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Investigation of blast-induced ground vibration effects on rural buildings

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Abstract. In this paper, blast-induced vibration effects on buildings located in rural areas were investigated. Damages to reinforced concrete, adobe and masonry buildings were evaluated in Çatakköprü and Susuz villages in Silvan district of Diyarbakır, Turkey. Blasting of stiff rocks to construct highway at vicinity of the villages damaged the buildings seriously. The most important reason of the damages is lack of engineering services and improper constructed buildings according to the current building design codes. Also, it is determined that, inappropriate blast method and soft soil class increased the damages to the buildings. The study focuses on four points: Blast effect on buildings, soil conditions in villages, building damages and evaluation of damage reasons according to the current Turkish Earthquake Code (TEC).

Keywords: structural damages; blast-induced ground vibration effect; rural buildings

1. Introduction

Mining can be defined as the extraction of valuable minerals from the earth crust and in general this extraction involves blasting, which is more economic than machinery excavation for almost all minerals except only a few soft ones such as talc, gypsum, peat and anhydride. Thus, blasting is one of the most important stages of whole mining operation and main purpose of mine blasting is crushing rocks in order to obtain desired fragmentation. But, in some cases blasting operations may have some unexpected consequences such as flying rocks, dust, air shock, and ground vibration.

Blast-induced ground vibrations which are a serious issue for mining industries have been investigated by researchers (Hoshino *et al.* 2000, Chen and Huang 2001, Tripath and Gupta 2002, Aldas and Ecevitoğlu 2008). Various approaches have been proposed by these researches in order to reduce the blast vibrations and their effects. According to these researches the most important parameters to control blast vibrations and their effects are considered as introducing delay-times between the blast-holes, reducing in the number of the blast-holes sharing the same delay-time and distance from blasting point.

Although, mining professionals and engineers try to control blast induced vibrations by using

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these parameters, unfortunately, still too many buildings located near quarry areas are badly effected by vibrations. Numbers of quarries producing aggregate in small scale have increased in last decade in Turkey where this study was performed according to increasing highway and mass housing projects which need quarry related raw materials. These small scale quarries were located near the highways or cities which caused vibration-related complains and lawsuits.

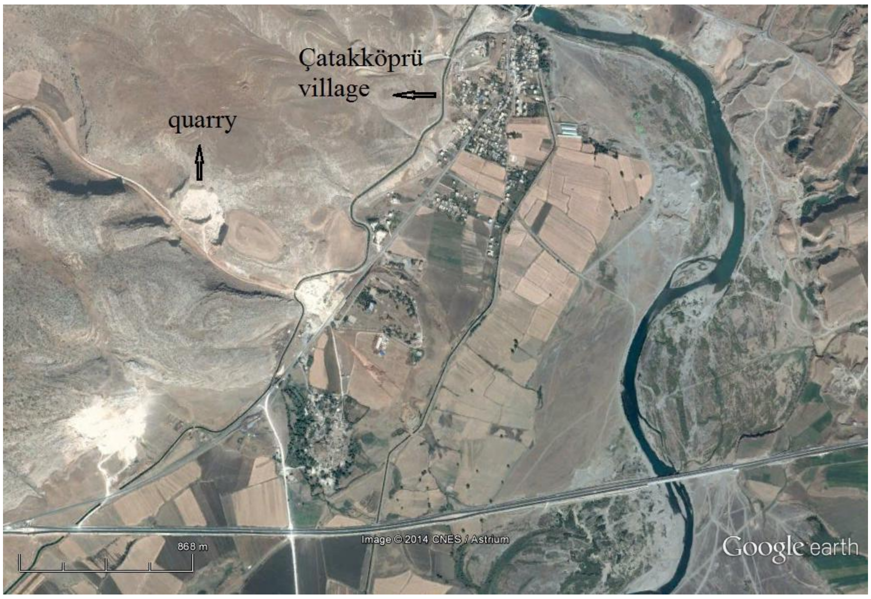
The ground vibration arose from the blast effect damaged the buildings located in Çatakköprü and Susuz villages. In this study, damages to buildings and structural deficiencies were evaluated. Many researchers studied the damages to buildings (adobe, masonry and reinforced concrete buildings) after earthquakes and blast-effects.

Doğangün (2004) studied the damages to reinforced concrete buildings after the 2003 Bingöl, Turkey earthquake. Bayraktar *et al.* (2007) assessed the seismic response of masonry buildings after the 2004 Aşkale, Erzurum earthquakes in Turkey. Zhao *et al.* (2009) studied the damages to structures after the 2008 Wenchuan earthquake in China. Bayraktar *et al.* (2010) evaluated the blast effects on reinforced concrete building behaviors. Maqsood and Schwarz (2010) assessed the failures of rural buildings after the 2008 Baluchistan, Pakistan earthquake. Augenti and Parisi (2010) assessed the performance of unreinforced masonry and reinforced concrete structures after the 2009 L'Aquila, Italy earthquake. Celep *et al.* (2011) carried out a study about the damages to reinforced concrete, masonry and adobe structures after the 2010 Kovancılar and Palu (Elazığ), Turkey earthquakes. Braga *et al.* (2011) evaluated the seismic behavior of non-structural elements of reinforced concrete buildings after 2009 L'Aquila, Italy earthquake. Calayır *et al.* (2012) carried out a study about failures of various structures during the 2010 Kovancılar, Elazığ earthquake occurred in Turkey. Sayın *et al.* (2013) assessed the damages to adobe and masonry buildings after the 2011 Maden (Elazığ), Turkey earthquake. Bayraktar *et al.* (2013) studied the seismic behavior and damages to reinforced concrete buildings after the 2011 Van, Turkey earthquakes. Yön *et al.* (2013) investigated the performance of buildings during the 2011 Simav (Kütahya), Turkey earthquake. Ateş *et al.* (2013) assessed the failures of reinforced concrete buildings after the 2011 Van, Turkey earthquakes. Parisi and Augenti (2013) investigated the earthquake damages to cultural heritage constructions and simplified assessment of artworks. Sayın *et al.* (2014) studied the damages to masonry and adobe buildings after 2011 Van, Turkey earthquakes. Rafi *et al.* (2015) studied reinforced concrete, masonry and adobe structures after 2013 Iran earthquake.

In this paper, blast-induced ground vibration effects on the buildings were investigated and reasons of failures were evaluated based on the building types classified for 67 buildings which are located close to two various quarries (Table 1). The locations of villages and quarries and distances between them are shown in Fig. 1(a)-(b).

Table 1 Damage levels of buildings in Çatakköprü and Susuz villages

<table>
<tr><th rowspan="4">Damage Level</th><th colspan="4">Village</th><th rowspan="4">Total</th></tr>
<tr><th colspan="2">Çatakköprü</th><th colspan="2">Susuz</th></tr>
<tr><th colspan="4">Building type</th></tr>
<tr><th>Adobe and Masonry</th><th>Reinforced Concrete</th><th>Adobe and Masonry</th><th>Reinforced Concrete</th></tr>
<tr><td>Heavy</td><td>3</td><td>-</td><td>12</td><td>-</td><td>15</td></tr>
<tr><td>Moderate</td><td>25</td><td>6</td><td>11</td><td>-</td><td>42</td></tr>
<tr><td>Light</td><td>3</td><td>7</td><td>-</td><td>-</td><td>10</td></tr>
<tr><td>Total</td><td>31</td><td>13</td><td>23</td><td>-</td><td>67</td></tr>
</table>



(a)

(b)

Fig. 1 (a-b) Location of quarries and villages

2. Properties of quarries, buildings and, soil and seismic characteristics

2.1 The quarries and blasting applications

According to the observations, most of damages on the buildings in the villages originated from rock blasting applications of two different quarries close to the villages. The quarries were operated by different companies to produce aggregate in different size for the construction of highway which goes through the village. The distance between quarries and village are about 1000-2000m. The companies selected the quarry sites close to the highway in order to reduce their aggregate transportation costs, but this selection on the other hand, reduced the distance between quarries and villages imposing the most important cause of the negative effects on the buildings.

These quarries were relatively small scale quarries and they were operated by small scale construction companies which worked as sub-contractor for the highway construction works. The companies did not employ professionals with required mining and blasting experience. Thus, unfortunately, any stable bench with proper height or working slope or suitable faces with enough slope angles were not observed during the quarry visits. Additionally these quarries were not actually operating quarries during the study and, all mining and production activities had been finished for more than one year before the study. That is, all observations and inspections were carried out when the quarries were not actually working. This may have affected the condition of benches and slope stabilities badly but still so many negations were observed such as one too high face (40 m) which was semi-abandoned, with no proper bench or angle of slope, or stable bench, with no drilling traces on face, no inner roads. Both of the quarries had the same conditions.

On the other hand, the explosive consumption reports which included 58 different blasting applications in quarries were also investigated. According to these official consumption reports all of the companies used dynamite as primer and Ammonium Nitrate + Fuel Oil (ANFO) as main and explosives with non-electric detonator systems. It seems that 267,976 kg ANFO, 8277 kg dynamite were used for all these 58 blasting operations. This means that about 4500 kg ANFO and 150 kg dynamite were used in average per blasting operation. The ANFO/dynamite ratio is calculated as 32.

The most important parameters on rock blasting induced ground vibration are distance and amount of explosives per delay values (Özer 2008). Any evidence about the use of special units by the companies to make delay time which control the ground vibration was not determined. It can be said that the blasting operations were not applied carefully in these quarries and these two parameters were not taken into account during the blasting operations based on the observations on quarries and explosive consumption reports. Therefore these careless blasting operations caused the most part of the damages on these buildings.

2.2 Soil and seismic characteristics

Silvan is located in the first degree seismic zone while Diyarbakır city center is located in the second degree seismic zone according to Turkey Seismic zone map which is divided into five seismic zones. Diyarbakır seismic zone map is shown in Fig. 2. In the TEC, seismic zone degree is indicated from Zone 1 to Zone 5. Here, 1 and 5 refers the most risky zone and the no risk zone, respectively.

Silvan geological formation is the only unit in Susuz village and all buildings are located over the formation. In Çatakköprü area, there are mainly two types of formation which are called as Silvan formation and Şelmo formation. Besides, in some small valley, the alluviums are also observed overlying the Şelmo formation. Silvan formation has beige colored yellow limestone, reddish detrital limestone and shows different lithological features in the vertical direction such as dolomitic limestone conglomerate bluish limestone, chalky limestone units. The quarries are located on Silvan formation and some nearby buildings are located over this formation. Şelmo formation is composed of the alternations of conglomerate (varying in colors, weakly cemented

Fig. 2 Diyarbakır seismic zone map

with carbonate, containing gypsum lenses and interbeds), sandstones (varying in colors, moderate-thin bedded, weak-moderate cemented, in somewhere cross-bedded and laminated), shale (light gray colored) and marn (yellowish gray, brown, light gray in colors). The alluvium is composed up of loose uncemented silt, sands, gravels and blocks deposited in the streams and valleys. Although the alluvium unit is at relatively farther distance to the quarry, it is known that the frequencies decrease within the soft soil and can approach the order of harmful frequencies for buildings. It is thought that the damages observed at some relatively distant buildings located above the alluvium unit arose from the reduction of frequency in this unit.

2.3 Buildings

There are reinforced concrete, masonry and adobe buildings among the buildings stock of the villages, which were damaged due to the blast-induced ground vibration effect, 67 buildings were investigated for the field observation. In the villages there are mainly one and two storey masonry and adobe buildings. Also there are three and four storey reinforced concrete buildings in the villages. The masonry and adobe buildings were constructed by using local materials. Hand-cast concrete was used for reinforced concrete buildings. Lack of homogeneity in the concrete mixings prevented the required, strength development in the concrete. It was determined that, investigated buildings did not have engineering service including design and construction.

3. Building damages

In this study, two villages (Çatakköprü and Susuz are located in Silvan in Diyarbakır, Turkey) were visited after blasting. 67 buildings were investigated in these villages. Determined damage levels corresponding to buildings type are given in Table 1. Damages to buildings (masonry, adobe and reinforced concrete) which occurred due to blast-induced ground vibration effect in the villages are presented.

Fig. 3 Flexural failure and diagonal crack at various adobe buildings

3.1 Damages to adobe buildings

Adobe buildings are preferred in the rural area of Turkey because of, economic reasons and some other advantages (thermal properties and simplicity of construction techniques). Ages of these buildings vary between a range of 10 and 40 years. As a result of increase in household population, new rooms were added to existing buildings by residents. Therefore the buildings were turned into irregular forms. Also, the adobe material is weaker against water and mechanical effects than other structural materials (such as brick and stone). For this reason the buildings were affected from the environmental conditions. This situation caused lost their strength capabilities against various loading conditions such as seismic and blast loading. The other deficiency of the investigated buildings was heavy earthen roof. These roofs become heavier in time, due to spreading new clay layers after precipitations. This heavy roof affects structural performance negatively, during vibration. For this reason, TEC does not allow this type of roof application in the first and the second seismic zones for adobe buildings. The other important deficiencies for the observed buildings were lack of the tie beam which provides continuity in plane of wall and inappropriate connection between walls and roof. According to TEC, timber tie beams should be made in adobe walls and the beams must consist of two elements with sections of 100 mm×100 mm. Different adobe buildings damaged by blast-induced ground vibration are illustrated in Figs. 3-7.

Fig. 4 Damages at corner walls of adobe buildings

Fig. 5 Out of plane mechanism arose from blast-induced vibration for various adobe buildings

Low resistance of the adobe materials and existence of heavy earthen roofs caused flexural failure, in which vertical compression cracks occurred due to cracking of adobe material. Also, these reasons caused increasing in shear stress effects and diagonal cracks (Fig. 3).

One of the major reasons of failures is the deficiencies of the tie beams at walls and inadequate connection at corner of the building walls. This type of wrong application caused serious damages. This type of damage is shown in Fig. 4.

Inappropriate connection detailing between wall and roof and between wall and wall, lack of tie beams and existence of heavy earthen roofs caused out-of plane failure mechanism in some adobe

Fig. 6 Corner damages at various brick masonry building

Fig. 7 Sliding failures in different brick masonry buildings

buildings. These damages are illustrated in Fig. 5 for different buildings.

3.2 Damages to masonry buildings

Masonry buildings with stone and brick walls are common in the affected villages. Rubble stones obtained from vicinity were used in construction of the residences. However, cement mortar which did not have adequate quality was used as binder material in most of buildings. This mortar did not provide sufficient adherence between bricks and stone materials. Severe damages occurred at various parts of the buildings because of low strength material, poor construction quality, poor detailing of the buildings and lack of horizontal tie beams and tie columns.

Brick masonry buildings in the affected villages were generally unreinforced and most of them did not have sufficient and appropriate horizontal tie beams and tie columns. Especially, lack of these beams at the corners of walls led to severe damages. Fig. 6 shows damages to brick masonry arising from blast effect. For these types of buildings, the TEC indicates that horizontal tie beams should be built monolithically with the reinforced concrete slabs. In addition to this, height of horizontal tie beams should not be less than 200 mm and their width should be equal to the width of wall. Also, the reinforced concrete tie columns should be constructed in building height on the corners of buildings, along the vertical intersections of the load-bearing walls and on both sides of the door and window openings. Also, dimensions of the tie columns should be equal to thicknesses of corner walls.

The blast effect caused the sliding failure in some buildings. This failure caused horizontal cracks at the longitudinal bed joints divided in two segments which slide along the fracture surface. Fig. 7 shows sliding failure in different brick and stone masonry buildings.

Fig. 8 Diagonal stepped cracks in various brick and stone masonry buildings

Fig. 9 Diagonal shear cracks in different brick and stone masonry buildings

Fig. 9 Continued

Stepped cracks from the bed to head joints or head to bed were seen in the affected region. When lateral displacement is low, the failure occurs as flexural stepped crack form. However, for higher displacements, the shear strength of the bed joints is overcome and diagonal stepped failure occurs along head and bed joints at the wall corners or edge of windows and doors. Fig. 8 shows diagonal stepped cracks in various brick and stone masonry buildings in the affected villages.

Shear diagonal failures are commonly seen at the edge of openings and in plane of walls at masonry buildings. Inappropriate window and door openings or their locations in wall enhance shear stresses under lateral load effects. Thus, stiffness of the wall decreases and diagonal crack occurs at the edges of openings. To prevent this type of damages, TEC requires using of horizontal tie beams and tie columns. Fig. 9 shows diagonal shear cracks in different brick and stone masonry buildings in the villages.

In some masonry buildings some light damages were determined arising from deficiencies of electrical wiring. Diagonal or vertical cracks occurred along the installation cables. Fig. 10 shows these types of failures.

It was observed that, especially stone masonry buildings suffered from flexural failure in which vertical compression cracks occurred in plane of wall because of yielding of masonry material. However, this mechanism is complex: That is, when lateral load enhances, shear failures that are more obvious than the flexural cracks occur in plane of masonry wall. This type of damage is shown in Fig. 11.

Fig. 10 Diagonal and vertical cracks arising from deficiencies electrical wirings

3.3 Damages to reinforced concrete buildings

In Turkey, non-bearing infill walls of reinforced concrete buildings have been constructed by using unreinforced brick masonry and cement mortar. Infill walls contribute to structural performance of buildings by increasing rigidity and, by limiting to the storey displacement. But, unreinforced brick masonry walls have lower deformation capacities than the reinforced concrete members. There are not any significant damages at structural element of the reinforced concrete buildings located in the affected villages. However, severe failures were observed at non-structural elements of these buildings. In the affected area, cracks occurred between column and beam and surrounding non-bearing infill walls. Crack widths at these walls were measured between the range of 2 mm and 10 mm. This type of damages can be considered as light damage. Fig. 12 shows this kind of damages at the buildings in the villages.

Dimensions of plan of the upper storeys of the buildings were changed because of need for larger usage area in the houses in the villages in Turkey. The increased area of upper storey of the building behaves as cantilever beam bearing heavy wall load at the unsupported end. The cantilever length may reach generally to 1-1.5 m. This wrong application causes additional weight and irregularity. Additional stresses and torsional moment takes place due to eccentricity. Fig. 13 shows this kind of damage in the affected area.

Fig. 11 Flexural cracks in various masonry buildings

Shear damages are seen commonly at non-bearing infill walls which are constructed between frames. In the case of a lateral force such as earthquake, blast etc. cracks which originate from the corners of openings occur in plane of these walls since unreinforced masonry walls have lower deformation capacities than the reinforced concrete structural elements.

These kinds of damages which occurred due to blast effect were observed in reinforced concrete buildings in the villages. Fig. 14 shows in plane failures in various reinforced concrete buildings.

Fig. 12 Damages to infill walls in various reinforced concrete buildings

Fig. 13 Damage arose from heavy cantilever in the reinforced concrete building

Fig. 14 In plane failures in various reinforced concrete buildings

4. Conclusions

In this study, effects of blast-induced ground vibration on rural buildings were investigated. Damages to reinforced concrete, masonry and adobe buildings were evaluated in Çatakköprü and Susuz villages in Silvan district of Diyarbakır, Turkey. Blast effect which occurred by blasting stiff rocks to construct highway at vicinity of the villages damaged the adobe and masonry buildings and infill walls of some of reinforced concrete buildings seriously. Based on our field observations and investigations, causes of damages were classified into three main groups as the blast operations, the soil conditions and the structural deficiencies. Subgroups for these causes were determined as follows:

In terms of blast operation;

• Failures in the use of special units to make delay time which control the ground vibration by the companies,

• Not applying the blasting operations carefully in these quarries,

• Not taking into account two parameters (delay time and applied carefully) during to blasting operations,

In terms of soil conditions;

• The reason for damages observed at some relatively distant buildings located above the alluvium unit are thought to arise from the reduction of frequency in this unit.

In terms of structural deficiencies;

• Using of low strength and poor quality local materials,

• Lack of engineering services and improper construction methods according to the Turkish Earthquake Code.

Consequently, it is determined that a code for blast operations is needed in conformity with international codes. However, soil conditions should be considered when buildings are constructed. Also, it is seen that if minimum requirements of Turkish Earthquake Code were put into practice in a proper way, especially many masonry and adobe buildings would not be damaged heavily. To avoid or to minimize the damages in the buildings located in rural regions, the buildings should be designed and constructed in conformity with the requirements of codes and constructed relying upon the engineering services and requirements for both design and construction phases.

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