Dissertations

Structural Applications of Metal Foams Considering Material and Geometrical Uncertainty

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Date of Award
9-2011

Document Type
Open Access Dissertation

Degree Name
Doctor of Philosophy (PhD)

Degree Program
Civil Engineering

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Keywords
Buckling, Metal Foam, Sensitivity Analysis, Sobol', Thin Walled Structures, Uncertainty

Subject Categories
Civil and Environmental Engineering

Abstract
Metal foam is a relatively new and potentially revolutionary material that allows for components to be replaced with elements capable of large energy dissipation, or components to be stiffened with elements which will generate significant supplementary energy dissipation when buckling occurs. Metal foams provide a means to explore reconfiguring steel structures to mitigate cross-section buckling in many cases and dramatically increase energy dissipation in all cases. The microstructure of metal foams consists of solid and void phases. These voids have random shape and size. Therefore, randomness ,which is introduced into metal foams during the manufacturing processes, creating more uncertainty in the behavior of metal foams compared to solid steel. Therefore, studying uncertainty in the performance metrics of structures which have metal foams is more crucial than for conventional structures. Therefore, in this study, structural application of metal foams considering material and

geometrical uncertainty is presented. This study applies the Sobol' decomposition of a function of many random variables to different problem in structural mechanics. First, the Sobol' decomposition itself is reviewed and extended to cover the case in which the input random variables have Gaussian distribution. Then two examples are given for a polynomial function of 3 random variables and the collapse load of a two story frame. In the structural example, the Sobol' decomposition is used to decompose the variance of the response, the collapse load, into contributions from the individual input variables. This decomposition reveals the relative importance of the individual member yield stresses in determining the collapse load of the frame. In applying the Sobol' decomposition to this structural problem the following issues are addressed: calculation of the components of the Sobol' decomposition by Monte Carlo simulation; the effect of input distribution on the Sobol' decomposition; convergence of estimates of the Sobol' decomposition with sample size using various sampling schemes; the possibility of model reduction guided by the results of the Sobol' decomposition. For the rest of the study the different structural applications of metal foam is investigated. In the first application, it is shown that metal foams have the potential to serve as hysteric dampers in the braces of braced building frames. Using metal foams in the structural braces decreases different dynamic responses such as roof drift, base shear and maximum moment in the columns. Optimum metal foam strengths are different for different earthquakes. In order to use metal foam in the structural braces, metal foams need to have stable cyclic response which might be achievable for metal foams with high relative density. The second application is to improve strength and ductility of a steel tube by filling it with steel foam. Steel tube beams and columns are able to provide significant strength for structures. They have an efficient shape with large second moment of inertia which leads to light elements with high bending strength. Steel foams with high strength to weight ratio are used to fill the steel tube to improves its mechanical behavior. The linear eigenvalue and plastic collapse finite element (FE) analysis are performed on steel foam filled tube under pure compression and three point bending simulation. It is shown that foam improves the maximum strength and the ability of energy absorption of the steel tubes significantly. Different configurations with different volume of steel foam and composite behavior are investigated. It is demonstrated that there are some optimum configurations with more efficient behavior. If composite action between steel foam and steel increases, the strength of the element will improve due to the change of the failure mode from local buckling to yielding. Moreover, the Sobol' decomposition is used to investigate uncertainty in the strength and ductility of the composite tube, including the sensitivity of the strength to input parameters such as the foam density, tube wall thickness, steel properties etc. Monte Carlo simulation is performed on aluminum foam filled tubes under three point bending conditions. The simulation method is nonlinear finite element analysis. Results show that the steel foam properties have a greater effect on ductility of the steel foam filled tube than its strength. Moreover, flexural strength is more sensitive to steel properties than to aluminum foam properties. Finally, the properties of hypothetical structural steel foam C-channels foamed are investigated via simulations. In thin-walled structural members, stability of the walls is the primary driver of structural limit states. Moreover, having a light weight is one of the main advantages of the thin-walled structural members. Therefore, thin-walled structural members made of steel foam exhibit improved strength while maintaining their low weight. Linear eigenvalue, finite strip method (FSM) and plastic collapse FE analysis is used to evaluate the strength and ductility of steel foam C-channels under uniform compression and bending. It is found that replacing steel walls of the C-channel with steel foam walls increases the local buckling resistance and decreases the global buckling resistance of the C-channel. By using the Sobol' decomposition, an optimum configuration for the variable density steel foam C-channel can be found. For high relative density, replacing solid steel of the lips and flange elements with steel foam increases the buckling strength. On the other hand, for low relative density replacing solid steel of the lips and flange elements with steel foam deceases the buckling strength. Moreover, it is shown that buckling strength of the steel foam C-channel is sensitive to the second order Sobol' indices. In summary, it is shown in this research that the metal foams have a great potential to improve different types of structural responses, and there are many promising application for metal foam in civil structures.