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Investigation of Seismic Behavior of Buildings With Different Infill Wall Materials

Pınar USTA[1*]

[1] Isparta University of Applied Science, Technology Faculty, Civil Engineering Department, Isparta, Türkiye
Pınar USTA ORCID No: 0000-0001-9809-3855

**Corresponding author: pinarusta@isparta.edu.tr*

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Infillwalls, Earthquake, AAC, Conventional Brick, Reinforced Concrete

Abstract: Different masonry materials are commonly used construction materials for buildings. When the current situation of reinforced concrete structures under the earthquake effect is examined, it is seen that there are differences in the behavior of the reinforced concrete structures depending on the properties of the materials that are used in the reinforced concrete structures. The reason for this situation is related to the physical properties of the preferred material. The frame systems of reinforced concrete structures are completed with infill walls. Aerated autoclaved concrete and conventional brick materials are used as infill wall materials in most of the reinforced concrete structures built in Turkey. In this paper, the finite element program was used to analyze the current state of reinforced concrete structures with infilled walls under the earthquake effects. A reinforced concrete framed structure model was designed using the SAP2000 finite element program, two different materials were preferred in the model structure and four different model combinations were designed. The first two models are designed with infill walls, but the ground floor and the other models are designed with infill walls for the whole building. Nonlinear static pushover analyses were conducted, and base shear, displacement, and story drift values were obtained. All the results were presented by graphics. The data obtained from the model with Aerated autoclaved concrete material, which has a low unit volume weight under the effect of the earthquake, is healthier than the model with conventional brick material.

Farklı Dolgu Duvar Malzemesine Sahip Binaların Deprem Davranışının İncelenmesi

Anahtar Kelimeler
Dolgu duvar, Deprem, Gazbeton, Tuğla, Betonarme bina

Öz: Binalarda yapı malzemesi olarak farklı yığma malzemeler yaygın olarak kullanılmaktadır. Betonarme yapıların deprem etkisi altındaki mevcut durumu incelendiğinde, betonarme yapılarda kullanılan malzemelerin özelliklerine bağlı olarak betonarme yapıların davranışlarında farklılıklar olduğu görülmektedir. Deprem etkisinde betonarme yapıların mevcut durumu incelediğinde betonarme yapıların kullanılan malzemelerin özelliklerine göre yapı davranışında farklılıklar meydana gelmiştir. Bu durumun sebebi tercihe dilen malzemenin fiziksel özellikleriyle ilişkilidir. Betonarme yapıların çerçeve sistemi dolgu duvarlarla tamamlanmaktır. Türkiye'de inşaa edilen betonarme yapılarda dolgu duvarlarda gazbeton ve tuğla malzemeler kullanılmıştır. Bu çalışmada, dolgu duvarlı betonarme yapıların deprem etkileri altındaki mevcut durumunu analiz etmek için sonlu elemanlar programı kullanılmıştır. SAP2000 sonlu elemanlar programı kullanılarak betonarme çerçeveli bir yapı modeli tasarlanmış, model yapısında iki farklı malzeme tercih edilmiş ve dört farklı model kombinasyonu tasarlanmıştır. İlk iki model dolgu duvarlı olarak tasarlanmıştır ancak zemin kat ve diğer modeller tüm bina için dolgu duvarlı olarak tasarlanmıştır. Doğrusal olmayan statik itme analizleri yapılarak taban kesme, deplasman ve kat öteleme değerleri elde edilmiştir. Sonuç olarak tüm sonuçlar grafiklerle sunulmuştur. deprem etkisi altında birim hacim ağırlığı düşük olan gaz beton malzemeli modelden elde edilen verilerin tuğla malzemeli modele göre daha sağlıklı olduğu tespit edilmiştir.

1. INTRODUCTION

Reinforced concrete skeleton (carcass) structures are often preferred due to the ease of construction and the rapid progress of the works, and generally, these frames are filled with wall infill panels (or) concrete blocks in most countries located in seismic zones. Masonry infills contribute significant lateral stiffness, strength, overall ductility, and energy dissipation capacity. These elements act as compression supports between column and beam, transferring forces from one node to another. the infill walls increase the mass of the building whereas reducing the natural vibration periods. Past earthquakes show that infill walls have significant structural effects on the earthquake performance of the building. Reinforced concrete (RC) frame buildings with masonry infill and shear walls for elevators are commonly constructed around the world, including in seismic areas. this reinforced concrete (RC) frame buildings are usually encountered as commercial, industrial and multi-storey residential apartments. Masonry infill walls and shear walls for elevators are extremely effective in resisting lateral seismic loads on the building. Therefore, the use of masonry infill and shear walls for elevator in reinforced concrete frames changes the lateral load transfer mechanism responsible for the reduction in bending moments and increase in axial forces. The elements called infill walls that are constructed between the columns and beams of the reinforced concrete frame are usually made with a conventional brick wall, aerated autoclaved concrete, pumice, and concrete block. These infill walls, which are generally not considered in the design process, are considered non-structural components [1]–[4].

Infill walls contribute significantly to the strength and rigidity of structures, neglect of infill walls causes buildings to collapse. Masonry walls are used for functional and architectural needs in reinforced concrete buildings. The term infilled frame describes a composite structure consisting of a moment resisting reinforced concrete frame and infill walls. In these infill walls, filling materials such as traditional clay brick, concrete block, AAC block are used as building materials [5].

Infill wall panels are widely used also in our country due to aesthetic and functional demands. Most of the existing building stock in Turkey is under seismic risk. In this context, it is thought that a significant part of the existing structures will probably collapse or be severely damaged during a strong earthquake.

The most common type of damage in reinforced concrete and masonry structures is shear cracks caused by shear forces [6]. Masonry structures have low tensile strength compared to reinforced concrete structures and their energy consumption capacity against earthquake forces is also very low [7], [8].

In this context, it is thought that a significant part of the existing structures will probably collapse or be severely damaged during a strong earthquake. Literature studies also support this fact [9], [10]. Turkey, one of the most seismically active countries of the world in terms of its geological features, is situated on an active area surrounded by active faults [11]. Earthquakes in Turkey demonstrate that 92% of the our country's land is susceptible to earthquake risk [12]. The earthquakes that occurred in Turkey between 1990 and 2021 and the distribution of these earthquakes are shown in Figure 1 and Figure 2.

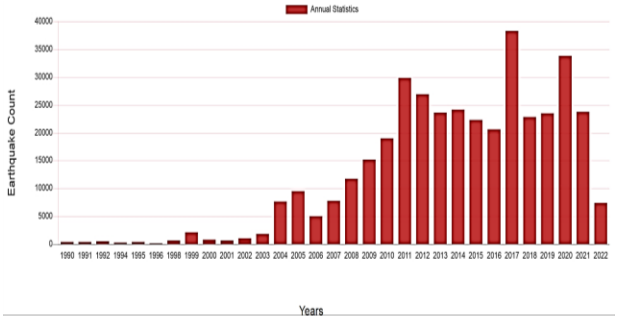

Figure 1. Earthquakes in Turkey between 1900-2022 [13]

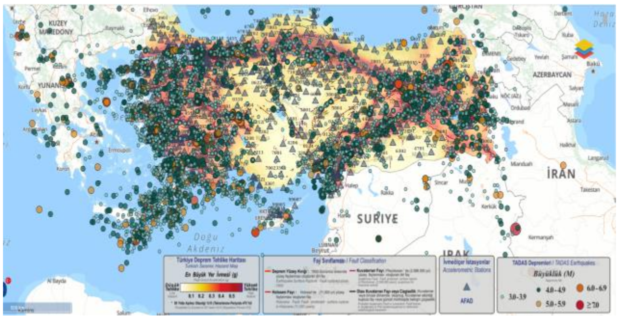

Figure 2. Turkey earthquake map and distribution of earthquakes [14]

Brick and stone have been used as building materials from past to present. As carrier material; While mostly brick material was used in the Seljuk period, stone was used in the Ottoman period. Brick is one of the most important building materials widely used to build walls and other elements, especially in the construction industry [6]. Brick is one of the most important building materials widely used to build walls and other elements, especially in the construction industry. However, the continued use of clay bricks in the construction industry leads to a large-scale loss of fertile topsoil in our country. This situation will inevitably create an environmentally destructive danger in the future. Environmental pollution from the brick production process contributes to global warming and climate change. Moreover, the air temperature can cause the brick surface to deteriorate due to frost damage, leading to global warming, which is now a global concern. Various types of blocks are used as an alternative to red bricks to reduce environmental pollution and global warming problems. Aerated autoclaved concrete blocks can be one of the solutions to replace traditional clay bricks [15].

Aerated autoclaved concrete is a material developed by Eriksson (1923) at the Royal Technical Institute in Stockholm, Sweden, and patented for production in 1924. Nowadays, Aerated autoclaved concrete is widely used in 135 countries on 6 continents [16]. Because Aerated autoclaved concrete wall panels are lightweight, highly thermally insulated, high fire protection, high sound insulation, low water absorption, environmentally friendly, and easy to apply [15].

As in different construction methods, it is necessary to verify whether the Aerated autoclaved concrete blocks used for structural purposes have sufficient and necessary resistance to seismic effects. Design rules for structures constructed with Aerated autoclaved concrete blocks that can be used as load-bearing elements in walls have recently been included in the Turkish earthquake code [10].

Soft-storey buildings are multi-storey buildings with wide gates, commercial areas at ground level, and open space usually for parking. A soft storey may occur due to the lower rigidity of the first floor as a result of using less masonry infill walls on the first floor, or because the first may have a greater height than the other storey due to commercial reasons. [17]. Soft storey collapse is due to the high column strength demand of the first storey compared to the other storey. The presence of traditional brick infill walls sharing the forces on the upper storey and the fact that the upper storey is more rigid than the first soft storey effectively reduces the column forces. The lateral displacement of the entire structure is governed by the first soft storey of the building. [18].

Soft floor irregularity is seen in the ground floors designed for commercial use, when walls are not built in order to obtain wide, glazed spaces with high floor heights. If the infill walls on the ground floor work together with the load-bearing system and the ground floor, which has no walls, does not work together with the carrier system, relative displacements occur on the floor and a soft floor situation occurs [19] [20].

In reinforced concrete structures, due to the difference in stiffness between the ground floor and the first floor, large cross-sectional effects occur on the ground floor carrier columns. Great stresses occur in the ground floor columns due to earthquake forces and plastic hinges occur due to the growth of lateral displacements [19].

Choosing the normal storey heights less than the ground storey height, discontinuity of the infill walls, designing more spacious areas for service-oriented commercial spaces on the ground storey in the frame design of reinforced concrete buildings are led to soft storey irregularities. When the damage conditions in the buildings are examined after the earthquakes, it is seen that the soft storey irregularity prevents the buildings from being reliable and stable [20]–[22].

Examining the building damage in past earthquakes, it has been observed that typically buildings with no or very few walls on the ground storey, compared to the upper storey, suffered major damage at the ground storey level. Because the resistance of the ground storey, which is devoid of walls, against horizontal displacements is very low compared to the upper storey, which are rich in walls. Ground Storey with no walls and/or relatively large storey heights are the focal point of earthquake damage in buildings [22].

In order to reduce human losses, it is imperative to evaluate the performance of structures exposed to natural events such as earthquakes; and it is an issue that concerns the whole world [23]. This paper works presents a numerical study to investigate the effect of the masonry infill material on the seismic performance of an RC framed building subjected to dynamic loading considering the effects of the different masonry infill material. For this purpose, reinforced concrete building was modeled in four different ways by using the SAP2000 (ver. 23.0) finite element program [24]. The building was analyzed according to two different masonry infill materials, aerated autoclaved concrete and brick building materials, and whether the building has an infill wall on the ground storey or not .

Nonlinear static thrust analysis was performed on the reinforced concrete structure and the base shear force, structure displacement and storey drift values of the models were obtained. The values are compared and presented with graphs.

2. MODELLING OF INFILL WALLS

Various equivalent diagonal strut formulas and methods are available to find the width of compression struts. The diagonal braces were connected to the beam-column junction with a joint moment-free connection; thus they can only receive compression forces. The modeling of the infill wall can be done using the finite element method or the static equivalent strut approach. This is the model used in the study. In this type of modeling, the stiffness of the wall is considered in the loading plane. In infill walls placed in a lateral load-resistant frame, the stiffness and strength contribution of the infill are taken into account by modeling the infill as an equivalent strut approach. In this study, FEMA-356 [25] is used to find the width of compression struts.

The equivalent width of a diagonal compression strut, a, is given by:

$$w = 0.172\ (\lambda_1 H)^{-0.4} d_{inf} \tag{1}$$

$$\lambda_1 = \left[\frac{E_{inf} t_{inf} \sin 2\theta}{4 E_c I_{col} h}\right]^{0.24} \tag{2}$$

$$\theta = \tan^{-1}\left(\frac{h_{inf}}{L_{inf}}\right) \tag{3}$$

From the above-given formula, the width of compression struts was calculated. Diagonal Strut Parameters are given in Figure 3.

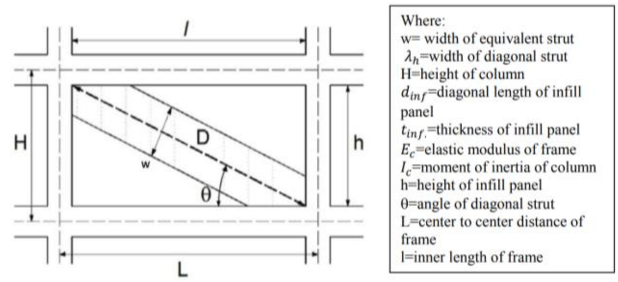

Figure 3. Diagonal Strut Parameters [26]

Mathematical models of these buildings were created by Sap 2000 finite element program. Afterward, strut elements representing the infill wall were added to these mathematical models and analyzed as a two-joint compression strut element, because the dominant behavior was axial stressing of the infill panel provided in-between the two consecutive columns. The hinges properties were defined in SAP2000. The P-M2-M3 model was used to define the hinges in the columns, M3 model was used to define in the beam and an axial hinge was used for the struts. Strut element model is shown in Figure 4.

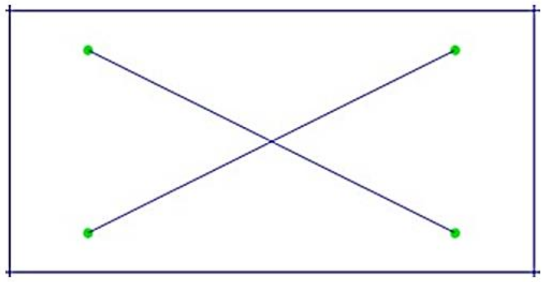

Figure 4. Strut element model

3. MATERIAL AND METHOD

In the study, the infill walls in the reinforced concrete frame were designed with conventional brick (CB) and aerated autoclaved concrete (AAC) filling materials. A total of four different model combinations were created. The first type model is consisting of an aerated autoclaved concrete infill wall from the ground to top (Model 1- AAC), the second type model is consisting of a conventional brick infill wall from the ground to top (Model 2- CB), the third type model is consisting of an aerated autoclaved concrete infill wall except for the ground floor (Model 3- AAC), the fourth type model is consisting of a conventional brick infill wall except for ground floor (Model 4-CB). The material characteristics used in modeling are given in Table 1.

Tablo 1. Material characteristics

	Aerated Autoclaved Concrete (AAC)	Conventional Brick (CB)
Compressive Strength (f)	3.5 MPa,	5 MPa,
Modulus of Elasticity *(E)*	8000 MPa,	3500 MPa
Poisson ratio	0.2	0.2
Density	5.3 kN/m^3	17.5 kN/m^3

The building is a reinforced concrete frame building structure. The model is formed by beams and columns whose joints connected to the ground story are made of fixed supports to be restrained in all directions The dimensions of the model building are 20.0 m x 20.0 m. The building has 7 storey including the ground storey. The height of each storey is 3 meters. The model is formed by beams and columns whose joints connected to the ground story are made fixed supports to be restrained in all directions.

The material and element dimensions of the model are shown in Table 2. The dimensions of the building and the elevation of the building are shown in Figure 5.

Table 2. Material and element dimensions of the model

	Elements Properties
Concrete Grade	C30
Steel Grade	S420
Column Size	50 cm x 50 cm
Beam Size	30 cm x 40 cm
Slab thickness	15 cm
Conventional Brick Struts	23 cm x 56 cm
AAC Struts	25 cm x 55 cm

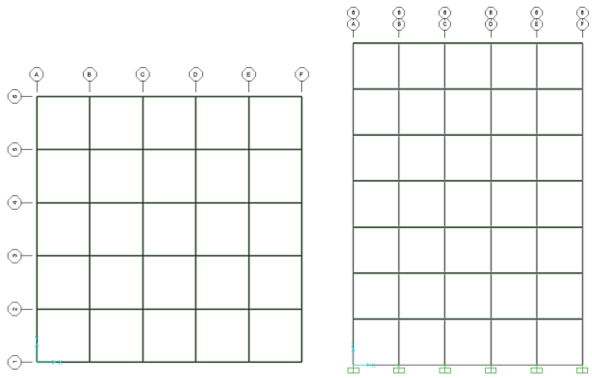

Figure 5. Plan and elevation of mid-rise building

Masonry infill walls consist entirely or partially of panels within the plane of the concrete frame bounded by columns and beams. In this study, the filled walls are modeled as equivalent diagonal strut model to make the structural analysis of the masonry infill wall frame system. Equivalent diagonal struts modeling of masonry fills in frames is extremely popular because of its simplicity and required a limited number of input parameters for the modeling. The building was modeled and analyzed using SAP2000 V23 finite element program. Finite element models of the building are given in Figure 6.

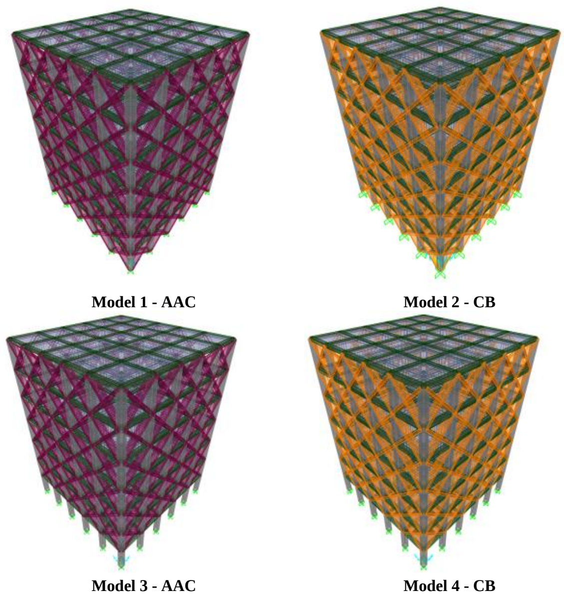

Figure 6. Models of aerated autoclaved concrete and conventional brick infill wall structures

The building is designed using the assumption that the floor systems serve as a rigid diaphragm. Infill walls are modeled as equivalent diagonal compression struts. In addition to live load and dead load, Conventional brick and aerated autoclaved concrete wall loads are also defined in the building. The building was designed for zone 2B. In the structure modeled in 3D, the infill walls were defined as two different materials, aerated autoclaved concrete and conventional brick, and the effect of the filling materials on the earthquake response of these type of structures were determined under both conditions.

4. ANALYSIS RESULTS

Pushover analysis is one of the important methods available to understand the behavior and vulnerability of structures subjected to earthquake loads. So, Nonlinear static pushover analysis was performed on the structure modeled in four different ways. This process was repeated for each combination with the Sap2000 (version 23) [24] program. As a result of the analysis, base shear force, top floor displacement values, and storey drift values obtained from four different models were found. First, the buildings modeled as infill walls from the ground to the top floor (Model 1- Model 2) were examined. Values of Model 1- Model 2 are given graphically in Figure 7, Figure 8, and Figure 9, respectively.

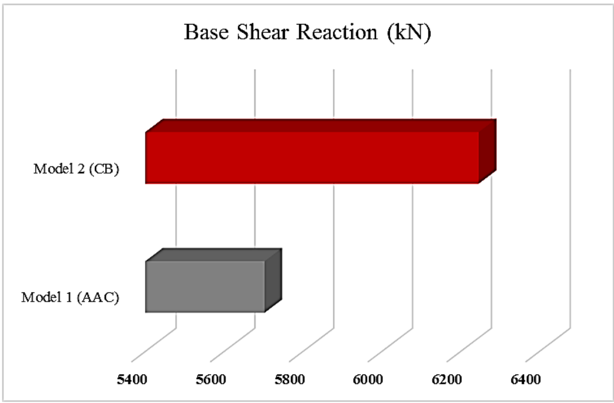

Figure 7. Base shear force of aerated autoclaved concrete (model 1) and conventional brick filled walls (model 2)

From Figure 7, it is seen that the base shear force value of the model with conventional brick material (Model 2) is higher than that of the model with aerated concrete block material (Model 1).

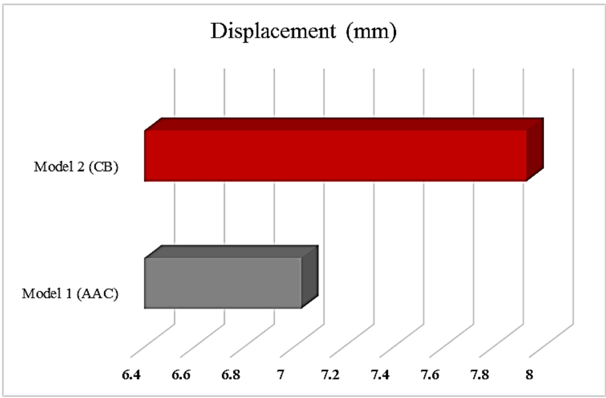

Figure 8. Top floor displacement values of aerated autoclaved concrete and conventional brick filled walls

Considering the top floor displacement values in model 1 and model 2, the displacement value in model 1 (conventional brick) is greater than model 2 (Aerated autoclaved concrete). When the storey drift values of the two models are compared (Figure 9) it is seen that the storey drift value of model 2 is higher due to the rigidity of the material it has.

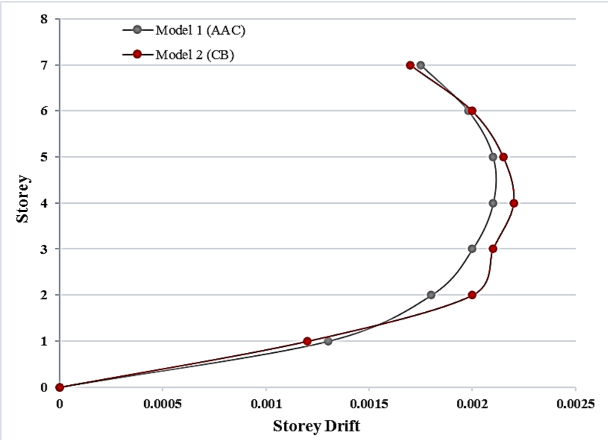

Figure 9. Storey drift value of Model 1 and Model 2

Secondly, static pushover analysis was performed for the building models Model 3 and Model 4, which are designed with no infill walls on the ground floor. The base shear force, top floor displacement, and storey drift values obtained from the static thrust analysis are given in Figure 10, Figure 11, and Figure 12, respectively.

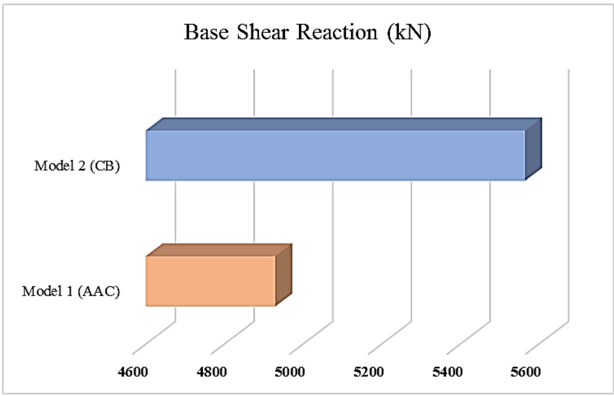

Figure 10. Base Reaction Forces of Models Without Ground Floor Infill Walls

As a result of the analysis, as seen in Figure 10, the base shear force value was found to be higher in Model 4 (conventional brick), similar to the ones in the filled model.

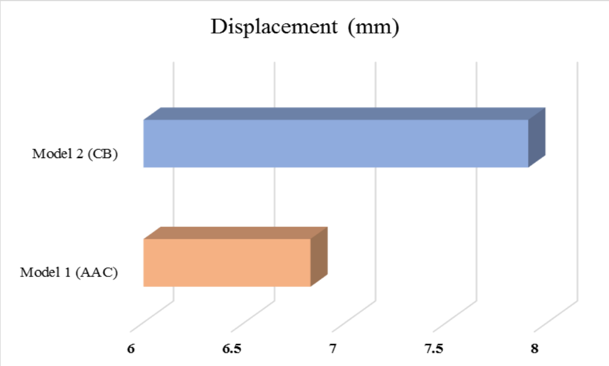

Figure 11. Top floor displacement values of models without ground floor infill walls

The peak displacement value of two different materials was found to be lower in Model 3 compared to Model 4.

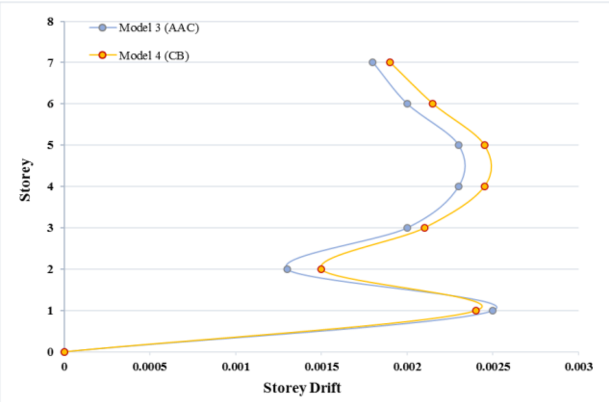

Figure 12. Storey drift values for models without ground storey infill walls

In the buildings modeled as the ground floor without walls, the storey drift values bounce on the ground floor where the stiffness was different, and the values were found to be higher in the conventional brick building material.

5. CONCLUSIONS

In this study, static pushover analysis of the building was conducted according to four different combinations, and the base shear force, displacement, and Storey drift value results were obtained for each model. The analyzes were conducted for 2 cases. First, model 1 and model 2, which have the same properties except for the filling wall material, were examined. Afterward, analyzes were conducted for Model 3 and Model 4. When the base shear force value obtained from Model 1 is compared with Model 2, the base shear force of the model with Aerated autoclaved concrete filling wall material was found 8.69% less. When the peak displacement values obtained from the same models are compared, 11.32% less displacement value was obtained in Model 1 (AAC) than in Model 2 (CB).

In the building models whose ground floor is designed without infill walls, the base shear force in Model 3 (AAC) was found to be 11.42% less than in Model 4 (CB). When the peak displacement values of the models are compared, 13.65% less displacement value was obtained in Model 3 (AAC) than in Model 4 (CB). Aerated autoclaved concrete has more rigidity than conventional brick. therefore, the storey drift values obtained from nonlinear analyzes are less in AAC filling wall material building models.

In addition, in Model 3 and Model 4, the drift ratio values on the ground storey are higher than the other storey, and soft storey behavior has emerged on the ground storey. This situation was caused by the using walls on the upper storey of the building and therefore the increased rigidity of the building.

To evaluate the infill wall materials in terms of "Soft Floor Behavior", when the models designed without infill walls on the ground storey are examined, Aerated autoclaved concrete gave slightly more negative values than conventional brick. In the design of the building, the designer should use shear and column sections that will provide sufficient rigidity on the ground storey to prevent soft storey for both materials.

As a result, the AAC block infill outperformed the Traditional brick infill in the RC frame. For reinforced concrete frames built in earthquake-prone areas, ACC block material is suitable to replace conventional bricks and can be used mainly as a substitute for traditional brick material. If we compare the performance of conventional clay bricks and AAC blocks were significantly superior.

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