

Abstract

The modal equation of motion is the foundation of structural dynamics, which plays a key role in earthquake engineering computations. Each modal equation of motion has a corresponding single-degree-of-freedom (SDOF) modal system. Thus, the modal equation of motion and the corresponding SDOF modal system are regarded as the most basic elements synthesizing the motion of the original multiple-degree-of-freedom (MDOF) structure. Modal response history analyses are widely used in structural dynamic analyses due to the efficiency in calculation and the clarity in conception. Although the vibration modes are only meaningful for elastic structures, the inelastic SDOF modal systems have also been developed based on the pushover curve representing the relationship of roof translation versus base shear for the original MDOF structure. The stated inelastic SDOF modal systems are widely applied to earthquake engineering. One of such applications is using inelastic response spectra to estimate the seismic demands of original MDOF structures. In recent years, the modal response history analyses considering the effects of higher vibration modes were proposed to approximately estimate the seismic responses of inelastic MDOF structures. However, there are three relationships of two roof translations versus two base shears and one roof rotation versus one base torque simultaneously available for two-way asymmetric-plan buildings subjected to seismic loads. Moreover, the pushover curves representing the stated three relationships in acceleration-displacement response spectra (ADRS) format are bifurcated after the original MDOF structure becomes inelastic. Thus, it is unable to use the conventional SDOF modal system to simultaneously simulate the stated three force-deformation relationships for inelastic asymmetric-plan structures. This research decomposed the SDOF modal equation of motion into a set of three coupled equations of motion for two-way asymmetric-plan structures. The mentioned set of three coupled equations of motion is called as three-degree-of-freedom (3DOF) modal equation of motion. The 3DOF modal system corresponding to each 3DOF modal equation of motion was constructed. The elastic properties of the 3DOF modal system are exactly obtained from the corresponding 3DOF modal equation of motion. The inelastic properties of the 3DOF modal system are determined from the properties of the mentioned three pushover curves of the original MDOF structure. It is verified that the modal response history analyses by using the proposed 3DOF modal systems for two-way asymmetric-plan inelastic building systems are more satisfactory than those by using conventional SDOF modal systems. It is also validated that the proposed 3DOF modal equations of motion are advantageous to the modal response history analyses for non-proportionally damped two-way asymmetric-plan elastic building systems.

Keywords: modal analysis, modal system, asymmetric-plan structure, nonlinear history analysis, non-proportional damping

摘要

振態運動方程式是結構動力的基礎，而結構動力在地震工程中扮演極重要的角色。每一個振態運動方程式都有一個相對應的單自由度(SDOF)振態系統，因此振態運動方程式與 SDOF 振態系統被視為是組成多自由度結構體運動的最基本要素。由於具備高效率的計算與簡易的觀念，振態歷時分析已被廣泛應用於各種結構的受震反應分析。雖然只有彈性結構具有不變的振態，但藉由振態側推分析，可以得到原多自由度結構屋頂位移與基底剪力的受力變形關係，由此非線性受力變形關係曲線，非彈性的 SDOF 振態系統亦被提出。此種非彈性的 SDOF 振態系統已廣泛地應用於地震工程當中，例如採用非彈性反應譜來估計多自由度結構的受震反應需求。在近幾年，一種能夠考慮結構高振態貢獻的振態分析已被發展與廣泛討論。然而，在振態側推分析雙向平面不對稱結構時，同時有兩個屋頂平移與基底剪力及屋頂旋轉與基底扭力的三種受力變形關係存在，並且當原多自由度結構進入非彈性時，代表前述三種受力變形關係的側推曲線在加速度一位移反應譜(ADRS)格式中會有分叉的現象產生。因此傳統 SDOF 振態系統無法同時模擬前述雙向平面不對稱非彈性結構的三種受力變形關係。本研究將雙向平面不對稱結構的振態運動方程式進一步分解成一組三個藕和的運動方程式，此一組三個藕和的運動方程式即稱為三個自由度(3DOF)振態運動方程式，並建立對應於此振態運動方程式的 3DOF 振態系統。利用 3DOF 振態運動方程式可精確求得 3DOF 振態系統的彈性參數，而藉由前述三種受力變形關係的側推曲線可以求得 3DOF 振態系統的非彈性參數。本研究證明採用 3DOF 振態系統對雙向平面不對稱結構進行振態歷時分析較採用傳統 SDOF 振態系統有效。本研亦究證實利用 3DOF 振態運動方程式可有效分析具非比例阻尼的雙向平面不對稱彈性結構的受震反應。

關鍵詞：振態分析、振態系統、平面不對稱結構、非線性歷時分析、非比例阻尼

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