CIMNE Verification of the validation analysis of Xfinas elements database

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1. Introduction

In order to validate the Xfinas code a very comprehensive series of test examples were solved by Prof Ki-Du Kim and his co-workers. A collection of the more representative benchmarks were chosen at CIMNE for testing the good behavior of every element implemented in the software.
The aim of the validation work carried out at CIMNE has been to asses the accuracy of the Xfinas program. This was done studying the whole validation process carried out by Prof Ki-Du Kim's team in detail. For this purpose we have chosen at CIMNE randomly the different benchmarks to be reproduced between those of the validation manual (VM from now on). In every example we checked the agreement of the results with the Xfinas validation data.

2. Verification of the validation

In the following sections the results of the different element examples are reported. The order of the sections follows that of the validation manual (VM). For each table or figure a reference to the correspondent section of the validation manual will be inserted into parenthesis such as "(table X, Sec.X, Ch.X of VM)".
A random criteria was adopted in the choice of the test examples in the Xfinas manual to be reproduced. In some cases all the test examples have been reproduced, in others only some.
For all the geometric data and the boundary conditions of the benchmarks, consulting of the Xfinas validation manual is recommended.
The tables presented in Section 2 and the correspondent Subsections correspond to the table they refer to in the validation manual. Also for each element analyzed there is a column with the results obtained by CIMNE, a column for the results that appear in the Xfinas validation manual and yet another column with the difference between the two values.

2.1. SHELL ELEMENT (Ch.1 VM)

Xfinas allows the choice of four different type of shell elements:
- The three noded element called X_shell 31A (or B depending from the considered mesh (see the validation manual for more explanations);
- The four noded element called X_shell 4QSI in the tables;
- The eight noded element called X_shell 8ANS in the tables;
- The nine noded element called X_shell 9 ANS in the tables;

All of them are tested for different mesh dimension in each example.
In the following sections both the linear static analysis and the non linear static analysis have been checked.

2.1.1. **Linear test** (Ch.1 Part A VM)

a) Hemispherical shell with 18º hole

The benchmark was reproduced completely with perfect agreement with the results of tables 1(a)-(b) of the VM as can be seen in table 2.1 and 2.2 were the results for the different element is tested for four meshes.

El per Side	X_shell 4QSI			X_shell 8ANS			X_shell 9ANS		
	CIMNE	VM		CIMNE	VM		CIMNE	VM	
2	1.035	1.035	0%	0.018	0.018	0%	0.526	0.526	0%
4	1.033	1.033	0%	0.414	0.414	0%	0.897	0.897	0%
8	1.011	1.011	0%	0.964	0.964	0%	0.997	0.997	0%
16	1.003	1.003	0%	1.003	1.003	0%	1.005	1.005	0%

Table 2.1. (table 1(a), Ch.1 VM) Quadrilateral shell element

Node per Side	El per Side	X_shell 31A			X_shell 31B		
		CIMNE	VM		CIMNE	VM	
3	2	0.207	0.207	0%	0.217	0.216	0.1%
5	4	0.152	0.152	0%	0.157	0.157	0%
9	8	0.456	0.456	0%	0.461	0.461	0%
17	16	0.898	0.898	0%	0.898	0.898	0%
21	20	0.953	0.954	0.1%	0.953	0.953	0%

Table 2.2. (table 1(b), Ch.1 VM)

b) Hemispherical shell

Also in this case the whole example of the VM was checked with perfect agreement as shown in table 2.3.

El per Side	X_shell 4QSI			X_shell 8ANS			X_shell 9ANS		
	CIMNE	VM		CIMNE	VM		CIMNE	VM	
2	1.0324	1.0324	0%	0.3394	0.3394	0%	0.8485	0.8485	0%
4	0.9998	0.9998	0%	0.9136	0.9136	0%	0.9655	0.9656	0%
8	0.9736	0.9800	0.7%	0.9811	0.9811	0%	0.9837	0.9838	0%

Table 2.3. (table 2(a) and 2(b), Ch.1 VM)

c) Pinched Cylinder

The triangular element were chosen to be tested in this example, chosing one of the two mesh configuration of the VM as can be seen in table 2.4.

Node per Side	El per Side	X_shell 31A		
		CIMNE	VM	
3	2	0.315	0.315	0%
5	4	0.643	0.643	0%
9	8	0.863	0.864	0.1%
17	16	0.960	0.960	0%
21	20	0.975	0.975	0%

Table 2.4. (table 4(b), Ch.1 VM)

d) Bending of Rombic Plate

Nearly all the quadrilateral test case have been reproduced as shown in table 2.5.

El per Side	X_shell 4QSI			X_shell 8ANS			X_shell 9ANS		
	CIMNE	VM		CIMNE	VM		CIMNE	VM	
4	1.069	1.069	0%	0.544	0.544	0%	0.954	0.954	0%
8	1.034	1.034	0%	0.779	0.779	0%			
14	1.032	1.032	0%	0.893	0.893	0%	1.003	1.003	0%
16	1.032	1.032	0%	0.913	0.913	0%			

Table 2.5. (table 5, Ch.1 VM)

e) Tapered and swept beam

A random choice of a case for each element was performed for the rest of the shell benchmark tests to verify the validation results were done correctly.

El per Side	X_shell 4QSI
2	CIMNE VM 0.816 0.816 0% X_shell 8ANS
4	CIMNE VM 0.991 0.992 0.1% X_shell 9ANS
16	CIMNE VM 0.998 0.998 0%

Table 2.6. (table 6(a), Ch.1 VM)

Node per Side	El per Side	X_shell 31A
		CIMNE VM
3	2	0.827 0.827 0% X_shell 31B
		CIMNE VM
9	8	0.982 0.982 0%

Table 2.7. (table (b), Ch.1 VM)

f) Cantilever beam   Straignt cantilever

	X_shell 4QSI		
Ref	CIMNE	VM	
|W| =0.4321	0.987	0.987	0%
|Rx|=0.03208	0.695	0.704	1.2%
	X_shell 8ANS		
	CIMNE	VM	
|V| =0.1081	0.999	0.999	0%
	X_shell 9ANS		
	CIMNE	VM	
|W| =0.4321	1.020	1.019	0.1%

Table 2.8. (table 7(a), Ch.1 VM)

	X_shell 31A		
Ref	CIMNE	VM	
|U| =3e-5	0.993	0.993	0%

Table 2.9. (table 7(b), Ch.1 VM)

g) Cantilever beam Curved cantilever

	X_shell 4QSI		
	CIMNE	VM	
In plane shear	0.833	0.833	0%
	X_shell 9ANS		
	CIMNE	VM	
Out of pl shear	0.982	0.982	0%

Table 2.10 (table 7(c), Ch.1 VM)

	X_shell 31		
	CIMNE	VM	
2x7 In plane shear	0.234	0.234	0%
2x31 Out of pl shear	0.915	0.915	0%

Table 2.11 (table 7(d), Ch.1 VM)

h) Cantilever beam Twist cantilever

t=0.32	X_shell 4QSI		
	CIMNE	VM	
2x12 In plane shear	0.997	0.997	0%
	X_shell 8ANS		
	CIMNE	VM	
4x24 Out of pl shear	0.999	0.999	0%

Table 2.12 (table 7(e), Ch.1 VM)

t=0.05	X_shell 4QSI
	CIMNE VM
1x6 Out of pl shear	1.018 1.018 0%
	X_shell 8ANS
	CIMNE VM
2x12 In plane shear	0.982 0.982 0%
	X_shell 9ANS
	CIMNE VM
4x24 In plane shear	0.997 0.997 0%

Table 2.13 (table 7(f), Ch.1 VM)

t=0.32	X_shell 31
	CIMNE VM
Out of pl shear	0.965 0.994 4%

Table 2.14 (table 7(g), Ch.1 VM)

i) Plate bending problem with Clamped Boundary condition

a/b=1	X_shell 4QSI
	CIMNE VM
6x6	0.998 0.998 0%
	X_shell 9ANS
	CIMNE VM
2x2	1.002 1.002 0%

Table 2.15 (table 8(b), Ch.1 VM)

a/b=5	X_shell 8QSI		
	CIMNE	VM	
6x6	0.209	0.209	0%
	X_shell 9ANS		
	CIMNE	VM	
4x4	0.987	0.987	0%

Table 2.16 (table 8(c), Ch.1 VM)

In the case of the triangular element an error could occur in typing the results because the results corresponding with mesh A were written in column of mesh B in the VM and viceversa.

a/b=1	X_shell 31**A**				
	CIMNE	VMmesh**A**		VMmesh**B**	
9	0.991	0.996	0.5%	0.991	0%
a/b=5	X_shell 31**B**				
	CIMNE	VMmesh**B**		VMmesh**A**	
3	0.951	0.924	2.8%	0.951	0%
4	0.972	0.955	1.7%	0.972	0%

Table 2.17 (table 8(e), Ch.1 VM)

a/b=5	X_shell 31A		
Nodes per side	CIMNE	VM	
5	0.811	0.811	0%
	X_shell 31B		
	CIMNE	VM	
5	0.767	0.767	0%

Table 2.18 (table 7(f), Ch.1 VM)

j) Square plate with distorted mesh

Regular mesh 4x4	X_shell 4QSI		
	CIMNE	VM	
Uniform load	0.997	0.998	0%
	X_shell 8ANS		
	CIMNE	VM	
Point load	0.123	0.123	0%
Distorted mesh 4x4	X_shell 9ANS		
	CIMNE	VM	
Uniform load	1.001	1.001	0%

Table 2.19 (table 9, Ch.1 VM)

2.1.2. **Non linear test** (Part C, Ch.1 VM)

Three examples were chosen between the many benchmarks of the non linear test and one shell element was controlled for each case.
In the following figures the very good matching of the results of the validation manual and the cimne verification is shown for different cases.

a) Square Clamped Plate Subjected to Uniform Pressure

The 4 node shell element was verified in this case as shown in Fig. 2.1.

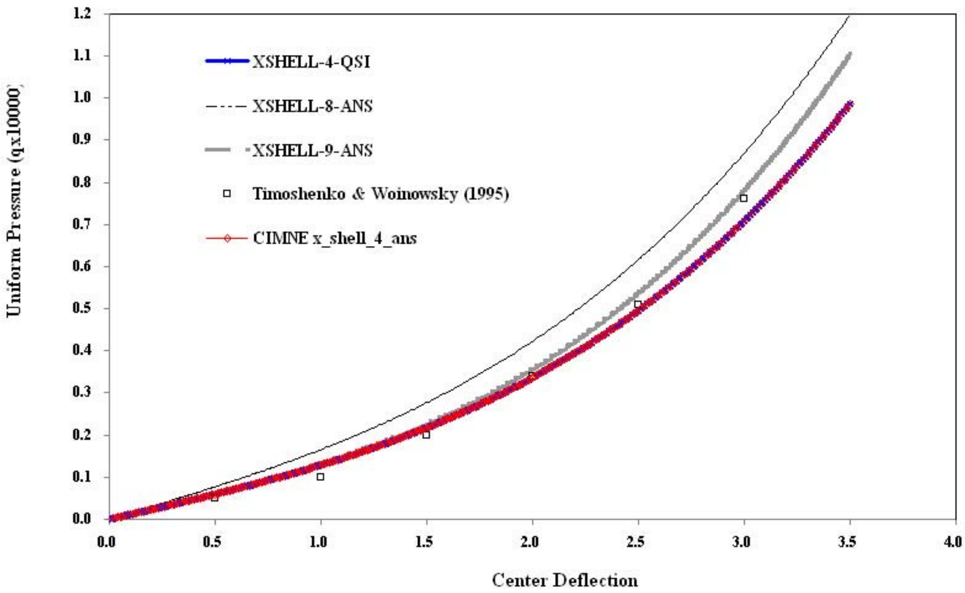

Figure 2.1 (Fig. 1.27(b), Sec. 1.11.1, Ch.1 , Part C) Plot of Uniform Pressure and Central Deflection.

b) Buckling of Stiffened Curved Panel

The 8 node quadrilateral element was verified in this case as shown in Fig. 2.2.

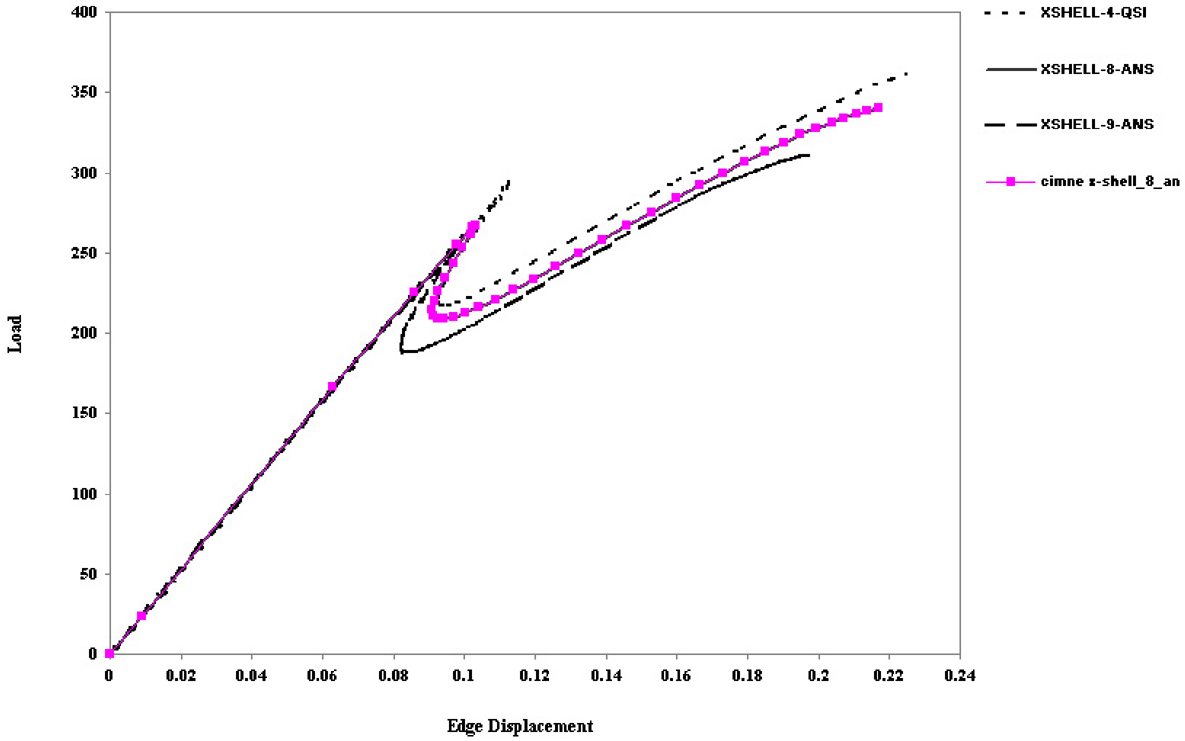

Figure 2.2 (Fig 1.31, Sec.1.11.5 , Ch.1, Part C) Stiffened Curved Panel.

c) Pinched Elasto-Plastic Cylinder with Isotropic Hardening

Both the 8 and the 9 node quadrilateral element were verified in this case as shown in Fig. 2.3.

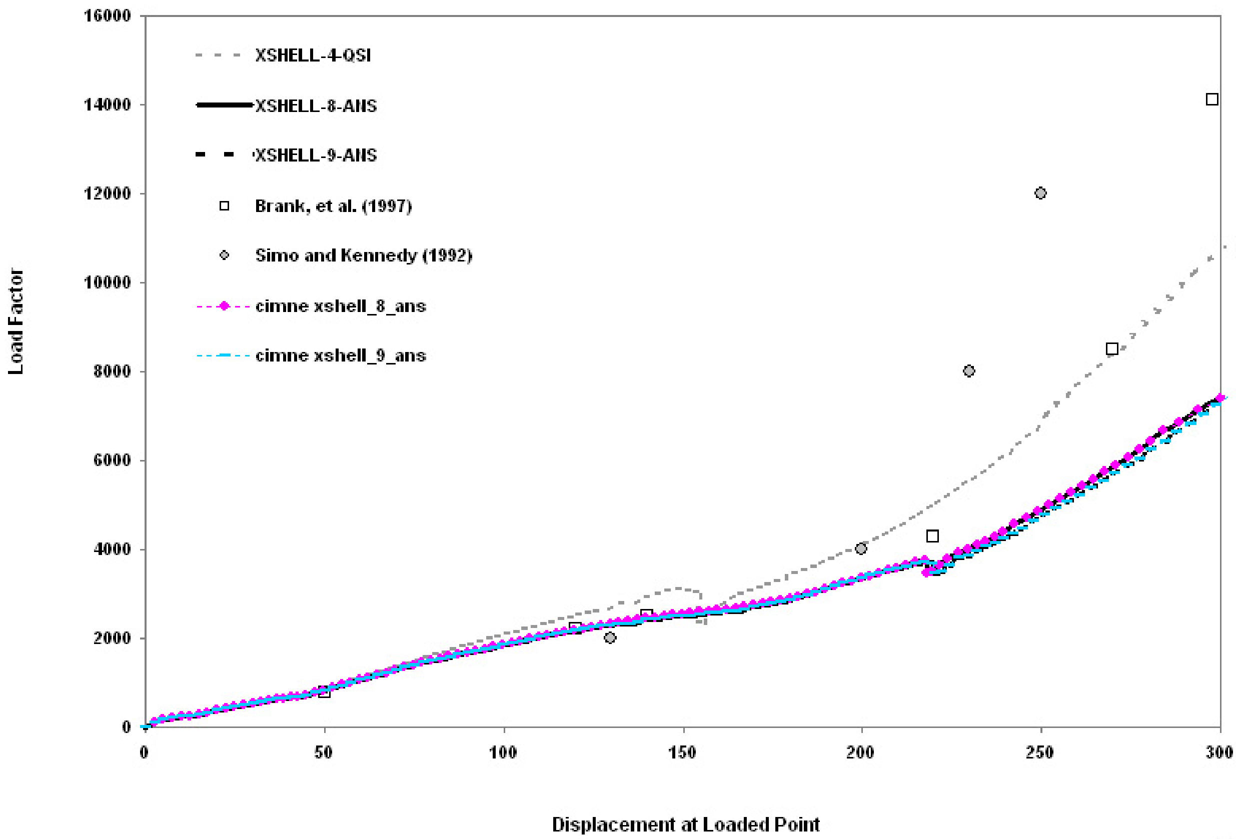

Figure2.3 (Fig.1.42, Sec 1.11.9, Ch1, Part C VM) Pinched elasto-plastic cylinder – displacement under force.

2.2. SOLID ELEMENT (Ch.2 VM)

Two kind of solid element are implemented inside Xfinas:

- XSOLID_8_EAS that is an element with 24 EAS terms
- XSOLID_8_ANS a solid shell element
- XSOLID_4T a four node tetrahedra element
- XSOLID_10T a 10 node tetrahedra.

Some examples of validation are checked in the following sections and the graph of the non linear analysis are qualitatevely compared with the results of the VM..

2.2.1. Linear test (Sec 2.2, Ch.2 VM)

a) Beams problem curved beam under in plane load (Sec.2.2.2)

El Side	XSOLID_8_EAS			XSOLID_8_ANS			XSOLID_4T			XSOLID_10T		
	CIMNE	VM		CIMNE	VM		CIMNE	VM		CIMNE	VM	
6x1x1	0.8802	0.8802	0%	0.8874	0.8875	0%				0.8976	0.8983	0%
8x1x1	0.9633	0.9636	0%	0.9682	0.9683	0%	0.0898	0.0898	0%	0.9666	0.9667	0%
12x1x1	0.9995	0.9994	0%	1.0026	1.0026	0%	0.1868	0.1868	0%	0.9980	0.9981	0%

T

Table 2.20 (table 2.2.1, Ch.2 VM)

b) Beams problem curved beam under out of plane load

El Side	XSOLID_8_EAS			XSOLID_8_ANS			XSOLID_4T			XSOLID_10T		
	CIMNE	VM		CIMNE	VM		CIMNE	VM		CIMNE	VM	
6x1x1	0.8244	0.8244	0%	0.9426	0.9426	0%	0.0157	0.0157		0.8902	0.8902	0%
8x1x1	0.9196	0.9196	0%	0.9494	0.9494	0%	0.0277	0.0277	0%			
12x1x1	0.9527	0.9527	0%	0.9551	0.9551	0%	0.0605	0.0605	0%	0.9334	0.9334	0%

Table 2.21 (table 2.2.2, Ch.2 VM)

c) Bending of rhombic plate

In the VM the results of the test cases are not the normalized one, also if in the title there is written “Normalized Solution”.
In the following table the results are normalized with respect to the reference value of displacement (W= 0.04455).

El Side	XSOLID_8_EAS			XSOLID_8_ANS			XSOLID_4T			XSOLID_10T		
	CIMNE	VM		CIMNE	VM		CIMNE	VM		CIMNE	VM	
4x4x1	0.9466	0.9466	0%	0.8855	0.8855	0%	0.0015	0.0015	0%	0.0713	0.0713	0%
8x8x1	0.9536	0.9536	0%	0.9063	0.9063	0%	0.0049	0.0049	0%	0.189	0.189	0%
16x16x1	0.9894	0.9894	0%	0.9741	0.9741	0%	0.0132	0.0132	0%	0.4604	0.4604	0%
20x20x1	0.9992	0.9992	0%	0.9906	0.9906	0%	0.0229	0.0229	0%			
32x32x1	1.0153	1.0153	0%	1.0151	1.0151	0%	0.0729	0.0729	0%			

Table 2.22 (table 2.7, Ch.2 VM)

2.2.2. Geometric non linear test

a) Clamped Plate under Uniform Pressure

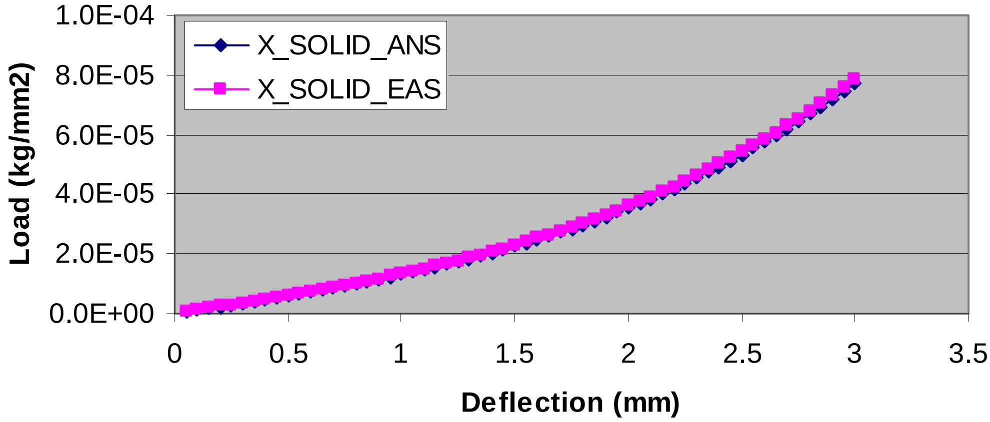

Figure2.4 (Fig.2.18, Sec 2.3.1, Ch2, VM) Clamped plate under uniform pressure.

b) Hinged Cylindrical Shell

The hinged cylindrical shell is another case of geometrical nonlinear analysis checked. In this case a good matching of the results is recover for the XSOLID_8_EAS.

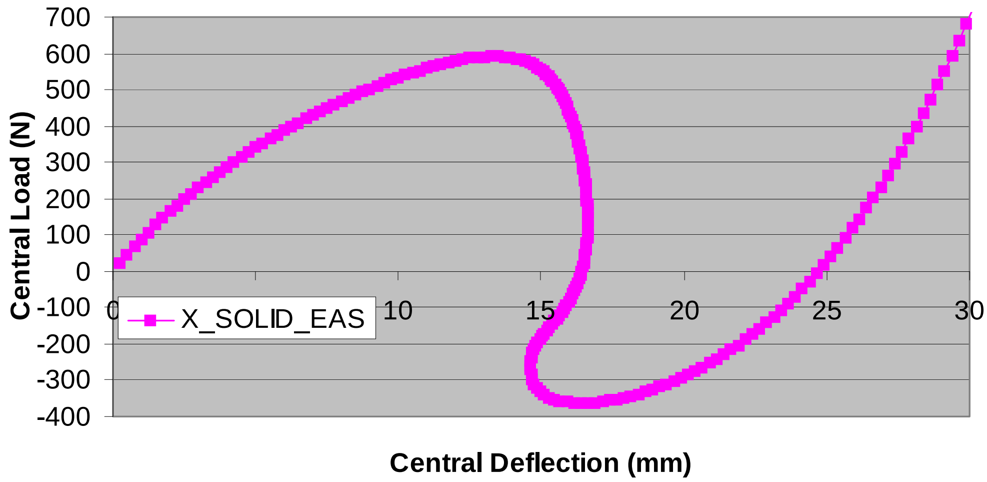

Figure2.5 (Fig.2.20, Sec 2.3.2, Ch2, VM) Hinged cylindrical shell

2.3. FRAME ELEMENT (Ch.3 VM)

Many different types of analysis were carried out for the validation of the frame element.
The frame element is XFRAME in the following tables At least one example for each type of analysis was checked as shown in the following sections.

2.3.1. Linear test

a) Straight cantilever beam and curved cantilever beam (Sec.3.2.1, Ch. 3 VM)

Problem	Tip load direction	Displ in direction of load	
		XFRAME CIMNE	VM
Straight beam	Extension	0.00003	0.00003
	In plane shear	0.108094	0.1081
	Out of plane shear	0.432094	0.4321
	Torsion	0.01872	0.01872
Curved beam	In plane shear	0.087347	0.08735

Table 2.23 (table 3.2, Ch.3 VM)

2.3.2. Geometrically non linear test

a) Cantilever beam under uniformly distributed load (Sec.3.3.1, Ch. 3 VM)

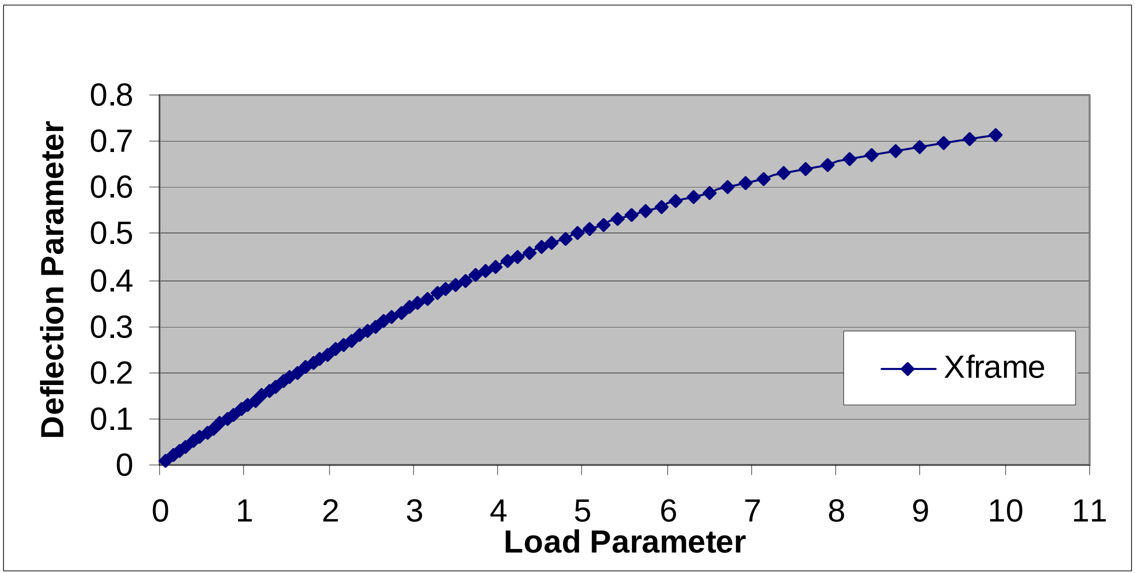

Figure2.6 (Fig.3.6, Sec 3.3.1, Ch3, VM) Cantilever beam

b) William toggle frame (Sec. 3.3.3, Ch. 3 VM)

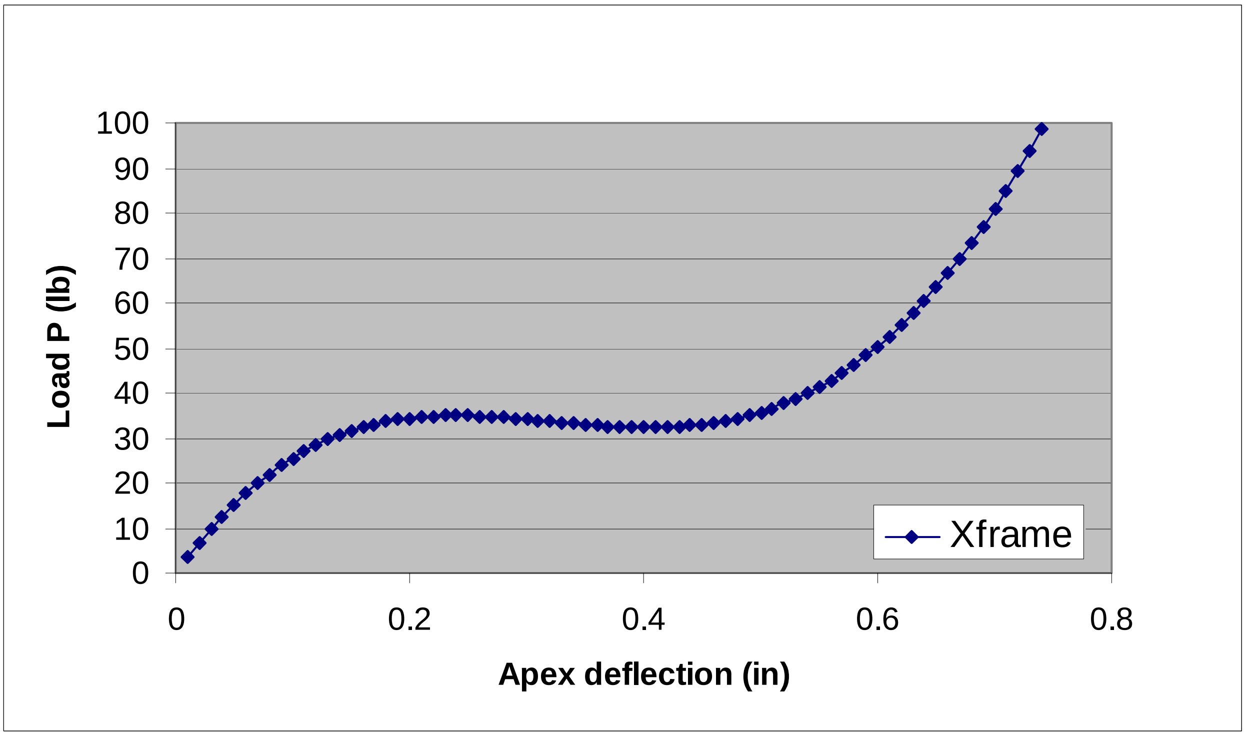

Figure2.7 (Fig.3.10, Sec 3.3.3, Ch3, VM) William toggle frame

2.3.3. Large displacement elasto-plastic test

a) Lee's elasto-plastc frame

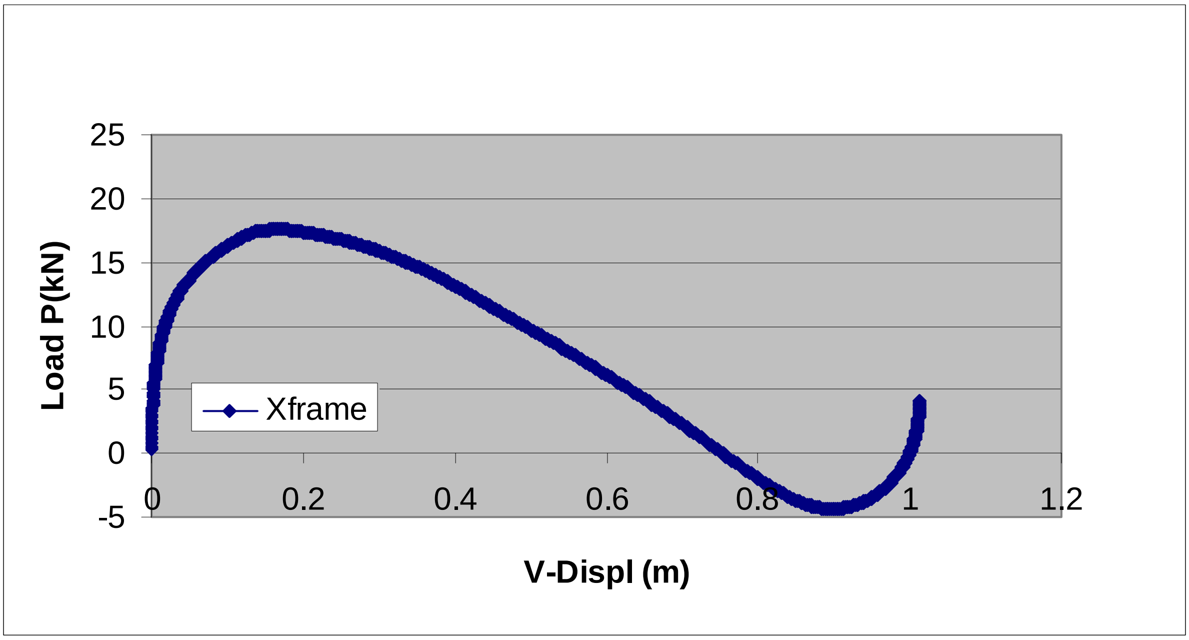

Figure2.8 (Fig.3.17, Sec 3.4.1, Ch3, VM) Lee's elasto-plastic frame

2.4. PLANE ELEMENT (Ch.4 VM)

Two plane elements are available in Xfinas database:
- Xplane 4EAS a 4-noded plane element with enhanced assumed strain;
- Xplane8 8 noded plane element;

2.4.1. Patch test and cantilever beam

a) Cantilever beam (Sec.4.1, Ch. 4 VM)

	Case 1			Case 2			Case 3			Case 4		
Element	u_A			v_A			v_A			v_A		
	CIMNE	VM		CIMNE	VM		CIMNE	VM		CIMNE	VM	
Xplane 4 eas	6	6	0%	17.6358	17.64	0%	96.1838	96.18	0%	98.1881	98.19	0%
Xplane 8	5.97	6	0%	17.6358	17.64	0%	99.7028	99.70	0%	101.444	101.44	0%

Table 2.24 (table 4.1, Ch.4 VM)

b) Tapered and swept beam (Sec.4.3, Ch. 4 VM)

Element	2x2			4x4		
	CIMNE	VM		CIMNE	VM	
4-EAS	21.94	21.94	0%	23.01	23.01	0%
XPlane8	23.02	23.02	0%	23.68	23.68	0%

Table 2.25 (table 4.3, Ch.4 VM)

2.4.2. Dynamic small displacement elastic-plastic response of a Simply supported beam

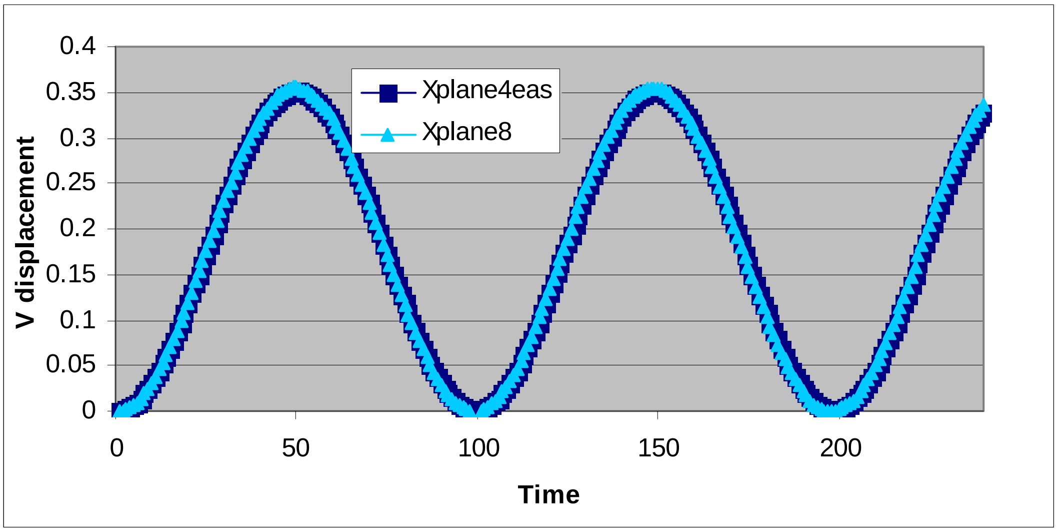

Figure2.9 (Fig.4.7(a), Sec 4.5, Ch4, VM) Non linear dynamic problem.

2.4.3. Geometrically non linear dynamic response of a clamped beam under a concentrated step load (sec. 4.6, ch. 4 VM)

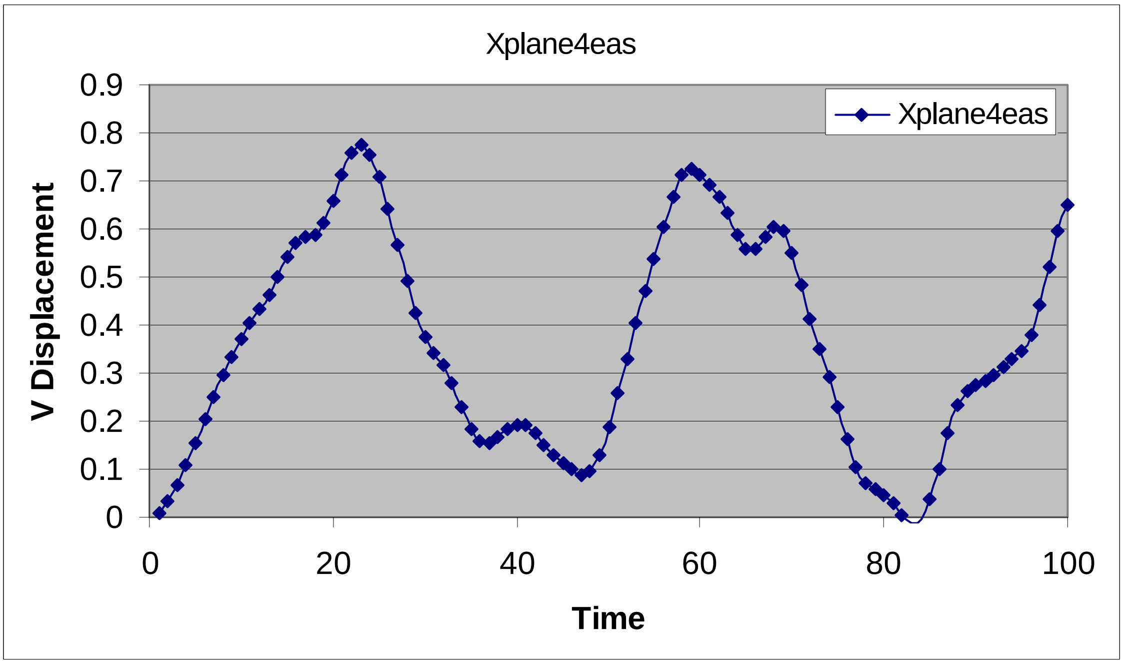

Figure2.10 (Fig.4.8, Sec 4.6, Ch4, VM) Geometrically nonlinear dynamic response of a clamped beam..

3. Conclusions

After a very accurate study of the validation analysis the following conclusions can be stated.

1) Xfinas element database offers a wide range of choices together with multiple possibilities in the method of analysis.

2) Every element have been accurately tested and validated considering the convergence analysis while increasing the quality of the mesh;

3) A wide range of benchmarks have been chosen to confirm the good behavior of each element and the matching between Xfina results and those obtained in literature is clearly shown in the validation manual;

The validation work was then randomly tested, as shown in the present paper, to confirm the results with the following conclusions:

1) The results that appears in the validation manual are acceptable and can be easily recovered using Xfinas as shown in all the previous sections;

2) Some mistakes are present in the validation manual but can be easily explained as editing errors, like for instance the one pointed out in section 2.1 (see table 2.17), or in section 2.2.