A User-Defined Element Interface in LS-DYNA v971

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Abstract:

The user-defined features in LS-DYNA are powerful tools that allow users in academia or industry to verify research results in the context of general and complicated finite element applications. Implementation work concerns only the special field of interest, and there is no need for the comprehensive task of developing and maintaining the complete finite element software. One of the new user-defined features in LS-DYNA v971 is the possibility to define structural solid and shell elements. Up to a total of ten element formulations can be implemented in a single LS-DYNA executable both for explicit and implicit analyses. A high abstraction-level interface is in particular provided for numerically integrated elements, and stabilization schemes can easily be incorporated. There is also the option to implement resultant or discrete elements, and property parameters and history variables can be associated with the element. The interface is equipped with additional features that facilitates research on element technology, but also makes it perfectly suited for educational purposes. An overview of the procedure of implementing an element in the new interface as well as invoking it from the keyword input file will be presented.

Keywords:

User interface, element technology, numerical integration, implementation.

Reference:

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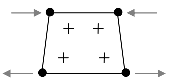
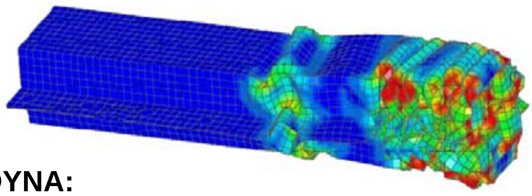
Motivation

- **Element technology: active area of research**
  → robustness, speed, accuracy, prevention of locking



➡ Verification in the context of general and complicated Finite Element applications ?



- **User interface in LS-DYNA: environment for large-scale real-world problems**
  → no need for the comprehensive task of developing and maintaining complete Finite Element software

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Overview

- Remarks on user-defined features
- Theoretical background: Element formulation
- Implementation aspects: Interface ingredients
- Usage in LS-DYNA keyword input
- Examples: Comparison with standard elements
- Conclusion

User defined features in LS-DYNA

Version 971 currently includes following items:

- Structural materials
- ***Structural elements***
- Thermal materials
- Equation of state
- Airbag sensors
- Solution control
- Friction
- Interface control
- Weld failure
- Loads
- Output control
- Material failure
- Adaptivity

User defined features in LS-DYNA

- **Object version of LS-DYNA** – available for all platforms and included in licence fee
- **FORTRAN compiler** – not included in package and must be bought separately
- **FORTRAN text file** (dyn21.f, dyn21b.f, lsdyna.f)
  – edit/add subroutines according to task to be accomplished
- **Compilation** – makefile script from command prompt or GUI

➡ **Executable** – treated as normal

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Element theory

Discrete equation of motion $\mathbf{M}\Delta\ddot{\mathbf{u}}_{n+1} + \mathbf{K}\Delta\mathbf{u}_{n+1} = \mathbf{f}_{n+1}^{ext} - \mathbf{f}_{n}^{int} - \mathbf{M}\ddot{\mathbf{u}}_{n}$

... as result of spatial discretization by Finite Elements:

$$\mathbf{M} = \bigcup_{e=1}^{n_e} \int_{\Omega_e} \rho \mathbf{N}_e^T \mathbf{N}_e \, dv \qquad \mathbf{f}^{ext} = \bigcup_{e=1}^{n_e} \int_{\Omega_e} \rho \mathbf{N}_e^T \mathbf{b} \, dv + \int_{\Gamma_e} \mathbf{N}_e^T \mathbf{t} \, da$$

$$\mathbf{f}^{int} = \bigcup_{e=1}^{n_e} \int_{\Omega_e} (\nabla \mathbf{N}_e)^T \boldsymbol{\sigma} \, dv = \bigcup_{e=1}^{n_e} \int_{\Omega_e} \mathbf{B}^T \boldsymbol{\sigma} \, dv$$

B *... gradient-displacement matrix*

$$\mathbf{K} = \bigcup_{e=1}^{n_e} \int_{\Omega_e} (\nabla \mathbf{N}_e)^T \mathbf{C} (\nabla \mathbf{N}_e) \, dv = \bigcup_{e=1}^{n_e} \int_{\Omega_e} \mathbf{B}^T \mathbf{C} \mathbf{B} \, dv$$

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Element theory

Velocity gradient $\mathbf{L} = \frac{\partial \mathbf{v}}{\partial \mathbf{x}} = \mathbf{v}_I \frac{\partial \mathbf{N}_I}{\partial \mathbf{x}} = \mathbf{v}_I \mathbf{B}_I^{\,T}$

Decomposition into rate-of-deformation $\mathbf{D}$ and spin $\mathbf{W}$

$$\mathbf{L} = \frac{1}{2}\left(\mathbf{L} + \mathbf{L}^T\right) + \frac{1}{2}\left(\mathbf{L} - \mathbf{L}^T\right) = \mathbf{D} + \mathbf{W}$$

Stress $\boldsymbol{\sigma} = \boldsymbol{\sigma}\left(\mathbf{D}, \mathbf{W}, \ldots\right)$

$$\mathbf{f}_S^{int} = \bigcup_{e=1}^{n_e} \int_{\Omega_e} \mathbf{B}^T\, \boldsymbol{\sigma}(\mathbf{B})\; dv \qquad \mathbf{K}_S = \bigcup_{e=1}^{n_e} \int_{\Omega_e} \mathbf{B}^T\, \mathbf{C}(\mathbf{B})\; \mathbf{B}\; dv$$

gradient-displacement matrix is key ingredient for internal force vector and stiffness matrix

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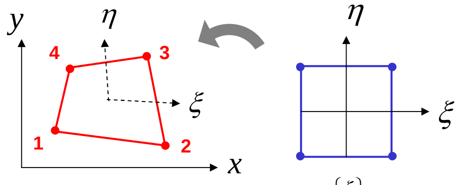
Mapping & Numerical integration

Mapping: Transformation from **physical element domain** to **isoparametric domain**

$$\int_{\Omega_e} \mathbf{A}\, dv = \int_{-1}^{1}\int_{-1}^{1}\int_{-1}^{1} \mathbf{A}\, J\; d\xi\, d\eta\, d\zeta$$

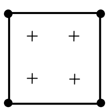
$$J = |\mathbf{J}| = \left|\frac{\partial \mathbf{x}}{\partial \boldsymbol{\xi}}\right|$$



$$-1 \le \begin{Bmatrix} \xi \\ \eta \end{Bmatrix} \le 1$$

Numerical integration using e.g. Gauss integration

$$\int_{-1}^{1}\int_{-1}^{1}\int_{-1}^{1} \mathbf{A}\, J\; d\xi\, d\eta\, d\zeta = \sum_{m=1}^{n_{IP}} w_m\, \mathbf{A}(\boldsymbol{\xi}_m)\, J(\boldsymbol{\xi}_m)$$



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Numerical integration

➡ Internal force vector

$$\mathbf{f}_S^{int} = \sum_{m=1}^{n_{IP}} \mathbf{B}(\xi_m)^T \, \boldsymbol{\sigma}(\xi_m) \, J(\xi_m) \, w_m$$

➡ Stiffness matrix

$$\mathbf{K}_S = \sum_{m=1}^{n_{IP}} \mathbf{B}(\xi_m)^T \, \mathbf{C}(\xi_m) \, \mathbf{B}(\xi_m) \, J(\xi_m) \, w_m$$

LS-DYNA needs **gradient-displacement matrix** and **isoparametric jacobian** to form internal force vector and stiffness matrix

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Additional contributions

Additional contributions for modes not covered by numerical integration

$$\mathbf{f}^{int} = \mathbf{f}_S^{int} + \mathbf{f}_H^{int} \qquad \mathbf{K} = \mathbf{K}_S + \mathbf{K}_H$$

... e.g. hourglass stabilization, drilling, etc.

... stiffness matrix is determined from variation of the stabilization force $\mathbf{K}_H \delta \mathbf{x} = \delta \mathbf{f}_H$

... could represent the total force (when $\mathbf{f}_S^{int} = \mathbf{0}$) and thus used to circumvent any forms of restrictions of the numerical integration approach

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Implementation

- Hexahedral shells and quadrilateral solids
- Up to 10 elements in a single LS-DYNA executable
- Explicit and implicit analyses
- Each element: 2 subroutines
- Property parameters and history variables
- Extra degrees of freedom are possible:
  e.g. shell thickness, hydrostatic pressure, ...
- Integration points at arbitrary positions

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Implementation

Subroutine for numerical integration

```
subroutine uXXX_bYYY(bmtrx,gmtrx,gjac,...)
```

`bmtrx(nlq,3,3,*)`	- gradient displacement matrix
`gmtrx(nlq,3,3)`	- Jacobian matrix
`gjac(nlq)`	- scalar Jacobian (volume change)

additional arguments

- nodal coordinates
- isoparametric coordinates
- shape function values and derivatives
- ...

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Implementation

Subroutine for additional force

```
subroutine uXXX_eYYY(force,stiff,...)
```

`force(nlq,*)` - force vector
`stiff(nlq,ndtot,*)` - stiffness matrix

additional arguments

- property parameters
- history variables
- physical stiffness for hourglass
- ...

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Usage of element interface

- Invoked on ***SECTION_SHELL** and ***SECTION_SOLID** card

Variable	SECID	ELFORM	...	...	
Type	A8	I	...	...	

- ELFORM between **101 and 105**
- **Additional cards** for reading of **associated parameters**
- **Appendix C** in Keyword User's Manual version 971

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Usage of element interface

Additional cards on *SECTION_SHELL

Variable	NIPP	NXDOF	IUNF	IHGF	ITAJ	LMC	NHSV	ILOC
Type	I	I	I	I	I	I	I	I

Variable	XI	ETA	WGT					
Type	F	F	F					

Variable	P1	P2	P3	P4	P5	P6	P7	P8
Type	I	I	I	I	I	I	I	I

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Usage of element interface

Additional cards on *SECTION_SOLID

Variable	NIP	NXDOF	IHGF	ITAJ	LMC	NHSV		
Type	I	I	I	I	I	I		

Variable	XI	ETA	ZETA	WGT				
Type	F	F	F	F				

Variable	P1	P2	P3	P4	P5	P6	P7	P8
Type	I	I	I	I	I	I	I	I

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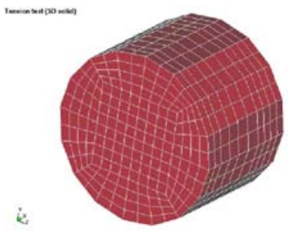
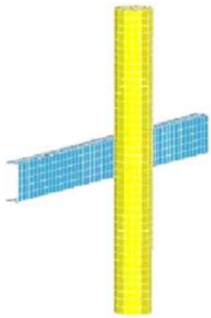
Examples



Constant stress solid

Belytschko-Tsay shell



➡ **Comparable results with standard elements**

➡ **Reduced computational efficiency (in consequence of a user friendly interface)**

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Conclusion

- **Element interface allows verification of research results in the context of general and complicated finite element applications**
- **High level of abstraction**
  - → easy to use
  - → research and education
- **Continuous development**
  - → add features (suggestions by users are welcome)
  - → improve efficiency
  - → remove restrictions
- **paper:** T. Borrvall, 9th International LS-DYNA Users Conference 2006

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