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A New Formulation For The Fundamental Period Of Reinforced Concrete Planar Shear Walls

Murat Pala[1], Naci Caglar[2], Zehra Sule Garip, Cihan Bayram[1] and Hakan Ozturk[1]

[1] *Department of Technical Program, Kilis 7 Aralık University, Kilis, Turkey*
[2]*Department of Civil Engineering, Sakarya University, Sakarya, Turkey*

ABSTRACT

The reinforced concrete shear wall system has become a popular structural component for lateral resistance in buildings and base shear of these structures has a vital effect on the earthquake induced lateral forces. The fundamental period of structures is used in most building codes to determine the lateral forces. However, accurate computation of period is not an easy task at the design stage.

The main objective of this study is to evaluate the empirical easy-to-use equation for the calculation of fundamental periods of concrete planar shear walls. Genetic programming has been used to generate the proposed formula. Finite element analysis, were carried out for various shear walls having a variety of height and length and the results were used to develop the proposed formula. The outcomes of formula are compared with the results from equations in the seismic codes and finite element analysis. The comparison results indicate good agreement with finite element analysis and show better performance than codes.

INTRODUCTION

One of the main steps of the dynamic analysis of the structures subjected to earthquake is the determination of the fundamental period. For many years various methodologies have been developed to predict the dynamic responses of plane Reinforced Concrete (RC) shear walls. These equations are based on the geometric dimensions of buildings and related to buildings with different lateral load resisting systems such as shear walls. Seismic building codes such as National Building Code of Canada (NBCC-95) [1], Uniform Building Code (UBC-97) [2] present analytical expressions for the computation of the fundamental period for moment resisting frames and shear walls. Current code formulas for estimating the fundamental period of concrete shear wall buildings are insufficient and usually give periods shorter than exact periods [3-4]. Compared to the analytical methods and Finite Element Analysis [5] (FEA), these formulas may give inaccurate results and may show big deviations.

Studies on the natural periods shear walls have been reported by many researchers and several empirical formulations proposed for the calculation of fundamental period of shear wall by hand [6-12]. Housner and Brady [6] carried out some theoretical analyses based on Rayleigh's method for shear wall buildings to develop a formula to determine the fundamental period. They compared the period of steel and reinforced concrete buildings measured during the Long Beach, California earthquake (1933) to the California Building Code of 1960. They concluded that reliable results for shear-wall buildings could be obtained when the wall stiffness was considered. Li and Mau [7] analyzed seismic records of Loma Prieta and Whittier earthquakes for 21 building. The measured period of buildings were compared using the formulas given in UBC-94 and concluded that the given formula T=CtH3/4 was insufficient and gave overestimated and underestimated results. Cole et al. [8] verified the empirical period formulas in UBC-91 with the data of some buildings and recorded motions. Goel and Chopra [15] investigated and compared the fundamental period of vibration of shear wall buildings measured from strong motion records with the code formula. They concluded that measured periods were generally longer than those computed by the code equations. They also proposed a new formula based on Dunkerley's method [13]. Lee et al. [14] presented a simple formula based on experimental data to calculate the lower bound fundamental period of tunnel form buildings having stories≥15. Balkaya and Kalkan [15] developed a set of new formulas to calculate the period of tunnel form buildings having stories ≤15.

The main objective of this study is to present a simple, easy to use and securer empirical formula based on genetic expression programming (GEP) [16] for estimation of the natural period of plane shear wall structure. The database used in this study for derivation of the formula was based on the finite element analysis of 148 plane shear wall models having a variety of heights and lengths. The advantage of this formulation is its simplicity. It can be used for different kind of reinforced plane shear wall structures. Therefore, it can be used instead of empirical formulation in the current seismic codes. In order to show validation of the proposed formula, the results of the formula are compared with the UBC-97, NBCC-95 Canada, FEA, Rayleigh's method [3].

GENETIC PROGRAMMING

Genetic programming is a variant of evolutionary computation with solutions (individuals) encoding definitions of functions, called alternative procedures. In the evaluation phase of an evolutionary run, each individual processes a training example and returns a result which is compared with a pre-defined desired value. The outcome of that comparison, usually averaged over multiple training examples, determines individual's fitness. GP proved extremely successful in many real-world applications, providing human-competitive solutions for different problems, including re-discovery of patented and discovery of patentable designs [17]

Genetic programming might be employed to solve a lot of engineering problems especially by offering precise and explicit formulation. Genetic programming maintains a population of structures that evolve according to the rules of natural selection and some operators inspired from natural genetics such as reproduction or cross-over. A function set F could contain functions such as basic mathematical operators (+, _, ·, /, etc.), Boolean logic functions (and, or ,not, etc.) or any other user defined function(s). The terminal set contains the arguments for the function in F and can consist of numerical constants, logical constants, variables, etc.

Each individual in the population receives a measure of its fitness in the current environment. The fitness criteria are calculated by the objective function i.e., how good the individual is at competing with the rest of the population. At each production a new population is created by the procedure of selecting individuals according to their fitness and breeding them together using the genetic operators (cross-over and mutation). The existing population will then be changed with the new population. [18-20].

Contrary to its similar, cellular Gene Expression Programming (GEP) is rather simple. The main players in GEP are only two: the chromosomes and the expression trees (ETs), the latter being the expression of the genetic information encoded in the chromosomes. As in nature, the process of information decoding is called translation. And this translation implies obviously a kind of code and a set of rules. The genetic code is very simple: a one-to-one relationship between the symbols of the chromosome and the functions or terminals they represent. The rules are also very simple: they determine the spatial organization of the functions and terminals in the ETs and the type of interaction between sub-ETs. In GEP there are therefore two languages: the language of the genes and the language of ETs and knowing the sequence or structure of one means knowing the other. In nature, despite being possible to infer the sequence of proteins given the sequence of genes and vice versa, we practically know nothing about the rules that determine the three-dimensional structure of proteins. But in GEP, thanks to the simple rules that determine the structure of ETs and their interactions, it is possible to infer immediately the phenotype that gives the sequence of a gene, and vice versa. This bilingual and unequivocal system is called Karva language [21].

The functions and terminals are chosen at random and constructed together to form a computer model in a tree-like structure with a root point with branches extending from each function and ending in a terminal (Fig. 1). Consider, for example, the algebraic expression (Eq1).

$$((a+b) \text{ x } c) \; x \; (d+\frac{f}{g}) \qquad (1)$$

It can also be represented as a diagram:

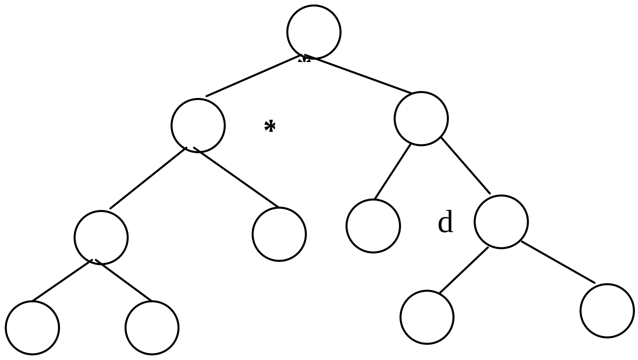


Figure 1. Expression tree

CODE FORMULAS FOR SHEAR WALL BUILDINGS

The 1995 edition of the National Building Code of Canada (NBCC-95) specifies that the fundamental period of structures, except the moment resisting, shall be calculated using the following formula (in S.I. Units):

$$T = 0.09\frac{H}{\sqrt{D_s}} \qquad (2)$$

where H and Ds are the height of the building and the length of the wall or braced frame in the direction parallel to the applied forces, in meters, respectively.

The 1997 Uniform Building Code states that the period shall be determined for: concrete or masonry shear walls as follows:

$$T = 0{,}0743H^{(3/4)}/\sqrt{\mathrm{A_c}} \qquad \text{(UBC)} \qquad (3)$$

where Ac is the combined effective area in square meters of shear walls defined as:

$$A_c = \sum A_e\left[0{,}2+\left(\frac{D_e}{h_n{}^2}\right)\right] \qquad (4)$$

in which Ae is the minimum cross-sectional shear area in square meters of a shear wall; De is the length in meters of a shear wall in the direction parallel to the applied forces; and hn is the height of the building in meters above the base. The value of De/Hn, should not exceed 0.9.

Goel a d Chopra [14,15] proposed a new expression to conservatively estimate periods. This formula is based on the Dunkeley's method of considering shear and flexure deformations in a cantilever. The stiffness and properties of individual walls are taken into account, as follows:

$$T = 0.0063 \frac{H}{\sqrt{A_e}} \qquad (\text{SI system}) \tag{5}$$

where

$$A_e = \sum_{i=1}^{NW} \left(\frac{H}{H_i} \right)^2 \frac{A_i}{\left[1 + 0.83 \left(\frac{H}{H_i} \right)^2 \right]} \tag{6}$$

Ai, Hi and Di in the above expressions represent the area, height and length of the ith shear wall at the base, in the direction being considered, in meters or feet. NW is the number of shear walls and AB is the plan area of the building in square meters or square feet. The coefficient 0.0063 (or 0.019) was obtained by regression analysis of the measured data. They suggested that the computed period from a rational analysis should not be grater than 1.4 times the value obtained by their proposed equation. These equations are applicable only for uncoupled shear walls, connected by rigid diaphragms [13].

The fundamental period can also be calculated using a rational method such as the Rayleigh’s method. The first or fundamental mode shape of vibration is that corresponding to flexure, therefore, the fundamental period of a flexural dominant shear wall based on Rayleigh's method can be written as shown below:

$$T = \frac{2\pi}{3.516} \sqrt{\frac{m}{EI} H^2} \tag{7}$$

where, m is mass per unit length of wall, E is the modulus of elasticity and H is the height of wall. From this equation it is evident that the fundamental period of a shear wall can be expressed in terms of height-to-moment of inertia ratio. The overall effect of the moment of inertia on buildings is calculated based on the summation of the moment of inertia of individual shear walls in a given direction [13].

SIMPLE FORMULATION FOR FUNDAMENTAL PERIOD OF RC SHEAR WALLS.

The analyzed shear wall structures are composed of 1-30 m width and 5-176 m height. The shell elements are selected as basic elements of shear wall for FEA and have bending and membrane capabilities. The sections of the structural elements are kept constant along the height of the buildings.

The proposed formulation was developed based on the database of FEA of 148 reinforced concrete shear wall having a variety of number of height and width (Fig. 2a). Fixed support conditions (without soil–structure interaction) are assumed in all computer models (Fig.2b). FEA database is separated into two cluster set; training set and testing set. Data in the training set is used to generate the formulation. Then this formulation is tested by using data in the testing set and in addition to this, a number of codes are used for verification.

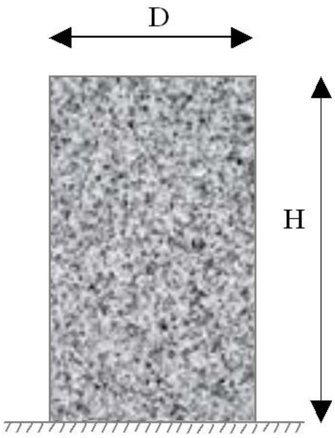


Figure 2a. Dimension of the shear wall model

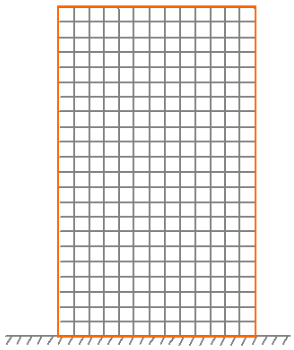


Figure 2b. FEA mesh model of the shear wall

Table 1 The training patterns and comparative analysis of proposed formulation with FEA results

D (m)	H (m)	FEA	$Pala$ $Eq.8$	$NBCC-95$	$UBC-97$	$Rayleigh$	$\frac{FEA}{Pala}$	$\frac{FEA}{NBCC-95}$	$\frac{FEA}{UBC-97}$	$\frac{FEA}{Rayleigh}$
4	78	2.930	2.966	3.510	3.083	4.627	0.988	0.835	0.950	0.633
4	68.25	2.247	2.271	3.071	2.790	3.543	0.990	0.732	0.806	0.634
4	64.5	2.000	2.028	2.903	2.674	3.164	0.986	0.689	0.748	0.632
4	59.25	1.695	1.711	2.666	2.509	2.670	0.990	0.636	0.676	0.635
4	52.5	1.332	1.344	2.363	2.291	2.096	0.991	0.564	0.581	0.635
4	47.25	1.080	1.088	2.126	2.117	1.698	0.992	0.508	0.510	0.636
4	41.25	0.824	0.830	1.856	1.912	1.294	0.993	0.444	0.431	0.637
4	33	0.530	0.531	1.485	1.617	0.828	0.998	0.357	0.328	0.640
4	21.25	0.233	0.220	0.956	1.163	0.343	1.058	0.244	0.200	0.678
4	17.25	0.148	0.145	0.776	0.994	0.226	1.020	0.191	0.149	0.654
4	13.5	0.090	0.089	0.608	0.827	0.139	1.013	0.148	0.109	0.649
4	9.75	0.051	0.046	0.439	0.648	0.072	1.100	0.116	0.079	0.705
4	6.75	0.026	0.022	0.304	0.492	0.035	1.171	0.086	0.053	0.750
6	102	3.346	3.381	3.748	3.079	4.307	0.990	0.893	1.087	0.777
6	93	2.780	2.811	3.417	2.873	3.580	0.989	0.814	0.968	0.776
6	84	2.272	2.293	3.086	2.661	2.921	0.991	0.736	0.854	0.778
6	75	1.813	1.828	2.756	2.445	2.329	0.992	0.658	0.742	0.779
6	56	1.014	1.019	2.058	1.964	1.298	0.995	0.493	0.516	0.781
6	47	0.717	0.718	1.727	1.722	0.914	0.999	0.415	0.416	0.784
6	39	0.496	0.494	1.433	1.497	0.630	1.003	0.346	0.331	0.788
6	28	0.259	0.255	1.029	1.168	0.325	1.016	0.252	0.222	0.798
6	21	0.149	0.143	0.772	0.941	0.183	1.040	0.193	0.158	0.816
6	16	0.089	0.083	0.588	0.767	0.106	1.070	0.151	0.116	0.840
6	11	0.046	0.039	0.404	0.579	0.050	1.170	0.114	0.079	0.918
6	7	0.022	0.016	0.257	0.413	0.020	1.381	0.086	0.053	1.085
8	102	2.514	2.536	3.246	2.666	2.797	0.991	0.775	0.943	0.899
8	86	1.790	1.803	2.737	2.346	1.989	0.993	0.654	0.763	0.900
8	74	1.329	1.335	2.355	2.096	1.472	0.996	0.564	0.634	0.903
8	65	1.028	1.030	2.068	1.902	1.136	0.998	0.497	0.541	0.905
8	57	0.793	0.792	1.814	1.723	0.874	1.001	0.437	0.460	0.908
8	55	0.738	0.737	1.750	1.678	0.813	1.001	0.422	0.440	0.907
8	51	0.637	0.634	1.623	1.585	0.699	1.005	0.393	0.402	0.911

Table 1 The training patterns and comparative analysis of proposed formulation with FEA results (cont.)

D (m)	H (m)	FEA	$Pala$ $Eq.8$	$NBCC-95$	$UBC-97$	$Rayleigh$	$\frac{FEA}{Pala}$	$\frac{FEA}{NBCC-95}$	$\frac{FEA}{UBC-97}$	$\frac{FEA}{Rayleigh}$
8	43	0.456	0.451	1.368	1.395	0.497	1.012	0.333	0.327	0.917
8	26	0.173	0.165	0.827	0.956	0.182	1.050	0.209	0.181	0.952
8	19	0.090	0.088	0.605	0.756	0.097	1.023	0.149	0.119	0.927
10	123	2.930	2.950	3.501	2.744	2.911	0.993	0.837	1.068	1.007
10	113	2.472	2.490	3.216	2.575	2.457	0.993	0.769	0.960	1.006
10	104	2.096	2.109	2.960	2.420	2.081	0.994	0.708	0.866	1.007
10	96	1.788	1.797	2.732	2.279	1.773	0.995	0.654	0.785	1.008
10	87	1.471	1.476	2.476	2.117	1.456	0.997	0.594	0.695	1.010
10	78	1.185	1.186	2.220	1.950	1.171	0.999	0.534	0.608	1.012
10	69	0.930	0.928	1.964	1.779	0.916	1.002	0.474	0.523	1.015
10	59	0.684	0.679	1.679	1.582	0.670	1.008	0.407	0.432	1.021
10	47	0.439	0.431	1.338	1.334	0.425	1.019	0.328	0.329	1.033
10	31	0.198	0.187	0.882	0.976	0.185	1.057	0.224	0.203	1.071
10	24	0.123	0.112	0.683	0.806	0.111	1.095	0.180	0.153	1.110
10	17	0.068	0.056	0.484	0.622	0.056	1.207	0.141	0.109	1.223
10	10	0.029	0.020	0.285	0.418	0.019	1.487	0.102	0.069	1.507
10	5	0.011	0.005	0.142	0.248	0.005	2.256	0.077	0.044	2.153
12	123	2.443	2.458	3.196	2.505	2.214	0.994	0.764	0.975	1.103
12	108	1.887	1.895	2.806	2.272	1.707	0.996	0.673	0.830	1.105
12	96	1.495	1.498	2.494	2.080	1.349	0.998	0.599	0.719	1.108
12	88	1.259	1.258	2.286	1.949	1.133	1.000	0.551	0.646	1.111
12	71	0.825	0.819	1.845	1.659	0.738	1.007	0.447	0.497	1.118
12	64	0.673	0.666	1.663	1.535	0.599	1.011	0.405	0.439	1.123
12	58	0.556	0.547	1.507	1.426	0.492	1.017	0.369	0.390	1.129
12	50	0.417	0.406	1.299	1.275	0.366	1.026	0.321	0.327	1.140
12	41	0.287	0.273	1.065	1.099	0.246	1.051	0.269	0.261	1.167
12	34	0.201	0.188	0.883	0.955	0.169	1.070	0.228	0.210	1.188
12	26	0.123	0.110	0.675	0.781	0.099	1.120	0.182	0.157	1.243
12	20	0.078	0.065	0.520	0.641	0.059	1.200	0.150	0.122	1.332
12	15	0.049	0.037	0.390	0.517	0.033	1.340	0.126	0.095	1.488
12	7	0.017	0.008	0.182	0.292	0.007	2.135	0.093	0.058	2.370
12	4	0.008	0.003	0.104	0.192	0.002	3.077	0.077	0.042	3.416
16	138	2.314	2.321	3.105	2.365	1.810	0.997	0.745	0.978	1.278
16	124	1.872	1.874	2.790	2.183	1.462	0.999	0.671	0.858	1.281
16	113	1.559	1.556	2.543	2.036	1.214	1.002	0.613	0.766	1.284
16	105	1.349	1.344	2.363	1.927	1.048	1.004	0.571	0.700	1.287
16	95	1.108	1.100	2.138	1.787	0.858	1.007	0.518	0.620	1.291
16	84	0.871	0.860	1.890	1.630	0.671	1.013	0.461	0.534	1.299
16	75	0.696	0.686	1.688	1.497	0.535	1.015	0.412	0.465	1.302
16	62	0.484	0.468	1.395	1.298	0.365	1.033	0.347	0.373	1.324
16	55	0.386	0.369	1.238	1.186	0.288	1.047	0.312	0.325	1.342
16	46	0.276	0.258	1.035	1.038	0.201	1.070	0.267	0.266	1.372
16	40	0.213	0.195	0.900	0.934	0.152	1.092	0.237	0.228	1.400
16	34	0.159	0.141	0.765	0.827	0.110	1.129	0.208	0.192	1.447
16	31	0.136	0.117	0.698	0.772	0.091	1.161	0.195	0.176	1.489
16	24	0.087	0.070	0.540	0.637	0.055	1.239	0.161	0.137	1.589
16	19	0.060	0.044	0.428	0.535	0.034	1.364	0.140	0.112	1.748
16	12	0.031	0.018	0.270	0.379	0.014	1.766	0.115	0.082	2.265
20	145	2.050	2.050	2.918	2.195	1.430	1.000	0.703	0.934	1.433
20	133	1.730	1.725	2.677	2.058	1.203	1.003	0.646	0.841	1.438

Table 1 The training patterns and comparative analysis of proposed formulation with FEA results (cont.)

D (m)	H (m)	FEA	$Pala$ $Eq.8$	$NBCC-95$	$UBC-97$	$Rayleigh$	$\frac{FEA}{Pala}$	$\frac{FEA}{NBCC-95}$	$\frac{FEA}{UBC-97}$	$\frac{FEA}{Rayleigh}$
20	114	1.278	1.267	2.294	1.833	0.884	1.009	0.557	0.697	1.446
20	103	1.049	1.034	2.073	1.699	0.722	1.014	0.506	0.618	1.454
20	95	0.896	0.880	1.912	1.599	0.614	1.018	0.469	0.560	1.460
20	80	0.643	0.624	1.610	1.405	0.435	1.030	0.399	0.458	1.477
20	67	0.459	0.438	1.348	1.230	0.305	1.049	0.340	0.373	1.503
20	52	0.286	0.264	1.046	1.017	0.184	1.085	0.273	0.281	1.555
20	36	0.149	0.126	0.724	0.772	0.088	1.179	0.206	0.193	1.690
20	10	0.023	0.010	0.201	0.295	0.007	2.359	0.114	0.078	3.381
2	60	3.460	3.510	3.818	3.582	7.744	0.986	0.906	0.966	0.447
2	54	2.801	2.843	3.437	3.310	6.272	0.985	0.815	0.846	0.447
2	48	2.218	2.246	3.055	3.030	4.956	0.987	0.726	0.732	0.448
2	43	1.780	1.803	2.737	2.790	3.977	0.987	0.650	0.638	0.448
2	40	1.541	1.560	2.546	2.643	3.442	0.988	0.605	0.583	0.448
2	36.5	1.284	1.299	2.323	2.467	2.866	0.988	0.553	0.520	0.448
2	29	0.812	0.820	1.846	2.076	1.809	0.990	0.440	0.391	0.449
2	25	0.604	0.609	1.591	1.858	1.344	0.991	0.380	0.325	0.449
2	21	0.427	0.430	1.336	1.630	0.949	0.993	0.320	0.262	0.450
2	17.5	0.297	0.299	1.114	1.422	0.659	0.995	0.267	0.209	0.451
2	15	0.219	0.219	0.955	1.266	0.484	0.998	0.229	0.173	0.452
2	12	0.141	0.140	0.764	1.071	0.310	1.004	0.185	0.132	0.455
2	9	0.081	0.079	0.573	0.863	0.174	1.026	0.141	0.094	0.465
2	6	0.037	0.035	0.382	0.637	0.077	1.054	0.097	0.058	0.478
25	48	0.208	0.180	0.864	0.857	0.112	1.157	0.241	0.243	1.855
25	105	0.883	0.860	1.890	1.541	0.537	1.027	0.467	0.573	1.645
25	100	0.804	0.780	1.800	1.486	0.487	1.031	0.447	0.541	1.652
25	84	0.577	0.550	1.512	1.304	0.343	1.048	0.382	0.443	1.680
25	72	0.432	0.404	1.296	1.161	0.252	1.068	0.333	0.372	1.712
25	36	0.128	0.101	0.648	0.691	0.063	1.266	0.198	0.185	2.029
25	24	0.073	0.045	0.432	0.510	0.028	1.625	0.169	0.143	2.604
25	15	0.036	0.018	0.270	0.358	0.011	2.051	0.133	0.101	3.287
36	15	0.033	0.012	0.225	0.298	0.006	2.708	0.147	0.111	5.207
36	96	0.539	0.499	1.440	1.201	0.260	1.080	0.374	0.449	2.076
36	32	0.088	0.055	0.480	0.527	0.029	1.587	0.183	0.167	3.051
7	32	0.291	0.285	1.089	1.195	0.336	1.020	0.267	0.244	0.865
3	30	0.581	0.585	1.559	1.739	1.054	0.993	0.373	0.334	0.551
3	21	0.286	0.287	1.091	1.331	0.516	0.998	0.262	0.215	0.554
3	8	0.041	0.042	0.416	0.645	0.075	0.986	0.099	0.064	0.547
5	63	1.535	1.548	2.536	2.350	2.160	0.992	0.605	0.653	0.711
5	54	1.129	1.137	2.173	2.093	1.587	0.993	0.519	0.539	0.711
5	35	0.478	0.478	1.409	1.512	0.667	1.001	0.339	0.316	0.717
5	28	0.309	0.306	1.127	1.279	0.427	1.009	0.274	0.241	0.723
1	28	1.503	1.529	2.520	2.860	4.770	0.983	0.596	0.526	0.315
1	13	0.326	0.330	1.170	1.609	1.028	0.989	0.279	0.203	0.317
1	37	2.637	2.670	3.330	3.525	8.329	0.988	0.792	0.748	0.317
1	33	2.097	2.124	2.970	3.235	6.626	0.987	0.706	0.648	0.317
14	78	0.918	0.847	1.876	1.648	0.707	1.083	0.489	0.557	1.299
14	67	0.702	0.625	1.612	1.471	0.521	1.123	0.436	0.477	1.346
14	52	0.418	0.377	1.251	1.216	0.314	1.110	0.334	0.344	1.331
14	39	0.242	0.212	0.938	0.980	0.177	1.142	0.258	0.247	1.370
14	31	0.159	0.134	0.746	0.825	0.112	1.188	0.213	0.193	1.425

Table 1 The testing patterns and comparative analysis of proposed formulation with FEA results (cont.)

D (m)	H (m)	FEA	$Pala$ $Eq.8$	$NBCC-95$	$UBC-97$	$Rayleigh$	$\frac{FEA}{Pala}$	$\frac{FEA}{NBCC-95}$	$\frac{FEA}{UBC-97}$	$\frac{FEA}{Rayleigh}$
4	26.25	0.339	0.336	1.181	1.362	0.524	1.009	0.287	0.249	0.647
6	65	1.363	1.373	2.388	2.196	1.749	0.993	0.571	0.621	0.779
8	91	2.000	2.018	2.896	2.448	2.227	0.991	0.691	0.817	0.898
8	13	0.050	0.041	0.414	0.569	0.045	1.214	0.121	0.088	1.100
10	39	0.306	0.297	1.110	1.160	0.293	1.032	0.276	0.264	1.046
12	80	1.043	1.040	2.078	1.814	0.937	1.003	0.502	0.575	1.113
12	11	0.031	0.020	0.286	0.410	0.018	1.577	0.108	0.076	1.750
16	69	0.594	0.580	1.553	1.406	0.453	1.024	0.383	0.422	1.312
20	162	2.554	2.559	3.260	2.386	1.785	0.998	0.783	1.071	1.431
20	26	0.087	0.066	0.523	0.605	0.046	1.320	0.166	0.144	1.892
2	33	1.050	1.062	2.100	2.287	2.342	0.989	0.500	0.459	0.448
30	48	0.117	0.150	0.789	0.782	0.085	0.781	0.148	0.150	1.371
36	150	1.252	1.219	2.250	1.678	0.634	1.027	0.556	0.746	1.976
5	44	0.752	0.755	1.771	1.795	1.054	0.996	0.425	0.419	0.714
1	6	0.071	0.070	0.540	0.901	0.219	1.017	0.132	0.079	0.326
14	24	0.101	0.080	0.577	0.681	0.067	1.259	0.175	0.148	1.510

In this study reliable and simple formula for estimating the fundamental period of RC planar shear walls has the following form:

$$T = 0{,}0195\frac{\mathrm{H}^2}{\mathrm{D}} \tag{8}$$

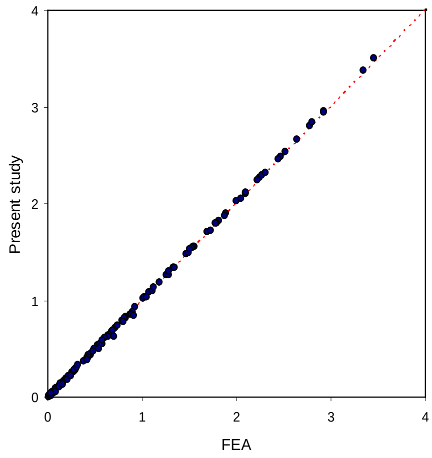
where T is the period in sec; H is the total height of building in meter; D is the length of the shear wall in direction to applied force in meter.

The period estimation via proposed formula is compared to UBC and NBCC and Rayleigh's method in Figure 3. In spite of the comparisons between the FEA results and other methods which show significant deviation, there is a good correlation between the estimated periods via proposed formula and FEA results.

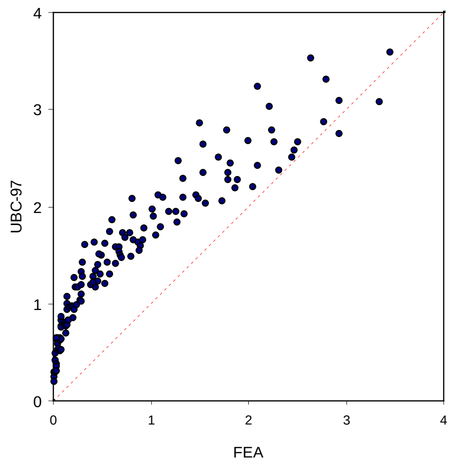
R^2 is for the absolute fraction of variance. In equation 9 T_i and out_i are the target and output of GP model.

$$R^2 = 1 - \left(\frac{\sum_i (T_i - out_i)^2}{\sum_i (out_i)^2} \right) \tag{9}$$

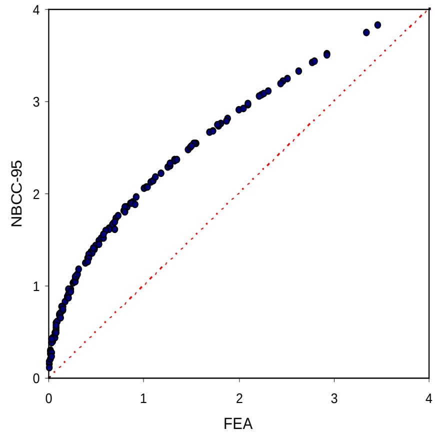
The R^2 value of the proposed formula with respect to FEA for training set is 99.97% and for testing set is 99.96%. The R2 values of the NBCC-95, UBC-97 and Raleigh method are 93.67%, 87.29%, and 72.38%, respectively. All of statistical values of proposed formula are the best in the comparison. The errors are observed to be quite satisfactory for each case. Thus, the trained GEP showed satisfactorily good results. Consequently, all of the comparisons in Table 1-2 demonstrate that the proposed formula is suitable and it predicts the fundamental period values precisely when compared with the results of seismic design codes and several methods.



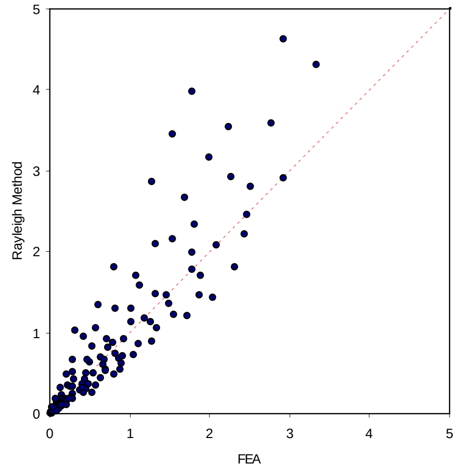
a) Present study results with FEA results



c) UBC results with FEA results



b) NBCC results with FEA



d) Rayleigh's method results with FEA results

Figure 3. Performance of the proposed formula regarding to seismic codes for training set

CONCLUSION

In order to estimate the fundamental period of shear wall structures, the equation formula given in the seismic codes are commonly used. There are a lot of methods for the determination of the periods of shear walls by hand calculation. This study deals with submission of GP for the formulation of fundamental period of planar concrete shear wall structures. By using finite element analysis, numerical computations were performed for 148 different concrete shear wall structures having a variety of height and length of shear walls.

The results were employed to develop the proposed formula. The results were in close agreement with the finite element method and the proposed formulation, were actually reliable, showed very good generalization capability and were confirmed by a lot of calculation methods in the literature. Proposed formulation is not cumbersome and abridges the computing time and a simple calculator would be enough to handle the periods of the planar shear wall structures. This formula is thought to be very useful for the seismic codes and engineering practice.

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