

Comparison of different element types in structural analysis

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1. Introduction

Components for occupant restraint systems usually undergo structural analysis before hardware prototypes are made. In most cases the simulation is nonlinear in geometry, material and boundary conditions. Additionally, the load case often is highly dynamic. For this purpose explicit FEM is a suitable tool. It is well known, that the accuracy of deformations and especially stresses has to be checked carefully in some cases. Therefore, a comparison of different modeling approaches has been performed for basic analytical load cases. The examined variations included: Shell and solid mesh, different degrees of discretization, element formulations. All models have been run in LS-DYNA, some selected ones as well in PAMCRASH and ABAQUS Standard, for reasons of comparison. Two basic load cases have been examined:

- a) Prismatic cantilever beam with rectangular cross section, under a single force load.
- b) Circular plate, fixed at the boundary, under pressure load.

These two models have been chosen in order to have an analytical solution to compare the numerical results with. All models have been run under linear conditions: Elastic, isotropic material behaviour and small deformations. The solution of each variation has been compared to the analytical one.

2. Load cases

The two chosen load cases are a rectangular beam under concentrated load as well as a circular plate under distributed (pressure) load. Both load cases represent typical loading situations in structural analysis. The analyses have been performed in linear conditions, both for material and for geometry. For this assumptions analytical solutions are available.

a. Rectangular beam under bending load

The rectangular beam has been defined with the following dimensions:

Length $l = 100$ mm, width $b = 10$ mm, height $h = 5$ mm.

The boundary conditions are: Fixation in all degrees of freedom on one end, force of $F = 20$ N on the opposing end.

Young's Modulus has been chosen as $E = 69000$ MPa, Poisson's Ratio as $\mu = 0.3$.

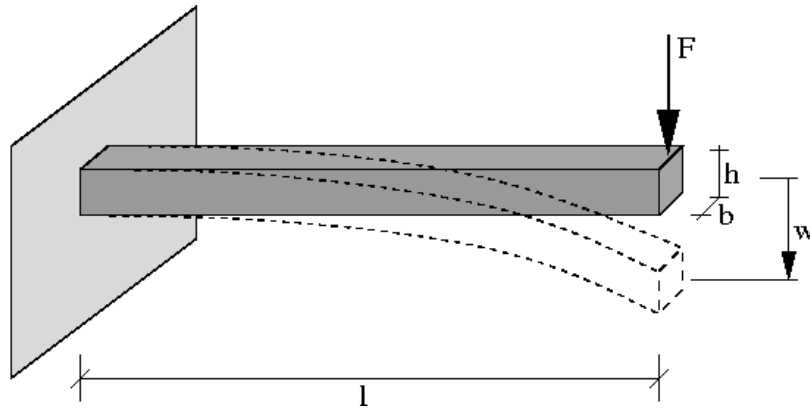


Figure 1: Dimensions of the cantilever beam

The analytical solution is given as:

Deflection: $w = \frac{Fl^3}{3EI}$ with I being the section

modulus to : $I = \frac{bh^3}{12}$.

The maximum stress is defined as: $\sigma_b = \frac{M_b}{W_b}$ with

$$M_b = Fl$$

and $W_b = \frac{I}{h/2}$

For the given dimensions and stiffness this yields to $w = 0,9275mm$ and $\sigma_b = 48MPa$.

b. Circular plate under pressure load

The circular plate has been defined with the following dimensions:

Radius $R = 50$ mm, height $h = 2$ mm (see Figure 2).

The boundary conditions are: Fixation in all degrees of freedom at the outer edge of the plate, distributed load of $p=0.25$ MPa on the whole surface.

Young's Modulus has been chosen as $E = 69000$ MPa, Poisson's Ratio as $\mu = 0.3$.

The analytical solution is given by:

Deflection: $w = 0.171 \frac{pR^4}{Eh^3}$

Stress in center of plate: $\sigma_r = \sigma_t = 0.488 \frac{pR^2}{h^2}$

For the given dimensions and stiffness this yields to $w = 0,484mm$ and

$$\sigma_b = 76.25MPa .$$

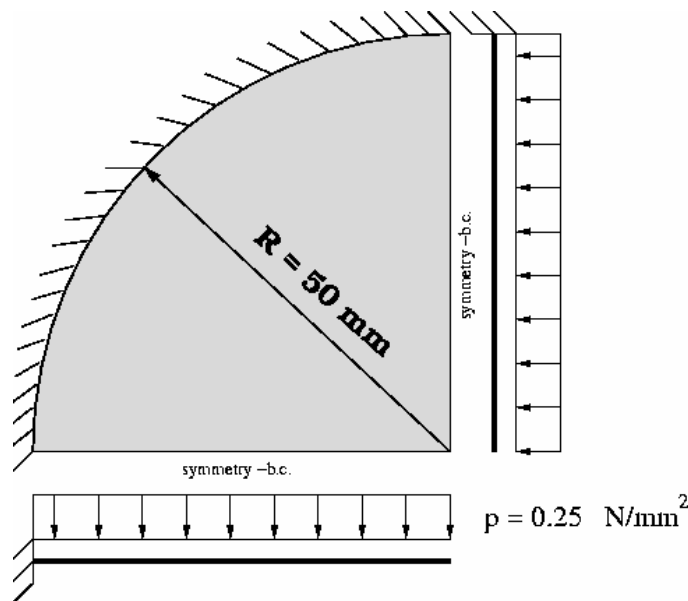


Figure 2: Boundary Conditions of the plate

3. Chosen models and element types

For the two chosen examples three different kinds of discretization levels for all element types are considered, see Figure below. The selected LS-DYNA element types are the most popular and the mainly used ones. For beams type 1 (Hughes-Liu, cross section integration) and type 2 (Belytschko-Schwer, resultant), for shells type 2 (Belytschko-Tsay, one point integrated) and type 16 (fully integrated), for solids type 1 (hexahedron, constant stress - one point integration), type 2 (hexahedron, selective reduced integrated) and type 10 (tetrahedron, one point integrated). For detailed informations to the different element types in LS-DYNA it is referenced to [3] and [4].

For the reduced integrated elements hourglass control is applied. The stiffness option is used for the Belytschko-Tsay shell element and the viscous option is selected for the solid element type 1. The used LS-DYNA version for the explicit calculations is V960-Rev.1106, for the implicit calculations the latest pre-version of V970 is applied. For the PAM-CRASH calculations (V2001) comparable element types with regard to the LS-DYNA element types have been chosen. The tetrahedron element of ABAQUS is a 10 node element (C3D10) with quadratic shape functions.

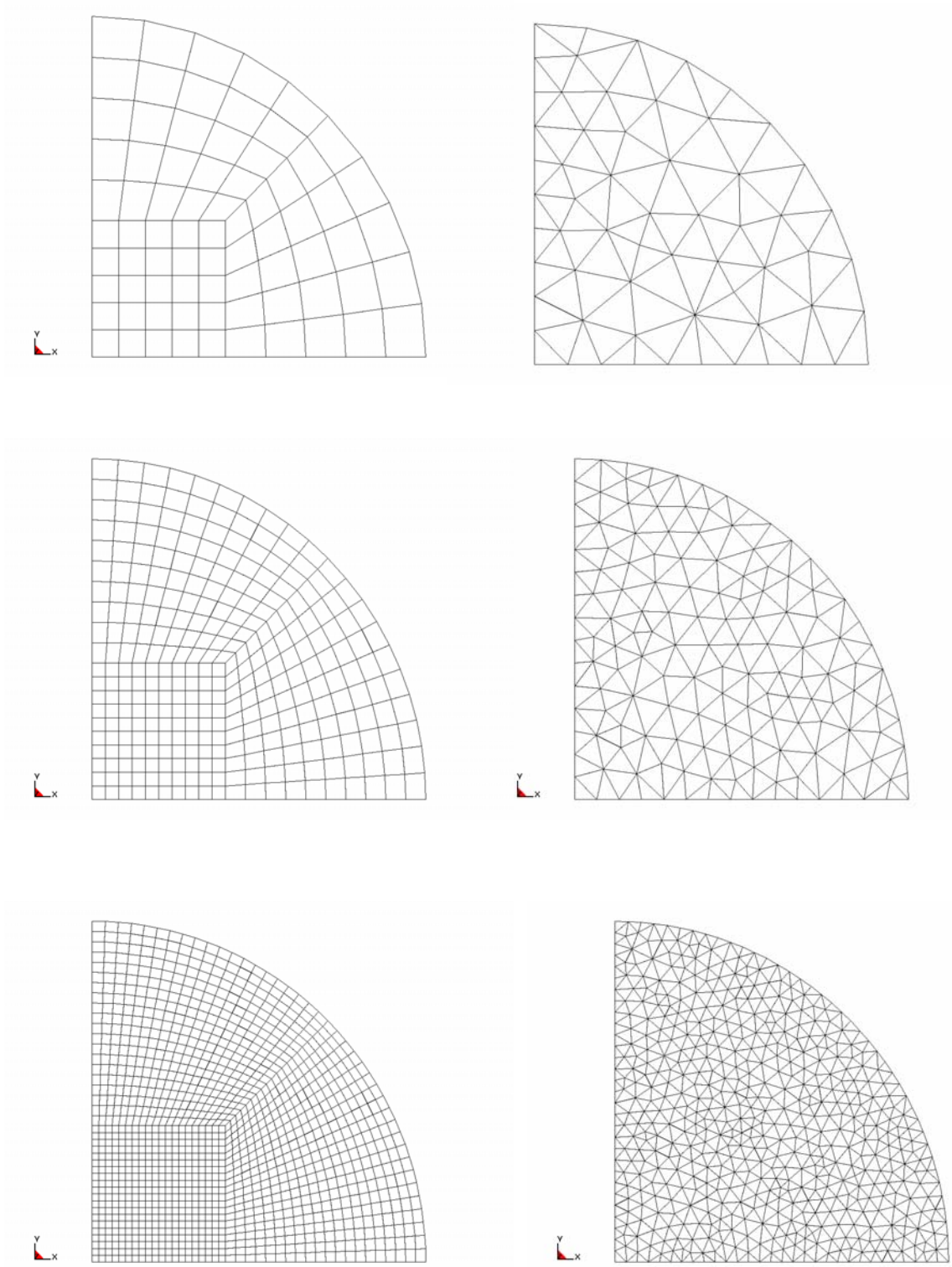


Figure 3: Finite-Element Discretization of one quarter of the plate

4. Numerical Results

The results of both problems the cantilever beam and the circular plate are summarized in a table to be found at the end of this paper.

a. Cantilever Beam

The stress values of the beam in the axial direction are given on the surface at the clamped end. They are calculated by extrapolation of the stress values given at the integration points, see Figure 4. This is only valid for linear material behaviour. For the resultant beam formulation (el.-type 2) the stress is given by the moment at the clamped end. The aspect ratio of the simulations with the quadrilateral shell elements is for the finer discretization very poor. Probably this is the reason, that the results become worse for the finer models.

b. Circular Plate

The stress values of the plate are evaluated at the center of the plate. The values are also extrapolated onto the element surface. The radial and the tangential stress values are equal to the stress values in x- and in z-direction (axisymmetry).

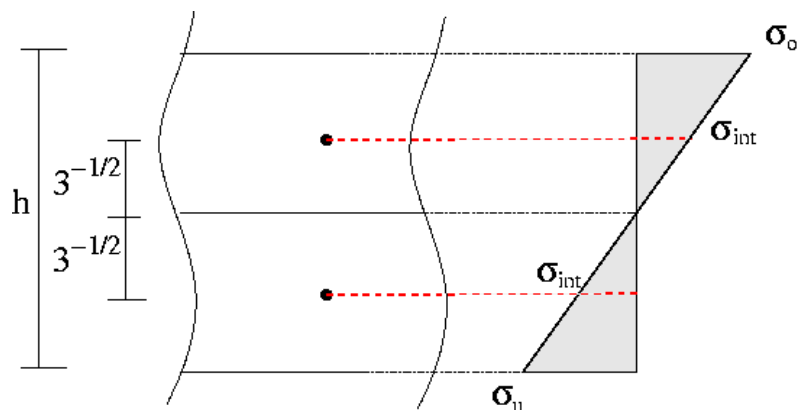


Figure 4: Extrapolation of stress values for a shell element with two Integration Points through thickness

5. Conclusions

The present paper demonstrates, that for a sufficient fine discretization the results of the explicit calculations are fairly close to the analytical solutions. An exception is for the tetrahedron elements of the cantilever beam. These elements behave very poorly for the case of bending and shear loading. The 10 nodes quadratic tetrahedron element of ABAQUS overcomes this problem.

The constant stress hexahedron elements of LS-DYNA give for the coarse discretization a much too soft response, but proceed with increasing refinement of

the discretization towards the analytical solution. The fully integrated LS-DYNA elements behave in the opposite way, they are too stiff for the coarse discretization and become better with finer discretization.

6. References

- [1] Dubbel, Taschenbuch für den Maschinenbau, Chapter C, 1995
- [2] LS-DYNA User's Manual Version 960
- [3] LS-DYNA Theory Manual
- [4] ABAQUS /Standard User's Manual, Version 6.1
- [5] PAM-CRASH, Version 2001, Solver Reference Manual

CANTILEVER BEAM

El.-Form	LS-DYNA El.-Typ	NIP (in plane)	NIP (thickn.)	Elements	LS-DYNA Explicit max w [mm]	PAM-Crash Explicit max w [mm]	LS-DYNA Implicit max w [mm]	ABAQUS Implicit max w [mm]	LS-DYNA Explicit x - stress [N/mm^2]	PAM-Crash Explicit x - stress [N/mm^2]	LS-DYNA Implicit x - stress [N/mm^2]	ABAQUS Implicit x - stress [N/mm^2]
ANALYT.					0.92753	0.92753	0.92753	0.92753	48.0	48.0	48.0	48.0
BEAMS												
BEAM	1	1	2X2	20	0.93069		0.92877		46.7957		46.8935	
BEAM	1	1	2X2	40	0.92937		0.9289		47.3958		47.3965	
BEAM	1	1	2X2	80	0.92988		0.92901		47.9643		47.6853	
BEAM	2			20	0.92868		0.92724		48.0		48.0	
BEAM	2			40	0.92795		0.92724		48.0		48.0	
BEAM	2			80	0.92516		0.92724		48.0		48.0	
SHELLS												
QUAD_4	2	1	2	20*2	0.93202		0.92717		46.7967		46.8612	
QUAD_4	2	2	2	40*5	0.92618	0.9203	0.92462		49.5276	47.40	48.6563	
QUAD_4	2	2	2	80*10	0.9258		0.92462		53.2924		49.4054	
QUAD_4	16	2	2	20*2	0.92353		0.92268		46.7971		46.7990	
QUAD_4	16	2	2	40*5	0.92537		0.92385		48.305		48.2542	
QUAD_4	16	2	2	80*10	0.92686		0.92435		52.7444		49.1099	
BRICKS												
HEX_8	1	1		20*2*2	1.0462		1.1902		62.4098		60.5960	
HEX_8	1	1		40*3*5	0.98685	1.0497	1.0251		55.0601	53.83	55.0374	
HEX_8	1	1		80*6*10	0.93809		0.94681		51.43788		51.3972	
HEX_8	2	8		20*2*2	0.70498		0.70501		38.782		38.8292	
HEX_8	2	8		40*3*5	0.86682		0.86688		47.0496		47.0540	
HEX_8	2	8		80*6*10	0.90755		0.90769		49.5264		49.5154	
TETRA_4	10	1		3076	0.62201		0.62226		-----		-----	
TETRA_4	10	1		4691	0.68496	0.908	0.68545		-----		-----	
TETRA_4	10	1		6320	0.72135		0.72134		-----		-----	
TETRA_4	10	1		8717	0.74591		0.74599		-----		-----	
TETRA_10				4691				0.9226				49.767- 51.358

CIRCULAR PLATE

El.-Form	LS-DYNA El.-Typ	NIP (in plane)	NIP (thickn.)	Elements	LS-DYNA Explicit	PAM-Crash Explicit	LS-DYNA Implicit	LS-DYNA Explicit	PAM-Crash Explicit	LS-DYNA Implicit
					max w [mm]	max w [mm]	max w [mm]	x - stress [N/mm ²]	x - stress [N/mm ²]	x - stress [N/mm ²]
ANALYT.					0.484	0.484	0.484	76.25	76.25	76.25
SHELLS										
QUAD_4	2	1	2	75	0,47042		0,45878	83.722		90.417
QUAD_4	2	2	2	300	0,47184		0,45960	83.687		90.352
QUAD_4	2	2	2	1200	0,47352		0,45980	84.952		90.332
QUAD_4	16	2	2	75	0,47042		0,47049	83.677		83.651
QUAD_4	16	2	2	300	0,47176	0.4851	0,47176	83.589	84.23	83.580
QUAD_4	16	2	2	1200	0,47219		0,47204	83.708		83.559
TRIA_3	1	1	2	90	0,46236		0,43827	82.324		89.036
TRIA_3	1	1	2	248	0,46912		0,45272	82.946		89.317
TRIA_3	1	1	2	994	0,47132		0,45786	83.511		90.037
BRICKS										
HEX_8	1	1		75*2	0,60243		0,55696	74.372		52.256
HEX_8	1	1		300*2	0,60342	0.5973	0,56107	73.808	72.08	51.864
HEX_8	1	1		1200*2	0,60523		0,56248	73.644		51.680