Effect of Tunnel Blasting Operation on the Surface Penstock Pipe

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Abstract This paper presents the investigation of the effect of ground vibration components induced blasting events in Ordu-Mesudiye Highway Topçam tunnel on the penstock pipe (PP) having 35-400 slopping of Topçam Hydro-Electrical Power Plant (HEPP). Until the tunnel excavation passed under the PP of HEPP, a total of 37 shots (26 upper halves and 11 lower half) were monitored and the ground vibration components (peak particle velocity, acceleration, displacement and frequency) were measured in two different stations. It was also examined whether the concrete platform under this PP had a crack, damage or etc. As a result of these workings, a maximum of 220 kg total charge was used and the charge weight per delay varied between 1.0-18 kg in the shots. The distance of shots to measurement station was between 78.04 and 170.16 m. 6 PPVs, 11 accelerations and a displacement value exceeded the threshold values determined. However, the vibration values were taken under control with changing the blasting parameters and it was provided that the tunnel excavation passed under the PP of Topçam HEPP.

1. Introduction
Drilling and blasting method is widely used for hard rock excavation activities in various engineering purposes such as mining, quarrying and tunnelling [1, 2]. In tunnel blasting, unpleasant ground vibrations and also inflict structural damage can occur if the magnitude of the explosion is not kept at minimum level. It is necessary for warranty to lower vibration levels which is the best specified by peak particle velocity (PPV), [3]. Groundwater pollution, interference with hydrogeology conditions, destruction of forests and buildings, noise pollution, vibrations caused by the blasting, dust emission, fly rocks at the outfall of the tunnel and subsidence are the most important environmental impacts of tunnelling [4]. Prediction of ground vibration components has a paramount importance for minimizing the environmental issues [5]. Blasting in horizontal tunnels aims at some objectives such as achieving longer pulls, reducing over-break and rock damage and optimizing drilling and blasting cost [6]. The environmental impacts of blasting can be minimized by modifying the blast design that affects the explosive/blasting parameters such as PPV, acceleration, displacement and frequency.

2. Geology of the Study
Study area is located in Topçam town in Mesudiye, Ordu. Kaçkar granitoids (upper cretaceous) which composed of syenite and hornblende syenite is widely outcropped in the study area. While feldspar and hornblende are mostly observed, biotite and quartz are slightly seen in the macroscopic examination of
the syenite rock. The pink colouring of syenite is due to the presence of alkali feldspar and the brown 
colour of the hornblende syenite because of the colour of the hornblende. The syenite cropped out in the 
study area and surroundings which generally present weathered and block in matrix structures. The talus 
deposits include rock/syenite detritus that vary silt, sand and gravel; upper part of the road cuts silty 
sand and lower part of the road cuts is sand, gravel and large and small syenite blocks.

3. Field Measurements and Methods
In this study, the ground vibration parameters induced blasting operation in Ordu-Mesudiye Highway 
Topçam T1 tunnel measured and investigated the effect on penstock pipe of Topçam Hydro-Electrical 
Power Plant (HEPP). There is a penstock pipe having 35-40 degrees of hydroelectric power plant in 
tunnel route (Figure 1). It was also examined whether the concrete platform under this penstock pipe 
had a crack, damage or etc. in this study.

Figure 1. The penstock pipe of Topçam hydroelectric power plant (up) and T1 tunnel input (down)

3.1. Excavation and blasting operation
Drilling and blasting techniques were selected as the excavation method at Topçam T1 tunnel. The 
excavation operation at tunnel is divided into upper half and lower half excavation. The V-cut method 
is used at upper half excavation. Drilling hole length was between 1.5-2.0 m and the spacing value was 
about 1 m (Figure 2a). The tunnel width and height between bottom and top of tunnel were 
approximately 10.5 and 6.0 m, respectively. The lower half was excavated as left and right lower half. 
The holes were drilled horizontally and parallel such as upper half excavation. Drilling hole length was 
between 3-4 m and the spacing value varied between 1.0 and 1.2 m (Figure 2c). During the excavation 
of T1 tunnel, 26 upper half and 11 lower half shots were practiced. 
During the shots done at tunnel, Solar Superpower 90 (38 mm/500 g) gelignite dynamite as explosive 
and delayed nonel detonators and detonating cords for ignition system were used. The detonator number 
and delayed time of delayed nonel detonators used in blasting operations were given in Table 1.

3.2. Measurement of vibration components
At the beginning of the study, drilling and blasting parameters (drilling and blasting design, explosive 
charge etc.) suggested by components of worksite were practiced and vibration values were measured. 
When the ground vibration components values (peak particle velocity, displacement and acceleration) 
exceeded the limit value or measured the close value, the new blasting design was applied to reduce the 
vibration values.
**Figure 2.** The plan views of upper half (a) and lower half (c) and the lateral section of them (b)

**Table 1.** Delay nonel detonators and its delay number and time used in blasting operations

| Delay number | Delay time [ms] | Delay number | Delay time [ms] |
|--------------|-----------------|--------------|-----------------|
| 1            | 100             | 14           | 1800            |
| 2            | 200             | 15           | 2000            |
| 3            | 300             | 16           | 2500            |
| 4            | 400             | 17           | 3000            |
| 5            | 500             | 18           | 3500            |
| 6            | 600             | 19           | 4000            |
| 7            | 700             | 20           | 4500            |
| 8            | 800             | 21           | 5000            |
| 9            | 900             | 22           | 5500            |
| 10           | 1000            | 23           | 6000            |
| 11           | 1200            | 24           | 6500            |
| 12           | 1400            | 25           | 7000            |
| 13           | 1600            | 26           | 7500            |

In the vibration measurements, the Central Mining Research Institute (CMRI) [7] and Australian (AS 2187) [8] standards were used. According to these standards, the peak particle velocity value is 2.0 mm/s for the critical and weak structures and structures having a specific value (Tables 2-3).

**Table 2.** The threshold value of PPV allowed by the Central Mining Research Institute [7].

| Structural specification                                                                 | Threshold value of PPV (mm/s) |
|-----------------------------------------------------------------------------------------|------------------------------|
| Objects of historical importance, very sensitive structures, more than 50 years old,  | ≤ 24 Hz                      |
| structures with poor state of condition and unrepaired                                   | 2                            |
| Domestic houses, dry wall interior, structures with plaster, bridges                    | 5                            |
| Industrial buildings, steel or reinforced concrete structures                             | 12.5                         |

**Table 3.** The threshold value of PPV allowed by Australian standards [8]

| Structural specification                                           | Threshold value of PPV (mm/s) |
|-------------------------------------------------------------------|-------------------------------|
| Historical buildings, monuments, structures of special value      | 2                             |
| Resistant houses, built in low-quality residential and commercial | 10                            |
| buildings                                                         |                               |
| Buildings                                                       |                               |
| Built in high quality commercial and industrial buildings, Industrial | 25                            |
| buildings, steel or reinforced concrete structures                |                               |
In addition, the displacement threshold value has to not exceed the 0.1 mm to not damnify on the critical and weak structures and structures having a specific value based on formation characteristics in the blasting region (Table 4). On the other hand, it is indicated that the acceleration value has to be lower than 0.1 g to not occur any landslide or the slide risk during the mining operations and reliable mining applications.

During the excavation of T1 tunnel, 26 upper half and 11 lower half shots investigated and to determine the potential effect on penstock pipe of each shot, the vibration components (peak particle velocity, peak displacement, peak acceleration and frequency values) were measured on two different stations as belt concrete wall of water reservoir (Figure 3a) and concrete platform nearby middle belt concrete (Figure 3b) using threshold values of components stated above. In these measurements, two seismographs (Instantel Minimate Plus) were used (Figure 3).

**Table 4.** The threshold value of displacement allowed [9]

| Structural specification                                      | Threshold value of displacement (mm) |
|--------------------------------------------------------------|--------------------------------------|
| Spiritual and high-value structures, Mine shafts, Weak conditional houses, Historical buildings (artifacts) | 0.10                                 |
| Houses very close together                                   | 0.20                                 |
| Home alone                                                   | 0.40                                 |
| Steel construction structures                                | 0.76                                 |

![Figure 3. The views of measurement stations; belt concrete wall of water reservoir (a) and concrete platform nearby middle belt concrete (b).](image)

**Figure 3.** The views of measurement stations; belt concrete wall of water reservoir (a) and concrete platform nearby middle belt concrete (b).

**4. Results of the Measurement**

In this study, the design parameters (number of hole, total amount of explosive per delay etc.) of blasting operations and results of vibration measurement (peak particle velocity, acceleration, peak displacement, frequency etc.) accompanied were given in Table 5. It shows that 26 upper half and 11 lower half shots were investigated.

The blasting in tunnel was applied in B3, B2 and B1 rock formations according to NATM. The shots usually were done in B3 and B2 rock classes. The last shot (37th shot) was only done in B1 rock class.
As stated on Table 5, it was passed from B3 to B2 at 35+275.95 and from B2 to B1 at 35+375.00. A total of 220 kg explosive and a maximum of 18 kg charge per delay were used in the last upper half shot (B1 rock formation).

When 26 upper and 11 lower half shots were analyzed in Table 5, the total charge weight is less than 50 kg and charge weight per delay ranged from 1.0 to 5.5 kg in 15 upper half shots. In the rest of upper half shots, the total charge weight and charge weight per delay varied between 50-220 kg and 3.0-18 kg, respectively. Furthermore, a maximum charge of 40 kg and a maximum of 9.0 kg charge per delay were used in lower half shots. The distance of shots to measurement stations was between 78.04 and 170.16 m. Peak particle velocity (PPV) and frequency values induced blasting’s were evaluated according to regulation of the evaluation and management of environmental noise and the values were showed in Figure 4. When the Figure 4 was analyzed, it was seen that PPV values depend on frequency values measured are considerably low according to standards of Turkey. However, the standards Turkey are suitable for ground vibrations induced blasting in mine and quarries. In this study, the penstock pipe has a 35-400 slope angle. Therefore, the specific values given in Part 3.2 were used the landslide to not occur in penstock pipe region because of blasting operations.

![Figure 4. Comparing of the measurement values according to the standards of Turkey](image)

Figure 5a) illustrates the results of ground vibration measurements. The peak particle velocity (PPV) values increased with decreasing the distance between shot and measurement station of concrete platform nearby middle belt concrete (Figure 3b). No measurement value was recorded by measurement station of belt concrete wall of water reservoir (Figure 3a).

The highest and lowest PPV values were 2.650 mm (24th shot, upper half) and 0.190 mm (3rd shot, right lower half) (Table 5) (Figure 5a). When the threshold value with the PPV in Tables 2 and 3 was considered, 6 PPV values were higher than 2.00 mm/s. 5 values of those were upper half shots and a value of those was lower half shot (20th shot). It was seen that the distance between shot and measurement station of the PPV values higher than 2.00 mm/s ranged from 78.76 m to 88.31 m. When the threshold value was exceeded, spacing value and drilling hole length were reduced from 1.0 to 0.8 m and from 4.0 m to 3.0 m, respectively. Therefore, PPV values were lowered under 2.0 mm/s from the 25th shot (Figure 5a).
Table 5. The blasting design values and results of vibration components

| No | Date       | Hour     | Face code | No. of holes | PPV (mm/s) | Freq. (Hz) | Displ. (mm) | Amount of explosive per delay (kg) | Total charge weight (kg) | Distance (m) | Excavation field | Rock class |
|----|------------|----------|-----------|--------------|------------|------------|------------|-----------------------------------|--------------------------|--------------|-----------------|------------|
| 1  | 22.06.2015 | 20:53:19 | 35+178.20 | 83           | 0.365      | 34         | 0.01160    | 0.00359                           | 4.5                      | 43.5         | Upper half       | B3         |
| 2  | 23.06.2015 | 17:37:12 | 35+180.20 | 79           | 0.413      | 12         | 0.00994    | 0.00436                           | 6.5                      | 80.0         | Upper half       | B3         |
| 3  | 24.06.2015 | 18:53:21 | 35+144.70 | 11           | 0.190      | 34         | 0.00665    | 0.00200                           | 9.0                      | 27.0         | Right lower half | B3         |
| 4  | 24.06.2015 | 20:04:37 | 35+182.70 | 23           | 0.429      | 37         | 0.00663    | 0.00182                           | 5.0                      | 21.0         | Upper half       | B3         |
| 5  | 26.06.2015 | 18:52:10 | 35+185.60 | 26           | 0.270      | 34         | 0.00663    | 0.00144                           | 4.0                      | 17.5         | Upper half       | B3         |
| 6  | 06.07.2015 | 13:01:55 | 35+176.20 | 8             | 0.206      | 20         | 0.00663    | 0.00114                           | 3.0                      | 10.5         | Upper half       | B3         |
| 7  | 25.06.2015 | 19:25:02 | 35+225.45 | 6             | 0.286      | 30         | 0.01330    | 0.00143                           | 1.0                      | 4.25         | Upper half       | B3         |
| 8  | 25.06.2015 | 19:25:06 | 35+193.10 | 7             | 0.222      | 32         | 0.00663    | 0.00114                           | 2.75                     | 7.25         | Upper half       | B3         |
| 9  | 15.08.2015 | 11:36:25 | 35+254.45 | 31           | 2.370      | 47         | 0.12600    | 0.03000                           | 5.5                      | 50.5         | Upper half       | B3         |
| 10 | 28.08.2015 | 02:19:11 | 35+272.45 | 63           | 1.430      | 51         | 0.04970    | 0.00545                           | 4.0                      | 65.0         | Upper half       | B3         |
| 11 | 17.08.2015 | 12:23:14 | 35+257.45 | 20           | 0.203      | 34         | 0.01330    | 0.00143                           | 4.0                      | 17.5         | Upper half       | B3         |
| 12 | 19.08.2015 | 18:11:53 | 35+261.45 | 20           | 0.222      | 32         | 0.00663    | 0.00114                           | 2.75                     | 7.25         | Upper half       | B3         |

Figure 5. The PPV (a), acceleration (b) values according to threshold value

When the acceleration values induced blasting in the tunnel were observed, 11 values that exceeded the threshold value were determined (Figure 5b).
The highest value of acceleration was measured as 0.184g (9.81 m.s\(^{-2}\)) in 30th shot (left lower half) and it was seen that the acceleration values decreased with the increase of the distance of shot to measurement station. Figure 6a shows the frequency values correspond with the peak particle velocity values. As stated on Figure 6a, 16% of frequencies were equal or lower than 24 Hz, and the rest of these values were higher than 24 Hz. It was also evident from Figure 6a that, the most of ground vibration values have high frequency rate. This could be attributed that the rock formations in tunnel included fault, crack and weathered composition. As for the peak displacement graph, a value having 24th shot (0.10100) exceeded the threshold value according to Table 4. It was determined that other values were considerably low level (Figure 6b).

![Figure 6. The distribution of the frequency (a) and peak displacement (b) values according to threshold value](image)

PPV, acceleration and peak displacement values generally occurred high in shots in which the distance is close to measurement station. The PPV values which depend on distance between shot and measurement station were demonstrated in Figure 7. It was clearly seen in Figure 7 that PPV values increased with decreasing the distance between shot and measurement station. The highest and lowest PPV values were measured in distances of 78.76 m and 170.16 m, respectively. Furthermore, the high values were recorded especially between 70 and 100 m (Figure 7). It could be ascribed that there were fault zones and contacts in these shots which had high vibration values. After the values (PPV, acceleration and peak displacement) occurred high, spacing value (from 1.0 m to 0.8 m) and drilling hole length (from 4.0 m to 3.0 m) were reduced and the values were lowered again under the threshold values.

![Figure 7. The PPV values depend on distance between shot and measurement station](image)
5. Conclusions
In this study, a total of 37 shots (26 upper halves and 11 lower half) were done and measured the ground vibration components (peak particle velocity, acceleration, peak displacement and frequency values) in Ordu-Mesudiye Highway Topçam T1 tunnel. The effect of shots on the penstock pipe having 35-40 degrees of Topçam Hydro-Electrical Power Plant in tunnel route was evaluated via these results obtained according to threshold values determined before.

The main conclusions are drawn as follows:
- A maximum of 220 kg total charge was used and the charge weight per delay varied between 1.0-18 kg in the shots. The distance of shots to measurement station was between 78.04 and 170.16 m.
- 6 PPVs, 11 accelerations and a displacement value exceeded the threshold values determined.
- 16% of frequencies were equal or lower than 24 Hz, and the rest of these values were higher than 24 Hz. 4 of PPV values of frequency values which are equal or lower than 24 Hz, were measured as higher than 2.0 mm/s.
- It was clearly seen that the vibration values were lower than the standards of our country published by Republic of Turkey Ministry of environment and Urbanization in accordance with the results of ground vibration components obtained from blasting in tunnel.
- According to the threshold value considered for critical structures, as well as the standards of Turkey, the ground vibration parameters of some shots done close range were exceeded the threshold values. But the vibration values were taken under control with changing the blasting parameters and it was provided that the tunnel excavation passed under the penstock pipe of Topçam Hydro-Electrical Power Plant.

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