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硕 士 学 位 论 文

风激励高层建筑基准问题的振动控制研究

Research on Vibration Control for Benchmark Problem of Wind-Excited Tall Buildings

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摘 要

随着我国经济的快速发展和人民生活水平的不断提高，城市化进程日益加剧。为了解决更多城市人口的居住问题，高层、超高层建筑大量兴起。众所周知，地震和飓风是严重危害人类的自然灾害。尤其是最近 20 余年全球发生了许多大地震和强烈龙卷风，造成了非常惨重的生命财产损失。由于人们不能事先准确地知道将来可能遇到的外荷载的大小和特性，而按传统方法设计的结构不具备根据外荷载的变化而变化的自我调节能力，因此即便是按很高的抗震设防烈度来设计，也很难保证高层、超高层结构在遭受到地震作用或飓风侵袭时的安全性。近年来迅速发展的结构振动控制技术为解决上述问题提供了一种有效的途径。因此高层、超高层结构的地震、风振控制研究，是摆在结构工程师面前的一个重大课题。本文在前人研究的基础上，以 Benchmark 模型作为研究对象对主动控制问题进行了研究。主要完成的工作如下：

从历届的国际结构控制大会中可以看出，高层建筑风激励振动控制问题一直是结构工程师致力讨论和研究的重点课题。本文通过对 76 层高层建筑风激励模型进行自由度缩减和降阶处理，得到大大简化的评估模型。运用不同的控制方法和控制策略对基准问题高层建筑在脉动风荷载作用下的位移、速度和加速度响应量进行分析，提出基于随机分析的均方根响应和基于确定性分析的峰值响应两种性能指标。对控制策略施加设计约束条件，并合理设计采样控制器以比较无控结构、TMD 控制结构和 LQG 控制结构在相同风激励作用下的均方根响应和峰值响应。最后评价和比较各种不同控制策略的性能指标和优化效果，以达到最优控制的目的。

仍以 76 层高层建筑风激励模型为研究对象，首先建立一套风荷载方程，然后阐述体系状态噪声测量法的风激励高层建筑的随机最优控制问题。接着将部分可观体系的随机最优控制问题转换成基于分离原理的完全可观体系的控制问题。再建立一套降阶平均 *Itô* 方程，此方程的模态能量通过运用拟可积 Hamilton 体系和有限时间及半无限时间控制动态规划方程的随机平均法得到。通过求解动态规划方程得到最优控制力，通过求解状态方程得到结构的响应，最后运用 NSO 控制算法求得数值解并与 LQG 算法求得的解答进行比较。得出一个重要的结论：NSO 控制算法比 LQG 控制算法更加有效和适用。

关键词：风激励；高层建筑；振动控制

ABSTRACT

With the rapid development of our economy and the increasing improvement of people's living standard, the urbanization progress is sharpening. In order to solve the housing problem for more urban population, high and high-rise buildings are built in a large amount. As is known to all, earthquakes and hurricanes are natural disasters seriously harmful to human beings. Especially in recent 20 years our nature has occurred many earthquakes and strong tornadoes, which has caused great damages and heavy losses of lives and property. Since people can't in advance precisely predict the magnitude and the property of external loads that may apply to our buildings in the future, and the structures don’t have the ability to adapt to the varied external loads by means of traditional design methods, therefore, it is very difficult to ensure the safety of high and high-rise buildings when they are subject to seismic action or strong wind action even though they are designed according to very high fortification intensity. In recent years, the rapid development of structural vibration control technology has helped to provide an efficient way in solving the above problem. Hence, the research of seismic and wind vibration control for high and high-rise buildings is a major issue confronting structural engineers. Regarding the Benchmark model as the research subject, this paper conducts the research on active control problem on the basis of previous studies. Main completed works are as follows:

The problem of vibration control for wind-excited tall buildings has been a key issue that structural engineers devote to discussing and researching, which can be easily figured out from all the previous International Conferences on Structural Control. This paper derives a greatly simplified evaluation model through DOF condensation and order reduction for a 76-storey wind-excited tall building. It makes analysis the response quantities of displacement, velocity and acceleration for the benchmark problem of tall buildings under pulse wind excitations by using different control methods and control strategies, puts forward two different kinds of performance criteria: RMS responses based on stochastic analysis and peak responses based on deterministic analysis. It imposes constraints on the proposed control

strategies, adequately designs sample controller for a comparison of RMS responses and peak responses of uncontrolled structure, TMD controlled structure and LQG controlled structure subject to the same wind excitations. In conclusion, some evaluations and comparisons are also made among performance criteria and optimization effects of various control strategies to obtain optimal control in this paper.

Still regard the 76-story tall building under wind excitation as the object of study. First of all, a set of equations for wind excitation are established, then the problem of stochastic optimal control for wind-excited tall buildings by means of noise contaminated measurement of system state is set forth. Then the stochastic optimal control problem of partially observable system is converted into that of completely observable system based on the separation principle. A set of dimension-reduced averaged Itoˆ equations for modal energies is obtained by using the stochastic averaging method for quasi-integral Hamiltonian system and the dynamical programming equations for finite time-interval and semi-infinite time interval controls are established. The optimal control force is obtained from solving the dynamical programming equation and the responses of the uncontrolled and controlled tall buildings are predicted from solving the system state equation. Finally, numerical result are obtained and compared with that obtained using LQG controller. We draw a very important conclusion that the results obtained from NSO control strategy is more effective and efficient than those obtained by using LQG controller.

Key Words: Wind excitation; Tall Buildings; Vibration Control

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