AD FALCON API Manual

Sponge Layer – Truncated Domain Absorption

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1 Sponge Layer – Truncated Domain Absorption

This page describes the tapered "sponge layer" feature used to attenuate spurious wave reflections at truncated model boundaries. The approach adds velocity-proportional damping toward selected outer faces. It does not change stiffness (E, K, G) or density.

1.1 Concept

- A computational domain is truncated at some distance from the region of interest. Outgoing waves reflect at the truncation unless energy is dissipated before reaching it.
- The sponge layer assigns a spatial ramp $r \in [0, 1]$ that increases toward selected outer faces over a thickness L. This ramp scales a mass-proportional damping coefficient used by the mechanical domain.

1.1.1 Distance-based ramp

For a Gauss point located at $\mathbf{x}$, let $d(\mathbf{x})$ denote its shortest distance to the enabled outer faces. The (polynomial) ramp is

$$r(d) = \left(1 - \frac{d}{L}\right)^{m}, \quad \text{clamped to } [0, 1] \tag{1}$$

- L: sponge thickness
- $m \geq 1$: ramp exponent (steeper near the boundary for larger m)

1.1.2 Mechanical damping (always available)

The damping coefficient at a Gauss point is

$$c_{\text{sponge}}(\mathbf{x}) = r(d(\mathbf{x}))\, c_{\max} \tag{2}$$

and contributes to the mechanical damping matrix as a Rayleigh-like mass term:

$$\Delta \mathrm{C}_e = \int_{\Omega_e} \rho\, c_{\text{sponge}}\, \mathrm{N}_u^{\mathsf{T}} \mathrm{N}_u \, \mathrm{d}V, \quad \text{(internally assembled)} \tag{3}$$

where ρ is the mixture density at the Gauss point and N_u are displacement shape functions.

> Stiffness is intentionally left unchanged to avoid impedance mismatch-induced reflections. Damping achieves attenuation without altering wave speeds.

1.2 Parameters

- **Thickness** L: Physical distance over which the sponge acts. Choose based on mesh resolution and the wavelengths you expect to attenuate.

- **MaxDamping** $c_{\max}$: Peak mechanical damping at the boundary. Select to achieve noticeable attenuation near the truncation without overdamping the interior.
- **Exponent** m: Controls how quickly damping increases toward the boundary. Use a moderate value to balance smoothness and effectiveness.
- **Sides**: Which outer faces are enabled (XMin/XMax/YMin/YMax[/ZMin/ZMax] or ALL). (No permeability manipulation is applied.)

1.3 Syntax

1.3.1 Section header

Use a dedicated percent-section. The following headers are equivalent (whitespace, _, and - are ignored):

```
% SpongeLayer
% Sponge Layer
% Sponge-Layer
```

The section ends at a line that is (after comment stripping and trimming) exactly `%%%` (for example, `%%%  # end` is accepted).

1.3.2 Directives

Inside the sponge section: - Only lines that start with `@` are parsed (other lines are ignored). - Keys are case-insensitive. - One or more leading `@` characters are accepted (e.g., `@Thickness:` and `@@Thickness:` are equivalent). - A space after `:` is optional (e.g., `@@Thickness:10.0` and `@@Thickness: 10.0` are equivalent).

Supported directives:

Directive	Required?	Default	Meaning
`@@Thickness`	Yes	—	Sponge thickness `L` (distance from the selected outer faces over which damping ramps from 0 → `Max Damping`).

Directive	Required?	Default	Meaning
`@@MaxDamping`	Yes	—	Peak mass-proportional damping coefficient `c_max` applied at the boundary (the Gauss-point damping target is `r(d)·c_max`).
`@@Exponent`	No	`3`	Ramp exponent `m`. Values `m ≤ 1` behave like a linear ramp; recommended `m ≥ 1`.
`@@Sides`	No	`ALL`	Which outer faces are damped: one or more of `ALL`, `XMin`, `XMax`, `YMin`, `YMax`, `ZMin`, `ZMax`.

```
@@Thickness:  <L>
@@MaxDamping: <c_max>
@@Exponent:   <m>
@@Sides:      <list>
```

Notes:

- If `@@Sides` is present, only the listed sides are enabled.
- For 2D/axisymmetric models, `ZMin`/`ZMax` are accepted but have no effect.

1.3.3 Example

```
% Sponge Layer
@@Thickness: 10.0
@@MaxDamping: 0.25
@@Exponent: 3
@@Sides: ALL
%%%
```

1.4 How the region is selected (no element tagging)

- You do not select elements manually. The sponge is **automatic**: it uses the model **bounding box** and computes the shortest distance from each Gauss point to the **enabled outer faces**. Any Gauss point with $d \le L$ gets sponge intensity $r(d)$ as in (1).
- The mechanical damping (2) is applied in all analysis types that assemble the velocity term. If an element/Gauss point already has a nonzero damping value from another mechanism, the sponge layer does not reduce it; it takes the maximum.

1.5 Recommendations

- Keep the sponge away from sources/contacts by several elements before the ramp begins.
- Favor a sponge thickness that spans several elements in the outward normal direction. Ensure the ramp begins after a buffer from where loads or contact act.
- Use a moderate ramp exponent; verify that damping increases smoothly and does not create a sharp transition.
- Calibrate the boundary damping by small trials: increase until reflections are acceptably attenuated, avoid levels that visibly suppress motion in the region of interest.
- Do not change stiffness in the sponge region.

1.6 Guidelines for selecting damping across analyses

- Dynamic (mechanical only)
  - Select $c_{\max}$ so the sponge absorbs outgoing waves near the truncation while leaving the response in the interior essentially unchanged.
  - Consider the dominant frequency content of your loading and the shortest wavelengths you care to attenuate when choosing L and m.
- Coupled / Fully coupled (dynamic)
  - Use the same approach as above. Choose L and m with respect to the relevant wave content. Keep stiffness and bulk moduli unchanged.
  - Avoid placing the sponge directly under sources or near critical boundaries where physical reflections are of interest.
- Consolidation (no mechanical inertia)
  - If used, keep the sponge mild. Its effect is a first-order drag; rely primarily on physical flow boundary conditions for parabolic problems.

Practical workflow - Start with a conservative sponge thickness spanning multiple elements normal to the boundary. - Pick a moderate ramp exponent; verify smooth spatial transitions. - Increase boundary damping gradually until boundary reflections are acceptably small in trial runs. - Re-check with oblique incidence and with your actual loading spectrum before production runs.

1.7 Validation checklist

1. 1D bar, normal incidence: reflected signals remain small compared to incident waves in the band of interest.
2. 2D/3D oblique incidence: grazing reflections are visibly attenuated by the sponge.
3. Saturated/unsaturated column pulse (if applicable): no persistent standing waves within the sponge zone.

1.8 Notes on advanced use

- The sponge is assigned during input parsing and is based on the model bounding box in the original (reference) coordinates. In large-deformation analyses or remeshing workflows, the sponge does not automatically follow the updated geometry. On checkpoint restart, the Gauss-point damping state is restored from the checkpoint, so changing `% Sponge Layer` in the input file will not change an in-progress restarted run unless the solver explicitly re-applies the sponge assignment.
- The mechanical damping term assembled internally is proportional to $\rho\, c_{\text{sponge}}$ and enters the global C matrix consistently with other velocity terms.