Improving of Damping Character of Chimney by Modified Concrete under Seismic Load

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Abstract: - As known concrete exhibits weak behavior on damping character and ductility. Effective nature disaster such as earthquakes largely affects structures as horizontal axis and cause deformations. As a result of deformations, fractures in the structure may be observed. Even, fractures may cause the collapse of structures. Based on this problem, damping and ductility properties improvement of engineering structures is significantly necessary. Rubber material demonstrates high ductile features under load. Particularly, it is used for the reduction of vibration in mechanical systems. In literature, some experimental research focused on utilizing rubber for concrete production, and several properties such as damping ratio and young modulus were investigated. In ,these numerical analyses, young modulus, compressive strength, and damping ratio properties of concrete-modified rubber fine aggregate from selected experimental research were assigned to finite element method (FEM) software and were realized numerical analyses of chimneys. Results reveal that Rubber incorporation causes increasing in accelerations. However, increasing ductility behavior and greater damping energy absorption are concluded.

Key-Words: - Damping, Chimney, Rubberized concrete, Numerical analyses, Kinetic energy, Potential energy.

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1 Introduction

Chimneys are utilized to transfer smoke and gases that occur as a result of industrial production to the atmosphere and are designed as high engineering structures in order to ensure transferring of smoke and gases to high altitude. Therefore, seismic load causes significant impacts such as high displacement-rotation and fractures because of fragile features. Rubber particles can be an alternative fine aggregate instead of conventional aggregate, [1]. Ductile and damping properties of fragile structure construction materials should be improved and may be achieved by the incorporation of rubber, [2]. The rubber content ratio reduces on mechanical properties of concrete by the reason of stiffness decreasing, [2], [3]. The incorporation of rubber into concrete mixes contributes to plastic energy capacity. Hence, high strains may be reported under impacts such as crashing, [4]. Powdered rubber raise fracture energy of concrete and create a benefit on usage for road material, [5]. While 4.5% rubber powder addition improves the damping character of styrene-acrylic emulsion concrete, the reduction of compressive strength is reported, [6]. In the numerical analyses of 2 varied heights (150m and 210 m), chimneys were achieved and specific earthquake waves produced an increase of tensile and compressive stresses, [7]. The authors revealed dynamic responses of concrete chimneys by numerical analysis methods, [8]. The realistic behavior of masonry chimney by the numerical method can be evaluated concerning the geometry of the chimney, the materials, and the damage state, [9]. Soil structure interaction presents an effective act on numerical analyses of chimneys under seismic loads, [10]. Numerical analyses of the 234 m concrete chimney report that vertical seismic loads are more effective on the upper part of the chimney. In general, maximum results are reported at 85% height of the tower, [11]. This numerical investigation aims to evaluate the dynamic responses of a 120-height concrete chimneys which are constructed by concrete-modified rubber fine aggregate under the Kahramanmaraş Pazarcik earthquake. Based on past study results [2], the experimental properties which are young modulus, compressive strength, and damping ratio of concrete were defined to FEM software, and displacement-rotation accelerations, displacements and damping energies of the structure were reported. Hence, this approach may lead to the utilization of rubber-modified concrete on fragile structures.

2 Material and Method

The numerical analyses were realized by utilizing FEM software (SAP 2000) as seen in Figure 1. The chimney geometric properties were assigned as demonstrated in Table 1. Four different concrete materials were defined to FEM software and the material properties were varied as per Table 2. These material properties of concrete were achieved replacement of fine aggregate with rubber powder which is between the No.8 sieve and No.16 sieve [2]. As shown in Figure 2, earthquake ground acceleration records were acquired from AFAD (Turkish earthquake community) and defined to software as acceleration in time history analyses method. In Modelling, dead load which considers with geometry and density of concrete, modal analyses, and earthquake analyses are achieved by nonlinear method. Modal analyses are reported as deformation of structure, frequencies, and periods due to 3 modes of structure. Chimney periods and frequencies were computed according to formulas where m is mass and k is stiffness below:

$$T = 2\pi\sqrt{\frac{m}{k}} \quad (1)$$

$$\omega = \sqrt{\frac{k}{m}} \quad (2)$$

Chimney dynamic performance can be referred as per (3) where k is stiffness, u is displacement, c is damping $\dot{u}$ is velocity and $\ddot{u}$ is acceleration.

$$F = ku + c\dot{u} + m\ddot{u} \quad (3)$$

Displacement and rotation acceleration results are reported for the top point of the chimney due to formula where k is stiffness, u is displacement-rotation:

$$\ddot{u}_c(t) = k\frac{u_c(t)}{dt^2} \quad (4)$$

In order to find out the impact of varied damping ratio and young modulus of concrete on ductility, the relative displacement of the concrete chimney is compared. Moreover, energy absorption on modal damping is exhibited based and compared. Modal damping energy was calculated as per:

$$[C] = \alpha[m] + \beta[k] \quad (5)$$

The input energy is explained as energy formation on the body of structure elements under acceleration and is computed formula where m is the mass of the structure, $\ddot{u}_g$ is the acceleration of ground and $\dot{u}$ is velocity of the structure.

$$E_I = -\int_0^{t_0} m\ddot{u}_g\dot{u}dt \quad (6)$$

The kinetic and potential energy of the structure are calculated as per (7) and (8) where m is the mass of the structure, $\dot{u}$ is the velocity of the structure, k is the stiffness of the structure and u is the displacement of the structure.

$$E_K = \int_0^{t_0}\frac{1}{2}m\dot{u}^2dt \quad (7)$$

$$E_P = \int_0^{t_0}\frac{1}{2}ku^2dt \quad (8)$$

Chimney velocities were computed as per:

$$\dot{u}(t) = k\frac{du(t)}{dt} \quad (9)$$

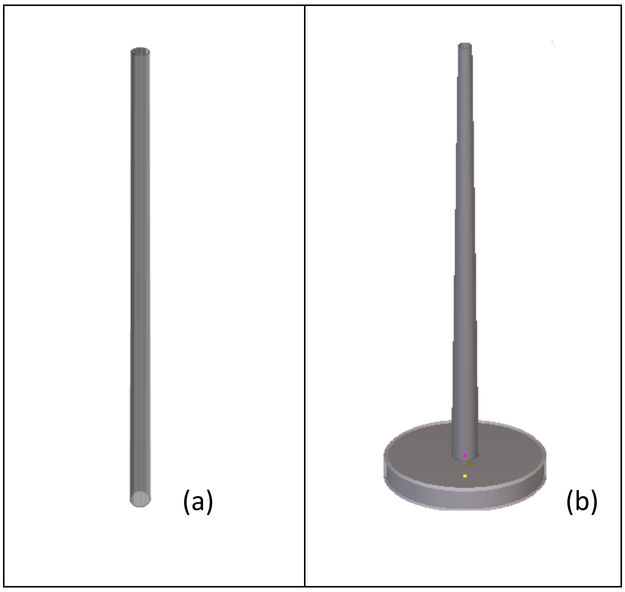

Fig. 1: 3D of FEM model (a), 3D of sketch model (b)

Table 1. Chimney tower properties

Height	120 m
Top diameter	2 m
Bottom diameter	5 m
Shell Thickness	0.1

Table 2. Properties of rubber-modified concrete, [2]

	0%	1.5%	2.5%	3.5%
Young Modulus	29183	26557	25049	24928
Compressive Strength	37.00	32.50	29.00	26.00
Material damping	1.11%	1.06%	1.73%	1.02%

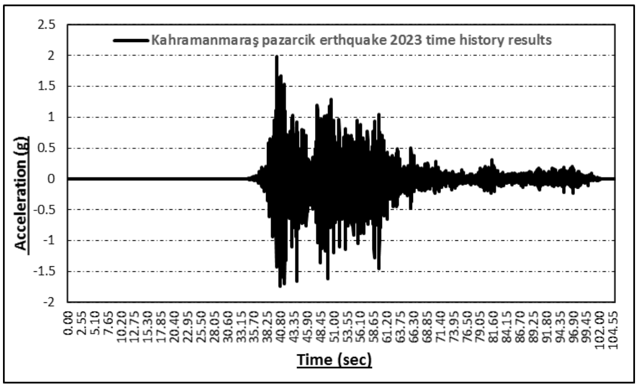

Fig. 2: Kahramanmaraş pazarcık earthquake 2023 recorded accelerations, [12]

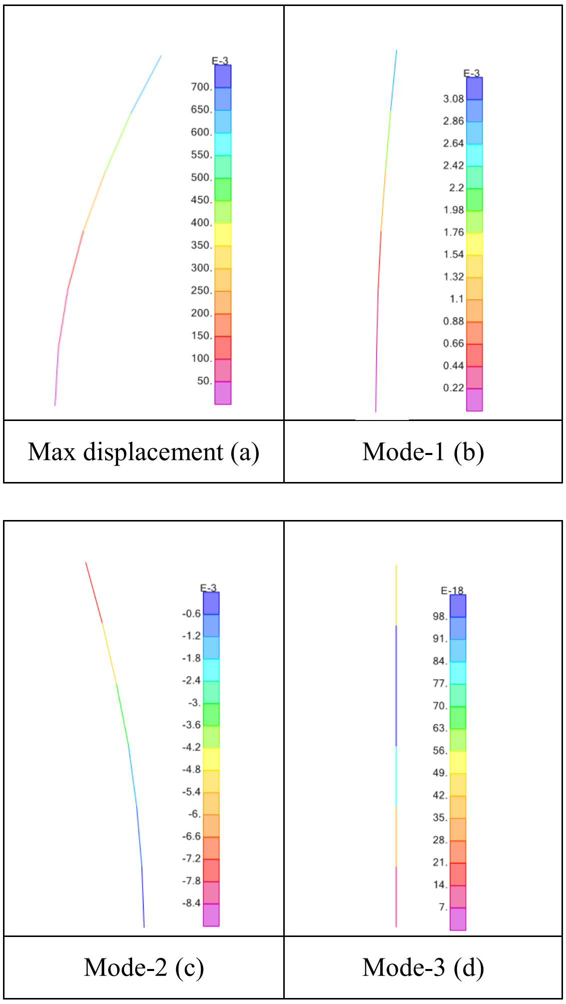

Fig. 3: Deformed shape view (a), Mode-1 deformed shape view (b), Mode-2 deformed shape view (c), Mode-3 deformed shape view (d)

3 Results and Discussion

3.1 Modal Frequencies and Periods

Table 3. Modal period and frequency results

		0%	1.5%	2.5%	3.5%
Mode-1	Period (T)	5.11223	5.35903	5.51798	5.53106
	Frequency (f)	0.19561	0.1866	0.18123	0.18079
Mode-2	Period (T)	5.11223	5.35903	5.51798	5.53106
	Frequency (f)	0.19561	0.1866	0.18123	0.18079
Mode-3	Period (T)	0.13278	0.13919	0.14332	0.14366
	Frequency (f)	7.53131	7.18448	6.97752	6.96064

As presented in Figure 3, maximum deformation under seismic load and 3 modes which are more effective increased up to the top point of the concrete chimney. As understood from Table 3, while period values of the structure increased with the raise of incorporation of rubber powder, frequency values demonstrated decrement acting on each mode. The stiffness of structures is directly related to directly young modulus, the geometry shape, and length. Young modulus reductions caused decreasing in stiffness and ensured more ductile behavior on chimney structure. Rubber content increment provides damping natural vibrations. Similarly, Mode-3 reveals demonstrated increasing due to reason of not being dominant mode.

3.2 Accelerations of Chimney under Seismic Loading

Displacement acceleration results of the chimney top point are shown in Figure 4. Lowest displacement accelerations were reported because of the higher stiffness property of 0% rubber powder-modified concrete. Despite similar values obtained for 1.5%, 2.5%, and 3.5% rubber modified, some dissimilarities were observed. The addition of rubber powder at a rate of 1.5% to the concrete mixture consisted 283% increase according to 0%, by increasing of rubber content, 2.5% rubber-modified concrete performed a reduction in rate of 1.17%. Whereas 3.5% rubber modified revealed a rise in rate of 5.31%. A major increase on displacement acceleration may be explained as the result of the reduction of the elasticity module. Rubber addition gains more elastic-plastic character to concrete material. Rotation accelerations of the chimney top point exhibited similar act to displacement acceleration results as shown in

Figure 5. Rubber aggregate that is incorporated into concrete material increases rotation at the top point. As the known rotation of structure elements is considered a moment, inertia moment, and young modulus. Reduce young modulus plays a significant role in the raise of rotation. Maximum rotation of chimneys was reported as 0.303 rad/sec, 5.797 rad/sec, 5.096 rad/sec, and 5.749 rad/sec, respectively. Rubber aggregate-modified concrete material utilization ensured an increment in the rate of 94.77%, 94.05%, and 94.72%, respectively. As understood from the figure, it is clearly intended that rotation acceleration increment realized as effective due to displacement acceleration.

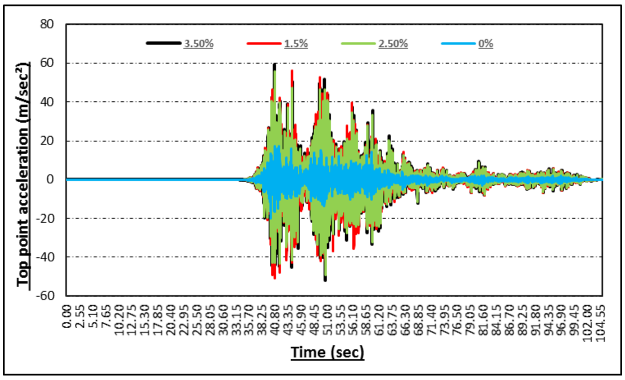

Fig. 4: Displacement accelerations of chimney top point

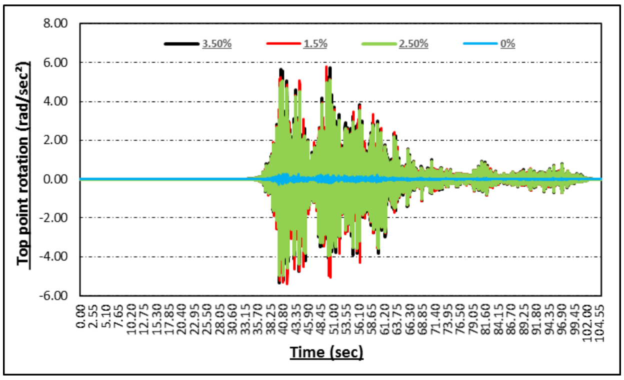

Fig. 5: Rotation accelerations of chimney top point

3.3 Maximum Displacements of Chimney under Seismic Loading

Figure 6 demonstrates maximum displacements as per the height of the chimney. Similar displacements were recorded up to 20 m and the values were computed as 0.032 m, 0.038 m, 0.037 m, and 0.040 m, respectively. As the height of the tower increased, variations in displacement were reported more clearly. At 60 m, 0%, 1.5 %, 2.5% and 3.5% presented displacements in values of 0.1784 m, 0.2069 m, 0.2014 m and 0.2095 m, respectively. Maximum displacements at 60 m present increasing rates of 82.06%, 81.63%, 81.62%, and 80.90%, respectively compared with maximum displacements at 20 m. Whereas at 100 m, the maximum displacement raises occurred at rates of 52.19%, 54.48%, 56.40%, and 56.22% compared with 60 m maximum displacements, respectively. It can be clearly intended that, rates of raises on displacement show decrement regarded with chimney height. The displacement changes demonstrated similar results to displacement and rotation accelerations. Maximum displacements were noted at 120 m and were obtained in order of 0.5405 m, 0.6795 m, 0.6855 m, and 0.7136 m. Additionally, the rubber concrete-modified chimney exhibited more movements in rates of 20.45%, 21.15%, and 24.25%, respectively. The main factor in the Increment of ductility may be mentioned as the young modulus. However, the damping ratio of the material impacts the behavior of the chimney. As clearly understood, displacement increases by reducing of young modulus. Yet, the damping ratio is an important factor that affects ductile act. While displacement increase is expected for 2.5%, a high damping ratio executed displacement decreasing. Nevertheless, the height parameter impacts this situation as negative based on displacement results at 120 m.

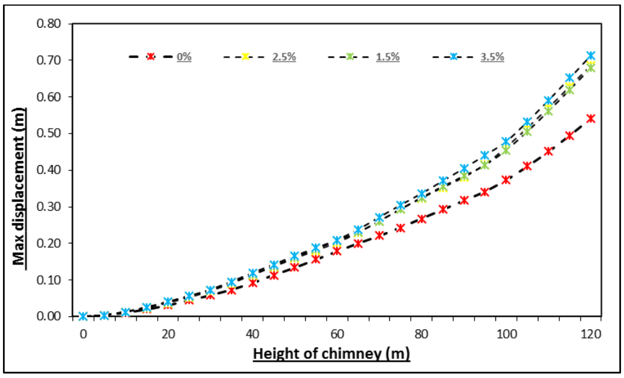

Fig. 6: Maximum displacements of chimney due to height

3.4 Modal Damping Energies of Chimney under Seismic Loading

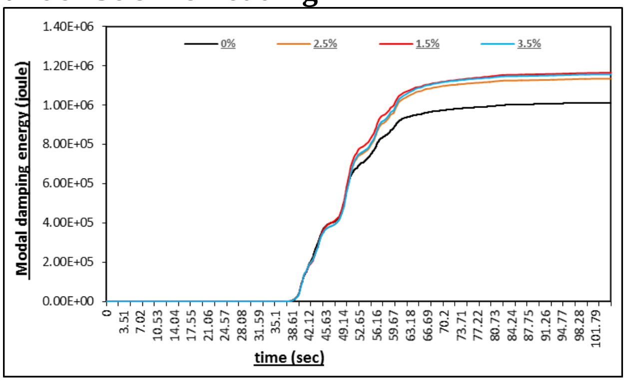

Fig. 7: Modal damping energies of chimney

Modal damping energies of the chimney due to material variation are examined in Figure 7, rubber addition contributed to capacity increase on damping of system. System damping energy proceeded as 0 joule up to starting a seismic movement and exhibited a raise by the effect of an earthquake. Afterward, as soon as the system reached total damping capacity, stable energy absorption was observed. As understood from the results, While 0% presented the worst damping energy absorption, 1.5%, and 3.5% showed excellent absorption. In addition damping character of systems modified varied concretes with approximately similar behavior showed up to 52.65 seconds of seismic movement. Maximum modal damping energy of 0%, 1.5%, 2.5%, and 3.5% was obtained as 1.01E+06 joule, 1.17E+06, 1.14E+06 and 1.16E+06, respectively, and the greatest modal damping energy absorption was achieved on 1.5%. The damping energy results show that, the damping character is not impacted only damping ratio property of the material and young modulus and damping ratio conformity is a significant that benefits the absorption of energy.

3.5 Velocities of Chimneys under Seismic Loading

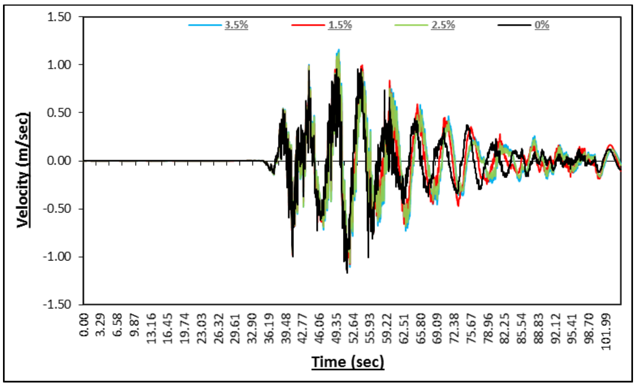

Fig. 8: Velocities of chimney

As seen in Figure 8, the velocities of chimneys increased by increasing of rubber aggregate rate. The velocities at the top point of chimneys were reported as 0.9579 m/sec, 1.0837 m/sec 1.1244 m/sec, and 1.1605 m/sec, respectively. The velocity of a dynamic system is obtained by displacement and stiffness parameters. The rise in velocity may be explained as the result of stiffness reduction and displacement increase. However, the varied results were observed due to earthquake exposure time. In addition, the increasing rates were calculated as 13.13%, 14.80%, and 17.45%, respectively. Rubber aggregate addition ensured the gaining of elastic behavior to concrete and increased the velocity of the chimney under dynamic load.

3.6 Input Energies of Chimney under Seismic Loading

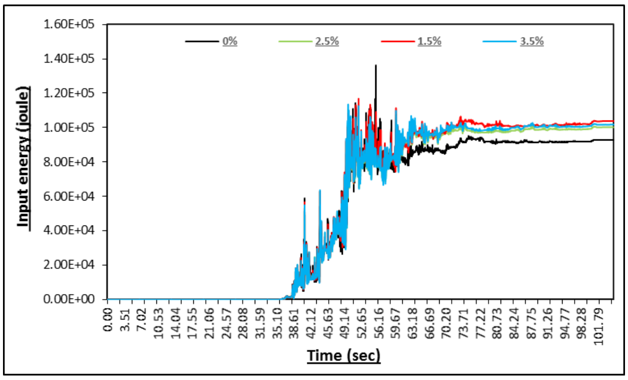

Fig. 9: Input energies of chimney

Figure 9 demonstrates the input energies of chimneys under seismic loading. Input energy occurs on the structure body because of dynamic loads. Input energies of chimney systems were recorded as 136386.35 joules, 116838.27 joule, 110529.23 joule and 113434.46 joule, respectively. Generally, rubber content increment executed decreasing of input energies. Rubber addition consisted of reducing rates of 14.33%, 18.95%, and 16.82%, respectively. Despite velocity increasing reducedreductions on input energy occurred. This reason may be explained by decreasing of chimney mass thanks to rubber aggregate addition. However, as understood from Figure 9, generally chimneys modified rubberized concrete presented higher input energies. Concrete includes 1.5% rubber aggregate caused often higher input energies.

3.6 Kinetic Energies of Chimney under Seismic Loading

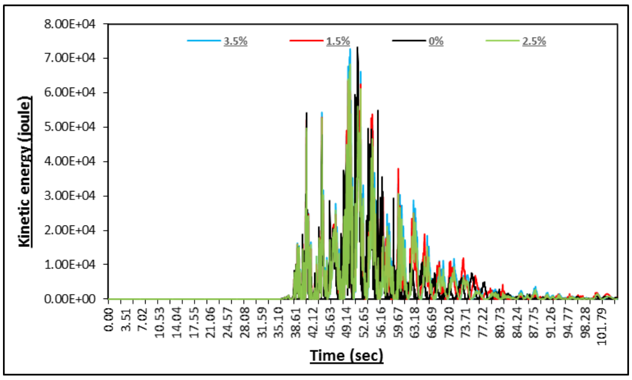

Fig. 10: Kinetic energies of chimney

Kinetic energies of chimney structures were achieved as shown in Figure 10. The highest kinetic energy was reported on the chimney concrete without rubber aggregate. Energies of kinetic were noted as 73195.99 joule, 69218.96 joule, 68295.42 joule and 72751.59 joule. The mass rate was effective in increasing kinetic energy and caused the highest kinetic energy on 0% rubber aggregate content. The reduced rates due to 0% were reported in rates of 5.43%, 6.69%, and 0.6%, respectively. Whereas the decrement was observed up to 2.5%, 3.5% rubber aggregate addition created increasing in kinetic energy. It can be explained by the reason for velocity rise based on the square of velocity in the kinetic energy formula.

3.7 Potential Energies of Chimney under Seismic Loading

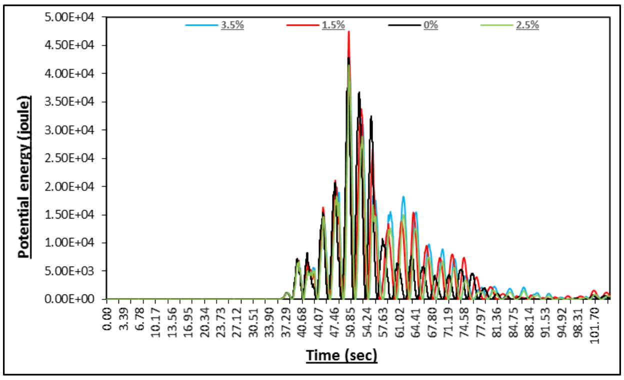

Fig. 11: Potential energies of chimney

Figure 11 exhibits the potential energies of chimneys. The potential energies of chimneys were computed in values of 42853.35 joule, 47504.06 joule, 41507.51 joule, and 44322.19 joule, respectively. The differences in variation may be put forward by varied stiffness according to young modulus and displacements. Due to 0% rubber modification, the variation rates were obtained as a 10.85% increment, 3.14% decrement, and 3.42% increment, respectively. Dominant parameters varied according to chimney concrete material, a larger rise of 1.5% may be explained by higher young modulus than the others. By increasing rubber content up to 2.5%, young modulus decreased and displacement increased. Yet, the effectiveness of stiffness caused decreasing of potential energy. Higher displacement of 3.5% chimney performed increasing on potential although decreasing of stiffness.

4 Conclusion

Improving on ductility and damping properties of tall and fragile structures is an unavoidable reality. This numerical analysis introduces that, rubber-modified concrete utilization in construction of tall and fragile structures provides expected improvements. According to the results;

- Rubber-modified concrete provides reducing on frequencies of major modes.
- Displacement and rotation accelerations of chimney modeled with rubberized concrete demonstrated increasing compared to conventional concrete.
- Reducing of young modulus ensures ductility development. In addition, the damping ratio impacts the displacement of structures under harmonic loads such as seismic loads.
- Top point velocities of chimneys increase by utilization of rubberized concrete.
- Maximum input energy occurs on %0 rubberized concrete chimney. However, rubberized concrete chimneys perform greater input energy:
- Rubberized concrete benefits to achieve better damping energy absorption due to conventional concrete and 1.5% rubber addition presents ideal damping energy absorption.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare.