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Eigenvalue-based topology optimization for aseismic design of structures and devices

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ABSTRACT

Topology optimization is a powerful instrument that has been used in a wide range of applications to solve practical problems one has to face when approaching design themes. Among the several fields interested by this discipline peculiar reference is made to the civil engineering area, where this design approach was firstly successfully experimented.

One of the more classical approaches operates in a static framework and has the aim of maximizing the stiffness of a structure, i.e. minimizing its compliance, or works of external forces. Well-known results of this procedure are the optimal design of truss structures or the preliminary design of bridge layouts, just to mention two of the several appreciated applications. In addition to this static point of view of the structural problem, other issues were considered in order to take into account and to control the dynamic performances of civil and mechanical systems. To this purpose reference is made to the wide branch of research of eigenvalue-based topology optimization. This area of investigation was traditionally characterized by the research of the best material layout for the maximization of the first eigenvalue, i.e. the achievement of the highest stiffness with respect to the dynamic behaviour [3]. The numerical procedure is not free from numerical complications. In fact one has to tackle the problem of the arising of undesired local modes due to the combined use of different interpolations for mass and stiffness in the topological framework. Moreover additional troubles exists related to the sensitivity calculation when dealing with repeated eigenvalues.

Apart from the numerical issues related to the implementation of eigenvalue-based optimization for which different solutions have been successfully proposed (i.e. in [4]), it is worth noticing that this design scheme may be, and has often been used, to address alternative dynamic problems, related to specific requirements in terms of performances of the structures. Within this framework the proposed contribution has the aim to implement the approach introduced in [2] to address specific problems of aseismic isolation in civil engineering. The methodology consists in a preliminary procedure that designs structures and devices in order to obtain the minimum vertical compliance with an upper limit on the first eigenvalue related the horizontal vibrations. This allows in fact to achieve the maximum vertical stiffness with a prescribed horizontal flexibility.

The work in [2] specializes the above approach for the preliminary design of isolation devices. The main issue is to tackle the optimal layout of base isolators that are required to stiffly bring the load of the structures, while exhibiting a prescribed shear flexibility to cut the seismic action that reaches the body of the overlaying structures. The present contribution presents additional results on the theme and mainly focuses on a similar design problem. It is in fact essentially concerned with the distribution of bracing systems in traditional framed structures in order to achieve a required horizontal flexibility under seismic oscillations. This can be made specializing the above formulation to enforce eigenvalue-based objective functions and constraints that determine the optimal distribution of bracing systems for a prescribed dynamic behaviour of the whole structure. In this case the result of the proposed optimal procedure is intimately tied to the structural dimensioning of earthquake resisting members of the whole structure. As detailed in seismic codes, the earthquake load directly descends from the overall flexibility of the system.

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