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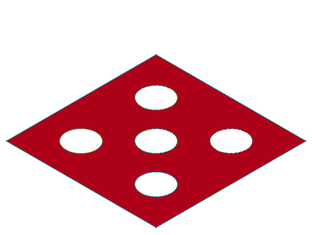
Modal analysis with trimmed NURBS finite elements using LS-DYNA

Problem statement

Trimmed NURBS patches are used in many computer aided design programs and they are used in IGES format for surface representation. A recent enhancement of LS-DYNA allows computations with isogeometric shell finite elements based on trimmed NURBS. Moreover, LS-PrePost supports import of IGES files into LS-PrePost as trimmed NURBS, creation of trimmed NURBS finite elements and defining loads/boundary conditions for these elements. The goal of this master thesis is to explore capabilities of the codes above for modal analysis of plate and shell structures.

Case study

This thesis focused on performing modal analysis to a flat plate with five circular holes and a bracket with eight holes using quadratic trimmed NURBS. The CAD geometry was created by using Rhinoceros and then the IGES file was imported into LS-PrePost as trimmed NURBS. The refinement for the geometry was using h-refinement method. The behaviour of the trimmed NURBS-finite elements were compared with the results achieved from standard element formulation. Results for 100 eigenmodes were extracted and compared with two types of standard shell formulations, ELFORM 16 (linear fully integrated shell element) and ELFORM 20 (quadratic fully integrated linear assumed strain C0 shell)



	Trimmed NURBS	ELFORM 16	ELFORM 20
Reference solution			0.25 mm
Mesh size	• 4 mm • 2 mm • 1 mm		
Polynomial order	2	1	2
Integration rules	• Full integration (INT1) • Reduced integration (INT0)	• Full integration	
Mass matrix types	• Row sum LMM (IMASS 0) • Diagonal weighting LMM (IMASS 1) • CMM	• LMM • CMM	
Boundary condition	• Fixed one end • Fixed both ends • Simply supported		

Benchmarking and efficiency comparison for plate with five holes

	Trimmed NURBS	ELFORM 16	ELFORM 20
Reference solution			0.1 mm
Mesh size	• 4 mm • 2 mm • 1 mm		
Polynomial order	2	1	2
Integration rules	• Full integration (INT1) • Reduced integration (INT0)	• Full integration	
Mass matrix types	• Row sum LMM (IMASS 0) • Diagonal weighting LMM (IMASS 1) • CMM	• LMM • CMM	

Benchmarking and efficiency comparison for bracket

Results

Method	DOF	Mesh size (mm)	CPU time (s)	Total memory (MB)	Error (%)
INT 0 IMASS 0	14520	2	10	15	0.56
INT 0 IMASS 1	14232	2	10	15	0.42
INT 1 IMASS 0	14520	2	10	15	0.44
INT 1 IMASS 1	14232	2	10	15	0.30
INT 0 CMM	14520	2	10	15	0.05
INT 1 CMM	14520	2	11	15	0.18
ELFORM 16 LMM	48120	1	9	4.36	0.38
ELFORM 16 CMM	48120	1	10	4.4	0.47
ELFORM 20 LMM	48120	1	10	4.475	0.03
ELFORM 20 CMM	48120	1	10	4.514	0.06

Plate with five holes: Fixed one end, mode 10

Method	DOF	Mesh size (mm)	CPU time (s)	Total memory (MB)	Error (%)
INT 0 IMASS 0	14208	2	10	15	0.59
INT 0 IMASS 1	13920	2	10	15	0.49
INT 1 IMASS 0	14208	2	10	15	0.26
INT 1 IMASS 1	13920	2	10	15	0.16
INT 0 CMM	14208	2	10	15	0.03
INT 1 CMM	14208	2	11	15	0.36
ELFORM 16 LMM	47514	1	9	4.365	0.22
ELFORM 16 CMM	47514	1	10	4.404	0.32
ELFORM 20 LMM	47514	1	10	4.479	0.04
ELFORM 20 CMM	47514	1	10	4.519	0.06

Plate with five holes: Fixed both ends, mode 10

Method	DOF	Mesh size (mm)	CPU time (s)	Total memory (MB)	Error (%)
INT 0 IMASS 0	14520	2	10	15	0.73
INT 0 IMASS 1	14232	2	10	15	0.54
INT 1 IMASS 0	14520	2	10	15	0.65
INT 1 IMASS 1	14232	2	10	15	0.46
INT 0 CMM	14520	2	11	15	0.12
INT 1 CMM	14520	2	11	15	0.20
ELFORM 16 LMM	48120	1	9	4.363	0.32
ELFORM 16 CMM	48120	1	10	4.403	0.46
ELFORM 20 LMM	48120	1	9	4.478	0.10
ELFORM 20 CMM	48120	1	10	4.517	0.04

Plate with five holes: Simply supported, mode 10

Method	DOF	Mesh size (mm)	CPU time (s)	Total memory (MB)	Error (%)
INT 0 IMASS 0	1 128	2	6	4.038	5.90
INT 0 IMASS 1	1 128	2	5	4.038	5.91
INT 1 IMASS 0	1 128	2	5	4.057	1.55
INT 1 IMASS 1	1 128	2	4	4.057	1.53
INT 0 CMM	1 128	2	5	4.240	2.93
INT 1 CMM	1 128	2	5	4.259	4.90
ELFORM 16 LMM	2 802	1	5	1.893	10.39
ELFORM 16 CMM	2 802	1	5	1.893	3.69
ELFORM 20 LMM	2 802	1	5	1.893	3.58
ELFORM 20 CMM	2 802	1	5	1.893	1.58

Bracket: Mode 9

For a plate with holes, trimmed NURBS finite element with reduced integration and consistent mass matrix (INT0 CMM) produces good results for all boundary conditions and better than standard shell formulation. The suitable average mesh size for a flat plate with holes is 2 mm. For a bracket, trimmed NURBS element with full integration and lump mass matrix (INT1 IMASS) provides less error.

References:

Cottrell, J A.; Hughes, Thomas J.; Bazilevs, Yuri: *Isogeometric analysis; toward integration of CAD and FEA*. John Wiley & Sons, 2009

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