Creative Design of Earthquake Resistant Tall Building Structures and Bridge Structures

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Summary

The design concept of earthquake-resistant structures is presented. The response of the structure under dynamic loading is interpreted on the base of modal analysis. Some modes are not dangerous for the safety of the structure and it is advantageous, when the big portion of the input energy is related to these modes. Modal shapes are connected to stiffness- and mass-distribution of the structure. The main idea is to optimize the stiffness- and mass-distribution in the structure considering the desired mode shapes. The structural topology optimization is applied. Mathematical tools of the optimization are sensitivity analysis and evolutionary procedures. Useful applications are shown in examples of tall building structures and bridge structures.

Keywords: Structure; tall building; bridge; optimization; topology; dynamics; modal analysis; earthquake; stiffness; mass density.

1. Introduction

The presented paper deals with earthquake-resistant structure design. Supports (support area) are considered as a part of designed structure. Analysis of modal contributions during dynamic motion enables to separate the forces and related energy, which influences the design.

2. Design – Structural topology optimization

The main idea is the control of the structural motion. The objective is to maximize the input energy consumption in allowed direction. In our case that means to maximize the rigid mode contribution among all considered modes of the structure. The objective is to maximize the term of the first mode and minimize reminder terms. Variables are stiffness densities of elements and support locations respectively. The density volume is constrained (density is related to stiffness).

$$\max\left(\boldsymbol{\varphi}_1 q_1 + \left\{\boldsymbol{\varphi}_2 q_2 + \ldots + \boldsymbol{\varphi}_N q_N\right\}^{-1}\right) \qquad V\left(\rho\left(k\right)\right) \le V \tag{1}$$

The optimization uses sensitivity analysis and evolutionary procedure.

3. Examples

3.1 Building structure example

The initial 2D finite element model of the building structure has a rectangular form with constant density and stiffness distribution. Supports in the bottom are horizontally excited. The objective and constraint are defined in (1). The above mentioned optimization algorithm gives result of the stiffness distribution shoved in the fig.1. The lowest values of material density and stuffness are obtained in the bottom of the structure. The results of this example are applicable in civil engineer practice. The layer in bottom serves as base isolation.

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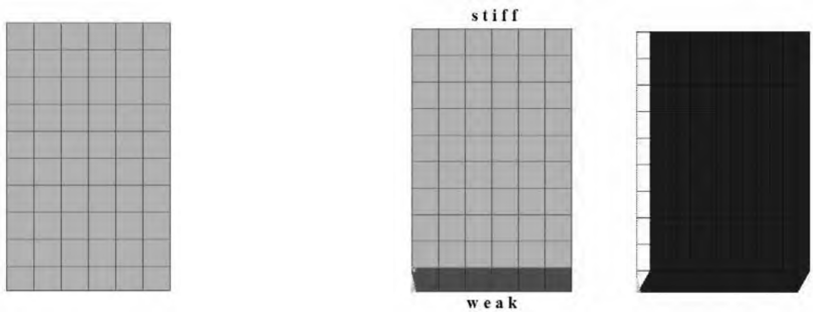

Fig.1: The initial and the optimized structure and the first mode

3.2 Bridge structure example

The constant force distribution (the force is time dependent) on the beam is given. The support area under the beam is optimized. We obtain a constant stiffness distribution under the beam or supports with the same stiffness in every node of the beam (fig.2). The first mode is “rigid body mode”. The technical application in suspension bridge structure is in this case realized with help of vertical cables. The idea is illustrated in fig.3.

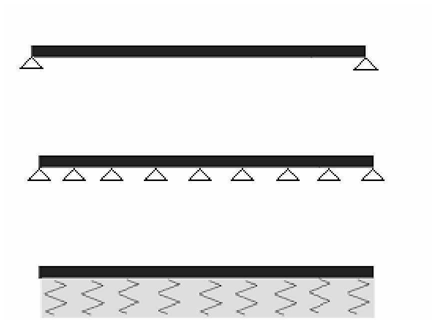

Fig.2: Support variation

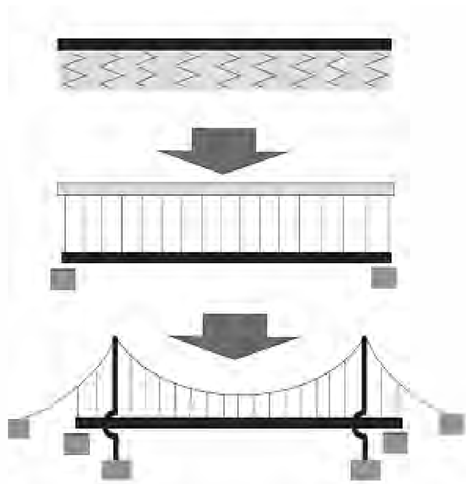

Fig.3:Analogical supports

4. Conclusion

The “rigid body” mode of structure is in some cases advantageous for behavior of dynamically loaded civil structures. Support design of structures influences the vibration modes.
Maximization of the part of the original input energy, which is going to be changed into the motion energy of the “rigid body” leads to safe behavior of the structure. The base isolation of buildings and the suspension bridge structural schema is legitimate because of this reason.

5. References

[1] ROSKO P., Simple civil structure models and earthquake excitation, In: *Proceedings of the 8th U.S. National Conference on Earthquake Engineering, Paper No.1924*, San Francisco, 2006, pp. 1-8.