ABSTRACT

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Title: Stiffness Reduction Identification in Spring-Mass Systems Using Linear Parameterized Inverse Eigenvalue Problem Solution and Partial Natural Frequency Data
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In vibration-based damage detection in structures, often changes in the dynamic properties such as natural frequencies, modeshapes, and derivatives of modeshapes are used to identify the damaged elements. Typically, it is assumed that only the stiffness distribution of the structure changes while the mass distribution remains the same. If only a partial list of natural frequencies is known, optimization methods may need to be used to identify the damage. In this research, the algorithm proposed by Podlevskyi & Yaroshko (2013) to solve Linear Parameterized Inverse Eigenvalue problems in spring-mass systems is used to determine the stiffness distribution in moment-resisting-frame buildings modeled as spring-mass systems. The modeling resolution is at story level, i.e., lateral load elements in a story are represented as a single equivalent spring and masses are lumped at floor levels. The proposed method calculates stiffness values directly, i.e., without optimization, from the known partial list of natural frequency data and mass distribution. It is shown that if the number of stories with reduced stiffness is fewer than the number of known natural frequencies, at least one frequency can be used to select the most likely stiffness configuration case among all possible configurations obtained from the other known frequencies. Numerical studies on building models with two stories and four stories are used to illustrate the solution method. Effect of error or noise in given natural frequencies on stiffness estimates and, conversely, sensitivity of natural frequencies to changes in stiffness are studied using 7-, 15-, 30-, and 50-story numerical models with stiffness reduced in a single story. It is shown that as the number of stories increases, the natural frequencies become less sensitive to stiffness changes. Additionally, eight laboratory experiments were conducted on a five-story aluminum structural model. Ten slender columns were used in each story of the specimen. Damage was simulated by removing columns in one, two, or three stories. The method was able to locate and quantify the damage in all cases directly. In one case, an additional natural frequency was required to correct the effect of noise in lower mode frequencies. The method was also applied on an actual building,

a 7-story reinforced concrete building, for which partial lists of natural frequencies were obtained from vibration data before and after an earthquake. This particular application demonstrated the limits of the method in its current form when used on buildings where damage is widespread and for which the number of observed natural frequencies is fewer than number of damaged stories. Additional challenges in applying the method to actual buildings include difficulties in obtaining the mass and stiffness distribution in the undamaged system; the requirement that the natural frequencies used in the analysis are for the structure only, i.e., effects of soil-structure interaction removed from the data. Lastly, presence of inaccuracies in the given frequencies and how these might influence the results need to be considered properly.