Structural dynamic analysis based on enhanced assumed strain method

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Project Outline

- IDMEC research on early stage fatigue failure of vehicle structures
- Balancing of Body and Chassis
- Optimizing the tools for testing structural strength
- We handle numerical methods to develop new techniques for testing the structural strength
- The idea is to use one technique called **Enhanced Assumed Strain** method
- To reduce the time consumed by the CPU which reduces time for conception
- This technique has proved to be reliable in 3D thin shell problems (**even with coarse meshes**)

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Review of Enhanced assumed strain method

- Inclusion of internal field of variables leads to an Enhanced strain field (or more deformation modes)
- It constructs a formulation with good behavior in near incompressible and bending situations
- To improve the performance of low order locking elements
- The formulation is based on Eight Gauss point integration
- To reduce the complexity of the problem and matrix manipulation
- $$\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}_d + \boldsymbol{\varepsilon}_\alpha = \begin{bmatrix} \mathbf{B}_d^e & \mathbf{B}_\alpha^e \end{bmatrix} \begin{bmatrix} \mathbf{d}^e \\ \boldsymbol{\alpha}^e \end{bmatrix}$$

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Formulation of a 3D solid-shell enhanced element – HCiS12

$$\begin{bmatrix} \mathbf{k}_{dd}^e & \mathbf{k}_{d\alpha}^e \\ \mathbf{k}_{\alpha d}^e & \mathbf{k}_{\alpha\alpha}^e \end{bmatrix} \begin{Bmatrix} \mathbf{d}_e \\ \boldsymbol{\alpha}_e \end{Bmatrix} = \begin{Bmatrix} \mathbf{f}_e^{ext} \\ \mathbf{0} \end{Bmatrix}$$

$$\mathbf{k}_{\alpha\alpha}^e = \int_{\Omega_e} \tilde{\mathbf{B}}_e^T \mathbf{C}_2 \tilde{\mathbf{B}}_e \, d\Omega_e$$

$$\mathbf{k}_{\alpha d}^e = \int_{\Omega_e} \tilde{\mathbf{B}}_e^T \mathbf{C}_2 \mathbf{B}_e \, d\Omega_e$$

$$\tilde{\mathbf{k}}_e \mathbf{d}_e = \mathbf{f}_{ext}^e$$

$$\tilde{\mathbf{k}}_e = \mathbf{k}_{dd}^e - \mathbf{k}_{d\alpha}^e \left(\mathbf{k}_{d\alpha}^e\right)^{-1} \mathbf{k}_{\alpha d}^e$$

$$\alpha_e = -\left(\mathbf{k}_{\alpha\alpha}^e\right)^{-1} \mathbf{k}_{\alpha d}^e \mathbf{d}_e$$

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Formulation of a 3D solid-shell enhanced element

$$\boldsymbol{M}^{\alpha}\big|_{HCi12} = \begin{bmatrix} \frac{\partial \boldsymbol{N}_{\alpha}}{\partial \xi^1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{\partial^2 \boldsymbol{N}^{\alpha}}{\partial \xi^1 \partial \xi^2} & \frac{\partial^2 \boldsymbol{N}^{\alpha}}{\partial \xi^1 \partial \xi^3} & \frac{\partial^2 \boldsymbol{N}^{\alpha}}{\partial \xi^2 \partial \xi^3} \\ 0 & \frac{\partial \boldsymbol{N}_{\alpha}}{\partial \xi^2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{\partial^2 \boldsymbol{N}^{\alpha}}{\partial \xi^1 \partial \xi^2} & \frac{\partial^2 \boldsymbol{N}^{\alpha}}{\partial \xi^1 \partial \xi^3} & \frac{\partial^2 \boldsymbol{N}^{\alpha}}{\partial \xi^2 \partial \xi^3} \\ 0 & 0 & \frac{\partial \boldsymbol{N}_{\alpha}}{\partial \xi^3} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{\partial^2 \boldsymbol{N}^{\alpha}}{\partial \xi^1 \partial \xi^2} & \frac{\partial^2 \boldsymbol{N}^{\alpha}}{\partial \xi^1 \partial \xi^3} & \frac{\partial^2 \boldsymbol{N}^{\alpha}}{\partial \xi^2 \partial \xi^3} \\ 0 & 0 & 0 & \frac{\partial \boldsymbol{N}_{\alpha}}{\partial \xi^1} & \frac{\partial \boldsymbol{N}_{\alpha}}{\partial \xi^2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{\partial \boldsymbol{N}_{\alpha}}{\partial \xi^1} & \frac{\partial \boldsymbol{N}_{\alpha}}{\partial \xi^3} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{\partial \boldsymbol{N}_{\alpha}}{\partial \xi^2} & \frac{\partial \boldsymbol{N}_{\alpha}}{\partial \xi^3} & 0 & 0 & 0 \end{bmatrix}$$

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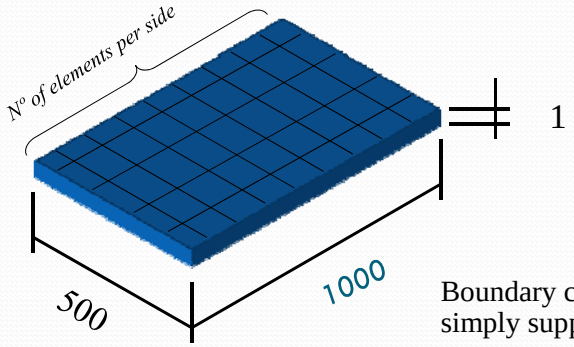
Previously developed elements by idmec

- Alternative approaches based on EAS method for solid-shell elements in order to use them for vehicle structures:
- HC9 Element – 9 additional variables
- HCi12 Element – 12 additional variables
- HCiS18 Element – 18 additional variables
- **HCis12** and HCis18 are volumetric and transversal shear locking free (specific for shell structures)

Previously developed elements by IDMEC (static results):

Elements per side	4	5	8	9	16	17	32
HciS12	0.937	NA	0.974	NA	0.990	NA	0.995
HciS18	1.028	NA	1.005	NA	0.997	NA	0.996
MITC4	0.937	NA	0.973	NA	0.993	NA	NA
EAS7-ANS	1.041	NA	1.006	NA	1.002	NA	Na
HEXDS	NA	NA	1.157	NA	1.137	NA	1.132
QPH	0.940	NA	0.980	NA	1.010	NA	NA

Analysis on a simple shell structure



Boundary conditions: simply supported

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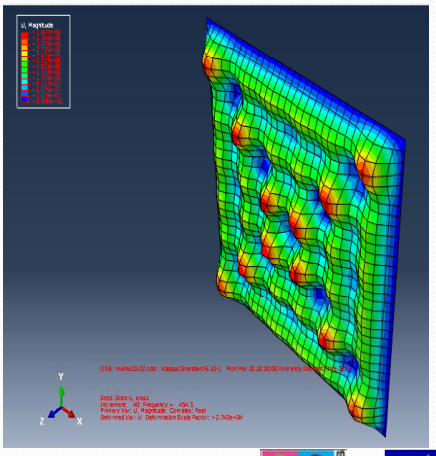
Analysis on a simple shell structure

- A simple shell structure with different mesh types was tested
- It is simply supported
- It is tested for HCiS12 element and a few other elements as well
- The external frequency applied ranges from 100-1000Hertz
- The displacement in “Z” direction (out of plane) is found



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Elements tested

Element type	Description
C3D8	8-node linear brick (ABAQUS)
C3D8H	8-node linear brick, hybrid with constant pressure (ABAQUS)
HCiS12	8-node linear brick, enhanced assumed strain
C3D8R	8-node linear brick, reduced integration with hourglass control (ABAQUS)
C3D8RH	8-node linear brick, reduced integration with hourglass control, hybrid with constant pressure (ABAQUS)

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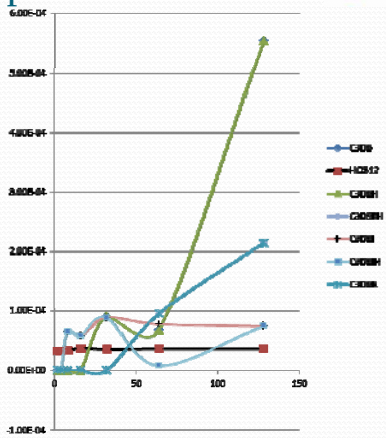
Results obtained for the plate structure

- The graph shown is maximum displacement in Z direction for the different elements
- "X" axis contains the range of mesh sizes
- "Y" axis is the maximum displacement
- The graph shown is for the minimum frequency limit of 100 Hertz



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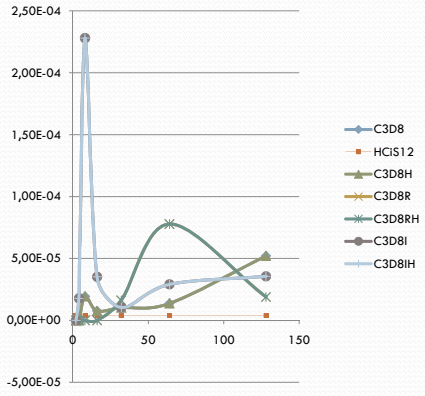
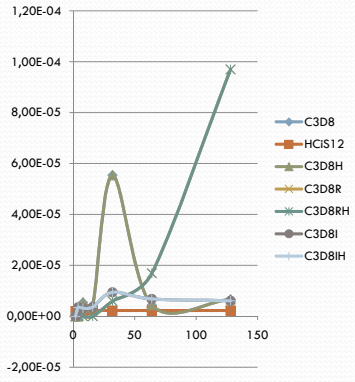
Results for higher frequency values





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Discussion of the plate results

- The element HCiS12 element exhibit a uniform displacement for different mesh sizes
- The displacement obtained with other formulations show its dependency on the mesh size
- If favorable results could be obtained with the coarse mesh, it helps in reducing time conception
- The validation of these results would be done with analytical calculations

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Application of finite element formulation to an automobile part

- The part (courtesy of Dr Cremers - BMW) is constrained at the fixation points
- A concentrated load of 100KN was applied (for excitation purposes)
- The load was applied to one particular node and the displacement was obtained
- HCiS12 element was implemented and tested
- Material properties
- Young's modulus=210e9 N/mm^2
- Poisson's ratio=0.3

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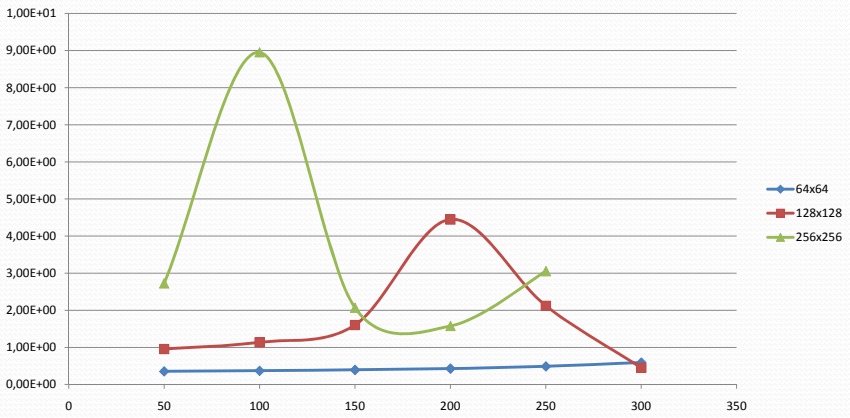
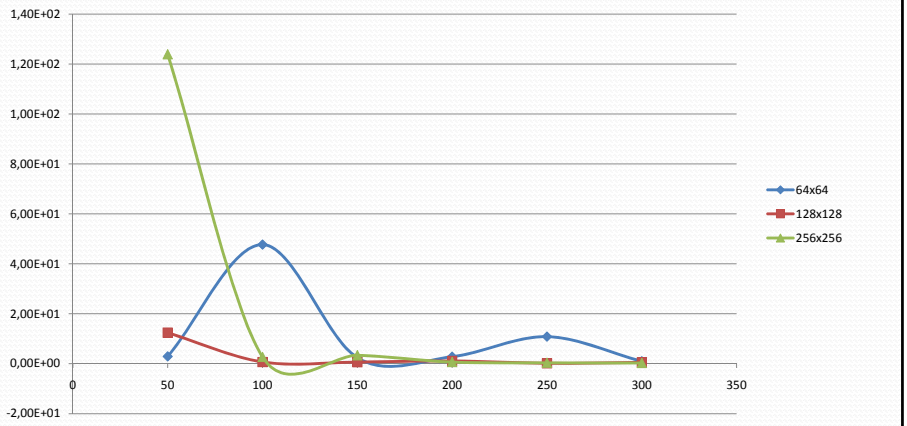
Comparison between Coarse and Refined mesh

- The part was meshed with three different meshes from coarse to more refined mesh
- A concentrated load of 100KN was applied (for excitation purposes)
- The necessary boundary conditions were applied to avoid singularity
- The analysis was done for different formulations based on EAS
- The idea is to test finite element formulations on a automotive part

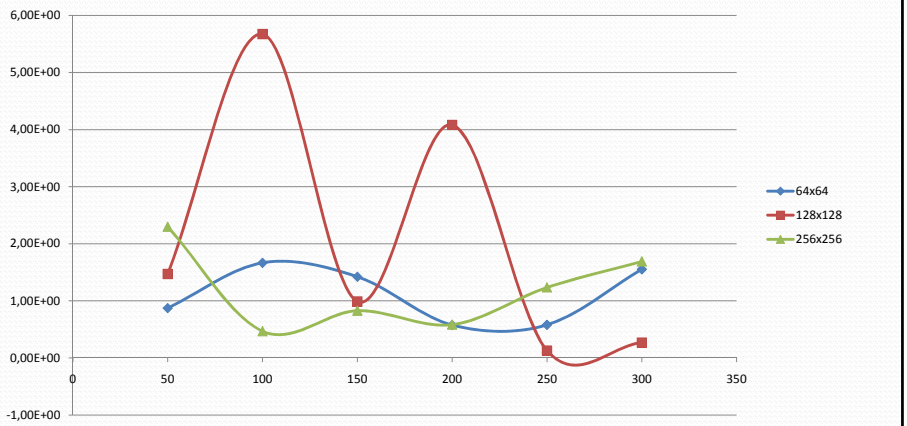
Element type C3D8



Element type HCiS12



Element type C3D8R



conclucions

- The preliminary analysis has been carried out with the element types available from Abaqus
- The HCiS12 results obtained are to be validated
- The formulations is also to be modified for better results
- The proposed enhanced assumed strain formulation can be applied in dynamic analysis of a real part.
- This technique could be used as a tool for reducing the time consumption

Future work

- HCiS12 element type is to be validated for a convincing conclusion
- More tests are to be carried out
- Comparison the results (based on 3D shell-like elements) with classical shell elements
- The element is to be used for major car parts
- CPU time needs to be evaluated
- More efficient algorithms need to be implemented

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