Seismic Assessment of a School Building Constructed with AAC panels and experienced 1999 Kocaeli Earthquake

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ABSTRACT: Usage of autoclaved aerated concrete (AAC) for the construction of non-structural walls increases very rapidly due to its practical advantages all around the world. Furthermore, in recent years, several research groups, particularly in the USA, extensively studied the usage of reinforced AAC panels as structural members. Interestingly, this type of structural panels have been used in Turkey for quite a long time as structural walls and slabs, particularly for supplying emergency housing after major earthquakes experienced in different regions. Currently, around 5000 buildings of different usages, such as housing units or schools, some of which have experienced earthquakes of different intensities, are still under service. On the other hand, while these buildings were designed and constructed based on certain engineering knowledge and judgment, this type of structural elements are not defined in Turkish seismic design documents.

This study is presented in three main sections after general introduction. Firstly, the state-of-the-art is summarized in terms of the recent research activities on reinforced AAC panels. Secondly, the observations on the seismic performance of an existing AAC panel school building, which experienced the catastrophic 1999 Kocaeli earthquake, are presented. Finally, this school building is analyzed numerically through finite element analysis and the analysis results are compared with the site observations.

1 INTRODUCTION

Autoclaved aerated concrete (AAC) is a lightweight cementitious building material with closed internal voids. AAC is made from cement, fine silica sand, mixing water, aluminum powder and unhydratedlime. The low density is achieved by the formation of non-connecting, macroscopic cells uniformly distributed within the mass. Chemical reactions between the aluminum powder and the alkaline slurry produce hydrogen gas bubbles that are kept in the matrix and subsequently increase its volume. After initial setting and cutting to shape with stainless-steel wires, the AAC elements are then autoclaved at a temperature of 190℃ and a pressure of 12 atmosphere for 10 hours (ACI, 2009).

AAC elements can mainly be classified in two groups as reinforced and unreinforced members. Unreinforced members are known as blocks used for infill or structural walls, insulation boards used for thermal insulation purposes and filler blocks used in hollow tile floor slabs. Reinforced AAC members are mainly used for vertical and horizontal wall panels, and floor and roof panels.

AAC has many advantages with respect to its alternatives. Some of these advantages are its lightweight, significant thermal insulation and non-flammable characteristics. In Table 1, the basic material properties of AAC in comparison with conventional concrete are presented.

Table 1. Material characteristics of AAC and conventional concrete (ACI, 2009)

Characteristic	AAC	Conventional Concrete
Density	400-600 kg/m^3	1400-2400 kg/m^3
Compressive Strength	2-4 MPa	16-55 MPa
Moisture Content After Autoclaving	30%	-
Coefficient of Thermal Expansion	8x10^{-6} /°C	9x10^{-6} /°C
Coefficient of Creep	0.72x10^{-4} /MPa	0.36x10^{-4}/MPa

1.1 AAC reinforced panels

AAC can be used to produce factory-reinforced panels as mentioned above (suitable for lintels, beams, floor panels, roof panels, and wall panels). Reinforced AAC panels use welded-wire reinforcement consisting of longitudinal and transverse wires. A typical detail of welded-wire reinforcement in an AAC reinforced panel is shown in Figure 1. It should be noted that, reinforced AAC panels are designed and produced according to engineering rules defined in CSN EN 12602 (2008). Vertical and horizontal walls (which behave as cladding materials, when used at the facade of the building), floor panels and roof panels are produced with a maximum length of 600 cm. Their width is fixed as 60 cm. The thicknesses of these panels vary between 10 and 30 cm. On the other hand, load bearing vertical walls have a maximum length of 300 cm. Their width is fixed as 60 cm. The thicknesses of these panels vary between 20 and 30 cm (Turk Ytong Sanayi A.S., 2012).

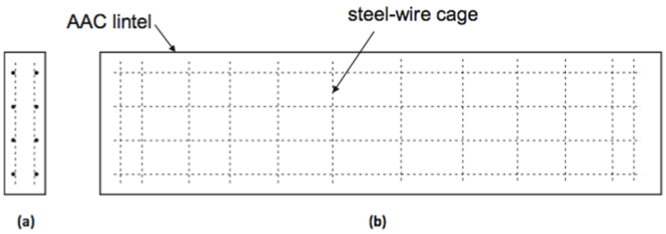

Figure 1. Typical detail of welded-wire reinforcement in an AAC reinforced panel (Fadaifard et al., 2011).

1.2 AAC structures constructed with AAC reinforced panels

Structures up to 2 – 3 stories have been constructed by using only AAC panels. In this type of structures, internal and external walls are constructed by using load bearing AAC vertical wall panels. Slabs and roofs are constructed by using AAC floor and roof panels. Connection between vertical walls and floor panels are formed via reinforced concrete bond beams.

In Turkey, since 1970 approximately 5000 structures (mainly housing units) were constructed by using this construction technique. About 250 out of 5000 buildings experienced destructive earthquakes like 1999 Kocaeli (7.4 M_w), 1999 Duzce (7.2 M_w) and 2011 Van (7.1 M_w)

earthquakes. It should be noted that, after these earthquakes some of these 250 buildings were inspected and no significant damage was reported (Sucuoglu and Alakoc, 2000). These buildings are still being used by their residents. Moreover, structures constructed with AAC reinforced panels were used as shelter houses for earthquake victims, as shown in Figures 2 and 3.

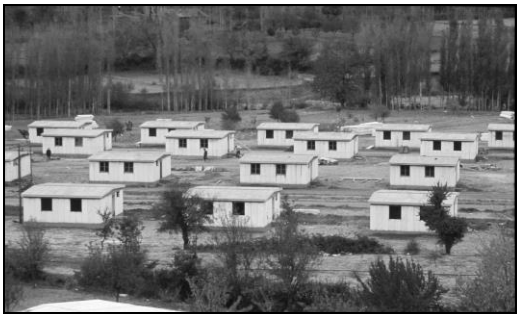

Figure 2. Izmit post-earthquake houses.

Figure 3. Surgu post-earthquake houses.

A school building in Kocaeli, Yuvacik region, which has been constructed with reinforced AAC wall and roof panels, was inspected by a team of researchers from Middle East Technical University right after the 1999 Kocaeli earthquake, and reported to experience no structural damage (Sucuoglu and Alakoc, 2000). This school building has two stories, and located at one of the most hazardous regions that experienced 1999 Kocaeli earthquake. The general appearance of the school building after the 1999 Kocaeli earthquake can be seen in Figure 4.

Figure 4. View from a visit right after the earthquake.

2 CONSTRUCTION METHODOLOGY

For better explanation of the seismic behavior, the stages of building construction with AAC panels are summarized below. After the RC foundation is constructed, dowels are anchored to the foundation before the application of AAC panels. Each dowel has a spacing of 60 cm between each other. The dowel length is 50 cm inside RC and 50 cm outside RC (100 cm in total). Then wall panels are placed between dowels. The intersection point of wall panels forms a hole where reinforcement can pass through. These holes are filled with grout after a reinforcing bar of 12 mm diameter is placed and overlapped with the anchored dowel. The length of the reinforcing bar is 50 cm longer than the wall panel so that this part of the bar is anchored to the bond beam above the wall panels. In Figures 5 and 6, the construction and connection plan can be seen for a typical building. In the next step, RC bond beams are formed on top of wall panels. Dowels for upper floor wall applications are also anchored into the bond beams to commence the construction of second story wall panels. Then floor panels are placed on bond beams, which behave as simply supported beams. The connection between each floor panel is filled with a reinforcement of 10 mm diameter and covered with grout. In Figures 7 and 8, details of the connections of floor panels can be seen. During the construction of the second story wall panels, the bond beams and roof panels are formed with the same manner as defined for the first story.

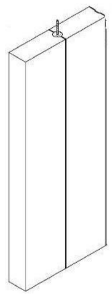

Figure 5. Vertical bar in panel connection.

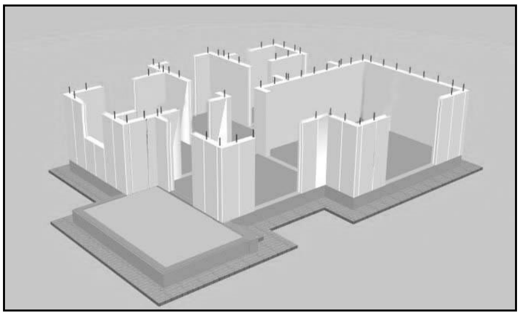

Figure 6. Typical ground floor wall connection plan.

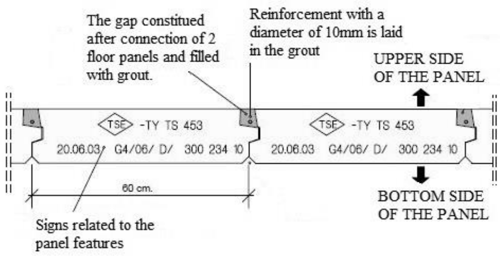

Figure 7. Section of floor panel connection.

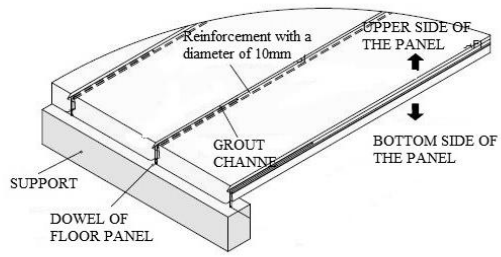

Figure 8. Floor panel connection.

3 STATE OF THE ART

3.1 Research

The state of the art regarding buildings constructed with AAC panels commenced extensively with the studies in University of Texas at Austin under the leadership of Prof. Dr. Richard Klingner, who has supervised 2 PhD and 2 MSc theses and Dr. Jennifer Tanner who has supervised the thesis of Storlie (2009), which all are related to this topic.

3.1.1 Design provisions for AAC structural systems (PhD Thesis), Tanner (2003)

A comprehensive testing program was developed. The first phase of the program was to determine the behavior of AAC shear walls subjected to reversed cyclic lateral loads. Walls were made of a variety of AAC units, including masonry-type units and reinforced panels, laid either horizontally or vertically. Each specimen was designed to fail in either shear or flexure. Based on the test results, procedures and corresponding design equations were developed to predict the behavior of AAC shear walls as governed by flexure, shear and other limit states. The second phase of the testing program involved the design, construction and testing, under reversed cyclic lateral loads, of a full-scale, two-story AAC assemblage specimen. Results from this second phase were used to validate the previously developed design provisions for shear walls, to evaluate proposed procedures for the design of AAC floor systems and connections, and to evaluate the overall behavior of AAC structures. Mechanical properties of AAC were determined at the Ferguson Structural Engineering Laboratory and validated with the results of material tests performed at other laboratories. Based on the results of those tests, design-related equations for material properties were developed for use in design provisions. The combination of these three facets has resulted in comprehensive and reliable design provisions for typical AAC structural systems, verified through extensive testing

3.1.2 Development of R and Cd factors for the seismic design of AAC structures (PhD Thesis), Rivera (2003)

In the International Building Code (ICC, 2012) the seismic force-reduction factor and the displacement-amplification factor are expressed as a response modification coefficient (R) and deflection amplification factor (Cd) respectively. The factor R is used to calculate the reduced design seismic forces of a structural system, and the factor Cd is used to estimate the corresponding maximum displacement that is likely to occur under an earthquake representing the design seismic forces. The values of the factors R and Cd prescribed in the IBC are based on observations of the performance of different structural systems in previous strong earthquakes, on technical justification, and on tradition.

The objectives of the thesis were, (1) Presenting a general procedure for selecting values of the factors (R) and (Cd) in order to use in the seismic design of structures; (2) By using that procedure, proposing preliminary values of the factors (R) and (Cd) for the seismic design of AAC shear wall structures.

The general procedure is based on comparing the predicted ductility and drift demands in AAC structures, as functions of the factors (R) and (Cd), with the ductility and drift capacities of AAC shear walls, observed in quasi-static testing under reversed cyclic loads. Nonlinear numerical simulations are carried out using hysteretic load displacement behavior, based on test results by using suites of natural and synthetic ground motions from different seismically active regions of the United States. Based on a combination of the experimental results of fourteen AAC shear wall specimens and a two-story assemblage, and analytical results on the performance of AAC shear wall structures, The value of the factor (R) was proposed as 3 for flexure-dominated shear-wall structures, and as 1.5 for shear-dominated AAC shear-wall structures. The value of the factor (Cd) was proposed as 3.

3.1.3 Behavior of AAC shear walls with low strength AAC (MSc Thesis), Cancino (2003)

Three isolated full-scale shear walls of low-strength AAC were tested at the Structural Engineering Ferguson Laboratory of the University of Texas at Austin. One specimen was constructed with vertical panels, and the other two, with partially grouted reinforced masonry units. The main objective of this study was to validate previously proposed design provisions for low-strength AAC material. The variables considered in these shear wall specimens were the compressive strength of the material, the flexural reinforcement, and the geometry. Test results indicate good agreement between observed and predicted behavior and validate the previously proposed design provisions. The results support the extension of those design provisions to low strength AAC shear wall structures located in seismic zones.

3.1.4 Evaluation and synthesis of experimental data for AAC (MSc Thesis), Argudo (2003)

In this thesis, available data for key mechanical properties of AAC are evaluated and synthesized. The synthesized data are then used to develop a technical justification for proposed design provisions for ACC elements and structures.

3.1.5 Applicability of mid-rise AAC buildings with reinforced panels in low seismicity areas, Sesigur et al. (2007)

Seismic forces are proportional to the building's own weight. Lighter buildings produce smaller earthquake forces. In addition, the energy absorption capability of structures during earthquakes is proportional to the ductility of the building itself. In earthquake prone areas, it is aimed to build lightweight and ductile buildings. In this respect, this study proposes a method for the lateral load analysis of autoclaved aerated concrete (AAC) buildings with reinforced panels, and the potential applicability of these buildings in mid-rise buildings (3~4 stories) as alternative to conventional reinforced concrete moment frames in low seismicity areas is investigated. For this, a four-story, reinforced concrete building with brick infill walls and a corresponding AAC building with reinforced panels are chosen and designed following the related codes in Turkey. Seismic performances of these buildings are compared. The analysis results show that mid-rise AAC buildings with reinforced panels can be used with confidence in low seismicity areas as an alternative to the conventional reinforced concrete moment framed buildings.

3.1.6 Behavior of AAC floor diaphragms subject to in-plane reverse cyclic loading (MSc Thesis), Storlie (2009)

Half-scale AAC floor diaphragms were constructed using standard construction methods and tested. Two of these specimens were subjected to monotonic loading, while four specimens were subjected to reverse cyclic loading. Specimens were constructed in identical ways except that two monotonically tested specimens had different confining reinforcement in the lower bond beam. In addition, two specimens were constructed with AAC 6.0 blocks with 200 mm thickness while the remaining four specimens were constructed with AAC 4.0 panels with 150 mm thickness. The notations 6.0 and 4.0 describe the strength classes of AAC material. AAC 4.0 strength class has a specified compressive strength of 4 MPa with a nominal dry bulk density of 600 kg/m^3, where 6.0 strength class has a specified compressive strength of 6 MPa with a nominal dry bulk density of 800 kg/m^3 (ACI, 2009). Displacement of the specimen and steel reinforcement strains were measured during testing. The research completed, suggests that floor diaphragms constructed of AAC are capable of withstanding the deformations and forces likely to be imposed on the diaphragm during an earthquake.

3.1.7 Testing of Reinforced AAC Walls under Lateral and Racking Loads, Edgell and Fudge (2011)

Reinforced AAC panels in the UK have been used in past, but these tended to be acting as roof units and to a limited extent floor units, with walling elements occasionally used horizontally as fire walls or thinner vertical elements for partitions. In more recent times, their use in housing has been explored as a series of vertical story height, solid wall elements (each element being 600 mm wide) to form the outer fabric of construction. In this form of construction a thickness of 200 mm will act as the main load-bearing component of the structure as well as making a significant contribution to the overall thermal performance of the building.

The vertical load resistance can be determined using the European Standard EN 12602 (2008). However, little data existed in the UK to enable the design of the walls to resist horizontal lateral load and resistance to racking. This paper reports on some preliminary tests to determine the vertical and horizontal spanning capacity of walls made with large elements. These tests were on story height walls or 1 m high walls each 2.4 m long for the determination of their vertical and horizontal spanning capacity respectively. The walls were built off a slip plane to ensure as little friction at the base as possible and the loads were applied using air bags. The racking tests followed the principles of EN 594 (2011) which applies to timber structures. The modes of failure in the flexural tests were as expected although the results were quite variable. In the racking tests localized failure occurred at the point of applying the racking load in half of the tests although the results were not so low as to be discounted. Further tests are needed to establish the variability to be expected and to eliminate the localized failure in the racking tests.

3.2 Existing Codes Related to AAC

In the US, design of AAC masonry is addressed by Building Code Requirements and Specification for Masonry Structures (MSJC, 2008). This document is referenced by the IBC (ICC, 2012).

AAC masonry is a permitted structural system in ASCE7 (ASCE, 2010) Seismic Design Categories A, B and C. For simple residential structures (detached one- and two-story dwellings), AAC masonry is permitted in any seismic design category.

Design of reinforced AAC panels is addressed by ACI 523.4R-09 (ACI, 2009). According to the general provisions of the IBC (ICC, 2012), any structure can be built with the approval of the building official having jurisdiction. ACI Committee 526 is now working on a mandatory-language version of ACI (2009) (Klingner, 2013).

In Japan, AAC is named as ALC, which stands for Autoclaved Lightweight Concrete. The following standards are prepared by ALC Association in years 2003 and 2004 and these documents were approved by Ministry of Public Works of Japan.: Guide for ALC Structural Design (Japanese ALC Association, 2003), ALC Installation Method Standard (Japanese ALC Association, 2004a), ALC Structural Design Standard and ALC Installation System Standard (Japanese ALC Association, 2004b).

In “ALC Structural Design Standard and ALC Installation System Standard (Japanese ALC Association, 2004b)”, the requirements for AAC load bearing vertical walls in residential buildings are described. This standard limits the story number of this type of buildings to 2 and limits the story height to 3.2 m. The height from ground to the eave of the structure is limited with 7 m

In Europe design of masonry units constructed with AAC can be designed by using Eurocode 6 (CEN-EN, 2005). Eurocode 6 covers the design of reinforced and unreinforced masonry, deals with structural fire design, selection and execution of masonry and covers simplified calculation methods for unreinforced masonry structures.

In Turkey, all masonry structures are designed according to rules specified by the Turkish Seismic Design Code (Ministry of Public Works and Settlement, 2007).

All the documents mentioned above except ACI 523.4R-09 (ACI, 2009), Guide for ALC Structural Design (Japanese ALC Association, 2003), ALC Installation Method Standard (Japanese ALC Association, 2004a), ALC Structural Design Standard and ALC Installation System Standard (Japanese ALC Association, 2004b) deal with masonry structures constructed with AAC blocks.

4 AAC PANEL SCHOOL BUILDING

The school building shown in Figure 4 is further analyzed in this study. General information about the characteristics of 1999 Kocaeli earthquake, geotechnical conditions and general features of the school building are summarized below.

4.1 Kocaeli earthquake (1999) and location of AAC school building

On August 17, 1999 a magnitude M_w 7.4 earthquake struck the Kocaeli and Sakarya provinces in northwestern Turkey. The epicenter of the earthquake was located near Golcuk, a town near Kocaeli province, 110 km away from Istanbul. The August 17, 1999, Kocaeli earthquake produced right-lateral onshore surface slips along an east-west trending zone of right-stepping fault strands over a distance of about 120 km. The slip was typically 2.5 to 4.5 m, reaching a maximum of approximately 5 m at a location about 30 km to the east of the epicenter. August 17, 1999 (M_w 7.4) Kocaeli earthquake is consequence of the motion of a wedge of continental crust, known as the Anatolian Block, being squeezed between the Arabian and the Eurasian plate (Erdik, 2000).

The maximum MSK intensity of the Kocaeli earthquake was X, essentially assigned on the basis of fault rupture and excessive ground deformations. Isoseismal map of the earthquake, prepared by Earthquake Research Division of General Directorate of Turkish Disaster Affairs, can be seen in Figure 9. As it can be seen from Figure 10, the school building examined in this study is located in the intensity X (MSK) zone, which is the highest intensity in the effected region. The coordinates of the school building are 40˚42’45 61’’ North and 29˚56’21’’ East.

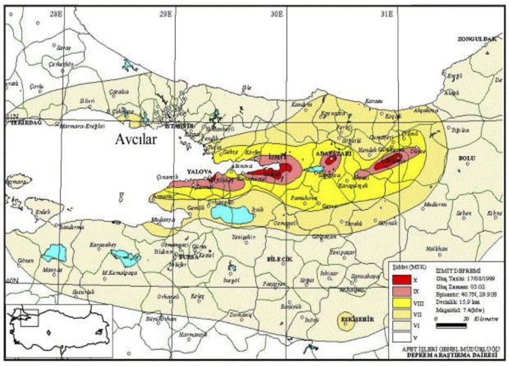

Figure 9 Isoseismal map of Kocaeli earthquake.

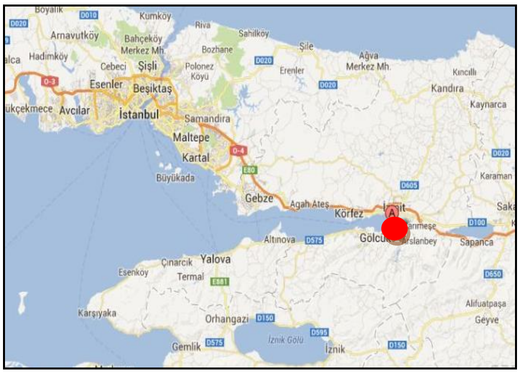

Figure 10. Location of the school building in Golcuk.

4.2 Geotechnical conditions of the Yuvacik region and the school site

The geotechnical report of the Yuvacik region in Kocaeli province, where the AAC Basiskele Anadolu Ogretmen High School building exists, is prepared by Yuvacik Municipality (Kandemir, 2001). The study is limited with the borders of Yuvacik region, which is totally 1524 ha.

The North Anatolian Fault passes through this site. The south of inspected region, which is 917 ha, Pliocene aged, a member of Samanlidag formation, comprise of clay stone, siltstone, sandstone and conglomerate. The northwest of the inspected area, which is 88 ha, comprise of sandy clay and gravel clay. On the north of the inspected area a flood area appears in a region of 1 ha. Alluviums are spread at the northwest of the inspected area as lowlands.

In all these three regions, there is no expectation of ground water impact to foundations. The andesite region is also at the south of the inspected area. The allowable stress at the andesite region is 4 kg/cm^2 and the allowable stress at Pliocene region is 1 kg/cm^2. The region, which consists of alluvium, has an allowable stress of 1.7 kg/cm^2. This region can have probable liquefaction problems.

Another geotechnical investigation report exists for the parcel next to the Basiskele Anadolu Ogretmen High School. This technical report by Zorlu et al. (2012) can provide a very close estimation for the soil conditions beneath the AAC school building.

Inside the inspected area, 2 boreholes with a depth of 15 m had been drilled, 2 pieces of seismic refraction and 2 pieces of electrical resistivity studies had been applied in order to prepare the site condition report. Alluvium, sand, silt and gravel units appear from the drilled boreholes. No groundwater is inspected in the boreholes. Regarding the Atterberg limits test results, the soil units are generally classified as having high and excessive plasticity. The plasticity index value at the inspected area is between 28-38 and the swell percentage is classified as very high and high with a percentage between 20-30 % and >30%.

The results of the seismic refraction tests indicate that, V_p (P wave velocity) is between 888-942 m/sec and V_s (S wave velocity) is between 474-489 m/sec. These values locate the soil class to Z3 class according to the Turkish Seismic Design Code (Ministry of Public Works and Settlement, 2007). The load bearing capacity from the seismic refraction tests is between 8.43-8.75 kg/cm^2 and the allowable bearing value of the site is between 2.02-2.10 kg/cm^2. The bearing capacity calculated from the triaxial test is between 2.32-2.38 kg/cm^2.

4.3 Basiskele Anadolu Ogretmen High School

This school building was reported to have no damage during the 1999 Kocaeli earthquake (Sucuoglu and Alakoc, 2000). In Figure 11, recent view of the school from a visit in June 2013 can be seen. The story plan of ground floor is provided in Figure 12. Internal and external walls of the two story building are built with reinforced AAC load bearing wall panels, whereas the floor and the roof are constructed with AAC reinforced floor and roof panels. The floor panels behave as simply supported beams and the reinforcement inside these panels are designed according to this simply supported beam behavior. The panels have a specified compressive strength of 4 MPa with a nominal dry bulk density of 600 kg/m^3. The amount of reinforcement in these panels were calculated according to DIN 4223 (DIN, 1978). The vertical reinforcements used in the panel joints are reported to have a yield strength of 420 MPa.

Figure 11. Front facade view of the examined school building.

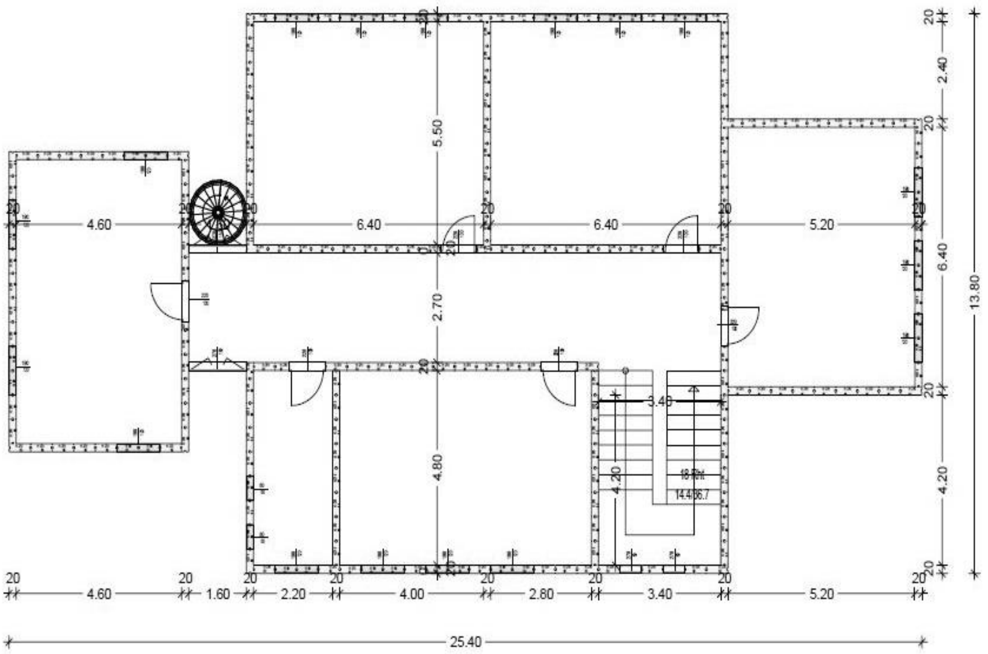

Figure 12. Ground floor layout for the school building.

5 FINITE ELEMENT ANALYSIS OF THE SCHOOL BUILDING

Abaqus finite element analysis software (Simulia, D. C. S., 2011) was used to analyze the AAC school building and obtain the stresses and displacements that the building might have experienced during the 1999 Kocaeli earthquake. The three dimensional finite element model was developed by following a micro-level approach where each wall panel was separated from the other members via an interface definition (Figure 13). Accordingly, as also done in the construction practice, the grout, which included a 12 mm diameter bar, was placed in between the panels (Figure 14). The reinforcements were embedded into the grout elements between the wall panels and extended into the foundation and bond beam. A friction type interface property was defined between the panel and grout elements. The floor panels were resting on the wall panels (Figure 15), again, with a friction type of interface definition, in addition to the vertical bars extending from the grouts. Since the target of this study is to have an idea on the level of earthquake-induced stresses and drifts and since no significant inelastic deformations are expected, the behavior of the building components was assumed to be linear elastic. The properties of each material defined in the model are shown in Table 2.

Table 2 – Properties of materials defined in the finite element model

	AAC	Grout	Concrete	Steel
Density (kg/m^3)	840	2000	2400	7850
Elastic Modulus (MPa)	2250	6900	28000	200000
Poisson Ratio	0.20	0.20	0.20	0.30

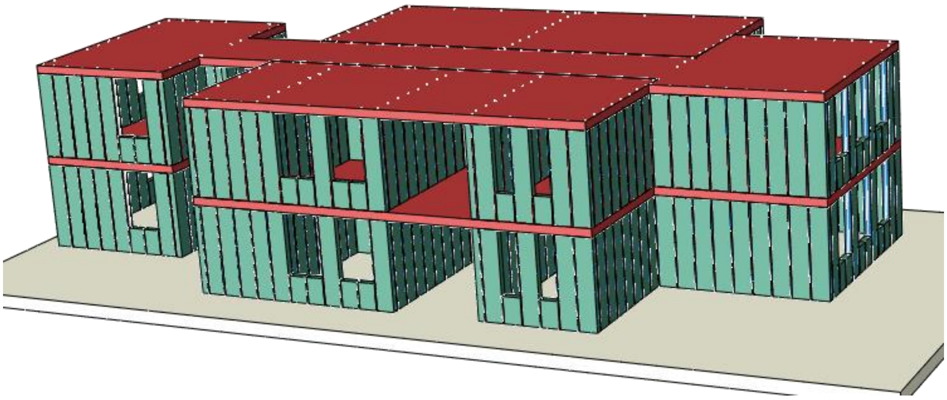

Figure 13. 3D View of school model adapted in Abaqus.

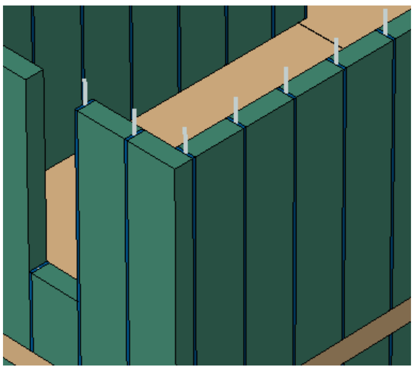

Figure 14. Vertical wall connections.

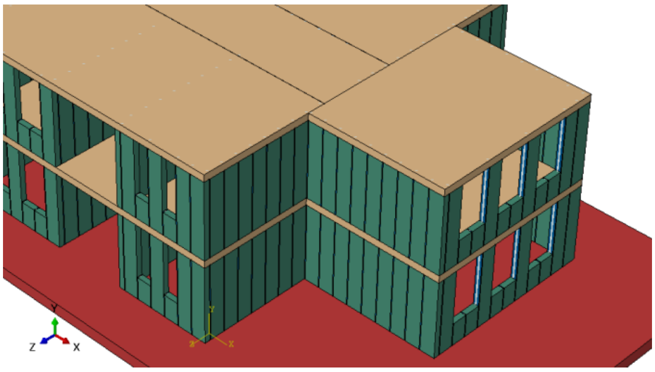

Figure 15. Slabs resting on wall panels.

The earthquake load was applied as acceleration in the x-direction. The maximum acceleration acted in the analysis was 0.46g, which was obtained by using the seismological characteristics of the 1999 Kocaeli earthquake and the attenuation relationship proposed by Boore et al. (1997).

6 ANALYSIS RESULTS

The lateral displacements obtained from the finite element analysis point to a maximum drift ratio in the order of 0.005 (Figure 16), which is less than the 0.02 drift ratio limit given by the Turkish Seismic Design Code for life safety performance level. This amount of drift can be commented as unlikely to cause a significant damage, since it is even less than the drift level given by the Turkish Seismic Design Code (Ministry of Public Works and Settlement, 2007) for immediate occupancy performance level (minimum damage). This finding is in agreement with the observations made on site.

Distribution of compressive and maximum principal stresses can be seen in Figures 17 and 18, respectively. Due to the overturning actions, the compressive and tensile stresses are mainly concentrated at the upper and lower corners of the wall panels, which were restrained, only by the tangent (friction) and normal forces at the edges. The maximum compressive stresses under vertical and earthquake loads are about 2.5 MPa, while the average stresses at mid-height of the panels are in the order of 0.5 MPa. It should be noted that these compressive stress values are less than the 4.0 MPa compressive strength of the AAC material.

Similarly, the maximum principal stresses are also observed and accumulated around the panel corners with a maximum value of 0.7 MPa and panel mid-height value of 0.04 MPa. In order to make a comparison between seismic demand and capacity in terms of tensile stresses, the tensile strength of the panels are calculated as 0.4 MPa by using the equation provided by the Building Code Requirements and Specification for Masonry Structures (MSJC, 2008), where f_t and f_{AAC} are the splitting tensile and the specified compressive strengths of the AAC material.

$$f_t = 0.2\sqrt{f_{AAC}} \quad \text{(MPa)} \tag{1}$$

When compared with the calculated tensile strength, the panel mid-height tensile stresses are much less than the limit for cracking. However, the maximum principal stresses at the corners of the panels exceed the value calculated. Consequently, considering the reinforcements inside the panels, narrow cracks or micro-cracks can be expected around the wall panel corners. The authors could not observe any systematical visible cracks on site. This may be attributed to a) occurrence of only micro-cracks, b) the safety margin included in Equation (1), c) more distributed and less localized nature of actual stresses with respect to finite element analysis results, or d) painting of wall panels which prevent the cracks to be seen.

Finally, according to the finite element analysis, the average tensile stresses of the vertical bars between the wall panels reach to approximately 100 MPa. None of these joint reinforcements reach the 420 MPa tensile strength, which means that all reinforcements remain in the elastic range.

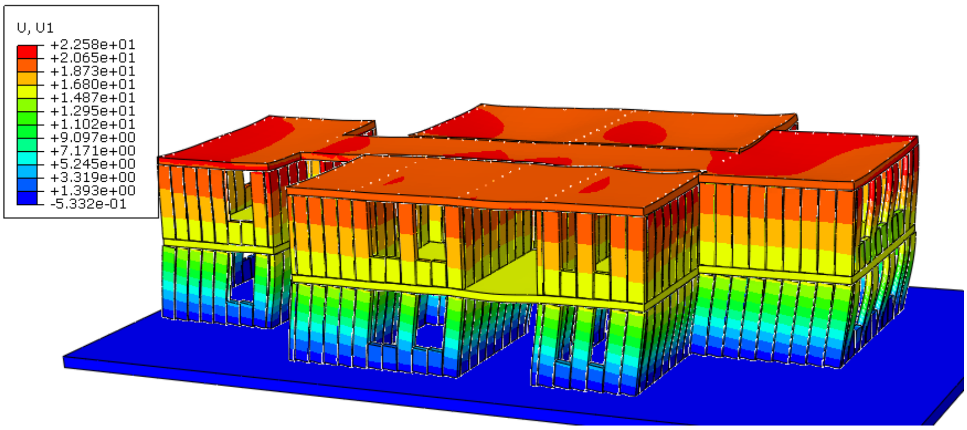

Figure 16. Deformed shape and lateral displacements. [mm]

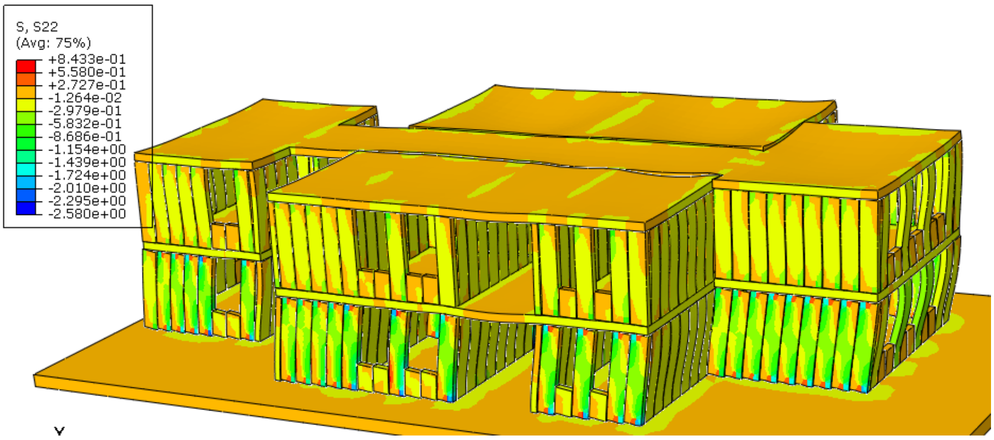

Figure 17. Compressive stresses obtained for the wall panels. [MPa]

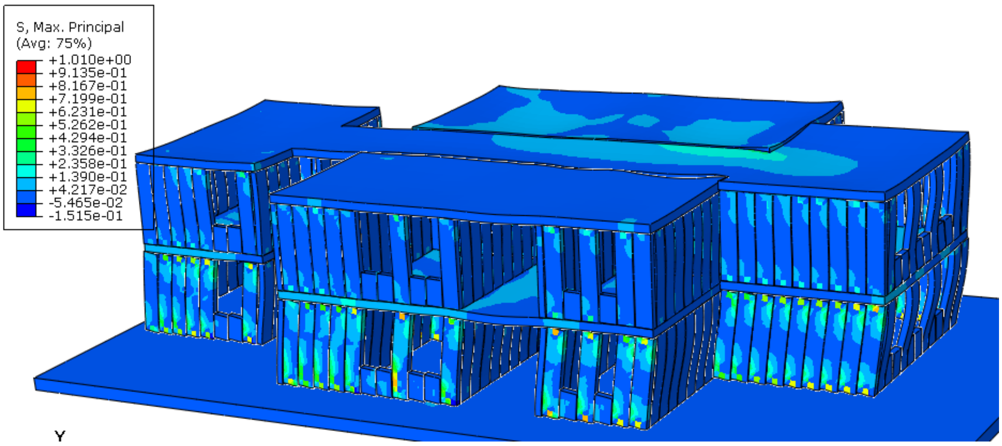

Figure 18. Maximum principal stresses obtained for the wall panels. [MPa]

7 CONCLUSIONS

In this study, after an overview of AAC panel construction technique, an existing AAC panel school building that has experienced the destructive 1999 Kocaeli and Duzce earthquakes is investigated and post-earthquake site observations are verified with the finite element analysis results. Accordingly:

- The school has been inspected and no damage has visually been observed.

- Compressive stresses that occur on the wall panels are well below the compressive strength of the AAC material.

- Tensile stresses on the panels are less than the tensile strength of the panel. However, the tensile stresses at the upper and lower corners of the panels slightly exceed the strength. Therefore, micro-cracks may have occurred at these regions. No visible crack was observed on-site. This indicates that no significant degradation in seismic capacity is expected.

- The reinforcements in the joints of the panels remain in the elastic range.

- As a whole, the analysis verifies the visual observations where no damage has been reported.

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