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A Simple Formula to Estimate Fundamental Period of Tunnel Form Buildings

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Abstract

In many seismic design codes and guidelines, such as UBC (1997) and Turkish Seismic Code (1998), prediction of fundamental period of shear-wall dominant buildings to compute the anticipated seismic forces is given by empirical equations. However, it has been long recognized that these formulas are incapable of predicting the true fundamental period of tunnel form buildings. Based on the premise that such formulas are commonly and widely used in engineering practice, a simple, yet effective predictive equation was developed based on the three-dimensional (3D) finite element analysis of 140 buildings having a variety of plans, heights and wall-configurations. Comparisons with experimental results show that proposed formula can adequately predict the fundamental period of tunnel form buildings.

Introduction

Multi-storey reinforced concrete (RC) tunnel form buildings (i.e., box type buildings) are finding widespread use in seismic regions. The main ingredients of such buildings are their relatively thinner shear-walls and flat-slabs compared to those of traditional RC buildings. Shear-walls in tunnel form buildings are utilized as the primary lateral load resisting and vertical load carrying members due to absence of beams and columns. The typical implementation of a tunnel form system and its details are exhibited in Figure 1.

Seismic performances of tunnel form buildings have recently been observed during the recent earthquakes (Mw 7.4 Kocaeli and Mw 7.2 Duzce) in Turkey in 1999. These earthquakes hit the most populated environments, and caused substantial structural damage, casualties and economic loss. In the aftermath of these events, neither demolished nor damaged tunnel form buildings located in the vicinity of damage-suffering regions were reported in contrast to severely damaged conditions of many conventional RC buildings. Such performance of tunnel form buildings has stimulated their construction in Turkey in replacement of many severely damaged and collapsed RC frame-type buildings. Not only in Turkey, but also in many other countries prone to seismic risk, tunnel form buildings are gaining an increasing popularity. That accentuates an urgent need to clarify their seismic behavior, design and safety issues. Toward that purpose, nonlinear seismic response of tunnel form buildings was examined with special attention to 2D and 3D capacity and performance evaluation [Balkaya and Kalkan, 2003a]. The identification of overstrength and response modification (R-factor) factors for tunnel form building have been studied through the concept of performance based design [Balkaya and Kalkan, 2004a]. The effects of openings on lateral load resistant of tunnel form buildings as well as the three-dimensional effects on shear walls have been also investigated with the objective of incorporating special reinforcement detailing around the openings of tunnel form buildings [Balkaya and Kalkan, 2004b].

As the part of the multi-purpose study conducted on tunnel form buildings by the authors, the objective of this paper is to develop a simple formula in a theoretically and practically consistent manner to predict the fundamental period of tunnel form buildings. The performance of this formula is demonstrated through comparison with experimental results.

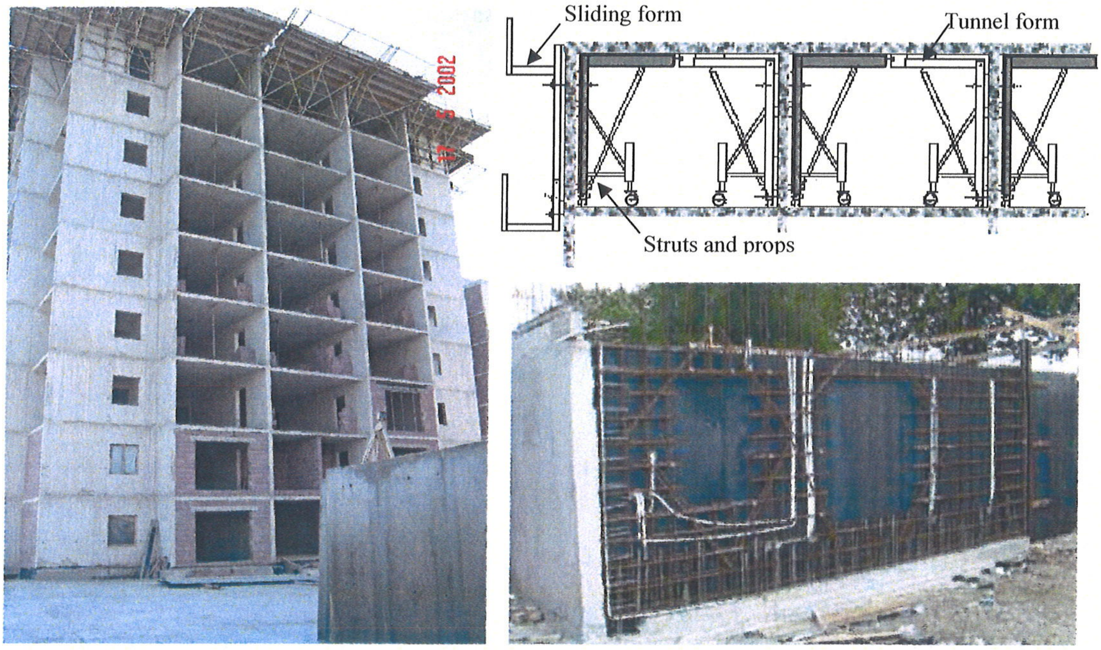

Figure 1. A typical tunnel form building construction system *

* Source of photos: www.eeri.org

Prediction of Fundamental Period

It is customary in practice to obtain the lower bound fundamental period of a structure via code-given expressions to establish the proper design force level unless modal analysis based on the detailed finite element model is conducted. Therefore accurate estimation of the fundamental period is inevitably essential to calculate the reliable design forces. It has long been realized that significant errors are tend to occur when the code-given equations such as those given in the UBC (1997) and the Turkish Seismic Code, TSC (1998) are utilized for shear-wall dominant systems [Lee et al., 2000; Balkaya and Kalkan, 2003b and 2004a]. To compensate for this deficiency, Lee et al. (2000) proposed a simple formula based on their experimental data to estimate the lower bound fundamental period of tunnel form buildings having stories ≥15. A set of new formulas to estimate the period of such buildings having stories ≤15 has recently been developed by Balkaya and Kalkan, 2003b. The objective here is to present updated information on the period of such buildings using an extended building inventory as the continuation of our earlier work. In this paper, a simpler formula that can be applicable for both mid-rise (storey level ≤15) and high-rise (storey level >15) tunnel form buildings is developed based on the finite element analyses of 20 different buildings (most have as-built plans and already been constructed). Each building was studied for 7 different storey levels (i.e., 5, 10, 12, 15, 18, 20 and 25). Shear-wall thickness was taken as 12cm for buildings up to 15 stories, 15cm for 18-story buildings and 20 cm for 20- and 25-story buildings. The database compiled constitutes 140 buildings, their plan dimensions, number of stories and heights, shear-wall areas in two horizontal directions as well as computed fundamental periods using 3D FEM analyses. This ensemble is presented in Table 1. The equation developed to predict the fundamental period of the tunnel form buildings has the following form

$$T = Ch\frac{\sqrt{R}}{(R^{a}_{length} + R^{a}_{width})} \qquad (1)$$

where T is the period in sec, h is the total height of building in m; R *is the r*atio of long side dimension to short side dimension of the building; R_{length} is the ratio of shear-wall area oriented along the length to typical story area; and R_{width} is the ratio of shear-wall area oriented along the width to typical story area. In this equation C and a are the estimator parameters obtained from regression analysis, and are equal to 0.138 and -0.4, respectively. The results obtained were also used to compute the associated errors in the estimation. The standard deviation of residuals, σ_T, expressing the random variability of periods, is 0.3 and the value of R^2 (i.e., indication of goodness of fit) is equal to 0.80. There is no significant bias observed from the investigation of residuals. Equation (1) is similar to code-base equations (e.g. UBC, 1997 and TSC, 1998) except for the three new parameters that we have introduced. Analysis of results herein and from our earlier studies [Balkaya and Kalkan, 2003a and 2003b] show that tunnel form buildings are significantly susceptible to torsion due to the plan shear-wall configuration that is restricted by the tunnel form construction technique (first mode deformed shapes of the buildings are also described in Table 1). To account for this behavior and the effects of shear-walls into the period estimation, an additional R factor is plugged into Equation (1) with two other parameters, R_{width} and R_{length}.

Table 1. Structural and dynamic properties of buildings

Plan	# of	Height	Dimension (m)		Shear wall Area (m^2)		FEM Results		Predicted Period T(sec)		
No	Story	(m)	Length	Width	Length	Width	T (sec)	1st Mode	Equation (1)	TSC98	UBC97
1	5	14.0	29.70	15.70	4.78	17.80	0.13	Long.	0.27	0.17	0.17
	10	28.0	29.70	15.70	4.78	17.80	0.29		0.53	0.38	0.37
	12	33.6	29.70	15.70	4.78	17.80	0.37		0.64	0.45	0.44
	15	42.0	29.70	15.70	4.78	17.80	0.49		0.80	0.55	0.54
	18	50.4	29.70	15.70	5.98	22.25	0.70		1.05	0.57	0.57
	20	56.0	29.70	15.70	7.97	29.67	0.74		1.31	0.54	0.54
	25	70.0	29.70	15.70	7.97	29.67	1.03		1.64	0.65	0.64
2	5	14.0	31.04	19.92	3.40	19.92	0.12	Long.	0.20	0.15	0.15
	10	28.0	31.04	19.92	3.40	19.92	0.28		0.40	0.35	0.35
	12	33.6	31.04	19.92	3.40	19.92	0.35		0.48	0.42	0.42
	15	42.0	31.04	19.92	3.40	19.92	0.47		0.60	0.52	0.52
	18	50.4	31.04	19.92	4.25	24.90	0.58		0.79	0.55	0.54
	20	56.0	31.04	19.92	5.67	33.20	0.64		0.99	0.52	0.52
	25	70.0	31.04	19.92	5.67	33.20	0.95		1.24	0.63	0.62
3	5	14.0	38.80	17.03	3.98	19.60	0.14	Long.	0.25	0.18	0.18
	10	28.0	38.80	17.03	3.98	19.60	0.31		0.49	0.39	0.39
	12	33.6	38.80	17.03	3.98	19.60	0.39		0.59	0.47	0.46
	15	42.0	38.80	17.03	3.98	19.60	0.50		0.74	0.57	0.57
	18	50.4	38.80	17.03	4.98	24.50	0.59		0.97	0.60	0.59
	20	56.0	38.80	17.03	6.64	32.67	0.64		1.21	0.57	0.56
	25	70.0	38.80	17.03	6.64	32.67	0.93		1.51	0.68	0.67
4	5	14.0	12.00	8.00	1.44	2.88	0.14	Trans.	0.25	0.32	0.32
	10	28.0	12.00	8.00	1.44	2.88	0.35		0.50	0.61	0.77
	12	33.6	12.00	8.00	1.44	2.88	0.49		0.60	0.70	0.94
	15	42.0	12.00	8.00	1.44	2.88	0.76		0.75	0.82	1.18
	18	50.4	12.00	8.00	1.80	3.60	1.01		0.99	0.95	1.25
	20	56.0	12.00	8.00	2.40	4.80	1.17		1.23	1.02	1.18
	25	70.0	12.00	8.00	2.40	4.80	1.81		1.54	1.21	1.43
5	5	14.0	12.00	8.00	3.84	1.92	0.16	Torsion	0.28	0.36	0.42
	10	28.0	12.00	8.00	3.84	1.92	0.43		0.56	0.61	0.80
	12	33.6	12.00	8.00	3.84	1.92	0.55		0.68	0.70	0.93
	15	42.0	12.00	8.00	3.84	1.92	0.74		0.84	0.82	1.12
	18	50.4	12.00	8.00	4.80	2.40	0.89		1.11	0.95	1.15
	20	56.0	12.00	8.00	6.40	3.20	0.97		1.38	1.02	1.08
	25	70.0	12.00	8.00	6.40	3.20	1.28		1.73	1.21	1.29
6	5	14.0	12.00	8.00	1.44	3.84	0.11	Long.	0.26	0.30	0.29
	10	28.0	12.00	8.00	1.44	3.84	0.32		0.53	0.61	0.71
	12	33.6	12.00	8.00	1.44	3.84	0.45		0.63	0.70	0.86
	15	42.0	12.00	8.00	1.44	3.84	0.69		0.79	0.82	1.07
	18	50.4	12.00	8.00	1.80	4.80	0.93		1.04	0.95	1.13
	20	56.0	12.00	8.00	2.40	6.40	1.08		1.29	1.02	1.08
	25	70.0	12.00	8.00	2.40	6.40	1.68		1.61	1.21	1.30
7	5	14.0	12.00	8.00	2.88	2.64	0.13	Torsion	0.29	0.36	0.46
	10	28.0	12.00	8.00	2.88	2.64	0.35		0.57	0.61	0.84
	12	33.6	12.00	8.00	2.88	2.64	0.50		0.69	0.70	0.97
	15	42.0	12.00	8.00	2.88	2.64	0.75		0.86	0.82	1.15
	18	50.4	12.00	8.00	3.60	3.30	1.02		1.13	0.95	1.19
	20	56.0	12.00	8.00	4.80	4.40	1.18		1.40	1.02	1.11
	25	70.0	12.00	8.00	4.80	4.40	1.83		1.75	1.21	1.32
8	5	14.0	38.80	17.03	3.98	19.60	0.14	Torsion	0.25	0.36	0.44
	10	28.0	38.80	17.03	3.98	19.60	0.44		0.49	0.61	0.81
	12	33.6	38.80	17.03	3.98	19.60	0.58		0.59	0.70	0.94
	15	42.0	38.80	17.03	3.98	19.60	0.82		0.74	0.82	1.12
	18	50.4	38.80	17.03	4.98	24.50	1.03		0.97	0.95	1.16
	20	56.0	38.80	17.03	6.64	32.67	1.15		1.21	1.02	1.09
	25	70.0	38.80	17.03	6.64	32.67	1.69		1.51	1.21	1.29
9	5	14.0	12.00	8.00	4.80	1.92	0.16	Torsion	0.29	0.36	0.40
	10	28.0	12.00	8.00	4.80	1.92	0.43		0.58	0.61	0.75
	12	33.6	12.00	8.00	4.80	1.92	0.55		0.70	0.70	0.87
	15	42.0	12.00	8.00	4.80	1.92	0.74		0.88	0.82	1.04
	18	50.4	12.00	8.00	6.00	2.40	0.89		1.15	0.95	1.07
	20	56.0	12.00	8.00	8.00	3.20	0.98		1.43	1.01	1.01
	25	70.0	12.00	8.00	8.00	3.20	1.28		1.79	1.20	1.19
10	5	14.0	35.00	20.00	7.20	12.96	0.16	Long.	0.23	0.17	0.17
	10	28.0	35.00	20.00	7.20	12.96	0.38		0.46	0.39	0.39
	12	33.6	35.00	20.00	7.20	12.96	0.48		0.55	0.47	0.46
	15	42.0	35.00	20.00	7.20	12.96	0.64		0.69	0.57	0.57
	18	50.4	35.00	20.00	9.00	16.20	0.80		0.90	0.60	0.59
	20	56.0	35.00	20.00	12.00	21.60	0.92		1.12	0.57	0.56
	25	70.0	35.00	20.00	12.00	21.60	1.22		1.40	0.68	0.67

Table 1. Cont'd.

Plan No	# of Story	Height (m)	Dimension (m)		Shear wall Area (m^2)		FEM Results		Predicted Period T(sec)		
			Length	Width	Length	Width	T (sec)	1^{st} Mode	Equation (1)	TSC98	UBC97
11	5	14.0	11.00	9.00	2.64	1.80	0.23	Torsion	0.23	0.34	0.33
	10	28.0	11.00	9.00	2.64	1.80	0.63		0.46	0.61	0.79
	12	33.6	11.00	9.00	2.64	1.80	0.82		0.56	0.70	0.95
	15	42.0	11.00	9.00	2.64	1.80	0.83		0.69	0.82	1.18
	18	50.4	11.00	9.00	3.30	2.25	1.35		0.91	0.95	1.24
	20	56.0	11.00	9.00	4.40	3.00	1.44		1.14	1.02	1.18
	25	70.0	11.00	9.00	4.40	3.00	1.94		1.42	1.21	1.42
12	5	14.0	31.50	27.15	9.70	13.86	0.16	Torsion	0.19	0.26	0.26
	10	28.0	31.50	27.15	9.70	13.86	0.42		0.37	0.61	0.63
	12	33.6	31.50	27.15	9.70	13.86	0.55		0.45	0.70	0.76
	15	42.0	31.50	27.15	9.70	13.86	0.77		0.56	0.82	0.95
	18	50.4	31.50	27.15	12.13	17.33	0.98		0.73	0.95	1.00
	20	56.0	31.50	27.15	16.17	23.10	1.10		0.91	0.96	0.95
	25	70.0	31.50	27.15	16.17	23.10	1.54		1.14	1.16	1.15
13	5	14.0	25.50	25.04	10.70	10.88	0.14	Torsion	0.19	0.19	0.19
	10	28.0	25.50	25.04	10.70	10.88	0.40		0.38	0.41	0.41
	12	33.6	25.50	25.04	10.70	10.88	0.55		0.46	0.49	0.48
	15	42.0	25.50	25.04	10.70	10.88	0.80		0.57	0.59	0.59
	18	50.4	25.50	25.04	13.38	13.60	1.03		0.75	0.62	0.61
	20	56.0	25.50	25.04	17.83	18.13	1.17		0.94	0.59	0.58
	25	70.0	25.50	25.04	17.83	18.13	1.69		1.17	0.70	0.69
14	5	14.0	28.00	12.00	2.88	3.60	0.13	Long.	0.23	0.30	0.29
	10	28.0	28.00	12.00	2.88	3.60	0.40		0.46	0.57	0.56
	12	33.6	28.00	12.00	2.88	3.60	0.54		0.55	0.66	0.65
	15	42.0	28.00	12.00	2.88	3.60	0.79		0.69	0.79	0.78
	18	50.4	28.00	12.00	3.60	4.50	1.02		0.90	0.81	0.81
	20	56.0	28.00	12.00	4.80	6.00	1.16		1.13	0.77	0.76
	25	70.0	28.00	12.00	4.80	6.00	1.70		1.41	0.91	0.90
15	5	14.0	27.00	24.00	8.40	13.55	0.17	Torsion	0.20	0.19	0.18
	10	28.0	27.00	24.00	8.40	13.55	0.49		0.39	0.40	0.39
	12	33.6	27.00	24.00	8.40	13.55	0.65		0.47	0.47	0.47
	15	42.0	27.00	24.00	8.40	13.55	0.92		0.59	0.57	0.57
	18	50.4	27.00	24.00	10.50	16.94	1.16		0.78	0.60	0.59
	20	56.0	27.00	24.00	14.00	22.58	1.32		0.97	0.57	0.56
	25	70.0	27.00	24.00	14.00	22.58	1.84		1.21	0.68	0.67
16	5	14.0	32.00	26.00	9.40	15.00	0.17	Torsion	0.19	0.17	0.17
	10	28.0	32.00	26.00	9.40	15.00	0.49		0.39	0.36	0.36
	12	33.6	32.00	26.00	9.40	15.00	0.64		0.47	0.43	0.43
	15	42.0	32.00	26.00	9.40	15.00	0.88		0.58	0.53	0.52
	18	50.4	32.00	26.00	11.75	18.75	1.10		0.77	0.55	0.55
	20	56.0	32.00	26.00	15.67	25.00	1.24		0.96	0.52	0.51
	25	70.0	32.00	26.00	15.67	25.00	1.69		1.20	0.62	0.62
17	5	14.0	24.00	14.00	4.80	7.44	0.17	Torsion	0.25	0.28	0.28
	10	28.0	24.00	14.00	4.80	7.44	0.48		0.50	0.55	0.54
	12	33.6	24.00	14.00	4.80	7.44	0.63		0.60	0.64	0.63
	15	42.0	24.00	14.00	4.80	7.44	0.88		0.75	0.77	0.76
	18	50.4	24.00	14.00	6.00	9.30	1.12		0.99	0.79	0.79
	20	56.0	24.00	14.00	8.00	12.40	1.29		1.23	0.75	0.74
	25	70.0	24.00	14.00	8.00	12.40	1.80		1.54	0.89	0.88
18	5	14.0	16.00	12.00	3.84	8.16	0.11	Torsion	0.27	0.32	0.32
	10	28.0	16.00	12.00	3.84	8.16	0.26		0.54	0.60	0.60
	12	33.6	16.00	12.00	3.84	8.16	0.33		0.64	0.70	0.69
	15	42.0	16.00	12.00	3.84	8.16	0.45		0.80	0.82	0.83
	18	50.4	16.00	12.00	4.80	10.20	0.59		1.06	0.86	0.85
	20	56.0	16.00	12.00	6.40	13.60	0.68		1.32	0.81	0.80
	25	70.0	16.00	12.00	6.40	13.60	1.03		1.64	0.96	0.95
19	5	14.0	28.00	12.00	5.76	6.00	0.13	Torsion	0.29	0.30	0.29
	10	28.0	28.00	12.00	5.76	6.00	0.40		0.59	0.57	0.56
	12	33.6	28.00	12.00	5.76	6.00	0.54		0.70	0.66	0.65
	15	42.0	28.00	12.00	5.76	6.00	0.79		0.88	0.79	0.78
	18	50.4	28.00	12.00	7.20	7.50	1.02		1.15	0.81	0.81
	20	56.0	28.00	12.00	9.60	10.00	1.16		1.44	0.77	0.76
	25	70.0	28.00	12.00	9.60	10.00	1.70		1.79	0.91	0.90
20	5	14.0	16.00	12.00	3.84	5.76	0.12	Trans.	0.25	0.33	0.33
	10	28.0	16.00	12.00	3.84	5.76	0.31		0.50	0.61	0.62
	12	33.6	16.00	12.00	3.84	5.76	0.39		0.61	0.70	0.72
	15	42.0	16.00	12.00	3.84	5.76	0.52		0.76	0.82	0.87
	18	50.4	16.00	12.00	4.80	7.20	0.64		0.99	0.90	0.89
	20	56.0	16.00	12.00	6.40	9.60	0.73		1.24	0.85	0.84
	25	70.0	16.00	12.00	6.40	9.60	1.06		1.55	1.01	1.00

* Long. implies longitudional direction; Trans. implies transverse direction

Performance of Equation (1) is compared with code equations given in both the TSC (1998) and UBC (1997). Turkish Seismic Code concerning the constructions in seismic areas has recently been modified in 1998. In TSC, the equation for predicting fundamental period of structures was taken directly from the UBC (1997) with small modifications. The general form of the equation given in these provisions is as follows (note that all equations are in SI unit system):

$$T = C_t\,(h_n)^{3/4}\ (\leq 0.05) \tag{2}$$

where T is the period in seconds; C_t = 0.0853 (0.08) for steel moment-resisting frames, C_t = 0.0731 (0.07) for reinforced concrete moment-resisting frames and eccentrically-braced frames and C_t = 0.0488 (0.05) for all other buildings. Alternatively, the value of C_t for structures where seismic loads are fully resisted by reinforced concrete structural walls, can be taken as $0.0743(0.075)/(A_c)^{1/2}$. The numbers within the parentheses show the corresponding values given in the TSC. The value of A_c shall be calculated from the following formula:

$$A_c = \Sigma A_e\,[0.2 + (D_e / h_n)^2] \tag{3}$$

The value of D_e/h_n used in Equation (3) shall not exceed 0.9. The period estimation via Equation (1) and also UBC and TSC equations were compared in Figure 2 for various buildings in the database (Table 1). Also shown in this figure are the finite element analysis results as benchmark solutions. Comparisons show that there exists significant deviation between the FEM results and those computed using code equations. For many cases, code equations give a period much longer than computed for low- and mid-rise (i.e., 5, 10 and 12 stories) buildings, whereas for high-rise buildings (i.e., stories $\geq$15) reverse is observed, and they underestimate the computed periods. In fact, estimated periods should be the same or less than the actual period of the structure, thus their estimation should be conservative. In general comparisons reveal that there is a good agreement between estimated periods via Equation (1) and FEM results. For some of the 5-story buildings in the database, our equation could not capture the computed periods, and estimations result in higher deviation and become non-conservative.

Comparison with Experimental Data

The estimated periods using Equation (1) are next compared with experimental data of Celebi et al. (1977) and Lee et al. (2000). Celebi et al. measured the fundamental period of a mid-rise tunnel form building with and without outside panel configuration (i.e., they are non-structural components). Most recently, Lee et al. conducted ambient surveys on fifty high rise tunnel form buildings having 15 to 25 stories. The tested buildings have wall thickness of 20cm. Figure 3 shows this compiled experimental data and the fundamental periods of the structures in our database. The details of the buildings where ambient surveys were conducted are given in Table 2 including their plan dimensions, heights and shear-wall areas. The estimated fundamental periods via Equation (1) are also given in this table for comparison. The experimental data presented on first 50 buildings has two periods, one along longitudinal direction and second along transverse direction. On the other hand Equation (1) is aimed to estimate the fundamental period regardless of the direction, attempting to consider the shear-wall configuration along both longitudinal and transverse directions as well as the effects of possible torsion. Therefore it may only yield a single value assumed as the fundamental period. Based on this premise, the comparisons show that Equation (1) gives estimates close to periods along the longitudinal direction for the majority of the buildings, but for only a few cases underestimates transverse periods or overestimates longitudinal periods. These results imply that Equation (1) is generally conservative as expected from any code-given equations. In fact, the period of the structures elongate during inelastic response because of stiffness degradation. Hence Equation (1) can be used to estimate the lower bound fundamental period of tunnel form buildings having stories 5 to 25. In this study, the effects of non-structural elements (e.g. outside panel walls) as well as local-site effects on period estimation were ignored (i.e., fixed support conditions were assumed in all computer models) but have been the part of our ongoing research. It should be noted that the proposed equation in this paper is based on the general consensus of engineering applications. Pending the accumulation of additional new data from the experimental studies and analysis of different buildings, the derived equation here can be modified and improved.

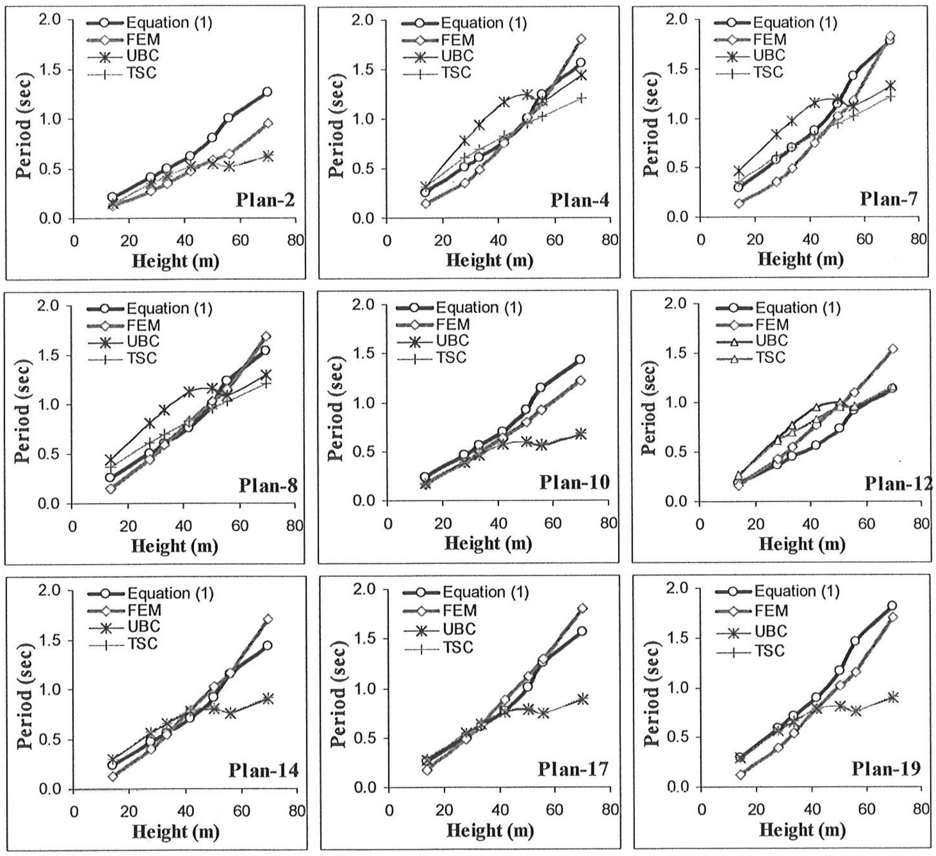

Figure 2. Comparison of predicted periods via Equation (1) with FEM, UBC (1997) and TSC (1998) equations

Table 2. Comparison of results based on Equation (1) with experimental periods of Lee et al. (2000)

Plan No **	# of Story	Height (m)	Dimension (m) Length	Dimension (m) Width	Shear wall Area (m^2) Length	Shear wall Area (m^2) Width	Measured Period T (sec) Long. *	Measured Period T (sec) Trans. *	Predicted Period T(sec) Equation (1)
1	15	40.0	38.98	11.26	13.17	24.58	1.92	0.71	1.42
2	15	40.0	27.22	12.83	10.48	18.16	N/A *	1.08	1.10
3	20	53.5	30.94	12.38	9.96	17.62	1.89	1.19	1.51
4	20	53.5	31.66	12.02	10.66	15.98	1.90	1.44	1.55
5	20	53.5	30.94	10.88	9.43	18.18	1.93	N/A	1.68
6	15	40.0	49.22	11.61	8.00	22.86	N/A	1.27	1.24
7	15	40.0	27.22	12.83	8.38	18.16	2.22	N/A	1.04

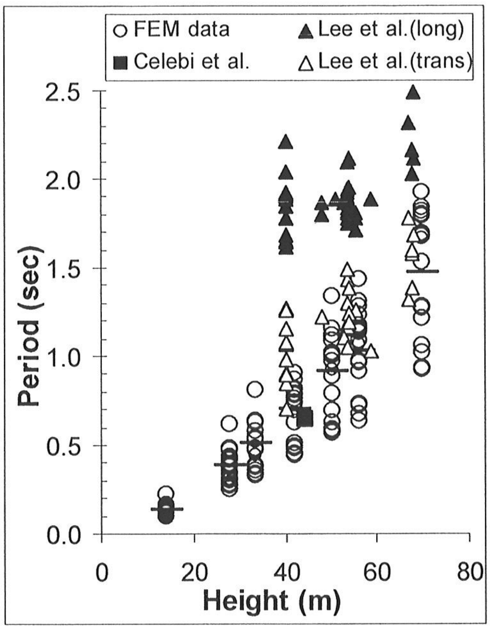

Figure 3. Distribution of periods in Celebi et al. (1977) and Lee et al. (2000) and our database (Table 1), with respect to building height (solid bars denote mean of periods at a specific height for the buildings in Table 1; *long* stands for longitudinal direction; *trans* stands for transverse direction)

Conclusions

In this study, consistency of code-base empirical formulas to estimate the fundamental period of buildings was evaluated for tunnel form buildings. The comparative analysis results revealed that common formulas involved in the Turkish Seismic Code (1998), and the Uniform Building Code (1997) may yield inaccurate results for explicit determination of fundamental period of tunnel form buildings. Based on the premise that such formulas are commonly used in engineering practice, a new predictive equation was proposed herein. This equation was developed based on the finite element analysis of 140 buildings having a variety of plans, heights and wall-configurations. Comparisons with experimental results show good correlation, and lend further credibility to proposed equation for its use in practice. The results of the presented study are considered to be an essential step regarding the reliable design and analysis of the buildings of concern against earthquake forces.

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