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Topology Optimization of Non-linear Structures

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For structures operating in the linear regime, numerical design optimization schemes has successfully been applied to generate optimal designs. Simple objectives such as stiffness and eigenfrequency for linear elasticity can be found in commercial softwares packages and they are today used on daily basis in industry. For non-linear systems, design performance is predicted by complex simulations which exhibit, multiple length scales, nonlinearities and transients. Numerical models that can predict the non-linear and irreversible response of structures are well established, thus needed is the link that connects the simulation schemes to computational optimization schemes. In this talk, recent steps towards closing the gap between non-linear analysis and topology optimization will be discussed. For all applications we use density based topology optimization and gradient based optimization. To regularize the problem formulation we use a PDE based filter technique. All problems are solved using the MMA scheme.

Stiffness optimization of non-linear structures

A common objective of small strain topology optimization is stiffness maximization. This objective has for instance the advantage of being self-adjoint, which leads to that the sensitivities are trivially obtained. The generalization of the small strain stiffness optimization to large strains is not unique and in this talk we show that the choice if objective plays an important role for the optimized design. In the area of finite strain topology optimization the vast majority of the contributions are based on Saint-Venant's elasticity where the Green-Lagrange strain is linearly connected to the second Piola stress. This model is known to perform poorly and therefore we use a neo-Hookean strain energy. From the implementation point of view this choice of material model adds complexity, but we show that it can be handled efficiently within the standard finite element framework. In the numerical examples we compare the secant stiffness, minimum potential and the tangent stiffness for some well-known structures and we show that the optimized designs are higly influenced by the choice of definition of the stiffness.

Energy absorbing structures of visco-plastic structures

Path-dependent material response has previously been used in the context of topology optimization but the amount of research is limited. The research that address irreversible response has so far been limited to small strains and are it is therefore of lesser relevance for design of energy mitigating structures since the strains and deformations in general are large during such processes. In the present talk, we extend the topology optimization framework to take large plastic strains into account. Since energy absorption frequently takes place at elevated strain rates, visco- plasticity is utilized and, moreover, since inertial effects might be of importance we solve the transient response using the Newmark time stepping procedure. The sensitivities required to update the design is obtained by the adjoint approach which for the transient visco-plastic problem becomes a terminal value problem, i.e. we first solve the primal visco-plastic problem and then based on this solution we calculate the sensitivity with respect to the element densities. We apply the theory to design structures that are optimized for energy absorption. The results show that the rate of impact plays an important role when designing energy absorbing structures.

Buckling and eigenvalue optimization of hyper-elastic structures

Topology optimization often renders structures where the load is transferred in pure tension and compression. Since the load carrying members that are subject to compression are at the risk of buckling, this must be taken into account in the design process. A simple route to address this problem is to make use of a linearized buckling which leads to an eigenvalue problem. This approach may be used for small strains, however, for situations where buckling is preceded by large deformations it can not be used. In the present talk, we show possible routes to include buckling constraints into topology optimization. The buckling modes that the algorithm detect may occur in void regions, i.e. artificial buckling modes may be present. In the talk we will illustrate possible routes to eliminate these artificial modes. A companion problem to the buckling problem is that of eigenvalue optimization. Also for this problem, we will show that the deformation level will significantly influence the eigen frequency; a matter that is often ignored.

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