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Investigation and evaluation of seismic isolated hospital building complexes in the earthquake zone affected by Kahramanmaraş-Hatay earthquake sequence on February 6 and 20, 2023.

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Abstract

Purpose: This study aims to technically observe and evaluate the level of earthquake performance of the superstructure and seismic isolated substructure of eight hospital building complexes in the provinces affected by the earthquake after the Kahramanmaraş-Hatay earthquake sequence on February 6 and 20, 2023. For this purpose, The research objectives are whether the seismic isolation units of the hospital building complexes in the seismic zone work as predicted, how their condition is, the effect of torsional motion induced by the building complexes on the horizontal movement of the seismic isolation units, how the seismic behavior of the hospital building complexes is, the level of damage of the non-structural parts of the buildings, flexible joint of infill wall would be required, and whether immediate occupancy seismic performance level of the hospital building complexes is satisfied or the level is acceptable for this type buildings.
Study design/methodology/approach: Observations and hand-made measurements over the field were used as a method.
Findings: Seismic isolation units have different residual or non-permanent displacements; there is no residual displacement in some seismic isolation units; hospital building complexes consist of building groups of different heights on the same seismic isolated substructure; infill wall damages, and their collapses are observed; some of the seismic isolation units are not adequately protected against external environmental effects; It has been observed that there is an unexpected connection of the downstairs infill walls with seismically isolated substructure, and the seismic flexibility tolerance in the mechanical installation should be checked.
Originality/value: This study is invaluable because it includes the evaluation of seismic responses of the superstructure and isolated substructure of hospital building complexes with seismic isolation units, which are not widely used in Türkiye.

Keywords: Seismic Isolation; Hospital Building Complexes; Kahramanmaraş-Hatay Earthquake Sequence; Torsional Movement Of The Isolated Substructure;

1. Introduction

On February 6, 2023, two major earthquakes hit Türkiye, with the epicentres in Pazarcık (Mw 7.7; focal depth: 8.6 km) and Elbistan (Mw 7.6; focal depth: 7 km) districts of Kahramanmaraş, at 04:17 and 13:24 local time, respectively. On February 20, 2023, another earthquake with a magnitude of Mw 6.4 occurred,

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with the epicentre of Yayladağı, Hatay, at 20:04 local time (URL-1, 2023). After Kahramanmaraş-Hatay Earthquake Sequence, It aims to make evaluations by observing the findings obtained in the light of the studies carried out on the structural conditions of 8 hospital buildings with seismic isolation units located in the earthquake zone and analyzing them together with the data of the five stations closest to the hospitals with seismic isolation units in the region. In addition, before the observations, some inferences and suggestions were made on the situations that are likely to be seen on-site for buildings with seismic isolation units designed according to TBDY-2018. After the examinations, evaluations were made about how observable these inferences were.

1.1. Assessment Over Design of Isolated Building Within TBEC-2018

Building design with seismic isolation units comes to the fore by ensuring that the energy needed by the seismic isolation units is dissipated instead of the energy that conventional structures dissipate by getting damaged. Thanks to this feature, the force applied to the structure can be reduced by 70-80%. This reduced force is used by converting it into design force with an earthquake load reduction coefficient of 1-1.5, and it is aimed to obtain a linear or nearly linear building behavior on the upper foundation with seismic isolation units. While the design of buildings with seismic isolation units is consistent with the purpose and importance of the buildings, there is a requirement for the buildings to provide immediate occupancy, minimum damage, or controlled performance level after the earthquake, according to the Turkish Building Earthquake Code (TBEC-2018). This condition, which is likely sufficient for the structural elements of buildings, will not be sufficient to determine the performance levels for using non-structural elements such as infill walls since the allowable drift values will likely not prevent damage to the walls. Therefore, the application of flexible joints, detailed in TBEC-2018, between structural elements and infill walls, even in buildings with seismic isolation units, should be mandatory to continue the service provided, especially in hospital buildings.

Torsion effects in the design of seismic isolation units may cause an excessive increase in the displacement capacity of the seismic isolation units on the seismic isolation unit layer. The warnings emphasized in TBEC-2018 should be followed, especially regarding limiting the values obtained for the largest earthquake movement level obtained from the design spectrum of the earthquake effect as much as possible in places where the risk of exceeding is high. For example, the effective stiffness of the seismic isolation units on the seismic isolation unit layer where the seismic isolation units are located should be as close to the geometric center as possible, and the upper foundations with seismic isolation units should be as square or circular as possible, which will limit the torsion effect caused by the seismic isolation unit layer. The torsion effect is even more important in seismic isolation units with curved surfaces, where the displacement limit is limited geometrically due to the high risk of damage to the seismic isolation unit if the limits are exceeded. The force required for the initial activation of curved surface seismic isolation units is higher than the effective yield strength. It is understood that even in solutions containing the same type but different sizes of seismic isolation units used, this value being different from the effective value may make the occurrence of the torsion effect inevitable. On the other hand, in elastomer seismic isolation units, this orientation is expected to be less due to the nature of this seismic isolation unit.

Since the design force in solutions with seismic isolation units decreases due to the dissipated energy, the superstructure will develop its own response like conventional structures under the reduced effects transmitted to the superstructure. Here, when the behavior of the seismic isolation units and the superstructure is considered in a series of interactions, such as the structure-soil interaction, under the reduced effects on the superstructure, the superstructure will create a response with its mass inertia according to its own rigidity center (which can be considered as the situation where the seismic isolation units do not move) and transmit it to the seismic isolation unit layer. In this case, the seismic isolation units will be exposed to an interaction that will improve their response not only from the ground but also from the superstructure. Therefore, if a

torsional movement occurs in the superstructure, this movement will be transferred to the substructure. The source of torsion may also be the structural system itself in the superstructure, just like in conventional structures, due to the nature of this interaction. In the Equivalent Earthquake Load Method (ELM), which is the first of the three methods mentioned in the calculation methods section of the TBEC-2018 regulation, torsional irregularity in the superstructure is allowed up to a specific value, as in conventional structures. In the second method, the Modal Combination Method (MCM), for the presence or absence of torsional irregularity (no threshold value is given for torsional irregularity), the seismic isolation unit displacement value obtained according to this method must be greater than 90% or 80%, respectively, of the value obtained according to the first method. That is, in case of torsional irregularity, the permissible ratio is reduced by 10%. In the third method, the Time History Analysis Method (THAM), there is a limitation that the seismic isolation unit displacement value obtained will not be less than 80% of the value obtained according to the first method, and no additional situation is given regarding torsional irregularity. In other words, no increase in the limit values of seismic isolation units is foreseen due to the torsional irregularity in the superstructure. Therefore, it would be meaningful to define and use a parameter resulting from the superstructure's torsion in determining the limits of the seismic isolation units.

It is thought that the purpose of using the 1.3 coefficient used in the seismic isolation unit displacement in the TBEC-2018 regulation is to obtain the resultant displacement value. This coefficient gives safe results if the ratio of the small dimension to the large dimension in the plane of the seismic isolation unit layer is less than 83%. If the size ratio is greater than this ratio, that is, if the seismic isolation layer shape approaches the square shape, this coefficient converges to the value of 1.41.

According to TBEC-2018, the resultant value is obtained by multiplying it with a coefficient of 1.3. Then, to include the torsion effect, the seismic isolation unit displacement is magnified by another coefficient calculation that takes into account the eccentricity (between the center of rigidity of the seismic isolation units and the center of mass of the structure), the solid dimensions of the seismic isolation unit and the geometric positions of the seismic isolation units (relative to the center of stiffness). If the resultant displacement calculation is made after obtaining the orthogonal displacement values, which inherently involve torsional movement, even if the size ratio is 83%, instead of the coefficient of 1.3, 1.45 or larger values should be used because the seismic isolation units have more unfavorable positions relative to the center of rigidity. Therefore, the coefficient of 1.3 used to obtain the resultant displacement value should be examined better by the design engineer.

Since the torsion effect on the seismic isolation layer directly increases and decreases with the location of the seismic isolation units relative to the rigidity center, the rigidity center being close to the geometric center will limit the enhancing effect of the geometric position on the torsion effect. Suppose it is impossible to bring the rigidity center closer to the seismic isolation layer's geometric center. In that case, dividing the seismic isolation layer with joints may be meaningful. Especially if buildings of different heights are on the same seismic isolation layer and have a non-symmetrical floor plan, this will cause the center of rigidity to move away from the geometric center, which may cause the capacity of the seismic isolation units to be chosen larger by the design engineer.

The fact that the torsion effect is seen in the superstructure as well as in the seismic isolation units' layer where the seismic isolation units are located may cause the performance values not to be achieved due to the increase in the relative displacement value due to non-uniform floor drift within the floor. In addition, due to the increase in relative displacement due to torsion, wall damage will be observed more than it should be. Since torsional movement increases the relative displacement, it can be predicted that it may cause wall damage even on floors where the floor drift is low.

In seismic isolation unit design, it is not only to ensure that the design engineer minimizes the torsional effects caused by the superstructure or the seismic isolation unit layer, but also to meet the limits in the

TBEC-2018. In addition, it is crucial to pave the way for more economical seismic isolation unit solutions and, more importantly, to increase the predictability of the structure's response if the earthquake ground motion level approaches the maximum considered earthquake (MCE).

In TBEC-2018, the effective damping ratio should be below 30% in the ELM, and MCM defined as a condition of the usability of these methods. In the THAM, there is no condition regarding effective damping. Here, in the ELM and MCM, it is not clarified whether the effective damping should be calculated according to the design displacement or the largest displacement. As it is known, as the seismic isolation units begin to move closer to the design displacement, the effective damping value decreases. Therefore, providing the 30% limitation under the largest displacement instead of the design displacement will be more conservative as it will increase the amount of dissipated energy at the design displacement and the largest displacement. On the other hand, since the shear force transferred to the superstructure will decrease in the design basis earthquake (DBE), the resistance of the superstructure to damage will decrease, although it is not foreseen that the structural system of the superstructure will be damaged in the design with seismic isolation units. Although it is not necessary to consider ductile behavior in the design of the superstructure in a building with seismic isolation units, having the reinforced concrete or steel structural elements manufactured in ductility conditions can be considered as an additional damage-based damping source against the collapse of the superstructure. Since there is no guidance in TBDY-2018 about whether or not ductility conditions should be met in the design of the structural system elements in the superstructure, it is unclear what the design engineer will take into account in the project he will present when giving the cross-sectional details of these elements. Although it is not necessary to consider whether the superstructure and substructure system are ductile or not in seismic isolation building design, limited ductility conditions can be considered in the structural system elements, sections and materials with a conservative approach.

All three analysis methods such as ELM, MCM, and THAM recommended in TBDY-2018 for building design with seismic isolation units use the spectrum values given in the Turkey Earthquake Hazard Map (TDHM) and the spectrum values here are calculated according to 5% damping value. Therefore, the data produced here with 5% damping values may be important in the type of seismic isolation unit, displacement of the seismic isolation unit or acceleration in the superstructure (Kanbir et al., 2022). Since earthquake records generally show high damping in seismic isolation units at low displacement values at high frequencies, the above-mentioned situation may be more critical in cases where the displacement at low frequencies approaches the design or maximum displacement.

Although buildings with seismic isolation units reduce the amount of movements passing to the superstructure with low displacements and large damping in high-frequency recordings, they will be insufficient to prevent the discomfort in non-structural elements and people caused by low-amplitude acceleration changing at high frequencies in the superstructure. Comfort can be achieved by reducing the change in acceleration or by reducing the acceleration value below 0.01 g, which humans do not feel. Therefore, other precautions should be considered to ensure that buildings with seismic isolation units are operational according to their purpose during and after the earthquake. This situation will be more evident, especially in hospital buildings.

1.2. Observations on some isolated hospital buildings in the earthquake zone

The locations of the hospital buildings with seismic isolation units examined in the region in Figure 1 and Figure 2 are shown in Figure 1(a) and Figure 2(b), which contain the PGA contour lines of the Kahramanmaraş earthquakes centered in Pazarcık and Elbistan, respectively. Figure 1 and Figure 2 also show the PGV contour lines. Table 1 gives the names and code names of the hospitals with seismic isolation units examined.

When looking at Figure 1 and Figure 2, it can be seen that public hospitals with seismic isolation units in Malatya and Kahramanmaraş were exposed to impacts around and above 20% g acceleration and 200 mm/s velocity data in both earthquakes. In state hospitals with seismic isolation units in Osmaniye and Hatay, Mw=7.7 Pazarcık-Kahramanmaraş earthquake had effects around or above 20% g acceleration and 200 mm/s velocity data, while these hospitals had Mw=7.6 Elbistan-Kahramanmaraş earthquake above 5% g acceleration or 50 mm/s velocity data. The state hospital with seismic isolation units in Adana was exposed to an acceleration of around 5% g and above and a velocity of around 200 mm/s and below during the Mw=7.7 Pazarcık-Kahramanmaraş earthquake. It is understood that the same hospital was exposed to an acceleration below 5% g and a speed above 50 mm/s in the Mw=7.6 Elbistan-Kahramanmaraş earthquake. Figure 3 shows the locations of AFAD stations and active faults in the earthquake zone.

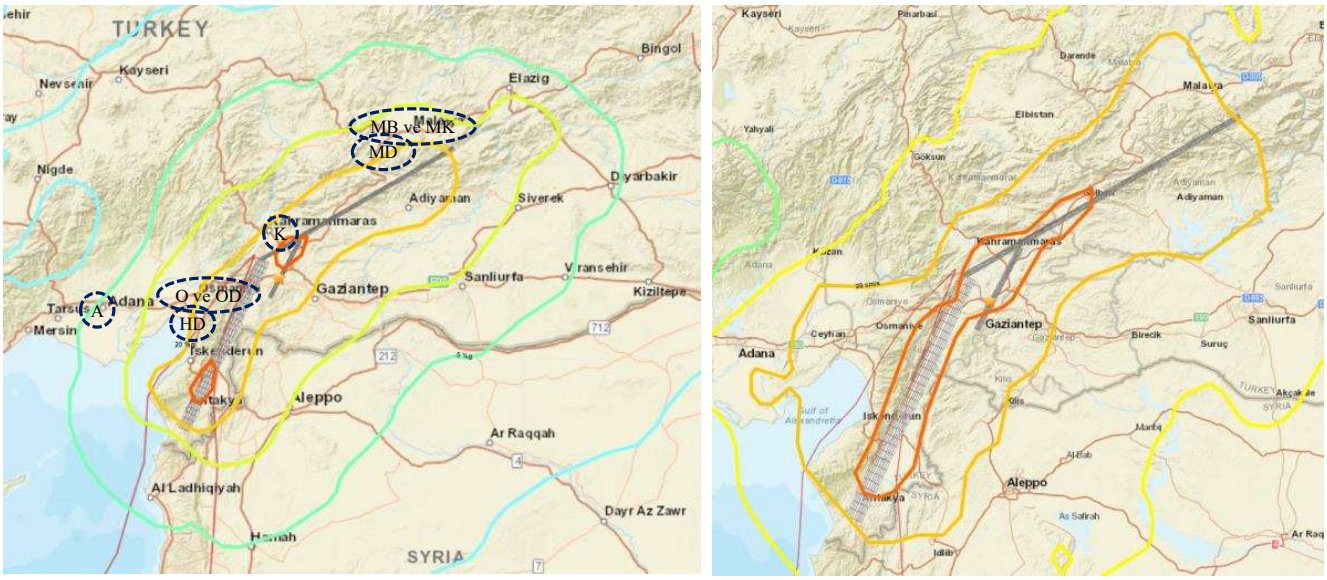


Fig. 1. (a) PGA from USGS (orange line- %20 g, green line-%5 g), (b) PGV from USGS (orange line 200 mm/s, green line-50 mm/s) of Mw=7.7 Pazarcık-Kahramanmaraş Earthquake (URL-2, 2023)

Table 1. Names and code names of hospitals with seismic isolation units examined in the earthquake zone

Hospital name	Code	Map View		Code	Map View
Kahramanmaraş Maternity and Children's Hospital	K		Hatay Dörtyol State Hospital	HD	
Malatya Doğanşehir Şehit Esra Köse Başaran State Hospital	MD		Osmaniye Düziçi State Hospital	OD	

Table 1. (Continued)

Malatya Battalgazi State Hospital	MB		Osmaniye State Hospital	O	
Malatya Maternity and Children's Hospital	MK		Adana City Training and Research Hospital	A	

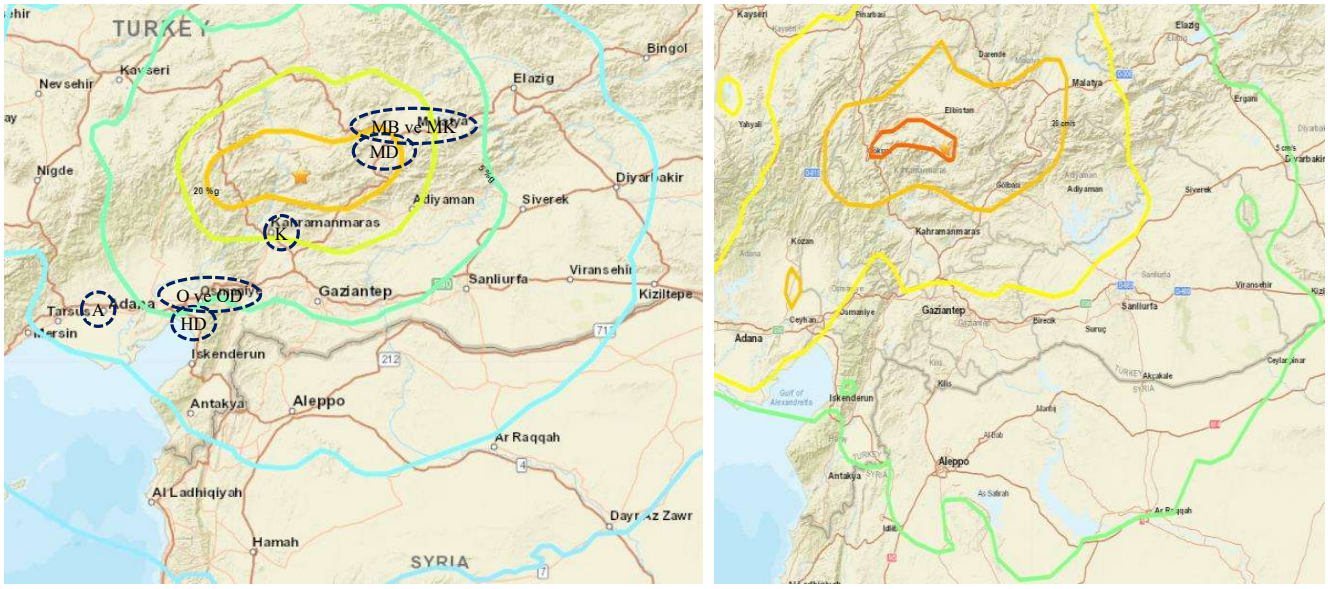


Fig. 2. (a) PGA from USGS (orange line- %20 g, green line-%5 g), (b) PGV from USGS (orange line 200 mm/s, green line-50 mm/s) of Mw=7.6 Elbistan-Kahramanmaraş Earthquake (URL-3, 2023)

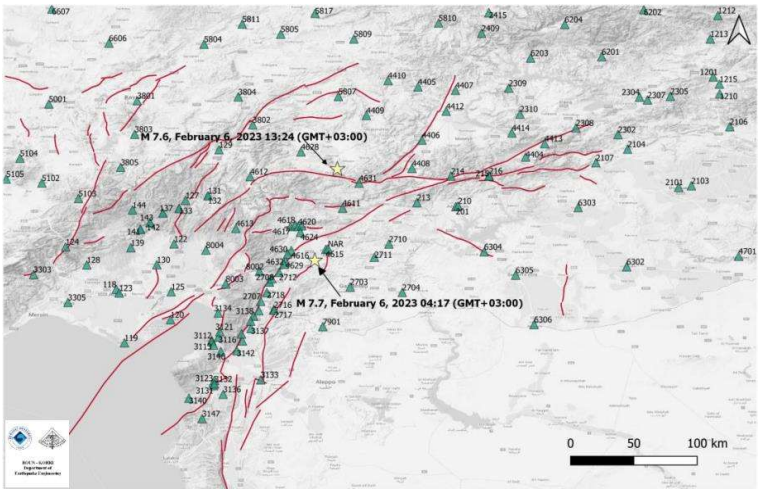


Fig. 3. AFAD stations shown with green triangles, the epicenters shown with yellow stars of the Mw= 7.7 Pazarcık-Kahramanmaraş and Mw= 7.6 Elbistan – Kahramanmaraş Earthquakes and the faults shown with red line (Hancılar et al., 2023)

2. Observations and Assessments

In this study, after examining the relationships among the data at the stations in the earthquake zone under subheading 2.1, the data and observations obtained from hospital buildings with seismic isolation units and their relationships with the station data will be examined under subheading 2.2. In subheading 2.2, the damages observed in the hospital buildings and the evaluations made based on the observations will also be included.

2.1. Assessment of relationships of data from earthquake stations near the hospitals

After the Kahramanmaraş earthquakes, data derived from the five stations thought to be closest to the hospitals [Boğaziçi Report] among 109 stations in the region were used. These data can be listed as follows: peak ground displacement (PGD), peak ground acceleration (PGA), average shear-wave velocity of the upper 30 meters of soil (V_{S30}), aria intensity (AI), epcentral fault distance (R_{epi}), rupture, fault distance (R_{rup}), distance to the surface projection of the rupture (R_{jb}), significant duration of the strong ground motion the time interval between 5% and 95% of the arias intensity ($Dur_{5\text{-}95}$), cumulative of absolute velocity (CAV). The PGD* value presented in Table 2 was obtained by combining the PGD values of the horizontal components at the stations with Eq (1). Here, the situation where the peak values of the horizontal components do not occur at the same time is ignored. PGA* value is the one with the highest aria intensity value among the horizontally combined records at the stations.

$$PGD^{*} = (PGD_{East}^{2} + PGD_{North}^{2})^{0.5} \quad (1)$$

Additionally, pseudo wave length (PWL) values calculated with the help of Eq. (2-3) are evaluated in Table 2. The V_{S30} speed used in Eq. (2) is accepted as the transmission speed of the medium. In Table 2, the PWL value was calculated using the PGA and PGD values of the horizontal component of the one with the highest aria intensity value in the records obtained from the stations.

$$Dominant\ Frequency\ (DF) = \frac{1}{2\pi}\left(\frac{PGA}{PGD}\right)^{0.5} \quad (2)$$

$$PWL = V_{S30}/DF \quad (3)$$

In this evaluation, correlation coefficients between data vectors consisting of the values of each data type at the stations were calculated. The significant threshold value for the calculated correlation coefficients was accepted as 0.58, and values above this threshold are presented in Table 2. Even though the evaluations to be made for station data through correlation coefficients will be made from a narrow pool of data, it is seen that the obtained relationships are compatible with known evaluations. An example of this is that the R_{epi} or R_{jb} distances are inversely proportional to the peak displacement and acceleration values.

Table 2. Correlation coefficients of data types at stations close to hospitals (Station No: 4624, 4406, 3134, 8003, 118)

	PGD (Vertical)	R_{epi}	R_{jb} or R_{rup}	V_{S30}	PGA*	AI	Dur_{5-95}	CAV	PWL
PGD* (Horizontal)	0.93	-0.87	-0.72	-0.77	0.95	0.99		0.98	
PGD (Vertical)		-0.83	-0.88	-0.73	0.93	0.90		0.91	
R_{epi}			0.74	0.96	-0.89	-0.87		-0.95	0.75
R_{jb} or R_{rup}				0.78	-0.87	-0.63	0.73	-0.74	
V_{S30}					-0.87	-0.73		-0.87	0.73
PGA*						0.90		0.96	
AI								0.97	-0.58
CAV									-0.65

When relations other than the known relations are examined through the correlation coefficients presented according to Table 2, although the peak vertical and horizontal displacement values are inversely proportional to Vs30, Repi, and Rjb are directly proportional to Vs30. However, as is known, peak vertical and horizontal displacements are inversely proportional to Repi and Rjb. In this case, it is understood that the stations in the region are located on relatively more flexible ground in places close to the fault and on more rigid ground in distant places. Although the pseudo wavelength of the ground motion calculated using Vs30 with peak acceleration and displacement is directly proportional to both Vs30 and Repi, no significant relationship with Rjb was obtained. Although the pseudo wavelength is directly proportional to both Vs30 and Repi at stations close to hospital buildings, it is also inversely proportional to AI and CAV. In this case, it is understood that the earthquake waves at peak values are transmitted to relatively rigid soils that are far from the epicenter with larger wavelengths. Large wavelengths mean that low-frequency waves are transmitted to solid ground, which means that multi-storey structures on rigid ground will be more affected. Normally, multi-storey buildings on rigid soils are expected to be less affected by earthquake movements due to the reduced possibility of resonance.

Table 2 also shows that Dur_{5-95} is directly proportional to R_{jb} or R_{rup}. In other words, as we get closer to the fault, the Dur_{5-95} duration decreases as expected, but the AI and CAV values increase. This increase is also directly proportional to PGA and PGD.

2.2. Assessment of information over observed isolated state hospitals in the earthquake zone

The observed total and residual displacement amounts of the hospital buildings and the ratio of the total displacement to the allowed displacement amounts of the seismic isolation units are given in Figure 4. In Figure 4, values for which no displacement movement could be detected as a result of observation were entered as zero.

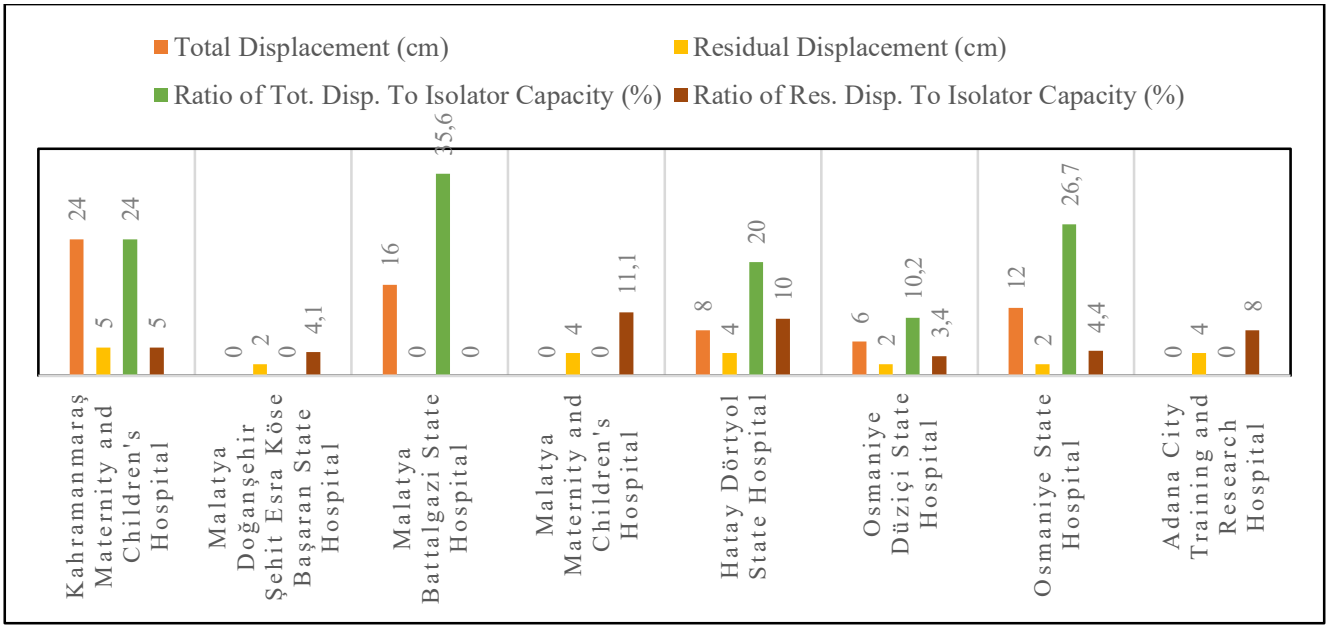


Fig. 4. (a) Total and (b) residual displacement amounts of seismic isolation units according to observations made between 21-25 February 2023

According to Figure 4, three of the eight hospital buildings for which data were observed have not been put into service, and the structural system of the hospital in Kahramanmaraş, one of which has not been put into service, is incomplete. In other words, there are seven hospitals that may or may not be in service but whose structural systems have been completed. The inferences obtained from the graph given in Figure 4 are presented in Table 3.

Table 3. Information about hospitals with seismic isolation units that experienced extreme total and permanent displacement after the earthquake

Hospital name	The greatest features	Value	The least features	Value
Kahramanmaraş Maternity and Children's Hospital	Total displacement / Residual displacement	24 cm / 5 cm		
Malatya Doğanşehir State Hospital				
Malatya Battalgazi State Hospital	The ratio of total displacement to displacement capacity of the seismic isolation unit	%35.6	Residual displacement / Ratio of residual displacement to displacement capacity of the seismic isolation unit	0/ %0
Malatya Maternity and Children's Hospital	The ratio of residual displacement to displacement capacity of the seismic isolation unit	%11.1		
Hatay Dörtyol State Hospital				
Osmaniye Düziçi State Hospital			Total displacement / The ratio of total displacement to displacement capacity of the seismic isolation unit	6 cm / %10.2
Osmaniye State Hospital				
Adana City Training and Research Hospital				

According to Figure 4 and Table 3, the hospital that made the most total and residual displacement was Kahramanmaraş Maternity and Children's Hospital, whose structural system was not completed, while the hospitals that made the most total and residual displacement compared to the displacement capacity were Malatya Battalgazi State Hospital and Malatya Maternity and Children's Hospital, respectively. In addition, the hospitals that made the least total and residual displacement were Osmaniye Düziçi State Hospital and Malatya Battalgazi State Hospital, respectively, while the hospitals that made the least total and residual displacement compared to their displacement capacities were Osmaniye Düziçi State Hospital and Malatya Battalgazi State Hospital, respectively. According to these comparisons, the hospital with the highest total displacement of the seismic isolation units, the one that uses the displacement capacity, and the one with the most minor residual displacement is Malatya Battalgazi State Hospital. Table 4 presents the correlation of information collected from hospital buildings and nearby station data.

The number of seismic isolation units in hospitals with seismic isolation units, the largest total displacement observed in the seismic isolation units, the minimum distances of the hospitals to the fault, and the observed infill wall damage situations have been tried to be correlated in Table 4 through the correlation coefficients calculated with the data types obtained from the stations. Here, infill wall damages are quantified by scoring from zero to three. The significant threshold value for the calculated correlation coefficients was accepted as 0.58, data types at five stations thought to be close to the hospital buildings were used, and values above this value are presented in Table 4 as in Table 2. Since the correlation coefficients of the data types included in Table 2 but not included in Table 4 remain below the significant threshold value, they are not included in Table 4 for simple presentation.

While the total displacements observed in the seismic isolation units are directly proportional to PGA*, AI, and CAV values, it is seen that it is inversely proportional to R_{epi}, R_{jb}, R_{rup}, and V_{S30}. It is understood that the hospital buildings in the earthquake zone experience less total displacement as they move away from the fault. On the other hand, it is understood that the number of floors of hospitals in the earthquake zone increases or decreases in direct proportion to the Repi value of the stations. According to these evaluations, it can be expected that there is an inverse proportion between the total displacement of the seismic isolation units of hospital buildings and the number of floors. Although PGA* is inversely proportional to the minimum distances of hospitals to the fault, the Dur_{5-95} value is seen to be directly proportional. In other words, it is understood that the earthquake energy is transferred to the hospital buildings over a more extended period of time. A direct proportion is observed between the number of seismic isolation units used in hospitals and the R_{jb} and Dur_{5-95} values of stations close to the hospitals. It is seen that the total amount of displacement in the seismic isolation units increases with the increase of the PGA* value in the stations close to the hospitals and the rigidity of the soil under the stations. Additionally, there is a direct proportion between the infill wall damage observed in hospital buildings and the PWL value. In the evaluations of Table 2, it was inferred that large wavelengths were transmitted in rigid grounds and that multi-storey buildings would be more affected by earthquakes. Here, the increase in infill wall damage in hospital buildings in direct proportion to PWL supports this inference.

Table 4. Correlation coefficients of data at stations close to hospital buildings with seismic isolation units and hospital information

	Observed infill wall damage status	Maximum Number of Floors in the superstructure	Number of seismic isolation units	Minimum distance of hospitals to fault	The total displacement of the seismic isolation unit
PGD (Vertical)		-0.64	-0.58	-0.68	
Repi		0.61			-0.70
R_{jb} or R_{rup}			0.82	0.91	-0.60
V_{S30}					-0.60
PGA*				-0.63	0.73
AI					0.78
Dur_{5-95}			0.87	0.87	
CAV					0.77
PWL	0.82				

Table 5 presents the hospitals in which torsion effects, wall damages, and mechanical installation damages were detected through observations made in hospitals with seismic isolation units. The amount of closed area and the number of seismic isolation units given in Table 5 were obtained from the websites of manufacturing companies or from open sources on the Internet. The seismic isolation layer state, symmetry state, and seismic isolation layer aspect ratio were obtained directly or by measurement from the images on digital maps on the Internet. Hospitals with seismic isolation units where observation is made are located 20-40 km away from the fault lines (Adana City and Education Hospital is more than 100 km away). It is understood from Figure 1 and Figure 2 that, except for the hospital with seismic isolation unit in Adana, other hospitals with seismic isolation units are exposed to the PGA effect of around 20% g or above and the PGV effect of around or above 200 mm/s in at least one earthquake. Since the hospital buildings are more than 20 km away from the fault lines and their velocity values are relatively around 200 mm/s, it can be thought that they are not under the influence of close faults.

In three of the eight hospitals examined in Table 5 (one of which is an uncompleted building), the torsional movement was detected in the seismic isolation unit layer and one in the superstructure. When looking at the aspect ratios of the seismic isolation unit layers, the ratios are greater than 83% in six hospital buildings. In hospital buildings where torsional movement is observed on the seismic isolation layer, this ratio is below 83%, and the capacity utilization ratio of the seismic isolation unit is around 25%. When the presence of torsional motion is coded as "1" and the absence of it as "0", the correlation coefficient between the aspect ratio and torsional motion is obtained as 0.57. However, no significant correlation could be obtained between the amount of wall damage observed and torsional movement.

In three of the observed hospital buildings, mechanical installation was found on the seismic isolation layer; in one of them, no damage was observed; in one of them, it was determined that there were infill walls that could damage the mechanical installation; and in one of them, it was observed that there was not enough space left in the walls above the sub-base for the low elevation parts of the upper foundation.

The existence of a correlation with torsional movement in cases where the aspect ratio is below 83%, and the inability to obtain a significant correlation with the observed wall damages suggest that the presence of torsional movement may be due to the fact that the center of rigidity is different from the geometric center or the center of rigidity and the center of mass are different.

In all hospital buildings with seismic isolation units observed, there were parts of the seismic isolation units layer at different elevations. It is understood that this part is generally where retaining walls are dense. In this case, it is understood that additional forces come to these parts due to the friction forces of the seismic isolation units at higher levels. It is unclear whether this situation is a necessity or a compulsory application that the designer must make. In addition, friction forces originating from different elevation levels may be transmitted to the seismic isolation units at lower elevations. In this case, it may be necessary to increase the damping provided in the seismic isolation units, as the friction forces of the seismic isolation units at the top level will be transferred to the seismic isolation units at the bottom level through the carrier system.

It is understood from the video images in some hospitals with seismic isolation units that more considerable than expected acceleration was transferred to the superstructure so that it moved objects and severely affected the walking of people.

Except for the hospital with seismic isolation units in Adana, dust inside the seismic isolation units, contamination within the seismic isolation unit due to environmental conditions, and water accumulation due to condensation have been observed in other hospitals, and it would be healthy to take precautions to keep the seismic isolation units clean in a sustainable manner.

Table 5. Information about hospitals with seismic isolation units and observations

Hospital name	The torsional movement state	State of seismic isolation unit layer / Symmetry state	Rough aspect ratio of seismic isolation unit layer	Stae of infill wall damages	Max. Number of floors in the superstructure	The amount of closed area (m^2)	The number of seismic isolation unit	State of mechanical installation
Kahramanmaraş Maternity and Children's Hospital	Available	Approximately square/No symmetrical	1	Under construction	5 (Tamamlan-dığında 9)	48390	361	Under construction
Malatya Doğanşehir State Hospital	Not detected	T-shaped/ Single axis of symmetry	1	Severely Existent (Also Suspended Ceiling Damage)	6	28000	122	No mechanical installation was found on the seismic isolation unit layer
Malatya Battalgazi State Hospital	Not detected	Approximately square/No symmetrical	0.96	Moderate	9	60566	222	As far as the mechanical installation was concerned, there was no damage.
Malatya Maternity and Children's Hospital	Available	T-shaped/ Single axis of symmetry	0.69	Little to moderate	13	52307	246	There are infill wall applications on the seismic isolation unit layer, which may damage the mechanical installation.

Table 5. (Continued)

Hospital name	The torsional movement state	State of seismic isolation unit layer / Symmetry state	Rough aspect ratio of seismic isolation unit layer	Stae of infill wall damages	Max. Number of floors in the superstructure	The amount of closed area (m^2)	The number of seismic isolation unit	State of mechanical installation
Hatay Dörtyol State Hospital	It was detected on the floors in the superstructure, not on the seismic isolation unit layer	Approximately square / Single symmetry Axial (Due to different number of floors)	0.89	Moderate	11	48357	340	No mechanical installation was found on the seismic isolation unit layer
Osmaniye Düziçi State Hospital	Not detected	T-shaped / No symmetry	0.87	None (Under the construction)	6	20000	200	No mechanical installation was found on the seismic isolation unit layer
Osmaniye State Hospital	Available	Approximately rectangular / No symmetry	0.68	None (Under construction)	8	180000	541	No mechanical installation was found on the seismic isolation unit layer
Adana City Training and Research Hospital	None	Approximately square / Single symmetry Axial (Due to different number of floors)	0.94	None	12	55000	1512	There is not sufficient space left in the walls above the subbase for the low-elevation parts of the upper base

3. Conclusion and Recommendations

This study aimed to detect the presence of torsional movement in hospitals with insulation units in the earthquake zone, to make inferences about the amount of torsion movement taken into account in the TBEC-2018 regulation, and to evaluate the damage situations in these hospitals. The conclusions and recommendations are presented below:

1. In TBEC-2018, it would be meaningful to calculate a coefficient for the amount of torsion caused by the superstructure and add it to the seismic isolation unit displacement amount calculation.
2. It would be meaningful to consider the method of obtaining the resultant displacement value according to the size ratio in the seismic isolation layer in TBEC-2018. Because the calculation of the resultant value based on orthogonal displacements increased by the torsion effect should be discussed.
3. The field effects of seismic isolation unit applications at different elevations seen in hospital applications with seismic isolation units should be further examined.

4. It is important to use elastomer type or different seismic isolation units as well as solutions with pendulum type seismic isolation units, which are frequently used in applications in our country, to provide diversity. It is important to understand the advantages and disadvantages of these uses later.
5. It is important to make flexible wall joints mandatory, even in buildings with seismic isolation units.
6. It has been seen in most of the hospital buildings examined that it is important to consider the analysis of hospital buildings with seismic isolation units, taking into account the functional use of hospitals after the earthquake and the load-bearing system.
7. To fully determine the residual and total displacements of the seismic isolation units, it is important to install systems with checked operation in buildings with seismic isolation units and to monitor them in terms of the measures that need to be taken.
8. Reporting the performance of hospital buildings with seismic isolation units by an independent commission and evaluating them with the manufacturer, producer, and design firm is important for the measures to be taken to be meaningful.
9. A directly proportional relationship between pseudo wavelength (PWL) and wall damage was obtained through seismically isolated hospital buildings. Using and testing the so-called wavelength in damage assessment on other building stocks exposed to earthquakes would be meaningful.
10. Scale shaking table tests can be performed to determine the torsion amounts in structures with seismic isolation units. Scale testing to determine wind loads is a method that engineers use despite the availability of numerical modeling in special structures. In shaking table experiments, the contribution of wave propagation, which is not taken into account in the numerical programs used by many design engineers in modeling, to the amount of torsion in the seismic isolation layer of the superstructure can be better revealed.
11. It should be noted that it would be very meaningful to establish an effective building health monitoring system in seismically isolated hospital buildings.
12. The adequacy of the flexibility in mechanical installations and their ability to stretch in all directions should be reviewed.
13. In infill wall applications between the sub-base and the upper base, sufficient space must be left in all directions in the parts of the mechanical installation passing through the wall. These infill walls should not be joined to the upper foundation. Precautions must be taken on the sub-base to support their own weight and prevent them from tipping out of the plane.
14. Measures should be taken to allow the free movement of low-level parts of the upper foundation from under the upper foundation.
15. It should be checked whether the cracks in the sub-base, which are thought to be caused by the swelling of the ground over time, load the insulation units within the prescribed vertical force limit.

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