A Comparison between Initial and Effective Fundamental Period of RC Frames with Steel Eccentric Bracing

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Abstract: In earthquake resistant designs the value of fundamental period needs to be set close to reality. Special emphasis can be placed on designs which are based either on static equivalent method or performance level. The static equivalent method employs the seismic factor which is strongly dependant on fundamental period. Also during the later design, target displacement is directly connected with square of fundamental period. In this connection most of seismic codes (including Iranian National Seismic Standard) offer an experimental equation distributed for different structural systems to present fundamental period. To make sure for required modifications on seismic design codes, one hundred eighty concrete moment resisting frames with steel eccentric braces has been considered to capture vibration period by performing two-dimensional nonlinear pushover analyses. Pushover Analyses have been conducted using SAP-2000 program, which can consider material nonlinearities almost near reality. In this case the applied forces have been considered as the lateral forces of the Seismic Standard. At the end, fundamental period and effective fundamental period both derived by analysis and the experimental has been discussed concerning bracing kind of spans, length of link beam and height of structure. Analytical results confirm the validity of the experimental equation for presenting fundamental period in the case of reminded frames.

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1. Introduction

Structure's attitudes toward the moderate and major earthquakes lie in inelastic ranges, so inelastic analysis should be selected for them. But because of the time and cost concerns, lack of comprehensiveness of inelastic analysis softwares, and availability of elastic methods (or other practical methods), the designs are preferred to be conducted by elastic analysis together with seismic reduced forces (Hoseinzadeh, 2010). Reducing strength of structure from elastic strength is usually introduced by strength reduction factor. In this regard, the building codes extract seismic loads of inelastic designs from a linear spectrum (Fig. 1) which is dependent on natural period of structure, and ground zone type (Tasnimi et al., 2007).

One of the important dynamic properties of buildings toward the seismic vibrations is natural period defined as the time required for one cycle of simple harmonic motion. Dynamic excitations induce dynamic loads that are greater than the static loads into the buildings. Also, for the excitation with shorter natural period, the greater loads are expected. But the conclusion is not completed because the response spectrum of structure should be contemplated. Generally the response of structure is dependent on response spectrum which is calculated based on maximum response of a single degree freedom system at various periods or frequencies. This put more emphasize on investigation the period of vibration which can be conducted by one of analytical or experimental methods.

Under the provisions of NEHRP, UBC, SEAOC, ATC3-06, and Iranian Code (issued in 1988 and revised in 2005) vibration period of buildings can be extracted experimentally by:

$$\begin{cases} T = 0.08H^{0.75} & \textit{for steel frame} \\ T = 0.07H^{0.75} & \textit{for concrete frame} \\ T = 0.05H^{0.75} & \textit{for other system} \end{cases} \quad (1)$$

To make a point, one eighty concrete moment resisting frames by eccentric braces, designed based on the Iranian National Seismic Standard, has been considered to capture seismic parameters by performing two-dimensional nonlinear pushover analyses. This paper has made more intense study on reliability of Equation 1, which is suggested by the mentioned codes. Seismic parameters including fundamental period and effective fundamental period are excerpted then investigated in connection with length of link beam, bracing kind of spans and height of building.

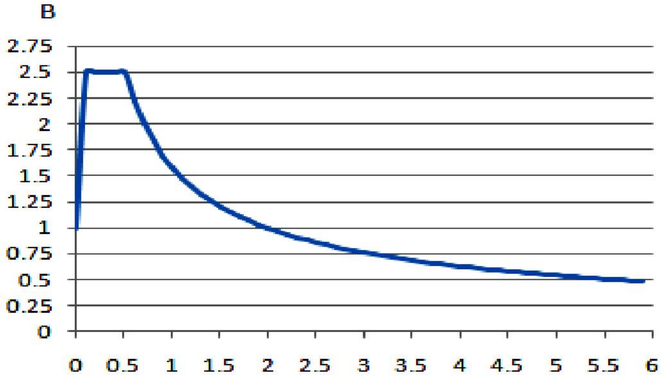

Fig. 1 linear spectrum of Period-Reflection Factor at ground type 2 (Iranian Code).

2. Materials and Methods

Fundamental period is directly derived by solving the characteristic equation (equation 2) while acquiring aid of Equation 3, sets value of initial vibration period (Chopra, 1995).

$$\left|[K]-\omega^2[M]\right|=0 \qquad (2)$$

$$T_i = 2\pi / \omega_i \qquad (3)$$

Where $[K],[M],\omega$ respectively are stiffness matrix, mass matrix and modal frequency of structure. T_i is defined as fundamental (initial) period and ω_i is initial frequency of structure. Effective fundamental period needs referring to bilinear diagram belonging to Roof Drift/Shear Base curve (Figs. 2, 3) in case of structure under lateral displacement up to the target point (Code-360).

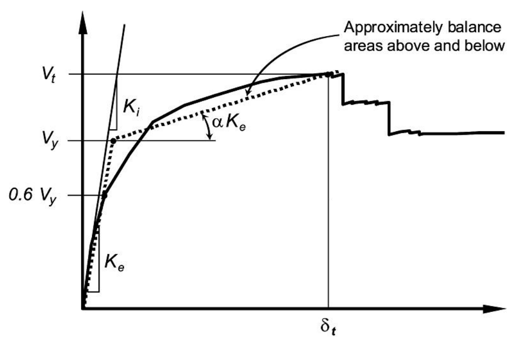

Figure 2. Idealized force displacement curves, Positive post-yield slope (FEMA-356).

Figs. 2, 3 employ K_i, K_e respectively as initial stiffness and effective stiffness

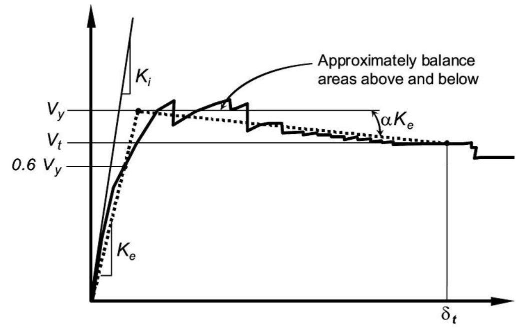

Figure 3. Idealized force displacement curves, Negative post-yield slope (FEMA-356).

V_y is referred to shear base of total yielding, also δ_y, δ_t are displacement at yield base shear and target displacement. Now effective fundamental period can be calculated from:

$$T_e = T_i \sqrt{\frac{K_i}{K_e}} \qquad (4)$$

3. Results

To draw a concrete conclusion, wide variety of concrete frame structures has been scrutinized under earthquake designs. One hundred eighty braced moment resisting frames giving variety in number of stories (1, 2, 4, 6, 8, 10, 12, 14, 15), bracing kinds of spans, length of link beam (0.5, 1, 1.5, 2 meters) and number of spans (1, 3) have been investigated under elastic-inelastic analysis procedures. Also the five models applied for bracing the spans are plotted at Fig. 4. Analysis methodology covering provision of Iranian Code has been followed by using SAP-2000 (version 12) computer program which consider both gravity and lateral loads. Details of the frames profile in this study are presented at Tables 1, 2.

Zone Type	High Risk Level
Ground Type	Type 2
Ductility of building	Intermediate
Frame Type	Middle
Length of Loading Span	4 m
Length of Spans	4 m
Height of Stories	3.2
Dead Load	550 kg/m^2
Live Load	200 kg/m^2
Equivalent Partition Load	100 kg/m^2

Table 1. Characteristics of frames.

Concrete	F_c	240 kg/cm^2
	V	0.15
	E	2100000 kg/cm^2
Bar	V	0.3
	E	2100000 kg/cm^2
	F_y	3000 kg/cm^2
Brace	V	0.3
	E	2100000 kg/cm^2
	F_y	2400 kg/cm^2
	F_u	3700 kg/cm^2

Table 2. Properties of materials.

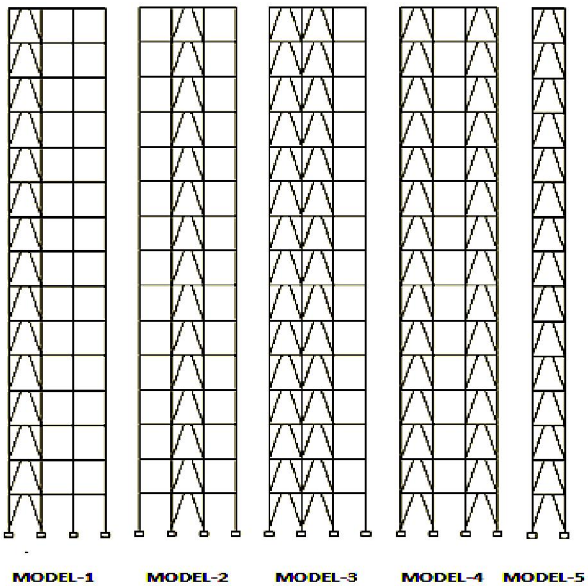

Figure 4. Number of bracing models.

4. Discussion

Generally speaking, vibration period of structures in the first mode can be taken as fundamental period. The application of fundamental period can be extended to finding response factor of building during static equivalence method. Also fundamental period has been presented by Iranian Code by Equation 1; with this in mind the third term of the equation addresses all unmentioned structural systems. On the other side, effective fundamental period, required to make bilinear pushover curve, is mostly functional at estimating target displacements during the designs based on performance level.

In this section, three types of diagrams discuss the vibration period in connection with bracing kind of spans, length of link beam, and height of building. Because of attending wide variety of buildings and weighty structural elaborations, presenting results has been abbreviated only to averages for two first items.

Attention in Fig. 5 will be focused on the effects of bracing type of spans on the vibration period. In the usual sense adding the number of bracing spans is associated with rising in stiffness. So, shorter vibration periods are expected in this condition as we can see at Fig. 5.

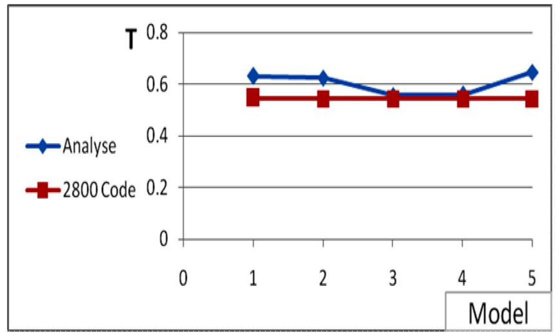

Fig. 5 Variation of vibration period considering bracing kind of spans.

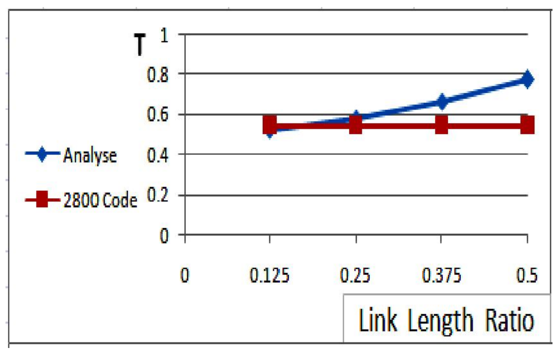

Fig. 6 Variation of vibration period considering length of link beam.

Length of link beam over the span beam is concerned in Fig. 6 to present vibration period. In this connection increasing length of link beam has led to rise vibration period.

Investigating variation of vibration period via height of building has been depicted in Figure 7. The values for fundamental period and effective fundamental period both extracted by analysis, together with fundamental period calculated by Iranian Code (third term of equation 1) are included respectively by red, blue and green pencils with this in mind the red and blue lines have been coincided in almost all of the Figure's presentations. By this presents, fundamental period in the first mode can be taken as effective fundamental period.

To make a conclusion, the averages of parameters in Fig. 7, have been gathered in Fig. 8. By this mean the analytical equation ($T=0.057H^{0.75}$) is suggested to assess validity of the equation 1. Close fitness is observable through the Fig. 8 to support the idea.

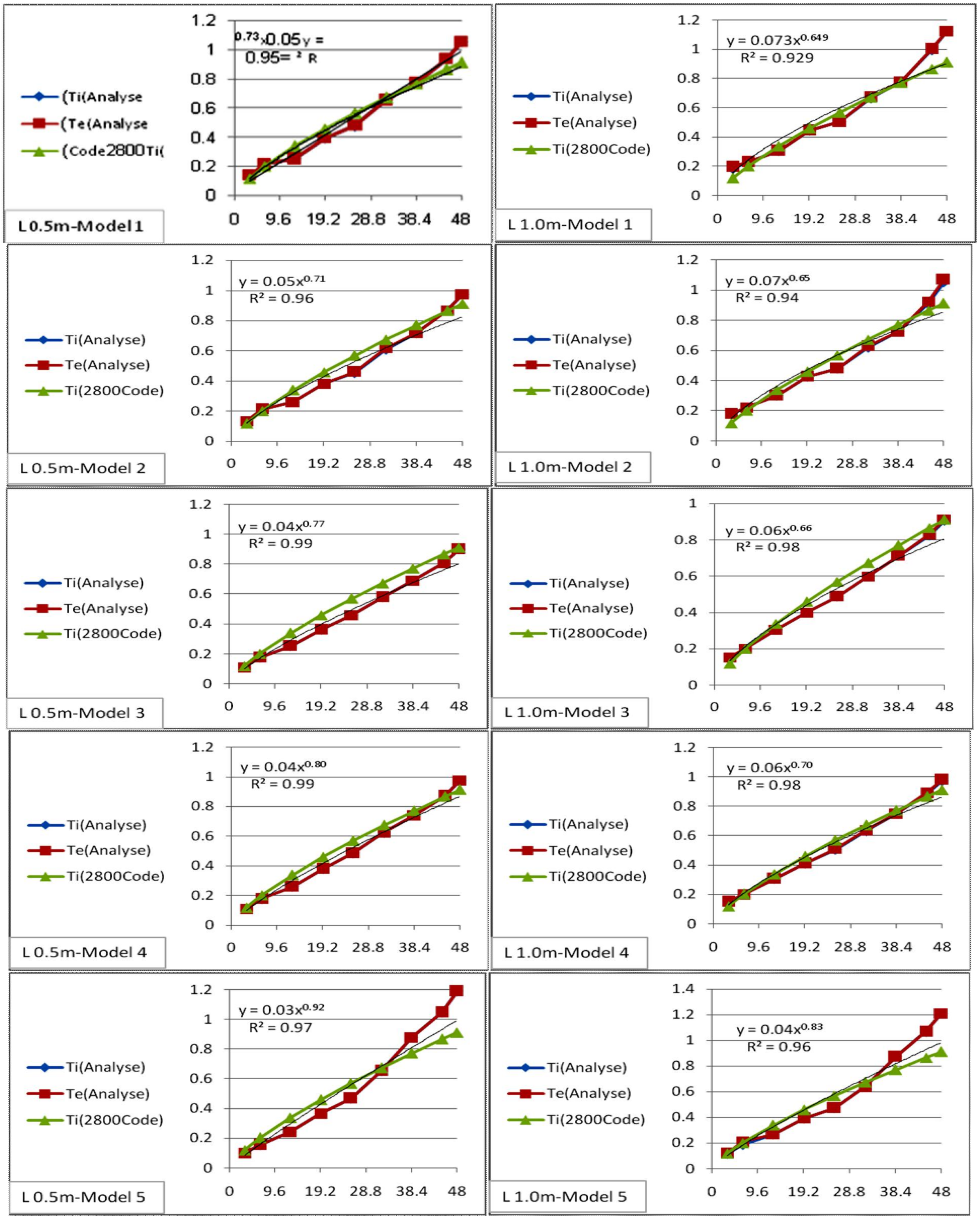

Figure 7(a). Height of building versus fundamental period and effective fundamental period of RC frames for the length of link beam 0.5, and 1 meter.

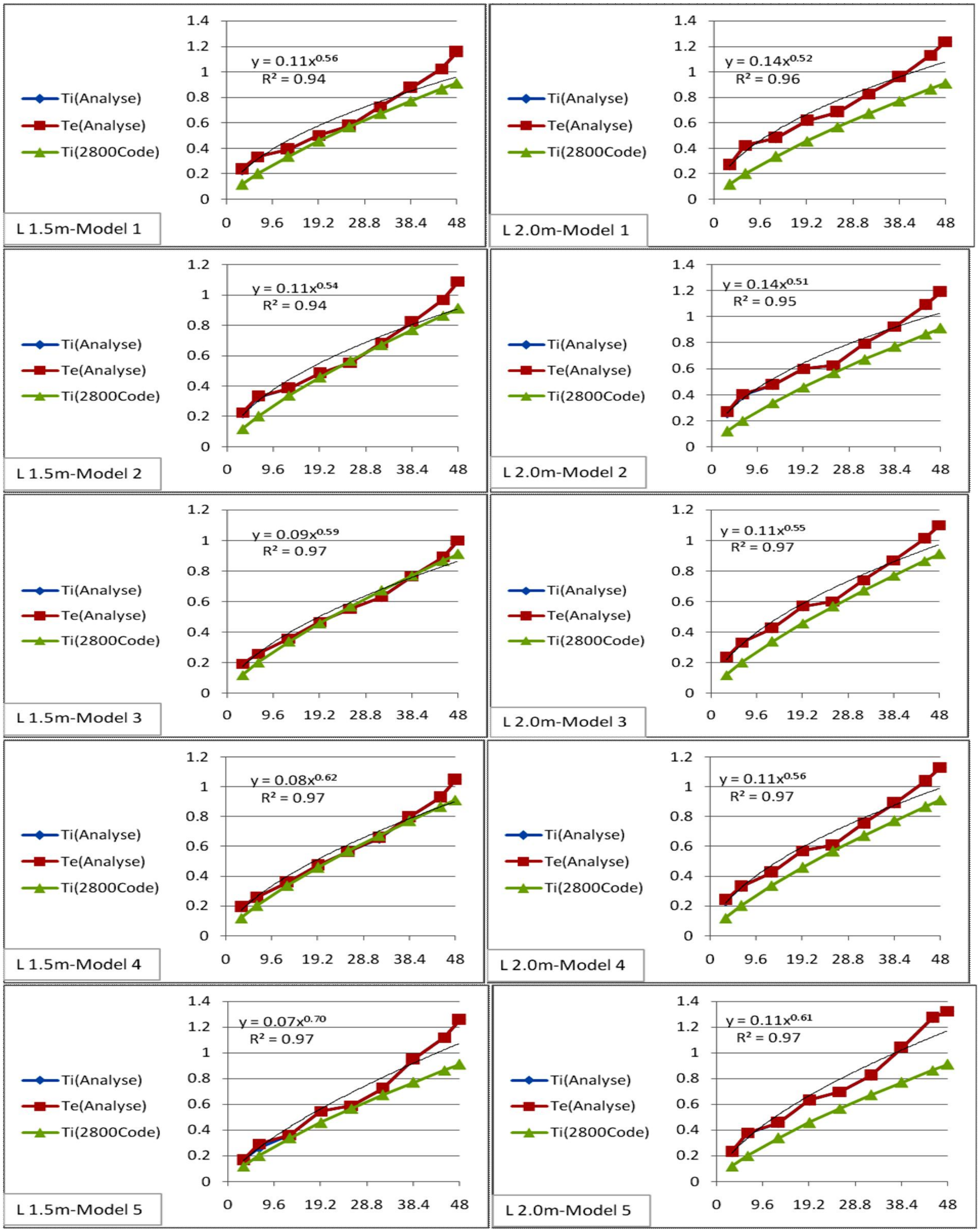

Figure 7(b). Height of building versus fundamental period and effective fundamental period of RC frames for the length of link beam 1.5, and 2 meter.

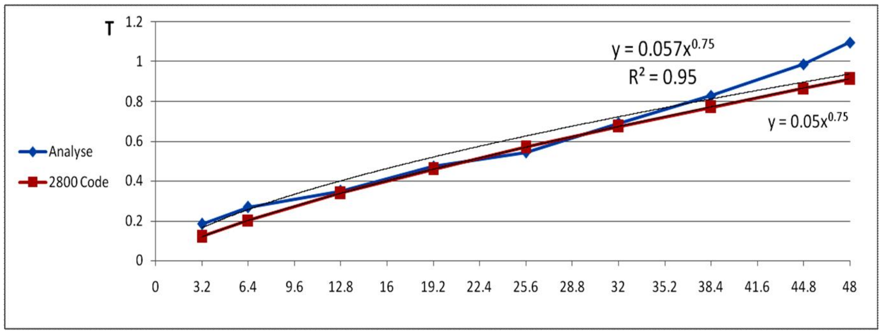

Figure 8. Height of building versus the average of vibration period of RC frames.

5. Conclusions

To capture fundamental period and effective fundamental period, one eighty concrete moment resisting frames with eccentric steel bracing are analyzed by performing two dimensional pushover analysis. The following conclusions can be drawn:

- For initial estimation of target displacement at the design based on performance level, the analysis has presented close values for fundamental period and effective fundamental period parameters. So, it is of interest to take fundamental period (vibration period at the first mode) as a reliable estimation on effective fundamental period for the mentioned structural systems.
- Adding number of bracing spans has made shorter vibration period. As a corollary, Figure 4 has reported longer vibration periods for the models with one bracing span then the ones having two bracing spans.
- The frames with symmetric or antisymmetric bracing spans had the same vibration period.
- Increasing length of link beam has led to rise the vibration period of building.
- To validate experimental relation of seismic codes (such as Iranian code) for presenting vibration period ($T=0.05H^{0.75}$), the analysis has suggested an analytical equation in Fig.7 ($T=0.057H^{0.75}$). Concerning the connection between reflection factor and fundamental period in Fig. 1, the experimental equation 1 was detected very satisfactory for short and intermediate tall buildings. Also, by this equation tall buildings have been designed for more safety. In summing up, the experimental equation proposed in the mentioned Codes was monitored very close to reality.

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