GROUND MOTION EFFECTS IN İZMİR: MEASUREMENTS IN DISACCORD WITH DESIGN SPECTRA

Vesile Hatun Akansel[1], H. Polat Gülkan[2] and Erol Kalkan[3]

ABSTRACT

The earthquake centered about 16 km north of Samos (Sisam) island that in western Turkey struck Izmir and its environment on October 30, 2020 was the first major event to occur since the new Building Earthquake Design Regulation of Turkey gained currency on January 1, 2019. The moment magnitude of the earthquake has been reported variously as 6.6, 6.9 and 7.0 by different agencies. A good many strong motion instruments were triggered in both Turkish and Greek territories, and proper interpretation of the acceleration time series from these stations will probably have enduring lessons for future regulation revisions. This paper is an early examination of selected accelerograms from the region, and focuses on possible future clashes between design spectra embedded in the current Turkish seismic regulation and implications of measurements.

INTRODUCTION

A major magnitude M_w 6.6 earthquake[4] struck offshore in the Aegean Sea about 16 km northeast of the island of Samos (named as Sisam in Turkish) (AFAD, 2020a,b). The closest settlement on the island was the city of Neon Karlovasion where an acceleration recording instrument was triggered. Doğanbey, Payamlı, Ürkmez, Gümüldür, Kavakdere were the closest coastal villages administratively linked with İzmir to the epicenter. İzmir, situated northeast at a distance of 60-65 km from the epicenter and the third largest city of Turkey with a population of over three million persons (and 4.5 million when its aggregation of urban communities is included) was the settlement that bore the brunt of strong ground shaking. In central İzmir 116 persons lost their lives, most in multistory, multifamily apartment buildings that collapsed in a recently developed part of the urban area (METU EERC, 2020, AFAD, 2020a,b, Makra et al. 2020).

A good many strong motion acceleration records were recovered from the mainshock by networks in both national territories. According to data released by AFAD (AFAD, 2020c), the Disaster and Emergency Management Authority of Turkey, the rupture originated at a depth of 16 kilometers. The earthquake affected worst the mid-rise buildings located on the young fluvial deposits of soft soil in İzmir. There was also a tsunami that reached the coastal town called Sığacık and its neighboring beaches near Seferihisar, causing more than a meter high runup and several hundred-meter inundations with unprecedented material loss. Figure 1 describes the seismic backdrop of the region in terms of the mapped faults and epicenters of former earthquakes. Table 1 lists major earthquakes since 1975 (AFAD, 2020c).

This contribution to the comprehensive Joint Turkish, Greek, EERI, GEER Reconnaissance Report focuses on the regulation implications of the records from the broad array of records. In the interest of minimizing duplications with other parts of the report we will focus only on our interpretation of the regulation implications for public safety gleaned from these records. The complete description of the earthquake and the effects it created on the built environment are described in the remainder of this

[1] Department of Civil Engineering, Muğla Sıtkı Koçman University, Kötekli, Muğla, TR
[2] Department of Civil Engineering, Başkent University, Bağlıca Campus, 06790 Ankara, TR
[3] QuakeLogic, Roseville, 95747 CA, USA

[4] There exist conflicts between moment magnitudes that have been reported by different agencies. The Disaster and Emergency Management Authority of Turkey (AFAD) lists it as M6.6. Despite concerns that this may have been misreported the agency has not retracted its value. The "Environmental Disasters & Crises Management Strategies" of the National & Kapodistrian University of Athens gives M6.9 in its Issue No. 21, of November 2020. USGS has reported a value of M7.0.

reconnaissance report. Our objective in this part is to view the picture that has been produced by the strong motion stations in the region, and the interpret its suggestions from a building construction perspective. This review will include a description of the evolution of the spectral shapes in seismic regulations in Turkey over the last sixty years.

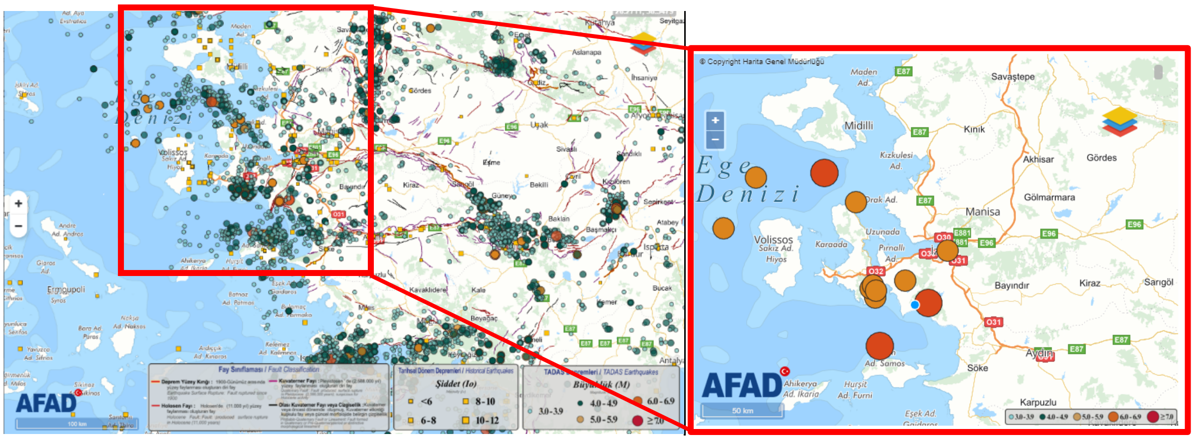


Figure 1. Quaternary faults and epicenters of earthquakes in the region surrounding İzmir. (adapted from tadas.afad.gov.tr). Left: Regional Turkish accelerometric database and earthquakes with M ≥ 3.0 since 1975. Right: Earthquakes since 1975 with 5.5 ≤ M ≤ 7.0.

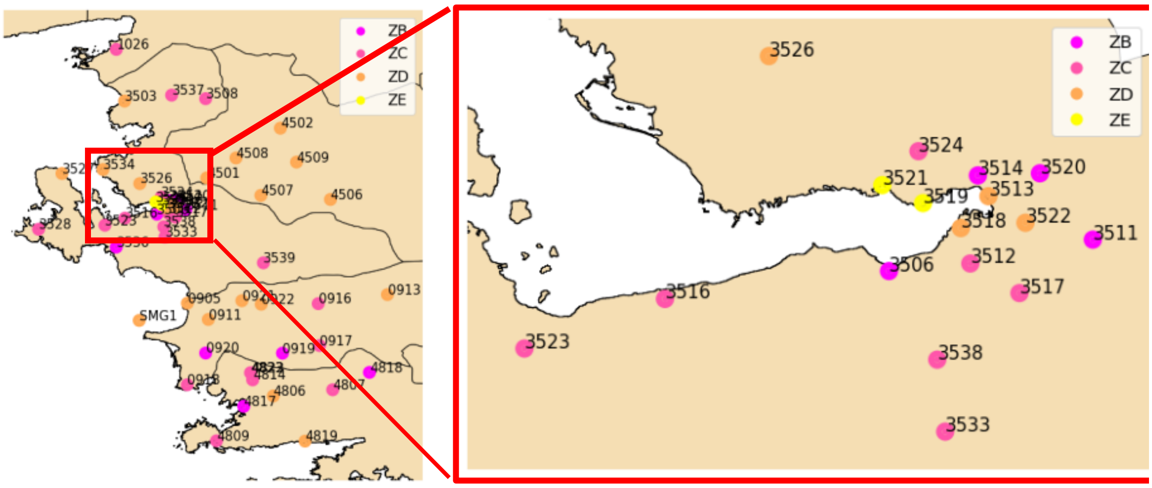
Table 1. Historical earthquakes 5.5 ≤ M ≤ 7.0 in and around İzmir since 1975 (tadas.afad.gov.tr) (AFAD, 2020c)

EventID	Event Date	Epicenter Agency	Lon.	Lat.	Type	Magnitude	Depth	Location
483762	30-10-2020	AFAD	26.7030	37.8790	M	6.6	14.9	(Sisam) (Izmir)
375576	12-06-2017	AFAD	26.3126	38.8488	M	6.2	15.86	Karaburun (Izmir)
263786	20-10-2005	GDDA	26.6708	38.1535	M	5.8	15.4	-/-/Turkey
264639	17-10-2005	GDDA	26.6406	38.2048	MD	5.5	11.0	Urla (İzmir)
253004	17-10-2005	GDDA	26.6586	38.2202	M	5.8	18.6	Urla (İzmir)
252972	17-10-2005	GDDA	26.6770	38.1921	M	5.5	20.5	-/-/Turkey
236780	10-04-2003	ISC	26.8895	38.2466	M	5.7	11.3	Urla (İzmir)
243329	10-06-2001	ISC	25.5930	38.5410	M	5.6	32.0	Aegean Sea (-)
	14-11-1997	ISC	25.8212	38.8243	M	5.8	2.3	
	20-07-1996	GDDA	27.0500	38.1200	M	6.1		
243796	24-05-1994	ISC	26.5335	38.6863	M	5.5	10.0	-/-/Turkey
247417	06-11-1992	ISC	26.9560	38.1091	M	6.0	17.2	Menderes (İzmir)
	16-12-1977	ISC	27.1882	38.4140	M	5.6	24.2	

MEASURED STRONG GROUND MOTIONS

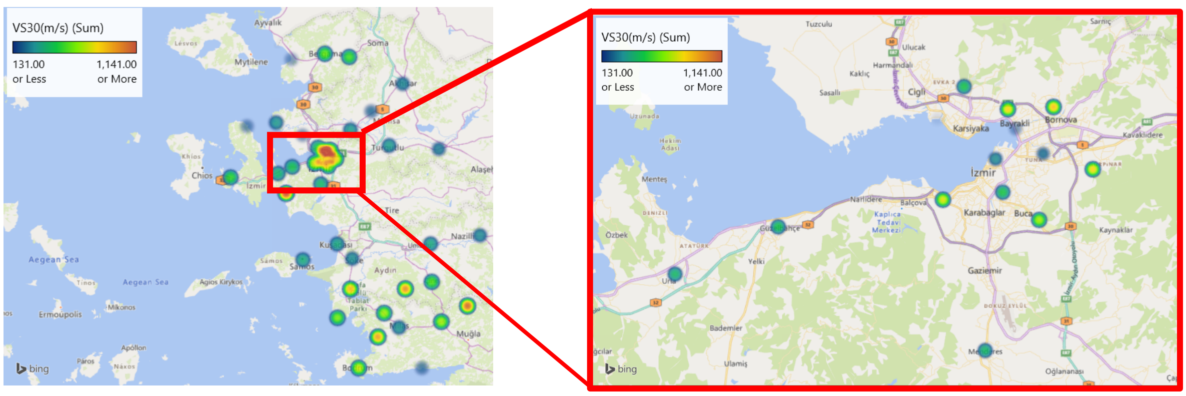
The earthquake nucleated at a point with comparable distances to the Turkish coastline and the northern edge of Samos-Sisam, but it was closer to the latter. It activated many strong motion instruments run by the respective national agencies in both countries. Table 2 lists the stations and their relevant information where ground shaking traces of significance were recovered. Owing to the wider affected area in Turkey the stations in the table are mostly those that belong to AFAD, the one exception being the Neo Karlovasi station on Samos (Sisam). We have chosen not to use any data from networks that are operated by universities or other agencies because of possible ownership or copyright issues. In Figure 2 we show the locations of these stations, given in finer detail in the immediate vicinity of İzmir. The 12 records that we will examine in finer detail later in the text are marked in Table 2 with an asterisk (*). The $V_{s,30}$ values for the stations are given in Figure 3. In Figure 4 we show in color-coded format the measured pga values that belong to the stations in that figure. The largest pga value of 0.23 g is associated with the E-W components of the Samos trace. No component with a value exceeding 0.18 g exists for the remainder. These values might in conventional wisdom be interpreted as being rather muted. The majority of the site classes for the stations comprises soft (ZD) or stiff soil (ZC) profiles. Nine stations operated by AFAD sit on Class B ($v_{s,30\,m}$ > 700 m/s, and 4 on Class E ($v_{s,30\,m}$ < 200 m/s).

The three-component records from the selected 12 stations are arrayed in Figure 5.



(a) (b)

Figure 2. a) Strong ground motion stations within 150 km from the epicenter of the Sisam Earthquake; numbers indicate station codes according to AFAD b) İzmir, closer stations with focus on the Bayraklı district



(a) (b)

Figure 3. V_{S30} values at selected strong motion stations operated by AFAD. The minimum and maximum V_{S30} values are given on the legends.

Table 2. Strong motion stations (tadas.afad.gov.tr, ITSAK-EPPO Network [AFAD, 2020c, ITSAK, 2020a, NOA, 2020)]

Station Code	Name	V_{S30} (m/s)	Latitude	Longitude	PGA_NS (cm/s^2)	PGA_EW (cm/s^2)	PGA_UD (cm/s^2)	Rjb (km)	Rrup (km)	Repi (km)	Rhyp (km)	Soil Class	S_s	S_1	Mw
SMG1	Sisam/Samos*	380	37.7	26.84	158	227	134	-	-	15	-	ZD	-	-	6.9
0905	Kuşadası*	369	37.86	27.27	179	144	80	36	41	43	46	ZD	1.1	0.3	6.6**
911	Söke*	307	37.76	27.39	48	67	47	48	53	56	58	ZD	1.3	0.3	6.6
0913	Aydın-Kuyucak	301	37.91	28.47	7.5	11	4.2	141	142	148	149	ZD	1.4	0.3	6.6
0916	Aydın-Köşk	371	37.86	28.05	9.8	15	7.4	104	106	112	113	ZC	1.4	0.4	6.6
0917	Çine	580	37.61	28.06	13	13	8.6	110	111	117	118	ZC	0.8	0.2	6.6
0918	Didim	630	37.37	27.26	38	31	21	64	68	72	74	ZC	0.8	0.2	6.6
0919	Karpuzlu	986	37.56	27.84	21	18	15	93	95	100	101	ZB	0.8	0.2	6.6
0920	Söke-2	894	37.56	27.37	26	31	22	57	60	64	66	ZB	1.0	0.2	6.6
3503	Dikili	193	39.07	26.89	56	45	17	125	127	132	133	ZD	1.0	0.2	6.6
3506	Konak*	771	38.39	27.08	44	41	24	55	59	62	64	ZB	1.1	0.3	6.6
3508	Kınık	558	39.09	27.37	14	17	7.5	136	137	143	144	ZC	1.0	0.2	6.6
3511	Bornova-Enko	827	38.42	27.26	29	41	19	65	68	73	74	ZB	1.1	0.3	6.6
3512	Buca*	468	38.4	27.15	58	57	28	58	62	66	68	ZC	1.1	0.3	6.6
3513	Bayraklı*	195	38.46	27.17	106	95	44	65	68	72	74	ZD	1.1	0.3	6.6
3514	Bayraklı-Teknik Lise*	836	38.48	27.16	39	56	25	66	69	73	75	ZB	1.1	0.3	6.6
3516	Güzelbahçe	460	38.37	26.89	47	48	32	47	51	55	57	ZC	1.1	0.3	6.6
3517	Buca-Dokuz Eylül	695	38.38	27.19	40	36	20	58	61	65	67	ZC	1.1	0.3	6.6
3518	Konak-Kültürpark*	301	38.43	27.14	106	91	31	61	64	68	70	ZD	1.1	0.3	6.6
3519	Karşıyaka-Orman İşletme*	131	38.45	27.11	150	110	34	62	65	69	71	ZE	1.1	0.3	6.6
3520	Bornova-İstasyon	875	38.48	27.21	36	59	19	68	71	76	78	ZB	1.1	0.3	6.6
3521	Karşıyaka	145	38.47	27.08	111	94	40	62	66	70	72	ZE	1.1	0.3	6.6
3522	Bornova	249	38.44	27.2	74	64	25	64	67	71	73	ZD	1.1	0.3	6.6
3523	Urla	414	38.33	26.77	80	64	37	42	46	49	52	ZC	1.1	0.3	6.6
3524	Karşıyaka-2	459	38.5	27.11	65	68	30	66	69	74	75	ZC	1.1	0.3	6.6
3526	Menemen	205	38.58	26.98	89	82	29	71	74	79	80	ZD	1.0	0.2	6.6
3527	Karaburun	207	38.64	26.51	81	57	47	79	82	87	88	ZD	1.1	0.3	6.6
3528	Çeşme*	532	38.3	26.37	118	149	77	51	55	58	61	ZC	1.0	0.2	6.6
3533	Menderes*	415	38.26	27.13	74	46	37	44	49	51	54	ZC	1.0	0.3	6.6
3534	Foça*	327	38.66	26.76	73	92	38	79	81	86	88	ZD	1.1	0.3	6.6
3536	Seferihisar	1141	38.2	26.84	50	79	31	27	34	35	38	ZB	1.1	0.3	6.6
3537	Bergama	608	39.11	27.17	7.5	7.8	7.1	133	134	140	141	ZC	1.1	0.2	6.6
4501	Manisa-Yunusemre	340	38.61	27.38	35	40	24	89	91	96	98	ZD	1.2	0.3	6.6
4502	Akhisar	292	38.91	27.82	23	29	12	138	140	146	147	ZD	1.0	0.2	6.6
4506	Salihli	273	38.48	28.12	24	22	22	128	129	135	136	ZD	1.1	0.3	6.6
4507	Turgutlu	341	38.51	27.71	27	34	19	99	101	106	108	ZD	1.2	0.3	6.6
4508	Saruhanlı	229	38.73	27.56	35	39	16	109	110	116	117	ZD	1.0	0.2	6.6
4806	Milas-3	323	37.3	27.78	23	26	7.4	102	104	110	111	ZD	0.9	0.2	6.6

Table 2 (Cont.). The strong motion stations (tadas.afad.gov.tr, ITSAK-EPPO Network)

4807	Yatağan	696	37.34	28.14	8.3	4.3	3.5	127	129	134	135	ZC	0.8	0.2	6.6
4809	Bodrum	747	37.03	27.44	8.2	9.3	6.6	104	106	112	113	ZC	1.0	0.2	6.6
4814	Milas-2	694	37.4	27.66	25	23	10	87	90	95	96	ZC	0.8	0.2	6.6
4817	Milas-4	948	37.24	27.6	16	14	7.6	95	97	102	104	ZB	0.9	0.2	6.6
4818	Kavakdere	1080	37.44	28.36	6.9	3.9	3.4	140	142	148	149	ZB	0.7	0.2	6.6
4819	Milas-5	219	37.03	27.97	16	15	7.4	135	136	142	143	ZD	1.1	0.3	6.6
1026	Balıkesir-Gömeç	-	39.38	26.84	24	31	9.1	159	160	166	167	-	1.0	0.2	6.6
3538	Gaziemir	-	38.32	27.12	85	77	39	49	53	57	59	-	1.1	0.3	6.6
3539	Tire	-	38.1	27.72	38	27	22	79	81	86	88	-	0.8	0.2	6.6
4822	Milas	-	37.44	27.65	33	80	38	84	86	91	93	-	0.8	0.2	6.6
4823	Milas-6	-	37.44	27.64	23	26	19	84	86	91	93	-	0.8	0.2	6.6
921	Germencik	-	37.87	27.59	55	71	23	64	67	72	73	-	1.3	0.3	6.6
922	İncirliova	-	37.85	27.71	60	59	56	74	77	82	83	-	1.4	0.3	6.6
4509	Gölmarmara	-	38.71	27.92	9.1	10	5.8	128	129	135	136	-	1.0	0.2	6.6

* Stations whose records have been used for further processing.
** See Footnote 4.

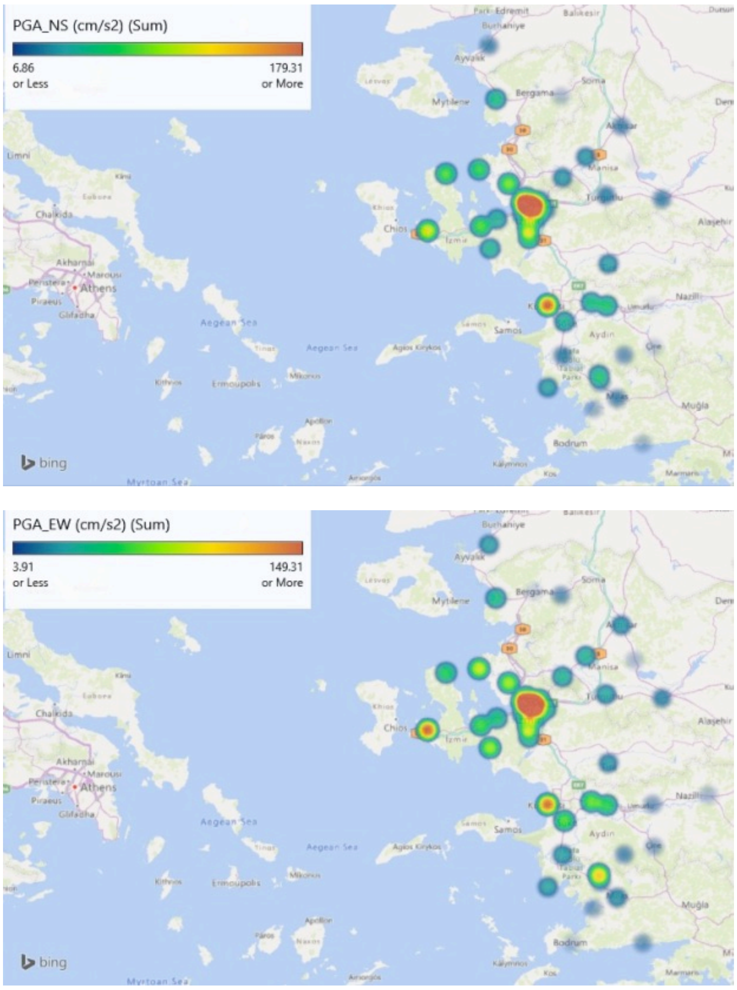


Figure 4. Peak ground accelerations recorded at selected stations in North-South (NS) and East-west (EW) directions in and around İzmir.

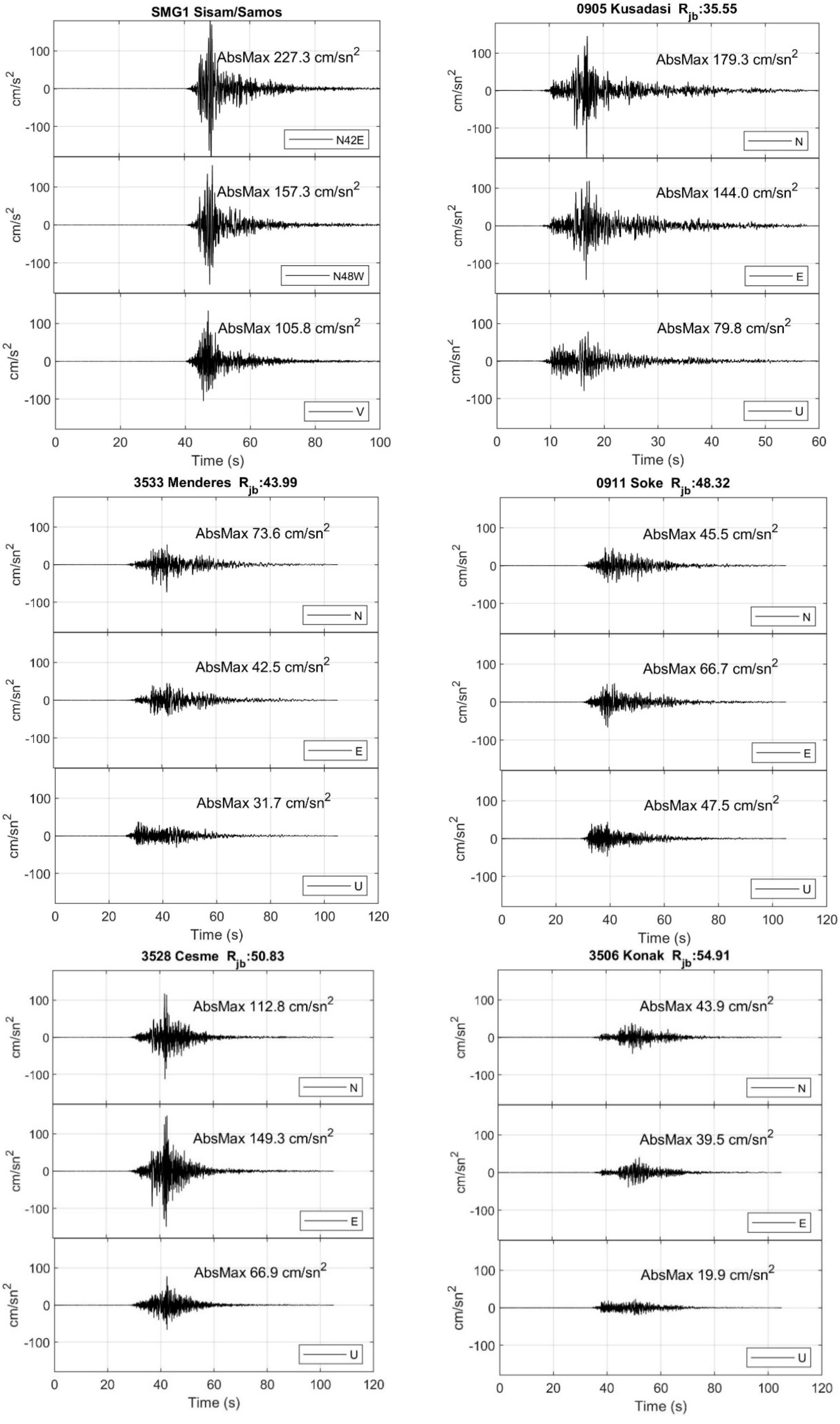


Figure 5. Ground motion records at selected stations (Rjb = Joyner-Boore distance; N: North-South; E: East-West; U: Up-down).

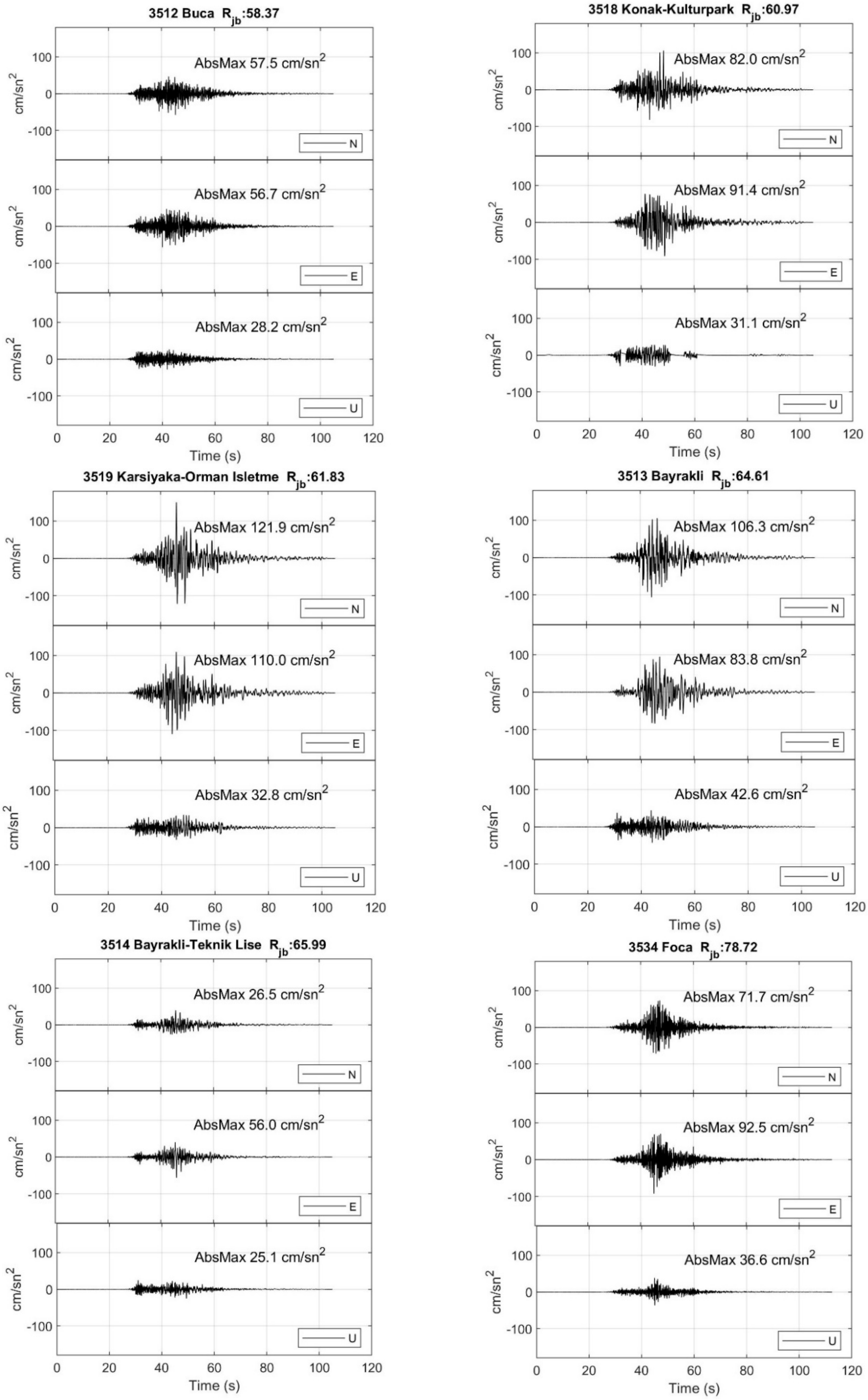


Figure 5 (Cont.). Ground motion records at selected stations (Rjb = Joyner-Boore distance; N: North-South; E: East-West; U: Up-down).

PREDICTED VS MEASURED GROUND MOTION PARAMETERS

The focus of engineering seismology during the course of the last fifty years has been on the prediction of the various indicators that permit safer design for components of the built environment. Initially the interest focused on peak ground acceleration because this is a parameter that is associated with the destructive power of an earthquake, serves to construct a design spectrum and is instinctively recognized as a distinct parameter that serves conveniently in ranking different earthquakes. There exist other measures of earthquake characterization, and there are ample grounds for promoting ground velocity, displacement and other indicators such as Arias or Housner intensities as more stable quantities to use in engineering applications. The basic challenge is, given magnitude, distance and the site geology can we come up with what to expect in terms of ground shaking during a future earthquake? This is of crucial importance in achieving the safety objectives of rational design in addition to explaining the complex chain of events that cause a part of the crust to rupture and release energy that is conveyed away from the source. The processes that occur in the crust of the earth are poorly known, however, and do not lend themselves to formulations based on the few natural laws of science. This has forced earth scientists to resort to statistics in the hope that future earthquakes will mimic past ones in some way. They do, statistically speaking, but each earthquake still harbors enough differences from our collection of instruments of predictive power to foreshadow what ground motion will occur at a given point given an earthquake nearby. A compendium assembled by Douglas (2018) is instructive in displaying the magnitude of the intellectual capital that has been invested in ground motion prediction equations (GMPEs).

The relatively abundant records that have been recovered from the October 30, 2020 earthquake in the north Samos-Sisam area enable a very limited test of a few GMPEs to be run within the limitations of this preliminary report. The yardsticks that we use are the functionals that have been developed by Kalkan and Gülkan (2004), Boore et al. (2014) and Kale et al. (2015). Figures 6 – 8 each contains 9 frames with curves in it: three different references listed here, three different ground motion indexes pga, SA(T = 0.2 s), SA(T = 1.0 s) and three different $v_{s, 30\ m}$ values: 200, 400 and 700 m/s. We have accounted for the uncertainty in the magnitude of the earthquake by marking the GMPE curves for the disputed value of M = 6.6 and the more readily adopted M = 7 in each frame.

We refrain at this early stage from making any quantitative judgment of the goodness of any of these GMPEs. In other parts of this Report such issues are treated more comprehensively. It appears that, if any bias is truly revealed by these curves, the magnitude value appears to be smaller than 7.

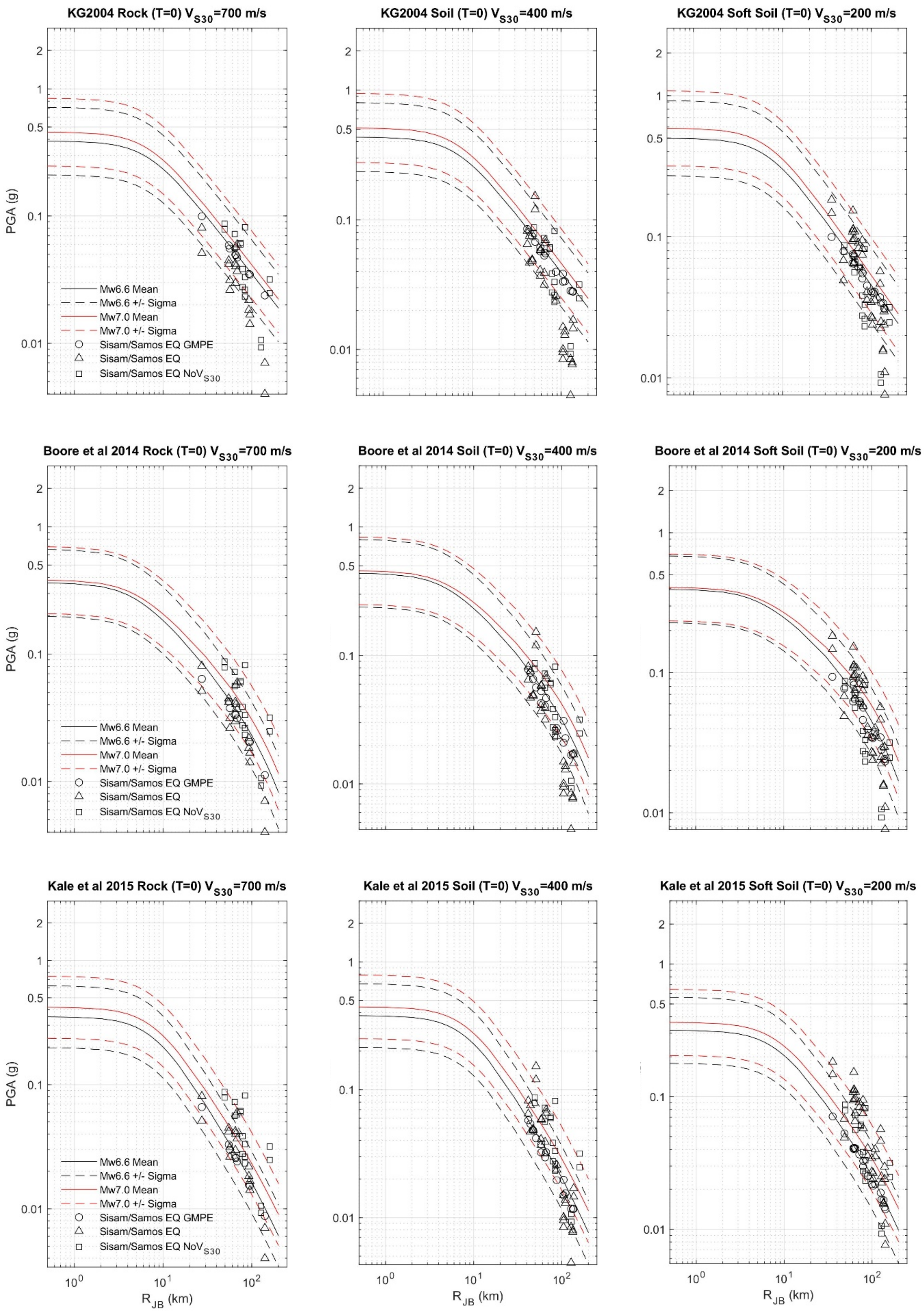


Figure 6. PGA predictions vs measurements among three GMPEs.

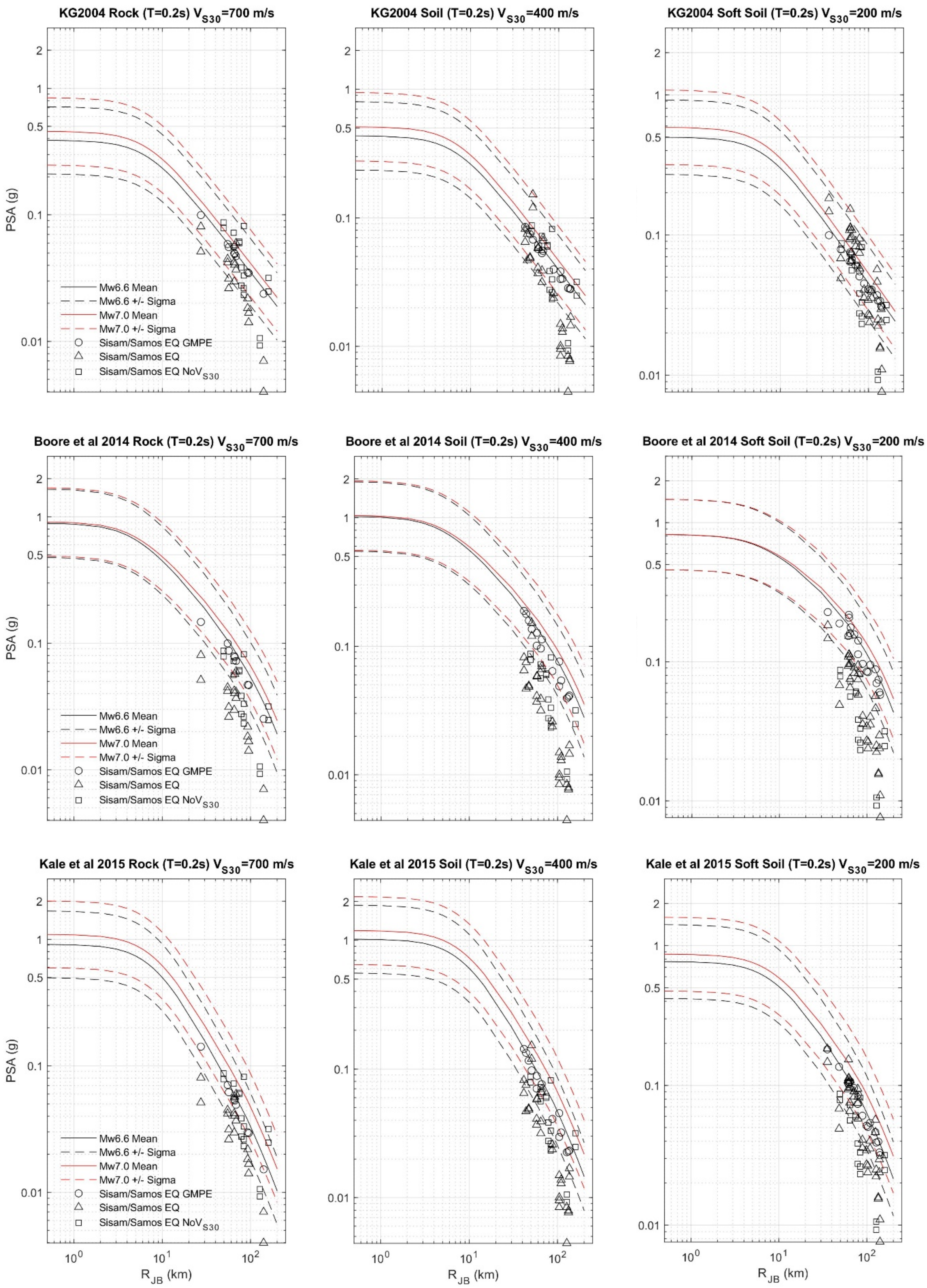


Figure 7. SA(T = 0.2 s) predictions vs measurements among three GMPEs.

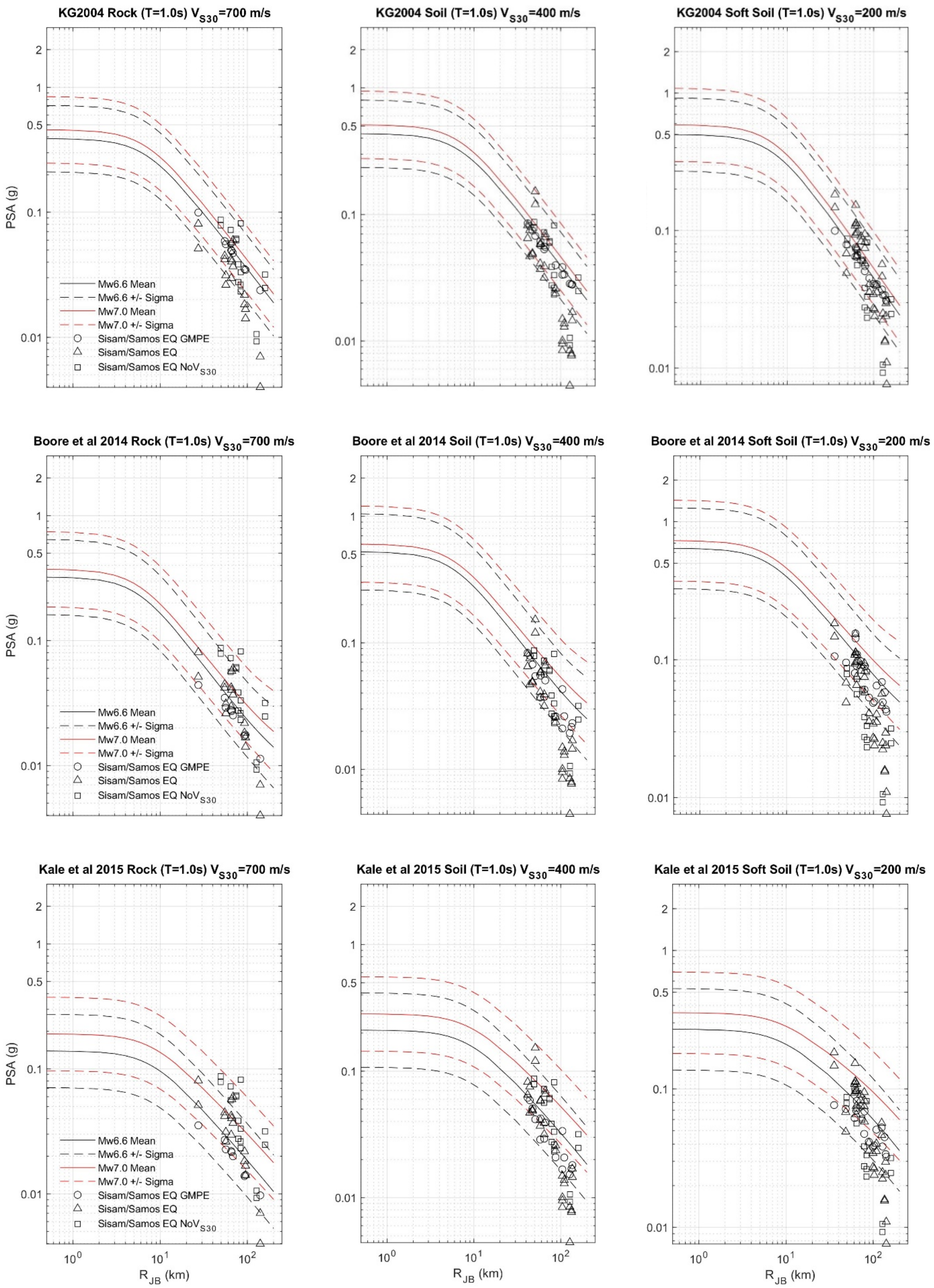


Figure 8. SA(T = 1.0 s) predictions vs measurements among three GMPEs.

EARTHQUAKE ZONE MAP VS HAZARD MAP

Until 2019 seismic design for buildings and other civil engineering structures in Turkey included in the Regulation was carried out in relation to a seismic zones map that was promulgated by forerunner public agencies of AFAD. Starting with the 2019 update engineers are now required to abide with the provisions of the Seismic Building Regulation of Turkey (with a name that is truncated to TBDY) that refers to the Earthquake Hazard Map of Turkey (accessible at tdth.afad.gov.tr). The interactive map permits the determination of hazard with precisely defined return periods, and given the soil characterization information, it will prepare a short report with a design spectrum that is suitable as input to the computational platform used by the engineer. The numbers that define the ordinates of the design spectrum are made available to the user.

Using this feature of the hazard map we have plotted the local site geology matched design spectrum for all 12 stations with the exception of Samos-Sisam that lies outside TDTH, and superposed that figure on the response spectrum of the two horizontal components of the recorded motion in Figure 6. Not unexpectedly, all of the response spectrum curves in Figure 9 fall below what TDTH currently dictates. Had TDTH been in effect when the buildings in İzmir that performed poorly had been designed then the causes of that performance should be sought elsewhere.

But TDTH and its affiliated Regulation wasn't in effect in the 1980s and 1990s when the poorly performing buildings of 2020 were designed. While these types of spectra serve different purposes, it is of more than idle curiosity to examine the similarity of their shapes because that has a significant impact on the capacity of buildings that are being analyzed and designed today for an earthquake that is yet to occur. The part of the building stock that is currently being created must not have deficiencies on account of the dissimilarities between ground shaking effects that the Regulation insists they should be designed for, and those that the recorded experience of the event on October 30, 2020 has revealed.

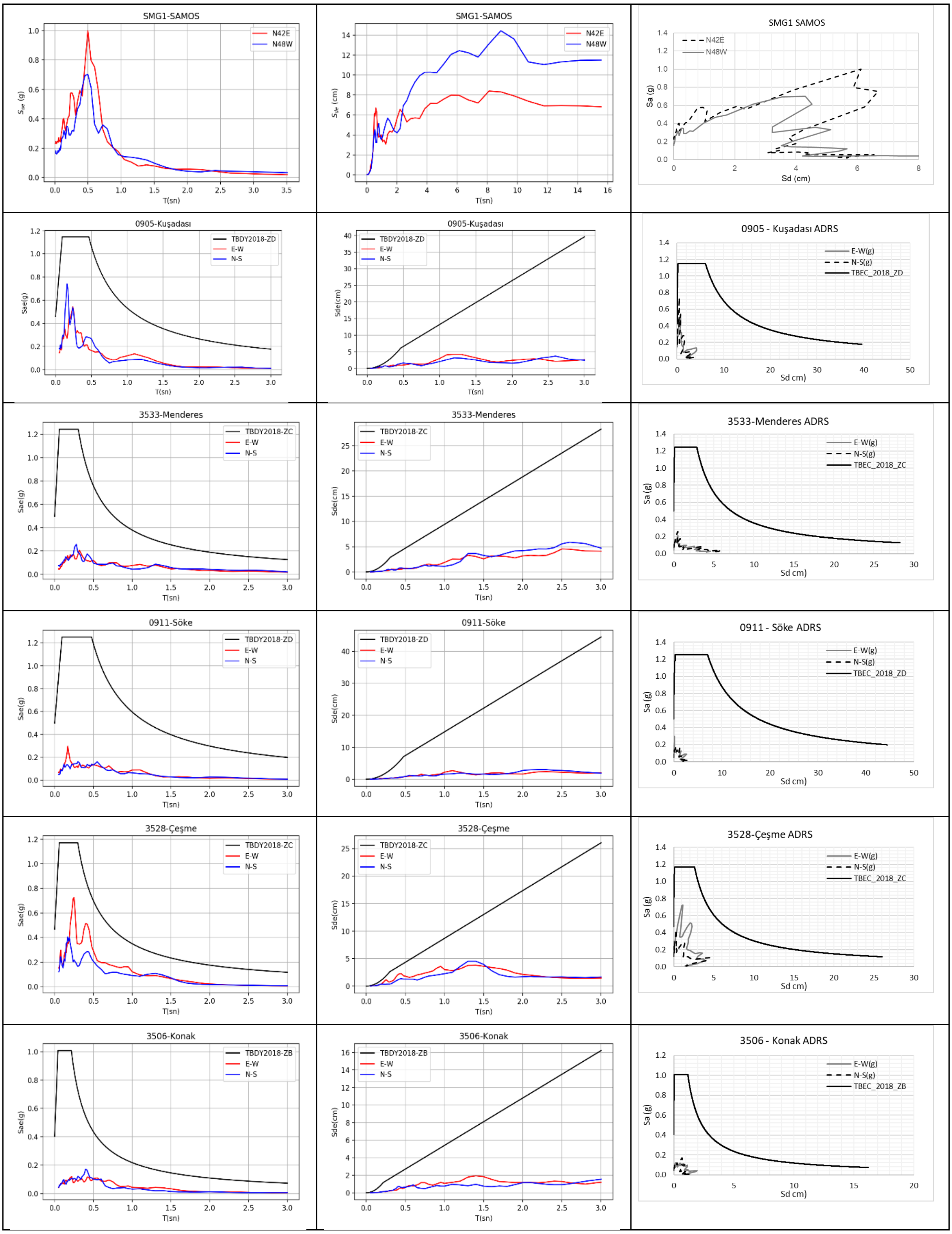


Figure 9. Spectral accelerations, spectral displacements and acceleration-displacement-response-spectrum (ADRS) plots at selected stations with the corresponding regulation-based design spectrum.

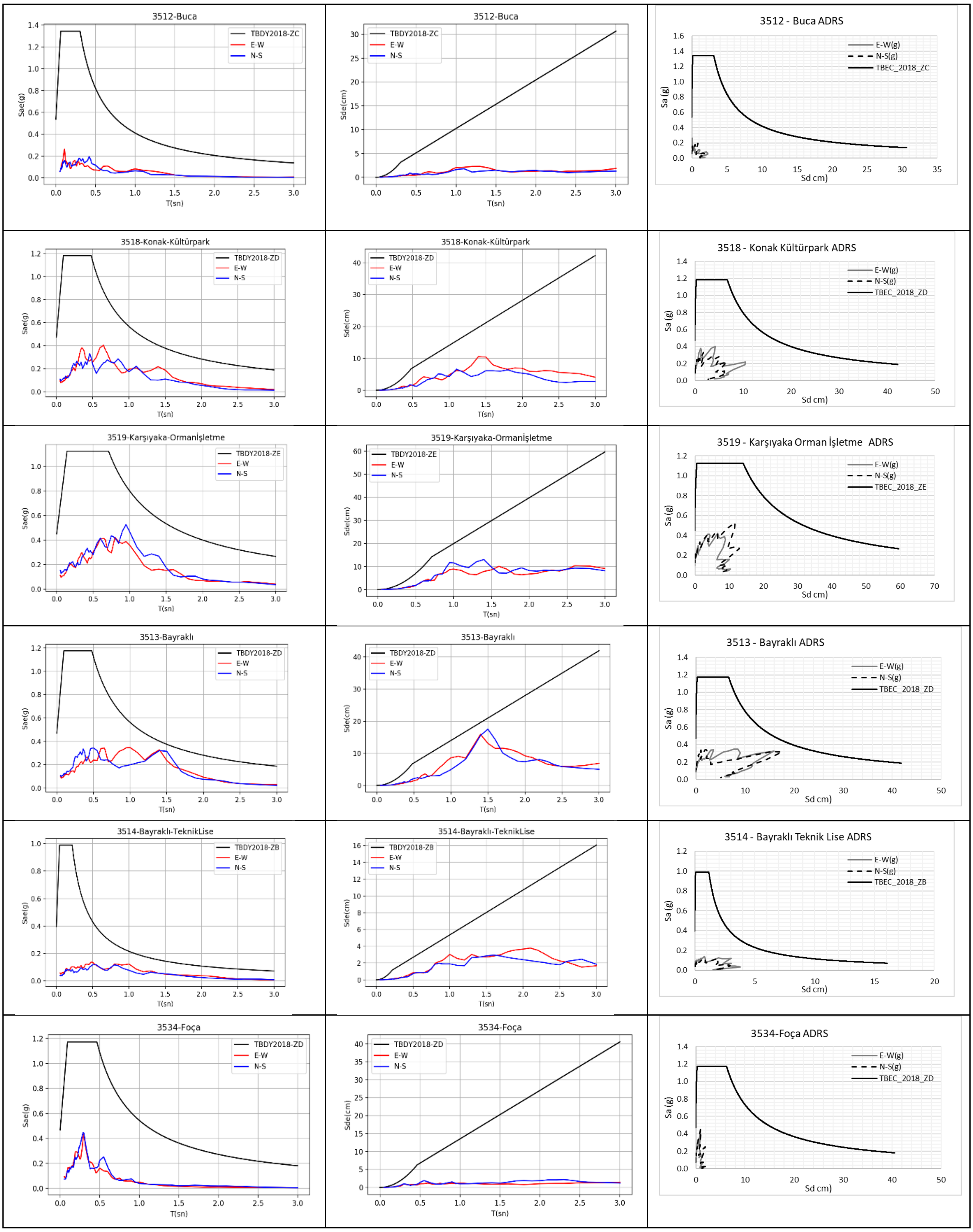


Figure 9 (Cont.). Spectral accelerations, spectral displacements and acceleration-displacement-response-spectrum (ADRS) plots at selected stations with the corresponding regulation-based design spectrum.

EVOLUTION OF THE SPECTRAL SHAPE SPECIFIED IN TURKISH REGULATIONS

A word is in order at this point concerning the evolution of the spectral shapes that successive updates of the Turkish Regulation have prescribed This brief account is partly excerpted from Gülkan (2000).

The first seismic building regulation to be issued after the creation of the Ministry of Reconstruction and Resettlement is dated from 1961. The title of the regulation was lengthy and cumbersome: "Regulation for Buildings to Be Built in Disaster Areas." (The title survived until 2019.) Municipal governments, where they existed, were designated as enforcers of the regulation, and the Councils of Village Elders were empowered in rural areas. This document ignored the dynamic character of seismic design, and did not provide any guidance on the distribution of the base shear or its dependence on the building period.

A revised Regulation was issued in 1968 (TEC 1968). In addition to the customary detailing and construction requirements this document contained an improvement over its predecessor because the base shear coefficient C was made a function of the calculated fundamental period of the building, and the inverted triangular distribution of the story level lateral forces was formulated. In terms of the basic magnitude of the lateral force, not much was changed:

The base shear coefficient $C = C_0\ \alpha\ \beta\ \gamma$

The Zone Factor C_0 that we may interpret as the indicator of hazard varied as follows:

Zone	C_0
1	0.06
2	0.04
3	0.02

The coefficient α was called the "soil" factor, and varied between 0.8 – 1.2, increasing for soft soilr conditions. β was the importance factor, and equaled 1.5 for critical facilities including all public assembly buildings and 1.0 for most others. The factor γ was the dynamic coefficient, and for period T < 0.5 s, it equaled 1.0. For T > 0.5 s, $\gamma = 0.5/T$. This way, the constant velocity fall-off in the spectrum was fixed for a period of 0.5 s.

The 1975 (TEC 1975) issue of the Regulation addressed a conflict in the number of seismic zones, and brought many additional requirements in the design and detailing of reinforced concrete buildings. This update was influenced partly by the "Blue Book," the California design requirements of the time. One important revision was the increase of the basic base shear coefficient for Zone 1 from 0.06 to 0.10, a 67 percent change. The remaining zones were also proportionately increased. The 1975 regulation (TER 1975) is generally considered to be an adequate seismic regulation, although a retroactive evaluation of it has not been done.

The 1975 base shear coefficient was expressed as

$$C=C_0 \text{ x } K \text{ x } S \text{ x } I$$

With K referring to the building framing type and I referring to building importance, the number S was designated as the spectrum coefficient that was a function of the site soil profile.

$$S = \frac{1}{|0.8 + T - T_0|} \leq 1$$

Here T designated the building's fundamental period and T_0 the tabulated dominant site period. For softer soil profiles T_0 is larger, with recommended mean values shown in Figure 10. The figure below shows the variation of S where the four classes of classes are listed as I - IV.

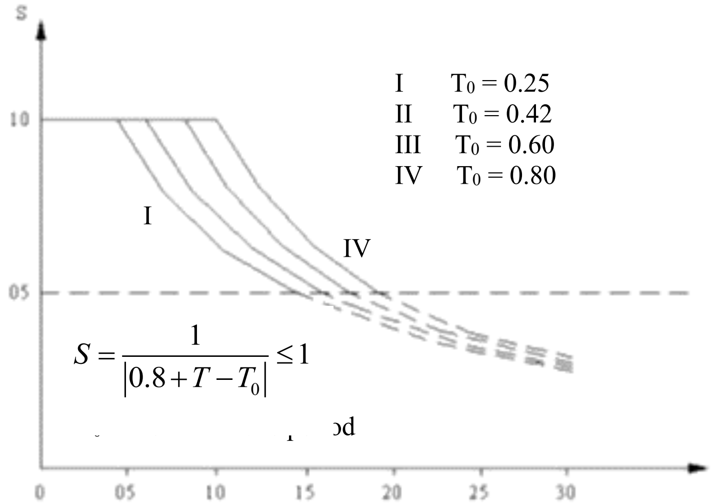


Figure 10. Spectral coefficient in the 1975 Regulation.

The penultimate revision of the Regulation became effective in 1998, accompanied, for the first time, by a probabilistically determined map. The Regulation was augmented in 2007 with the inclusion of retrofit requirements, but the part dealing with the spectral analysis part was left unchanged. The design spectrum is shown in Figure 11, and the two corner periods are listed in Table 3. In the interest of a "safety margin" the decay of the spectral coefficient with increasing period was formulated as $T^{0.8}$. This contravened structural dynamics principles and both the 1968 and the 1975 Regulations (TEC 1975,1998).

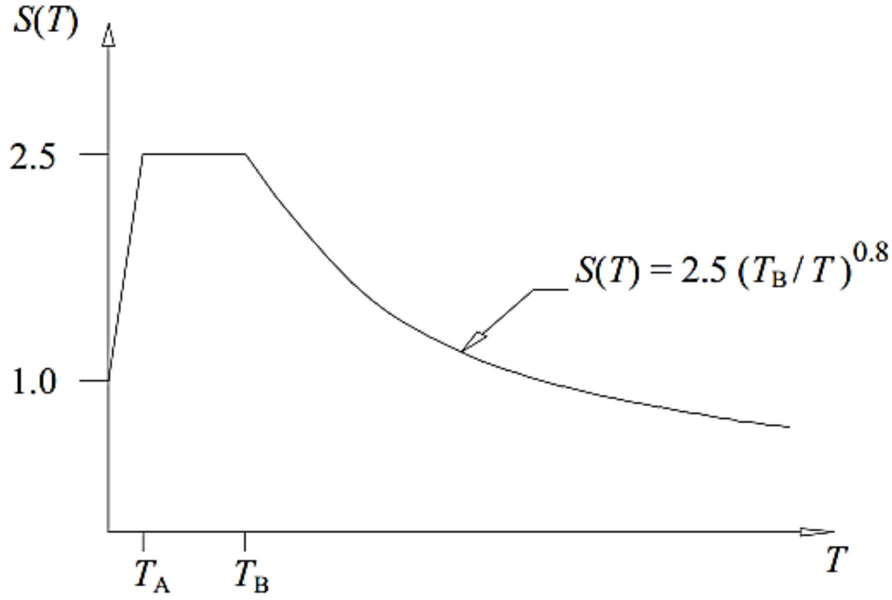


Figure 11. Spectral coefficient in the 1998 (2007) Regulation.

Table 3. Spectrum corner periods (T_A, T_B) in the 1998 (2007) Regulation

Local Site Class	T_A *(second)*	T_B *(second)*
Z1	0.10	0.30
Z2	0.15	0.40
Z3	0.15	0.60
Z4	0.20	0.90

Assuming that the soil profile descriptions between the 1975 and 1998 issues match exactly (they don't, but for purposes of this discussion they can be assumed to correspond) then the roll-off periods have been revised as follows:

Soil Type 1975	T_B, s	Site Class 1998	T_B, s
I	0.45	Z1	0.3
II	0.62	Z2	0.4
III	0.80	Z3	0.6
IV	1.0	Z4	0.9

The part dealing with the design spectrum analysis in the 2019 Regulation is a replication of ASCE7-16 (ASCE/SEI (2016)) with a few arbitrarily eyeballed values inserted into the tables for F_a and F_v.

2019 Regulation: $F_s = F_a$

Site Class	$S_S \le 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S = 1.25$	$S_S \ge 1.50$
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.9	0.9	0.9	0.9	0.9	0.9
ZC	1.3	1.3	1.2	1.2	1.2	1.2
ZD	1.6	1.4	1.2	1.1	1.0	1.0
ZE	2.4	1.7	1.3	1.1	0.9	0.8
ZF	Site investigations must be done.					

2019 Regulation: $F_1 = F_v$

Site Class	$S_1 \le 0.10$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 = 0.50$	$S_1 \ge 0.60$
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.8	0.8	0.8	0.8	0.8	0.8
ZC	1.5	1.5	1.5	1.5	1.5	1.4
ZD	2.4	2.2	2.0	1.9	1.8	1.7
ZE	4.2	3.3	2.8	2.4	2.2	2.0
ZF	Site investigations must be done.					

The design spectrum is then constructed as described in Figure 12.

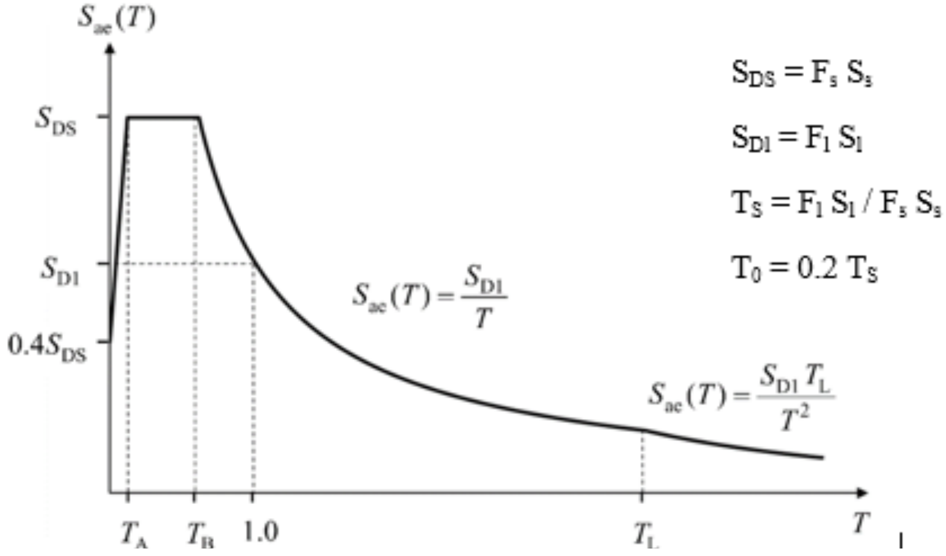


Figure 12. Construction of the design spectrum, Turkish Regulation 2019.

The velocity roll-off period is therefore made dependent on the vagaries of spectral accelerations at 0.2 s and 1.0 s and the equally erratic multipliers F_S and F_1. They are all controlled by the flawed site response proxy $v_{s,\,30\,m}$ as we surmise in the next section. The statistics of none of these variables are known a priori in most applications, and it is not surprising that we might be confronted by results that are counterintuitive or even counterfactual.

COMPARISON WITH MEASURED SPECTRA

A theoretical question of debatable admissibility may now be framed as follows. If the ground motion at each station location had been at the same level that TDTH says it will be on average every 475 years over very long periods of time for the same soil class of that station, then what would the corresponding response spectrum curve look like? We do this by upscaling the response spectrum from the measured ground motion by a factor equal to 0.4 SA(T = 0.2 s)/$(pga)_{measured}$. This way both sets of curves share the same point at very small periods, but the rest of the graphics displays the disaccord between implied spectral demands according to the current Turkish Regulation and the measured earthquake ground motions. We are not unaware that the seismic hazard in İzmir is not significantly controlled by the faulting that caused the October 30, 2020 earthquake and that longer period components that appear in Figure 13 are caused by the distance effects and surface waves. The results are displayed in Figure 13 where a consistent pattern emerges. With the arguable exception of the stations in Kuşadası, Söke and Foça the remaining 8 stations are dominated by demands in the 0.9 s – 1.6 s range that the custom-tailored design spectrum in the Regulation does not recognize. This range corresponds to the first period of many of the 8 – 15 story buildings in the stock that is being developed today. Extrapolating this observation an all-important question arises that begs an answer: if all buildings during the next thirty years are designed using the spectral shape in Regulation 2019 (TBEC (2018)) do we run the risk of exposing part of the future building stock to possible under capacity? Amplification factors F_s and F_1 that omit dependence on frequency may be partially responsible for that anomaly.

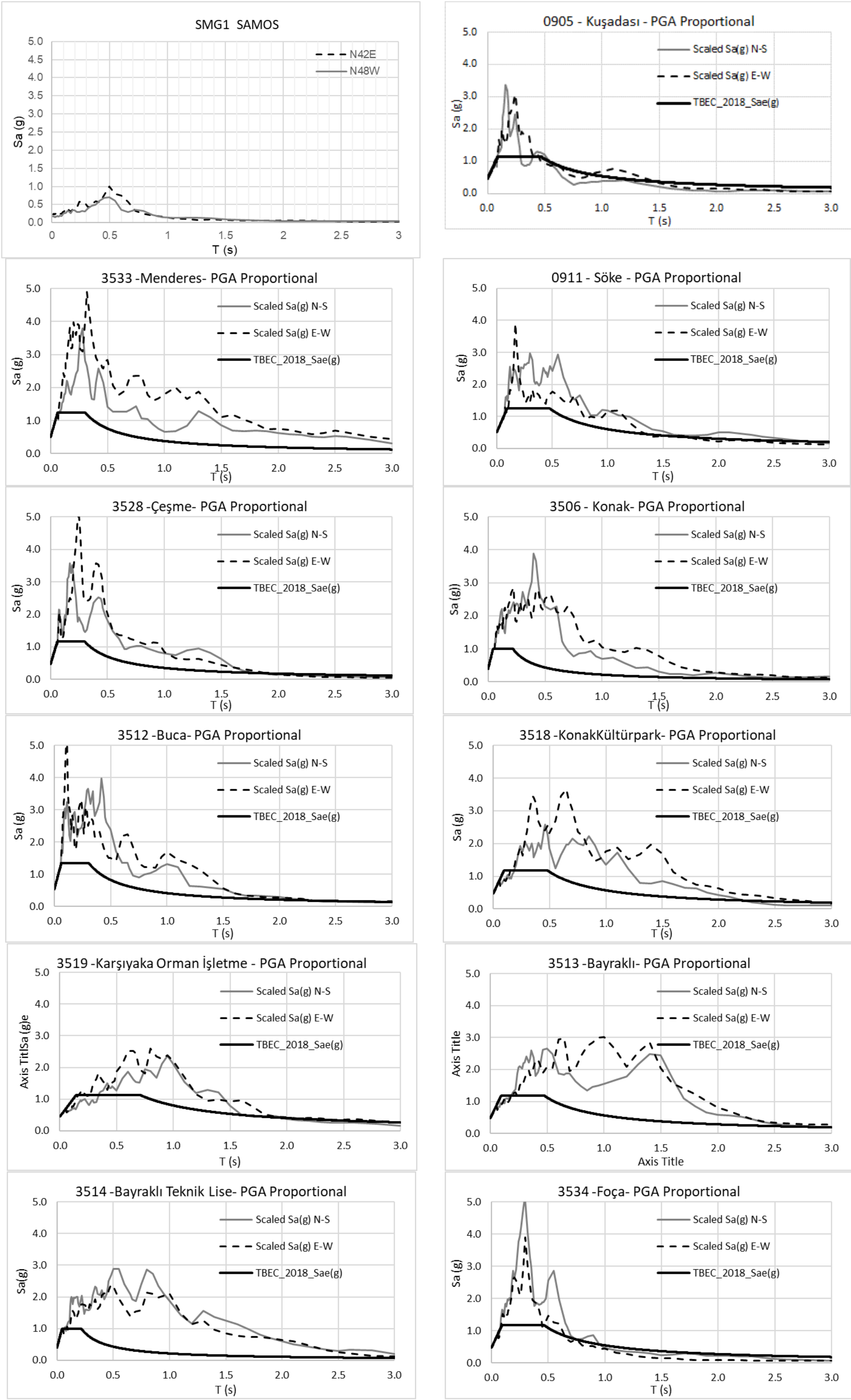


Figure 13. Scaled spectral accelerations with respect to PGA of the regulation-based spectrum at selected stations.

CONCLUSIONS

The earthquake that struck on October 30, 2020 offshore from the shores of Samos (Sisam) in Greece and the middle part of the western Turkish coastline has generated a sizeable number of strong motion records in both countries while permitting an exhaustive set of investigations to be launched for other aspects of a major seismic event. Every earthquake creates its own opportunities to learn lessons for better protection of the public. In this part of the joint report, we have concentrated on the implications of the ground acceleration records. A new seismic Regulation has gone into effect in Turkey at the beginning of 2019, and it is an opportune time now to evaluate some of its merits as an instrument of safe design. Of course, seismic design requirements do not all relate to the narrow band of items that deal with the spectral properties of future ground motions, but ultimately, they shape the rest of those requirements in some intrinsic way. As distillers of knowledge to be collected from our observations we cannot drape our eyes by pulling gauze over them and escape into contrived reality. Instead, we must compare what nature has informed us with our anticipation of codified wisdom in technical documents.

We find evidence that the design spectrum in the new Turkish Regulation may miss the longer period demand which this earthquake (and possibly others in the future) has generated. There may be many causes of the omission, but we surmise that the uncertainty in weaving together S_s, S_l, F_s and F_l to come up with a lean design spectrum may be too optimistic. The topic needs further investigation. Regardless of how attractive a theory looks to the eye, if it doesn't match facts most of the time then it cannot but be incorrect.

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