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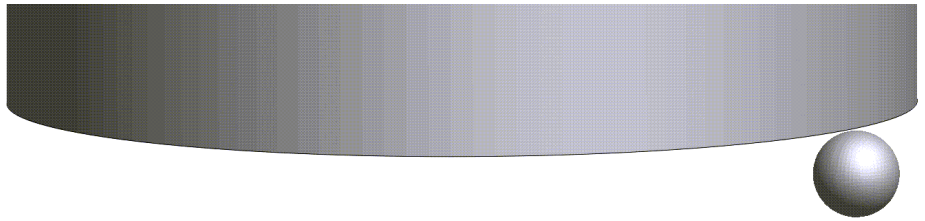
Ørsted

Monopile damage assessment from impact with a sub-sea boulder

Using an LS-DYNA methodology



David McLennan

Presented by **Francois Lancelot**

Who are Ørsted?

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Ørsted

- Danish multinational energy company
- Energy produced: 90% from renewable sources
- Offshore wind farms: built more than any other company

Arup's partnership with Ørsted

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Ørsted

- LS-DYNA analysis and design consultancy
- Installation of offshore wind turbine monopile (MP) foundations

Arup's partnership with Ørsted

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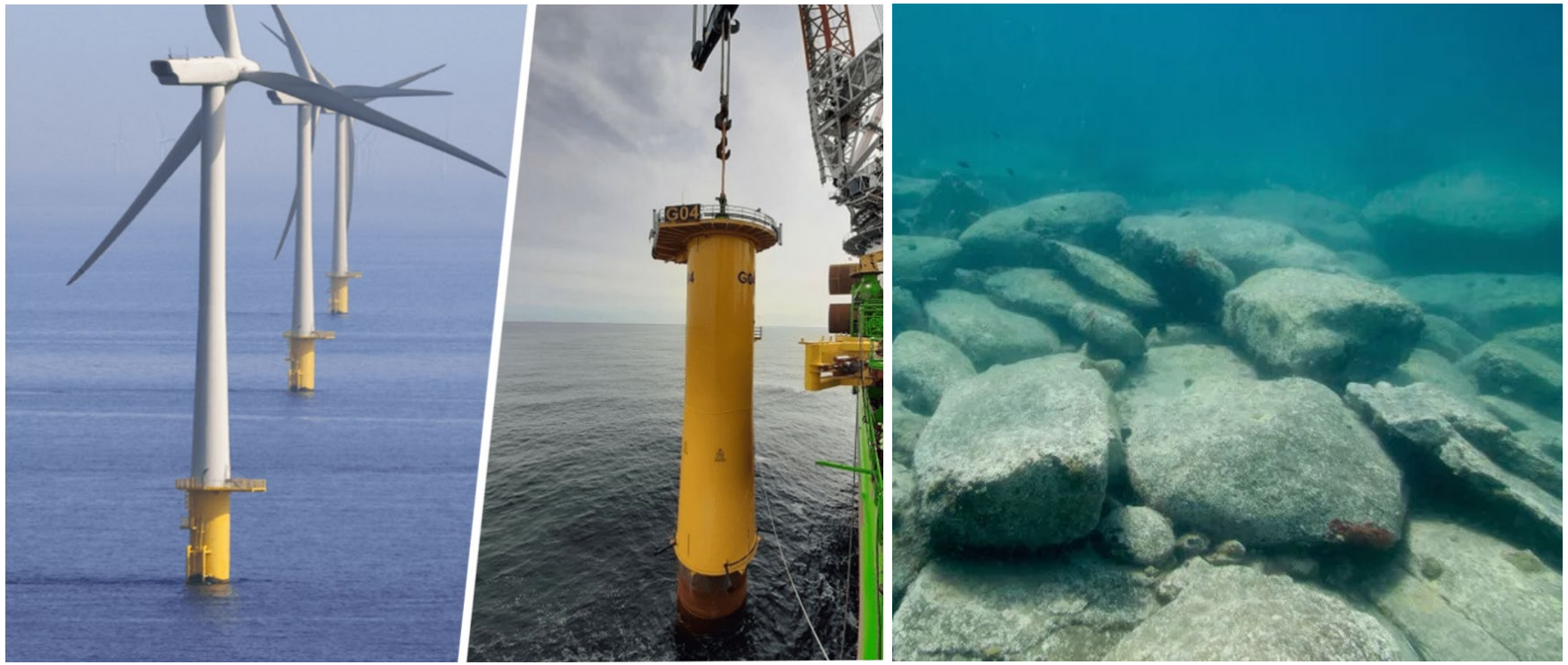
Ørsted

- LS-DYNA analysis and design consultancy
- Installation of offshore wind turbine monopile (MP) foundations
- **To quantify the risk of MP damage due to subsea boulder impact**



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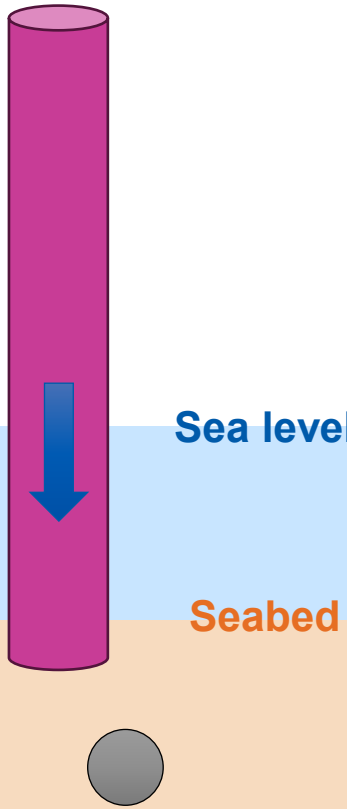

1) MP installation begins (unknown boulder location and size)

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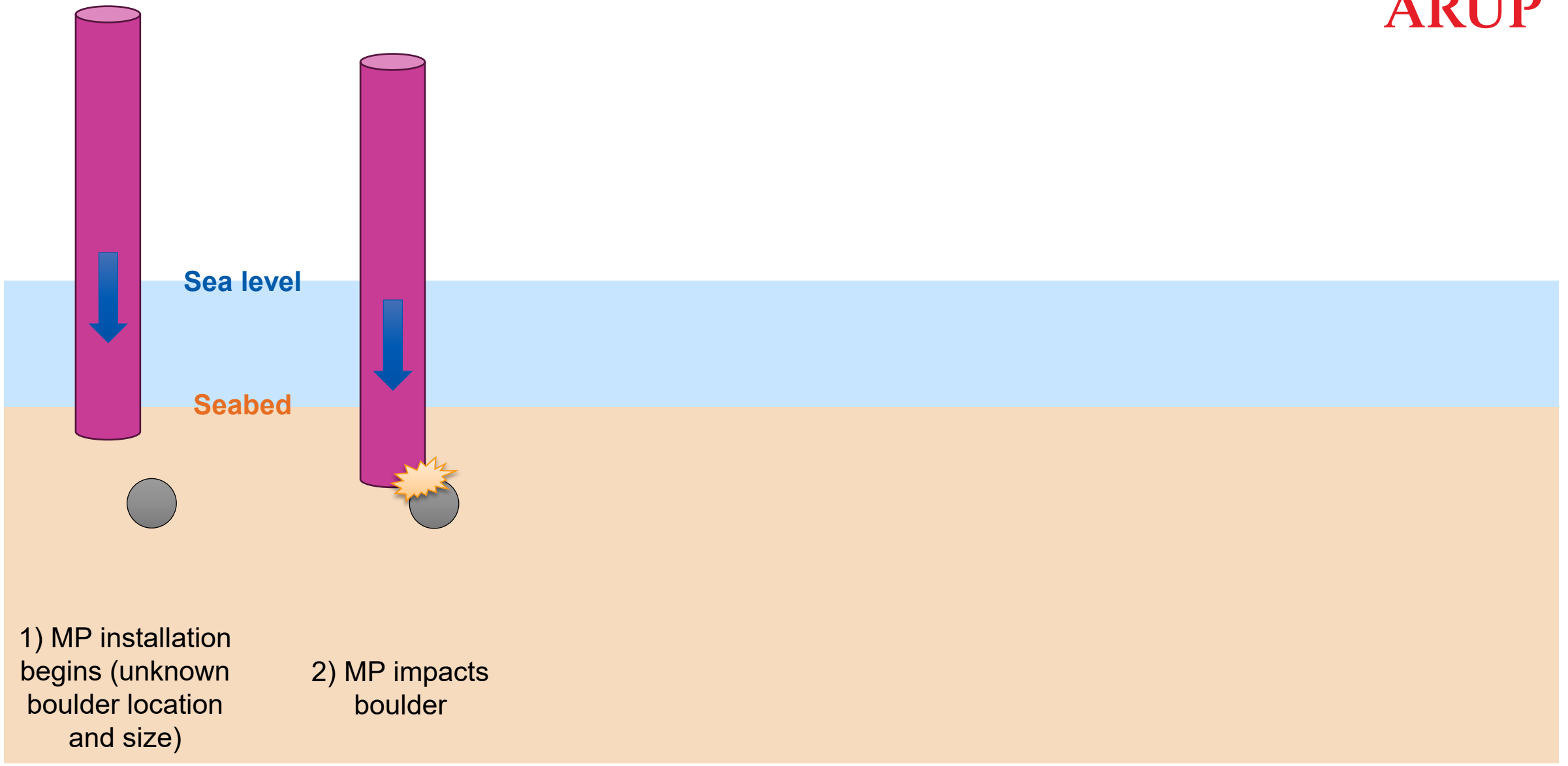

1) MP installation begins (unknown boulder location and size)

2) MP impacts boulder

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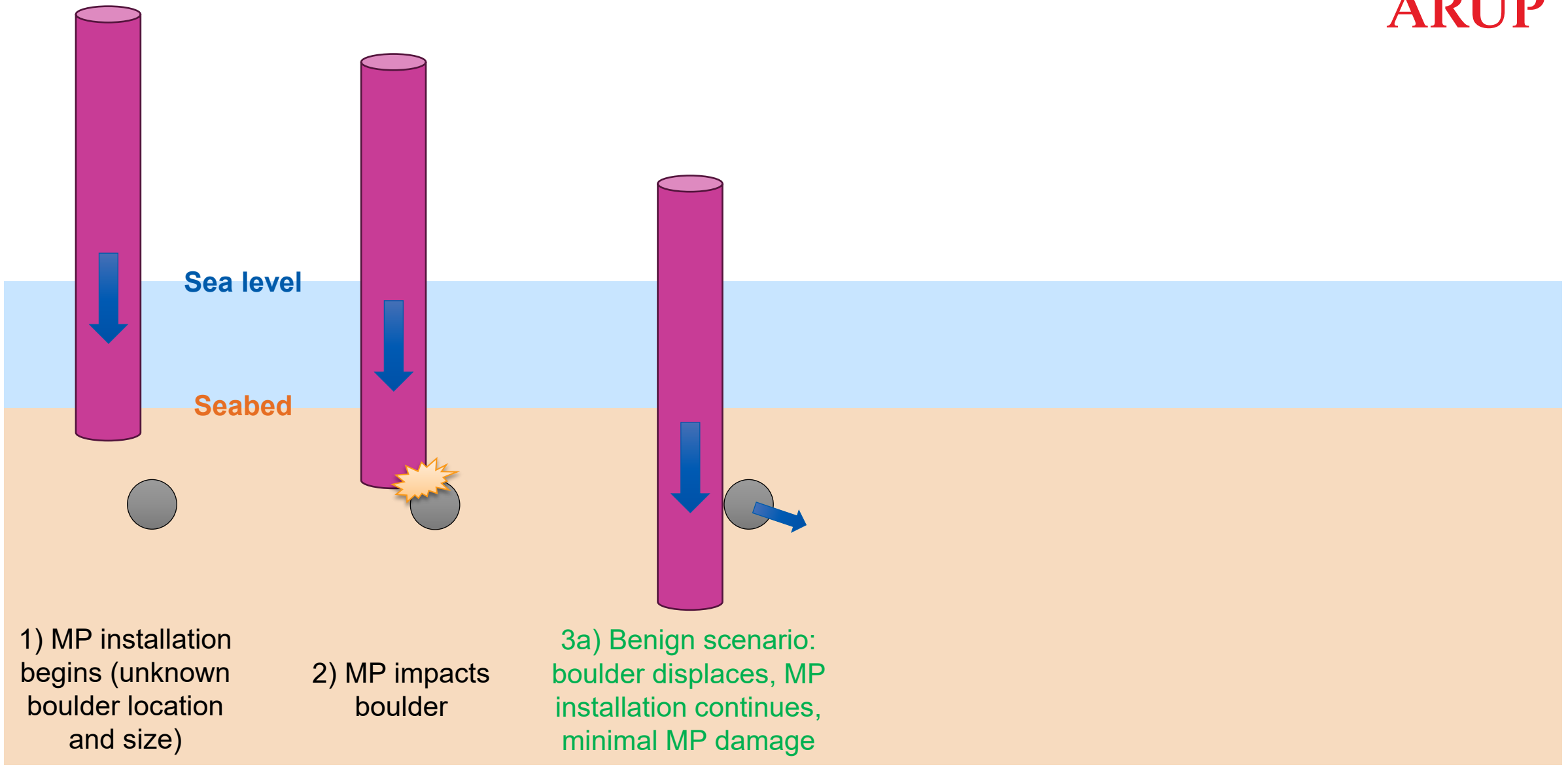

1) MP installation begins (unknown boulder location and size)

2) MP impacts boulder

3a) Benign scenario: boulder displaces, MP installation continues, minimal MP damage

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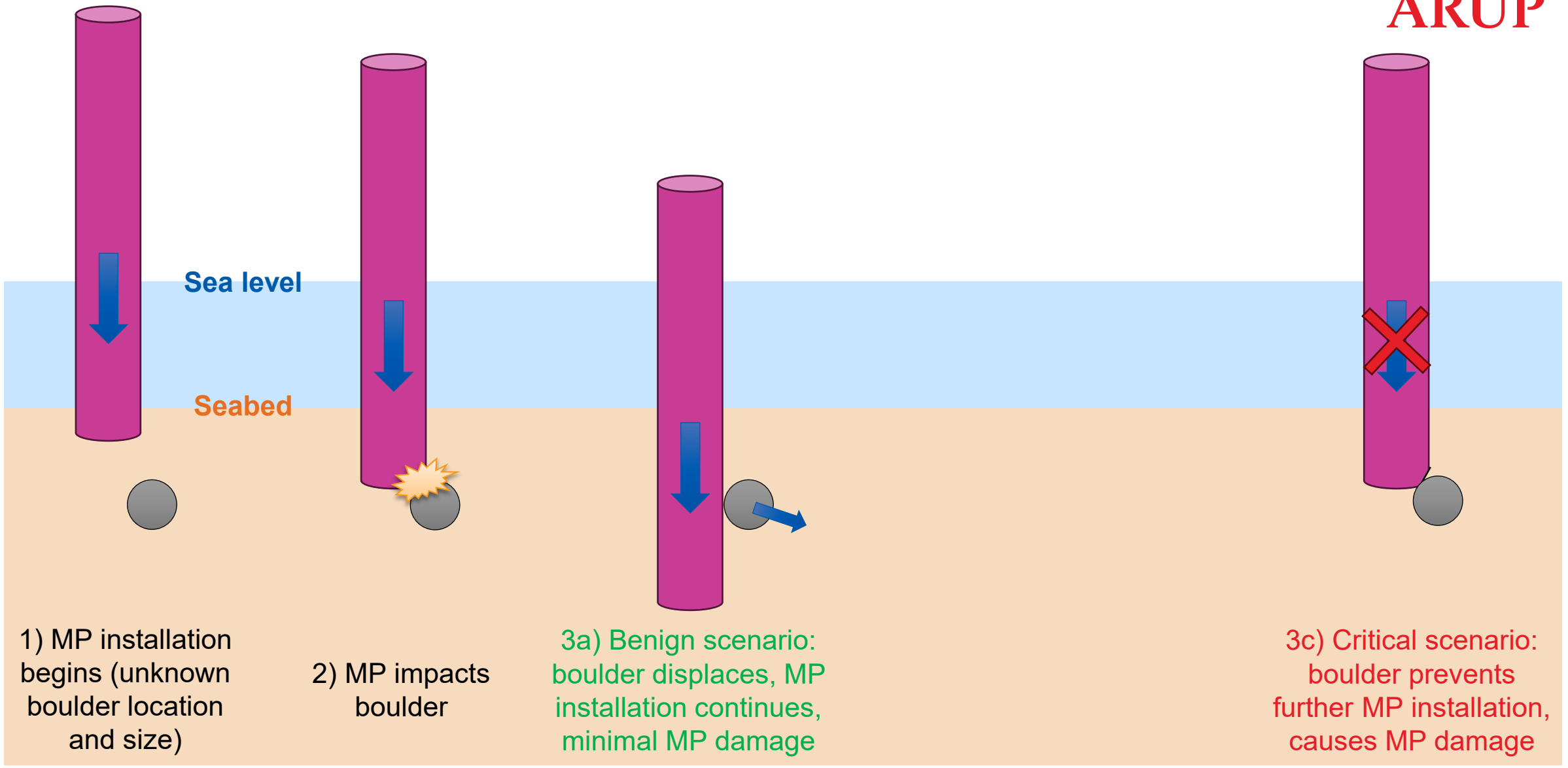

1) MP installation begins (unknown boulder location and size)

2) MP impacts boulder

3a) Benign scenario: boulder displaces, MP installation continues, minimal MP damage

3c) Critical scenario: boulder prevents further MP installation, causes MP damage

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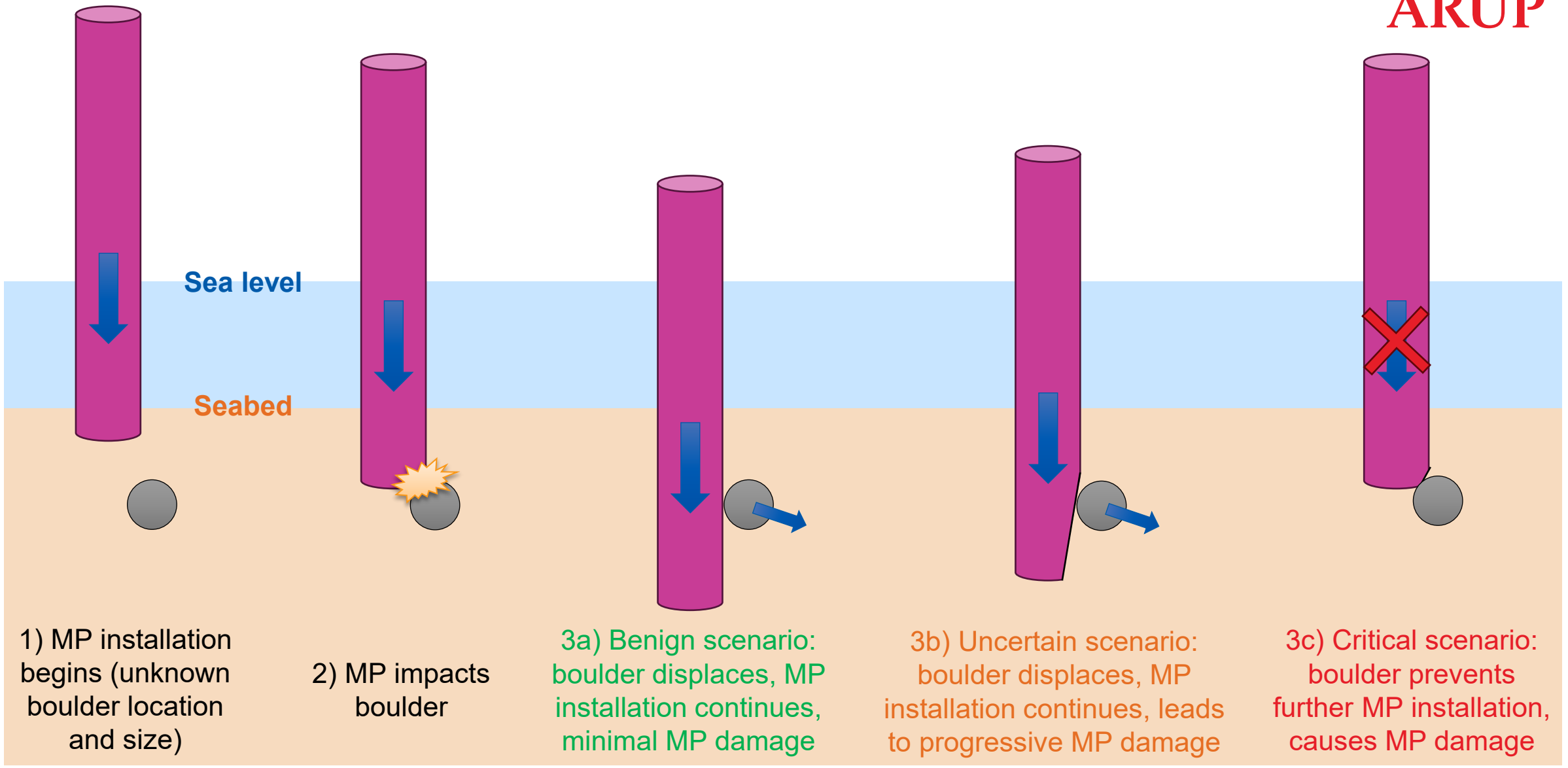

1) MP installation begins (unknown boulder location and size)

2) MP impacts boulder

3a) Benign scenario: boulder displaces, MP installation continues, minimal MP damage

3b) Uncertain scenario: boulder displaces, MP installation continues, leads to progressive MP damage

3c) Critical scenario: boulder prevents further MP installation, causes MP damage

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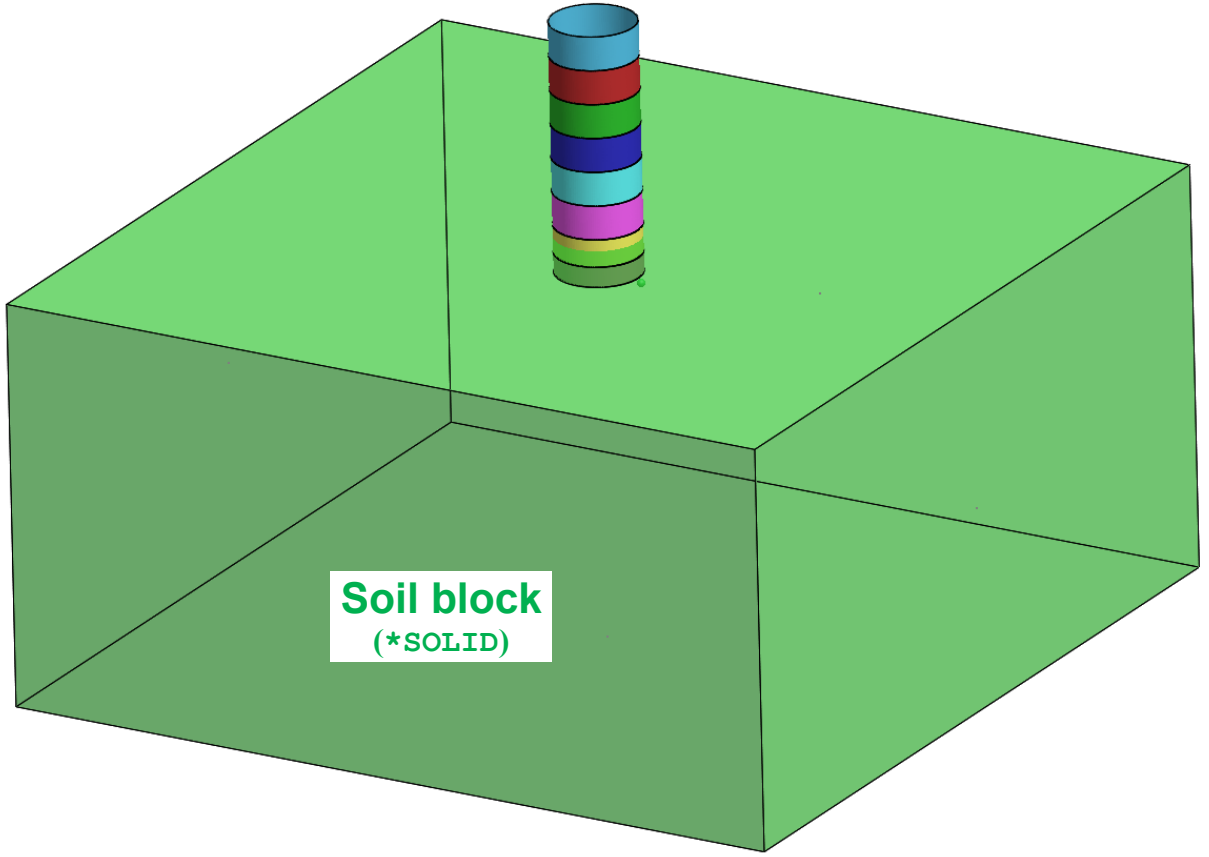
LS-DYNA modelling



Traditional approach (large model, slow to analyse)
~100 million elements

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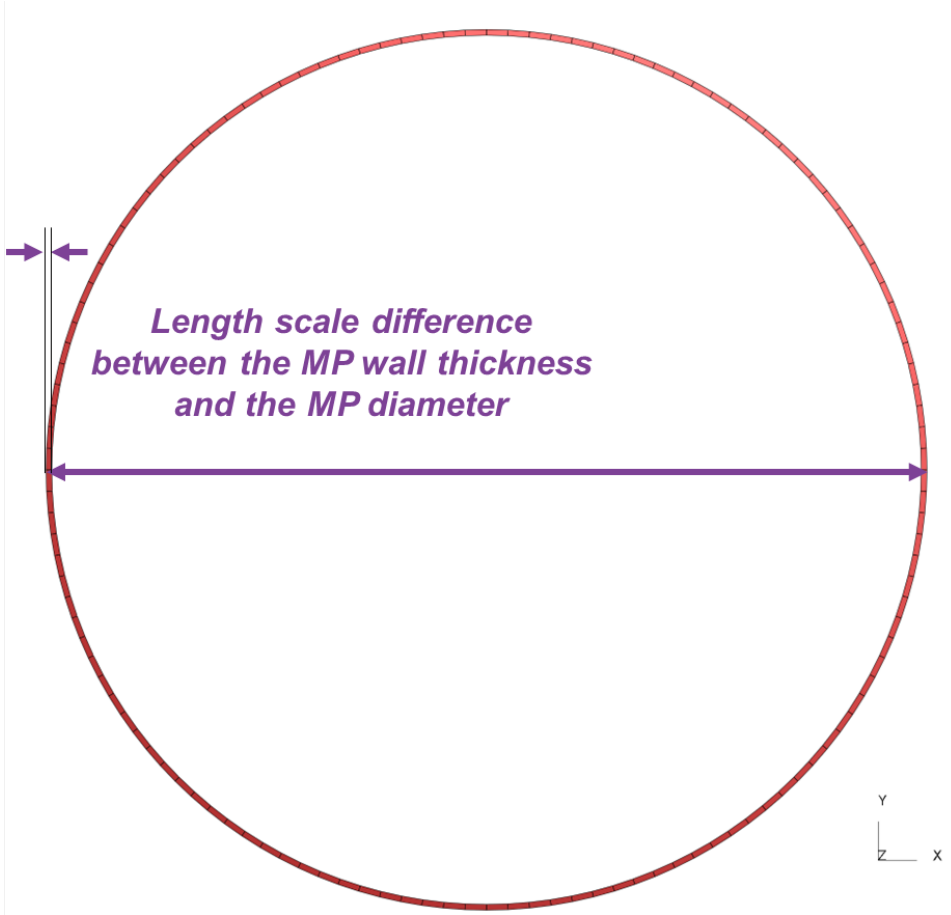
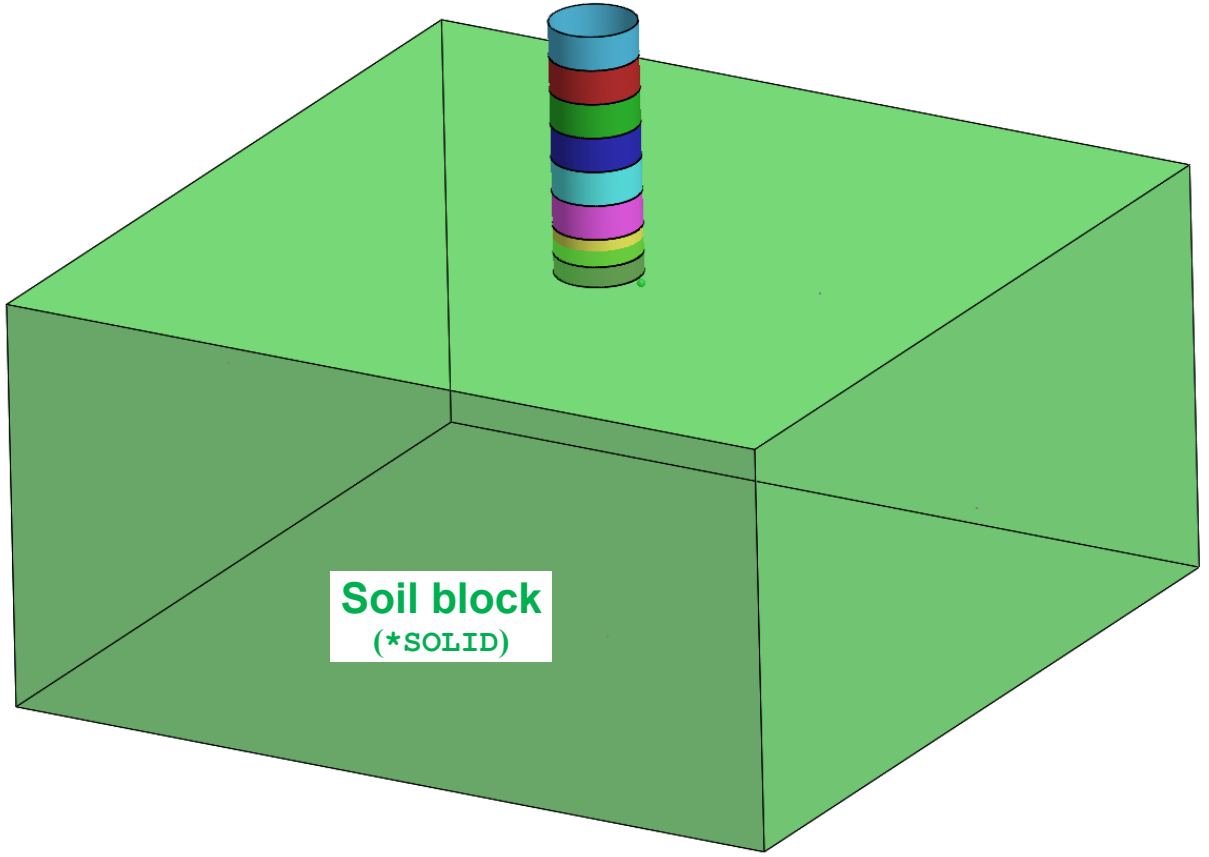
LS-DYNA modelling





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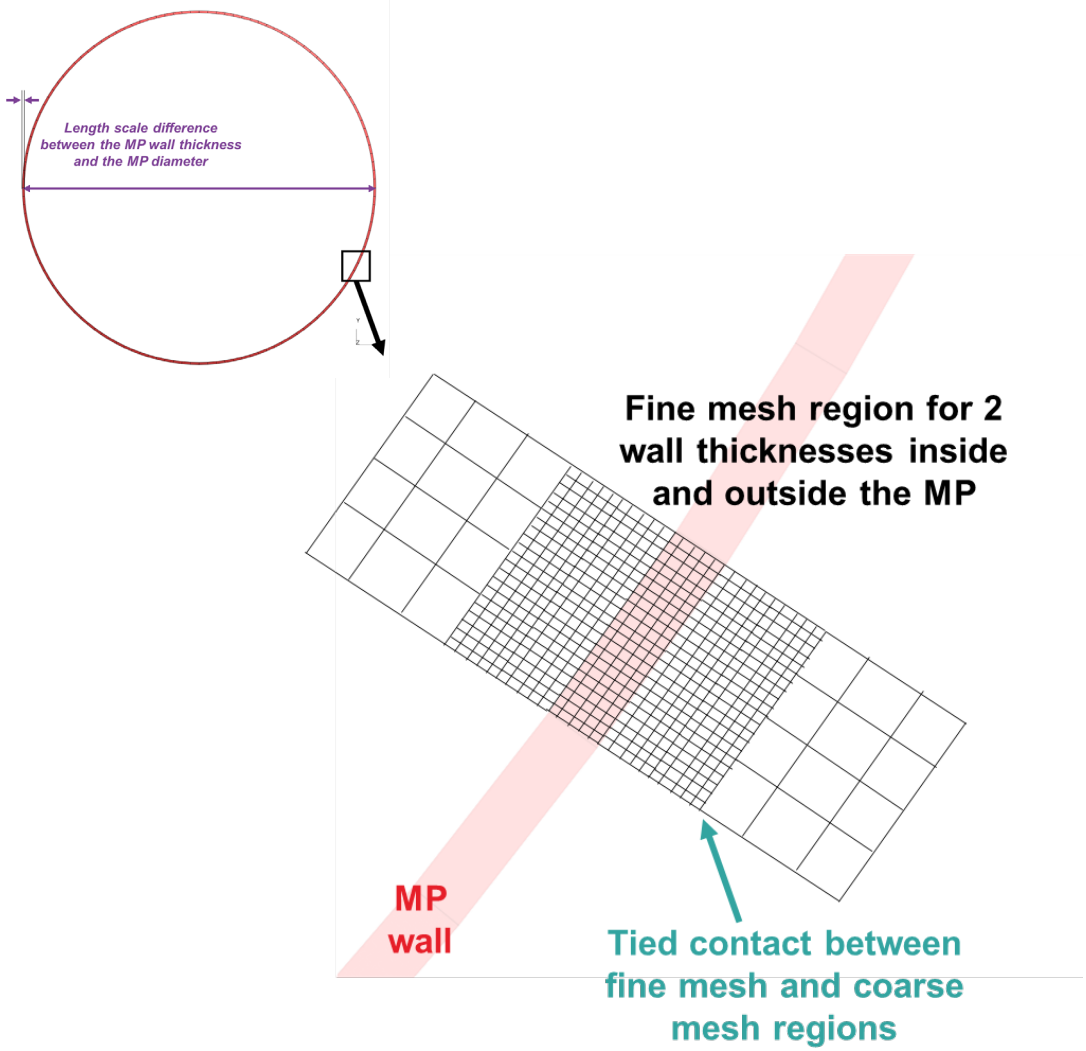

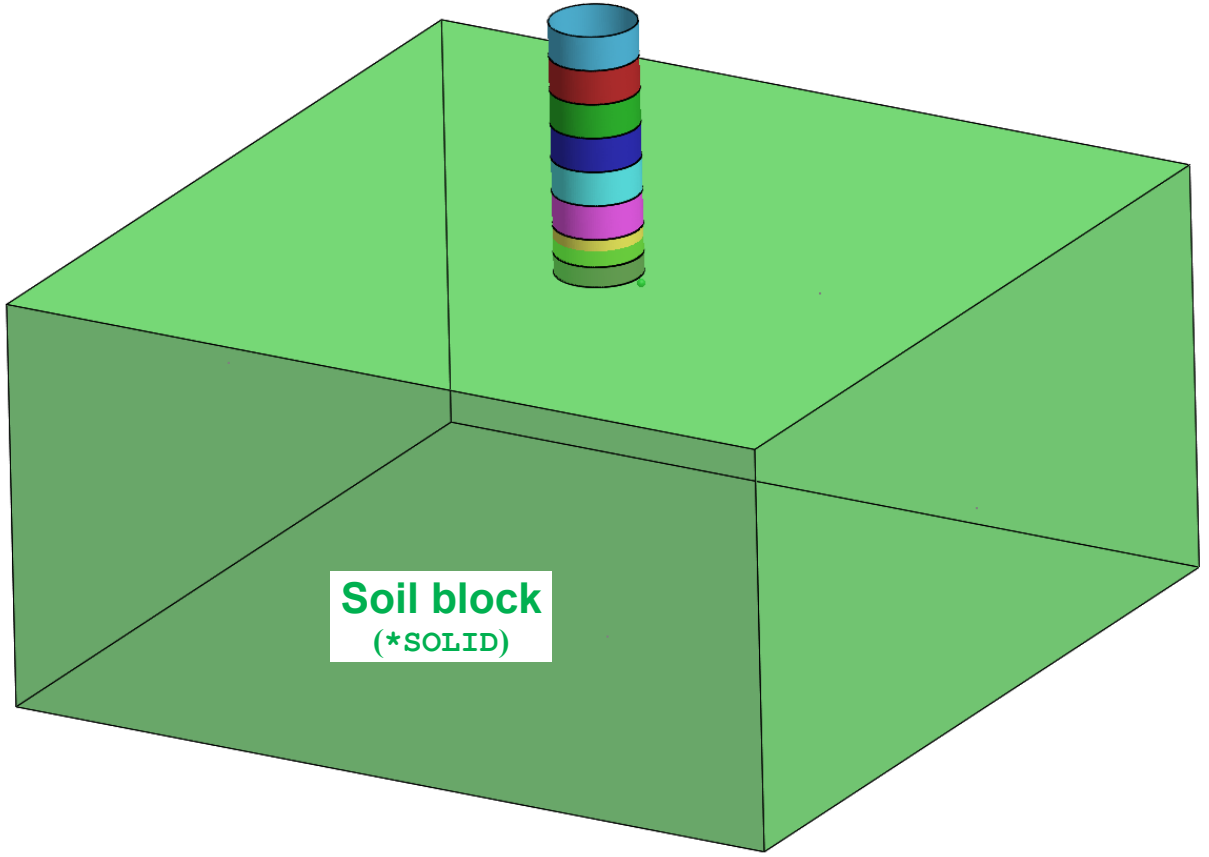

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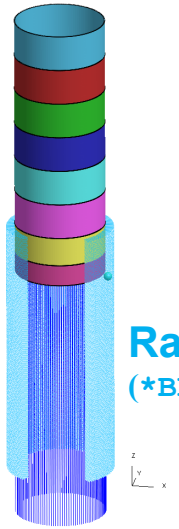
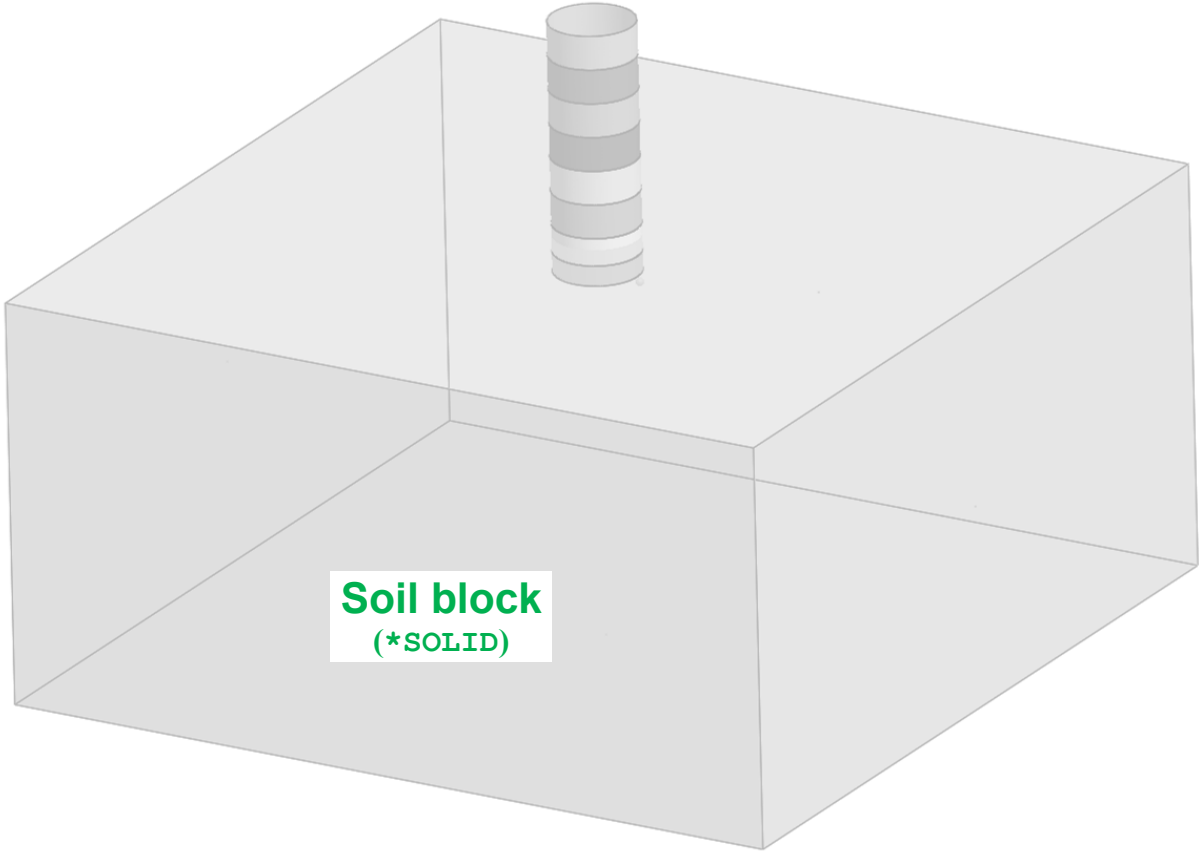


Radial resistance
(*BEAM, discrete elform)

Toe resistance
(*BEAM, discrete elform)

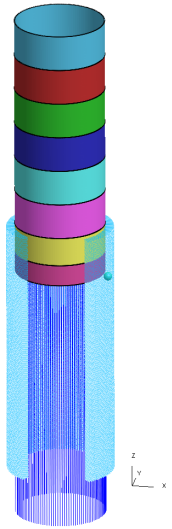
Approach used here (efficient methodology)
~0.3 million elements

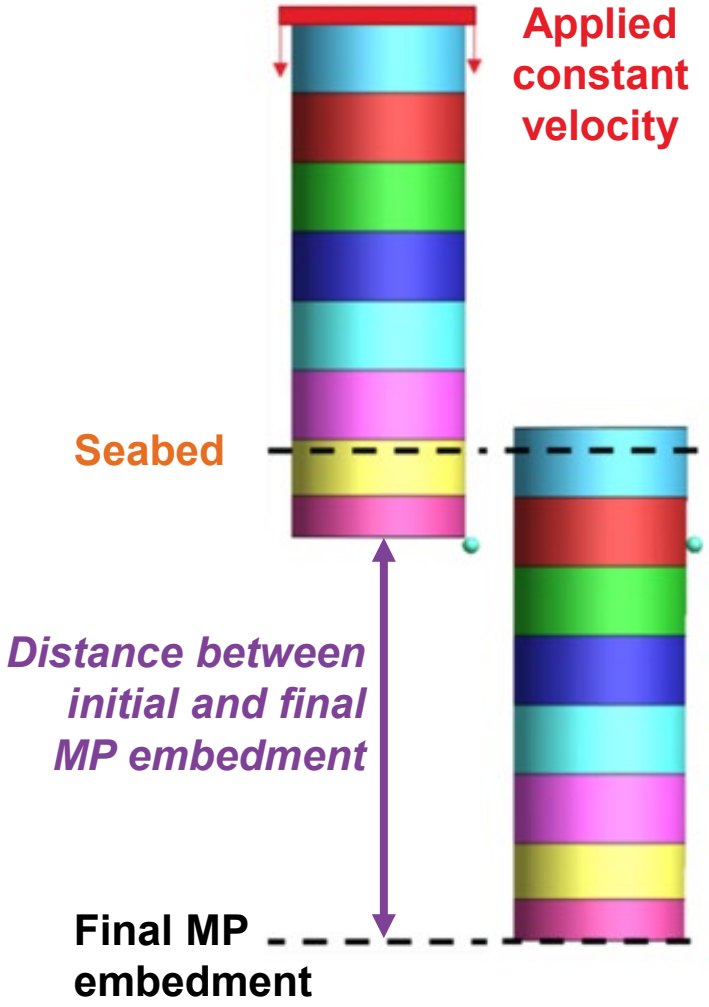


Soil block
(*SOLID)

Traditional approach (large model, slow to analyse)
~100 million elements

LS-DYNA modelling





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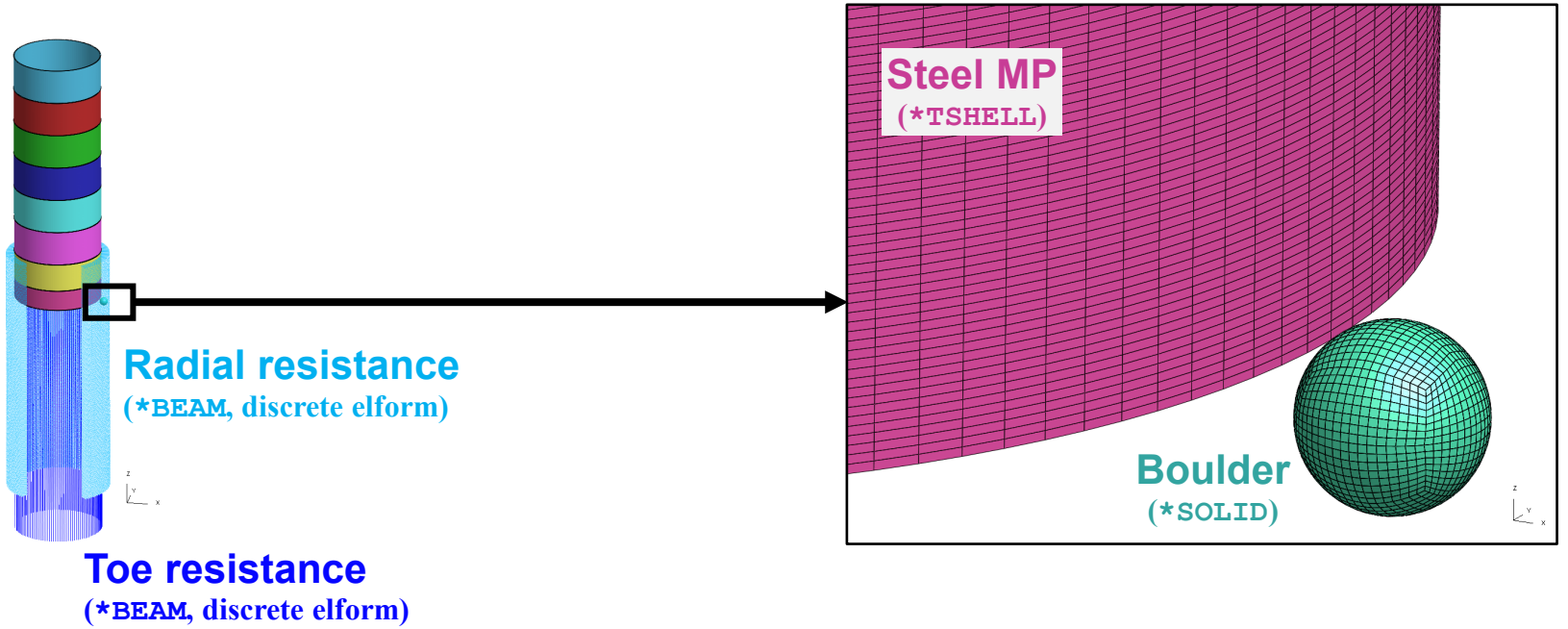

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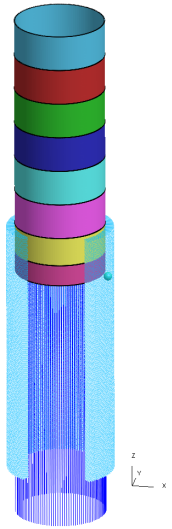
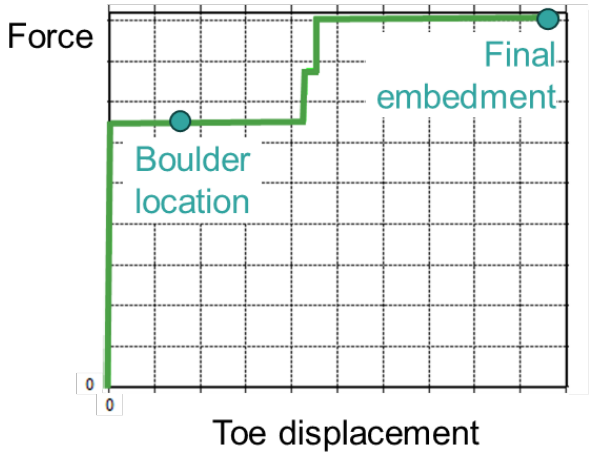


Toe resistance

Toe resistance



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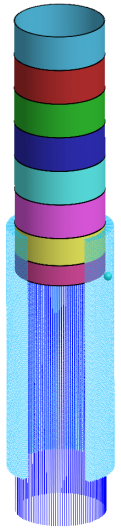
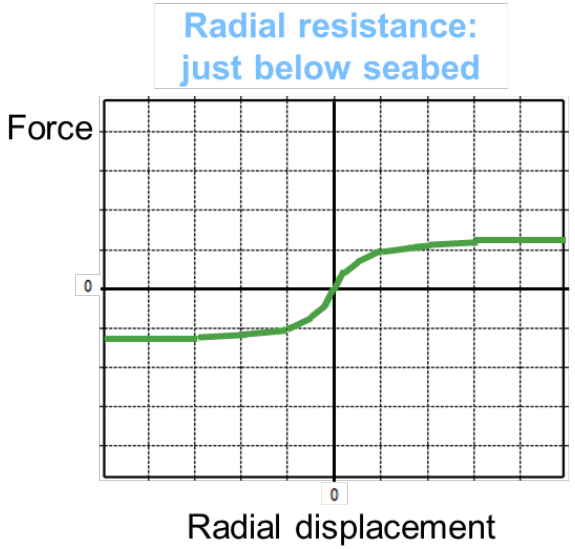
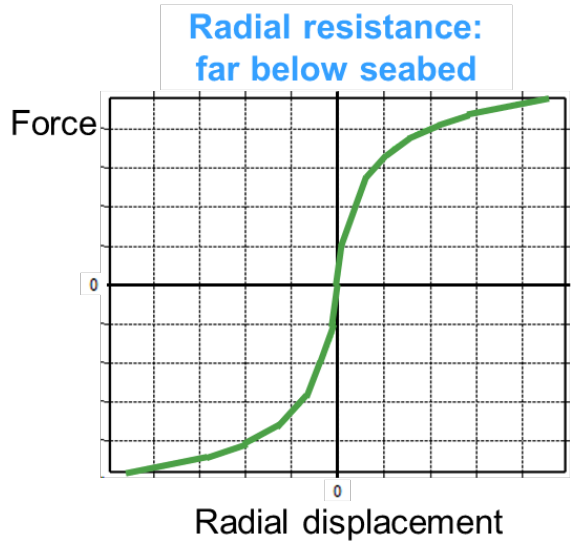
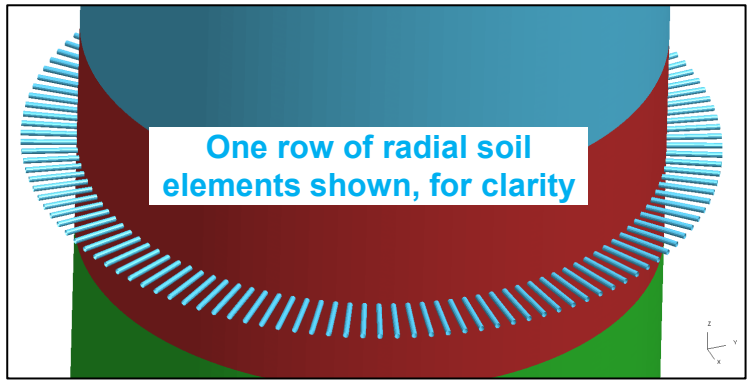


Radial: just below seabed

Radial: far below seabed







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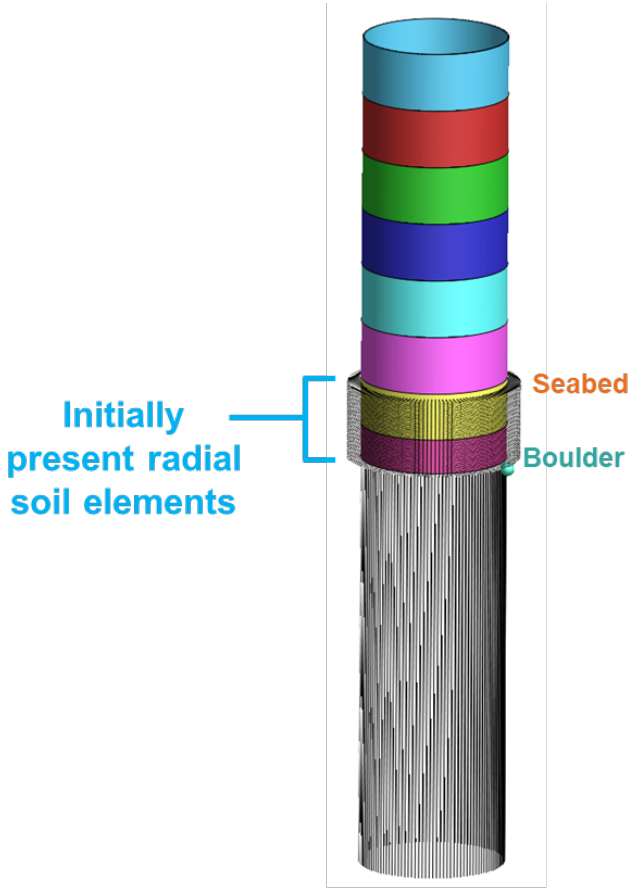

1) MP embedment before boulder impact; only radial soil elements between the seabed and boulder locations are present

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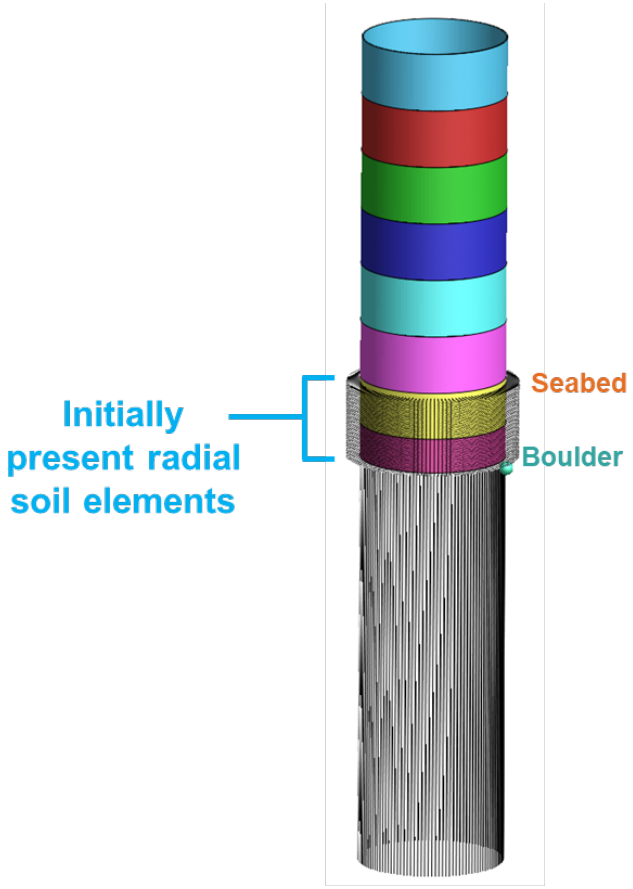
LS-DYNA modelling



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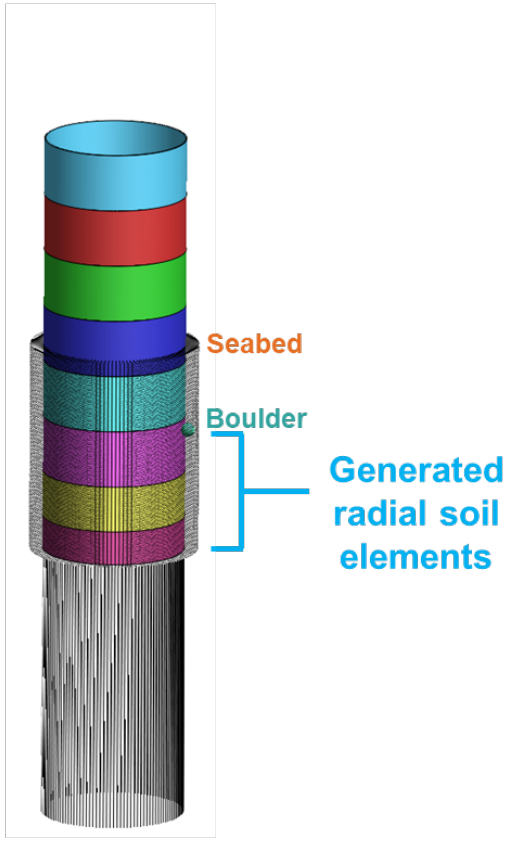
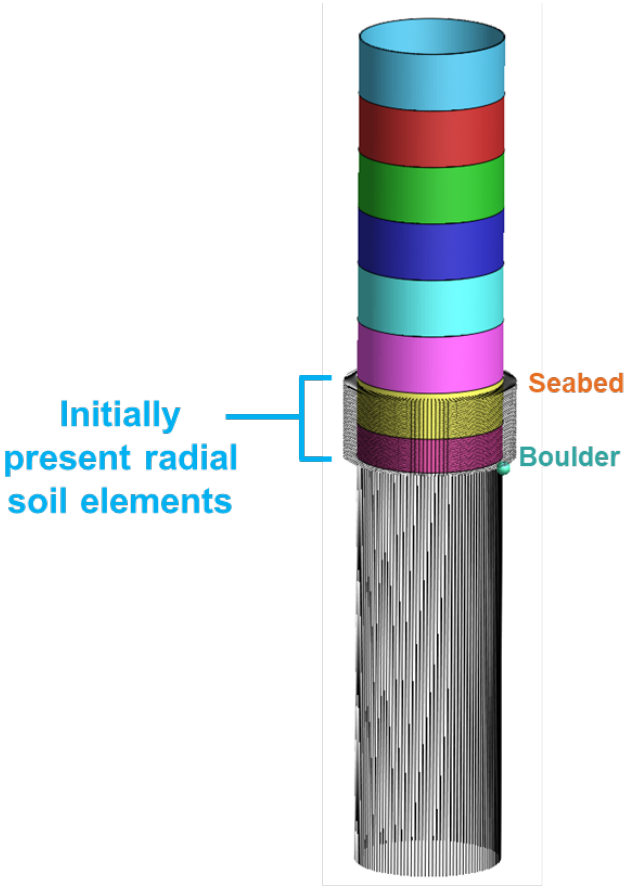


2) Intermediate embedment; radial soil elements generated to meet the moving MP toe

LS-DYNA modelling



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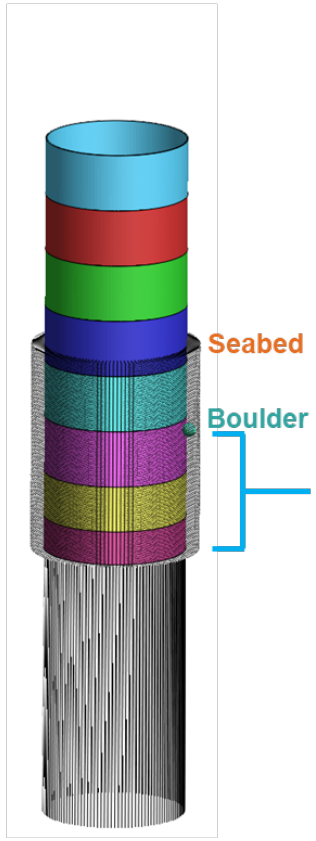

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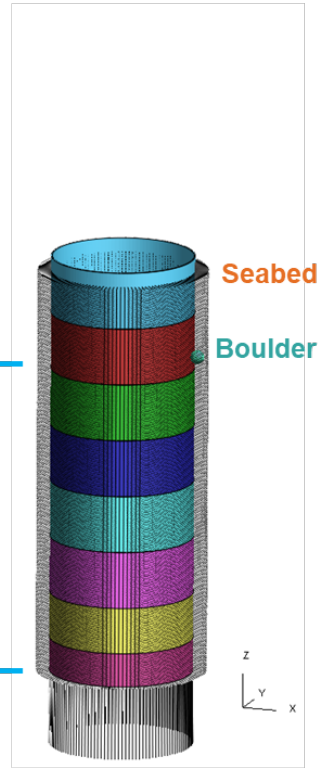

3) MP final embedment; all radial soil elements generated

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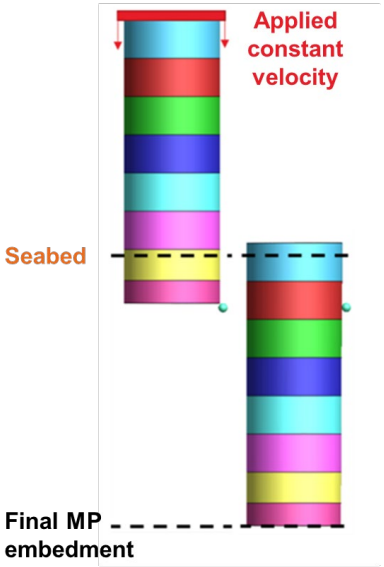
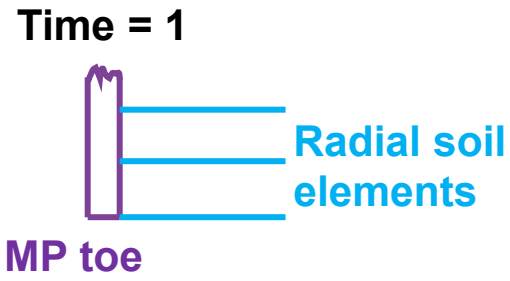
LS-DYNA modelling





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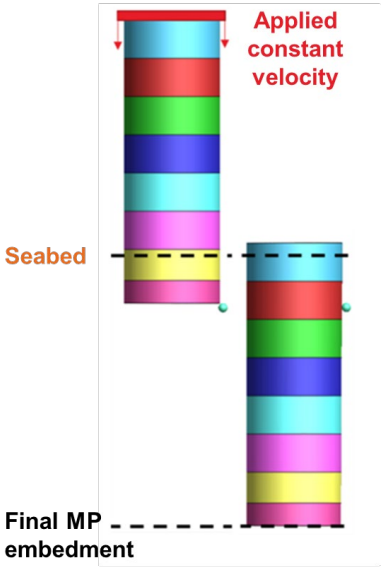

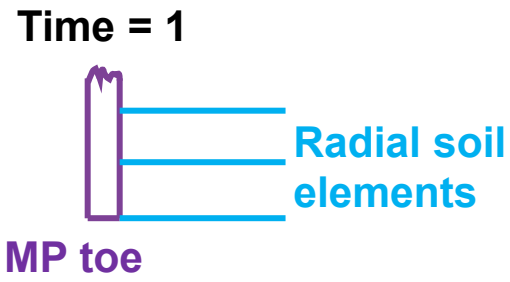

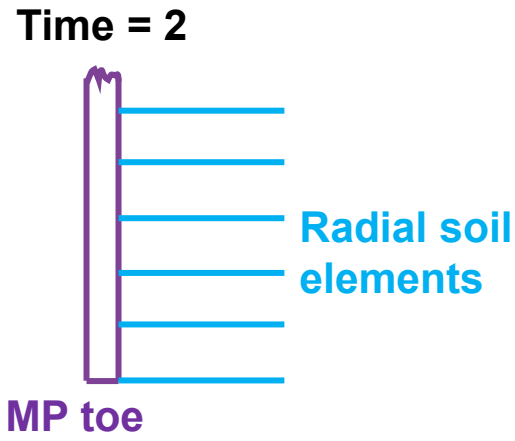

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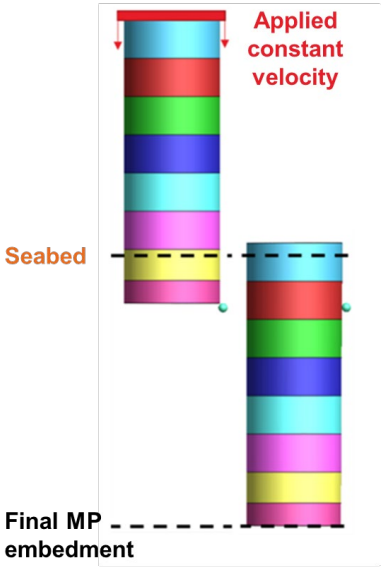

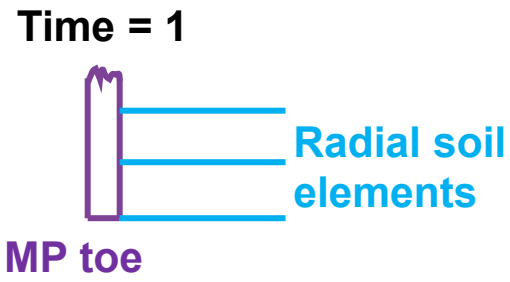

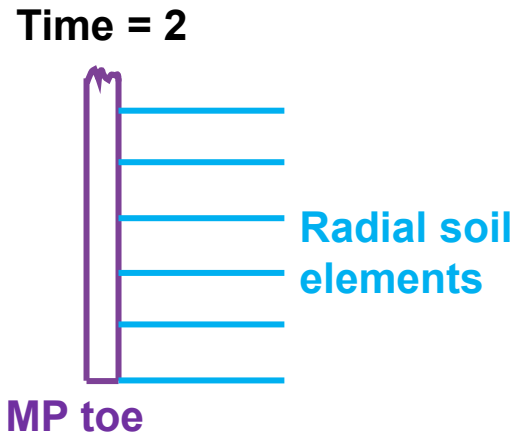

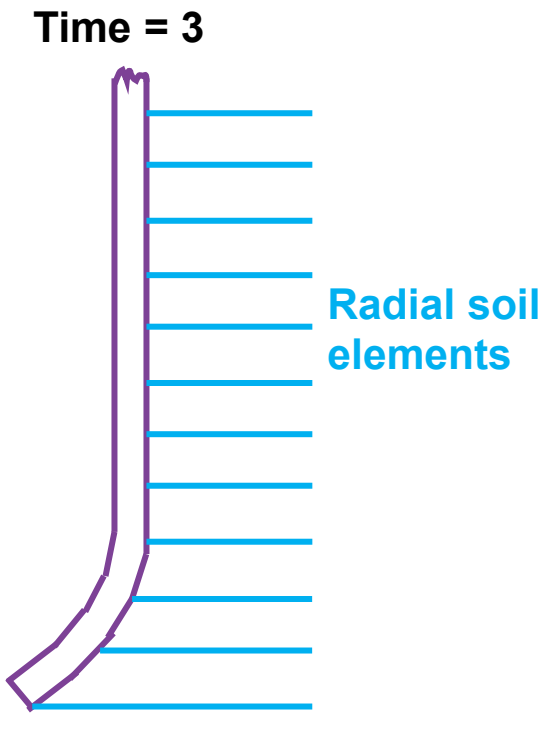

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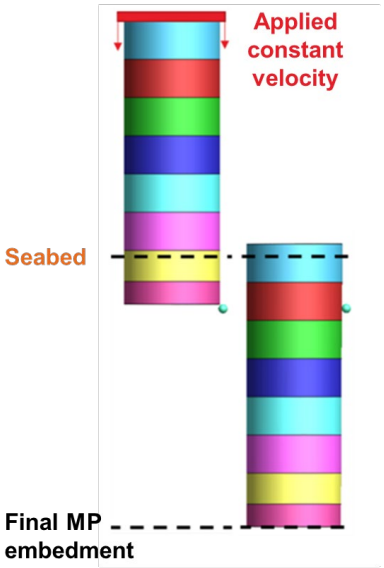

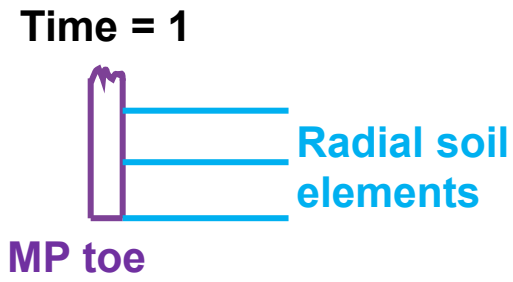

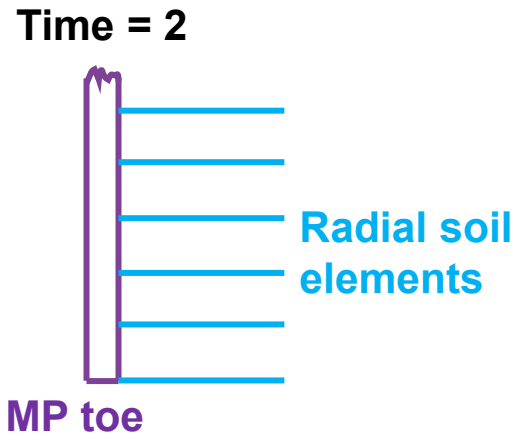

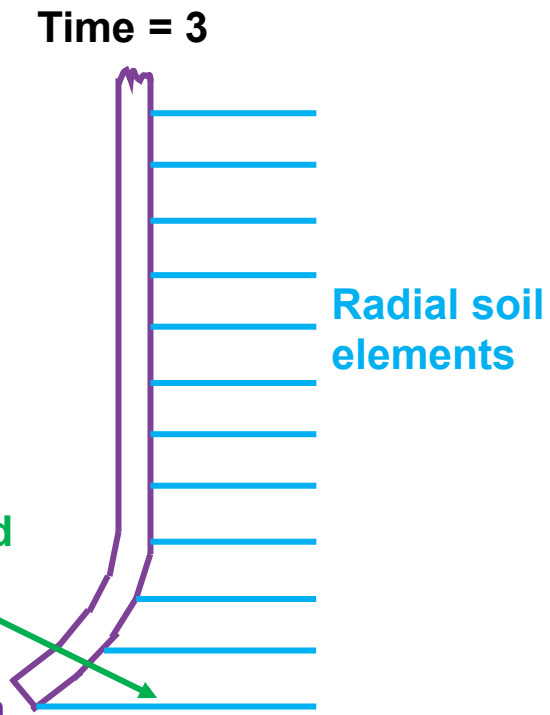

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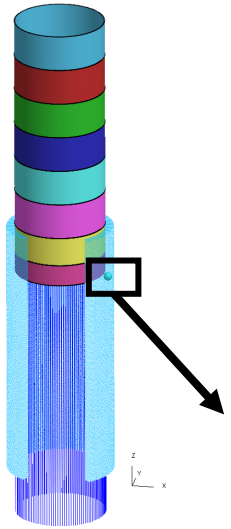
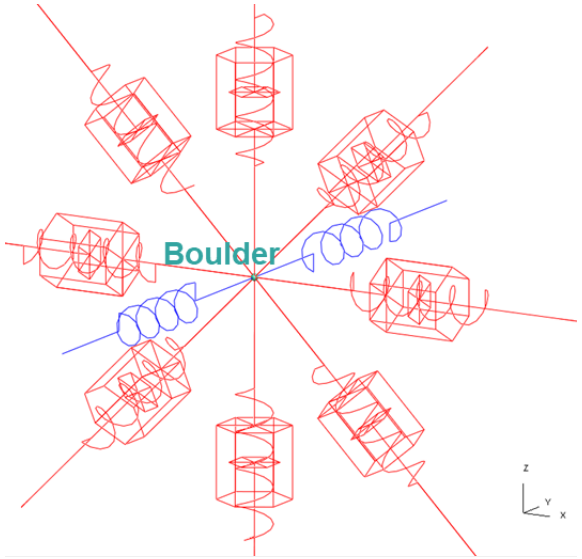
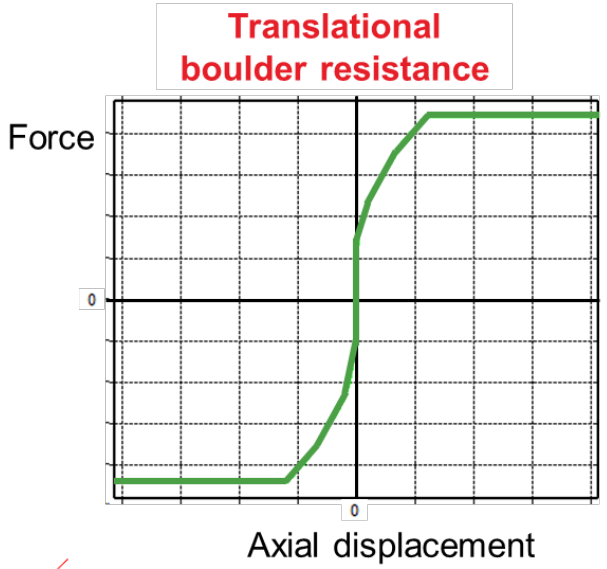
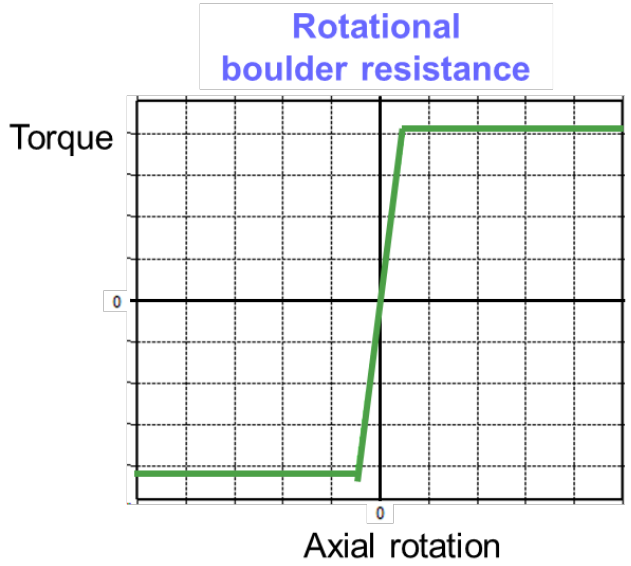




Translational boulder resistance
and rotational boulder resistance





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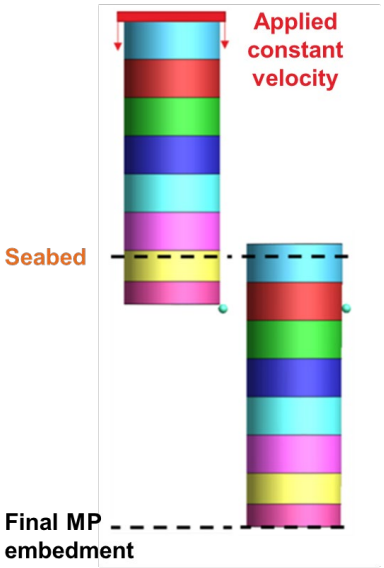
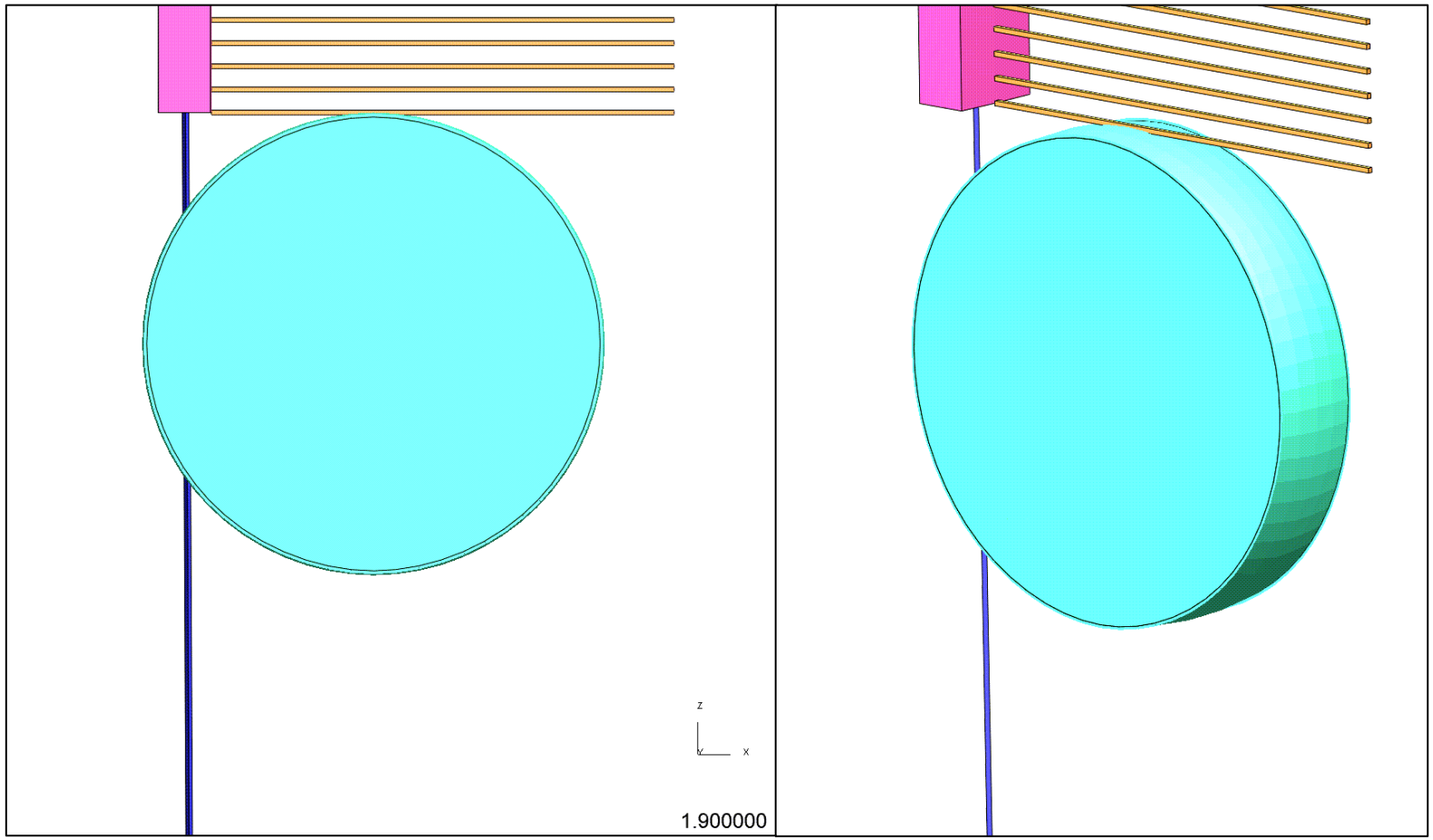
Interaction between MP, boulder, and soil





(Section through MP and boulder; boulder resistance elements not shown)

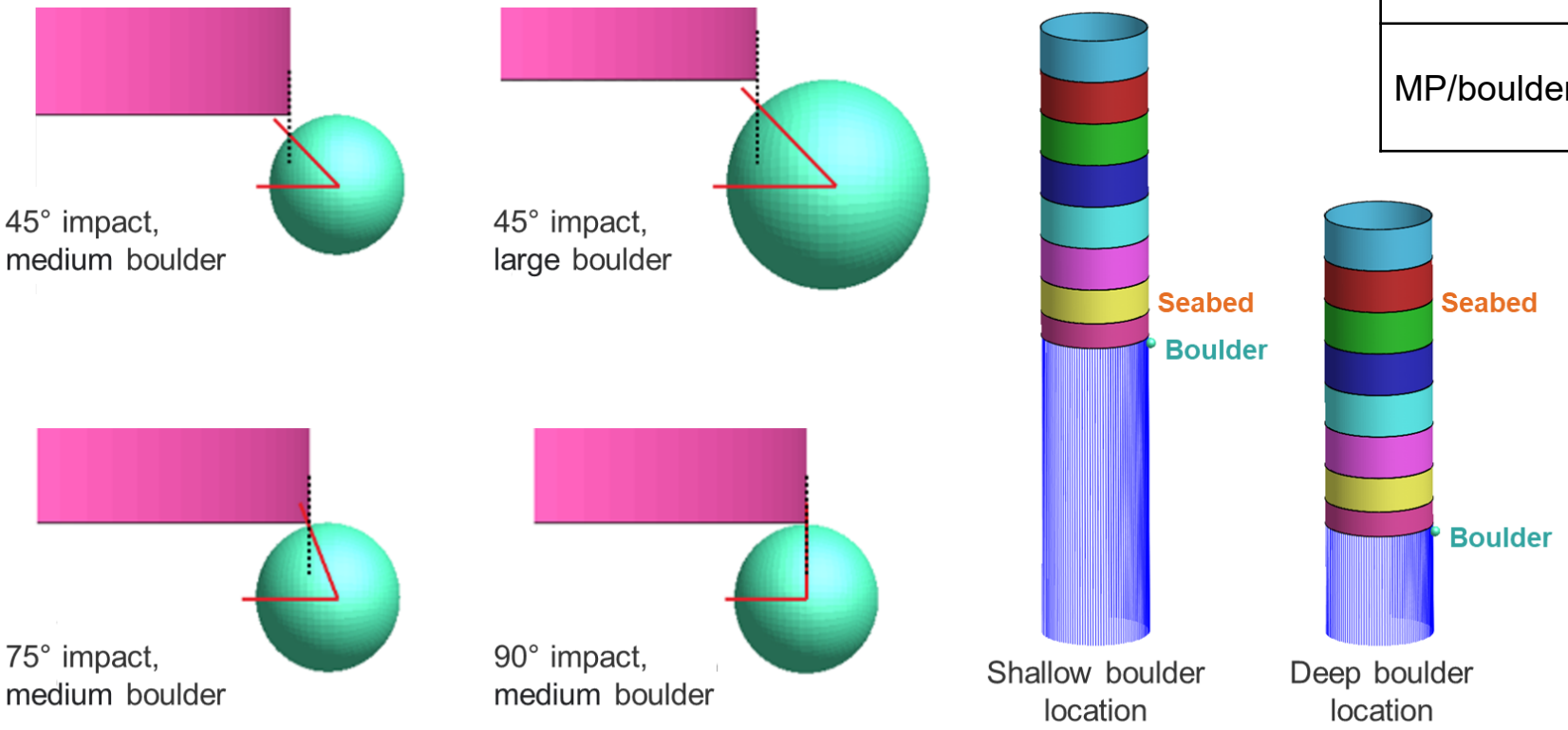
Initially present radial soil elements

Generated radial soil elements

LS-DYNA analyses and variables

- The likely range conditions for a specific MP installation site:

Variable	Values
Soil material properties	Upper Bound (UB) Lower Bound (LB)
Boulder location (depth)	Shallow Deep
Boulder diameter	Medium Large
MP/boulder impact angle	45° 75° 90°



LS-DYNA results

- Key metrics to quantify the potential damage to be expected on a MP for a specific installation site:

Change in MP diameter
Correlates to an increased risk of refusal to drive the MP further

Plastic strain in the MP
Correlates to future fatigue performance due to cyclic loading from wind and wave

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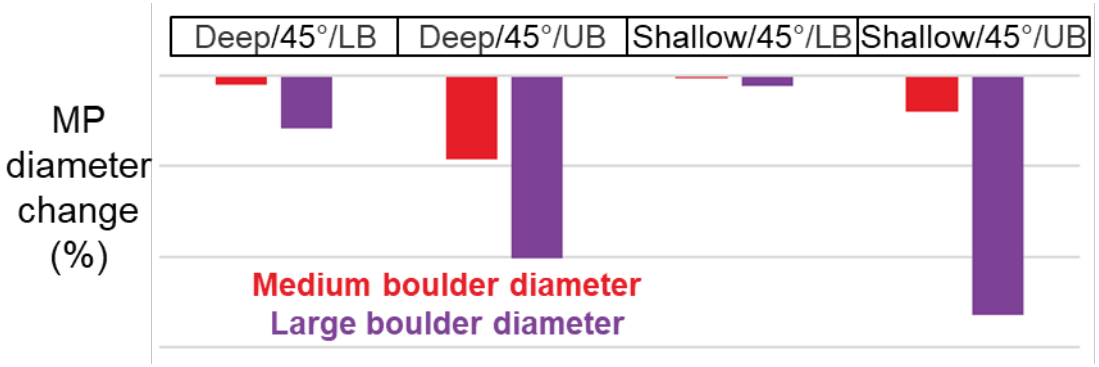

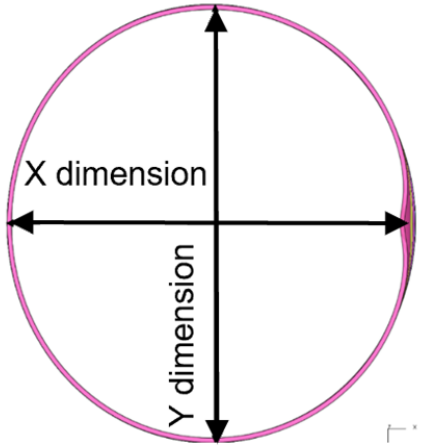

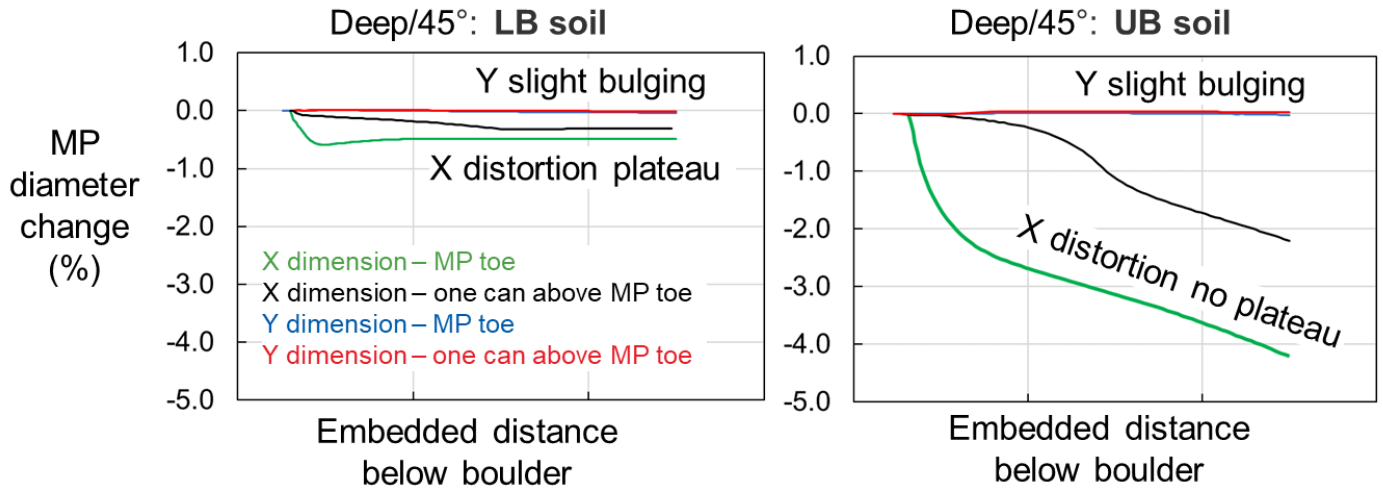

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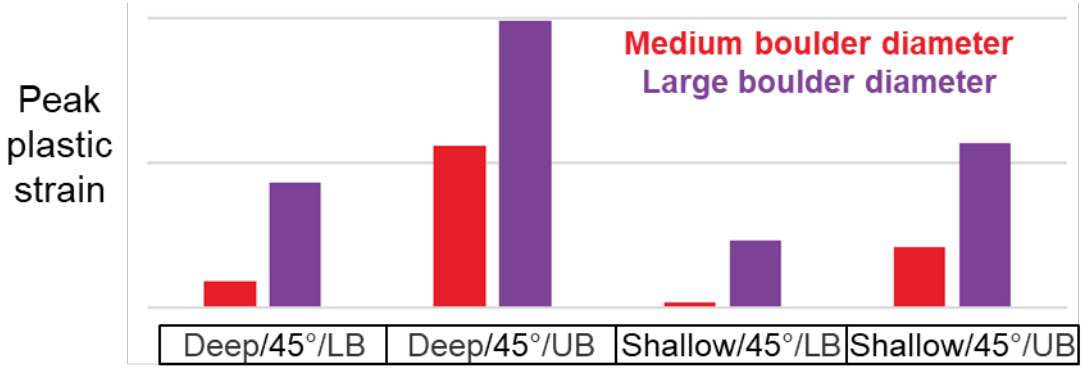
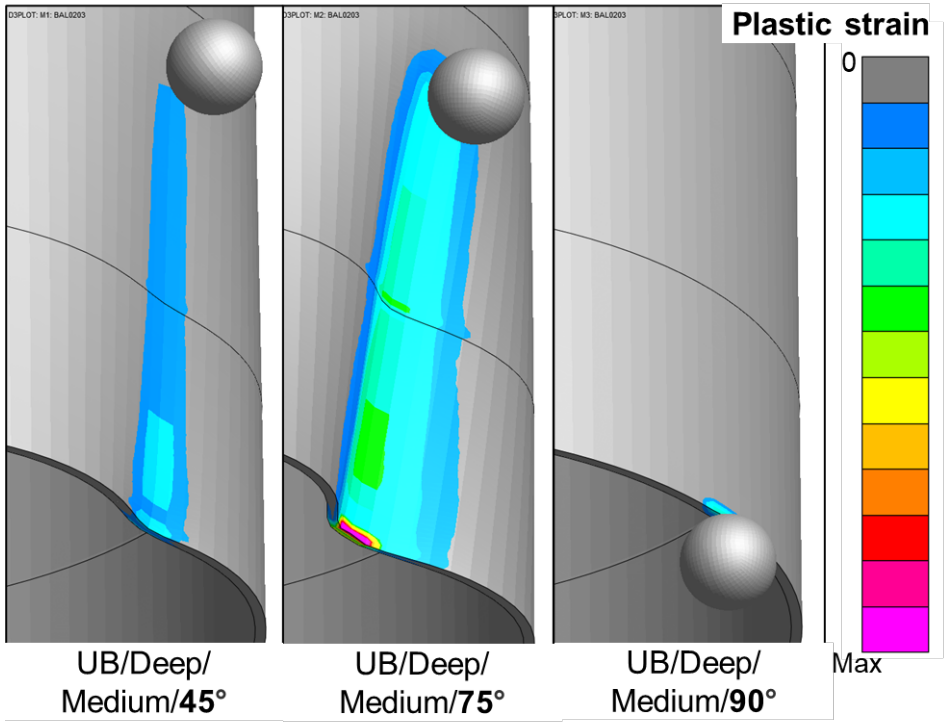
Correlates to future fatigue performance due to cyclic loading from wind and wave





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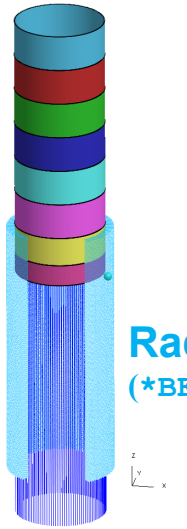
Benefits of this LS-DYNA methodology



Radial resistance
(*BEAM, discrete elform)

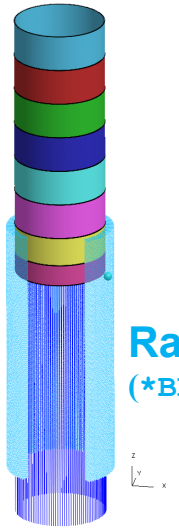
Toe resistance
(*BEAM, discrete elform)

Approach used here (efficient methodology)
~0.3 million elements

- Soil resistance modelled by discrete beam elements (~100x fewer elements, so ~100x faster analysis)
- Uses bespoke Oasys PRIMER JavaScripts, to reduce model set-up time from days to hours
- Constant velocity prescribed motion (faster than reality, but not so fast to cause unreasonable results)

ARUP

Benefits of this LS-DYNA methodology



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Therefore:

- Can simulate the entire installation process, from seabed to final embedment, including obstacles
- Can observe the build-up of stresses and strains in the MP over time (and the change in diameter etc)
- Can conduct parametric studies (for example, varying soil properties, boulder sizes/locations)

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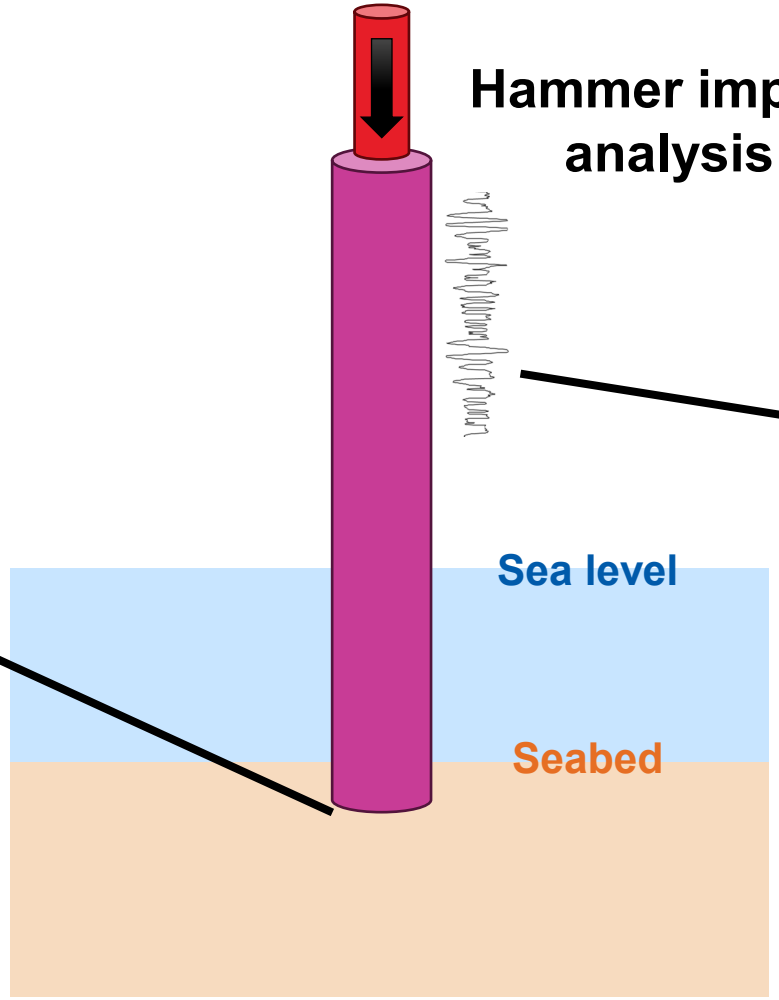
Other LS-DYNA capabilities

Hammer impact analysis



Driveability assessment
for expected embedment distance per hammer impact at different depths

Fatigue assessment
of welds (and other stress concentration regions) due to 1000s of hammer impacts

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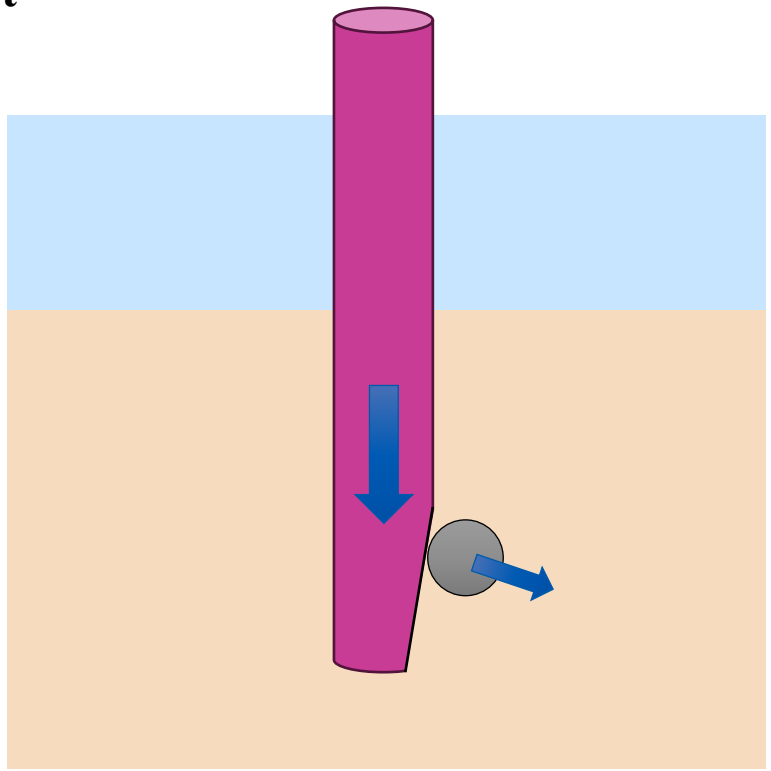
Benefits of LS-DYNA for MP installation

Assess risk of MP damage due to subsea boulder impact

Inform site-specific MP installation strategies



Assess risk of MP refusal to embed

Predict total number of hammer impacts required to drive MP

Efficiently analyse a large range of scenarios computationally

Assess risk of MP fatigue failure during operational life, based on installation damage

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Contact

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Thank you!

Any questions?