Assessment of the Dynamic Loads Effect on Underground Mines Supports

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ABSTRACT

Blasting operations generate seismic effects in underground mines. These effects apply additional dynamic loads on the support system, which should bear both static and dynamic loads. Static loads are caused by the weight of the superincumbent strata, while dynamic loads occur as a result of blasting in the mining area. Identification of the origin and determination of the support system behavior in natural frequencies is crucial in assessing the stability of underground mines. This is because resonance occurs when a support is vibrated with its natural frequencies, which can cause a vibration with the maximum amplitude and subsequently cause extreme deformations. The mechanism of support system deformation during dynamic load displacement has been studied and numerical simulation for the impact of the dynamic loads on stability of supports is carried out using finite element method.

The paper introduces a simple technique for improving stability and safety of mining operations. Results obtained and the methodology adopted in this research can help mining design engineers make decisions on adequate support for active mining operations.

INTRODUCTION

Mining is an exploitive process; blasting, nevertheless, is identified as one of the key mining activities. It is the cheapest method of excavation in surface and underground mining. It provides appropriate rock material granulation or size that is suitable for loading and transportation. Although blasting proves useful, it generates a few detrimental impacts such as fly rock, air blasts and ground vibrations. Ground vibrations from blasting have been a continual problem for the mining activities. Underground openings must be stabilized during their service life. In a region with seismic activities, stabilization against dynamic loads is as important as stabilization against static loads; therefore, additional effects occurring in supports due to dynamic loads should also be considered. Supports must be able to bear static and dynamic loads simultaneously with the proper safety factor.

VIBRATION PRINCIPLES

A mechanical periodic or random oscillation about an equilibrium point generates vibration. The maximum displacement from the equilibrium position is called amplitude vibration (measuring the strength of a vibration), and number of vibrations per second is defined as frequency (measured in Hertz). The size of amplitude is highest at a particular frequency (Figure 1).

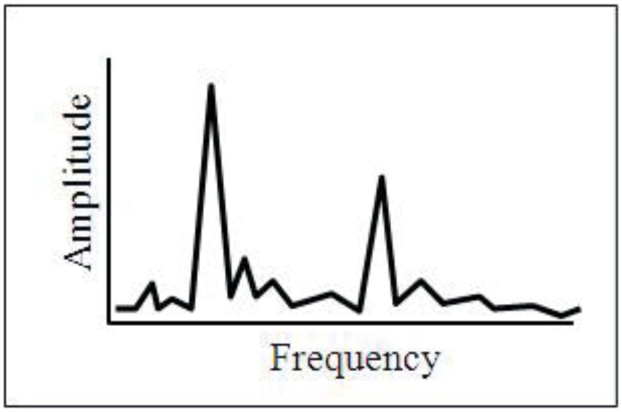

Figure 1. The relation between amplitude and frequency in vibration.

A mode of vibration is a characteristic pattern or shape in which a system will vibrate. Most systems have many modes of vibration, and it is the task of modal analysis to determine these mode shapes. Natural (resonant or modal) frequency is the frequency at which a system naturally vibrates once it has been set into motion. In other words, natural frequency is the number of times a system will oscillate between its original position and its displaced position if there is no outside interference (the peak points in Figure 1). The actual vibration of a system is always a combination or mixture of all vibration modes, but they need not all be excited to the same degree.

Free vibration and forced vibration are two typical types of vibration. Free vibration occurs when a system is set off with an initial input and then allowed to vibrate at one or more of its natural frequencies and to damp down to zero freely. Forced vibration is when an alternating force is applied to a system. In forced vibration, the frequency of the vibration is the frequency of the force applied, with the order of magnitude being dependent on the actual system. The vibration of a structure during a blasting operation is an example of this type of vibration.

MODAL ANALYSIS

A small amount of input force can cause a large response at or near certain natural frequencies of the system.

Modes, or resonances, are determined by the material properties and boundary conditions of the system. The majority of systems can be made to resonate. Real systems have an infinite number of modes. The modal analysis of a system is particularly useful for dynamic analysis of a system. Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a system while it is being designed. It also is a starting point for more detailed and dynamic analysis. Since a system's vibration characteristics determine how it responds to any type of dynamic load, one must always perform a modal analysis first before trying any other dynamic analysis. Modal analysis allows the design to avoid resonant vibrations or to vibrate at a specified frequency.

VIBRATION ON THE GROUND

Vibration is produced by the radiation of energy from a blast. A rapid release of energy in an explosive causes a strong compression of the medium next to it, creating a shock wave. Blasting waves are mechanical waves that can travel through a gas, liquid or solid. A detonation of explosive charge shakes the ground, and the different particle motions in medium in rock create a group of waves. Transverse and longitudinal waves travel radially outward in all directions (Figure 2).

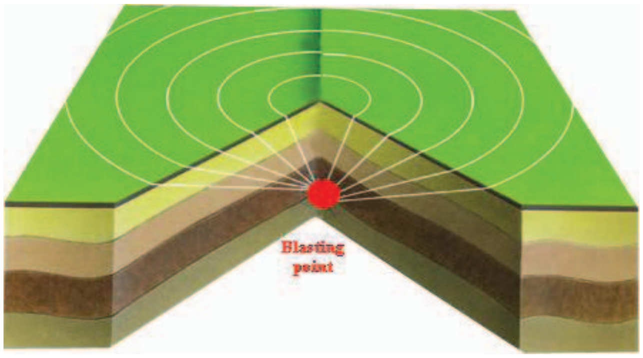

Figure 2. Seismic body and surface waves.

Transverse waves are generated by the back-and-forth oscillation of small elements of the rock at right angles to the direction in which the wave is traveling. Longitudinal waves are also generated by the parallel oscillations to the direction of travel. The actual vibrations produced by blasting are similar in many respects to those produced by earthquakes.

The degree of shaking in ground vibrations is determined by ground vibration amplitude (peak particle velocity), duration and frequency. Underground operations are sensitive to ground vibration and deformations caused from this vibration. Increasing deformations can cause the failure around mine openings.

VIBRATION EFFECTS ON THE SUPPORT SYSTEMS

Seismic waves from blasting are full of energy, and excessive levels of ground vibration can result in the damage or failure of a support in an underground mine.

Vibrations in the support system can be amplified relative to the forcing vibration in the ground. Amplification of ground vibration depends on the amount of energy in the ground vibration spectrum that is in the vicinity of the supports and their resonant frequencies, together with the damping ratio of the structure at these particular frequencies. The blast vibrations near the support's resonant frequency and the resulting responses for each type of test support systems at the mining site were determined. The peak support system response and the incoming ground vibrations waveforms were superimposed for absolute and differential response analyses. The maximum amplifications occurred at the natural frequency of the support because of low differential responses. The frequencies below natural frequency did not show amplifications because there were no relative displacement and hence, no strain. Similar exercises were performed to determine the natural frequency of the test structures at both the experimental sites.

TIMBERING IN TUNNELS

A drift progresses along the seam, while timbering is left standing to support the mine roof. It is required in order to maintain the stability of the openings that are excavated (Figure 3).

Figure 3. Timbering in tunnels.

Wooden frames are mainly used in mines of small cross-sectional areas and those with short service life. Trapeziform frames (caps and props) are usually installed apart from the roof and walls of the tunnel, and then are fixed by half-round timbers (laggings). The wooden frames are made of round or squared timbers and are connected with double-notched joints, and barring sets are usually connected to props by slot joints. A single view is not sufficient to show all the measurements, and two views are used to capture all the geometric features of a frame. The dimensions of the frame are shown in Figure 4.

MODELING

Modeling is a basic approach to simulate the behavior of systems. With a simple three-dimensional dynamic model of blasting vibration on support systems, one is able to improve the performance of the support system in an easily accessible manner to reduce the exposure of miners to rock fall hazards.

Numerical modeling techniques such as the finite element method utilize the analyses of supports deformations around openings. They are effective in ground control because they enable comparisons of a variety of mining situations and serve as a design procedure. ANSYS computer programming, which is based on the finite element theory, is a high-capability engineering software in numerical problem solution. In this program, through graphical definition of the problem, complicated modeling and element creation in shapes are easily performed.

The main goal of a finite element analysis is to examine how a system responds to certain loading conditions. Three dimensional modeling can generally provide a more accurate representation of the geometric configuration of the timber supports. Modal analysis was applied to a set of wooden frames, which is the critical system for underground mine stability. The model was made of wood with the properties shown in Table 2.

Building a finite element model requires defining the element type, material properties and the model geometry. First, the volume of a model (a wooden frame) was defined with five key points to the working plane (Table 1). Four pillars and a plane represented a set of timber supports for modeling dynamic loads (Figure 5). The frame is fixed to the ground on the ends of props. The available degrees of freedom per node were defined at the next step. The constraints were applied to all contacted nodes between the props and the ground. All other nodes of the props, the caps and the laggings were able to move along the positive and negative directions of the coordinate system axes (Figure 6).

Table 1. The key points used in the model (geometric properties).

Key Points	X1	X2	Y1	Y2	Z1	Z2
1	0	2	0	1.8	0	0.2
2	0.2	0.4	0.2	0.4	0	-2
3	1.6	1.8	1.4	1.6	0	-2
4	1.6	1.8	0.2	0.4	0	-2
5	0.2	0.4	1.4	1.6	0	-2

Table 2. Material properties used in the model.

Material properties	Value
Density	415 Kg/m^3 (26 lbs/ft^3)
Young's modulus	10 GP
Shear Modulus	0.5 GP

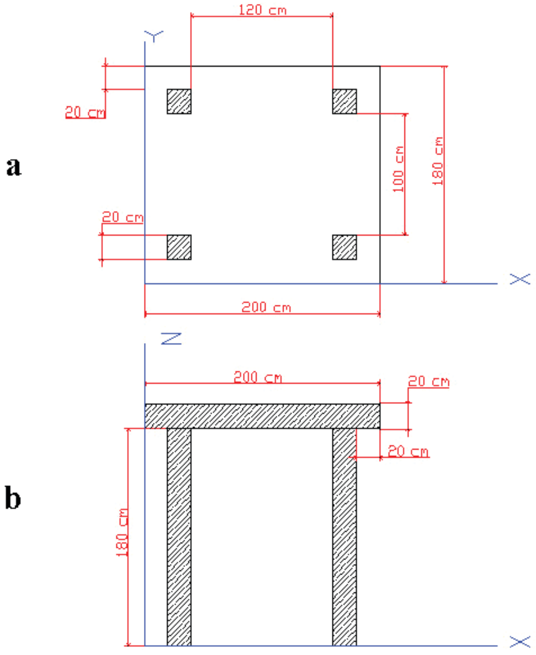

Figure 4. Timbering in tunnels: a: a vertical section of the wooden frame and b) a horizontal section of the wooden frame.

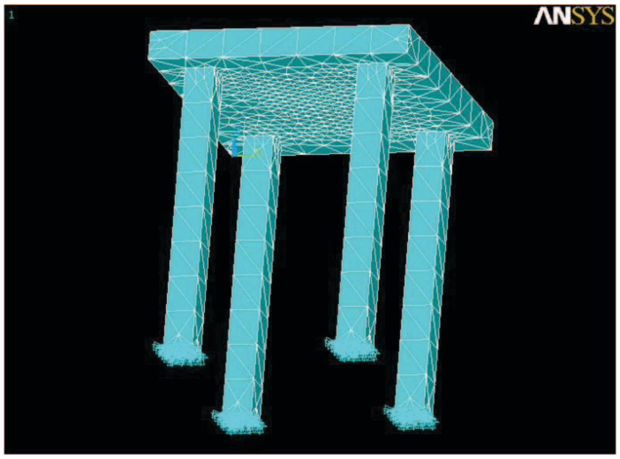

Figure 5. A 3D view of the model after creating the model geometry; applying loads include boundary condition and meshing the model.

The model was made of wood with the properties shown in Table 2. Solid45 element was incorporated into a finite element mesh for this analysis. The mesh area was discretized into 1959 elements with 735 nodes. This element was used for three-dimensional modeling of solid structures such as wooden frames. The element was defined by eight nodes, having three degrees of freedom at each node (Figure 7).

THE MODEL ANALYSIS

Experimental modal analysis is the process of extracting dynamic characteristics of a vibrating system from measured force inputs and vibratory responses, whereas numerical modal analysis

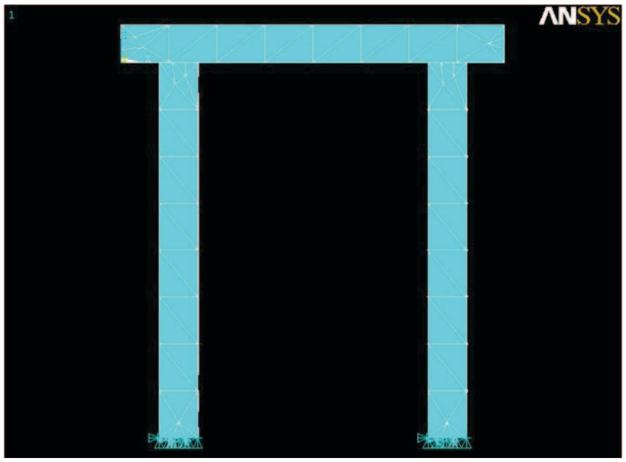

Figure 6. A vertical section of the model.

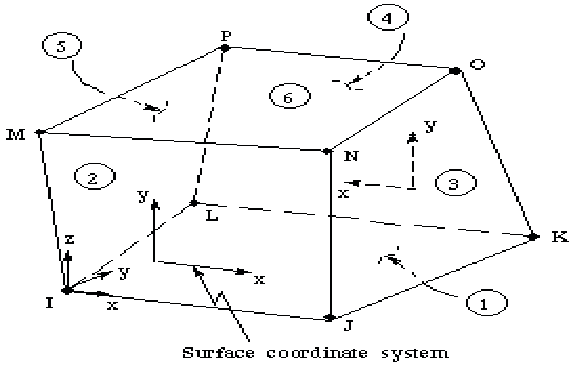

Figure 7. Solid45 element.

extracts the dynamic characteristics of a vibrating system from a numerical method. It is a more mature technique in comparison to experimental modal analysis, and is extremely useful in the design of supported systems, which tend to be dominated by the mode shape of the resonance.

Many vibration problems are caused, or are at least amplified, by the excitation of one or more flexible body modes. The resonant frequencies of a supported system need to be identified and quantified.

The results of the numerical analysis are shown in Figures 8–13. The response motion was measured as deformations. The figures show deformation from resonant vibrations. In these cases, the resonance situations are dominated by natural frequencies, and therefore are the closest approximation to the mode shapes. The data from the figures are listed in Table 3.

Mode shapes are important parameters in the design of a system for dynamic loading conditions. Significant deformations can result from small forces in resonance, and damage can possibly be induced. The mode shapes, the resonant frequencies and the deformations were determined by ANSYS (Figures 8–13). A little bending and torsion appeared in the mode shapes.

Table 3. The resonant frequencies and the maximum deformation for the model.

Natural frequency	Maximum deformation
205.435 Hz	0.163123 m
207.638 Hz	0.160517 m
210.267 Hz	0.171264 m
214.017 Hz	0.150243 m
220.324 Hz	0.205324 m
261.109 Hz	0.101302 m

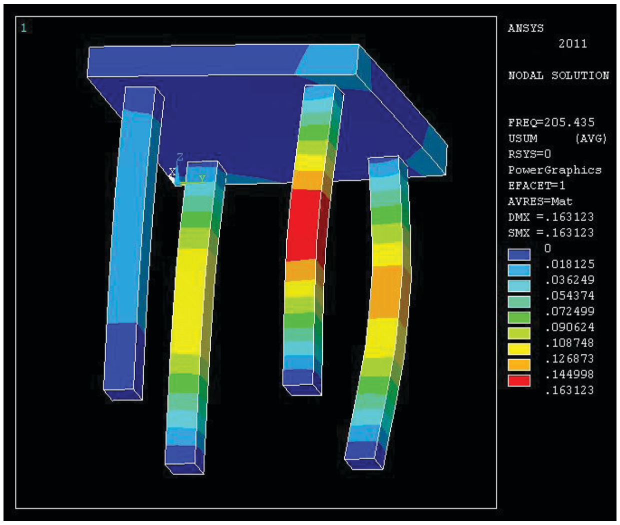

Figure 8. Mode shape of the wooden frame for a modal frequency of 205.4 Hz.

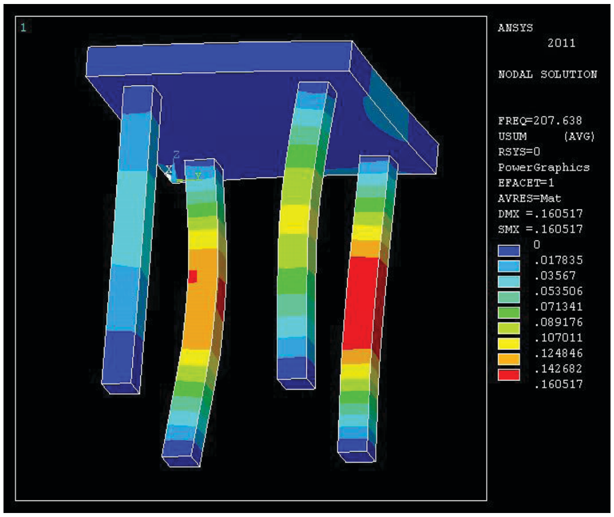

Figure 9. Mode shape of the wooden frame for a modal frequency of 207.6 Hz.

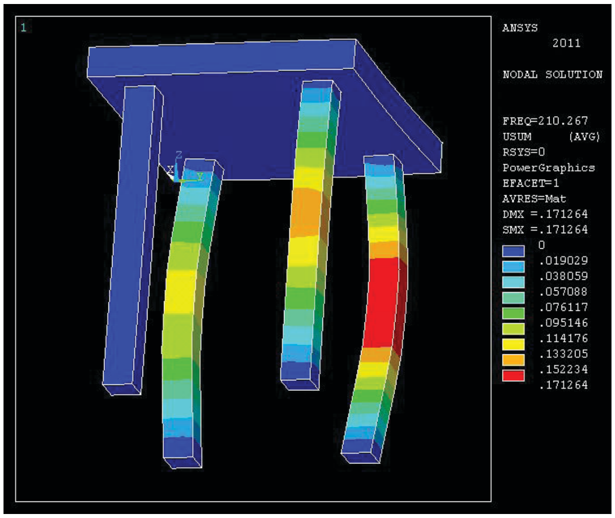

Figure 10. Mode shape of the wooden frame for a modal frequency of 210.3 Hz.

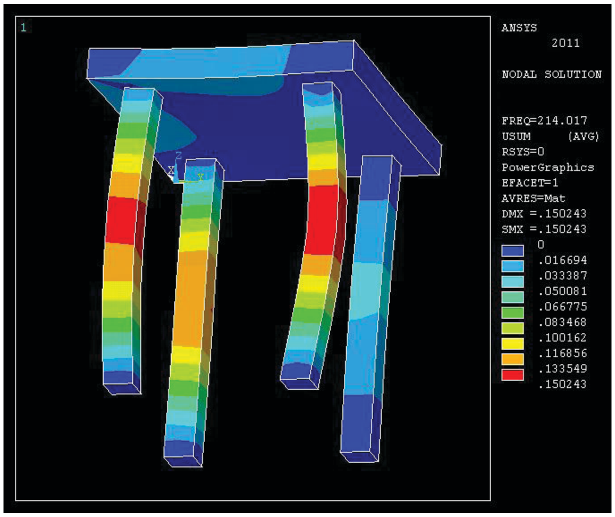

Figure 11. Mode shape of the wooden frame for a modal frequency of 214.0 Hz.

Support stability can be affected by blasting. The structural stability of a system is down to avoiding the apparent resonance. The increase in the amplitude of oscillation of a supported system exposed to a periodic external force whose frequency is equal to, or is some multiple of, the natural frequency of the system causes many vibration problems in the supported system.

CONCLUSION

In regions with seismic activity, additional effects occurring around the support openings due to blasting loads should be considered in the design stage. By applying appropriate quality control and proper design to the supported systems, blasting operations can not only improve the mine's safety, but also most likely improve productivity and long-term sustainability.

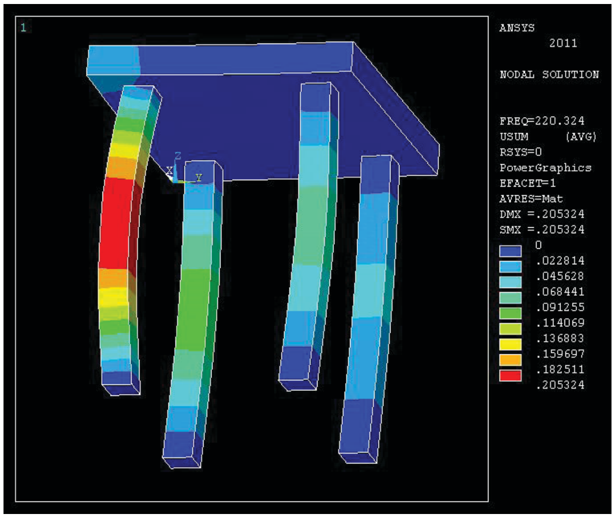

Figure 12. Mode shape of the wooden frame for a modal frequency of 220.3 Hz.

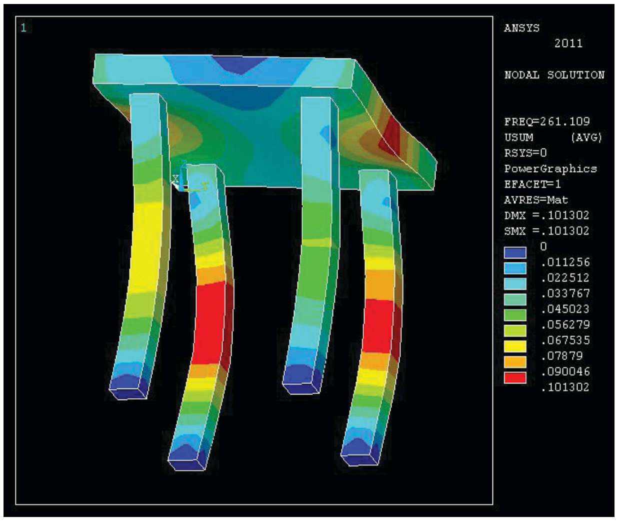

Figure 13. Mode shape of the wooden frame for a modal frequency of 261.1 Hz.

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