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Predictive equations for fundamental period of steel moment frames considering the effects of irregularity in the floor plan and height and soil-structure interaction

M. J. Hamidia*, F. Nejabati
Department of Civil, Water and Environmental Engineering, Shahid Beheshti University, Tehran, Iran

ABSTRACT: Robust estimation of the fundamental elastic period of the buildings is essential for obtaining realistic seismic base shear. Seismic design codes provide a variety of equations to calculate the fundamental elastic period of vibration for steel moment frame buildings. The empirical equations are mainly based on the building height and do not take into account the effects of irregularity and soil-structure interaction. In this paper, an empirical predictive equation is developed to estimate the fundamental elastic period of steel moment frames. The predictive equation includes parameters that represent irregularity effects and soil-structure interaction. The database used in this study consists of architectural and geotechnical data for 45 building cases. The proposed predictive equation shows satisfactory accuracy. The predicted results are then compared to the values obtained from Iranian 2800 seismic design code, ASCE7-16 and UBC-97. The proposed predictive equation is also verified by 10 fundamental elastic periods obtained from analytical models. The fundamental elastic period was derived using the predictive equations that are specifically more accurate for mid- and high-rise buildings compared to seismic design codes. The values obtained from seismic codes are well below the realistic values for the buildings.

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1- Introduction

Earthquake is one of the risks that can cause irreparable loss of life and property. The response of any structure in the elastic state relies solely on the fundamental period and damping ratio of the structure. In the nonlinear regime also, the fundamental period of the structure is one of the most important parameters in the quantification of the seismic response of structures; In the initial analysis stage for seismic design, it is necessary to accurately estimate the fundamental period of vibration of the building in order to calculate the base shear force. The equation stated in the Earthquake Design Regulations (2800) [1] to calculate the fundamental period of buildings is obtained by modification to the equations of various regulations such as UBC [2]. In the equation presented in Iranian Standard 2800 (Fourth Edition), among the structural specifications, only the height of the building is considered, which can reduce the accuracy of the recent equation because, for two buildings of the same height with different dimensions in the plan and different heights and conditions of the building soil, they yield an identical fundamental period. Also, in 2014, Yang and Adeli [3] analyzed 24-moment frame models, including regular, irregular in plan, and irregular in height, to provide an experimental equation to estimate the period time of steel moment frame, in addition to the height of the building, it uses the Parameters of the ratio of average height to maximum floor height and also the ratio of the average dimension to the maximum dimension in the desired direction.

2- Methodology

Given the above issues, the parameter of height and the consideration of irregular effects on the plan and height of the building in the experimental equation of fundamental period can greatly impact its accuracy. In this paper, first by extracting the fundamental period, architectural and geotechnical information of 23 real moment frame steel structure (Table 1) has estimated the experimental equation of the main period time by considering irregular effects in the plan and height and interaction and comparing it with the equation between 2800, ASCE7-16 [4] and UBC-97 standards. Then, the proposed equation was validated using 10 fundamental periods obtained from analytical modeling of real structures in Tehran (Table 2).

In Tables 1 and 2, H is the height of the structure in meters from the base level, h_{ave} / h_{max} ratio of average floor height to maximum floor height, D_{ave} / D_{max} ratio of the average building dimension to the maximum available dimension, A_{ave} / A_{max} is the ratio of the average floor area to the maximum

*Corresponding author's email: m_hamidia@sbu.ac.ir

Table 1. Mean and standard deviation of experimental data

	***Height*(m)**	h_{ave}/h_{max}	D_{ave}/D_{max}	A_{ave}/A_{max}	V_{s30}/V_{max}	***T*(sec)**
Mean	36.22	0.79	0.95	0.84	0.25	1.61
SD	21.61	0.19	0.12	0.19	0.09	0.89

Table 2. Mean and standard deviation of analytical data

	***Height*(m)**	h_{ave}/h_{max}	D_{ave}/D_{max}	A_{ave}/A_{max}	V_{s30}/V_{max}	***T*(sec)**
Mean	37.85	0.83	0.91	0.71	0.37	1.89
SD	11.5	0.07	0.06	0.14	0.09	0.54

available area, and V_{s30}/V_{max} Shear waves speed up to a depth of 30 meters from the site to its maximum. In this paper, the maximum speed of shear waves is 1500 meters per second.

Equation 1 shows the empirical equation with the above-mentioned 4 dimensionless variables along with the height of the building for a more accurate estimate of the period time:

$$T_e = 0.05(H)^{0.85}\left(\frac{h_{ave}}{h_{max}}\right)^{-0.08}\left(\frac{D_{ave}}{D_{max}}\right)^{-0.44}\left(\frac{A_{ave}}{A_{max}}\right)^{0.25} 1.88^{\left(1-\frac{v_{s,30}}{v_{max}}\right)} \qquad (1)$$

provided by ASCE7-16 and the real periodicity values. (c) Shows the period time values provided by UBC-97 and the real period time values, as is clear from these forms, equation proposed by 2800, ASCE7-16, UBC-97 standards do not have acceptable accuracy, forms, equation proposed by 2800, ASCE7-16, UBC-97 standards do not have acceptable accuracy, especially for values of period time greater than 2 seconds, and the proposed equation have a favorable estimate.

3- Results and Discussion

Figure 1 shows the values of predicted fundamental period values obtained by Equation 1 proposed in this paper, the values obtained using 2800, ASCE7-16 and UBC-97 seismic codes, all versus the measured fundamental period values for experimental database.

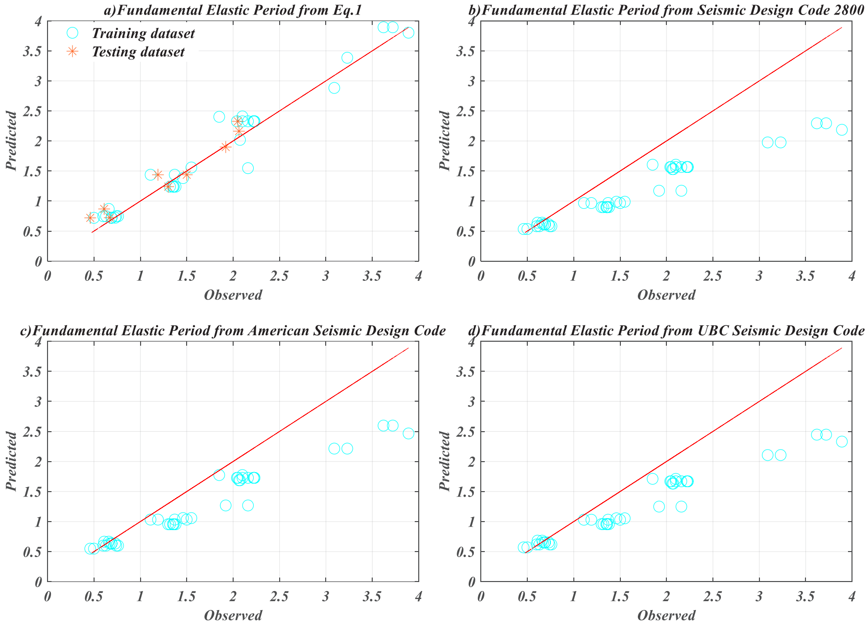

Fig. 1. Comparison of fundamental periods obtained from Equation 7, 2800, ASCE7-16 and UBC-97 seismic codes

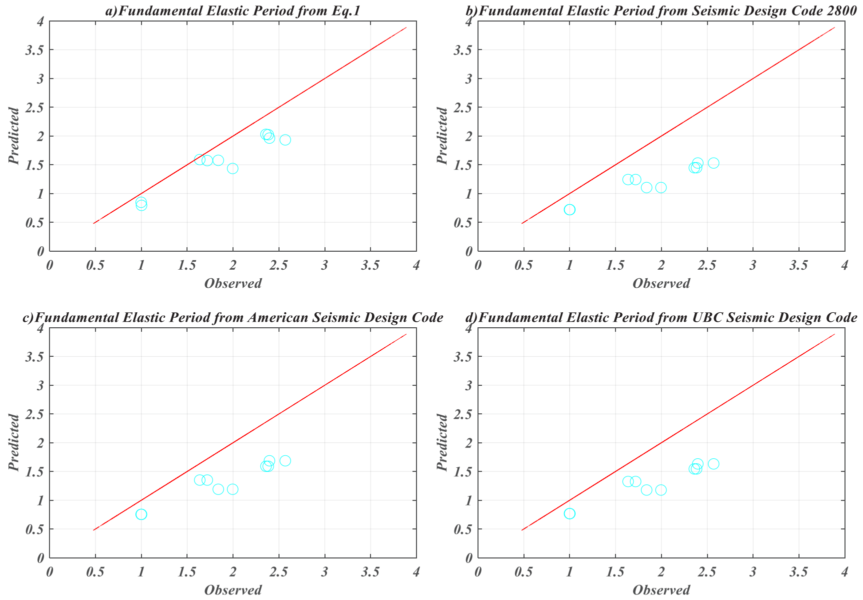

Fig. 2. Comparison of fundamental periods for numerical cases obtained from Equation 7, 2800, ASCE7-16 and UBC-97 seismic codes

Figure 2 shows the values of predicted fundamental period values obtained by Equation 1 proposed in this paper, the values obtained using 2800, ASCE7-16 and UBC-97 seismic codes, all versus the derived fundamental period values for the numerical database.

As clearly shown in the Figures, equations proposed by 2800, ASCE7-16, UBC-97 standards do not have acceptable accuracy, especially for values of period time greater than 1.5 seconds, and the proposed equation has acceptable accuracy.

4- Conclusion

In this paper, an empirical equation is developed for estimating the fundamental period of the steel frame buildings. The proposed equation has acceptable accuracy. The following results indicate the accuracy of the proposed equation compared to the existing seismic code equations:

1. The root mean square of error (*RMSE*) for training the proposed formula for 45 field databases is 0.2, the RMSE for test data is equal to 0.18, the RMSE of the equation prescribed by 2800 is equal to 0.62, the value for ASCE7-16 equation is equal to 0.5, and for the UBC-97 equation is equal to 0.54.

2. The *RMSE* of the proposed equation for 10 data from the numerical dataset equals 0.36. The corresponding value for the 2800 seismic code equals 0.74, the value for ASCE7-16 seismic code equals 0.63 and the value for UBC-97 seismic code is equal to 0.66.

3- The coefficient of determination (R^2) for training the proposed equation for 45 field databases equals 0.96. The corresponding value for the testing dataset with the proposed equation test, the 2800 seismic code equation, the ASCE7-16 seismic code equation, and the UBC-97 seismic code equation are all equal to 0.95.

4- The coefficient of determination (R^2) for training the proposed equation for 10 numerical databases equals 0.91. The corresponding value for the testing dataset with the proposed equation test, the 2800 seismic code equation, the ASCE7-16 seismic code equation, and the UBC-97 seismic code equation are all equal to 0.90.

Medium- and high-rise steel moment frame structures located in the descending region of the reflection spectrum benefit the most from the proposed equation by the reduction in the base shear force.

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