

# New Trends on Green Buildings: Investigation of the Feasibility of Using Plastic Members in RC Buildings with SWs

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**Abstract.** Shear walled (SW) reinforced concrete (RC) buildings are considered to be a type of high seismic safety building. Although this structural system has an important seismic advantage, it also has some disadvantages, especially in acoustic and thermal comfort. In this study, experimental studies have been conducted on RC members produced with plastic material having circular sections to determine structural performance. RC members have been produced with and without 6 cm diameter balls to analyze the structural behaviour under loading and to investigate the thermal performance and sound absorption behaviour of the members. In the study, structural parameters have been determined for RC members such as slabs and SWs produced with and without balls to discover the feasibility of the research and discuss the findings comparatively. The results obtained from the experimental studies show that PB used in RC with suitable positions do not significantly decrease strength but improve the thermal and acoustic features. It has been also seen that using plastic balls reduce the total concrete materials.

## 1. Introduction

Concrete is a man-made stone composed of natural resources aggregate (sand and gravel combination), a binding agent (cement) and water. The need for new resources in concrete manufacturing is apparent because the aggregate making up 75 % of the concrete's weight is extracted from natural resources and increased building construction increases the concrete demand and decreases natural resources.

In recent years, recycled aggregates made from recyclable plastic, similar solid wastes or building wastes, and waste car tires have been preferred for reducing concrete cost and restricting the use of natural resources. The material used in these studies is mixed in the concrete at a definite ratio, and discussions about how the mechanical characteristics of the concrete changes are made by observing the compressive strength of the manufactured concrete [1], [2]. Materials such as plastic, tires, and recycled aggregates that are substitutes for the aggregate very negatively affect the compressive strength of the concrete if their usage ratios exceed specific ratios.

Producing structural members using plastic space formers, which is the newest method for structural members, was developed in Europe and found an application area in Europe and the USA. The Bubbledeck and Cobiax firms first discovered this innovation and started to use hollow PB with diameters of 18-45 cm inside RC floor slabs [3]. These new designs were first applied by these two companies. The weight of the building decreased significantly because of the decrease in concrete consumption with this invention. Experimental studies in accordance with Eurocodes were performed in research centers of several European countries. In the literature [4], research on this concept has



focused on the shear load carrying capacity and the punching strength of the RC slab section because the space former affects the shear capacity strength. According to these studies, due to these hollow balls, the weight of the floor decreases by 35 %. Moreover, the thermal strength decreases by 17-39%, meaning that the hollows balls significant contribute to heat insulation. In the literature [5], using the balls in a flat slab with thicknesses ranging between 20 and 50 cm is common.

The main goal of using plastic material is based on the stress distribution and the deformation shape of a typical RC section under bending moment. Under bending, the neutral axis (approximately the middle of the section) and its surroundings have no effect on the bending moment capacity or the loading capacity of a RC member. Therefore, the related zero stress region can be removed from the RC section.

Shear walled (SW) reinforced concrete (RC) systems are the primary monolithic housing systems in many countries due to their fast construction technique in which in-situ concrete is poured into shear walls and floor slabs simultaneously. The economic gains from the faster construction than conventional systems increased the demand for this type of construction. Moreover, the standardized dimensions and precast elements that are added to the system increase the quality of the carrying system. In these buildings, all of the vertical carrying members are made from shear walls, and the slab system is flat plate; therefore, the lateral rigidity of the system is greater than in classic frame and shear wall-frame structures. In all of the studies based on lessons from earthquakes [6], researchers mention the importance of larger cross-sectional areas such as shear walls in a structural system. For this reason, shear walled buildings are known as a high seismic safety building type in earthquake prone regions such as Turkey, Greece and Italy. After the earthquakes in Turkey in 1999, more than 100,000 RC buildings were heavily damaged or totally collapsed and more than 250,000 people needed houses. Turkey is located on a significant seismic belt, and the main reason for the damage in classic RC systems that happened after the last earthquakes is the carrying system and less use of the shear walls than needed. (A substantial number of the demolished and heavily damaged buildings had no shear walls). For this reason, the earthquake performance of the SW buildings carrying systems that consist of shear walls and additional architectural elements is considerably better compared to the buildings with RC frame systems; the carrying system configuration makes the buildings safe.

In SWRC buildings, where slabs are mainly subjected to the bending moment, shear walls are subjected to especially high bending moments with shear forces and low axial loads. The effects of the shear force and axial force on the section are usually negligible, especially in RC sections such as slabs under the effect of bending moments. Therefore, such a contraction in the neutral axis will not substantially change the behaviours of elements such as floors. However, the behavior of the shear walls, which are the most critical members under earthquake loading, are not as basic as slabs. The main objective is similar to the other studies [7], [8], and the initial aim of this study is to explore the shear wall behaviour produced with PB under lateral loading.

Beyond the seismic advantage of the SW building, this type of system also has some disadvantages, especially in acoustic and thermal comfort. For instance, non-structural components such as facade walls, stairs, landings and partition walls are produced as precast members to expedite the construction phase and can cause some comfort problems in SW buildings. In addition to the acoustic and thermal disadvantages of the SW system, several weaknesses with regard to its use can be classified as lack of architectural solutions from being a modular system and having standard formworks, insufficient numbers of heat and sound absorbing elements in the building, details that are omitted to reduce cost by the manufacturing firms and noise and heat problems [9]. In the buildings where SW system are applied, finer sections are created using concrete with low porosity and a high modulus of elasticity, and the sound absorption capacity remains insufficient due to using hollow masonry units inadequately. Joint defects emerge during the suspension process of the precast elements that are applied on the external walls of the SW buildings and suspended on the wall; the quality of the grouting materials and high tolerances of the components considerably exceed the ideal values in manufacturing lead to substantial losses in heat and sound. Various researches about both consumer satisfaction and perceptual evaluations on heat, sound etc. in SW systems were performed. Several studies also question the quality concept based on some visual effect criteria within the scope of the conducted studies according to the inner climate. Additionally, some of the studies emphasized the

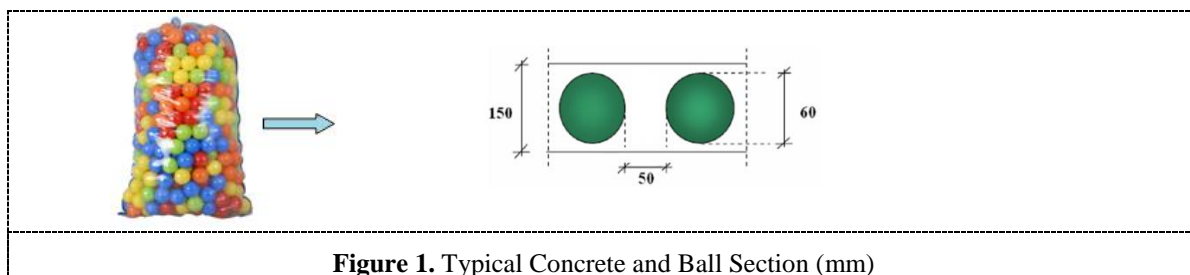
quality loss caused by the wrong combination details of the precast wall panels used in SW buildings [10].

## 2. Research significance and scope

The significance of this study is to produce RC structural members using plastic space formers (PB) that find application areas, especially in SW buildings due to their weak acoustic and thermal comfort. The PB used in the RC section do not negatively affect the structural behaviour under static and dynamic loads (earthquake, wind etc.) and positively change the thermal and acoustic parameters; therefore, the use of plastic ball materials in members of buildings with RC SW systems will be a new technique in civil engineering practice. In this study, experimental studies have been conducted on RC members produced with plastic material with circular sections (PB). The main aim of the study is to eliminate the thermal and acoustics insulation deficiencies in SW buildings, lighten the structural system, reduce concrete consumption and maintain the lateral and horizontal load carrying capacities of the structural members using PB in the RC members. In this scope, research has been performed on the feasibility of using PB with 6 cm diameter in RC systems. RC members have been produced with and without balls to analyse the structural behaviour under static and quasi-static loading and to investigate the thermal performance and sound absorption behaviour of the members. In the study, the structural parameters of the RC members such as slab and shear wall produced with and without balls have been determined, the feasibility of the research has been explained and the findings have been discussed comparatively.

## 3. Experimental program

In the experimental study, two different test groups with different targets and their corresponding results were analyzed. The targets of the experiments are a) Studying the changes in the characteristics of horizontal and vertical load carrying capacities that are observed due to the use of PB in the shear walls and slabs, b) Determining the extent to which the PB used in the shear walls and slabs improved the heat and sound insulation in the system section compared to the RC sections without balls; and c) Analyzing the pros and cons of using PB in RC members. The ball diameter was selected as 6 cm, and the cross section of a typical section is shown in Figure 1. The balls replaced the neutral axis of the sections. Because the main function of the balls is to create a hollow inside the RC section, the criteria of having a hollow inside and an adequate wall thickness to avoid any deformation during concrete casting are regarded as sufficient. The balls were purchased from toy stores, and no specific dimensions or material manufacturing were requested because of the size of the experimental study. The balls used in the shear walls were kept within the neutral axis during concrete casting.



**Figure 1.** Typical Concrete and Ball Section (mm)

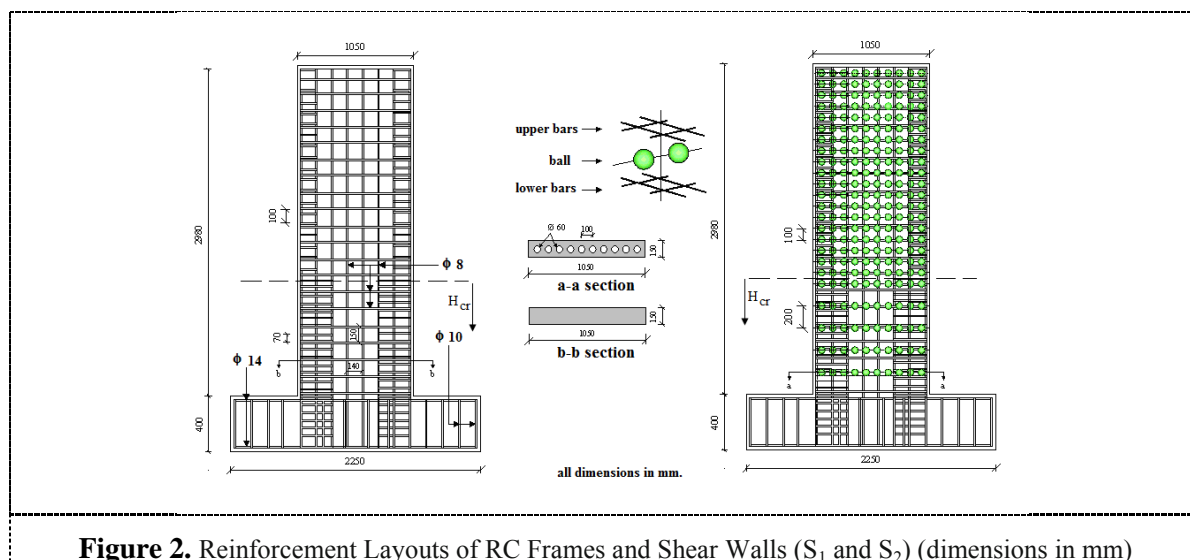
### 3.1. Shear wall tests

To conduct a behavioral analysis of the shear walls under cyclic lateral loading or quasi-static lateral loading resembling the earthquake effect, two specimens at full scale were tested. The shear walls with 150 mm thickness were produced with and without balls, and these specimens were called  $S_1$  and  $S_2$ , respectively. The concrete used in the shear walls had a compressive strength of approximately 29 MPa. According to TEC-2007 (Turkish Earthquake Code, 2007) [11], the minimum comprehensive strength of concrete must be 20 MPa, and the minimum tensile strength of the reinforcement bars must be 420 MPa. The RC shear wall was 150×1050 mm in section. Longitudinal deformed bars of 16 $\phi$ 8 mm and a mesh reinforcement horizontal web bars of  $\phi$ 8/150 mm were used in the shear wall. The test

samples produced with and without balls and the reinforcement layouts of the SW (dimensions in mm) are given in Figure 2. The shear walls were cast horizontally and then lifted and placed. A wooden mold kept at room temperature for nearly 28 days was used to cast the concrete of the RC shear wall in a vertical position where the reinforcement was placed on both faces of the wall. In the tests carried out on the plane frame model, the out-of-plane behaviors were prevented or ignored. The earthquake-simulating reversed-cyclic loading was applied either from the top story or, at different rates (triangular load distribution), from the story levels representing real earthquake behavior of the building. In the tests, particularly those that used the quasi-static loadings, the load was applied as load-controlled until the yield displacement of the frame system and was then displacement-controlled. The lateral load-top displacement graphs obtained during the tests of the two test samples are presented in Figure 3.

### 3.2. Slab tests

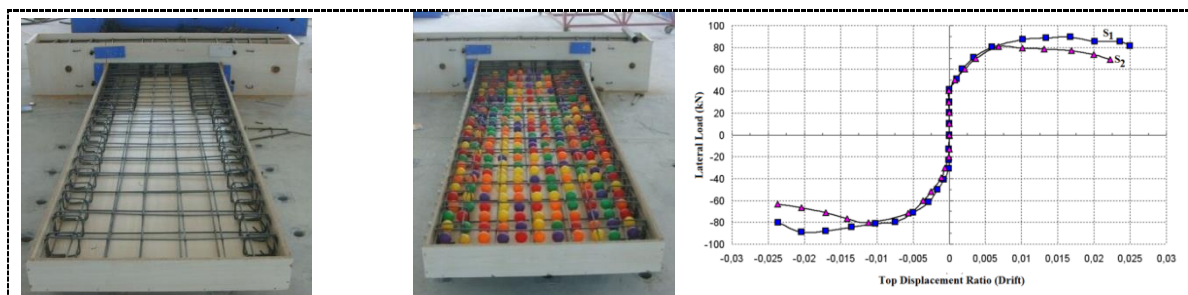
To conduct a behavioral analysis of the slabs under static vertical loading, two specimens at full scale were tested. The slabs with 150 mm thickness were produced with and without balls, and these specimens were called  $F_1$  and  $F_2$ , respectively. The length and width of all of the slabs were 2100 mm and 800 mm, respectively, with a clear span of 1950 mm, and these dimensions were kept constant throughout the study. The thickness of the slabs was 150 mm according to the requirements of the TBC-500-2000 [12]. A concrete cover of 30 mm was used for the longitudinal reinforcements. Initially, the slabs were designed as under-balanced. The longitudinal reinforcement ratio was 0,0035. The slabs had same longitudinal reinforcement in the upper and lower sections. In the slab samples, the same concrete and reinforcement steel bars were used as with the shear walls. The balls used in the slabs were kept within the neutral axis during concrete casting. For this purpose, the wires passing through the balls' axes were fixed on the formwork heads to suspend the balls.



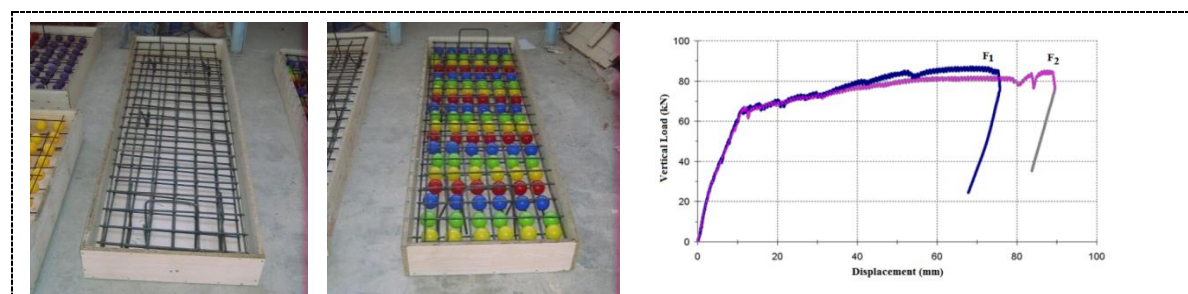
**Figure 2.** Reinforcement Layouts of RC Frames and Shear Walls ( $S_1$  and  $S_2$ ) (dimensions in mm)

The simply supported  $F_1$  and  $F_2$  slabs were tested under monotonically increased loads, using a 500-kN-capacity rigid steel loading frame. The slabs were instrumented to measure the applied load and the midspan deflections. The loads were applied at the mid-point of the slab. The test samples  $F_1$  and  $F_2$  produced with and without balls and the vertical load-displacement graphs obtained during the tests of the two test samples  $F_1$  and  $F_2$  are presented in Figure 4.





**Figure 3.** Test Samples ( $S_1$  and  $S_2$ ) and Base Shear-Top Story Displacement Envelope Curves ( $S_1$ -  $S_2$ )

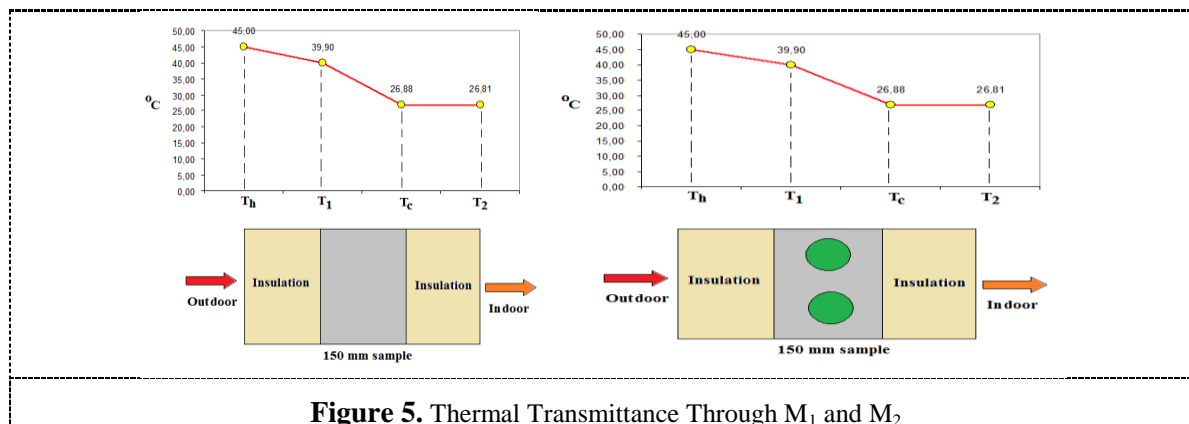


**Figure 4.** Test Samples ( $F_1$  and  $F_2$ ) and Load-Displacement Capacity Curves of the Slabs ( $F_1$  and  $F_2$ )

### 3.3. Thermal test

After the results of the loading experiments for the first target were deemed satisfactory, the second phase of the experimental study began to obtain the acoustic and thermal characteristics of the specimens. The members produced with and without balls are shown in Figure 1. The main object of the thermal tests presented here is to investigate the effect of the balls on the thermal transmittance of the RC members. For this aim, six different specimen walls with 150 mm thickness were manufactured both with and without balls. The walls were 1200 x 1200 mm in plan. The concrete used in the sample ( $M_1$  and  $M_2$ ) walls had a compressive strength of approximately 30 MPa. The average data that were calculated in the experiments and the behaviors of the six samples under the influence of heat were compared and interpreted. The data showed that the thermal conductivity value of the section changed depending on the inner structure of the sample and the quantity of hollows. Figure 5 shows the  $M_1$  and  $M_2$  sample performances under the influence of heat. The thermal conductivity ( $k$ ) is the main parameter of thermal performance. According to the experimental results in the literature [13], the aggregate volume fraction, the moisture condition, the age of the concrete, the mortar conductivity, the W/C ratio and the cement paste are the main factors that affect the conductivity of concrete. Because the samples were produced, stored and tested under equal conditions, all of the parameters of the samples were regarded as equal. The mass per unit volume of the sample without balls,  $M_1$ , was 2257 kg/m<sup>3</sup>, and the mass per unit volume of the sample with balls,  $M_2$ , was calculated as 1024 kg/m<sup>3</sup>. The density of the section and the ratio of the hollows and/or porosity in the section affect the heat conductivity value. The balls used in the RC section may be expected to ensure effective heat insulation because of their distribution in the section and smaller diameter. In other words, a high number of pores is more appropriate than a low number of pores. However, the properties and locations of the balls should be constant due to the reasons mentioned previously. The heat storage property of the construction component is related to the heat transmission coefficient of the material. Thus, the thermal properties of all types of materials used as construction components should be analyzed in detail when performing thermal comfort studies. When the values obtained from the heat tests were analyzed, a decrease in the thermal conductivity value from 1,974 to 0,626 can be seen as an increase in the RC section to the desired levels of thermal comfort. According to the table, the thermal conductivity variations of the samples showed a similar trend as their density variations. According to Turkish Standards TS 825 [14], the thermal conductivity ( $k$ ) is given as 2,5

W/mK and 1,1 W/mK for normal and lightweight RC materials, respectively. In this study,  $M_2$  had a lower thermal conductivity ( $k$ ) than the value for lightweight concrete given in the related code.



**Figure 5.** Thermal Transmittance Through  $M_1$  and  $M_2$

### 3.4. Acoustic test

Acoustic measurements of the sound insulation in the RC members with and without balls were performed [15]. The difference in the sound (noise) levels from one side of a wall to the other indicates the sound transmission loss through the wall. In this experiment, the sound transmissions of the samples were obtained, and the sound absorption coefficients of the samples were measured under the same humidity conditions. The relative humidity was 50 %, and the frequency of the sound was between 100 and 3150 Hz. In the literature [16], the same method has been used in acoustic measurements of sound insulation. Six specimen walls with 150 mm thickness were manufactured both with and without balls. The walls were 120 x 120 cm in plan. The concrete used in the samples walls had a compressive strength of approximately 30 MPa. In Table 1, the sound absorption values are given for  $A_1$  and  $A_2$ , respectively. For example, if the sound generated inside a room is 90 decibels (dB) and 40 db is measured on the other side of the wall (adjoining room), then a reduction of 50 dB is achieved. Acoustic tests relate the sound loss through a wall at various frequencies. The results are averaged to provide a single absolute value number. This rating system is necessary to compare other wall systems to a specific wall design. This absolute value is known as the Sound Transmission Class (STC). STC is a rating system used to estimate the sound insulation properties of a wall. According to the test, the average values of  $A_1$  and  $A_2$  are 52,75 dB and 73,25 dB, respectively. In Europe, some countries have detailed regulations [17] for STC values with four classes: A, B, C and D. The A and B classes (approximately 63 and 58, respectively) represent higher levels of acoustic comfort. For instance, the Ontario Building Code [18] requires an STC rating of 50 as a minimum acceptable value and STC of 55 in specific areas. Due to changing lifestyles, i.e., condominium living, many builders prefer to design for STC of 55 or more if end users are demanding and willing to pay for higher quality. In addition, STC findings are based on laboratory results under ideal working conditions, but on-site construction conditions are not the same. Therefore, wall assemblies constructed in the field have significantly lower STC than the laboratory ratings.

## 4. Results and conclusion

In this study, different experimental studies were conducted on RC members produced with PB. First, RC members produced with and without balls were analyzed under loading. Then, the thermal performance and the sound absorption behavior of the members were explored experimentally. The following are the research findings from this study.

**Table 1.** Measure Sound Levels for Different Frequencies in A<sub>1</sub> and A<sub>2</sub>

Frequencies (Hz)	Sound levels inside of the wall (dB)		Sound levels outside of the wall (dB)		Sound Absorption (dB)	
	A <sub>1</sub> and A <sub>2</sub>		A <sub>1</sub> and A <sub>2</sub>			
100	81.77	81.81	34.87	14.41	46.9	67.4
125	83.47	83.51	34.97	14.51	48.5	69.0
160	84.87	84.91	33.97	13.51	50.9	71.4
200	86.27	86.31	34.37	13.91	51.9	72.4
250	86.77	86.81	35.07	14.61	51.7	72.2
315	87.47	87.51	35.37	14.91	52.1	72.6
400	88.67	88.71	35.57	15.11	53.1	73.6
500	89.67	89.71	35.87	15.41	53.8	74.3
630	90.27	90.31	35.37	14.91	54.9	75.4
800	92.37	92.41	34.97	14.51	57.4	77.9
1000	92.97	93.01	34.27	13.81	58.7	79.2
1250	93.17	93.21	35.17	14.71	58.0	78.5
1600	92.77	92.81	36.87	16.41	55.9	76.4
2000	93.07	93.11	39.07	18.61	54.0	74.5
2500	92.77	92.81	44.07	23.61	48.7	69.2
3150	92.67	92.71	45.17	24.71	47.5	68.0

- Using 6 cm diameter PB in RC shear walls with 15 cm thickness, the lateral load carrying capacity of the specimens decreased by approximately 1-7 % at the failure loading level. At the yielding and maximum loading levels, the specimen behavior was very similar. The addition of balls in the shear walls decreased the initial stiffness but had no effect on the final stiffness. The ductility of the walls was approximately equal. The load-displacement curves are used to determine the general behaviors and strengths of the specimens. The addition of balls in the specimen did not significantly change the strength or ductility. Therefore, the PB did not considerably affect the SW behavior.
- The vertical load carrying capacity did not change with the presence of the balls in the slab members. The inertia rigidity and the seismic energy absorption of the two sections was the same in the slabs. The cracks appeared at the tension region of the slab when the concrete stress at the extreme tensile fiber reached the flexural tensile strength of concrete. The slab specimens showed the same crack development up to failure.
- The thermal conductivity coefficient (k) in the reference section was calculated as 1,974 W/m<sup>2</sup>K; the same coefficient in section with balls was 0,626 W/m<sup>2</sup>K. According to the tests, the thermal conductivity variations of the samples showed a similar trend as their density variations, and decreasing the density improved the sound and thermal insulation performance. The experiments showed that PB in RC increased the absorption coefficient of these walls.
- Acoustic tests measured sound loss through a wall at various frequencies. For all of the frequency levels, the sound absorption level was very different in the two members. For instance, for the reference section produced without balls, the STC coefficient was approximately 52,75 decibels (dB). However, the section with balls had a coefficient of 73,25dB. The RC wall produced with balls had a higher level of acoustical comfort.
- As a result of the study, the thermal and acoustic comfort conditions will be improved for the residents and a positive contribution to a sustainable environment will be ensured due to the use of the balls inside the slabs and walls in SWwork systems.

In this study, structural and comfort parameters have been investigated in RC sections such as slabs and shear walls produced with and without balls. The results obtained from the experimental studies show that 6 cm diameter PB used in RCSW and slabs with suitable positions do not significantly decrease the strength but show important improvements in thermal and acoustic features. In future

work and applications, manufacturing PB with a diameter of 6 cm located inside the formwork members in recycling facilities will reduce the production cost of construction. Moreover, using plastic waste, which has the longest degradation period, as a raw material significantly contributes to the protection of our natural resources, the prevention of environmental pollution, affordability and energy conservation. From the environmental aspect of the study, reducing the harmful effects of concrete and cement production on nature and creating an eco-friendly carrying system over the long term by manufacturing the PB using plastic waste are indirect outcomes of this method. At this point, comparing the cost of the PB with the concrete cost will not be as meaningful; likewise, the cost of raw materials will be minimized by manufacturing PB by recycling methods, particularly for the purpose of recycling plastic waste. In addition, economic solutions can be found in foundation systems by decreasing the concrete consumption and decreasing the weight of the building. Other than offering greater safety to the resident, the weight of the carrying system will be decreased by reducing the concrete inside the slabs and walls. Being a construction manufacturing system with a broad application area, the development described here will make a significant contribution to the construction industry and thereby the national economy.

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