دراسة تأثير نوع التربة على استجابة الأبنية خلال زلزال شباط 2023 باستخدام طريقتي العناصر المحيطية والعناصر المحدودة

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الملخص

في هذا البحث تمت دراسة تأثير نوع التربة على استجابات الأبنية تحت تأثير الزلازل، وذلك بمقارنة الإزاحة الطابقية والقوى الزلزالية. تم اعتبار ثلاثة محاور للدراسة. الأول يعتمد على نمذجة التربة وفق طريقة العناصر المحيطية ونمذجة الأساس وفق طريقة العناصر المحدودة ثم الربط بينهما باستخدام كود برمجي معد في بيئة MATLAB وذلك في مجال التواتر. في هذه المرحلة تمت نمذجة ثلاث أنواع من التربة وهي (S_B, S_C,S_D) حيث أظهرت النتائج أن التربة S_D أعطت أكبر معامل تضخيم زلزالي بنسبة 40% عند الذروة.

في المحور الثاني تم إجراء 72 تحليل طيف استجابة مع الأخذ بالاعتبار أنماط الاهتزاز باستخدام برنامج Robot Structural Analysis وذلك على ثمانية نماذج أبنية مختلفة عدد الطوابق تتراوح بين 2 طابق و14 طابق وهي موثوقة الأساسات، حيث تم اعتماد جدران القص كنظام إنشائي مقاوم للزلازل كونه الأكثر شيوعاً في التصميم. تم تطبيق 9 أطياف استجابة زلزالية حقيقية مختلفة أنواع التربة على هذه الأبنية. أعطت النتائج أن عدد الطوابق الحرج من أجل التربة الصلبة هو 6 طوابق والتربة المتوسطة هو 7 طوابق بينما أعطت الترب الرخوة استجابة عظمى من أجل 12 طابق.

تمت دراسة أثر صلابة الأساسات في المحور الثالث حيث تمت نمذجة الأبنية مع اعتبار الأساسات غير موثوقة. حيث تم إيجاد أثر صلابة التربة على تضخيم الانتقالات والإزاحة الطابقية حيث كانت نسب التضخيم بين 1%–16% على حسب صلابة التربة.

كلمات مفتاحية: طريقة العناصر المحيطية، طريقة العناصر المحدودة، مجال التواتر، أحمال زلزالية، الربط بين العناصر المحدودة والمحيطية، تأثير التربة

Analysis of Soil Type Effect on Building Response under February-2023 Earthquake Using Boundary Elements and Finite Elements Methods

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Abstract

This paper discusses the effect of soil type on the behavior of the buildings under seismic event's data in terms of story drift and seismic force. Three stages of analysis were adopted. The first one used finite elements- boundary elements coupling in MATLAB environment under seismic loading. Where the soil was modelled by boundary elements and the foundation was modelled by finite elements. Three different soil type was analyzed (S_B, S_C,S_D). the results showed that soil type S_D has the most amplifying ratio in frequency domain which was 40% for the peak.

In the second stage Robot Structural Analysis Program was

used to perform 72 Response Spectra analysis of 8 fixed-base different height buildings under 9 different soil type seismic were done. The results showed that the critical number of stories that gave the maximum response in terms of seismic force and story drift for hard soils is 6 stories, the critical number of stories for medium soils was 7 stories, and the critical number of stories for soft soils was 12 stories.

In the third stage the foundation – soil stiffness was introduced to the supporting system of the building instead of fixed base. Again the analysis of the critical buildings under seismic events was performed in order to find out the effect on story drift, which increase about 1%−16% depending on soil type.

Keywords: Boundary elements method, Finite elements method, Frequency domain, Seismic load, FEM−BEM Coupling. Soil effect

1. Introduction

Soil type plays an important role during an earthquake. It is noticed that the buildings behave differently according to soil type under seismic loads. Seismic acceleration and Response Spectra also is affected highly with soil type. In this research soil type is studied comparatively in three directions: Finite elements – boundary elements coupling of foundation – soil model for three types of soil concerning 6 February Earthquake in Turkey 2023 since it has affected vast areas in Syria and the sites are very close to the borders so the soil type might be very similar. Yayladagi – soft soil (S_D: C_s=283 m/sec), Nurdagi –medium soil (S_C: C_s=599 m/sec), Malatya–hard soil (S_B: C_s=815 m/sec). Then an amplification spectrum of acceleration in frequency domain is obtained for each soil type. The critical number of stories is also studied for number of fixed base models under about nine seismic events in Turkey with different soil types in order to find out the critical number of stories that shows the maximum story drift for each soil type. The same models are analyzed considering the stiffness of the soil–foundation support and the amplification of story drift is predicted.

2. Research aim

During February 2023 Earthquake in Turkey the buildings behaved differently according to foundation soil. This research highlights the differences in response under different soil types. The study covers three aspects: the amplification of excitation in frequency domain, The critical number of stories for fixed based buildings that shows the maximum response under an Earthquake, and the increase in story drift due to considering the soil−foundation stiffness in modeling.

3. Research Materials and methodology

3.1. Literature review

A lot of research was done in order to study structures' behaviour under seismic loading. Altarshah. E. et. al, [1] 2024 - studied the elevated water tanks under seismic loading in terms of nonlinear time history of El-Centro Earthquake,1940 scaled to Homs site. Taking into account water level in the tank. As a result the most dangerous case by design was the case of half full tank, where it forms the first plastic joint at the lowest base.

Turikieh. A, et.al, [2] 2025 - studied the behaviour of dual systems' RC buildings (Shear wall- Frames) under seismic loadings. Three models of dual systems with 10, 15 and 20 stories were analysed using performance based design procedure. The result shows that the performance based design procedure gives better design method than the traditional static linear methods.

Song. Q, et. al, [3] 2025 – studied the site effect on buildings behavior in Antakya and Kahraman Marash in Turkey under 6 Februray Earthquake. Horizontal-to-Vertical Spectral Ratio (H/V) statistical technique is used to decipher how site effects affect ground motion and damage using the strong motion records. Structures located in areas where the predominant frequency matches their natural frequency are more prone to resonance effects. Most earthquake damage was due to the amplification of ground motion caused by soft soil conditions.

Başar. T, et. al, [4] 2025 – studied the behavior of masonary minarets under 6 Februray Earthquake in Kahraman Marash in Turkey. Two soil types were considered S_A, S_D the models were analyzed using finite element method in SAP2000 program. The results show that the soil type S_D gave the maximum displaement ratios.

3.2. Finite elements- Boundary elements coupling

It was proved that the seismic shear wave and seismic pressure wave will be decreased when crossing soft soils, [5]. On the other hand, the damping will be so trivial or negligible when crossing hard soils or rock. This was proved by using boundary element method –direct integration procedure in MATLAB environment. On the contrary, the soil effect on the response will be the opposite when reaching the building. Studying soil–foundation interaction using boundary element – finite element coupling proves that soft soils effect will be amplifying with a noticeable value in comparison with the hard soil,[6].

The studied model is a flexible, massive foundation settling in an elastic, isotropic and homogeneous soil medium. The foundation is subjected to a dynamic load which is better prescribed as free field acceleration in the frequency domain.

- **Soil modelling and analysis:**

Boundary Element equations:

$$HU = GP \tag{3-1}$$

Where:

$$G^{ij} = \int_{\Gamma_j} \overset{*}{u}\, d\Gamma \qquad \hat{H}_{ij} = \int_{\Gamma_j} \overset{*}{p}\, d\Gamma \tag{3-2}$$

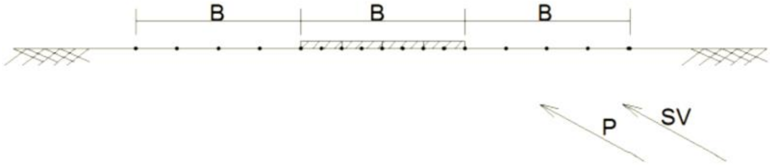

Fig.1 soil and foundation elements, [8]

Using these equations the parameters could be calculated on the boundary which is divided into M element while the problem is a plain strain problem.

The function u^* is a Green Function which is defined as in the Table.1. [7].

Table. 1 Green function, [7]

	Elastic Dynamic	Elastic Static
2D	$\frac{1}{2\pi} K_0\left(\frac{i\omega}{c} r\right)$	$-\frac{1}{2\pi}\ln(r)$
3D	$\frac{e^{\left(\frac{-i\omega}{c}\right)}}{4\pi r}$	$\frac{1}{4\pi}\frac{1}{r}$

Where G, H can be calculated for In-plane problem by using a principle solution:

$$u_{lk}^{*}(x,\xi;\omega) = \frac{1}{2\pi\rho {c_2}^2}\left(\psi\delta_{lk} - \chi r_{,l} r_{,k}\right) \tag{3-3}$$

Where:

$$\psi = K_0\left(\frac{i\omega}{c_2}r\right)+\frac{c_2}{i\omega r}\left[K_1\left(\frac{i\omega}{c_2}r\right)-\frac{c_2}{c_1}K_1\left(\frac{i\omega}{c_1}r\right)\right] \qquad (3\text{-}4)$$

$$\chi = K_2\left(\frac{i\omega}{c_2}r\right)-\left(\frac{c_2}{c_1}\right)^2 K_2\left(\frac{i\omega}{c_1}r\right) \qquad (3\text{-}5), [8].$$

Where Bessel function is defined mathematically as:

$$K_0(z)=-\ln\frac{z}{2}I_0(z)-\gamma+\left(\frac{z^2/4}{(1!)^2}(1-\gamma)\right)+\left(\frac{(z^2/4)^2}{(2!)^2}\left(1+\frac{1}{2}-\gamma\right)\right)+\left(\frac{(z^2/4)^3}{(3!)^2}\left(1+\frac{1}{2}-\gamma\right)\right)+$$
$$+\left(\frac{(z^2/4)^4}{(4!)^2}\left(1+\frac{1}{2}+\frac{1}{3}-\gamma\right)\right)+\left(\frac{(z^2/4)^5}{(5!)^2}\left(1+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}-\gamma\right)\right)+\ldots\ldots\ldots\ldots(3-6)$$

Where:

$$\gamma = 0.577215664 \qquad (3\text{-}7)$$

$$I_n(z)=\sum_{k=0}^{\infty}\frac{1}{k!(k+n)!}\left(\frac{z}{2}\right)^{2k+n} \qquad (3\text{-}8)$$

Where $\hat{H}^{ij}$ is calculated form Green Function because u^* is derived from p^*.

- **Foundation modelling and analysis:**

The foundation is divided into $\frac{M_c}{2}$ finite element where number of nodes is $N=\frac{M_c}{2}+1$ where every finite element encounters two boundary elements on the soil surface. The foundation equations will be:

$$\begin{bmatrix} [K_{vv}] & [K_{v\theta}] \\ [K_{\theta v}] & [K_{\theta\theta}] \end{bmatrix} \begin{Bmatrix} \{v\} \\ \{\theta\} \end{Bmatrix} = -\begin{Bmatrix} \{R\} \\ \{0\} \end{Bmatrix} \qquad (3\text{-}9)$$

Where $[K_{vv}]$ is $(2N \times 2N)$, $[K_{\theta\theta}]$ is $(N \times N)$, $[K_{\theta v}]$ is $(N \times 2N)$ and $[K_{v\theta}]$ is $(2N \times N)$

All of them represents the stiffness matrix of the foundation in the Frequency domain.

v : translation vector

θ : rotation vector

$\{R\}$: the friction stresses between soil and foundation.

- **Coupling between boundary elements and finite elements:**

In order to apply the compatibility condition between the displacement on the contact surface, every finite element node's displacement equals the displacement of the two boundary elements that this node is between, [7].

$$v_1^i = u_1^j = u_1^{j-1} \qquad (3\text{-}10)$$

$$v_2^i = u_2^j = u_2^{j-1} \qquad (3\text{-}11)$$

Applying the force equilibrium condition on the contact surface the force in each finite element node equals the result of the surface stresses of the two boundary elements that this node is between.

$$R_1^i = L_{j-1} p_1^{j-1} + L_j p_1^j \qquad (3-12)$$

$$R_2^i = L_{j-1} p_2^{j-1} + L_j p_2^j \qquad (3-13)$$

L_j : the length of element j

3.3. Soil – Foundation stiffness, [11] (FEMA 273)

Most of the designers considers the base of the structure as a fixed base. Which is very different of the fact because of the soil stiffness, which differs from soil to soil and plays a great role in supporting the buildings. Here is a simple calculation that considers the soil type in supports. Which is considered in the applications in order to make comparisons in seismic response between fixed supports and soil foundation stiffness for different soil types of several events.

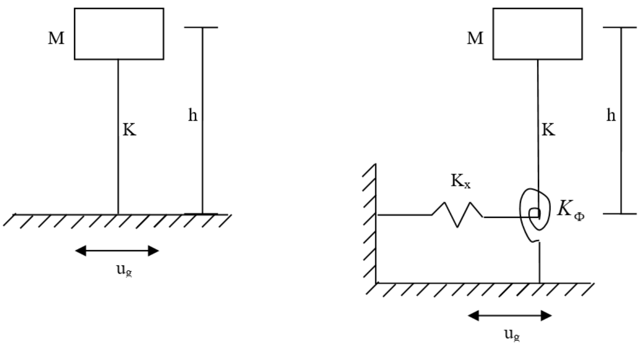

Fig. 2 soil and foundation stiffness representation, [11].

First of all it is needed to calculate the equivalent radius of the isolated foundation.

Table. 2 Equivalent radius of the foundation

Degree of Freedom				
	Translation	Rotation		Torsion
		About X Axis	About Y Axis	About Z Axis
Equivalent Radius	$\left[\frac{BL}{\pi}\right]^{1/2}$	$\left[\frac{BL^3}{3\pi}\right]^{1/4}$	$\left[\frac{B^3L}{3\pi}\right]^{1/4}$	$\left[\frac{BL\left(B^2+L^2\right)}{6\pi}\right]^{1/4}$

Then soil effect will be introduced by G – Soil long term shear modulus and v – Soil poison modulus.

Table. 3 Soil– Foundation stiffness

Degree of Freedom	K_0
Vertical Translation	$\frac{4GR}{1-\nu}$
Horizontal Translation	$\frac{8GR}{2-\nu}$
Torsional Translation	$\frac{16GR^3}{3}$
Rocking Rotation	$\frac{8GR^3}{3(1-\nu)}$

Most of soils behave nonlinearly where the shear modulus G degreases with the increase of shear strain. The shear wave velocity Cs decreases as well for large strains.

Table. 4 Long term soil shear modulus and shear wave velocity

PGA	≥ 0.3	$\geq 0.2 \& < 0.3$	$\geq 0.15 \& < 0.2$	≤ 0.1
G/G_0	0.42	0.49	0.64	0.81
C_s/C_{s0}	0.62	0.7	0.8	0.90

Where the primary shear modulus G_0 and the primary shear wave velocity C_{s0} are calculated for small strains. They are related with the equation: $G_0 = \rho . C_{s0}{}^2$.

4. Applications and methods

4.1 Finite elements – boundary elements coupling in frequency domain

Three different soil-type events is considered: Yayladagi – soft soil (S_D: C_s=283 m/sec), Nurdagi –medium soil (S_C: C_s=599 m/sec), Malatya–hard soil (S_B: C_s=815 m/sec). The three events took place in February 2023 in Turkey, [10] (AFAD,2023) and have a similar epicenter distance.

The goal is to find out the movement values of the surface between the foundation and the soil according to three soil types listed in the Table.1. Considering isolated shallow foundation, which is divided into four finite elements, the soil surface under the foundation is divided into eight boundary elements. Where the boundary element equals half length of the finite element under the foundation and full length outside the foundation, therefore the soil surface outside the foundation is divided into four boundary elements on each side.

A boundary element code in MATLAB environment (Coupling.m) was used to calculate the interaction between a strip foundation and the soil in frequency domain under harmonic in-plane load using direct integration method – constant shape function since using the linear shape function does not enhance accuracy so much wile takes a huge programming effort.

Table. 5 Soil type parameters

Event 2023	Yayladagi	Nurdagi	Malatya
Parameter	S_D	S_C	S_B
v (Poisson)	0.3	0.25	0.2

E (kN/m^2)	2.82E+05	1.57E+06	3.11E+06
Density (kg/m^3)	1350	1750	1950
G (kN/m^2)	108461.5	628000	1295833
C_s (m/sec)	283.4464	599.0469	815.187
Damping	0.02	0.02	0.02

Then the soil–foundation interaction was studied considering unit impulse load $e^{i\omega t}$ impacted on the soil free surface in frequency domain for the frequency range noticed in 6 February −2023 Earthquake. Using the code (coupling.m) table.6. The amplification factor spectra for three soil types, table.5 under shear waves SV and Pressure waves SP were drawn.

Table.6 Coupling.m code flow in MATLAB

```
Coupling.m
% coupling at points under foundation
Cinput
for e=1:Nfr
% Form matrices of soil
GHmat
% Form matrices of foundation
Found
% solve them
Dipl
End
% Plot amplification spectrum in frequency domain
Vplot
```

The frequency content of February -2023 Earthquake can be ranged from zero to forty as it is shown in Figure. 3 which contains the Fast Fourier Transformation of Malatya event-2023. The procedure is to find out the amplification factor spectrum that results form finite elements-boundary elements coupling. This spectrum will be multiplied with fast Fourier transformation of the earthquake in frequency domain then it could be transform into time domain easily.

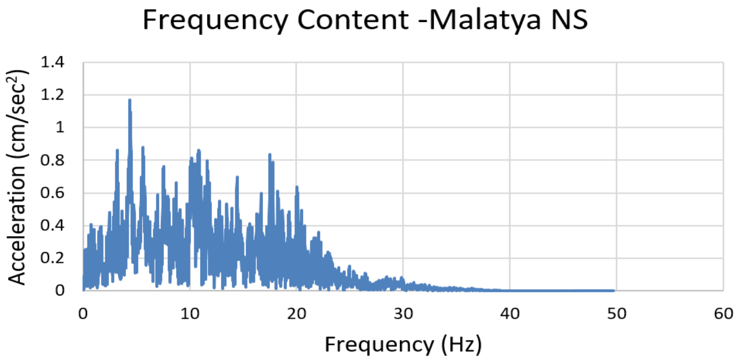

Fig. 3 FFT of Malatya event-2023, [10]

After applying the soil types the program will plot the amplification factor spectra for each soil type, Fig. 4. It is obvious that the softer soil will give the maximum amplification with a sinusoidal-like graph while the stiff soils will give a slight amplification of excitation with an exponential- like graph. the ratios are tabulated in Table.7

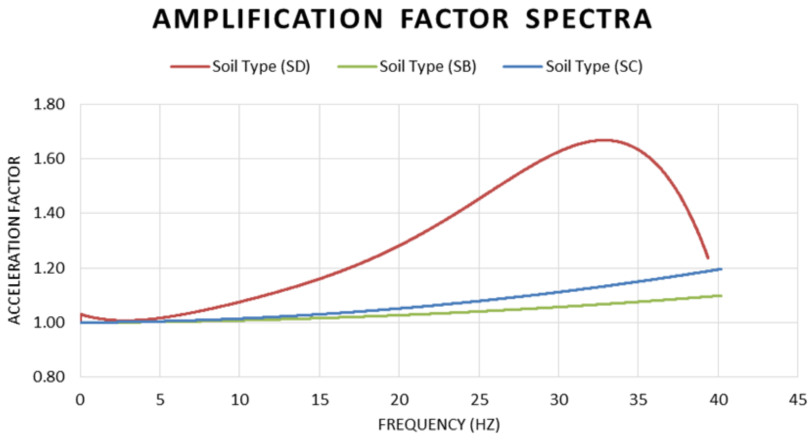

Fig. 4 Amplification factor spectra

Table. 7 Amplification factor spectra maximum values

Soil Type	S_D	S_C	S_B
Max. Value	1.667	1.2	1.1
Diff.	40%	16.67%	9.1%

4.2 Fixed base model analysis

A fixed base symmetrical model of shear walls seismic resisting system is considered. It is analyzed using Robot Structural Analysis, (RSA, 2019). The number of stories was: (2-3-4-6-7-10-12-14) under number of Response Spectra for events which took place in Turkey. In terms of seismic force and storey drift, the critical number of stories that gave maximum response is different form soil type to another.

- **Model Description:**

The lateral load resisting system is shear wall since it is very popular in design. 40x40m area floors, ground floor height equals 4.2m while typical floor height equals 3.4m. Life load equals 3.0 kN/m2, flooring load equals 3.0 kN/m2. Shear wall thickness

25cm. 64 columns 65x65cm of concrete grade C25, Slab thickness equals 15cm- Concrete grade C20, Figure 5.

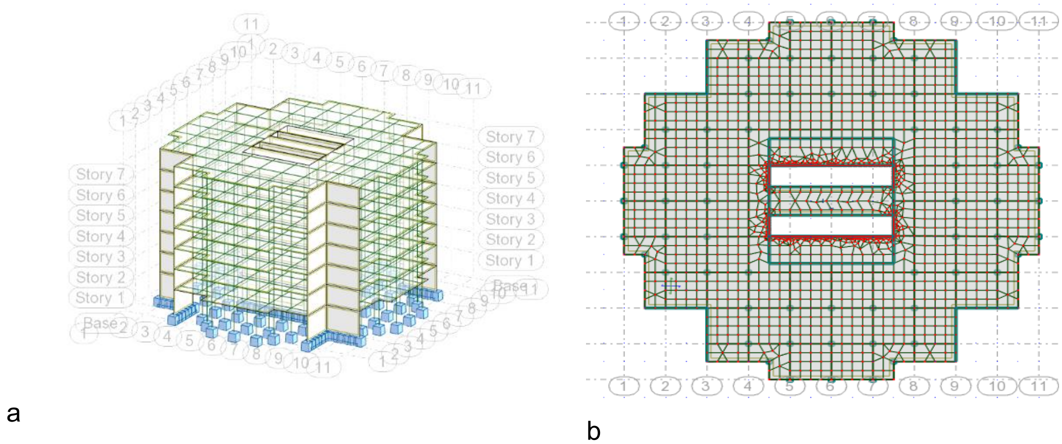

Fig. 5 the analyzed model in Robot Structural Analysis: a- 3D view, b- Slab meshing

Table.8 shows the modal analysis results of all different stories models in terms of fundamental period and frequency. Sparce direct solver method were executed using Ritz-Lanczos algorithm of 45 vector. 90% of mass participation was achieved by 12-15 modes was enough since the plan is symmetrical.

Table. 8 Modal analysis results

No. Stories	Frequency (Hz)	Fundamental Period (sec)
2	8.86	0.11
3	6	0.17
4	4.48	0.22
6	2.95	0.34
7	2.46	0.41
10	1.59	0.63
12	1.27	0.79
14	1.05	0.96

- **Hard soil**

The models were analyzed under two events' response spectra – hard soils site, Table. 9 one of them took place in 1999 in Kocaeli near Istanbul and had a very destructive effect very near to epicenter with a PGA of 11.14 m/sec^2– soil type (S_B) –according to (ASCE 7-16) , [9] with shear wave velocity of 827m/sec. The other one took place in 2023 in Malatya in the south with a PGA of 6.78 m/sec^2– soil type (S_B) – according to (ASCE 7-16), [9] with shear wave velocity of 815m/sec.

Table. 9 Hard soil events parameters, [10] (AFAD, 2023)

Parameter	Malatya-2023	Kocaeli-1999
EVENT_DATE_YYYYMMDD:	20230206	19990817
EVENT_LATITUDE_DEGREE:	38.332	40.756
EVENT_LONGITUDE_DEGREE:	38.271	29.955
EVENT_DEPTH_KM:	6.89	15.9
MAGNITUDE_L_REFERENCE:	AFAD	AFAD
STATION_CODE:	4406	4101
STATION_ELEVATION_M:	1050	77
LOCATION:	Malatya_Yesilyurt_Turkiye	KOCAELI_MERKEZ
VS30_M/S:	**815**	**827**
SITE_CLASSIFICATION_EC8:	A	A
SITE_CLASSIFICATION_ASCE 7-16	B	B
EPICENTRAL_DISTANCE_KM:	**25.96**	**3.39**
UNITS:	cm/s^2	cm/s^2
PGA_CM/S^2:	**678.781**	**1114.294**

The scaled Response Spectra of both events shown in Figure. 6, [10] (AFAD, 2023) It is noticed that both of them are narrow spiked peak which coincides with very small periods.

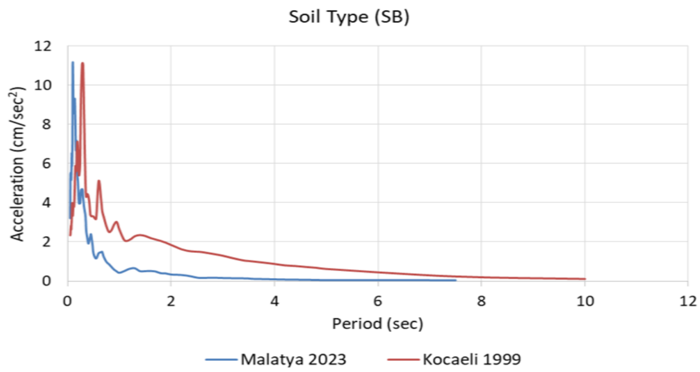

Fig.6 The scaled response spectra of hard soil events

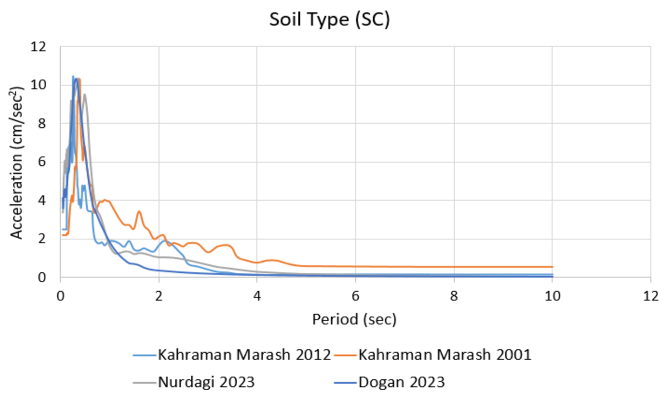

Fig.7 The scaled response spectra of medium soil events

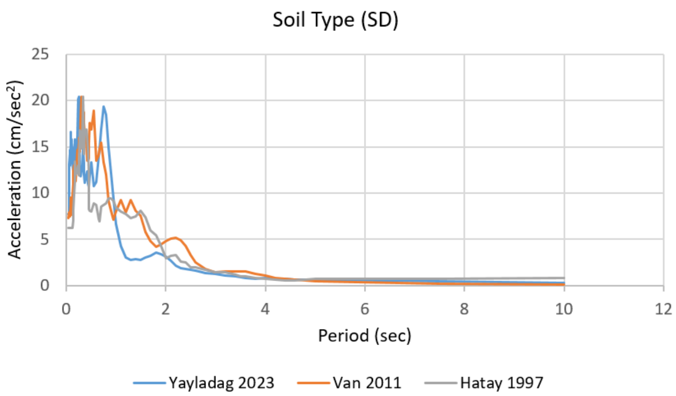

Fig.8 The scaled response spectra of soft soil events

- **Medium Soil**

The scaled Response Spectra of four different incident time seismic events on medium soil are shown in Figure. 7, [10] (AFAD, 2023) It is noticed that all of them are a little bit wider than hard soils events several peaks which coincides with higher periods and shifted to the right. Table.9 contains the four seismic events parameters. Their shear wave velocities ranges between 465-655 m/sec which locates in type S_C soil according to ASCSE 7-16, [9]. Despite the fact that they have different distances of epicenter their response spectra are very similar.

Table. 9 Medium soil events parameters, [10] (AFAD, 2023)

Parameters	Kahraman Marash – 2012	Kahraman Marash – 2001	Nurdagi–2023	Doganshehir –2023
EVENT_DATE_YYYYMMDD:	2012091	2001062	2023020	20230206
EVENT_LATITUDE_DEGREE:	37.2838	37.193	37.304	37.898
EVENT_LONGITUDE_DEGRE	37.1398	36.225	36.92	37.957
EVENT_DEPTH_KM:	22.35	10.9	6.2	9.65
MAGNITUDE_L_REFERENCE:	AFAD	AFAD	AFAD	AFAD
STATION_CODE:	4606	4603	2712	4408
STATION_ELEVATION_M:	581	562	536	1215
LOCATION:	Kahrama	Kahrama	Gaziante	Dogansehir
VS30_M/S:	**485**	**465**	**599**	**655**
SITE_CLASSIFICATION_EC8:	B	B	B	B
SITE_CLASSIFICATION _ASCE 7-16	C	C	C	C
EPICENTRAL_DISTANCE_KM	**11.45**	**75.75**	**21.27**	**22.86**
UNITS:	cm/s^2	cm/s^2	cm/s^2	cm/s^2
PGA_CM/S^2:	**175.687**	**65.775**	**1035.03**	**118.648**

- **Soft soil**

  The scaled response spectra of three different time events on soft soil are depicted in Figure.8, (AFAD, 2023) , [10] it is very clear that the Response spectra are shifted to the right with numerous peaks and much wider range in comparison with events on medium and hard soil. The seismic events parameters are tabulated in table. 10; Their shear wave velocities ranges between 283-304 m/sec which locates in type S_D soil according to ASCSE 7-16, [9]. it is noticed that they are all have a close and similar event depth.

Table. 10 Soft soil events parameters, [10] (AFAD, 2023)

Parameter	Yayladagi-	Van-	Hatay-1997
EVENT_DATE_YYYYMMDD	20230220	2011102	19970122
EVENT_LATITUDE_DEGRE	36.037	38.689	36.1852
EVENT_LONGITUDE_DEG	36.021	43.4657	35.9419
EVENT_DEPTH_KM:	**21.73**	**19.02**	**23**
MAGNITUDE_L_REFEREN	AFAD	AFAD	AFAD
STATION_CODE:	3147	6503	3102
STATION_ELEVATION_M:	419	1712	-
LOCATION:	Hatay_Yaylad		HATAY_MERKEZ_BAYINDI
VS30_M/S:	**283**	**292**	**304, (Kurtulus, et al 2021)**
SITE_CLASSIFICATION_ASCE 7-16	D	D	D
EPICENTRAL_DISTANCE_	**15.47**	**42.24**	**19.72**
UNITS:	cm/s^2	cm/s^2	cm/s^2
PGA_CM/S^2:	**57.522**	**445.801**	**485.448**

After proceeding analysis of different stories fixed base models under all the listed seismic events the maximum seismic force and story drift is tabulated in table.11. from which it is very clear that the events which have the same soil type gives the maximum response for the same number of stories, Fig. 9.

Table. 11 Soft soil events analysis results

Event	Soil Type	No. Stories	Period (sec)	Seismic Force (kN)	Max. Drift (mm)
Malatya 2023	S_B	6	0.34	18777.75	1.7
Kocaeli 1999	S_B	6	0.34	60508.56	5.8
Kahraman Marash 2012	S_C	7	0.41	5525.63	0.6
Kahraman Marash 2001	S_C	7	0.41	5133.24	0.68
Nurdagi 2023	S_C	7	0.41	105847.2	12.1
Doganshehir	S_C	7	0.41	8387.62	0.912
Yayladagi 2023	S_D	12	0.79	254797.3	42.8
Van 2011	S_D	12	0.79	35827.1	5.9
Hatay 1997	S_D	12	0.79	36078.68	5.7

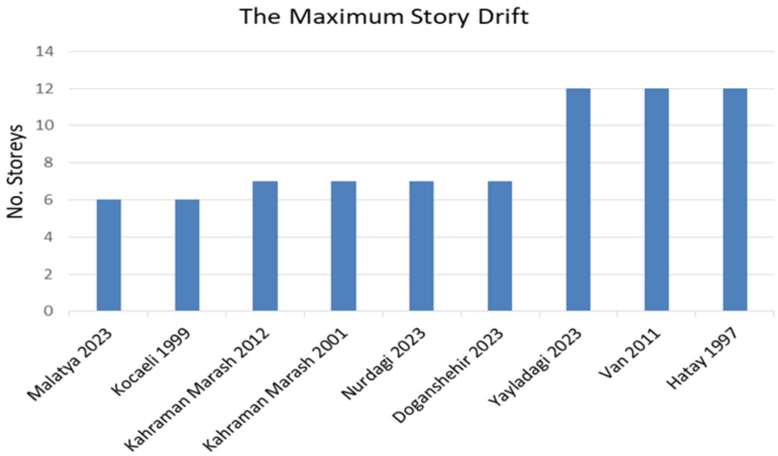

Fig.9 The critical number of stories for each seismic event

For better understanding of this behavior, the story drifts of all stories are drawn under three reference seismic events. Malatya 2023- Hard soil, Nurdagi 2023- Medium soil and Yayaldagi 2023- soft soil. The three events have a close distance of epicenter 25.96km, 21.27km and 15.74km respectively, [10] (AFAD 2023). It is very clear that the hard and medium soils gives the maximum response in buildings of 6–7 stories. However, the soft soils gives the maximum response for higher buildings i.e. 12 stories.

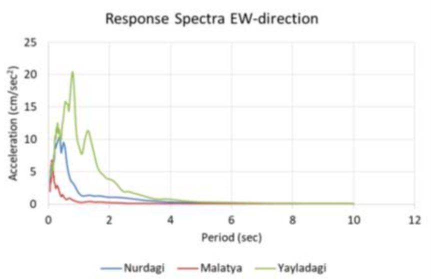

Fig.10 Yayladagi –Nurdagi– Malatya RS

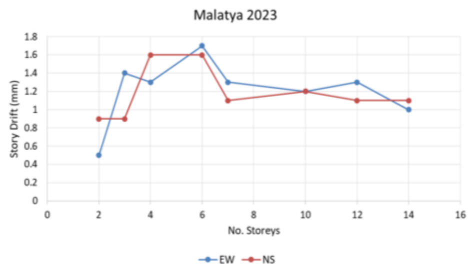

Fig 11. Story drift vs. No. stories of Malatya event

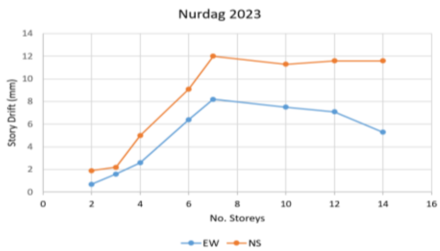

Fig 12. Story drift vs. No. stories of Nurdagi event

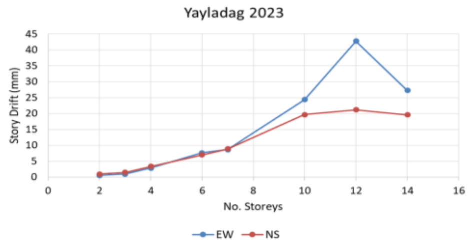

Fig 13. Story drift vs. No. stories of Yayladagi event

When inspecting 6 February 2023 pictures it is noticed in Nurdagi that the buildings around 6–7 stories were collapsed while the higher buildings remained stable, which matches the analysis results, Figure. 14.

Fig 14. Nurdagi after February Earthquake 2023, Aljazeera news

4.3 Considering foundation- soil stiffness analysis

At this stage, the critical models that showed the maximum response for each soil are analyzed again considering the foundation-soil stiffness as a support rather than fixed support, Fig.15. The foundation sizes are calculated and the equivalent radius of each. Then the stiffness is calculated including soil type through shear modulus of soil G and Passion's ratio. The nine different seismic events are applied. The hard and medium soils gave very slight amplification while it is very noticeable in soft soil, table. 12.

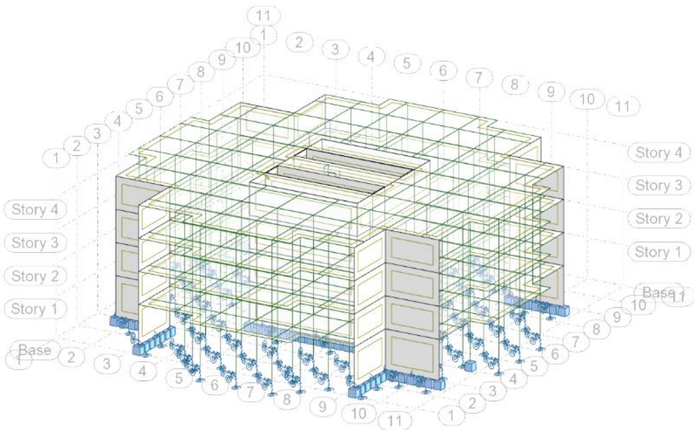

Fig.15 considering foundation – soil stiffness model

Table12. Amplification of story drift under different soil types

Event	Soil Type	Fixed Base	Flexible Base	Ratio %
Malatya 2023	S_B	1.7	1.72	101.18
Kocaeli 1999	S_B	5.8	5.91	101.90
Kahraman Marash	S_C	0.6	0.62	103.33
Kahraman Marash	S_C	0.68	0.71	104.41
Nurdagi 2023	S_C	12.1	12.45	102.89
Doganshehir 2023	S_C	0.912	0.932	102.19
Yayladagi 2023	S_D	42.8	50.05	116.94
Van 2011	S_D	5.9	6.81	115.42
Hatay 1997	S_D	5.7	6.48	113.68

5. Conclusion

- Finite elements- boundary elements coupling was proceeded in MATLAB environment for three seismic events of different soil types: Malatya 2023 (S_B), Nurdagi 2023 (S_C) and Yayladagi 2023 (S_D) showed very similar behavior for Type B and C and different behavior for type D. where the amplification factor spectra in frequency domain for hard and medium soil gave the exponential- similar function, and it gave a sinusoidal-similar shape function for soft soil. The Type B gave a maximum amplification ratio of 9.1% , Type C gave 16.67% while type D gave about 40% maximum amplification ratio.
- The analysis of 8 fixed based models of different number of stories between 2-14 under 9 seismic events in Turkey between 1997-2023 was performed in Robot Structural Analysis. The results of theses 72 analysis gave a hint of

the critical number of stories that gives the maximum response for each soil type.

- Seismic events on hard soils which have shear wave velocity between 815−827m/sec gave the maximum story drift for buildings of 6 stories – fundamental period of 0.34 and frequency of 2.95Hz.
- Seismic events on medium soils which have shear wave velocity between 485−655m/sec gave the maximum story drift for buildings of 7 stories – fundamental period of 0.41 and frequency of 2.46Hz.
- However, seismic events on soft soils which have shear wave velocity between 283−304 m/sec gave the maximum story drift for buildings of 12 stories – fundamental period of 0.79 and frequency of 1.27Hz.
- When considering foundation soil stiffness in the modelling of the building the story drift would increase about 1%−2% for hard soils, 2−4% for medium soils, and 13−16% for soft soils. This increase should be taken in consideration since it can damage nonstructural components in the building such as cladding and cement partitions and walls. Which may cause a noticeable economic loss.

6. Future Work

- Analysis of seismic shear wave propagation through different soils modelled by finite element method using Plaxis computer program.
- Analysis of finite elements soil model interaction with finite element model foundation using Plaxis computer program under different seismic events with different soil types in terms of settlement.
- Analysis of finite elements soil model interaction with finite element model foundation using Plaxis computer program under different seismic events with different soil types in terms of liquefaction.
- Studying the response under seismic events of similar distance of epicenter.
- Studying the effect of depth of epicenter on the response of the structures and the soil structure interaction.

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