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Beam Modeling of Hydraulic Energy Absorbers

Dr. Philipp Heinzl, Richard Graf, Glenn Gough, Christoph Schmied

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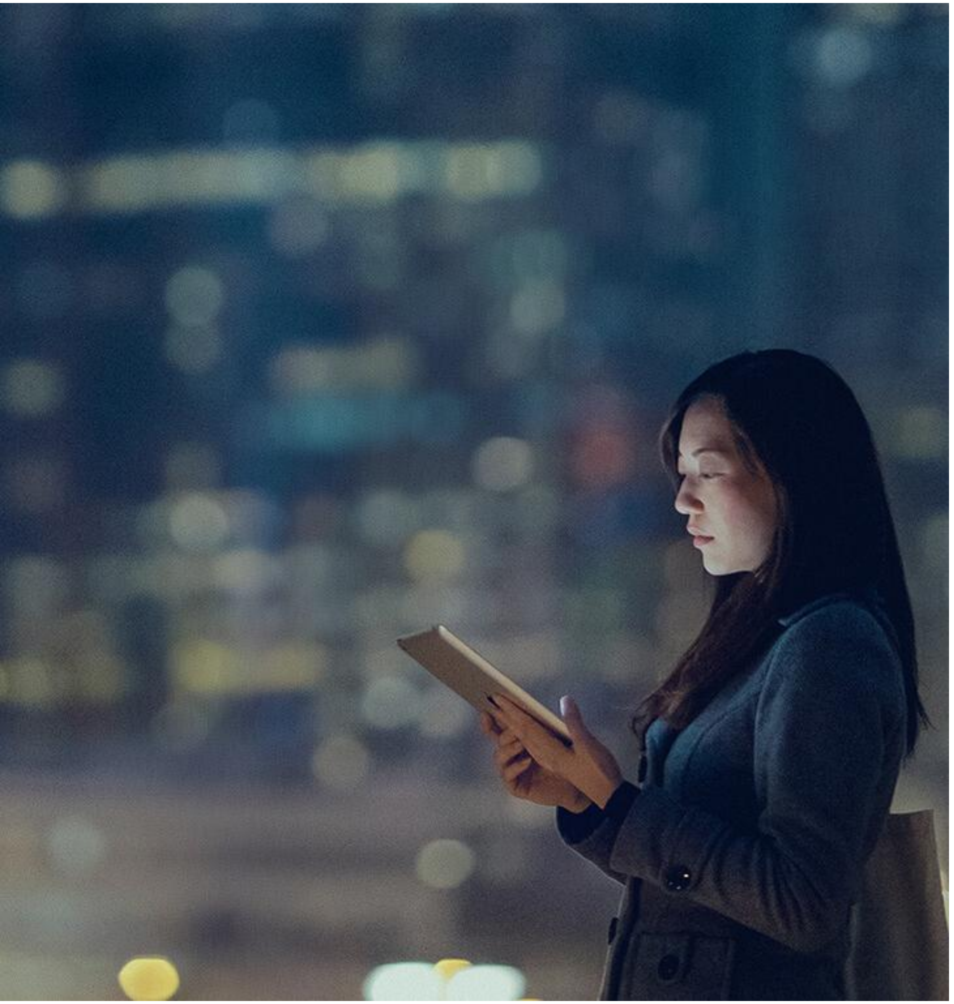
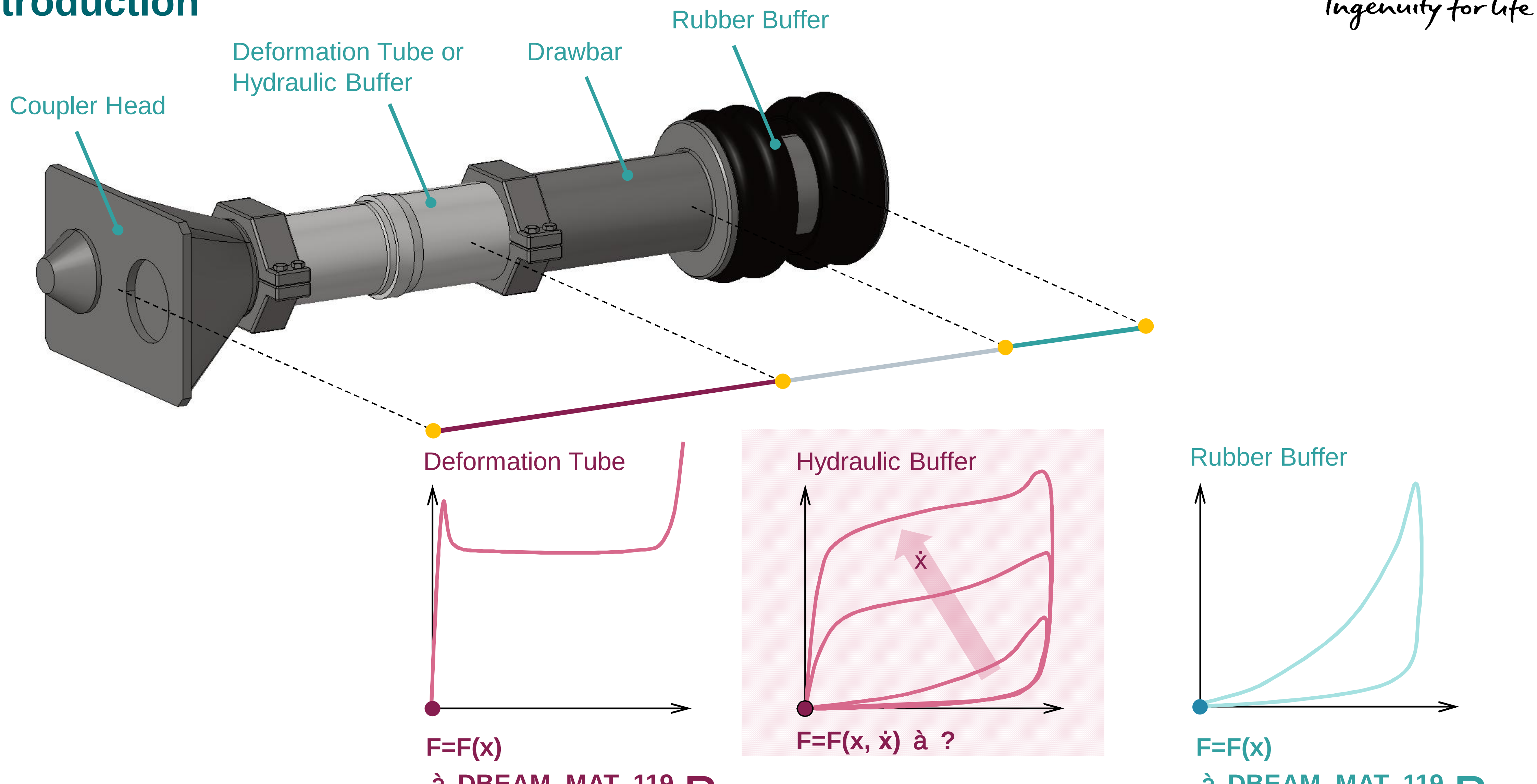


Beam Modeling of Hydraulic Energy Absorbers
Introduction



Beam Modeling of Hydraulic Energy Absorbers
Introduction – Task

The coupler beam shall be modeled as simple as possible and numerically efficient but authentically in its force vs. stroke behavior.

Preconditions:

1 **The whole coupler is to be modeled as series of beam elements.**

2 **The coupler length shall be represented correctly.**

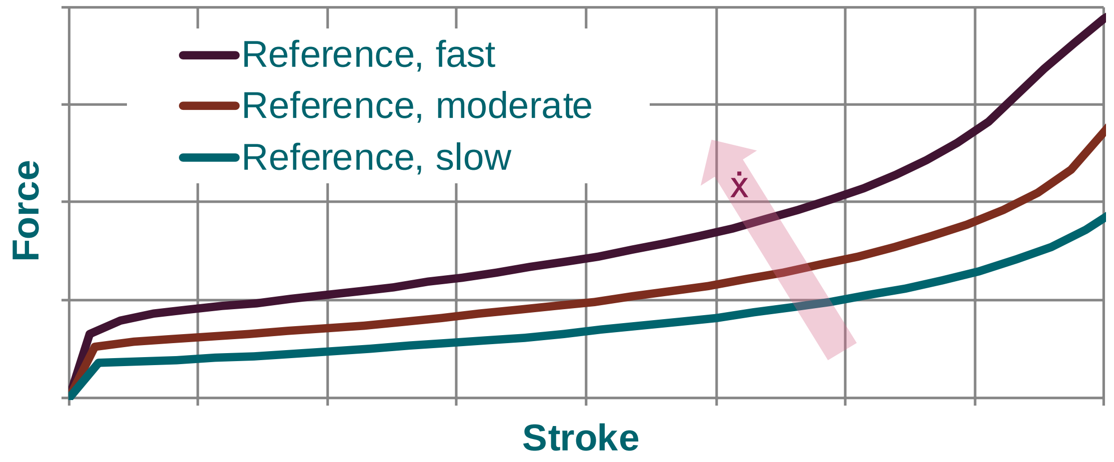
3 **DBEAMS (discrete beam elements) are preferred.**

4 **The behavior of hydraulic energy absorbers is presumed to be described by series of force-stroke characteristics for a multitude of actuation speeds.**

Beam Modeling of Hydraulic Energy Absorbers
Introduction – Modeling Approaches

Four modelling approaches for a given series of characteristics are presented:

- **MAT_24** – MAT_PIECEWISE_LINEAR_PLASTICITY
- **MAT_70** – MAT_HYDRAULIC_GAS_DAMPER_DISCRETE_BEAM
- **MAT_121** – MAT_GENERAL_NONLINEAR_1DOF_DISCRETE_BEAM
- **UMAT** – User Defined Interpolation within Series of Characteristics



Beam Modeling of Hydraulic Energy Absorbers
MAT_24 – MAT_PIECEWISE_LINEAR_PLASTICITY

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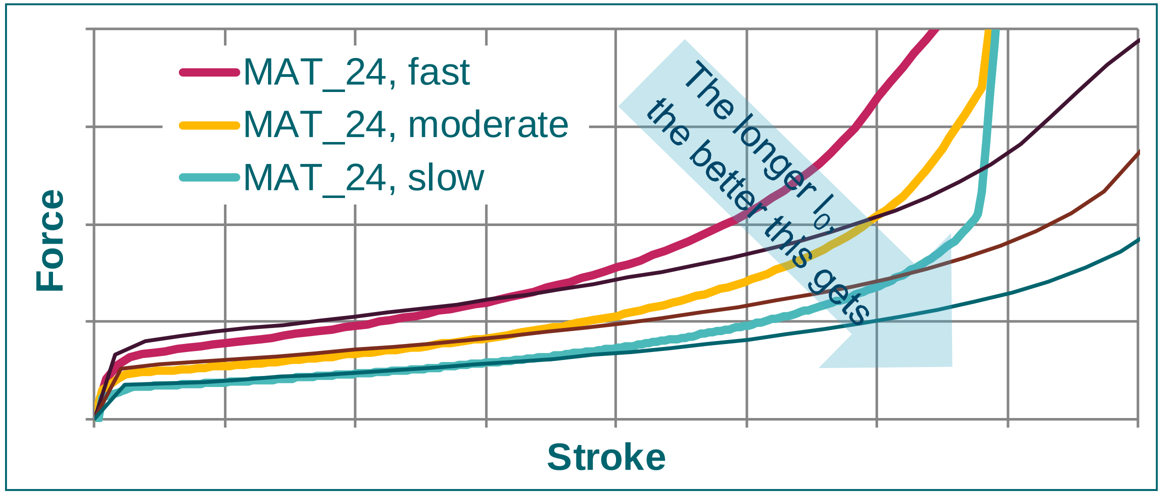
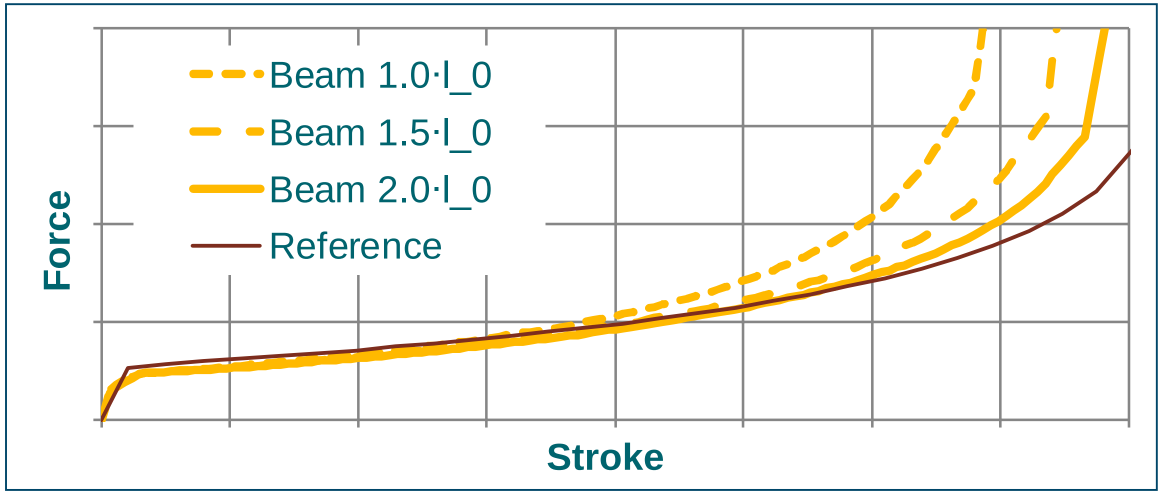
- ELFORM 1 → no DBEAM
- $F(x, \dot{x}) \rightarrow \sigma(\varepsilon, \dot{\varepsilon})$
- But if $\dot{x}$ is constant $\dot{\varepsilon}$ won't be constant:

$$\dot{x} = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} \quad \text{but} \quad \dot{\varepsilon} = \lim_{\Delta t \to 0} \frac{\Delta \varepsilon}{\Delta t} = \lim_{\Delta t \to 0} \frac{\Delta x / l(t)}{\Delta t}$$





Beam Modeling of Hydraulic Energy Absorbers
MAT_70 – MAT_HYDRAULIC_GAS_DAMPER_DISCRETE_BEAM

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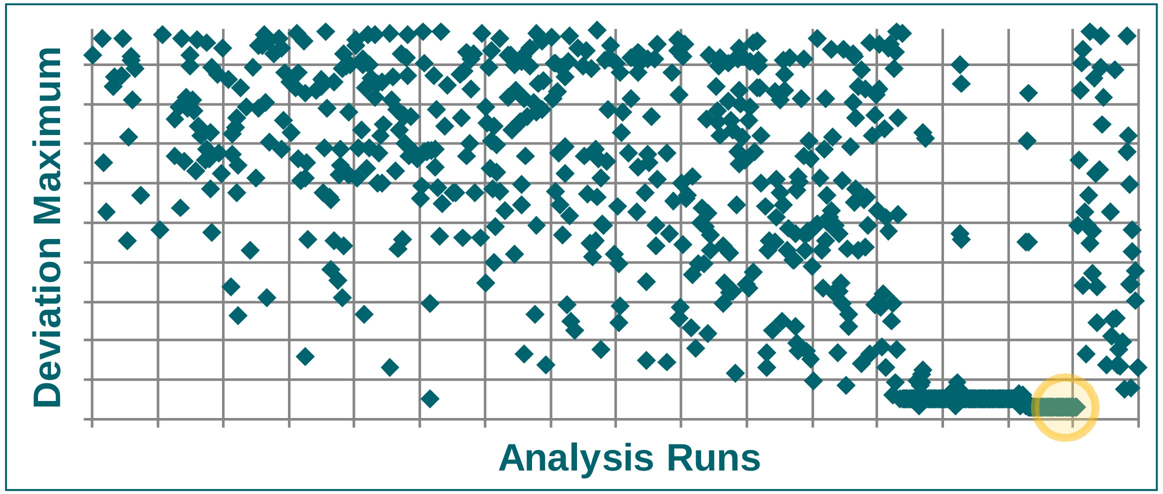
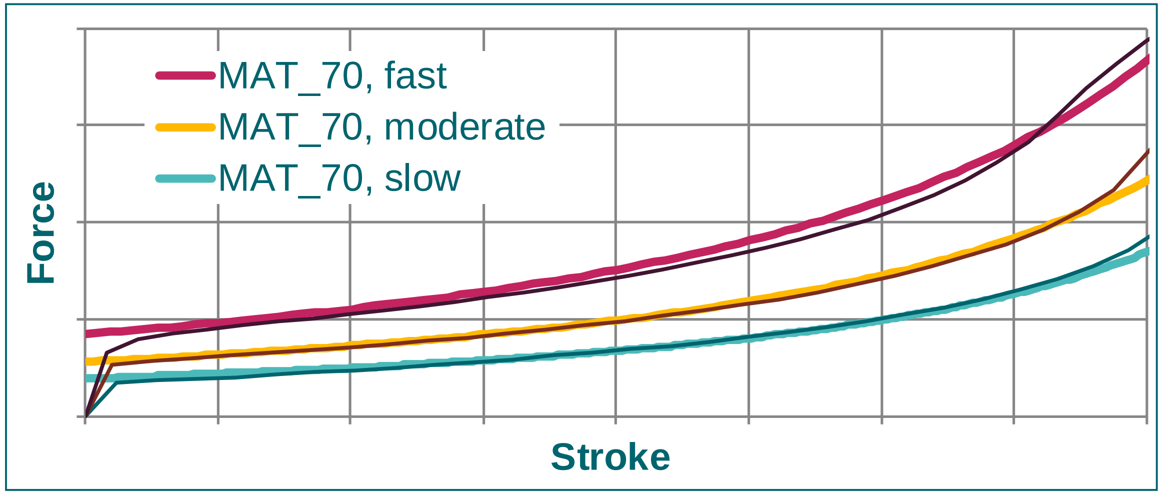
- Discrete Beam
- Physical model of a gas-hydraulic damper
- Force formula:

$$F(x,\dot{x}) = S_F \left\{ c_H \left(\frac{\dot{x}}{a(x)} \right)^2 + \left[p_0 \left(\frac{l_0}{l_0 - x} \right)^n - p_a \right] \cdot A_p \right\}$$

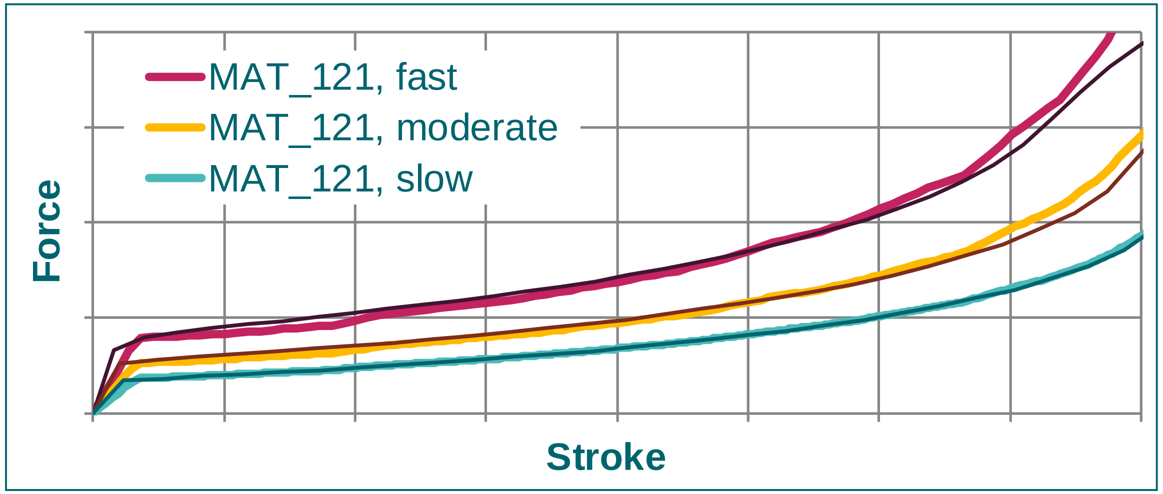
- 10 parameters defined
- Optimization:
  - Genetic algorithm
  - Max. deviations → Min
  - ~2000 runs, ~10 iterations and ~10 attempts → ~200000 runs in total





Beam Modeling of Hydraulic Energy Absorbers
MAT_121 – MAT_GENERAL_NONLINEAR_1DOF_DISCRETE_BEAM

- Discrete Beam
- A base curve can be offset velocity dependently and gradients can be adjusted displacement dependently (definable via two curves)
- Simple and fast approach
- Similarity of reference curves helpful
- Could also be improved by optimization



Beam Modeling of Hydraulic Energy Absorbers
LS-Dyna UMAT programming – How to get started

Literature

1 LS Dyna Manual Appendix A **à General Information, example codes, `tabval`-routine, …**

2 Erhart, T.: "An Overview of User-Defined Interfaces in LS-DYNA", 9. LS-DYNA Forum 2010 **à User Interfaces in general**

3 Kleinbach, Ch. et al.: "Implementation and validation of the extended Hill-type muscle model with robust routing capabilities in LS-DYNA for active human body models", BioMed Eng OnLine, 2017 **à Source Codes, e.g. information of how to extract kinematic data, ...**

<u>To get actually started follow this steps:</u>

- Get the proper User Material Package (operating system, mpi, …)
- Edit the file dyn21.f (e.g. `urmatd` for DBEAMs, `umat41` … `umat50`)
- Compile an own LS Dyna executable

Beam Modeling of Hydraulic Energy Absorbers
LS-Dyna UMAT programming – DBEAM specific UMAT issues

urmatd

```
      common/aux14loc/
     1 sig1(nlq),sig2(nlq),sig3(nlq),sig4(nlq),
     2 sig5(nlq),sig6(nlq),epsps(nlq),hsvs(nlq,71),
     3 el12(nlq),el22(nlq),el32(nlq),el18(nlq),el28(nlq),el38(nlq)
```

umat43 (e.g.)

```
      capa(i)=capa(i)+F_hydro_mean*delta_l
      …
      sig(1)=F_hydro …
      sig(6)=0.0
```

urmatd

```
      el12(i) =-sig1(i)
      el22(i) =-sig2(i)
      …
      el38(i) =-sig6(i)
```

Beam Modeling of Hydraulic Energy Absorbers
UMAT – User Defined Interpolation within Series of Characteristics

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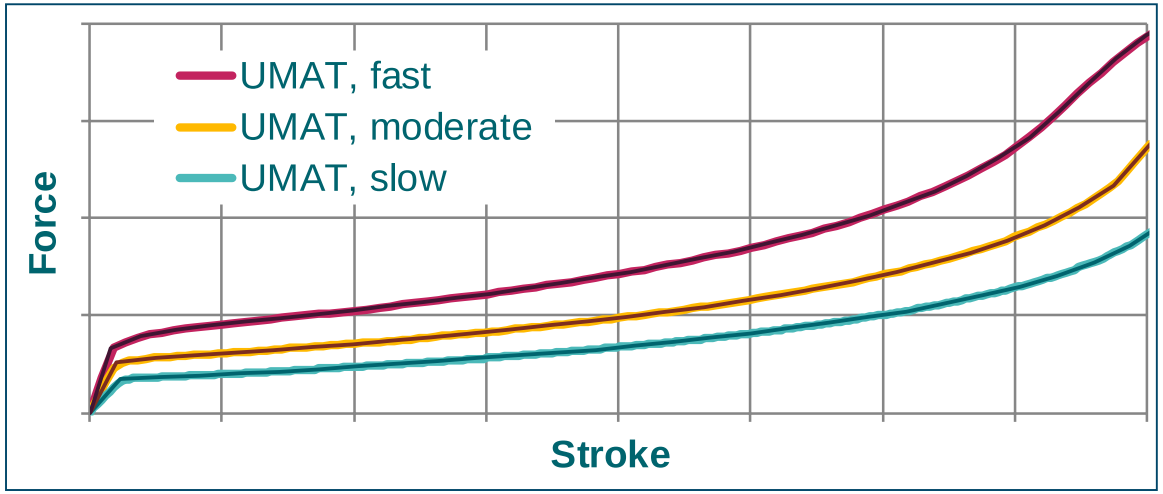
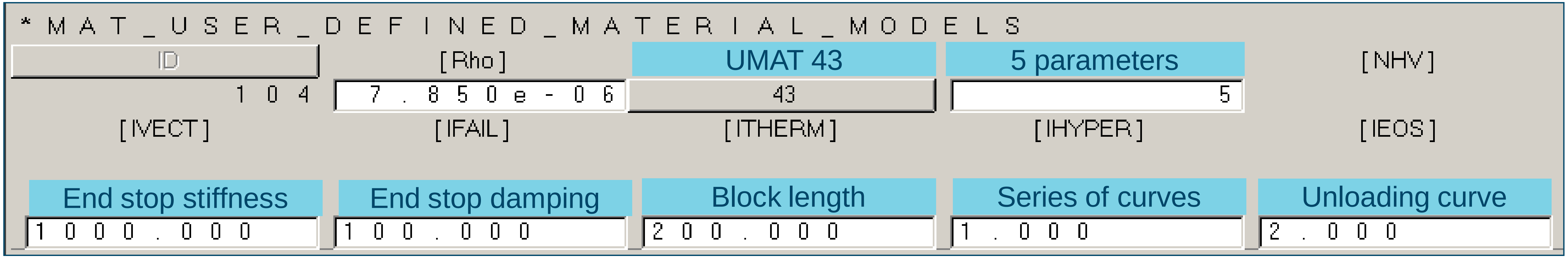
- Discrete Beam
- Series of curves is interpolated displacement and velocity dependently (`tabval`-routine)
- End stops are already integrated (linear model from end stops on)





*MAT_USER_DEFINED_MATERIAL_MODELS

ID	[Rho]	UMAT 43	5 parameters	[NHV]
104	7.850e-06	43	5	
[IVECT]	[IFAIL]	[ITHERM]	[IHYPER]	[IEOS]
End stop stiffness	End stop damping	Block length	Series of curves	Unloading curve
1000.000	100.000	200.000	1.000	2.000

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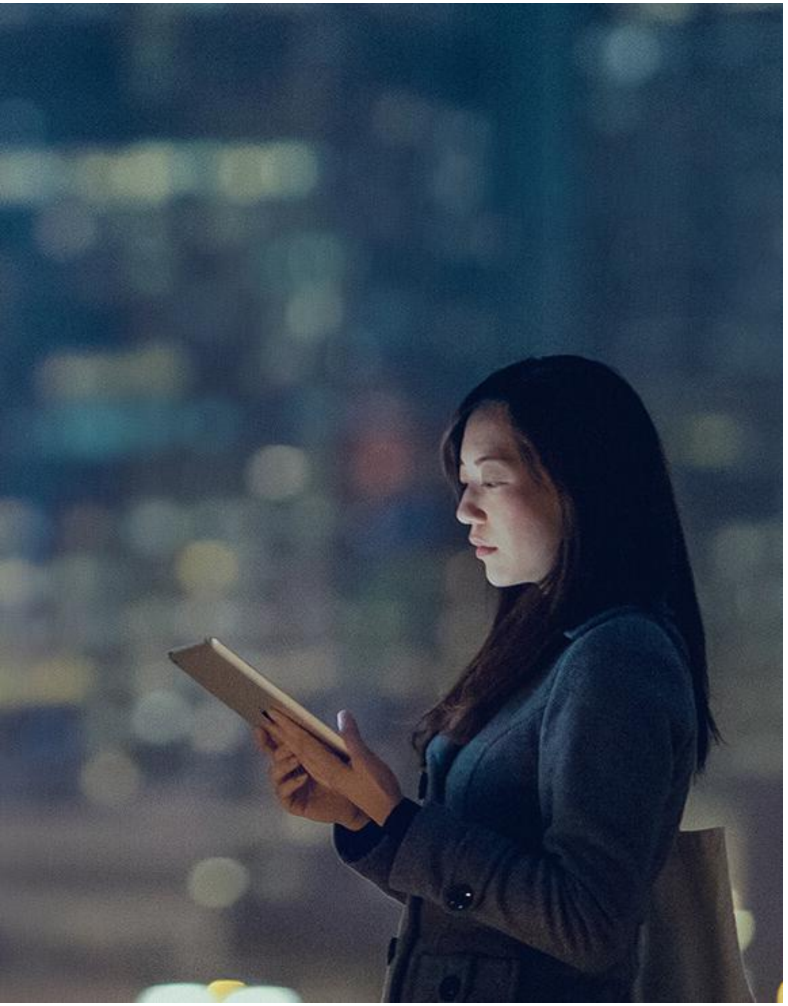
Beam Modeling of Hydraulic Energy Absorbers
Conclusion

- **All presented approaches can lead to acceptable results.**
- **Their individual pros and cons are highlighted and the results are compared.**
- **Once the UMAT programming hurdle is cleared this definitely is the most preferable approach since the given series of curves is always matched perfectly.**

Contact page



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