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Research Article

Reinforced Concrete Design of Tall Buildings According to the Turkish Earthquake Code

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Abstract

The new Turkish earthquake code (TEC 19) is primarily based on Performance Based Seismic Design, and includes elements from the "Guidelines for Performance-Based Seismic Design of Tall Buildings," a code published by the Pacific Earthquake Engineering Research Center in the United States. This article studies the advantages and disadvantages of TEC 19 with respect to the preexisting code (TEC 07), and the impact of the new code on the design of high rise buildings. In order to understand the effects of the new code, two 30 story residential buildings—one constructed using tunnel formwork, and the other with special moment resisting frames—were designed according to TEC 19 and TEC 07. The design results of the earthquake analyses were used to understand the impact of TEC 19 on high rise buildings, since these buildings with similar framing systems are now commonly being built in most of the major cities of Turkey. The analyses also included the total base shear, axial forces, shear forces, and bending moments of some structural members. Based on the design results, it was observed that the new code generally generated higher earthquake forces on both buildings with tunnel formwork and special moment framing system.

Keywords: Building design, Earthquake analysis, Turkish earthquake codes, High rise buildings.

Türkiye Bina Deprem Yönetmeliğine Göre Betonarme Yüksek Binaların Tasarımı

Öz

Yeni Türkiye Bina Deprem Yönetmeliği (TBDY 19) Performansa Dayalı Tasarım ilkelerine uygun olup aynı zamanda ABD'deki the Pacific Earthquake Engineering Research Center tarafından yayınlanan "Guidelines for Performance-Based Seismic Design of Tall Buildings," adlı tavsiye niteliği taşıyan yönetmelikten de bazı kısımlar içermektedir. Bu makalede yeni deprem yönetmeliğinin bir önceki yönetmeliğe (DBYBHY 07) göre avantaj ve dezavantajları incelenecek, özellikle yüksek bina tasarımı üzerindeki etkileri araştırılacaktır. Bu kapsamda biri tünel kalıp inşaatına uygun diğeri ise moment aktaran süneklik düzeyi yüksek çerçeveli sistemden oluşan, toplamda 2 adet 30 katlı konut binası hem yeni hem de bir önceki deprem yönetmeliklerine uygun olarak tasarlanacak ve analizleri yapılacaktır. Deprem analizi ve tasarım sonuçları kullanılarak TBDY 19'un günümüzde pek çok büyük şehirde inşa edilen özellikle yüksek binalar üzerindeki etkisi incelenecektir. Analiz sonuçları sırası ile seçili olan yapısal elemanlardaki taban kesme kuvveti, eksenel yük, kesme kuvveti ve eğilme momenti değerlerini içerecektir. Analiz ve tasarım sonuçlarına göre ortaya çıkan sonuçlar incelendiğinde ise yeni deprem yönetmeliğinin bir önceki yönetmeliğe göre her iki bina türü için de daha fazla deprem yükleri ürettiği görülmüştür.

Anahtar Kelimeler: Bina tasarımı, Deprem analizi, Türkiye deprem yönetmelikleri, Yüksek binalar

1. Introduction and Objective

Earthquakes are the most devastating natural disasters in Turkey. The country suffered significantly from the lack of construction quality which resulted in human loss of 75 thousand people in 100 years (MCEER, 2019). The country's first earthquake code was in effect in 1940, and was directly adapted from the Italian earthquake code (Sezen et al., 2000). Since then the code was revised ten times specifically after a major earthquake. The most comprehensive earthquake code was prepared in 1968, and it was led by the three others published in 1975, 1997 and 2007. The current earthquake code, TEC 19, was published in 2019 (AFAD, 2019).

TEC 19 is primarily based on Performance Based Seismic Design, and it includes elements from "Guidelines for Performance-Based Seismic Design of Tall Buildings," a code published by the Pacific Earthquake Engineering Research Center (PEER) in the United States (Pacific Earthquake Engineering Center, 2017). Since the current code is quite new, there are many research and studies conducted in this area (Tunc and Tanfener, 2016; Tunc and Tanfener, 2018; Sucuoglu, 2019; Elci and Goker, 2018; Nemutlu and Sarı, 2018). The initial findings of the research were shared at a conference, and the article was mainly extracted from this conference presentation (Tunc and Tanfener, 2018). This study discusses the advantages and disadvantages of TEC 19, with respect to the preexisting code, TEC 07 (Turkish Ministry of Public Works and Housing, 2007) so that the changes imposed by TEC19 can be well understood. For this purpose, two 30-story residential buildings—one with tunnel formwork, and the other one with special moment resisting frames—were analyzed using the guidelines stated in these two earthquake codes. The analyses results were, then, used to determine the impact of TEC 19 on high rise buildings, since these types of buildings are now commonly being built in most cities of Turkey. The results include the, total base shear, axial forces, shear forces, and bending moments of critical structural members.

2. Method of the Study

In TEC 19, buildings are classified as tall buildings if their heights exceed the code specified limits that are directly linked to the seismicity and soil conditions of building's location. As defined in the code, tall buildings are subjected to more stringent design rules and procedures. In this study, the goal is to analyze tall buildings according to both TEC 07 and TEC 19 (the current and the preexisting); thus, intending to emphasize the significance of expected changes in the reinforced concrete design stage.

In order to achieve the aforementioned goal, two distinct floor layouts are considered. The first-floor layout is a structural system containing moment resisting frames with a core wall. The other layout represents a typical tunnel formwork structural framing system with shear walls only. The prototype buildings are assumed to have thirty stories with a floor height of 3.4 meters, which makes them 102 meters tall in total. This height with its selected seismic parameters exceeds the "tall building" limit defined in TEC 19. The prototype buildings are modeled and analyzed by using a commercially available software package of ETABS 2016 (Computers and Structures, 2016).

2.1 Building properties and modeling preferences

2.1.1 Loads and building layouts

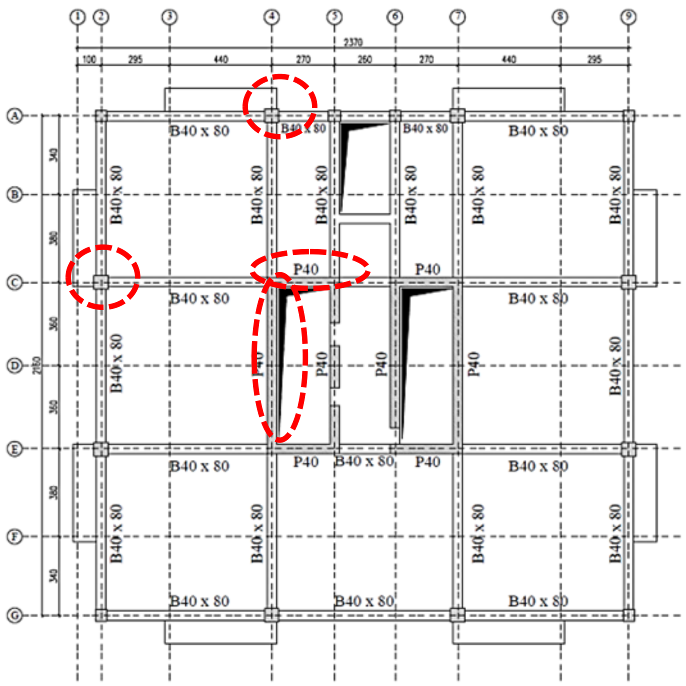
The structural member sizes are determined according to the minimum requirements of TEC 19. These member sizes are validated based on the preliminary design of buildings; however, no further optimization is considered since this is not the scope of this study. In order to compare the results, the same member sizes are used for the analyses conducted according to the current and the preexisting codes.

The first layout (Layout-1) comprises moment resisting frames and solid core walls (Figure 1-a). The shape of the floor plan is almost like a square with 24 meters by 25 meters in-plan dimensions. The building has three spans in each of its orthogonal direction. The core walls (shear walls) are located in the center of building each with 40 cm thickness. The walls are assumed to have the same thickness for all thirty floors. The columns are located along the building perimeter. The largest column dimension is 80 cm by 160 cm and assigned to all columns of the lower three floors. The column sizes are optimized by changing their dimensions at the fourth, tenth and twentieth floors. Beyond the twentieth floor, the dimensions of corner and middle columns located along the building perimeter are 50 cm by 50 cm and 60 cm by 60 cm, respectively. All beams are assumed to have the same dimensions with a width of 40 cm and a depth of 80 cm. The slab thickness is calculated 20 cm, and is assumed to be the same for all floors.

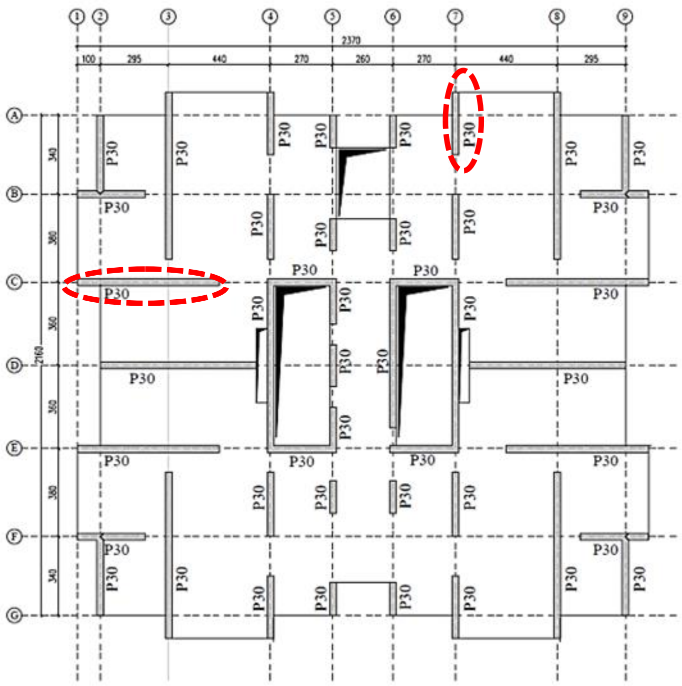
The second layout (Layout-2) represents a typical tunnel formwork framing system with solid walls in both directions (Figure 1-b). The floor plan of the building is similar to Layout-1 with 25 meters to 24 meters in-plan dimensions. All shear walls are 30 cm thick walls and their thicknesses are determined based on the minimum thickness requirement of TEC 19. The slab thickness is determined 12 cm, and accepted to be the same for all floors.

Structural analysis models are constructed in ETABS 2016 by using shell elements for shear walls and slabs, and frame elements for columns and beams. Shell elements are discretized using approximately 1.0 meter by 1.0 meter mesh size. All shell elements are assumed thin elements, thus their transverse deformations due to shear are neglected.

The concrete class is C40 with a modulus of elasticity of 35,000 MPa and a Poisson's ratio of 0.2. The unit weight of reinforced concrete is assumed 25 kN/m^3. Other gravity loads include 3.0 kN/m^2 of superimposed dead load and 2.0 kN/m^2 of live load imposed on all floors.



(a)



(b)

Figure 1. Floor layouts a) layout-1: moment resisting frame, b) layout-2: tunnel formwork

2.1.2. Seismic design parameters according to TEC 07

All buildings are assumed to be residential located in downtown Antalya, Turkey. According to TEC 07, there are four seismic zones; the first zone is for the highest seismic risk, while the fourth one is for the lowest risk. The downtown Antalya is located in the second zone and the corresponding magnitude of ground acceleration is 0.3g. In TEC 07, the design earthquake for buildings is defined with a 10% probability of exceedance within a period of 50 years. Buildings shall be designed and built to satisfy the "life safety" performance level under that earthquake level. The seismic parameters of TEC 07 are listed in Table 1.

Table 1. TEC 07 seismic parameters

Seismic Design Parameters	**Layout-1**	**Layout-2**
Soil Class	Z3	Z3
Seismic Zone	Zone 2	Zone 2
Effective Ground Acceleration Coefficient	0.30	0.30
Spectrum Characteristic Periods (T_A, T_B)	0.15s ; 0.60s	0.15s ; 0.60s
Structural Behavior Factor (R)	7.0	6.0
Building Importance Factor (I)	1.0	1.0

2.1.3 Seismic design parameters according to TEC 19

To provide a realistic comparison between the current and preexisting seismic codes, similar building properties and seismic parameters are used in the analyses according to TEC 19. Therefore, a specific location somewhere near Antalya is selected to be the most appropriate location, where the magnitude of peak ground acceleration is 0.3g.

In the current code, the vertical component of seismic effects is not accounted. However, TEC 19 requires the vertical component of seismic effects, $E_d^{(z)}$, to be taken into account. The vertical seismic load is, then, calculated using Equation 1, and added to the seismic combinations with a multiplication coefficient of 0.3.

$$E_d^{(z)} \approx (\tfrac{2}{3}) \times S_{DS} \times G \qquad (1)$$

TEC 19 has a separate chapter designated for the seismic design of tall buildings (chapter 13). According to this chapter, seismic design of tall buildings shall be performed in line with a three stage procedure. The first design stage has similar procedures to those of TEC 07 code. Therefore, response spectrum analysis is permitted, and a strength-based design is used. In this stage, the preliminary design is completed, and structural members are detailed. In TEC 19, there are four earthquake levels ranging from DD-1 to DD-4 (DD-1 is used to simulate the most intensive earthquake level). The considered level of earthquake in the design stage has a 10% probability of exceedance within 50 years, which is the same in TEC 07 code, and is categorized DD-2. The required seismic design parameters of DD-2 are presented in Table 2.

The second design stage is performed by considering DD-4 earthquake which has a 68% probability of exceedance in 50 years. As defined in TEC19, buildings shall be designed to satisfy "operational" performance level under this earthquake level. In the second stage, if the building's importance factor is 1.5 (utmost importance level such as hospitals, schools etc.) then the design earthquake level and the required performance level increases to DD-3 and "immediate occupancy", respectively. In this case, a deformation-based design and time-history analysis becomes obligatory. In this study, the buildings are assumed residential and the second stage analyses are performed according to the DD-4 level earthquake and response spectrum analysis. Besides, the response spectrum curve is modified to conform to a 2.5% damping ratio by increasing the spectral acceleration values.

Table 2. TEC 19 seismic parameters (DD-2 earthquake)

Parameters for Seismic Design	**Layout-1**	**Layout-2**
Soil Class	ZC	ZC
Peak Ground Acceleration (PGA)	0.3g	0.3g
Mapped Spectral Response Acceleration Parameter for Short Periods (S_S)	0.650	0.650
Mapped Spectral Response Acceleration Parameter at a Period of 1 s (S_1)	0.179	0.179
Design Spectral Acceleration Parameter for Short Periods (S_{DS})	0.806	0.806
Design Spectral Acceleration Parameter at a Period of 1 s (S_{D1})	0.269	0.269
Spectrum Characteristic Periods (T_A, T_B)	0.066s ; 0.334s	0.066s ; 0.334s
Structural Behavior Factor (R)	7.0	6.0
Overstrength Factor (D)	2.5	2.5
Occupancy Category	BKS = 3	BKS = 3
Building Importance Factor (I)	1.0	1.0
Seismic Design Category	DTS = 1	DTS = 1
Building Height Category	BYS = 1	BYS = 1

In the second stage, structural behavior and overstrength factors are not used (both of them are equal to 1), however, a similar approach to that of the first stage is used discretely for ductile and non-ductile forces. For this purpose, demand/capacity ratios are specified separately for member strength verification. Demand/Capacity (D/C) ratio is 1.5 for ductile, and 0.7 for non-ductile forces (Table 3). As specified in TEC 19, structural member capacities are calculated based on the expected material strengths. In this study, the obtained results are modified on this basis. Ductile forces are decreased while non-ductile forces are increased to be able to compare the results of two stages.

Table 3. TEC 19 seismic parameters (DD-4 earthquake)

Soil Class	ZC
Peak Ground Acceleration (PGA)	0.097g
Mapped Spectral Response Acceleration Parameter for Short Periods (S_S)	0.208
Mapped Spectral Response Acceleration Parameter at a Period of 1 s (S_1)	0.055
Design Spectral Acceleration Parameter for Short Periods (S_{DS})	0.270
Design Spectral Acceleration Parameter at a Period of 1 s (S_{D1})	0.082
Spectrum Characteristic Periods (T_A, T_B)	0.061s ; 0.304s
Structural Behavior Factor (R)	1.0
Overstrength Factor (D)	1.0

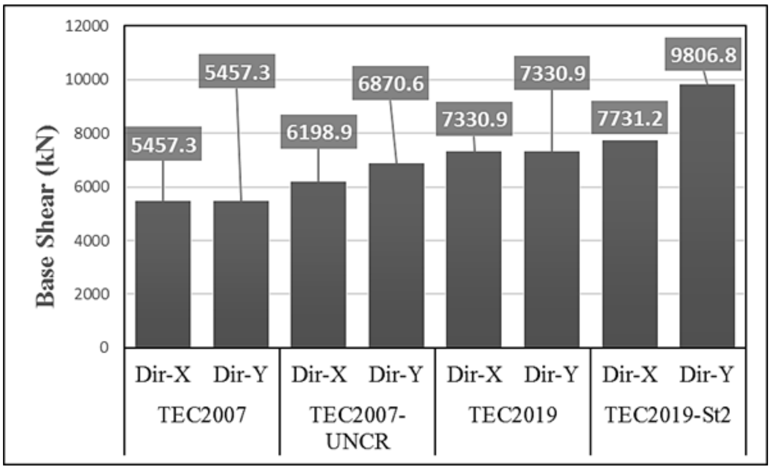
The third and final stage of tall building design requires the "life safety" performance objective that will be satisfied under DD-1 (highest earthquake level – probability of exceedance is 2% within 50 years) earthquake. In this stage, both displacement-based design and time history analysis are obligatory. Based on the results of this stage, optimization of structural members such as beams, coupling beams etc. is permitted; however, the optimization of vertical structural members is not permitted. In this study, the focus was primarily on the first and the second design stages since the structural members were not intended to be optimized and the detailed design was not the emphasis of this study. Therefore, the results of the final design stage are not performed, and only the first and second stage results are considered.

2.1.4 Effective section stiffness coefficients

In TEC 07 seismic code, there is no requirement for reducing section stiffnesses when conducting elastic analysis. However, TEC 19 enforces the use of effective section stiffnesses for building analysis. In this study, analyses according to the current code has been performed both using gross and effective section stiffnesses (uncracked and cracked section properties). In TEC 19, two sets of different effective stiffness values are specified for the first and second design stages. Since the considered level of earthquake intensity is far less than the first stage, the reduction in stiffnesses becomes less for the second stage analysis. The values of effective stiffness coefficients are in TEC 19, but they are not provided here due to space limitation.

3. Analysis and Design Results

Analyses and design results are provided for the base shear and the internal forces of both columns and walls. The results are plotted in two separate figures, one with the base shear forces and the other one with the normalized values. The normalized values are obtained by comparing the results of all four cases to those from TEC 07. These four cases are TEC 07, TEC 07-UNCR, TEC 19, TEC 19–St2. TEC 07 is used to display the results based on cracked section properties, while TEC 07–UNCR is used for uncracked section properties. The notation for TEC 19 is selected for the results of Stage 1, and TEC 19–St2 is for the results of Stage 2. In Layout-1, the base shear forces increased as high as 42% in the x and 80% in the y direction compared to their counterparts resulting from TEC 07 (Figure 2). Based on the results from cases 1 through 4, a steady increase in the base shear forces was noted for both directions. However, this pattern of Layout-1 was not observed for Layout-2 (Figure 3).



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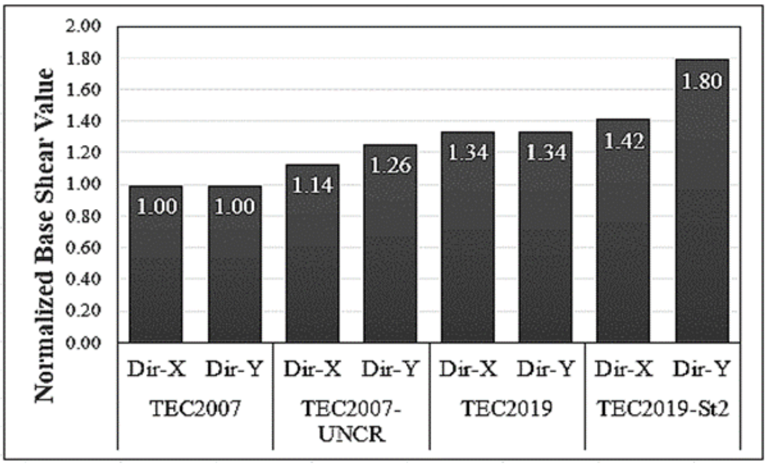
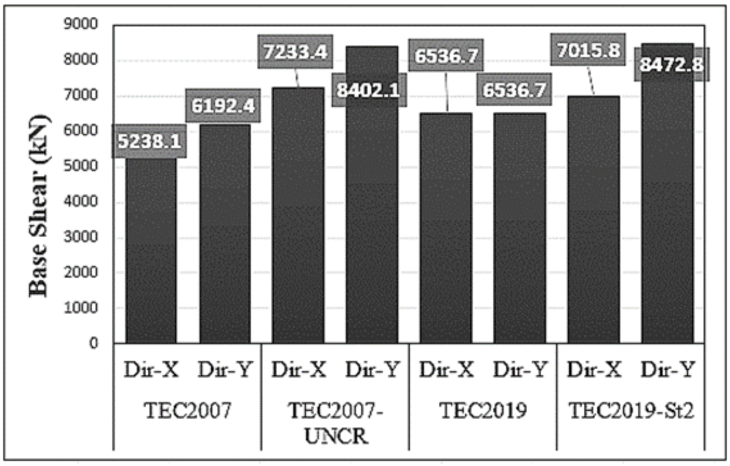


(b)

Figure 2. Frame system (layout-1): a) base shear forces, b) normalized base shear values



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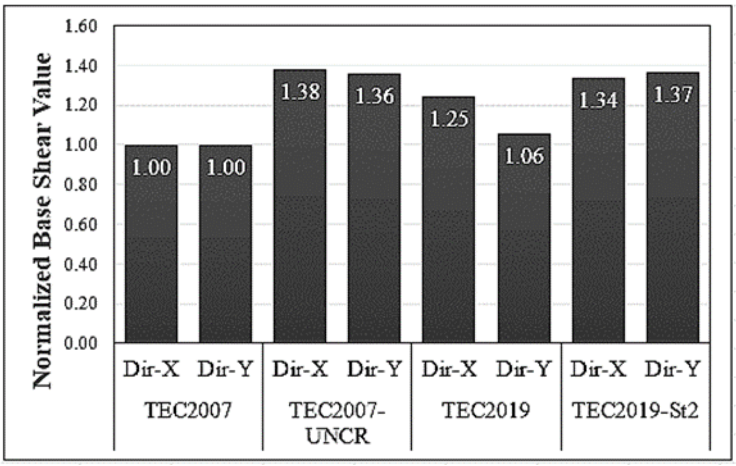
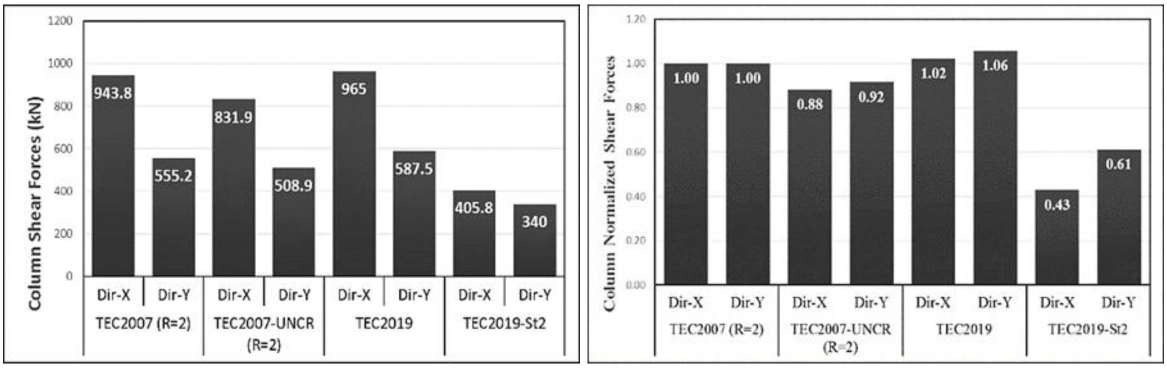


(b)

Figure 3. Tunnel formwork (layout-2): a) base shear forces, b) normalized base shear values



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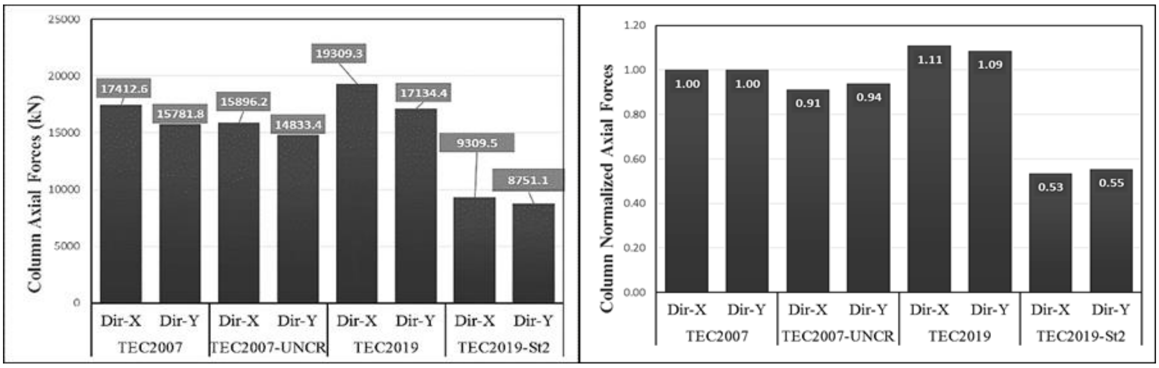

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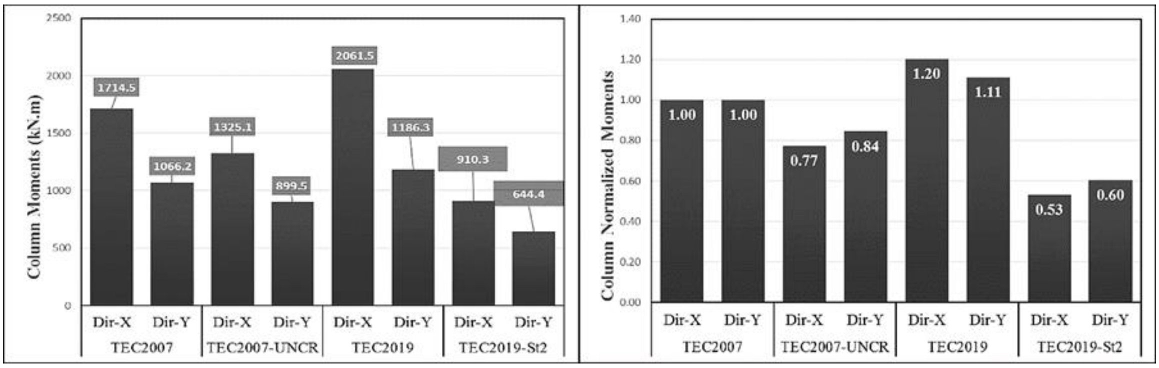
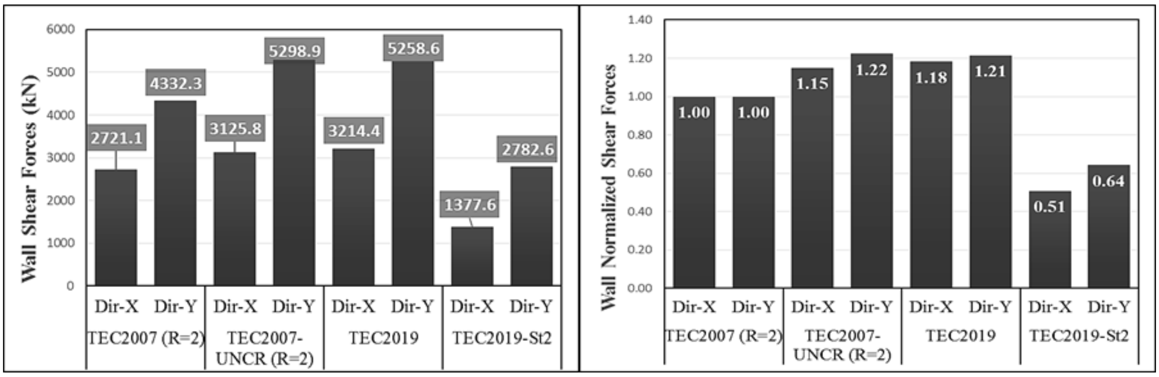


(c)

Figure 4. Column internal forces and their normalized values: (a) shear forces, (b) axial forces, and (c) bending moments

Two shear walls in Layout-1, one in the *x* and the other one in the *y* direction, are selected for this study (Figure-1). The shear forces of TEC 07 -except for those from Stage 2 of TEC 19- increased by an average of 20% both in the *x* and *y* directions when TEC 19 was used (Figure 5-a). This pattern was similar to the one observed for the axial forces with an increase of approximately 12% in both directions (Figure 5-b). For the bending moments, the same pattern – except for those from TEC 19 in the *y* direction- repeated itself (Figure 5-c). Based on the results of Stage 2 of TEC 19, all forces and moments extracted from other cases in both directions were observed to decrease by 20% to 50%.



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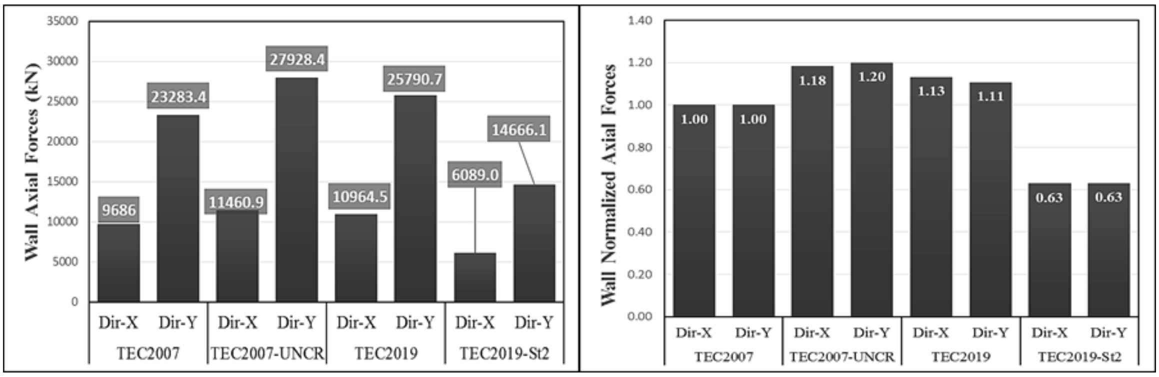

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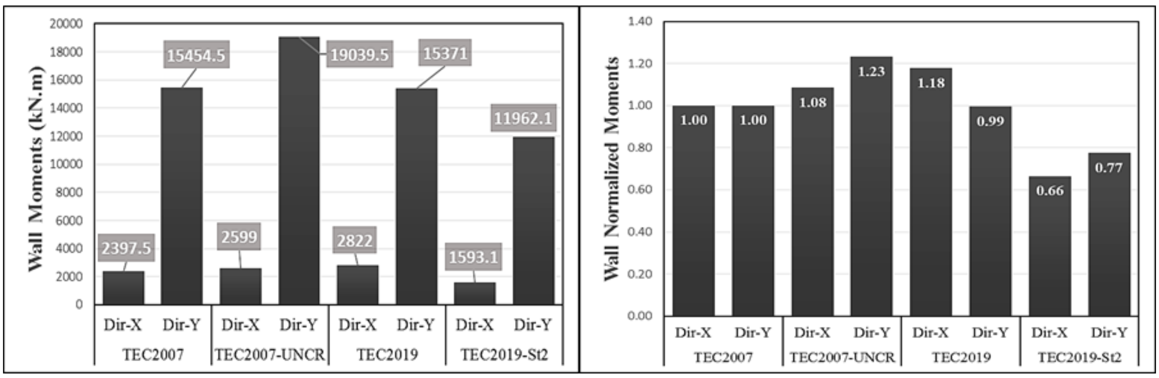
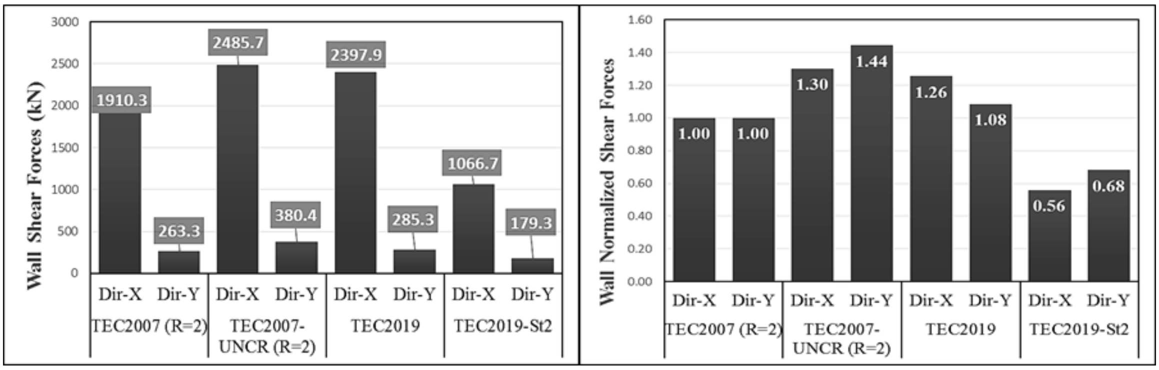


(c)

Figure 5. Shear wall (layout-1) internal forces and their normalized values: (a) shear forces, (b) axial forces, and (c) bending moments

Similar to the shear wall selection in Layout-1, two shear walls are, again, selected in Layout-2 (Figure-1). The shear and axial forces of TEC 07 -except for those from Stage 2 of TEC 19- increased by 26% in the *x* direction. A less obvious increase is observed for shear force in the *y* direction, and axial force in both directions by an average of 8% when TEC 19 was used (Figures 6-a and b). In contrast with the shear and axial force results, the bending moments decreased by 10% in the *y* direction but remained almost unchanged in the *x* direction, when the results of TEC 07 compared to those of TEC 19 (Figure 6-c). When the results of TEC 07 were compared to those of TEC 19-Stage 2, the shear and axial forces and bending moments all decreased by an average of 40%.



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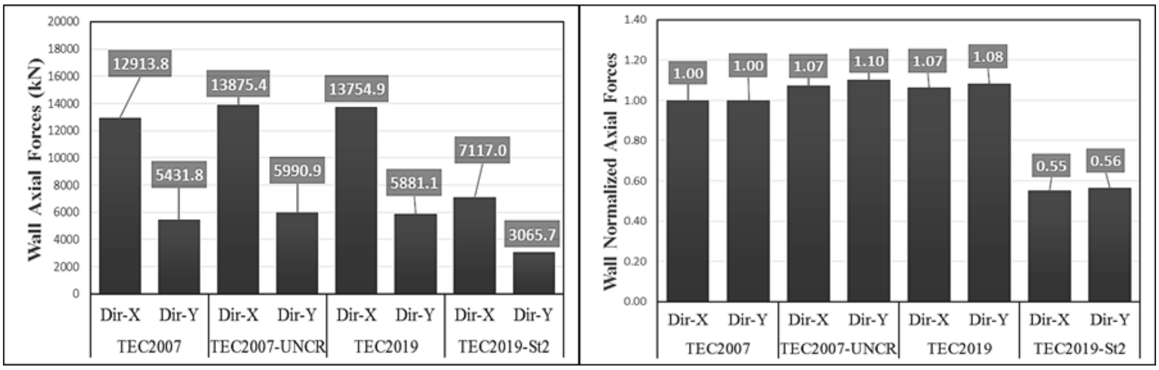

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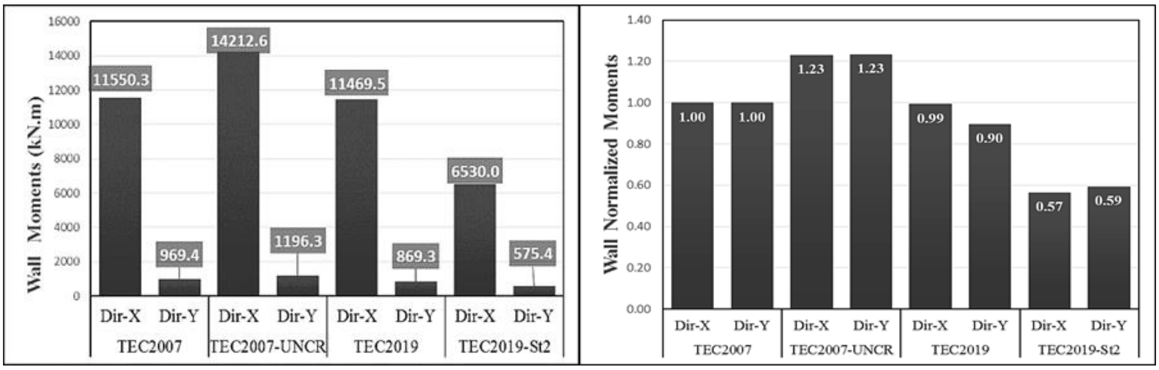

(c)

Figure 6. Shear wall (layout-2) internal forces and their normalized values: (a) shear forces, (b) axial forces, and (c) bending moments

4. Conclusions

When the results of TEC 07 (with cracked section properties) was compared to TEC 19, both the shear and axial forces in the shear walls of Layout-1 increased by 20% and 12%, respectively. In Layout-2, the same forces increased by 17% and 8%. The wall moments of Layout-1 increased by 18% in the *x* direction, while almost no change occurred in the *y* direction. In Layout-2 the moment values decreased by 10% in the *y* direction with no change in the *x* direction. The internal forces of the columns all increased when the results of TEC 07 were compared to those of TEC 19. The increase was around 4% in the shear, 10% in the axial, and 15% in the bending moment cases. The base shear forces of both Layouts 1 and 2 increased by an average of 34% and 15%, respectively. For all cases, Stage-1 of TEC 19 produced more critical design values when compared to those of Stage-2.

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