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Top disconnection versus base disconnection in structures subjected to harmonic base excitation

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ABSTRACT

Aim of the present study is to investigate the opportunity of improving the dynamic response of a structure by making an intermediate disconnection through it. In this context it is of interest to wonder if the disconnection works mainly as tuned mass damper for the lower structure or it works mainly as base isolation for the upper structure. This paper is the first stage of this study. An archetype model, constituted by a simple two-degree of freedom system, has been taken as representative of structures provided with a disconnection, where a base isolation or a tuned mass damper scheme is used. The system has a constant total mass, while stiffness and mass ratios are taken as variable parameters. Two parameters capable of evaluating the efficiency of the disconnection, called the gain indicators, have been introduced, being the system subjected to an harmonic base excitation. Two different types of behavior maps, one referring to the base isolation and the other to the tuned mass damper, have been obtained. In these maps the regions where a base isolation or a tuned mass damper system works properly are well recognizable and it is also possible to point out some other regions of the parameters space where both systems work well.

1. Introduction

The use of the Base Isolation (*BI*) and of the Tuned Mass Damper (*TMD*) to reduce vibrations in structures is well known from several years. Many papers have been devoted to the study of these methods of protection of structures. Until some years ago, the *BI* and *TMD* have been treated as two distinct opportunities to improve the dynamic behavior of structures, due to their different intrinsic characteristics. Specifically, the *BI* works better when used in not very flexible structures subject to earthquake excitation, while the *TMD* is more suitable for flexible structures, under wind excitation, although some papers have demonstrated that *TMD*, especially in the case of high mass ratio, may represent a valid protection system against earthquake excitation as well.

It is interesting to note that, in a conceptual point of view, both these techniques are principally based on an appropriate "disconnection" (i.e. substantial variation of stiffness) of vibrating masses, therefore the basic differences between them are mainly represented by the location of the disconnection within the structure and by the "nature" of the masses (i.e. source of the mass and/or whether the mass represent something to be mainly protected). In *BI* the disconnection is typically located between the foundation and the upper structure who represents itself the vibrating mass, while the *TMD*, in its classical configuration, is a supplemental mass placed on the roof level and disconnected from the rest of the lower structure.

In the last years various studies have started to investigate the opportunity to move from the conceptual frame described above towards new and more complex solutions. For example, in [1,2] it is investigated the use of the *TMD*, shifted down on the first floor above the isolation layer, in a base isolated structure, in order to reduce the base displacements. On the other hand, the fact that a "suitably heavy" *TMD* may well perform as a protection device against the earthquake action, has suggested the basic idea that sufficient mass for the damper could be obtained from the structure to be protected itself, instead of adding supplemental and somehow functionally useless mass. This overall idea has been developed by researchers with different proposals, whose conceptual approach might be related to the characteristics pointed out before: the mass source and the location of the disconnection. However it must be highlighted that most of the works dedicated to this specific issue are principally focused on the search of the optimum parameters related to the disconnection layer (i.e. mass, damping and frequency ratios). In [3] an optimal design method for *TMD* with large mass ratio specifically developed to implement

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High-Damping Rubber Bearings (*HDRB*) to connect the device mass to the main structure is formulated. In [4,5] the mass of the damper is represented by the entire roof system of the building while the disconnection stands on top of the structure in a classical manner. In [6,7] entire portions of the structure (the substructures) are turned into vibrating masses with a uniform disconnection, along the building's height, with respect to the rest of the structure (the superstructure). In [8] new storeys (2 or 4) are placed on an isolation layer on the rooftop of an existing 12-storeys building, so that they can act as a *TMD* system to control the vibration of the lower structures. Although this latter paper deals with supplemental mass, added as a retrofitting strategy, it is possible to consider the overall structural model as the one of a unique structure with a mid-story disconnection and the mass of the upper portion turned into a *TMD*.

Regarding the mid-story disconnection, various works [9–11] have studied, analytically and experimentally, the dynamic behaviour of building structures equipped with an isolation layer, placed mainly above the 1st floor. Lately the performance of a mid-story disconnection in a structural system has been analysed in [12] where, using an energy approach, an optimal design method has been defined with the aim of protecting both the upper and lower structural portions divided by the isolation layer. Regarding the possibility to disconnect the structure at different levels, to improve its overall dynamic response, it would be of interest to wonder if the disconnection works mainly as tuned mass damper for the lower structure or it works mainly as base isolation for the upper structure.

This paper tries to give an answer to this question by introducing a simple two-degree of freedom model. Similarly to what performed in [13–16] and in most of the above mentioned works, a simple two-degree of freedom model may be taken, as a matter of fact, as representative of structures where a *BI*- or a *TMD*-scheme is used.

This "archetype" 2-DOF system has a constant total mass while stiffness and mass ratios, related to the two degrees of freedom, are taken as variable parameters, together with the frequency of the harmonic external base excitation. In is worth remarking that the validity of the proposed method does not depend on the nature of the excitation, then it can be used also in seismic analyses, by defining properly the seismic behavior maps.

An extensive parametric analysis is performed to characterize the system. Two different types of behaviour maps, one referring to the *BI* and the other to the *TMD*, are introduced. To make them comparable, they will be represented in the same parameters space. In these maps the regions, where a base isolation or a tuned mass damper system works properly, are well recognizable and, beside them, it is also possible to point out some other regions of the parameters space where both systems work well.

2. Archetype models

A main archetype two-degree of freedom model (2-*DOF*) with constant total mass m is used to describe the behaviour of general multi-degree of freedom systems in which a structural disconnection may be identified. A structural disconnection is hereby considered as a substantial variation in stiffness between two parts of a global structure. Such a variation is represented, within the proposed model, by means of an ideal cutting plane (discontinuity plane) that divides the system (with global mass m) in two parts (lower and upper structure) with mass m_1 and m_2, each one associated to the two degree of freedom of the model. In the main 2-*DOF* system this discontinuity plane can be represented exclusively by a physical disconnection (Fig. 1). It is worth remarking that, in real multi degree of freedom structures, such a discontinuity may not correspond to a proper physical disconnection, but it can represent a sudden change of some mechanical quantity of the system (i.e. stiffness of the system).

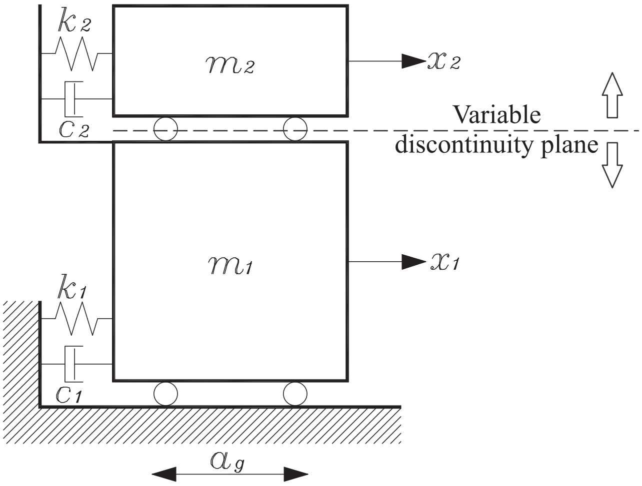

Fig. 1. Main two-degree of freedom system.

Two auxiliary single-degree of freedom systems ($S-DOF$) are introduced as reference cases.

2.1. Main two-degree of freedom model

The main structural model studied in this paper is a simple 2-*DOF* system (Fig. 1) subject to ground acceleration a_g. The total mass $m = m_1 + m_2$ is considered constant, while the ratio of the two masses is considered variable. According to Fig. 1, this configuration can be derived from an ideal block, with mass m, cut by a virtual horizontal plane at various heights. Both masses are linked to linear elastic springs whose stiffnesses are k_1 and k_2 and linear viscous dampers whose coefficients are c_1 and c_2.

Two dimensionless parameters are introduced to describe the variability of the disconnecting plane and of the stiffness of the linear springs. Specifically:

$$\mu = \frac{m_2}{m} = \frac{m_2}{m_1 + m_2} \qquad \rho = \frac{k_2}{k_1} \tag{1}$$

where μ is the mass ratio and ρ is the stiffness ratio. The parameter μ, consistently with a constant global mass m, is contained in the range $\mu \in [0.1, 0.9]$. It is of interest to note that when μ is equal to the extreme values of its definition range, the main 2-*DOF* may suggest some particular structural schemes (Fig. 2). Specifically, these schemes describe two different vibration reduction strategies, the Tuned Mass Damper (*TMD*, Fig. 2_a) and the Base Isolation (*BI*, Fig. 2_b), applied to a simple shear-type frame. Fig. 2 gives the occasion to explain better the relationships existing between the main 2-*DOF* and the real structure. The disconnection of the archetype model of Fig. 2_a in the *TMD*-scheme corresponds to a physical disconnection between the two masses m_1 and m_2 in the real structure; moreover this physical disconnection provides the possibility to realize the discontinuity of the stiffness in correspondence of the division line. On the contrary, the disconnection of the archetype model of Fig. 2_b in the *BI*-scheme does not correspond to a physical disconnection between the two masses in the real structure. In this case, the discontinuity of the stiffness in correspondence of the division line is obtained by reducing the stiffness of the lower part of the system, by introducing a physical disconnection at the base of the structure.

It is worth remarking that this study has been developed considering that two vibration reducing techniques, such as *TMD*