Mitigation of Adverse Vibrations in Nearby Structures Arising from a Large Forge Hammer

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MITIGATION OF ADVERSE VIBRATIONS IN NEARBY STRUCTURES ARISING FROM A LARGE FORGE HAMMER

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ABSTRACT

This study is concerned in developing a rapid solution of unwanted vibrations arising from a forging facility in Düzce Industrial Park (DIP), Turkey. A site visit revealed that the foundation of the impact hammer was constructed based on judgment. After collecting the relevant data to the extend possible, the system was modeled with two single degrees of freedom having two masses and two springs without any appreciable damping. The results of the analysis indicated that the best solution would be to improve the foundation soil or support the machine on piles, which was unacceptable to the owner because of the backup of the orders. The short-term solution was to use the vibration absorber approach in the reverse order by assuming the foundation slab to be protected from vibrations and by assuming the machine to act as a vibration isolator block. In other words, the foundation amplitude was reduced by allowing the machine to have higher amplitude. This was done by reducing the springs between the foundation and the machine, which was completed in six hours. Amplitude of the foundation displacement is reduced by 50% while the amplitude of the machine is allowed to increase about 85%, which was acceptable for both the owner and the DIP authority.

INTRODUCTION

This study is concerned in developing a rapid solution of unwanted vibrations arising from a forging facility in Düzce Industrial Park (DIP), Turkey. The facility has been completed at the beginning of 2007 and right after the opening, the DIP authority has begun receiving calls from other facilities surrounding the forging facility as far away as 300 meters. A site visit revealed that the foundation of the impact hammer was constructed based on judgment without sufficient engineering analysis.

In order to understand the extent of the vibrations, surrounding facilities within a radius of 300 meters were visited while the forging hammer was operating. The degree of vibrations varied from noticeable to troublesome depending on the proximity of the forge hammer. The main problem was the lack of appropriate engineering design for the machine foundation.

Analysis procedure employed the methods proposed by Prakash (1991). The forge hammer and its foundation was modeled as two single degrees of freedom system with two masses and two springs without any appreciable damping. The main objective was to develop a rapid solution with a minimal cost.

FORGE HAMMER

Machine Characteristics

The weight of the hammer at the facility was 20kN and the machine weight including all attachments was 1020 kN. The hammer was released with an air pressure of 600 kPa through a piston of 0.38 meters in diameter. Drop distance of the hammer was 1.2 meters. The machine had been mounted on 96 springs each having a spring constant of 1705 kN/m. In addition to the springs, four polyurethane blocks serving as additional springs mounted at each corner of the machine slab existed. Total spring constant was calculated as 280.000 kN/m.

Coefficient of elastic restitution (*e*) of the hammer and the metal being forged depends on the working temperature and varies between 0.1 for hot forging to 0.5 for cold forging (Barkan, 1962). Higher values of *e* translate into higher forces, and hence, the amplitudes. Although the facility uses hot forging, the coefficient of elastic restitution was selected as 0.5 for conservatism and for the fact that as the forging in progress the metal piece gets colder.

According to Barkan (1962), the efficiency of the drop (*n*) varies between 0.45 and 0.80 and the average value for *n* is around 0.65. In the analysis *n* is assumed as 0.65.

Existing Machine Foundation

Dimensions of the existing foundation was 4 m x 5.5 m with an area of 22 m^2 carrying the machine frame, anvil and the concrete slab resting on 96 springs and 4 polyurethane blocks. Embedment of the foundation was approximately 3 m. from the ground surface. The schematic illustrations of the components of the machine and the model used in the analysis are shown in Fig. 1.

Soil Conditions

Information about the site soil was limited to two borings conducted not on site but near proximity of the site with SPT values and surface geophysical measurements of shear wave velocity, without any dynamic soil test data. According to borings, the site soil is mostly silty clay with random sand pockets. The average SPT N value was around 17 and the average shear wave velocity (V_s) was around 150 m/sec for areas beneath the machine foundation.

According to Barkan (1962), the vertical spring constant of a soil can be approximated by

$$k_z = AC \tag{1}$$

where, *A* is the foundation area and *C* is the soil coefficient. For *A* =22 m^2 and *C*=30.000 kN/m^3, k_z can be estimated as 660.000 kN/m.

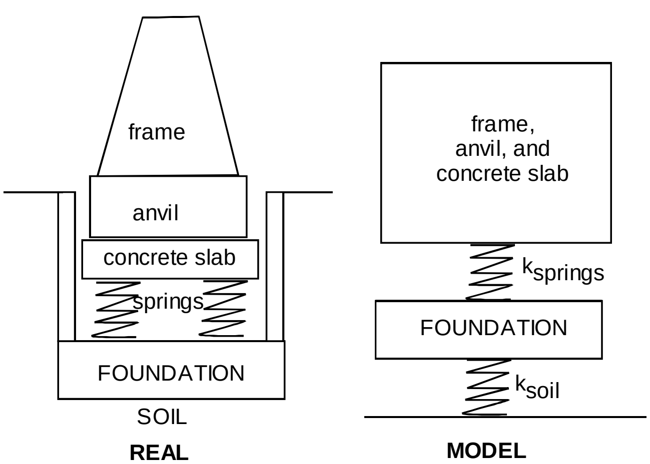

Fig. 1. Schematic illustration of the machine and its foundation and model used in the analysis.

The vertical spring constant can also be determined from the measured values of the shear wave velocity. The shear modulus (*G*) is first determined by

$$G = V_s^2 \rho \tag{2}$$

Where, V_s is the shear wave velocity, assumed as 120 m/sec for the working displacement level and ρ is the density of the site soil, 1.800 kg/m^3. For these values, the shear modulus can be estimated as 25920 kN/ m^2.

According to Lysmer and Richart (1966), the vertical spring constant of a soil can be calculated by

$$k_z = \frac{4Gr_0}{1-\upsilon} \tag{3}$$

Where, r_0 is the equivalent radius of the foundation slab and ν is the Poisson ratio. For $r_0 = \sqrt{22/\pi}$ and ν = 0.4, the vertical spring constant can be estimated as 1.210.000 kN/m.

It was concluded that the spring constant of the site soil can be chosen as 900.000 kN/m, which is the average of the two different estimates presented above.

ANALYSIS FOR EXISTING CONDITIONS

Analysis procedure employed the methods proposed by Prakash (1991), which is based on permissible displacement amplitudes. The system was modeled as two single degrees of freedom system with two masses and two springs without any appreciable damping. Natural frequency of a single degree system without damping is calculated by

$$\omega_n = \sqrt{\frac{k}{m}} \tag{3}$$

In which, k is the spring constant and m is the mass of the system. If the machine and the foundation are considered independently, their natural frequencies are calculated as 52.89 Hz. and 71.44 Hz., respectively. The combined natural frequencies of the hammer-foundation-soil system can be obtained by solving the following equations of motion of free vibrations.

$$m_f \ddot{z}_f + k_s z_f + k_s (z_f - z_s) = 0 \tag{4}$$

$$m_m \ddot{z}_m + k_{sytem} (z_s - z_f) = 0 \tag{5}$$

Where, subscript *f* stands for foundation, *s* stands for soil and *m* stands for machine. The solution is obtained by assuming

$z_f = A \sin \omega_n t$ and $z_m = B \sin \omega_n t$ and substituting these in Eq. (4) and (5) above and solving for natural frequencies and the constants of A and B. When solved, the combined natural frequencies are obtained as 130.5 Hz. for the foundation and 44.34 Hz. for the machine.

Amplitudes of the displacements of the foundation and the machine were calculated as 1.10 mm and 4.09 mm, respectively. The amplitude of the foundation is generally acceptable but the machine amplitude is higher than the typical value expected for this type of hammer. Moreover, existence of nearby structures necessitates reduction in the foundation amplitude.

MITIGATING VIBRATIONS

When dealing a vibration problem in general, the solution is selected from three alternatives below (Barkan, 1962; Richard et al., 1970; Prakash and Puri, 1988):

1. Reducing the vibrations at the source,
2. Measures taken near source in limiting the travel of vibrations to nearby sites (active vibration barriers), and
3. Measures taken at other structures (passive vibration barriers).

A vibration barrier at other structures could not be requested. An active vibration barrier at site in the form of an open or specially filled trench may not serve well unless it is deep enough (Naggar and Chehab, 2005). Data on the properties of the foundation soil is very limited. Furthermore, keeping the trench in its effective condition in the long run may not be achieved. The remaining choice is to reduce the vibrations at the source.

In reducing the vibrations, the best solution would be to improve the soil and/or to use piles as foundation support in conjunction with a vibration barrier after obtaining the necessary soil data. However, the owner has orders to finish and does not have enough funding for any significant improvement in the short time and the management insists that the vibration levels be reduced immediately.

In order to reduce the machine vibrations, springs under the machine must be increased but, this would further increase the foundation vibrations. Reducing the springs under the machine would decrease the foundation amplitudes but it would increase the machine vibrations.

The major constraints of the problem were:

1. Solution should be very cost effective
2. Solution should be implemented without appreciable production delay
3. Solution should be developed within a few days

Under the constraints above, the only rapid short-term solution was to use the vibration absorber approach in the reverse order by assuming the foundation slab is to be protected from vibrations and by assuming the machine is to act as a vibration isolator block. In other words, the foundation amplitude was reduced by allowing the machine to have even higher amplitude. This could be done by reducing the springs between the foundation and the machine. The biggest side effect of this solution was the significantly increased machine displacements. This could, in turn, cause production quality problems and production delays. Another, disadvantage was the increased stresses in the springs, which may cause the springs to break frequently and requiring time for replacement.

Disadvantages of the reverse vibration absorber solution were shared with the owner of the forging facility. It was decided to reduce the foundation settlement and implement the solution. Several spring configurations were tried as shown in Table 1. Analysis with 40 springs indicated that the foundation displacement amplitude is to be reduced by 50% but the amplitude of the machine is estimated to increase about 85%. The mechanical engineer responsible for production has developed additional measures on the lifelines of the hammer and has developed minor adjustments during production.

Table 1. Alternatives considered for mitigating vibrations

Alternative	Amplitude M* (mm)	Amplitude F* (mm)	Description
Current State	4.1	1.1	Acceptable for machine, but not for surrounding facilities
If k_{soil} is improved to double	3.9	0.57	Desired solution, requires time and funding
Trench	-	-	Effectiveness of vibration isolation is questionable (see Naggar and Chehab, 2005)
Foundation support by 96 springs	6.2	0.72	Reverse vibration absorber solution
Foundation support by 40 springs	7.7	0.57	Limit of reverse vibration absorber solution.

* M: Machine, F: Foundation

The reduction of the springs took six hours to complete and the reverse vibration block solution has turned out to be acceptable for both parties in the short run. The effectiveness of the solution was immediately felt by all parties involved.

MEASURED VIBRATION AMPLITUDES

The levels of vibrations at six different locations were measured by a three axial accelerometer after reducing the supporting springs to 40 and while having the forging hammer was running. Measurement locations were selected at locations where excessive vibration complaints were received and each point had a distance varying from 40 m to 200 m to the forge hammer. Unfortunately, measurements prior to changes could not been taken due to unwillingness of the owner. Table 2 and 3 show the amplitudes measured at selected locations for vertical and horizontal vibrations in terms of both velocity and accelerations.

Table 2. Vertical Vibration Amplitudes at Selected Locations

Measurement Point	Maximum velocity (mm/sn)	Maximum Acceleration (mm/sn^2)
Near Machine	1.055	139.745
1	0.130	5.050
2	0.434	32.612
3	0.159	76.406
4	0.151	8.513
5	0.172	9.520

Table 3. Horizontal Vibration Amplitudes at Selected Locations

Measurement Point	Maximum velocity (mm/sn)	Maximum Acceleration (mm/sn^2)
Near Machine	0.652	166.512
1	0.027	8.510
2	0.150	23.522
3	0.149	7.072
4	0.097	5.843
5	0.164	13.852

Vibration measurements can be evaluated based on the recommendations of Skipp (1965). Additionally, it is assumed that a peak velocity of 0,2 mm/sec or less is considered adequate. Overall, the measured amplitudes can be classified as barely noticeable or better, except for point 2, which was on site of the facility and not causing any complaints. Visit to complaining facilities confirmed that vibrations were no longer a problem.

RESULTS AND CONCLUSIONS

This study has concerned in developing a rapid solution of unwanted vibrations arising from a forging facility in Düzce Industrial Park (DIP), Turkey. Major constraints of the study were time and funding, which dictated the solution. Vibration isolation by open or filled trenches was not considered because their effectiveness was questionable for the site. As a result, the reverse vibration absorber approach was developed in which the foundation slab is assumed to be protected from vibrations and the machine itself is to act as a vibration isolator block. In other words, the foundation amplitude was reduced by allowing the machine to have even higher amplitude. This has been done by reducing the number of springs between the foundation and the machine.

The disadvantages of the applied solution have been absorbed by implementing additional measures on the lifeline connections of the machine. At the time of this writing, the reverse vibration solution has been in use for 6 months and the machine was operable in acceptable conditions with rare spring replacement delays. However, a cost effective solution for the long run is being studied.

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