

Safety Envelope for Load Tolerance Using Generalized Convex Hulls and its Application in Reliability Analysis

When more than one parameter is involved in load tolerance estimation, the safe region of the parameters constitutes a closed, multi-dimensional domain. The boundary of the domain is called the safety envelope. When one considers two parameters in a bi-variable case, and when the two parameters are gradually increased from zero, the initial safe structure becomes unsafe at certain values of the parameters. Due to the property of a truncated cone, a single failure boundary can be found when two parameters are increased proportionally. If all combinations of the parameter values that make the structure unsafe are connected, a closed envelope can be constructed. However, searching for all possible values of parameters is time consuming and, in many applications, impractical. The technical challenge is how to find the boundary of the envelope without using the trial-and-error approach.

Current Work

A convex hull based approach is used in this work to get this safety envelope. Uniformly spaced DOE in the space of variables of interest is created. The samples of the DoE are the mean of the design variables. There is a standard deviation and hence a failure probability associated with each sample. Samples can be grouped as per their failure probability values. Each group can be bounded by the convex hull. The boundary of the hull serves as the safety envelope. The proposed approach was demonstrated on a simple bi-axially loaded cantilevered beam problem. This example did not have a disjoint group. Another example namely the tuned mass damper features a disjoint group. That is, samples with the same values of failure probability appear in patches (for a 2D case) that are disjoint. We call this an island. The convex hull fails in the island situation and we use the alpha shapes to approximate the boundaries of the islands. The concept of alpha-hulls is a natural generalization of convex hulls. An alpha hull of a set of points is the space generated, edges constructed by point pairs that can be touched by an empty disc of radius alpha. Alpha hulls have curved edges resembling the curved disc periphery. When these curved edges are replaced by straight lines they are called alpha shapes. The boundaries of the alpha shapes are the safety envelope. Now that each sample is associated with a failure probability, the boundaries also provide additional information in terms of reliability.

Future Work

The idea of safety envelope is to see the capacity of the current design as a future reference for design upgrade. The current work, though obtained the safety envelope, estimated a failure probability at each DoE sample. This could be computationally expensive. The final paper will present a sequential sampling approach that will reduce the number of samples at which the failure probability is estimated to obtain the safety envelope. The approach will be extended and demonstrated to 3-D cases.