Seismic Base Shear Force Depending on Building Fundamental Period and Site Conditions: Deterministic Formulation and Probabilistic Analysis

S. Dorbani, M. Badaoui, D. Benouar

***Abstract*—**The aim of this paper is to investigate the effect of the building fundamental period of reinforced concrete buildings of (6, 9, and 12-storey), with different floor plans: Symmetric, mono-symmetric, and unsymmetric. These structures are erected at different epicentral distances. Using the Boumerdes, Algeria (2003) earthquake data, we focused primarily on the establishment of the deterministic formulation linking the base shear force to two parameters: The first one is the fundamental period that represents the numerical fingerprint of the structure, and the second one is the epicentral distance used to represent the impact of the earthquake on this force. In a second step, with a view to highlight the effect of uncertainty in these parameters on the analyzed response, these parameters are modeled as random variables with a log-normal distribution. The variability of the coefficients of variation of the chosen uncertain parameters, on the statistics on the seismic base shear force, showed that the effect of uncertainty on fundamental period on this force statistics is low compared to the epicentral distance uncertainty influence.

***Keywords*—**Base shear force, fundamental period, epicentral distance, uncertainty, lognormal variable, statistics

I. Introduction

BEHAVIOR of structures during an earthquake depends on several parameters: those depending on the building conception and those depending on earthquake parameters and the nature and topography of the soil crossed by the seismic waves.

Herein, the study aims at developing a formula giving the variation of the base shear force depending to the building natural period and the epicentral distance. Then, using Monte Carlo simulations, a probabilistic analysis is carried out in order to investigate the effect of the uncertainty of the chosen parameter on the statistics of the base shear force through the developed expression.

II. Deterministic Formulation

The analyzed structures are reinforced concrete buildings of 6, 9, and 12 stories with various floor geometry depending on the bracing positions chosen to vary the natural period: Symmetric (SB), mono-symmetric (MB), and unsymmetric (UB).

The story height is 3 m, while the dimensions of the standard plan buildings are 22.7 × 13.75 m².

The analysis is done separately in the longitudinal and transverse direction; however, only the maximum values are presented. Table I gives the Boumerdes earthquake Pic values at the 10 considered stations. The E-W component is higher than the N-S one [1]. This is explained that by directional effect related to the fault orientation.

TABLE I
Recorded Peak Ground Accelerations, Velocities and Displacements of the Boumerdes Earthquake [1]

	E-W			N-S			Vertical (g)		
D (km)	A (g)	V (cm/s)	Displ (cm)	A (g)	V (cm/s)	Displ (cm)	A (g)	V (cm/s)	Displ (cm)
20	0.34	18.9	4.6	0.26	12.7	5.4	0.25	15.8	7.7
29	0.52	27.5	9.1	0.46	40.6	16.8	0.16	10.7	4.4
36	0.27	16.5	3.9	0.23	9.1	2.7	0.09	7.7	1.8
49	0,2	9.0	2.0	0.19	7.0	1.2	0.09	6.4	0.9
72	0.05	3.4	1.0	0.04	3.5	0.9	0.03	1.3	0.5
75	0.12	14.1	4.0	0.09	12.0	2.9	0.05	8.5	4.7
86	0.16	5.0	0.4	0.09	5.4	0.3	0.03	1.2	0.1
110	0.1	10.2	1.3	0.07	7.1	1.6	0.06	4.8	0.7
130	0.03	2.3	1.4	0.026	1.9	0.6	0.016	1.6	1.5
151	0.03	1.6	0.9	0.02	1.2	0.7	0.01	1.3	1.2

A. Results

1. Fundamental Period of the Buildings

As required by the different building codes, all the modes whose corresponding participation factor exceeds 90% are considered [2]. The number of modes for 6 and 9-story building is 12 and 24 for the 12-story buildings. Table II summarizes the first nine periods on the analyzed buildings.

TABLE II
First Nine Periods for the Different Considered Buildings

	6-story buildings			**9 -story buildings**			**12-story buildings**		
	SB	**MB**	**UB**	**SB**	**MB**	**UB**	**SB**	**MB**	**UB**
1	0.81	0.66	0.67	1.29	1.07	1.12	1.60	1.53	1.21
2	0.55	0.43	0.52	0.97	0.76	0.91	0.96	1.02	1.12
3	0.48	0.42	0.44	0.82	0.71	0.77	0.76	0.80	0.80
4	0.27	0.21	0.19	0.42	0.34	0.33	0.58	0.46	0.31
5	0.15	0.11	0.13	0.26	0.20	0.24	0.33	0.25	0.28
6	0.14	0.11	0.11	0.24	0.20	0.20	0.23	0.23	0.18
7	0.13	0.11	0.09	0.23	0.18	0.16	0.21	0.19	0.14
8	0.10	0.07	0.06	0.16	0.12	0.11	0.18	0.14	0.12
9	0.07	0.05	0.05	0.12	0.10	0.10	0.17	0.11	0.08

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The fundamental periods of the studied buildings evolve with their heights. They are between 1.21 and 1.6 s for the 12-story buildings, from 1.07 to 1.29 for the 9-story buildings and between 0.66 and 0.81 s for 6-story buildings. This is explained by the fact that when the building height increases, its mass increases and its stiffness decreases [3]-[10].

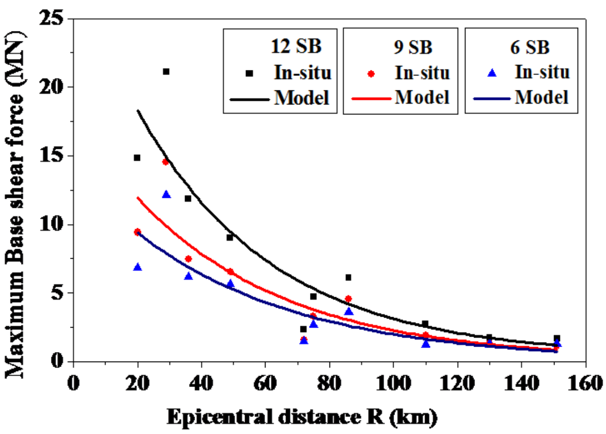
2. Base Shear Force

The base shear force is the resultant of the lateral forces generated by ground motion. It is applied at the base at base of the structure.

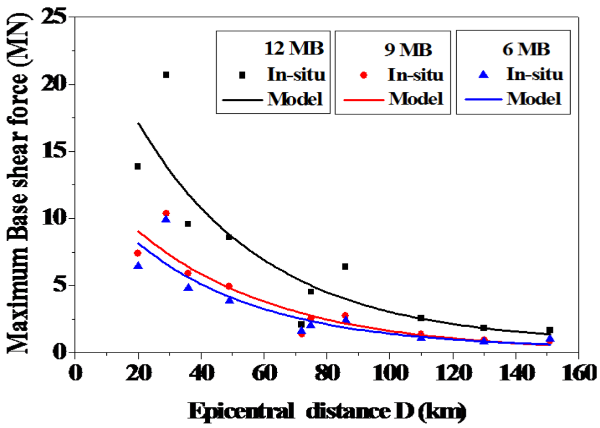
The base shear force value depends on several parameters: those depending on the ground motion such as its acceleration, velocity and displacement, epicentral distance, and those depending on the building designs like mass, stiffness, geometry, and the soil condition.

Figs. 1 (a)-(c) illustrate the base shear force with respect to the epicenter distance and the number of stories.

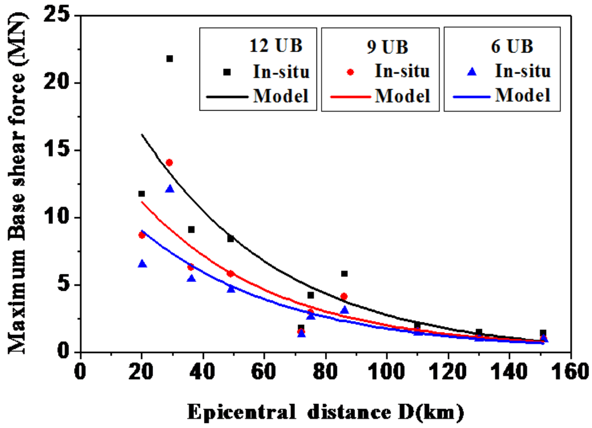
The building height causes an important increase in the base shear force. This is explained by the fact that when the number of stories increases, weight increases and consequently the base shear force increases [3], [4].



(a) SB Buildings



(b) MB Buildings



(c) UB Buildings

Fig. 1 Base shear force versus epicentral distance and number of stories fitted by the following expression

At specific stations situated respectively at D = 29 km and 86 km, the base shear values are greater for buildings erected closer to the epicenter [5]-[8]. This is explained by a local site effect due to the soft soil and is confirmed by the high PGA values recorded at these stations given in Table I [1]. One notes that this force is directly proportional to building fundamental period "T" and inversely proportional to the epicentral distance "D" [3]-[8], [10]. Depending on these two parameters, the base shear variation can be expressed by the following expression, with an $R^2 > 90\%$ for all the cases:

$$V = \frac{6.56}{1-0.44\mathrm{T}} e^{-0.02\,\mathrm{D}}$$

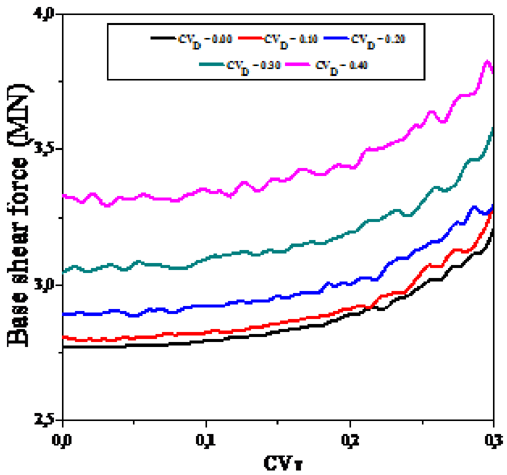
A good estimation of the seismic behavior is vital concern because it can allow to the structure to respond safely, where an overestimate gives effect to extra-costs, whereas an underestimation can lead to major damage. This paper presents the development of formula giving the base shear force versus the building natural period and the epicentral distance, for a given earthquake with a good accuracy. This expression can allow researchers to study the effect of a major earthquake that heated northern Algeria on a range of RC building erected at different epicentral distances [3]-[8], [10].

III. Probabilistic Analysis

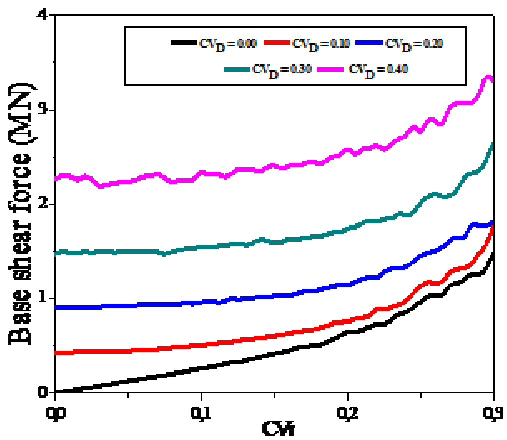
This section deals with the analysis for the effect of the uncertainty of the chosen parameters; namely, the building natural period and epicentral distance on the base shear force through the expression detailed above. The uncertainty parameters are modeled by random variables defined by their moments of order 1 and 2, which are, respectively, the mean and variance and they are supposed to follow a log-normal distribution [11]-[14], through Monte Carlo simulation. A parametric study, which incorporates the influence of the coefficient of variation of the fundamental period CV_T and the epicentral distance CV_D, on the statistics of these responses consists of the mean and standard deviation [7].

A. The Statistics of Shear at the Base Depending on the Variability of the Building Fundamental Period T

Fig. 2 shows the statistics of base shear force depending to the variability of the fundamental period variation coefficient CV_T which varies from 0 to 0.3, when the coefficient of variation of CV_D epicentral distance is equal to 0.4. It is emanating from these figures that the increase in CV_T led to a small increase for the mean, which is more pronounced for the standard deviation of base shear force. This increase is more uttered with the increase of CV_D. On the other hand, one can notice that as far as the coefficient of variation of the epicentral distance CV_D increases, the dispersion curves become more important, and the mean of the base force becomes larger, indicating that the CV_D increase influences significantly the variation of the mean [7], [8], [10].



(a) Mean



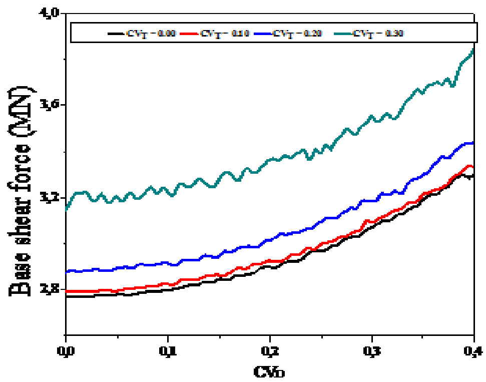
(b) Standard deviation

Fig. 2 Base shear Statistics versus CV_T

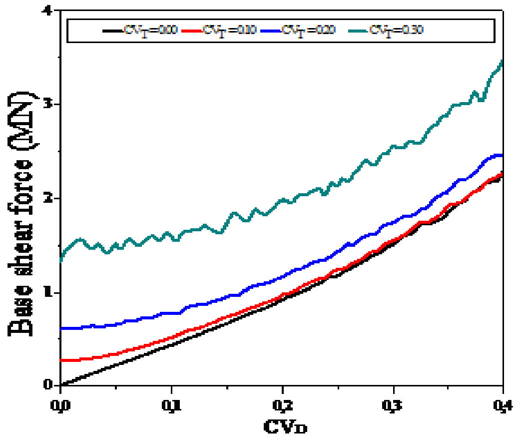
B. The Statistics of Shear at the Base Depending on the Variability of the Epicentral Distance

In Fig. 3, the change of the base shear force statistics depending on CV_D is given. The mean and standard deviation of this structural response increases almost linearly. While the CV_T effect is small compared to that of CV_D, this is translated graphically by the juxtaposition of corresponding curves CV_T between 0 and 0.2.

For the case of extreme heterogeneity matching CVT = 0.3, curve stands reflecting a more important development. One can say that the epicentral distance uncertainty has more influence on the base shear statistics than the natural period one [7], [8], [10].



(a) Mean



(b) Standard deviation

Fig. 3 Base shear Statistics versus CV_D

IV. Conclusion

The base shear force is an estimate of the maximum lateral force expected to take place following a seismic movement applied to the base of a structure [3], [7], [8]. So, a good estimate of this force allows the structure to respond safely. An overestimate can give effect to the additional costs, while an underestimation can lead to major damage.

In a first step, an analytical formulation of the base shear force has been carried out through an elastic analysis, using response spectrum of the Boumerdes, Algeria 2003 earthquake records. The expression links this force variation to the building natural period and the epicentral distance. After that, an investigation of the effect of the chosen parameter uncertainty on the developed expression is given, under the hypothesis that the both parameters are log normal variables.

The statistics of shear at the base is affected by the CV_T and CV_D, where the mean and the standard deviations increase with the evolution of the coefficients of variation for each parameter. This increase is more pronounced in relation to the CV_D increase and this expresses the weak influence of uncertainty combined with the fundamental period before the association with the epicentral distance [7]. We can therefore conclude that the base shear force is more sensitive to the epicentral distance uncertainty than that related to the fundamental period [7].

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