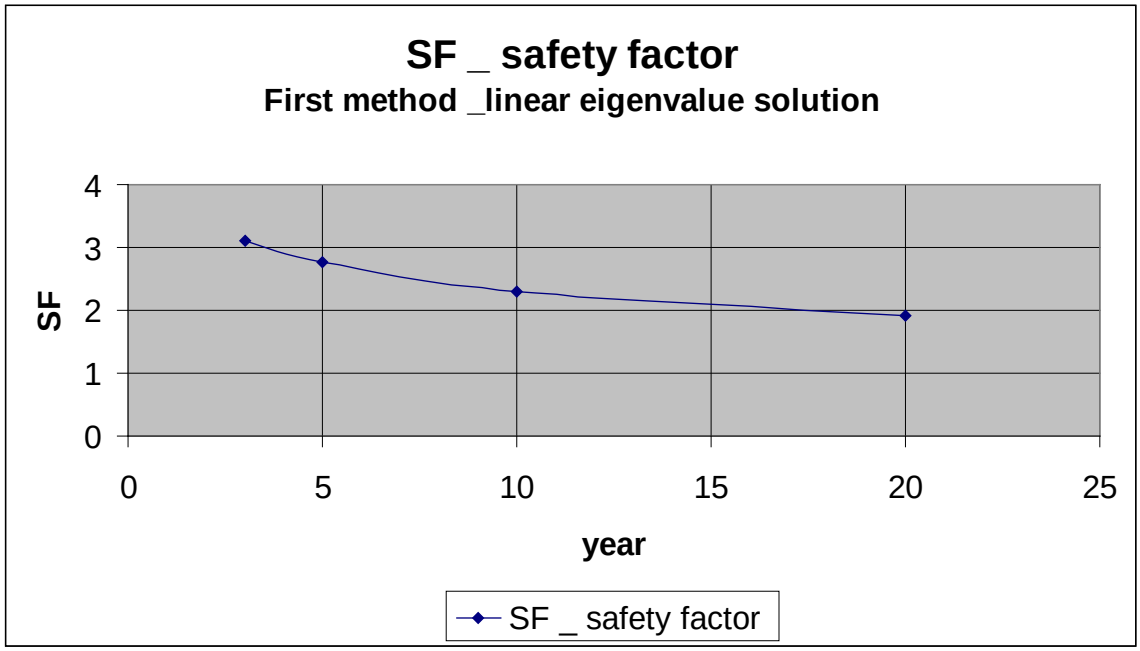

Fig 3 Safety factor of SF as function of the year

2) Result based on the second method

A static nonlinear large deflection approach is used for the second analysis. E=E creep (20y)=0.136 mpsi is used for the calculation. Initially, it is assumed that the structure has 1" off-set at its top to simulate the structure imperfection. Then, the load/force has been increased gradually to seek a maximum value at which the structure becomes unstable. The element stiffness matrix is updated during the iterations such that the geometry nonlinearity is captured. It is considered to be much accurate method with a drawback of computational time. Fig 4 shows the deflection UX (beam direction) as a function of the loading. It shows that the structure deflection increases rapidly after 1.75 G load. For a load ~1.75 G, its top deflection is about 5" inch over 53 ft high. It gives SF=1.75. As the load increased to 2.5 G load, the deflection becomes so excessive (150") and the structure simply collapses. Compared with the result from eigen value solution for E=0.136 mpsi, the difference is negligible as shown in Table 2.

Table 2 Comparison for an Eigen value (Euler) and static nonlinear large deflection solution with E(20y)=0.136 mpsi

E(20y)=0.136 msi	Eigenvalue (Euler)	Static nonlinear large deflection
SF	1.85	1.75

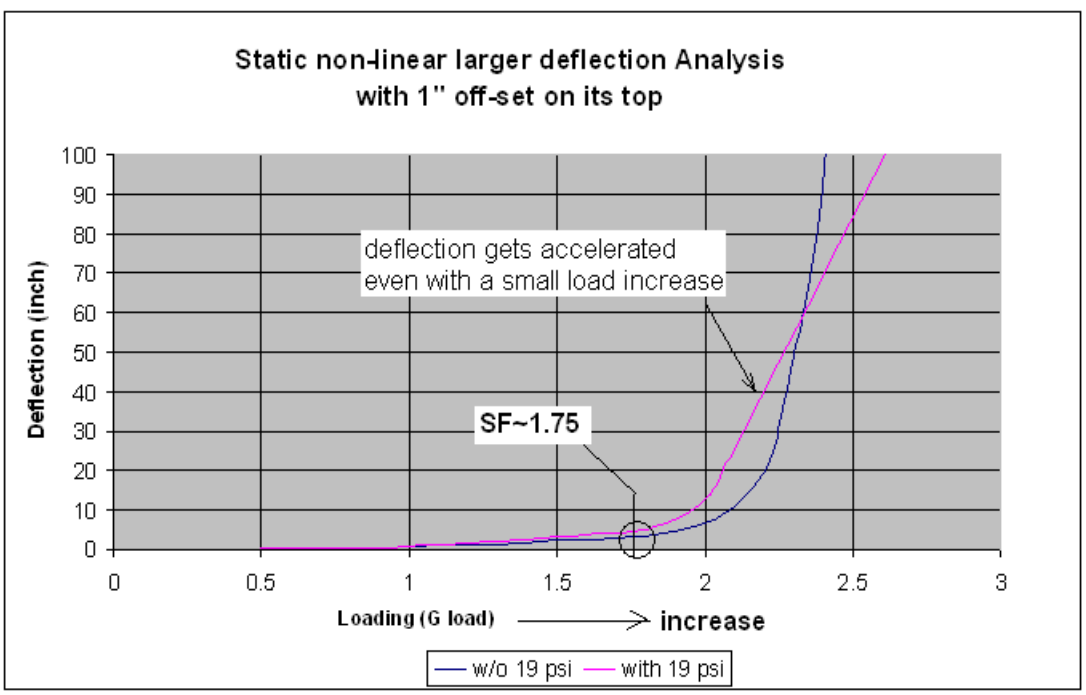

Fig 4 Deflection as a function of the G load

Above two approaches give the estimation of the how much additional force (ΔF) which structure may be able to withstand before it breaks (buckle). However, it does not address how much time is needed to develop the excessive deformation for the structure if the load is a constant.

3) Third analysis __ time dependent of nonlinear large deflection analysis.

a) <u>Stability</u>

A similar model is used as the method 2 above, except a constant loading is applied with E as a function of time t. E(t) has a polynomial form provided by reference 4. The solution starts with an initial imperfection of 1" off-set at its top with a 19 psi and G load. The modulus of E(t) curve is updated every year for first 20 years and every five years after that up to a point when an excessive deformation is developed. A critical time, t_{cr}, is found. The calculation indicates that the critical time is around 140 year as shown in Fig 5. For a 20 year of life span, the deflection on the top is less than 1" as shown in Fig 6

It is also very interesting to note that the tcr=140 yeas, calculated based on time dependent of non linear analysis, <u>is very comparable</u> to the value estimated by using eigenvalue approach as shown in Table 1. It is not surprising since tcr is found by using method 1 is also based on graphically fitting E (t) curve, which already includes a "time dependent factor " as suggested by reference 3.

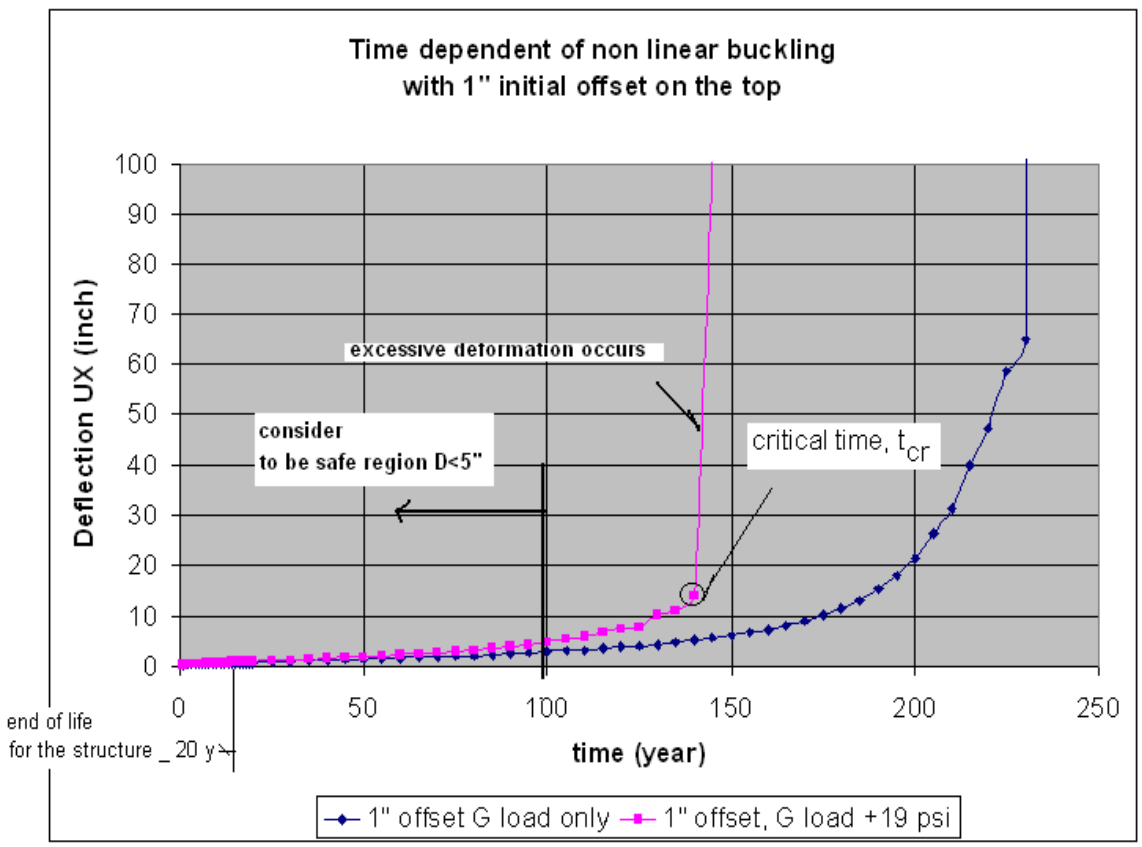

Fig 5 The deflection as function of the time based on the 3rd approach

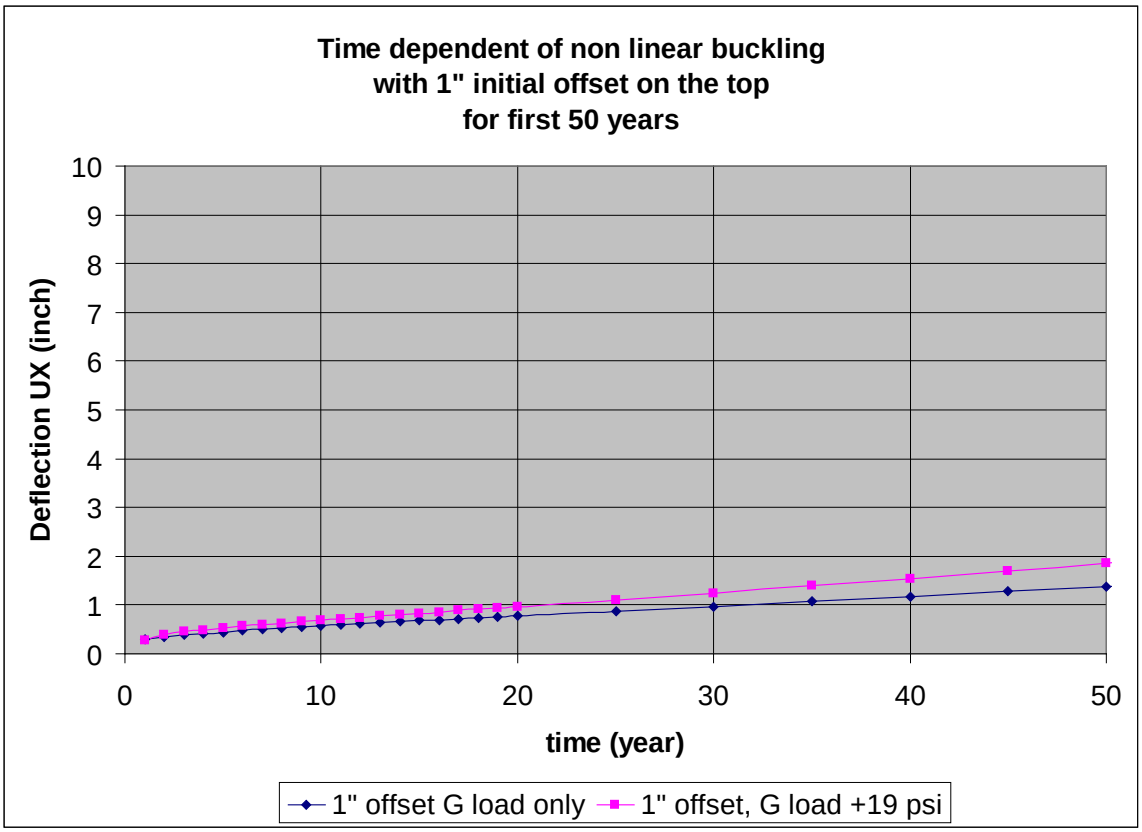

Fig 6 Deflection as function of the time based on the 3rd approach for first 50 year

b) <u>Stress</u>

PVC and adhesive stress, at 20 and 40 year interval, is also extracted from same model as shown in table 2. There is no significant stress change between 20 and 40 years since the deflection is still relative small with 0.996" for t=20 year and 1.527" for t=40 year over 53' high.

Table 2 The Stress and deflection based the time dependent of nonlinear large deflection

Time (year)	Deflection At top (inch)	*Maximum stress (psi)	*Maximum Strain (%)	*Maximum adhesive Shear (psi)	*Maximum Adhesive Peeling (psi)
20	0.996	832/540	0.605/0.3934	169	24.45
40	1.527	846/551	0.7625/0.497	171	25.19

* Note: Stress and strain column has a form of " corner peak value/ without considering corner peak value" as illustrated in Fig 7 and Fig 8. The adhesive stress is an average stress over the adhesive area

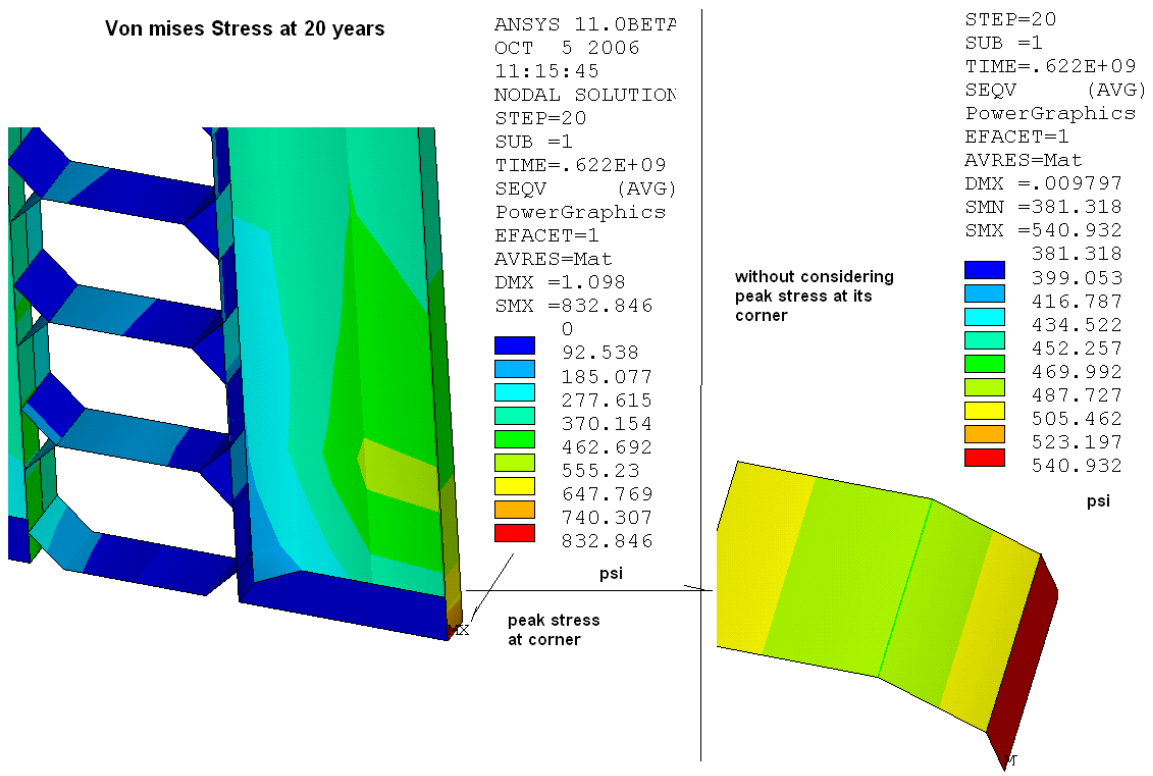

Fig 7 Von Mises **stress at t=20 years**

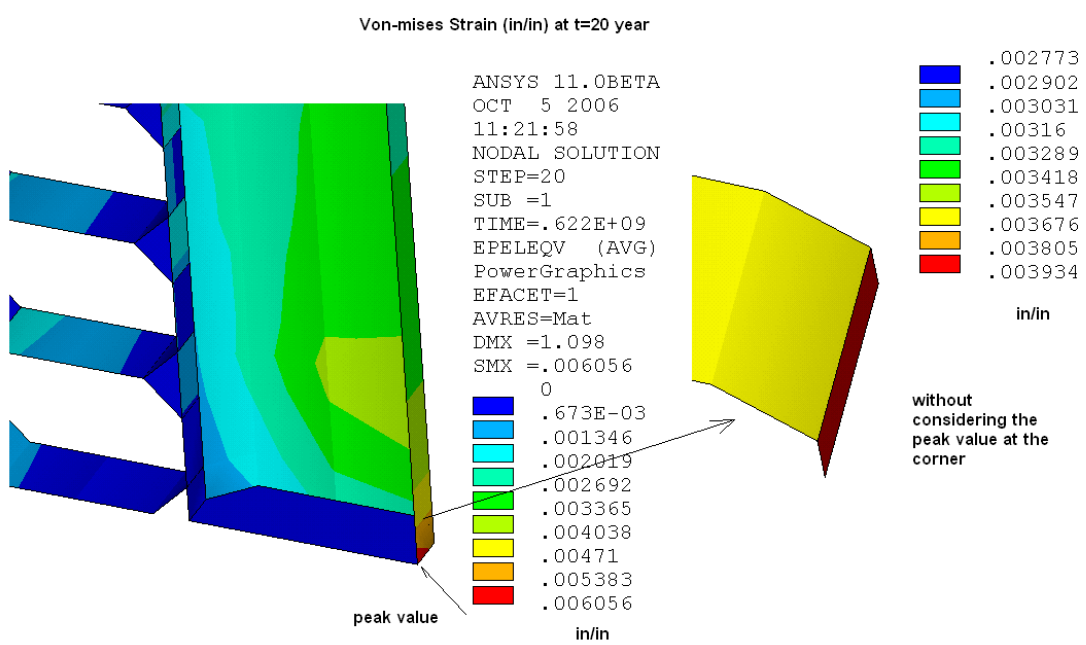

Fig 8 Von Mises strain at t=20 year

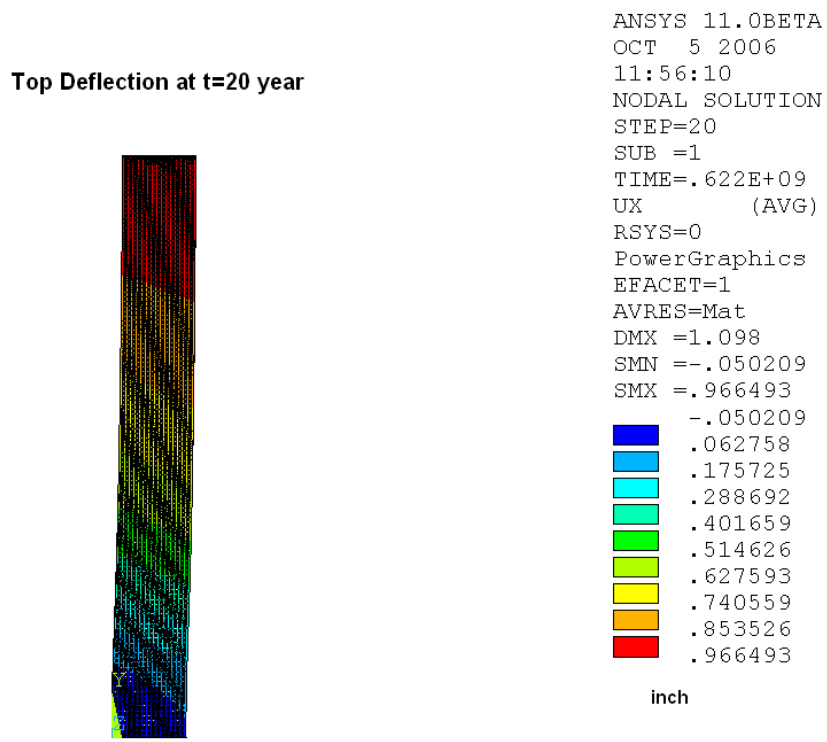

Fig 9 Top deflection at t=20 years

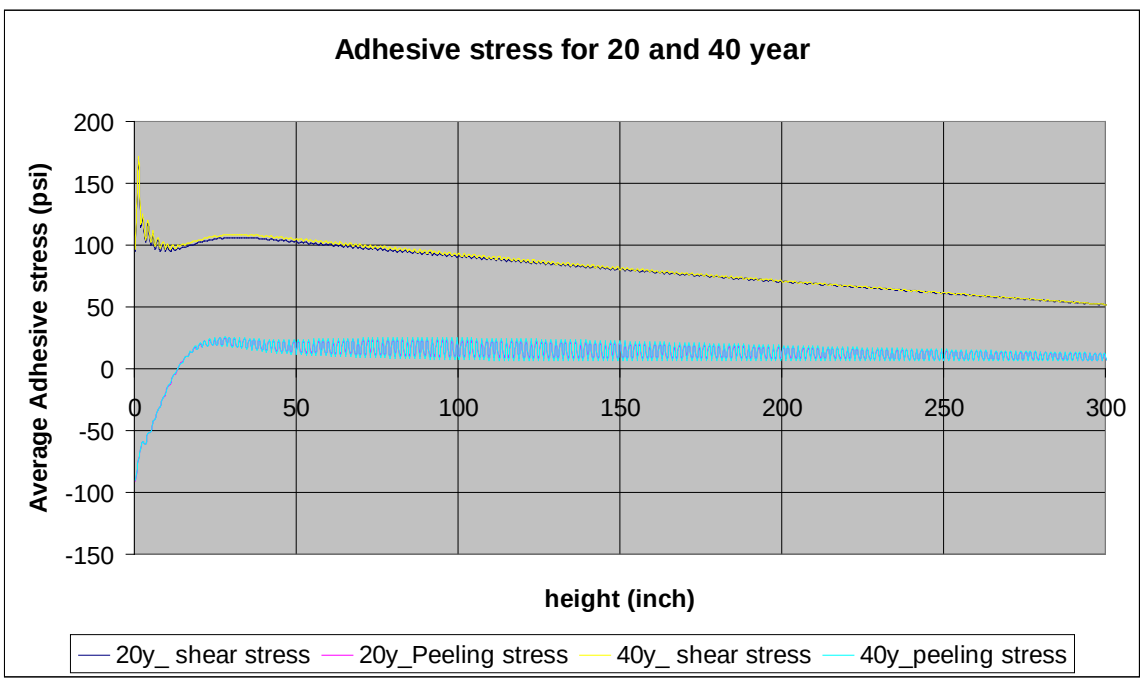

Fig 10 Adhesive stress for t=20 and 40 year

c) Comparison for the operating condition

Since many of earlier calculations is done based on "one step" linear approach by using the PVC modulus of E(20y)=0.136 mpsi as an equivalent/effective modulus. It is considered to be a standard structure approach, used by many references [1,2,3,5] .It will be very interesting to see whether it is the true here for the 31 layer structure. Table 3 is a comparison for the 31 block under 19 psi and G load of the liquid (operating case). Result indicates that there is virtually no difference at all. It explains why it is widely acceptable practice by using a standard structure equation with its modulus E being a value of E_{creep} for a given time of t.

Table 3 Comparison for the "one step" and "time step" solution

31 layer block	One step _ linear theory E=0.136 mspi	One step_ large deflection theory E=0.136 mpsi	Time step _large Deflection theory E=E(t)
Maximum deflection (mils)	59.7	60.1	59.7
*Maximum Stress (psi)	776/540	781/499	781/499
*Maximum Strain (%)	5.7/3.6	5.7/3.6	5.68/3.65

* Stress and strain has a form of " corner peak value/ without considering corner peak value"

Conclusion:

It seems that both eigenvalue and static non-linear analysis gives a very similar result to insure the accuracy of the buckling calculation. First & second method gives SF related to how much additional force , ΔF, for which the structure can withstand for a given time t. If one can be convinced that the loading will be very much kept constant during the life of structure, the critical time t_{cr}, needed to develop an excessive deformation, is quite long for a given E(t) curve. However, an extra caution should be taken for the uncertainty of the material property since the simulation is done based on a given E(t) curve.

Reference

1) "Handbook of Polyethylene pipe", Plastic pipe institute, Chapter 3 & 6
2) " GE plastic design guide", 1997, charter 4.
3) H. Kraus, "Creep Analysis", UMI book on demand, 1980, pp 130-pp 133
4) PolySciCon LLC, "20 year Creep Prediction for Nova 2P", July 25, 2006, Nova-docdb-1402-v1
5) G. Trantina & R. Nimmer, "Structure Analysis of Thermoplastic Components ", McGraw-Hill,Inc, 1994, pp313-pp315

Appendix A:
Result from ANSYS
1) Solution for the first method

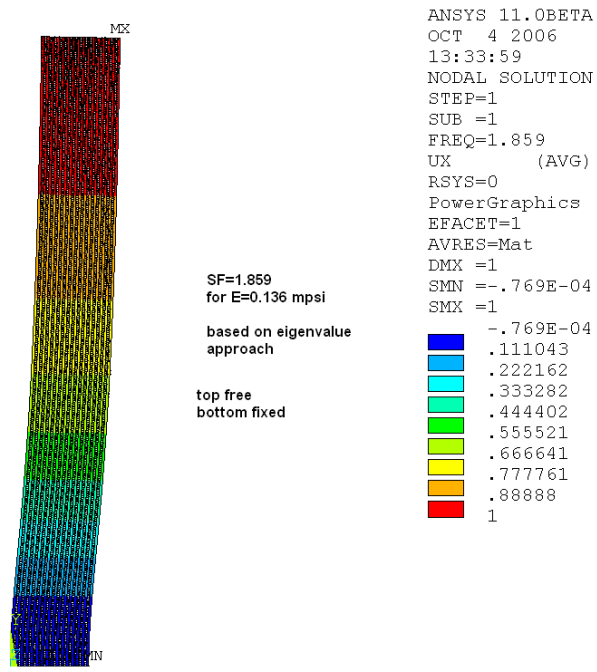

Fig A-1 Eigen value calculation for E(20y)=0.136 mpsi

2) Solution for the 2nd approach

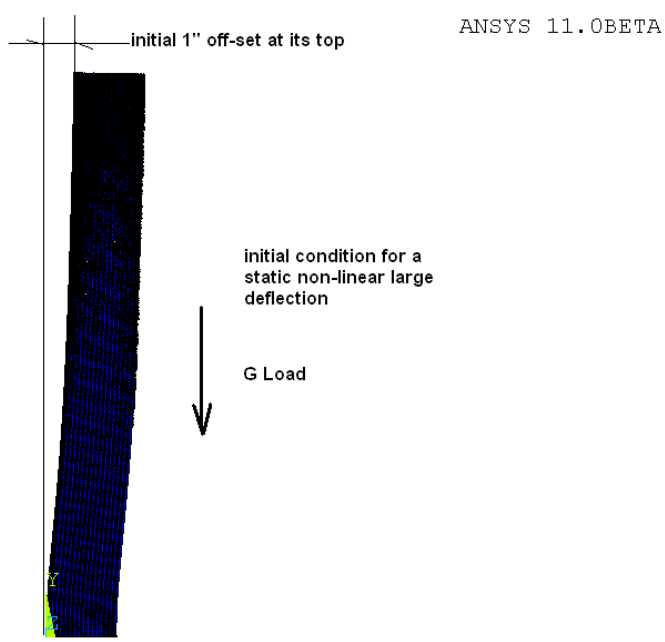

Fig A-2 Initial 1" off set on its top for a static non-linear direction

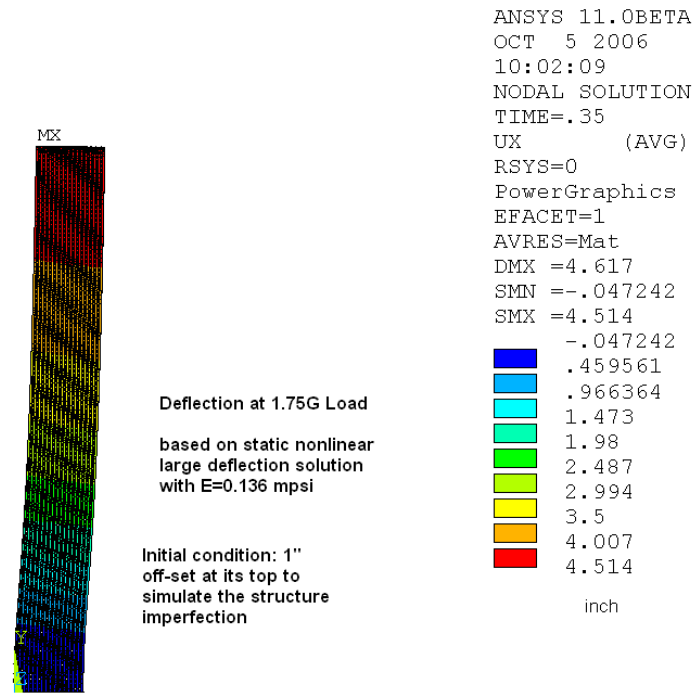

Fig A-3 Deflection along the beam direction at 1.75 G load

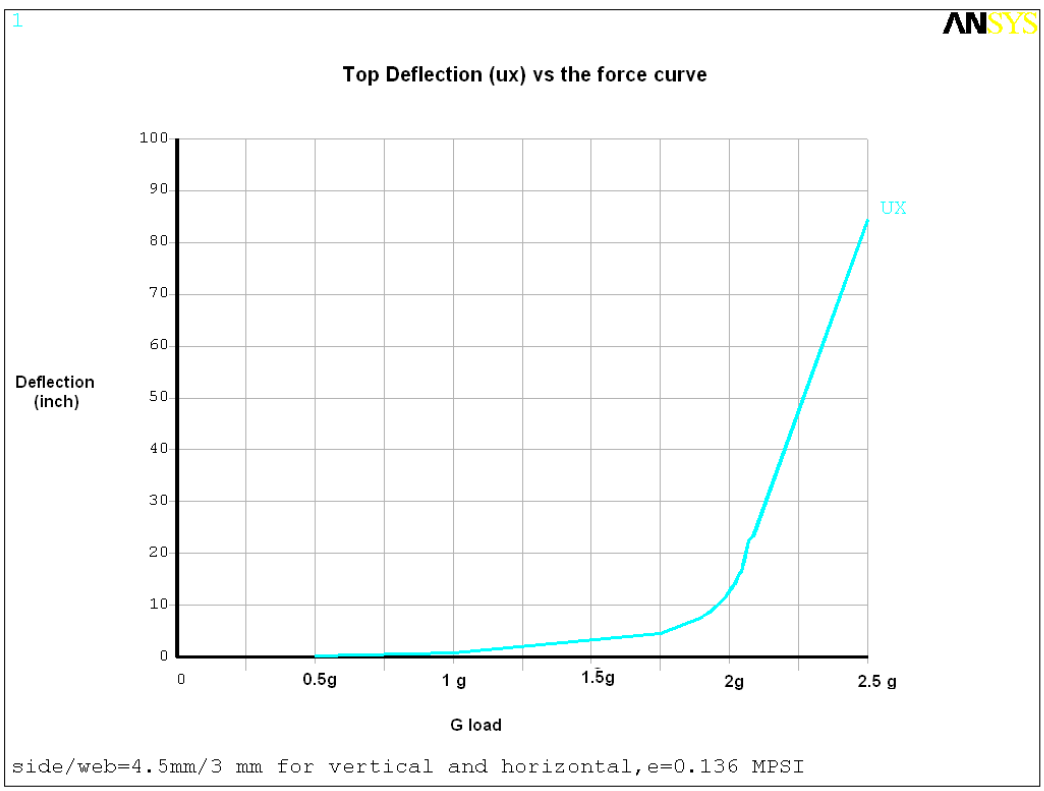

Fig A-4 Deflection history at the top

3) Solution for 3rd approach

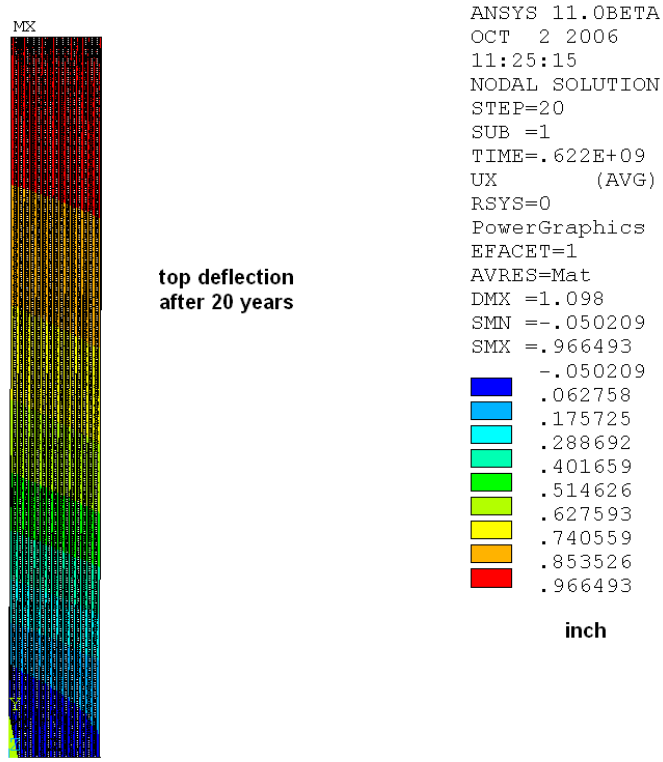

Fig A-5 Top deflection after 20 year

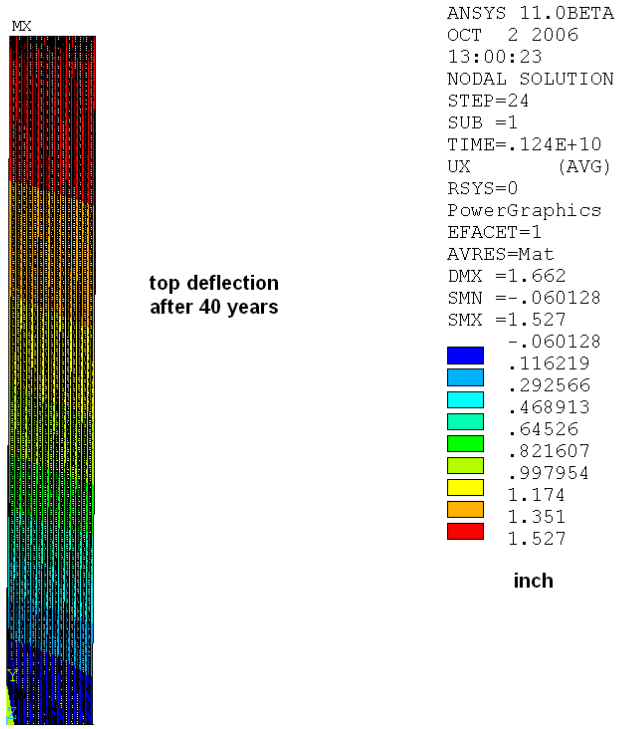

Fig A-6 Top deflection after 40 year

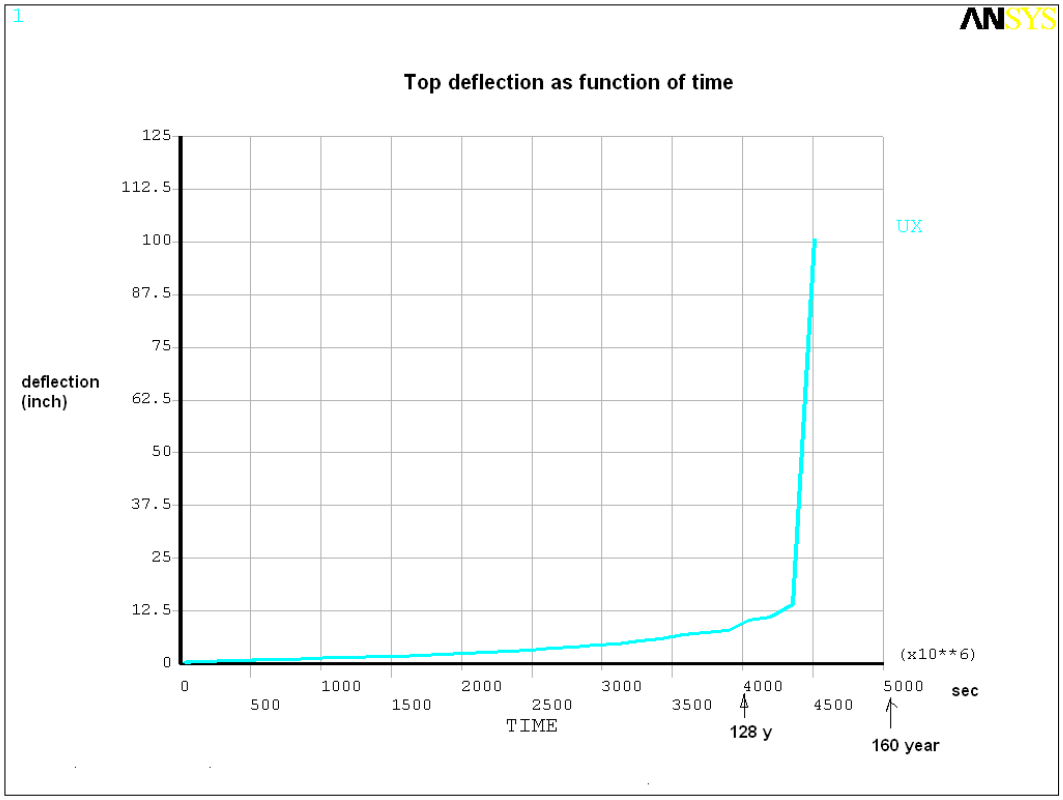

Fig A-7 Top deflection curve as function of time

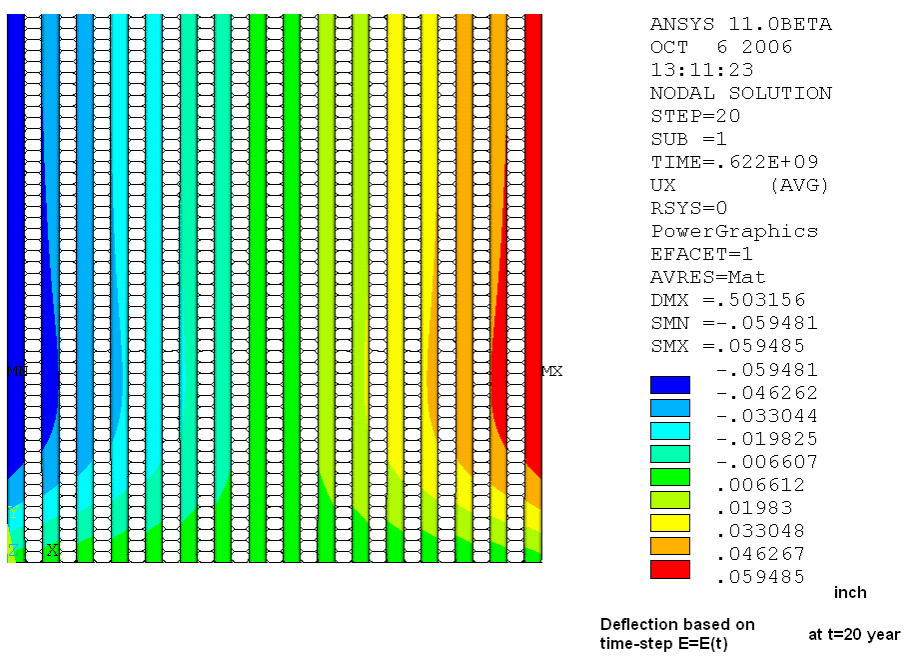

Fig A-8 Deflection based on time-step E=E(t) for an operating case at t=20 year

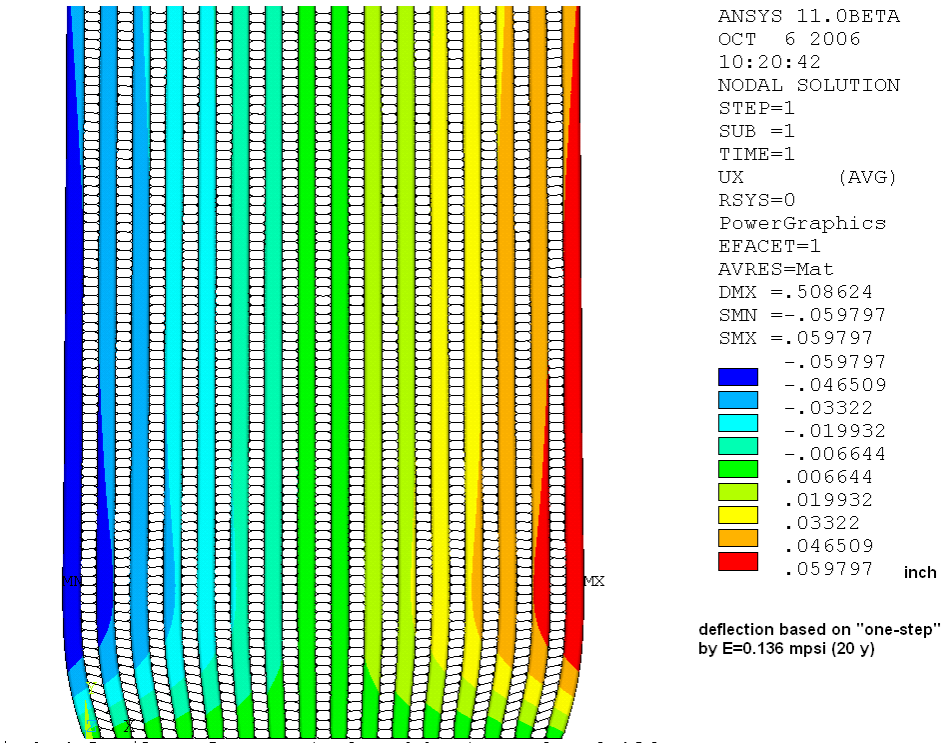

Fig A-9 Deflection based on one-step linear calculation with E=0.136 mpsi