Webinar

Implicit / explicit switching in LS-DYNA

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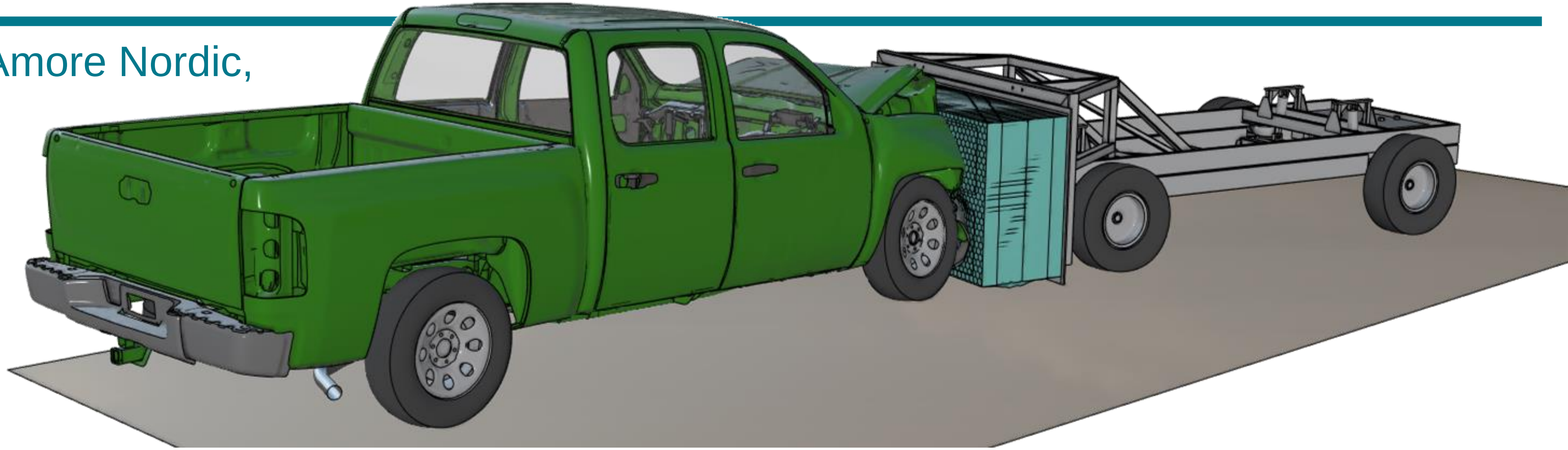
an Ansys company



Acknowledgements

- This presentation contains examples based on public FE-models:
  - 2010-toyota-yaris-detailed-v2j.zip
    - from The Center for Collision Safety and Analysis (CCSA) at the George Mason University (GMU) developed under a contract with the Federal Highway Administration (FHWA)
    - The work of the CCSA at GMU is gratefully acknowledged.
  - Honda Accord, [Oblique THOR Accord Model]
    - developed by EDAG, Inc. under sponsorship from NHTSA
  - Chevrolet Silverado (2007)
    - from the National Crash Analysis Center (NCAC) at
      The George Washington University (GWU).
    - The work of NCAC at GWU is gratefully acknowledged
- The FBO model was created by Eric Piskula, Ansys EMEA ACE
  - Eric's contributions are gratefully acknowledged

Implicit / explicit switching in LS-DYNA

Overview

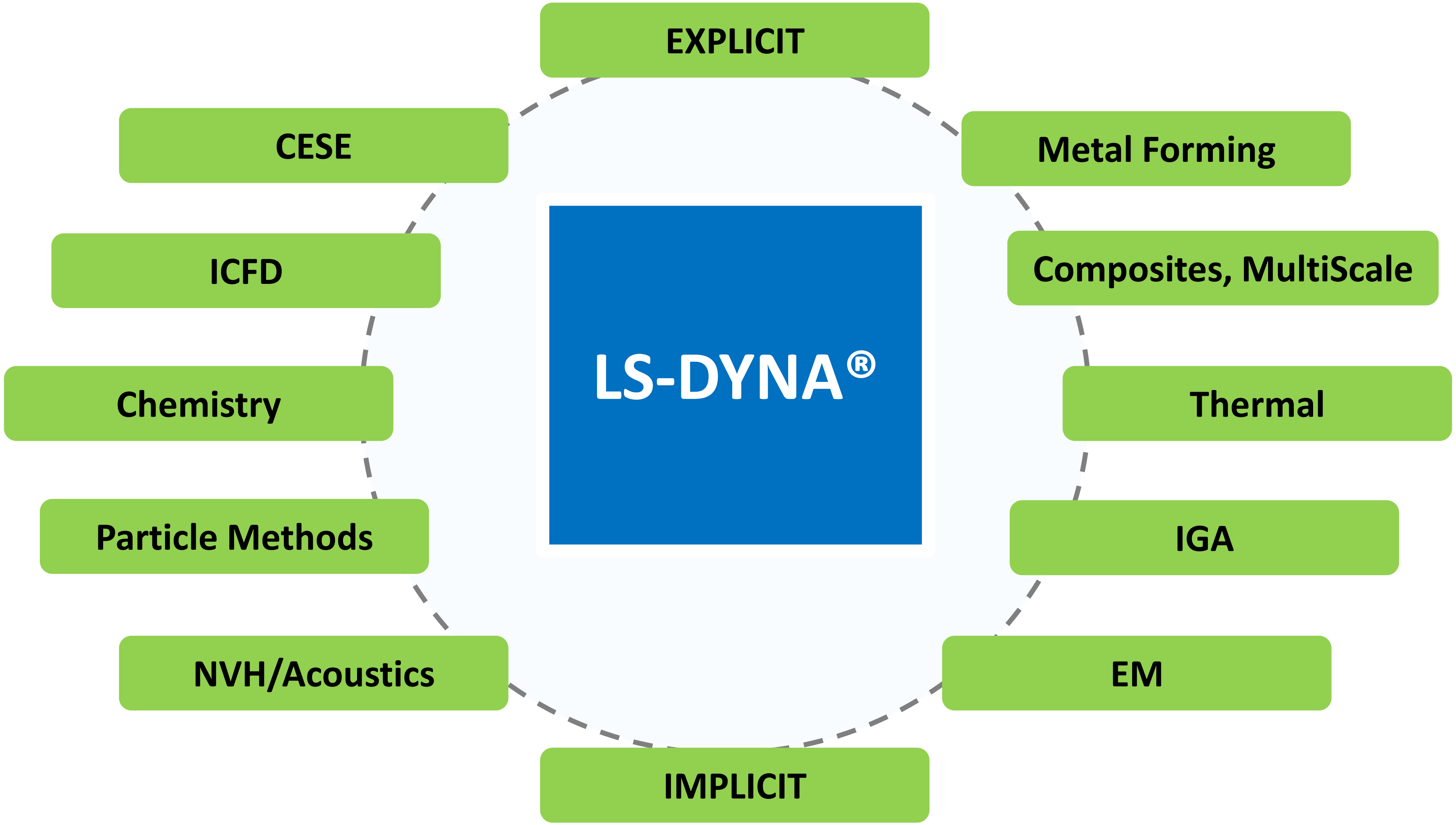
- Introduction
- Different ways to switch
  - Dynamic Relaxation
  - Different options on `*CONTROL_IMPLICIT_GENERAL`
  - Multi-stage analysis
    - Using `*CASE` and dynain.lsdyna
  - Springback after forming analysis
  - ...
- Some differences between implicit and explicit
  - Making the simulation work for both implicit and explicit
- Summary

Introduction

Multi-physics capabilities and solvers in LS-DYNA

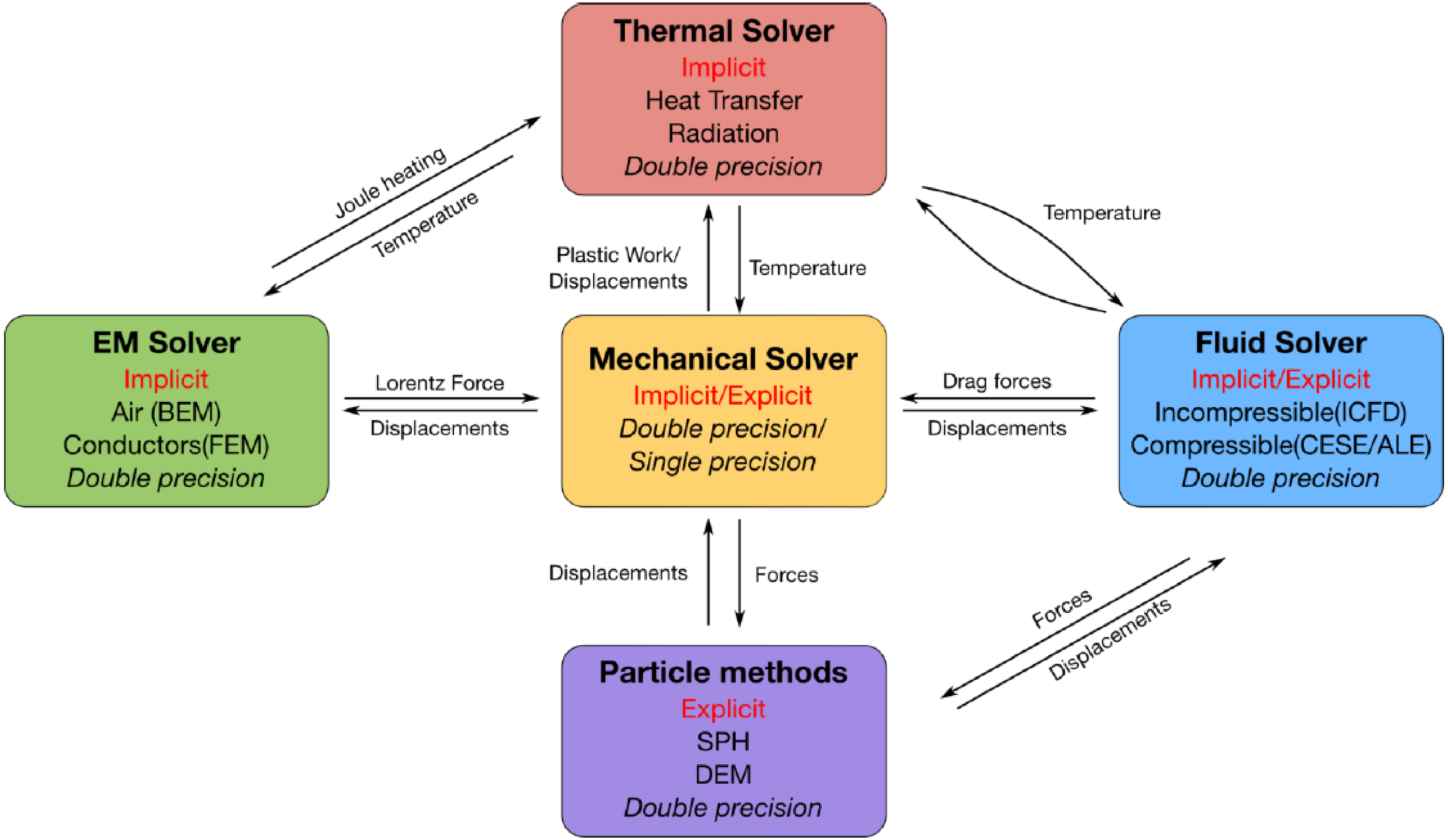
LS-DYNA

A versatile multi-physics solver package



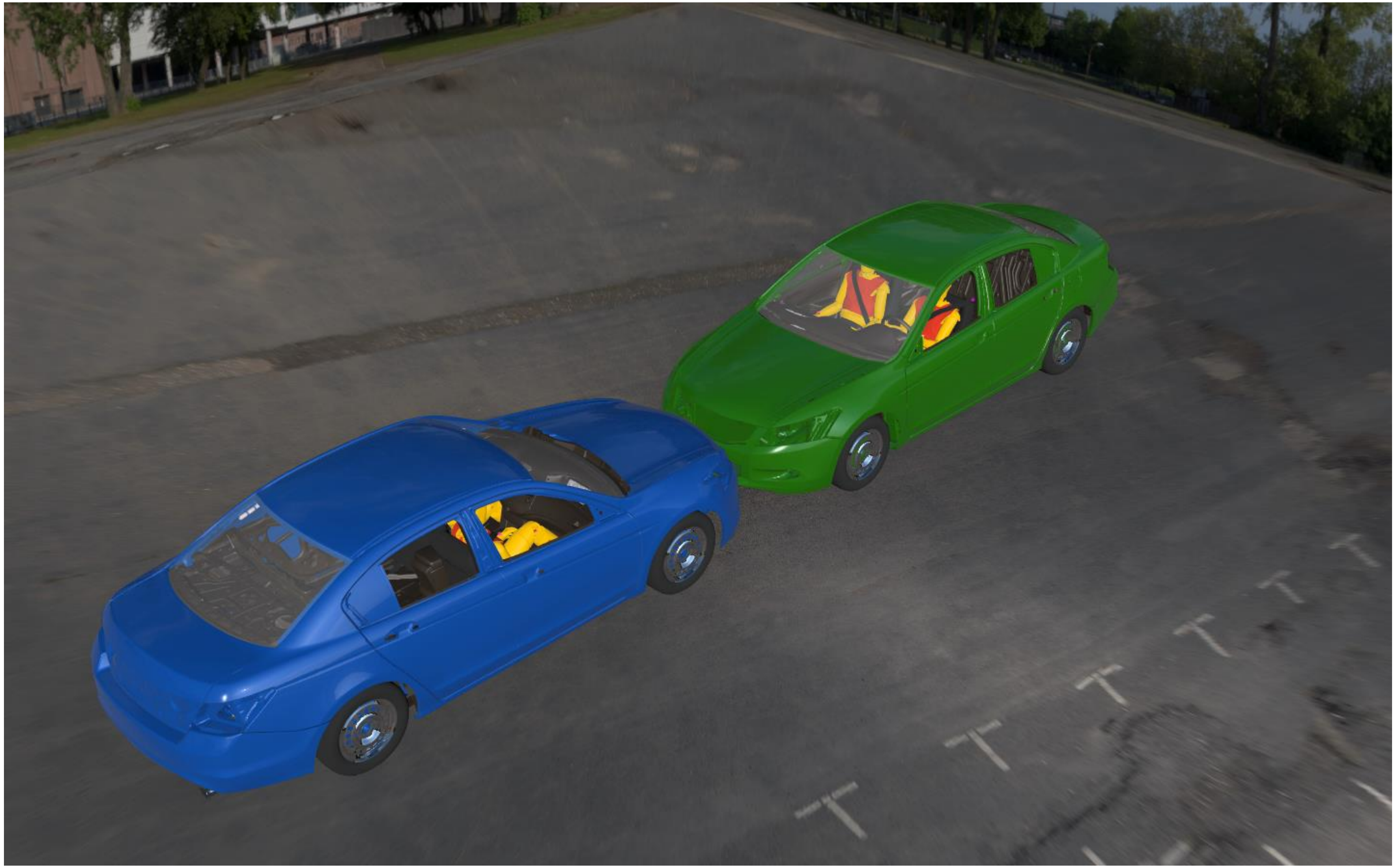
LS-DYNA

A versatile multi-physics solver package



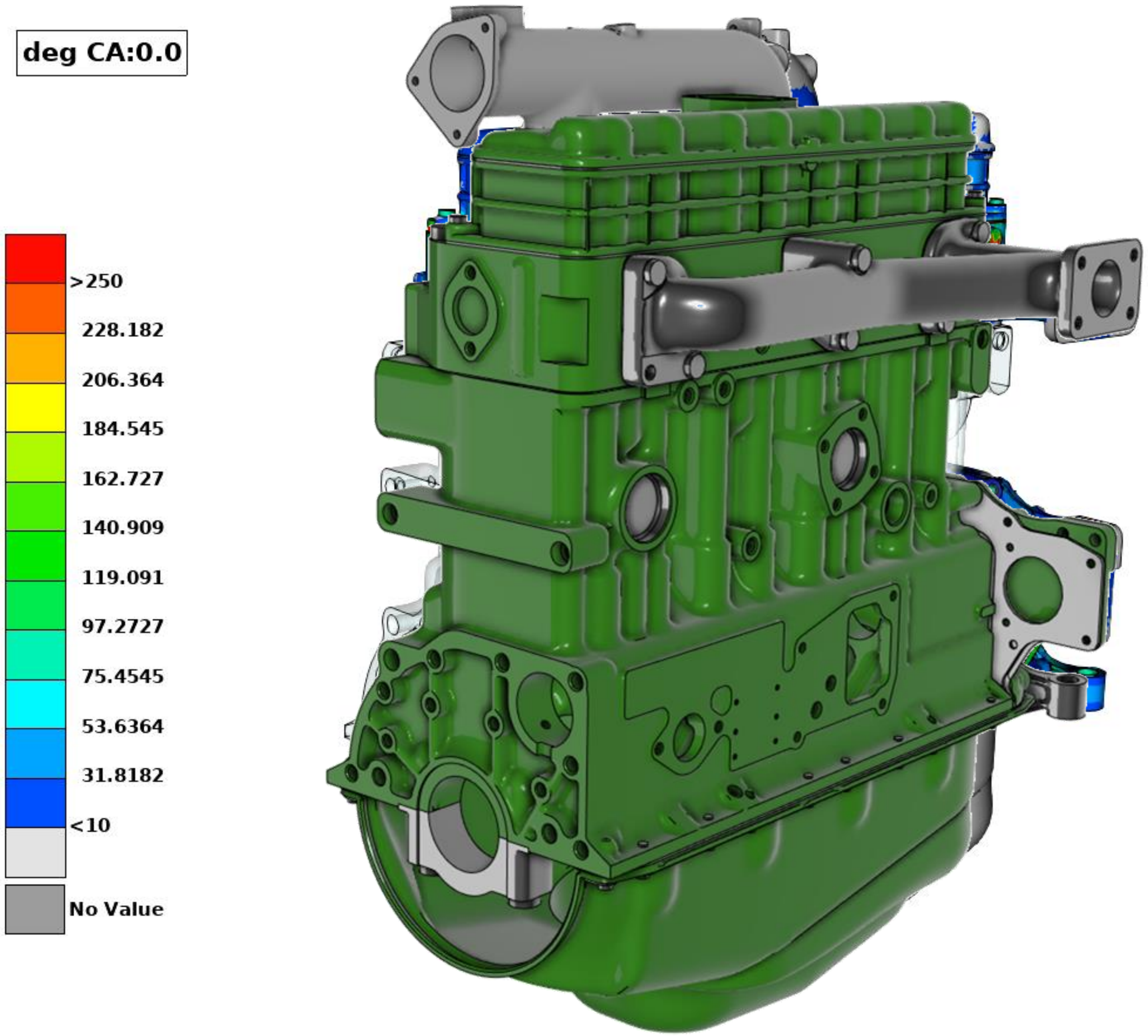
LS-DYNA Mechanical solvers

Explicit ...



LS-DYNA Mechanical solvers

... and Implicit



LS-DYNA Mechanical solvers

Implicit and explicit

Explicit

- Functions of earlier configurations only

$$\mathbf{x}_{n+1} = \mathbf{f}(\mathbf{x}_n, \mathbf{x}_{n-1}, \ldots, t_{n+1}, t_n, \ldots)$$

- Equilibrium at time ***t***

$$\mathbf{M}\ddot{\mathbf{U}}_t = f_{e,t} - f_{i,t} - f_{d,t}$$

- Conditionally stable: $\boldsymbol{\Delta t_{crit}}$

Implicit

- Solve an equation system

$$\mathbf{0} = \mathbf{f}(\mathbf{x}_{n+1}, \mathbf{x}_n, \mathbf{x}_{n-1}, \ldots, t_{n+1}, t_n, \ldots)$$

- Equilibrium at time ***t+Δt***

$$\mathbf{M}\ddot{\mathbf{U}}_{t+\Delta t} = f_{e,t+\Delta t} - f_{i,t+\Delta t} - f_{d,t+\Delta t}$$

- Can be made unconditionally stable

LS-DYNA Mechanical solvers

Implicit and explicit

Explicit

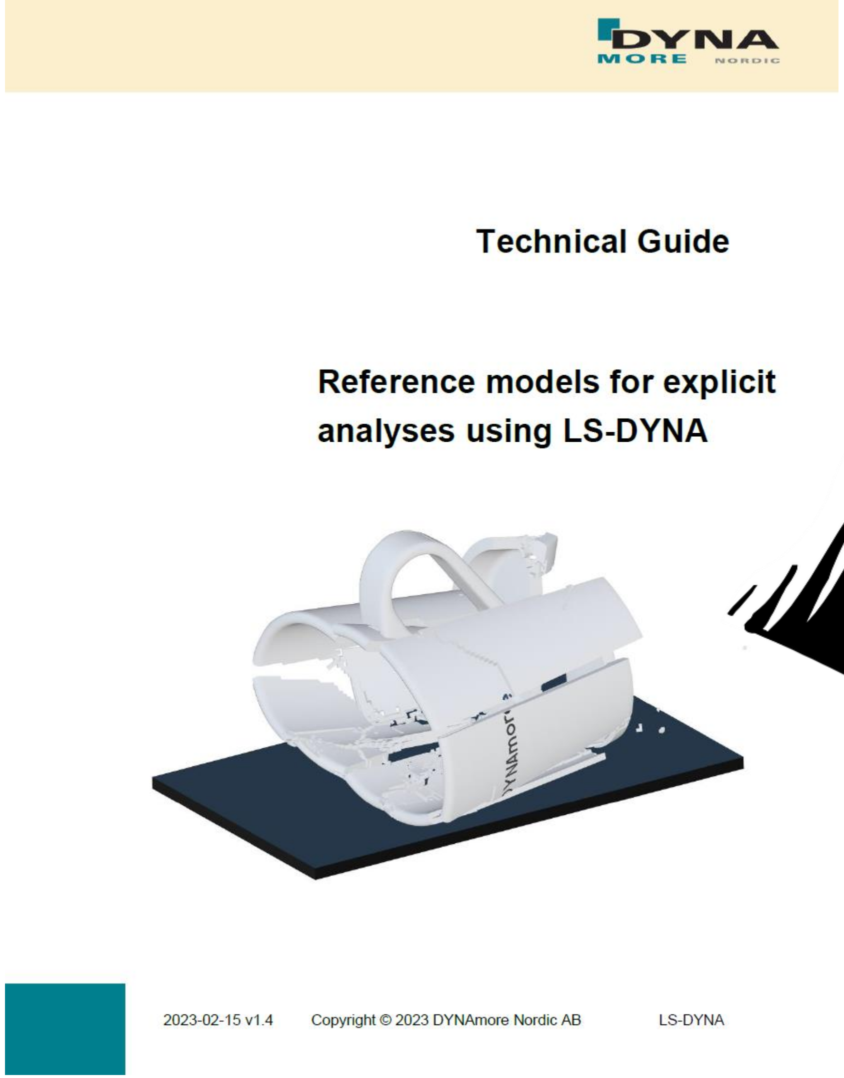
- Many small time steps
  - Possible to simplify elements, material models, contact algorithms etc.
- Direct solution
  - Efficient
  - Accurate
  - Decoupled ➔ Easy to parallelize
- Sequential treatment of constraints
  - Penalty formulation for joints

Implicit

- Few large steps
  - Requires strong objectivity
  - Large strain increments
- Iterative solution of a non-linear equation system
  - Factorization of matrices
- Higher accuracy in elements, materials, contacts etc. beneficial for convergence
- Simultaneous treatment of constraints
  - Constraint formulation for joints

LS-DYNA Implicit and explicit

Getting along



Technical Guide

Reference models for explicit analyses using LS-DYNA

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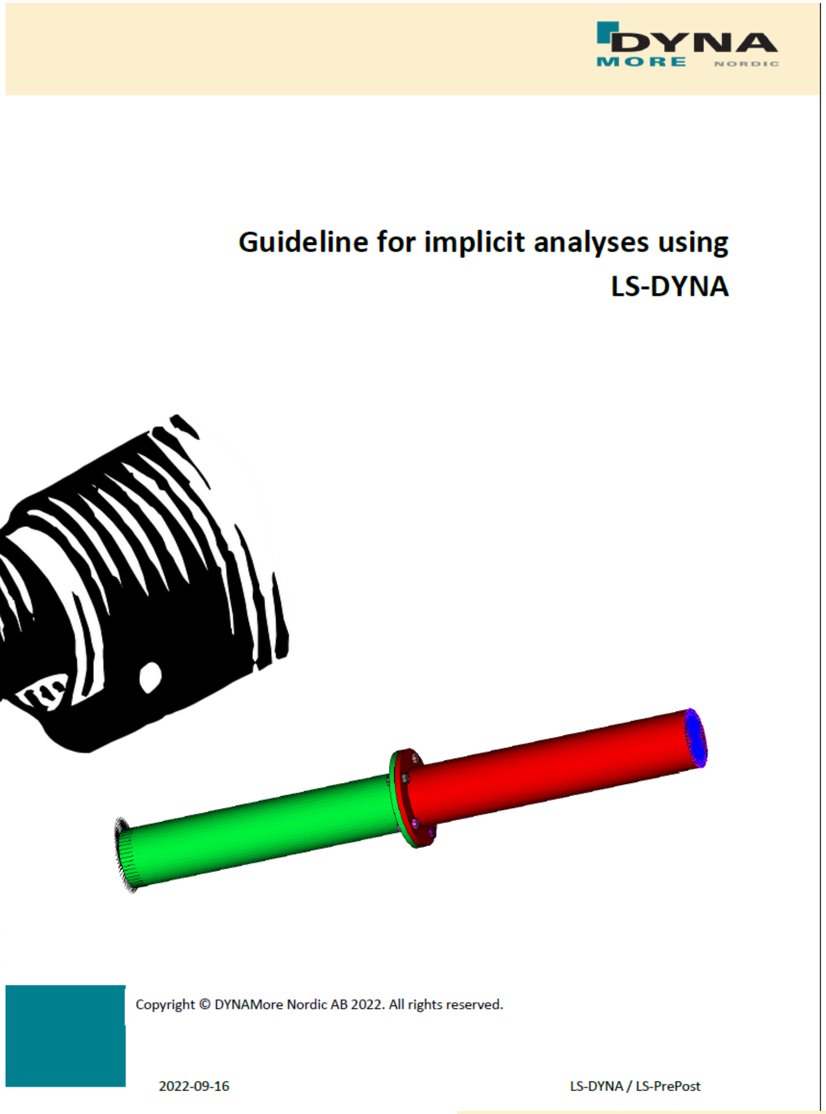
CLIENT AREA



Guideline for implicit analyses using LS-DYNA

2022-09-16 LS-DYNA / LS-PrePost

LS-DYNA implicit / explicit switching

Getting along

- The Guideline for implicit analyses using LS-DYNA contains Appendix F
- Implicit / explicit switching is described
- Including some examples
- Also Appendices D, E could be of interest

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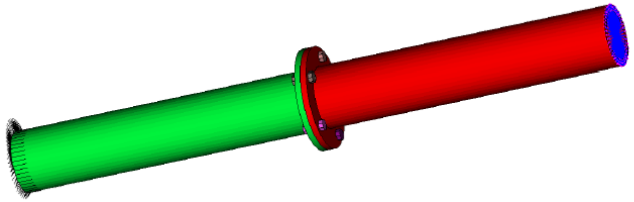
Guideline for implicit analyses using LS-DYNA



2022-09-16

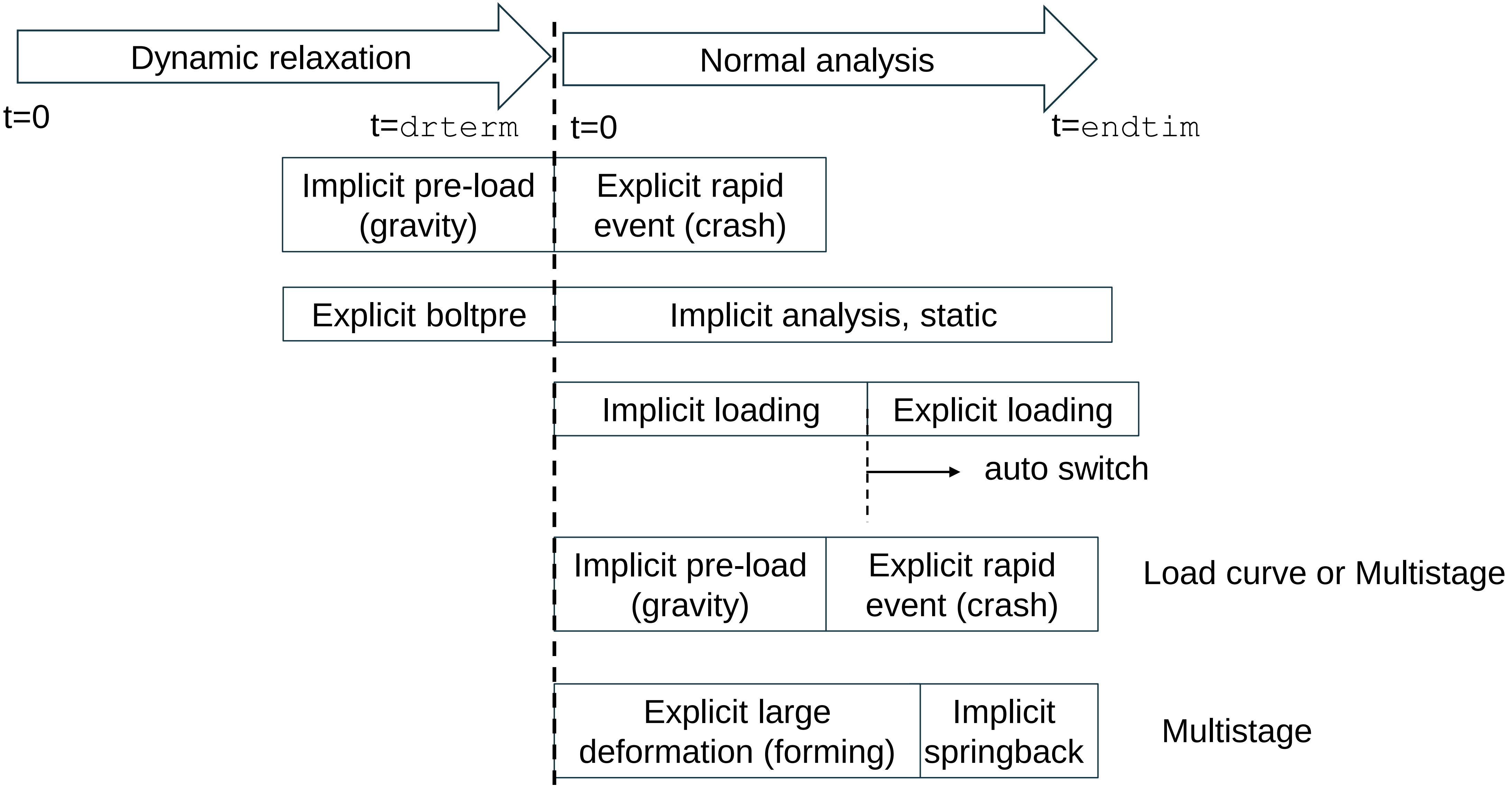
LS-DYNA / LS-PrePost

Different ways to switch

Options for switching between implicit and explicit in LS-DYNA

Different ways to switch

Overview



Dynamic relaxation

Two-stage analysis

Dynamic relaxation

t=0 t=`drterm`

- Activated by *`SIDR`* > 0 on `*DEFINE_CURVE`
- Additional control parameters on `*CONTROL_DYNAMIC_RELAXATION`
- Load curves with *`SIDR`* = 1, 2 active
- Possible to specify separate implicit settings, `*CONTROL_IMPLICIT_..._DYN`
- Output may be requested by `*DATABASE_BINARY_D3DRLF`

Normal analysis

t=0 t=`endtim`

- Load curves with *`SIDR`* = 0, 2 are active

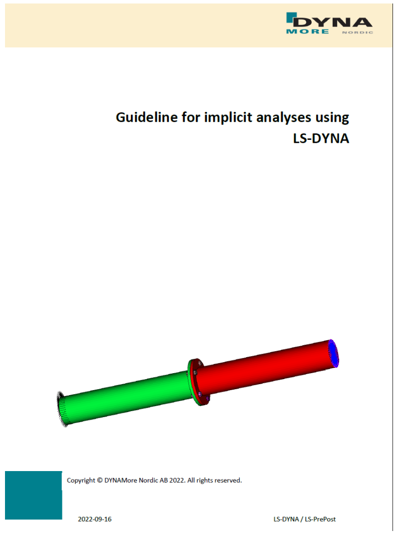
Dynamic relaxation

For implicit / explicit switching

- See also previous webinars, on Damping and Dynamic Relaxation available from the Client Area
  - Hallén, A., Pre-tensioning and dynamic relaxation, Webinar 2022-12-01
  - Bernhardsson, A., Damping in explicit LS-DYNA, Webinar 2021-04-22
- The most common application of DR is explicit bolt pre-loading followed by an explicit main analysis
- Two cases for using DR for implicit / explicit switching
  - Explicit DR phase, followed by an implicit main simulation
    - Can be very efficient for bolt pre-tensioning
  - Implicit DR phase, followed by an explicit main simulation
- To use Dynamic Relaxation (DR) for implicit / explicit switching, the keyword `*CONTROL_DYNAMIC_RELAXATION` is required

Explicit Dynamic Relaxation / Implicit main run

*CONTROL_DYNAMIC_RELAXATION


Guideline for implicit analyses using
LS-DYNA

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2022-09-16

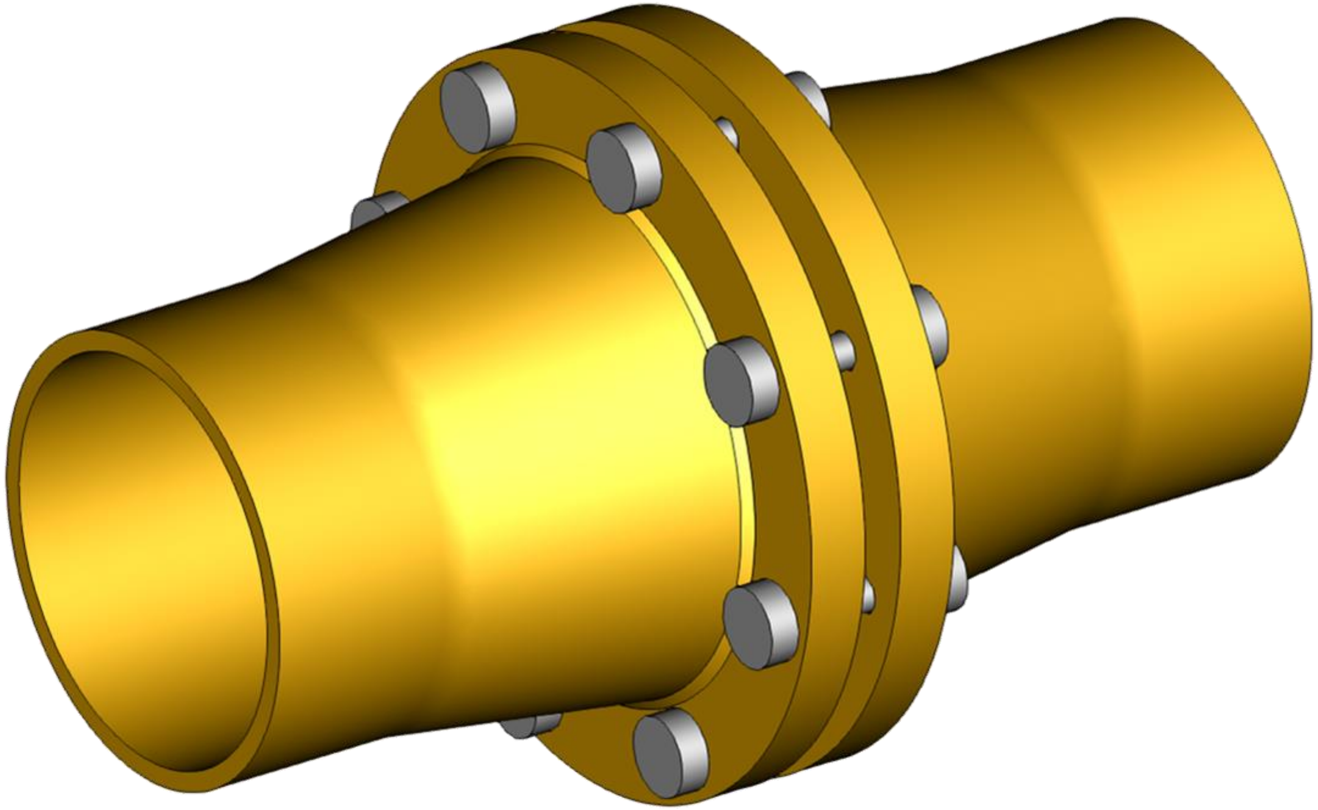
LS-DYNA / LS-PrePost

- Use mainly implicit settings / control cards
  - Fully integrated elements
  - Mortar contacts – possibly add contact damping, VDC ≈ 10 – 40
  - Mainly implicit control cards, from for example “Guideline for implicit analyses ...”
- *CONTROL_DYNAMIC_RELAXATION is required
  - *IDRFLG* = 1 to activate explicit DR
  - Start out with the default values for other variables
- Adding *CONTROL_TIMESTEP is recommended
  - *DT2MS* < 0
  - (Allow ~ 5 – 10 % added mass)

Explicit Dynamic Relaxation / Implicit main run

Example: Pipe joint

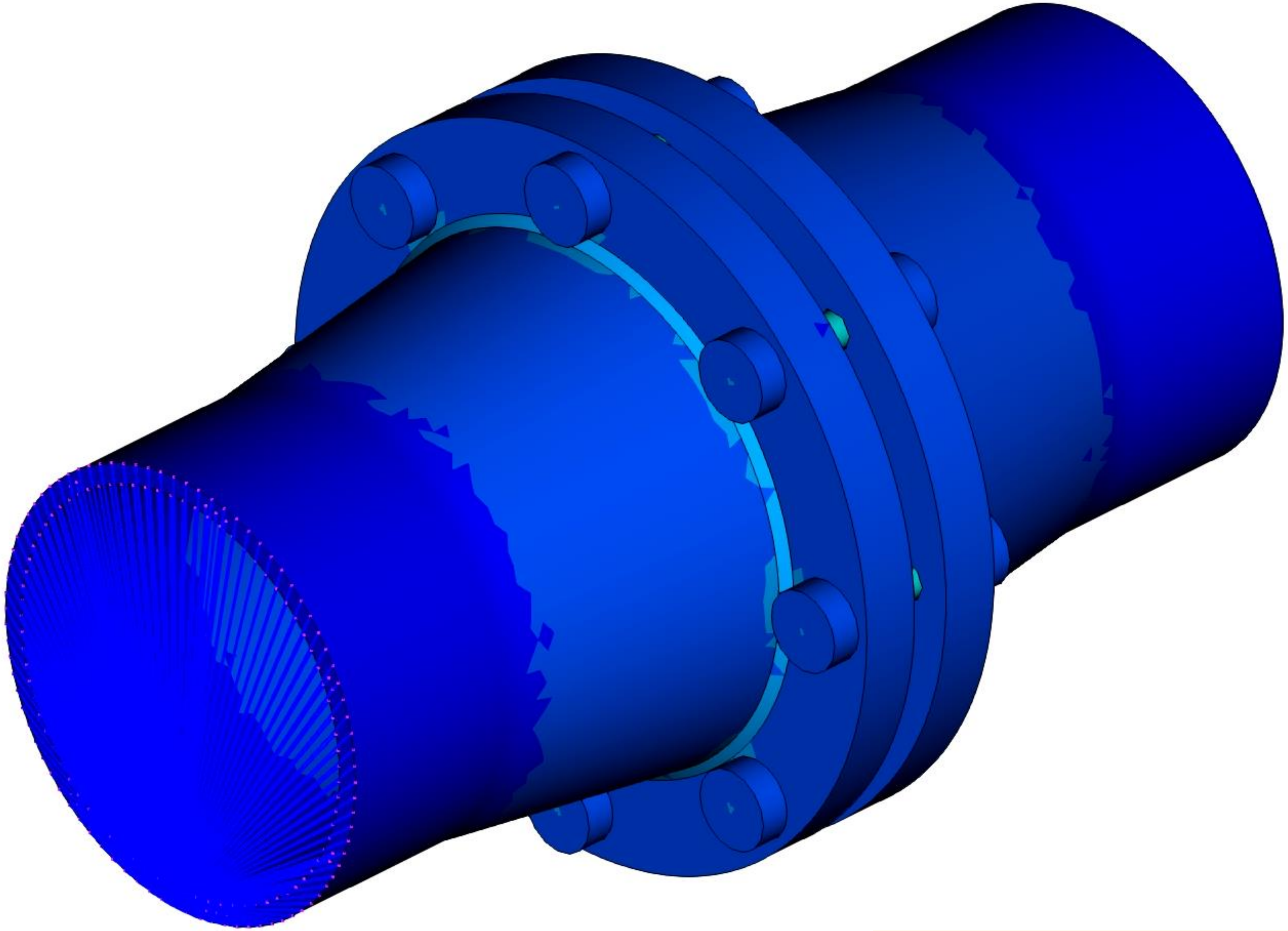
- M18x8
- Pre-tension: 99.2 kN
  - Using explicit DR
- Torque loading: 500 kNm
  - Implicit statics



Explicit Dynamic Relaxation / Implicit main run

Result: Pipe joint

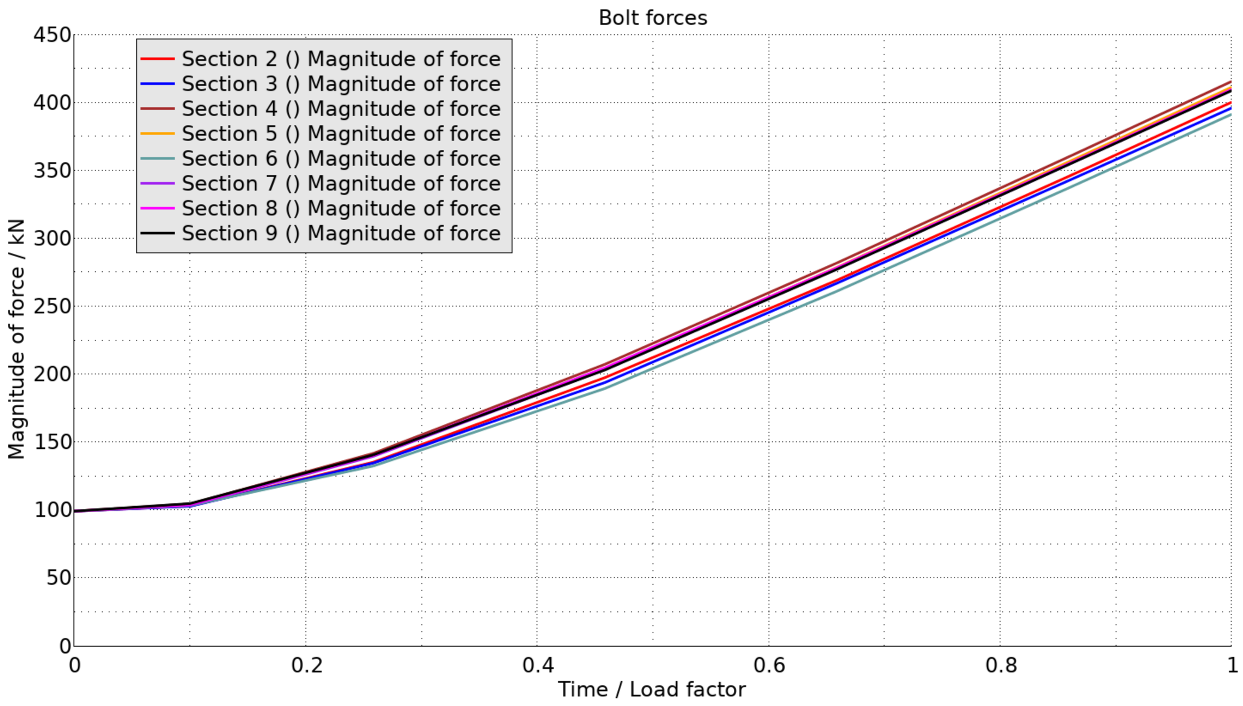
- M18x8
- Pre-tension: 99.2 kN
  - Using explicit DR
- Torque loading: 500 kNm
  - Implicit statics



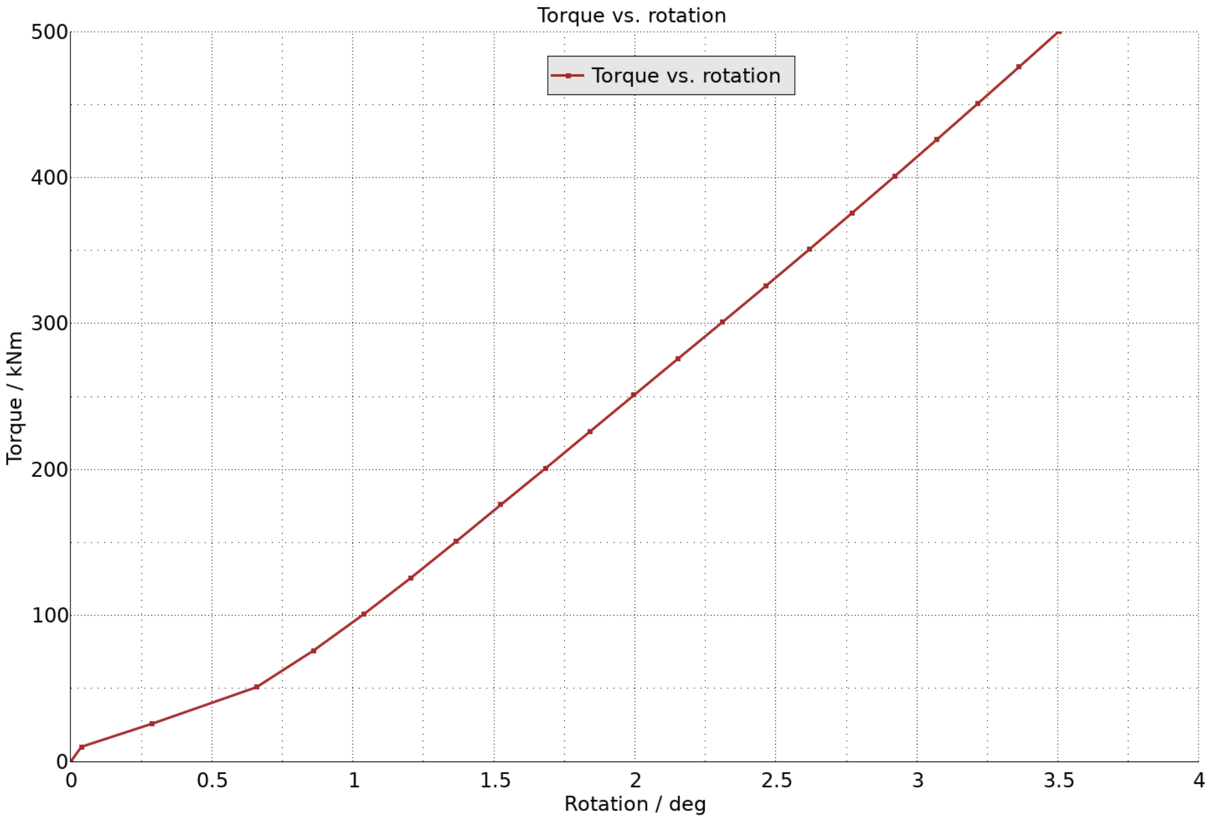
Explicit Dynamic Relaxation / Implicit main run

Results: Pipe joint

Bolt forces



Torque vs. rotation



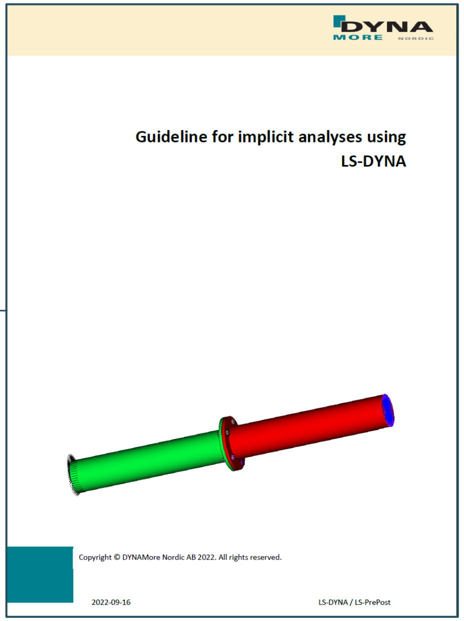
Explicit Dynamic Relaxation / Implicit main run

Keywords

```
*INCLUDE
control_cards_nonlin.key
*INCLUDE
database_cards_static.key
*CONTROL_DYNAMIC_RELAXATION
$#   nrcyck      drtol     drfctr     drterm     tssfdr     irelal      edttl     idrflg
                                                                                       1

*CONTROL_TIMESTEP
$#   dtinit     tssfac       isdo     tslimt      dt2ms       lctm      erode      ms1st
                                                -5.E-7

*CONTROL_TERMINATION
$    ENDTIM     ENDCYC      DTMIN     ENDENG     ENDMAS
         1.
```


Guideline for implicit analyses using LS-DYNA

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2022-09-16

LS-DYNA / LS-PrePost

Set explicit time step

Activate explicit DR

Implicit Dynamic Relaxation / Explicit main run

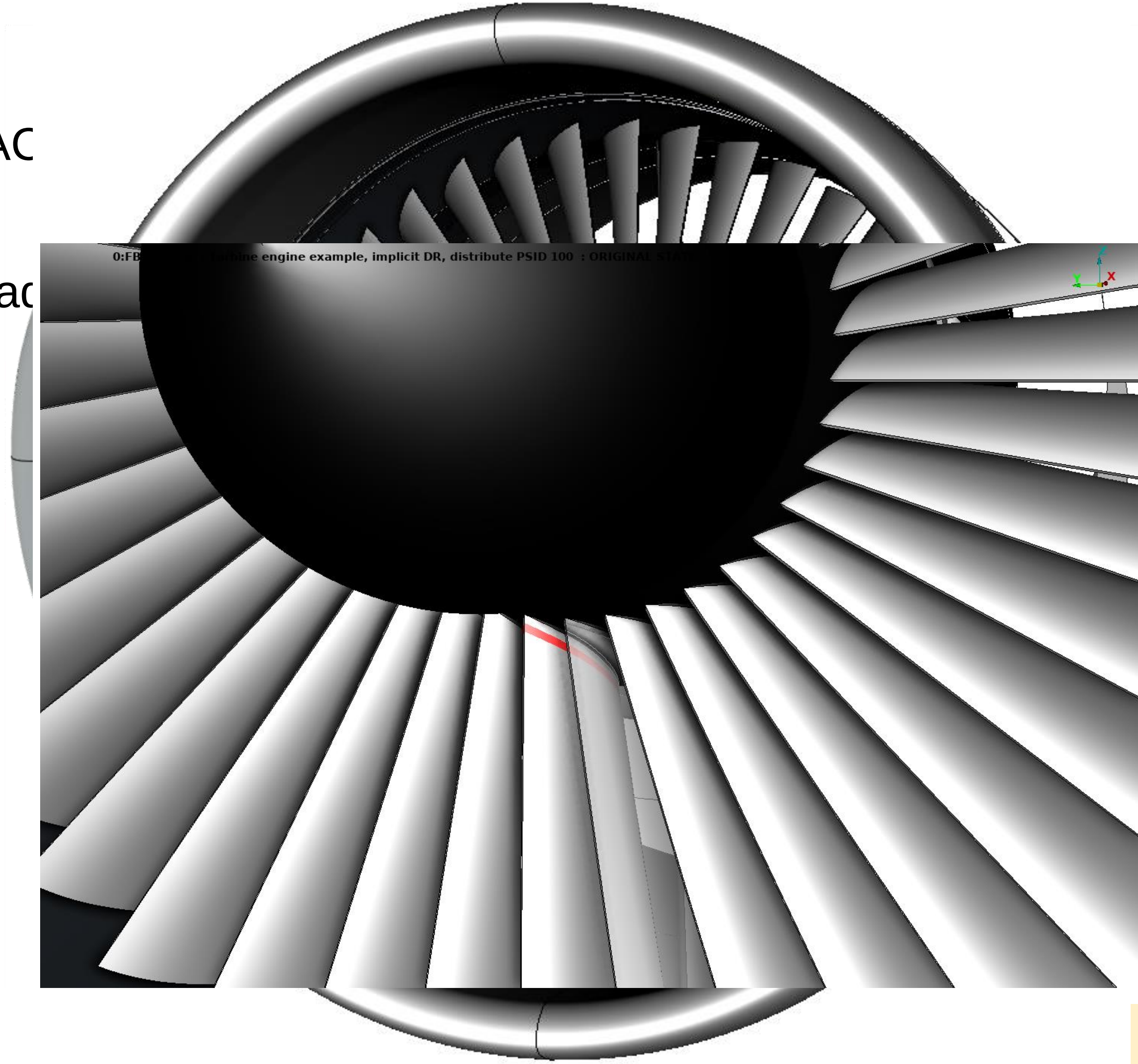
*CONTROL_DYNAMIC_RELAXATION

- Use mainly explicit settings / control cards
  - Mainly explicit control cards, from for example "Technical Guide ... "
  - Add implicit control cards, from for example "Guideline for implicit analyses ..."
- *CONTROL_DYNAMIC_RELAXATION is required
  - *IDRFLG* = 5, to activate implicit DR
  - *IDRFLG* = 6, to activate implicit DR on only some parts of the model, as specified by *DRPSET*
  - Set *NRCYCL* = 1
  - *DRTERM to* specify time when implicit solution is completed
- *CONTROL_IMPLICIT_GENERAL_DYN is required
  - *IMFLAG* = 1
  - Set *DT0* (initial time step size)

Implicit Dynamic Relaxation / Explicit main run

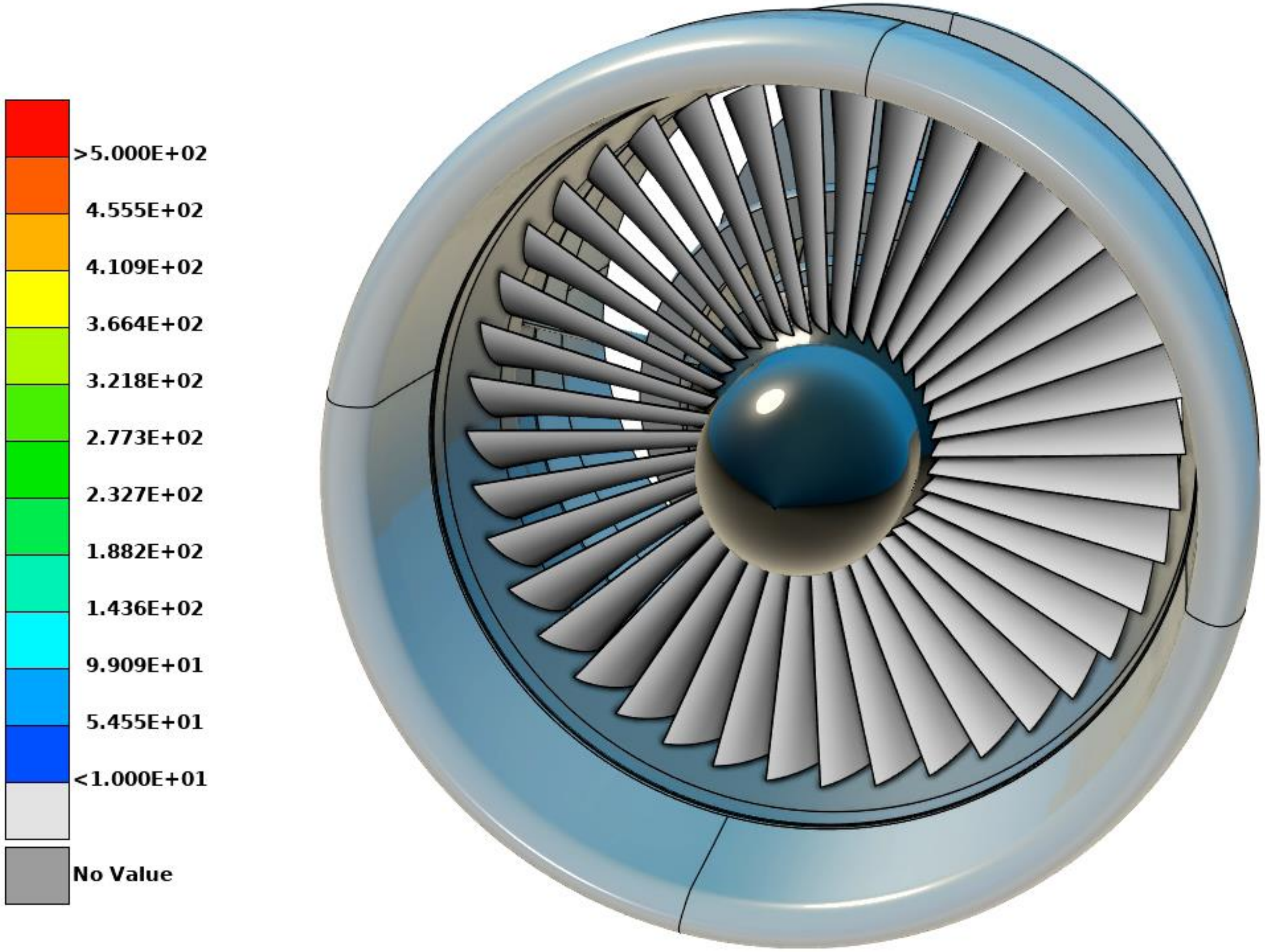
Example: Fan Blade Out analysis

- Example provided by Erik Piskula, Ansys EMEA AC
  - His contribution is gratefully acknowledged
- Pre-tension: Centrifugal acceleration of the fan blac
  - Using implicit DR of a part set (*IDRFLG* = 6)
- FBO Analysis:
  - 5000 rpm
  - Element set at the base of a fan blade deleted
  - Explicit analysis, 10 ms



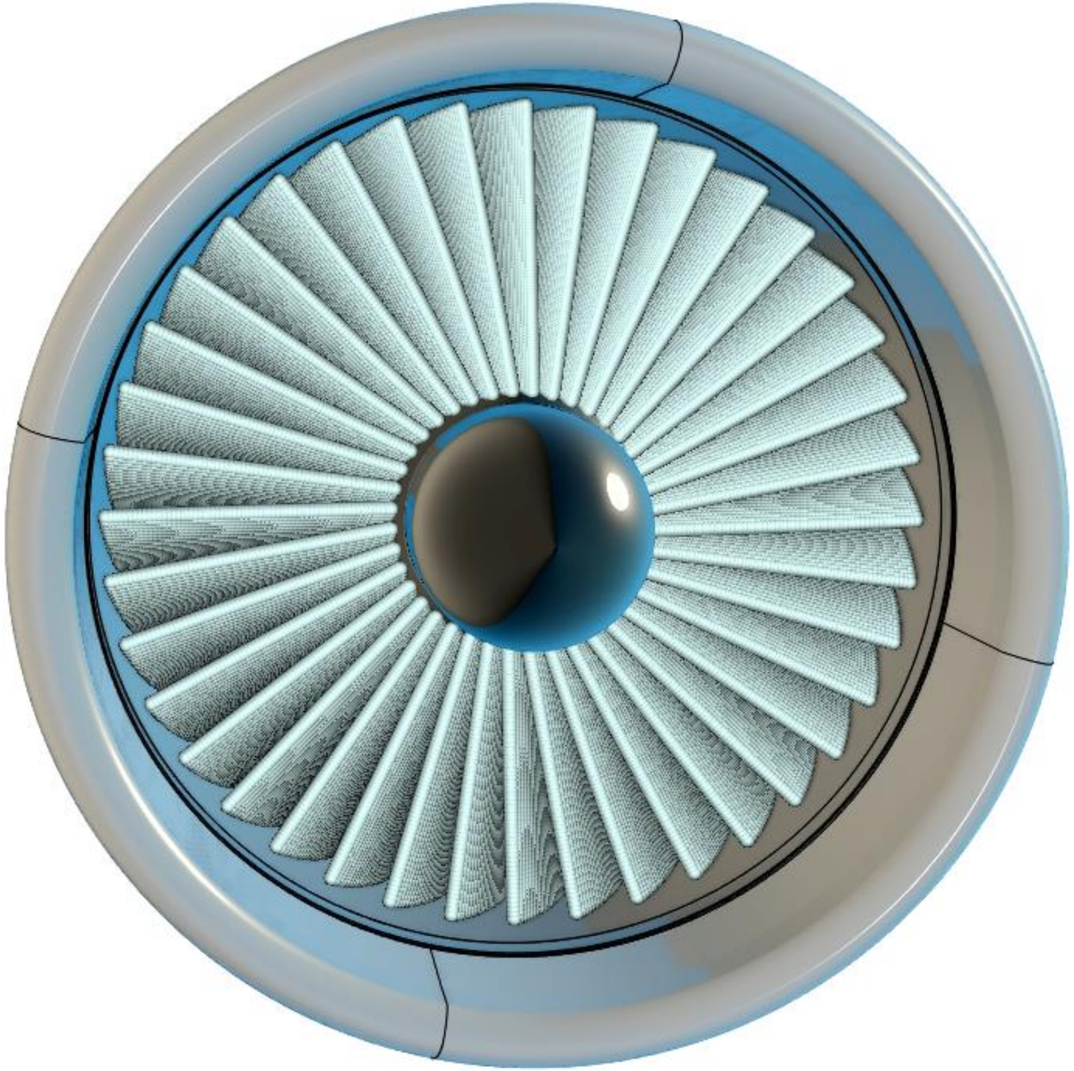
Implicit Dynamic Relaxation / Explicit main run

Results: Fan Blade Out analysis - preloading



Implicit Dynamic Relaxation / Explicit main run

Results: Fan Blade Out analysis – explicit main run

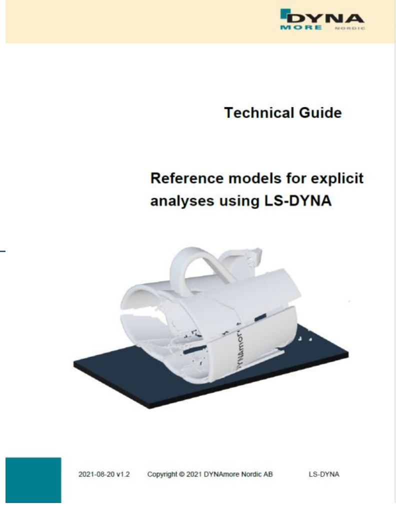


Implicit Dynamic Relaxation / Explicit main run

Keywords

```
*INCLUDE
control_database.k
*CONTROL_DYNAMIC_RELAXATION
$#  nrcyck     drtol    drfctr    drterm    tssfdr    irelal     edttl    idrflg
         1                             1.                                     5
$===============================================================================
$ Implicit LS-DYNA control cards (for Dynamic Relaxation)
$===============================================================================
*CONTROL_IMPLICIT_GENERAL_DYN
$    IMFLAG       DT0    IMFORM      NSBS       IGS     CNSTN      FORM
         1      0.10         2         0
*CONTROL_IMPLICIT_SOLUTION
$#  nsolvr    ilimit    maxref     dctol     ectol     rctol     lstol    abstol
        12        11        15     1.E-3     1.E-2                        1.E-20
$#   dnorm    diverg     istif   nlprint    nlnorm   d3itctl
         1         1         1         3         4         1
$#  arcctl    arcdir    arclen    arcmth    arcdmp

$#   lsmtd
         5
*CONTROL_IMPLICIT_AUTO
$    IAUTO    ITEOPT    ITEWIN     DTMIN     DTMAX     DTEXP
         1       100        20     1.E-5     -700.        0.
*DEFINE_CURVE_TITLE
Implicit DR timesteps
 700, 1
....
```

```
*CONTROL_IMPLICIT_DYNAMICS_DYN
$    IMFLAG       DT0    IMFORM      NSBS       IGS     CNSTN      FORM
```



Activate implicit DR

Recommended implicit settings (starting point)

Implicit Dynamic Relaxation / Explicit main run

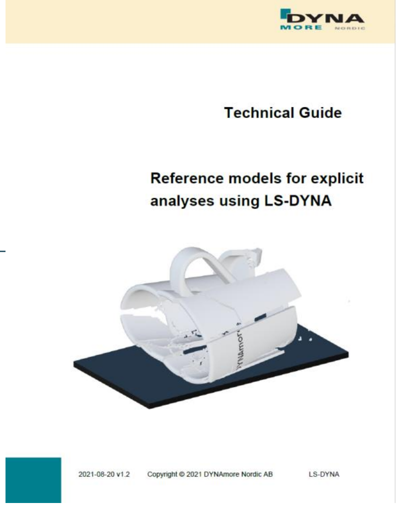
Keywords

```
*INCLUDE
control_database.k
*CONTROL_DYNAMIC_RELAXATION
$#   nrcyck     drtol    drfctr    drterm    tssfdr    irelal     edttl    idrflg
          1                           1.                                        6
$#   drpset
        100
$===============================================================================
$ Implicit LS-DYNA control cards (for Dynamic Relaxation)
$===============================================================================
*CONTROL_IMPLICIT_GENERAL_DYN
$    IMFLAG       DT0    IMFORM      NSBS       IGS     CNSTN      FORM
          1      0.10         2         0
*CONTROL_IMPLICIT_SOLUTION
$#   nsolvr    ilimit    maxref     dctol     ectol     rctol     lstol    abstol
         12        11        15     1.E-3     1.E-2                       1.E-20
$#    dnorm    diverg     istif   nlprint    nlnorm   d3itctl
          1         1         1         3         4         1
$#   arcctl    arcdir    arclen    arcmth    arcdmp

$#    lsmtd
          5
*CONTROL_IMPLICIT_AUTO
$     IAUTO    ITEOPT    ITEWIN     DTMIN     DTMAX     DTEXP
          1       100        20     1.E-5     -700.        0.
.
.
.
```

Part set for implicit DR

Activate implicit DR

Recommended implicit settings (starting point)



Implicit / explicit switching

*CONTROL_IMPLICIT_GENERAL, *CONTROL_IMPLICIT_AUTO

- Implicit / explicit switching by *CONTROL_IMPLICIT_GENERAL, variable *IMFLAG*
  - *IMFLAG* < 0: Curve with ID = -1**IMFLAG* selects implicit or explicit analysis
  - *IMFLAG* = 4: Start implicit, automatic implicit / explicit switching
  - *IMFLAG* = 5: Start implicit, automatic implicit / explicit switching, mandatory implicit finish
  - *IMFLAG* = 6: Explicit with intermittent eigenvalue extraction. Also requires *CONTROL_IMPLICIT_EIGENVALUE
- All options listed above require a double precision version of LS-DYNA
- Mind output timesteps on *DATABASE_BINARY_D3PLOT, *DATABASE_...
  - Small timestep often used in implicit analyses
  - Can cause very large amount of output data when applied to explicit analyses

Automatic implicit / explicit switching

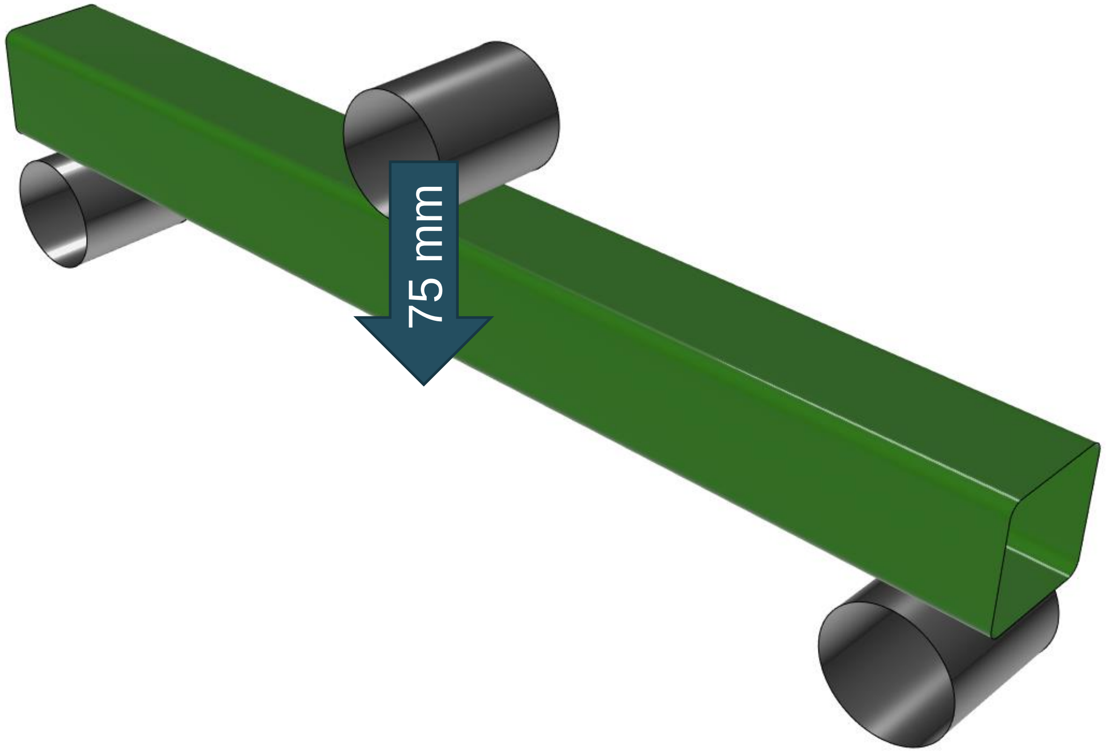
`*CONTROL_IMPLICIT_GENERAL, *CONTROL_IMPLICIT_AUTO`

- The simulation starts out in implicit, switch to explicit when convergence fails
  - Use mainly implicit control cards
- Problem time must be physical time
  - The time scale must be in agreement with the physical time.
  - For example loading is applied in 1000 ms, or 10 s. The end time must be adjusted according to unit system
  - Time cannot be a load parameter from 0 to 1
- Switching according to `*CONTROL_IMPLICIT_AUTO`
  - Based on *kfail* number of failed attempts to find equilibrium
  - *dtexp* determines how long time to run in explicit
  - To make a “irreversible” switch, use *imflag* = 4 and set *dtexp* > *endtim*

Automatic implicit / explicit switching

Example: 3-point bending

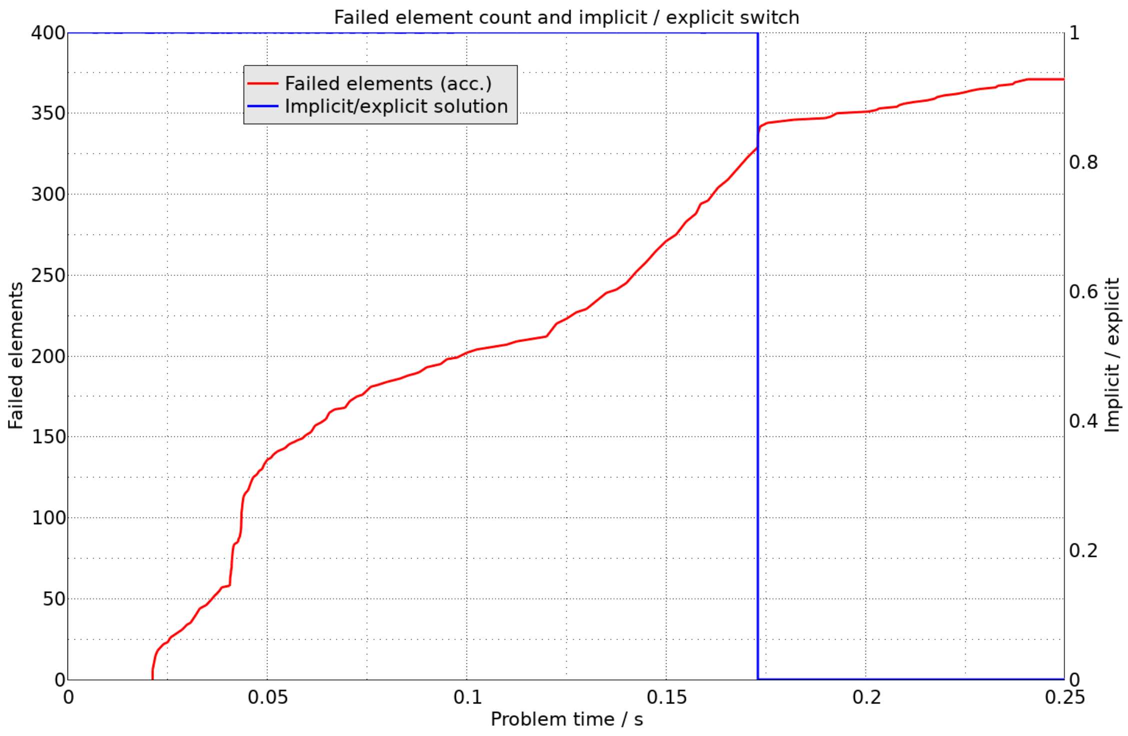
- Elasto-plastic material
  - `*MAT_MODIFIED_PIECEWISE_LINEAR_PLASTICITY_RTCL`
  - RTCL failure used for demonstrational purpose in this case
- Dimensions: 50x50 mm profile (t = 2 mm)
  L = 500 mm
- Prescribed displacement
  - target: 75 mm

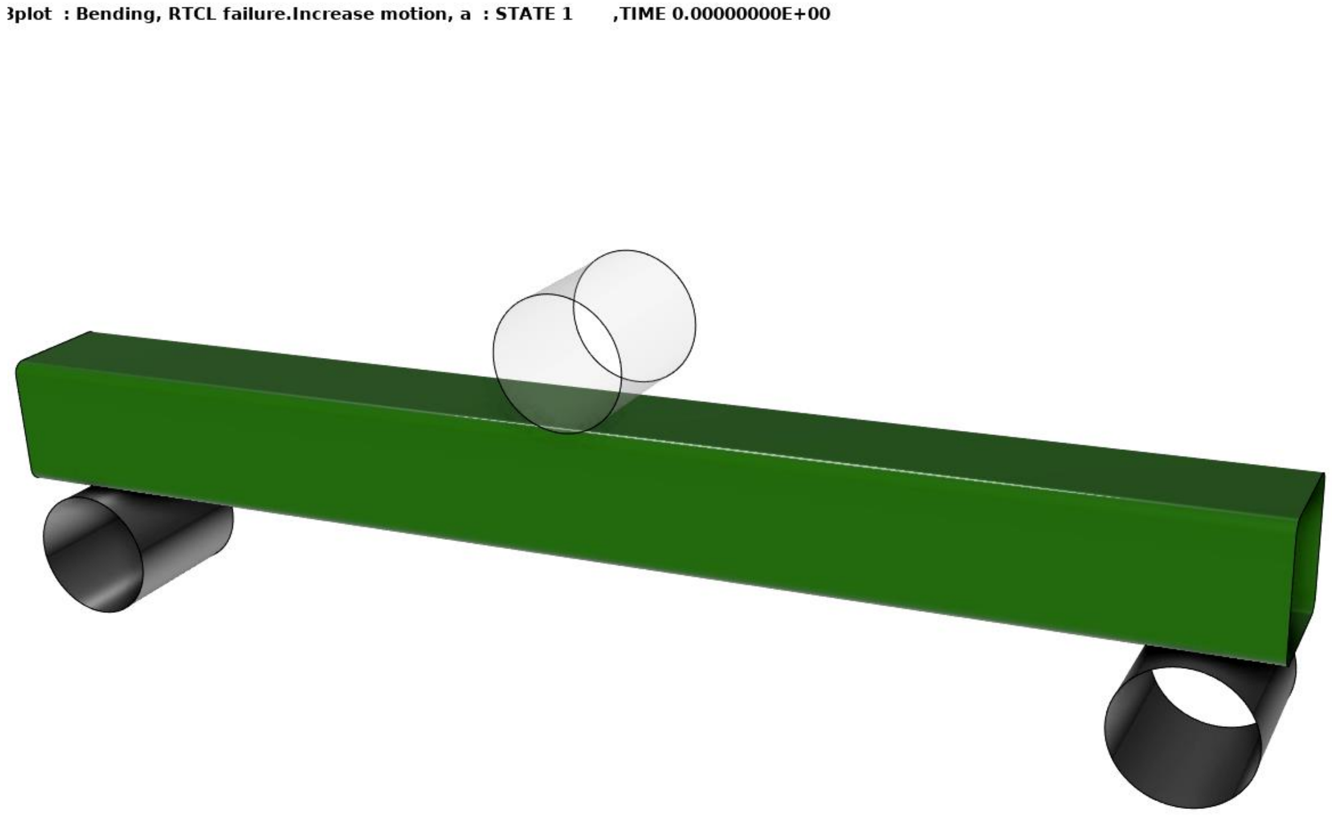


Automatic implicit / explicit switching

Results: 3-point bending

- Failed elements and solution method

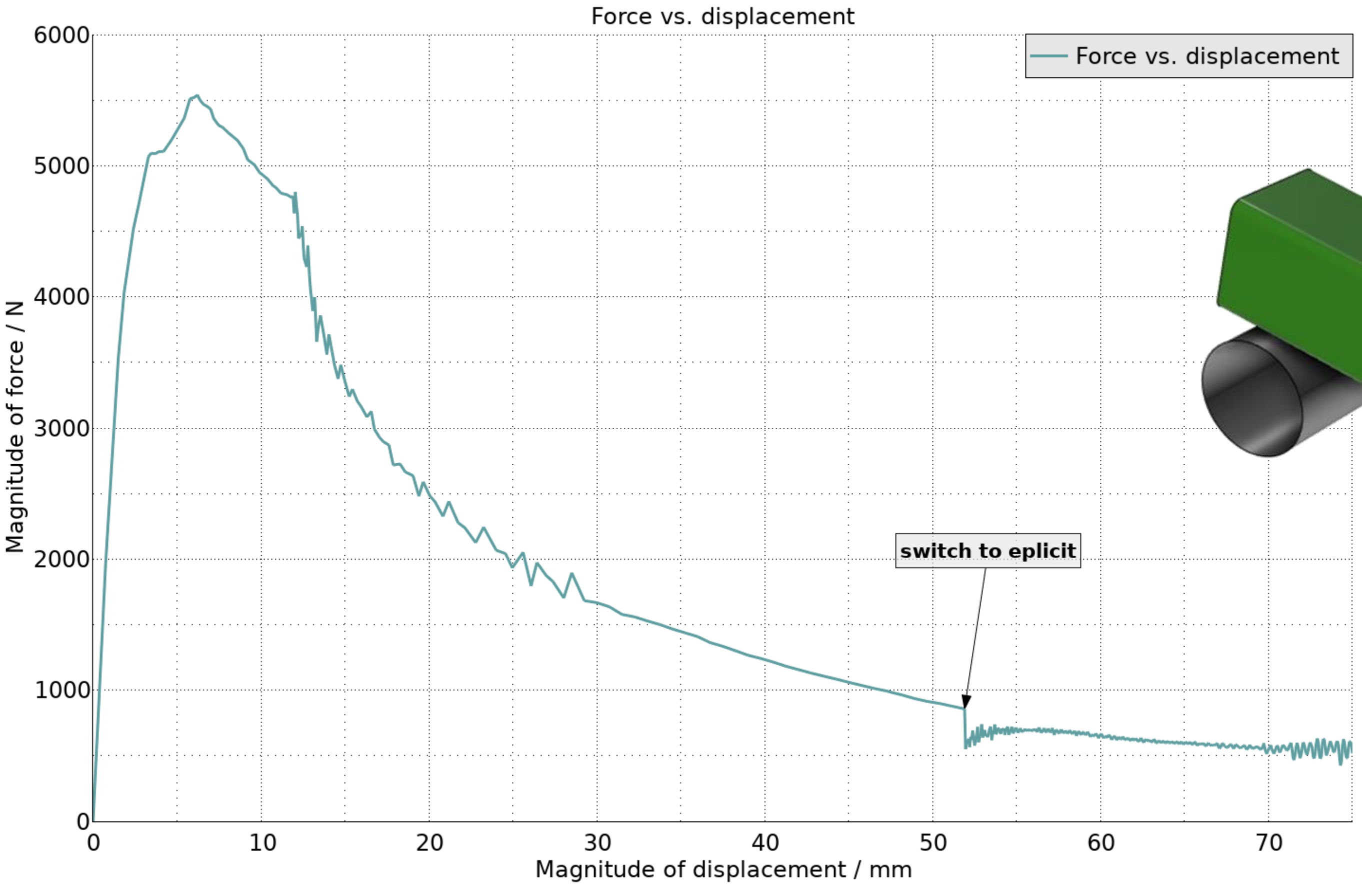


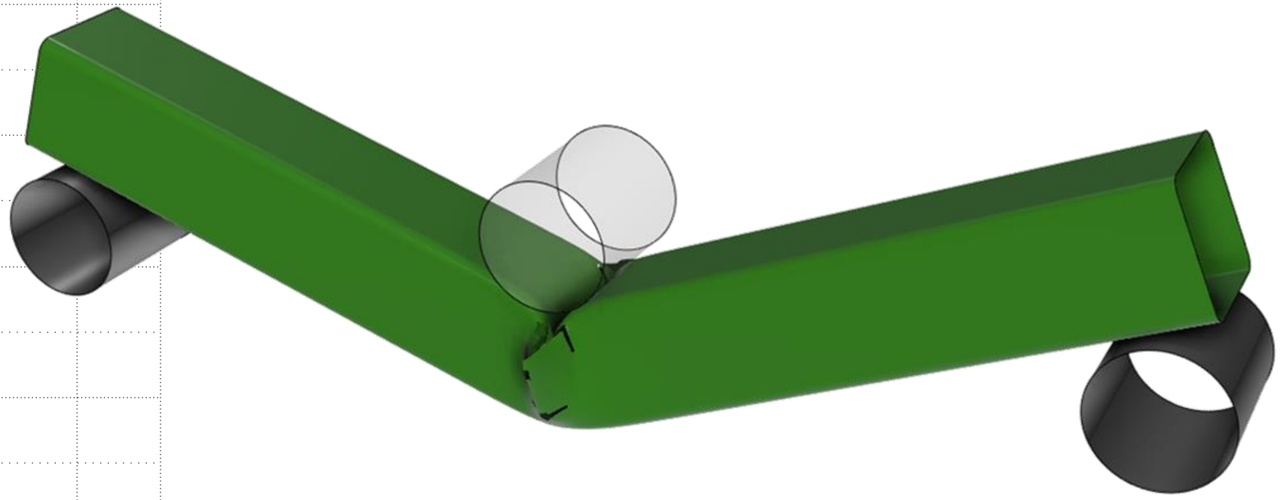


Automatic implicit / explicit switching

Results: 3-point bending

- Force vs. displacement



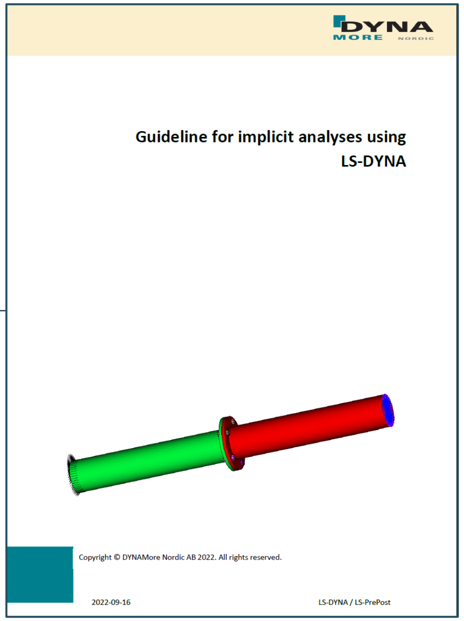


Automatic implicit / explicit switching

Keywords

```
*INCLUDE
control_cards_nonlin.key
*PARAMETER
Rdbparu, 2.E-3
*INCLUDE
database_cards_expl.key
*CONTROL_IMPLICIT_DYNAMICS
$     IMASS     GAMMA      BETA    TDYBIR    TDYDTH    TDYBUR     IRATE     alpha
         1                                                                    0.5
*CONTROL_TERMINATION
$    ENDTIM    ENDCYC     DTMIN    ENDENG    ENDMAS
   250.E-3
*CONTROL_TIMESTEP
$#   dtinit    tssfac      isdo    tslimt     dt2ms      lctm     erode     ms1st
                                          -1.4E-7
*CONTROL_IMPLICIT_GENERAL
$    IMFLAG       DT0    IMFORM      NSBS       IGS     CNSTN      FORM
          4      0.10         2         0
*CONTROL_IMPLICIT_AUTO
$     IAUTO    ITEOPT    ITEWIN     DTMIN     DTMAX     DTEXP     KFAIL
          1       100        20     1.E-5     -700.      100.         3
*DEFINE
Time st
...
```

```
*** Warning 60102 (IMP+102)
     failed to find equilibrium after 16 iterations **

--------------------------------------------------------------
formulation switch at time = 1.7300E-01   IMPLICIT -> EXPLICIT
--------------------------------------------------------------
```



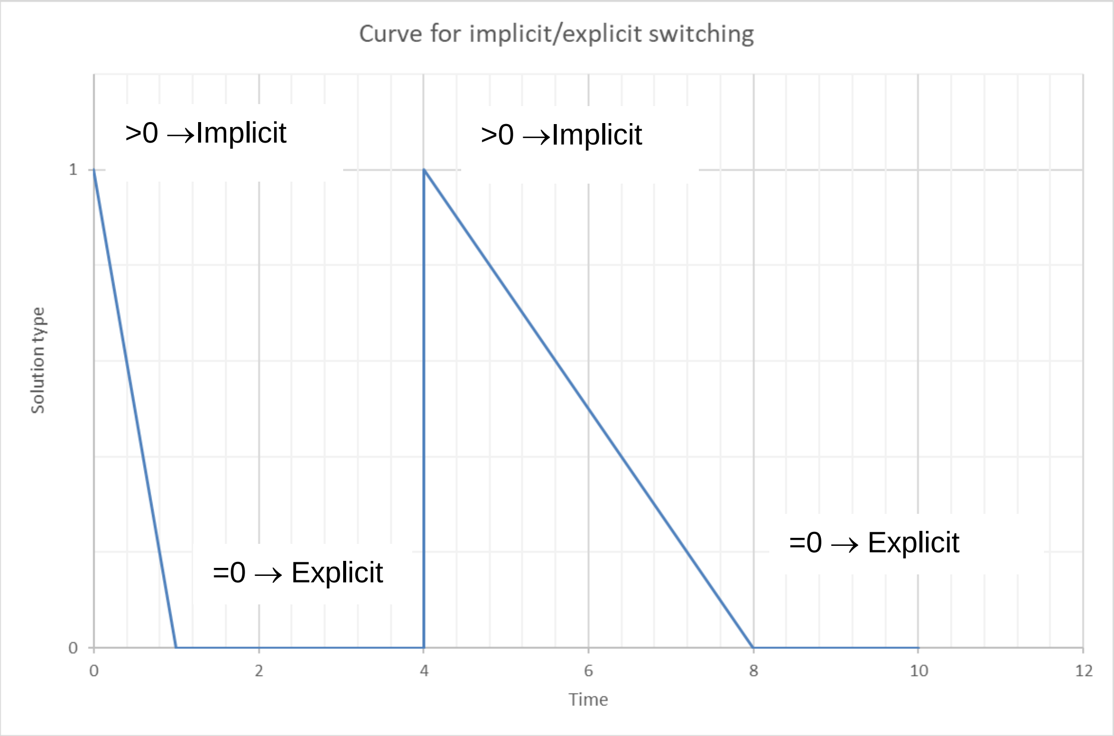
Time step for the explicit phase

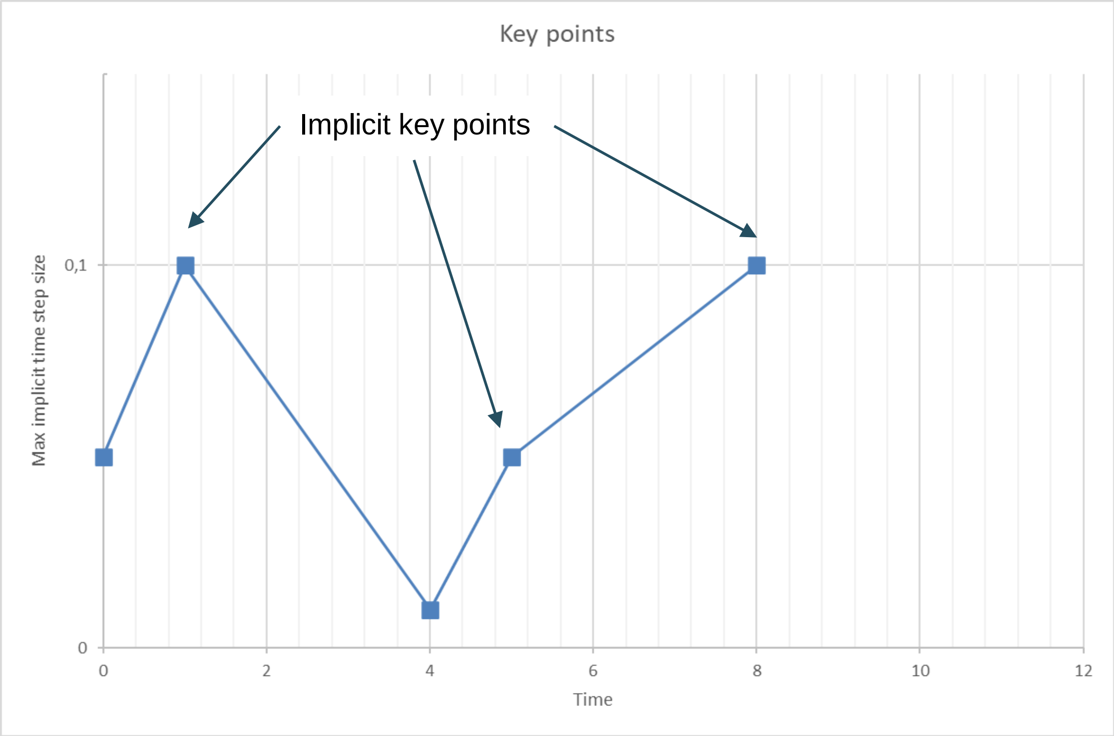
Activate auto switching rameters

Switching at specified times

*CONTROL_IMPLICIT_GENERAL

- Use implicit and explicit solver during specified times during the analysis
- Set *IMFLAG* = -LCID on *CONTROL_IMPLICIT_GENERAL
- Synchronize with keypoints using *DTMAX* = -LCID2 on *CONTROL_IMPLICIT_AUTO

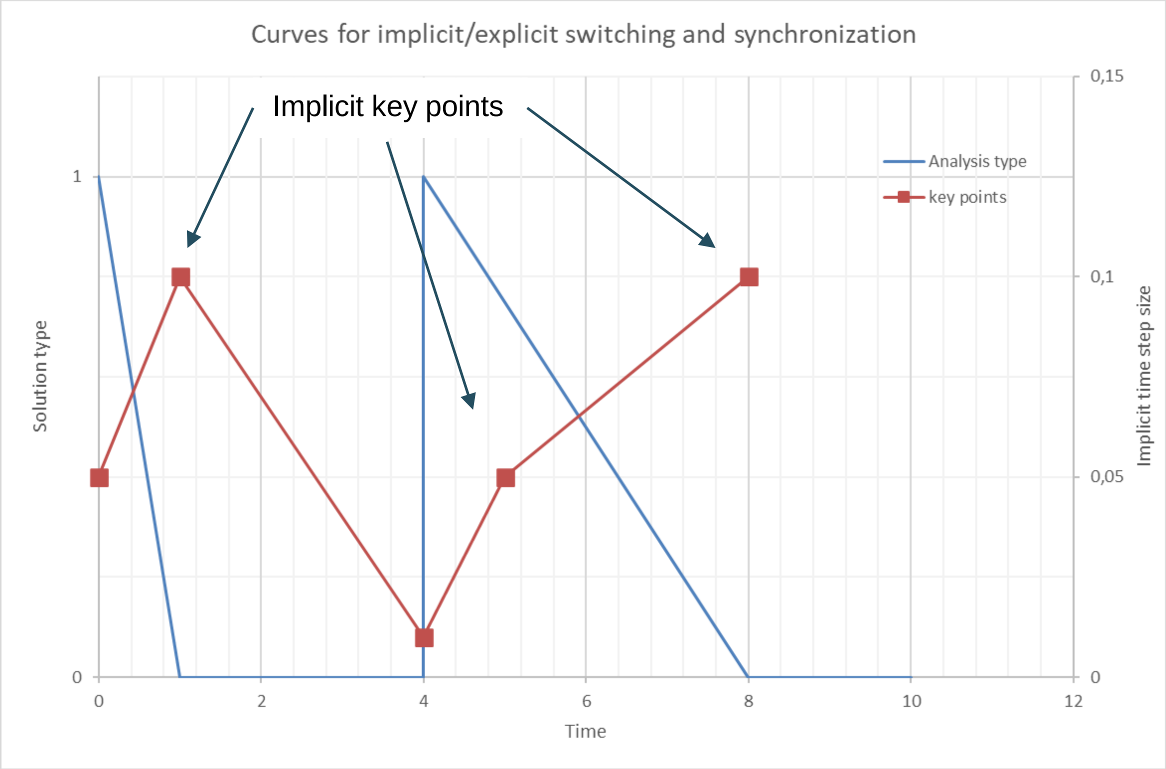




Switching at specified times

*CONTROL_IMPLICIT_GENERAL, *CONTROL_IMPLICIT_AUTO

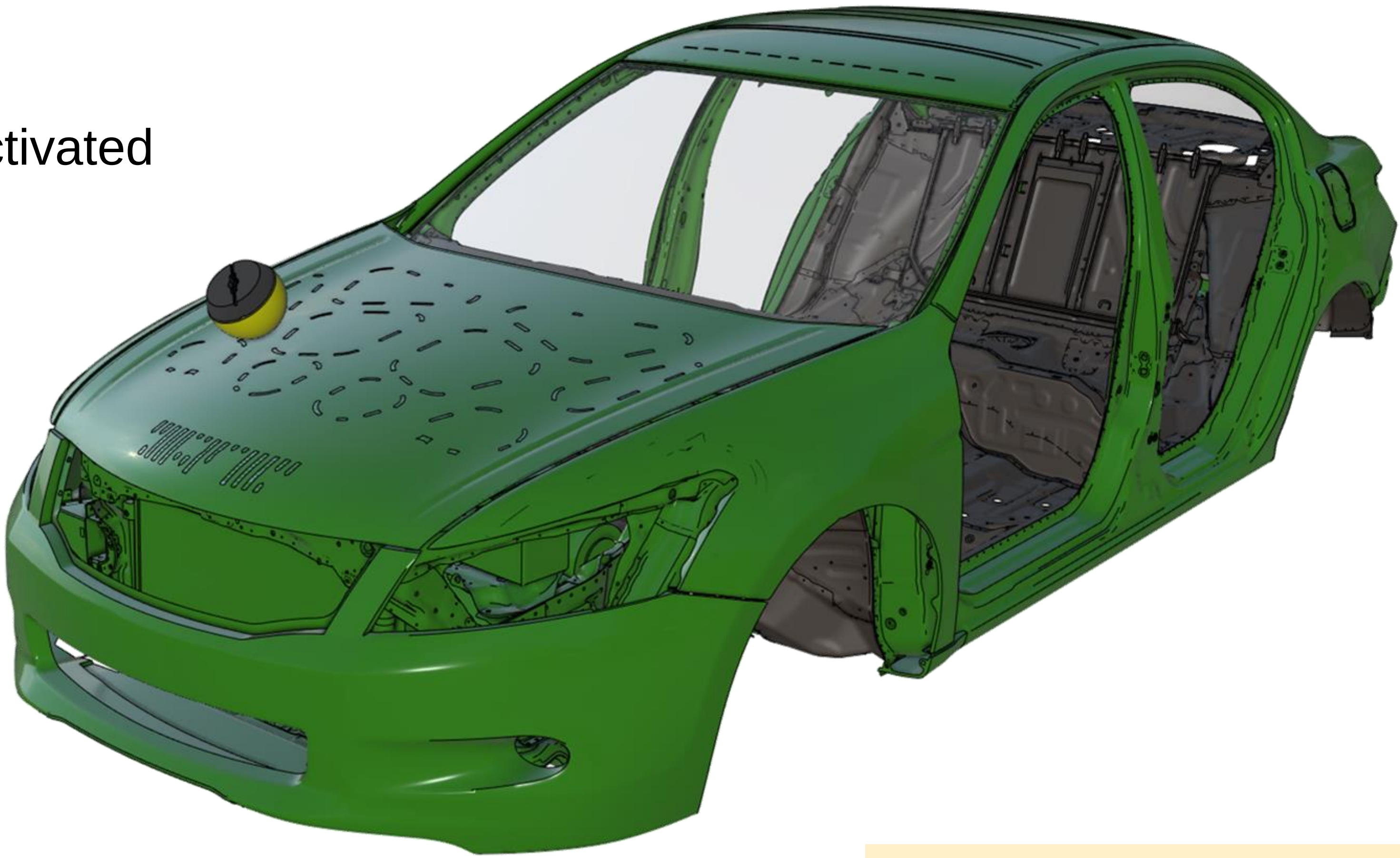
- Use implicit and explicit solver during specified times during the analysis
- Set *IMFLAG* = -LCID on *CONTROL_IMPLICIT_GENERAL
- Synchronize with keypoints using *DTMAX* = -LCID2 on *CONTROL_IMPLICIT_AUTO



Switching at specified times

Example: Headform impact after gravity loading

- Gravity loading is applied from t = 0 to t = 1.0 s
  - Implicit
- Switch to explicit at t = 1.0 s
- After that, the headform initial velocity is activated
  - Explicit impact simlation

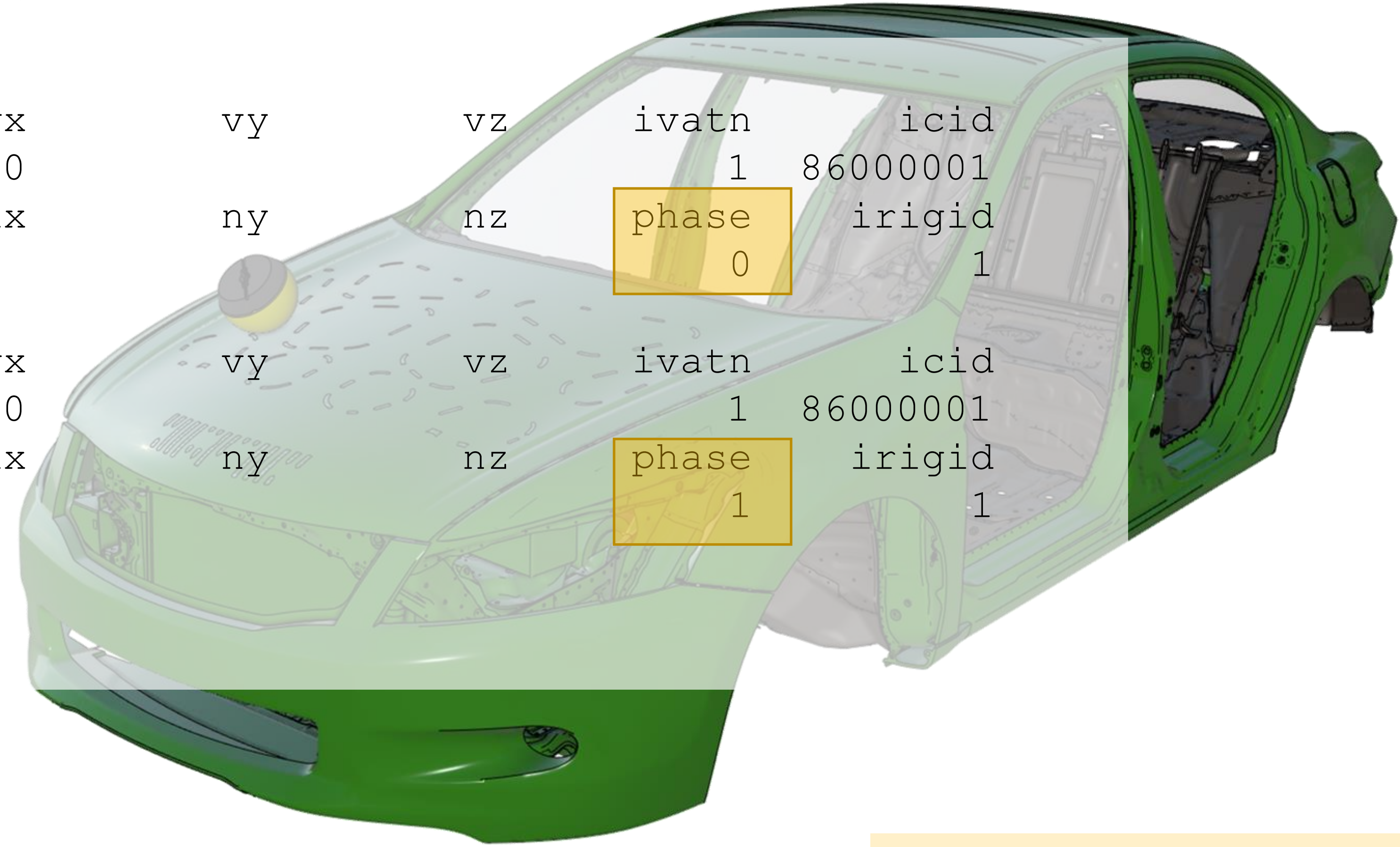


Switching at specified times

Example: Headform impact after gravity loading

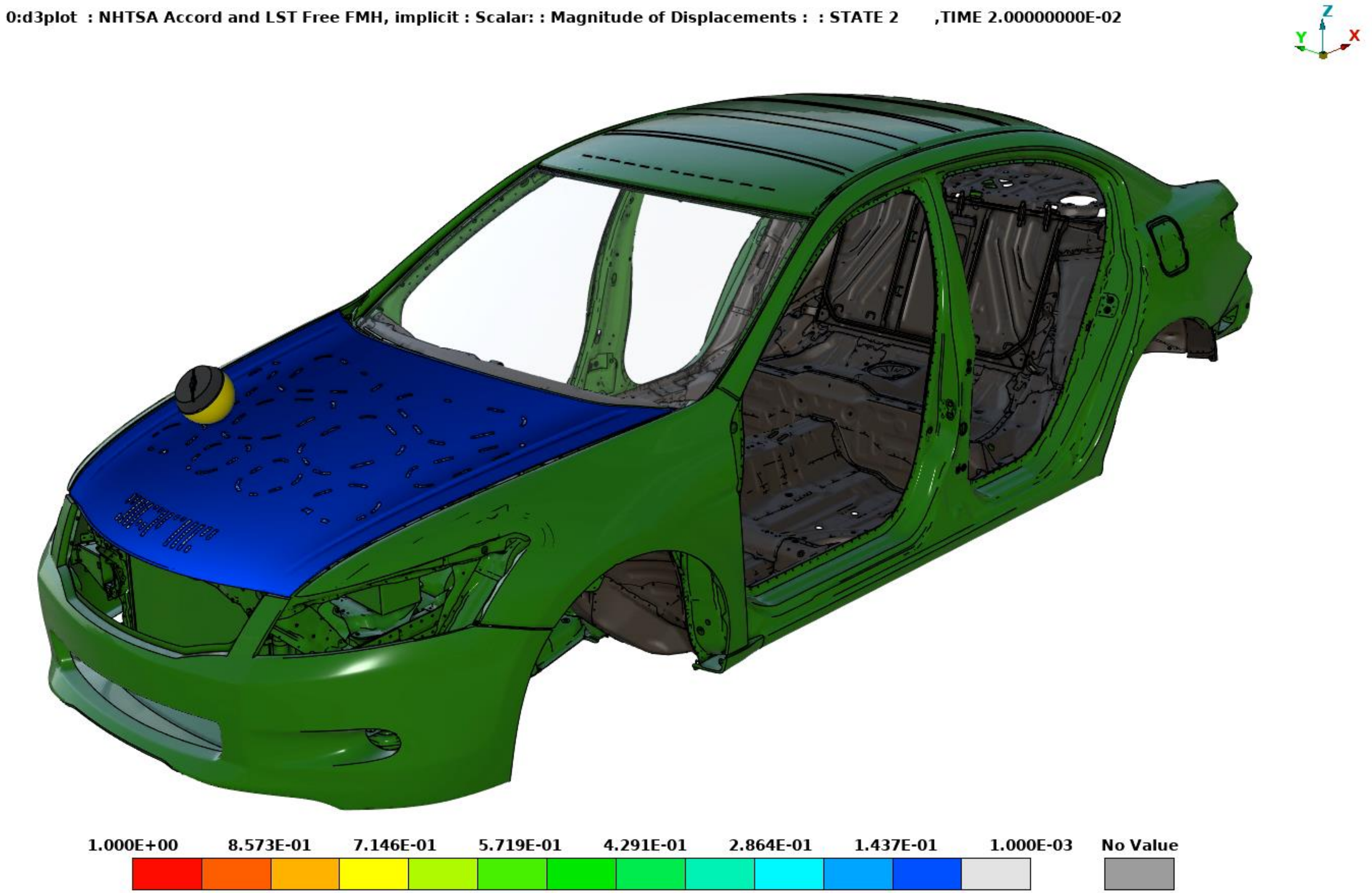
- Gravity loading is applied from t = 0 to t = 1.0 s (implicit)
- After that, the headform velocity is activated:

```
*INITIAL_VELOCITY_GENERATION
$#        id      styp     omega        vx        vy        vz     ivatn      icid
   86000107         1             11111.0                                1  86000001
$#        xc        yc        zc        nx        ny        nz     phase    irigid
                                                                         0         1

*INITIAL_VELOCITY_GENERATION
$#        id      styp     omega        vx        vy        vz     ivatn      icid
   86000107         1             11111.0                                1  86000001
$#        xc        yc        zc        nx        ny        nz     phase    irigid
                                                                         1         1

*INITIAL_VELOCITY_GENERATION_START_TIME
$#     stime
     1.00001
```



Switching at specified times

Results: Headform impact after gravity loading

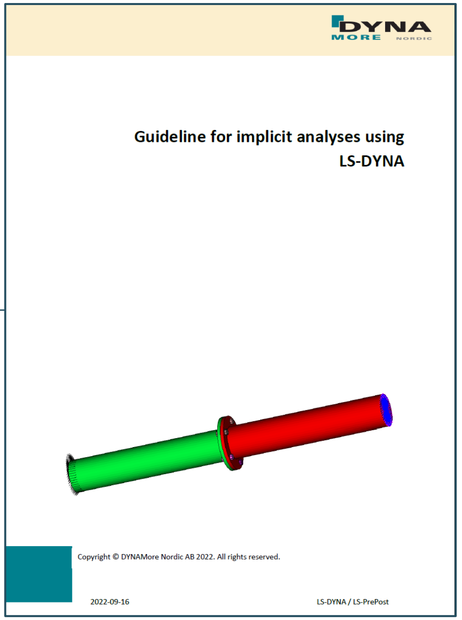


Switching at specified times

Keywords

```
*INCLUDE
control_cards_nonlin.key
*PARAMETER
Rdbparu, 1.E-3
*INCLUDE
database_cards_expl.key
*CONTROL_IMPLICIT_DYNAMICS
$    IMASS     GAMMA      BETA                                      IRATE
         1       0.6      0.38                                          1
*CONTROL_TERMINATION
$   ENDTIM    ENDCYC     DTMIN    ENDENG    ENDMAS
       1.1
*CONTROL_TIMESTEP
$#  dtinit    tssfac      isdo    tslimt     dt2ms      lctm     erode     ms1st
                                           -5.E-7
*CONTROL_IMPLICIT_GENERAL
$   IMFLAG       DT0    IMFORM      NSBS       IGS     CNSTN      FORM
      -701      0.10         2         0
*DEFINE_CURVE_TITLE
Implicit/explicit switch
       701
                    0.                  1.
                    1.
*DEFINE_CURVE_TITLE
Time stepping curve
       700
...
```

```
--------------------------------------------------------------
formulation switch at time = 1.0000E+00   IMPLICIT -> EXPLICIT
--------------------------------------------------------------
```



Time step for the explicit phase

Curve ID for specifying solver

Eigenvalue analysis and explicit

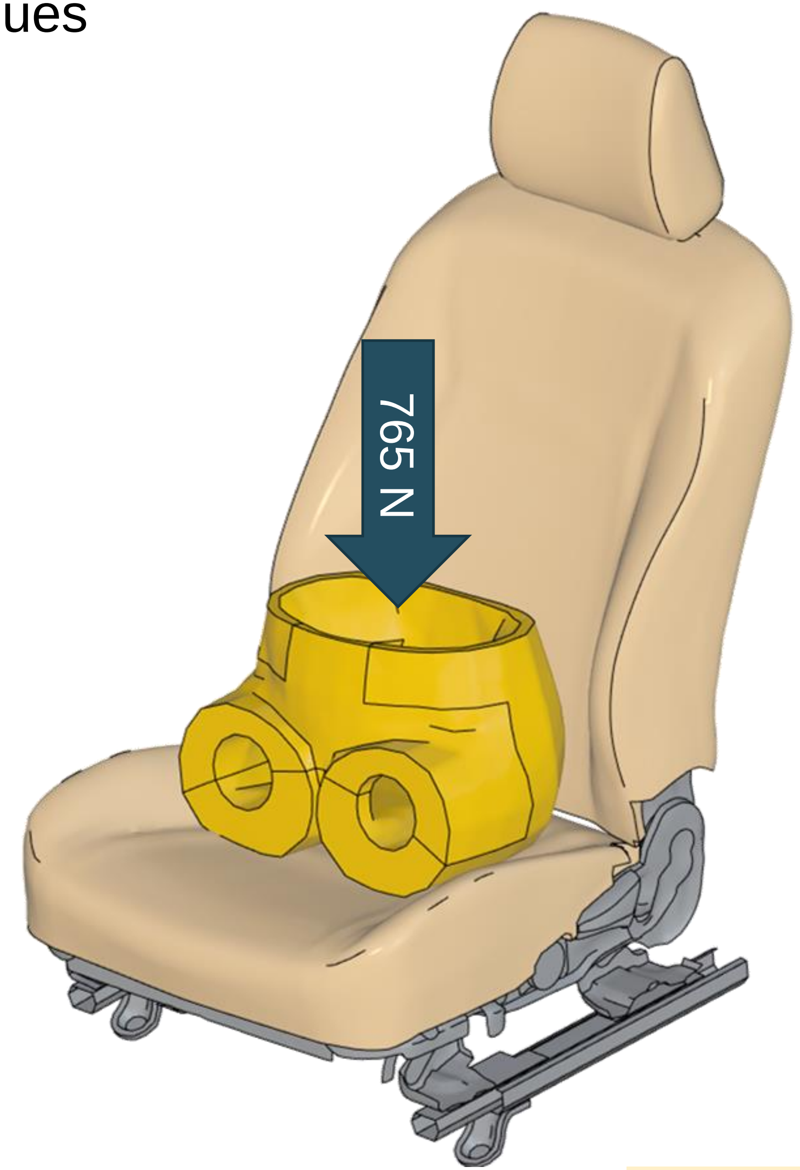
`*CONTROL_IMPLICIT_GENERAL, *CONTROL_IMPLICIT_EIGENVALUE`

- Explicit analysis
  - Explicit control cards
  - Use *SOFT* = 2 or Mortar contacts
- Eigenvalue analysis of the intermittent or final configuration
  - Set *IMFLAG* = 6 on `*CONTROL_IMPLICIT_GENERAL`
  - Set *NEIG* = -LCID on `*CONTROL_IMPLICIT_EIGENVALUES`
- Notes:
  - Requires double precision LS-DYNA
  - If you want eigenvalues at the end time, then increase `endt` by a small value
  - Added mass from explicit analysis is included in eigenvalue analysis

Eigenvalue analysis and explicit

Example 1: Explicit seating analysis and implicit eigenvalues

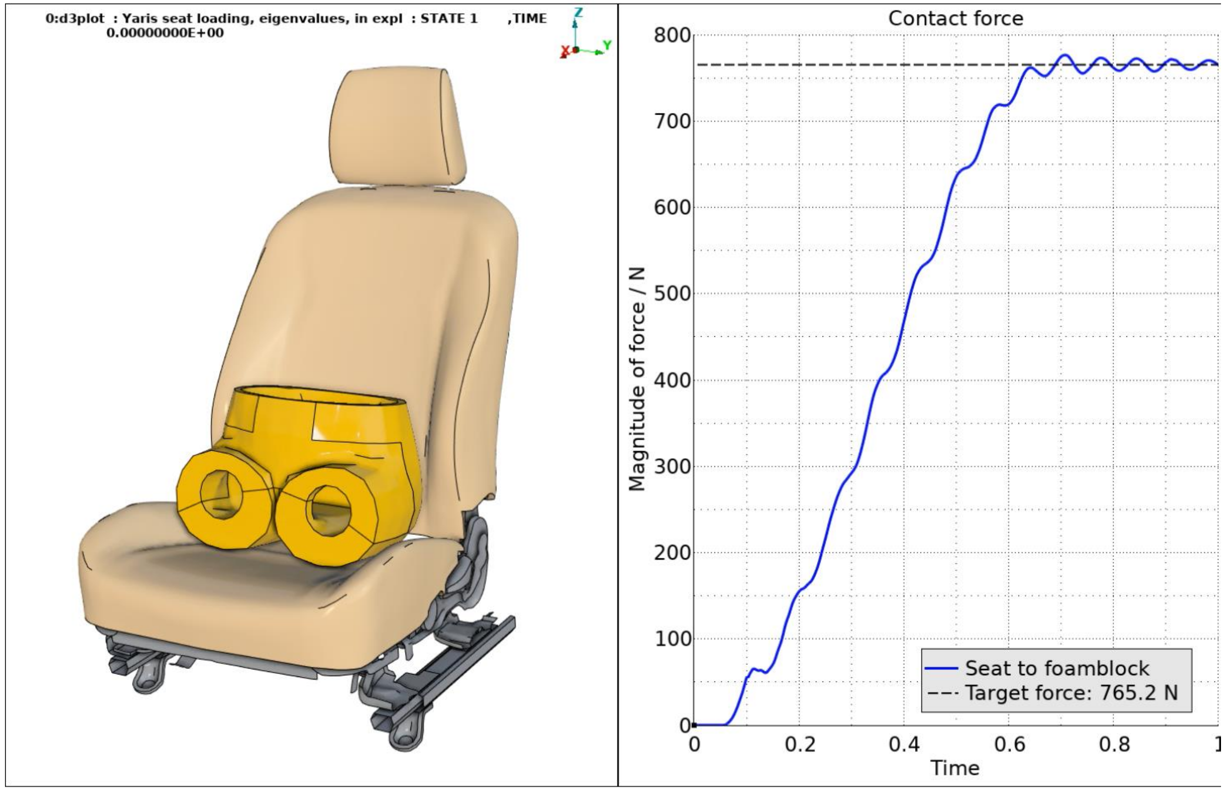
- Explicit analysis
- Pelvis of Hybird III dummy pressed into seat
- 250 eigenvalues requested at end of analysis



Eigenvalue analysis and explicit

Result 1: Explicit seating analysis and implicit eigenvalues

Explicit pre-load

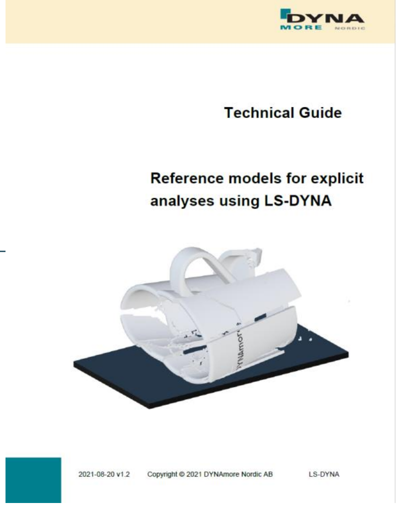


Eigenvalues (Mode 3, 11.4 Hz)

Egienvalue analysis and explicit

Keywords

```
*INCLUDE
control database.k
*CONTROL_TIMESTEP
$    DTINIT    TSSFAC      ISDO    TSLIMT     DT2MS      LCTM     ERODE     MS1ST
                                          -1.2E-06
*CONTROL_TERMINATION
$    ENDTIM    ENDCYC     DTMIN    ENDENG    ENDMAS
        1.0
*CONTROL_IMPLICIT_GENERAL
$    IMFLAG       DT0    IMFORM      NSBS       IGS     CNSTN      FORM
          6      0.10         2         0
*CONTROL_IMPLICIT_EIGENVALUE
$      NEIG
       -702
*DEFINE_CURVE_TITLE
Eigenvalues
        702
                  0.5                150.
                  0.9                250.
```



Eigenvalues in explicit analysis

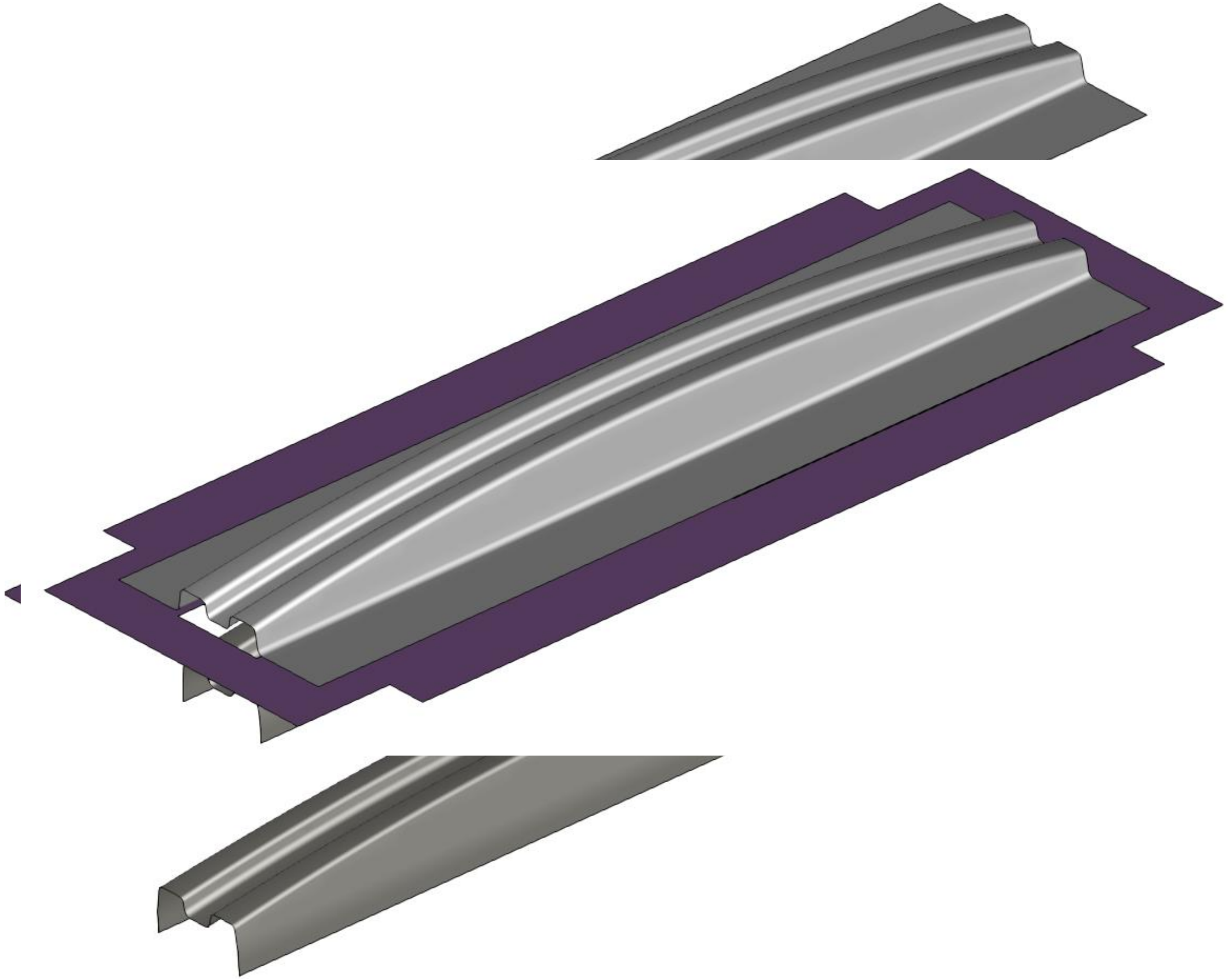
Set NEIG = -LCID

Specify *y* eigenvalues at time *x*

Eigenvalue analysis after explicit forming

Example 2: Forming analysis of bumper rail

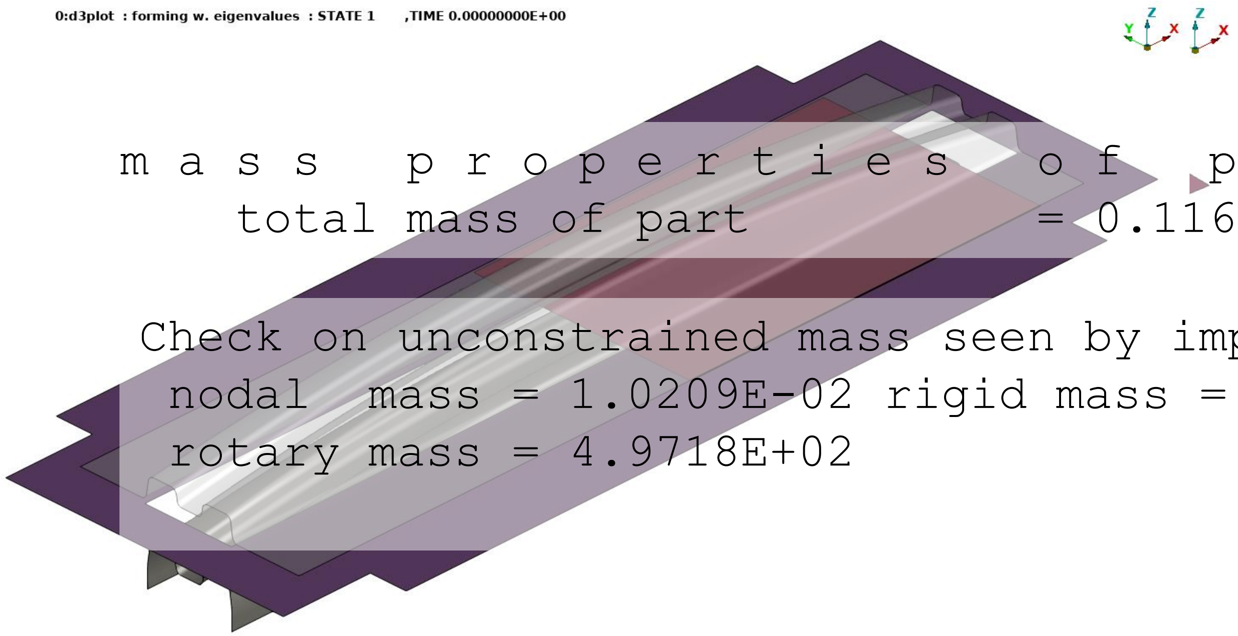
- Explicit analysis
- Egienvalue analyses after completed process
  - Termination time extended
  - Contacts disabled
  - Eigenvalue analysis



Eigenvalue analysis after explicit forming

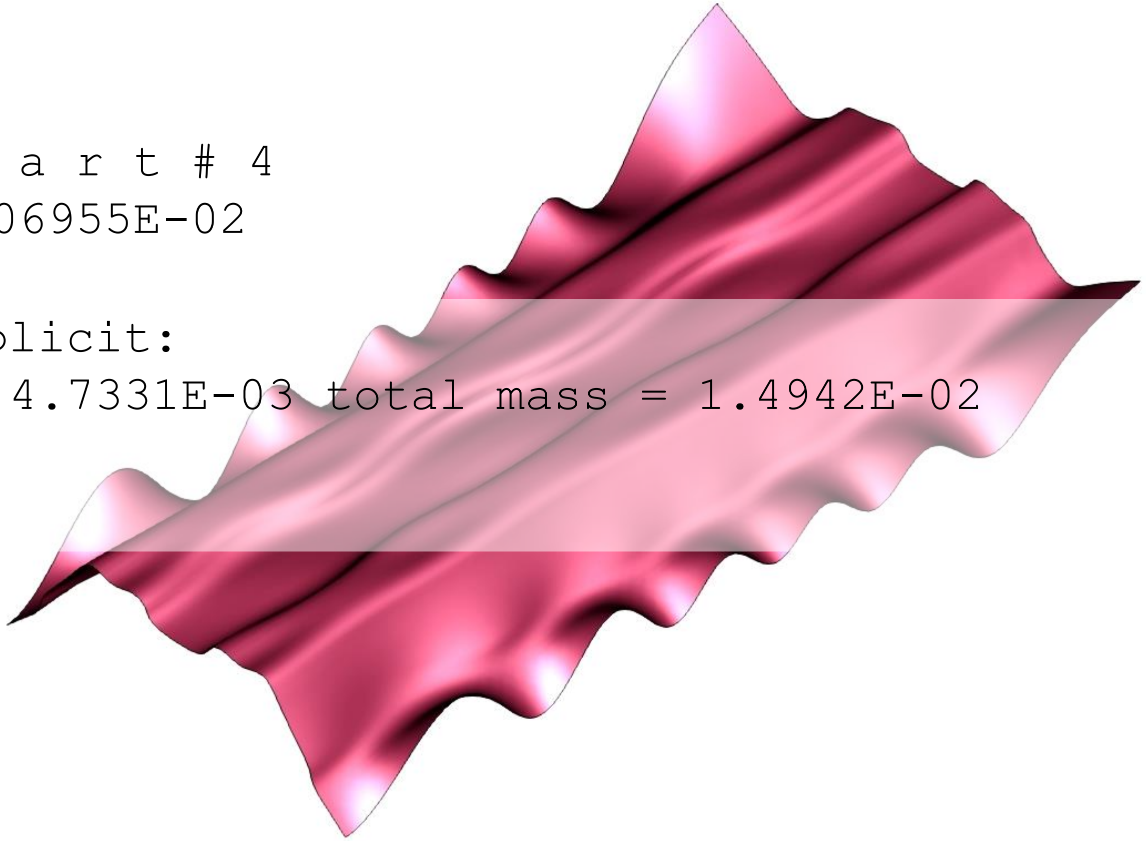
Result 2: Forming analysis of bumper rail

Explicit forming



Eigenvalues

- Mode 45, 95.5 Hz

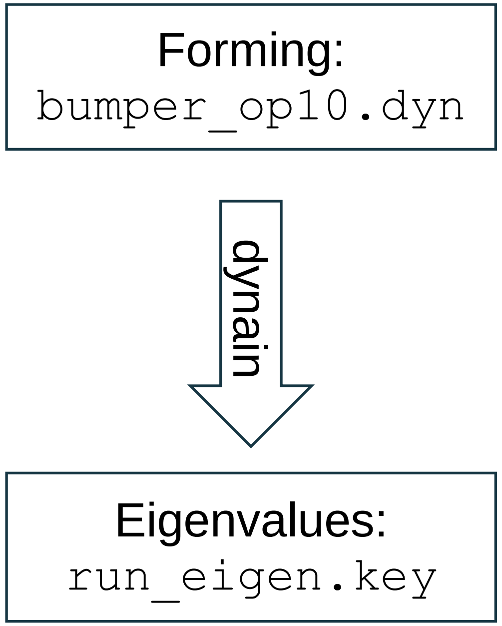


```
 m a s s   p r o p e r t i e s   o f   p a r t # 4
     total mass of part               = 0.11606955E-02

  Check on unconstrained mass seen by implicit:
   nodal  mass = 1.0209E-02 rigid mass = 4.7331E-03 total mass = 1.4942E-02
   rotary mass = 4.9718E+02
```

Eigenvalue analysis after explicit forming

Example 2: Forming analysis / multistage

- Forming: Explicit analysis
  - Single precision possible
- Final deformed shape, with residual stresses etc. is output in a dynain-file
  - Keyword: `*INTERFACE_SPRINGBACK_LSDYNA`
  - Common practice in forming analyses
  - Used for springback analyses
- Separate egienvalue analyses using dynain



Eigenvalue analysis after explicit forming

Result 2.2: Eigenvalues using `dynain` file

- First non-rigid body mode, 143 Hz

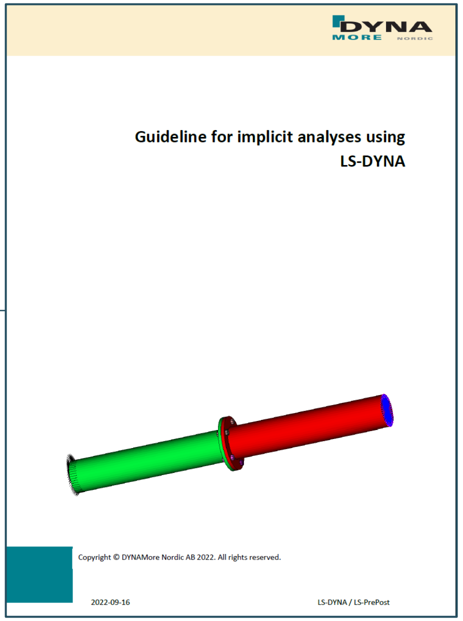
```
m a s s   p r o p e r t i e s   o f   p a r t # 4
    total mass of part            = 0.11606955E-02

Check on unconstrained mass seen by implicit:
 nodal  mass = 1.1603E-03 rigid mass = 0.0000E+00 total mass = 1.1603E-03
 rotary mass = 2.1284E-07
```

Egienvalues after forming using dynain

Keywords

```
*INCLUDE
dynain
*INCLUDE
blank.key.partsec
.
.
*INCLUDE
control_cards_linear.key
*INCLUDE
database_cards_static.key
*CONTROL_TERMINATION
$    ENDTIM     ENDCYC      DTMIN     ENDENG     ENDMAS
        1.0
*CONTROL_IMPLICIT_EIGENVALUE
$      NEIG
        150
.
.
.
```

Final configuration of the forming analysis


Guideline for implicit analyses using LS-DYNA

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2022-09-16

LS-DYNA / LS-PrePost

Requested number of eigenvalues

Multistage analyses

The `*CASE / dynain.lsda` - concept

- Analysis of a sequence of load stages is run as a sequence of analyses
  - Possible to mix implicit and explicit stages
  - A more intuitive way of setting up a load history
  - Clear definition of which features that are active in each stage
  - Reduce need for birth/death times of contacts, boundary conditions etc.
  - Stages are set up using the `*CASE` keyword

- Information is propagated from stage to stage using a binary dynain file
  - Contains deformations, stresses, history variables, contact state for **Mortar contacts only,** etc.
  - Can be opened for 3d visualization in LS-PrePost (from version 4.8)
  - Keyword: `*INTERFACE_SPRINGBACK_LSDYNA`

- Easy to re-use pre-tensioned configuration is obtained after each stage

Multistage analyses

The `*CASE / dynain.lsda` - concept

- `*CASE` in LS-DYNA
  - Functionality for setting up many analyses in one keyword file
- `dynain` files
  - A keyword file containing the final state of an analysis
- Combining `*CASE` and `dynain` files: a new approach for multi-stage analyses in LS-DYNA
  - For a background, see
    Borrvall, T., [Solution explorer in LS-PrePost- a GUI for Nonlinear Implicit FE](), 12th European LS-DYNA conference, Koblenz 2019.
  - Webinar: “Load history management”, 2021-05-27
  - Webinar: “Simulation of ROPS and FOPS”, 2023-02-09
  - Appendix B of the “Guideline for implicit analyses using LS-DYNA”
  - Appendix X in coming revisions of the keyword manual

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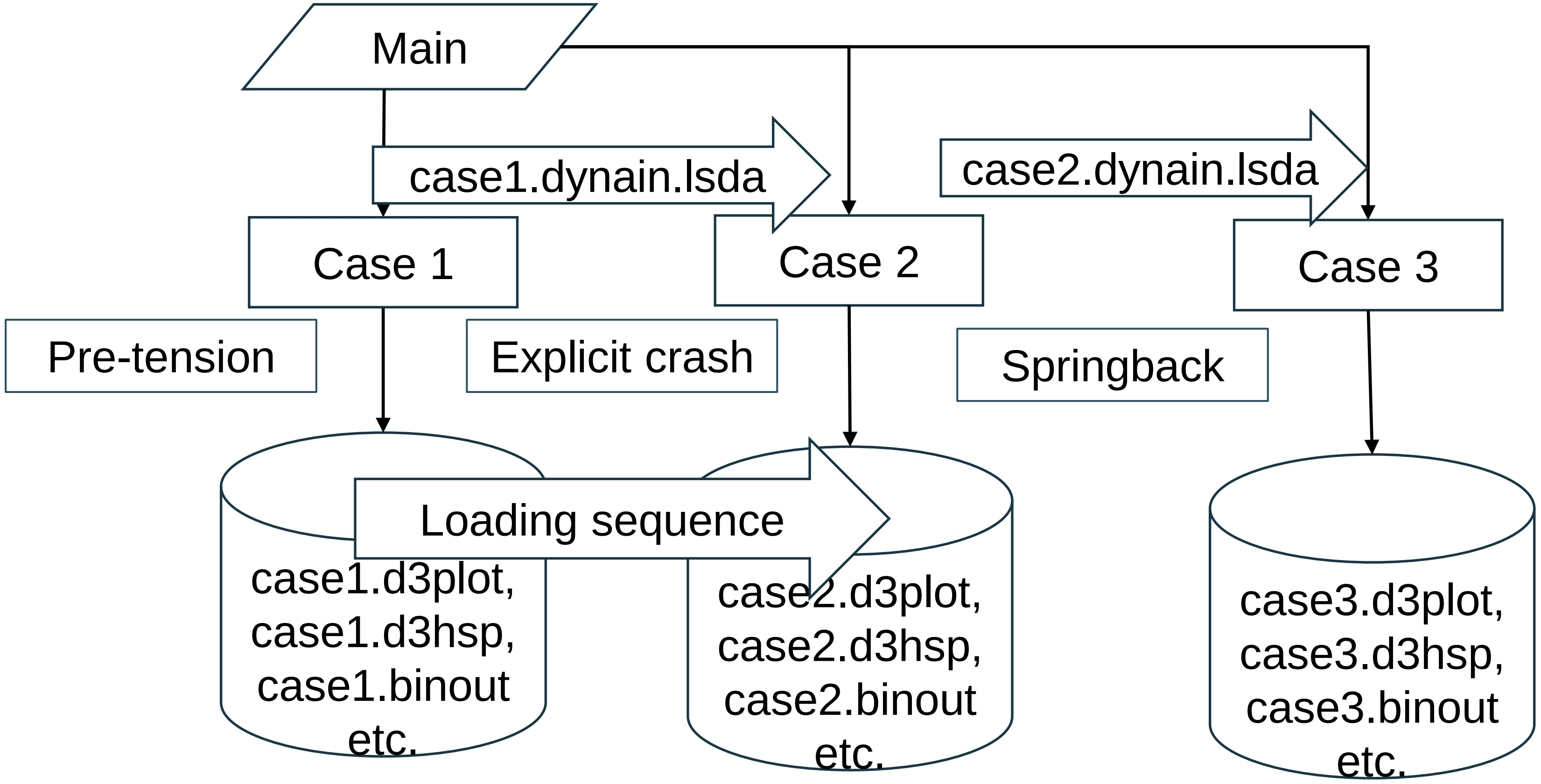
Multistage analyses for implicit/explicit switching

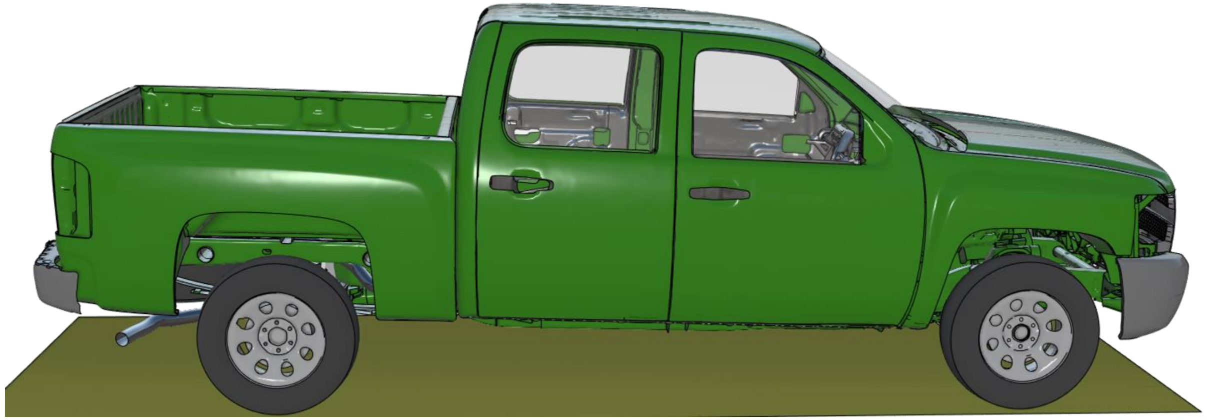
The `*CASE / dynain.lsda` - concept



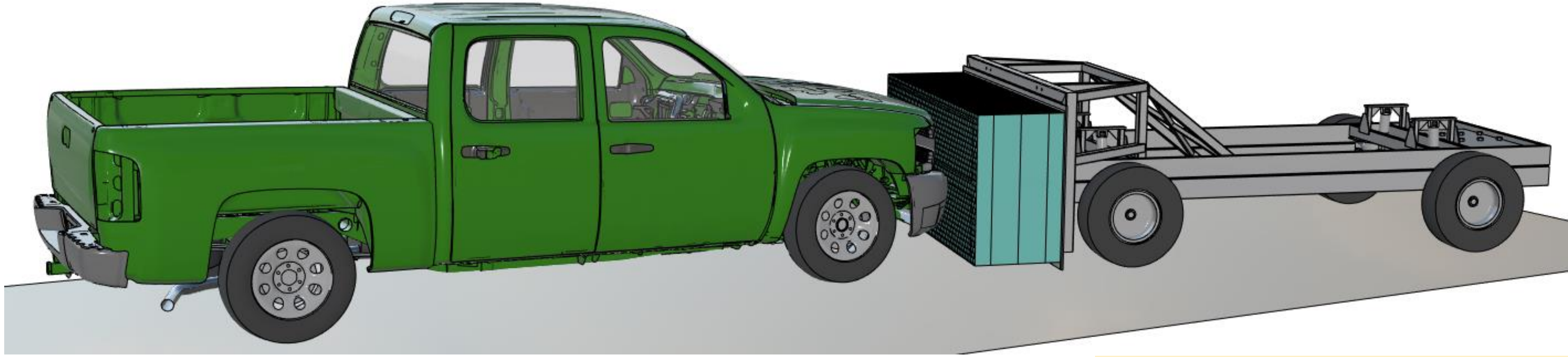
Multistage analysis for implicit/explicit switching

Example: Gravity loading followed by moving barrier impact

- A Chevrolet Silverado is subjected to
  - gravity loading (Stage 1, implicit) and

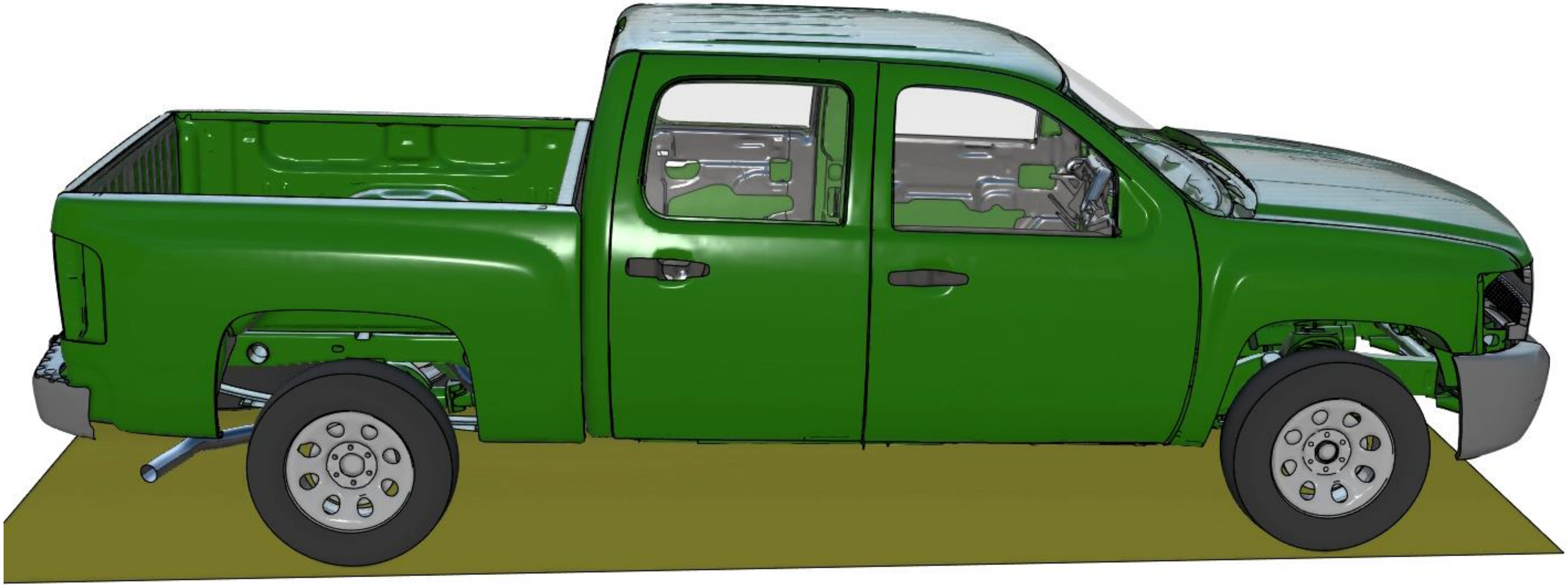


  - impact with a moving barrier (Stage 2, explicit)



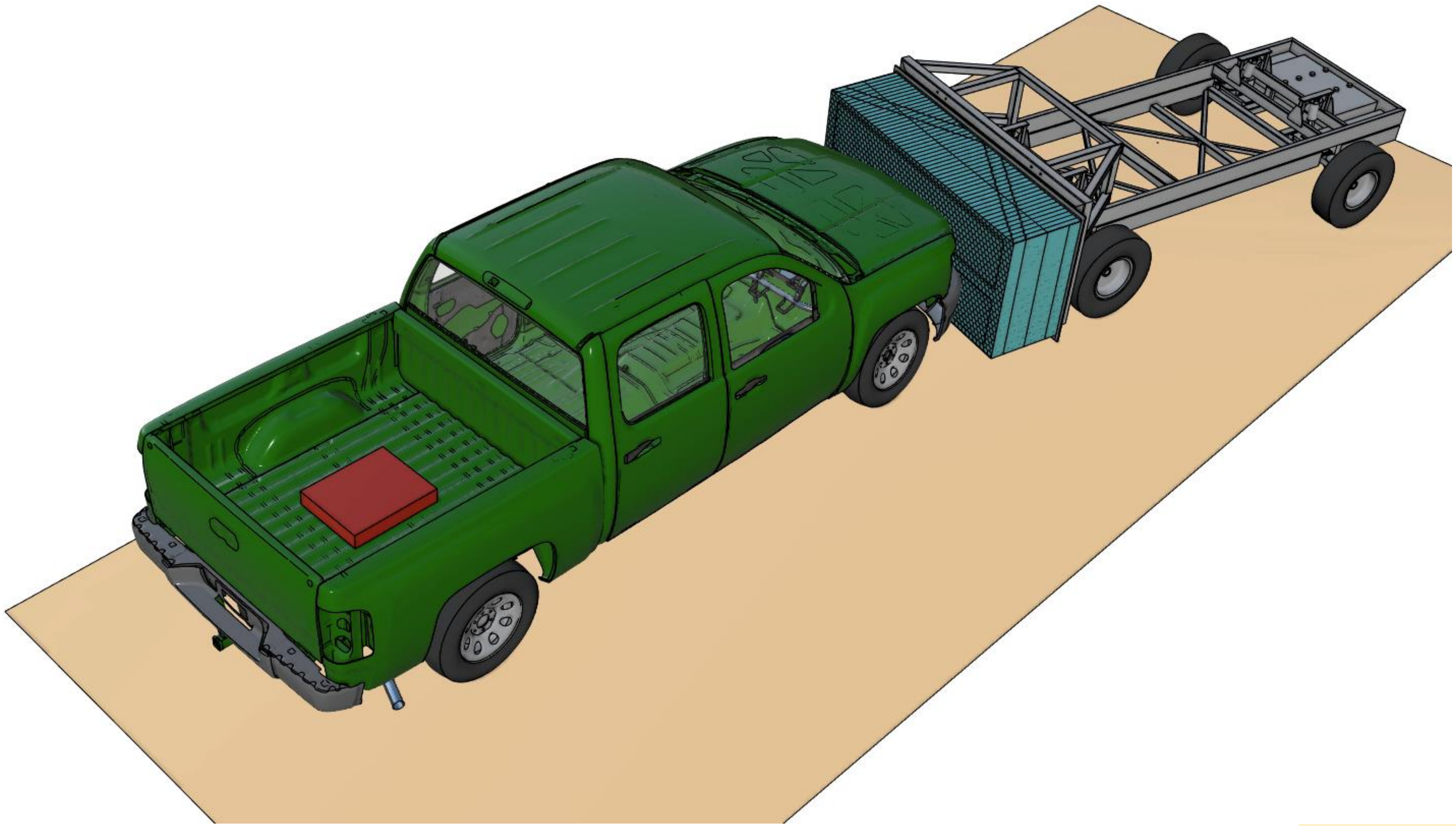
Multistage analysis for implicit/explicit switching

Result: Stage 1 - Gravity loading



Multistage analysis for implicit/explicit switching

Result: Stage 2 - moving barrier impact



Multistage analysis for implicit/explicit switching

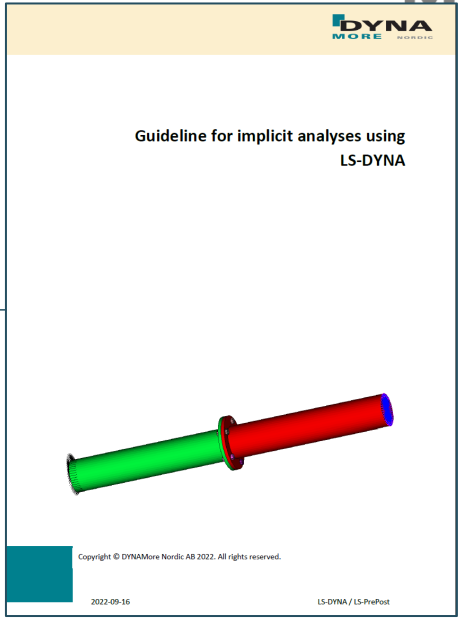
Keywords, stage 1: Implicit

```
*INCLUDE
control_cards_nonlin.key
*INCLUDE
database_cards_static.key
*CONTROL_TERMINATION
$    ENDTIM     ENDCYC      DTMIN     ENDENG     ENDMAS
        1.5
*DEFINE_CURVE_TITLE
Implicit_timesteps
700,
0.,0.05
.1,0.05
1.,0.1
2.,0.2
*CONTROL_IMPLICIT_DYNAMICS
$     IMASS      GAMMA       BETA                TDYDTH     TDYBUR      IRATE
          1        0.6       0.38                    1.        1.2          1
*CONTROL_MPP_IO_NODUMP
...
*INTERFACE_SPRINGBACK_LSDYNA
$#     psid       nshv      ftype          _     ftensr     nthhsv      rflag    intstrn
        338        999          3          0          0          0          1          0
$#     optc       sldo       ncyc     fsplit     ndflag      cflag      hflag
OPTCARD              0          0          0          1          1          1
*INTERFACE_SPRINGBACK_EXCLUDE
$#                                                                       kwdname
BOUNDARY_SPC_NODE
```

Implicit dynamics initially active

then ramped down

To get dynain.lsda file


Guideline for implicit analyses using
LS-DYNA

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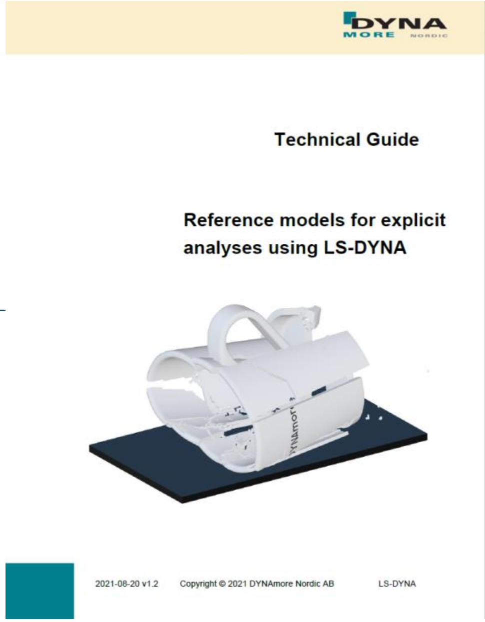
2022-09-16 LS-DYNA / LS-PrePost

Multistage analysis for implicit/explicit switching

Keywords, stage 2: Explicit

```
*KEYWORD
$===============================================================================
$ Silverado truck geo
$===============================================================================
*INCLUDE
case1.dynain.lsda
*INCLUDE
silverado_geo12.key.partsec
...
$===============================================================================
*INCLUDE
control_database.k
*CONTROL_TIMESTEP
$    DTINIT    TSSFAC      ISDO    TSLIMT     DT2MS      LCTM     ERODE     MS1ST
                                           -1.5E-06
*CONTROL_TERMINATION
$    ENDTIM    ENDCYC     DTMIN    ENDENG    ENDMAS
   140.E-3
```

Pre-loaded configuration from Stage 1



Multistage analysis for implicit/explicit switching

- Makes it possible to use your
  - preferred implicit control cards for the implicit stages, and
  - preferred explicit control cards for the explicit stages
- Possible to switch to under-integrated elforms for explicit
- Explicit stages can be run using single precision LS-DYNA
  - Or use different number of cores

Some differences

Differences in modelling possibilities between implicit and explicit

Some differences between explicit and implicit

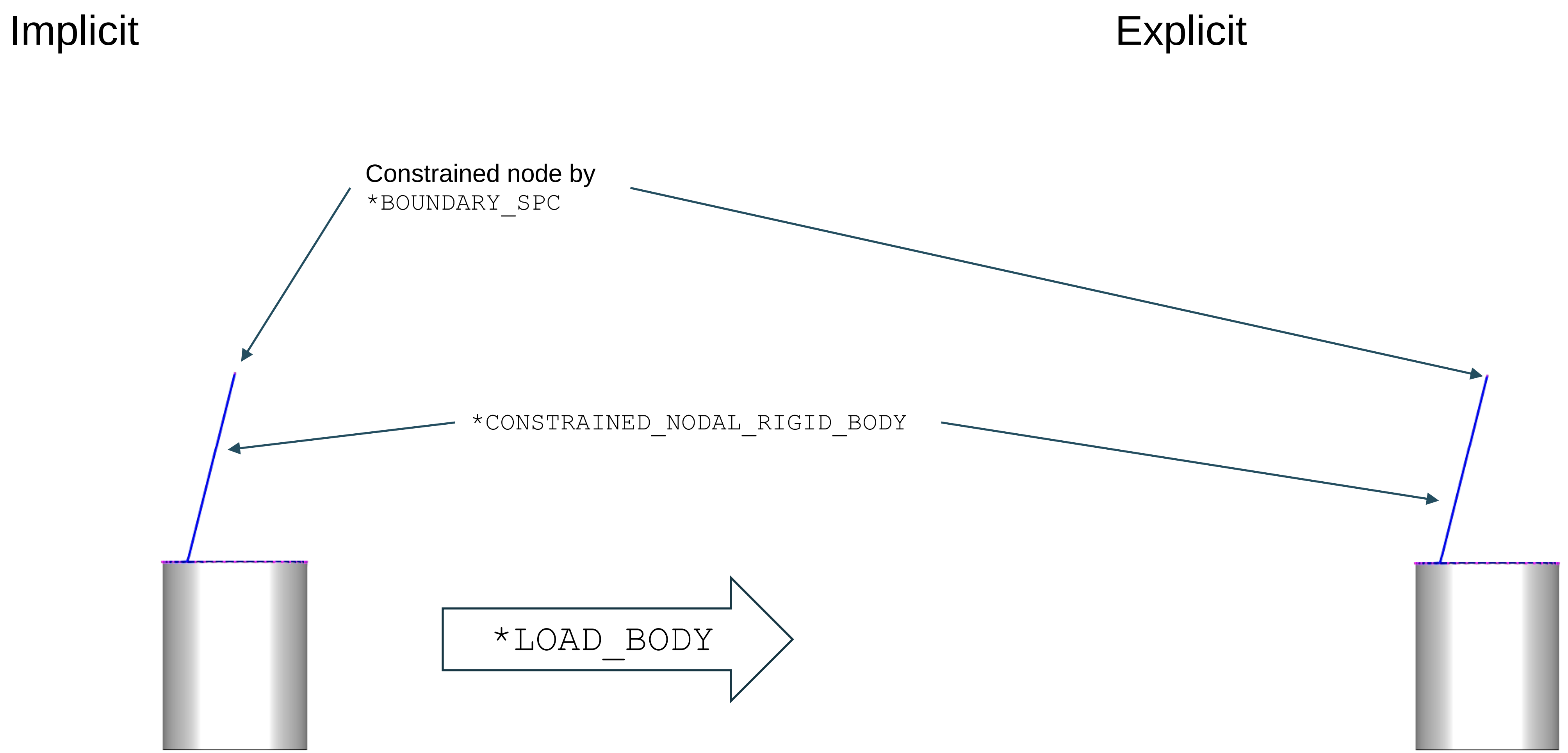
- Boundary conditions
- Joints
- Contacts
- Elements
- Materials
- New option in R14
  - `*CONTROL_ACCURACY`, *IACC* = 2

Some differences between explicit and implicit

- Boundary conditions
  - Applied simultaneously in implicit
  - Sequentially in explicit
- Joints
  - Constraint based implementation in implicit
  - Penalty based in explicit

Boundary conditions

Multiple constraints on rigid bodies



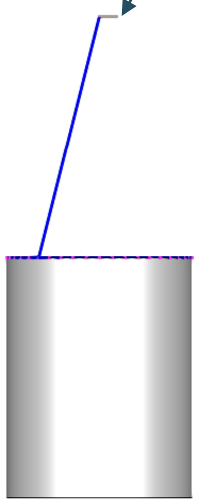
Boundary conditions

Multiple constraints on rigid bodies

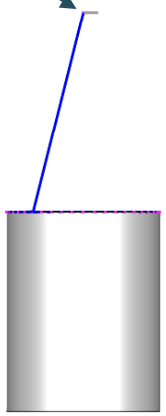
Implicit

Explicit

Constrained translation by extra fixed rigid part and
`*CONSTRAINED_JOINT_SPHERICAL`



`*LOAD_BODY`

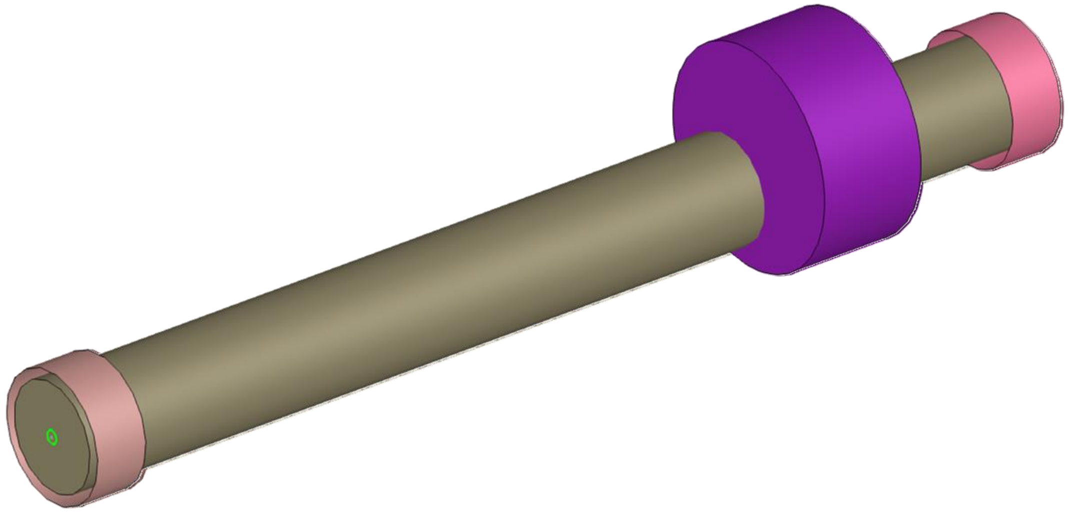


Joints

Boundary conditions, Joints

- Multiple constraints on rigid bodies
  - Implicit can handle multiple constraints as long as they are not in conflict
  - Explicit cannot
- Joints
  - Explicit uses a penalty formulation
  - Implicit uses constraints – redundant constraints are not allowed

*CONSTRAINED_JOINT_REVOLUTE



*CONSTRAINED_JOINT_CYLINDRICAL

Modelling approach

- Boundary conditions
  - applied consistently in implicit
  - sequentially in explicit
  - For switching, apply a modelling technique suited for <u>explicit</u>
- Joints
  - Constraint based implementation in implicit
  - Penalty based in explicit
  - For switching, apply a modelling technique suited for <u>implicit</u>

Contacts

Contact definitions for implicit and explicit

- Sliding contact
  - For explicit, typically soft = 2 or soft = 1 is used
    - Optimized for performance, fast solution
    - See also Webinar ”Contact settings for crash applications”, 2023-02-23
  - For implicit, Mortar contact is strongly recommended
    - Optimized for implicit convergence
    - Works well also for explicit
    - See also Webinar ”Mortar in explicit simulation”, 2020-12-17
- Tied contact
  - Implicit uses a strongly objective formulation
    - Can handle finite rotations in each time step
  - Explicit uses an incrementally objective formulation
  - Differences rarely noted

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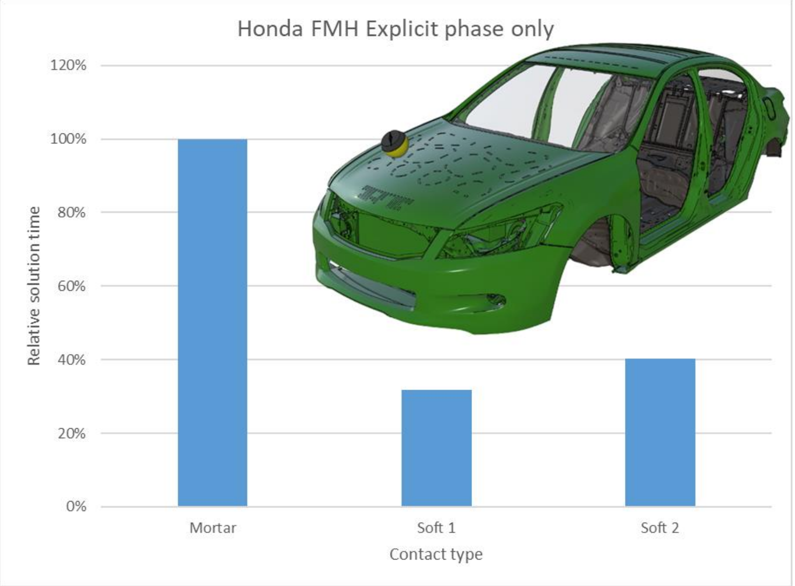
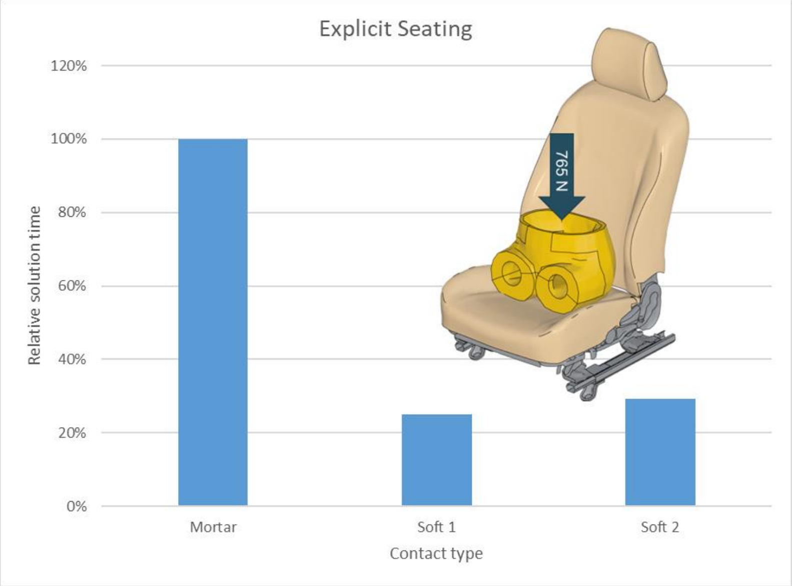
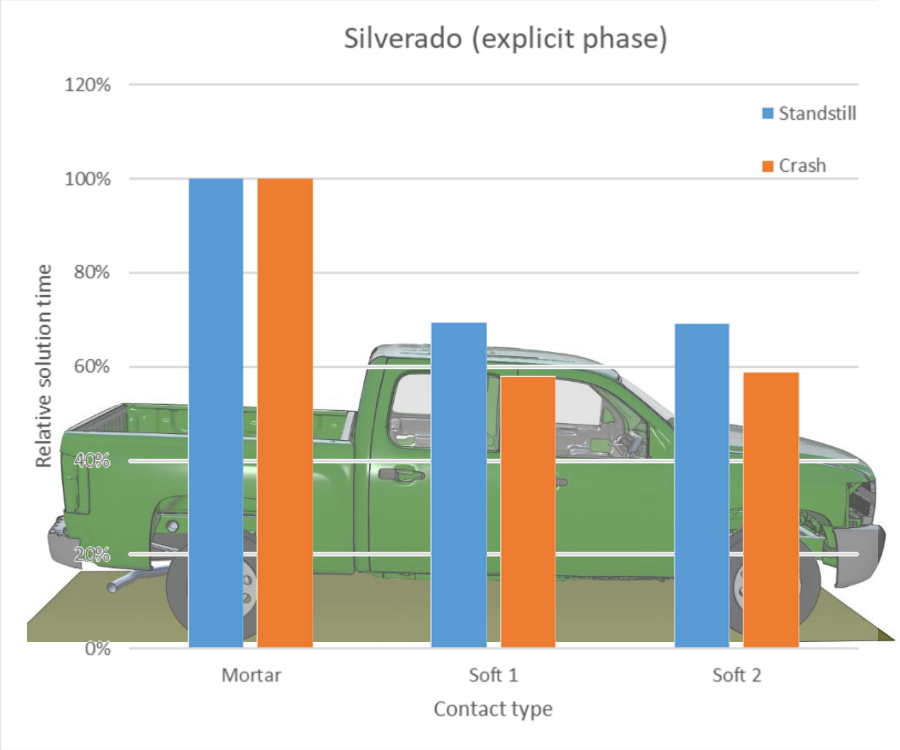
Contacts

Sliding contacts: Timing comparison



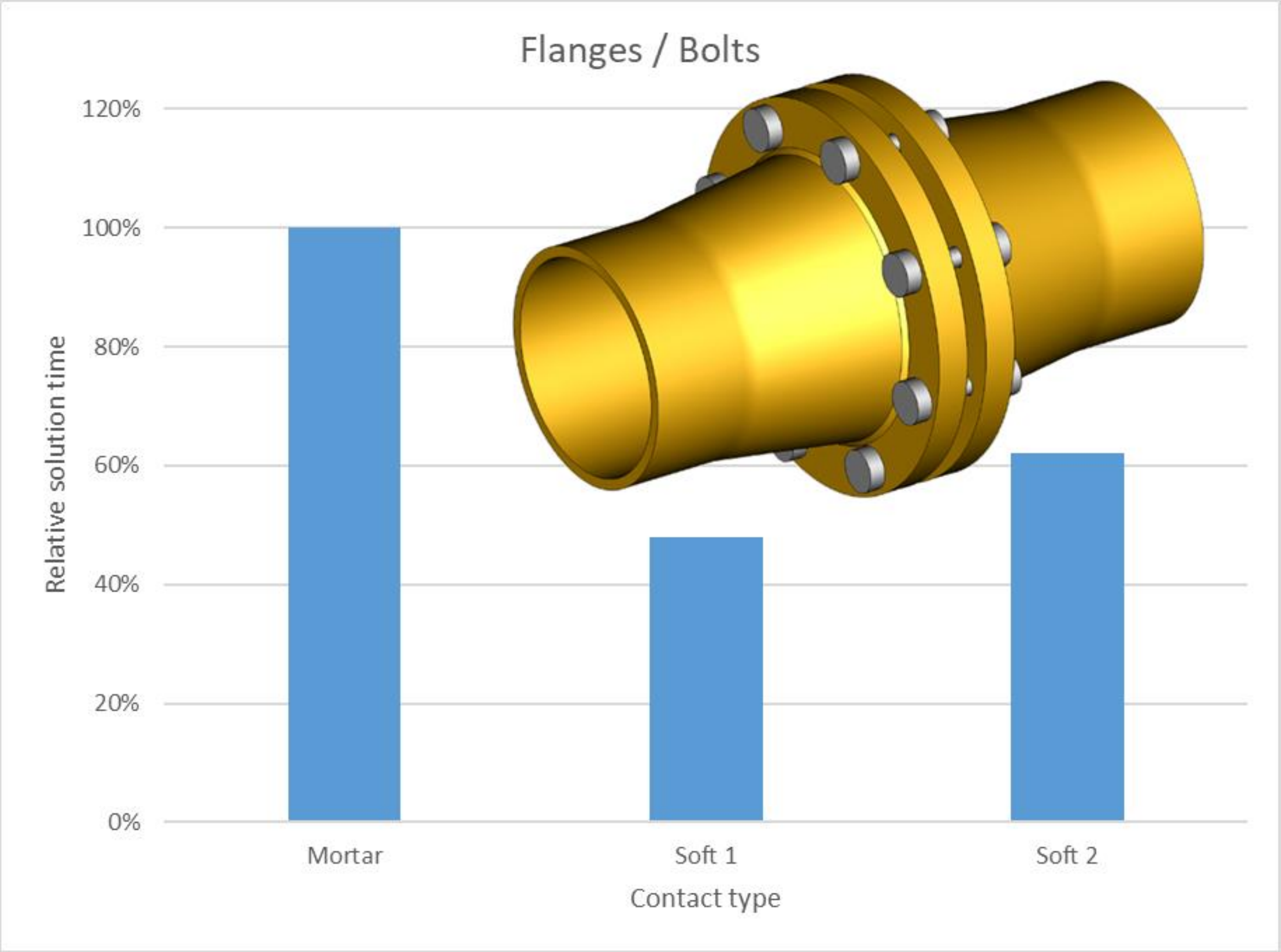




Contacts

Switching contacts

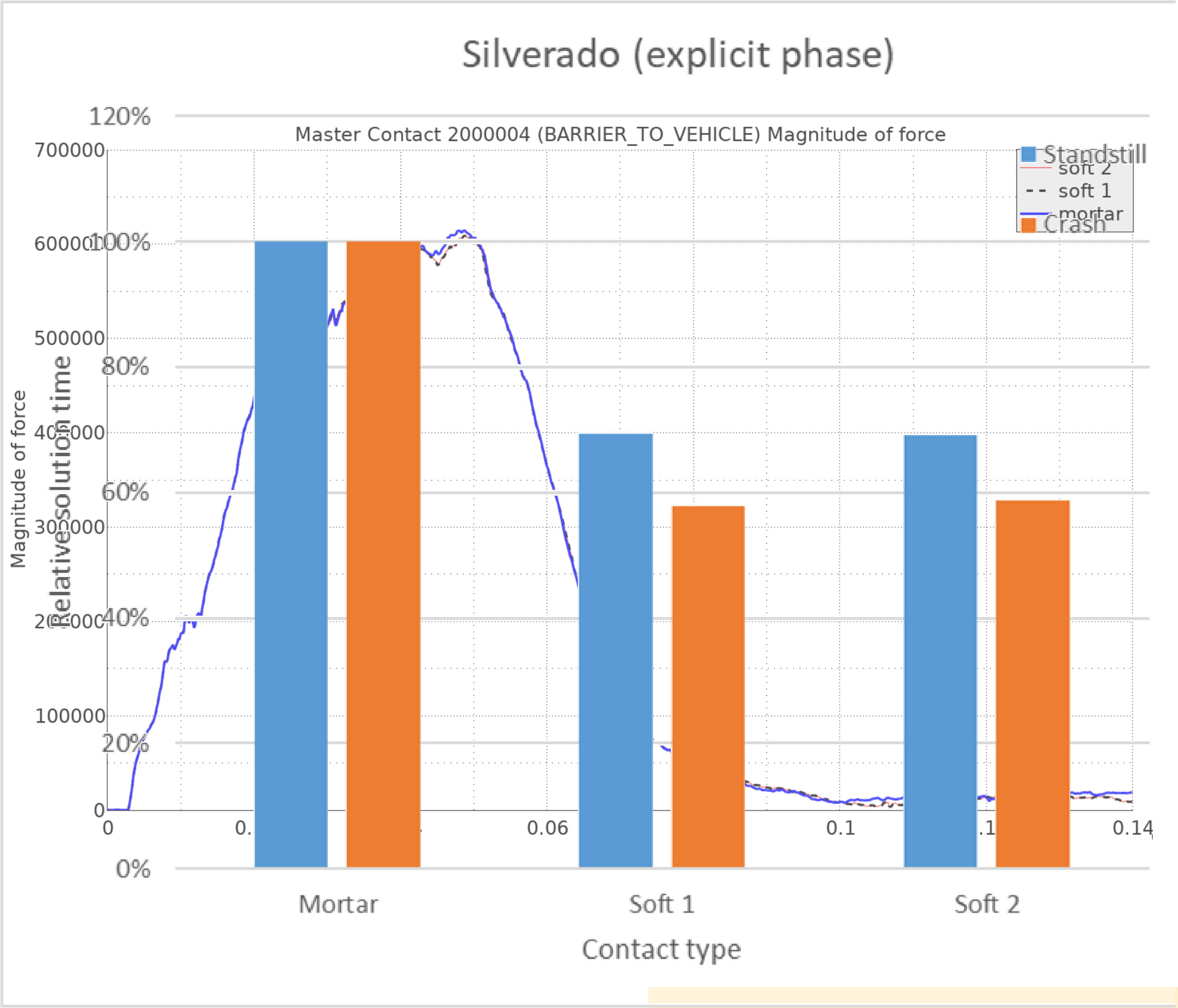
- User Mortar during the implicit phase
- Activate explicit contact at start of explicit phase
- Let the Mortar contact overlap for some time
- Deactivate the Mortar contact a bit into the explicit phase



Contacts

Switching contacts

- User Mortar during the implicit phase
- Activate explicit contact at start of explicit phase
- Let the Mortar contact overlap for some time
- Deactivate the Mortar contact a bit into the explicit phase



Elements

Some differences between explicit and implicit

- Implicit
  - Fully integrated elements, typically: shell elform 16, solids -2
  - Higher order elements, for example solids elform 16.
- Implicit and *IACC* = 1 on `*CONTROL_ACCURACY`
  - Nodal averaged 1st order tet (solids elform 13) supports all materials
  - Automatic switching of element formulations, for example shell elform 2 to elform (-)16
  - Strong objectivity for many element formulations
- Explicit
  - (Used to be) under integrated elements, typically: shell elform 2, solids elform 1
  - Nodal averaged 1st order tet (solids elform 13) supports a subset of materials
  - For fully integrated shells, use elform -16 for consistency

Material models

Some differences between explicit and implicit

- Many material models are first implemented for explicit, then augmented for implicit
  - Tangent matrix
  - Some models requires complete re-implementation for implicit
- Implicit and *IACC* = 1 on `*CONTROL_ACCURACY`
  - Fully iterative radial return for `*MAT_24` and `*MAT_123`
  - Automatic switch of `*MAT_LOW_DENSITY_FOAM` to `*MAT_FU-CHANG_FOAM`
  - Switch *FORM* to 14 on `*MAT_FABRIC`, unless *FORM* = ±14 already.
- In explicit, strain-rate dependency of hardening for (metallic) materials is commonly used
  - Hard to resolve high strain rates in implicit – may lead to inaccuracies
  - Use *IRATE* of `*CONTROL_IMPLICIT_DYNAMICS` to disable strain rate effects in implicit
- Some materials / combinations are not available in implicit
  - Solid elements + `*MAT_NULL` + `*EOS`

Some differences between explicit and implicit

Coming in R14: *IACC* = 2 on `*CONTROL_ACCURACY`

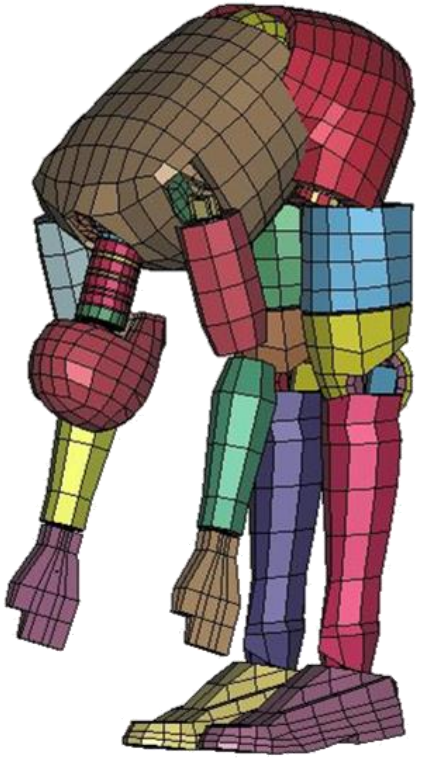
- Implicit/explicit and *IACC* = 2 on `*CONTROL_ACCURACY`
  - Use strongly objective tied contacts
  - Nodal averaged 1st order tet (solids elform 13) supports all materials
  - More features to come ...

Implicit / explicit switching in LS-DYNA

Summary

- Using LS-DYNA implicit and explicit together offers great possibilities
- Many ways of switching
- Most useful are
  - Explicit DR + implicit Main run, for e.g. bolt pre-tensioning
  - Implicit + automatic switch to explicit for e.g. material failure
    - Mind the time scale for loading
  - Multistage analysis
    - Offers greatest freedom
- Simulation model must work in both implicit and explicit
  - Boundary conditions – explicit modelling
  - Joints – implicit modelling approach
  - Materials, for example `*MAT_FABRIC`

Thank You



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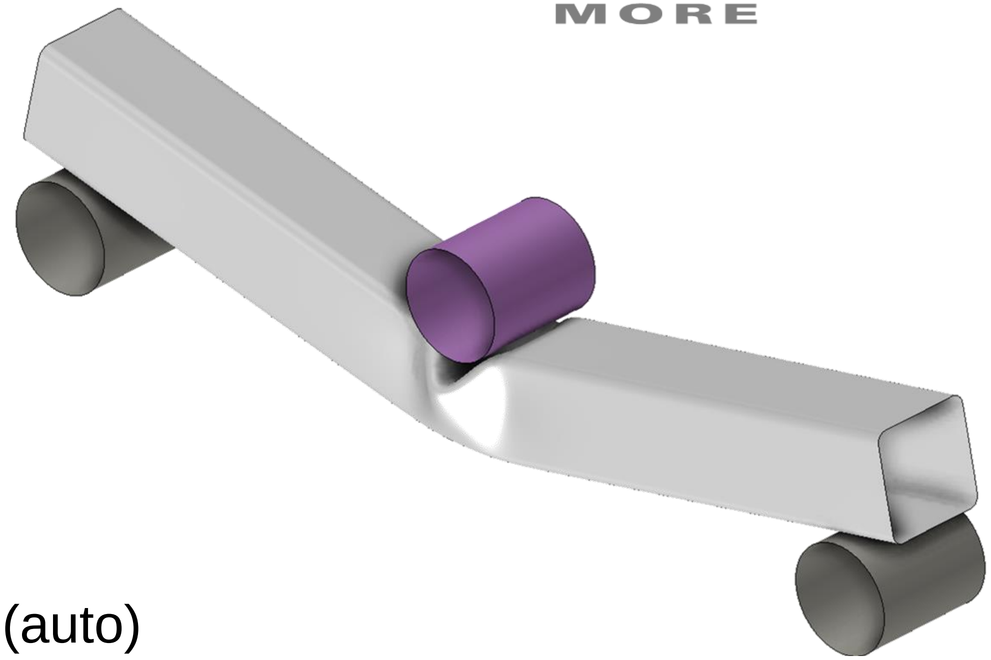
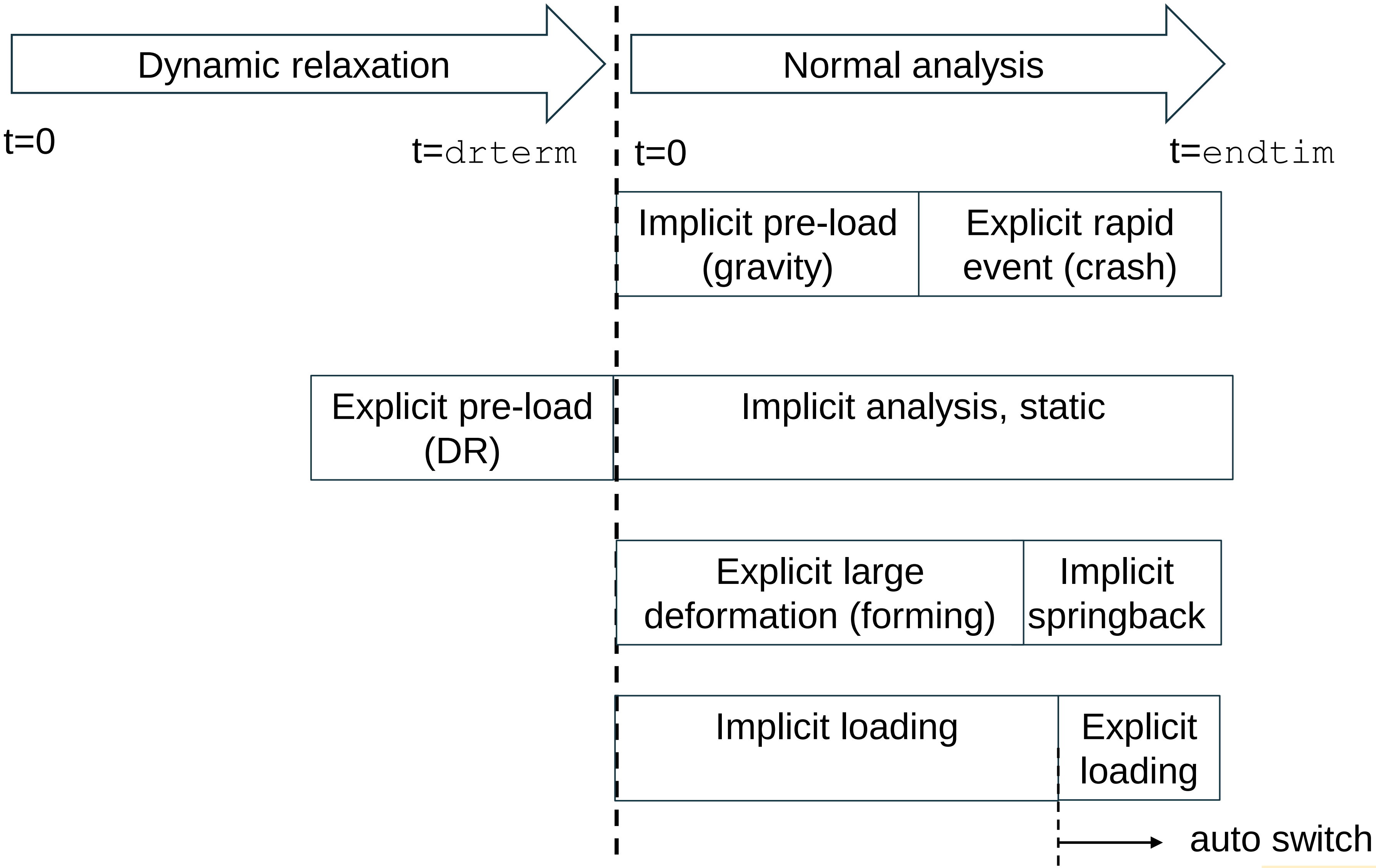
Applications

... notes?



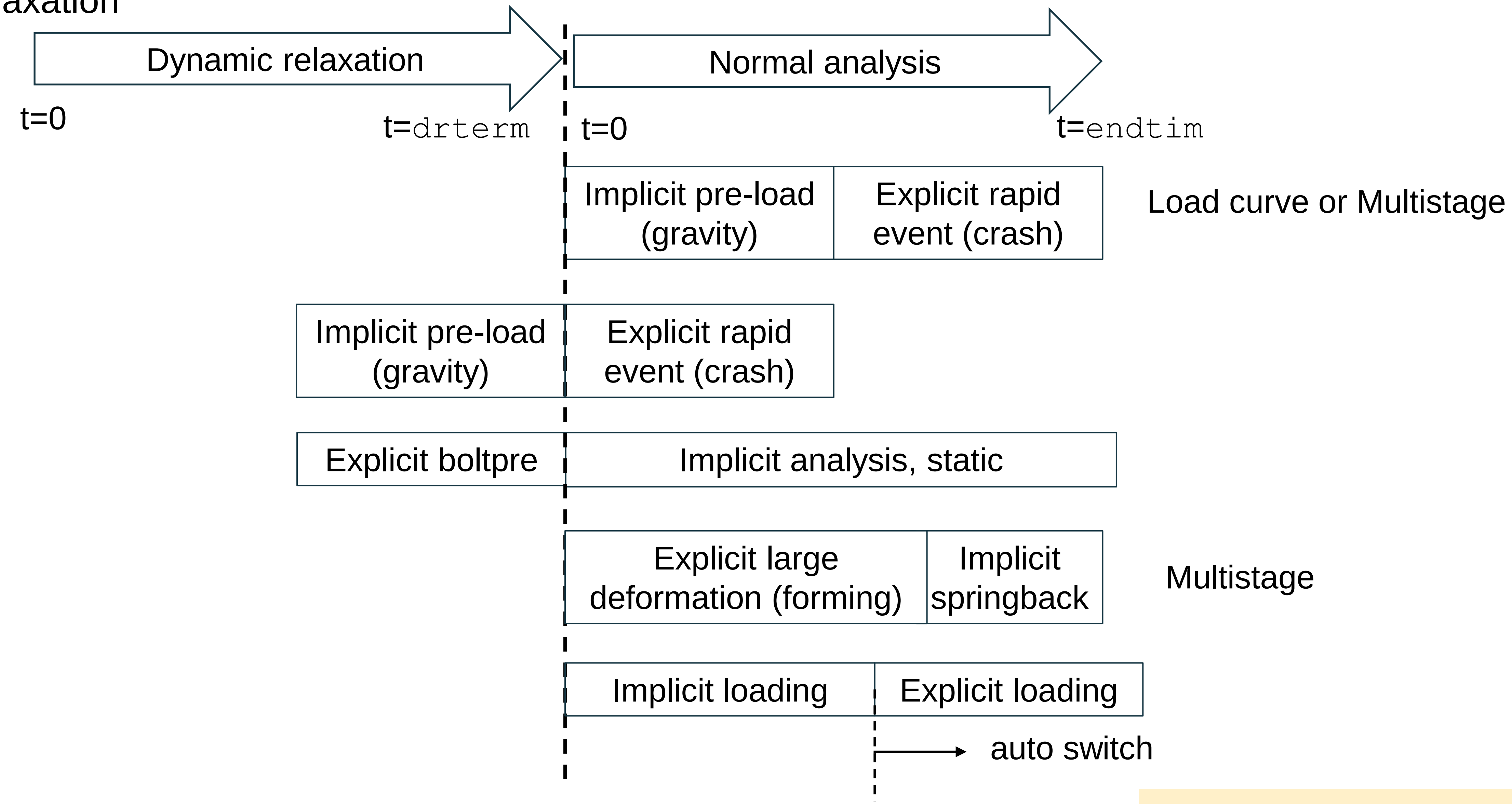
- pre-tensioning, of bolts?
  - expl DR for bolt pre-tensioning, implicit main sim
  - impl. multistage, boltpre + expl. loading
  - create example of this, the profile w. bolts?
- gravity loading ...
- failure modelling / element erosion, by impl -> expl switch (auto)
  - 3pt bending from mesh convergence study

Implicit/explicit switching – different cases



Implicit/explicit switching

Dynamic Relaxation



Overview

... notes

- LS-DYNA, implicit and explicit, general introduction
  - important with LS-DYNA, use the best solver best fit for the present analysis

- Differences between implicit and explicit
  - Boundary conditions
  - Materials
  - Elements
  - Joints
  - Contacts
  - ...
- Switching
- Different ways to switch
  - Manual
  - Automatic
  - DR
  - Cases, multi-stage --- also general about multi-stage
  - Springback ...
  - ...
- Important things to think about
- IACC = 2, from R14, for compatibility

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