Analysis of Buildings Response to 6 February -2023 Earthquake in Turkey in terms Number of Storeys

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Abstract

6 February −2023 earthquake which took place in Turkey and spread to Syria was very destructive in many cities. However, the most damaged city was Nurdag which is under Gaziantep Governorate. It was the closest to the epicenter. Therefore, the data of earthquake in Nurdag is analyzed in this paper in terms of the Response Spectra. It is applied to typical buildings of the same plan and different number of storeys; (one, two, three, five, seven and ten storeys). Since most of the seismic resistant buildings are designed as per UBC97 code, the analysis was compared with UBC97 Response Spectrum. It is compared with Kocaeli earthquake−1999 which was very destructive in Turkey as well. All models were analyzed using Robot Structural Analysis Program.

The results showed that the 5 storey building is the critical. Therefore, the existing 5 storey buildings needs retrofitting. In this paper five retrofitting methods were applied in order to find out which one is the best. In terms of displacements and stresses. Which are: adding core, shear walls, RC belt, steel belt, and steel braces. All of them were added to the first storey only. The results showed that adding a reinforced concrete belt to the first storey is

the best. It showed a noticeable reduction in seismic force and shear stress.

Key words: Response Spectrum, Dominant Frequency, Maximum Response, 6 February -2023 Earthquake, Retrofitting methods, Fast Fourier Transform (FFT)

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1. Introduction

Most of the buildings in Syria are designed as per Arab Syrian Seismic Code, which adopted UBC97 response spectra. However, in 6 February -2023 earthquake a lot of seismic resistant buildings have been destroyed while others stayed stable. Hence, it is useful to inspect one of the factors that played a role in the buildings' behavior during this catastrophic earthquake. This factor is the number of Storeys. Which can be defined by the natural period of the building. In order to identify the critical storey number that showed a maximum response, a symmetrical model was dynamically analyzed by changing the number of Storeys under 6 February -2023 earthquake in terms of Response Spectrum. A thorough comparison was made with UBC97 and Kocaeli earthquake -1999 in Turkey as well.

2. Research Aim

This research highlights the importance role that the number of storeys of a building plays during an earthquake. Moreover, one can say that there is a critical number of storeys that shows a maximum response and deep damage. Hence, when identifying these critical buildings. They can be retrofitted to sustain such a catastrophic earthquake.

3. Theoretical Background

3.1. Linear Response Analysis using Modal Superposition

The response results from superposition of appropriate amplitudes of normal modes, for example the response u_n is represented by the multiplication of mode shapes vector ϕ_n and the modal amplitude y_n ,(FEMA P1051, 2016).

$$u_n = \phi_n . y_n \tag{3-1}$$

Then the total response would be:

$$u = \phi_1 . y_1 + \phi_2 . y_2 + \phi_3 . y_3 + \ldots . + \phi_N . y_N \tag{3-2}$$

In matrix form:

$$u = \Phi . Y \tag{3-3}$$

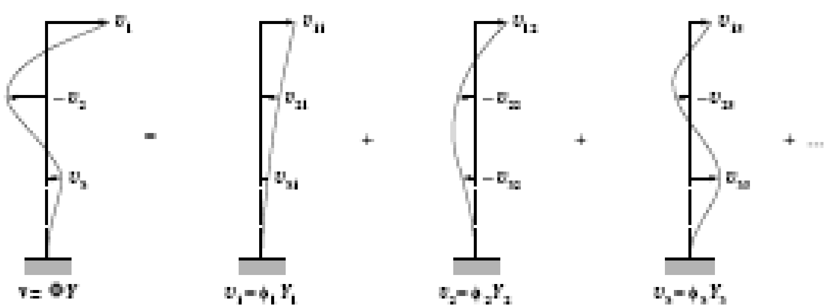

Figure 1. Mode shapes, (J. Clough, R. P. 1995)

Therefore, mode shapes matrix Φ transforms the vector Y from the normal coordinates to a vector u in Geometric coordinates. In order to identify any normal coordinate y_n the equation should be multiplied by $\phi_n^T . m$.

$$\phi_n^T.m.u = \phi_n^T.m.\phi_1.y_1 + \phi_n^T.m.\phi_2.y_2 + \phi_n^T.m.\phi_3.y_3 + ...+ \phi_n^T.m.\phi_N.y_N \quad (3-4)$$

Due to the orthogonality of the vectors, all non-orthogonal values will be zero. Then $\phi_n^T.k.\phi_m = 0, \phi_n^T.m.\phi_m = 0; m \neq n$. Therefore, equation (3-4) will be:

$$\phi_n^T.m.u = \phi_n^T.m.\phi_n.y_n \quad (3-5)$$

Then:

$$y_n = \frac{\phi_n^T.m.u}{\phi_n^T.m.\phi_n} \text{ ,n=1,2,3,....N} \quad (3-6)$$

3.2. Analysis of Multi Degree Three Dimensional Buildings

Slabs and beams are modeled as rigid diaphragm which simulates the real behavior of many types of slabs such as reinforced concrete slabs. Since they are very rigid in plane and flexible out of plane. Then many factors can be eliminated:

- Axial deformations in beams and columns.
- The effect of axial forces on columns' stiffness.

Therefore, the so-called rigid diaphragm slab has three degrees of freedom: the horizontal displacement in x direction u_{jx}, the horizontal displacement in y direction u_{jy}, and the rotation about z $u_{j\theta}$. The degrees of freedom of all nodes of the storey will be related to the three degrees of freedom of the center of the storey, (Chopra, 2003).

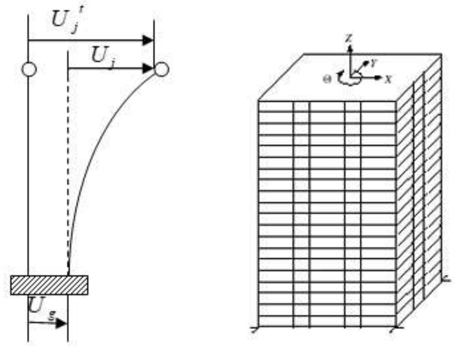

Figure 2. (3D) Building with rigid diaphragm degrees of freedom, (Chopra, 2003)

Equation of motion in general case will be:

$$\begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & I_o \end{bmatrix} . \begin{bmatrix} \ddot{u}_x \\ \ddot{u}_y \\ \ddot{u}_\theta \end{bmatrix} + \begin{bmatrix} k_{xx} & k_{xy} & k_{x\theta} \\ k_{yx} & k_{yy} & k_{y\theta} \\ k_{\theta x} & k_{\theta y} & k_{\theta\theta} \end{bmatrix} . \begin{bmatrix} u_x \\ u_y \\ u_\theta \end{bmatrix} = -. \begin{bmatrix} m.\ddot{u}_{gx} \\ m.\ddot{u}_{gy} \\ I_o.\ddot{u}_{g\theta} \end{bmatrix} \quad (3\text{-}7)$$

Whereas m represents a diagonal matrix of N degree, when an element m_j of the diagonal represents the lumped mass at the center of gravity of slab j . I_o represents a diagonal matrix of N degree, when an element m_j of the diagonal represents the rotational moment of inertia of slab j.

4. 6 February−2023 Earthquake in Turkey− Nurdag Station:

The event took place in 6−February−2023. It was one of the most destructive earthquakes in centuries. Spread to area about 1000 km^2 between Turkey and Syria. Since Nurdag city (station: 2712) is the nearest to the epicenter (about 21.27km) it had the most damage. The soil shear velocity denotes 599 m/sec, (AFAD, 2023). which means that it is S_C type. Table(1−1) contains the main parameters of Nurdag−2023 earthquake vs. Kocaeli −1999 Earthquake in terms of response spectra. Both of the events were very destructive. However, Nurdag is very close to Syria and the soil deposits is very close as well. Nurdag is located south of Turkey near the boarders of Syria, and Kocaeli is Located in the north of Turkey south of Istanbul, With soil shear velocity of 827 m/sec (S_B Type). Although Kocaeli is closer to the epicenter (about 3.39km), the epicenter itself is deeper than Nurdag (15.9 km vs. 6.2km). The PGA of NS component of Nurdag event is the greatest (13.02 m/sec^2). However, the other components PGA are very close.

Figure 3. represents the Response Spectra of the three components of Nurdag event. From which it is noticed that it is Multiple-peaked, narrow banded, (Nourzadeh et.al, 2019).

Table 1. Nurdag event vs. Kocaeli event parameters, (AFAD, 2023)

PARAMETER	NURDAG	KOCAELI
EVENT_DATE:	06-02-2023	17-08-1999
LATITUDE_DEGREE:	37.304	40.756
LONGITUDE_DEGREE:	36.92	29.955
EVENT_DEPTH_km:	6.2	15.9
HYPOCENTER_REFERENCE:	AFAD	AFAD
STATION_CODE:	2712	4101
LOCATION:	GAZIANTEP_NURDAG	KOCAELI_MERKEZ
Soil Shear Velocity VS30_m/s:	599	827
EPICENTRAL_DISTANCE_km:	21.27	3.39
DATA_TYPE:	Acceleration	Acceleration
E-W PGA_m/s^2:	**10.35**	**11.14**
N-S PGA_m/s^2:	**13.02**	**7.04**
Vertical PGA_m/s^2:	**7.68**	**6.091**

While Figure 4. Represents the Time History three components of the event. It is about 10501 points. Lasted for 105.01 sec with maximum acceleration of: NS 4.542 m/sec2- EW 3.378 m/sec2 -V 3.592

m/sec^2. Kocaeli event's time history is about 5182 points– lasted for 51.77sec.

a

b

c

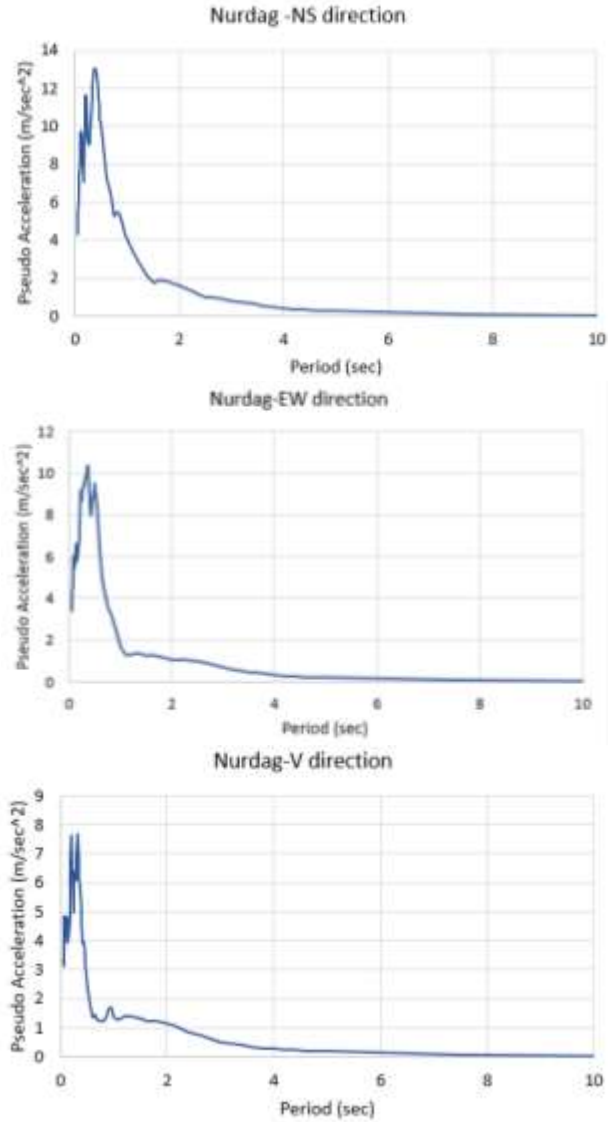

Figure 3. Response spectra of Nurdag earthquake (2023): a- NS direction, b- EW direction, c- Vertical direction

a

b

c

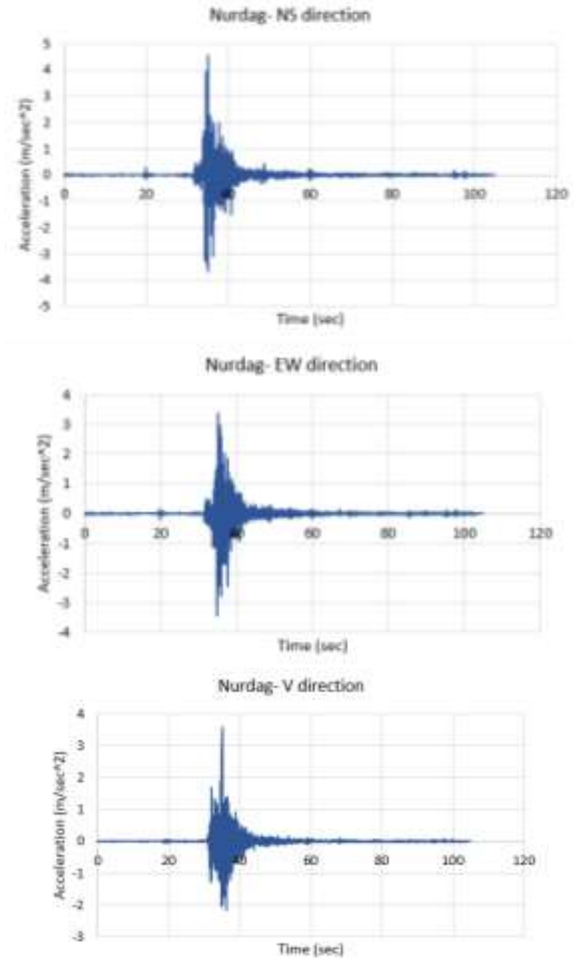

Figure 4. Ground time−histories of Nurdag earthquake (2023) : a- NS direction, b- EW direction, c- Vertical direction

In order to make a useful comparison, and evaluate the condition of the current buildings in Syria. UBC−97 Response Spectra is also analyzed. Since most of the buildings in Syria were designed as per Arab Syrian Seismic Code−Second commentary which adopted Uniform Building Code response spectra, (UBC97). It is known that UBC97 Response Spectra has a uniform−hazard of 10% in 50 year −return period 475 years ground motions. Table 2. Represents the seismic zone parameters which was selected to be of most high seismicity in Syria with Soil type S_C.

Therefore, the analyzed Response Spectra will be:

- Nurdag station 6 February- 2023, S_C Soil Type.
- Kocaeli station 17 August- 1999, S_B Soil Type.
- UBC97 : Zone 4, S_C Soil Type.

Table 2. Seismic parameters of UBC97 Response Spectrum

Seismic Parameters UBC97			
Zone	4	N_a , N_v	1
Z	0.4	I	1
C_a (/g)	0.4	R	5
C_v (/g)	0.56	T_0	0.112
Site Class	C	T_s	0.56

Figure 5. contains the Response Spectra of each of Kocaeli , Nurdag, UBC97. From which it is noticed that Nurdag- NS component is the only one that exceeds UBC97 Response Spectrum. In order to figure out the frequency of the building that has the most response one should analyze the Fast Fourier Transform (FFT) of the event. Figure 6. Represents the (FFT) of Nurdag event. Fast Fourier Transform decomposes an accelogram into its constituent frequency components. The seismic waves observed in earthquake records includes wide frequency content but just a few of them are dominant. a very narrow range of frequency has the greatest spectral amplitude while the others' spectral amplitudes are small.

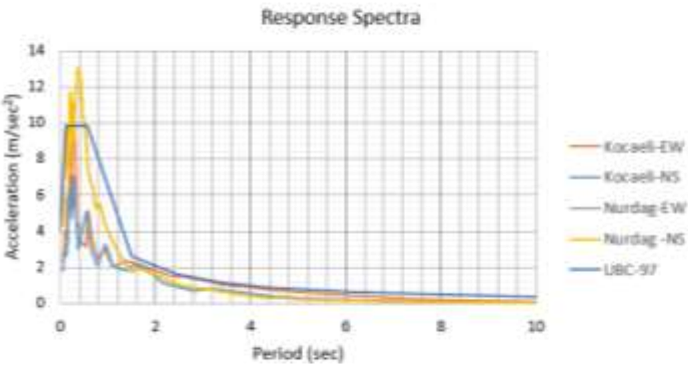

Figure 5. Response Spectra of Nurdag, Kocaeli , UBC−97

It is noticeable from Figure 6. That the critical frequencies are in range between (1.9−2.5 Hz) this should be very important when evaluating structures that has natural frequency within this range.

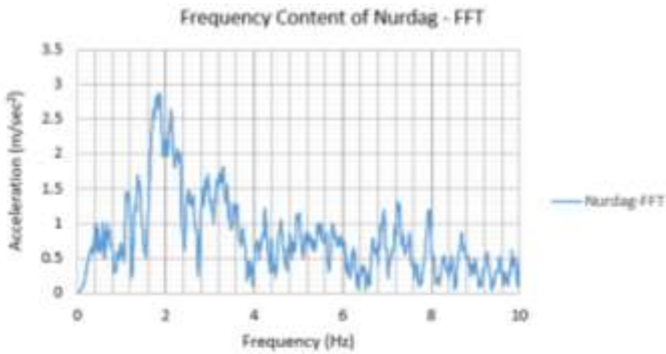

Figure 6. FFT of Nurdag event, (AFAD, 2023)

5. Research Methodology

A symmetrical model of shear walls seismic resisting system was dynamically analyzed using Robot Structural Analysis, (RSA, 2019). the number of storeys was changed by: (1−2−3−5−7−10) under each of the above mentioned Response Spectra, i.e. Nurdag−Ns, Nurdag−EW, Kocaeli−NS, Kocaeli−EW, UBC97. In terms of horizontal displacement in the NS and EW directions and shear stress of shear walls, the critical number of storeys that gave an excessive response under Nurdag earthquake that exceeded UBC97 values. Then several choices of retrofitting methods were applied to identify the best way to improve its seismic resistance. These methods can be described as:

- Adding peripheral shear walls.
- Core shear walls of 25cm thickness and C28 material.
- Concrete Belt beam of 25x50cm dimensions and C28 material.
- Steel Belt beam of IPE400 and S275 material.
- Peripheral Braces of 120mm square section with S275 material.

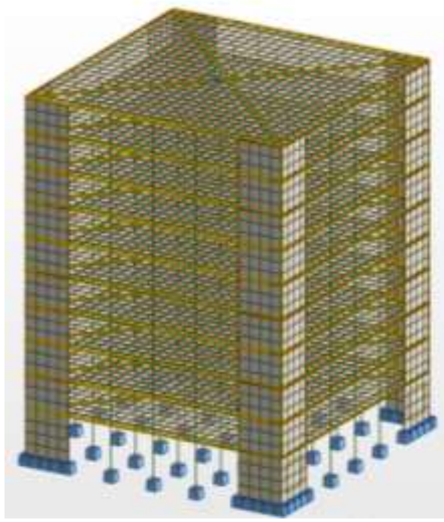

Figure 7. The analyzed model

6. Analysis and Results

6.1. Analysis of different Storey's Models

The analyzed model's plan is depicted in Figure 8. It is symmetrical with 24mx24m the slab thickness is 160mm, beams dimensions are 40x60cm whereas the Columns dimensions are 45x45cm and the shear walls are of 25cm. the materials are C28 for concrete, i.e. characteristic strength of concrete is 28 MPa, 420MPa longitudinal reinforcement, i.e. yield stress 420MPa and 300MPa transverse reinforcement, i.e. yield stress 300MPa.

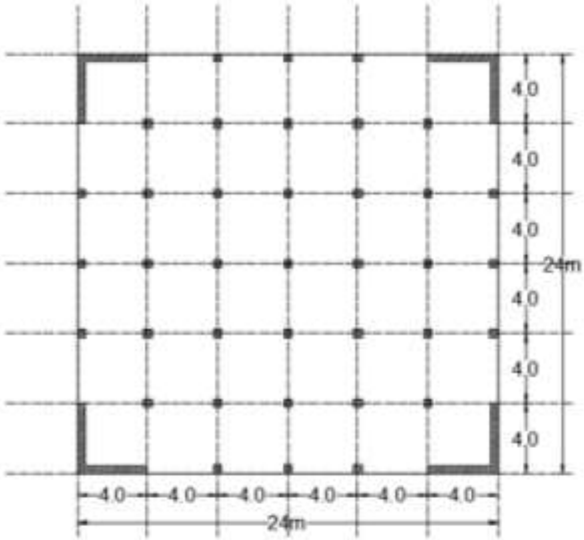

Figure 8. Model Plan

Modal analysis was applied for all models and about 95% of mass ratio participation was applied. Ritz vectors were adopted-block Lanczos algorithm, number of iterations=40. Mass matrix: lumped with rotations. 5% damping ratio. About 10 modes were included in dynamic response specifications. Method of solving equations: Sparse Matrix. DSC algorithm used for bar releases. Table 3. and Table 4. Contain the first five periods and frequencies of each model as respect.

Table 3. The first five natural periods of each model

Period (sec)							
No.	D	1 Storey	2 Storeys	3 Storeys	5 Storeys	7 Storeys	10 Storeys
1	X	0.080	0.153	0.246	0.471	0.728	1.146
2	Y	0.080	0.153	0.246	0.471	0.728	1.146
3	θ	0.043	0.082	0.134	0.274	0.451	0.763

4	X	0.030	0.042	0.064	0.117	0.181	0.296
5	Y	0.030	0.042	0.064	0.117	0.181	0.296

From table 4. One we can see that the five storeys model's natural frequency lays within the critical range of the FFT chart of Nurdag earthquake, Figure 6.

Table 4. The first five natural frequencies of each model

Frequency (Hz)							
No.	D	1 Storey	2 Storeys	3 Storeys	5 Storeys	7 Storeys	10 Storeys
1	X	12.50	6.53	4.07	**2.12**	1.37	0.87
2	Y	12.50	6.53	4.07	**2.12**	1.37	0.87
3	θ	23.11	12.14	7.45	3.65	2.22	1.31
4	X	33.27	23.78	15.67	8.58	5.52	3.38
5	Y	33.33	23.78	15.67	8.58	5.53	3.38

As a result of the analysis the maximum displacement of each model under the specified Response Spectra was obtained and they are depicted in Figure 9, i.e. U_x–displacement for EW−direction, U_y–displacement for NS– direction and U_y displacement for Ubc−97 due to the symmetry of the model.

From which it is noticeable that the only curve that exceeds the UBC97 maximum values is of Nurdag− NS direction for 5 storeys while it is lower for other number of storeys.

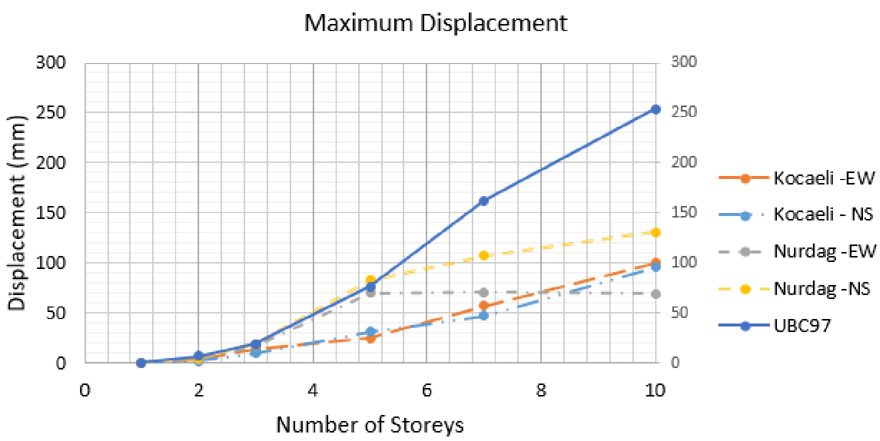

Figure 9. Maximum displacement vs. number of storeys

Therefore, it is necessary to analyze the stresses of each model under the specified Response Spectra one by one. The results of maximum shear stress S_{xy} for shear walls are tabulated in table 5. From which it is obvious that the 3 and 5 storey models under Nurdag earthquake are the models that there stresses exceeds the maximum values of UBC97. Which means that these buildings – presumably designed as per UBC97– will be damaged severely. However, the 5 storey model's frequency is within the dominant range of Nurdag frequency content. Therefore, the 5 storey model is the critical one. Therefore, this 5 storey model will be analyzed after applying several retrofitting methods that are easier to construct for an existing building in order to identify which one would help. All of them are applied only on the first storey only.

Table 5. The maximum shear stress S_{XY} (MPa) for shear walls of each model

No. Storeys	Nurdag - NS	Nurdag - EW	Kocaeli - NS	Kocaeli - EW	UBC-97
1	2.25	1.75	0.93	1	2.81
2	5.17	3.74	2.08	3.49	6.56
3	9.14	8.14	4.55	6.12	8.5
5	**16.61**	14.02	5.17	6.33	14.14
7	13.2	7.7	6.52	6	17.8

10	10.74	6.74	6.6	9.1	17.75

Figure 10. Maximum stress vs. number of storeys

6.2. Analysis Of 5 Storey Model Retrofitted With Different Methods

The critical 5 storey model was analyzed under Nurdag earthquake NS component, after applying 5 methods of retrofitting for the first storey only which was:

- Adding shear walls.
- Core shear walls of 25cm thickness and C28 material.
- Concrete Belt beam of 25x50cm dimensions and C28 material.
- Steel Belt beam of IPE400 and S275 material.
- Peripheral Braces of 120mm square section with S275 material.

The maximum displacement and forces in addition to the weight are shown in table 6.

Table 6. Values of each model

Model	Displacement U_y (mm)	Force F_y (kN)	Weight W (kN)	Frequency (Hz)	Period (sec)
Original Model	83.494	17753.33	30986.78	2.12379	0.47086
Core	79.879	18194.05	31362.78	2.29183	0.43633
Shear wall	80.243	17964.59	31362.78	2.27145	0.44025

RC Belt	83.506	16608.95	31174.78	2.13325	0.46877
Steel Belt	83.477	16559.22	31028.39	2.13061	0.46935
Braces	82.085	17522.54	31087.15	2.21581	0.4513

The resulted forces are figured in the bar chart in Figure 11. One can see that the best choices was the RC belt and the Steel belt.

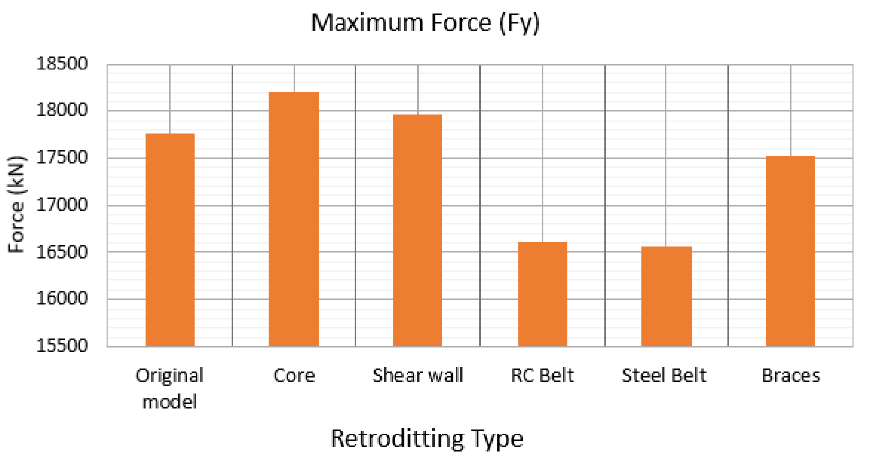

Figure 11. Maximum seismic force

However, the stresses showed a slightly different results. They are tabulated in table 7. And figured in contours in Figure 12. It is obvious that the best method was adding RC belt in the middle storey height of the first storey.

Table 7. The maximum shear stress S_{XY} for shear walls of each model

Model	Stress (MPa)
Original Model	16.61
Core	17.6
Adding Shear wall	18
RC Belt	14
Steel Belt	16.65
Braces	15.92

b

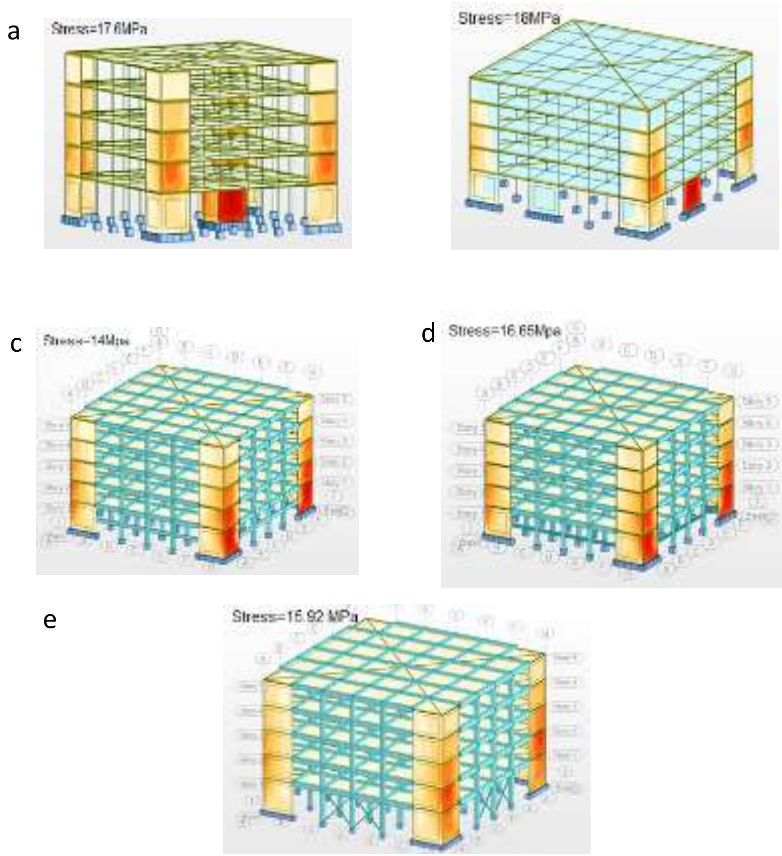

Figure 12. Maximum stresses contours of each model: a- Core, b- Shear wall, c-RC belt, d- Steel belt, e- Braces

These stresses are figured in the bar chart in figure 13. Furthermore, one can find from figure 14. That the minimum Force/Weight value is belonging to the RC belt method. Which validate that choice that it is the best for stress reducing and it is the most economical.

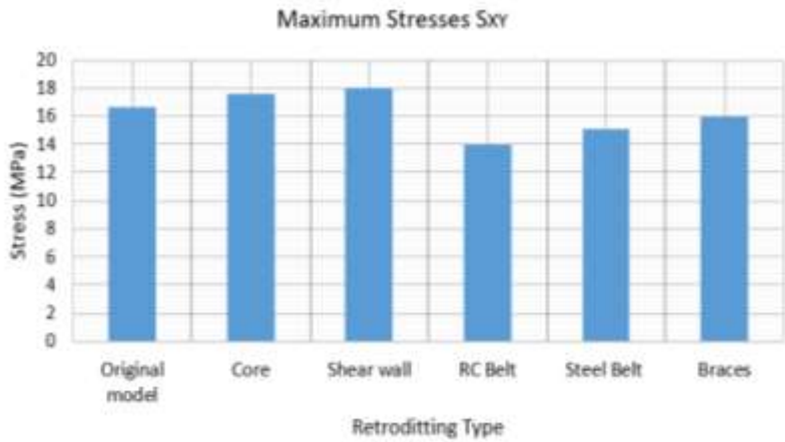

Figure 13. Maximum stresses of each model bar chart

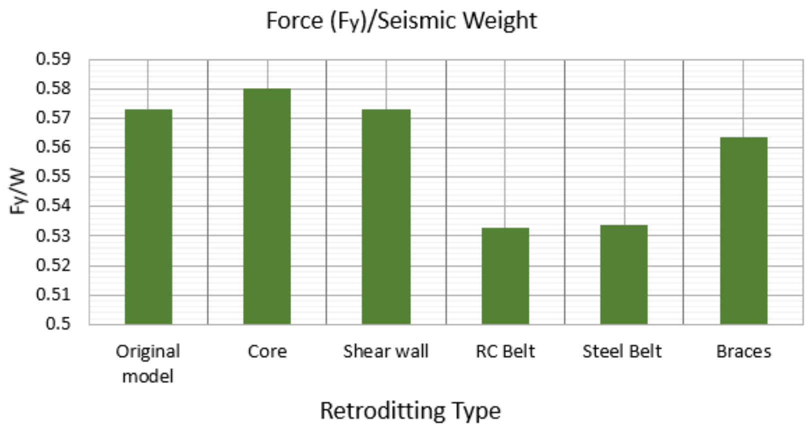

Figure 14. Maximum Force per unit weight of each model bar chart

7. Conclusion

- The Nurdag earthquake FFT showed a dominant frequency range between (1.9–2.5 rad/sec).
- The dynamic analysis of different number of storeys models showed that the 5 storey model has the maximum response in terms of shear stress of shear wall.

- Nurdag earthquake exceeded Kocaeli earthquake in terms of displacement and shear stress of shear walls for all cases, i. e. one, two, three, five, seven and ten storeys.
- The maximum displacement under Kocaeli earthquake was for the 3 storeys model with a ratio to UBC97 of EW:70%, NS:52%. While the maximum displacement under Nurdag earthquake was for the 5 storeys model with a ratio to UBC97 of EW:92%, NS:109%.
- Shear stress of shear walls under Nurdag earthquake exceeded shear stress under UBC97 for the 5 storey model. Where the stress ratio to UBC97 was 117%.
- Adding RC belt to the peripheral of the first storey as a retrofitting method gave the minimum shear stress with a reducing stress ratio of 16%. Which made it the best choice.
- Adding a steel belt to the peripheral of the first storey as a retrofitting method has reduced the shear stress of the shear wall with a 10% ratio.

8. Recommendations

- Considering adding a reinforced concrete belt to the peripheral of the first storey as a retrofitting method.
- 5 storey buildings need more attention when designing. Where UBC97 Response Spectra is not enough. Therefore, ASCE7-10 Response Spectra is recommended for example or any higher acceleration.

9. Future Research

- Analyzing the effect of soil type under 6 February Earthquake.
- Analyzing the effect of slab type as a diaphragm under 6 February Earthquake.
- Analyzing the effect torsional irregularity under 6 February Earthquake.
- Finding the best structural system under 6 February Earthquake.

References

1. Chopra, A. (2003). *Dynamics of Structures.* Prentice-Hall, INC.

2. Code, A. S. (2012). *Seismic commentry.* Damascus: Engineering Syndicate.

3. Dan Nourzadeh, e. a. (2019). *SPATIAL COMBINATIONS OF SEISMIC RESPONSE SPECTRUM AND TIME-HISTORY ANALYSIS RESULTS FOR DESIGN OF NUCLEAR STRUCTURES.* Charlotte, NC, USA: SMiRT-25.

4. *Disaster and Emergency Management Autority (AFAD).* (n.d.). Turkey: 2023.

5. H. Jarallah, e. a. (2016). *A Comparative Study on the Design Spectra Defined by Several Codes of Practice on RC Building Located in Baghdad City.* Baghdad: Al-Nahrain Journal for Engineering Sciences (NJES).

6. Huerta-Lopez, C. I. (n.d.). *TIME-FREQUENCY ANALYSIS OF EARTHQUAKE RECORDS.* 12WCEE20.

7. I. A. Karnovsky, O. L. (2010). *Advanced Methods of Structural Analysis.* Springer.

8. J. Clough, R. P. (1995). *Dynamic of Structures.* Berkelry. USA: Computers and Structures, INC.

9. Khose, V. e. (2011). *A Comparative Study of Design Base Shear for RC Buildings in Selected Seismic Design Codes.* Research Gate.

10. P-1051, F. (2016). *2015 NEHRP Recommended Seismic Provisions Design Examples.* Washington, D.C.: BUILDING SEISMIC SAFETY COUNCIL.

11. *Robot Structural Analysis.* (2019). USA: Autodesk.

12. UBC97. (1997). *UNIFORM BUILDING CODE.*

تحليل استجابة الأبنية تحت تأثير زلزال 6 شباط –2023 في تركيا من ناحية عدد الطوابق

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ملخص

إن زلزال 6 شباط –2023 الذي كان مركزه في تركيا وانتشر إلى سوريا كان مدمراً إلى حد كبير. إن المدينة الأكثر ضرراً كانت نورداغ التابعة إلى محافظة غازي عنتاب جنوب تركيا، حيث كانت الأقرب إلى مركز الزلزال. في هذا البحث تتم دراسة الاستجابة الزلزالية تحت تأثير بيانات الزلزال في نورداغ بشكل طيف الاستجابة. تم تطبيق التحليل الديناميكي على بناء متناظر متعدد الطوابق باعتبار عدد طوابق مختلف لأجل ذات المسقط وهي: طابق، طابقين، ثلاث طوابق، خمس، سبع وعشر طوابق. بما أن معظم الأبينة المصممّة في سوريا لمقاومة الزلازل تم تصميمها بما يتوافق مع ملحق الزلازل للكود العربي السوري– والذي يتبنى طريقة كود البناء الموحد UBC97، لذلك تمت المقارنة مع طيف الاستجابة الأعظمي للكود UBC97. كذلك الأمر تمت المقارنة مع طيف الاستجابة لزلزال كوجايلي في تركيا عام 1999 والذي كانت له صفة تدميرية شديدة أيضاً.

أظهرت النتائج أن البناء ذو الخمس طوابق هو الأكثر خطورة. لذلك تحتاج الأبنية القائمة ذات الخمس طوابق إلى تقوية الجملة المقاومة للزلازل. تم تطبيق خمس طرائق تقوية بحيث تطبق في الطابق الأرضي فقط وتكون سهلة التنفيذ، وهي إضافة جدران قص، نواة بيتونية، حزام بيتوني، حزام معدني، و عناصر تربيط. حيث تم التحليل على مستوى الانتقالات والإجهادات. بالنهاية تم تحديد الطريقة الأفضل من هذه الطرق وهي طريقة الحزام البيتوني حيث أعطت انخفاضاً في القوة الزلزالية وفي إجهادات القص.

كلمات مفتاحية: طيف الاستجابة، التواتر المسيطر، الاستجابة العظمى، زلزال شباط 2023، طرق التدعيم، تحويل فوريه السريع