AN ANALYTICAL STUDY ON THE SEISMIC CHARACTERISTICS OF THE GROUND AND STRUCTURE IN DAMASCUS-SYRIA INCLUDING SOIL-STRUCTURE INTERACTION

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In order to implement the proper design of structures in Damascus, the seismic behavior of soil and structure was examined numerically, and the seismic characteristics of both of them were determined. The study is carried out through two major steps; first, examining the seismic response of ground due to strong and weak earthquake motions; second, examining the soil-structure interaction due to the same motions. All seismic characteristics of both ground and structure will be determined from these analyses such as shear forces, displacements, bending moments, stresses …etc. strong nonlinear properties were displayed, which proved the equivalent static method used in Syria insufficient.

Key words: *Seismic characteristics, Damascus-Syria, Soil-Structure interaction, Seismic response analysis*

1. INTRODUCTION

Syria occupies a large segment of the Arab plate north slope which is rich in geologically divergent structural formations which are of paramount importance as they are linked with so many economic resources including oil, gas, chromium etc…Taking into consideration the proximity of Syria to many active plates (Eurasian plate and Anatolian subplate)[1)] Figure 1, the study of the earthquake effects on the ground and structures in Syria emerges as a very important step in the proper design for earthquake resistant structures. Syria has experienced many strong earthquakes in the past including 1872 earthquake in the southern region of Syria (With magnitude of 7.8 degrees on Richter scale). Damascus is the capital city and is located in the riskiest region of Syria[2)] (high seismicity area which exposed to earthquakes ≥ VIII degrees on the modified Mercalli scale) Figure 2. It has many important structures that are not designed to resist earthquakes. That is why this research concentrates on Damascus city. This paper is a step forward to reach the best possible design for earthquake resistant structures. Up to date, the Syrian code uses the static method in the design of the structures under the effect of earthquakes, which is not accurate because it does not take into account many important factors such as earthquake acceleration, the ground and structure characteristics. This research is new in the area (Syria), so the importance of it comes from the new aspects that this study tries to focus on. It is very important to clarify the dynamic behavior of the ground and structures including the interaction between both of them. Since there is no earthquake data in Syria, we will use different observed earthquake data from Japan including strong motions (Hanshin earthquake in Kobe) and weak motions (Zushi prerecorded data) in the horizontal and vertical directions.

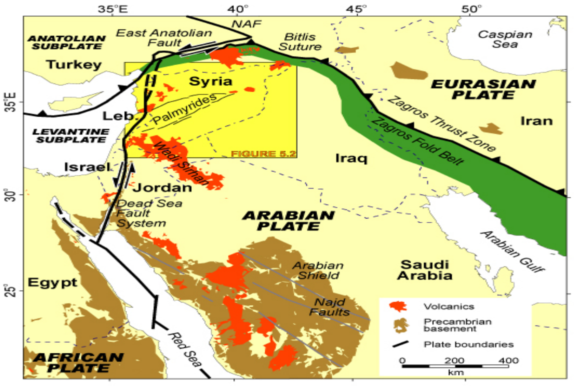


Figure 1. Tectonic map of the region

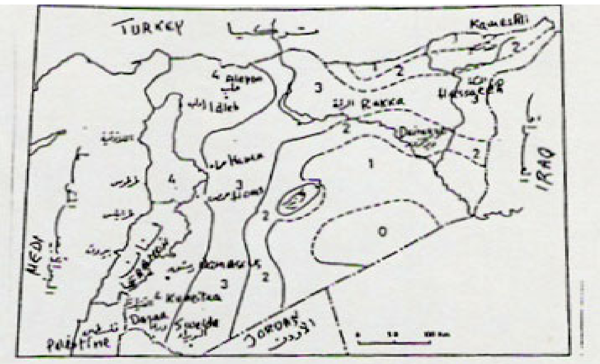


Figure 2. Chart of distribution of seismic risk regions in Syria

2. METHODOLOGY

(1) Numerical Simulation

A schematic of the numerical simulation is shown in Figure 3. Simulation consists of two major steps. The first one is the analysis of the seismic ground response only, and the second one is the analysis of the combined seismic response of the structure (tall building) and ground.

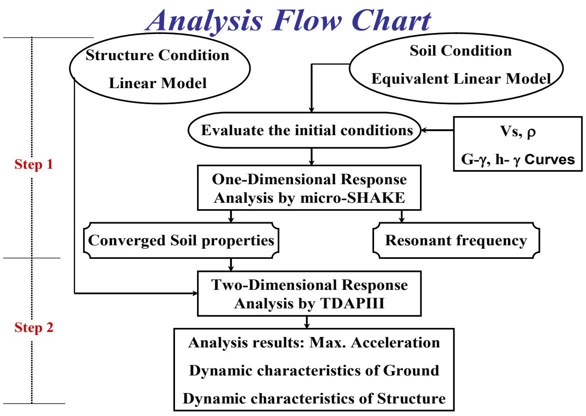


Figure 3. Simulation Analysis Flow

(2) Numerical Procedures

Seismic Response Analysis of Ground: The dynamic response of the ground model during an earthquake is estimated using the micro-SHAKE program (one-dimensional seismic response analysis used with multiple-reflection theory)[3)] Figure 4, by considering the non-linearity of soil properties from G - γ, h - γ curves generated from experimental results. Figure 5.

The initial values for the numerical model are estimated as follows

* The shear velocity (Vs) of the ground model is determined by the following equations (where Vs value depends on the soil type):

C ≠0 (cohesion soil):

$$Vs= 100N^{1/3} \ (1 \leq N \leq 25) \tag{1-a}$$

C =0 Sandy Soil (cohesionless soil):

$$Vs= 80N^{1/3} \ (1 \leq N \leq 50) \tag{1-b}$$

In the case of the vertical motion, the equation of shear wave velocity (Vs) and longitudinal wave velocity (Vp) is written as follows

$$Vp / Vs = [2(1- \nu) / (1-2\nu)]^{1/2} \tag{2}$$

The boring data of the soil was collected at eighteen points in Dummar a district in the northern west of Damascus.[4)] (ρ = 1.71 ~ 1.95 tf/m^3 and Vs = 172.4 ~ 259.6 m/sec in the subsurface layer, ρ = 1.95 ~ 2.18 tf/m^3 and Vs = 207.7 ~ 275.8 m/sec in the bearing stratum).

**The initial shear modulus is:

$$G = \rho Vs^2 / g \tag{3}$$

The initial modulus of longitudinal elasticity is

$$E = \rho Vp^2 / g \tag{4}$$

The damping constant of soil is 0.05.

This research concentrates mainly on the effect of Kobe earthquake (Hanshin earthquake) on the soil and structures of the area mentioned above in Damascus – Syria.

The model ground of all points is subjected to Kobe earthquake motions with different amplifications (1/1 = 8.18 m/sec^2, 1/2, 1/4, 1/8 and 1/40) in the horizontal direction, (1/1 =3.33 m/sec^2, 1/2, 1/4) in the vertical direction Figure 6, a pre-recorded earthquake data of Zushi city (in the point K3, N-S direction (0.18 m/sec^2), T2-1 standard waves in Japan (7 m/sec2), and Sine sweep tests (4, 2, 1 , 0.5, 0.2 m/sec^2) in the horizontal direction.

The ground in all points is modeled by dividing it into the main layers (Sand, clay… etc), which has the same density and shear velocity, then dividing each main layer into sub layers (layers with smaller thickness between 0.5 to 1 m). Figure 4.

The input motion in this analysis is applied to the basis. (1/1 indicates 100% amplification of motion).

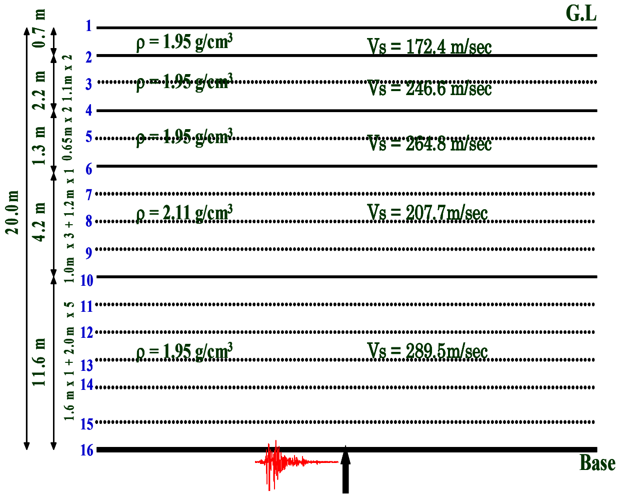
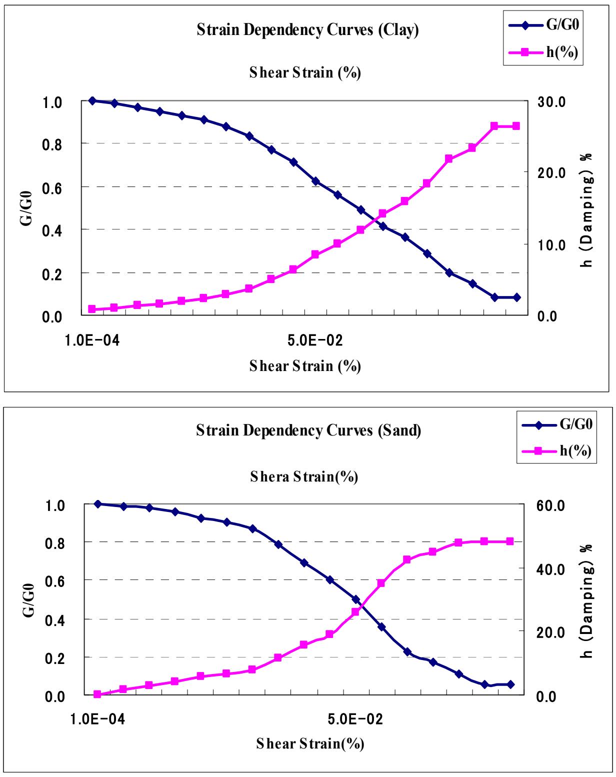


Figure 4. One-dimensional analysis model of the ground



$$\frac{G}{G_0} = \frac{1}{1 + \dfrac{\gamma}{\gamma_t}}$$

$$h = \frac{4}{\pi}\left[\frac{G}{G_0}\left\{\frac{\gamma_t}{\gamma} - \left(\frac{\gamma_t}{\gamma}\right)^2 \ln\left(1 + \frac{\gamma}{\gamma_t}\right)\right\} - \frac{1}{2}\right] + 0.02$$

γ_t : Criterion strain ($=3.5\times10^{-4}$)

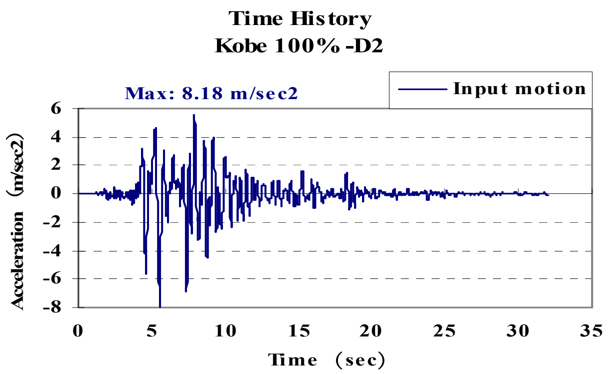
G_0 : Initial shear modulus

Figure5. Strain dependency curves of the ground model

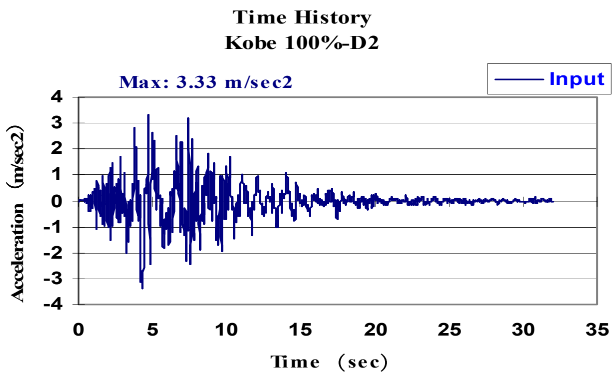
The initial values of the ground model in case of horizontal input motion are shown in Table 1.

Table 1 Initial values of the ground model

Layer No	Thickness (m)	Shear Modulus G (tf/m^2)	Damping Constant H	Density ρ (tf/m^3)	N	Vs (m/sec)
1	0.7	5908.00	0.05	1.95	10	172.4
2	2.2	12087.92	0.05	1.95	15	246.6
3	1.3	13938.04	0.05	1.95	19	264.8
4	4.2	9278.69	0.05	2.11	18	207.7
5	11.6	16659.53	0.05	1.95	25	289.5



Horizontal Input motion (NS)



Vertical Input motion (UD)

Figure 6. Kobe Earthquake observatory record

Analysis of Structure: The examined structure in this paper is a typical tall building with the following specifications:

(a) High building (23 stories, 2 Basements).
(b) RC elements (Columns, Beams, Foundations…etc).
(c) Building shape is nonidentical (story height, Area of the story…etc).
(d) Total height: 92.3 m (without basements).
(e) Depth of the embedded part: 12.25m.

The dynamic response of the structure (one and two dimensional analyses) was analyzed using TDAP III (Time domain Dynamic Analysis Program III).

The ground was modeled using two-dimensional finite elements and the converged values of the soil properties used. Table 2, Table 3.

The structure was modeled as a set of elastic beams elements.

The dynamic behavior of the structure, the dynamic forces (shear forces, compression forces…etc) acting on the structure were evaluated.

The analysis in fact is a Time history response analysis, which uses the Newmark's βmethod of non-delta form.

As mentioned above, the seismic response analysis of the structure contains two steps.

One Dimensional Analysis (Spring-Mass model), which is a Linear analysis.

The structure was modeled as a set of elastic beams elements, and provided with a set of springs, which support the embedded part of the structure. Figure 7.

We used two kinds of springs in this model (Horizontal springs, and Rocking springs).

Each kind of those springs has its own constants: [7)]

C: damping constant of the spring

K: stiffness constant of the spring

The notation ($_H$) refers to the horizontal springs, while ($_R$) refers to the rocking springs.

The constants are calculated as follows: [5)]

$$K_R = \pi \cdot G \cdot a_1^3 / 2\,(1-\upsilon) \qquad (5)$$

$$C_R = 0.35 \times \rho \times Vs \times \pi \times r_0^4 \times a_0^2 \qquad (6)$$

$$K_H = \pi \cdot G \cdot a / (1-\upsilon) \qquad (7)$$

$$C_H = 0.55 \times \rho \times Vs \times \pi \times r_0^2 \qquad (8)$$

Where

$r_0 = a \times b$, $a_0 = r_0 \times \omega / Vs$

$a_1 = (a_3 \times b / 3\pi)^{1/4}$, ρ: Density of the soil (tf/m^3)

Vs: Shear velocity of that soil (m/sec^2)

G: Shear Modulus, υ : Poisson Ratio

a, b: Basement Dimensions (m)

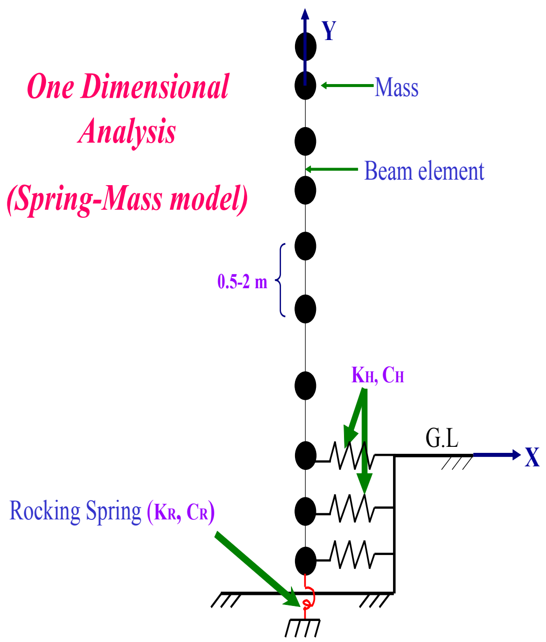


Figure 7. One-dimensional model (Mass-Spring)

The second step of the structure analysis is the two-dimensional analysis (Finite Element Method).

The ground was modeled using two-dimensional finite elements (plane strain elements) and the converged values of the soil properties were used, while the structure was modeled as a set of elastic beams elements. Figure 8.

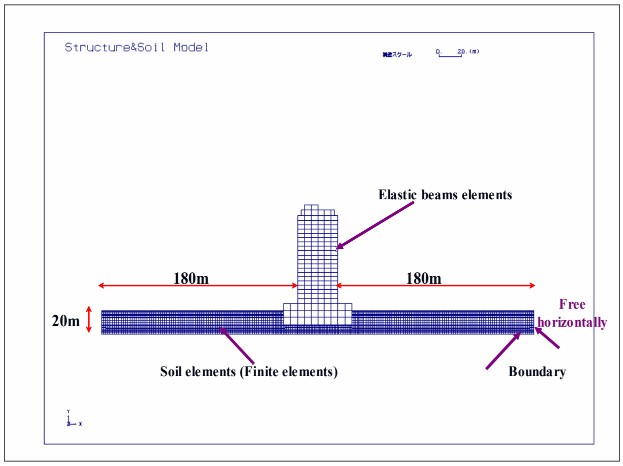


Figure 8. Two-dimensional model (F.E.M)

Table 2 Converged values for horizontal motion (Kobe 100%)

No	Thickness (m)	Density (tf/m3)	Damping constant	Poisson ratio ν	Shear Modulus G (tf/m2)
1	0.70	1.95	0.0804	0.45	5117.35
2	2.20	1.95	0.0486	0.45	9368.83
3	1.30	1.95	0.0613	0.45	10066.7
4	4.20	2.11	0.4773	0.45	845.298
5	11.60	1.95	0.4800	0.45	966.23

Table 3 Converged values for vertical motion (Kobe 100%)

No	Thickness (m)	Density (tf/m3)	Damping constant	Poisson ratio ν	Shear Modulus G (tf/m2)
1	0.70	1.95	0.0645	0.45	5340.43
2	2.20	1.95	0.0385	0.45	9990.75
3	1.30	1.95	0.0461	0.45	10989.6
4	4.20	2.11	0.3985	0.45	2504.13
5	11.60	1.95	0.4361	0.45	3275.1

Syrian Arab code method: This method is an equivalent static method, where the overall horizontal strength is computed in the studied trend (mantle shearing strength) at the level of the base connection with the structure, according to the following relation: [2)]

$$V = Z \cdot I \cdot K \cdot C \cdot S \cdot W \qquad (9)$$

Where

V: Base shearing force at the level of the structure bottom.

Z: studied region seismic factor whose value is taken from Table 4.

I: Coefficient of importance of structure and nature of its use.

K: Effect of structures inflexible behavior on seismic loads, briefly called "inflexible behavior coefficient".
C: Ratio between the acceleration caused by the quake and the ground acceleration. Its value is determined from the following relation:

$$C = 1/\,15\,T^{1/2} \qquad (10)$$

Where
T: Natural period value of the shaken structure in studied direction, estimated by second. The T value is experimentally determined from the following relation:

$$T\,(sec) = 0.09 h_n / D^{1/2} \qquad (11)$$

Where
h_n: structure height from foundation up to highest level, estimated by meter.
D: Structure dimension estimated by meter in the direction parallel to seismic loads.
If the structure is made of reinforced concrete ductile hollow frame blocks without being connected with other robust components precluding them from movement under the effect of seismic forces, the structure natural period value estimated by second can be determined according to the following experimental relation:

$$T = 0.1 \cdot N \qquad (12)$$

Where
N: number of structure stories.

Table 4 Values of coefficient Z

Region	0	1	2	3	4
Z value	0	0.1	0.2	0.3	0.4

3. RESULTS

(1) Dynamic Behavior of the Ground Model

1- In the case of a horizontal motion, the resonant frequency of the ground model was 0.7 Hz for Kobe 1/1, 1.4 Hz for Kobe 1/2 and 1.9 Hz for Kobe 1/4.
The resonant frequency decreased with the increase of earthquake amplification. Different cases are shown in Figure 9.
The ground model displayed strong nonlinear properties.
By checking the resonant frequency of the sinusoidal wave for different amplification we get Figure 10, where we can see that the resonant frequency for 20 gal (0.2 m/sec^2) is 3 Hz while it is 1.5 Hz for 400 gal (4 m /sec2) waves. This result agrees with the experimental equation

$$f = Vs/4H \qquad (13)$$

The resonant frequency decreased with the increasing of the amplification.

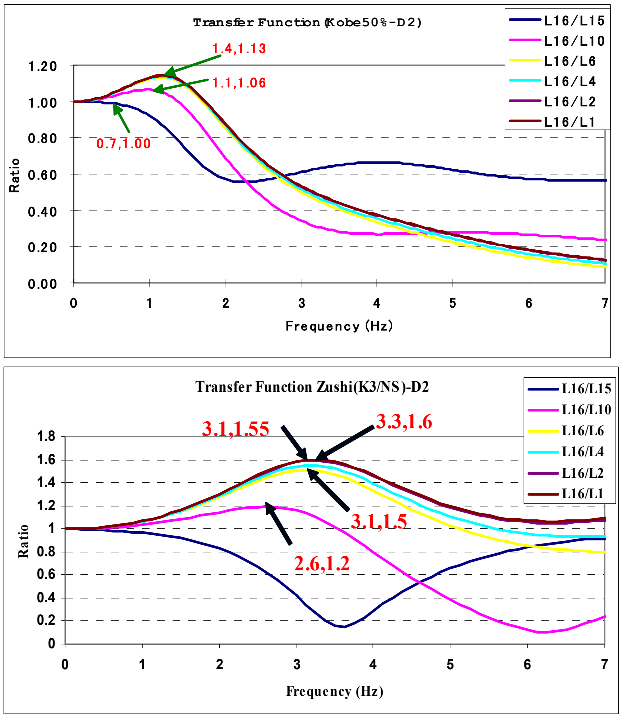


Figure 9. Resonant frequency for different earthquake amplifications (Horizontal motion)

2- By examining the resonant frequencies for vertical motions, the resonant frequency was 6.2 Hz for Kobe 1/2 and 6.7 Hz for Kobe 1/4.
The resonant frequency did not decrease notably with increasing base acceleration.
The model of ground did not display strong nonlinear properties.
3- The shear strain level increased suddenly when there was a sudden change in the shear velocity Vs and not in the soil density (in Kobe 1/1 case, shear strain level increased from 1.57E-03 to 9.67E-03 when Vs changed from 289.5 to 207.7 m/sec). The same was observed in Zushi's case but not at the same rate (strain increased from 3.15E-05 to 5.46E-05 for the same change in Vs), and this is normal because of the big difference in the earthquake amplifications in both cases which generates different nonlinearity effects on the soil characteristics. Figure 11

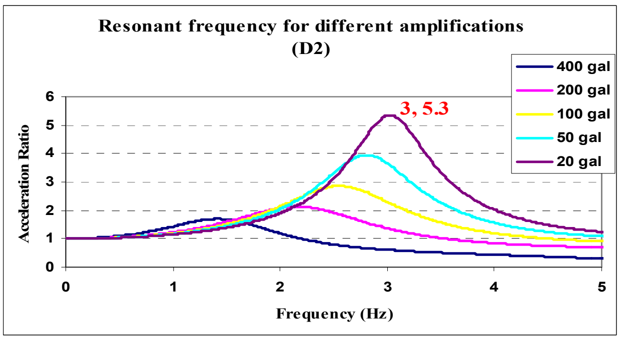


Figure 10. Resonant frequency for Sinusoidal wave with different amplifications

This wasn't noticed in the other points because there wasn't such a sudden change as in point No.2 (ex. Point D1, the change in Vs was small (from 239 to 243.5 m/sec).

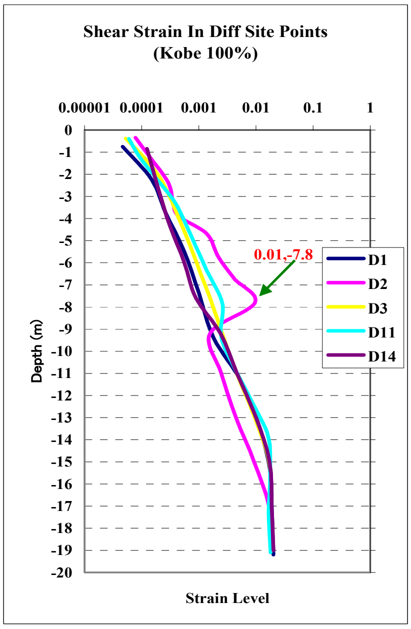


Figure 11. Shear strain level against Depth (strong motions)

4- The above mentioned result is also true when damping ratio level is examined (in Kobe 1/1 damping ratio increased from 0.35 to 0.48 when Vs changed from 289.5 to 207.7 m/sec). The same can be seen in Kobe 1/2 and Zushi cases. Figure 12. This is also because of the sudden change in the shear velocity of the soil layers at that depth (-7.8 m), which can not be seen in the other points of the examined site.

5- For any earthquake amplification, the frequency increased towards the surface, while in the same soil layer frequency increased when the amplitude decreased (in Kobe 1/2 case, frequency increased from 0.7 Hz on the bottom to 1.4 Hz on the surface, while in Kobe 1/4 the change was from 0.9 to 1.9 Hz). Figure 13. The same can be obtained from Zushi case.

6- By comparing the effect of the horizontal motion of Kobe earthquake with the vertical motion of the same earthquake, we found that the effect of the horizontal motion is larger in terms of surface acceleration. The rate range was 1.7 times in case of Kobe 1/1 to 1.2 times in case of Kobe 1/2.

This leads us to say that the horizontal motion is riskier than the vertical one. Figure 14

In terms of displacement, the maximum displacement of the horizontal motion of Kobe 1/1 was 0.19 m, while it was 0.14 m in the vertical motion of the same earthquake.

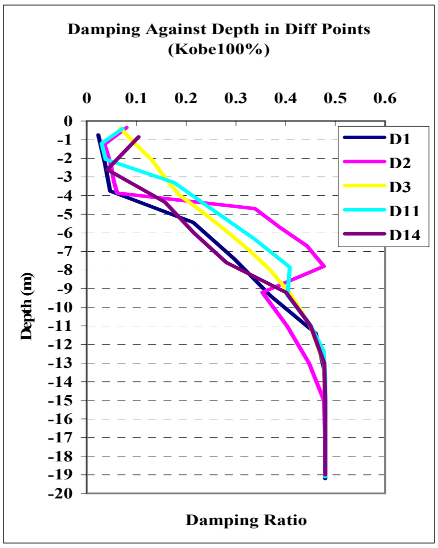


Figure 12. Damping against Depth (Kobe 100%)

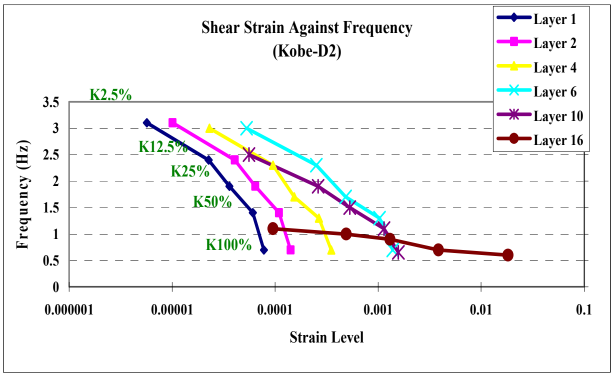


Figure 13. Shear strain level against frequency (different amplification of Kobe)

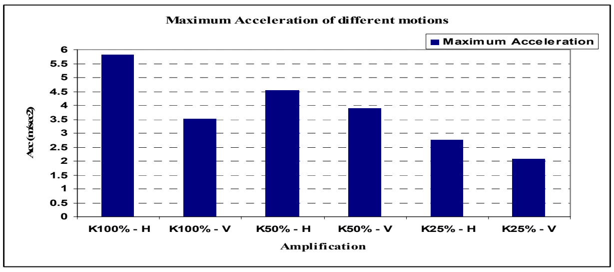


Figure 14. Maximum acceleration at surface (Horizontal and Vertical Kobe input motions)

(2) Dynamic Behavior of the Structure

One-dimensional model:

The maximum displacement of the structure was 0.166 m in the horizontal input motion of Kobe 1/1, while with input motion of Kobe 1/2; the maximum displacement was 0.0829 m which is half of that of Kobe 1/1).Since the performed analysis in this paper is linear analysis, the results of different input earthquake motions showed a close agreement with each other. The same applies to the other parameters (acceleration, shear forces and bending moments). Figure 15

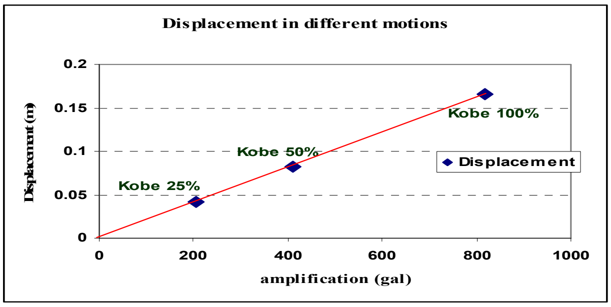


Figure 15. Maximum Displacement for different motions (one-dimensional model)

Two-dimensional model:

1- The Structure & Soil model displayed strong nonlinear properties when Kobe 1/1-H was examined, which affected the results of the linear analysis (the results were not compatible with those of Kobe 1/2 and 1/4) Figure 16

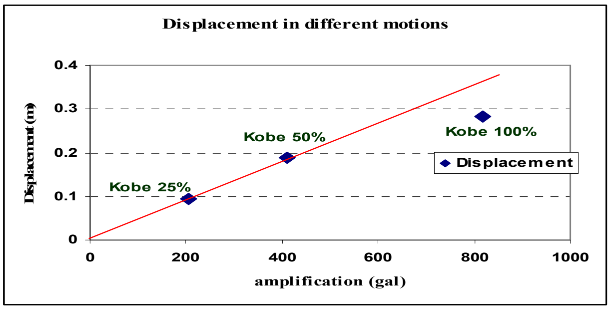


Figure 16. Maximum Displacement for different motions (two-dimensional model)

2- The results of the ground analysis under different amplifications of Kobe earthquake, showed that all parameters did not change linearly (despite performing linear analysis), because the equivalent linear analysis considers the non-linearity of soil properties from G - γ, h - γ curves. The soil characteristics showed strong nonlinear properties in, which was proved previously in the study of the seismic response of the ground.

Figures 17 and 18 show the comparison of maximum shear stress and maximum shear strain respectively under different amplifications of Kobe earthquake motion in the horizontal direction.

3- In the case of a horizontal motion, the resonant frequency of the structure and soil model was 1.434 Hz for weak motions (Kobe 1/4) and 0.95 Hz for strong motions (Kobe 1/1) Figure 19

The model exhibited strong nonlinear properties.

In the case of a vertical motion, the resonant frequency of the model was 1.437 Hz for Kobe 1/2 and 1.434 Hz for Kobe 1/1.

The amplification and resonant frequency did not decrease notably with increasing base acceleration.

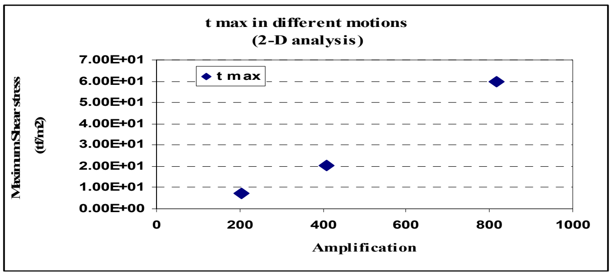


Figure 17. Maximum shear stress τ for different motions

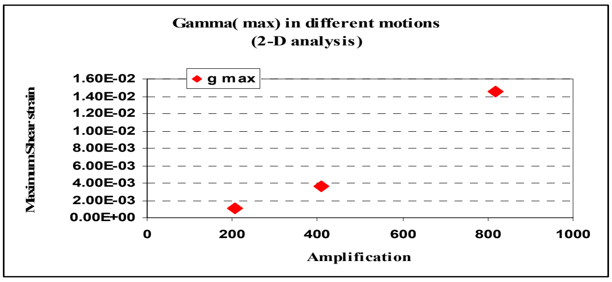


Figure 18. Maximum shear strain γ for different motions

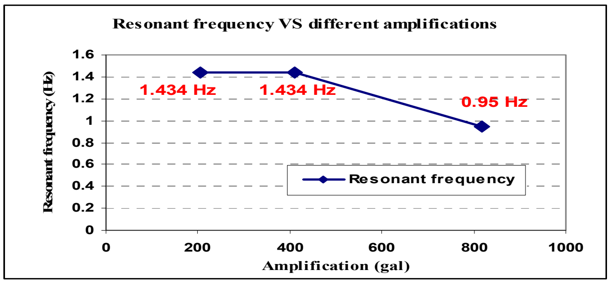


Figure 19. Resonant frequency Vs amplification

4- By comparing the analysis results of horizontal motion with those of vertical motion, the effect of the horizontal motion was almost twice of the vertical one when very strong motions were applied (Kobe 1/1), and 3 times when moderate ones were applied (Kobe 1/2). (maximum displacement was 0.284 m in Kobe1/1-H, while it was 0.137 m in the vertical one).

So, the influence of the horizontal motion is more significant than the vertical motion. It is concluded that if the structure is meant to collapse, it will be due to horizontal motion.

Figure 20 shows the comparison of bending moment in the horizontal and vertical input motions of Kobe.

5- When comparing the analysis results of TDAP III with the method of Syrian Arab code, which is derived from American uniform building code (UBC) [6)], the shear force derived from Syrian code was 1541 tf, while in Kobe 1/1 case the shear force was 2090 tf. Figure 21

The method of Syrian code assumes that Damascus is located in the riskiest zone, which means it is exposed to the strongest earthquakes. The result of Syrian code is smaller than the result of TDAP with Kobe 1/1 motion, but close to the one of Kobe 1/2 case.

A previous study conducted in Syria[7], proved that the computed shear force from Syrian code is smaller than the one of UBC, and the same is seen now comparing with TDAP results.

It is needed to reformulate the general equation of Base shear force in Syrian code because it does not take into account the other characteristics of soil and structure, including the amplification of the earthquake. All these parameters are not included, so the result can not be so accurate.

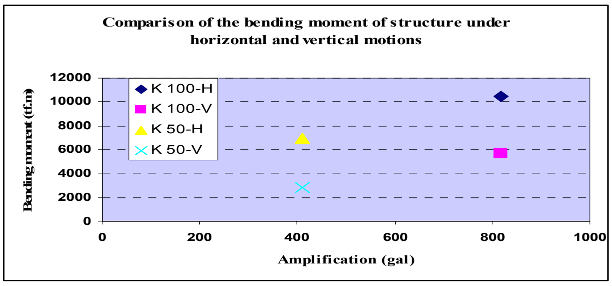


Figure 20. Comparison between horizontal and vertical motion (Bending moment)

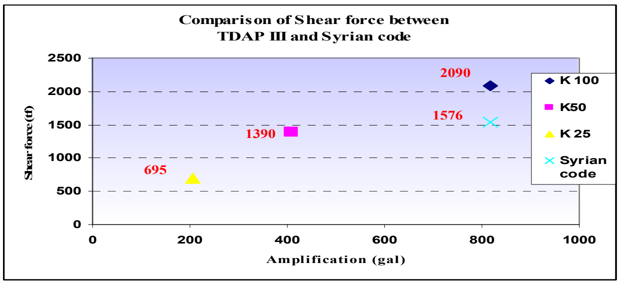


Figure 21. Comparison of Shear force due to different methods

4. CONCLUSIONS

1- The Structure & Soil model displayed strong nonlinear properties due to a large amplitude of input motion (Kobe 1/1 in the horizontal direction), which affected the results of the linear analysis.

2- The resonant frequency decreased notably with the increase of earthquake amplification. On the contrary it was the case of vertical motion. The strong nonlinearity displayed by ground was due to the horizontal earthquake motion. (the same applies to structure too).

3- The sudden change of the shear velocity in the ground model caused a notable increase in the shear strain level, and also in the damping constant.

4- The influence of horizontal motion on the ground model was more significant than the one of vertical motion (in terms of surface acceleration). But It is important to study the effect of earthquake vertical motion on the ground model (It showed some close results in terms of displacement).

5- The influence of the horizontal motion is more significant than the vertical motion. It is concluded that if the structure is meant to collapse, it will be due to horizontal motion.

6- It is needed to reformulate the general equation of Base shear force in Syrian code because it does not take into account the other characteristics of soil and structure, including the amplification of the earthquake.

7- The two-dimensional analysis with equivalent linear method can not evaluate precisely the dynamic behavior up to the failure of the structure because it does not consider the nonlinear material properties of the elements.

To conclude this dissertation, the results from this study will be used in earthquake disaster mitigation of Damascus city (SYRIA).

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