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EFFECTS OF ADDING OF VISCOUS DAMPERS IN FUNCTION OF THE MODEL OF DYNAMIC BEHAVIOUR OF BUILDINGS

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Abstract

This study examines the efficiency of the addition of viscous dampers on the dynamic response of regular buildings (i.e. with a periodicity in vertical direction) in function of their dynamic behavior model. The addition of viscous dampers is particularly interesting because these devices can be used with either new or existing structures, they are very reliable over time with little maintenance and require no energy source. By increasing the level of damping, resonance effect is reduced and dissipation increased, involving the decrease of the levels of displacement and stress in the structure. However, the activation of the dampers depends on the speed of their attachment points, generally proportional to the displacement between two levels. This latter depends of the behavior model of the building, and his level can be very different between shear and bending models. The model of behavior is also an important factor to take into account, under penalty of inefficiency of the device.

The procedure adopted in this study is based on homogenization method of idealized periodic buildings. This approach, which is purely analytical, allows the building of analytical models of dynamic behavior whose parameters are deduced from the material and geometric properties of the local elements. Applied on idealized periodic structures, this method had allowed in previous study to find the classical beam models, as shear or bending models but also no usual models as Timoshenko or Sandwich models. A generic model, including three basic mechanisms (one shear and two bendings), presented in [Hans&al., 2008] describes the whole behaviors and the three non-dimensional parameters allowing the assessment of the importance of each mechanism. In this study, the adding of viscous dampers is taken into account by the application the homogenization method. Consequently, a global modal integrating a new viscous parameter are obtained, what allows a parametric study of the effect of the dampers in function of the other non-dimensional parameter, i.e. in function of the type of the considered model: basic beams like shear beam or bending beams or more complex like Timoshenko or Sandwich beams.

In conclusion, the level of apparent damping is also studied in function of the different models of behavior and a design of the devices can be proposed.

Keywords: viscous dampers, behavior model, design

1. Introduction

This study examines the efficiency of the addition of viscous dampers on the dynamic response of regular buildings (i.e. with a periodicity in vertical direction) in function of their dynamic behavior model. The addition of viscous dampers is particularly interesting because these devices can be used with either new or existing structures, they are very reliable over time with little maintenance and require no energy source [1]. By increasing the level of damping, resonance effect is reduced and dissipation increased, involving the decrease of the levels of displacement and stress in the structure. However, the activation of the dampers depends on the speed of their attachment points, generally proportional to the displacement between two levels. This latter depends of the behavior model of the building, and his level can be very different between shear and bending models. The model of behavior is also an important factor to take into account, under penalty of inefficiency of the device.

The procedure used in this study lies on the modeling with homogenization method applied on periodic idealized buildings. This entirely analytical approach makes it possible to construct models of dynamic behavior whose parameters are deduced from the material and geometrical properties of the constituent elements. This results in general models incorporating the properties of the dampers and their arrangements in the structure. From the models obtained, the influence of the properties of the shock absorbers on the modal responses is evaluated, for different behavior models: shear beam, bending beam or more general models such as the Timoshenko or Sandwich beam. It is then possible to propose a pre-sizing of these devices according to the models studied. Some examples of dynamic responses illustrate the method.

2. Global description of dynamic behavior of regular periodic buildings

This paragraph summarizes previous work on the dynamic behavior of a periodic building class in vertical direction, the details of which can be found in [2,3]. This work has been motivated in particular by the fact that, for a long time, the dynamic behavior of periodically elevated buildings has been approached by continuous models of beams, such as the bending or shear beams – from the latter, in particular the formula T = N/10 – or, even more rarely, Timoshenko or Sandwich beams.

2.1 Periodic idealized buildings and method of scale change

To justify these beam models and to determine the set of possible behaviors for this class of periodic building, an analytical approach, based on the method of scaling called 'method of homogenization of discrete periodic media' [4, 5, 6] was conducted on a family of idealized periodic buildings. These idealized buildings consist of a repeat of a cell consisting of only two identical walls and a floor (Fig 1).

2.2.1 Framework

The working assumptions were as follows:

- the study range being limited to small deformations, the mechanical behavior of the materials is isotropic linear elastic,

- the study being carried out in the plane of the figure, the various elements are modeled as Euler-Bernoulli beams, perfectly connected to their junction massless points,

- one places oneself in harmonic mode, the variables are writing as D(x,t) = D(x) $e^{i\omega t}$; in the equations that follow, the term time $e^{i\omega t}$ is systematically omitted.

The applicability of this method of scale change is limited to the modes of vibration of large lengths, that is to say in practice to the first modes of vibration. This is linked to the introduction of a small scale parameter named ε defined by the ratio between the height ℓ of a level on the length characteristic of the studied mode L and thus:

$$\varepsilon = \frac{\ell}{L} \ll 1$$

It is shown [7] that the value of this parameter (linked to the studied mode) is $\varepsilon_k = \frac{(2k-1)\pi}{2N}$ with respectively k the mode number and N the number of levels.

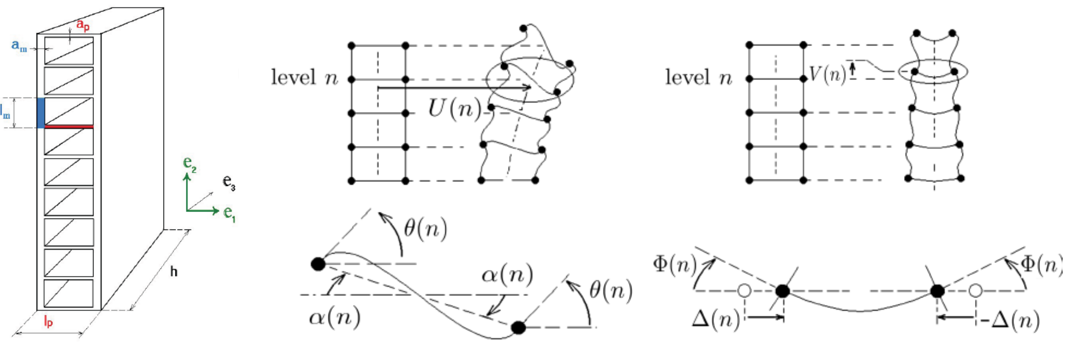

Fig. 1 – Left: the idealized building and the study plane (e1, e2)
Middle: the transverse kinematic – Right: the longitudinal kinematic.

2.2.2 Steps of the modeling

The modelling takes place in three phases:

- a phase of discretization of dynamic balance: the local dynamic balance of each beam is integrated according to the movements of the nodes, which allows, without loss of information, to rewrite the overall equilibrium at the level of the nodes of the system, with as new unknowns the movements of these nodes,

- a homogenisation phase: a continuous description of the variables is introduced in asymptotic form:

$$D(x) = D^0(x) + \varepsilon\, D^1(x) + \varepsilon^2\, D^2(x) + \cdots$$

and the contrasts between the mechanical and geometrical parameters of the various elements and also the frequency are weighted according to the powers of ε, what allows the mathematical translation of the balances between the different mechanical and dynamic efforts.

- the resolution phase: in the chosen frequency range, it is then possible to develop mathematically the different terms of the equilibrium equation in different order of ε. This parameter being considered mathematically as infinitely small, these balances of different orders can be separated, which leads to prioritizing phenomena according to their importance, order 0 being the dominant component, successive orders being less and less important components called 'correctors'.

In practice, the dominant order equations are used to determine the behaviour model, the effective value of ε allowing to define the degree of its precision.

2.2 Overview of possible models and associated criteria

For the transverse dynamics of this class of periodic buildings, a general model was found (Fig. 2). This model combines three basis mechanisms, characterized by a specific stiffness: a global bending mechanism (Euler-Bernoulli beam - EI), a shear mechanism (K) and an inner bending mechanism (EIμ). In function of the contrast of stiffness of the elements of the cell (storey) and of the number of cells, one or several mechanisms can be dominant. This generates different models, from the simpler (Bending or Shear) to the more complex (Timoshenko, Sandwich or Generic) (Fig.2).

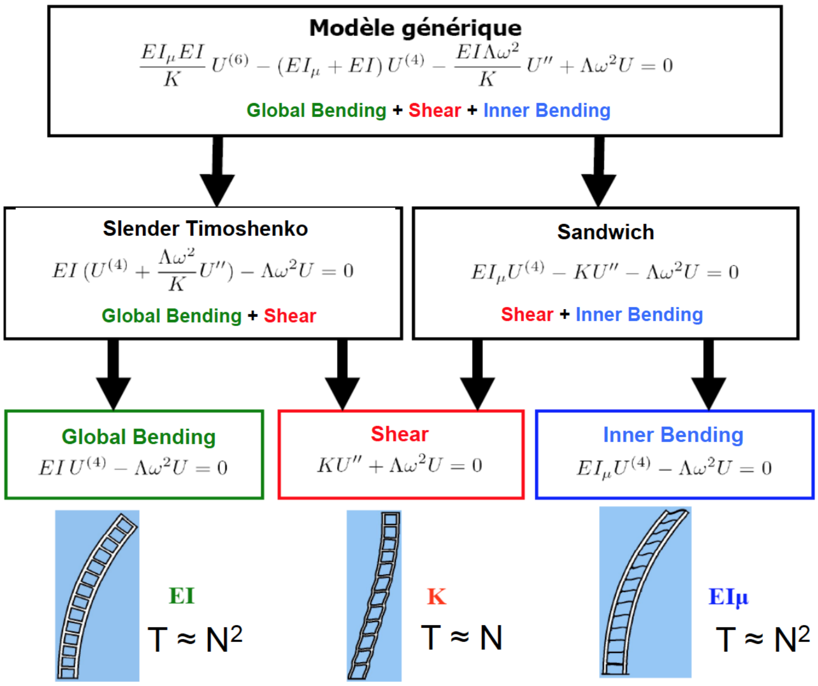

Fig. 2 – Overview of the possible models of dynamic behavior deriving from three basis models (T, the period of the fundamental mode, is proportional to N or N^2, the number of level, in the basis models).

The Generic Beam model can be described, like for an Euler-Bernoulli beam, by a set of two local balance equations, but three laws of behaviors (in place to one) between the kinematics variables U (displacement of the level) and α (rotation of a level) and the three macroscopic forces: T (shear force), M (global bending moment) and $\mathcal{M}$ (local bending moment) – see Figure 2 :

Local Balance

$$\mathbb{T}(x)' = \big(T(x) - \mathcal{M}'(x)\big)' = \Lambda\omega^2 U(x)$$

$$M'(x) + T(x) = 0$$

Behavior relations

$$T(x) = -K(U'(x) - \alpha(x))$$

$$M(x) = -EI\alpha'(x)$$

$$\mathcal{M}(x) = -EI_\mu\, U''(x)$$

By introducing non-dimensional parameters (C the ratio between the global bending stiffness and the shear stiffness and γ the contrast between the two bending stiffness), the Generic Beam model is described by the sixth degree equation:

$$C\gamma\, U^{(6)}(X) - (1+\gamma)U^{(4)}(X) - \Omega^2 U^{(2)}(X) + \frac{\Omega^2}{C} U(X) = 0$$

$$\text{with} \quad C = \frac{EI}{KL^2},\ \gamma = \frac{EI_\mu}{EI},\ \Omega^2 = \frac{\Lambda\omega^2 L^2}{K} \quad \text{et} \quad X = \frac{x}{L}$$

Then, from these parameters weighted with the scale parameter ϵ, the domain of validity of each models (derived of the Generic Beam model – Fig.2) can be drawn (Fig.3).

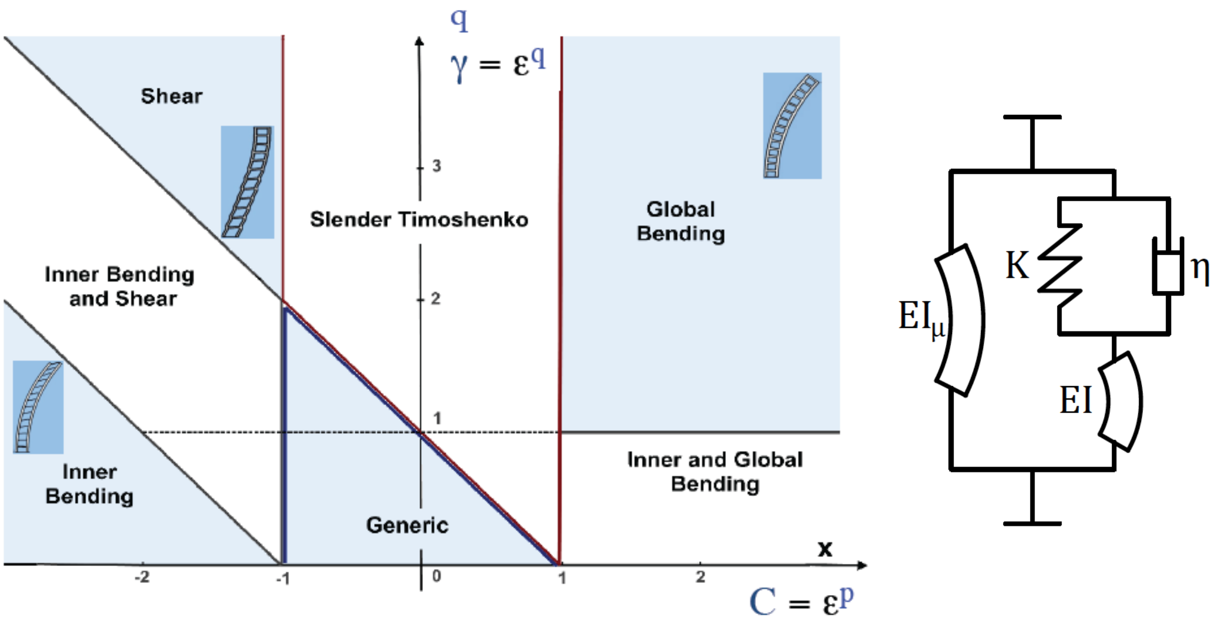

Fig. 3 – Domain of validity of beams models derived of the Generic Beam model and analogical representation of the model.

2.3 Calculus of the eigenmodes

The modes of the Generic beam model can be calculated analytically, with the clamped-free limit conditions, which are deduced from the energetic formulation of the model (Kinetic energy = Work of limit conditions + Elastic energy):

$$\frac{1}{2}\int_0^H \Lambda\omega^2 U^2 dx = \frac{1}{2}[\mathbb{T}(x)U(x) + M(x)\alpha(x) + \mathcal{M}(x)U'^{(x)}]_0^H + \frac{1}{2}\int_0^H \left(\frac{T^2}{K} + \frac{M^2}{EI} + \frac{\mathcal{M}^2}{EI_\mu}\right)dx$$

Limits conditions: $\{U(0) = 0, \alpha(0) = 0,\ U'(0) = 0\}$ $\{\mathbb{T}(H) = 0,\ M(H) = 0,\ \mathcal{M}(H) = 0\}$

This leads to the calculus of eigenfrequencies ω_i and eigenvectors $\phi_i^U\, and\ \phi_i^\alpha$, whose orthogonal properties are:

$$\int_0^H \Lambda\phi_i^U\phi_j^U dx = 0 \ \ si\ i \neq j$$

$$\int_0^H \left(\frac{T_iT_j}{K} + \frac{M_iM_j}{EI} + \frac{\mathcal{M}_i\mathcal{M}_j}{EI_\mu}\right)dx = 0 \quad si \quad i \neq j$$

with the relationships between the eigenvectors $\phi_i^U\, and\ \phi_i^\alpha$, and also the eigenfrequencies:

$$\phi_i^{\alpha}(x) = \phi_i^{U'}(x) + \frac{EI}{K}\left(\frac{\Lambda\omega^2}{K}\phi_i^{U'}(x) + \phi_i^{U^{(3)}}(x) - \frac{EI_\mu}{K}\phi_i^{U^{(5)}}(x)\right)$$

$$\omega_i{}^2 = \frac{\int_0^H \left(\frac{T_i{}^2}{K} + \frac{M_i{}^2}{EI} + \frac{\mathcal{M}_i{}^2}{EI_\mu}\right)dx}{\int_0^H \Lambda\phi_i^{U^2} dx}$$

3. Effect of addition of dampers on the models

3.1 Studied case and modification in equations of the generic beam model

The addition of linear viscous dampers on the two diagonals of each level is now considered. The effort generated is proportional to the differential speed between the anchor points. In this configuration, the structure remains symmetrical and the longitudinal and transverse directions remain decoupled. The study is resumed, considering various orders of magnitude of the parameter η of the linear viscous dampers.

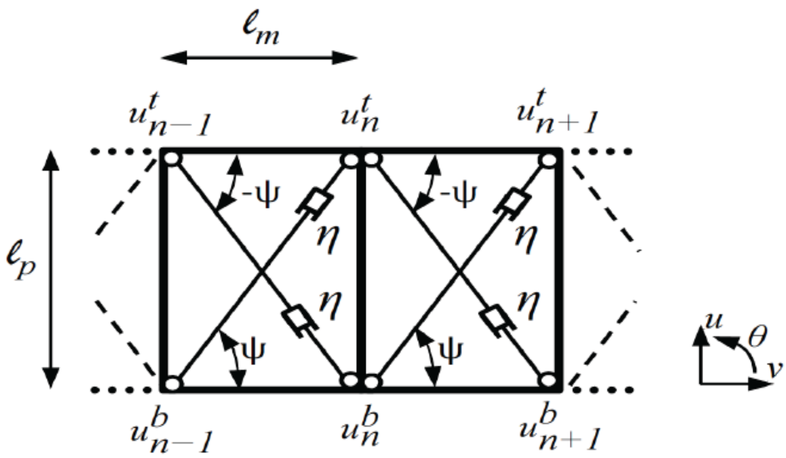

Fig. 4 – Position of the viscous dampers (building drawn horizontally)

The addition of diagonal shock absorbers induces in the generic model a change in the law of behaviour of the shear force, with a complex stiffness parameter K^*.

$$T^*(x) = -K^*(U'(x) - \alpha(x))$$
$$\text{with } K^* = K + i\eta\omega\ell$$

3.2 Effects on the models

The new model is scaled as previously:

$$\frac{C\gamma}{\mathscr{k}} U^{(6)}(X) - (1+\gamma)U^{(4)}(X) - \frac{\Omega^2}{\mathscr{k}} U^{(2)}(X) + \frac{\Omega^2}{C} U(X) = 0$$
$$\text{with } \mathscr{k} = \frac{K^*}{K} = 1 + i\,A \text{ and } A = \frac{\eta\omega\ell}{K}$$

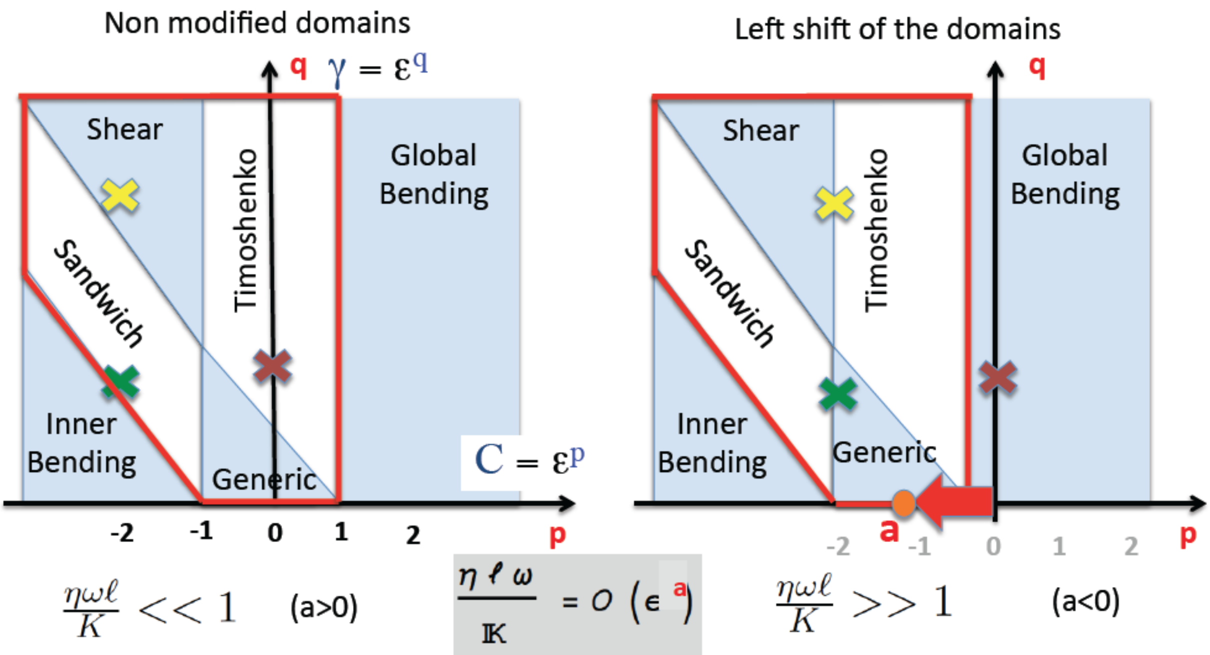

Fig. 5 – Effect of the dampers parameter on the domains of validity of the models

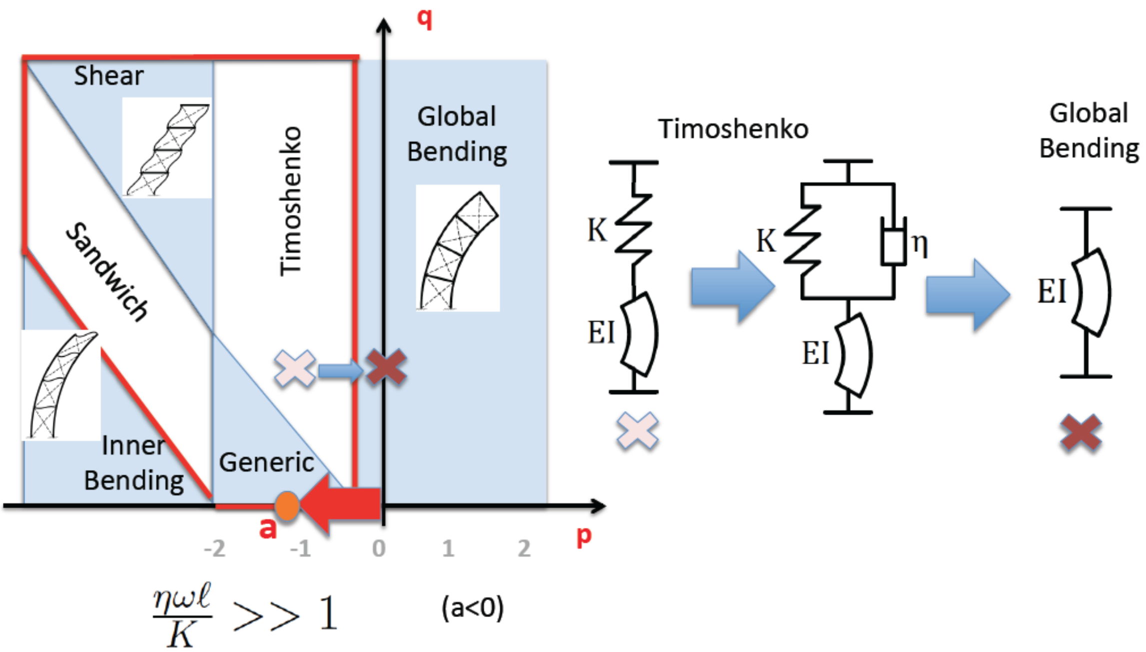

Fig. 6 – Modification of Timoshenko beam model into a Global Bending beam model by addition of dampers.

The original model is modified by a new non dimensional parameter $\hbar$, in which the effects of the addition of the dampers is taking into account in the non dimensional parameter $A = \frac{\eta\omega\ell}{K}$. Two situations are then possible depending on the order of magnitude of this latter parameter:

1. This parameter A is small compared to 1, and the mapping of the models is not changed.
2. If the order of magnitude of this parameter is greater than 1, the limits of the models shift to the left (Fig.5), especially as the order of this parameter increases.

In this second case, the model can be modified (Fig.5 & Fig.6) and for example, a Timoshenko beam (brown cross) can derived into a global bending beam if the dampers bring enough 'stiffness' in the system.

3.3 Links between dampers and damping of the structure

The damping of the structure depends obviously of the characteristic (parameter η) of the dampers. But not only: the nature of the initial model (without dampers) has also to be considered. This is illustrated on Fig. 6 in the case of a Timoshenko model with very stiff dampers: in this case, the addition of dampers turns the Timoshenko model into a Global Bending model and unfortunately, the effect of the dampers on the damping of the structure becomes negligible.

On the figure 7, the calculation of complex frequencies for different types of model is conducted: Shear, Sandwich and Global Bending. In the case of the shear beam model, there is usually a decrease in the real frequency in parallel with the rapid increase in the rate of damping, then with the shift of behaviour towards an global bending model, a decrease in damping and an increase in frequency are observed, showing that the dampers act also as stiffeners. For the global bending beam model, the addition of dampers in this way, whatever their properties are, is virtually inefficient.

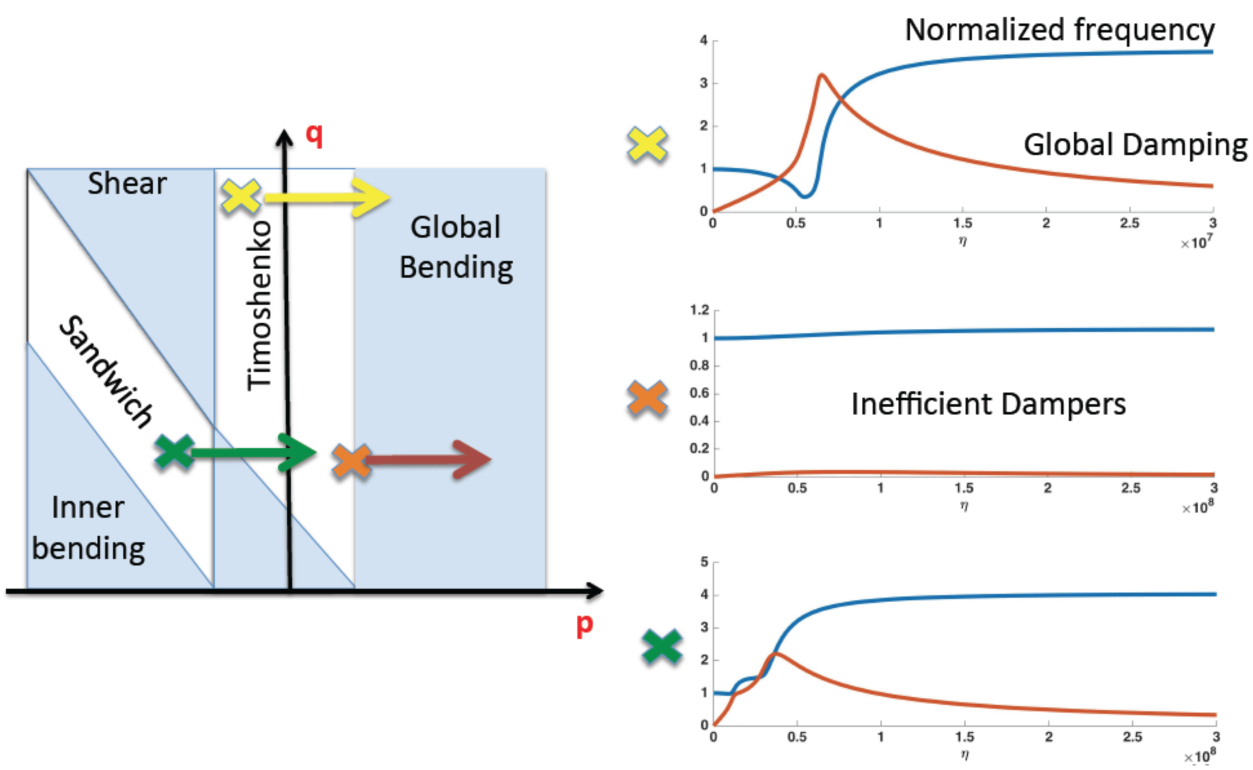

Fig. 7 – Effects of the dampers on the fundamental frequency and on the level of damping of buildings in function of their original behavior.

3.4 Dynamic equation under earthquake with dampers

In the following, the natural modes (cf. 2.3) are used to partially decoupled the dynamic equation of the Generic model, considering the situation of a building with dampers under earthquake solicitation. By taking the following decomposition on the modes and taking into account their orthogonality:

$$U(x,t) = \sum_i \ s_i(t)\phi_i^U(x) \quad \text{and} \quad \alpha(x,t) = \sum_i \ s_i(t)\phi_i^\alpha(x)$$

It comes:

$$\ddot{s}_K(t) + \frac{\eta\ell}{K} \ \frac{\int_0^H \frac{T_i T_K}{K} dx + T_i(H)\phi_K^U(H)}{\int_0^H \Lambda \phi_K^{U^2} dx} \dot{s}_i(t) + \omega_K^2 \, s_K(t) = \ -\frac{\int_0^H \Lambda \phi_K^U dx}{\int_0^H \Lambda \phi_K^{U^2} dx} \, A_{soil}(t)$$

It appears that the damping terms implies a coupling effect of the modes. With weak level of damping, this coupling disappears. Note that for shear beam model, this coupling also is negligible. But for others models, this coupling induces a transfer of energy between the different modes.

With these equations, it becomes possible to evaluate the level of real damping induced by adding of dampers in function of the characteristics of the building.

4. Conclusion

This article presents a theoretical study on the effect of the adding of dampers in buildings in function of their dynamic behavior. It was shown that this effect depends of the type of behavior, in particular, for buildings whose behavior can be approached like global bending beam, it is necessary to be very careful how add dampers, if a real effect is expected.

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