Side Member Crumple Section Simulation and Structural Optimization

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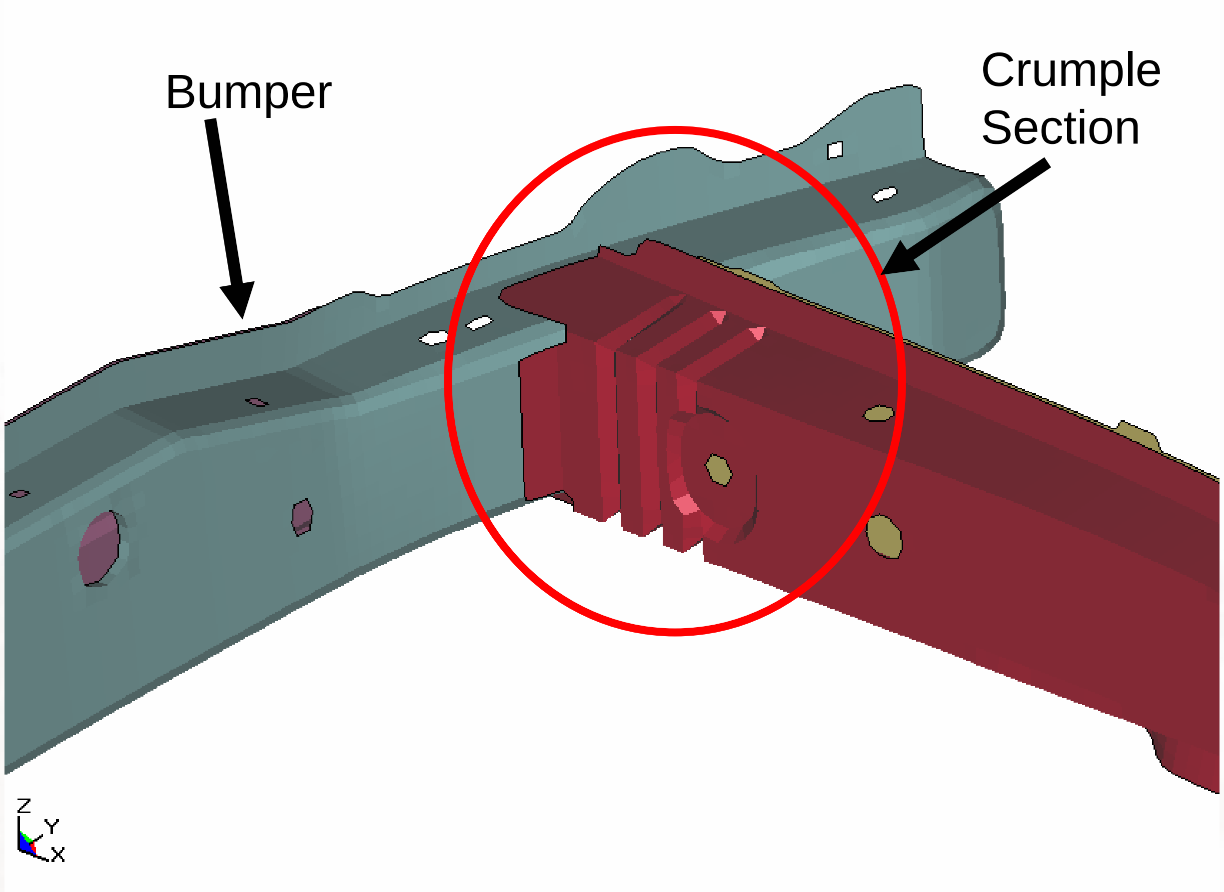
Energy absorbing structural component in a car front impact

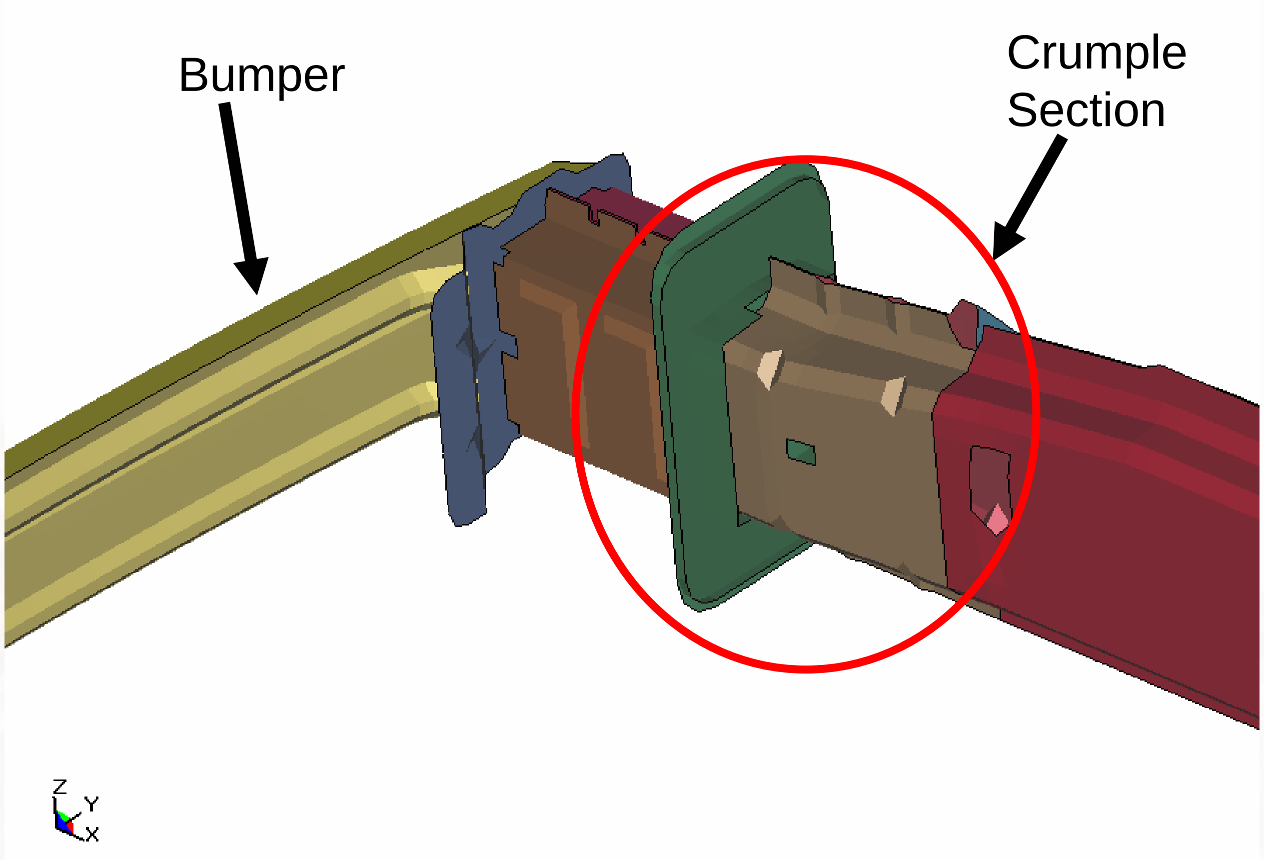
The study shows the energy management of the front end structure it's stiffness, strength and crush mode as function of occupant load. A well designed front end structure will have loads well below the tolerance limit of actual injury criteria (FMVSS 208, ECE R94)

Progressive tube axial crushing and s-shape tube bending are commonly used as energy absorbers

This paper presents experimental and FE parametric study of side member energy absorption capability, its force characteristic and the collapse mechanism



Top-hat design

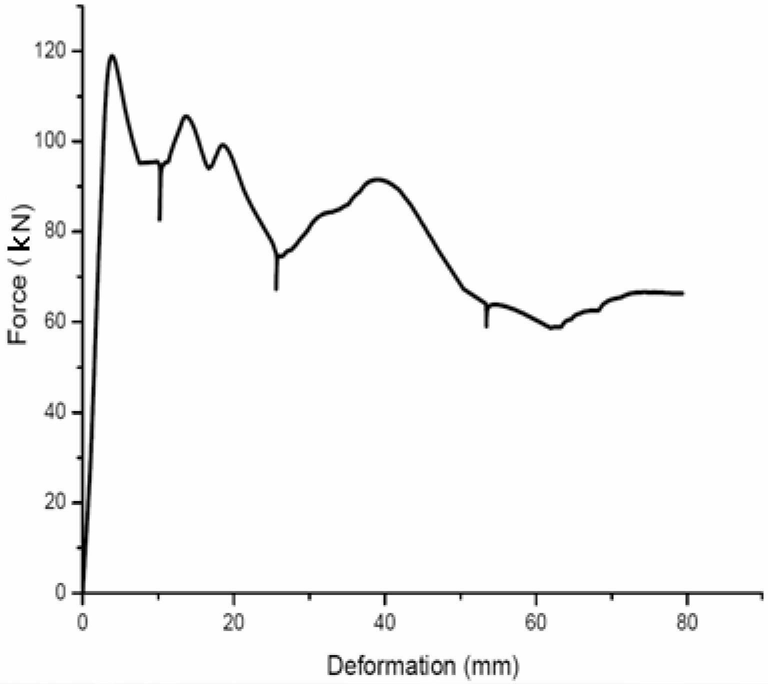


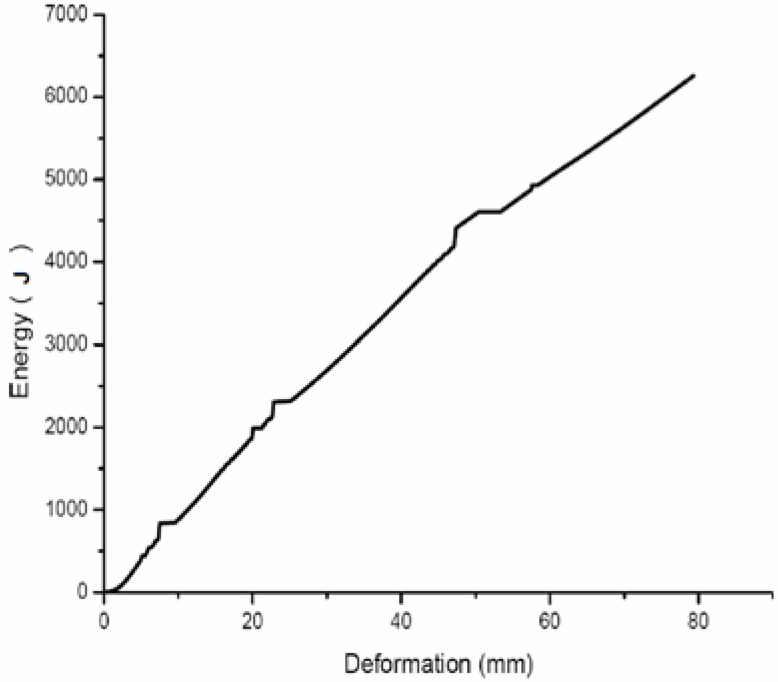
Double-hat design

Quasi-static test

Spot welds

Spot welds



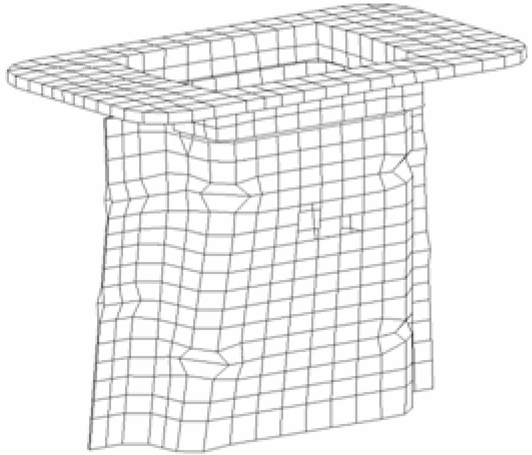


Quasi-static test results

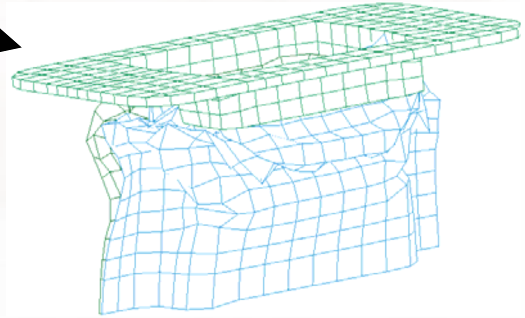
Test specimen

Before collapse

After collapse



FE model



Element type: shell (Belytschko-tray)

Spot welds: nodal rigid body

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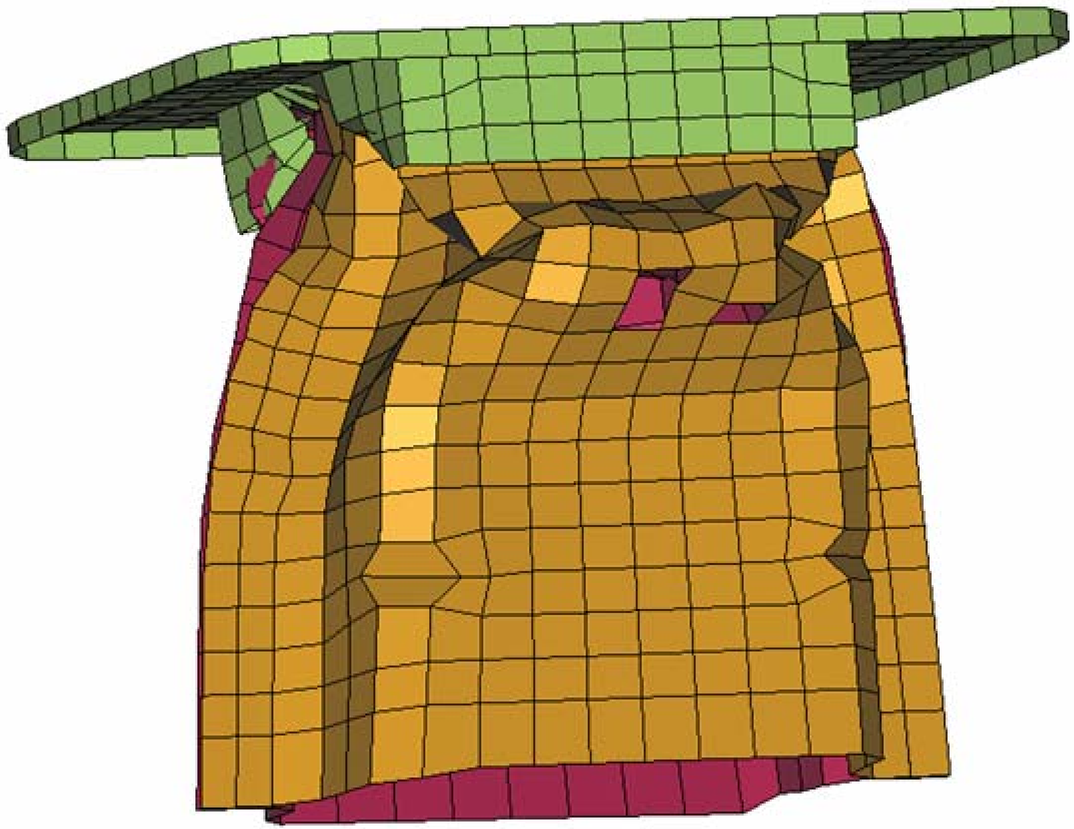
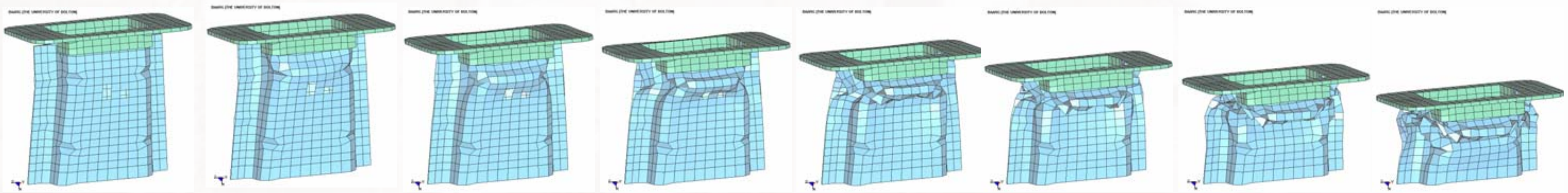
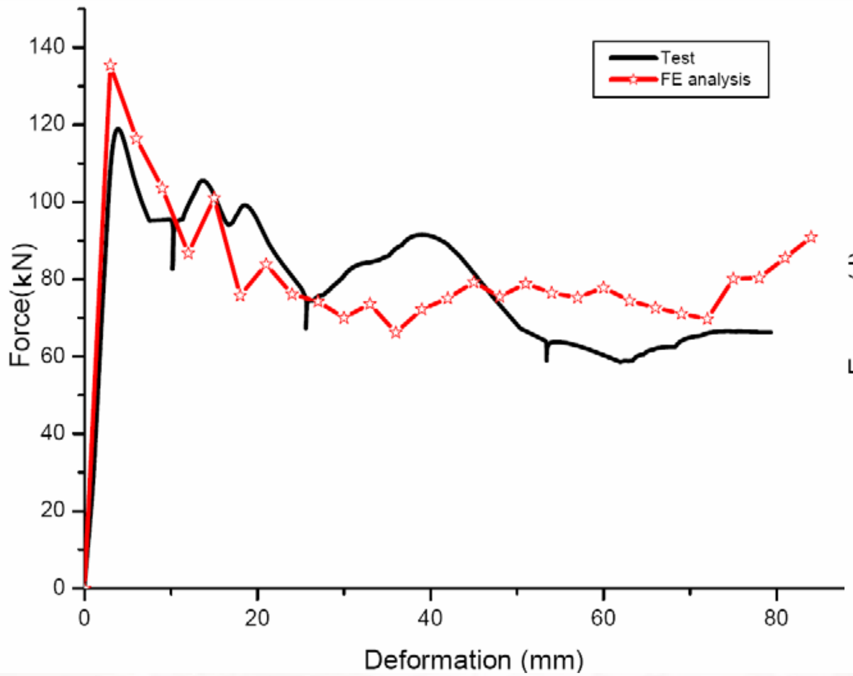


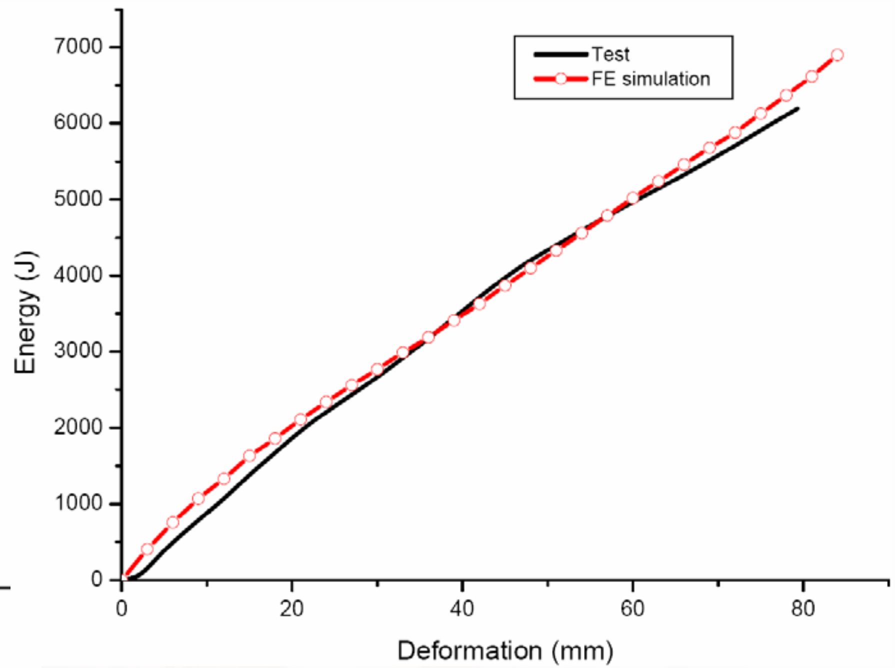
FE model validation

Test

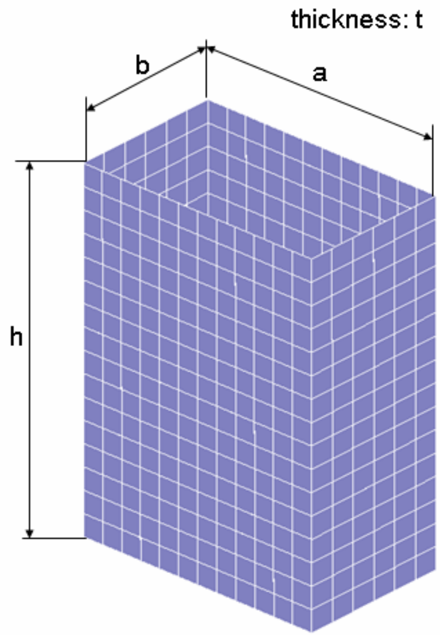


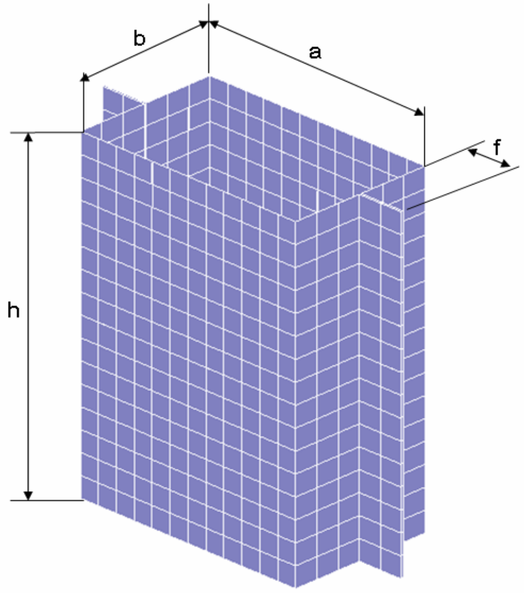
Simulation





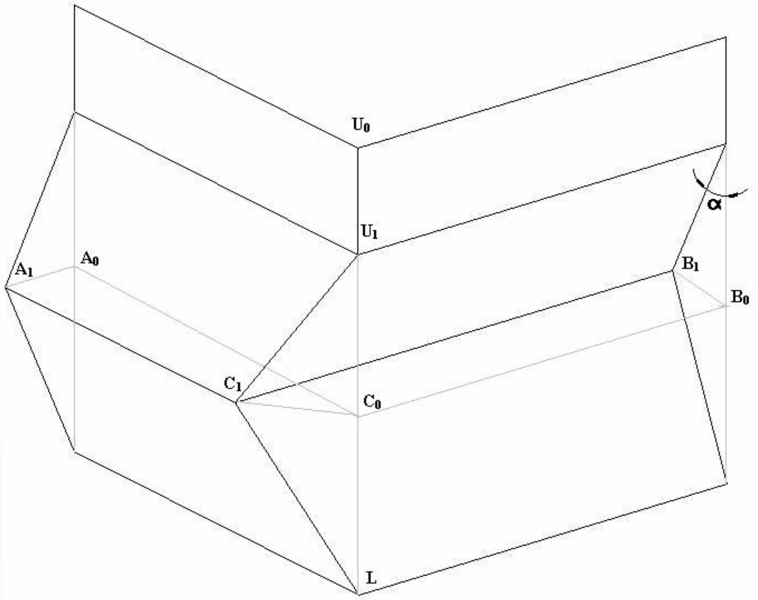
Simulation and experimental results are in good agreement





a=115, b=70, h=155, f=22.5, t=1.8

Rectangular tube & double-hat section



Asymmetric Superfolding Element

Asymmetric

Superfolding Element

Study from W. ABRAMOWICZ

Mean collapse force

$$P_m = \frac{t^2}{4}\left\{\sigma_0^{(1)} A_1 \frac{r}{t} + \sigma_0^{(2)} A_2 \frac{C}{H} + \sigma_0^{(3)} A_3 \frac{H}{r} + \sigma_0^{(4)} A_4 \frac{H}{t} + \sigma_0^{(5)} A_5\right\} \frac{2H}{\delta_e}$$

Study from H.F.Mahmood

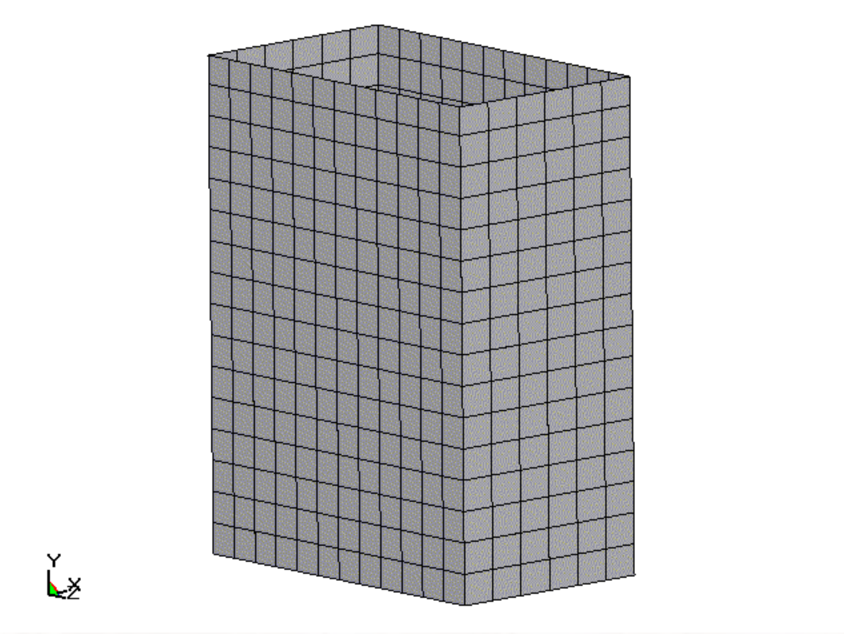
Rectangular section stability of collapse threshold

$$t/b < 0.48[\sigma_y(1-\nu^2)/E]^{1/2}$$

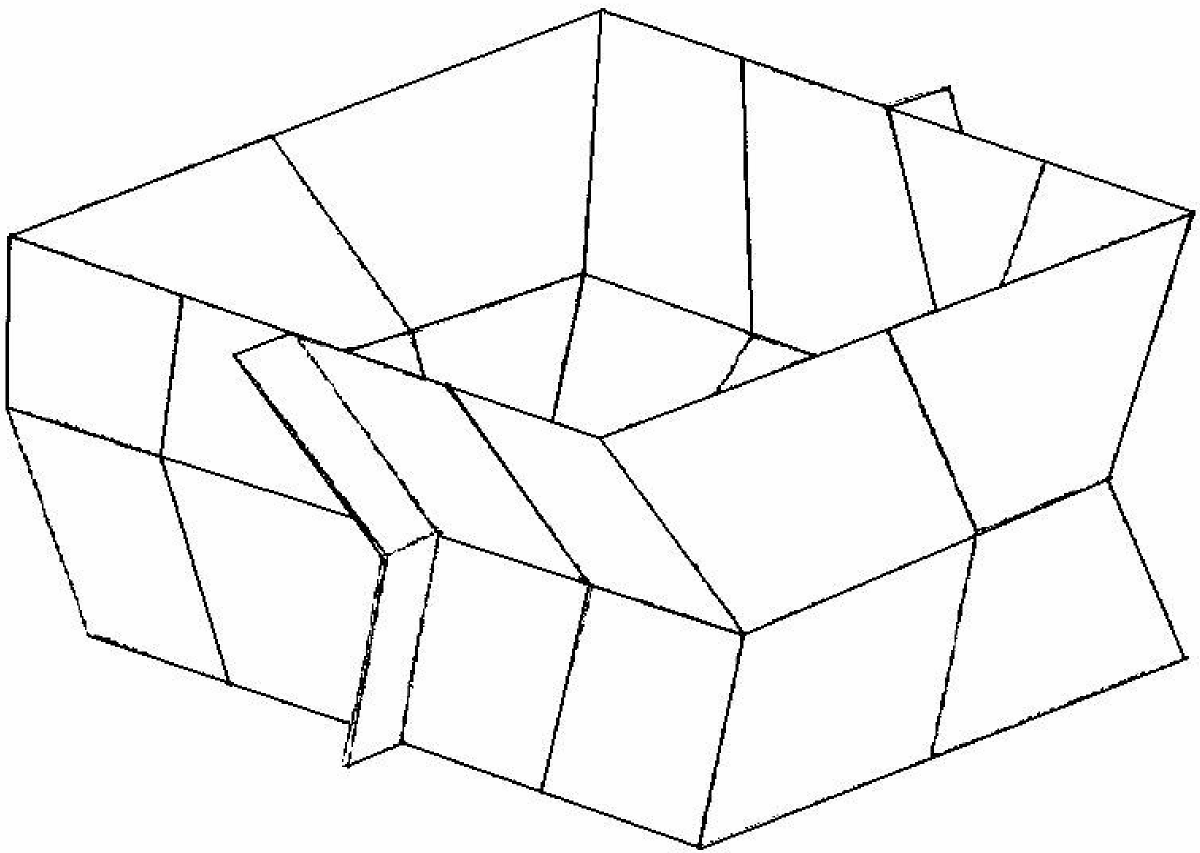
Rectangular section maximum crippling load

$$P_{max}=2[kpE/\beta(1-\nu^2)]^{0.43}\, t^{1.86}\, b^{0.14}\, \sigma_y^{0.57}$$

Axial Loading



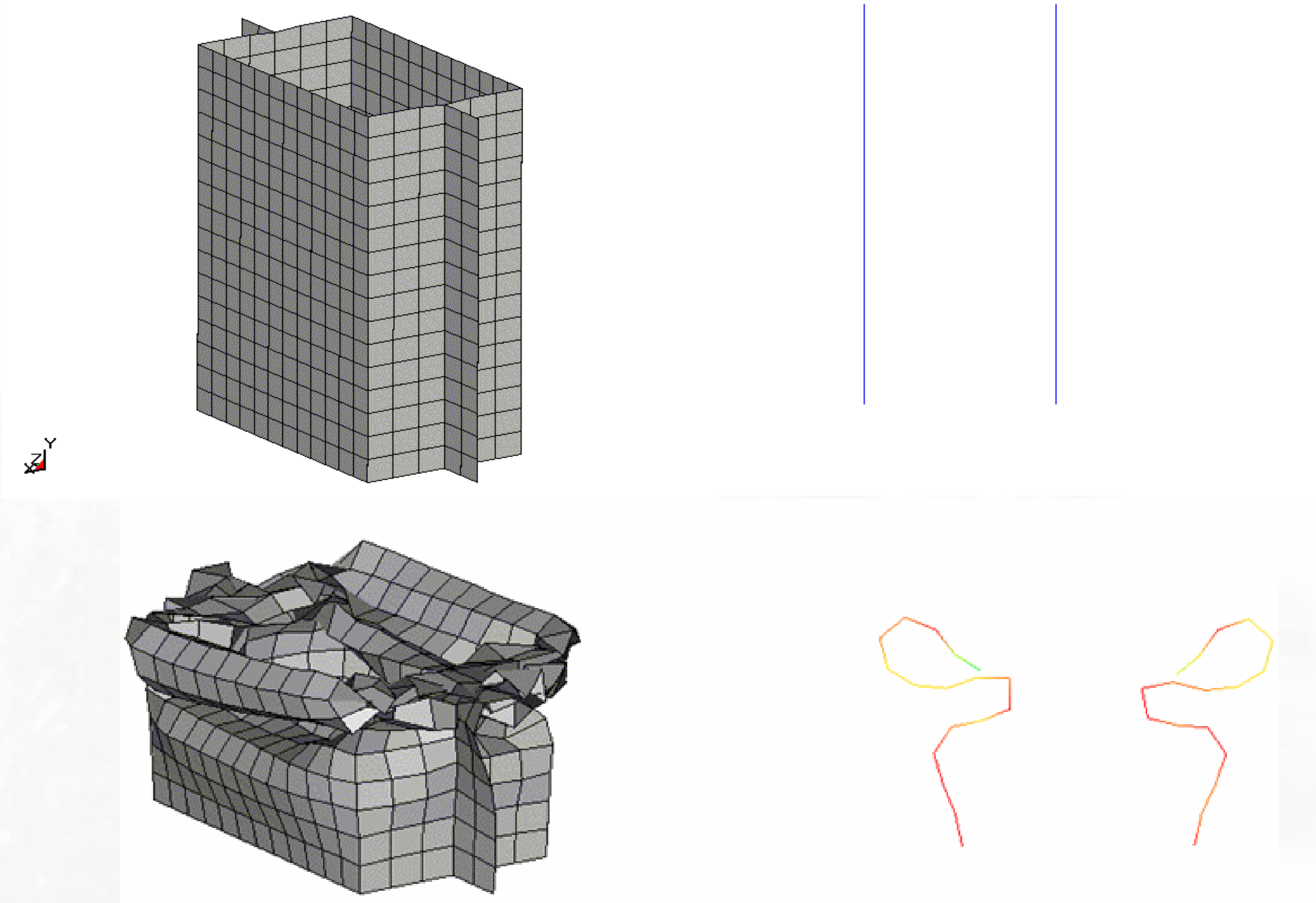
Progressive folding – rectangular tube FE simulation



Double-hat was considered consisting of eight Superfolding element

(M.D.White, N.Jones, W.Abramowicz)

Axial Loading



No spot welds considered (Rigid Joint) – idealized FE Model

Proper folding as assumed in the theoretical analysis

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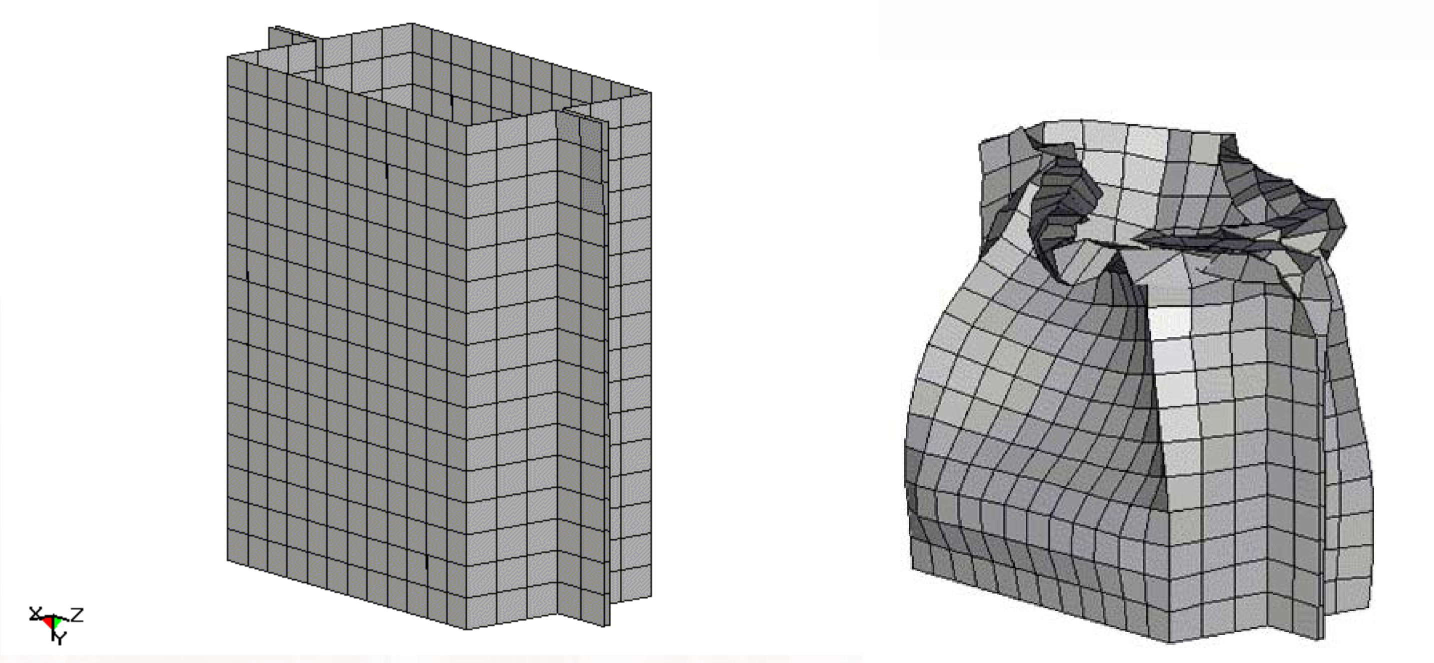
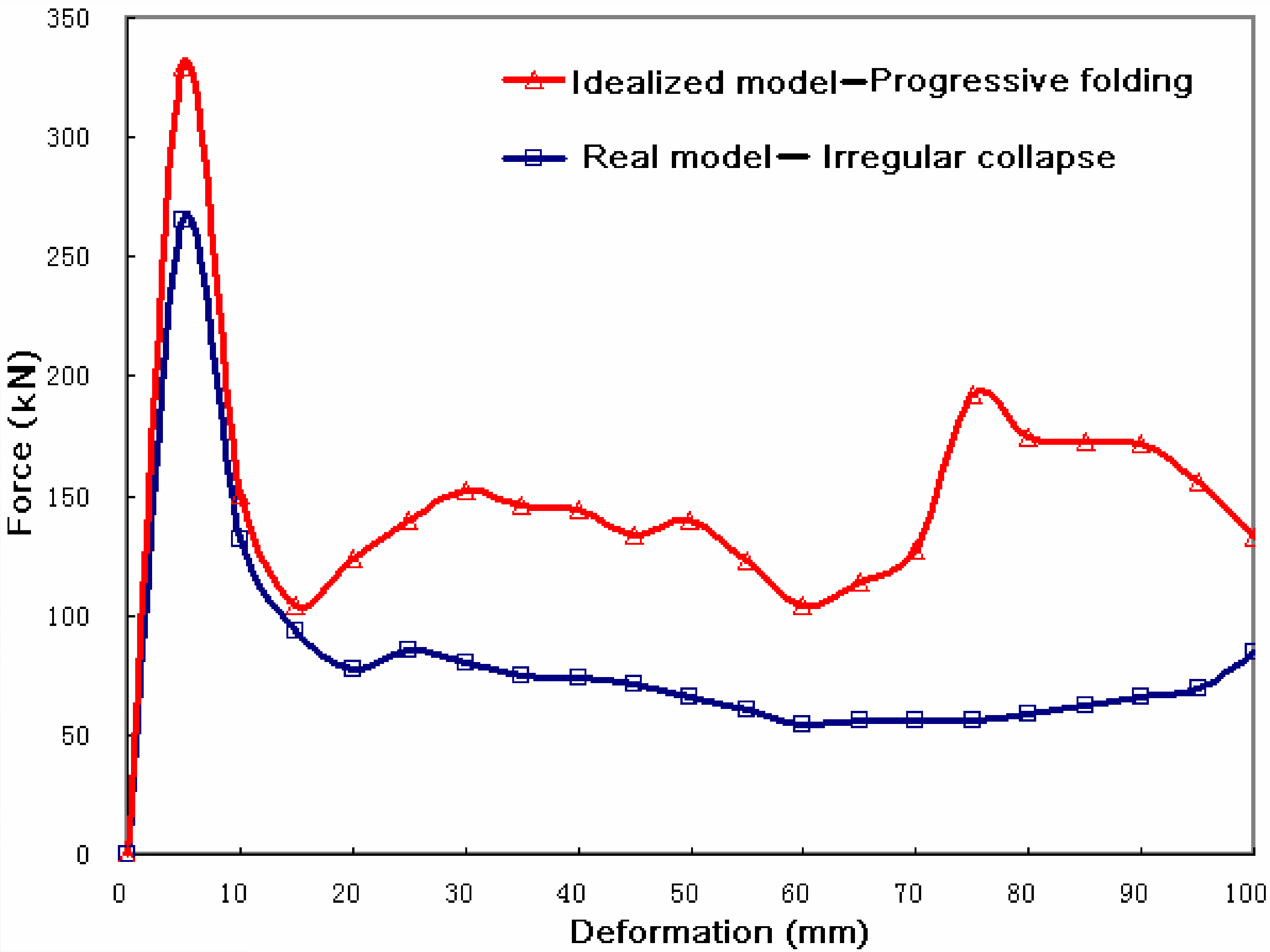
Axial Loading

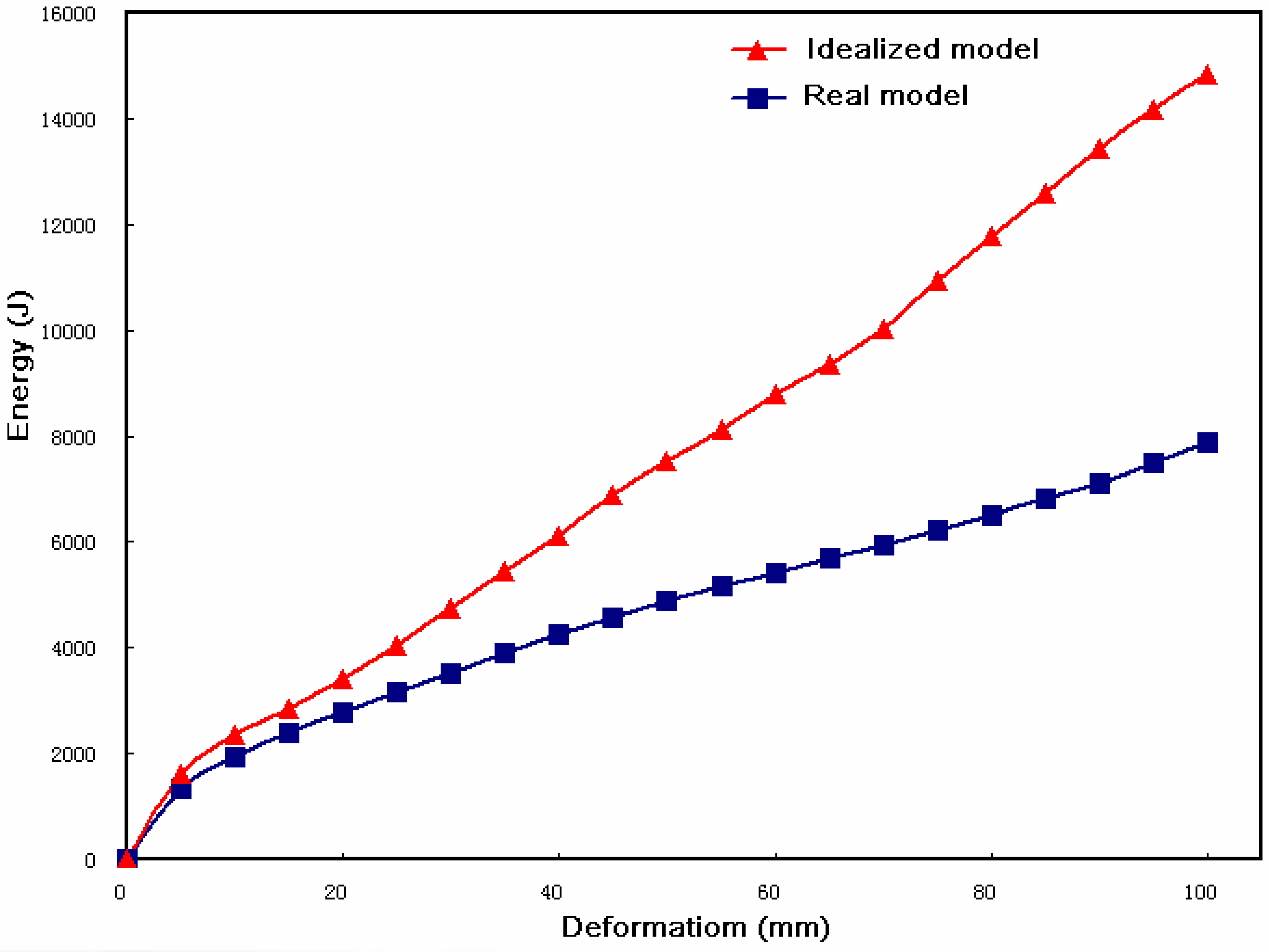


Spot welds considered similar to real structure

Irregular collapse was found in the simulation



Idealized model—Progressive folding
Real model— Irregular collapse
Force (kN)
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
Deformation (mm)


Idealized model
Real model
Energy (J)
Deformatiom (mm)
16000
14000
12000
10000
8000
6000
4000
2000
0
0
20
40
60
80
100

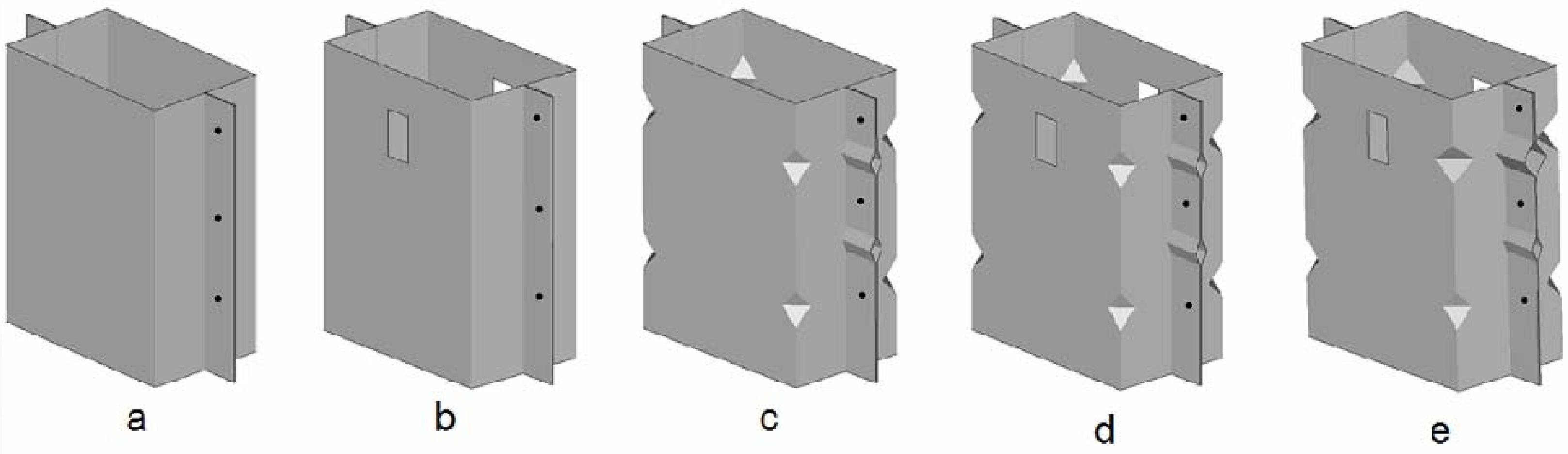
Cause of irregular collapse

- Geometrical parameter width-thickness ratio out of allowable limits
- Geometrical parameter length-thickness ratio allowing longer folder lengths that are inefficient in absorbing energy
- Material properties
- Overall component geometric design not optimised
- Discontinuous features
- Oblique loading
- ….

Solutions

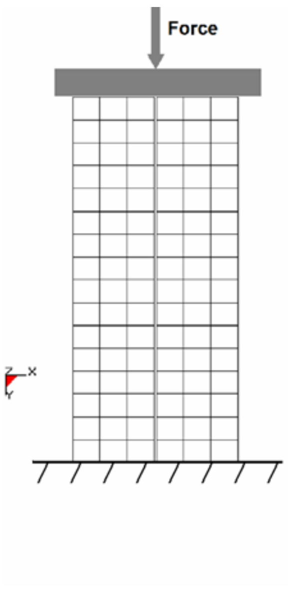
Improving structural geometrical design to:

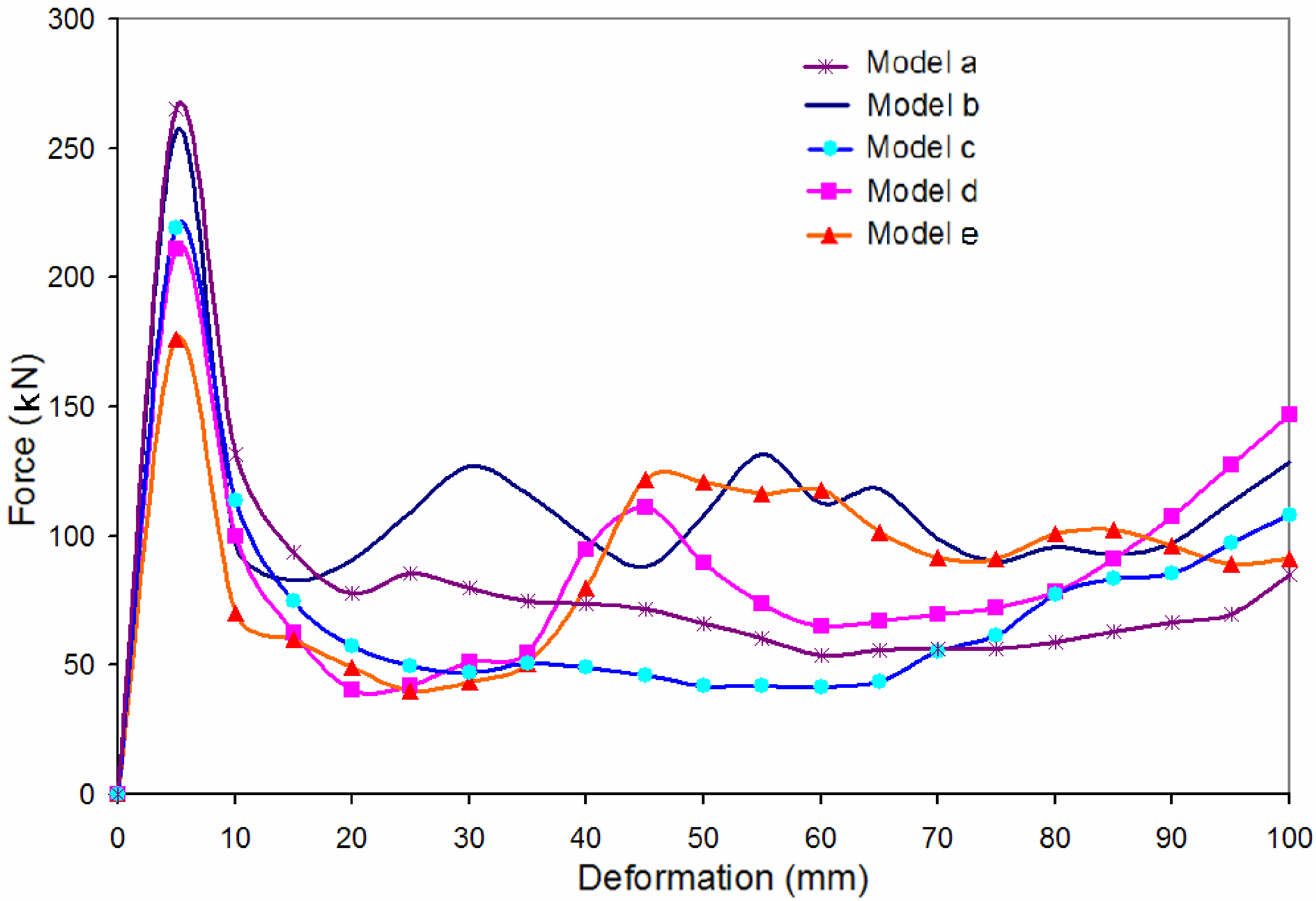
- **Make progressive folding**
- **Stable collapse**
- **Reduce peak force**
- **Maximise energy absorption capability**



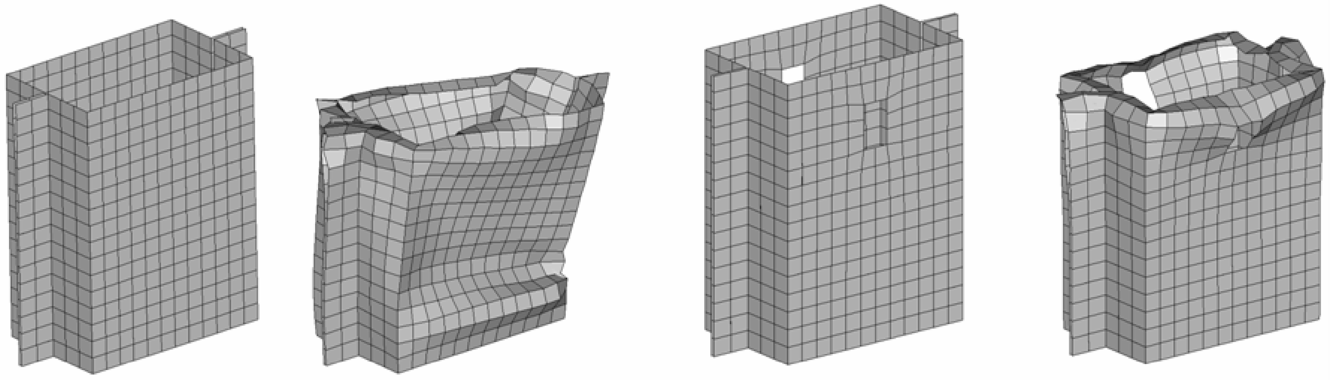
Model a: simple double-hat structure
Model b: simple double-hat structure with holes on each side
Model c: constant trigger dent design at corners and flanges
Model d: constant trigger dent design at corners and flanges with holes on each side
Model e: varied trigger dent design at corners and flanges with holes on each side

All models have same width, length, thickness and spot welds location. Fixed bottom and free on top side.

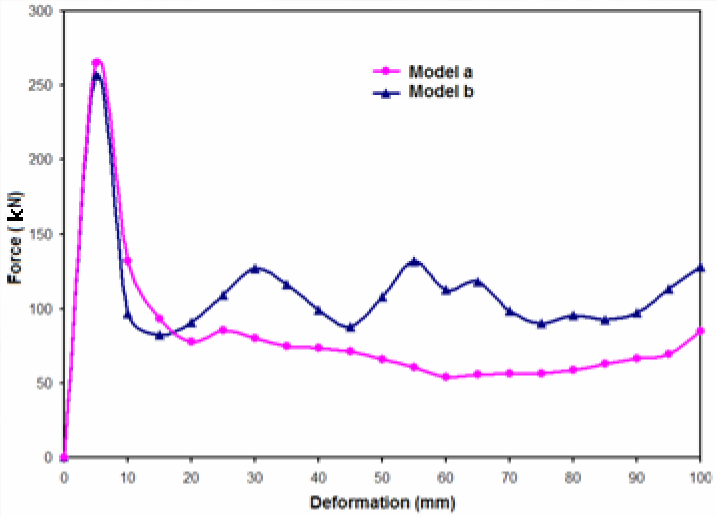


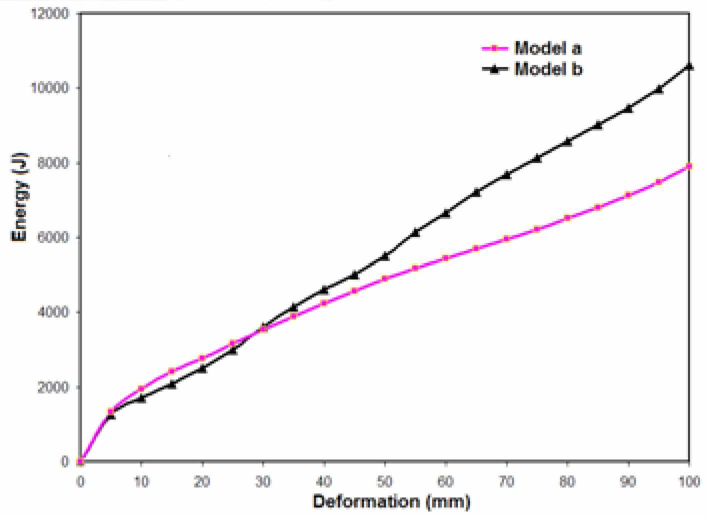


FE simulation results: Force-Deformation curve

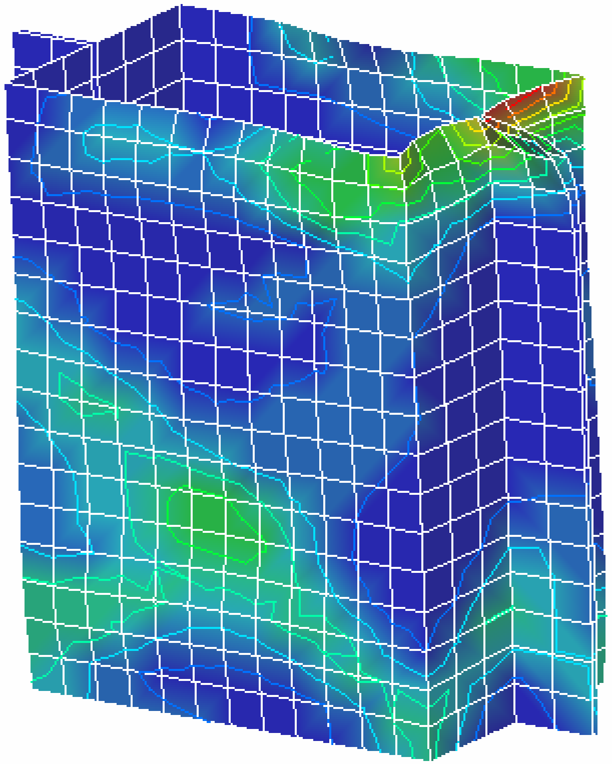


a b

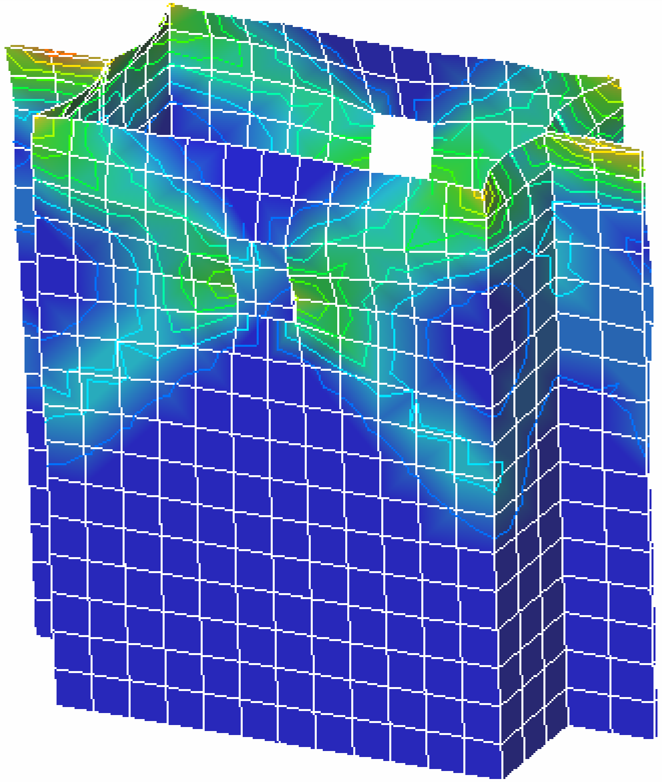




Irregular collapse vs. progressive folding

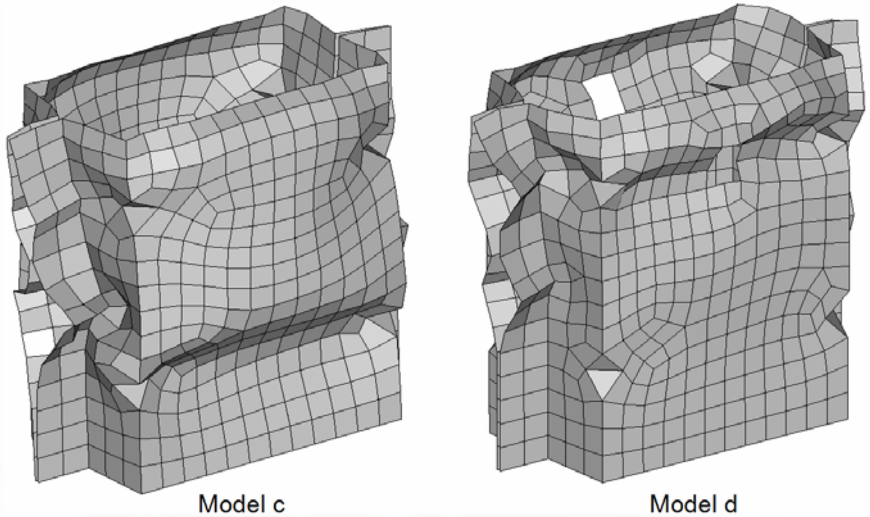


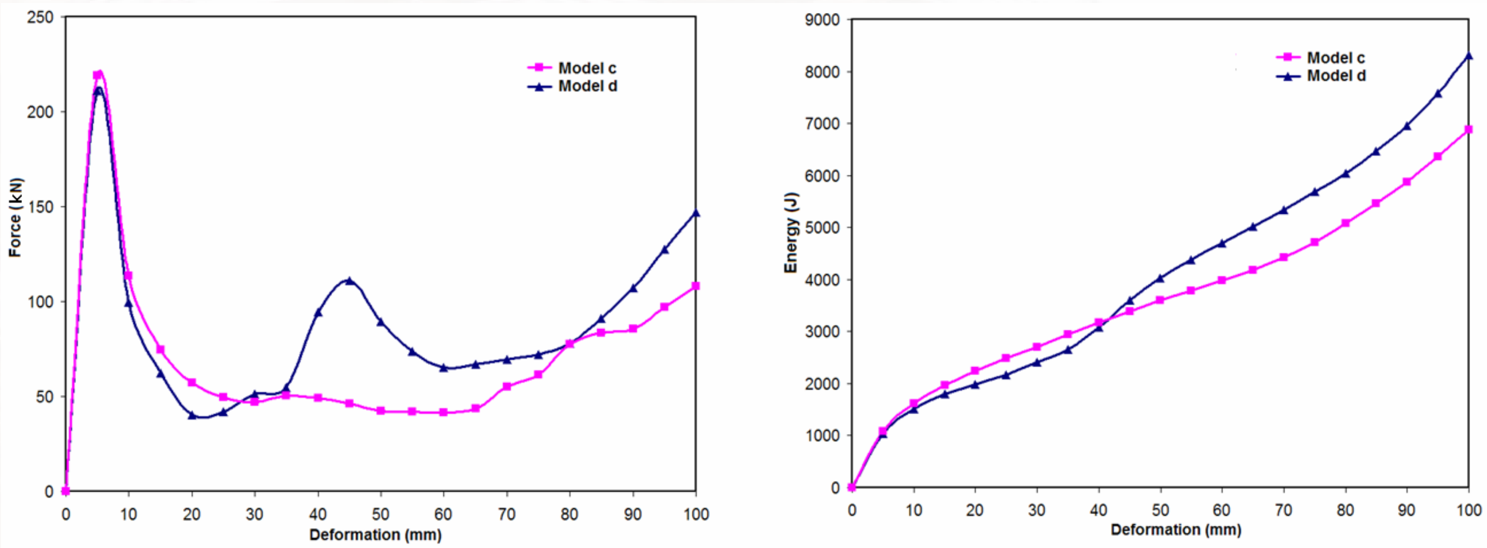
Model a



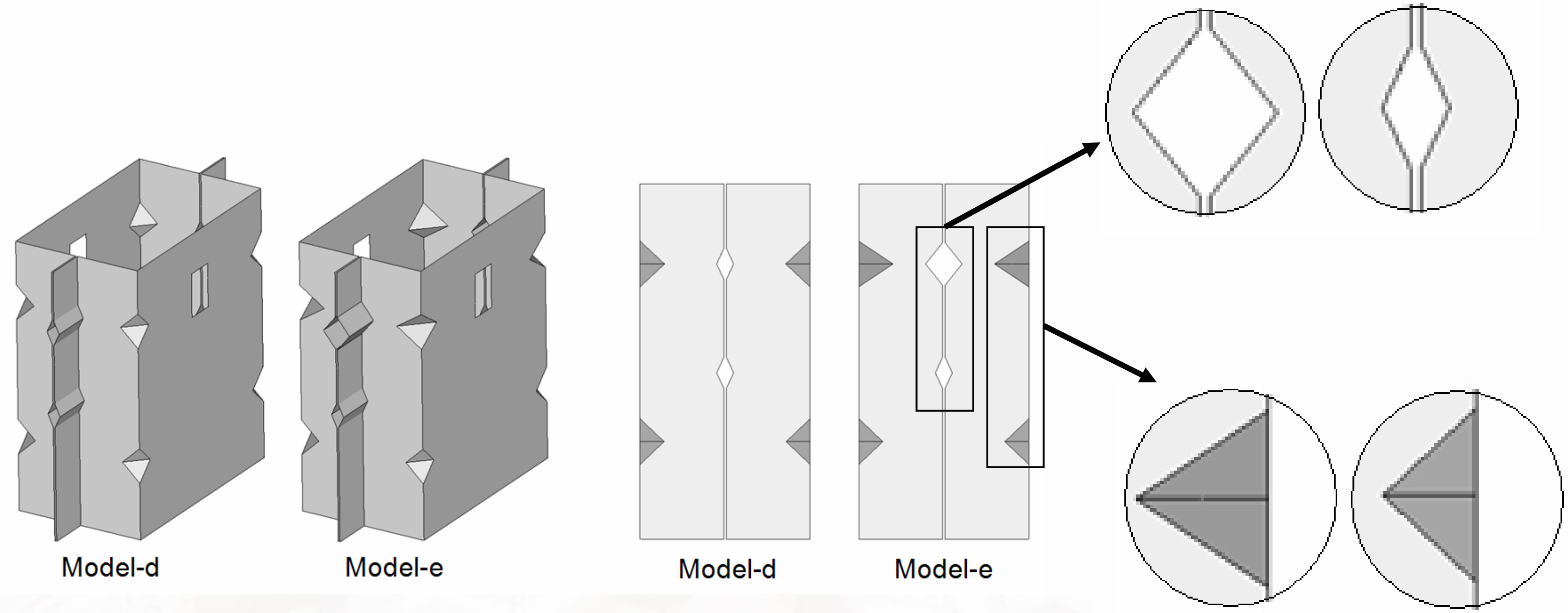
Model b

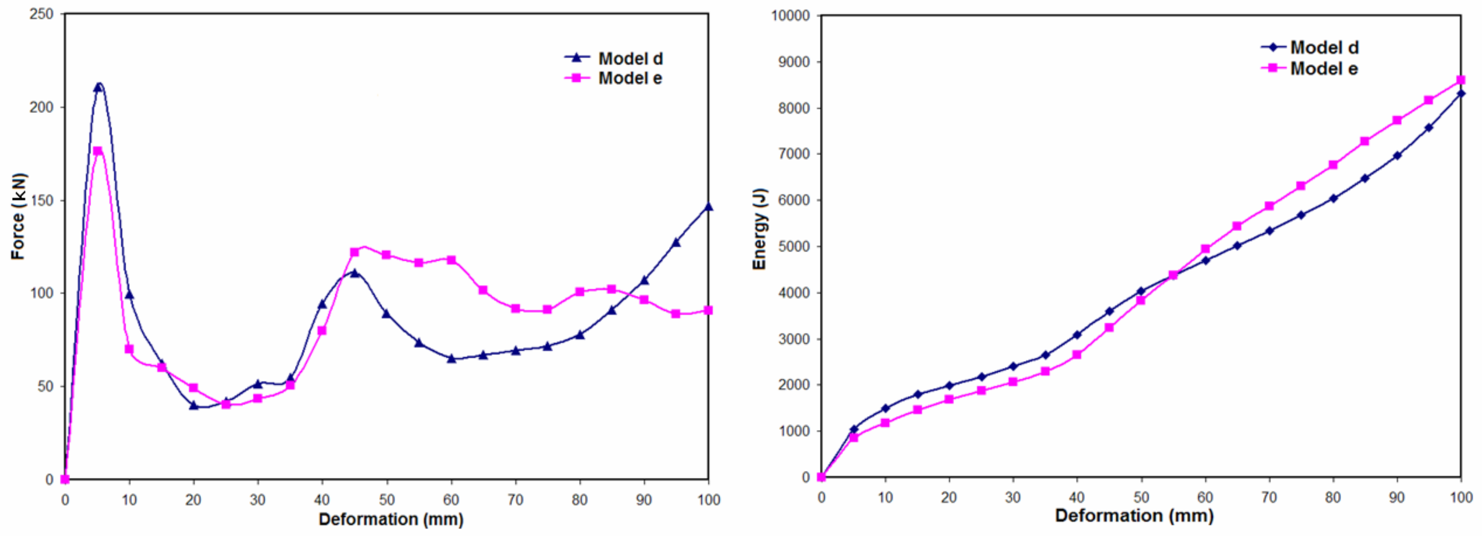
Irregular collapse vs. progressive folding



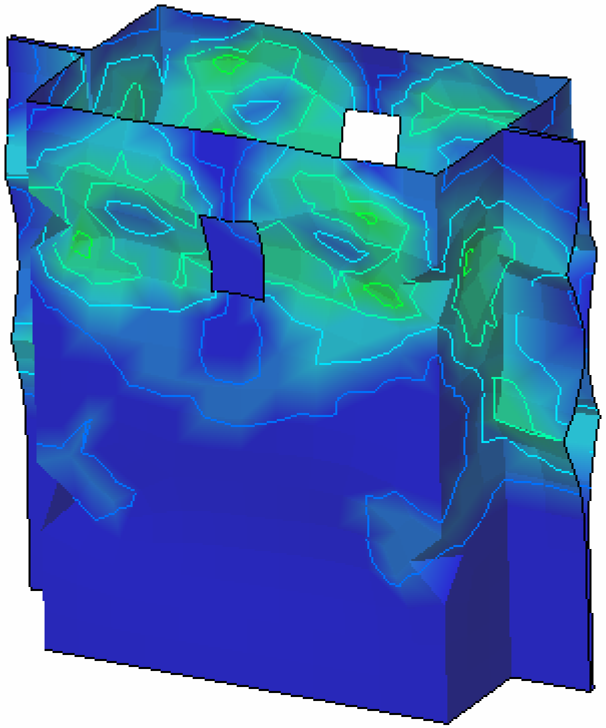


Triggered points and their collapse sequence different for model c & d – affecting performance

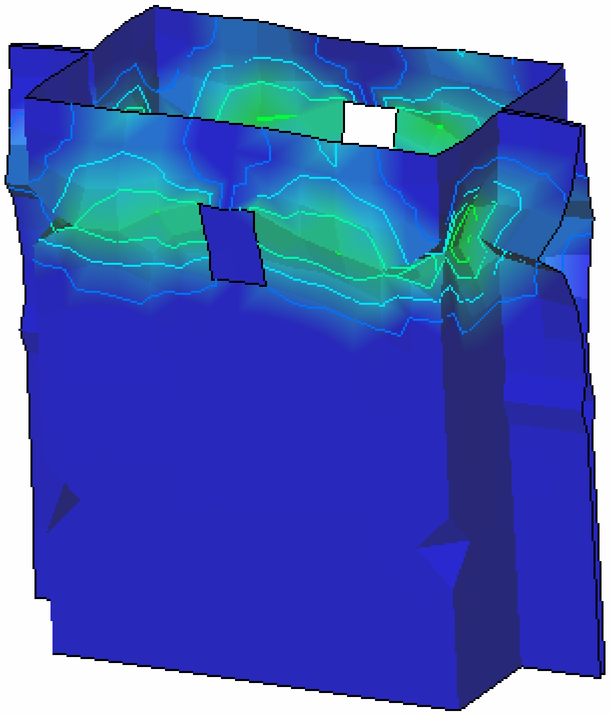




Comparison between constant and varied trigger dent design



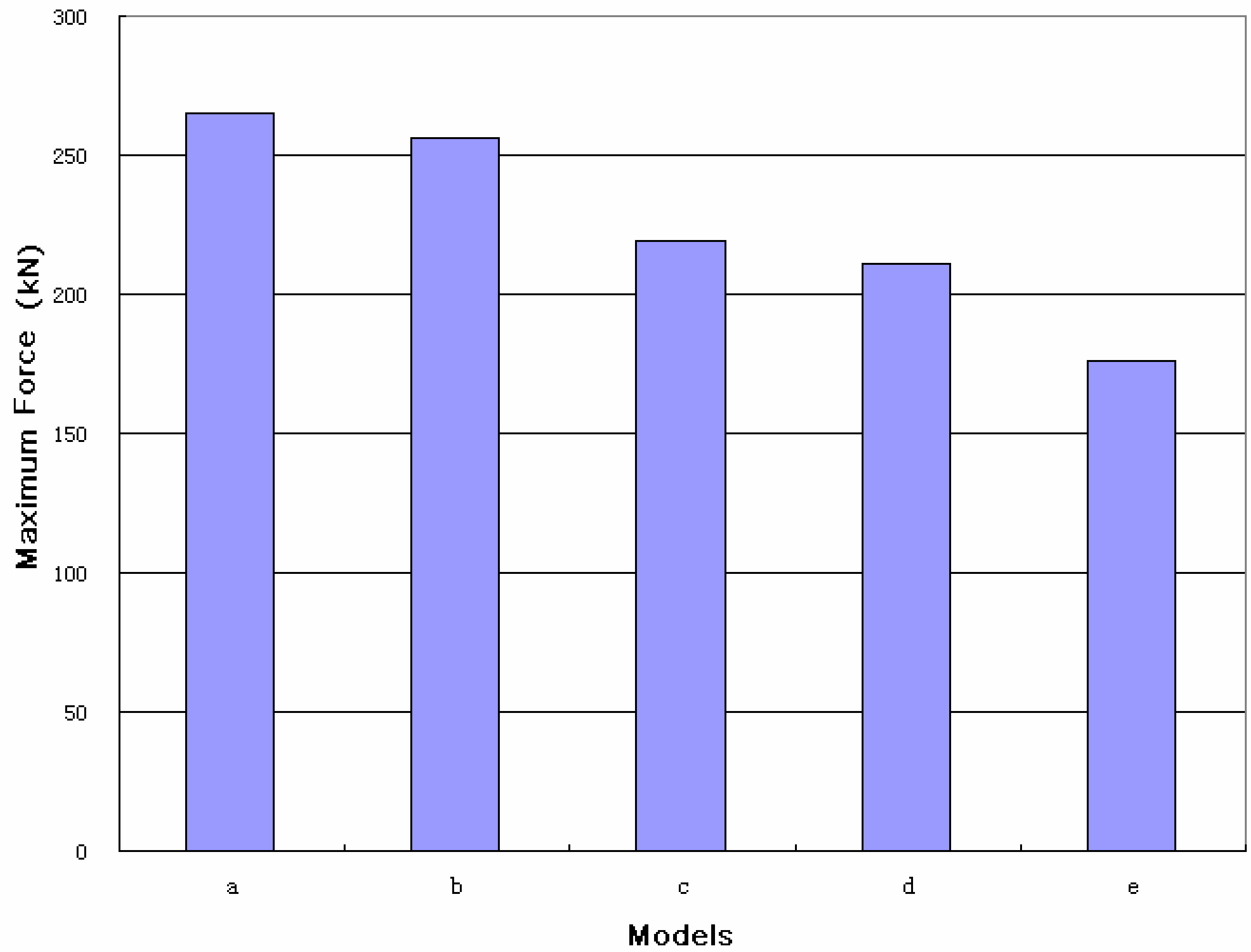
Model d



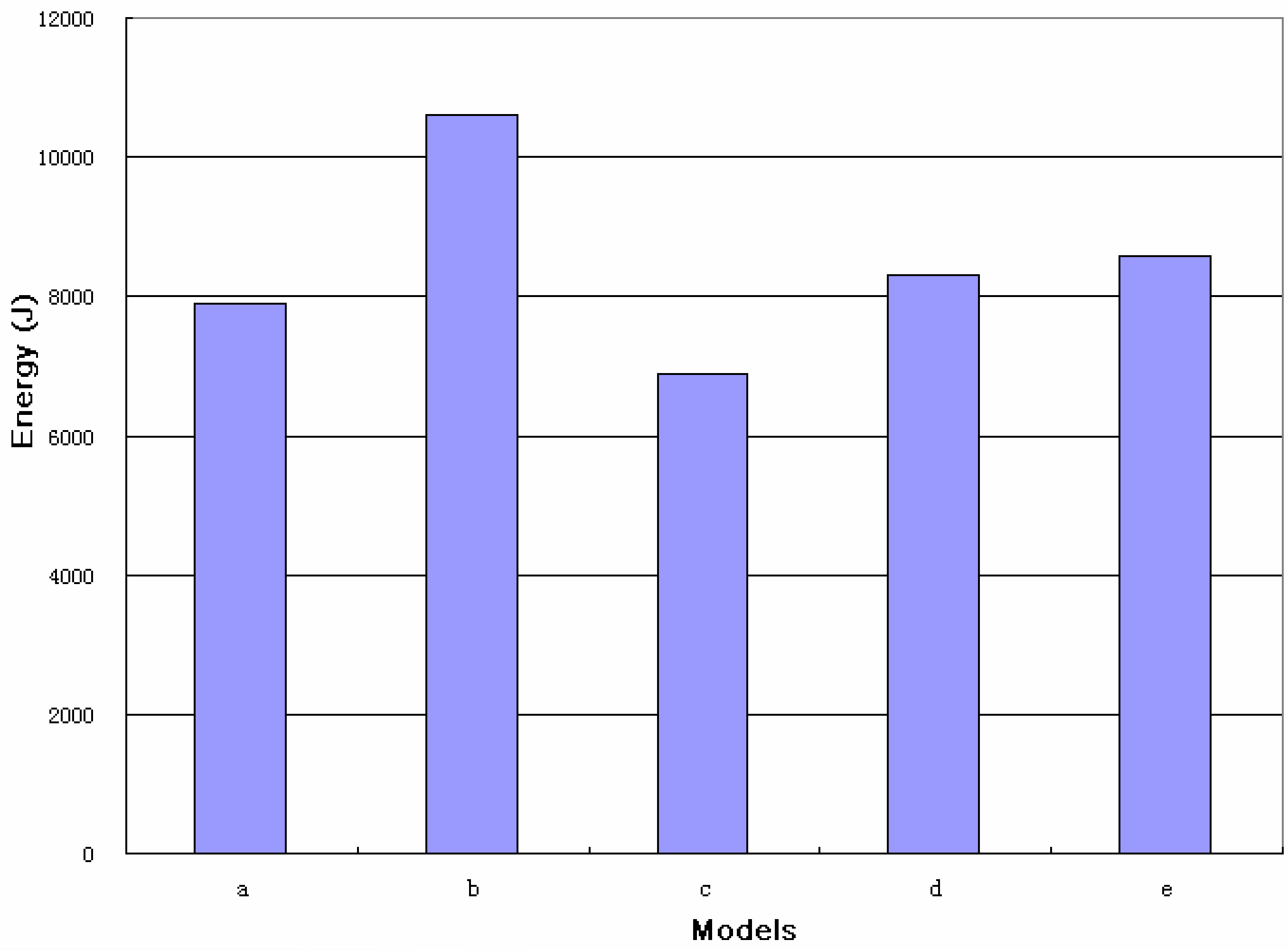
Model e

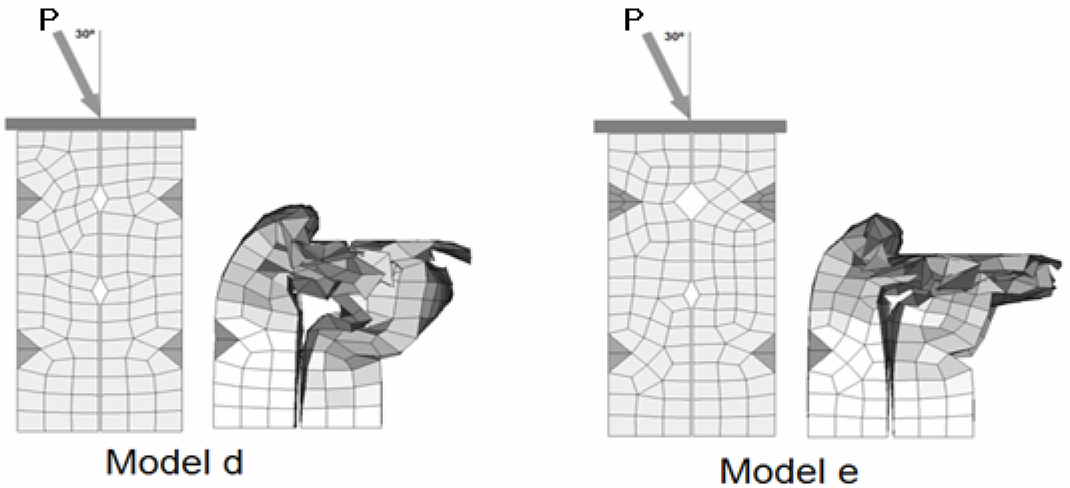
Progressive folding more easily in model e

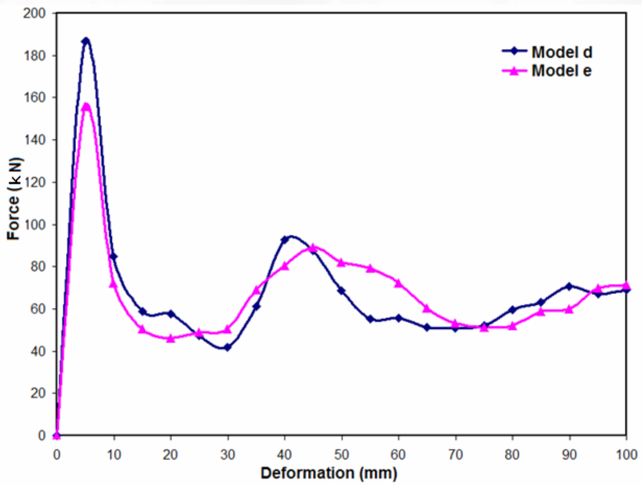
Peak force comparison for all models

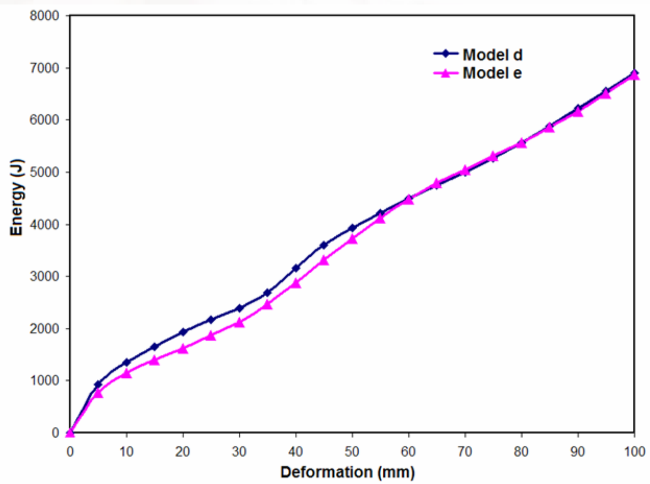


Energy comparison for all models









oblique loading of the side member structure

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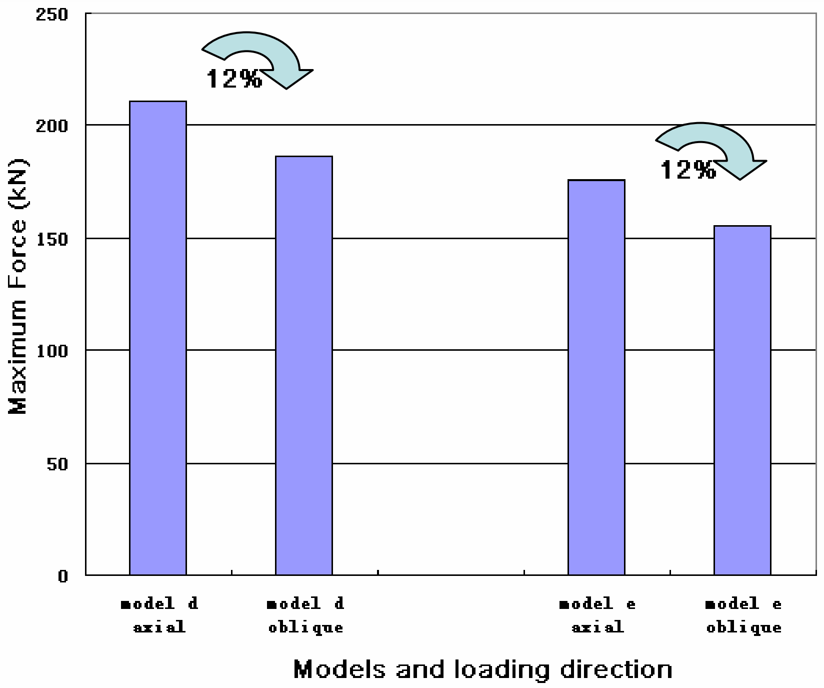
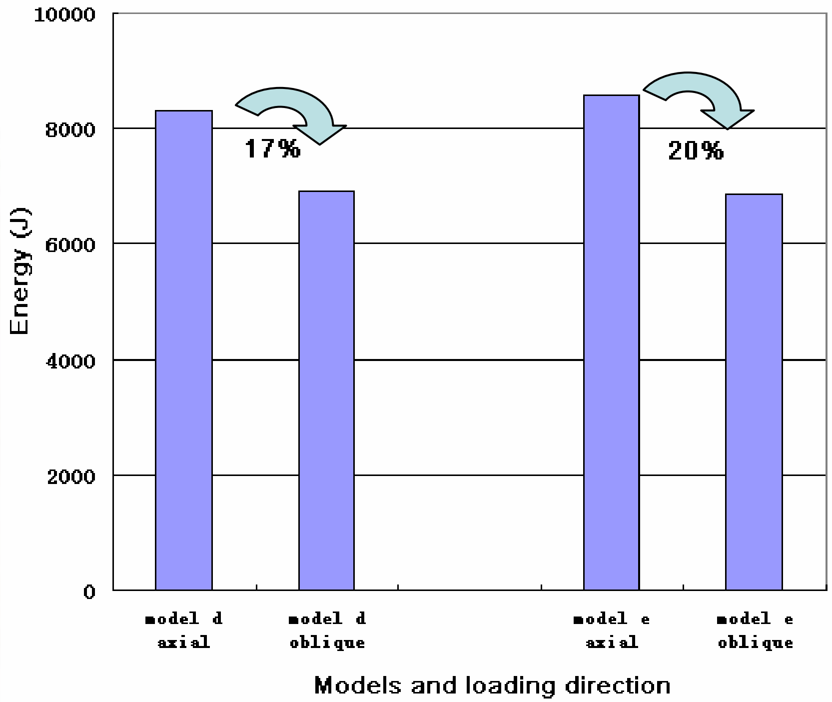
Force and Energy comparison for axial and oblique loading

Model d & e





Conclusions

- Theoretical analysis method could be a useful tool in the prototype design stage to make quick decision on the overall size and energy absorption capability of the structure
- Axial progressive collapse mode of the structure maximise energy absorption capability
- Detailed feature employment of imperfections and trigger points of the structure could play important role in the collapse mode and impact performance. Spot welds location and surface contact should be considered in the structural analysis
- Structure geometric optimisation results in desired deformation modes and their possible sequence, so as to maximise the energy absorption capability and hence improve the impact performance
- Numerical simulation could be a good tool to evaluate structures and their optimisation in structural design

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