

Seismic Isolation Design of Structures

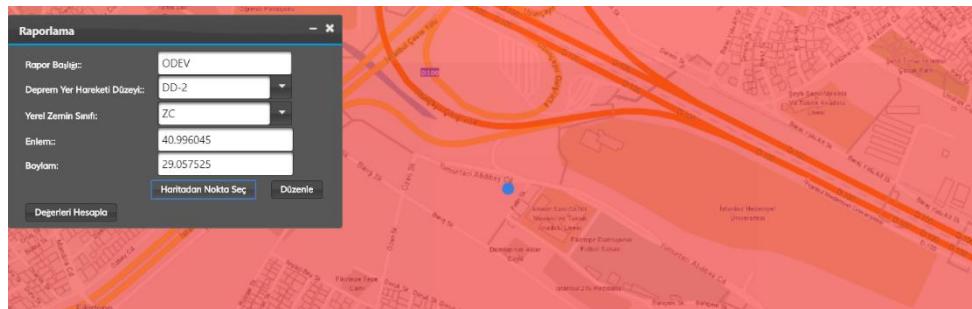
Term Project

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1. Introduction

In this study, seismic isolation system of a **school building** were designed according to TBSC-18 chapter -14. Friction pendulum isolation system were preferred and designed. Isolator demands were first evaluated via the Equivalent Lateral Force (ELF). Afterwards, nonlinear time history method were used. Relevant cod criteria were checked.

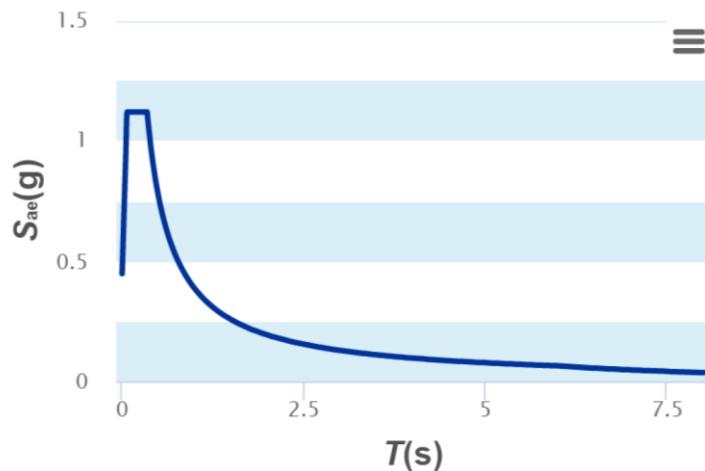
Site specific accelerations were obtained by Seismic Hazard Map of Turkey.



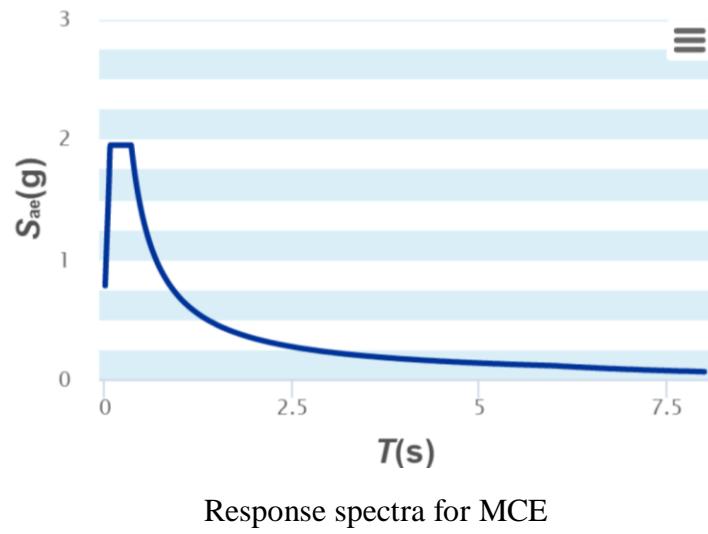
Local seismic acceleration map of building.

	MCE (DD-1)	DESIGN (DD-2)
S _{DS}	1.95	1.12
S _{D1}	0.68	0.4

Site spectral acceleration values of the school building.



Design response spectra.



Response spectra for MCE

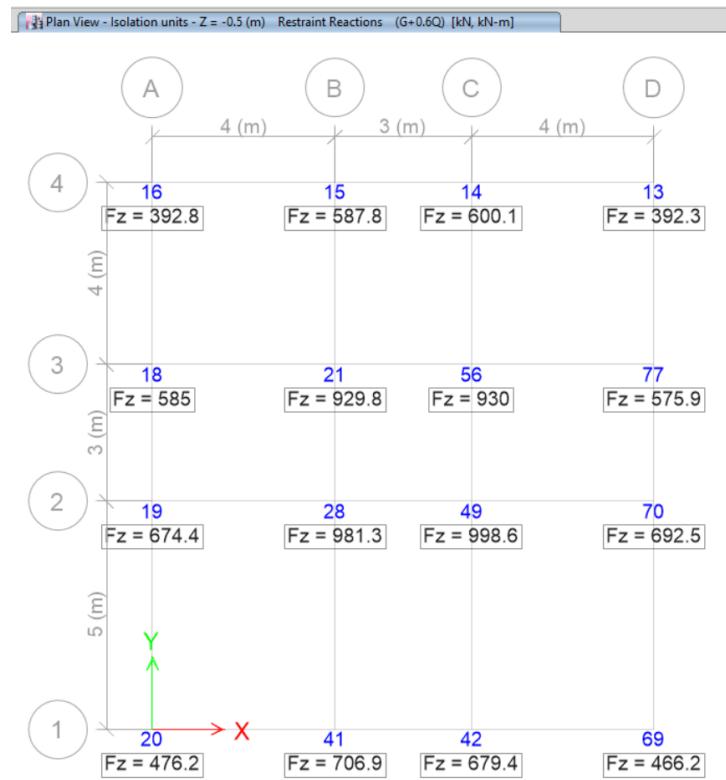
2. Loads

Superimposed dead load: 2.5 kN/m²

Live load: 3.5 kN/m²

Self-weight for concrete members: 2.5 kN/m³

3. Design of Isolation System and Unit



Fixed-base, axial load of values of columns.

Axial load considered as **1000 kN** for dimensioning the FP isolator units.

Nsd/Ned	0.5	Safety	75
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Diameter of Plug	180mm
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FF1	37.4	kN	μ_{Eff}
u*	0.054	m	R Eff
FF2	48.35	kN/m	μ_1
F max	161.13		μ_2
D1	609.40		
F(w)	0.1611		
Kd	0.26	kN/m	
T	3.90		
Damping	14.78		
DMF	0.71		
SA	0.17		
DSA	0.12		
D	609.40		
		T	
0.45ds	0.78	0	0
Sds	1.98	Ta	0.06974359
Sd1	0.68	Tb	0.348717949
		T1	1
		TL	6

An iterative EXCEL datasheet were prepared for F-D calculations of FP.

		μ	
		<i>alt</i>	<i>üst</i>
λ_{ae}	1.00	1.20	
λ_{deney}	0.70	1.30	
λ_{spek}	0.85	1.15	

$$\lambda_{üst} = [1 + 0.75(\lambda_{ae,üst} - 1)]\lambda_{deney,üst}\lambda_{spek,üst}$$

$$\lambda_{alt} = [1 - 0.75(1 - \lambda_{ae,alt})]\lambda_{deney,alt}\lambda_{spek,alt}$$

Material uncertainty coefficients in the code for FPS.

R_{eff}	4925
μ_{Eff}	6.29
Load on the column	1000
μ_1	4.46
μ_2	8.13
R_{1eff}	2470
R_{2eff}	2455

Seismic isolation unit properties.

Period of Secondary Stiffness;

According to code the period of secondary stiffness have to less than 6 seconds.

$$T = 2 * \pi * \sqrt{\frac{4.925}{9.81}} = 4.45 < 6sec.$$

	λ	$\mu(\text{eff})$	$\mu 1$	$\mu 2$
Nominal	1	6.29	4.46	8.13
Lower	0.595	3.74	2.65	4.83
Upper	1.719	10.81	7.66	13.97

Calculated material coefficients.

Parameter	Nominal	Lower	Upper
λ	1	0.595	1.719
Isolator Displacement	410.34	609.40	320.46
$S_a(T_{\text{Isolated}}, \xi_{\text{Isolated}})$	0.11	0.12	0.13
Effective Period	3.36	3.90	2.73
ξ_{isolator}	27.37	14.78	30.00

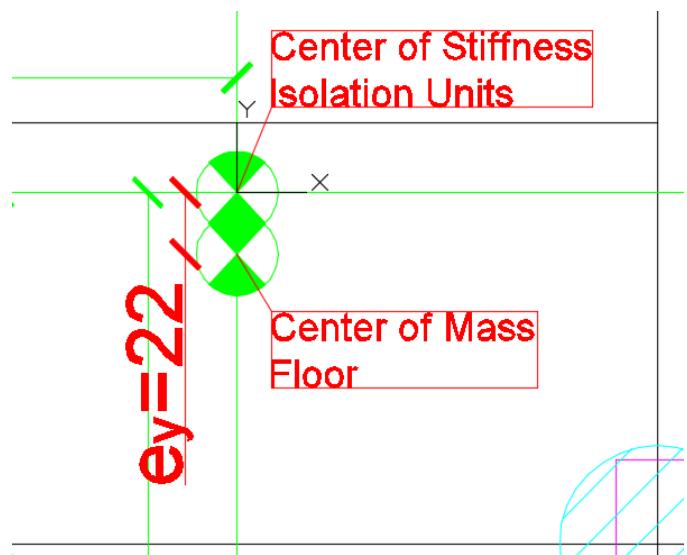
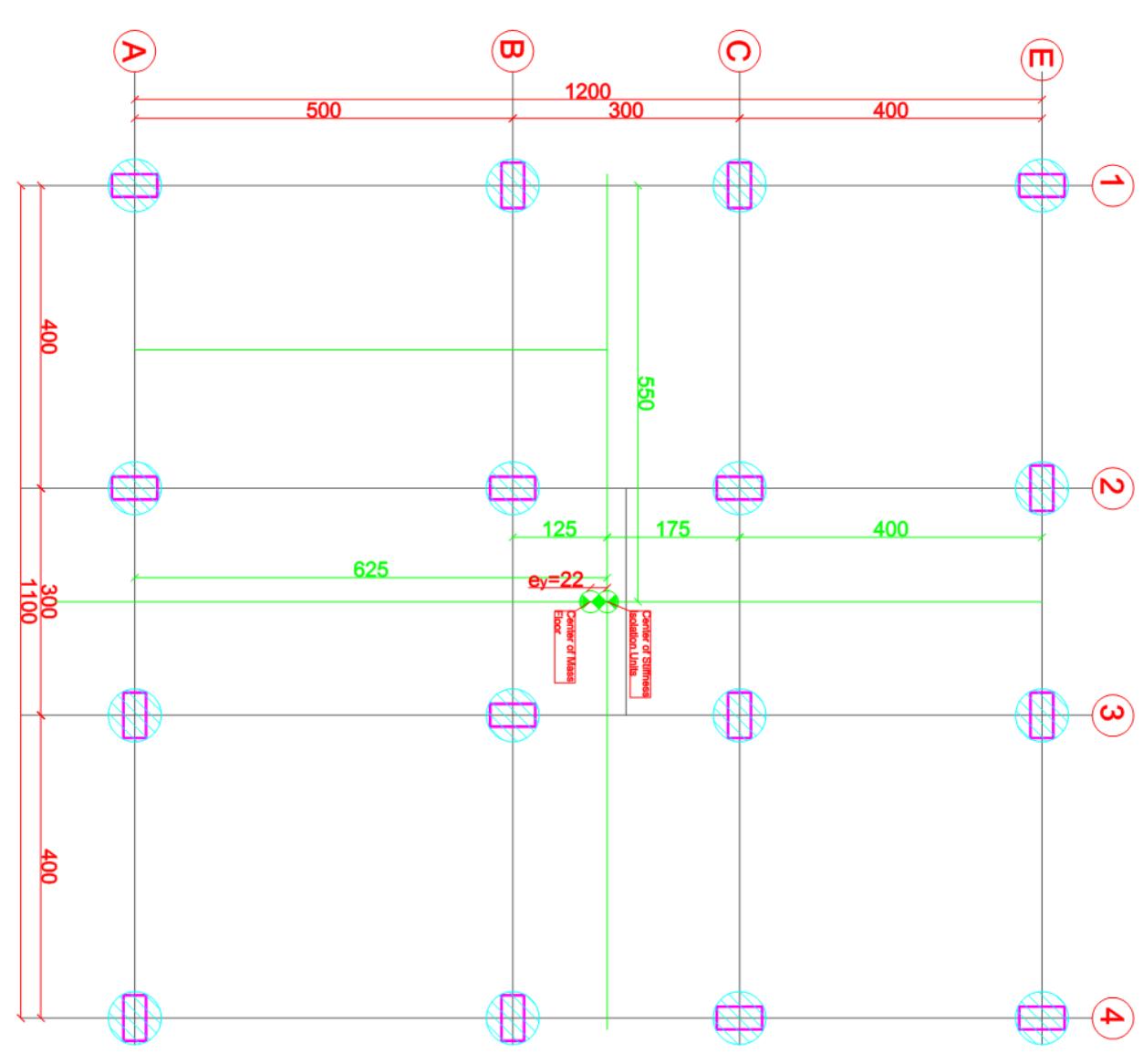
Damping and displacement demand of design spectrum for MCE (DD-1).

Parameter	Nominal	Lower	Upper
λ	1	0.595	1.719
Isolator Displacement	189.47	239.07	140.54
$S_a(T_{\text{Isolated}}, \xi_{\text{Isolated}})$	0.08	0.07	0.11
Effective Period	2.74	3.35	2.03
ξ_{isolator}	30.00	27.70	30.00

Damping and displacement demand of design spectrum for design earthquake (DD-2).

14.3.6 – Yalıtım sisteminin en büyük yerdeğiştirme hesabı DD-1 deprem yer hareketi düzeyinde yalıtım birimlerine ait parametrelerin *alt sınır değerleri* ile, üstyapıya etkiyen en büyük yatay kuvvetin hesabı ise DD-2 deprem yer hareketi düzeyinde yalıtım birimlerine ait parametrelerin *üst sınır değerleri* ile yapılacaktır.

Maximum Isolation Unit Displacement(D_M)	610 mm
S_a (Superstructure)(g)	0.11
S_a (Isolation Unit)(g)	0.13



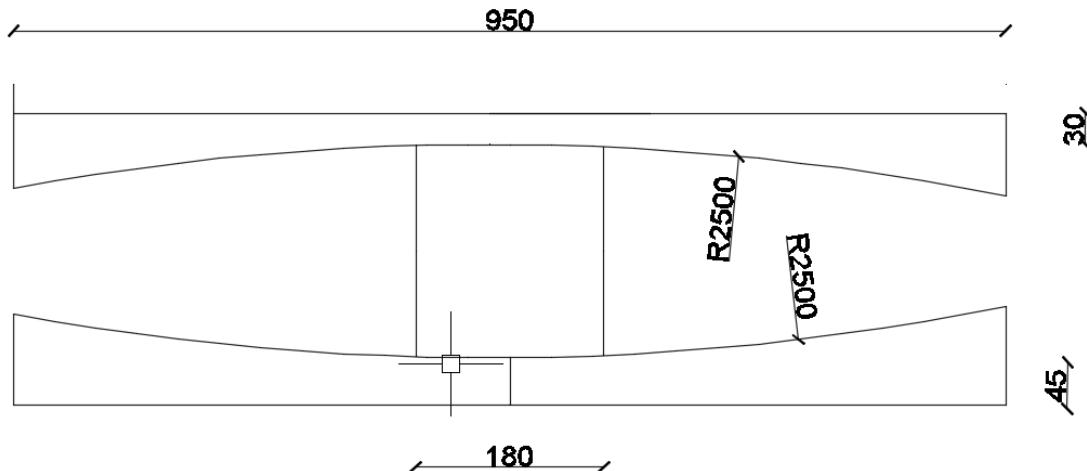
14.14.2.6 – DD-2 ve DD-1 deprem yer hareketi düzeylerindeki yalıtm arayüzü toplam yerdeğiştirmesi, **Denk.(14.28)** ve **Denk.(14.30)**'dan hesaplanan yerdeğiştirme değerlerine üstyapı ve yalıtm sistemi burulmasından gelen ilave yer değiştirmelerin eklenmesi ile hesaplanacaktır. Düzgün bir dağılm olması durumunda toplam yerdeğiştirmeler **Denk.(14.33)** ve **Denk.(14.34)** ile hesaplanan değerlerden daha az olamaz.

$$D_{TD} = D_D \left[1 + y \frac{12e}{b^2 + d^2} \right] \quad (14.33)$$

$$D_{TM} = D_M \left[1 + y \frac{12e}{b^2 + d^2} \right] \quad (14.34)$$

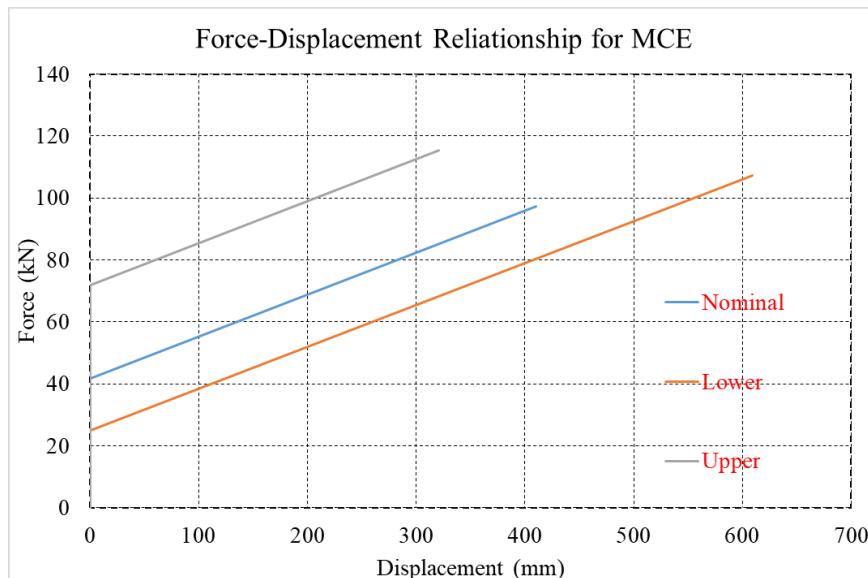
Burulmaların dikkate alınması ile hesaplanan yerdeğiştirme değerlerinin **Denk.(14.33)** ve **Denk.(14.34)** ile hesaplanan değerlerden daha küçük olması durumunda **Denk.(14.33)** ve **Denk.(14.34)** ile hesaplanan değerler yerine, hesaptan elde edilen değerler ile $1.1D_M$ ve $1.1D_D$ değerlerinden büyük olanları dikkate alınacaktır.

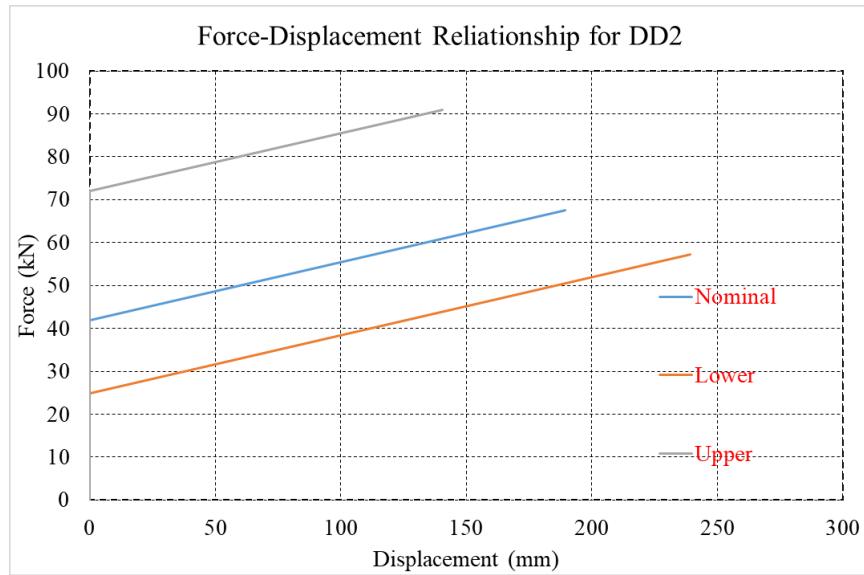
Axis	Distance Between Center of Stiffness and Unit		Measured Eccentricity (in cm)		Code Eccentricity (in cm)		Total Eccentricity (e.)		Plan	Dd	Dm	Y direction		X direction		
	X	Y	ex	ey	0.05B	0.05H	ex	ey	b^2+d^2	mm	mm	Dtd	Dtm	Dtd	Dtm	
A	1	550	625	0	22	55	60	0.55	0.82	265	240	610	273	735	296	752
	2	150	625	0	22	55	60	0.55	0.82	265	240	610	249	644	296	752
	3	150	625	0	22	55	60	0.55	0.82	265	240	610	249	644	296	752
	4	550	625	0	22	55	60	0.55	0.82	265	240	610	273	735	296	752
B	1	550	125	0	22	55	60	0.55	0.82	265	240	610	273	735	251	638
	2	150	125	0	22	55	60	0.55	0.82	265	240	610	249	644	251	638
	3	150	125	0	22	55	60	0.55	0.82	265	240	610	249	644	251	638
	4	550	125	0	22	55	60	0.55	0.82	265	240	610	273	735	251	638
C	1	550	175	0	22	55	60	0.55	0.82	265	240	610	273	735	256	650
	2	150	175	0	22	55	60	0.55	0.82	265	240	610	249	644	256	650
	3	150	175	0	22	55	60	0.55	0.82	265	240	610	249	644	256	650
	4	550	175	0	22	55	60	0.55	0.82	265	240	610	273	735	256	650
E	1	550	575	0	22	55	60	0.55	0.82	265	240	610	273	735	291	740
	2	150	575	0	22	55	60	0.55	0.82	265	240	610	249	644	291	740
	3	150	575	0	22	55	60	0.55	0.82	265	240	610	249	644	291	740
	4	550	575	0	22	55	60	0.55	0.82	265	240	610	273	735	291	740



Force Displacement Relationships of Isolator for Earthquakes

14.3.7 – Yağtum sisteminin DD-1 deprem yer hareketi altında meydana gelen en büyük yerdeğiştirme durumunda sahip olduğu iç kuvvet ile en büyük yerdeğiştirmenin %50'sinde sahip olduğu iç kuvvet arasındaki fark en az $0.025W$ olacaktır. Bunun yanı sıra yağtum sistemi herhangi bir D yerdeğiştirmesinde yatay merkezleme kuvveti oluşturabilecek şekilde tasarlanacak ve ikincil (elastik ötesi) rıjilik kullanılarak hesaplanan titreşim periyodu 6 saniyeden daha büyük olmayacağından emin olacak. Merkezleme kuvveti ve teğetsel rıjilik koşullarının sağlanmasında yerdeğiştirmeden bağımsız kuvvetler göz önüne alınmayacaktır.



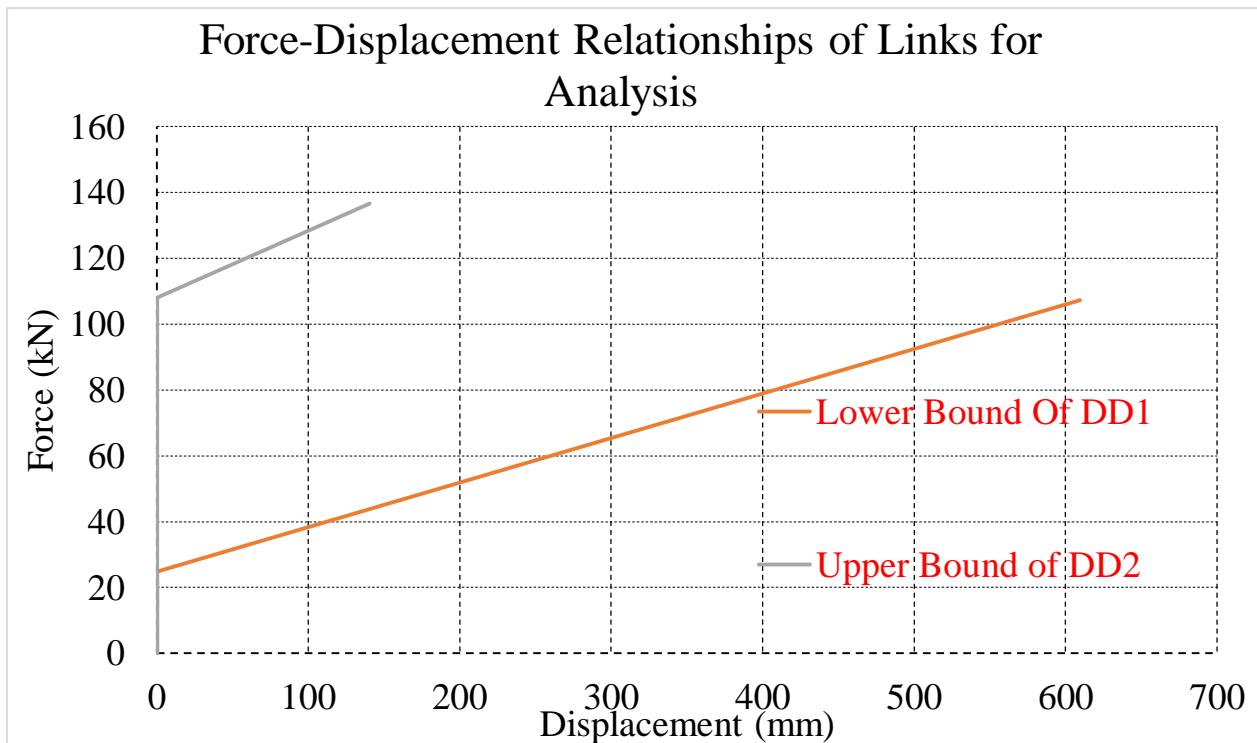


Isolators will defined in ETABS as EPP link element.

14.3.6 – Yalıtm sistemini en büyük yerdeğiştirme hesabı DD-1 deprem yer hareketi düzeyinde yalıtm birimlerine ait parametrelerin *alt sınır değerleri* ile, üstyapıya etkiyen en büyük yatay kuvvetin hesabı ise DD-2 deprem yer hareketi düzeyinde yalıtm birimlerine ait parametrelerin *üst sınır değerleri* ile yapılacaktır.

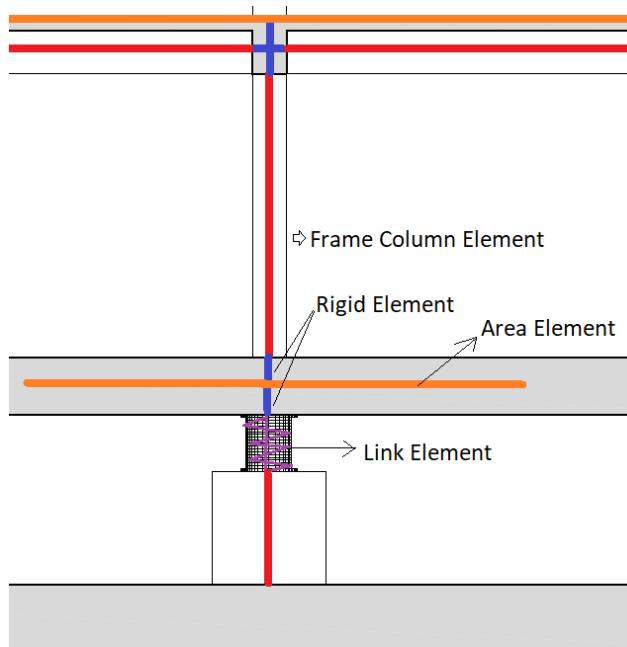
Lower Bounds				
FF1	24.9	kN	μ_{Eff}	3.74
u^*	0.054	m	R Eff	4925
FF2	32.20	kN/m	μ_1	2.65
F max	107.31		μ_2	4.83
K2	135.228	kN/m	Keff	
			176.0999977	
D1	609.40			
F(w)	0.1611			
Kd	0.26	kN/m		
T	3.90			
Damping	14.78			
DMF	0.71			
SA	0.17			
DSA	0.12			
D	609.40			
		T		
0.45sds	0.78	0	0	
Sds	1.95Ta		0.06974359	
Sd1	0.68Tb		0.348717949	
		T1	1	
		TL	6	

Upper Bounds				
FF1	108.1	kN	μ Eff	10.81
u*	0.156	kN/m	R Eff	4925
FF2	139.70	kN/m	μ 1	7.66
F max	136.60		μ 2	13.97
			Keff=	971.9
D1	140.54			
F	0.1366			
Kd	0.97	kN/m		
T	2.03			
Damping	30.00			
DMF	0.53			
SA	0.20			
DSA	0.105			
D	140.54			
		T		
0.4Sds	0.448	0	0	
Sds	1.12	Ta	0.071428571	
Sd1	0.4	Tb	0.357142857	
		T1	1	
		TL	6	



4. Mathematical Model of Structure

In this model the superstructure was modelled using linear elastic frame and shell elements in accordance with the structural drawings.



Mathematical Model Specifications of Building

Tablo 4.3. Hareketli Yük Kütle Katılım Katsayısı

Binanın Kullanım Amacı	<i>n</i>
Depo, antrepo, vb.	0.80
Okul, öğrenci yurdu, spor tesisi, sinema, tiyatro, konser salonu, ibadethane, lokanta, mağaza, vb.	0.60
Konut, işyeri, otel, hastane, otopark, vb.	0.30

For the seismic mass of mass live load participation factor were chosen as 0.6.

Cracked section modifiers;

14.3.9 – Yapının modellemesinde kullanılacak etkin kesit rıjitiği çarpanları **Tablo 13.1** kullanılarak belirlenecektir.

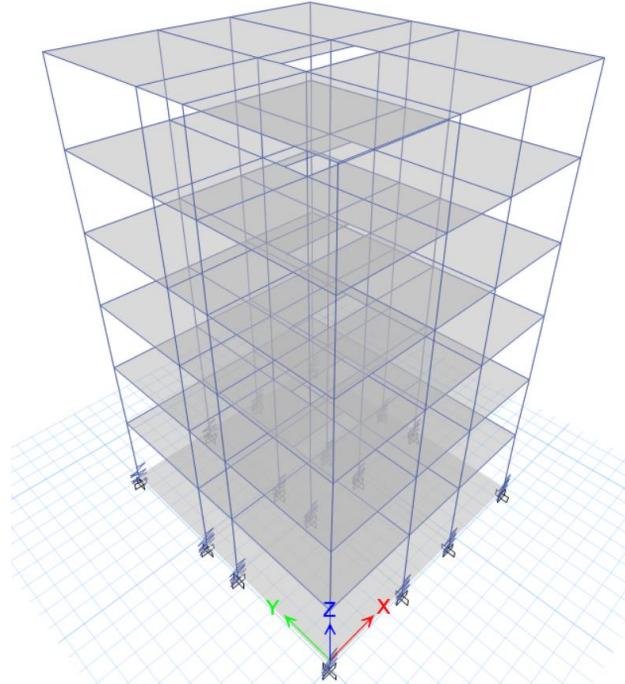
Stiffness modification factors were applied to all concrete elements in order to allow for the level of cracking that is anticipated when they attain their ultimate strength.

Isolated buildings are expected to take very low damage during earthquake excitations. Therefore, cracked section properties are different from ordinary building.

Tablo 13.1. Betonarme Taşıyıcı Sistem Elemanları İçin II. Aşamada Uygulanacak Etkin Kesit Rıjitliği Çarpanları

Betonarme Taşıyıcı Sistem Elemanı	Etkin Kesit Rıjitliği Çarpanı	
<i>Perde – Döşeme (Düzlem İçi)</i>	<i>Eksenel</i>	<i>Kayma</i>
Perde	0.75	1.00
Bodrum perdesi	1.00	1.00
Döşeme	0.50	0.80
<i>Perde – Döşeme (Düzlem Dışı)</i>	<i>Eğilme</i>	<i>Kesme</i>
Perde	1.00	1.00
Bodrum perdesi	1.00	1.00
Döşeme	0.50	1.00
<i>Çubuk eleman</i>	<i>Eğilme</i>	<i>Kesme</i>
Bağ kırığı	0.30	1.00
Çerçeve kırığı	0.70	1.00
Çerçeve kolonu	0.90	1.00
Perde (eşdeğer çubuk)	0.80	1.00

Effective section properties were assigned as section modifier.



Fixed base mathematical model of the building.

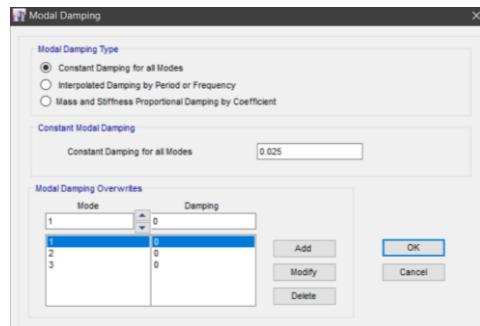
5. Modal Analysis

Mode	Period	UX	UY	UZ	Sum UX	Sum UY	Sum UZ
	sec						
1	3.9540	0.9659	0.0010	0.0000	0.9659	0.0010	0.0000
2	3.9470	0.0010	0.9988	0.0000	0.9669	0.9998	0.0000
3	3.3670	0.0108	0.0000	0.0000	0.9777	0.9998	0.0000
4	0.3970	0.0002	0.0000	0.0000	0.9780	0.9998	0.0000
5	0.3910	0.0000	0.0002	0.0000	0.9780	1.0000	0.0000
6	0.3120	0.0000	0.0000	0.0000	0.9780	1.0000	0.0000
7	0.1610	0.0000	0.0000	0.0000	0.9780	1.0000	0.0000
8	0.1560	0.0000	0.0000	0.0001	0.9780	1.0000	0.0001
9	0.1240	0.0000	0.0000	0.0000	0.9780	1.0000	0.0001
10	0.0850	0.0000	0.0000	0.5086	0.9780	1.0000	0.5087
11	0.0540	0.0000	0.0000	0.2961	0.9780	1.0000	0.8049
12	0.0140	0.0001	0.0000	0.0000	0.9781	1.0000	0.8049

6. Seismic Analysis Process

Damping;

Modal damping ratio is constant for all modes %2.5 in analysis phase except for the first isolator dominant three mod damping ratio equals to 0.



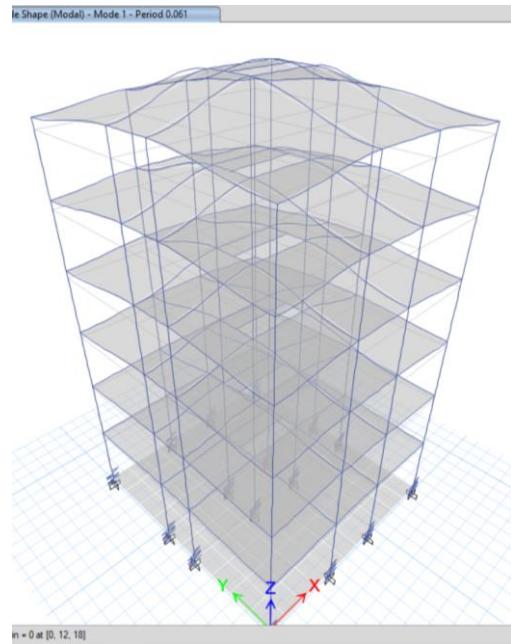
5.7.2. Deprem Kayıtlarının Seçimi ve Ölçeklendirilmesi

5.7.2.1 – Zaman tanım alanında yapılacak doğrusal olmayan hesaplarda en az onbir deprem yer hareketi takımı kullanılacaktır. Birbirine dik yatay iki doğrultudaki ivme kayıtları taşıyıcı sistemin (X) ve (Y) asal eksenleri doğrultusunda aynı anda birlikte etki ettirilecektir. Daha sonra ivme kayıtlarının eksenleri 90° döndürülerek hesap tekrarlanacaktır.

5.7.2.2 – Hesaplarda kullanılacak deprem kayıtlarının seçimi ve ölçeklendirilmesi 2.5'e göre yapılacaktır.

Binanın düşey doğrultudaki titreşim periyodu $T_v \leq 0.1$ olduğu durumlarda depremin 2 yatay bileşeni, sağlanamadığı durumlarda ise depremin 2 yatay bileşenine ek olarak **düşey bileşeni** de kullanılacaktır.

Code limitations of vertical period.



The vertical period of the building was calculated as 0.061 seconds, therefore, it is enough to use two orthogonal directions of the accelerograms.

7. Determination of Isolation System Demands

7.1 Displacement Demands

Determination of Displacement Demand of Isolation Units under DD1 Earthquake Excitations (with Lower Bound Props.)

All of the time-displacement response of isolation system were taken from ETABS. With an excel datasheet SRSS calculations were performed and maximum displacement of isolation units calculated.

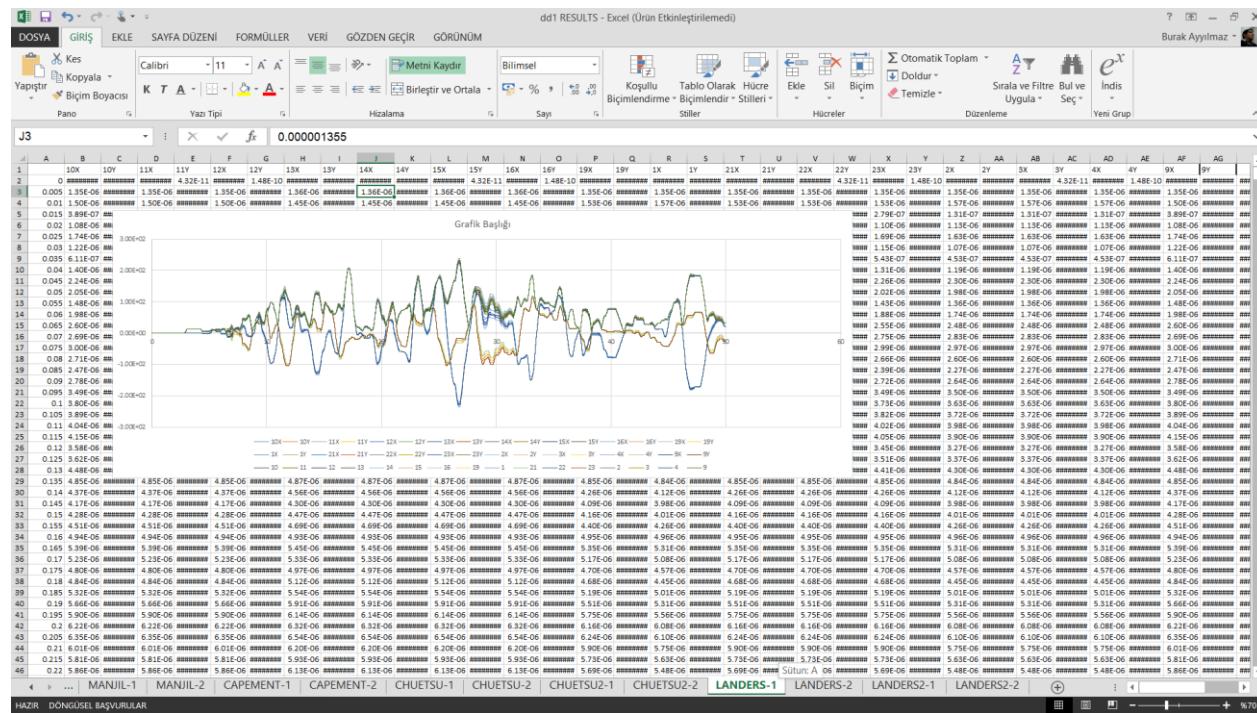
(14.14.4.6) – Zaman tanım alanında doğrusal olmayan hesap sonucunda yalıtm arayüzünde hesaplanan yerdeğiştirmeler 14.14.2.6'ya göre hesaplanan değerlerin %80'inden az olmayacağı.

D_{tm} and D_{td} were calculated previous sections.

14.14.2.6 – DD-2 ve DD-1 deprem yer hareketi düzeylerindeki yalıtm arayüzü toplam yerdeğiştirmesi, Denk.(14.28) ve Denk.(14.30)'dan hesaplanan yerdeğiştirme değerlerine üstüyapi ve yalıtm sistemi burulmasından gelen ilave yer değişimlerinin eklenmesi ile hesaplanacaktır. Düzgün bir dağılm olması durumunda toplam yerdeğiştirmeler Denk.(14.33) ve Denk.(14.34) ile hesaplanan değerlerden daha az olamaz.

$$D_{TD} = D_D \left[1 + y \frac{12e}{b^2 + d^2} \right] \quad (14.33)$$

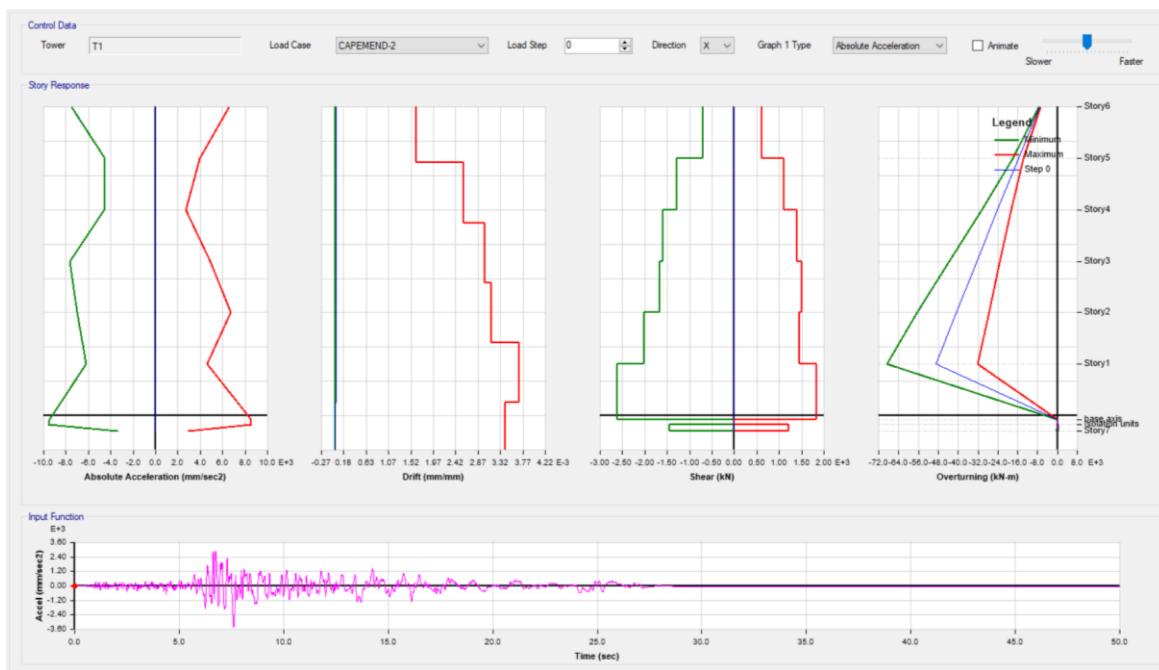
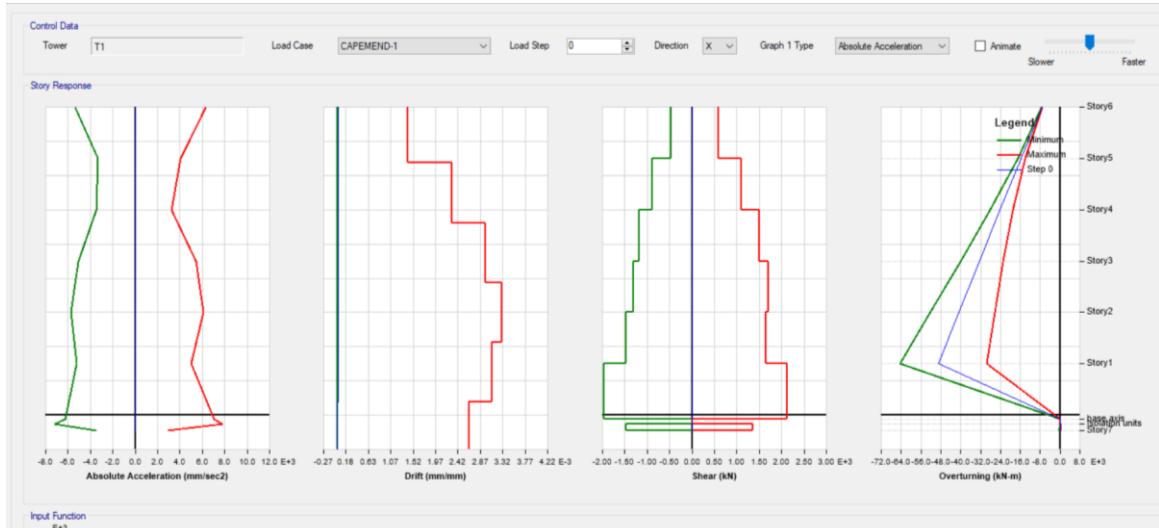
$$D_{TM} = D_M \left[1 + y \frac{12e}{b^2 + d^2} \right] \quad (14.34)$$

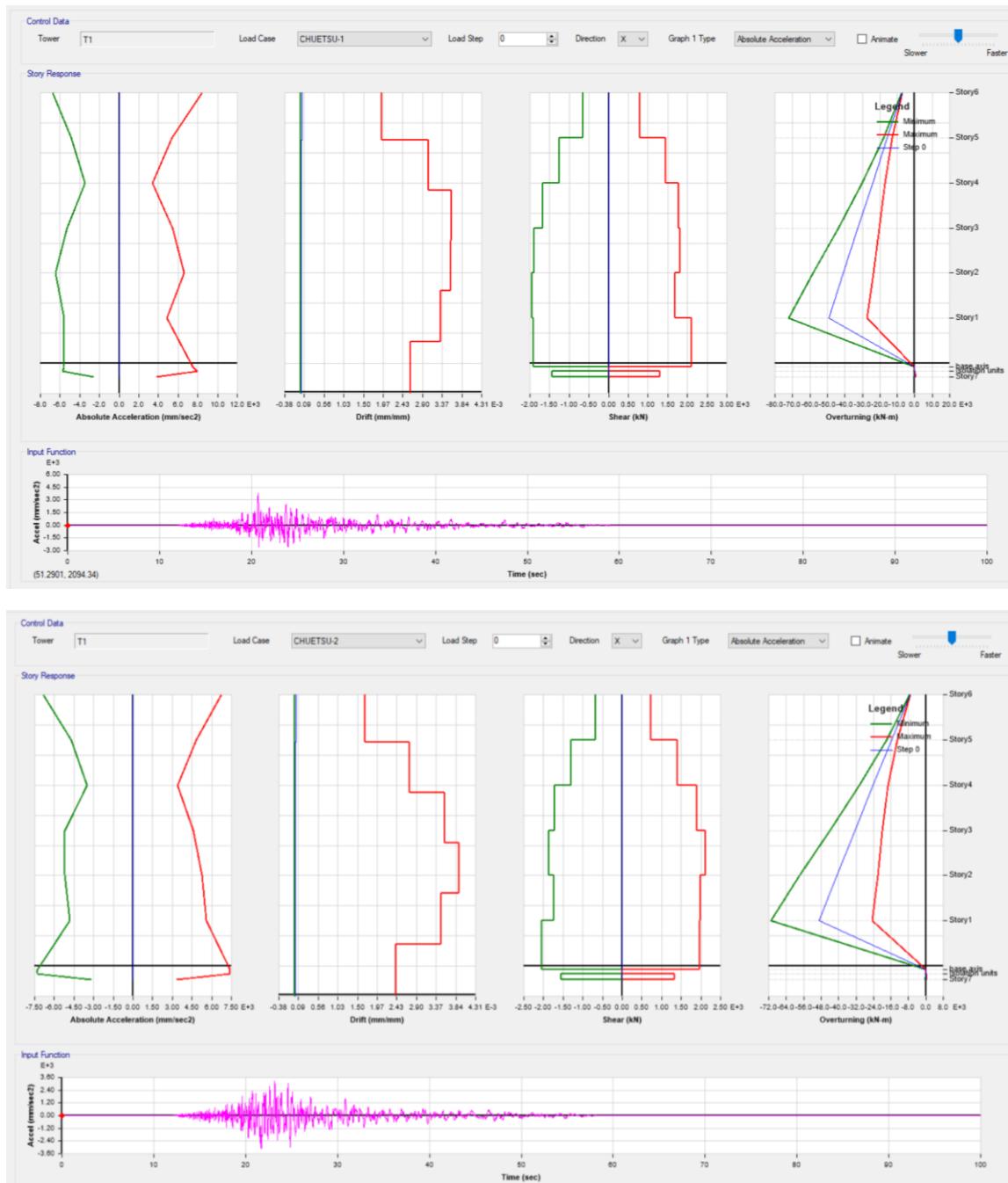


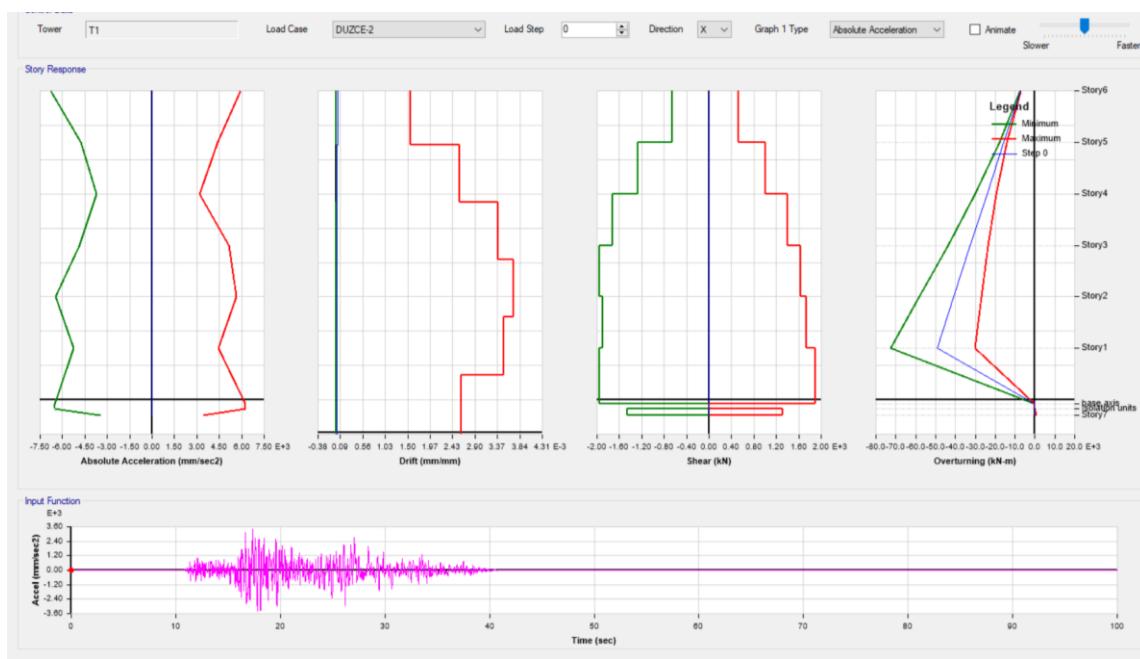
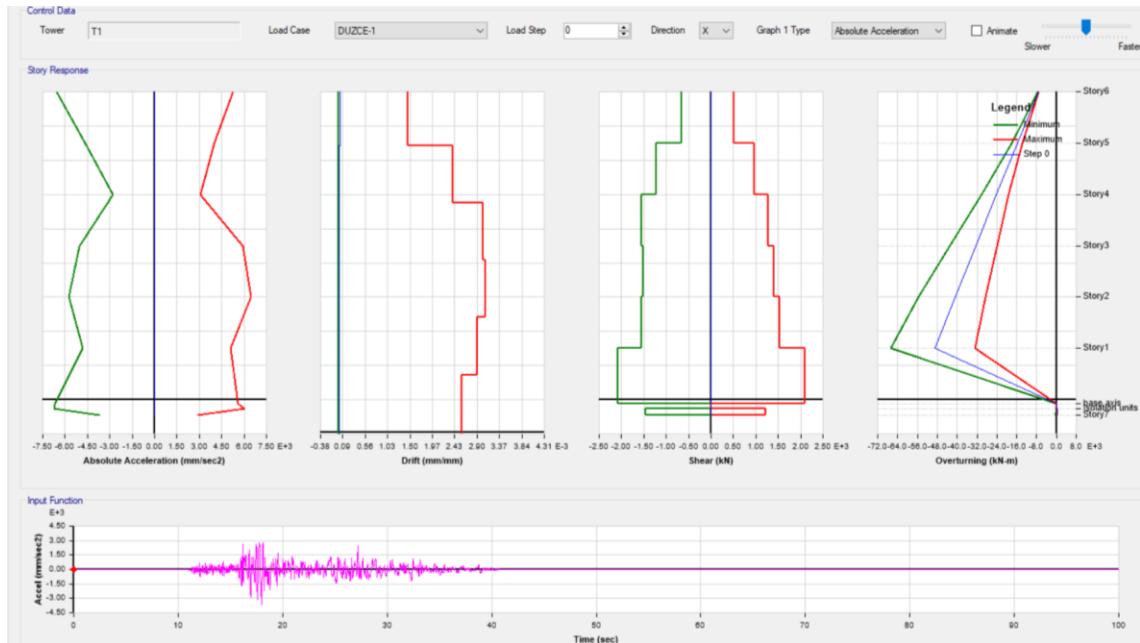
An example chart of Nonlinear Analyses.

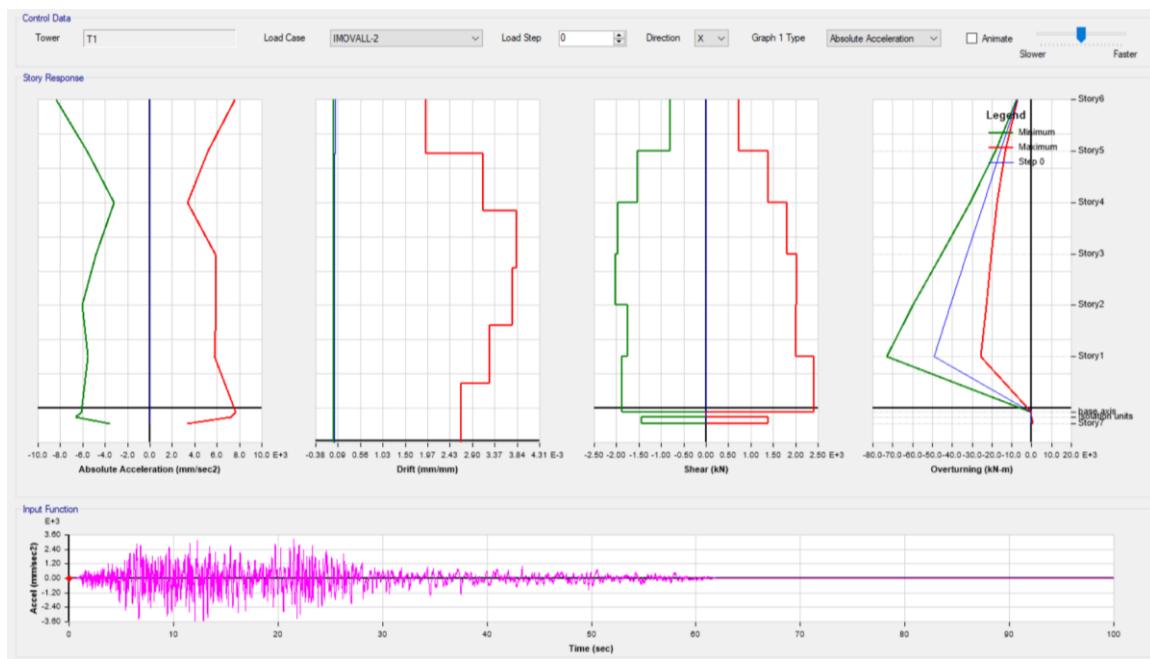
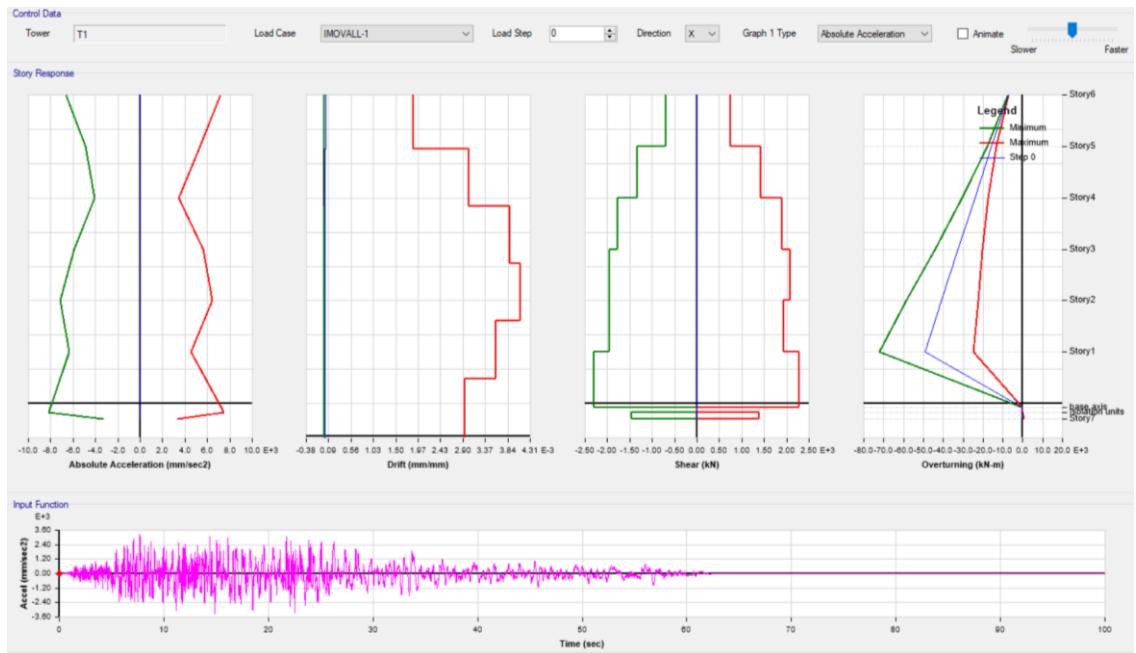
Demand Table		MAXIMUM DISPLACEMENT (considered SRSS and direction effect of Eqs.) (in mm.)															
Isolator Label Number		1	2	3	4	9	10	11	12	13	14	15	16	19	21	22	23
EARTHQUAKE NAME	SFERN	82.1	83.4	82.5	82.8	82.8	79.9	79.9	81.1	84.2	79.7	81.3	82.6	82.0	80.2	80.5	80.8
	IMPVALL	350.1	348.3	349.4	348.9	348.5	349.6	349.6	349.0	348.6	350.3	349.7	349.2	348.4	350.2	349.5	349.0
	LOMAP	236.4	240.4	237.8	238.9	239.2	236.7	236.7	237.7	238.4	234.5	235.9	236.9	239.7	235.8	237.2	238.2
	DUZCE	219.8	218.6	219.4	219.0	218.7	219.4	219.4	219.1	218.7	219.9	219.5	219.2	218.7	219.8	219.4	219.1
	NORTHRDG	254.0	251.5	253.1	252.4	257.5	259.1	259.1	258.4	262.0	265.0	263.8	263.0	254.9	257.5	256.5	255.8
	MANJIL	308.6	288.9	301.4	296.0	299.3	311.4	311.4	306.2	307.1	325.8	318.9	313.8	294.8	314.2	307.0	301.7
	CAPEMENT	278.9	292.3	283.7	287.3	303.1	294.8	294.8	298.3	311.0	298.4	302.9	306.3	298.5	285.3	290.0	293.6
	CHUETSU	170.7	170.2	170.5	170.4	169.9	170.3	170.3	170.1	169.7	170.3	170.1	169.9	170.0	170.6	170.4	170.2
	CHUETSU2	155.9	161.4	157.7	159.1	162.2	158.3	158.3	159.9	162.9	156.9	158.9	160.6	161.8	156.2	158.0	159.5
	LANDERS	222.0	223.4	222.4	222.8	231.8	230.8	230.8	231.2	237.7	236.4	236.8	237.2	228.2	226.8	227.2	227.6
	LANDERS2	107.8	108.0	107.8	107.9	108.8	108.6	108.6	108.7	109.3	109.1	109.2	109.3	108.4	108.2	108.3	108.3

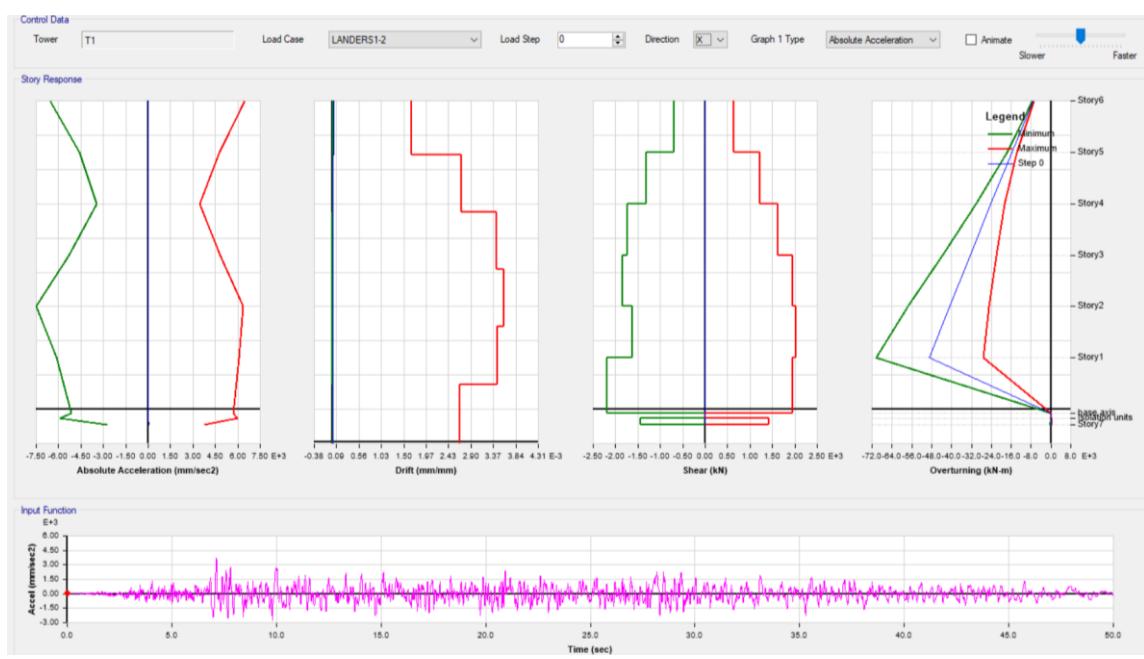
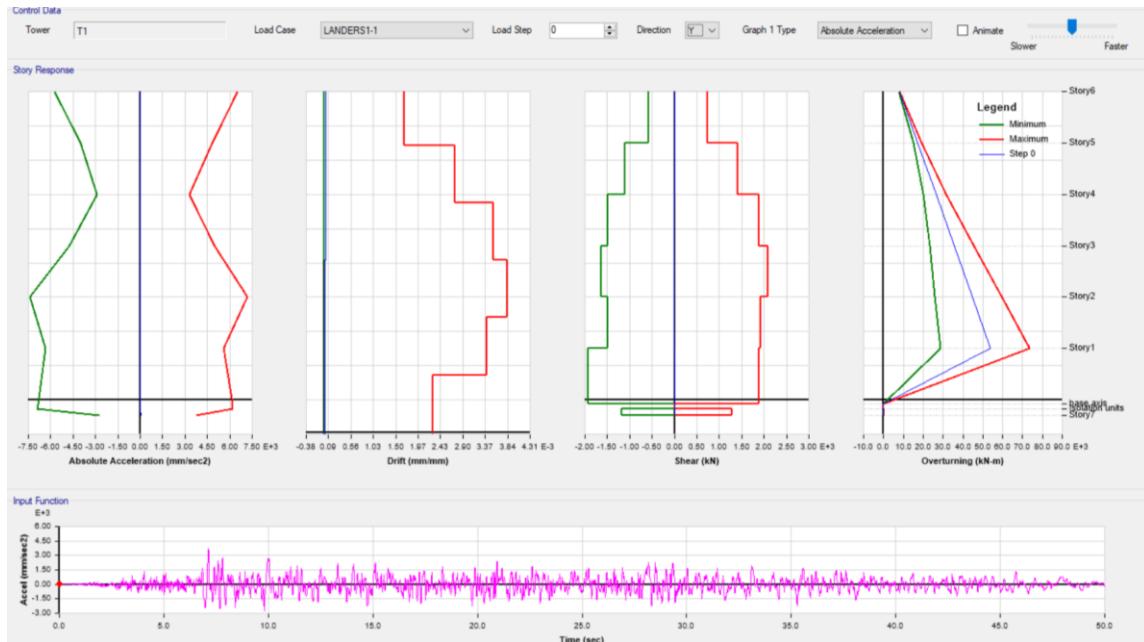
7.2 Maximum Drift Ratios under DD2 Earthquake Excitations (with Upper Bound props.)

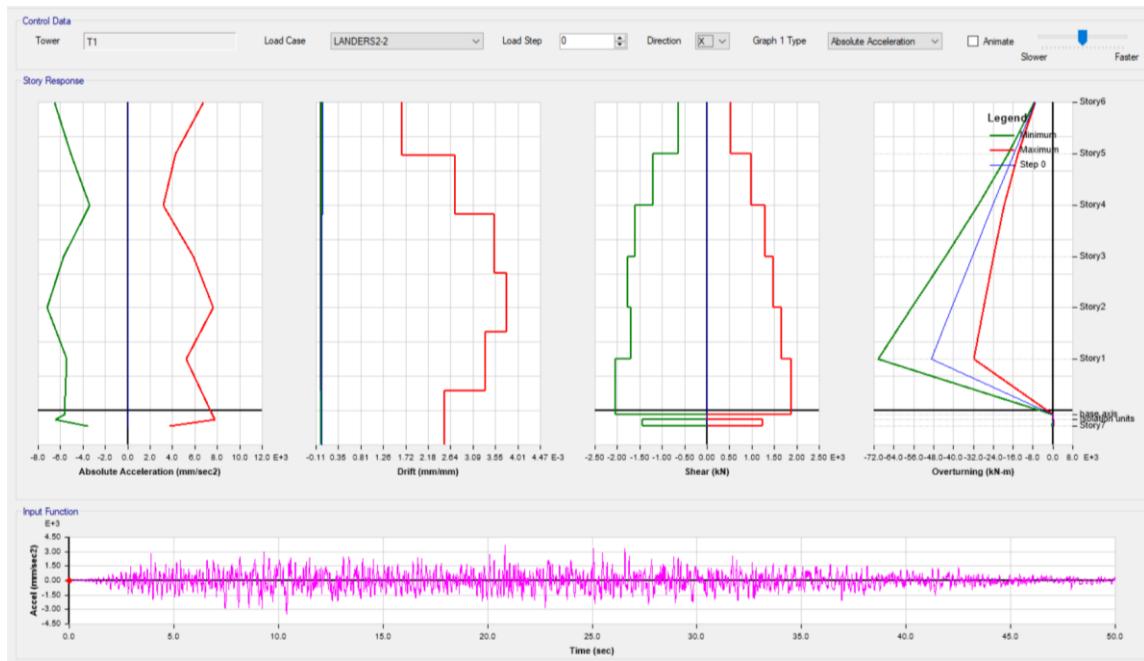
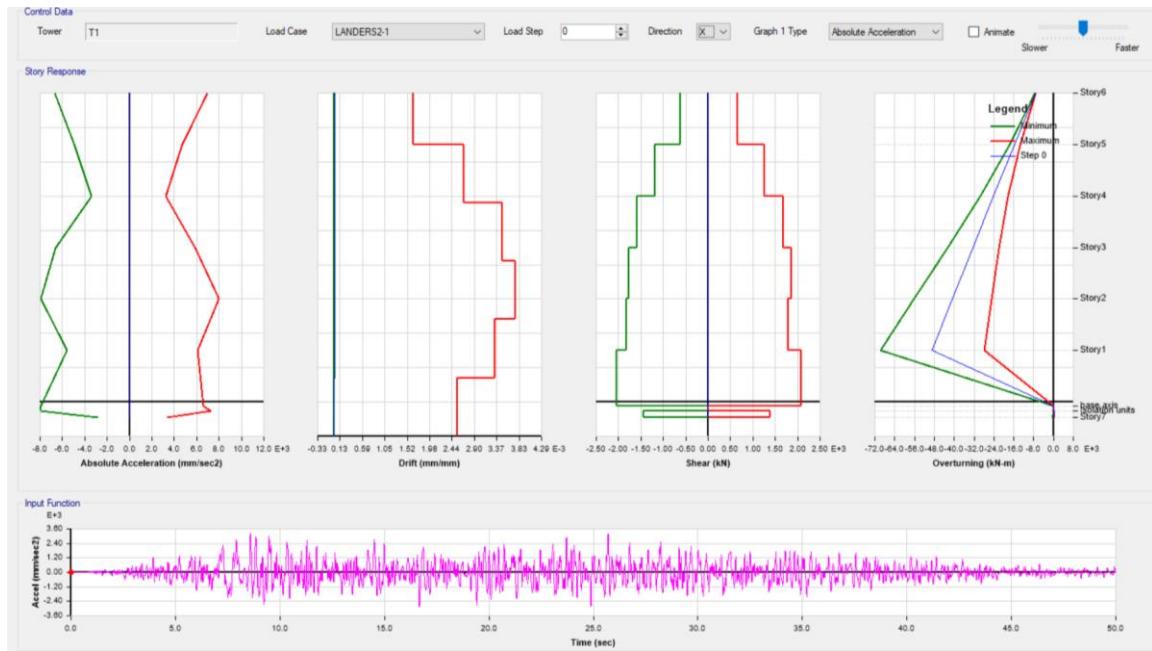


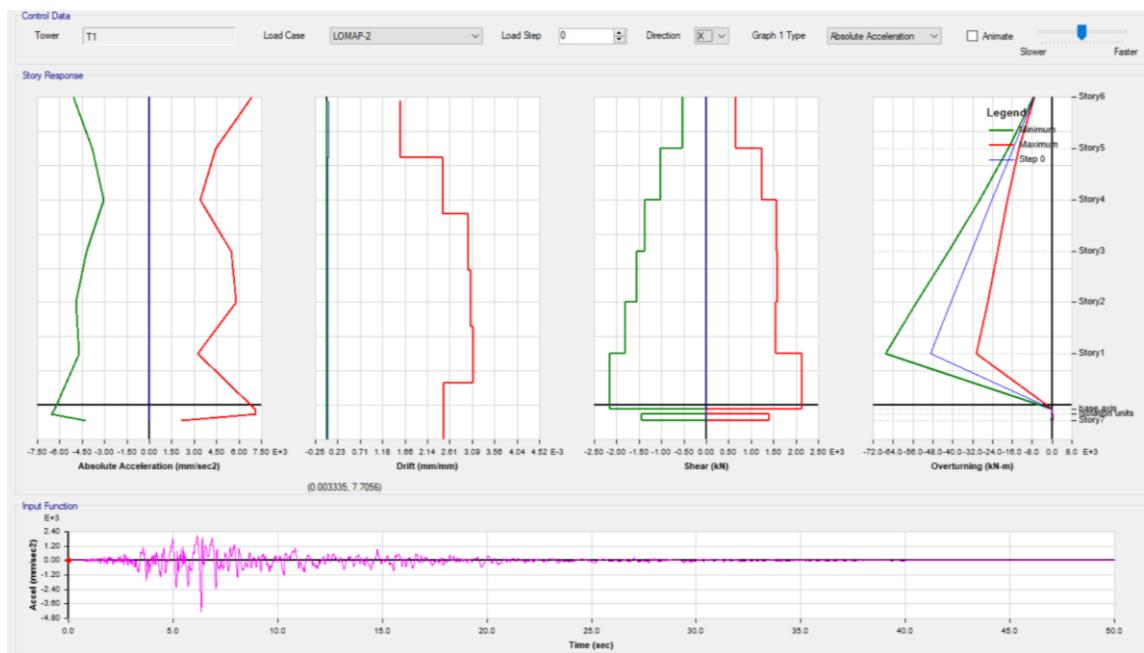
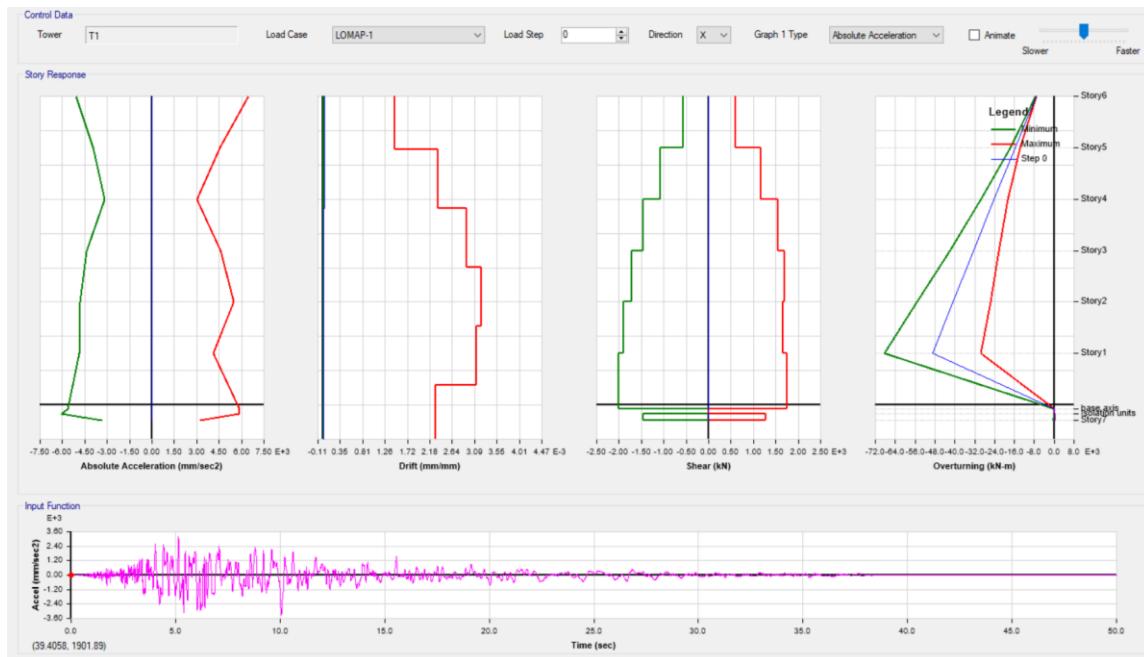


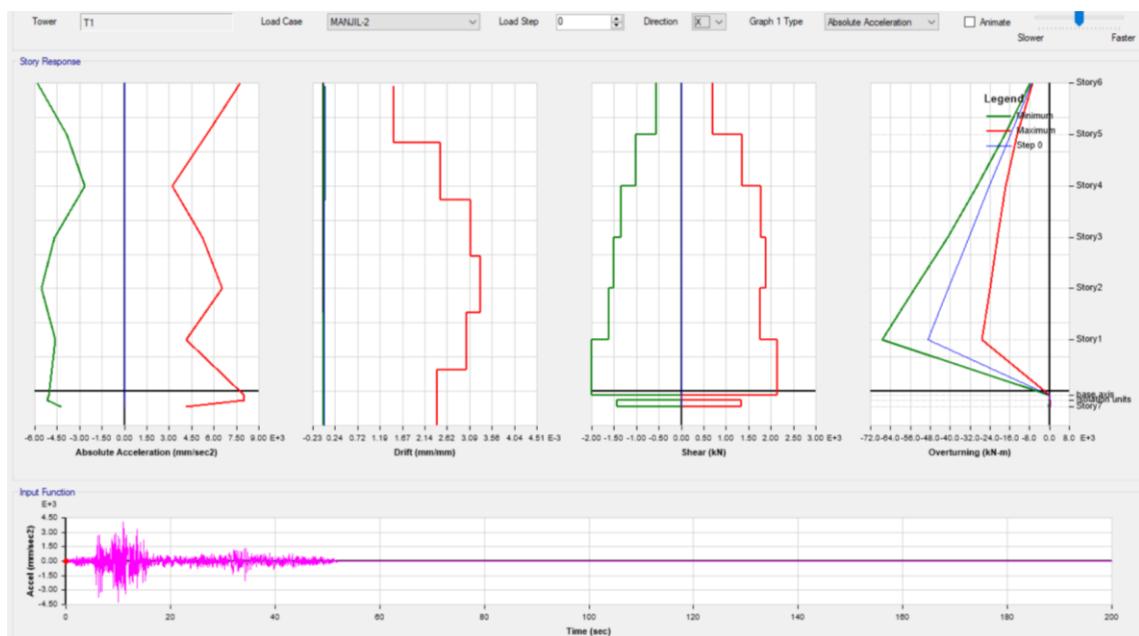
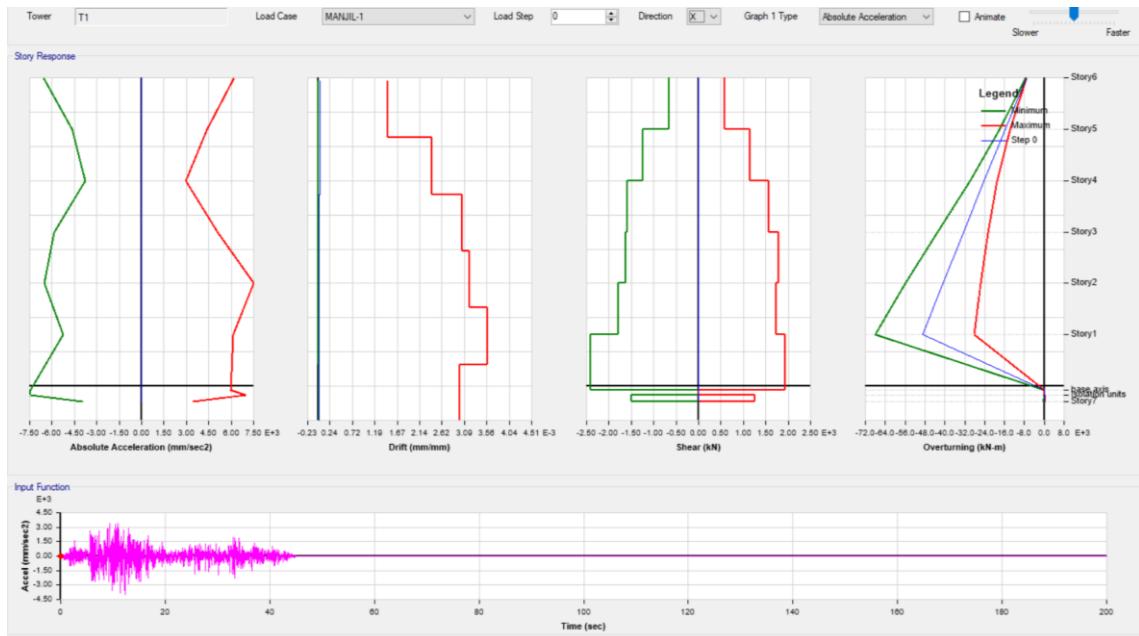


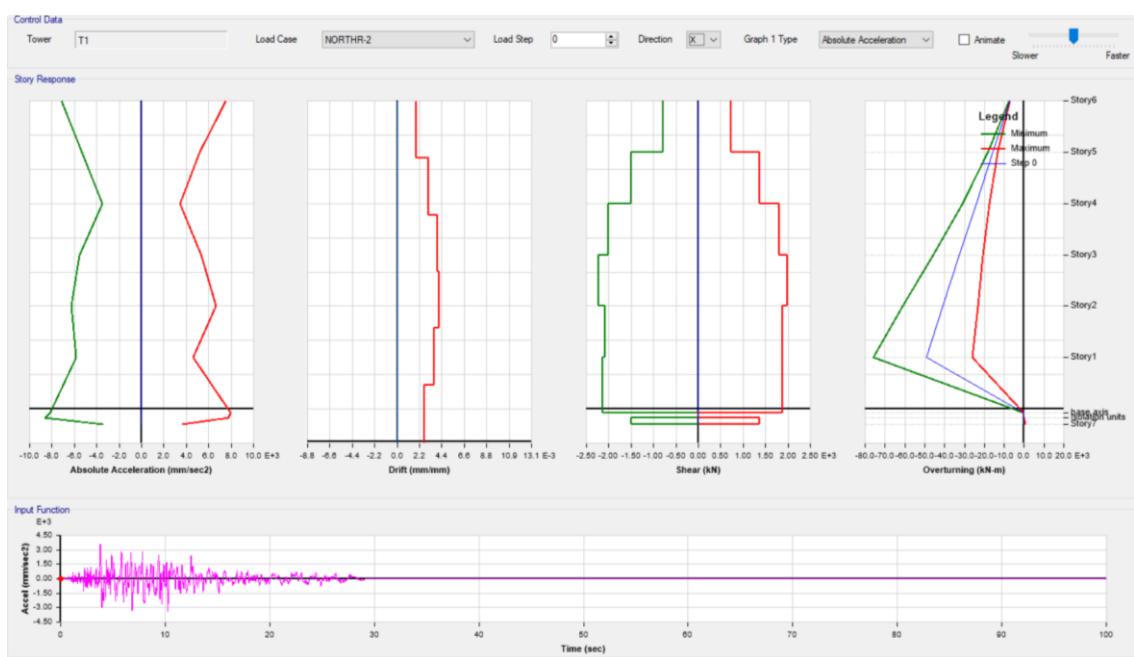
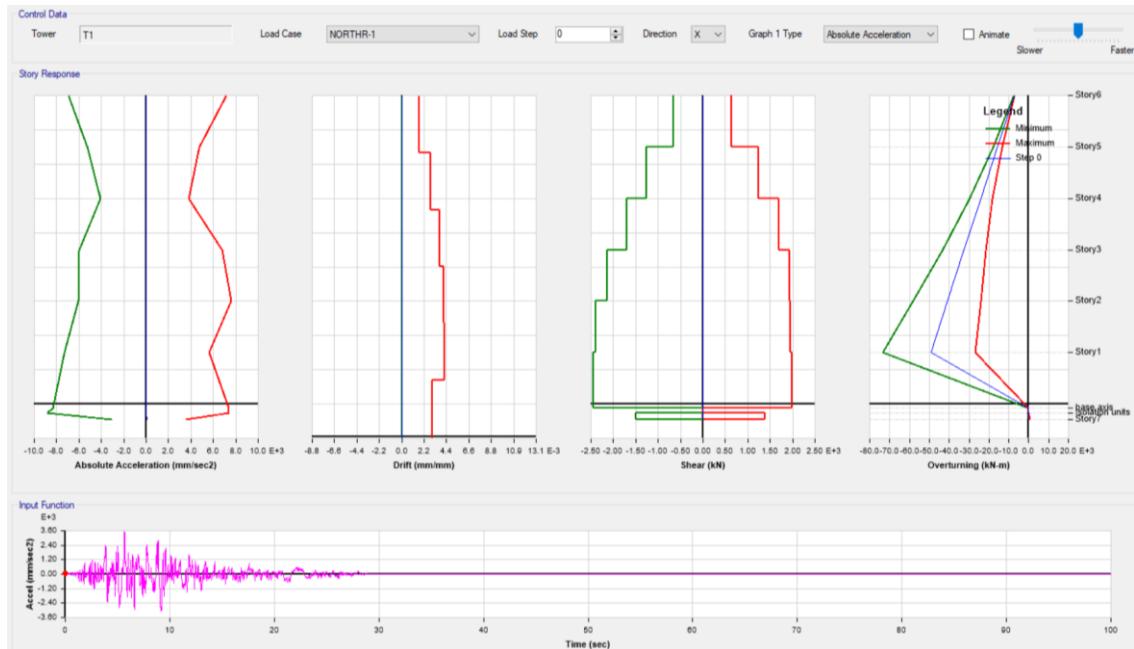


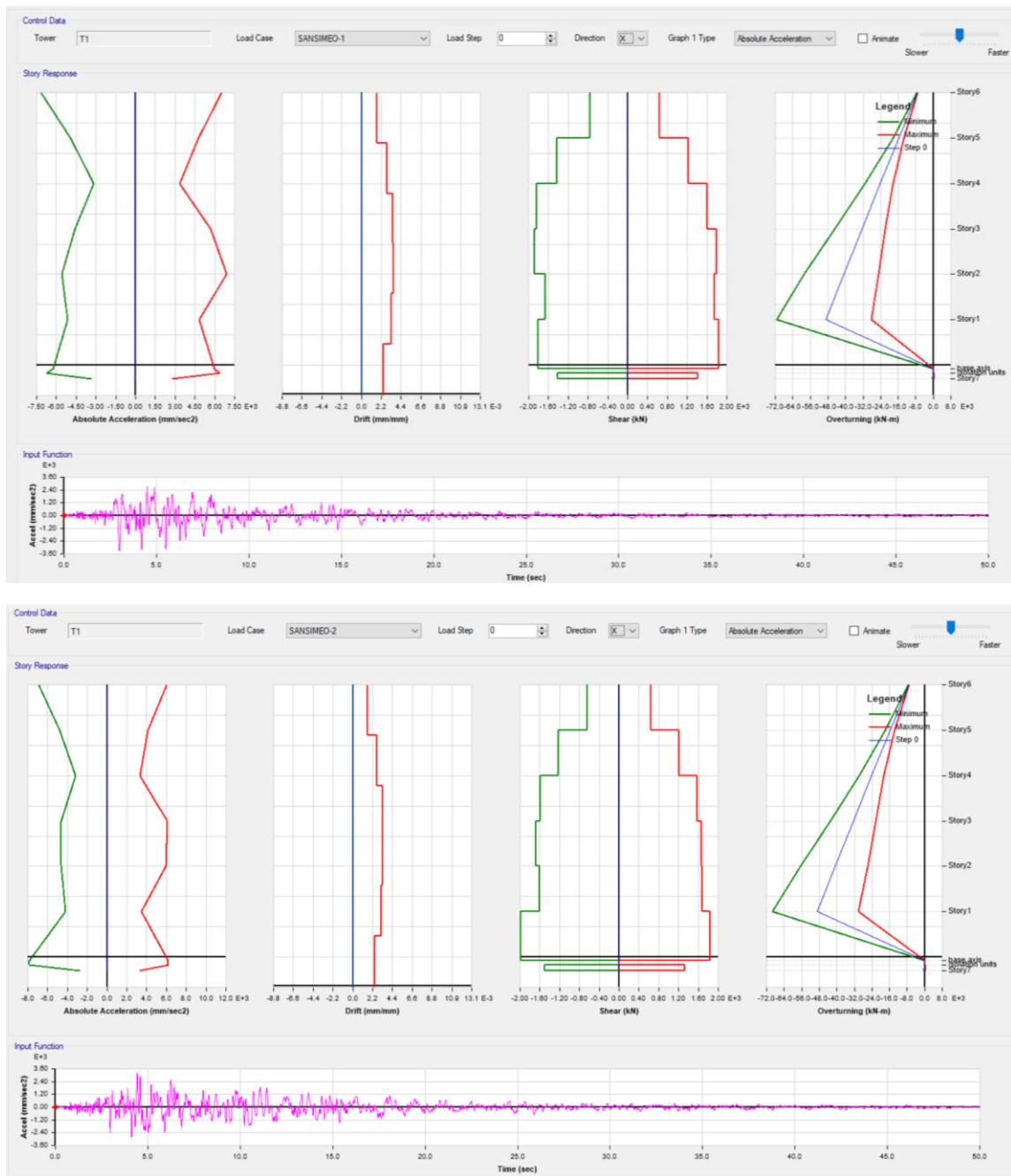


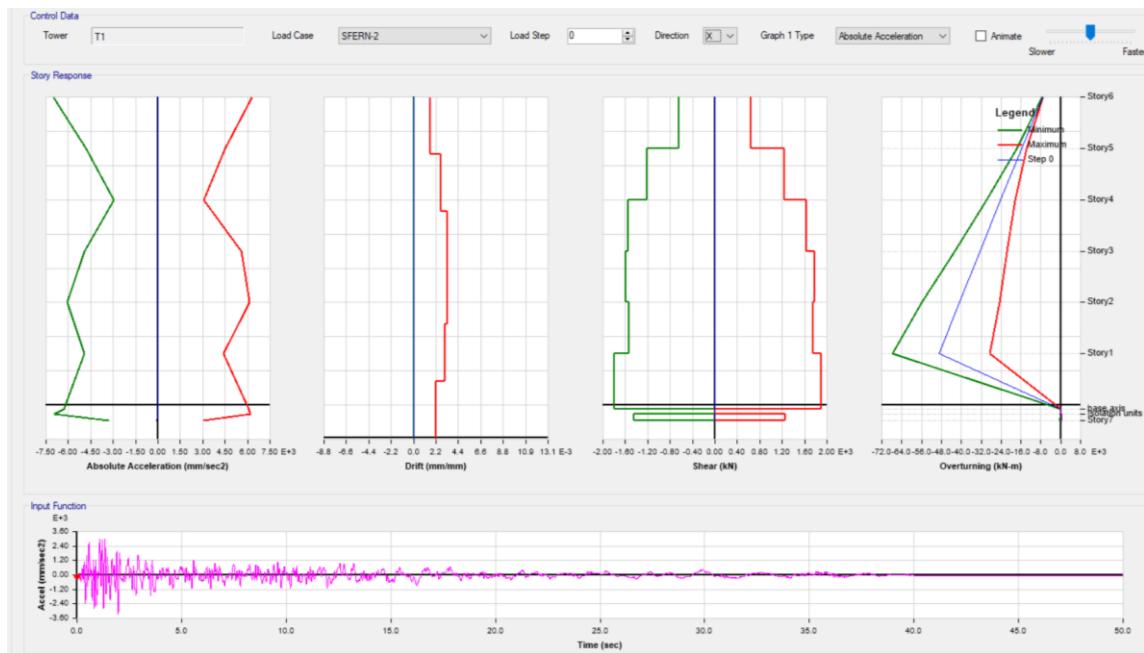
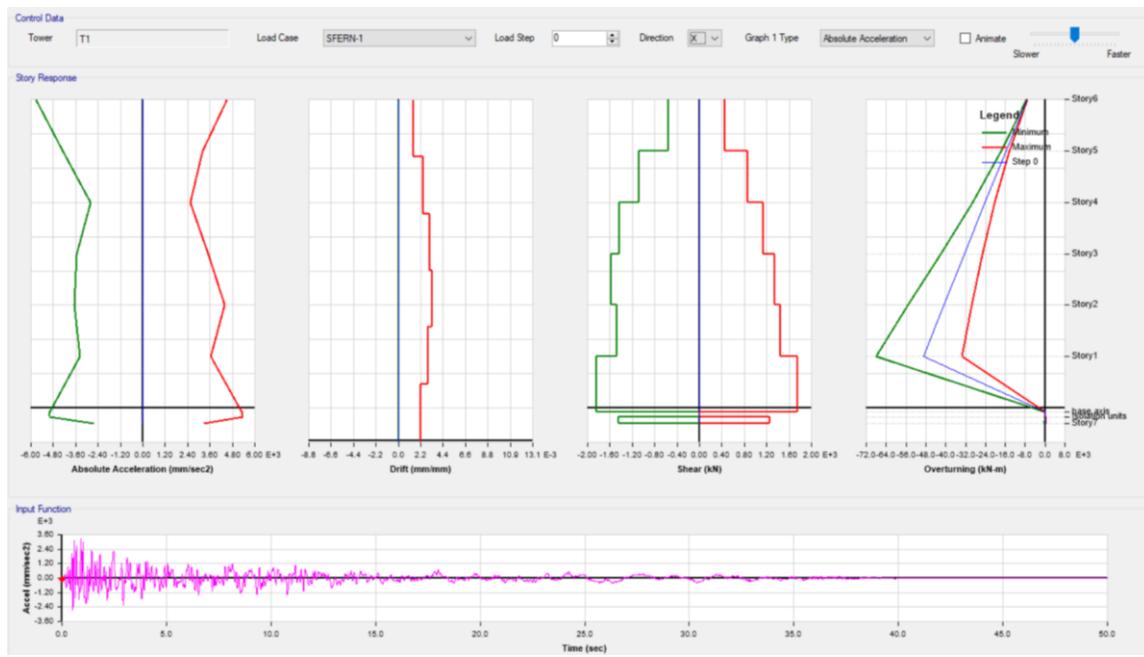












7.3 Force Demands of Isolation Units

Calculation of Design Force Demands of isolation system.

14.14.4.7 – Zaman tamam alanında doğrusal olmayan hesap sonucunda elde edilen üstyapı ve altyapı kuvvetleri, binada dizensizlik bulunmaması halinde **14.14.2.7**'ye göre hesaplanan değerlerin %80'inden az olmayacağıdır.

14.14.2.7 – Üstyapıya etkiyen kuvvet, tasarım deprem yer hareketi düzeyi DD-2 için Denk.(14.35) ile hesaplanacaktır.

$$V_D = \frac{S_{ae}^{(DD-2)}(T_D)W\eta_D}{R} \quad (14.35)$$

R=1.2

Results of nonlinear history is given following table.

Average force calculated as the given code;

14.14.4.4 – Doğrusal olmayan hesap her deprem yer hareketi seviyesinde ve her doğrultuda **5.7.2.1**'e göre en az onbir kayıt çifti için tekrarlanacak, ilgili deprem seviyesinde ve doğrultuda yapılan hesaplarda elde edilen en büyük değerlerin ortalamaları tasarıma esas değer olarak dikkate alınacaktır.

Demand Table		MAXIMUM FORCE on The Units (considered SRSS and direction effect of Eqs.) (in kN.)															
Isolator Label Number		1	2	3	4	9	10	11	12	13	14	15	16	19	21	22	23
EARTHQUAKE NAME	Capemend	116.44	116.90	117.15	117.47	117.95	118.46	118.84	119.29	118.65	119.15	119.54	119.98	117.57	118.08	118.46	118.91
	Chuetsu	116.29	116.36	116.36	119.44	115.65	116.29	116.29	119.44	119.00	118.94	118.94	119.44	115.49	116.29	116.29	119.44
	Duzce	116.15	116.76	116.58	116.33	116.52	116.41	116.54	116.80	116.35	116.60	116.85	117.11	116.76	116.65	116.47	116.57
	Imperial Valley	119.00	118.67	118.41	118.09	119.75	119.42	119.10	118.78	120.13	119.81	119.48	119.16	119.38	119.05	118.79	118.47
	Landers	118.21	117.96	117.71	117.00	120.82	120.75	120.75	120.69	119.66	119.59	119.59	119.59	118.59	118.27	118.02	117.39
	Landers2	114.85	114.91	115.24	114.92	115.24	115.13	115.16	115.23	115.47	115.37	115.40	115.54	115.08	114.98	115.01	115.15
	Lomaprieta	118.20	117.56	118.33	116.91	116.99	115.99	116.59	115.74	116.09	114.88	115.49	114.87	117.44	116.66	117.26	116.25
	MANJIL	119.39	119.19	119.06	117.75	119.90	119.63	119.49	119.22	120.27	120.00	119.86	119.60	119.75	119.48	119.35	119.08
	NortRidge	120.92	121.46	121.78	122.18	121.07	122.37	122.69	123.14	121.15	122.98	123.30	123.75	121.00	121.98	122.31	122.76
	San Simao	115.30	115.10	115.86	116.81	116.70	116.43	116.16	116.59	117.14	116.88	116.61	116.37	116.47	116.21	115.94	116.67
SFERN	Sfern	115.57	115.63	115.69	115.76	115.47	115.54	115.60	115.66	115.40	115.46	115.52	115.58	115.55	115.62	115.68	115.74

8. TBSC 2019 Checks of Isolation System

Conclusions

From analyses ii

Damage States;

All of the drifts ratios observed below 0.5% IMMEDIATE OCCUPANCY criteria according to code were verified.

Deprem Yer H. Düzeyi	DTS = 1, 2, 3, 3a, 4, 4a		DTS = 1a, 2a	
	Normal Performans Hedefi	Degerlendirme/Tasarım Yaklaşımı	Beni Performans Hedefi	Degerlendirme/Tasarım Yaklaşımı
DD-2	SH	DGT	KK	DGT
DD-1	—	—	—	—

14.14.5. Yahtımlı Binalarda Göreli Kat Ötelemesi Sınırları ve Deprem Derzleri

14.14.5.1 – Üst yapıdaki göreli kat öteleşmeleri, *Kesintisiz Kullanım* (KK) performans seviyesi için $0.005h_i$, *Sınırlı Hasar* (SH) performans seviyesi için $0.01h_i$, *Kontrollü Hasar* (KH) performans seviyesi için ise $0.015h_i$ değerini aşmayacaktır.

Force Demand of Isolation Units;

Force demands of units were calculated according to code yielded with the results all of the members passed the limits.

Isolation Displacement Demand;

Because of unscaled records, nonlinear analyses are not true. But the results prove that for given DD1 acceleration data, maximum time history displacement of isolation units is not exceed the design limits.