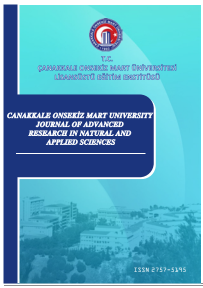
e-ISSN 2757-5195



Çanakkale Onsekiz Mart University
Journal of Advanced Research in Natural and Applied Sciences
Open Access

doi.org/10.28979/jarnas.1024247 2022, Vol 8, Issue 3, Pages: 527-542 dergipark.org.tr/tr/pub/jarnas

The Effect of Vertical Earthquake Motion on Steel Structures Behaviour in Different Seismic Zones

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Article History
Received: 16.11.2021
Accepted: 03.03.2022
Published: 25.09.2022
Research Article

Abstract − Each geographical location has its own seismicity and this affects the seismic behaviour of structures. In this study, four different settlements with different seismicity such as İzmir, Bitlis, Samsun and Konya were considered. Seismic risks and parameters for these provinces were compared. Analyses were carried out separately for a ten-storey steel building with the same structural characteristics in each of these provinces. The sample building model was created by considering the provisions of Principles for the Design, Calculation and Construction of Steel Structures-2016 and Turkish Building Earthquake Code-2018. The nonlinear time history analysis method for the sample steel building was made separately for each province considering different earthquake directions, by using the SAP200 program. Records of the 2020 İzmir earthquake (Mw=6.9) were used in the analyses. The displacement, base shear force and moments were obtained for each province for each direction taken into account. The aim of the study is to reveal the effect of both earthquake direction and different seismic regions. The displacement, rotation, base shear force and moment values obtained in the provinces with higher PGA values were also higher. It was determined that the vertical earthquake effect did not significantly change the results obtained for the horizontal direction in this study.

Keywords − *Steel structure, site-specific, tbec-2018, vertical earthquake effect*

1. Introduction

Earthquake resistant building design principles should be considered in structures to be built in high earthquake-risk areas. It is inevitable to change and update these principles over time depend on the developments in the civil and earthquake engineering fields (Büyüksaraç et al., 2021; Aksoylu et al., 2020). Studies on Turkey's earthquake hazard map and seismic design codes were initiated after 1939 Erzincan (Mw = 7.9) earthquake, that was known as the largest and most destructive earthquake in the country and continued with earthquakes that induced significant casualties over time (Özmen, 2012; Işık, 2021). The legal earthquake zonation map in Turkey was arranged in 1945, initially. (Özmen and Pampal, 2017). The maps, which were changed in 1945, 1947, 1963, 1972, were updated in 1996 and this map was used until 2018. The earthquake hazard map was also updated and started to be used according to Turkish Building Earthquake Code (TBEC-2018), that was updated in 2018 (Özmen, 2012; Işık et al., 2021a). Turkey earthquake hazard maps used so far are given in Table 1 comparatively.

Table 1

Earthquake hazard maps used in Turkey

Year	Names of Maps	Method Used	Zoning Type	Number of Zones
1945	Earthquake Zones	Damage based	Regional	3
1947	Earthquake Zones	Damage based	Regional	3
1963	Earthquake Zones of Turkey	Deterministic	Regional	4
1972	Earthquake Zones of Turkey	Deterministic	Regional	5
1996	Earthquake Zones of Turkey	Probabilistic	Regional	5
2018	Turkish Earthquake Hazard	Probabilistic	Site-specific	Site-specific

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The six earthquake hazard maps used in Turkey are shown in Figure 1.

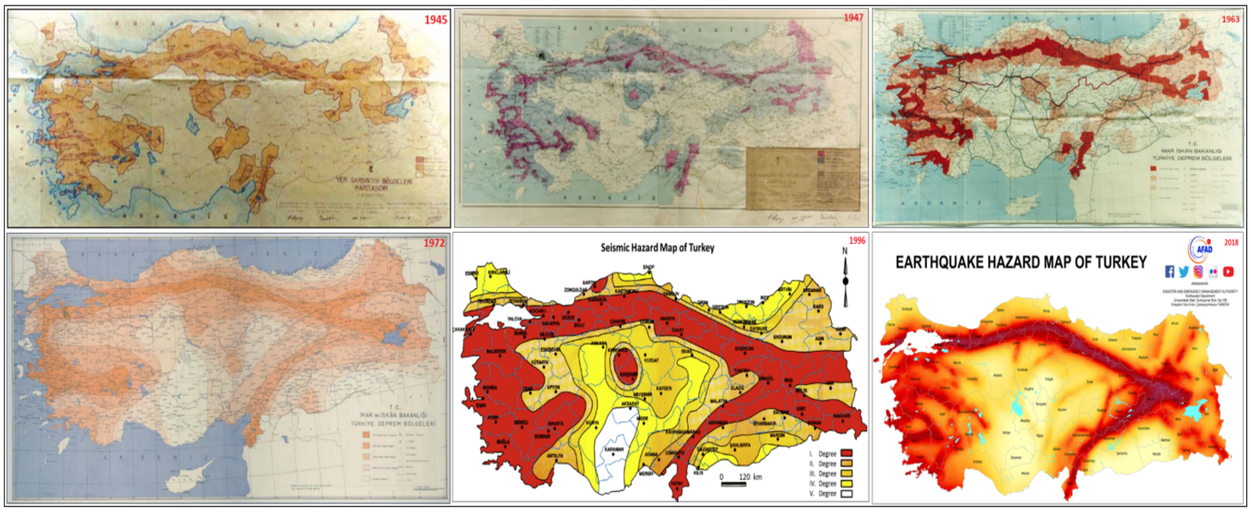

Figure 1. Development of Turkey earthquake hazard maps (adopted from Özmen and Pampal, 2017; Güneş, 2015; AFAD, 2021)

Turkey Earthquake Hazard Map was arranged by AFAD (Disaster and Emergency Management Presidency) within the scope of the project titled Updating the Seismic Hazard Map of Turkey. The concept of seismic region has been removed and replaced by site-specific seismic risk with this map. However, regional-based design spectra have been replaced by design spectra specific to each geographical location (Akkar et al., 2014; Çeken et al., 2017; Akkar et al., 2018; Akkar et al. 2018a; Karaşin et al., 2020; Işık et al., 2021b). Update has become inevitable not only in earthquake hazard maps, but also in seismic design codes, due to developing technology, scientific innovations and new generation mathematical equations. The ongoing changes and updates on ten different dates were finally completed in 2018 and entered into force in 2019 and was named TBEC-2018. The current seismic design code is much more comprehensive and detailed than previous codes. One of the innovations in the current code, which includes many innovations and updates, is the usage of the vertical earthquake effect in structural analyzes and evaluations.

Buildings are exposed to earthquake movements in three directions under earthquake impact (Yavaş et al., 2019). The first studies using different earthquake records in order to reveal the vertical effect of the earthquake were made by Chopra (1966); Newmark et al. (1973); Weichert et al. (1986); Abrahamson and Litehiser (1989); Bozorgnia et al. (1995); Papazoglou and Elnashai (1996) and Ambraseys and Douglas (2003a). As a result of field observations, it has been proved that the damage of buildings during the earthquake can be caused not only by exceeding the shear or bending capacity, but also by excessive axial stresses caused by the vertical effect of the earthquake (Farsangi and Tasnimi, 2016). The vertical earthquake effect is an important factor in increasing the axial forces in the structure (Papazoglou and Elnashai, 1996). Since the vertical component of the earthquake is smaller than the horizontal component and the vertical loads are more effective, the vertical component effect of the earthquake is ignored in the design of building-type structures (Doğan ve Elmas, 2004). Unlike other earthquake codes, the vertical effect of the earthquake has been taken into account initially with the updated seismic design regulation in Turkey. Structural analysis were performed by researchers on buildings with dissimilar structural systems regarding the vertical effect of the earthquake, and different results have been obtained (Gürel and Kısa, 2002; Doğan and Elmas, 2004; Baş et al., 2015; Eren and Beyen 2015; Eren and Beyen, 2017; Kim et al., 2017; Abdolahiparsa et al., 2016; Loghman et al., 2015; Chopra, 1966). It has also been clearly demonstrated in other studies that the vertical component of earthquake effect must be included in the structural analyses for design of earthquake-resistant buildings (Kalkan and Graizer, 2007; Kunnath et al., 2008; Kadid et al., 2010; Ambraseys and Douglas, 2003b; Jakayev and Aydemir, 2019). These studies have shown that excessive axial stresses occur due to the vertical effect of the earthquake, cause different damage distributions together with the change of axial forces in the columns, significant increases in column shear forces with the addition of the vertical component of the earthquake, and as a result, they may have serious effects on some structural elements.

Structural analyzes were carried out for a steel building selected as an example, taking into account different variables within the scope of this study. Four settlements with different earthquake hazards are one of the variables. In this context, İzmir, which is located in the 1st degree, Bitlis for the 2nd degree, Samsun for the 3rd degree and Konya for the 4th degree seismic zone in the prior earthquake zone map was selected. A random geographical location was chosen in these provinces. Peak ground velocity (PGV), peak ground acceleration (PGA), spectral acceleration coefficients (S_s, S_1) and spectral acceleration coefficients for short and long periods (S_{DS}, S_{D1}) for selected provinces were obtained using the Turkish Earthquake Hazard Map Interactive Web Earthquake Application (TEHMIWA) (AFAD, 2021). The vertical and horizontal design spectrum of these provinces have been obtained and compared. These current values were compared with recommended values in the previous code. Structural analyzes for a 10-storey steel building selected as an example using the obtained spectrum curves were carried out separately for each province with SAP2000 software. The steel building model, designed by the authors, was modeled within the framework of the provisions given in the Principles for the Design, Calculation and Construction of Steel Structures-2016 (PDCCSS-2016) and TBEC-2018. Nonlinear time history analysis was used in all structural analysis. In these analyses, earthquake effects in different directions were obtained separately for each province by using the acceleration records of the 2020 İzmir (Mw = 6.9) earthquake. The displacement, rotation, base shear and moment values for each direction were obtained separately. In this study, the earthquake behaviour of the building was examined for different earthquake directions as well as the different design spectra to be obtained for settlements with different seismicity. The results were evaluated, and interpretations were made.

2. Earthquake Parameters Considered in the Study

It is known that site-specific design spectrum importantly affects the expected target displacements from the structure (Işık et al., 2016; Kutanis et al., 2018; Işık et al., 2020). The design spectra obtained on a regional-based in the prior earthquake code have been replaced by the site-specific design spectrum with the current earthquake code. This study aims to obtain the impact of different design spectra, four different settlements located in different earthquake zones in the 1996 Turkey Earthquake Zones Map, İzmir, Bitlis, Samsun and Konya were selected. The seismicity of these provinces is different from each other. While making the selection, İzmir (Center) as the 1st degree earthquake zone, 2nd degree Bitlis (Güroymak), 3rd degree Samsun (Center) and Konya (Center) as the 4th degree earthquake zone was taken into consideration in the previous earthquake risk map. The representation of these settlements on the Earthquake Zones Map in 1996 is given in Figure 2.

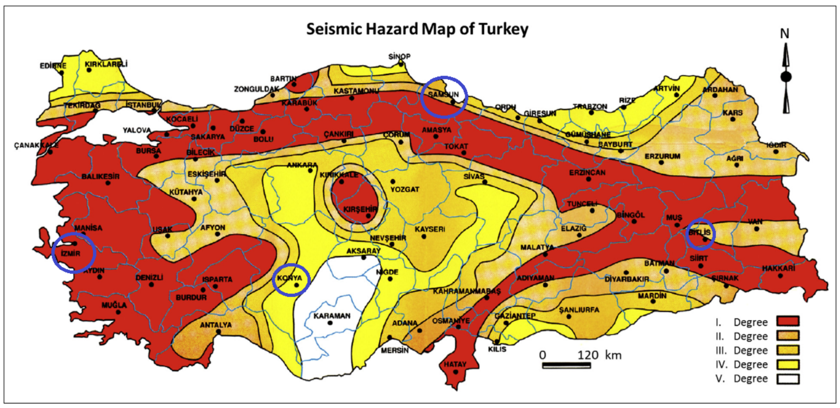

Figure 2. Turkey earthquake zoning map published in 1996 (Güneş, 2015) and selected settlements

A random geographic location from these settlements was chosen. The representation of the locations considered in the research and the current Earthquake Hazard Map of Turkey is given in Figure 3.

In TBEC-2018, which is currently used, the spectrum is defined in standard form or by site-specific earthquake hazard analyzes depending on the map spectral acceleration coefficients and local ground effect coefficients for

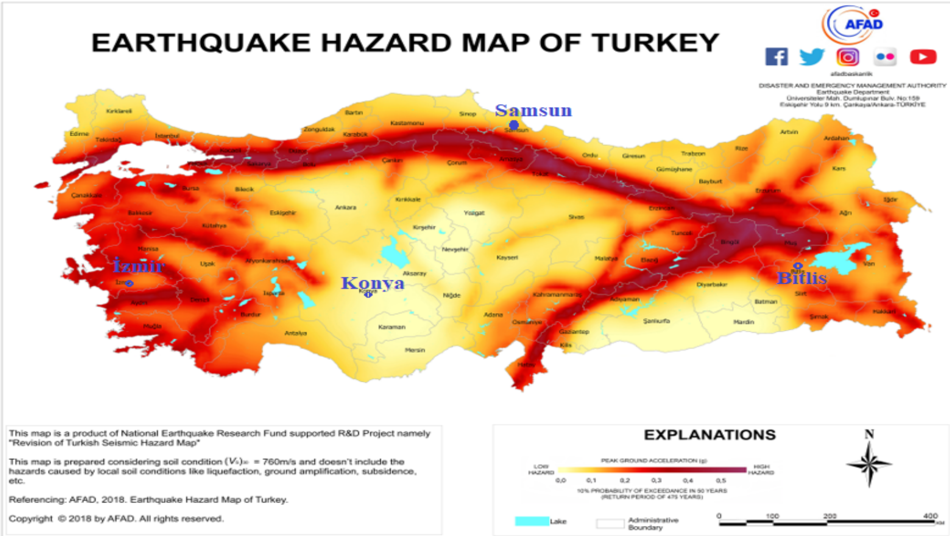

Figure 3. Turkey Earthquake Hazard Map (AFAD, 2021) and selected settlements

5% damping rate based on a certain earthquake ground motion level (TBEC-2018; Koçer et al., 2018). Map spectral acceleration coefficients corresponding to the geometric mean of earthquake effects in two perpendicular horizontal directions, based on the reference ground condition (V_s=760 m/s) for a given earthquake ground motion level, dividing the map spectral accelerations by the gravitational acceleration for 5% damping ratio are defined as dimensionless coefficients. Dimensionless map spectral acceleration coefficients are defined within the scope of Turkey Earthquake Hazard Maps for four different earthquake ground motion levels. The map spectral acceleration coefficient (S_s) for the short period (0.2s) and the map spectral acceleration coefficient (S_1) for the long period (1s) can be obtained from the Interactive Web Earthquake Application, except for the ZF ground class. These two coefficients have been used for the first time with the current code. In the previous earthquake code, design spectra were obtained according to the maximum ground acceleration depending on the earthquake region, while in the current code, design spectra are used depending on earthquake parameters such as spectral accelerations in short and long periods to be determined with the help of this application. The map spectral acceleration coefficients S_S and S_1 are converted to the design spectral acceleration coefficients S_{DS} (Equation 2.1) and S_{D1} (Equation 2.2) for short and long periods as follows:

$$S_{DS} = S_s.\ F_s \tag{2.1}$$

$$S_{D1}=S_1.F_1 \tag{2.2}$$

where Fs and F_1 are local ground coefficients that are being used for the first time with the current regulation. S_S, PGA, S_1, F_S, PGV, S_{DS}, F_1 and S_{D1} and vertical/horizontal design spectra have been obtained separately for each of the different exceedance probabilities by using the earthquake web application. The comparison of the PGA and PGV values obtained for the settlements considered in this study at four different earthquake ground motion levels is shown in Table 2.

Table 2

Comparison of PGA and PGV for different exceedance probabilities

Province	PGA (Peak Ground Acceleration) (g) Probability of exceeding in 50 years				PGV (Peak Ground Velocity) (cm/s) Probability of exceeding in 50 years			
	2%	10%	50%	68%	2%	10%	50%	68%
İzmir (Center)	0.844	0.454	0.174	0.124	52.739	27.621	10.237	7.422
Bitlis (Güroymak)	0.549	0.296	0.118	0.085	32.870	17.748	7.483	5.408
Samsun (Center)	0.422	0.232	0.096	0.067	28.497	16.241	6.798	4.783
Konya (Center)	0.291	0.132	0.044	0.031	14.080	6.633	2.449	1.761

The comparison of S_S, S_1 values for different earthquake ground motion levels is given in Table 3 for each geographical location considered in this study by using the TEHMIWA.

Table 3

Comparison of map spectral acceleration coefficients for different exceedance probabilities

Province	S_s (Short period acceleration coefficient)				S_1 (Map spectral acceleration coefficient for a 1.0 s period)			
	Probability of exceeding in 50 years				Probability of exceeding in 50 years			
	2%	10%	50%	68%	2%	10%	50%	68%
İzmir (Center)	2.127	1.115	0.416	0.297	0.544	0.274	0.104	0.076
Bitlis (Güroymak)	1.355	0.705	0.277	0.199	0.360	0.198	0.083	0.059
Samsun (Center)	1.017	0.549	0.219	0.153	0.345	0.194	0.079	0.055
Konya (Center)	0.681	0.304	0.100	0.070	0.147	0.072	0.027	0.020

One of the important changes in the current code has been in earthquake ground motion levels. While the previous code there was only a design earthquake with a probability of 10% to be exceeded in 50 years, four different earthquake ground motion levels were expressed with the current code as 2%, 10%, 50% and 68% probability of exceedance in 50 years. The spectral coefficients and corner periods of the horizontal and vertical elastic design spectra were shown in Figure 4.

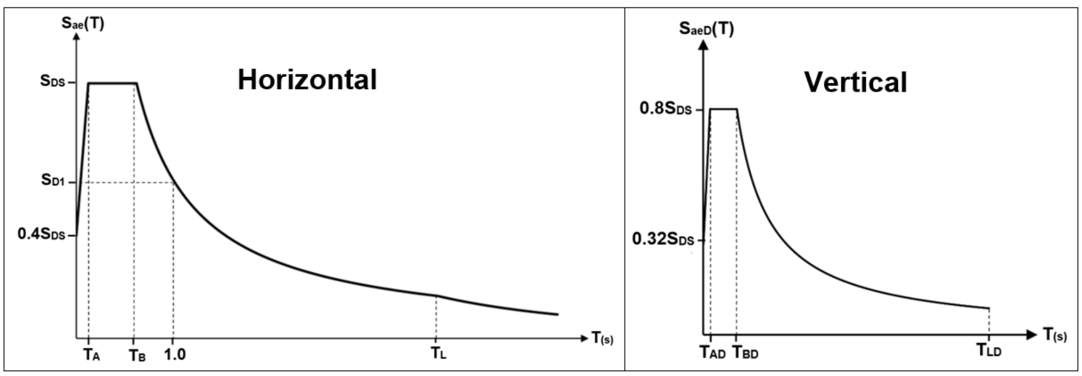

Figure 4. The spectral coefficients and corner periods of the horizontal and vertical elastic design spectra

The spectral acceleration coefficients and corner period values of the design spectra for DD-2 earthquake ground motion level in the last two codes were compared (Table 4). The same soil class was used in each location to make comparisons of structural analysis results and seismic parameters among six different soil classes envisaged in TBEC-2018. Considering the ZE soil class, both seismic and structural parameters were obtained. As the weakest soil class, the ZE local soil class is considered for comparisons for all locations.

Table 4

Comparison of design spectral acceleration and period values

10% probability of exceedance in 50 years	Spectral Acceleration Coefficients				Horizontal					Vertical	
	All Type Soils				ZE						
Province	TSDC-2007		TBEC-2018		TSDC-2007		TBEC-2018		TSDC-2007	TBEC-2018	
	S_{DS}	$0.40S_{Ds}$	S_{DS}	$0.40S_{Ds}$	T_A	T_B	T_A	T_B	T_{AD} T_{BD}	T_{AD}	T_{BD}
İzmir (Center)	1	0.40	1.124	0.450	0.15	0.90	0.143	0.714	There is no data	0.048	0.238
Bitlis (Güroymak)	0.75	0.30	0.967	0.387	0.15	0.90	0.136	0.679		0.045	0.226
Samsun (Center)	0.50	0.20	0.890	0.356	0.15	0.90	0.146	0.731		0.049	0.244
Konya (Center)	0.25	0.10	0.684	0.274	0.15	0.90	0.088	0.442		0.029	0.147

The comparison of the PGA(g) values is given in Table 5, which have a 10% probability of exceeding in the last two earthquake codes in 50 years.

Table 5

Comparison of PGA values for the last two earthquake codes

Province	PGA (2018)	Earthquake Zone (1996)	PGA (2007)	PGA $_{2018}$/PGA$_{2007}$	Change (%)
İzmir (Center)	0.454	1	0.400	1.135	13.50
Bitlis (Güroymak)	0.296	2	0.300	0.987	1.33
Samsun Center)	0.232	3	0.200	1.160	16
Konya (Center)	0.132	4	0.100	1.320	32

The comparison of the horizontal design spectra obtained by using the Interactive Web Earthquake Application for four different settlements is given in Figure 5.

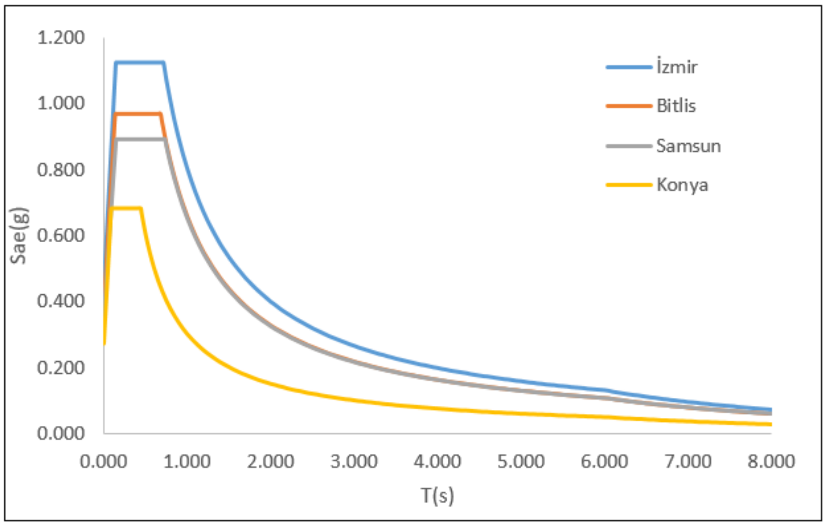

Figure 5. The comparison of horizontal design spectrum

One of the concepts that entered with the updated seismic design code is the vertical elastic design spectrum. In this context, the comparison of the vertical elastic design spectra obtained from the earthquake application for these settlements is given in Figure 6.

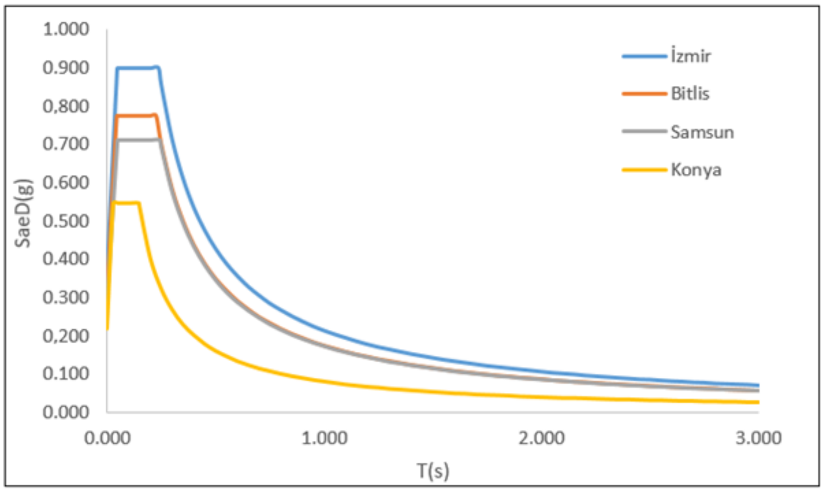

Figure 6. Comparison of vertical elastic design spectra

3. Aegean Sea Earthquake (Mw=6.9) on 30th of October 2020

An earthquake (Mw=6.9) strikes the epicenter of which was off the Aegean Sea, İzmir (Seferihisar) On 30th of October 2020. The earthquake lasted for about 16s and was felt in Greece, a neighboring country to Turkey. The greatest acceleration was measured as 180.16 gal in the N-S component at Kuşadası (Aydın) station (AFAD, 2020a). The station locations and measured acceleration values at the five stations closest to the epicenter of this earthquake are given in Table 6.

Table 6

The five stations closest to the epicenter and the measured acceleration values (AFAD, 2020a)

Station				Acceleration (gal)			Distance
Province	Town	Latitude	Longitude	N-S	E-W	Vertical	km
İzmir	Seferihisar	38.1968	26.8384	51.035	81.116	34.453	34.75
Aydın	Kuşadası	37.8600	27.2650	180.164	144.564	87.161	42.95
İzmir	Urla	38.3232	26.7706	82.072	64.950	43.174	48.94
İzmir	Menderes	38.2572	27.1302	763.916	46.433	43.701	51.38
İzmir	Güzelbahçe	38.3706	26.8707	47.418	48.544	35.011	54.57

This earthquake, which is thought to have caused a 30 km long faulting on the Samos Fault, caused loss of life and property in İzmir city center due to the soil amplification effect and structural defects. 117 people were died and 1032 people were injured after this earthquake (AFAD, 2020b). The acceleration records of the 2020 Aegean Sea Earthquake were used in the structural analyzes for the sample steel building within the scope of this study. The acceleration records of this earthquake in different directions are shown in Figure 7.

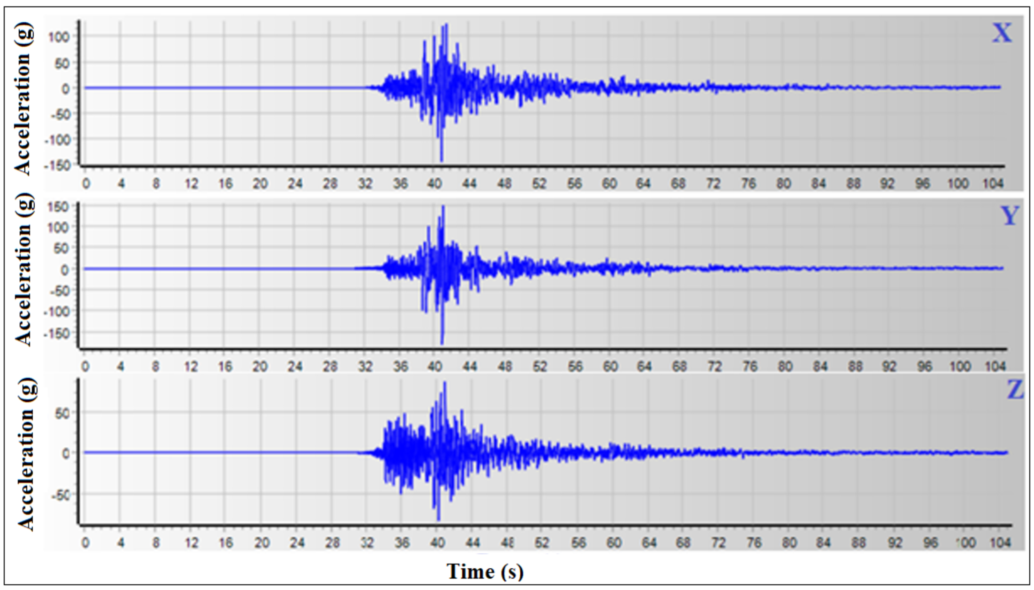

Figure 7. Records of Aegean Sea Earthquake (Mw=6.9) on 30th of October 2020

Izmir (2020) earthquake records were used in the study and the records were obtained from the AFAD database. Considering the horizontal components of the earthquake and the vertical earthquake effect for the earthquake record taken into consideration, dynamic analyzes were carried out by creating functions in the time history with the response spectrums and earthquake records defined in the SAP2000 program in accordance with the TBEC-2018.

4. Results and Discussion

Structural analyzes were carried out by using the SAP2000 software. The directions and freedoms in the software program are shown in Figure 8.

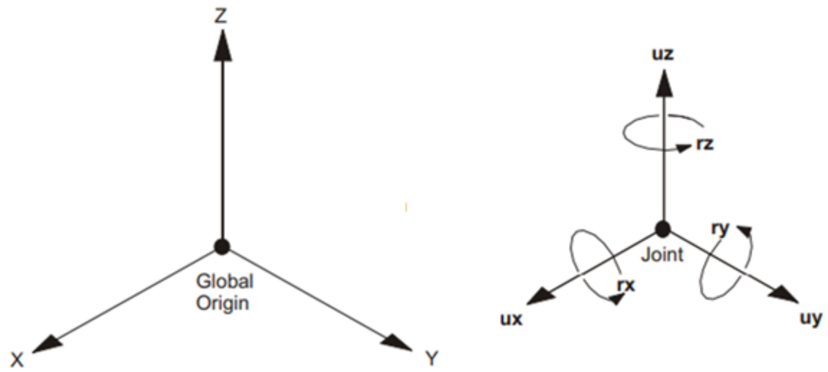

Figure 8. Directions and freedoms in the software used (SAP2000)

When making a definition with the local axis, the numbers 1,2,3 are used, and when defining with the global axis, the X, Y, Z axes are used. Linear and nonlinear structural analyzes were performed within the scope of this study. Time history analysis provides linear or nonlinear assessment of dynamic responses in the structure under varying loading according to a certain time function. The dynamic equilibrium equations specified by Equation 4.1 can be solved using modal or direct integration methods.

$$Ku(t) + C^{d}/_{dt}\, u(t) + Md^{2}/_{dt}\, u(t) = r(t) \qquad (4.1)$$

Nonlinear direct integration history analysis is a nonlinear dynamic analysis method in which the equilibrium equations of motion are fully integrated while a structure is subjected to dynamic loading. The analysis includes the integration of structural features and behaviors over a series of time steps that are small relative to the loading time (Tazarv, 2011). This type of analysis was used in this study. The steel building chosen as an example was modeled by the authors considering the provisions of PDCCSS-2016 and TBEC-2018. Structural analyzes were carried out separately using the design spectra obtained for four different settlements considered within the scope of this study and the earthquake acceleration record taken into account. The structure has 5 spans in the X direction and each span is 10 m, and in the Y direction 7 spans and each span is 8 m. The total height of the building is 30 m, the floor heights are equal to each other and are 3 m. The X-Z, Y-Z and X-Z axis sections of this structure are shown in Figure 9. In the steel structure chosen as an example, IPE270 profiles for transverse beams, IPE400 for longitudinal beams, HEB550 for columns, and CHS 114.3×3.6 profiles for cross beams are used.

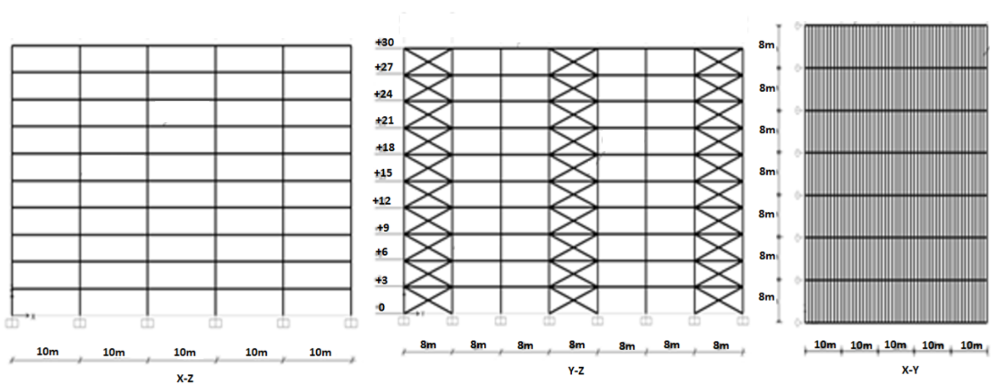

Figure 9. Sections of the sample steel structure model

Nonlinear behavior parameters for steel structures are specified in FEMA 273 Chapter-5. In this regulation, the joint properties that must be defined for columns and beams are defined. The analysis model and behavior properties of the structure in SAP2000 were carried out with the help of plastic hinges defined in FEMA 273, with the intensified plasticity model. Plastic hinge properties were determined by the nonlinear behavior coefficients given in FEMA 273. The properties of plastic hinges were determined with the help of the coefficients given in FEMA 273.

Structural analyzes were carried out separately for each province, taking into account the X, Y, XY, YZ and XYZ directions of earthquake effects in the steel building chosen as an example. Analyzes were made using vertical and horizontal design spectrum which were obtained from the Interactive Web Earthquake Application (TEHMIWA) and acceleration record of the Aegean Sea Earthquake (Mw=6.9) on 30th of October 2020 and the structural analysis results were obtained. The maximum displacement and rotation values obtained for earthquake loads effects in different directions for the provinces considered in this study are shown in Table 7. The maximum displacement, rotation, base shear force and moment values were obtained at the 3764 joint point and comparisons were made considering this joint.

Table 7

Maximum displacement and rotation values obtained for different provinces and directions

Joint	Province	u_1 m	u_2 m	u_3 m	r_1 Radians	r_2 Radians	r_3 Radians
3764	İZMİR X	0.23802	~0	~0	~0	0.004518	~0
3764	BİTLİS X	0.17307	~0	~0	~0	0.003815	~0
3764	SAMSUN X	0.13716	~0	~0	~0	0.002677	~0
3764	KONYA X	0.13418	~0	~0	~0	0.002616	~0
3764	İZMİR Y	~0	0.176943	0.00896	0.005176	0.000043	~0
3764	BİTLİS Y	~0	0.170053	0.00774	0.004279	0.000027	~0
3764	SAMSUN Y	~0	0.10919	0.0052	0.002839	0.000024	~0
3764	KONYA Y	~0	0.065722	0.00261	0.001862	0.000022	~0
3764	İZMİR XZ	0.23802	~0	0.01539	~0	0.005092	~0
3764	BİTLİS XZ	0.17307	~0	0.01331	~0	0.004824	~0
3764	SAMSUN XZ	0.13716	~0	0.01068	~0	0.003689	~0
3764	KONYA XZ	0.13418	~0	0.00839	~0	0.003108	~0
3764	İZMİR XY	0.23802	0.176943	0.00892	0.005176	0.004523	~0
3764	BİTLİS XY	0.17307	0.170053	0.00776	0.004279	0.003801	~0
3764	SAMSUN XY	0.13716	0.10919	0.00523	0.002839	0.002661	~0
3764	KONYA XY	0.13418	0.065722	0.0026	0.001862	0.002626	~0
3764	İZMİR YZ	~0	0.176943	0.02247	0.005176	0.002271	~0
3764	BİTLİS YZ	~0	0.170053	0.01654	0.004279	0.00164	~0
3764	SAMSUN YZ	~0	0.10919	0.01636	0.002839	0.001097	~0
3764	KONYA YZ	~0	0.065722	0.00969	0.001862	0.001029	~0
3764	İZMİR XYZ	0.23802	0.176943	0.02247	0.005176	0.005086	~0
3764	BİTLİS XYZ	0.17306	0.170053	0.01654	0.004279	0.004827	~0
3764	SAMSUNXYZ	0.13716	0.10919	0.01636	0.002839	0.003698	~0
3764	KONYA XYZ	0.13418	0.065722	0.00972	0.001862	0.003106	~0

In the structural analysis, base shear forces and moment values were also obtained separately for each province in the earthquake directions considered. The maximum base shear forces and moment values obtained were shown in Table 8.

Table 8

Maximum base shear forces and moments obtained for different directions

Joint	Province	F_X kN	F_Y kN	F_Z kN	M_X kNm	M_Y kNm	M_Z kNm
3764	İZMİR X	10179	~0	~0	~0	166582.9	278135
3764	BİTLİS X	8557.4	~0	~0	~0	129936	225745
3764	SAMSUN X	7094	~0	~0	~0	99017.21	176770
3764	KONYA X	5962.4	~0	~0	~0	87579.08	174110
3764	İZMİR Y	~0	24081	~0	346149.9	~0	602036
3764	BİTLİS Y	~0	21297	~0	345487.8	~0	532432
3764	SAMSUN Y	~0	13377	~0	205205	~0	334437
3764	KONYA Y	~0	10086	~0	138152.6	~0	252154
3764	İZMİR XZ	10179	~0	153273	4291656	3944923	278135
3764	BİTLİS XZ	8557.4	~0	116602	3264845	2914633	225745
3764	SAMSUN XZ	7094	~0	98305	2752548	2331024	176770
3764	KONYA XZ	5962.4	~0	47179	1321014	1261650	174110
3764	İZMİR XY	10179	21297	~0	3264845	2914633	761694
3764	BİTLİS XY	8557.4	13377	~0	345487.8	166582.9	477177
3764	SAMSUN XY	7094	10086	~0	205205	129936	333662
3764	KONYA XY	5962.4	~0	~0	138152.6	99017.21	174110
3764	İZMİR YZ	~0	24081	153273	4353242	3972752	602036
3764	BİTLİS YZ	~0	21297	116602	3445749	2896088	532432
3764	SAMSUN YZ	~0	13377	98305	2800802	2302348	334437
3764	KONYA YZ	~0	10086	47179	1349552	1153268	252154
3764	İZMİR XYZ	10179	24081	153273	4353242	3944923	761694
3764	BİTLİS XYZ	8557.4	21297	116602	3445749	2914633	699676
3764	SAMSUNXYZ	7093.8	13377	98305	2800802	2331024	477177
3764	KONYA XYZ	5962.4	10086	47179	1349552	1261646	333655

The comparison of the displacement and rotation values obtained for different directions for the province of İzmir, which has the highest PGA value among the provinces considered, is presented in Table 9.

The comparison of the displacement and rotation values obtained for different loading situations in different load conditions in İzmir is shown in Figure 10.

Table 9

Comparison of displacement and rotation values for İzmir

Point	Province	u_1 m	u_2 m	u_3 m	r_1 Radians	r_2 Radians	r_3 Radians
3764	İZMİR X	0.23802	~0	~0	~0	0.004518	~0
3764	İZMİR Y	~0	0.176943	0.00896	0.005176	0.000043	~0
3764	İZMİR XZ	0.23802	~0	0.01539	~0	0.005092	~0
3764	İZMİR XY	0.23802	0.176943	0.00892	0.005176	0.004523	~0
3764	İZMİR YZ	~0	0.176943	0.02247	0.005176	0.002271	~0
3764	İZMİR XYZ	0.23802	0.176943	0.02247	0.005176	0.005086	~0

The comparison of the displacement and rotation values obtained for different loading situations in different load conditions in İzmir is shown in Figure 10.

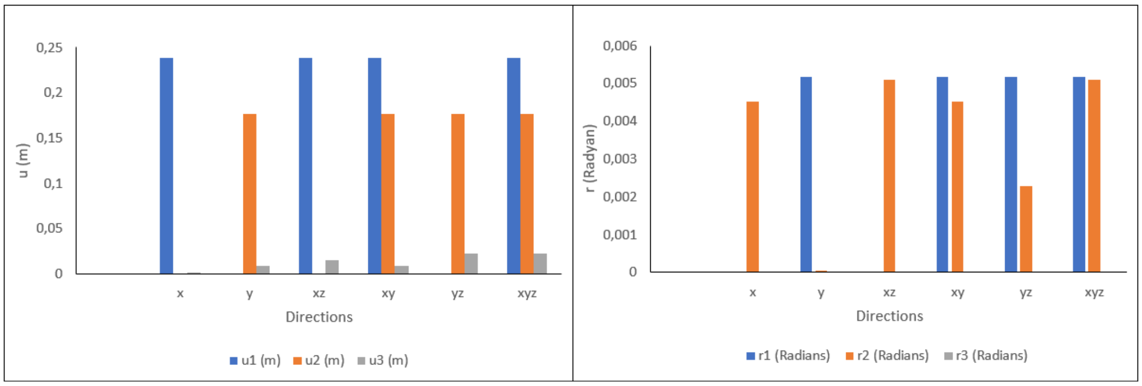

Figure 10. Comparison of displacements and rotations for İzmir

The comparison of the base shear force and moment values obtained for the 3764 joint point for the province of İzmir, which has the highest seismic risk among the provinces considered in this study, is shown in Table 10.

Table 10

Comparison of base shear force and moment values for İzmir

Point	Direction	F_X kN	F_Y kN	F_Z kN	M_X kNm	M_Y kNm	M_Z kNm
3764	İZMİR X	10179	~0	~0	~0	166582.9	278135
3764	İZMİR Y	~0	24081	~0	346149.9	~0	602036
3764	İZMİR XZ	10179	~0	153273	4291656	3944923	278135
3764	İZMİR XY	10179	21297	~0	3264845	2914633	761694
3764	İZMİR YZ	~0	24081	153273	4353242	3972752	602036
3764	İZMİR XYZ	10179	24081	153273	4353242	3944923	761694

The comparison of the base shear force and moments obtained for different loading situations in different loads conditions in İzmir is shown in Figure 11.

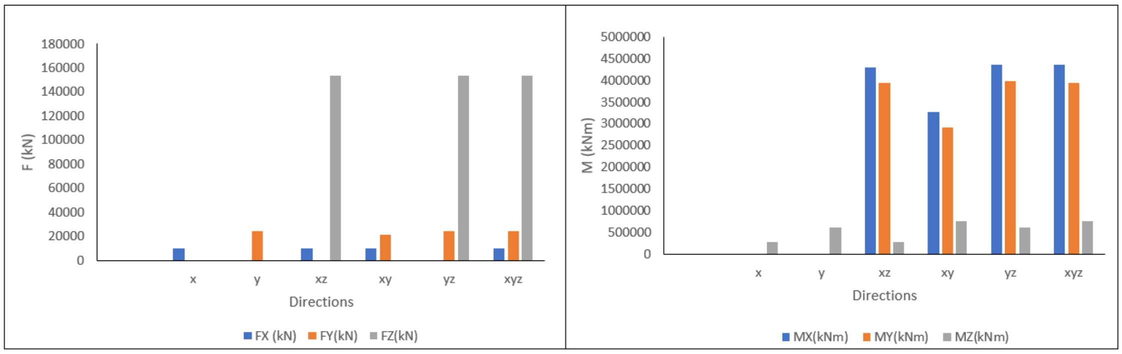

Figure 11. Comparison of base shear force and moment for İzmir

5. Conclusions

Considering major earthquake damages and developments in earthquake engineering, renewal, updating and additions are inevitable in earthquake risk zoning maps and earthquake resistant building design principles. In Turkey, these processes have been carried out in seismic hazard maps and seismic design codes over time. At different times, both earthquake resistant building design principles and the arrangements made in earthquake hazard maps contain very important studies and achievements in reducing earthquake damages. Structural analyzes were carried out for a sample steel building by considering both the current map and the important changes in the regulation, taking into account the provinces with different seismic risks and different earthquake directions within the scope of this study. In the structural analysis, the acceleration records of the Aegean Sea Earthquake (Mw=6.9) on 30th of October 2020, which is one of the most important earthquakes in Turkey recently, were used. It has been tried to reveal the effects of different design spectra obtained depending on different earthquake zones and earthquake effects in different directions on the earthquake behavior of the building with this study.

For the provinces considered in this study, the highest PGA value for the earthquake ground motion level, which has a 10% probability of exceeding in 50 years, was calculated for İzmir as 0.454g, while the lowest PGA value was obtained as 0.132 g for the same motion level for Konya. This situation preserved its validity in PGV and map spectral acceleration coefficients, while the highest values were obtained for İzmir and the lowest values for Konya. Since there are randomly selected points, these values may differ according to different geographical locations. The design spectral acceleration coefficients obtained according to the current regulation for all the provinces considered were larger than the values predicted in the previous earthquake regulation. The increase in design spectral acceleration coefficients was 12.4% for İzmir, 28.5% for Bitlis, 78% for Samsun and 174% for Konya. PGA values, on the other hand, increased for the other three provinces, excluding the geographical location selected in Bitlis. There was a small decrease in Bitlis compared to the previous map. Vertical ground dominant periods (T_{AD}, T_{BD}) have been used for the first time with the current regulation. While T_A and T_B values, which are horizontal spectrum corner points, took the same values for the same soil groups in the previous regulation, they take different values for each geographical location in the current regulation. The displacement, rotation, base shear and moment values obtained from the structural analysis results for the province of İzmir, where the PGA value is the highest, have the highest values in all the directions considered in the study. The lowest values were found in Konya, where the PGA value was the lowest. This once again revealed the direct effect of the PGA value on the design spectra and thus on the structural analysis results. In this context, together with the current earthquake code, it reveals the necessity of site-specific design spectra.

The acceleration value measured for the Izmir earthquake was well below the PGA values predicted in the last two earthquake codes and earthquake maps for Izmir. This shows that the current seismic design code and map are sufficient for the province of Izmir. It can be said that it was caused an increase in structural damage due to soil enlargement and insufficient structural characteristics and similar reasons.

All displacement, rotation, base shear force and moment values obtained for four provinces were obtained in complete harmony. With the increase in PGA, the results of the structural analysis obtained for each direction also took higher values. In this context, the highest displacement, rotation, base shear force and moment values were obtained for İzmir, while the lowest values were obtained for Konya. This once again revealed that the seismic parameters of any region directly affect the structural analysis. For u_1, the component in the X direction is active and the highest value is taken from the load combination where this component is taken into account. For u_2, the component in the Y direction is active and the highest value is taken from the load combination where this component is taken into account. The highest values for u_3 were obtained for the loading case YZ and XYZ. In this case, it can be said that the Y and Z components are effective for the displacement in this direction. The r_1, rotation values have their highest value in the loading cases of Y, XY, YZ and XYZ is taken into account. Here, it can be said that the Y component is more effective. While the highest value for r_2 was obtained in XZ loading condition, the highest value was obtained for r_3 in Y and XY loading conditions. Considering all the load combinations, the highest u_1 was obtained for X, XZ, XY, XYZ; for u_2; Y, XY, YX, XYZ and u_3 for YZ, XYZ. The highest displacement was calculated as 0.238 m at u_1. The largest rotation was obtained for r_1 as 0.00517 radians. While the highest values for F_x were obtained from the loads with the component in the X direction, the highest values were obtained from the loads with the Y component in general. The highest values were obtained as a result of the loads in which the Z-direction component was active in F_z. All the results obtained reveal the importance of using all data related to the earthquake when calculating the impact of the earthquake on the structures. The effects of different earthquakes with different components on structures will also be different.

When the displacement, rotation, base shear force and moment values obtained for the provinces and different directions considered in this study were examined, it was determined that the vertical earthquake effect did not significantly change the results obtained for the horizontal direction. Within the scope of this study, only one earthquake record, namely the Aegean Sea Earthquake (Mw=6.9) on 30th of October 2020, was used for a regular steel building without irregularities. These results may vary in earthquakes with different frequency content and structures with irregularity. In addition, the dominance of the horizontal and vertical components of the earthquake, which will be taken into account in the structural analysis, may also affect the results.

Acknowledgements

This study is derived from the presentation titled “Investigation of the Effect of Vertical Earthquake Motion on Structural Behavior in Multi-Storey Steel Buildings According to Turkish Building Earthquake Regulation” pres ented at the 22nd National Mechanics Congress.

Author Contributions

Ercan Işık: Collected data, planned, and designed the analysis.

Fatma Ülker Peker: Collected and analyzed data.

Aydın Büyüksaraç: Made statistical and seismic analyzes of the study.

Conflict of Interest

The authors declared no conflict of interest.

References

Abdollahiparsa, H., Homami, P., & Khoshnoudian, F. (2016). Effect of vertical component of an earthquake on steel frames considering soil-structure interaction. *KSCE Journal of Civil Engineering*, 20(7), 2790-2801. https://doi.org/10.1007/s12205-016-0687-y

Abrahamson, N.A., Litehiser, J.J. (1989). Attenuation of vertical peak acceleration. *Bulletin of the Seismological Society of America*, 79(3), 549-580. https://doi.org/10.1785/BSSA0790030549.

AFAD (2021). Türkiye Deprem Tehlike Haritası. https://tdth.afad.gov.tr/

AFAD (2020a). İzmir Seferihisar Depremi-Duyuru 81. Erişim tarihi:07.12.2020, https://www.afad.gov.tr/izmir-seferihisar-depremiduyuru-81-26112020---2100

AFAD Deprem Dairesi Başkanlığı. (2020b). 30 Ekim 2020 Sisam Adası (İzmir Seferihisar Açıkları) Mw 6.6 Depremi Raporu. Erişim Tarihi: 18.12.2020, https://deprem.afad.gov.tr/depremdokumanlari/2065

Akkar, S., Kale, Ö., Yakut, A., & Ceken, U. (2018). Ground-motion characterization for the probabilistic seismic hazard assessment in Turkey. *Bulletin of Earthquake Engineering*, *16*(8), 3439-3463. https://doi.org/10.1007/s10518-017-0101-2

Akkar, S., Azak, T., Çan, T., Çeken, U., Tümsa, M. D., Duman, T. Y., ... & Zülfikar, Ö. (2018a). Evolution of seismic hazard maps in Turkey. *Bulletin of Earthquake Engineering*, *16*(8), 3197-3228. https://doi.org/10.1007/s10518-018-0349-1

Akkar, S., Azak, Çan, T., Çeken, U., Demircioğlu, M.B., Duman,T., Kartal,R.F., (2014). Türkiye Sismik Tehlike Haritasının Güncellenmesi. (UDAP-Ç-13-06). In *Ulusal Deprem Araştırma Programı*; Disaster and Emergency Management Presidency Press: Ankara, Turkey, Available online: http://www.deprem.gov.tr/belgeler2016/tsth.Pdf (2014) (Erişim tarihi: 22 Haziran 2021).

Aksoylu, C., Mobark, A., Arslan, M.H., Hakkı Erkan, İ. (2020). A comparative study on ASCE 7-16, TBEC-2018 and TEC-2007 for reinforced concrete buildings. *Revista de la construcción*, 19(2), 282-305. http://dx.doi.org/10.7764/rdlc.19.2.282

Ambraseys, N.N., Douglas, J. (2003a). Effect of vertical ground motions on horizontal response of structures. *International Journal of Structural Stability and Dynamics*, 3(02), 227-265. https://doi.org/10.1142/S0219455403000902

Ambraseys, N. N., Douglas, J. (2003b). Near-field horizontal and vertical earthquake ground motions. *Soil Dynamics and Earthquake Engineering*, *23*(1), 1-18. https://doi.org/10.1016/S0267-7261(02)00153-7.

Baş, S., Sevinç, M., Kalkan, İ., Aykaç,S. (2015). Düşey deprem etkisi altındaki çok katlı betonarme yapıların davranışının incelenmesi, *3. Türkiye Deprem Mühendisliği ve Sismoloji Konferansı,* **İzmir,** Türkiye. http://www.tdmd.org.tr/TR/Genel/pdf2015/TDMSK_063.pdf

Bozorgnia, Y., Niazi, M., Campbell, K. W. (1995). Characteristics of free-field vertical ground motion during the Northridge earthquake. *Earthquake spectra*, *11*(4), 515-525. https://doi.org/10.1193/1.1585825.

Büyüksaraç, A., Işık, E., Harirchian, E. (2021). A case study for determination of seismic risk priorities in Van (Eastern Turkey). *Earthquakes and Structures*, 20(4), 445-455. https://doi.org/10.12989/eas.2021.20.4.445

Chopra, A. K. (1966). The importance of the vertical component of earthquake motions. *Bulletin of the Seismological Society of America*, 56(5), 1163-1175. https://doi.org/10.1785/BSSA0560051163

Çeken, U., Dalyan, İ., Kılıç, N., Köksal, T.S., Tekin, B.M. (2017). Türkiye deprem tehlike haritaları interaktif web uygulaması. *4. Uluslararası Deprem Mühendisliği ve Sismoloji Konferansı 11-13 Ekim 2017 – Eskişehir*). http://www.tdmd.org.tr/TR/Genel/4UDMSK/pdf2017/4008.pdf

Çelik Yapıların Tasarım, Hesap ve Yapım Esaslarına Dair Yönetmelik, PDCCSS (2016). https://www.imo.org.tr/resimler/dosya_ekler/5ba6a974eb906bf_ek.pdf

Doğan, E., Elmas, M. (2004). Binalarda düşey deprem etkisinin zaman tanım alanında hesap yöntemi ile incelenmesi. *Sakarya Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 8(1), 9-17. http://www.saujs.sakarya.edu.tr/tr/download/article-file/192893

Eren,G., Beyen, K. (2015). Düşey deprem etkisinde tipik bir binada gözlenen performansın tartışılması. *8UDMK, İstanbul, Türkiye*. s.199-211. https://www.imo.org.tr/resimler/ekutuphane/pdf/17371_51_01.pdf

Eren, G., Beyen,K., (2017). Tarihi yapı davranışına zemin, mesnet, yatay ve düşey deprem koşullarının etkisi, *Uluslararası Katılımlı 6. Tarihi Yapıların Korunması ve Güçlendirilmesi Sempozyumu*, *Istanbul, Türkiye.* s.401-410. https://www.imo.org.tr/resimler/ekutuphane/pdf/17952_15_50.pdf

Farsangi, E. N., Tasnimi, A. A. (2016). The influence of coupled horizontal–vertical ground excitations on the collapse margins of modern RC-MRFs. *International Journal of Advanced Structural Engineering (IJASE)*, *8*(2), 169-192. https://doi.org/10.1007/s40091-016-0122-0.

Güneş, O. (2015). Turkey's grand challenge: Disaster-proof building inventory within 20 years. *Case Studies in Construction Materials*, *2*, 18-34. https://doi.org/10.1016/j.cscm.2014.12.003

Gürel, M.A., Kısa, M. (2002). Deprem Hareketinin Düşey Bileşeninin Çeşitli Yapı Elemanları Üzerindeki Etkileri ve Hasar Potansiyeli. *Uluslararası Yapı ve Deprem Mühendisliği Sempozyumu ECAS2002, Ankara, s. 118-125*. http://bupim.com/yayinlar/bupim-pdf/ECAS20.pdf

Işık, E., Kutanis, M., Bal, İ.E. (2016). Displacement of the buildings according to site-specific earthquake spectra. *Periodica Polytechnica Civil Engineering*, 60(1), 37-43. https://doi.org/10.3311/PPci.7661

Işık, E. (2021). A comparative study on the structural performance of an RC building based on updated seismic design codes: case of Turkey. *Challenge Journal of Structural Mechanics*, 7(3), 123-134. https://doi.org/10.20528/cjsmec.2021.03.002

Işık, E., Harirchian, E., Bilgin, H., Jadhav, K. (2021a). The effect of material strength and discontinuity in RC structures according to different site-specific design spectra. *Research on Engineering Structures and Materials*. 7(3) 413-430. http://dx.doi.org/10.17515/resm2021.273st0303

Işık, E., Büyüksaraç, A., Ekinci, Y. L., Aydın, M. C., Harirchian, E. (2020). The effect of site-specific design spectrum on earthquake-building parameters: A case study from the Marmara region (NW Turkey). *Applied Sciences*, 10(20), 7247. https://doi.org/10.3390/app10207247

Işık, E., Harirchian, E., Büyüksaraç, A., & Ekinci, Y. L. (2021b). Seismic and structural analyses of the eastern anatolian region (Turkey) using different probabilities of exceedance. *Applied System Innovation*, *4*(4), 89. https://doi.org/10.3390/asi4040089.

Jakayev, S., Aydemir, M. E. (2019). Düzenli bir betonarme binada düşey deprem bileşeninin yapısal davranışa etkisi. *Afet ve Risk Dergisi*, *2*(1), 1-13.

Kadid, A., Yahiaoui, D., Chebili, R. (2010). Behavior of reinforced concrete buildings under simultaneous horizontal and vertical ground motions. *Asıan Journal Of Civil Engineering (Building And Housing),* 11(4), 463-476. https://www.sid.ir/en/journal/ViewPaper.aspx?id=185518

Kalkan, E., Graizer, V. (2007). Multi-component ground motion response spectra for coupled horizontal, vertical, angular accelerations and tilt. *ISET Journal of Earthquake Technology*, 44(1), 259-284. http://home.iitk.ac.in/~vinaykg/Iset485.pdf

Karaşin, İ.B., Işık, E., Demirci, A., Aydın, M.C. (2020). Coğrafi konuma özel tasarım spektrumlarının betonarme yapı performansına etkisi. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, 11(3), 1319-1330. https://doi.org/10.24012/dumf.682377

Kim, S.J., Holub, C.J., Elnashai, A.S. (2011). Analytical assessment of the effect of vertical earthquake motion on RC bridge piers. *Journal of Structural Engineering*, 137(2), 252-260. https://doi.org/10.1061/(ASCE)ST.1943-541X.0000306

Koçer, M., Nakipoğlu, A., Öztürk, B., Al-hagri, M. G., Arslan, M. H. (2018). Deprem kuvvetine esas spektral ivme değerlerinin TBDY 2018 ve TDY 2007'ye göre karşılaştırılması. *Selçuk-Teknik Dergisi*, 17(2), 43-58. http://sutod.selcuk.edu.tr/sutod/article/view/437

Kunnath, S. K., Erduran, E., Chai, Y. H., Yashinsky, M. (2008). Effect of near-fault vertical ground motions on seismic response of highway overcrossings. *Journal of Bridge Engineering*, 13(3), 282-290. https://doi.org/10.1061/(ASCE)1084-0702(2008)13:3(282)

Kutanis, M., Ulutaş, H., Işik, E. (2018). PSHA of Van province for performance assessment using spectrally matched strong ground motion records. *Journal of Earth System Science*, 127(7), 1-14. https://doi.org/10.1007/s12040-018-1004-6

Loghman, V., Khoshnoudian, F., Banazadeh, M. (2015). Effect of vertical component of earthquake on seismic responses of triple concave friction pendulum base-isolated structures. *Journal of Vibration and Control*, *21*(11), 2099-2113. https://doi.org/10.1177/1077546313503359

Newmark, N.M., Blume, J.A., Kapur, K.K. (1973). Seismic Design Spectra for Nuclear Power Plants. *Journal of the Power Division*, 99(02), 287–303. https://doi.org/10.1061/JPWEAM.0000753

Özmen, B. (2012). Türkiye deprem bölgeleri haritalarının tarihsel gelişimi. *Türkiye Jeoloji Bülteni*, *55*(1), 43-55. https://www.jmo.org.tr/resimler/ekler/742ef3153c914cf_ek.pdf

Özmen, B., Pampal, S. (2017). Türkiye Deprem Bölgeleri Haritalarının Evrimi. *4. Uluslararası Deprem Mühendisliği ve Sismoloji Konferansı*, Eskişehir, Türkiye. http://www.tdmd.org.tr/TR/Genel/4UDMSK/pdf2017/3708.pdf

Papazoglou, A.J., Elnashai, A.S. (1996). Analytical and field evidence of the damaging effect of vertical earthquake ground motion. *Earthquake Engineering & Structural Dynamics*, *25*(10), 1109-1137.https://doi.org/10.1002/(SICI)1096-9845(199610)25:10<1109::AID-

SAP2000, Version 17, Computers and Structures, Inc., Berkeley, California

Tazarv, M. Linear Time History Analysis of MDOF Structure by Mode Superposition Method. http://alum.sharif.edu/~tazarv/

TBEC-2018. *Türkiye Bina Deprem Yönetmeliği*; T.C. Resmi Gazete: Ankara, Turkey, (2018). https://www.afad.gov.tr/ (Erişim tarihi:1 Haziran 2021).

Weichert, D. H., Wetmiller, R. J., Munro, P. (1986). Vertical earthquake acceleration exceeding 2 g? The case of the missing peak. *Bulletin of the Seismological Society of America*, *76*(5), 1473-1478. https://doi.org/10.1785/BSSA0760051473

Yavaş, M., Teloğlu,A.N., Celep, Z. (2019). Türkiye Bina Deprem Yönetmeliği'nde binaların taşıyıcı sisteminde tanımlanan düşey deprem etkisi üzerine. In *International Conference on Earthquake Engineering and Seismology (5ICEES)*, 8, s.11.