An-Najah National University
Faculty of Graduates Studies

The Effect of Earthquake Vertical Component on the Response of Cantilever Beams in Multi-Storey Reinforced Concrete Building

By

Ahmad Mahmoud Saleem Al-Beik

Supervisor

Dr. Monther Dwaikat

Co- Supervisor

Dr. Monther Thiab

This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Structural Engineering, Faculty of Graduate Studies, An-Najah National University, Nablus, Palestine.

2021

The Effect of Earthquake Vertical Component on the Response of Cantilever Beams in Multi-Storey Reinforced Concrete Building

By

Ahmad Mahmoud Saleem Al-Beik

This Thesis was defended Successfully on 15/07/2021 and approved by:

Defense Committee Members	**Signature**
– **Dr. Monther Dwaikat / Supervisor**	………….
– **Dr. Monther Thiab / Co- Supervisor**	………….
– **Dr. Abdul Al Razzaq Touqan / Internal Examiner**	………….
– **Dr. Bilal Almasri / External Examiner**	………….

Dedication

To my father

To my mother

To my brothers

To my sister

To my teachers

To all friends and colleagues

To everyone working in this field

To all of them

I literally dedicate this work

Acknowledgment

Praise be to Allah, Lord of the World's, first of all.

I would like to thank whoever participated in this effort.

Many thanks and regards to Dr. Monther Dwaikat, and Dr. Monther Thiab for their valuable efforts in completing this work.

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل عنوان:

The Effect of Earthquake Vertical Component on the Response of Cantilever Beams in Multi-Storey Reinforced Concrete Building

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تم الإشارة اليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification

Student's Name: **اسم الطالب: أحمد محمود سليم البيك**

Signature: **التوقيع :**

Date: **التاريخ :**

Table of Contents

List of Figures

List of Tables

List of Symbols

A_B:	Ground floor area of structure in square feet (m2) to include area covered by all overhangs and projections
a_{vg}:	Vertical acceleration of earthquake
a_g	Design ground acceleration on type A ground
D:	Dead load
E_c	Modulus of elasticity for concrete
E_m:	Seismic load effect including overstrength
E_{mh}:	Effect of horizontal seismic forces, including overstrength
E_{Edx}	Represents the action effects due to the application of the seismic action along the chosen horizontal axis x of the structure
E_{Edy}	Represents the action effects due to the application of the same seismic action along the orthogonal horizontal axis y of the structure.
L:	Live load
E_v:	Vertical earthquake load
E_h:	Horizontal earthquake load
ρ:	From ASCE code (redundancy factor)
S:	Snow load
w:	Wind load
S_{MS}:	The MCER spectral response acceleration parameter at short periods as $S_{MS} = F_a\ S_S$
F_a:	Short Period Site Coefficient.
S_{DS}:	Design, 5% damped, spectral response acceleration parameter at short periods as $\frac{2}{3}\ S_{MS}$

Ω_o:	Overstrength factor
Q_E:	Effects of horizontal seismic forces
ρ:	Mass per unit length
S_{av}:	Design vertical response spectral acceleration
Sa_{mv}:	Vertical response spectral acceleration,
C_v:	Values of vertical coefficient and is a term of S_S
T_v:	Vertical fundamental period
I_g:	Moment of inertia for cantilever beam section
C_a:	seismic coefficient, as set forth
r_{max}:	Max element story shear ratio
I:	Importance Factor
η:	The damping correction factor with a reference value of η = 1 for 50% viscous damping.
S_1:	mapped MCER, 5% damped, spectral response acceleration parameter at a period of 1 sec
S_S:	Mapped MCER, 5% damped, spectral response acceleration parameter at short periods
SDC:	Seismic design category
R:	response modification coefficient
C_d:	Deflection amplification factor
Δ:	Story displacement
W:	Distributed load
P:	Concentrated load
k^*:	Stiffness star

m^*:	Mass star
L:	Length of cantilever beams
Ψ:	Shape function of cantilever beams
f_i:	Lateral force at level i of the floor.
δ_i:	Elastic deflection due to lateral force at level i of the floor.
g:	Gravity acceleration.
w_i:	Weight at level i of the floor.

The Effect of Earthquake Vertical Component on the Response of Cantilever Beams in Multi-Storey Reinforced Concrete Building

By

Ahmad Mahmoud Saleem Al-Beik

Supervisor

Dr. Monther Dwaikat

Co- Supervisor

Dr. Monther Thiab

Abstract

Structural design to withstand seismic loading is mainly governed by horizontal ground motion, and the effects of vertical ground motion have long been considered insignificant or secondary. However, an emerging evidence indicates that vertical ground motions have significant destructive potential, especially under specific site conditions. Evidence suggests that the vertical component of ground motion is more important than previously thought, especially for events close to the fault and when buildings have a cantilever beam. The purpose of this thesis is to investigate the effect of vertical component of earthquake on the response of cantilever beams of multi-story reinforced concrete building. Finite Element (F.E) analysis using available commercial software (Etabs) is used to investigate the effect of vertical component of earthquake on cantilever beams in 2D and 3D models with different cases. The models are verified by comparing the periods of models to hand calculation of single degree of freedom. Many different models have been constructed with different cases.

The results show that the equivalent static equation in ASCE 7-16 ($0.2S_{DS}$ D) code can be considered to be conservative for structures with seismic design category (B). A proposed equivalent static equation is suggested to account for the effect of vertical components of earthquake on the response of cantilever. The proposed equation is generally conservative for most of the cases with different seismic deign categories (B, C, D).

Keywords: Cantilever, Beams, Earthquake, Vertical Response, vertical static, Codes.

1. Introduction

1.1 Scope

Buildings should have sufficient capacity to resist earthquake forces or any lateral loads. Seismic design of the reinforced concrete structure is mainly governed by horizontal ground motion, which it resists by frames and shear walls. However, the effects of vertical ground movement have always been considered insignificant or secondary, but buildings located near the fault are considered to be affected by vertical ground motions [Eurocode 8 (EN 1998-1),2005].

In this chapter, vertical component of earthquake will be briefly introduced and the cantilever beam, problem statement, research objectives and methodology will be discussed.

1.2 The vertical component of earthquake

Earthquakes generate seismic movement in both horizontal and vertical directions. In the past, engineers were generally concerned with the effects of horizontal movement on buildings. The building codes for seismic design determine the seismic forces on the building by the horizontal direction. When performing dynamic analysis, ASCE Code 7-16 specifies that the vertical response spectrum must be scaled to $\frac{2}{3}$ of the horizontal response spectrum. The 1994 Northridge earthquake set have considerable vertical and horizontal acceleration values, some values exceeding 1g. This guided some engineers to consider that some of damage was due to the high values of the vertical acceleration [Papazoglou and Elnashai 1996]. Figure 1.1 shows Northridge earthquake damage in 1994.

Figure 1.1: Northridge earthquake damage in 1994 (USGS science for changing world ,1994).

Northridge ground motion records showed that, with the exception of a few isolated cases, the peak vertical acceleration was typically about two-thirds of the horizontal acceleration [Shakal et al 1996]. Some damage to highway structures increases the awareness of the importance of vertical acceleration. Studies were performed to assess the relative magnitude of the vertical acceleration with respect to the horizontal acceleration. After the 1971 San Fernando earthquake, the importance of the vertical motion measured at the Holiday Inn Building in Van Nuys was assessed. The effect of vertical motion is small compared to the gravity loads [Blume 1972].

The following is a fairly comprehensive list of structures and structural components that have been identified as being particularly critical to vertical earthquake [S.K. Ghosh and Prabuddha Das Gupta ,2018].

Building structures include:

- Horizontal structural members with long spans.
- Horizontal cantilever members.
- Horizontal prestressed members.
- Vertical elements which have opening.
- Base-isolated structures.

1.3 Cantilever Beam

A cantilever beam is a member with one end located outside of support. Figure 1.2 shows cantilever beam.

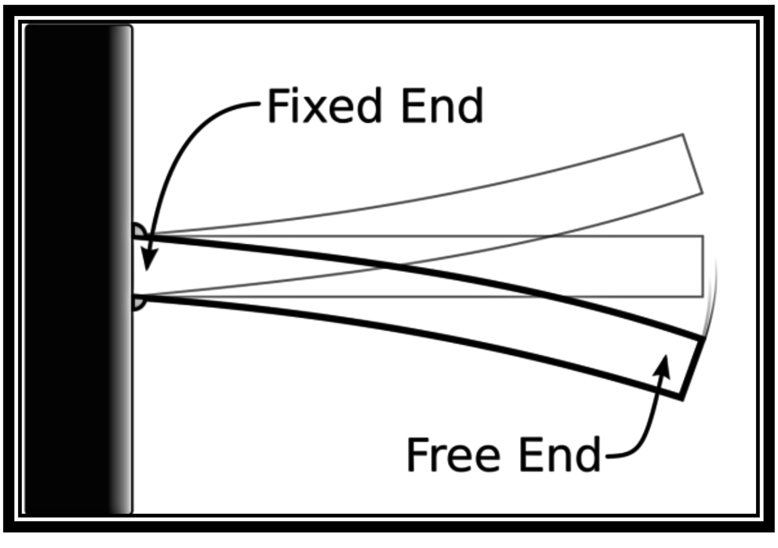

Figure 1.2: Cantilever Beam with One end Fixed and Other End Free

The cantilever beams have many disadvantages [Avci, O., & Bhargava, A. ,2019]. For example: Cantilever beams generally suffer large deflections, give larger moments loads and have low stiffness and high period compared with simple beam.

The causes for taking cantilever beam in the models of thesis are these disadvantages of cantilever beam.

1.4 Problem statement

The use of cantilever beams in buildings may cause an increase in the overall fundamental period of the building in vertical direction. The designers generally ignore the effect of vertical earthquake ground motion or they do not use response spectrum analysis in the vertical direction. This ignorance may not be conservative especially for structures located near faults [ASCE7-16 code ,2016]. Moreover, the equivalent static method specified in ASCE 7-16 code ($0.2S_{DS}$ D) for the vertical component of the earthquake is conservative when comparing with vertical response spectrum with seismic design category (B). A proposed equivalent static equation is suggested to account for the effect of vertical components of earthquake on the response of cantilever with different seismic design category (B, C, D).

1.5 Research objectives

The objectives in this study are the following:

- Investigating the effect of earthquake vertical component on the response of reinforce concrete buildings having cantilever beams by study the vertical base reaction and max story displacement.

- Investigating the effect of earthquake vertical component on the response of reinforce concrete cantilever beams.
- Evaluate a proposed vertical static equation for estimating the vertical component of earthquake force with different seismic design category.

1.6 Methodology

First, a literature review is conducted to know the parameters which affect to the fundamental period estimation in cantilever beams, and to understand the effect of vertical component of earthquake on reinforced concrete buildings. Finite Element (F.E) analysis using available commercial software (Etabs) is used to investigate the effect of vertical component of earthquake on cantilever beams in 2D and 3D models with different cases. The study will be divided into two parts: The first part is to study the effect of vertical component of earthquake on whole building with different cases. The second part is to study the effect of vertical component of earthquake on cantilever beams, this part has two sections: 2D Models and 3D Models. 2D Models are used to study the effect of vertical component of earthquake on cantilever beams with different cases, and the 3D models is used to generalize results of 2D models.

The methodology that will be used is to compare static formula and dynamic analysis of vertical component of earthquake. The compare will consider the vertical reaction of cantilever support by static and dynamic analysis. The formula that will be used to find the difference is

$$\frac{F_{z\ from\ dynamic\ analysis} - F_{z\ from\ static\ analysis}}{F_{z\ from\ dynamic\ analysis}}\ x\ 100\%.$$

The 2D and 3D models are verified against manual results of periods of structures.

2 Literature review

2.1 overview

In the past, there were two arguments about the unimportance of vertical component of earthquake: the low energy content of strong vertical motion peaks; and the fact that structure components have a large safety factor in the vertical direction. These arguments can be easily confuted. The relationship between structural and excitation periods is more important than energy content, [Papazoglou & Elnashai, 1996].

Structural design to withstand seismic loading is mainly governed by horizontal ground movement, and the effects of vertical ground movement have long been considered insignificant or secondary. However, researches have indicated that the vertical ground motions have significant destructive potential, especially under specific site conditions [Alex Piolatto ,2009].

2.2. Code Provisions

2.2.1 ASCE 7-16 (Minimum Design Loads and Associated Criteria for Buildings and Other Structures)

Referring to Section 2.3.6 in ASCE 7-16, the following load combinations must be used with the basic load combinations in Section 2.3.1 of the code when a building is subjected to earthquake load effects. In the load combinations, $E = f(E_v, E_h)$ (defined in Section 12.4.2 or 12.14.3.1 of the code). Hence, the following earthquake load combinations must be used:

$$1.2D + E_v + E_h + L + 0.2S \qquad \text{Eq.2.1}$$

$$0.9D - E_v + E_h \qquad \text{Eq.2.2}$$

Referring to section 2.4.5, the allowable load combinations are:

$$1.0D + 0.7E_v + 0.7E_h \qquad \text{Eq.2.5}$$

$$1.0D + 0.525E_v + 0.525E_h + 0.75L + 0.75S \qquad \text{Eq.2.6}$$

$$0.6D - 0.7E_v + 0.7E_h \qquad \text{Eq.2.7}$$

The horizontal earthquake (E_h) is taken as:

$$E_h = \rho\, Q_E \qquad \text{Eq.2.8}$$

Where:

- L: live load effect
- D: dead load effect
- S: snow load effect
- Q_E :effect of horizontal seismic (earthquake-induced) forces.
- ρ : redundancy factor.

If the seismic design category is A or B, the vertical earthquake (E_v) is taken.

as:

$$E_v = 0.2S_{DS}D \qquad \text{Eq.2.9}$$

But if the seismic design category is C, D, E, or F, the vertical earthquake (E_v) is taken as:

$$E_v = 0.3 S_{av} D. \qquad \text{Eq.2.10}$$

Where :

1. S_{DS} : design 5% damped, spectral response acceleration parameter at short period defined as Eq.2.11.
2. S_{av}, is taken as $\frac{2}{3}$ S_{aMv} and S_{aMv} defined as Eq.2.13.

$$S_{DS} = \frac{2}{3} S_{MS} \qquad \text{Eq.2.11}$$

$$S_{MS} = F_a\, S_S \qquad \text{Eq.2.12}$$

Where:

- F_a: Short-Period Site Coefficient as Table 2.1 according to section 11.4 in ASCE7-16 code.
- S_S : mapped MCER, 5% damped, spectral response acceleration parameter at short periods.
- S_{MS} : the MCER, 5% damped, spectral response acceleration parameter at short periods adjusted for site class effects.

According to Section 11.9.3 in the code, the design of vertical response spectral acceleration. and S_{aMv} is defined as Eq 2.13.

E_v can be taken zero for the following conditions:

a) For buildings located in seismic design category B.
b) In equations ($E = E_v - E_h$) when computing the demands on the soil–structure interface of foundations.

Table 2.1: Short-Period Site Coefficient F_a [ASCE 7-16 code,2016]

Site Class	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at Short Period					
	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S = 1.25$	$S_S \geq 1.5$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.3	1.2	1.2	1.2	1.2
D	1.6	1.4	1.2	1.1	1.0	1.0
E	2.4	1.7	1.3	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8
F	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8

It can be noted that straight line interpolation for intermediate values of Ss may be used.

According to Section 11.9 of the code, MCER Vertical Response Spectrum must only be used to buildings in Seismic Design Categories C, D, E, and F. In section 11.9.2, vertical response spectral acceleration, S_{aMv}, must be taken as follows:

$S_{aMv=}$

$$\left\{ \begin{array}{ll} T_v \leq 0.025\ sec & 0.3 C_v S_{MS} \\ 0.025\ sec < T_v \leq 0.05\ sec & 20\ C_v S_{MS}\ (T_v - 0.025) + (0.3 C_v S_{MS}) \\ 0.05\ sec < T_v \leq 0.15\ sec & 0.8\ C_v S_{MS} \\ 0.15\ sec < T_v \leq 2\ sec & 0.8\ \mathrm{Cv\ SMS}\ (\frac{0.15}{T_V})^{0.75} \end{array} \right\} \quad \text{Eq. 2.13}$$

Where:

C_v = is vertical coefficient in terms of S_S in Table 2.2,

S_{MS} = the MCER spectral response acceleration parameter at short periods,

T_v = the vertical period of seismic.

Table 2.2: Values of Vertical Coefficient C_v [ASCE 7-16 code,2016].

Mapped M_{CER} Spectral Response Parameter at Short Periods[a]	Site Class A, B	Site Class C	Site Class D, E, F
$S_S \geq 2.0$	0.9	1.3	1.5
$S_S = 1.0$	0.9	1.1	1.3
$S_S = 0.6$	0.9	1.0	1.1
$S_S = 0.3$	0.8	0.8	0.9
$S_S \leq 0.2$	0.7	0.7	0.7

S_{aMv} must not be less than 0.5 of S_{aM} for horizontal motion determined in according to Section 11.4 or Chapter 21, respectively.

According to section 12.4.4 in ASCE 7-16, and for buildings assigned to seismic design category D, E, or F, cantilever members must be designed for a minimum vertical force of 0.2 times dead load.

2.2.2. UBC (Uniform Building Code)

As referred in the UBC section 1620.3.2, horizontal cantilever and horizontal pre-stressed elements are required to be verified against vertical acceleration and vertical component of earthquake ground motion.

According to UBC 1997v2, Section 1612, the strength load combinations that include seismic effects are:

$$1.2D + 1.0E + (f_1 L + f_2 S) \qquad \text{Eq.2.14}$$

$$0.9D \pm (1.0E \text{ or } 1.3W) \qquad \text{Eq.2.15}$$

Where: f_1 = 1.0 for garage live load and for live loads more than 4.9 kN/m^2.

= 0.5 for rest live loads.

f_2 = 0.7 For roof defrost configurations.

= 0.2 for rest roof configurations.

E = the earthquake load which take as:

$$E = \rho E_h + E_v \qquad \text{Eq.2.16}$$

E_h = the horizontal earthquake loads as given in Section 1630.2 or Section 1632 of the code.

E_v = the vertical earthquake loads which take as:

$$E_v = 0.5\ Ca\ I\ D \qquad \text{Eq.2.17}$$

and can be taken zero for allowable stress design.

Ca: vertical coefficient.

ρ = Redundancy factor as following formula:

$$\rho = 2 - \frac{20}{r_{max}\sqrt{A_B}} \qquad \text{Eq.2.18}$$

r_{max} = the maximum element-story shear ratio.

A_B =ground floor area of structure in m^2 to include area covered by all overhangs and projections.

2.2.3 Eurocode 8 (EN 1998-1 & EN 1998-2)

According to Section 4.3.3.5.2 in EN 1998-1, the vertical component should not be neglected if a_{vg} (vertical ground acceleration) is greater than

0,25g, and for structures that have horizontal or approximately horizontal members length 20 m or more, for structures that have horizontal or approximately horizontal cantilever member longer than 5 m, for structures that have horizontal or approximately horizontal pre-stressed members; for structures that have beams supporting columns; and for structures that have base-isolation. Moreover, according to Section 3.2.2.3 in EN 1998-2, near source effects shall be considered when the site is located within 10 km of fault. Section 4.1.7 of the same code states that the effects of the vertical component acting in the upward direction on pre-stressed concrete decks shall be considered.

Also, according to EN 1998-1, Section 3.2.2.3, the elastic vertical response spectrum $S_{vc}(T)$ is:

$$0 \leq T \leq T_B : S_{vc}(T) = a_{vg} \,.\left(1 + \frac{T}{T_B}.\,(3.\,\eta - 1)\right) \qquad \text{Eq. 2.19}$$

$$T_B \leq T \leq T_C : S_{vc}(T) = 3.\,a_{vg} \,.\,\eta \qquad \text{Eq.2.20}$$

$$T_C \leq T \leq T_D : S_{vc}(T) = 3.\,a_{vg} \,.\,\eta \,.\left(\frac{T_C}{T}\right) \qquad \text{Eq.2.21}$$

$$T_D \leq T \leq 4s : S_{vc}(T) = 3.\,a_{vg} \,.\,\eta \,.\left(\frac{T_C . T_D}{T^2}\right) \qquad \text{Eq.2.22}$$

The values of T_B, T_C, T_D and a_{vg} for each type can be found in National Annex of each country. The choice is to use vertical spectra for two types: Type 1 and Type 2. It is recommended to use type 2 for the spectra that use to know the horizontal motion of earthquake, and the magnitude of the surface wave (M_s) on them is no more than 5.5. Variables of a_{vg} ,T_B ,T_c and T_D are given in Table 2.3.

Table 2.3: variables that use in vertical response equations [EN 1998-1,2004]

Spectrum	a_{vg}/a_g	T_B(s)	T_C(s)	T_D(s)
Type 1	0.9	0.05	0.15	1.0
Type 2	0.45	0.05	0.15	1.0

2.2.4. IS 1893 (Indian Standard Criteria for Earthquake)

According to IS 1893 (Part 1): 2016 Section 6.1.2, the effects of vertical motion of earthquake can be sensitive for a) structures were stability failure is important b) structures have large spans. The decrease in the force of gravity due to earthquake vertical motion can be particularly detrimental in pre-stressed horizontal members, cantilever members, and gravitational structures. Hence, special attention must be paid to the effects of vertical movement of the ground on beams, girders and prestressed or cantilevered beams. However, the consideration of vertical acceleration is not mandated for any structure.

IS 1893 (Part 1): 2016 Section 6.4.6 provides a vertical design spectrum that is essentially two-thirds of the design horizontal spectrum given in Section 6.4.2.

IS 1893 (Part 1) : 2016 Section 6.3.4.1 provides the same combinations of earthquake effects in two mutually perpendicular horizontal directions and the vertical direction EL_x, EL_y and EL_z of IS 1893 are the same as E_{Edx}, E_{Edy} and E_{Edz} respectively, of Eurocode 8 (2004). In IS 1893, Section

6.3.4.2 provides an alternative to the procedure in Section 6.3.4.1, which probably is not all that sensible.

2.2.5. NZS (New Zealand Standards)

According to the NZS sections 5.5.1 and 6.4.1, structures or parts of structures which are sensitive to vertical accelerations, such as the horizontal cantilevers or equipment items have to be analyzed using a vertical component of the earthquake ground motion record simultaneously with their two counterpart horizontal components.

2.3. Previous studies

The reason for some researchers considers that vertical earthquake is unimportant that regression in the context of attenuation relations was performed for the entire range of epicentral distances and magnitudes instead of focusing on specific interval. Therefore, the results are biased (Papazoglou & Elnashai, 1996).

The most popular design is to consider that vertical response spectra is $\frac{2}{3}$ of the horizontal response spectra. However, this $\frac{2}{3}$ rule is imprecise for medium and large near-source earthquakes (Friedland, Power, & Mayes, 1997). It can be considered that 2/3 ratio is conservative for medium periods but unconservative for long and short periods [KEHOE, Mourad and Attalla, 2000].

The records of ground motion for Northridge and other earthquakes have shown that vertical accelerations are less in magnitude than horizontal accelerations. However, for regions located near faults, the vertical acceleration may exceed the horizontal acceleration (KEHOE, Mourad and Attalla, 2000). The vertical component of earthquake effect on the vertical members of the structure. For example, the compression forces in columns increases with increasing the vertical excitation. These forces could be increased up to three or four times as much as the original gravity forces. The strong vertical excitation caused up to 70% of the total compression forces on the columns. The interior and the upper story columns were the most affected by the vertical excitation. (Adam and shaaban, 2002).

Some codes such as the European Building Code, recognize that V/H depend on period, although UBC-97 and old version of IBC code do not offer guidance on a vertical design spectrum (Bozorgnia & Campbell, 2004).

Furthermore, vertical response spectra for light components that mounted on frame structures are influenced by the strength of the supporting structure and the modal periods. (Ricardo, Ragunath and Kevin, 2006).

The Tabas earthquake in Iran, the vertical component of earthquake has significant effect on bridge piers, the maximum axial force of pier is increased about 30% due to vertical component effect of earthquake. These increasing effects for maximum bending moment and maximum shear force of pier are 10% and 15% respectively. In addition, the crack width is increased by about 60% due to vertical component of earthquake with changing of crack pattern from bending to diagonal shear cracking (Hosseinzadeh, 2008). Also, the vertical component of ground motion had no effect on story drift. Moreover, the changes in shear at the column ends was negligible. Likewise, there was no change in column torsion. At the base of the column, the absolute maximum bending moment did not significantly change, although there was a slight increase at the other column end on the order of 10 % (Piolatto, 2009). Moreover, the axial forces in columns are significantly affected by the vertical motion, especially the interior columns. The vertical ground motion does not have a great influence on horizontal displacements and story shears (Kadid, Yahiaoui and Chebili,2010).

The vertical spectral acceleration affected by three factors: a) ductility level of structure that related to overstrength of structure. b) the height of structure. (c) natural period of non-structural components with respect to the structural period. (Petrone, Magliulo and Manfredi, 2016).

Finally, Ghosh and Gupta in 2018 make suggestion to edit the ASCE 7-16 code equation for static vertical component of earthquake that is mention in Section 2.2.1 in Eq 2.9.

The equation is simply derived by considering a design vertical ground motion component that is 2/3rd (0.67) of the corresponding horizontal component. This resulted in a maximum vertical design spectral acceleration value of $0.67S_{DS}$. This was combined with the member force due to design horizontal ground motion component by using the "100+30" orthogonal combination rule similar to that specified in ASCE 7-16 Section 12.5.3.1(a), where 100% of the member force due to horizontal ground motion component is combined with 30% of the member force due to vertical ground motion component. 30% of 0.67%S_{DS} produces the code specified value of 0.2S_{DS} D. In the absence of a detailed study to investigate the adequacy of the code-specified design force of 0.2 S_{DS} D for structural members subjected to vertical ground motion, it is suggested that a designer might consider incorporating the following additional expression for earthquake effect for structural members that are particularly vulnerable to vertical ground motion:

$$E=\pm 0.3E_h + 0.67S_{DS}D \qquad \text{Eq.2.23}$$

The above combination simply considers a situation where 30% of the member force due to horizontal ground motion component is combined with 100% of the member force due to vertical ground motion component. This combination is not currently required for structures assigned to RC I through IV (Ghosh and Gupta, 2018).

The justification lacks two major issues. First why it is only function of dead load and not weight of structures. Second where are I and R in the vertical earthquake equation.

2.4 Summary

Based on the literature survey displayed in the previous section, researches did not have enough information about response of vertical component of earthquake on cantilever beams of multi-story reinforced concrete buildings. Thus, this research will focus on the effect of vertical component of earthquake on cantilevers of multi-story reinforced concrete building. Results are used to suggest modifications to the ASCE 7-16 equivalent static equation for predicting the seismic force from the vertical component of an earthquake.

3. Effects on all structure (by find vertical base reaction and max story displacement): Modelling and Results

3.1 Overview

In this chapter, the effect of vertical earthquake on the structural behavior is studied using vertical response spectrum and vertical equivalent static equation according to ASCE 7-16 and the results are discussed. A number of case studies (by changing the number and position of cantilever beams & number of stories) are conducted. The first case study has 4 models and second case study has 3 models. The effect of vertical component of earthquake on cantilever members is discussed in the next chapter. Finite element simulation using Etabs is used in all models. Linear elastic analysis is carried out for each case study with suitable mesh size. Moreover, modal analysis is used to get the fundamental period of the structures.

3.2 Assumptions

This thesis is restricted in assumptions to the following:

1. Material behaves linearly and yielding effect can be neglected.
2. ASCE (7-16) code will be used to calculate the static and dynamic (response spectrum) vertical component of earthquake.
3. The thickness of the shear walls, beams and slabs are calculated according to ACI 318M-19.and they found 30 cm for shear walls and 20 cm for slabs.

3.3 Model description

In the models, the supports for both columns and shear walls are assumed to be fixed because the common practice is to use footings with tie beams. Linear modal analysis is used to get the fundamental period of these structures. The superimposed dead load is assumed 1.2 kN/m^2, partition 1.2 kN/m^2, stone load 18.97 kN/m and live load 2 kN/m. The mass considered in calculating the fundamental period is from dead load only. The characteristics of all structural members used are *2*shown in Table 3.1.

Table 3.1 Details of the building

Building Parameters	**Details**
Beams size	30 cm X 60 cm
Columns size	50 cm X 50 cm
Building system	Building frame system with ordinary shear wall
Thickness of shear walls	30 cm
Height of story	3.38m
Slab type	2-way solid slab
Slab thickness	20 cm
Plan dimensions (without Cantilevers dimensions)	20m X 20m
Slabs diaphragms type	Rigid
strength of concrete fc`	24 MPa
Strength of Steel Fy	420 MPa
The modifiers of beams	0.35
The modifiers of Columns	0.7
The modifiers of walls	0.7
modifiers of slabs	0.25
Mesh size	0.5 m X 0.5 m X 0.5 m

Fares, A. M., & Touqan, A. (2018) made sensitive study for mesh size and they noted that error of mesh size 0.5m X0.5m X0.5 m can be negligible.

Load combination :

- 1.4D
- 1.2D+1.6L
- 1.2D + E_v + E_h +L
- 0.9D − E_v + E_h
- 1.0D + 0.7E_v + 0.7E_h
- 1.0D +0.525E_v + 0.525E_h + 0.75L
- 0.6D − 0.7E_v +0.7E_h

Which D: dead load

L: live load

E_v: vertical component of earthquake

E_h: horizontal component of earthquake

The seismic parameters are calculated according of ASCE 7-16 code and shown Table 3.2.

Table 3.2: Shows seismic parameters for models.

Risk Category	**II**
Seismic Importance Factor (I_e)	1.0
Ss	1
S1	0.18
Soil Site Classification	C
SDC	D
R	6
Ω_o	2.5

C_d	5
S_{MS}	1.2
S_{DS}	0.8
Equivalent static (0.2 $_{SDS}$ D)	0.16 D
Cv	1.1

3.4 Cases studies

Two case studies are conducted and the main variable are the number and position of cantilever beams & number of stories. The used number of stories is 7, 10 and 14 stories.

3.4.1 First case study: number and position of cantilever beams:

Figures 3.1 through 3.8 show the number and position of cantilever in the beams of each of the studied cases.

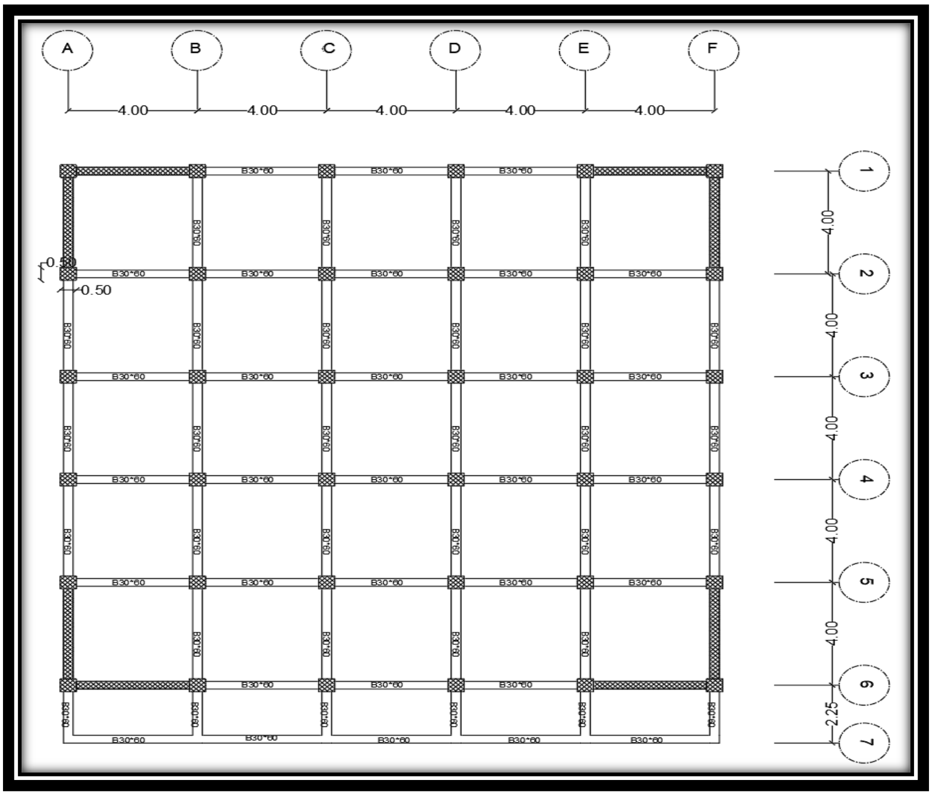

Figure 3.1: Plan view for cantilever on one side (Type A1)

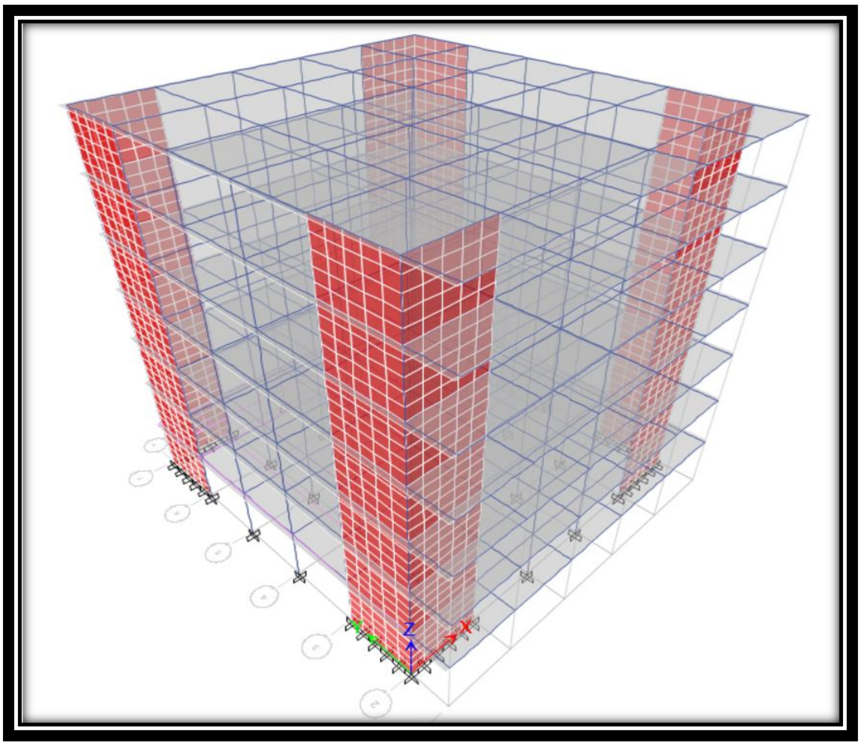

Figure 3.2: 3D Model for Building with cantilever on one side (Type A1)

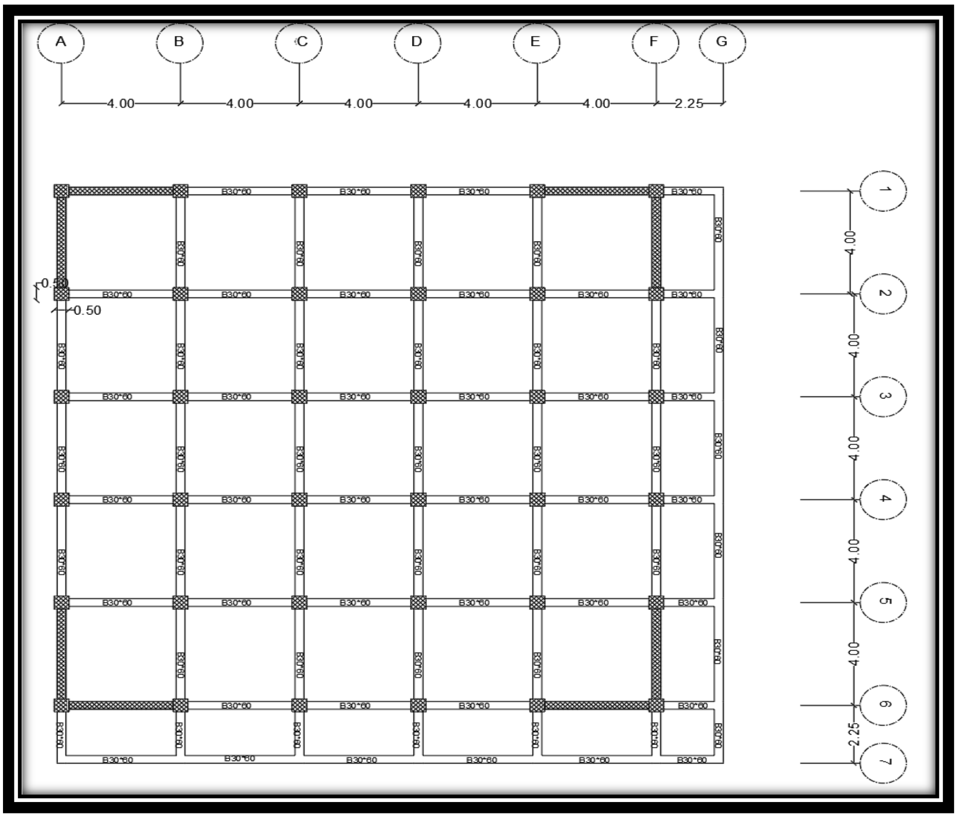

Figure 3.3: Plan view of building that has cantilever on two side (Type A2)

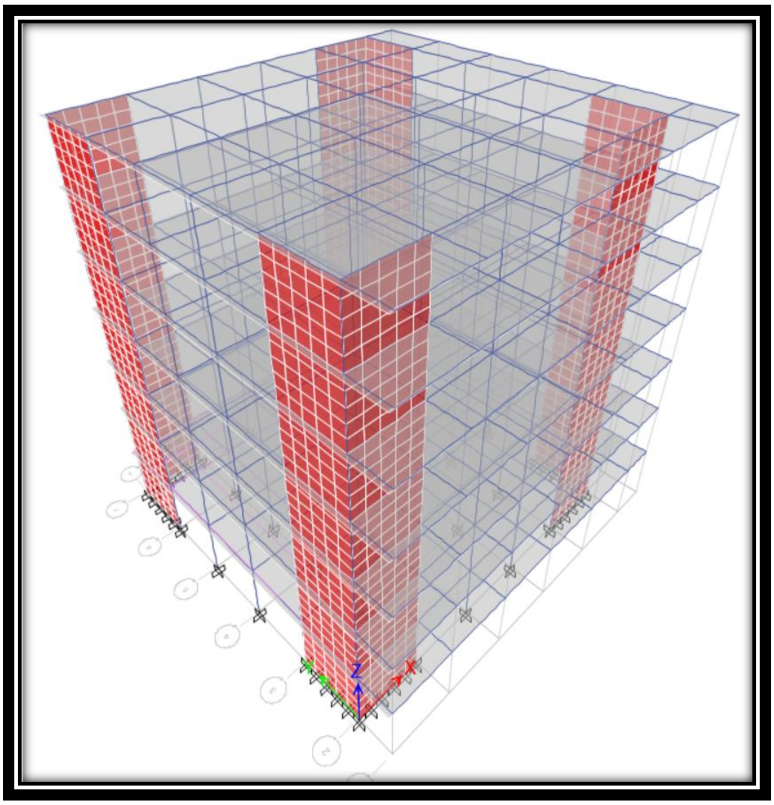

Figure 3.4: 3D Model for cantilever on two side (Type A2)

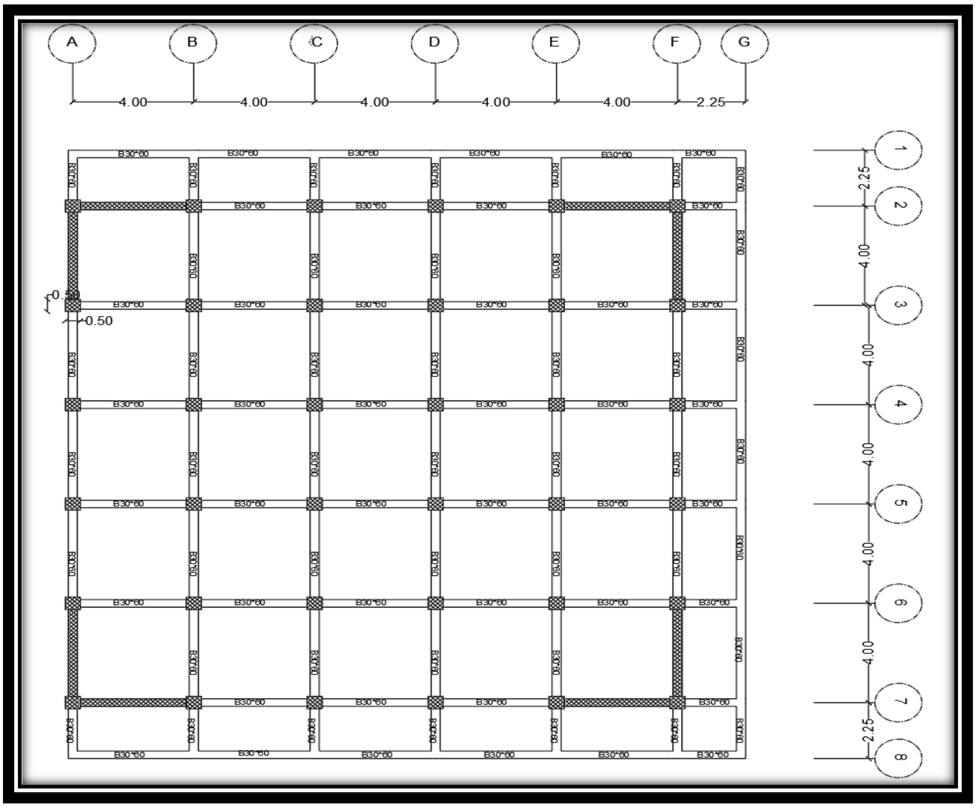

Figure 3.5: Plan view of building that has cantilever on three sides (Type A3)

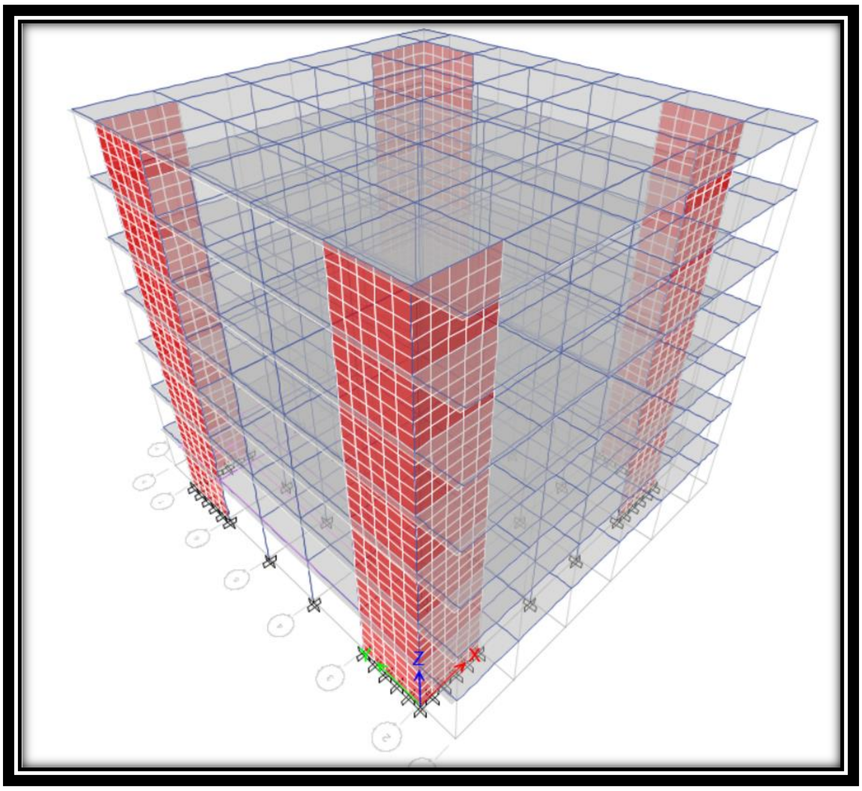

Figure 3.6: 3D model for cantilever on three sides (Type A3)

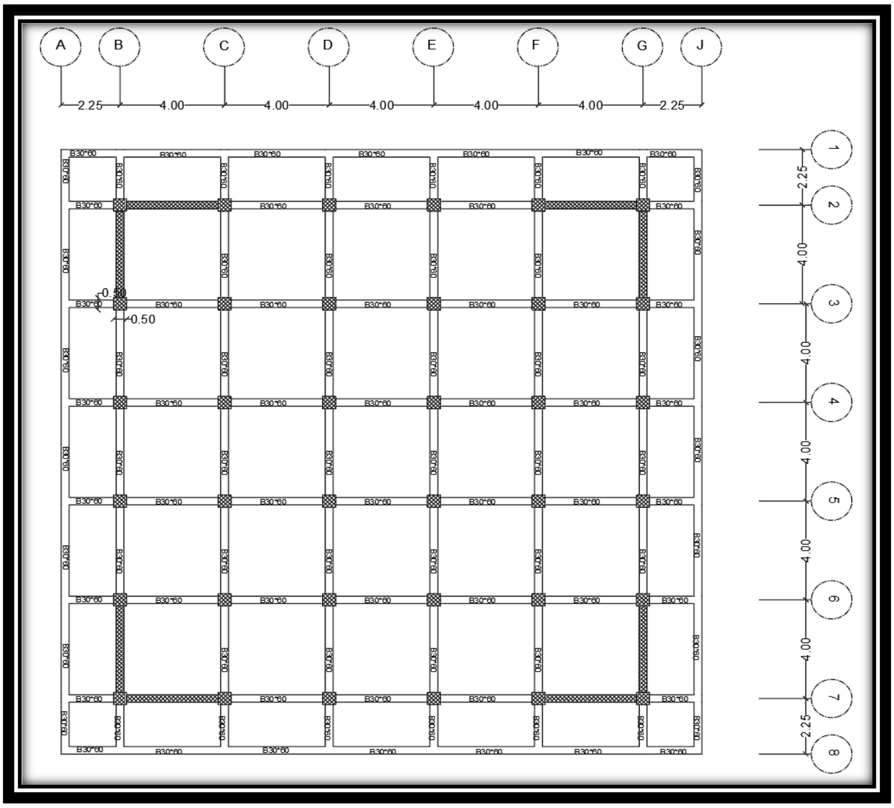

Figure 3.7: Plan view of building that has cantilever on four sides (Type A4)

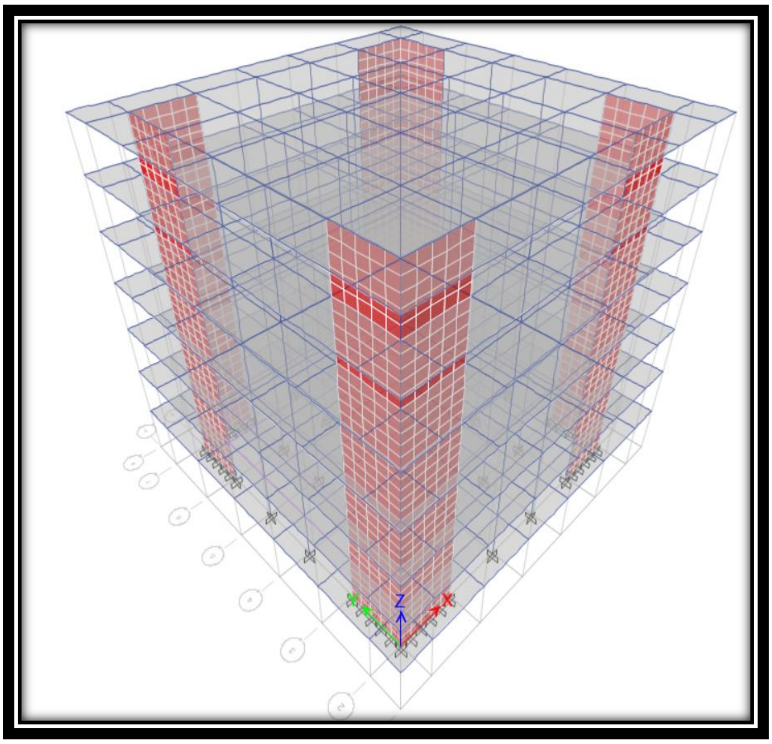

Figure 3.8: 3D model for cantilever on four sides (Type A4)

The periods of the structures in the models of the case studies are verified using Rayleigh method that is shown in Appendix A.

3.4.1.1 Results and Discussion:

The vertical period (fundamental period) for 4 cases (A1, B1, C1, D1) was constant and it was about 0.1 sec as shown in Table 3.3. Table 3.4 shows the differences of vertical base reaction between using vertical static equation and vertical response spectrum analysis. As shown in this table, the difference between them was about 3.33% and 7.95 % and the difference was constant despite change of number and position of cantilever beams.

Table 3.3: Results of number and position of cantilever beams parameter for vertical base reaction force and vertical period

Parameter	*Vertical period (sec)	*Fz static (max) KN	Fz static (min) KN	Fz Response (max) KN	Fz Response (min) KN
Type A1	0.101	79450	25980	82185	24066
Type B1	0.101	85651	27948	88594	25887
Type C1	0.103	108660	35907	112442	33260
Type D1	0.1	98294	32248	101672	29884

*here the period is fundamental vertical period

**all values from envelope load for horizontal and vertical earthquake

***The symbol (Fz) means the vertical force reaction at base of building. static and response mean envelope load with static of vertical component of earthquake or vertical response spectrum.

Table 3.4: Percentage of difference of vertical base reaction between static and response analysis for vertical component of earthquake for number and position of cantilever beams parameter

Parameter	Diff. between response &static Fz (max) (KN)	Diff. between response &static Fz (min) (KN)	Diff. between response &static Fz (max) (%)	Diff. between response &static Fz (min) (%)
Type A1	2735	-1914	3.33	-7.95
Type B1	2943	-2061	3.32	-7.96
Type C1	3782	-2647	3.36	-7.96
Type D1	3378	-2364	3.32	-7.91

The max story displacement increases when the building become irregular as shown in Table 3.5. Table 3.6 shows the differences of max story displacement between using vertical static equation and vertical response spectrum analysis. This table shows that the difference between them was about zero in spite of change of number and position of cantilever beams. It should be noted that vertical earthquake does not affect on the max story displacement.

Table 3.5: Results of number and position of cantilever beams parameter for max story displacement

Parameter	Max story Δ static max(m)	Max story Δ static min(m)	Max story Δ response max(m)	Max story Δ response min(m)
Type A1	0.00897	-0.01072	0.00897	-0.01085
Type B1	0.01439	-0.01092	0.01457	-0.01107
Type C1	0.0158	-0.00727	0.00727	-0.0161
Type D1	0.01	-0.0079	0.01	-0.0079

* Where Δ means displacement of story.

Table 3.6: Percentage of difference of max story displacement between static and response analysis for vertical component of earthquake for number and position of cantilever beams parameter

Parameter	Diff. between response &static Max story Δ (max)(m)	Diff. between response &static max story Δ (min) (m)	Diff. between response &static max story Δ (max) (%)	Diff. between response &static max story Δ (min) (%)
Type A1	0	-0.00013	0.00	1.20
Type B1	-0.00018	-0.00015	1.24	1.36
Type C1	-0.00030	0	1.86	0.00
Type D1	0	0	0.00	0.00

3.4.2 Second case study: Number of stories:

It can be seen from the results in Table 3.4 that the difference between vertical force of equivalent static and response spectrum methods is approximately constant during the change of cantilever beams position and number. Hence, Type D1 will be taken in the analysis for this case study. Figure 3.9-3.11 shows the models for number of storeys case study.

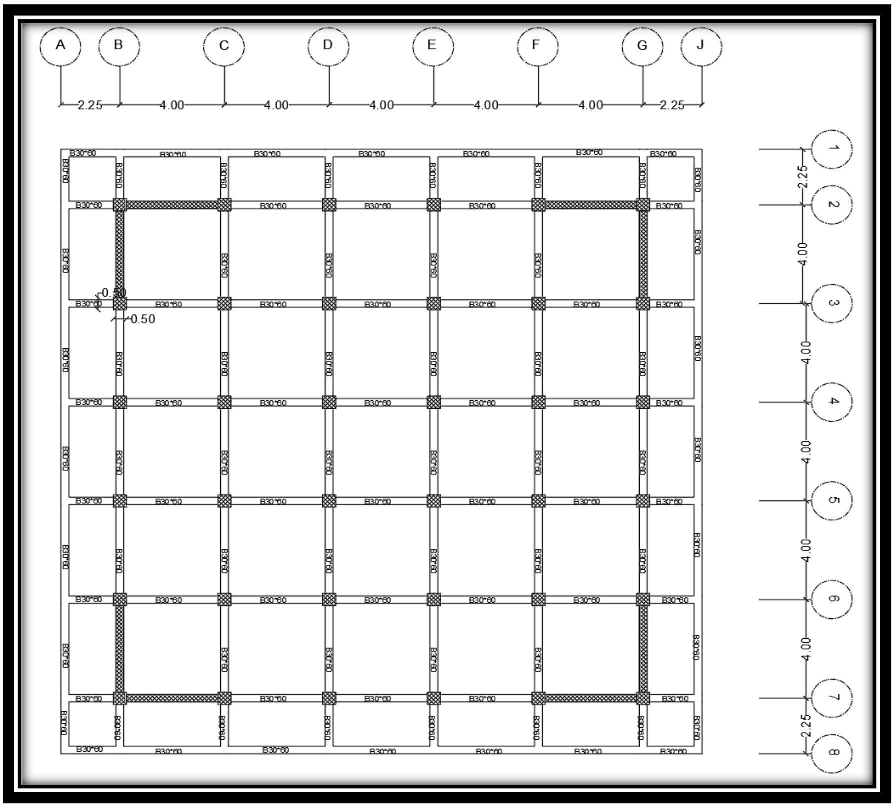

Figure 3.9: Plan view of the building that will use for case number of storeys

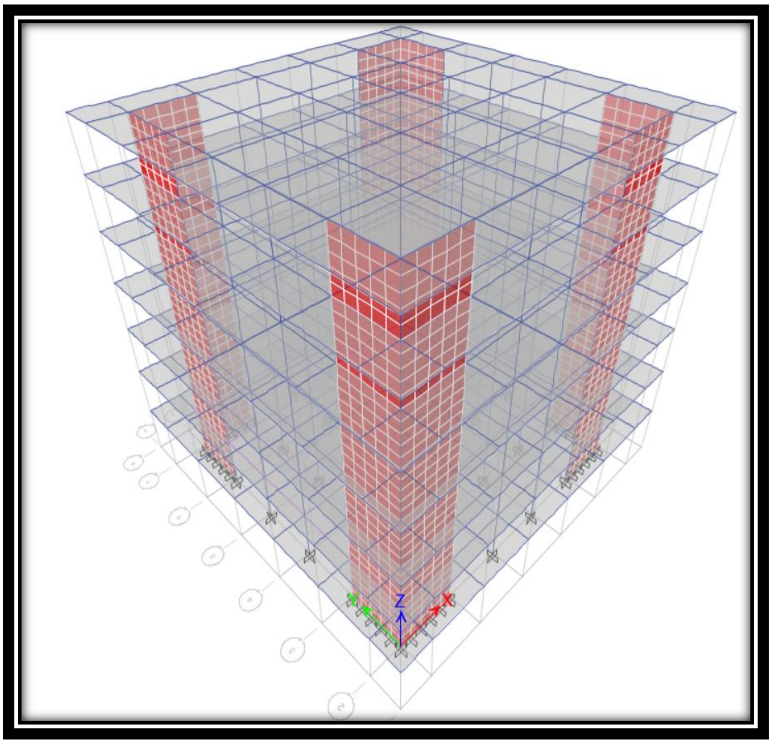

Figure 3.10: 3D model for 7 storeys building case (Type A2)

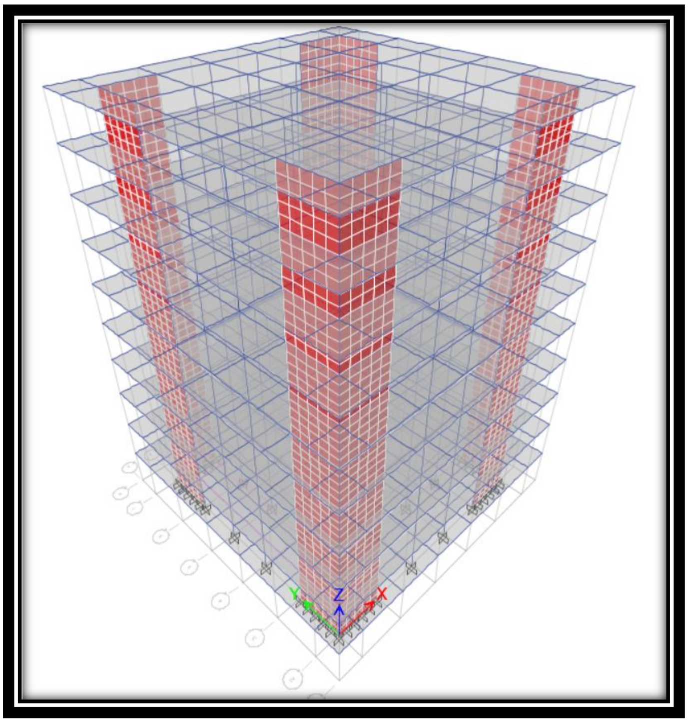

Figure 3.11: 3D model for 10 storeys building case (Type B2)

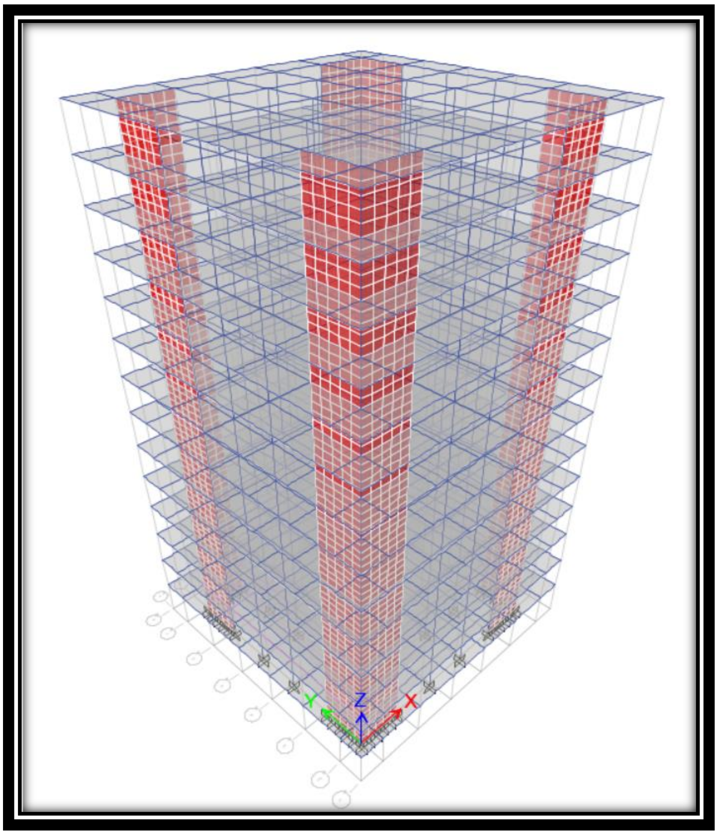

Figure 3.12: 3D model model for 14 storeys building case (Type C2)

3.4.2.1 Results and Discussion

The vertical period for 3 cases (A2, B2, C2) is increased when the number of stories increases as shown in Table 3.7. Table 3.8 shows the differences between the base vertical reaction force computed from the two methods. It can be seen that the difference is about 3.32% (max EQ) and 7.91(min EQ) and the difference is constant except case C2 (with 14 stories) is about 0.85 % and 1.76%.

Table 3.7: Results of number of storeys parameter for vertical base reaction force and vertical period

Parameter	*Vertical period (sec)	*Fz static (max) KN	Fz static (min) KN	Fz Response (max) KN	Fz Response (min) KN
Type A2	0.1	98294	32248	101672	29884
Type B2	0.13	140420	46068	145245	42691
Type C2	0.24	196575	64505	194923	65662

*here the period is fundamental vertical period

**all values from envelope load for horizontal and vertical earthquake

***The symbol (Fz) means the vertical force reaction at base of building. static and response mean envelope load with static of vertical component of earthquake or vertical response spectrum.

Table 3.8: Percentage of difference of vertical base reaction between static and response analysis for vertical component of earthquake for number of storeys parameter

Parameter	Diff. between response &static Fz (max) (KN)	Diff. between response &static Fz (min) (KN)	Diff. between response &static Fz (max) (%)	Diff. between response &static Fz (min) (%)
Type A2	3378	-2364	3.32	-7.91
Type B2	4825	-3377	3.32	-7.91
Type C2	-1652	1157	-0.85	1.76

Table 3.9 shows the max story displacement with changing in number of storeys, it is clear that when the number of storeys increase the max story displacement increase in vertical static and response analysis. Table 3.10 shows the differences between use of vertical static equation and vertical response spectrum analysis for max story displacement. It is clear that the difference between them was about zero despite change of number of stories.

Table 3.9: Results of number and position of cantilever beams for max story displacement

Parameter	Max story Δ static max(m)	Max story Δ static min(m)	Max story Δ response max(m)	Max story Δ response min(m)
Type A2	0.01	-0.0079	0.01	-0.0079
Type B2	0.0168	0.0145	0.0169	-0.0145
Type C2	0.0274	-0.0249	0.0274	-0.0249

* Where Δ means displacement of story.

Table 3.10: Percentage of difference of max story displacement between static and response analysis for vertical component of earthquake for number storeys parameter

Parameter	Diff. between response &static Max story Δ (max)(m)	Diff. between response &static (min) max story Δ (m)	Diff. between response &static (max) max story Δ (%)	Diff. between response &static (min) max story Δ (%)
Type A2	0	0	0	0
Type B2	1E-04	0	0.59	0
Type C2	0	0	0	0

Finally, the effect of the vertical earthquake on building is small and can be ignored. Therefore, in the next chapter focuses on the effect of vertical earthquake on cantilever beam with different cases. The considered building is the one designated as Type A2.

4. Effect on Cantilever Beams: Modelling and Results

4.1 Overview

In this chapter, the effect of vertical component of earthquake on cantilever beams is studied and the results are discussed. The vertical response spectrum analysis and the vertical equivalent static equation according to ASCE 7-16 code are used. Two levels of modeling are used, namely: 2D Models (153 models) and 3D Models (6 models). 2D Models are used to study the effect of vertical component of earthquake on cantilever beams with different length, load, site zone, soil classification and seismic design category. The results from the 2D models are used to propose vertical equivalent static equation for vertical component of earthquakes. The 3D models are used to verify the proposed equation. Finite element simulation by Etabs program is used in all models. Linear elastic analysis is performed for each model with suitable mesh size. Moreover, modal analysis is used to obtain the fundamental period of the buildings.

4.2 Model description for 2D model:

The advantage of using 2D model is its simplicity and easy verification. The dead load (self-weight and stone load) and vertical earthquake major effect on cantilever beam. Table 4.1 shows the details for 2D models.

Table 4.1: Details for 2D models

Building Parameters	Details
Beam size	30X60 cm (2.25 cantilever length) 40 cm X 70 cm (4.25 cantilever length) and 40 cm X 80(6.25 cantilever length)
strength of concrete fc`	24 MPa
Strength of Steel Fy	420 MPa
The modifiers of beams	0.35

4.3 Cases study:

The main case study will include change of stone loads, seismic hazard, site classification and length of cantilever beam. The loads used in the models are a concentrated load at end of the cantilever and a distributed load. In Palestine, the courses of stone are generally 3, 12 or 20, and these corresponds to loads of 4.74 kN/m, 18.97 kN/m and 31.6 kN/m, respectively. Three lengths of cantilever, namely: 2.25 m, 4.25 m and 6.25 m are used in the models. The seismic hazard used is near the fault and far from the fault. Two sites, namely: site C (sand soil) and site E (clay soil) are considered. Three seismic design categories namely (B, C, D) are considered. For seismic design category B, the vertical static equation is 0.2 S_{DS} D .However, for seismic design categories C or D, it becomes the same as the response spectrum equations in code ASCE 7-16 but without the first two equations .This is due to the vertical period that is small for the first two equation and it rarely to happen in cantilever beams .This modified equation is called here in theses the proposed equation is proposed equation. Figure 4.1 shows the 2D model of the cantilever beam.

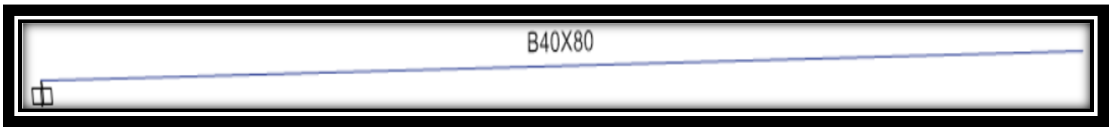

Figure 4.1: 2D Model for the Cantilever beaam

The proposed equation is:

$$E_{v=}\begin{cases} 0\ sec < T_v \leq 0.15\ sec & 0.1608\ C_v S_{MS} \\ 0.15\ sec < T_v \leq 2\ sec & 0.1608\ \text{Cv SMS}\ \left(\frac{0.15}{T_V}\right)^{0.75} \end{cases} \qquad \text{Eq. 4.2}$$

The constant value 0.1608 from 0.8 *0.67(to convert Sa_{mv} to S_{av}) *0.3(to convert S_{av} to E_v) =0.1608

Where:

C_v = is defined in terms of S_S in Table 2.1,

S_{MS} = the MCER spectral response acceleration parameter at short periods as $S_{MS} = F_a\ S_S$

T_v = the vertical period of vibration.

The periods of the structures in the models of the case studies are verified using Rayleigh method by using exact shape function that is shown in Appendix C.

To estimate the vertical fundamental period the cantilever. The following equation can be used to estimate the vertical period of a cantilever beam under concentrated and distributed load. The derivation of this equation is provided in Appendix B.

$$T_v = 0.96\pi \sqrt{\frac{(0.1(\rho+w)L+0.41P)L^3}{Ec\ Ig}} \text{ ---- Eq.4.1}$$

Where:

ρ: weight per unit length.

P: concentrated load.

w: distributed load.

E_c: modulus of elasticity for concrete

I_g: moment of inertia of cantilever beam section.

L: length of cantilever beam.

4.4 Results and Discussion

Figure 4.2 show the difference between vertical static analysis ($0.2S_{DS}D$) and dynamic analysis (vertical response spectrum) by finding the vertical force reaction of 2D cantilever beam with different loads, seismic hazards, soil classifications and lengths of cantilever beam. When the seismic design category is A or B , the vertical static equation that should use is Eq.2.9, but when it is C, D ,E or F) the vertical static equation is Eq.4.2.

It should be noted that in the Figure 4.2, “F model” means the vertical force reaction of a cantilever from the vertical response spectrum analysis by using ASCE 7-16 Code. On the other hand, “F ASCE7-16 vertical static equation” means the vertical force reaction of a cantilever beam from vertical static equation 0.2 S_{DS} D.

It can be seen in Figure 4.2 that the cantilever beams are safe under vertical earthquake when using the vertical static equation according to ASCE 7-16. In Figure 4.3, when using the proposed equation, the cantilevers are also safe under vertical earthquake. Hence, the proposed equation can be used also when the case is seismic design category B.

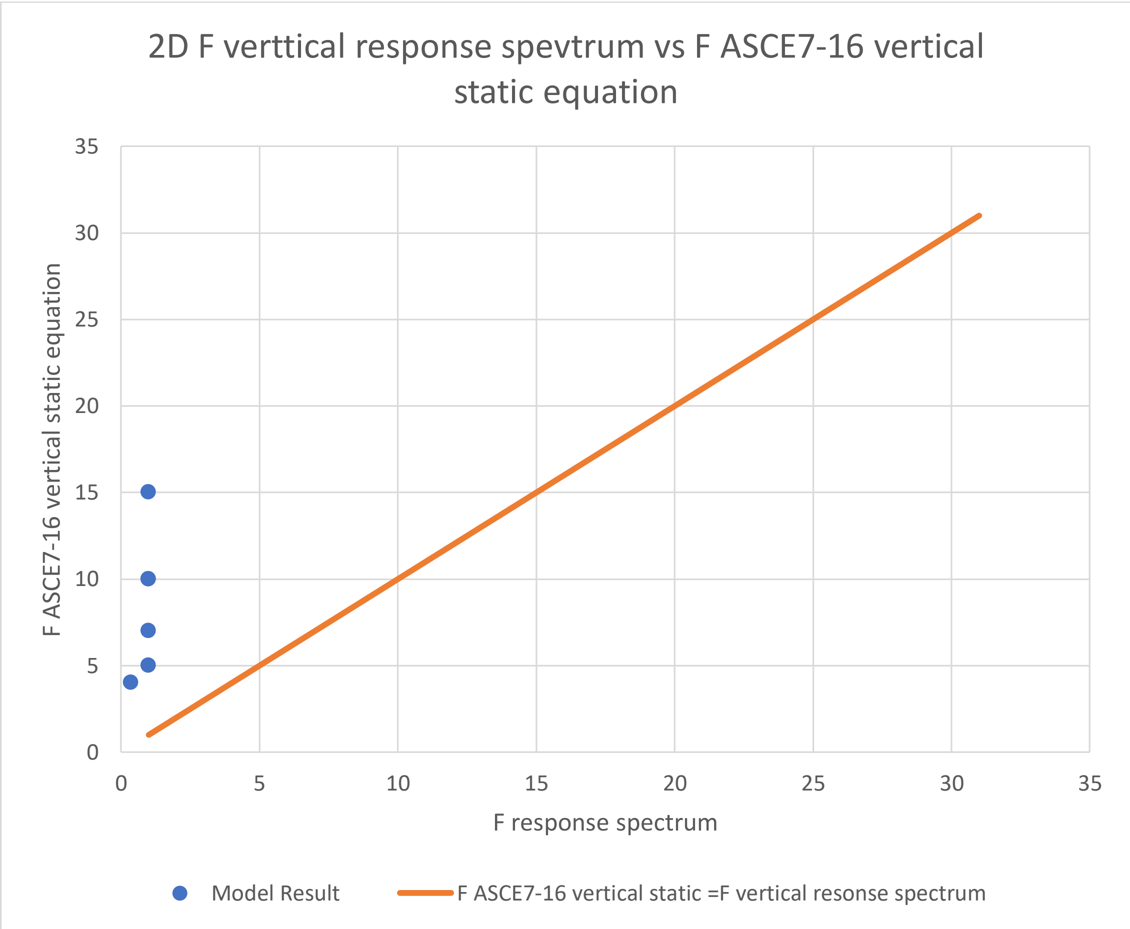

Figure 4.2: The differences between using ASCE7-16 vertical static equation and dynamic analysis by finding base reaction of 2D cantilever beam (in sesmic desin category B)with different cases.

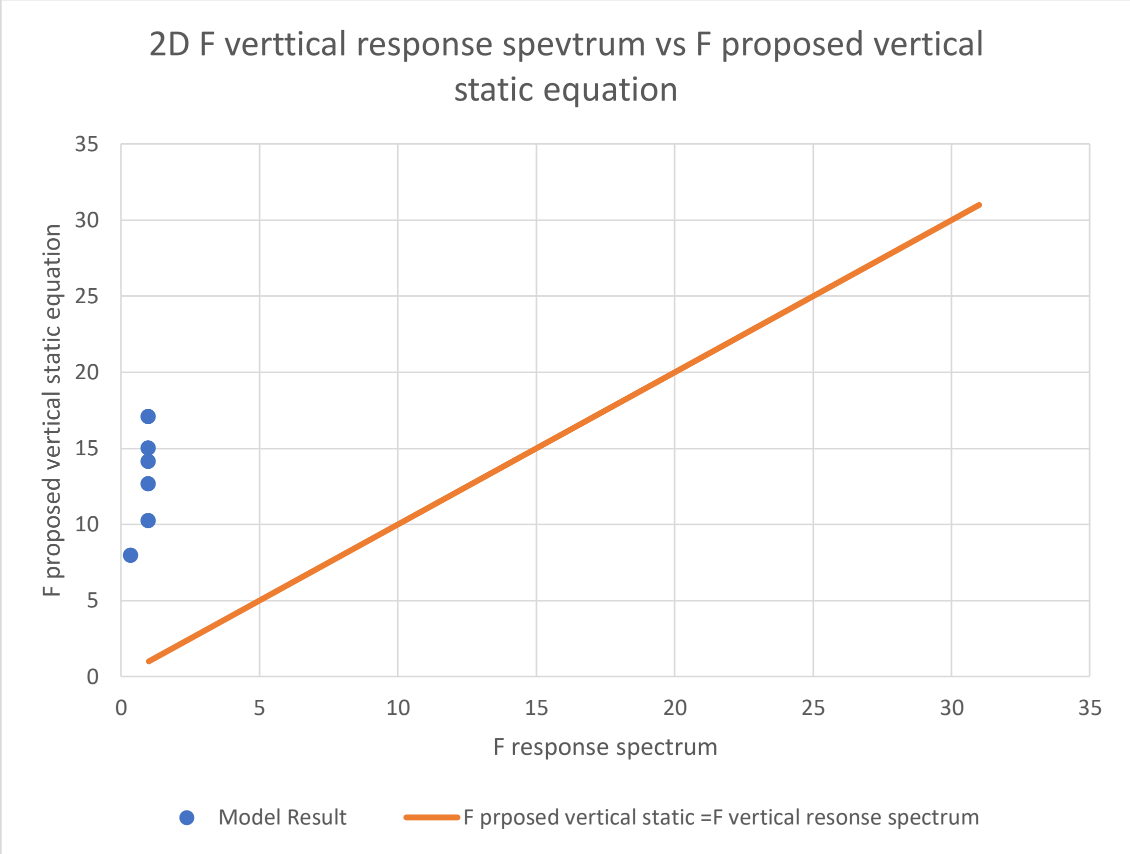

Figure 4.3: The differences between using proposed vertical static equation and dynamic analysis by finding base reaction of 2D cantilever beam (in sesmic desin category B)with different cases.

Figures 4.4 shows the vertical base shear of 2D models with different loads, seismic hazards, soil classifications, lengths of cantilever beam (2.25m, 4.25m, 6.25m) and seismic design category (C, D) .Figure 4.5 is the same as Figure 4.4 but for 1.25m length of cantilever beam that is the common length of cantilever beams in Palestine. All units are in KN. Table 4.3 shows sample of results for base shear of 2D cantilever beams with different cases. The complete results are shown in Appendix C.

In Figures 4.4&4.5, “F model” means the vertical force reaction of a cantilever from the vertical response spectrum analysis by using ASCE 7-

16 Code. On the other hand, "F proposed equation" means the vertical force reaction of a cantilever beam from Eq.4.2.

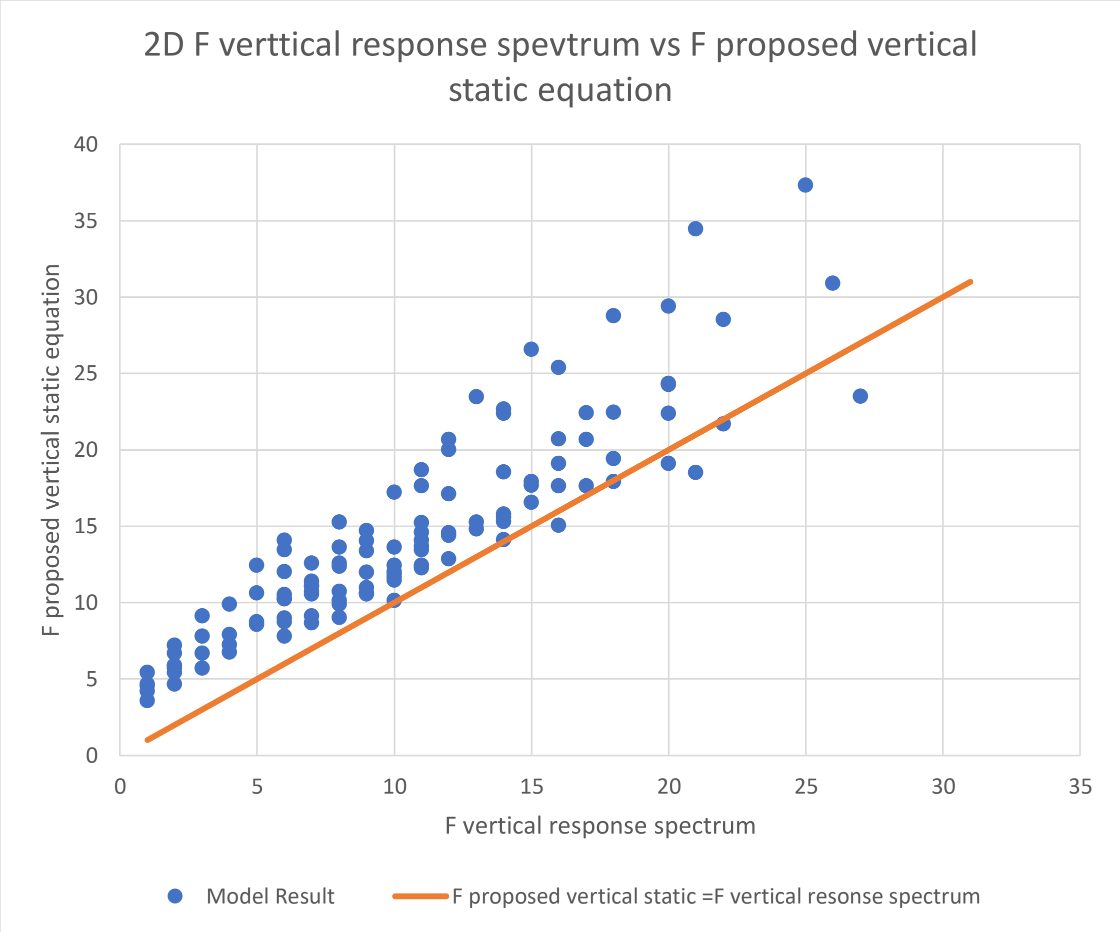

Figure 4.4: The differences between using proposed vertical static equation and dynamic analysis by finding base reaction of 2D cantilever beam (in sesmic desin category C or D)with different cases.

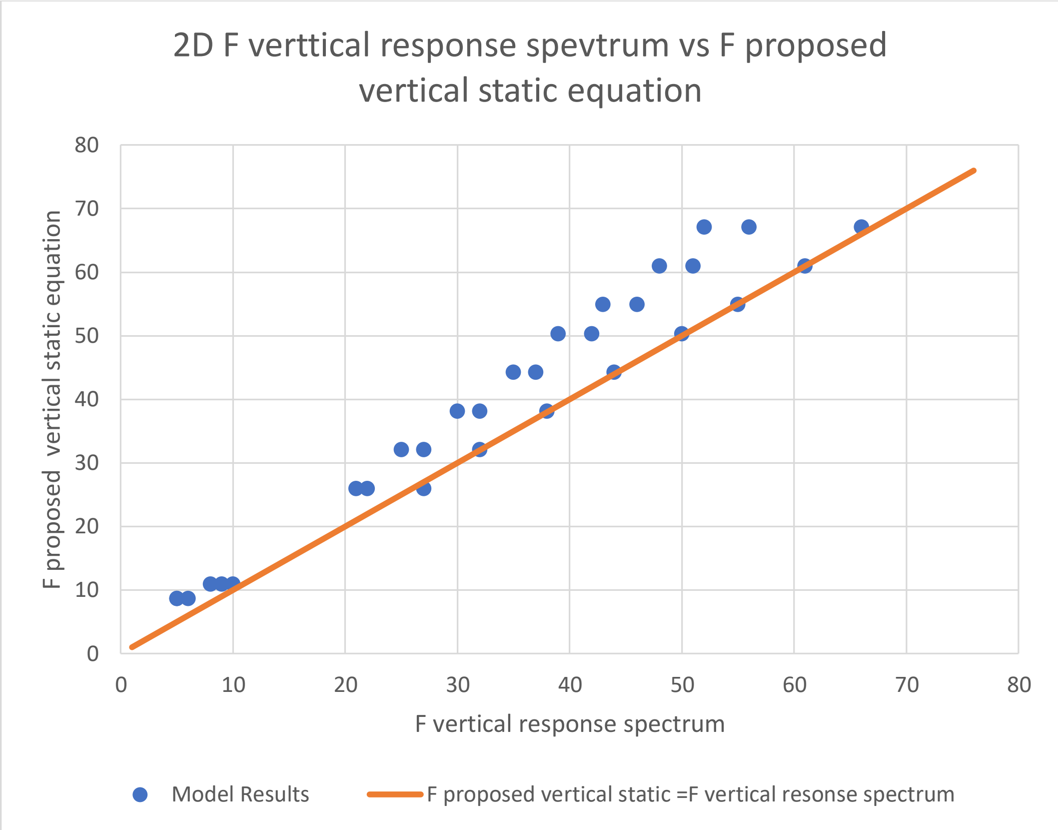

Figure 4.5: The differences between using proposed vertical static equation and dynamic analysis by finding base reaction of 2D cantilever beam (in sesmic desin category C or D)which has length 1.25 m with different cases.

Figures 4.4 and 4.5 show that the proposed equation is generally conservative for most of the cases .However it may not be safe in some models cantilever of 4.25 m but the max difference between using proposed equation and vertical response spectrum is 15 %.This can be considered a small difference .Thus, the proposed equation can be considered to sufficiently represent the effect of the vertical component of earthquake on the response of cantilevers beam with different seismic design category (B, C, D) different length (1.25m,2.25m,4.25m,6.25m), different soil class (B, C,E) , seismic zone(Ramallah, Jericho, Jenin) and different load of stone. Table 4.2 shows sample of results for base shear of

2D cantilever beam with different cases. Appendix C shows the details of 2D results.

Table 4.2: shows sample of results for base shear of 2D cantilever beam with different cases.

Parameter	Fz (Static proposed E_V)KN	Fz (Response E_V)KN	T_v (sec)
2.25m, 18.97 KN/m , *R3& Site C	14	6	0.042
2.25m, 71.1 KN, R3& Site C	21	17	0.093
4.25m,31.6 KN/m,R3& Site C	34	21	0.177
6.25m, 31.6 KN/m,R3& Site C	28	22	0.381
6.25m,18.97 KN/m ,R3& Site C	29	17	0.315
2.25m, 71.1 KN,R1& Site E	18	16	0.093
2.25m, 42.7 KN,R1& Site E	12	10	0.073
4.25m, 40.3 KN,R1& Site E	12	11	0.191
6.25m,31.6 KN/m,R1& Site E	24	20	0.381
4.25m, 80.6 KN,R3& Site E	19	20	0.259
6.25m, 197.5 KN,R3& Site E	19	18	0.708
6.25m, 15.8KN/m ,R3& Site E	22	18	0.296
1.25m,35 KN ,5KN/m ,R1&site E	11	8	0.049
1.25m,100 KN, 5 KN/m ,R1&site E	26	21	0.081

* It can be noted that R1(Jenin site) and R2 (Ramallah site) and R3(Jericho site).

The vertical static equation ($0.2S_{DS}$ D) is compared to the vertical response spectrum curves for six different cases with variable seismic hazard and site classification. To perform this comparison 6 graphs were drawn. The seismic parameters used for these graphs are shown in Table 4.3.

Table 4.3: Shows seismic parameters for models.

Risk Category	II
Jericho seismic hazard	
Ss	1
S1	0.18
Soil Site Classification	B
Cv	0.9
SDS	0.6
SMS	0.9
SDC	D
Jericho seismic hazard	
Ss	1
S1	0.18
Soil Site Classification	C
Cv	1.2
SDS	0.8
SMS	1.2
SDC	D
Jericho seismic hazard	
Ss	1
S1	0.18
Soil Site Classification	E
Cv	1.3
SDS	0.8
SMS	1.2
SDC	D
Jenin seismic hazard	
Ss	0.8
S1	0.16
Soil Site Classification	B
Cv	0.9
SDS	0.48
SMS	0.72
SDC	C

Jenin seismic hazard	
Ss	0.8
S1	0.16
Soil Site Classification	C
Cv	1.05
SDS	0.64
SMS	0.96
SDC	D
Jenin seismic hazard	
Ss	0.8
S1	0.16
Soil Site Classification	E
Cv	1.2
SDS	0.683
SMS	1.024
SDC	D
Ramallah seismic hazard	
Ss	0.44
S1	0.11
Soil Site Classification	B
Cv	0.85
SDS	0.3
SMS	0.44
SDC	B

It should be noted that Jericho site is near the fault and Jenin site is far the fault. Figures 4.6 through 4.12 show differences between vertical response spectrum and vertical static equation.

The figures show that they have been a period interval that vertical response spectrum has higher values of acceleration than that from the vertical static equation. They also have period interval where the vertical static equation provides overdesign values.

The Difference between vertical static and vertical response in region which response is higher than static is calculated as shown below:

For Jericho site B:

D1= $\frac{0.13-0.12}{0.12} * 100\%$ =8.3%, it is small difference so vertical static equation is correct in this situation.

For Jericho site C:

D2=$\frac{0.21-0.16}{0.16} * 100\%$ =31.25%, it is effective difference so vertical static equation doesn’t correct in this situation. The period which response is higher than static=> (0.04-0.217) sec

For Jericho site E:

D3=$\frac{0.25-0.16}{0.16} * 100\%$ =56.25%, it is effective difference, so vertical static equation doesn’t correct in this situation. The Period which response is higher than static=> (0.035-0.272) sec.

For Jenin site B:

D4=$\frac{0.104-0.096}{0.096} * 100\%$ =8.333%, it is small difference so vertical static equation is correct in this situation.

For Jenin site C:

D5=$\frac{0.161-0.128}{0.128} * 100\%$ =25.78 %, it is effective difference, so vertical static equation doesn’t correct in this situation. The Period which response is higher than static=> (0.041-0.203) sec

For Jenin site E:

D6=$\frac{0.196-0.136}{0.136} * 100\%$ =44.12 %, it is effective difference so vertical static equation doesn't correct in this situation. The Period which response is higher than static=>0.037-0.244.

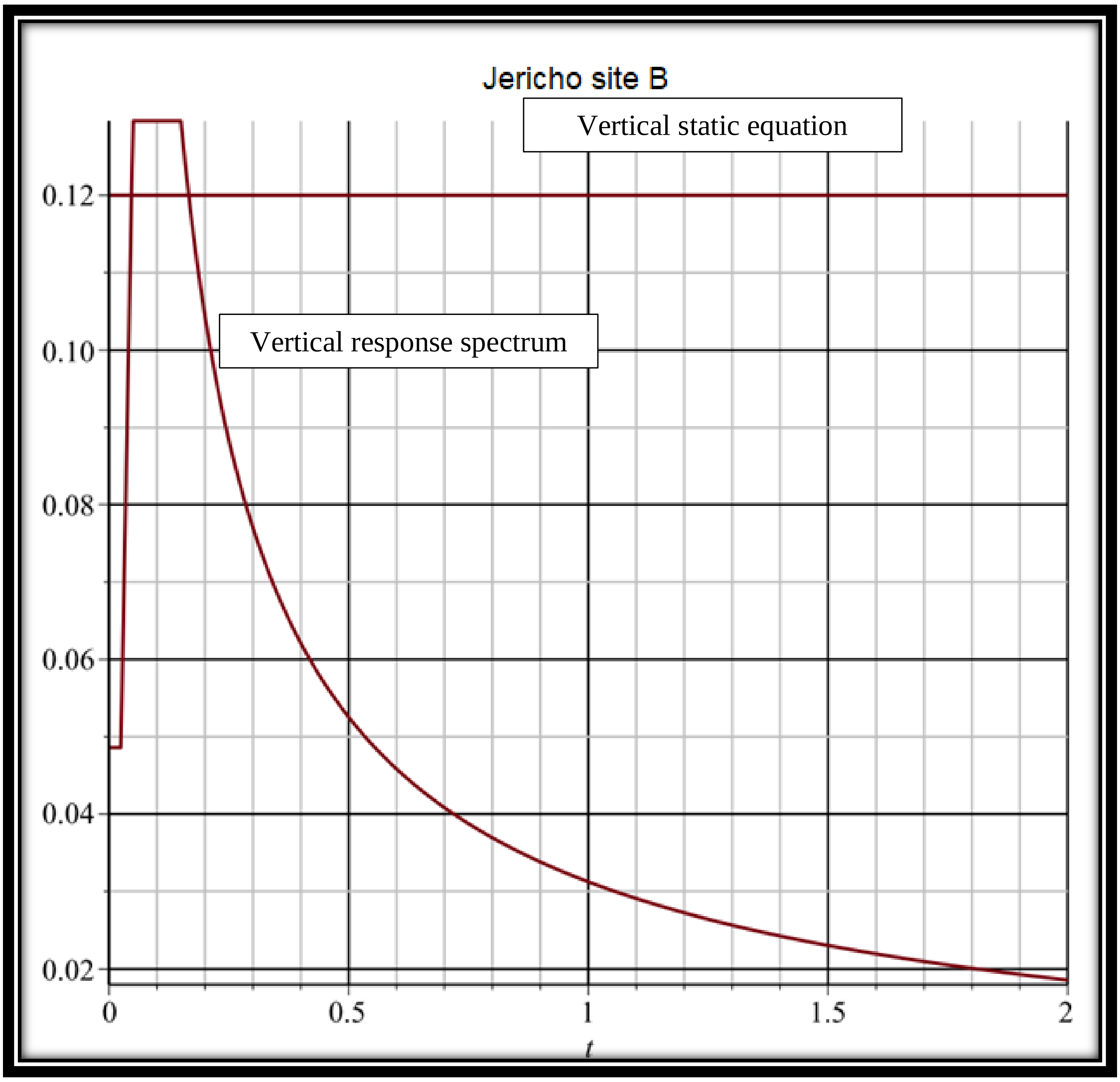

Figure 4.6: differences between vertical response spectrum and vertical static equation in Jericho site and soil class. B

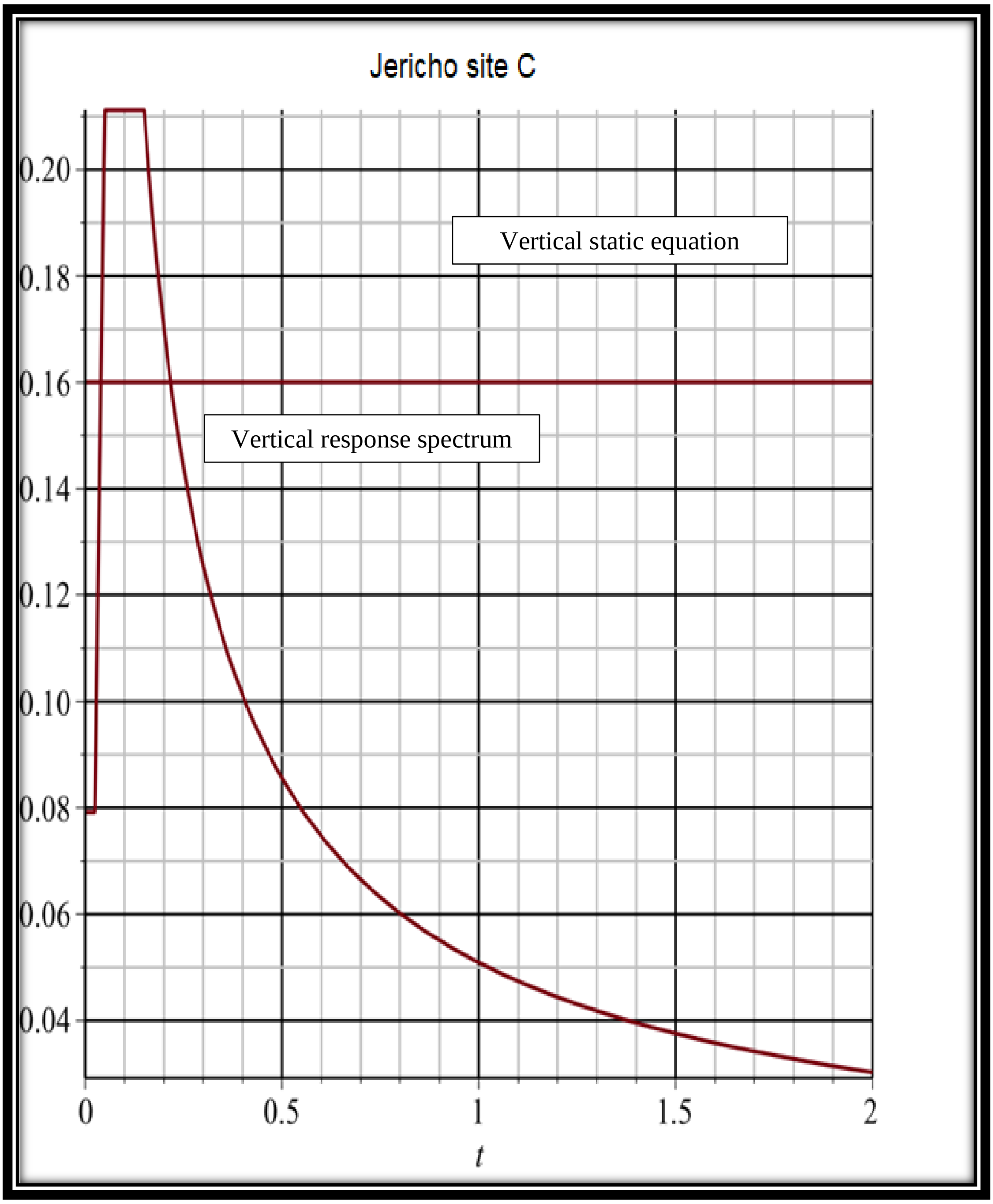

Figure 4.7: differences between vertical response spectrum and vertical static equation in Jericho site and soil class. C.

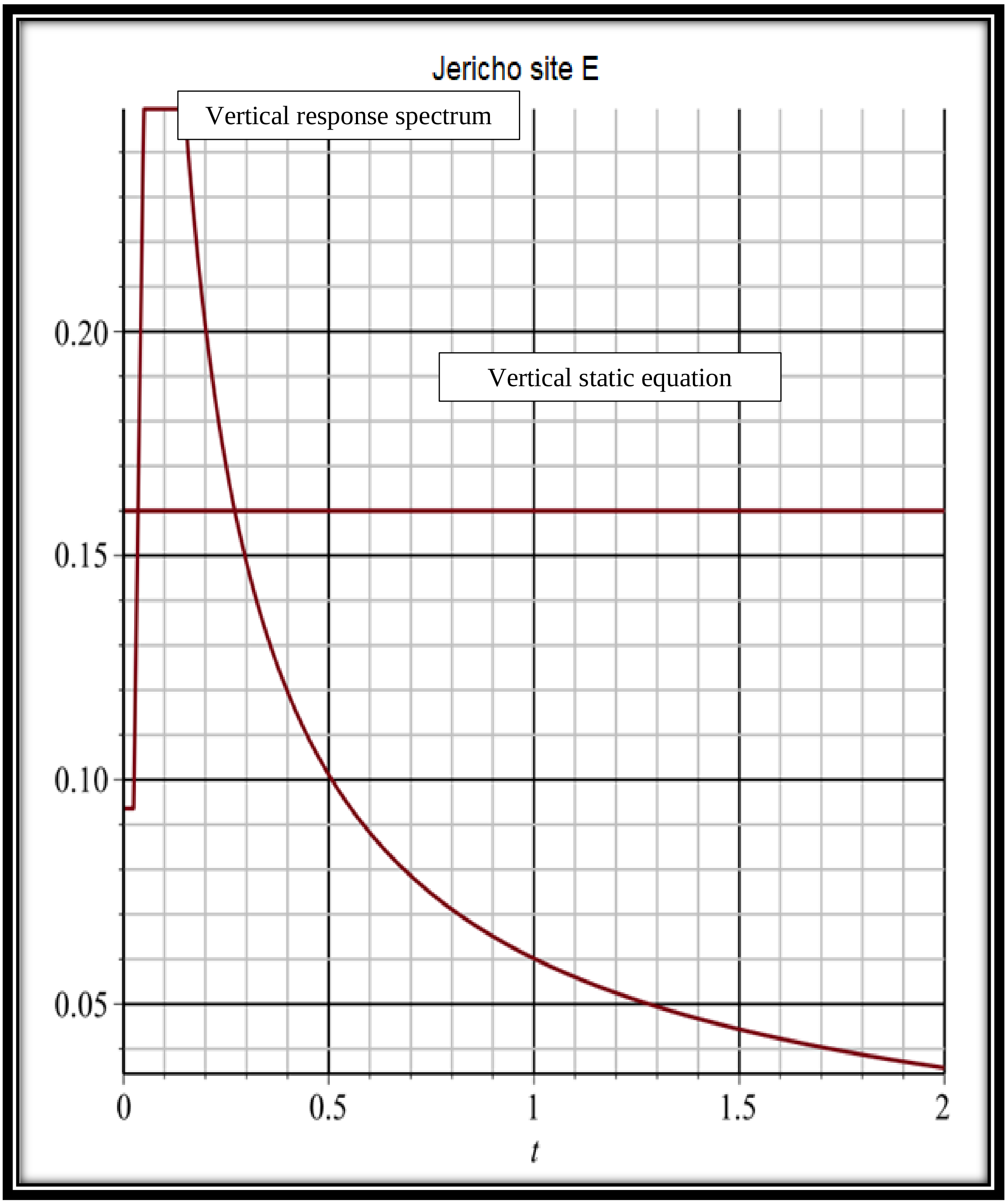

Figure 4.8: differences between vertical response spectrum and vertical static equation in Jericho site and soil class. E

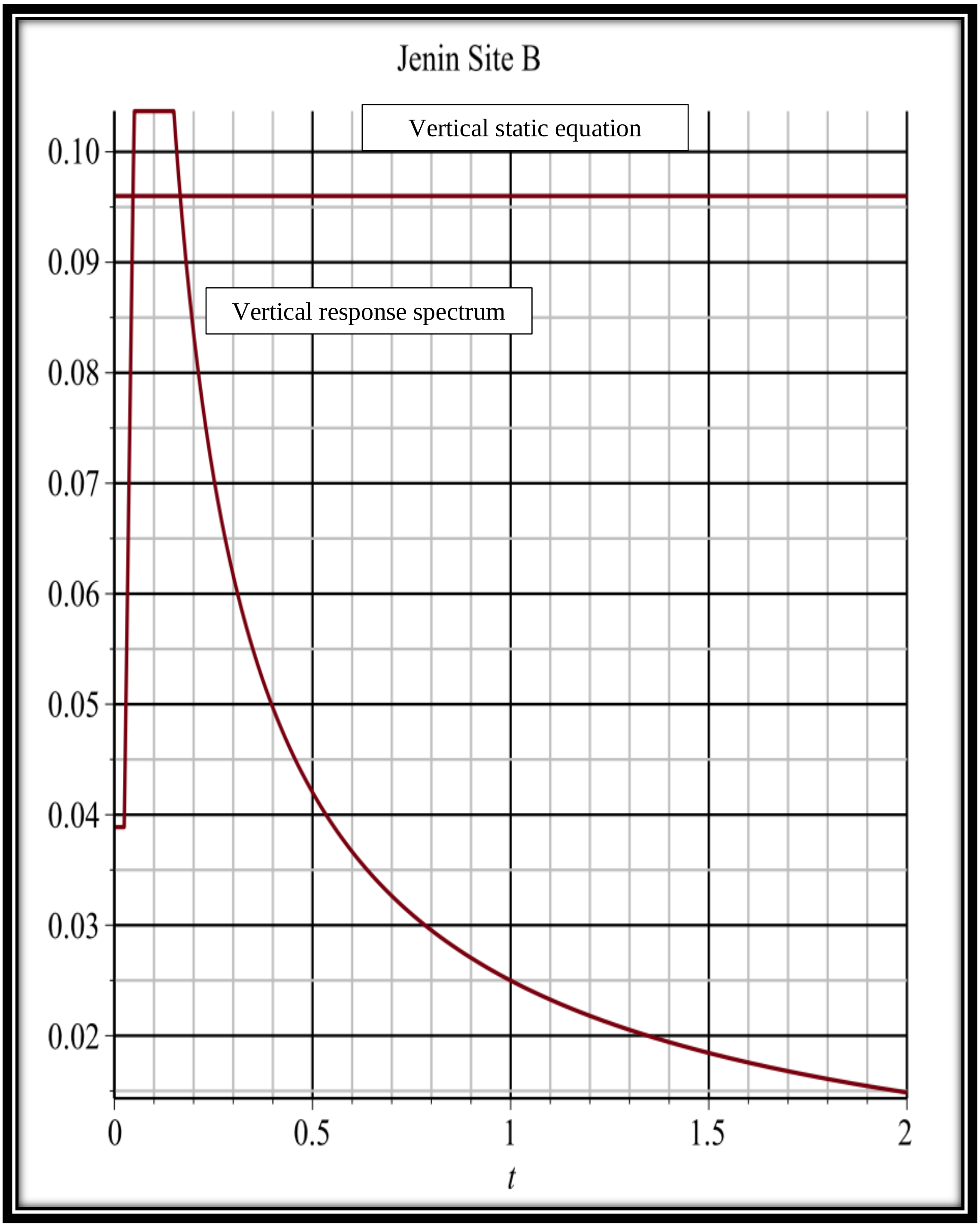

Figure 4.9: differences between vertical response spectrum and vertical static equation in Jenin site and soil class. B.

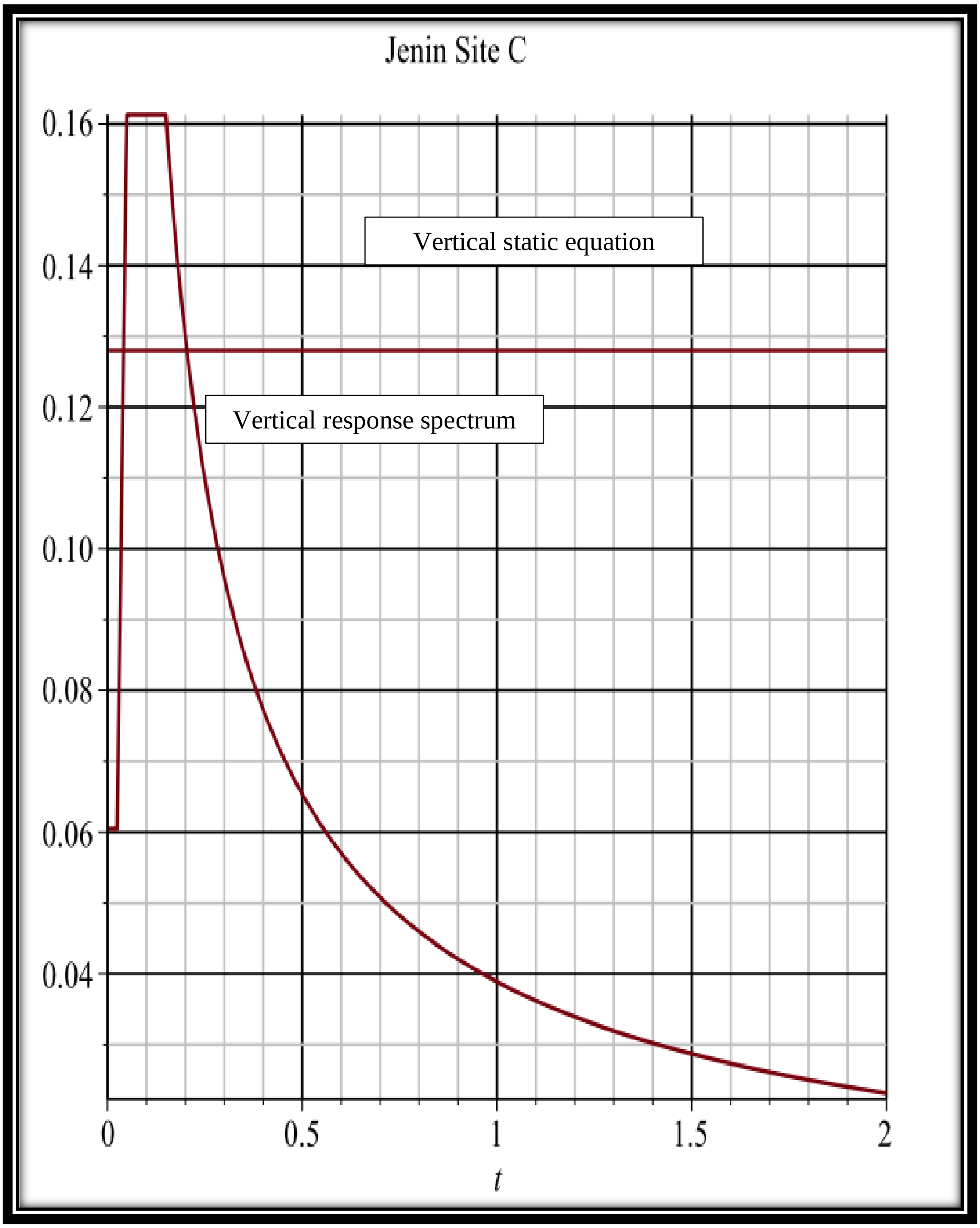

Figure 4.10: differences between vertical response spectrum and vertical static equation in Jenin site and soil class. C.

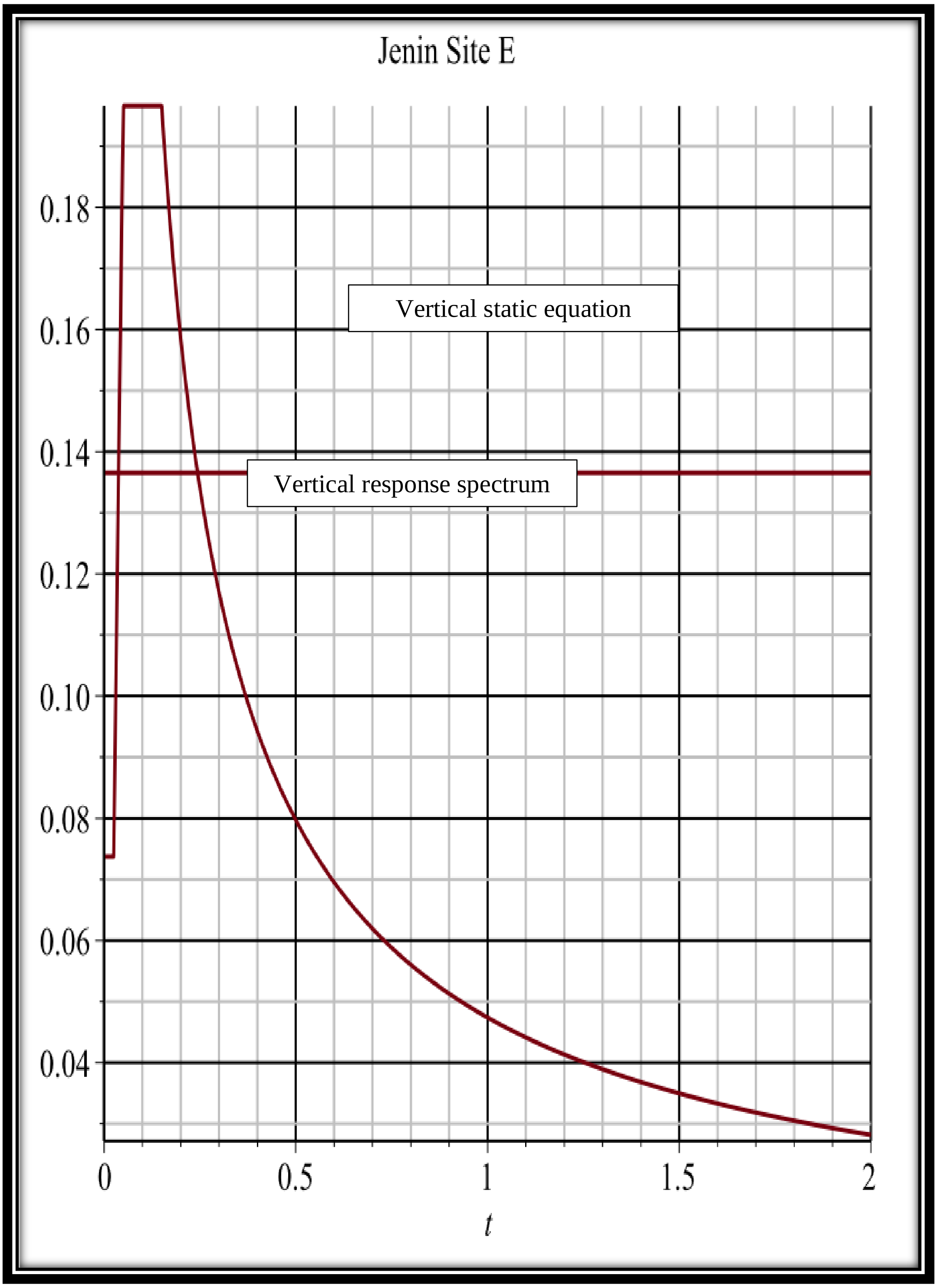

Figure 4.11: differences between vertical response spectrum and vertical static equation in Jenin site and soil class. E.

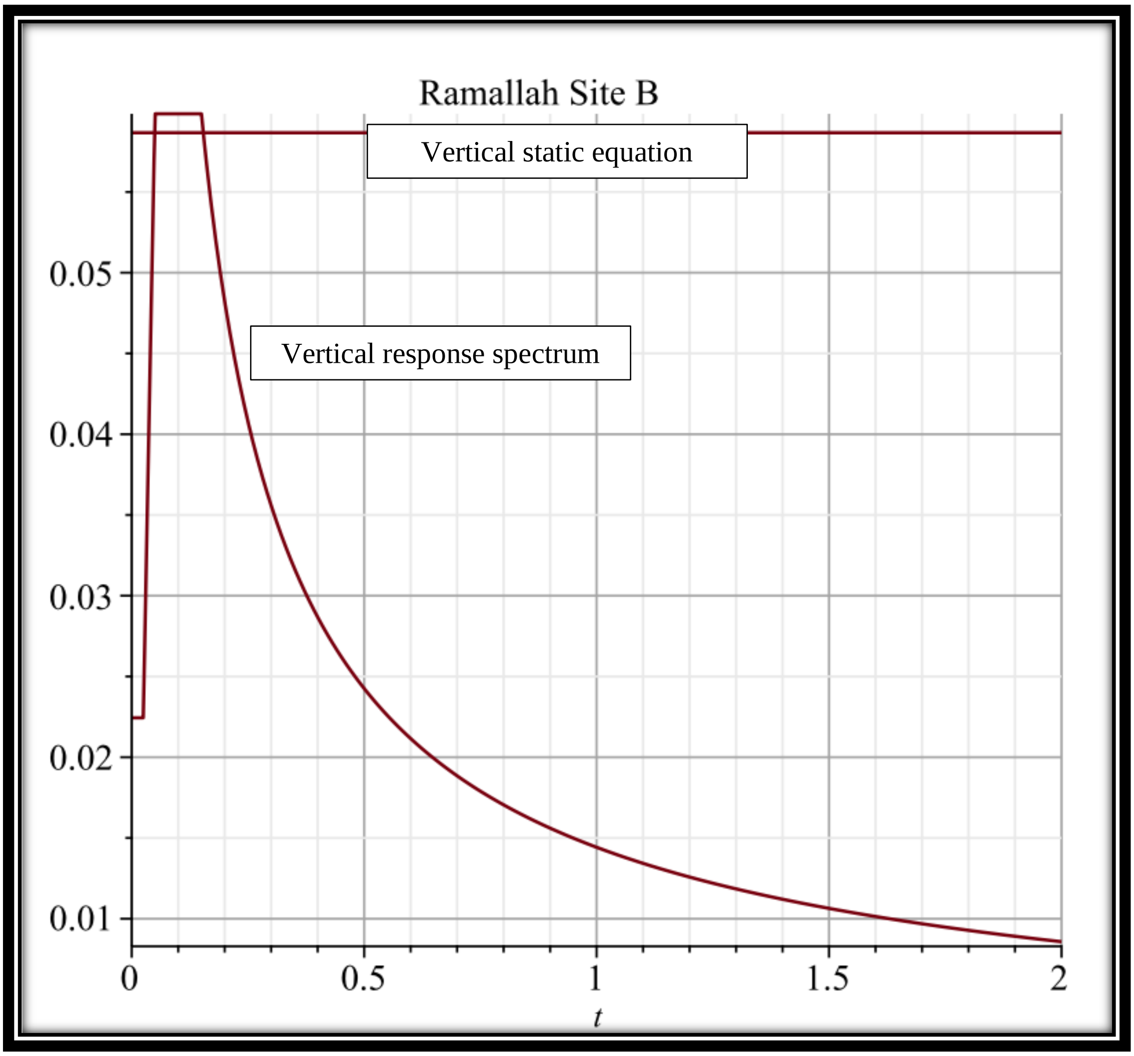

Figure 4.12: differences between vertical response spectrum and vertical static equation in Ramallah site and soil class B.

Therefore, using the equivalent static equation (0.2 S_{DS} D) to all cases is generally unsafe for some cases and can be overdesign for others for SDC C or D but safe and conservative if SDC is B. However, when using the "proposed equation" (Eq4.2), the cantilever beams are generally safe for most of cases regardless of the SDC in Palestine (B, C, D).

4.5 3D models (Effect on cantilever beams):

For further verification of the proposed equation, 3D models of building having cantilevers are used. The assumption and model description are as

Chapter 3 Table 3.1 and section 3.2 with different beam size (30X60 cm (2.25 cantilever length) 40 cm X 70 cm (4.25 cantilever length) and 40 cm X 80(6.25 cantilever length). The building of plan shown in Figure 3.7 is used for the 3D models. The building is assumed to have 7 stories and three lengths of cantilever (2.25 m, 4.25 m, 6.25 m), three stone loads (L_1 (31.6KN/m), L_2 (18.97 KN/m), L_3 (4.74KN/m)), two seismic hazards (R1 (Jenin site) and R3 (Jericho site)) , two site classifications (site C(sand) and site E (clay)) and three seismic design category (B,C,D). Figure 4.13 shows 3D models results for the differences between using proposed vertical static equation according to Eq.4.2 and dynamic analysis by finding vertical reaction of certain cantilever beams in SDC (C or D) with different cases. Figure 4.14 shows 3D models results for the differences between using proposed vertical static equation according to ASCE7-16 code (0.2 S_{DS}D) and dynamic analysis by finding vertical reaction of certain cantilever beams in SDC(B) with different cases. Figure 4.15 shows 3D models results for the differences between using proposed vertical static equation according to Eq.4.2 and dynamic analysis by finding vertical reaction of certain cantilever beams in SDC (B) with different cases. Moreover, the models are verified by finding the fundamental vertical period by using Eq.4.1 and to show example of verification see Appendix A.

It should be noted that, in the figures, F model means the vertical force reaction of cantilever beam from vertical response spectrum analysis by using ASCE 7-16 Code. And the proposed static means the vertical force reaction of cantilever beam from proposed vertical static equation according to Eq. 4.2. The details of the results are shown in Appendix C.

Figure 4.13 shows the results of 3D models in SDC C or D used to verify the proposed equation Eq.4.2. It also shows that some values of proposed equation Eq 4.2 are unconservative and unsafe for different length of cantilever beams although the 2D results show conservative values for these cases. This can be attributed that 3D models the modal mass participation ratio play an important role when the cantilever beam becomes longer. The first mode becomes less important in modal mass participation ratio due the fixed supports assumed in the 2D models which is not the case for the more realistic 3D models. However, the max difference between using proposed equation and response spectrum analysis is 28.57%. This value is within the factor of safety given to dead load for gravity design and hence it may nit have a significant effect in seismic design.

Figure 4.14 and 4.15 show that cantilever beams are safe under vertical earthquake when using the vertical static equation (0.2 S_{DS} D) or proposed equation for SDC B. This shows the proposed equation can be extended to SDC B.

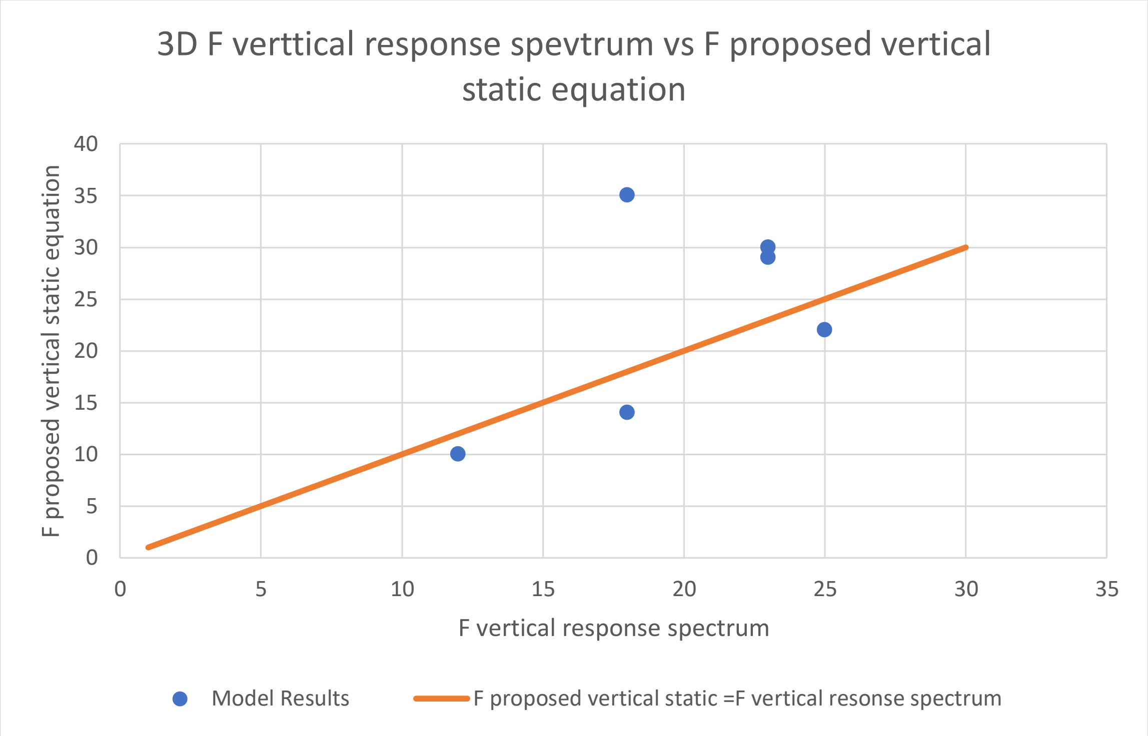

Figure 4.13: The differences between using proposed vertical static equation (according to according to Eq.4.2) and dynamic analysis by finding base reaction of 3D cantilever beam with different cases.

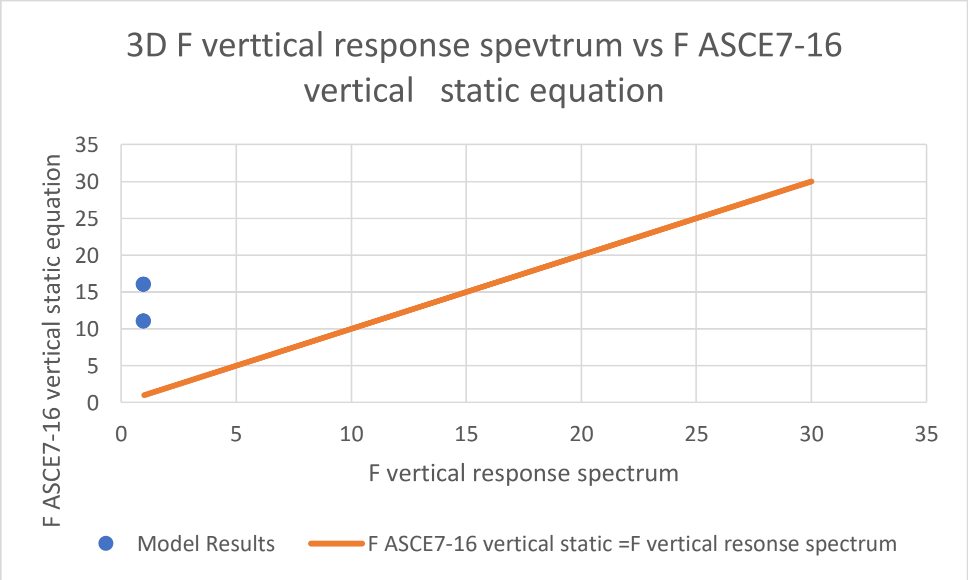

Figure 4.14: The differences between using proposed vertical static equation according to ASCE 7-16 Code ($0.2S_{DS}$ D) and dynamic analysis by finding base reaction of 3D cantilever beam in SDC B with different cases.

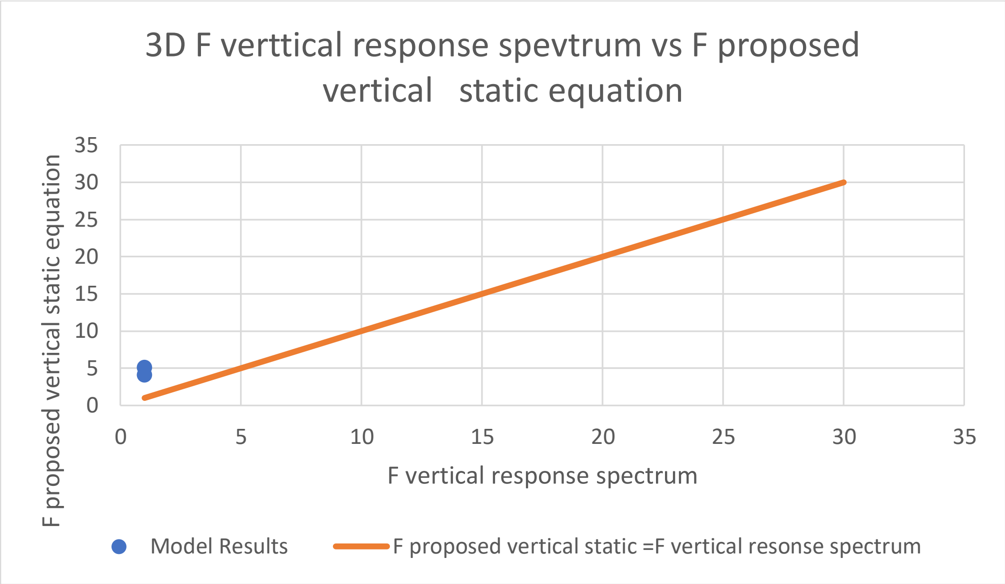

Figure 4.15: The differences between using proposed vertical static equation (according to according to Eq.4.2) and dynamic analysis by finding base reaction of 3D cantilever beam in SDC(B)with different cases.

4.6 Summary:

The proposed equation is generally conservative for most of the cases. However it may not be safe in some models cantilever of 4.25 m but the max difference between using proposed equation and vertical response spectrum is 15 %.This can be considered a small difference .Thus, the proposed equation can be considered to sufficiently represent the effect of the vertical component of earthquake on the response of cantilevers beam with different seismic design category (B, C, D) different length (1.25m ,2.25m ,4.25m ,6.25m), different soil class (B, C,E) , seismic zone(Ramallah, Jericho, Jenin) and different load of stone. Table 4.2 shows sample of results for base shear of 2D cantilever beam with different cases. Appendix C shows the details of 2D results.

The results of 3D models in SDC C or D used to verify the proposed equation Eq.4.2. It also shows that some values of proposed equation Eq

4.2 are unconservative and unsafe for different length of cantilever beams although the 2D results show conservative values for these cases. This can be attributed that 3D models the modal mass participation ratio play an important role when the cantilever beam becomes longer. The first mode becomes less important in modal mass participation ratio due the fixed supports assumed in the 2D models which is not the case for the more realistic 3D models. However, the max difference between using proposed equation and response spectrum analysis is 28.57%. This value is within the factor of safety given to dead load for gravity design and hence it may nit have a significant effect in seismic design .Moreover,cantilever beams are safe under vertical earthquake when using the vertical static equation (0.2 S_{DS} D) or proposed equation for SDC B. This shows the proposed equation can be extended to SDC B.Appendix D show an example to explain how can use the proposed equation.

5 Conclusions, Research finding, and Future work

5.1 Overview

The effect of vertical component on the response of cantilevers is studied. The thesis is divided into two phases: The first phase studies the effect of vertical component of earthquake on the whole building having cantilevers. The second phase is to study the effect of vertical component of earthquake on cantilevers. In this phase, 2D models and 3D models are used. 2D models are used to study the effect of vertical component of earthquake on cantilever beams with different lengths, loads, seismic hazards and site classifications. The 3D models are used to verify the results of 2D models. A proposed equation of vertical static equation is also proposed. In the following sections, the main findings and results of the study will be summarized.

5.2 Research findings

Based on this thesis results, the following conclusions are drawn:

1- The effect of earthquake vertical component on base reaction of building ranges between 3.3% and 7.9%. This effect is generally small and can be ignored.

2- The effect of earthquake vertical component on max story displacement is small and can be neglected.

3- The vertical fundamental period can be considered independent of the number and position of cantilevers. However, the period increases as the number of stories increases.

4- ASCE 7-16 code equation($0.2S_{DS}D$) for vertical equivalent static force is conservative for predicting the vertical shear force in cantilever beams with seismic design category (B).

5- The proposed equation for vertical equivalent static force is generally conservative for predicting the vertical shear force in cantilever beams for seismic design category (B, C, D).

5.3 Future work

The following also are suggested researches to be continued:

- Studying the effect of opening on the response of building under earthquake vertical components.
- Studying the effect of diaphragm rigidity on the response of building under earthquake vertical component.
- How to find the period of the cantilever in 3D models to be used in the proposed equation.

References

- ADAM, M., & Shaaban, I. G. (2002**). Seismic Response of RC Building Frames Subjected to Combined Horizontal and Vertical Excitations. In Engng. Research Journal, Faculty of Engineering (Mattaria)** ***(Vol. 82, pp. 59-75).*** Helwan University**.**
- American Society of Civil Engineers (2016). **Minimum Design Loads for Building and Other Structures (ASCE7-16), Structural Engineering Institute of the American Society of Civil Engineers,** Reston, VA.
- Avci, O., & Bhargava, A. (2019). **Finite-element analysis of cantilever slab deflections with ANSYS SOLID65 3D reinforced-concrete element with cracking and crushing capabilities. Practice Periodical on Structural Design and Construction,** ***24(1), 05018007.***
- Blume, John A and Associates, 1972, San Fernando, California**, Earthquake of February 9, 1971,** ***Volume I, Part A, pp 359-393.***
- Bureau of Indian Standards, 2016.**Criteria for Earthquake Resistant Design of Structures, IS 1893 (Part1): 2016** ***(Sixth Revision),*** New Delhi, India.
- Chopra, A. K. (2017). **Dynamics of structures. theory and applications to Earthquake Engineering**.
- Code, P. (2005). **Eurocode 8: Design of structures for earthquake resistance-part 1: general rules, seismic actions and rules for buildings**. Brussels: European Committee for Standardization.

- Code, P. (2005). Eurocode 8: **Design of structures for earthquake resistance-part 2: Bridges.** Brussels: European Committee for Standardization.
- Code, U. B. (1997, April). **Uniform building code. International Conference of Building Officials,** Whittier, CA.
- Etabs version 18.0.1 [Computer software]. **Computers and Structures, Inc**.
- Fares, A. M., & Touqan, A. (2018). **Effect of shear wall openings on the fundamental period of shear wall structures'** (Doctoral dissertation, Master thesis, Faculty of graduate studies, An-Najah National University).
- Hosseinzadeh, N. (2008, October). **Vertical component effect of earthquake in seismic performance of reinforced concrete bridge piers. In Proceedings of 14th World Conference on Earthquake Engineering, Beijing**, China ***(pp. 06-0050).***
- International Conference of Building Officials, 1994, **Uniform Building Code**, ***p 2-20 – 2-22.***
- Kadid, A., Yahiaoui ,D. and Chebili ,R.(2010) .**Behaviour of reinforced concrete building under simultaneous horizontal and vertical ground motions. Asian journal of civil engineering (building and housing).** ***VOL. 11, NO. 4. PAGES 463-476.***
- Kaplan AEC Engineering ICBO Staff (2009, April), **UBC-IBC structural (1997-2000): Comparison & Cross Reference. In international Conference of Building Officials.**

- KEHOE, B. E., & ATTALLA, M. R. (2000 ,February). *Considerations of Vertical Acceleration on Structural.* **In 12th World Conference on Earthquake Engineering,** Auckland, New Zealand.
- Medina, R. A., Sankaranarayanan, R., & Kingston, K. M. (2006). **Floor response spectra for light components mounted on regular moment-resisting frame structures. Engineering structures,** ***28(14), 1927-1940***.
- Papazouglou, A.J. and A.S. Elnashai . (1996), **"Analytical and Field Evidence of Damaging Effect of Vertical Ground Motion", Earthquake Engineering & Structural Dynamics,** ***Volume 25, Number 10, pp 1109-1137.***
- Part, S. D. A. (2004). 5**: Earthquake Actions-New Zealand. Standards New Zealand.**
- Paz, M., & Leigh, W. (2004). **International Building Code IBC-2000. In Structural Dynamics** ***(pp. 757-781).*** Springer, Boston, MA.
- Petrone, C., Magliulo, G., & Manfredi, G. (2016). **Floor response spectra in RC frame structures designed according to Eurocode 8. Bulletin of Earthquake Engineering,** ***P (747-767).***
- Piolatto, A. (2009). **Structural Response Including Vertical Component of Ground Motion** (Doctoral dissertation, Southern Illinois University Carbondale).
- Shakal, A.F., M.J. Huang, and R.B. Darragh, 1996, **"Some Implications of Strong-Motion Records From the 1994 Northridge**

Earthquake", SMIPS94 Seminar on Seismological and Engineering Implications of Recent Strong-Motion Data, ***pp 1-20.***

- S.K. Ghosh and Prabuddha Das Gupta (2018, December). *Explicit Consideration of Vertical Earthquake Ground Motion in the Design of Structures.* **In 3rd R. N. Raikar Memorial International Conference & 'Gettu - Kodur' International Symposium,** Mumbai, India.
- USGS science for changing world (1994, January,17), www.usgs.gov/media/images/northridge-ca-earthquake-damage .

Appendices

Appendix A: Verification of 3D Models

In Rayleigh's method the estimation of the natural period of the system is given by using lumped masses distribution model for quick estimation. This method depends on the conservation of energy principle assuming no damping, which states that the maximum kinetic energy must equal the maximum potential energy. The method is useful for multi-degrees of freedom system. Many codes use this method as a rational method and the time period is calculating using the following equation: [UBC97 Code ,1997]

$$T = 2\pi\sqrt{\frac{(\sum_{i=1}^{n} w_i {\delta_i}^2}{g\ \sum_{i=1}^{n} f_i \delta_i}} \quad \text{---Eq A.1}$$

Where:

fi: Lateral force at level i of the floor.

δi: Elastic deflection due to lateral force at level i of the floor.

g: Gravity acceleration.

wi: Weight at level i of the floor.

The lateral force (y direction) is assumed to be 1kN/m^2. Elastic deflection for each floor is found from Etabs and used in Rayleigh's formula as shown in Table A.1.

Table A.1: Verification of the fundamental period of model Type A1.

Story	**mass(ton)**	**force(KN)**	**delta(m)**	**mass*delta2**	**force*delta**
Story7	5352.47	461.25	0.00126	0.00849758	0.581175
Story6	5352.47	461.25	0.000989	0.00523536	0.4561763
Story5	5352.47	461.25	0.000735	0.00289154	0.3390188
Story4	5352.47	461.25	0.000504	0.00135961	0.23247
Story3	5352.47	461.25	0.000304	0.00049465	0.14022
Story2	5352.47	461.25	0.000146	0.00011409	0.0673425
Story1	5352.47	461.25	0.000039	8.1411E-06	0.0179888
Sum				0.01860098	1.8343913
Period from Rayleigh y	**0.632**				

Table A.2: Results of verification of fundamental period of model Type A1.

Parameter	T from Rayleigh Methods	T from Etabs	Error%
T from modal y direction	0.632	0.614	3.757

Thus, the difference between Rayleigh's method and modal analysis equal to 3.757% less than 10% which is accepted.

And by using the vertical fundamental period by EqA.2 that verify in Appendix B.

$$T_v = 0.96\pi \sqrt{\frac{(0.1(\rho+w)L+0.41P)L^3}{Ec\, Ig}} \quad \text{---- Eq.A.2}$$

Where:

ρ: weight per unit length.

P: concentrated load.

w: distributed load.

E_c: modulus of elasticity for concrete

I_g: moment of inertia of cantilever beam section.

L: length of cantilever beam.

And by find the load on the cantilever beam (40x70cm) according to 3d model:

distributed load (w)=32 KN/m and concentrated load (P)= 116 KN

$E_c=4700\sqrt{fc`}=4700\sqrt{24}=23025.2$ MPa,

$I_g=\frac{BH^3}{12}=\frac{0.4*0.7^3}{12}=0.0114\ m^4$,

$\rho=25*0.4*0.7=7$ KN/m

now by using Eq.B.5

16.575

$$T_v=0.96\pi\sqrt{\frac{(0.1(\rho+w)L+0.41P)L^3}{Ec\,Ig}}\quad=0.96\pi\sqrt{\frac{(0.1(7+32)4.25+0.41(116))4.25^3}{(23025203.58)*0.0114}}$$

=0.413sec.

Parameter	**Tv(sec) 3D model**	**Tv(sec) Eq A.2**	Error%
4m, TWSS, L1,Site E&R1	0.460	0.413	10.00%

Thus, the difference between Eq A.2 and modal analysis equal to 10.00% so the error is acceptable.

Appendix B: Deriving Equation of vertical fundamental period

Shape function of cantilever beams according to dynamic analysis is: [Chopra, A. K.,2017]

$$\Psi=\cosh(\frac{1.87\,x}{L})-\cos\left(\frac{1.87\,x}{L}\right)-0.73\sinh\left(\frac{1.87\,x}{L}\right)+0.73\sin\left(\frac{1.87\,x}{L}\right) \quad \text{Eq.B.1}$$

Using Rayleigh method:

$$m^{*}=\frac{((\rho+w).\int_0^L \psi^2\,dx)+P*(\psi(L))^2}{9.81} \text{ ------- Eq.B.2}$$

$$k^{*}=0.35\text{ EI}\int_0^L(\frac{d^2\psi}{dx^2})^2 \text{ ------- Eq.B.3}$$

$$T_v=2\,\pi(\frac{m^*}{k^*}) \text{---------- Eq.B.4}$$

After calculation and simplify the equation above:

$$T_v=0.96\pi\sqrt{\frac{(0.1(\rho+w)L+0.41P)L^3}{Ec\,Ig}} \text{ -------Eq.B.5}$$

Where:

Ψ: shape function of cantilever beams

L: length of cantilever beams

m^*: mass star.

k^*: stiffness star.

ρ: weight per unit length.

P: concentrated load.

W: distributed load.

E_c: modulus of elasticity for concrete.

I_g: moment of inertia for cantilever beam section.

Appendix C: Verification and results of 2D and 3D Models (Effect on cantilever beams):

Firstly, the main parameters that will be used:

I. Length of cantilevers beam (2.25m ,4.25m and 6.25m).

II. the load on cantilever beam (31.6 KN/m(L1),18.97 KN/m(L2) 4.74 KN/m(L3),(Self weight)(SF)),71.1 KN(2PL1),42.7 KN (2PL2) , 10.7KN (2PL3),15.8 KN/m(L1/2),9.5 KN/m(L2/2) 2.37 KN/m (L3/2),35.6 KN (2PL1/2) ,21.4 KN (2PL2/2) ,5.35KN (2PL3/2) ,134.3KN (4PL1) ,80.6KN (4PL2) ,20.15KN (4PL3),67.15 KN(4PL1/2) ,40.3KN (4PL2/2) ,10.1KN (4PL3/2),197.5KN (6PL1),118.6KN (6PL2), 29.6KN (6PL3),98.75 KN (6PL1/2) ,59.3KN (6PL2/2),14.8KN (6PL3/2).

III. Seismic Hazard (Jenin(R1), Ramallah (R2), Jericho R (3)).

Then, by using Eq.B.5 to find fundamental vertical period manually and then find it by Etabs program as shown in Table C.1.

Table C.1: Verification of 2D Models using Rayleigh method

Parameter	Vertical Period (sec) Etabs	Vertical Period (sec) Rayleigh	Error %
2.25m,SF,R3&Site C	0.023	0.022	4.3
4.25m,L1,R3&Site C	0.177	0.175	1.1
6.25m,L1,R3&Site E	0.381	0.378	0.8
1.25m,P(160),w(20),R1&site E	0.103	0.099	3.9
1.25m,P(180),w(25),R3&site C	0.11	0.105	4.5
4.25m,4PL1,R1&Site E	0.328	0.322	1.8

Note :P mean point load at the free end of cantilever beam and the load between brackets in KN and w mean distributed load in KN/m.

Thus, the max difference between Rayleigh's method and modal analysis equal to 4.5 % less than 10% which is accepted. Table C.2 shows the details results of 2D models with different cases in SDC C&D. Table C.3 shows the details results of 2D models with different cases in SDC B. Table C.4 shows the details results of 2D models with 1.25 m length of cantilever beam with different cases in SDC C&D. Table C.5 shows the details results of 3D models in SDC (C or D) with different cases. Table C.5 shows the details results of 3D models in SDC(B) with different cases.

The section of cantilever beam that used for these (Table C.2) models is 30X60 cm for 2.25 cantilever length, 40 cm X 70 cm for 4.25 cantilever length and 40 cm X 80 for 6.25 cantilever length.

Table C.2 shows the details results of 2D models with different cases in SDC C&D.

Parameter	Fz (Static proposed E_V)KN	Fz (Response E_V)KN	T_v (sec)	Difference Fz Static proposed & Response %
2.25m,SF,R3&Site C	4	1	0.023	76.01
2.25m,L1,R3&Site C	21	12	0.05	41.84
2.25m,L2,R3&Site C	14	6	0.042	57.30
2.25m,L3,R3&Site C	7	2	0.029	69.87

2.25m,2PL1,R3&Site C	21	17	0.093	17.60
2.25m,2PL2,R3&Site C	14	11	0.073	21.74
2.25m,2PL3,R3&Site C	7	3	0.042	54.86
2.25m,L1/2,R3&Site C	12	5	0.039	59.68
2.25m,L2/2,R3&Site C	9	3	0.034	67.07
2.25m,L3/2,R3&Site C	5	1	0.026	81.49
2.25m,2PL1/2,R3&Site C	12	10	0.068	19.35
2.25m,2PL2/2,R3&Site C	9	7	0.054	23.17
2.25m,2PL3/2,R3&Site C	5	2	0.033	63.01
4.25m,SF,R3&Site C	8	4	0.08	49.19
4.25m,L1,R3&Site C	34	21	0.177	38.99
4.25m,L2,R3&Site C	27	15	0.146	43.48
4.25m,L3,R3&Site C	13	7	0.1	44.17
4.25m,4PL1,R3&Site C	22	22	0.328	-1.51
4.25m,4PL2,R3&Site C	18	17	0.259	3.50
4.25m,4PL3,R3&Site C	13	8	0.146	36.20
4.25m,L1/2,R3&Site C	23	13	0.137	44.50
4.25m,L2/2,R3&Site C	17	10	0.118	41.88
4.25m,L3/2,R3&Site C	10	6	0.091	41.21
4.25m,4PL1/2,R3&Site C	17	15	0.239	9.17
4.25m,4PL2/2,R3&Site C	14	12	0.191	16.39
4.25m,4PL3/2,R3&Site C	10	6	0.118	41.21
6.25m,SF,R3&Site C	10	6	0.171	42.82

6.25m,L1,R3&Site C	28	22	0.381	22.76
6.25m,L2,R3&Site C	22	17	0.315	24.02
6.25m,L3,R3&Site C	14	9	0.216	35.83
6.25m,6PL1,R3&Site C	18	15	0.708	16.18
6.25m,6PL2,R3&Site C	15	12	0.559	17.55
6.25m,6PL3,R3&Site C	11	9	0.316	14.62
6.25m,L1/2,R3&Site C	21	16	0.296	22.66
6.25m,L2/2,R3&Site C	17	12	0.253	29.81
6.25m,L3/2,R3&Site C	12	8	0.195	35.10
6.25m,6PL1/2,R3&Site C	14	11	0.515	19.45
6.25m,6PL2/2,R3&Site C	12	10	0.413	15.54
6.25m,6PL3/2,R3&Site C	10	8	0.254	20.86
2.25m,SF,R1&Site E	4	1	0.023	71.88
2.25m,L1,R1&Site E	18	11	0.05	37.52
2.25m,L2,R1&Site E	12	6	0.042	49.96
2.25m,L3,R1&Site E	6	2	0.029	64.69
2.25m,2PL1,R1&Site E	18	16	0.093	9.12
2.25m,2PL2,R1&Site E	12	10	0.073	16.62
2.25m,2PL3,R1&Site E	6	3	0.042	47.10
2.25m,L1/2,R1&Site E	11	5	0.039	52.75
2.25m,L2/2,R1&Site E	8	3	0.034	61.41
2.25m,L3/2,R1&Site E	5	1	0.026	78.31
2.25m,2PL1/2,R1&Site E	11	9	0.068	14.94

2.25m,2PL2/2,R1&Site E	8	6	0.054	22.83
2.25m,2PL3/2,R1&Site E	5	2	0.033	56.65
4.25m,SF,R1&Site E	7	4	0.08	40.46
4.25m,L1,R1&Site E	29	20	0.177	31.91
4.25m,L2,R1&Site E	23	14	0.146	38.19
4.25m,L3,R1&Site E	11	7	0.1	34.57
4.25m,4PL1,R1&Site E	18	21	0.328	-13.55
4.25m,4PL2,R1&Site E	15	16	0.259	-6.43
4.25m,4PL3,R1&Site E	11	8	0.146	25.23
4.25m,L1/2,R1&Site E	20	12	0.137	39.96
4.25m,L2/2,R1&Site E	15	9	0.118	38.71
4.25m,L3/2,R1&Site E	9	5	0.091	42.58
4.25m,4PL1/2,R1&Site E	14	14	0.239	0.66
4.25m,4PL2/2,R1&Site E	12	11	0.191	10.19
4.25m,4PL3/2,R1&Site E	9	6	0.118	31.10
6.25m,SF,R1&Site E	9	6	0.171	33.00
6.25m,L1,R1&Site E	24	20	0.381	17.72
6.25m,L2,R1&Site E	19	16	0.315	16.20
6.25m,L3,R1&Site E	12	9	0.216	24.80
6.25m,6PL1,R1&Site E	15	14	0.708	8.33
6.25m,6PL2,R1&Site E	12	11	0.559	11.44
6.25m,6PL3,R1&Site E	9	8	0.316	11.06
6.25m,L1/2,R1&Site E	18	15	0.296	15.03

6.25m,L2/2,R1&Site E	15	11	0.253	24.60
6.25m,L3/2,R1&Site E	11	7	0.195	33.45
6.25m,6PL1/2,R1&Site E	12	10	0.515	14.19
6.25m,6PL2/2,R1&Site E	10	10	0.413	1.03
6.25m,6PL3/2,R1&Site E	9	7	0.254	18.85
2.25m,SF,R3&Site E	5	1	0.023	77.85
2.25m,L1,R3&Site E	22	14	0.05	37.36
2.25m,L2,R3&Site E	15	8	0.042	47.44
2.25m,L3,R3&Site E	7	2	0.029	72.19
2.25m,2PL1,R3&Site E	22	20	0.093	10.52
2.25m,2PL2,R3&Site E	15	13	0.073	14.62
2.25m,2PL3,R3&Site E	7	4	0.042	44.44
2.25m,L1/2,R3&Site E	13	6	0.039	55.33
2.25m,L2/2,R3&Site E	10	4	0.034	59.47
2.25m,L3/2,R3&Site E	6	2	0.026	65.83
2.25m,2PL1/2,R3&SiteE	13	11	0.068	18.11
2.25m,2PL2/2,R3&Site E	10	8	0.054	18.95
2.25m,2PL3/2,R3&Site E	6	2	0.033	65.85
4.25m,SF,R3&Site E	9	5	0.08	41.38
4.25m,L1,R3&Site E	37	25	0.177	32.96
4.25m,L2,R3&Site E	29	18	0.146	37.40
4.25m,L3,R3&Site E	14	8	0.1	41.10
4.25m,4PL1,R3&Site E	23	27	0.328	-15.00

4.25m,4PL2,R3&Site E	19	20	0.259	-4.80
4.25m,4PL3,R3&Site E	14	10	0.146	26.38
4.25m,L1/2,R3&Site E	25	16	0.137	36.94
4.25m,L2/2,R3&Site E	19	11	0.118	40.99
4.25m,L3/2,R3&Site E	11	7	0.091	36.68
4.25m,4PL1/2,R3&Site E	18	18	0.239	-0.61
4.25m,4PL2/2,R3&Site E	16	14	0.191	9.96
4.25m,4PL3/2,R3&Site E	11	7	0.118	36.69
6.25m,SF,R3&Site E	11	7	0.171	38.43
6.25m,L1,R3&Site E	31	26	0.381	15.74
6.25m,L2,R3&Site E	24	20	0.315	17.49
6.25m,L3,R3&Site E	15	11	0.216	27.61
6.25m,6PL1,R3&Site E	19	18	0.708	7.16
6.25m,6PL2,R3&Site E	16	14	0.559	11.21
6.25m,6PL3,R3&Site E	11	10	0.316	12.43
6.25m,L1/2,R3&Site E	22	18	0.296	19.68
6.25m,L2/2,R3&Site E	19	14	0.253	24.41
6.25m,L3/2,R3&Site E	13	9	0.195	32.60
6.25m,6PL1/2,R3&Site E	15	13	0.515	12.13
6.25m,6PL2/2,R3&Site E	13	12	0.413	6.45
6.25m,6PL3/2,R3&Site E	11	9	0.254	17.81

Table C.3 shows the details results of 2D models with different cases in SDC B.

Parameter	Fz static ($0.2S_{DS}$ D)KN	Fz (Static proposed EV)KN	Fz (Response EV)KN	Tv (sec)	Difference Fz static($0.2S_{DS}$ D)& Response %
2.25m,L1,R2&Site B	5	10	1	0.05	80.00
2.25m,L2,R2&Site B	4	8	0.36	0.042	91.00
4.25m,L1,R2&Site B	10	17	1	0.177	90.00
4.25m,L2,R2&Site B	7	15	1	0.146	85.71
6.25m,L1,R2&Site B	15	14	1	0.381	93.33
6.25m,L2,R2&Site B	10	13	1	0.315	90.00

The section of cantilever beam that used for these models is 30cmx60cm

Table C.4 shows the details results of 2D models with 1.25 length cantilever beam with different cases in SDC C&D.

Parameter	Fz (Response E_V)KN	Fz (Static proposed E_V)KN	T_v (sec)	Difference Fz Static proposed & Response %
1.25m,P(25),w(5),R1& site E	5	9	0.042	41.44
1.25m,P(35),w(5),R1& site E	8	11	0.049	26.29
1.25m,P(100),w(5),R1 &site E	21	26	0.081	18.93
1.25m,P(120),w(10),R1	25	32	0.089	21.83

&site E				
1.25m,P(140),w(15),R1 &site E	30	38	0.096	21.18
1.25m,P(160),w(20),R1 &site E	35	44	0.103	20.71
1.25m,P(180),w(25),R1 &site E	39	50	0.11	22.34
1.25m,P(200),w(25),R1 &site E	43	55	0.115	21.60
1.25m,P(220),w(30),R1 &site E	48	61	0.121	21.22
1.25m,P(240),w(35),R1 &site E	52	67	0.127	22.39
1.25m,P(25),w(5),R3& site C	5	9	0.042	41.44
1.25m,P(35),w(5),R3& site C	9	11	0.049	17.08
1.25m,P(100),w(5),R3 &site C	22	26	0.081	15.07
1.25m,P(120),w(10),R3 &site C	27	32	0.089	15.58
1.25m,P(140),w(15),R3 &site C	32	38	0.096	15.93
1.25m,P(160),w(20),R3 &site C	37	44	0.103	16.18
1.25m,P(180),w(25),R3 &site C	42	50	0.11	16.36
1.25m,P(200),w(25),R3 &site C	46	55	0.115	16.13
1.25m,P(220),w(30),R3	51	61	0.121	16.29

&site C				
1.25m,P(240),w(35),R3 &site C	56	67	0.127	16.42
1.25m,P(25),w(5),R3& site E	6	9	0.042	29.73
1.25m,P(35),w(5),R3& site E	10	11	0.049	7.87
1.25m,P(100),w(5),R3 &site E	27	26	0.081	-4.23
1.25m,P(120),w(10),R3 &site E	32	32	0.089	-0.05
1.25m,P(140),w(15),R3 &site E	38	38	0.096	0.16
1.25m,P(160),w(20),R3 &site E	44	44	0.103	0.32
1.25m,P(180),w(25),R3 &site E	50	50	0.11	0.43
1.25m,P(200),w(25),R3 &site E	55	55	0.115	-0.28
1.25m,P(220),w(30),R3 &site E	61	61	0.121	-0.12
1.25m,P(240),w(35),R3 &site E	66	67	0.127	1.50

Table C.5 shows the details results of 3D models in SDC(C or D) with different cases.

Parameter	Fz (Response E_V)KN	Fz (Static proposed E_V)KN	T_v (sec)	Difference Fz Static proposed & Response %
2m, TWSS, L1,Site C&R3	25	22	0.257	-13.64
4m, TWSS, L2,Site C&R3	23	29	0.424	20.69
4m, TWSS, L1,Site E&R1	23	30	0.481	23.33
2m, TWSS, L3,Site C&R3	12	10	0.16	-20.00
6m, TWSS, L1,Site E&R1	18	35	0.975	48.57
2m, TWSS, L2,Site E&R1	18	14	0.214	-28.57

Table C.6 shows the details results of 3D models in SDC(B) with different cases.

Parameter	Fz static ($0.2S_{DS}$ D)KN	Fz (Static proposed EV)KN	Fz (Response EV)KN	Tv (sec)	Difference Fz static ($0.2S_{DS}$ D)& Response %
4m, TWSS, L2,Site B&R1	11	1	5	0.424	91
6m, TWSS, L1,Site B&R1	16	1	4	0.975	94

Appendix D: An example of cantilever beam and explain how can use this proposed equation.

Table D.1 show the description of model that will use as example. Assume that seismic hazard in Jenin(R1) and soil classification.

Table D.1: Description of model that will use as example

Parameter	Details
Beam section	30cm x 60cm
Length of cantilever beam	2 m
$f`_C$(MPa)	24 MPa
Cv	1.2
SDS	0.683
SMS	1.024

Assume that the distributed load (w)=30 KN/m and concentrated load (P)= 10 KN as shown in Figure D.1.

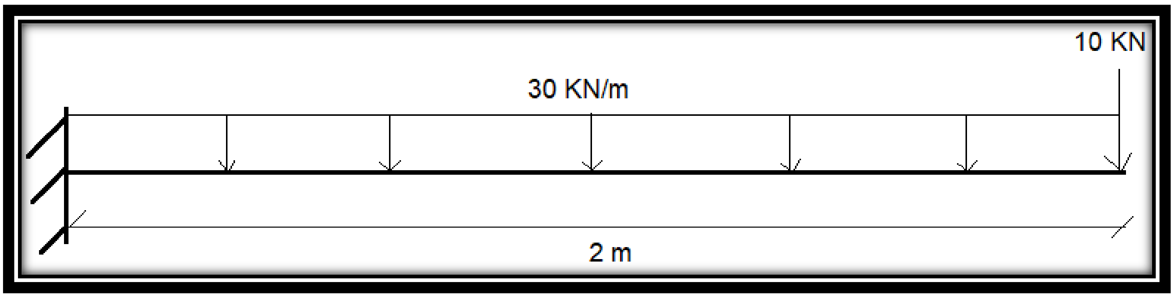

Figure D.1:2D frame example solutions by proposed vertical static equation

First, E_c=4700$\sqrt{fc`}$=4700$\sqrt{24}$ =23025.2 MPa,

$$I_g = \frac{BH^3}{12} = \frac{0.3*0.6^3}{12} = 0.0054 \text{ m}^4,$$

ρ= 2.5*0.3*0.6 = 4.5 KN/m

now by using Eq.B.5

$T_v=0.96\pi\sqrt{\frac{(0.1(\rho+w)L+0.41P)L^3}{Ec\,Ig}} \quad =0.96\pi\sqrt{\frac{(0.1(4.5+30)2+0.41(10))2^3}{(23025203.58)*0.0054}}$

=0.08 sec.

Dead load (D) = (4.5+30) * 2+10=79 KN

Then by using Eq.4.2 to find earthquake vertical component by proposed static equation:

$$F_v=E_{v=}\begin{cases} 0\ sec < T_v \leq 0.15\ sec & 0.1608\ C_v S_{MS} \\ 0.15\ sec < T_v \leq 2\ sec & 0.1608\ \mathrm{Cv\ SMS}\ (\frac{0.15}{T_V})^{0.75} \end{cases} \quad \text{Eq. 4.2}$$

Here T_v <0.15 so use $F_{v=}0.1608\ C_v S_{MS} D$=0.1608*1.2*1.024 *79=15.61 KN

جامعة النجاح الوطنية

كلية الدارسات العليا

تأثير استجابة المركبة العامودية للقوة الزلزالية على البلاكين للمباني الخرسانية المسلحة متعددة الطوابق

اعداد

أحمد محمود سليم البيك

اشراف

د. منذر دويكات

د. منذر ذياب

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الإنشاءات بكلية الدارسات العليا في جامعة النجاح الوطنية، نابلس فلسطين.

2021

تأثير استجابة المركبة العامودية للقوة الزلزالية على البلاكين للمباني الخرسانية المسلحة متعددة الطوابق

اعداد

احمد محمود سليم البيك

اشراف

د. منذر دويكات

د. منذر ذياب

الملخص

يخضع تصميم المباني التي تصمم لأحمال الزلزال بشكل أساسي للحركة الأرضية الأفقية، وقد اعتُبرت تأثيرات الحركة الأرضية الرأسية منذ فترة طويلة غير مهمة أو ثانوية. ومع ذلك، تشير مجموعة من الأدلة الناشئة إلى أن الحركات الأرضية العمودية لها إمكانات تدميرية كبيرة، خاصةً في ظروف معينة في الموقع. تشير الدلائل إلى أن المكون الرأسي للحركة الأرضية أكثر أهمية مما كان يعتقد سابقًا، خاصة بالنسبة للمباني القريبة من الصدع وعندما تحتوي المباني على البلاكين. هدف هذا البحث هو دراسة تأثير المكون الرأسي للزلزال على استجابة البلاكين لمبنى خرساني مسلح متعدد الطوابق. استخدم برنامج تحليل العناصر المحدودة (Etabs) لتحقيق تأثير المكون الرأسي للزلازل على البلاكين في النماذج ثنائية وثلاثية الأبعاد مع حالات مختلفة. يتم التحقق من النماذج من خلال مقارنة النتائج بالحل اليدوي. تم إنشاء العديد من النماذج المختلفة مع حالات مختلفة. تظهر النتائج أن المعادلة الثابتة المكافئة المقترحة متحفظة باختلاف فئة التصميم الزلزالي(B,C,D).