Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (41) No. (3) July, 2019

REVIEW FOR TIME PERIOD FORMULAS FOR SHEAR WALL (SW) BUILDINGS AND MOMENT RESISTING FRAME (MRF) BUILDINGS

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ملخص البحث:
الزمن الدورى الأساسى للأجسام بما في ذلك المنشآت هو الزمن اللازم لإتمام اهتزازة كاملة ويمكن اختباره للمنشآت عندما يتعرض المنشأ لأحمال ديناميكية ناتجة من سيارة متحركة، قطار متحرك أو زلزال ... إلخ. الزمن الدورى الأساسى يُعتبر من أهم المتغيرات التى تعتمد عليها معادلات اكواد الزلازل لحساب القوى العرضية المؤثرة على المنشأ. علاوةً على ذلك فإن جميع اكواد الزلازل تُقدم معادلات وضعية لحساب الزمن الدورى الأساسى لجميع أنواع المنشآت. تم إستخدام التحليل الانحدارى لاستنتاج هذه المعادلات لحساب الزمن الدورى الأساسى اعتماداً على البيانات المستنتجة من استخدام برنامج حاسوبى او من تلك المسجلة للمنشآت المهتزة تحت تأثير الزلازل في مناطق مختلفة من العالم. يقدم هذا البحث مراجعه للعديد من الأبحاث السابقة التى قدمت معادلات محسنة لحساب الزمن الدورى لمنشآت حوائط القص او التى يكون النظام الإنشائى لها إطارات مقاومة للعزوم.

Abstract

It is important to estimate the value of time period of vibrating structures to simulate the response to dynamic loads. The most important property that affects the dynamic response of buildings is the vibration time period (*T*). All of the building codes provide height dependent formulas to estimate the value of fundamental time period. Also, many researchers devoted their efforts to propose enhanced formulas using regression analysis for estimating *T*. This research targets to review some of the pioneer achievements in developing *T* formulas for both shear wall (SW) buildings and moment resisting frames (MRF) buildings.

Keywords: Seismic codes, Time period formula, Shear wall buildings, MRF buildings.

1. Introduction

Earthquakes are the most dangerous natural hazards which cause loss of life and money. Therefore, it is important to design the buildings to withstand the ground motions resulting from earthquakes. Indeed, the vibration time period of buildings (the time consumed to endure a complete vibration cycle) is the most important dynamic property. There are two methods for determining *T* of structures. The first method is experimental measurements by installing accelerographs in the examined buildings; the second method is numerical modal analysis which is performed through three dimensional (3-D) finite element analysis (FEA) of examined buildings by proper computer software. After determining the values of T either experimentally or numerically, regression analysis is carried out to propose mathematical formulas.

2. Use of Regression Analysis in Deriving Time Period Formulas

Regression analysis method is a statistical process for estimating the association between a scalar dependent variable and one or more independent variables. Researchers use various types of regression analysis such as constrained and unconstrained regression analysis (**Gilles and McClure (2011), Velani and Ramancharla (2017) and Goel and Chopra (1997)**), simple linear regression analysis (**Hong and Hwang (2000), Chiauzzi, Masi, Mucciarelli, Cassidy, Kutyn, Traber, Ventura and Yao (2012), Vaidya and Awchat (2016), Balkaya and Kalkan (2003) and Crowley and Pinho (2006),** multiple linear regression analysis (**Velani and Ramancharla (2017), Chun, Yang, Chang and Lee (2000) and Kim and Lee (2014)**) and non-linear regression analysis (**Balkaya and Kalkan (2003)**) for proposing time period formula. Generally, this method is widely used by researchers (**Goel and Chopra (1998)**, **Ditommaso, Vona, Gallipoli and Mucciarelli (2013)**, **Chun, Yang, Chang and Lee (2000)**, **Chiauzzi, Masi, Mucciarelli, Cassidy, Kutyn, Traber, Ventura and Yao (2012)**, **Naveen, Shetty and Kumar (2015)**, **Hadzima-Nyarko, Moric, Draganic and Stefic (2015) and Gong, Sun and Xie (2011)**) to propose the vibration time period formulas.

3. Time period Formulas for Reinforced Concrete SW Buildings

This section is divided into two subsections; the first subsection is concerning with the researches proposed formulas for estimating *T* based on experimental observation and the second subsection is concerning with the researches proposed formulas for estimating *T* based on numerical simulation and also the analytically achieved formulas.

3.1 Time period Formulas for Reinforced Concrete SW Buildings Based on Experimental Measurements

Badkoubeh and Massumi (2017) compared the values of vibration periods measured during California earthquakes with those obtained from building codes. The comparison shows that the codes formulas lead to longer vibration periods and consequently underestimated base shear force. The researcher improved a simple expression for estimating the fundamental *T* starting with Rayleigh's method. The improved expression meets the lower bond of measured periods.

Ditommaso, Vona, Gallipoli and Mucciarelli (2013) performed regression analysis to propose an empirical relationship to estimate fundamental *T* as a function of building height. The values of fundamental *T* were measured experimentally for Sixty eight reinforced concrete buildings in southern Italy. Data were recorded using a portable three-directional tromometer (Micromed Tromino) after the 2009 L'Aquila earthquake. The values of *T* were estimated using the horizontal to vertical spectral ratio (HVSR) method. Damaged and undamaged buildings were considered with heights range from 11 up to 27 m and age of construction from 1905 to 2000. They found that the fundamental periods obtained from building codes are longer than those obtained experimentally for both damaged and undamaged buildings. They recommended that it is important to take into account the influence of damaged or undamaged of non-structural elements in the evaluation of time period formula.

Chiauzzi, Masi, Mucciarelli, Cassidy, Kutyn, Traber, Ventura and Yao (2012) performed regression analysis to improve a height dependent expression for estimating the fundamental *T* for reinforced concrete SW buildings. They measured the fundamental time period of twelve reinforced concrete SW buildings experimentally by a digital tri-directional tromometer. The studied buildings located on the west coast of Canada and their heights are between 12 and 70 meters. Finally, they compared the experimentally obtained fundamental periods with those obtained by building codes and concluded that the values of *T* achieved by codes expressions are longer.

Kwon and Kim (2010) evaluated the time period formulas in seismic design codes for several reinforced concrete SW buildings based on experimental measurements. The results show that the code formulas overestimate the measured periods.

Chun, Yang, Chang and Lee (2000) performed regression analysis to produce a simple expression for determining the fundamental *T* as a function of building height and the SW length per unit plan area. They carried out full scale measurements on reinforced concrete SW buildings in Korea to produce enhanced expression and to compare the results of fundamental *T* with those obtained from building codes. Fifty Reinforced concrete SW buildings with heights range from 40 up to 53.5 m were encountered through this study. Two couples of accelerometers (Dytran Model 3191A with 5.0 V/g sensitivity and 0.1Hz to 1.0 kHz frequency range) perpendicular to each other were set on the top floor of the buildings to measure the dynamic response. They concluded that the values of *T* obtained from local code formula are much shorter for longitudinal direction and longer for transverse direction than those measured experimentally.

Goel and Chopra (1998) proposed a new mathematical expression based on Dunkerley's method by using regression analysis for estimating the values of fundamental *T*. They compared the fundamental *T* of sixteen SW buildings recorded during several earthquakes in California with those evaluated from empirical code formulas and they concluded that the codes expressions result in overestimated *T* which produce non-conservative design base shear. Also, they improved an upper limit factor for the value of vibration periods calculated from modal analysis using computer software.

3.2 Time period Formulas for Reinforced Concrete SW Buildings Based on Numerical Simulation

Naveen, Shetty and Kumar (2015) employed regression analysis to propose simple formulas for estimating the value of fundamental *T* for reinforced concrete buildings. The researchers used finite element software package to perform 3-D modal analysis to estimate the values of fundamental *T* of fifty four open stilt floor buildings with shear walls (SW). The studied buildings were regular and irregular. Both of them were modeled with different heights (10, 15 and 20 meters) and with three different soils (hard rock, medium soil and soft soil). They estimated three formulas to estimate *T* as a function of building height for each type of soil and another general formula for all studied buildings. Also, they concluded that the value of *T* does not depend only on the height but also depend on other features like type of irregularity, soil type, structure stiffness and building materials.

Kim and Lee (2014) accomplished a study to propose formula for determining fundamental *T* of reinforced concrete staggered wall system structures. Thirty two buildings (sixteen buildings without a middle corridor and another sixteen buildings with a middle corridor) were modeled using Midas Gen software (**Midas, 2013**) with various numbers of stories (8, 12, 16 and 20 stories) and various span lengths. The values of fundamental *T* were calculated numerically by modal analysis. Regression analysis was utilized to produce a formula to estimate the value of fundamental *T* as a function of building height and the effective area of walls along the direction under consideration. Finally, they concluded that the value of fundamental *T* of staggered wall structures are very close to those of shear walls structures with similar dimensions.

Balkaya and Kalkan (2003) carried out non-linear regression analysis to propose an empirical expression for estimating *T* of reinforced concrete buildings. They used ETABS software (**CSI, 2001**) to perform 3-D modal analysis of eighty reinforced concrete SW buildings of tunnel form to estimate the values of fundamental *T* numerically. The proposed formula estimates the fundamental *T* as a function of the total height of the building, the ratio of longitudinal to transverse dimension, the ratio of transverse SW area to total floor area, the ratio of longitudinal SW area to total floor area, ratio of minimum SW area to total floor area and the polar moment of inertia of the plan. The proposed formula matched well with the numerical analysis results.

4. Time period Formulas for Reinforced Concrete or Steel MRF Buildings

This section reviews the past researches which concerning with the fundamental *T* of MRF. This section is divided into two subsections; the first subsection is concerning with the researches proposed formulas for estimating *T* based on experimental observation and the second subsection is concerning with the researches proposed formulas for estimating *T* based on numerical simulation.

4.1 Time period Formulas for Reinforced Concrete or Steel MRF Buildings Based on Experimental Measurements

Gong, Sun and Xie (2011) carried out regression analysis to propose a new formula for estimating *T* as a function of building height for steel MRF. Thirty six buildings were investigated and the values of vibration periods were measured experimentally (before and after damage) during earthquake events. They used the measured periods before damaging to propose this expression for estimating the values of fundamental *T*. Also, they noticed that the periods of damaged buildings are longer than those of initial state.

Kwon and Kim (2010) assessed the time period formulas in seismic design codes for several reinforced concrete and steel MRF buildings based on experimental measurements. The results show that the code formulas fitted the lower limit of measured periods well.

Masi and Vona (2010) conducted an investigation on two reinforced concrete MRF buildings in southern Italy which were experienced to ground motion. Modal analyses were performed to estimate the fundamental *T* for the undamaged states while the values of fundamental *T* for damaged states were determined experimentally using ambient vibration method. They also proposed a laboratory test on a prototype reinforced concrete MRF. The test model was subjected to strong ground motion using shaking table in order to inspect the damage evolution in terms of fundamental period elongation. The results show that the buildings subjected to moderate ground motions have longer values of fundamental *T* with maximum period elongation around 15-30%. Meanwhile, the buildings subjected to strong ground motion have longer values of fundamental *T* with maximum period elongation around 40-50%.

Guler, Yuksel and Kocak (2008) proposed an experimental study on reinforced concrete MRF with infill walls located in Turkey. They measured the values of *T* for six reinforced concrete MRF buildings using the ambient vibration method. The measured values of *T* were used to check the accuracy of the expression developed by the researchers based on numerical simulation. The results show that the mathematical expression provides an accurate estimation of *T* with an average error of 13.1%. Finally, they concluded that the proposed expression can be used for estimating the value of fundamental *T* for mid-rise reinforced concrete MRF in Turkey.

Hong and Hwang (2000) carried out regression analysis to propose a height dependent formula for reinforced concrete MRF buildings. They investigated and measured the fundamental *T* of twenty one reinforced concrete MRF buildings in Taiwan which were experienced to moderate intensity ground motion. Buildings have various heights (between 8.45 and 77.1m), various length and width. The results show that the building height is the most important independent variable in estimating the period formulas. Also, they concluded that the measured periods of Taiwanese buildings are shorter than those measured in California because buildings in Taiwan are stiffer so that they recommended developing specific formula for each region based on design and adopted construction tradition.

Goel and Chopra (1997) carried out constrained and unconstrained regression analysis to propose enhanced expressions for estimating the values of fundamental *T* based on experimentally measured data. They compared the fundamental *T* of twenty seven reinforced concrete MRF buildings and forty two steel MRF recorded during several earthquakes in California with those evaluated from empirical code formulas. The results show that that the expressions in building codes result in periods which are much smaller than measured period especially for steel MRF. The proposed expressions provide good improvement for those presented in building codes. Also, they improved an upper limit factor for the period calculated from modal analysis using computer software.

4.2 Time period Formulas for Reinforced Concrete or Steel MRF Buildings Based on Numerical Simulation

Vaidya and Awchat (2016) provided a parametric study on irregular reinforced concrete MRF buildings to evaluate the height dependent formulas proposed by building codes. They prepared 556 buildings with various type of irregularity (horizontal, vertical, mass and torsional irregularity). A computer software package was used to analyze these buildings and to calculate the values of fundamental *T* based on Rayleigh’s method. They recommended improving a multivariable power model formula to estimate the fundamental *T* taking in consideration the effect of irregularities.

Varadharajana, Sehgal and Saini (2014) performed regression analysis to propose a new empirical formula for estimating the values of fundamental *T* for reinforced concrete MRF buildings. They used the periods of 305 buildings with different types of set-back irregularities. Finally, they found that the proposed expression provides an accurate estimation of *T*.

Kocak and Yildirim (2011) employed regression analysis to evaluate an empirical formula for estimating *T* reinforced concrete MRF buildings in Turkey. They used a computer software package to perform 3-D modal analysis to estimate the values of *T* and to accomplish a numerical study to examine the effect of infill walls area on the fundamental *T* for reinforced concrete MRF buildings. Four buildings were studied with various numbers of stories (3, 6, 9 and 11 stories) and various condition of infill walls layout. They found that the values of *T* decrease significantly with increasing of the infill walls area. Finally, they used.

Kose (2009) carried out regression analysis to propose an enhanced formula for estimating the fundamental *T* reinforced concrete MRF. The researcher used a finite element software package to perform 3-D modal analysis to estimate *T*. 189 buildings were prepared with various parameters (Building height, number of bays, ratio of the

SW area to floor plan area, ratio of infilled panels to total number of panels and frame type). the results show that the presence of infill walls shortens the vibration period by 5%-10% and also the presence of SW shorten the vibration period by 6%-10%. The formula proposed by local code underestimates the fundamental *T* by 2%-47% and the proposed one provide more realistic estimation of *T*.

Guler, Yuksel and Kocak (2008) carried out regression analysis to propose simple expression to estimate the values of *T* for reinforced concrete MRF buildings with infill walls. Eight buildings which located in Turkey were modeled with number of stories varies between 4 and 11 stories using SAP2000 software (**CSI, 2000**). The values of *T* were obtained numerically from 3-D modal analysis for each direction based on eigenvalue analysis. Finally, they concluded that the proposed expression can be used for estimating the value of fundamental *T* for mid-rise reinforced concrete MRF in Turkey.

Crowley and Pinho (2006) carried out regression analysis to propose a height dependent formula for estimating the values of fundamental *T* for reinforced concrete MRF. They used SeismoStruct software (**SeismoSoft, 2006**) to calculate the fundamental *T* based on eigenvalue analysis for eleven reinforced concrete MRF buildings with infill panels. The studied buildings (located in five different European countries) have overall heights vary between 6 and 24 meters. The proposed formula provides an accurate estimation of fundamental *T* for similar buildings.

5. Conclusions

1. Time period is the most important property which affects the dynamic response of buildings.
2. There are two methods of determining the time period of a structure; the first is experimentally by installing accelerographs in the examined buildings and the second is numerically by performing three dimensional modal analysis using computer software package.
3. Regression analysis is widely used by researchers for proposing time period formulas.
4. Time period formulas presented in building codes are inadequate especially for SW buildings.
5. Time period formulas which introduced by building codes for MRF buildings provides acceptable estimation.

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