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Mixed-dimensional finite element formulations for beam-to-solid interaction

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Extended Abstract

The interaction between slender fiber- or rod-like components, where one spatial dimension is much larger than the other two, with three-dimensional structures (solids) is an essential mechanism of mechanical systems in numerous fields of science, engineering and bio-mechanics. Examples include reinforced concrete, supported concrete slabs, fiber-reinforced composite materials and the impact of a tennis ball on the string bed of a tennis racket. Applications can also be found in medicine, where stent grafts are a commonly used device for endovascular aneurysm repair, and in many biological systems such as arterial wall tissue with collagen fibers.

The different types of dimensionality of the interacting bodies, i.e., slender, almost one-dimensional fibers and general three-dimensional solids, pose a significant challenge for typical numerical simulation methods. The presentation focuses on developing novel computational approaches to simulate the interaction between these fiber-like structures and three-dimensional solids. The key idea is to model the slender components as one-dimensional Cosserat continua based on the geometrically exact beam theory, enabling an accurate and efficient description of the fibers. This results in a mixed-dimensional beam-to-solid interaction problem.

In a first step positional and rotational coupling between the beam centerline and the underlying solid in line-to-volume problems are addressed. Mortar-type methods, inspired by classical mortar methods from domain decomposition or surface-to-surface interface problems, are used to discretize the coupling constraints. In a second step, the previously developed algorithms for line-to-volume coupling are extended to to line-to-surface coupling. This introduces the additional complexity of having to account for the surface normal vector in the coupling constraints. Finally, a Gauss point-to-segment beam-to-solid surface contact scheme that allows for the modeling of unilateral contact between one-dimensional beams and two-dimensional solid surfaces is presented.

The previously mentioned building blocks constitute a novel mixed-dimensional beam-to-solid interaction framework, which is verified by theoretical discussions and numerical examples.

References

1. I. Steinbrecher, “Mixed-dimensional finite element formulations for beam-to-solid interaction”, University of the Bundeswehr Munich, 2022.