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Prediction of Blast Vibrations from Quarries using Machine Learning Algorithms and Empirical Formulae

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DECLARATION

I declare that this Research Report is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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ABSTRACT

The aim of this study was to, firstly, use machine learning algorithms to predict Peak Particle Velocity (PPV) in order to optimise blasting layouts and reduce the risk of damaging surface structures. Empirical models developed by the United States Bureau of Mines (USBM) (1963) and Ambraseys and Hendron (1968) were compared to the machine learning algorithms. The tests conducted were interpolation and extrapolation. Most of the data used in this report was obtained from the USBM's Bulletin 656. The data was analysed using a qualitative and quantitative research methods. The Cubist machine learning model (Kuhn, 2018) performed the best in the interpolation test with a coefficient of determination (R^2) of 83.39 % and a root mean squared error (RMSE) and mean absolute error (MAE) of 10.64 and 7.30 respectively. The empirical models performed the best with the extrapolation test with an average R^2 of 88 % and RMSE and MAE of 9.17 and 6.59 respectively. This research has shown the effectiveness of machine algorithms in predicting PPV and empirical formulae using historical data from different sites. However, explosive and geotechnical information was not available in the dataset and it is therefore recommended that further research be conducted with this data.

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LIST OF SYMBOLS

(adapted from (Kuhn and Johnson, 2013; Nicholls *et al.*, 1971))

Peak particle velocity, where * represents L, T, V components.	
L represents Longitudinal or Radial, T represents Transverse and V represents Vertical	PPV_*
A site constant that also indicates the energy transfer between an explosive and the rock in the ground being blasted	k
A decay function of the seismic wave	m
Scaled distance	SD
Site constant used in general form of the PPV empirical formula. The USBM model uses an α of 0.5 and the Ambraseys and Hendron (1968) model uses an α of 1/3	α
The total number of data points or total number of rows in a dataset	n
The total number of features or input parameters or predictor	P
The i^{th} measured value of the response, $i = 1 \dots n$	y_i
The i^{th} predicted value of the i^{th} data point	y_i^*
The mean of n measured values	$\bar{y}$
A vector of all n response values	$\mathbf{y}$
The value of the j^{th} input parameter for the i^{th} data point, $i = 1 \dots n$ and $j = 1 \dots P$	x_{ij}
The mean of n data points for the j^{th} feature	$\bar{x}_j$
A vector of all n features for the i^{th} data point	$\mathbf{x}_i$
A matrix of P features for all data points, which has n rows and P columns	$\mathbf{X}$
Summation operator over the index i	$\sum_{i=1}^n$
The expected value of *	$E[*]$
Function of *	$f(*)$
Unknown model coefficient	β
An estimated model coefficient based on a sample of data points	b

1 INTRODUCTION

Explosives play a critical role in the mining industry. In most surface mines, they are used to fragment the overburden and ore. Explosives are very well understood by the mining industry and have been used to fragment many types of rocks efficiently.

The wide use of explosives means that a new mine operation can rely on a vast library of knowledge from practising Explosive Engineers or people with blasting experience. Even though this choice seems obvious for most mining operations, the use of explosives comes with many challenges. Some of these challenges include the increased possibility of generating ground vibrations, air blast, dust and fly rock. This report will focus on Blast Induced Ground Vibrations (BIGV).

Quarries and open cast mines are sometimes close to national roads, malls, towns and houses. The proximity of these surface mines poses a high financial risk to them, especially if they do not control the level of ground vibrations they produce. The local communities have become aware of the legal recourse they have if mining operations have damaged their property. The ability to predict and subsequently control the level of blast-induced ground vibrations is thus very beneficial to surface mines. In this report the use of machine learning is considered as a viable alternative to traditional empirical prediction methods. In this report, machine learning is defined as the ability of a computer to learn from data and a machine learning algorithm is a procedure that a computer follows to determine the relationship between input parameters and outputs.

1.1 Problem Statement

When an explosive is detonated, a large amount of shock and gas energy is produced (Atlas Powder Company, 1987; Persson *et al.*, 1994; Pal Roy, 2005). Unfortunately, only 20-30 % of this energy is used to break the in situ rock mass and heave it (Monjezi *et al.*, 2011; Pal Roy, 2005). This means that 70-80 % of the total energy produced during the explosion is lost. This lost energy is responsible for the generation of BIGV, air blast and fly rock (Monjezi *et al.*, 2011).

The USBM determined that the component of BIGV that most closely correlates to structural damage was PPV. In order to reduce damage to property, it is therefore critical to accurately predict the PPV that can be produced by a specific blast design and then make necessary changes to the design. The combination of a good prediction tool combined with appropriate knowledge of blasting theory will enable a practitioner to optimise the blast layout.

1.2 Background

The purpose of Section 1.2 is to provide background information on the dataset used in the current research, including the history of the United States Bureau of Mines (USBM). Also, a description of the data and the method of acquisition is discussed.

1.2.1 History of the USBM

The organisation responsible for commissioning this research is the United States Department of the Interior, which was established on March 3 of 1849 (*Nicholls et al.*, 1971). The USBM and the Office of Surface Mining (OSM) were subsequently tasked to conduct extensive investigations into the effect of BIGV on neighbouring structures from 1930 to 1940 (Duvall and Fogelson, 1962; *Nicholls et al.*, 1971). These investigations did not produce any evidence of damage due to BIGV (Duvall and Fogelson, 1962). However, according to Duvall and Petkof (1959), a propagation law relating displacement amplitude, charge weight and distance was developed using data from quarry blasts.

In 1958 the USBM decided to reinvestigate BIGV due to the need for additional BIGV information and the availability of better seismic instruments (*Nicholls et al.*, 1971). This investigation was limited to measurements taken from quarries (*Nicholls et al.*, 1971). The study that was reported in Bulletin 656 concluded that Peak Particle Velocity (PPV) was more closely correlated with damage to residential structures than Peak Particle Displacement (PPD) and Peak Particle Acceleration (PPA), (*Nicholls et al.*, 1971). The selection of PPV as a more appropriate entity to predict damage to structures is discussed in Section 2.4. In addition to that the study recommended the use of a scaled distance of $50 \text{ ft/lb}^{1/2}$

(22.6 m/kg^{1/2}), in the absence of instrumentation, and a PPV of 2.0 ft/sec (50.8 mm/s) as a safe blast limit (Nicholls *et al.*, 1971; Siskind *et al.*, 1980). Nicholls *et al.* (1971) also concluded that millisecond delay systems could be used to reduce PPV because the amplitude of the wave at a Point of Interest (POI) depends on the maximum mass of explosives detonated at any one time (or per effective delay interval). A delay system is a method of connecting blastholes so that they are detonated in a particular sequence. The amount of time between the detonation of a single set of blastholes and a subsequent set of blastholes in a single blast is referred to as a delay. Nicholls *et al.* (1971) noted that the PPV decreased exponentially with increasing distance, thus making the distance from the source of the blast a key contributor to PPV.

1.2.2 Background on Bulletin 656

The dataset used in the investigation described in this report was taken from Bulletin 656. Bulletin 656 was a product of a ten-year study of the air-blast and ground vibrations generated by blasting. The research was commissioned after a meeting of the relevant stakeholders in 1959 at the USBM's facility at College Park, Maryland (Nicholls *et al.*, 1971). The stakeholders in attendance included quarry operators, scientists from the private sector and institutions of higher learning along with members of the Bureau of mines technical staff involved in blast research and cooperating groups (Nicholls *et al.*, 1971).

The research program that the USBM initiated had two major objectives, which are as follows (Nicholls *et al.*, 1971):

- To develop reliable damage criteria, which would establish a clear relationship between the magnitude of ground vibrations and the corresponding damage to structures and
- To develop a propagation law that would establish a quantifiable relationship between the magnitude of the ground vibrations experienced by structures or measured at any point of interest with the quantity of explosive charges used at a mine.

- Another key component of the research was to establish how the distance between the point of interest and the source of the blast, affects the magnitude and character of ground vibrations.

Other contributing factors to be investigated included, explosive types, method of initiation, geology and blast direction (Nicholls *et al.*, 1971). There were other objectives, but the current study focuses on the data generated as a result of measurements taken to test the relationships discussed in the second bullet point above.

1.2.3 Approach of the USBM Study

In an attempt to accomplish the first objective, it was decided that field studies would be too costly at that stage. An extensive review of published research, on damage caused by vibration amplitude and frequency, was therefore undertaken. At that stage, it was important to determine the entity which had the greatest effect on damage to structures. The entities assessed were displacement, particle velocity and acceleration of ground vibrations (Nicholls *et al.*, 1971).

The researchers found that there were serious limitations in the data that was contained in the literature. The limitations included the fact that only one or two three-component seismographs were used per blast and measurements were taken on exposed rock. The researchers resolved to restudy the problem and address the limitations of the data by using six to eight three-component seismographs in an array and the effect of ground vibrations on structures will be evaluated by measuring ground vibrations next to the structure. The literature review indicated that air-blast from routine blasting did not cause major damage and It was thus decided to focus on the measurement of blast vibration and frequency The new study involved the measurement of ground vibrations and frequency from 171 blasts at 26 different quarries (Nicholls *et al.*, 1971)..

1.2.4 Measuring Instruments

The researchers decided to conduct an extensive evaluation of the ground vibration instruments available at the time. This process led to the USBM developing a seismograph that met the needs of the study. The capabilities of the seismograph

included the ability to measure particle velocity, frequency and air-blast The final instrumentation was built into a 2,5 tonne mobile Light Duty Vehicle (LDV) body, which then became their mobile lab (Nicholls *et al.* 1971).

According to Nicholls *et al.* (1971), The instrumentation comprised the following components:

- 36 channel direct writing oscillograph.
- 36 linear integrating amplifiers.
- Velocity gages.
- Accelerometers.
- Power from a petrol-driven Alternating Current (AC) power generator in a trailer.
- 6 pressure gages were provided for measuring air-blast.

1.2.5 The Experiment Sites

The study at the different quarries was organised in such a way as to not disturb the operations and thus contributed to the USBM's decision to take vibrations measurements in 26 quarries. This approach allowed the researchers to measure the influence of blast design parameter like spacing, burden, hole size, bench height and the explosive type used. Other effects that were evaluated were the effect of overburden thickness, direction of propagation, site and rock type. The effect of explosive types was not measured and could only be accounted for in the site constants (Nicholls, Johnson and Duvall, 1971).

The researchers eventually evaluated 171 blasts with charge size ranges from 31.75 to 81 896 kg per blast and 11.34 to 8 901.75 kg per delay. The number of holes per blast ranged from 1 to 490 and the rock types included limestone, dolomite, basalt, sericite schist, trap rock granite, granite-gneiss and sandstone. The geology at the 171 sites was varied. The setting ranged from massive rocks to interbedded deposits that have also undergone folding (Nicholls *et al.*, 1971). The variability in the geology of the sites made them good proxies for any other quarry.

Figure 1.1 depicts the Webster City Quarry and the arrangements of the seismographs per test (or blast). Three blasts, which were labelled 22, 25 and 26, were taken at this quarry. During the tests, eight seismographs were arranged in a linear form and located at increasing distances away from the area that is being blasted. The researchers also took care to measure ground vibrations next to key features like a road, a river and a valley (Nicholls, Johnson and Duvall, 1971).

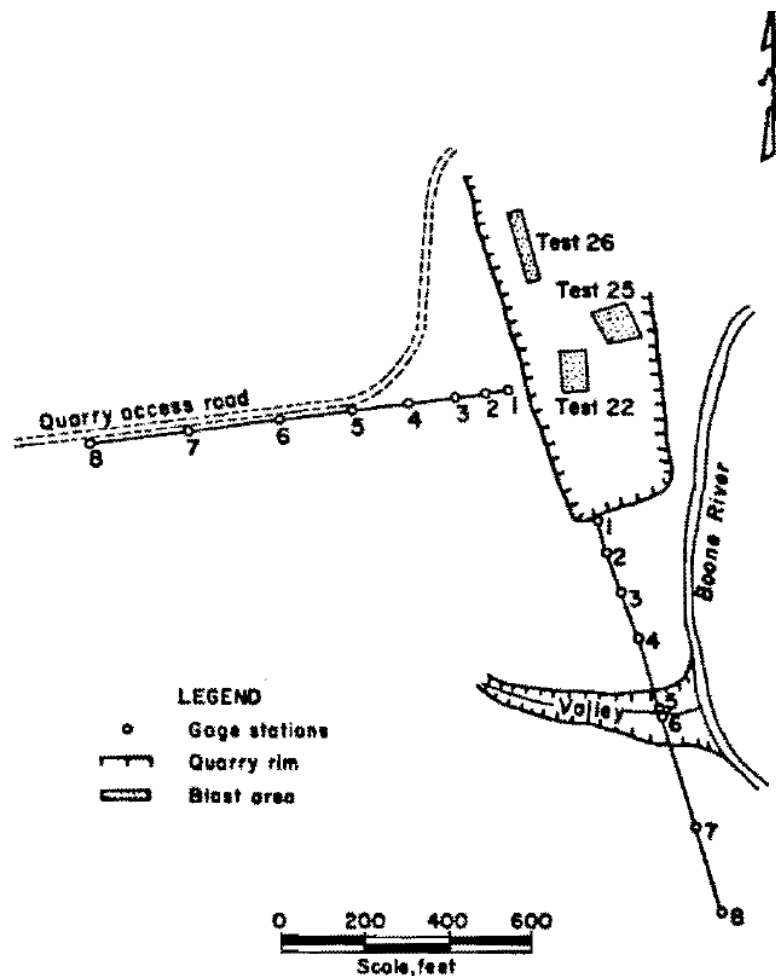


Figure 1.1: Blast vibration measurements at Webster City Quarry (Nicholls et al., 1971)

The benefit of this approach is that the researchers were able to capture the effect of distance and direction of the blast on the blast vibration measurements from one blast. Blast vibration attenuation could be observed.

1.2.6 The Data

The key component of the current study was the data collected and subsequently published in Bulletin 656. The data is significant and was thus useful for the current study because it contains enough detail and accuracy to be analysed using different methods. The use of machine learning algorithms would also improve the understanding of PPV and the physical parameters that contribute to the propagation and attenuation of blast vibrations. The data had, however, some notable omissions: The USBM researchers did not include details on the explosives used at the mines and they also did not include detailed geotechnical information about the quarries they were using as test sites. This means that the impact of different types of explosives and geology on the propagation and attenuation of the shock waves was not possible to evaluate in the current investigation.

The parameters provided in the dataset are as follows:

- Site – The name of the quarry and a short, but inadequate, description of the geology
- Test – number assigned to individual blast
- Total number of holes – total number of holes in one blast
- Hole size (in.) – diameter of blasthole
- Hole depth (ft.) – total length of blasthole
- Face Height (ft.) – the height of the bench being blasted
- Stemming Length (ft.) – length of blasthole to be filled with inert material that starts from the top of the explosive charge to the collar of the blasthole.
- Burden (ft.) – distance between the rows of blastholes or the distance between a blasthole and a free face.
- Spacing (ft.) – distance between the blastholes in individual rows.
- Charge per hole (lb) – mass of explosive in one blasthole
- Number of delay intervals
- Maximum charge per delay (lb)
- Length of Delay (ms)
- Initiation type
- Scaled distance (ft./lb^{1/2})

- Radial Particle Velocity (in./s) – peak particle velocity in the radial direction
- Vertical Particle Velocity (in./s) – peak particle velocity in the vertical direction
- Transverse Particle Velocity (in./s) – peak particle velocity in the transverse direction

1.3 Research Objectives of the Current Study

The purpose of this study is:

- To use Machine Learning to predict the PPV of blast induced ground vibrations of Bulletin 656 surface mines; and
- To compare the performance of the Machine Learning approach to the performance of empirical predictors

1.4 Structure of Report

This report contains eight chapters. The contents of the chapters are discussed below.

Chapter 2 is a Literature review of blast-induced ground vibrations.

Chapter 3 is the methodology section and describes the steps taken to collect and analyse the Bulletin 656 PPV data. The rationale for the chosen methods, model building and optimisation steps are described in this chapter.

Chapter 4 describes the results of the model building process.

Chapter 5 provides the Results and Analysis of the models discussed in chapter 4.

Chapter 6 is the concluding chapter

Chapter 7 provides some recommendations.

2 LITERATURE REVIEW

This chapter introduces the concept of blasting in surface mines and discusses the generation of BIGV along with the prediction of PPV. Two prediction methods are discussed; these include the empirical prediction models developed by the Duvall *et al.*, (1963), as part of the USBM investigations, and Ambraseys and Hendron (1968) along with eight machine learning algorithms.

This research focuses on the prediction of PPV from quarry blasting. It is therefore important to understand the parameters involved in a blast and how they relate to each other. Figure 2.1 shows a bench on a surface mine that has blastholes denoted by red dots and an explosive charge shown in green.

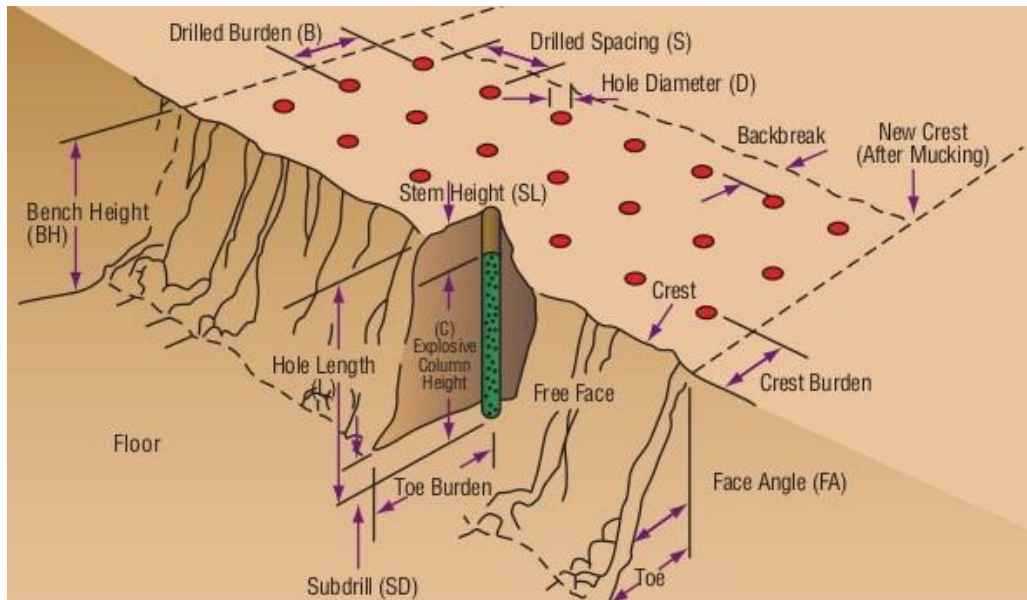


Figure 2.1: Blast design layout and terminology (Dyno Nobel, n.d.)

The following sections discuss key parameters that impact blast vibrations and the methods used to predict them.

2.1 Explosives History

Explosives are an important part of mining. Apart from providing the energy required for breaking rock, explosives are also the source of seismic waves that break rock by blasting. According to Persson *et al.* (1994), an explosive is a material that can rapidly decompose chemically and produce a large volume of hot gas that

generates enough borehole pressure to break the rock. This section discussed the history of explosives and their importance in minimising PPV.

2.1.1 Black Powder

The first mentions of saltpetre, which is a basic ingredient of black powder, was in the 13th century by Abd Allah. It is believed, however, that the Chinese used saltpetre around the 10th century for fireworks and rockets (International Society of Explosives Engineers, 1998).

In 1242 Roger Bacon published a formula for black powder (Atlas Powder Company, 1987; International Society of Explosives Engineers, 1998). The first use to break rock was 1627 at the Royal Mines of Schemnitz at Ober-Biberstollen, Hungary (International Society of Explosives Engineers, 1998). In 1689 black powder was used at the mines in Cornwall, England, to break rock, replacing fire setting. Fire setting involved the heating of rock and subsequent cooling by water to develop fractures through tension (Atlas Powder Company, 1987). This process was inefficient because there was no means of drilling, the high cost of powder and the poor quality of the final product (International Society of Explosives Engineers, 1998).

Black powder was then widely adopted in Europe to loosen rock (Atlas Powder Company, 1987). Blasting in America is reported to have started in 1773, where a Simsbury Connecticut Copper Mine was being converted into a Newgate Prison (Atlas Powder Company, 1987; International Society of Explosives Engineers, 1998).

2.1.2 Dynamites

After a concerted effort by Europe chemists, Ascanio Sobrero finally discovered nitro-glycerine (NG) (Atlas Powder Company, 1987; International Society of Explosives Engineers, 1998). NG was found to be very volatile and too unstable for industrial use (Atlas Powder Company, 1987; International Society of Explosives Engineers, 1998). In 1862 Alfred Noble Invented Dynamite by mixing NG with Kieselguhr, this made it less sensitive and thus easier to use for industrial purpose (Atlas Powder Company, 1987). The mixture was then packaged in paper and was

found to be relatively resistant to shock and it was named Dynamite in 1868 (Atlas Powder Company, 1987; International Society of Explosives Engineers, 1998).

2.1.3 Liquid Oxygen Explosives (L.O.X)

In 1917 the USBM investigated the use of carbonaceous material soaked in liquid oxygen. LOX was used extensively in the 160 mines in Germany in World War 1 due to the shortage of conventional explosives. The USBM then determined that carbon black was a better fuel to use with LOX and it was first used in this form in 1926 in the US. It was used extensively until 1953 when it was replaced with ammonium nitrate-based blasting agents (International Society of Explosives Engineers, 1998).

2.1.4 Ammonium Nitrate

The development of modern commercial explosives started with the synthesis of AN in 1659 by combining Nitric Acid and Ammonium Carbonate (International Society of Explosives Engineers, 1998). Ammonium Nitrate was first used in explosives in Sweden in 1867, where it was mixed with charcoal and NG (Atlas Powder Company, 1987). Alfred Noble bought the patent for the AN-based explosive (Atlas Powder Company, 1987). He had also started work on a solution to make NG-based Dynamites less sensitive to water and thus retain the quantity of NG in the explosives where there was water (Atlas Powder Company, 1987). He combined collodion and called it Gelatine Dynamite -1875 (Atlas Powder Company, 1987). In the 1870s Noble used AN as an ingredient in Dynamite, to partially replace NG, and called it Extra Dynamite (International Society of Explosives Engineers, 1998). In 1884 employees in New Jersey Plant found a way to coat nitrate with petroleum products or waxy materials (International Society of Explosives Engineers, 1998). From 1911-1971 brands of permissible explosives increased in number and additives, such as Sodium Chloride, were used to lower flame temperature (International Society of Explosives Engineers, 1998).

Dynamite accidents were also an issue where frozen dynamite caused blast-related accidents. Nitrating of ethylene glycol (ethylene glycol dinitrate) was presented as a partial replacement for nitrated glycerine. Dynamites flourished until the late 1950s, in the USA with 34 operating plants, but by 1996 only one plant had

remained in North America. The migration from packaged explosives to bulk (or pumpable) explosives started to take place by 1950s (International Society of Explosives Engineers, 1998).

In 1953 experiments were carried out with prilled fertiliser grade Ammonium Nitrate and Carbon Black or coal dust a surface coal mine in Indiana. The explosive mixture was poured into big polyethylene tubes and primed with 20 lbs (9.1 kg) charges of dynamite. The packaged explosives were then loaded into large diameter holes (International Society of Explosives Engineers, 1998).

In 1955 other mines started using AN with common No. 2 Diesel Fuel and called it ANFO. Bulk trucks were also used as early as 1956 for down-the-hole delivery of ANFO. Unfortunately, AN is hydrophilic and it cannot be used effectively in water-logged holes (International Society of Explosives Engineers, 1998).

2.1.5 Watergels

In 1957, Doctor Melvin A. Cook experimented with a mixture of AN, H₂O, guar gum (a gelling and crosslinking agent) and aluminium. This new mixture had a slurry consistency and was named a slurry, a name that persists to this day, and also known as Watergels. Manufacturing companies produced the slurry with different sensitisers and by 1960 bulk delivery of explosives down-the-hole was done. Sensitisation by chemical gassing was used from 1964 (International Society of Explosives Engineers, 1998). Sensitisation is the process of reducing the density of explosives, by adding air bubbles or glass bubbles, to the point below which detonation is possible. This density is referred to as the critical density.

2.1.6 Emulsions

Emulsions are a water-in-oil mixture (White and Robinson, 1988). Emulsions depend heavily on the colour and consistency of the oil used and they, therefore, take on different consistencies ranging from stiff putty-like composition to a fluid pumpable composition (Atlas Powder Company, 1987). The water phase consists of a saturated oxidising agent like AN, which is in the form of a droplet that is surrounded by a reducer like fuel oil (White and Robinson, 1988). In the 1960s, emulsion technology was applied to manufacture explosives (International Society

of Explosives Engineers, 1998). Commercialisation took place in the late 1970s due to the development of cap detonators (International Society of Explosives Engineers, 1998).

2.1.7 The Impact of the Omission of Explosive Data

It is clear that a wide range of explosives could have been used at the 26 Quarries where the USBM were conducting their studies. According to Nicholls *et al.* (1971), USBM did not deem it necessary to collect the explosive type data from the quarries where experiments were being held. Down-the-hole charging was available by 1964, but there is no reason to believe that it was used in all the Quarries under investigation. Packaged explosives have a smaller diameter than the blasthole to ensure smooth charging up, but explosives that are poured into the blasthole directly occupy a diameter equal to the blasthole diameter.

Where coupling is given by (Atlas Powder Company, 1987):

$$Coupling = \frac{Diameter\ of\ Explosive}{Diameter\ of\ Blasthole} \quad 2.1$$

Coupling can also be represented in percentage form. Coupling is important because 100 % coupling transfers all the explosive energy while less than 100 % transfers less. So, 100 % coupled and 80 % coupled explosives would produce different vibration levels.

According to Persson *et al.* (1994), when developing a risk assessment for a new site it is important to note that that ANFO, dynamite and an aluminised TNT-slurry, of the same charge weight, might generate different particle velocities. There is however no consensus on the contribution of explosive type on vibration levels. International Society of Explosives Engineers (1998) and Duvall and Petkof (1959) assert that the mass of explosive used is a far more significant contributor to the intensity of ground vibrations than the type of explosive used. Given the numerous possible explosive types and charging methods that could have been used at the quarries in question, it is expected that some of the variability in PPV would remain unexplained. The unexplained variability would, therefore, result in some error that cannot be reduced in the current study.

2.2 Blasting Theory

Rock breakage by explosives is a process of releasing a large amount of energy in a short space of time. The blasting process begins with the initiation of a detonator that may also be coupled with a booster. The combination of a detonator and a booster is referred to as a primer. The detonation of the detonator initiates the detonation of the booster. The booster then initiates the detonation of the explosive column. The reaction through the explosive column is propagated by the shock wavefront that is created by the detonation of the booster (Persson, Holmberg and Lee, 1994).

According to Persson *et al.* (1994), this shock wave must apply enough pressure on the explosive column so that hot spots, that have a higher temperature than that which can be dissipated through the surrounding explosive matrix, are created. Hot spots are created when gas bubbles are pressed by the advancing shock wave front, which produces a high temperature as the pressure increases to the point where the bubble bursts.

The decomposition, which is driven by hot spots, takes place in a reaction zone that lies between the Chapman-Jouguet Plane or C-J Plane and the wavefront (Persson *et al.*, 1994). When a commercial explosive is detonated, it produces a large amount of hot gas, which can be up to 1000 times the initial volume of the explosive within a few milliseconds (de Graaf, 2010).

The hot gas (about 5000 °C) generates an instantaneous pressure that pushes the particles around the borehole outwards (Cruise, 2010). The sudden acceleration of these particles from rest creates a dynamic strain wave (Persson *et al.*, 1994). The strain waves first produce plastic deformation. Beyond the plastic deformation zone, the pressure that the wave generates is not high enough to damage the rock and as a result, the wave becomes an elastic wave (International Society of Explosives Engineers, 1998). The strain wave pressure is initially much higher than the gas pressure and it is released first and then it is followed by the gas pressure (Pal Roy, 2005). As seen in Figure 2.2, the shock front moves along the explosive column and also expands into the surrounding rock.

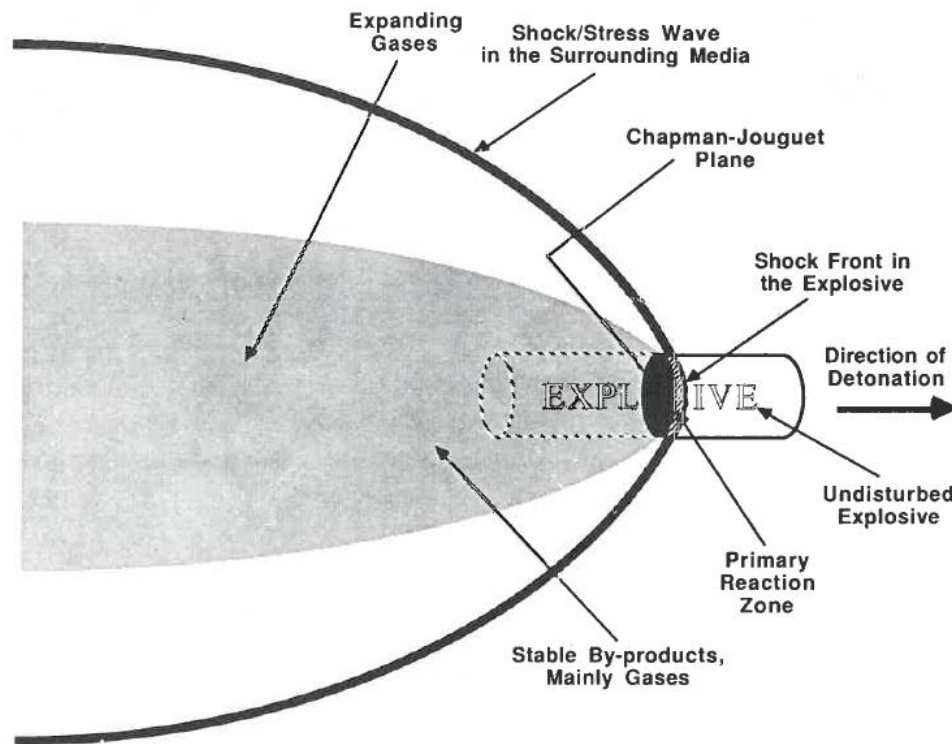


Figure 2.2: Illustration of detonation (Atlas Powder Company, 1987)

According to Persson *et al.* (1994), the shock wave produces a detonation pressure of between 1 GPa and 20 GPa, which is much higher than the Uniaxial Compressive Strength (UCS) of most rocks. The high-pressure compressive shock wave that is formed by the detonation of the explosive propagates outwards from the blasthole (see Figure 2.3) and crushes the rock surrounding blasthole (Atlas Powder Company, 1987). According Pal Roy (2005), the pressure generated can double the borehole size.

Figure 2.3 shows a seismic pulse from the detonation of one blasthole initiated from a toe primer. The seismic wave propagates outwards with the seismic waves generated at the bottom of the blasthole leading the seismic waves generated at the top of the explosive charge.

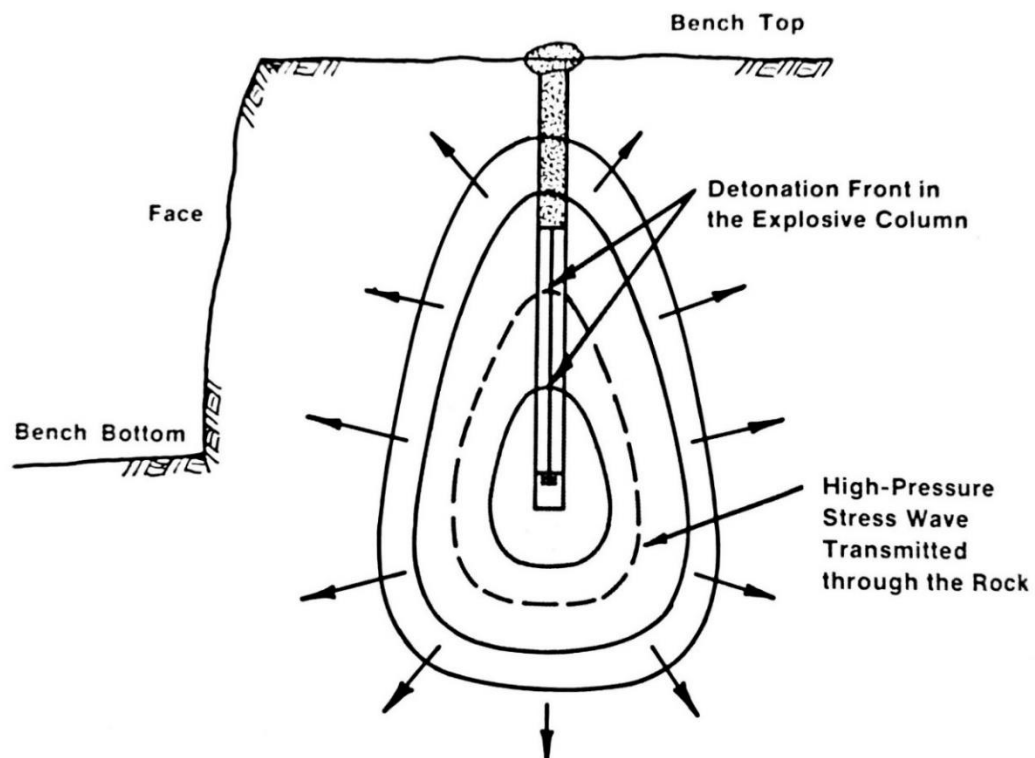


Figure 2.3: Illustration of a side view of an open pit bench during detonation (Atlas Powder Company, 1987)

As seen in Figure 2.4, the compressive stress wave produced by the detonation of the explosive crushes the rock along the blasthole wall and increases the blasthole size. The crushing of the blasthole wall creates radial cracks that further weaken the rock. The strength of the shock wave reduces and so does its effect with distance from the hole. The attenuation of the seismic wave is a significant point because if blastholes are spaced too far, the rock will not be completely broken. As this compressive wave expands, it produces tensile stress that is normal to the direction of propagation. This tensile stress is referred to as “hoop” stress, and it contributes to the widening and extension of radial cracks.

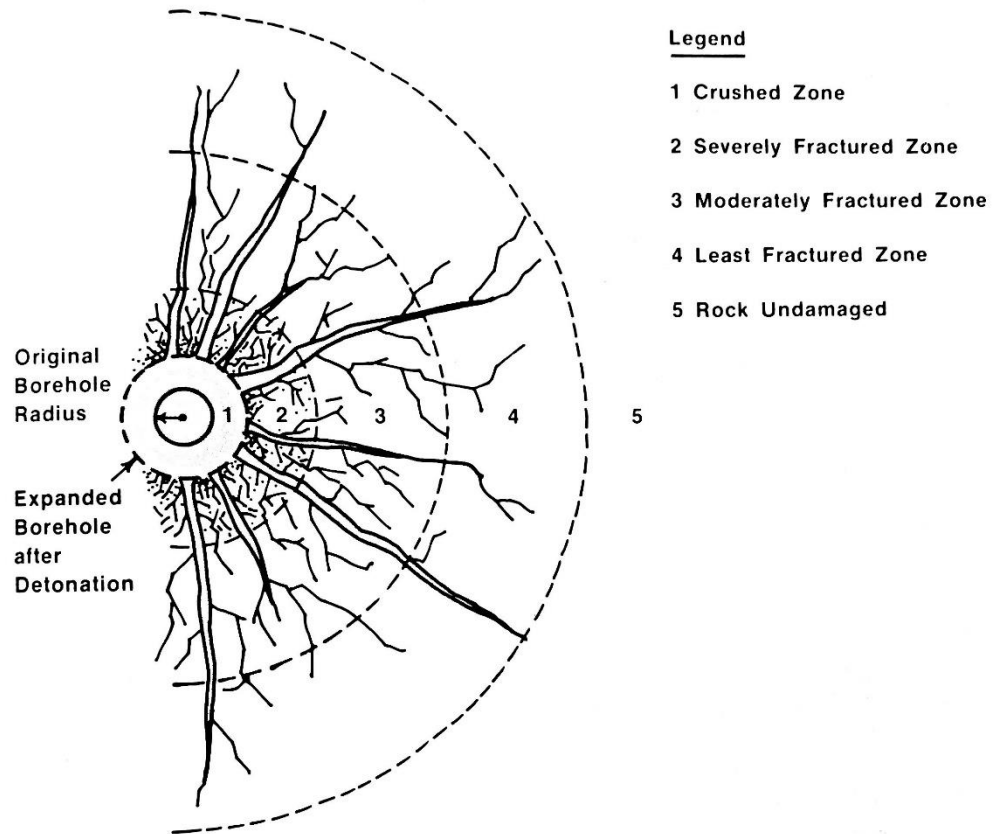


Figure 2.4: Plan view of zones of failure (Atlas Powder Company, 1987)

The speed of the shock wave is determined by the velocity of detonation (rate of reaction) of a specific explosive, for commercial explosives, this would be between 2000 to 8000 m/s (Atlas Powder Company, 1987; International Society of Explosives Engineers, 1998). In a normal bench, there will be a second free face. The shock wave will travel at supersonic speed to the free face and be reflected as a tension wave, which will cause the extension and expansion of radial cracks (Atlas Powder Company, 1987). The tensile stress significantly weakens the rock mass and allows the gas to enter into the cracks and further fragment and throw the rock mass (Atlas Powder Company, 1987). Further fragmentation of the rock may take place as a result of in-flight collision of the individual rocks (Atlas Powder Company, 1987).

As seen in Figure 2.5, the compressive wave turns into a tensile shock wave, which is high enough to cause further failure and increase the extent of fracturing around the blasthole. These stresses are effective because the UCS of rocks is 10 to 15

times higher than the Uniaxial Tensile Strength (UTS) of the same rocks (Atlas Powder Company, 1987).

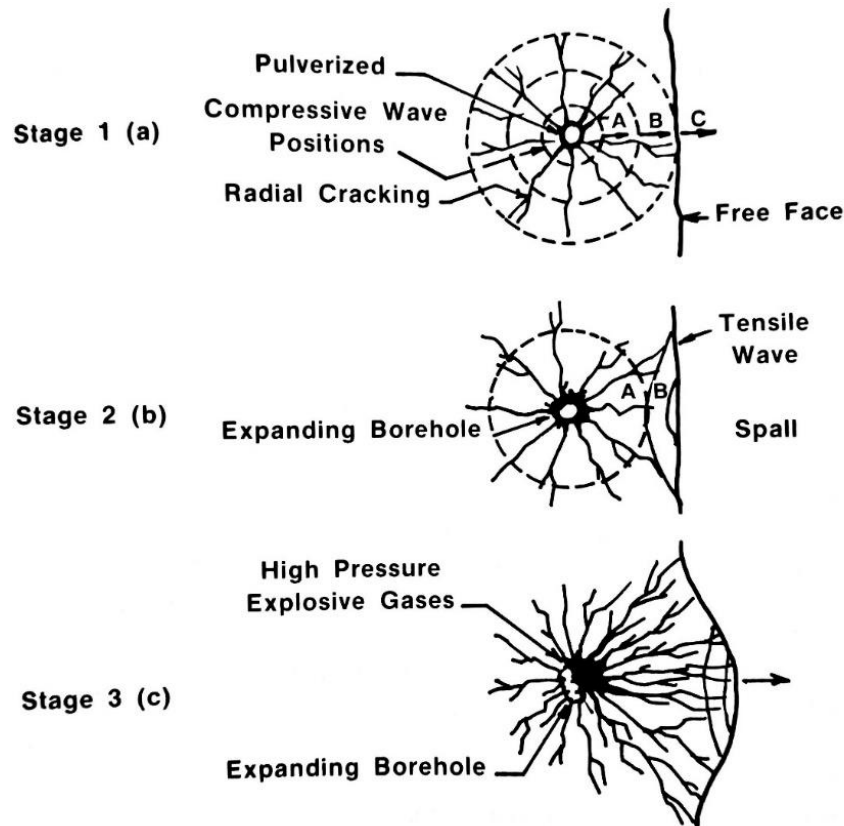


Figure 2.5: Plan view of fractures opened up and propagated by gas expansion (Atlas Powder Company, 1987)

The tensile stresses widen and extend the radial fractures created by the compressive wave. The gas produced by the explosion is much slower than the stress waves. The gas pressure builds until it is high enough to widen the radial fractures further and also cause the highly fractured rock to move. Stemming prevents the premature escape of gas and thus promotes the build-up of gas that is required to move rocks. Further breakage of the rock can occur due to collision with other rocks on the ground and partial crushing by loading machinery.

2.3 Blast-Induced Ground Vibrations

The strain wave produced, starts at a destructive amplitude and subsequently attenuates exponentially from the blast area, eventually becoming a sound wave (Cruise, 2010). Figure 2.6 illustrates the attenuation of the seismic wave generated

by blasting. There is, therefore, a large difference between near field vibration measurements and far-field vibration measurements. This report is concerned with the latter.

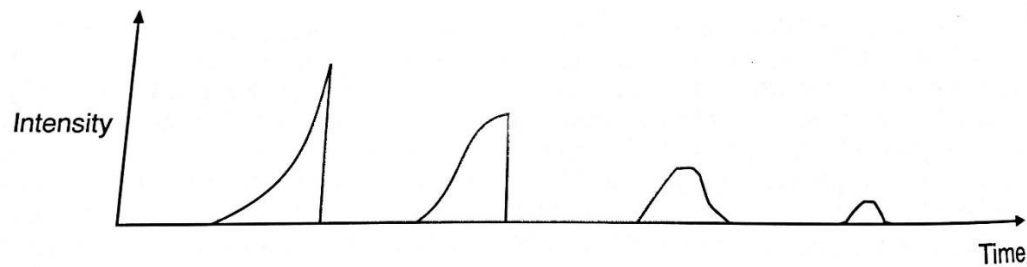


Figure 2.6: Attenuation of seismic waves (Cruise, 2010)

The shock wave loses energy through geometric spreading. According to Pal Roy (2005), geometric spreading occurs as the shock wave propagates outward from the source and encounters rocks particles it excites. The spreading of the wavefront over an increasing area, as illustrated in Figure 2.7, produces an attenuation of the wave energy. This spreading of the wavefront is also referred to as geometrical damping (Pal Roy, 2005).

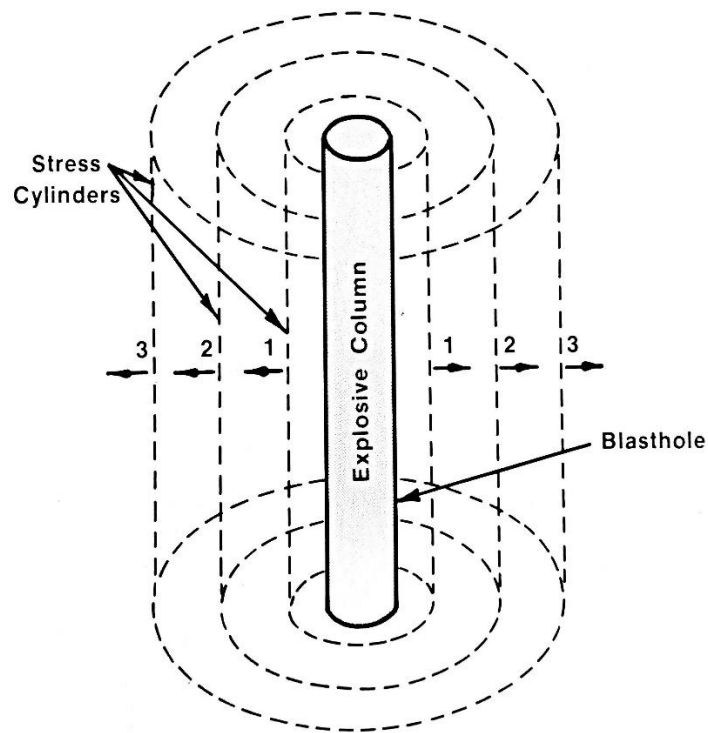
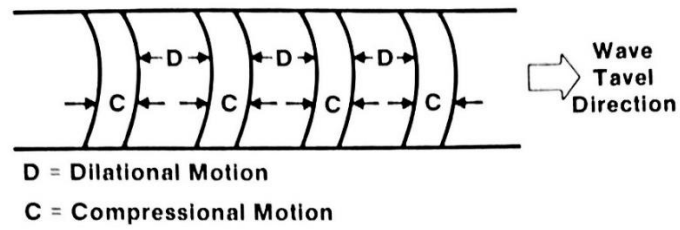


Figure 2.7: Geometric spreading of a cylindrical charge (Atlas Powder Company, 1987)

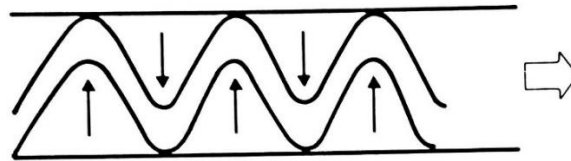
Figure 2.7 illustrates a very theoretical and idealistic process, but it does provide a reasonable explanation for the reduction in vibration intensity with distance. The shock waves can travel to large distances from the source of the explosion, depending on the total mass of explosive used per delay.

There are two types of seismic waves that are produced by the detonation of an explosive in a ground, which are body waves and surface waves (Bollinger, 1980; Dowding, 1985). Figure 2.8 shows the four main forms of seismic waves, which are Longitudinal Waves, Transverse Waves, Rayleigh Waves and Love Waves.

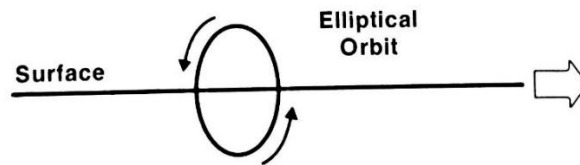
(a) Longitudinal Waves



(b) Transverse Waves



(c) Rayleigh Wave



(d) Love Wave

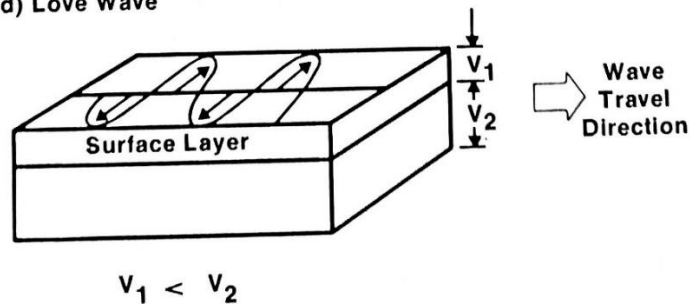


Figure 2.8: Illustration of the four different forms of seismic waves (Atlas Powder Company, 1987)

Body waves are also an important part of this report because according to Pal Roy (2005), up to 90 % of body waves can be converted into surface waves within a short distance as seen in Figure 2.9. The conversion of body waves is due to the fact that they are affected by the discontinuities and layers in the rock mass (Bollinger, 1980; Dowding, 1985). Primary or longitudinal waves (P waves) and secondary or

shear waves (S waves) are examples of body waves (Bollinger, 1980; Dowding, 1985). Figure 2.9 also shows the role of surface waves in disturbing surface structures.

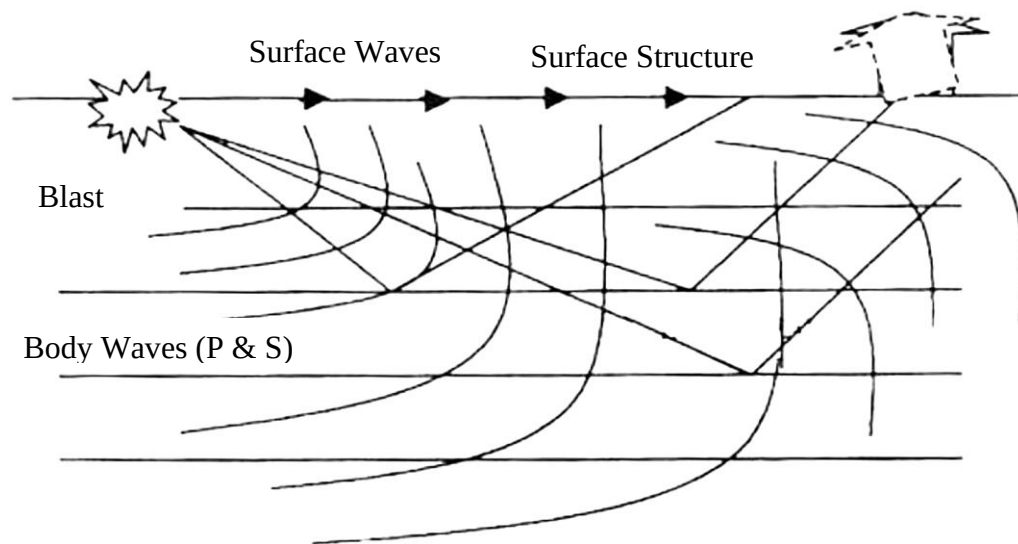


Figure 2.9: Body and surface waves (Khandelwal and Singh, 2007)

Figure 2.10 shows time-histories of the seismic wave arrival times at 170 m, 245 m and 300 m. The time-history in Figure 2.10 has a short time scale and can thus not show all the waves at 300 m. At 170 m, all the waves can be seen, but at 300 m, only the R and S waves are observed. This is because the P-wave is the fastest seismic wave followed by the S-wave, which has a velocity that is 0,6 the velocity of the P-wave and the R-wave is the slowest wave at 0,9 the velocity of the S-wave (International Society of Explosives Engineers, 1998).

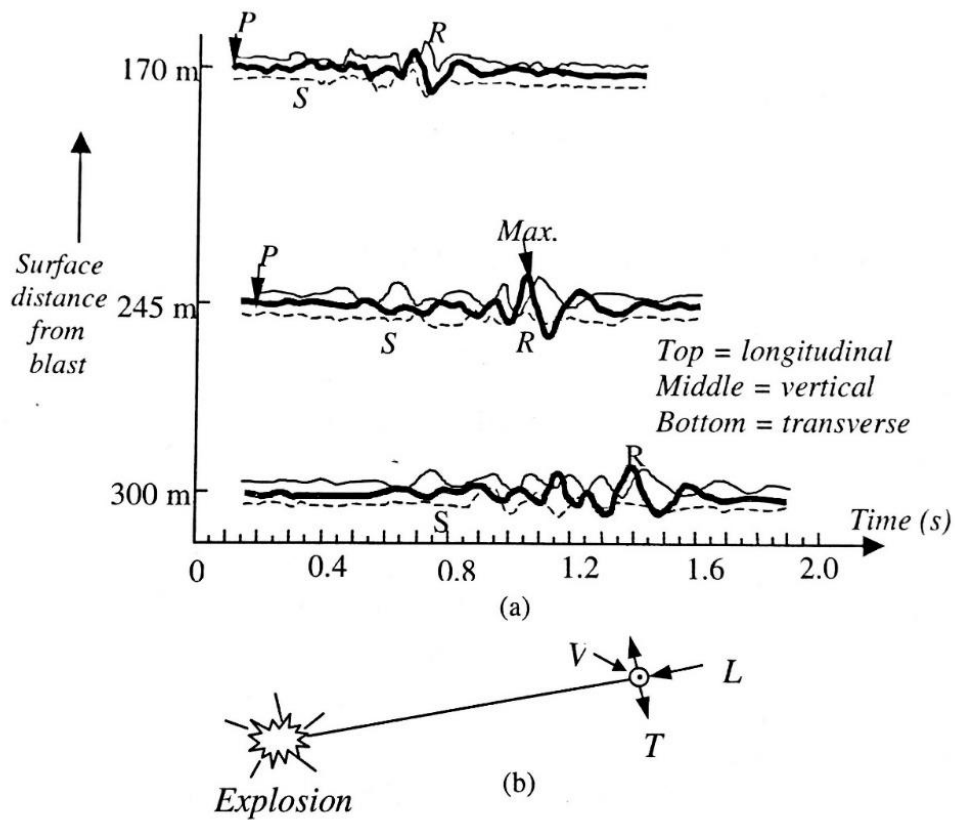


Figure 2.10: Wave time history (Pal Roy, 2005)

Surface waves travel on the surface of the ground and do not go deeper than one wavelength into the rock (Bollinger, 1980; Dowding, 1985). They are affected by surface structures and material composition of the surface rock or soil (Bollinger, 1980; Dowding, 1985; Pal Roy, 2005). Rayleigh and Love waves are types of surface waves (Bollinger, 1980; Dowding, 1985). These waves attenuate quickly with an increase in distance and have a much lower influence on far-field studies (Pal Roy, 2005). In general body, waves are more significant when studying the nearfield influence of blast-induced ground vibrations, such as the study of the influence of BIGV on high wall stability (Pal Roy, 2005). Far-field studies normally focus on the influence of BIGV on structures of significance such as houses, service structures, caves, etc. (Pal Roy, 2005).

When evaluating the effect of surface waves, it is important to note that there is a difference between wave velocity or propagation velocity and particle velocity. The wave velocity is the rate at which the wave propagates and is governed by the rock

acoustic wave properties. The particle velocity is the rate at which the particle oscillates and PPV is the maximum velocity this particle attains. The particle velocity is orders of magnitudes lower than the wave velocity. It is, however, the particle velocity that is responsible for the perceptible movement of the ground (Pal Roy, 2005).

2.4 Background Damage Criteria

This section describes why the USBM chose to use PPV as opposed to PPD, PPA or even Energy Ratio. PPD is defined as the maximum distance from the point of rest that particle travels and PPA is the maximum change in velocity with respect to time that the particle attains (Atlas Powder Company, 1987). In 1930, when the USBM started its investigations into blast-induced ground vibrations one of their main concerns was on the impact of blasting activities on surrounding structures. According to Duvall and Fogelson, (1962) damage criterion is the magnitude of one or more phenomena associated with blast-induced ground vibrations, which when exceeded causes the damage of a structure. These phenomena are discussed in this section.

2.4.1 USBM Experiments

In 1927 Rockwell measured PPD from quarry blasting using displacement seismographs (Nicholls *et al.*, 1971). Rockwell then concluded that blasting from quarries would not cause damage to properties greater than 200-300 feet (67-100 m) from the blast site (Duvall and Fogelson, 1962). According to Duvall and Fogelson (1962), Rockwell was one of the first people to call for the measurement of vibration levels of quarry blasting and establish a relationship between vibration levels with charge size and distance.

In the seven years between 1935 and 1942, the USBM researched the seismic effects of quarry blasting and the results of the experiments were recorded in Bulletin 442 (Duvall and Fogelson, 1962). The experiments included 14 buildings ranging from one to three stories, which were built from frames, brick or stone (Duvall and Fogelson, 1962). No concrete or steel reinforcement buildings were tested. Vibration amplitudes were measured using displacement seismometers that

measured all three components (Duvall and Fogelson, 1962). The damage criteria (Table 2.1), as stated in the report, was associated with acceleration because the authors believed that an acceleration equivalent to gravity (1.0 g), i.e. 9.81 m/s² would cause lift (Thoenen and Windes, 1942). Unfortunately, their conclusions were not based on statistical analysis (Duvall and Fogelson, 1962).

Table 2.1: PPA damage criteria (Thoenen and Windes, 1942).

Criteria (Peak Particle Acceleration – PPA)	Cause
< 0.1 g	No Damage
0.1 g – 1.0 g	Caution
> 1.0 g	Damage

2.4.2 Energy Ratio

The next significant study of the effects of ground vibrations was conducted in 1949 by FJ Crandell and his criteria of damage was based on energy ratio – see Table 2.2 (Duvall and Fogelson, 1962). In his experiments, Crandell measured ground vibrations in the ground next to 1000 residential homes, two storey business buildings, schools and churches (Nicholls *et al.*, 1971). Crandell defined energy ratio as acceleration squared divided by frequency squared, which relates to the energy that is transmitted through the ground (Duvall and Fogelson, 1962; Nicholls *et al.*, 1971). Crandell also noted that displacement and frequency could also be used to determine energy ratio (Nicholls *et al.*, 1971).

$$\text{Energy Ratio} = \frac{\text{Acceleration}^2}{\text{Frequency}^2} \quad 2.2$$

Table 2.2: Energy Ratio damage criterion (Duvall and Fogelson, 1962)

Criteria (Energy Ratio)	Cause
< 3	Safe
3 - 6	Caution
> 6	Danger

2.4.3 Swedish Experiments

In 1957, Langefors, Kihlstrom and Westerberg published the results of their blast vibration studies. The data were recorded during a reconstruction project in Stockholm, Sweden. The measurements were taken using Cambridge Vibrographs that measures displacement. After taking a few measurements of ground vibrations, the researchers realised that the magnitude of ground vibrations in the horizontal direction was the same as the vibration levels in the vertical direction, it was then decided that only vertical measurements would be taken. They used the data to develop damage criteria, as shown in Table 2.3, which is based on the velocity of ground motion in the vertical direction (Duvall and Fogelson, 1962).

Table 2.3: Swedish damage criteria (Duvall and Fogelson, 1962)

Criteria (Peak Particle Velocity – PPV)	Cause
< 2.8 in./s	No Noticeable Damage
≥ 4.3 in./s	Fine Cracks and Fall of Plaster
≥ 6.3 in./s	Cracking
≥ 9.1 in./s	Serious Cracking

2.4.4 Canadian Experiments

In 1959, Edwards and Northwood published the results of blast vibration experiments on six buildings that needed to be destructed to make way for the construction of power facilities along the St. Lawrence Seaway, Canada. The houses were constructed of frame or bricks and all contained basements built with stone. Vibration measurements were taken using accelerometers, velocity gages and displacement seismographs. They concluded that either velocity or acceleration could be used as damage criteria for two soil types, but velocity was the most suitable quantity. The data, however, was produced by the accelerometers and seismographs due to malfunctioning velocity gages (Duvall and Fogelson, 1962). The damage criteria are shown in Table 2.4.

Table 2.4: Canadian damage criteria (Duvall and Fogelson, 1962)

Criteria (Peak Particle Velocity – PPV)	Cause
< 2.0 in./s	Safe
2.0 – 4.0 in./s	Caution
> 4.0 in./s	Damage

2.4.5 Determination of Preferred Damage Criteria

According to Duvall and Fogelson (1962), there was a lot of work done on the seismic effects of blasting operations and some states adopted different damage criteria. Pennsylvania adopted 0.03 of an inch as a safe blasting limit, New Jersey and Massachusetts, US Corps of Engineers and the New York State Power Authority adopted the criteria of energy ratio of 1 as the allowable limit. Duvall and Fogelson (1962), stated that by 1962 researchers had also started using frequency spectrum analysis to predict damage to structures. It was, therefore, important for the USBM researchers to determine conclusively, which entity should be measured.

Regression analysis which included horizontal and vertical displacement together with the associated frequency data were classified into three groups. The first was major damage, which refers to large cracks and falling plaster, the second was minor damage and it referred to fine plaster cracks and the opening of old cracks and the final was no damage. The displacements in the data ranged from 10 to 350 mm and the frequencies ranged from 3 to 30 Hz. A correlation analysis was conducted on all three datasets from the three experiments where data was available for analysis, unfortunately, due to insufficient data, the energy ratio data was not analysed in this report. The results show that particle velocity correlates well with damage to structures and is thus a better predictor of damage (Duvall and Fogelson, 1962). Figure 2.11 shows the summary of PPVs observed in the experiments described in Section 2.4 and the level of damage they caused.

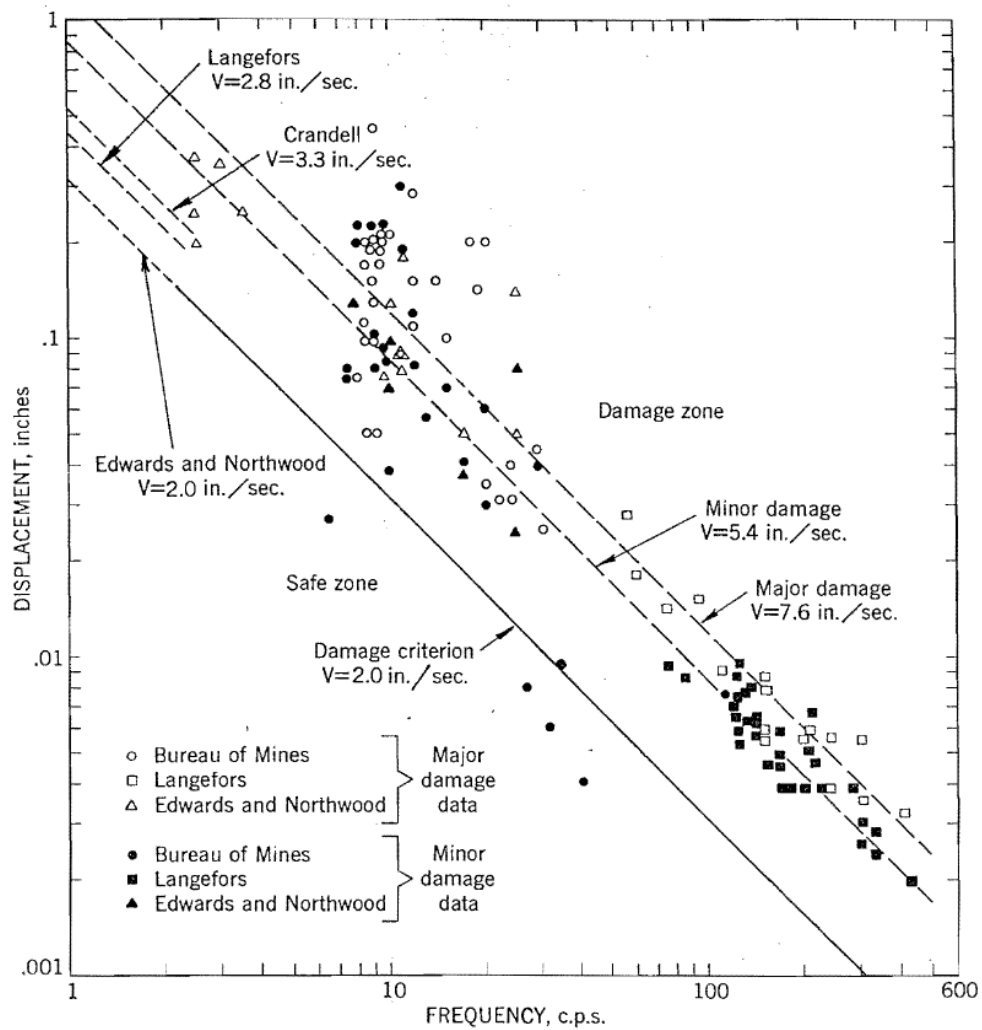


Figure 2.11: PPV damage criteria 1962 (Duvall and Fogelson, 1962)

Duvall and Fogelson (1962), concluded that particle velocity was more closely associated with the damage of structures than particle displacement or particle acceleration. The choice of PPV was beneficial in that, according to the International Society of Explosives Engineers (1998), particle velocity is less sensitive to changes in geology than particle displacement or particle acceleration. Results from different surface mines can thus be used to improve the prediction of Peak Particle Velocities on a specific site, especially when the operation is new and there is insufficient blast vibration data.

2.4.6 Why is PPV Prediction Still Important?

In 1974, the USBM started to conduct another series of experiments where they were assessing the damage of surface structures and potential annoyance of communities near mines due to BIGV. Direct measurements were taken in 76 homes over 219 production blasts. This data was combined with blasting data from nine other blasting studies including the three from USBM Bulletin 656. The investigation showed that PPV was a key contributor to damage of surface structure and they determined that safe levels of PPV for residential type structures was 12.7 mm - 50.8 mm/s. They also noticed that PPV of 12.7 mm - 19.05 mm/s was felt by 5-10 % of the people near the surface mines, which meant that surface mines could receive a lot of complaints even if the mine generates low PPVs. From this investigation, safe blasting criteria, which is based on PPV and Frequency, was developed as shown in Figure 2.12. Siskind *et al.* (1980) also found that frequencies of 4-12 Hz caused the most damage and in particular 10Hz. Masonry structures were at greater risk than wood houses and in general coal mines cause more damage than quarries and construction sites (Siskind *et al.*, 1980). Wooden houses were less likely to sustain damage because they are more flexible and tolerated a greater extent of deformation before failure took place.

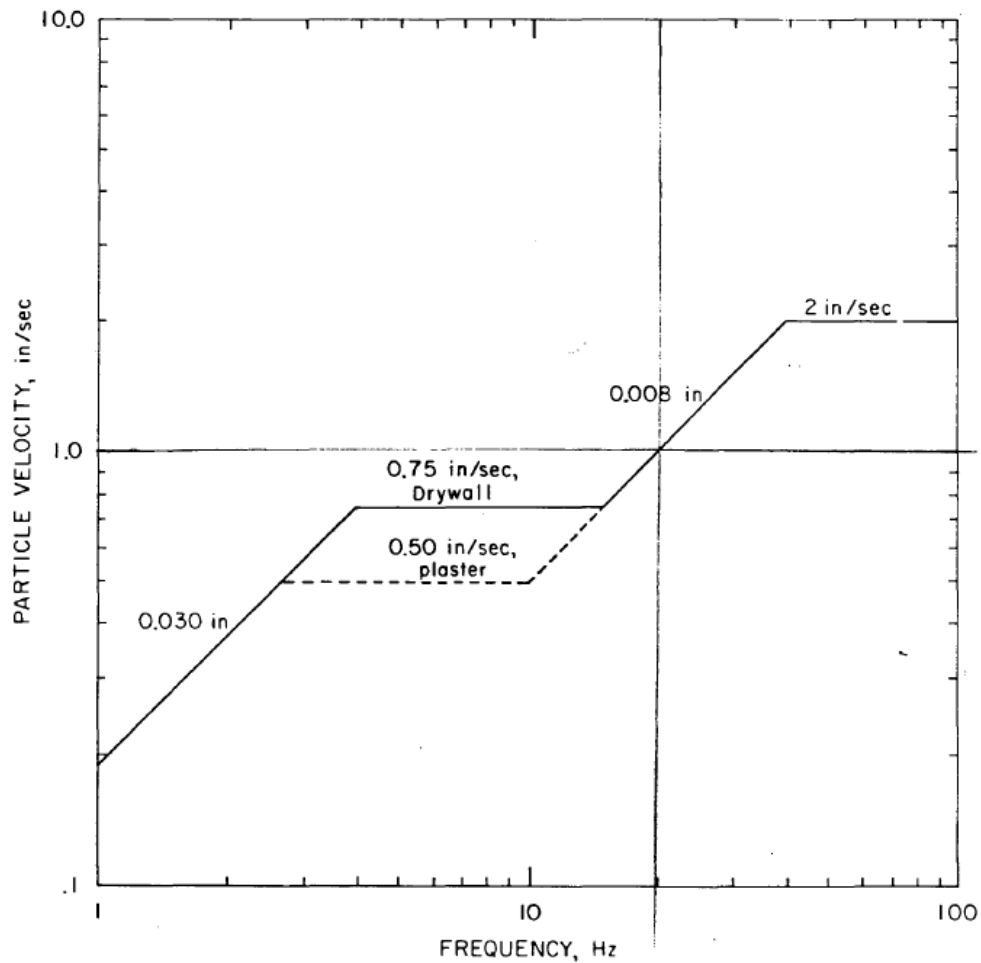


Figure 2.12: Safe blasting vibration levels for houses (Siskind *et al.*, 1980)

Coal mines caused more damage because they used more explosives per blasthole, they broke more rock per blast, and the softer nature of the rock and soil aided in the formation of long wavelength and low-frequency surface waves (Siskind *et al.*, 1980). According to the Atlas Powder Company (1987), seismic waves with long wavelength travel longer distances than seismic waves with a shorter wavelength. Low-frequency waves are also less likely to be refracted by discontinuities and they cause damage to structures by moving two sides of a structure in opposite directions.

It was clear according to the damage criteria that PPV and Frequency were properties to consider along with the property of the rock in which the wave propagates, the quantity of explosive per delay and the distance from the blast (Siskind *et al.*, 1980). Siskind's Damage Criteria is still being used widely in South

Africa to determine if a blast design will produce PPV in the safe zone that is below the line on Figure 2.12 (Zeeman, 2017).

In addition to the above-mentioned safe blasting levels, in South Africa for example, institutions like SANRAL, ESKOM and TRANSNET also provide maximum PPV levels for mines operating next to roads, pipelines, railway and power lines (Table 2.5).

Table 2.5: Maximum PPV levels next to critical structures in South Africa (Zeeman, 2017)

Structure	Maximum allowable PPV (mm/s)
National roads/tar roads	150
Steel pipelines	50
Electric power lines	75
Railway	150
Concrete aged less than three days	5
Concrete after ten days	200
Water wells	50
Telecoms tower	50
Mud houses	6

Other researchers have researched by measuring the response of buildings to blast vibrations. Table 2.6 shows a selection of damage criteria that are currently in use.

Table 2.6: Selection of damage criteria (Tiile, 2016)

Predictor	Effects and damage	Maximum allowable PPV (mm/s)
Langefors <i>et al.</i> (1958)	No damage	<50
	Fine crack	100
	Cracks	150
	Serious cracks	225
Edwards and Northwood (1960)	Safe zone	<50
	Damage zone	100-150
Duvall and Fogelson (1962)	Major damage (95 %)	50
Nicholls and Johnson (1971)	Safe zone (95 %)	>50
	Damage zone	<50
Indian standard (1973)	Soil, weathered or soft rock	70
	Hard rock conditions	100

Other notable damage criteria were developed in Germany and are shown in Table 2.7.

Table 2.7: DIN 4150-3 damage criteria (Aloui *et al.*, 2016)

Structure	Maximum allowable PPV (mm/s)		
	10 Hz	10 – 50 Hz	50 – 100 Hz
Industrial buildings	20	20 - 40	40 - 50
Residential buildings	5	5 - 15	15 - 20
More sensitive buildings than above	3	3 - 8	8 - 10

2.4.7 The Choice between PPV and PVS

There are two ways of representing PPV data. The first one takes the maximum PPV component of the three directions measured and the other is a vector sum of the PPV measured in all three directions and it is referred to as Peak Vector Sum (PVS) (Bollinger, 1980). The equations for PPV and PVS are (Bollinger, 1980):

$$PPV = \max (PPV_L, PPV_T, PPV_V) \quad 2.3$$

$$PVS = \sqrt{PPV_L^2 + PPV_T^2 + PPV_V^2} \quad 2.4$$

Where, the L, T, V stand for longitudinal, transverse and vertical.

It is clear to see that the PVS for a single blast would be larger than the PPV of the same blast. According to Bollinger (1980), the PVS is unnecessarily large because each of the peak velocity components occurs at different times. Empirical observations of damage were also made using single component peaks (Bollinger, 1980). This report thus uses single component peaks (PPV) as opposed to vector sums (PVS).

2.5 Model Validation

Model validation is a process of testing the performance of a model given a specified criterion. The purpose of this section was to discuss the role of validation in model selection and the different criteria used in the current research.

2.5.1 Correlation

Correlation is a measure of how much of the variability of $\mathbf{y}$ is explained by $\mathbf{x}$, and it is expressed in values from 0 to 1. Correlation is given by (James *et al.*, 2013):

$$Cor(\mathbf{x}, \mathbf{y}) = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} \quad 2.5$$

Where,

- $Cor(\mathbf{x}, \mathbf{y})$ of 0 indicates a change in $\mathbf{x}$ does not produce a response in $\mathbf{y}$
- $Cor(\mathbf{x}, \mathbf{y})$ of 1 indicates that $\mathbf{y}$ is completely dependent on $\mathbf{x}$.

2.5.2 Coefficient of Determination

The coefficient of determination (R^2) is a measure of the proportion of the variation in the data that is explained by a function. R^2 can be expressed as a number between 0 and 1 or in percentage form. R^2 is used in conjunction with error measures to show the fit of a model to training data and show the accuracy of a model's prediction (James *et al.*, 2013).

$$R^2 = \frac{TSS - RSS}{TSS} \quad 2.6$$

Where TSS is the total sum of squares and is given by (James *et al.*, 2013):

$$TSS = \sum_{i=1}^n (y_i - \bar{y})^2 \quad 2.7$$

Where y_i represents observations in the test data and $\bar{y}$ represents the mean of the observed responses in the test data (James *et al.*, 2013).

RSS is the residual sum of squares and it is given by (James *et al.*, 2013):

$$RSS = \sum_{i=0}^n (y_i - y_i^*)^2 \quad 2.8$$

According to James *et al.* (2013), TSS indicates the initial variation in the test data and RSS measures the amount of variation that is left unexplained by the model predictions. An R^2 value of 0 (or 0 %) thus explains none of the variation in the test responses while an R^2 of 1 (or 100 %) explains all the variation in the test responses.

2.5.3 Residuals

The coefficient of determination is an incomplete measure of a model's accuracy. The second part is a measure of how far the model's prediction is from the measured values. According to Kuhn and Johnson (2013), one of the most used error measure for regression problems is RMSE.

$$RMSE = \sqrt{MSE} \quad 2.9$$

RMSE is preferred in part because it is an error measure that is in the response parameter's units and enables a direct comparison about how far, on average, the model's predictions are from the observed values. Residual plots can also be used

along with RMSE to improve the researchers understanding about how the model performed on individual predictions.

2.5.4 Cross-Validation

In this report, eight machine learning algorithms were evaluated on training data. One of the eight models was chosen for test 1 and test 2. Cross-validation is used to produce a good approximation of the out-of-sample prediction error of the eight models. The type of cross-validation used in this report is known as k-fold cross-validation. According to Hastie *et al.* (2017), k values of 5 or 10 are usually chosen.

In the cross-validation process, the training data is divided into k roughly equal parts and the models are trained using k-1 parts and evaluated on the kth part (Hastie, Tibshirani and Friedman, 2017). The validation process produces an estimate of the out of sample prediction error (Hastie *et al.*, 2017). The cross-validation prediction error estimate is therefore given by (Hastie *et al.*, 2017):

$$CV(f^*) = \frac{1}{n} \sum_{i=1}^n L(y_i, f_{-k(i)}^*(x_i)) \quad 2.10$$

Where,

- n is the total number of observations in the training data,
- y_i is the i^{th} observation,
- $f_{-k(i)}^*(x_i)$ is the i^{th} prediction of the model fitted using k-1 data and
- $L(y_i, f_{-k(i)}^*(x_i))$ is a function that computes the i^{th} estimate prediction error.

The final estimate of the prediction error ($CV(f^*)$) is an average of the n prediction errors.

When the model being evaluated uses tuning parameters, the prediction error estimate is given by (Hastie *et al.*, 2017):

$$CV(f^*, \gamma) = \frac{1}{n} \sum_{i=1}^n L(y_i, f_{-k(i)}^*(x_i, \gamma)) \quad 2.11$$

Where γ represents a tuning parameter or a combination of two tuning parameters (Hastie *et al.*, 2017).

At the end of the cross-validation process, a model with the lowest prediction error is chosen and is fitted to all the data (Hastie *et al.*, 2017). The chosen model can then be compared with the results from other machine algorithms and the best algorithm can thus be chosen. Cross-validation has been shown to solve the overfitting problem along with finding a good balance of the bias-variance tradeoff by increasing the chances of a minimum out-of-sample error.

The test data was only used to evaluate the performance of the final machine learning model and the empirical models. R^2 , RMSE and Mean Absolute Error (MAE), were used to evaluate the performance of the models.

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - y_i^*| \quad 2.12$$

These measures are also used in Caret and thus provide a good understanding of the relationship of a model's performance during cross-validation and its performance during the testing phase. It was therefore expected that an algorithm's performance during cross-validation provided a good estimation of how the model would perform on the test data.

2.6 Empirical Models

Empirical models are the most used methods for predicting PPV in mining operations, largely because of their ease of use and their effectiveness in helping control PPV. Their success is also helped by the continued interest from research groups, academics and explosives manufacturing companies that has led to the development of new scaled distance formulae (Table 2.8).

Table 2.8: Summary of various PPV prediction models (Duvall *et al.*, 1963; Kumar *et al.*, 2016; Pal Roy, 2017)

No.	Researchers	Empirical models
1	Duvall <i>et al.</i> , 1963 - USBM	$v = k(R/Q^{1/2})^{-m}$
2	Langefors and Kihlstrom (1963)	$v = k(Q/R^{2/3})^{m/2}$
3	Ambraseys and Hendron (1968)	$v = k(R/Q^{1/3})^{-m}$
4	Nicholls <i>et al.</i> (1971)	$v = 0.362(R/Q^{1/2})^{-1.63}$
5	Bureau of Indian Standards (1973)	$v = k(Q_{\max}/R^{2/3})^m$
6	Siskind <i>et al.</i> (1980)	$v = 0.828(R/Q^{1/2})^{-1.32}$
7	Ghosh and Daemen (1983)	$v = k(R/Q^{1/2})^{-m}e^{-aR}$
8	Ghosh and Daemen (1983)	$v = k(R/Q^{1/3})^{-m}e^{-aR}$
9	Pal Roy (1991)	$v = n + k(R/Q^{1/2})^{-1}$
10	Pal Roy (1991)	$v = n + k(R/Q^{1/3})^{-1}$
11	CMRI (1993)	$v = n + k(R/Q^{1/2})^{-1}$
12	Kahriman (2002)	$v = 1.91(R/Q^{1/2})^{-1.13}$
13	Kahriman (2004)	$v = 0.34(R/Q^{1/2})^{-1.79}$
14	Kahriman <i>et al.</i> (2006)	$v = 0.561(R/Q^{1/2})^{-1.432}$
15	Rai and Singh (2004)	$v = kR^{-m}Q_{\max}e^{-\alpha}$
16	Nicholson (2005)	$v = 0.438(R/Q^{1/2})^{-1.52}$
17	Rai <i>et al.</i> (2005)	$Q_{\max} = k(v(R/Q^{1/2})^2)^m$
18	Ozer (2008) (sandstone)	$v = 0.257(R/Q^{1/2})^{-1.03}$
19	Ozer (2008) (shale)	$v = 6.31(R/Q^{1/2})^{-1.9}$
20	Ozer (2008) (limestone)	$v = 3.02(R/Q^{1/2})^{-1.69}$
21	Ak <i>et al.</i> (2009)	$v = 1.367(R/Q^{1/2})^{-1.59}$
22	Badal (2010)	$v = 0.29(R/Q^{1/2})^{-1.296}$
23	Mesec <i>et al.</i> (2010)	$v = 0.508(R/Q^{1/2})^{-1.37}$
24	Pal Roy (2016)	$v = k(R/a_t)^{-m}$, $a_t = (3Q_t/4\pi\rho)^{1/3}$
25	Pal Roy (2016)	$v = k(R/a_d)^{-m}$, $a_d = (3Q_d/4\pi\rho)^{1/3}$

This, of course, means that a mine operator's first job is to figure out which of these 25 empirical formulae to use for their project site. The current research focused on two empirical formulae, which were the USBM formula and the formula developed by Ambraseys and Hendron.

(Duvall *et al.*, 1963) – USBM:

$$PPV = k(R/Q^{1/2})^{-m} \quad 2.13$$

Ambraseys and Hendron (1968):

$$PPV = k(R/Q^{1/3})^{-m} \quad 2.14$$

Where,

- PPV – Peak Particle Velocity (mm/s),
- k and m – Dimensionless site-specific constants
- R – Distance from the source of the blast to the point of interest (m),
- Q – Mass of explosive per delay (kg)

The only difference between these two equations is in the scaled distance. This difference is the result of a difference in opinion and method of derivation. Figure 2.13 shows cylindrical and spherical geometrical spreading.

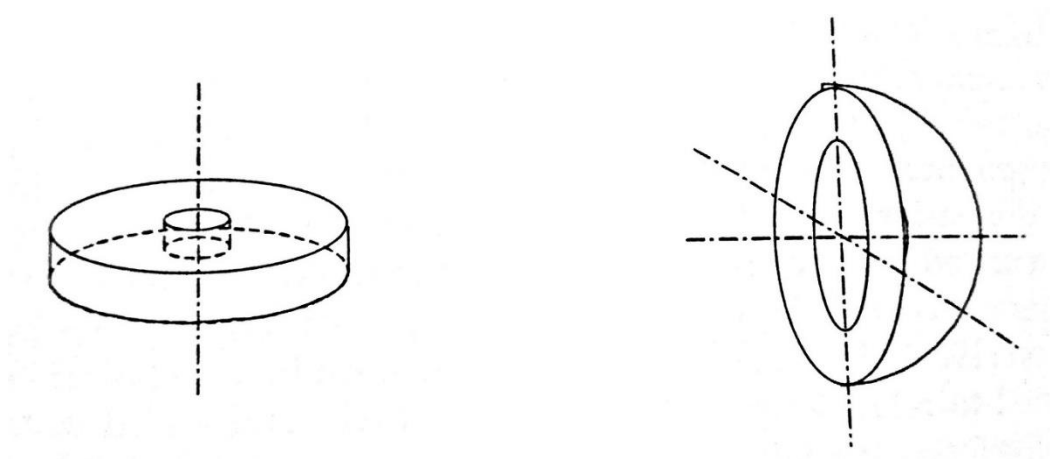


Figure 2.13: Cylindrical and spherical geometric spreading (Pal Roy, 2005)

The square root scaling distance was adopted by the USBM and it assumes that for charges with an L/D of greater than six, where L represents the charge length and D is the diameter of the blasthole (Nicholls *et al.*, 1971). This approach assumes

that the seismic wave propagates outwards in the shape of a cylinder. According to Nicholls *et al.* (1971), the cube root scaling distance is only used by the USBM when L/D is less than 6 where the wave propagation approximates spherical spreading. The square root was determined by using linear regression to estimate the value of α in Equation 2.15 and it was found to be approximately 0.5 (Devine *et al.*, 1966; Nicholls *et al.*, 1971).

$$PPV = k(R/Q^\alpha)^{-m} \quad 2.15$$

However, Ambraseys and Hendron (1968), disagreed with this approach and preferred that the value of α be determined by dimensional analysis. When using this approach α has to be 1/3. This fact had already been acknowledged by Duvall and Petkof (1959), but had previously argued that the cubed-root scaling law assumed that the peak pressure generated in the blasthole by the detonation explosive does not change with charge size. However, if the confinement on the explosive or its properties varies with size, then deviation from the cubed-root scaling law can be expected (Duvall and Petkof, 1959).

2.7 Machine Learning Models

Machine learning is a subset of Artificial Intelligence and it refers to the ability of an algorithm or model to learn from data. This algorithm can be trained using data with a labelled target function, or unstructured data can be used. The first instance refers to supervised learning and the second is called unsupervised learning. All the examples of machine learning usage described below used supervised learning to train the algorithm. Machine learning algorithms are used to solve problems which are related to medicine, mining, finance, insurance, sales, etc. (Alpaydin, 2010; Tiile, 2016). In Mining, they are used to solve problems related to fragmentation prediction, fly-rock prediction, air-blast prediction and BIGV prediction. The key benefit of machine learning algorithms is that they can be used to make predictions in complex systems where accurate or analytical models that represent the interactions between input parameters and the output cannot be built (Wang and Witten, 1997).

2.7.1 Background

The basic purpose of machine learning algorithms is to establish a relationship between the dependent variables ($\mathbf{y}$) and the independent variables ($\mathbf{x}$). This estimated relationship takes the form of a function ($f(\mathbf{x})$) that can be used on unseen data to make predictions or used to develop a greater understanding about how $\mathbf{x}$ affects $\mathbf{y}$ (James *et al.*, 2013). The former is referred to as prediction and the latter is Inference (James *et al.*, 2013). This report focuses on the predictive function of Machine Learning. The process of mapping inputs to outputs to develop a formal relationship is referred to as function approximation and takes the form (James *et al.*, 2013):

$$\mathbf{y} = f(\mathbf{x}) + \epsilon \quad 2.16$$

Where,

- $\mathbf{y}$ is the output being measured
- $f(\mathbf{x})$ is a fixed but unknown function that provides systematic information that $\mathbf{x}$, represented by $x_1, x_2, \dots, x_p$ in multivariate analysis, gives about $\mathbf{y}$ (James *et al.*, 2013).
- ϵ is a random error term that does not vary with $\mathbf{x}$ and has a mean of zero

In Equation 2.16, $f(\mathbf{x})$ can only be approximated and that is the main aim of Machine Learning. When making predictions, approximate function $f^*(\mathbf{x})$, makes use of the known relationship between $\mathbf{y}$ and available data ($x_1, x_2, \dots, x_p$) to make predictions about $\mathbf{y}$ (James *et al.*, 2013). $\mathbf{y}$ here represents a parameter of interest (PPV) at a specific location, which may be hard to obtain because of the numerous locations that need to be protected from blast damage. This is not always possible, so a prediction model is used and a value of $\mathbf{y}^*$ is obtained for points that can't be measured. For the relationship given by (James *et al.*, 2013):

$$\mathbf{y}^* = f^*(\mathbf{x}) \quad 2.17$$

Where,

- $\mathbf{y}^*$ represents the resulting prediction for $\mathbf{y}$
- $f^*(\mathbf{x})$ represents an estimate of $f(\mathbf{x})$

For prediction, $f(\mathbf{x})$ does not need to be known. What is important is that the predictions should be correct and thus for this application accuracy is more important than interpretability. There is, therefore, no need to force the relationship between $\mathbf{y}$ and $\mathbf{x}$ to be linear, such as it was the case for the empirical formulae. Unfortunately, this method can take on a “Black Box” form, where it is impossible to establish what $f^*(\mathbf{x})$ looks like (James *et al.*, 2013).

The difference between f^* and f consists of the reducible error and the irreducible error, and to improve accuracy, the reducible error needs to be reduced. This error can be reduced by using the appropriate model (James *et al.*, 2013). This is the main challenge because every algorithm contains assumptions about how this error function can be reduced.

These assumptions develop a natural bias towards a presumed shape of f and cause different algorithms to perform very differently on the same dataset. In order to produce a model that approximates f closely, a balance between bias and variance must be obtained. According to James *et al.* (2013), variance refers to the amount by which f^* would change if a different set of data is used to approximate f . Bias is defined as the error that is introduced when approximating an extremely complex real-life problem using a much simpler model (James *et al.*, 2013).

Figure 2.14 Shows the results of an experiment conducted with generated random data. The flexible model is readily influenced by the variability in the dataset and produces a good fit to the data, but performs poorly on data not seen before (James *et al.*, 2013). The poor performance is due to the fact that the algorithm was unduly influenced by patterns that are not reproducible (or noise); this is called overfitting (Kuhn and Johnson, 2013). The simpler model, which is biased, performs the same in the training data as in the testing data and therefore the predictions have low variance (James *et al.*, 2013). The simpler model thus does not respond adequately to the signals provided by the data and is referred to as under-fitting (Kuhn and Johnson, 2013).

Kuhn and Johnson (2013) also determined:

$$MSE = \frac{1}{n} \sum_{i=1}^n (y_i - y_i^*)^2 \quad 2.18$$

Where,

- MSE is the Mean Squared Error
- y_i is the observed outcome
- y_i^* is the predicted value

$$E[MSE] = \sigma^2 + (Model\ Bias)^2 + Model\ Variance \quad 2.19$$

Where,

- E is the expected value,
- σ^2 is the irrecoverable noise,
- $(Model\ Bias)^2$ is also the reducible error of the model and shows how close the approximated function gets to the actual function represented by the relationship of the input parameters to the output parameters.

It is clear from equation 2.19 above that a high bias or variance can adversely affect the accuracy of the model and Figure 2.14 shows this.

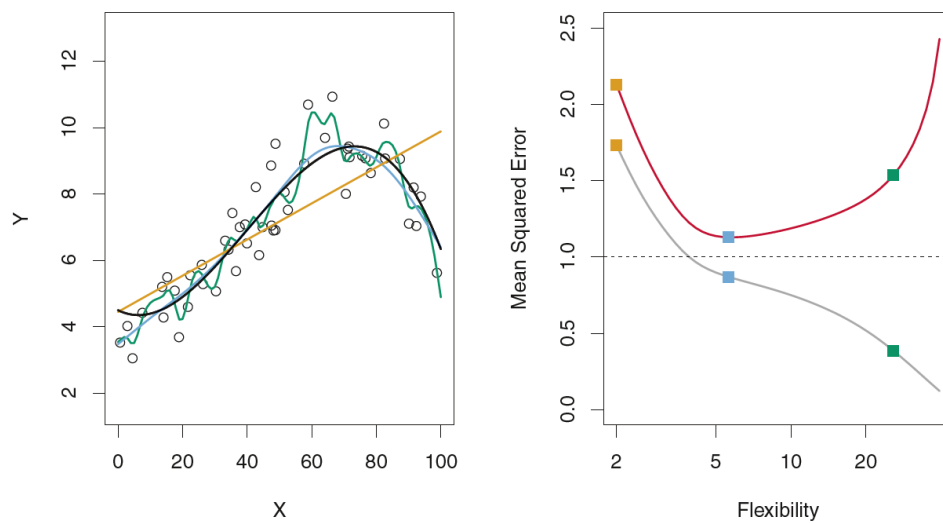


Figure 2.14: Effect of bias and flexible models (Kuhn and Johnson, 2013)

A well-functioning model must provide useful predictions that help to control the input parameters to produce the desired output. The performance measures are covered in Section 2.5. Machine learning methods that have been used to predict PPV along with algorithms used in the current research are discussed below.

2.7.2 Multivariate Regression Analysis (MVRA)

Multivariate linear regression is a method of function approximation where a linear relationship is assumed between the dependent variable and the independent variables. The resulting function is a flat plane and takes the form (Kuhn and Johnson, 2013).

$$y_i = b_0 + b_1x_{i1} + b_2x_{i2} + \dots + b_px_{ip} + e_i \quad 2.20$$

Where,

- y_i represents the numeric response i^{th} sample,
- b_0 represents the estimated intercept of the resulting flat plane,
- b_j represents the coefficient of the j^{th} predictor,
- x_{ij} represents the value of the j^{th} predictor for the i^{th} sample and
- e_i represents the random error that cannot be explained by the model.

The linear model seeks to minimise the sum of squared errors (SSE) as seen in the following equation.

$$SSE = \sum_{i=1}^n (y_i - y_i^*)^2 \quad 2.21$$

This method is also known as the sum of least squares. The squaring of the residuals makes it highly susceptible to outliers.

2.7.3 Artificial Neural Networks

Artificial neural networks (ANN) are an approximation of biological learning processes (Figure 2.15) and they offer a robust method of approximating real-valued, discrete-valued, and vector-valued target functions (Mitchell, 1997). ANNs are widely used to solve complex problems, which include interpreting real-world sensor data to recognise handwritten characters, spoken words and faces (Mitchell,

1997). ANNs were developed in an attempt to mimic the processing of sensory data by the human brain (Madigoe, 2014).

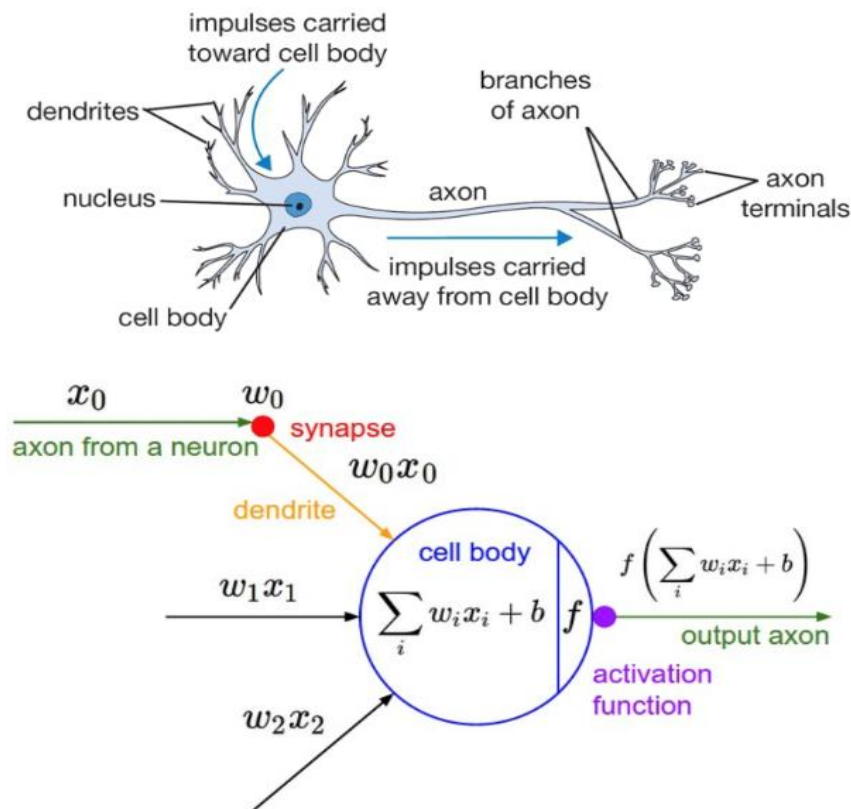


Figure 2.15: Simplified biological neuron compared to an artificial neuron (Changau, 2017)

As shown in Figure 2.15, the sensory data in the biological neuron is transferred by the dendrites and if the impulse exceeds a specific threshold, the neuron is activated and it then emits a signal through the axon (Madigoe, 2014). The artificial neuron mimics this process by processing all the weighted input data in a ‘neuron’ that outputs a target function. Figure 2.15 also shows a single layer perceptron (SLP) (Mitchell, 1997). However, According to Madigoe (2014), Multi-level perceptrons (MLP) are more useful in practice (Figure 2.16).

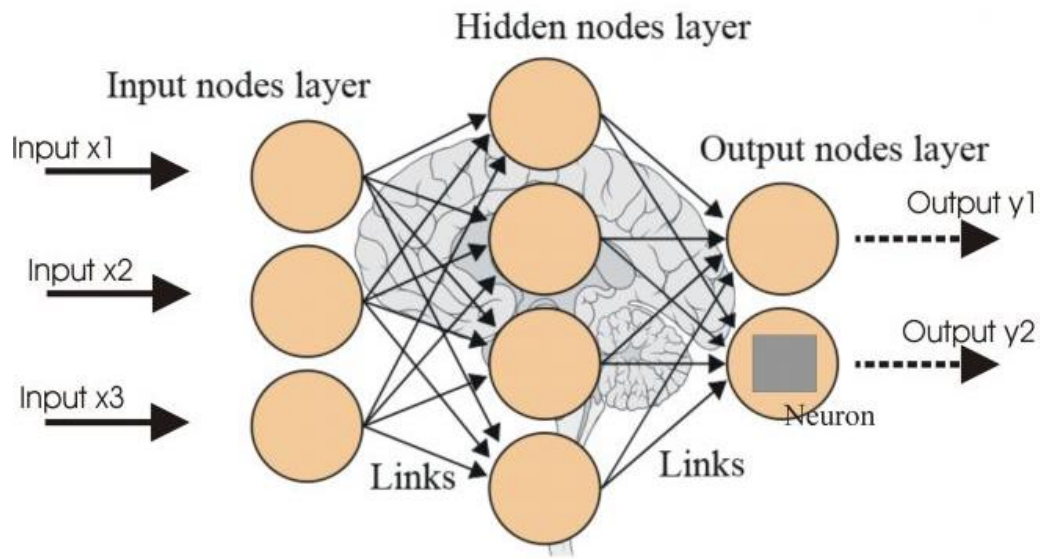


Figure 2.16: Artificial Neural Network structure (Ali and Ahuja, 2016)

As seen in Figure 2.16, the MLP structure consists of the input node, hidden node and output node. In this form ANNs have been used to predict PPV and examples are given below.

Tiile (2016) used ANN, the USBM (1963), Langefors-Kihlstrom (1963), Ambraseys-Hendron (1968) and Bureau of Indian Standards (1973) predictors to predict blast-induced ground vibrations, air-blast and fragmentation at an open pit gold mine located in Ghana. A total of 180 different production blast data was used for the analysis. The results showed that ANN obtained a coefficient of determination (R^2) of 0.97 compared to the one obtained by the USBM predictor, which had an R^2 of 0.32 (Tiile, 2016).

Parida (2016) used USBM (1963), Langefors-Kihlstrom (1963), Ambraseys-Hendron (1968), Bureau of Indian Standards (1973) and CMRI (1993) predict blast-induced ground vibrations, air-blast and fragmentation at iron ore open pit mines located in the Koira and Daitarido regions of India. A total of 37 different production blast data was used for the analysis. The results showed that ANN obtained an R^2 of 0.82 compared to the R^2 of the second best performing model, Ambraseys-Hendron, which was 0.37 (Parida, 2016).

Kamali and Ataei (2010) compared the performance of multivariate regression analysis (MVRA), empirical models and ANN in predicting blast-induced ground vibrations produced by the construction of the Karun III power plant and dam, which located in Iran. The empirical models used were the USBM (1963), Langefors–Kihlstrom (1963), General predictor, Ambraseys-Hendron (1968), Bureau of Indian Standard (1973), Ghosh–Daemen (1983) and CMRI (1993) prediction models. A dataset containing 28 PPV readings was used. The results showed that ANN obtained an R^2 of 0.98 and a mean squared error (MSE) of 9.19 compared to MVRA which had an R^2 of 0.94 and an MSE of 5 443.67 and the best performing empirical model, CMRI, had an R^2 of 0.92 and an MSE of 60.44 (Kamali and Ataei, 2010).

Monjezi *et al.* (2011) compared the performance of MVRA, empirical models and ANN in predicting blast-induced ground vibrations produced by the construction of the Siahsheh pumped storage dam and power plant, which located in Iran. The empirical models used were the used USBM (1963), Langefors-Kihlstrom (1963), Ambraseys-Hendron (1968), Bureau of Indian Standards (1973) and CMRI (1993) prediction models (Monjezi *et al.*, 2011). A total of 182 different production blast data was used for the analysis (Monjezi, Ghafurikalajahi and Bahrami, 2011). The results showed that ANN obtained an R^2 of 0.95 and a mean absolute error (MAE) of 0.002 compared to MVRA which had an R^2 of 0.69 and an MAE of 1.248 and the best performing empirical model, USBM, had an R^2 of 0.80 (Monjezi *et al.*, 2011).

Parida and Mishra (2015) compared the performance of MVRA, empirical models and ANN in predicting blast-induced ground vibrations produced by nine separate production blasts at an open pit iron ore mine located in the Koira region of India. The empirical models used were the USBM (1963), Langefors-Kihlstrom (1963), Ambraseys-Hendron (1968), Bureau of Indian Standards (1973) and CMRI (1993) prediction models. The results showed that ANN obtained an R^2 of 0.90 and a root mean square error (RMSE) of 0.908 compared to MVRA which had an R^2 of 0.63 and an RMSE of 1.668 and the best performing empirical model, IS 6922, had an R^2 of 0.69 and an RMSE of 1.540 (Parida and Mishra, 2015).

Khandelwal and Singh (2009) compared the performance of MVRA, empirical models and ANN in predicting blast-induced ground vibrations produced by 154 blasts at an opencast coal mine located in India. The empirical models used were the USBM (1963), Langefors–Kihlstrom (1963), General predictor, Ambraseys-Hendron (1968), Bureau of Indian Standard (1973), Ghosh–Daemen (1983) and CMRI (1993) prediction models. The results showed that ANN obtained an R^2 of 0.99 and MAE of 0.196 compared to MVRA which had an R^2 of 0.35 and an MAE of 1.673 and the best performing empirical model, USBM, had an R^2 of 0.54 and an MAE of 0.601 (Khandelwal and Singh, 2009).

Dehghani and Ataee-pour (2011) used ANN and dimensional analysis to develop a model to predict PPV. The performance of the new model was compared with other empirical models, which included the empirical models used by the USBM (1963), Langefors–Kihlstrom (1963), General predictor, Ambraseys-Hendron (1968), Bureau of Indian Standard (1973), Ghosh–Daemen (1983) and CMRI (1993) prediction models. A dataset of 116 blasts from an open pit copper mine located in Iran was analysed using ANN. A sensitivity analysis was performed using ANN and the parameters that contributed most to PPV were identified. In addition to that parameter identification, dimensional analysis was used to develop a new prediction model. The results showed that the new model obtained an R^2 of 0.75 and an RMSE of 3.49 compared to the best performing empirical model, General Predictor, that had an R^2 of 0.68 and an RMSE of 4.63 (Dehghani and Ataee-pour, 2011). ANN have thus been shown to be proficient in predicting BIGV and are therefore a useful addition to this research.

2.7.4 Support Vector Machines

Support Vector Machines (SVM) were initially developed for classification purposes. According to Kuhn and Johnson (2013), the application of SVMs for regression problems was motivated by Smola (1996) and Drucker *et al.* (1997). This approach, which is also referred to as SVR, seeks to build a robust regression model and equations that is less susceptible to outliers (Kuhn and Johnson, 2013). There are several implementations of SVMs, but the one used in this research is

based on the ϵ -insensitive regression technique (Kuhn and Johnson, 2013). Figure 2.17 shows the ϵ -insensitive error function.

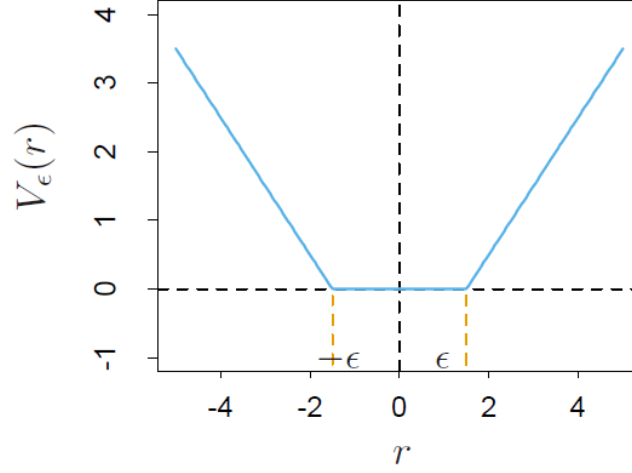


Figure 2.17: The ϵ -insensitive error function used by the support vector regression machine (Hastie et al., 2017)

Figure 2.17 is represented by the following conditional equation (Hastie et al., 2017)

$$V_{\epsilon}(r) = \begin{cases} 0, & \text{if } |r| < \epsilon, \\ |r| - \epsilon, & \text{otherwise.} \end{cases} \quad 2.22$$

Where,

- The epsilon (ϵ) is a threshold that is set by the user and serves as a loss function when taking the form of $V_{\epsilon}(r)$ (Kuhn and Johnson, 2013).

Epsilon (ϵ) is set at 0.1 in the kernlab package, but it can be changed by the user. Figure 2.17 shows the loss function on the y-axis and the residuals (r) on the x-axis. The effect of this function on the SVM is that data points with residuals that are smaller than the threshold are ignored and data points with residuals that are greater than the threshold are used in the model (Kuhn and Johnson, 2013).

The purpose of the SVM is to minimise (Kuhn and Johnson, 2013)

$$Cost \sum_{i=1}^n V_{\epsilon} (y_i - y_i^*) + \sum_{j=1}^P \beta_j^2 \quad 2.23$$

Where,

- Cost is the cost parameter that is set by the user and serves to penalise large residuals
- β_j is the unknown coefficient of the j^{th} predictor,

y_i^* for the general SVM is given by (Kuhn and Johnson, 2013):

$$y_i^* = \beta_0 + \sum_{i=1}^n \alpha_i K(\mathbf{x}_i, \mathbf{u}) \quad 2.24$$

Where α_i represents a set of unknown parameters of the i^{th} sample (Kuhn and Johnson, 2013). $K(\mathbf{x}_i, \mathbf{u})$ is a kernel function that can be implemented in three popular ways (Kuhn and Johnson, 2013):

Linear function:

$$K(\mathbf{x}_i, \mathbf{u}) = \sum_{j=1}^n x_{ij} u_j = \mathbf{x}_i' \mathbf{u} \quad 2.25$$

Polynomial function:

$$K(\mathbf{x}_i, \mathbf{u}) = \sum_{j=1}^n x_{ij} u_j = (\phi(\mathbf{x}' \mathbf{u}) + 1)^{degree} \quad 2.26$$

Radial basis function:

$$K(\mathbf{x}_i, \mathbf{u}) = \sum_{j=1}^n x_{ij} u_j = \exp(-\sigma ||\mathbf{x} - \mathbf{u}||^2) \quad 2.27$$

Where,

- x_{ij} is the i^{th} data point of the j^{th} predictor,
- u_j is the j^{th} sample
- ϕ and σ are scaling parameters

In this research, the radial basis function (RBF) was used as the kernel function because according to Kuhn and Johnson (2013), it is the best kernel to use and personal experience has proved this. The parameters that are tuned when using the

RBF kernel are the Cost and sigma (σ) and ϵ may be tuned but it was kept constant (Kuhn and Johnson, 2013).

The cost function is an important parameter and when it is large, the model becomes flexible because the effect of the residuals is amplified. However, when the cost is low, the model is stiffer and is thus less likely to overfit the data (Kuhn and Johnson, 2013).

Khandelwal *et al.* (2010) used SVM and empirical predictors to predict blast-induced ground vibrations at a Magnesite mine located in Pithoragarh, India. A dataset of 170 PPV readings was used for the analysis. The empirical predictors that were used are the USBM (1963), Langefors–Kihlstrom (1963), Ambraseys–Hendron (1968) and Bureau of Indian Standard predictors (1973). The results showed that SVM obtained an R^2 of 0.96 and an MAE of 11.13 compared to the best performing empirical model, Ambraseys–Hendron predictor, which had an R^2 of 0.34 and an MAE of 0.939 (Khandelwal *et al.*, 2010).

Dindarloo (2015) used SVM and partial least-square regression (PLSR) to predict blast-induced ground vibrations at Golegozar open-pit iron ore, Iran. A dataset of 100 PPV readings was used for the analysis and the results showed that SVM obtained an R^2 of 0.99 and a mean absolute percentage error (MAPE) of 8.5 % compared to PLSR which had an R^2 of 0.94 and an MAPE of 16.7 % (Dindarloo, 2015).

Mohamadnejad *et al.* (2012) used SVM, general regression neural network (GRNN) and empirical predictors to predict blast-induced ground vibrations in the construction of Masjed-Soleiman dam, Iran. A total of 37 PPV readings were used for the analysis and the results showed that SVM obtained an R^2 of 0.95 and an RMSE of 1.62 compared to GRNN which had an R^2 of 0.92 and an RMSE of 0.185 and the best performing empirical model, Indian Standard (1973), had an R^2 of 0.66 and an RMSE of 3.71 (Mohamadnejad *et al.*, 2012). The results achieved by the preceding researchers show that SVM can also be used for regression problems such as predicting PPV.

2.7.5 Genetic Algorithm

Genetic algorithms (GA) are a type of machine learning algorithm that was modelled after biological evolution. The problem addressed by GAs is the selection of the best hypothesis from a selection of candidate hypotheses. The best hypothesis in the case of PPV prediction is the hypothesis that most accurately fits the training data (Mitchell, 1997).

Verma and Singh (2011) used genetic algorithm (GA), the empirical predictors and MVRA to predict blast-induced ground vibrations at a Karusia Mine. Some of the empirical predictors used include USBM (1963), Ambraseys and Hendron (1968), Ghosh and Daemen (1983) and CMRI (1993) Predictor. A total of 127 PPV readings was used for the analysis (Verma and Singh, 2011). The results showed that GA obtained a coefficient of determination (R^2) of 0.997 and Verma and Singh (2011) concluded that the GA had outperformed the MVRA and the empirical predictors.

2.7.6 Random Forest

The Random forests algorithm is an algorithm that builds a number of models, m , set by the user based on a randomly selected k number of predictors from to P predictors in the dataset and averages all the models' predictions (Kuhn and Johnson, 2013). Figure 2.18 shows the steps taken to generate the RF models.

```
1 Select the number of models to build,  $m$ 
2 for  $i = 1$  to  $m$  do
3   Generate a bootstrap sample of the original data
4   Train a tree model on this sample
5   for each split do
6     Randomly select  $k$  ( $< P$ ) of the original predictors
7     Select the best predictor among the  $k$  predictors and
       partition the data
8   end
9   Use typical tree model stopping criteria to determine when a
     tree is complete (but do not prune)
10 end
```

Figure 2.18: Random Forests model building algorithm (Kuhn and Johnson, 2013)

The default setting for (m) in Caret is 1000, but this can be increased to improve predictive performance (Kuhn and Johnson, 2013). The tuning parameter in this algorithm is *mtry*, which is the number of predictors (k) to choose from at each split (Kuhn and Johnson, 2013).

Longjun *et al.* (2011) compared the performance of RF and support vector machines (SVM) to predict blast-induced ground vibrations and frequency at an open-pit mine. Data from 93 blasts were used for the analysis and the results showed that the average error from the SVM analysis was lower than that from the RF analysis. Even though RF was outperformed by SVM in this case, it has still proven to be a useful BIGV prediction tool.

2.7.7 Adaptive Neuro-Fuzzy Inference System

Adaptive neuro-fuzzy inference system (ANFIS) is a combination of ANN and fuzzy logic, of which the most popular model is the neuro-fuzzy hybrid model. ANFIS leverages the ability of ANN to identify patterns in complex systems and the ability of fuzzy logic to use human-like abilities to make inferences from data and then make decisions to map input/output relationships in a given dataset (Koçaslan *et al.*, 2017).

Soltan Mohamadi *et al.* (2011) used adaptive neuro-fuzzy inference system (ANFIS) to predict PPV caused by the use of ammonium nitrate fuel oil (ANFO) and Emolan explosives, at Sarcheshmeh copper mine, Iran. Data from 11 blasts were used for the analysis and the results showed that ANFIS obtained an R^2 of 0.97 for both explosive types and an MSE of 0.52 for ANFO and an MSE of 0.7 for Emolan (Soltan Mohamadi *et al.*, 2011).

Ataei and Kamali (2013) used adaptive neuro-fuzzy inference system (ANFIS) and USBM (1963) to predict PPV caused by the construction of Karun 3 power plant and dam, which located in Izeh town, Iran. Data from 29 blasts were used for the analysis and the results showed that ANFIS obtained an R^2 of 0.99 and the USBM model achieved an R^2 of 0.90 (Ataei and Kamali, 2013).

Koçaslan *et al.* (2017) used adaptive neuro-fuzzy inference system (ANFIS) and USBM (1963) to predict PPV at Kangal open-pit coal mine, the Tülü open-pit boron mine, the Kırka open-pit boron mine, and the TKI Çan coal mine. Data from 521 blasts was used for the analysis and the results showed that ANFIS obtained an R^2 of 1 for all the sites, whereas the USBM model achieved an R^2 of 0.62 at Kangal, 0.76 at Tülü, 0.57 at Kırka and 0.81 at Çan (Koçaslan *et al.*, 2017).

2.7.8 K-Nearest Neighbour - KNN

The KNN approach is normally used in classification problems where it uses the proximity of different observations in training data to estimate where a test datum should be allocated to (Kuhn and Johnson, 2013). Figure 2.19 shows the classification of the two black points using five nearest neighbours.

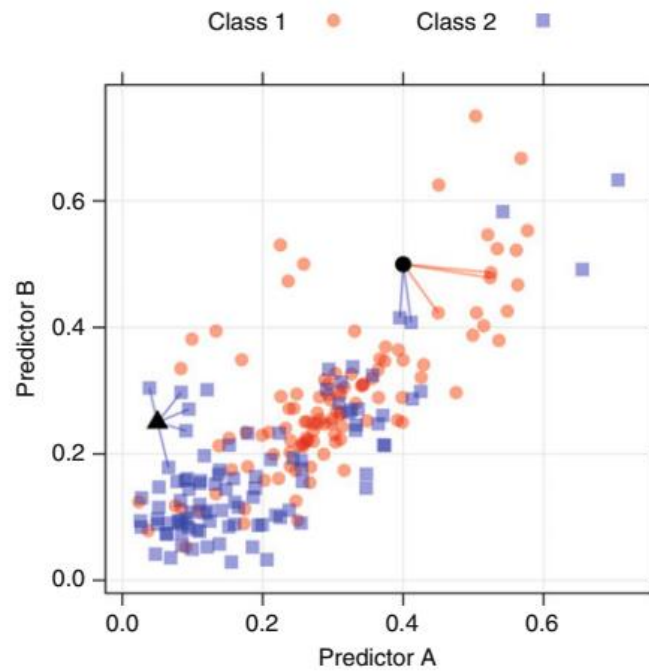


Figure 2.19: K-Nearest Neighbour classification model where two new positions are estimated using the training set (Kuhn and Johnson, 2013).

As seen above this approach uses distance measures to take the average (or less often the median) of the k-nearest neighbours. The k in this instance is 5. For regression purposes, this approach predicts a new sample using the k-closest samples from the training set (Kuhn and Johnson, 2013). According to Kuhn and

Johnson (2013), the most common distance measure used in KNN algorithms is the Euclidean distance given in the equation below.

$$\left[\sum_{j=1}^P (x_{aj} - x_{bj})^2 \right]^{\frac{1}{2}} \quad 2.28$$

Where,

- $\mathbf{x}_a$ and $\mathbf{x}_b$ are two separate samples that contain P predictors

This approach is sensitive to the scale of the training set and a predictor with a much higher scale can unduly influence the final prediction. It is, therefore, very important to scale and centre the predictors before using KNN. The tuning parameter for this algorithm is k and overfitting can be avoided by increasing k.

2.7.9 Multivariate Adaptive Regression Splines

Multivariate Adaptive Regression Splines (MARS) is an adaptive procedure for regression which is well suited for data sets that contain a large number of features. It is a stepwise linear regression where a cut point is determined by the model and takes the following form (Hastie *et al.*, 2017).

$$(x - t)_+ = \begin{cases} x - t, & \text{if } x > t, \\ 0, & \text{otherwise.} \end{cases} \quad 2.29$$

$$(t - x)_+ = \begin{cases} t - x, & \text{if } x < t, \\ 0, & \text{otherwise.} \end{cases} \quad 2.30$$

Where,

- x represents the individual data points and
- t is the cut point.

If, for example, t is given as 0.5, two functions are generated that contain splines defined by $(x - t)_+$ and $(t - x)_+$. These two linear splines combine to form one function that serves to fit the data better. Figure 2.20 shows The basis functions

$(x - t)_+$ (solid orange) and $(t - x)_+$ (broken blue) used by MARS (Hastie *et al.*, 2017).

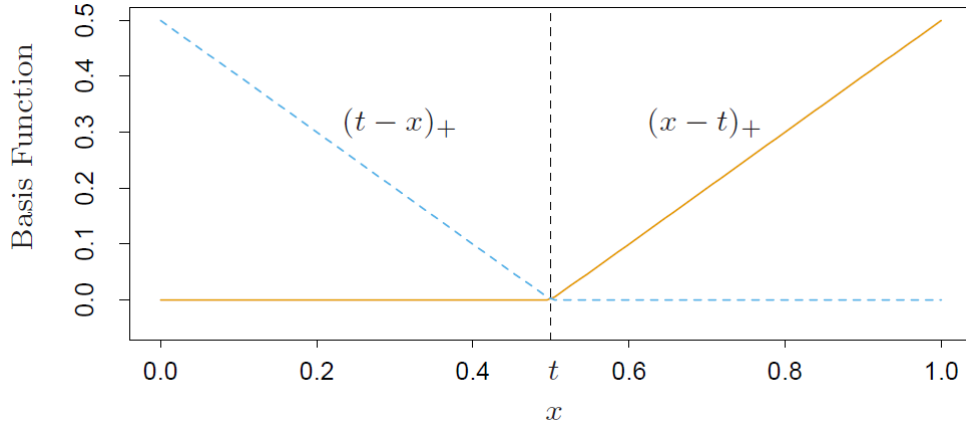


Figure 2.20: The basis functions (Hastie *et al.*, 2017)

The two functions are referred to as basis functions and when combined are referred to as reflected pairs. According to Hastie *et al.* (2017), these reflected pairs need to be formed for each input $\mathbf{x}_j$ with cut points at each observed value x_{ij} of that input. The combination of these basis functions would thus be (Hastie *et al.*, 2017):

$$C = \{(x_j - t)_+, (t - x_j)_+\} \quad 2.31$$

Where,

- $t \in \{x_{1j}, x_{2j}, \dots, x_{Nj}\}$
- $j = 1, 2, \dots, p$
- C represents the combination of reflected pairs for each data point. C is the set of reflected pairs shown on the right-hand side of Figure 2.20.

The model is built by means of stepwise linear regression using surrogate features, which are functions from set C and their products (Hastie *et al.*, 2017). According to Hastie *et al.* (2017), the model takes the form:

$$f(\mathbf{x}) = \beta_0 + \sum_{m=1}^M \beta_m h_m(\mathbf{x}) \quad 2.32$$

Where,

- $h_m(\mathbf{x})$ is a function in $\mathcal{C}$ or a product of two or more functions of the same kind.

The first step is to determine $h_m(\mathbf{x})$, after which the coefficients β_m are estimated by minimising SSE. Figure 2.21 shows the steps followed by the MARS algorithm.

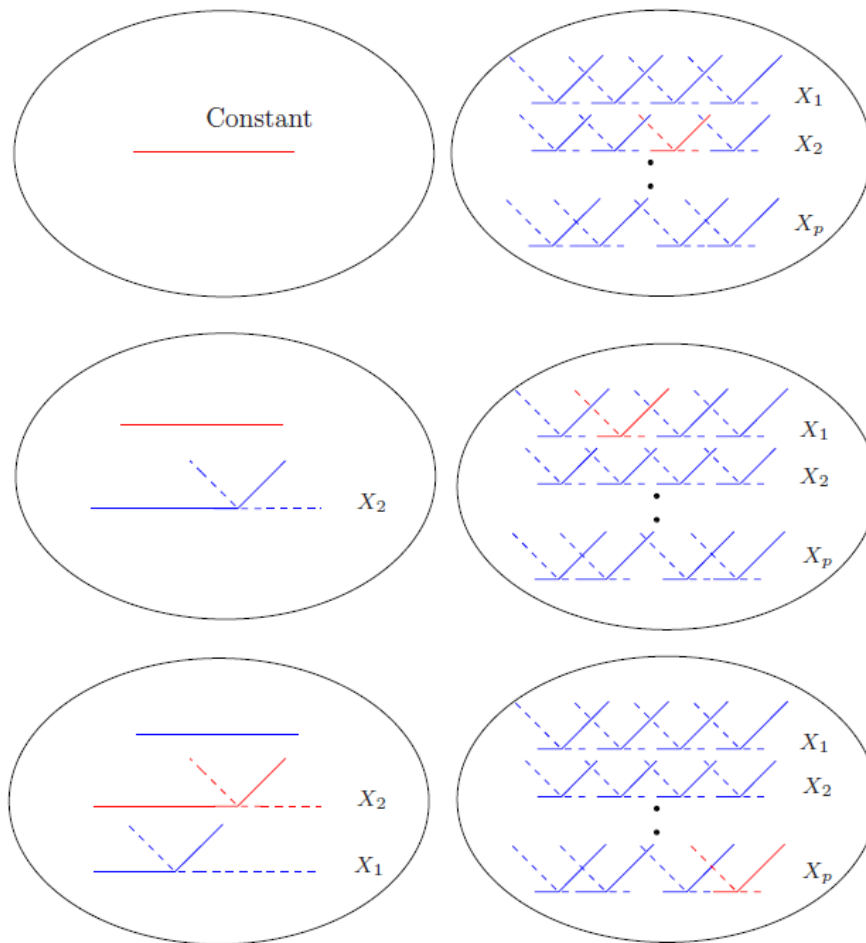


Figure 2.21: Three steps of the forward stepwise model building procedure (Hastie et al., 2017)

The left-hand side shows the functions included in the model and the right-hand side shows the reflected pairs that are in $\mathcal{C}$. The model building procedure progresses from top to bottom. The model building procedure starts with the constant, $h_0(\mathbf{x}) = 1$, which is multiplied with all reflected pairs in $\mathcal{C}$, the product

that reduces the residual the most is then added into the current model (Hastie, Tibshirani and Friedman, 2017). The procedure continues until the full set of features has been created and a large model of the form shown in equation (2.32) above is generated (Hastie *et al.*, 2017; Kuhn and Johnson, 2013). This model normally overfits the data and a backward pruning process must be conducted (Hastie *et al.*, 2017; Kuhn and Johnson, 2013). The algorithm then sequentially removes features that cause the smallest increase in the RSE. The final model contains only the features deemed important to the model.

2.7.10 Conditional Inference Trees

Conditional inference trees (CTrees) are a type of regression tree models that use statistical hypothesis tests to determine the appropriate features and their split points. The model building process starts with the use of test statistic p-value to conduct an extensive search of the feature space and their possible split points. Given a candidate split, the algorithm uses a statistical test to evaluate the difference in the means of the two groups created by the split and computes the p-value (Kuhn and Johnson, 2013).

A threshold, one minus the p-value, is used to determine whether or not additional splits should be created. Pruning is not necessary for this model as the p-value increases with a reduction in the number of samples and thus reduces the likelihood of new splits being created. A significance threshold of 0.05 is used as a default in the Caret package. The CTree model, therefore, does not tend to overfit the data. Given that inference does not directly relate to the predictive performance of a model, cross-validation has to be used to select the model complexity, determined by varying 1-p, that performs the best on the training data (Kuhn and Johnson, 2013).

2.7.11 Cubist

Cubist is a rule-based model that generates conditional multivariate regression models (Kuhn and Johnson, 2013). According to Kuhn and Johnson (2013), the model building process is similar to that used in the RF algorithm. The algorithm

generates trees that terminate with linear models. These linear models are generated during pruning process that takes place after the tree building process has been completed (Wang and Witten, 1997). Figure 2.22 shows an example of the type of tree model referred to in the section. The tree is split on the chosen feature, denoted by the ellipsoid nodes, given a condition that reduces the expected error (Wang and Witten, 1997).

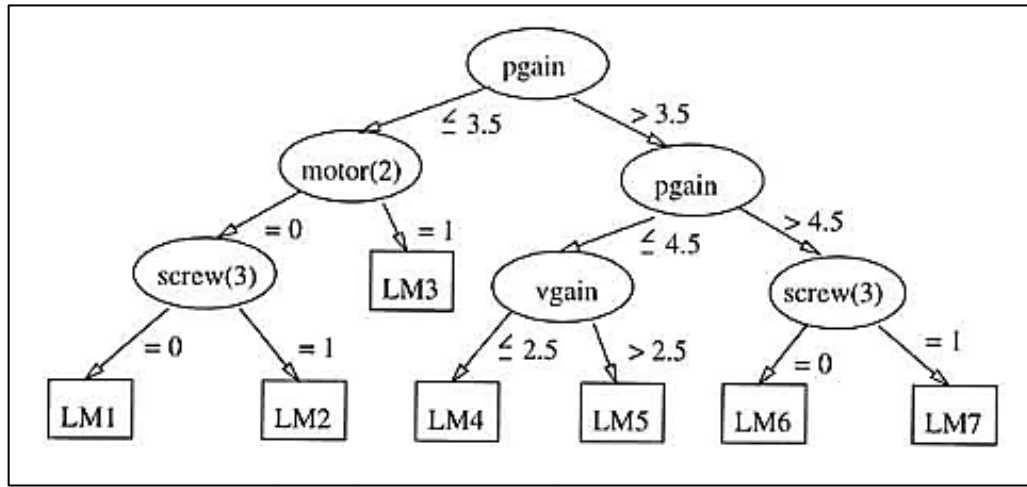


Figure 2.22: Example of tree model generated that terminates with linear models (Wang and Witten, 1997)

The final prediction of the model is a linear combination of the linear models, which take the following form (Kuhn and Johnson, 2013):

$$y_m^* = a \times y_k^* + (1 - a) \times y_p^* \quad 2.33$$

Where,

- y_k^* is the prediction from the current model,
- y_p^* is a prediction from the parent model.

In Figure 2.22, given LM1 and LM2, the parent model would be LM1. a is a mixing parameter or weight that is given by the formula (Kuhn and Johnson 2013):

$$a = \frac{Var[e_p] - Cov[e_k, e_p]}{Var[e_p - e_k]} \quad 2.34$$

Where,

- e_k is a collection of residuals of the current model given by $(y - y_k^*)$,
- e_p is a collection of residuals of the parent model given by $(y - y_p^*)$.

The final cubist model is a sequence of rules associated with their linear models stated in the form of *if-then* statements (Kuhn and Johnson, 2013). Once the final list of rules is completed a new prediction is made by averaging results from appropriate rules (Kuhn and Johnson, 2013).

Cubist also uses the concept of committees to improve the predictive performance of the final model (Kuhn and Johnson, 2013). Committees are tree models that have been created in the manner described above but are different in form. These committees contribute towards the final prediction by forming a series of rule-based models, i.e. if 15 committees are used and they are restricted to generating ten rules per model, the sequence of rules will be denoted from *Rule 1/1* to *Rule 15/10*. The first number refers to the model number and the second number refers to the rule number.

According to Kuhn and Johnson (2013), the training set outcome of the current model is changed based on the model fit (y_{m-1}^*) of the previous model. This is referred to as a pseudo-response ($\hat{y}_m$) and it is used by the current model to build new rules (Kuhn and Johnson, 2013).

$$\hat{y}_m = y - (y_{m-1}^* - y) \quad 2.35$$

This approach has the effect of correcting large training errors from prior models. When the full number of models is created (for example 15), predictions are made on new data and an average of the 15 predictions is computed at the end (Kuhn and Johnson, 2013).

Cubist also uses the concept of neighbours (like those covered in KNN), they are also referred to as instances. Cubist uses samples from the training set to adjust the final predictions. Given the final model prediction of y_m^* the model prediction that takes neighbours into account is (Kuhn and Johnson, 2013):

$$\frac{1}{K} \sum_{i=0}^n w_l [t_l + (y_m^* - t_l^*)] \quad 2.36$$

Where,

- t_l is the observed outcome of the neighbour.
- t_l^* is the model prediction of the neighbour.
- w_l is a weight.

w_l is calculated using a distance measure given the as (Kuhn and Johnson 2013):

$$w_l = \frac{1}{D_l + 0.5} \quad 2.37$$

Where,

- D_l is the distance of the neighbour to the prediction sample.

In Cubist, the Manhattan distance measure, which is given by the following formula (Kuhn and Johnson 2013):

$$\sum_{j=1}^P |x_{aj} - x_{bj}| \quad 2.38$$

The tuning parameters for Cubist are, therefore, the number of committees and the number of neighbours.

2.8 Conclusion

BIGV was a concern for regulators during 1930 in the United States of America and the experiments that the USBM conducted has helped improve the understanding and prediction of BIGV. The experiments succeeded in developing an empirical PPV prediction model and outlining safe blasting limits for most

structures. The experiments also showed that PPV depended mainly on the maximum charge per delay and the distance from the detonation source and the POI.

Machine learning algorithms are also an effective method for predicting PPV. The results shown above prove that machine learning algorithms can outperform empirical prediction models and statistical methods in predicting PPV. It is important to note that the machine learning algorithms discussed above are able to learn from input parameters and successfully mimic the behaviour of a complex system. They are then able to predict the output of the system given new input data. They are therefore all good models to consider in the development of a general machine learning prediction model.

The machine learning experiments conducted above were conducted on a specific site. The current use of empirical formulae is only used to predict PPV from the same site, where site constants are determined using historical data from the same site. The results above show that empirical models have not performed well because most of them achieved an R^2 of under 40 %. It is important to test the machine learning and empirical models and understand how well they would perform in an interpolation experiment and in an extrapolation experiments, where the ground vibrations being predicted were from a completely new site.

3 RESEARCH METHODOLOGY

The purpose of this chapter is to outline the methodology that was followed in the current research, as described in this report. A mixed research method using both qualitative and quantitative ideology was used. The data used consists of observations made by Nicholls *et al.* (1971) and these data is therefore considered secondary data for this research. According to Freedman (1949), an observation may be made by the actual researcher or by others whose evidence is considered to be reliable.

According to Murphy, (1950), there are two general characteristics of observations, which are qualitative and quantitative data. Qualitative data assist in providing an accurate description of a phenomenon so that it can be differentiated from any other phenomenon. Quantitative data are numerical observations that show the extent of occurrence of a phenomenon and help in distinguishing it from a qualitatively similar occurrence of different magnitude (Murphy, 1950). According to Oxford Dictionaries (n.d.), a phenomenon is “a fact or situation that is observed to exist or happen, especially one whose cause or explanation is in question”.

In this research, two prediction methods were used. The first method uses empirical models and the second method uses machine learning algorithms implemented in the R programming language using the caret package (Kuhn, 2008; Venables and Smith, 2018). The performance of the two models was compared on the same test data. Further details about data collection, data preparation and modelling are given below.

3.1 Data Collection

The data used in this analysis was taken from the USBM Bulletin 656 report of investigation by Nicholls *et al.* (1971). The data was digitised and saved in a Microsoft Excel 2016 document (Appendix A and B). This data was used for calibration/training of the two types of models and for testing.

3.2 Data Preparation

Blasting is a very well-known process of using high energy explosives to break rock to enable its movement and subsequent processing. The steps involved in the blasting process are well understood. This knowledge was then used in the data preparation process in order to ensure that only the most pertinent variables were included in the final training data. According to Murphy (1950), one of the two ways to develop prediction equations is to use careful observations and measurements to establish the effect of pertinent input parameters on the output parameter. In addition to that, the validity of the model depends on the manner in which the pertinent parameters were selected (Murphy, 1950). This was especially important when selecting parameters to be used in the machine learning models, since they have the ability to build multivariate models. Since the empirical models have already been established, the model building and testing processes are prescriptive.

A process of data preparation was conducted to ensure that the models were given a fair chance to perform well. Two different datasets from the same data were prepared. Relationships between input parameters and ground vibrations have been checked in 1936 by the USBM and the results of these tests and the author's understanding of the blasting process are used to eliminate variables that may impede the performance of the model.

3.3 Data Cleaning and Organisation

The data was initially separated into two sets of tables. The first set tables contained the test number and the blast parameters. The second set of tables contained the corresponding test numbers and the PPV, frequency and scaled distance. From the second set of tables the only the PPV and scaled distance values were used. The PPV values were presented in three columns where the radial, transverse and lateral components of PPV were recorded. The Peak Particle Velocity value chosen was the highest particle velocity component of the three recorded values, and the operation was computed in excel.

The original measurements contained some ranges and were recorded in imperial units. The ranges in the data were changed to medians of the ranges given and then all the data were converted into metric units.

The following steps were followed to clean the data and produce the final dataset:

- The data captured from Bulletin 656 contained missing PPV, so rows that did not contain all three PPV components were removed, reducing the set to 941 rows (See Appendix C).
- Test numbers 147,149 and 150 were removed because hole size, hole depth, face height, stemming, burden, spacing, number of delay intervals and length of delay were not captured in Bulletin 656.
- Test numbers 72,73 and 74 were removed because face height, stemming, burden and spacing were not captured in Bulletin 656.
- Tests numbers 151 and 171 were removed because according to Nicholls *et al.* (1971), only one large blast is taken per year with face height of 56 to 61 m and charge masses of 804 to 807 kg per hole.
- There instances where the USBM researchers did not measure the stemming length. The rows where stemming length was omitted were removed.

The final dataset consists of 799 rows and 17 variables (see Appendix D), which include two identifiers that were not used in the model building process and 15 variables that were used in the multivariate model building process. Scaled Distance was used only in the Empirical modelling process. Table 3.1 shows the final input parameters used the current experiment.

Table 3.1: Input parameters

No.	Column Name
1	Site No.
2	Test
3	Total No. of Holes
4	Overburden (m)
5	Hole Size (mm)
6	Hole Depth (m)
7	Face Height (m)
8	Stemming (m)
9	Burden (m)
10	Spacing (m)
11	Charge per Hole (kg)
12	No. of Delay Intervals
13	Max. Charge per Delay (kg)
14	Length of Delay (msec)
15	Scaled Distance ($\text{m/kg}^{1/2}$)
16	Distance (m)
17	PPV Peak (mm/sec)

3.4 Data Splitting

The data shown in Appendix C was split into three datasets, one was used for calibrating the models and the other two for testing. The two tests that were conducted were meant to determine the applicability and limitations of each model. Kuhn and Johnson (2013) state that there are two primary prediction methods, i.e. interpolation and extrapolation. Interpolation is when predictions are made about ground vibrations from the same mines on which the models were trained and extrapolation is the process of predicting ground vibrations from data collected from a mine that was not used to build the model (Kuhn and Johnson, 2013). The data used for the extrapolation test was extracted first. This data was taken from Superior Stone Company data, which contained 24 rows of data.

It was important to calibrate all the models on the same data and then test them all on the same data. An interpolation test set was produced in Microsoft Excel. A new

column was added in the dataset above in which random numbers were generated using Microsoft Excel's *RAND* function. The random numbers were copied and pasted as values to keep them for future processing. The data was then ordered in ascending order by the random number column. The top 700 rows were used as training data and the bottom 75 rows were used as the interpolation testing data. The performance of both models was evaluated in Microsoft Excel. Scatter and Residual plots were also used to show which model performed best. The best model must have the highest R^2 , and the lowest RMSE and MAE.

3.5 Data Exploration

Data exploration is a process used to provide Qualitative information about the data that would improve the model building process. When working with unfamiliar data, this process becomes the most critical step. This research assumes that the Qualitative information provided by the USBM is accurate. Given, the well-known blast design methodology, it was easy to eliminate non-essential features for the multivariate model-building process.

Building a robust predictive model requires informative input parameters. The USBM researchers chose scaled distance as the major parameter. When building machine learning models, the number of input parameters is not an issue. The problem with using too many input parameters is that the final model may not be interpretable because the model will try to find the relationships between input parameters and the output. It is, therefore, necessary to choose appropriate input parameters which are included on a sound theoretical basis. Table 3.2 shows the 13 variables remaining after the data cleaning process.

Given that the machine learning model building process included eight algorithms that processed the input parameters differently, given their different assumptions about how $\mathbf{x}$ should relate to $\mathbf{y}$, in-depth data exploration was not required. The best machine learning algorithm was expected to choose the most appropriate features to use in its model building process. Seven of the eight algorithms used for the current research are non-linear models, which means they do not assume a linear relationship between $\mathbf{x}$ and $\mathbf{y}$.

The input parameters chosen for the current study, following the process described in Section 3.3, fall within three key categories, which are the design parameters, explosives parameters and geology (Table 3.2). The design parameters and explosive parameters are under the controllable parameters and the geology parameters are not controllable.

Table 3.2: Final input parameters

Design Parameters	Explosive Parameters	Geology Parameters
Burden and Spacing	Mass per Hole	Overburden Thickness
Hole Diameter	Mass per Delay	Distance
Hole Depth	Length of Delay	
Face Height	No. of Delay Intervals	
Total Number of Holes		
Stemming		

Correlation analysis between the input parameters and the measured PPV was conducted and a correlation table along with a correlation plot were generated. The observed correlations were used to determine a basis point from which to evaluate the model's ability to establish the most important contributors to the intensity of the ground vibrations.

3.6 Empirical Model Training

The USBM method was explained in Bulletin 656. In the report provided by Nicholls *et al.* (1971) the input parameters that have the greatest influence on PPV at any POI were confirmed to be the maximum charge mass per delay and distance from the source of detonation to POI. Nicholls *et al.* (1971) also confirmed that the square root scaled distance formula was more suited to the dataset than the cubed root scaled distance formula. The square root scaled distance formula was therefore used in calibrating the USBM predictor. The USBM model was developed to use only the scaled distance input parameter. So, the data prepared for the USBM model were maximum charge per delay, distance from the blast to the POI, Scaled Distance and PPV. A model developed by Ambraseys and Hendron (1968) was chosen for the research since it used cubed-root scaling instead of square root

scaling. The two empirical models were evaluated and tested using two different datasets to determine which of the two is the most robust. Table 3.3 shows the empirical models to be evaluated alongside machine learning algorithms. Only the calibration of the USBM predictor was described since all the predictors have similar inputs.

Table 3.3: Empirical models evaluated

Names	Equation
USBM (1959)	$PPV = k(R/Q^{1/2})^{-m}$
Ambraseys–Hendron (1968)	$PPV = k(R/Q^{1/3})^{-m}$

The USBM predictor was calibrated by plotting PPV against SD. The purpose of this step was to determine k , which is the intercept of the PPV axis at $SD = 1$, and m which is the gradient of the line of best fit. However, when plotting PPV against SD on a linear scale, a non-linear curve is produced. A linear relationship is achieved when a log-log scale is used as seen in Figure 3.1.

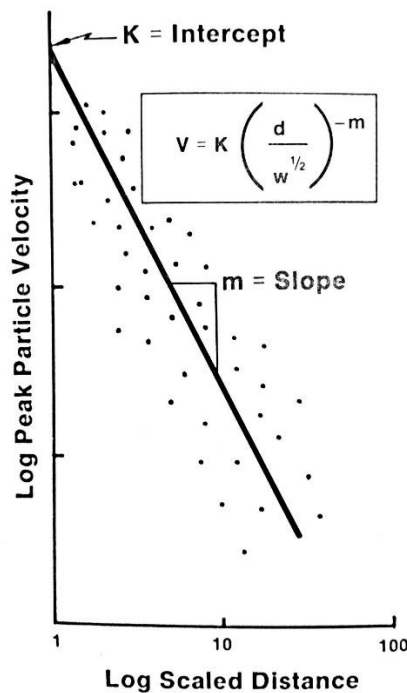


Figure 3.1: Determining k and m on the PPV versus SD log-log graph (Atlas Powder Company, 1987)

The calibrated model was then used to predict PPV given the maximum mass of explosive per delay and the distance from the source of detonation to the POI. The constants were obtained and Microsoft Excel was used to compute the predicted PPVs using the SD values in the test data. The predicted PPV values were then compared with the measured PPV values.

3.7 Machine Learning Model

The methodology chosen seeks to improve the chances of identifying the best performing machine learning model for a specific application. The rationale for this approach is based on the No-Free-Lunch theorem, which states that unless the subject is completely understood, there is no obvious preference for one model over another or others (Wolpert, 2001). Section 2.4 above showed that many machine learning models could be used to predict PPV. Eight machine learning algorithms were implemented in RStudio, using a machine learning package called caret. This section of the report thus outlines the steps taken in processing the data and then using the chosen model on the test data.

3.7.1 Caret Package

The R programming language was used to process the data using machine learning algorithms (Venables and Smith, 2018). The model building was conducted in RStudio, which is an integrated development environment (IDE) for R programming language (RStudio, 2014; Venables and Smith, 2018). RStudio enables one to manage the packages or extensions required to perform specific tasks. These packages contain functions that can be called in RStudio. The main package that was used in this project was the Classification and Regression Training (caret package). Caret was developed by Max Kuhn (2008) in order to provide a common platform to evaluate numerous machine learning algorithms at the same time. Eight machine learning algorithms were evaluated using caret. The algorithms evaluated are Linear Model, K-Nearest Neighbour, Conditional Inference Trees, Multivariate Adaptive Regression Splines, Artificial Neural Networks, Random Forest, Support Vector Machines and Cubist.

3.7.2 Model Selection

In order to improve the chances of developing a model that predicts PPV accurately, it is important to evaluate the performance of each of the models identified in 3.7.1. The reason for this process is due to the No-Free-Lunch Theorem, i.e. for any problem that consists of mechanisms that are not fully understood no one model has an obvious advantage over other models (Wolpert, 2001). This process also has the additional benefit of reducing inductive bias, which is an error that comes from making assumptions about the shape of the function to be approximated and thus improves the probability of developing a model that can perform well on unseen data.

In caret, model selection is accomplished by randomly resampling the training data and using a subset of the data to validate the results obtained from training. This process is referred to as k-fold cross-validation. In the current study, a k of 10 was used. The cross-validation was set to repeat five times. The choice of K was important because it breaks up the data into smaller observations. The number of K-folds and repeats used in this report were benchmarked from (Kuhn and Johnson, 2013). It is also important to avoid using too many repetitions because the algorithm may produce a model that over-fits the training data and may thus perform badly when tested. The cross-validation process in caret uses RMSE as a model selection criterion (Kuhn, 2018).

Seven of the eight algorithms used, excluding MVRA, make use of tuning parameters, referred to as hyperparameters that are critical to the performance of the model produced. The purpose of the cross-validation process was thus to search through a certain number of possible combinations of these hyperparameters. An extensive search can be conducted when working with one algorithm, when working with eight algorithms it was deemed necessary to constrain the search of the hypothesis space, which is a surface that is defined by all the possible combinations of hyperparameters. In this report, a tune length of 15 was used to randomly search the hypothesis space for the best combination of hyperparameters. The tune length defines the number of hyperparameter combinations to be evaluated.

The eight models were then compared to each other using RMSE, R^2 and MAE to determine the model with the highest R^2 and the lowest RMSE and MAE. A low variance is also desirable as it indicates how reliable the model will be when used on unseen data. The expectation is that the RMSE, R^2 and MAE obtained from the testing process will be similar to the RMSE, R^2 and MAE obtained from the cross-validation process.

3.7.3 Model Optimisation

The selected model was then optimised in order to improve its chances of performing well when predicting out of sample data. Models tend to have different hyperparameters that can be optimised, but they all seek to meet the requirements that all well-optimised models should adhere to. In caret hyperparameter optimisation is referred to as tuning. Some tuning is conducted in the model selection phase, but more rigorous tuning on the selected model is required to ensure only the best model is used in the testing phase. This process can be computationally intensive and may also lead to overfitting. Cross-validation was therefore used to help select the best model. In this report the tuning feature in caret was used through the *traincontrol* and *train* functions to determine the optimal hyperparameter values for each model.

3.8 Test 2 Site Description

The site chosen for test 2 was owned by Superior Stone Company and the quarry was situated in Greensboro, North Carolina. The name of the Quarry was Hi-Cone Quarry. According to Nicholls *et al.* (1971), the rock being blasted at the quarry was located in a granite diorite complex that contained a strong gneissic structure. The blasting geometry consisted of a bench height of 18 m and an overburden thickness of 9,14 m. The blasting pattern consisted of 635 mm to 889 mm blast holes that were drilled to a depth of up to 19.2 m and separated by up to 2.1 m burden and spacing. A safety fuse and cap were used as part of the initiation system (Nicholls *et al.*, 1971). Appendix E shows the arrangements of velocity gages used at the site and the test number conducted at the site denoted by 160, 161, 162 and 163.

The gages were numerated from 1 to 12, which coincides with the number of observations recorded in Table C-23 of Annexure C, Bulletin 656. The total observations per test were, therefore, ranged between 10 and 11 and there was a total of 41 observations for the site (Nicholls *et al.*, 1971). After removing rows that contained missing values, the final number of observations used for the test were reduced to 25.

4 MODEL BUILDING

The purpose of this chapter is to show the results of the methods described in Chapter 3. A basic correlation analysis between the input parameters and PPV was conducted. The machine learning algorithms were then evaluated using caret and the best algorithm was optimised and used on the test data. Two empirical models were calibrated and used on test data.

4.1 Correlation Analysis

The purpose of this section is to identify the most input parameters. Table 4.1 shows the features and their correlation to PPV.

Table 4.1: Input parameter correlation with PPV

Features	Correlations
Total No. of Holes	0,15
Overburden (m)	-0,17
Hole Size (mm)	0,03
Hole Depth (m)	0,04
Face Height (m)	0,04
Stemming (m)	0,10
Burden (m)	0,07
Spacing (m)	0,16
Charge per hole (kg)	-0,05
No. of delay intervals	0,03
Max. Charge per delay (kg)	0,21
Length of Delay (msec)	-0,09
Distance (m)	-0,50

From Table 4.1, it can be seen that Distance has a high negative correlation at 50 %, Max Charge per Delay seems to be the second most important feature with a correlation of 21 %. Table 4.1 also indicates that Total Number of Holes, Overburden and stemming are important features at 15 %, 17 % and 10 % correlation respectively. This indicates that there are five features, which the model may identify during the model building process. The algorithm may identify different features because the correlation in Table 4.1 indicates the correlation of a single feature with PPV, given that all other features are held constant. Since there

is some interaction between the features during blasting, it is conceivable that the winning model may consider a different set of features as being important.

4.2 Empirical Predictors

It is clear that the two most influential features are the maximum charge per delay and the distance to the point of interest. Two methods are evaluated in this section. The square root scaled distance and the cubed root scaled distance.

4.2.1 USBM

The USBM method assumes that the explosion radiates outwards in a cylindrical manner and can be described by approximating a circle growing in size. Figure 4.1 provides the results of the USBM model calibration.

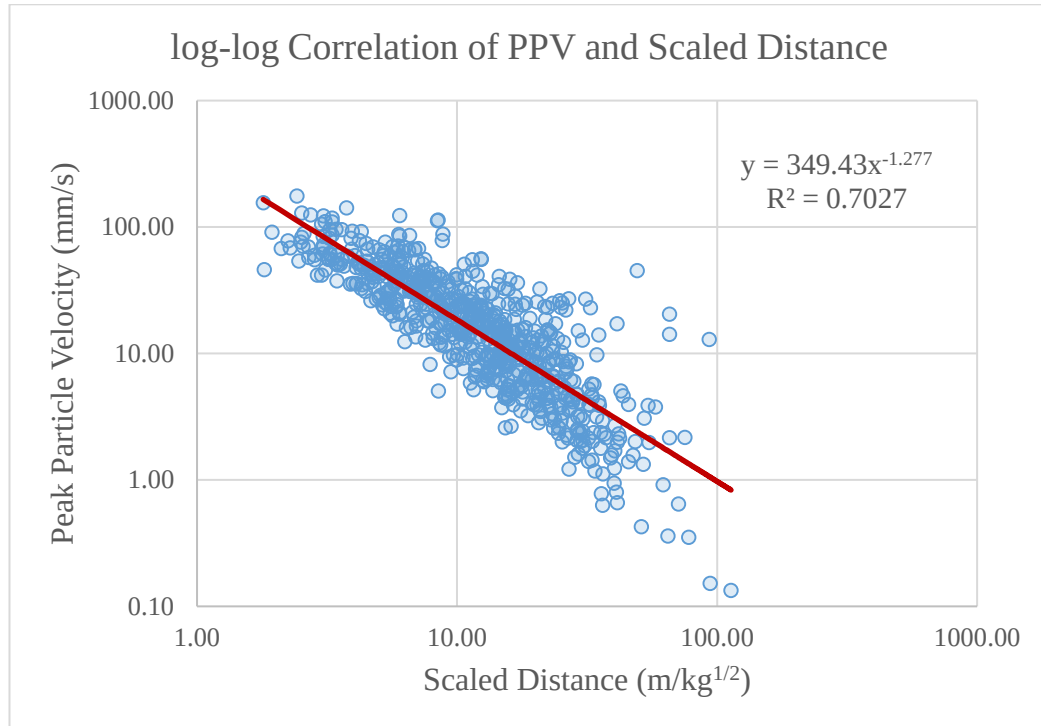


Figure 4.1: Calibration of USBM model

Figure 4.1 shows that the log-log scale produces a linear trend line that has an intercept of 349.43 at SD=1 and a slope of -1.277. The x in the equation refers to SD and will remain a variable in the equation. The graph also shows an R^2 of 70 %, which indicates that a high percentage of the data is explained by the resulting trend line. The trend line above is the calibrated model based on the USBM equation.

4.2.2 Cubed Root

This method tries to compensate for the three-dimensional expansion of the stress waves. It approximates spherical expansion. Figure 4.2 shows the calibration of the cubed-root empirical equation.

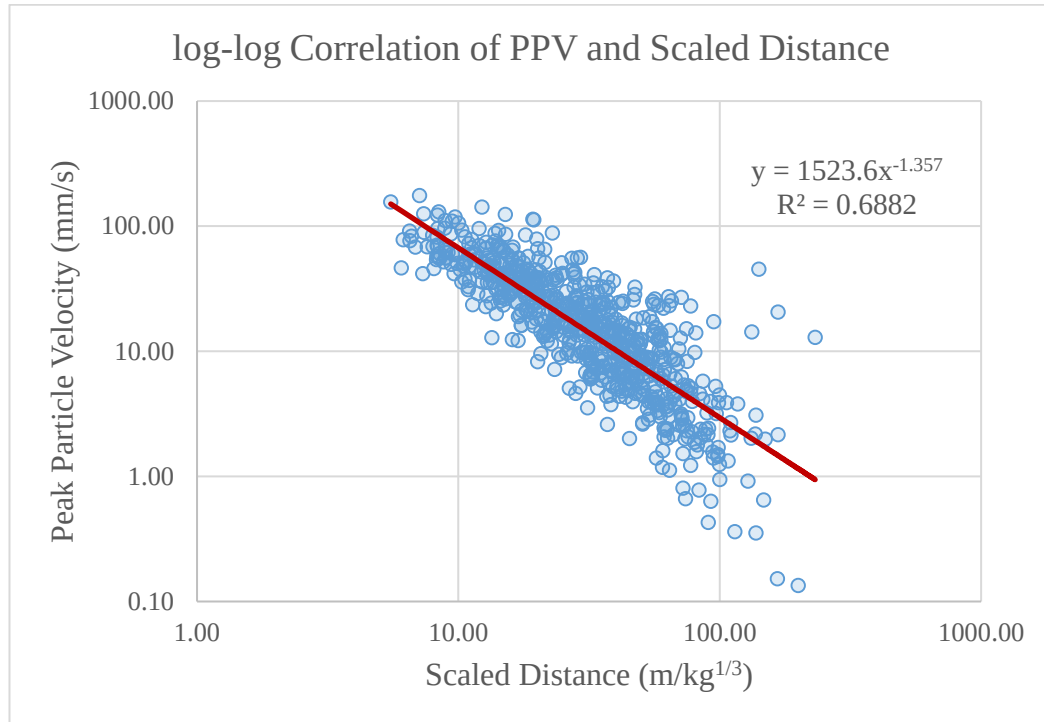


Figure 4.2: Calibration of Ambraseys-Hendron model

Figure 4.2 shows that the log-log scale produces a linear trend line that has an intercept of 1523.6 at SD=1 and a slope of -1.357. The graph also shows an R^2 of 69 %, which is slightly lower than that of the USBM formula.

4.3 Caret Method

Caret simplifies the model selection process through its integration of 247 machine learning models and several resampling options. The code used in the machine learning approach is in Appendix F.

4.3.1 Model Selection

In this process, eight models are tested on the training data and the model that performs the best on the training data is chosen. Caret's outputs of the individual models' cross-validation results are in Appendix G. Appendix G is also separated

into eight subsections where the cross-validation summary outputs and the cross-validation dot plots are located.

The first algorithm to be evaluated was the linear model and it has one tuning parameter (intercept). The tuning parameter was held constant, so only one model was created (see Appendix G-1). The MAE, RMSE and R^2 were 13.31, 19.31 and 43.26 % respectively. The next algorithm to be evaluated was KNN, which had one tuning parameter (k). The model with a k of 5 was chosen by the caret algorithm (see Appendix G-2). The MAE, RMSE and R^2 obtained by the model were 10.24, 16.33 and 58.14 % respectively. The third algorithm to be evaluated was MARS, which had two tuning parameters (degree and nprune). The model with an nprune of 17 and degree of 2 was chosen (see Appendix G-3). The MAE, RMSE and R^2 obtained by the model were 8.25, 12.60 and 75.86 % respectively. SVM was evaluated next SVM had two tuning parameters (sigma and cost). The model with a sigma of 0.41 and a cost of 1.27 was chosen (see Appendix G-4). The MAE, RMSE and R^2 obtained by the model were 8.23, 13.95 and 72.36 % respectively.

The fifth algorithm to be evaluated was ANN, which had two tuning parameters (size and decay). The model with a size of 5 and a decay parameter of 6.87 was chosen (see Appendix G-5). The MAE, RMSE and R^2 obtained by the model were 8.35, 13.00 and 74.02 % respectively. The sixth algorithm to be evaluated was RF, which had one tuning parameters (mtry). The model with an mtry of 8 was chosen (see Appendix G-6). The MAE, RMSE and R^2 obtained by the model were 7.23, 11.98 and 78.10 % respectively. CTree was the next algorithm to be evaluated. CTree had one tuning parameter (mincriterion, which is 1-p). The model with mincriterion of 0.20 was chosen (see Appendix G-7). The MAE, RMSE and R^2 obtained by the model were 9.15, 14.82 and 67.32 % respectively. The last algorithm to be evaluated was Cubist, which had two tuning parameters (committees and neighbours). The model with committees of 75 and neighbours of 8 was chosen (see Appendix G-8). The MAE, RMSE and R^2 obtained by the model were 6.89, 11.41 and 79.99 % respectively. The eight models that were chosen were trained and tested on the training data, and the MAE, RMSE and R^2 for the test were computed (see Appendix H).

Figure 4.3 is a dot plot of the eight models compared in terms of MAE, RMSE and R^2 . The y-axis is the list of machine learning algorithms evaluated and the x-axis are the MAE, RMSE and R^2 . The figure shows diamond shapes with lines extending horizontally on either side. The diamond in the middle is the median and the mark on the left and right of the centre-point is the 1st quartile number and 3rd quartile number, respectively. The data used to generate this graph can be seen in Appendix H.

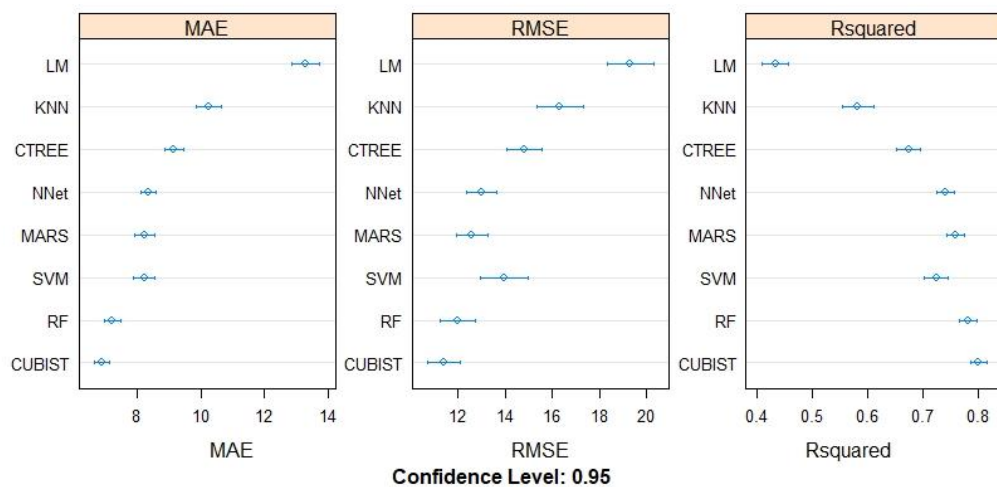


Figure 4.3: Dot plot of cross-validation results

The results of the resampling form a normal distribution with the median approximately equal to the mean. This indicates that the results of the cross-validation can be trusted and the performance of the model is good when processing previously unseen data. The generated results had a 95 % confidence level, showing that the Cubist model performed better than all other models, followed closely by Random Forest. Figure 4.3 also shows that there is a low variance in the results. Cubist has the added benefit of being a rule-based model, which are highly interpretable.

4.3.2 Optimisation

The chosen model needed to be optimised to ensure that it performs very well on the test data. Tuning options were evaluated and the final models were checked on the test data. Before commencing with the optimisation exercise, it is important to

understand which hyperparameters need to be optimised. A summary of the best model developed in the cross-validation process is shown in Appendix G-8.

Figure 4.4 shows the combination of hyperparameters used on the hypothesis space represented by the Number of Instances (y-axis) which is plotted against the Number of Committees (x-axis). The black dots represent the models that were built using the tuning parameters on the x and y-axis. The size of the dot is an indication of how high or low the RMSE was. A small dot represents a small RMSE.

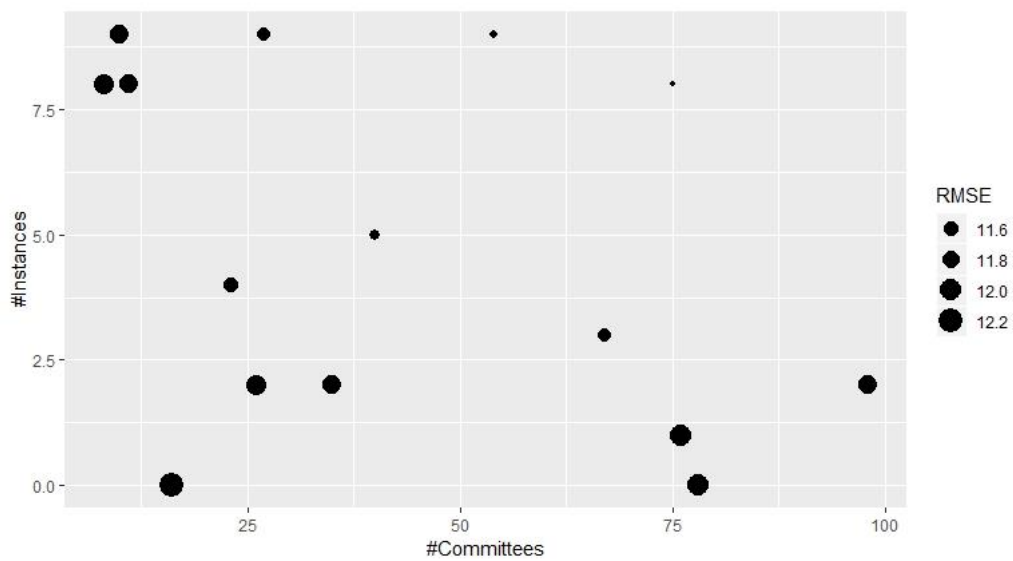


Figure 4.4: Plot of short hyperparameter search

The cross-validation results of the cubist algorithm above indicate that the two hyperparameters that were optimised were instances (also known as neighbours) and committees. The algorithm only allows a maximum of 9 instances and a maximum of 100 committees. Only 15 hyperparameter combinations were evaluated during cross-validation. For the optimisation exercise, a more thorough approach is needed. The results of a grid search for the best combination of committees and neighbours (instances) are shown in Appendix I. The grid consisted of neighbours that ranged from 0 to 9 and committees that ranged from 1 to 100 at increments of 3.

A graph of the RMSE vs the number of committees is shown in Figure 4.5. The lines on the graph represent the number of instances and it can be seen that 6, 7, 8

and nine performed very similarly. The combination of 6 instances and 22 committees was chosen by the algorithm due a lower RMSE.

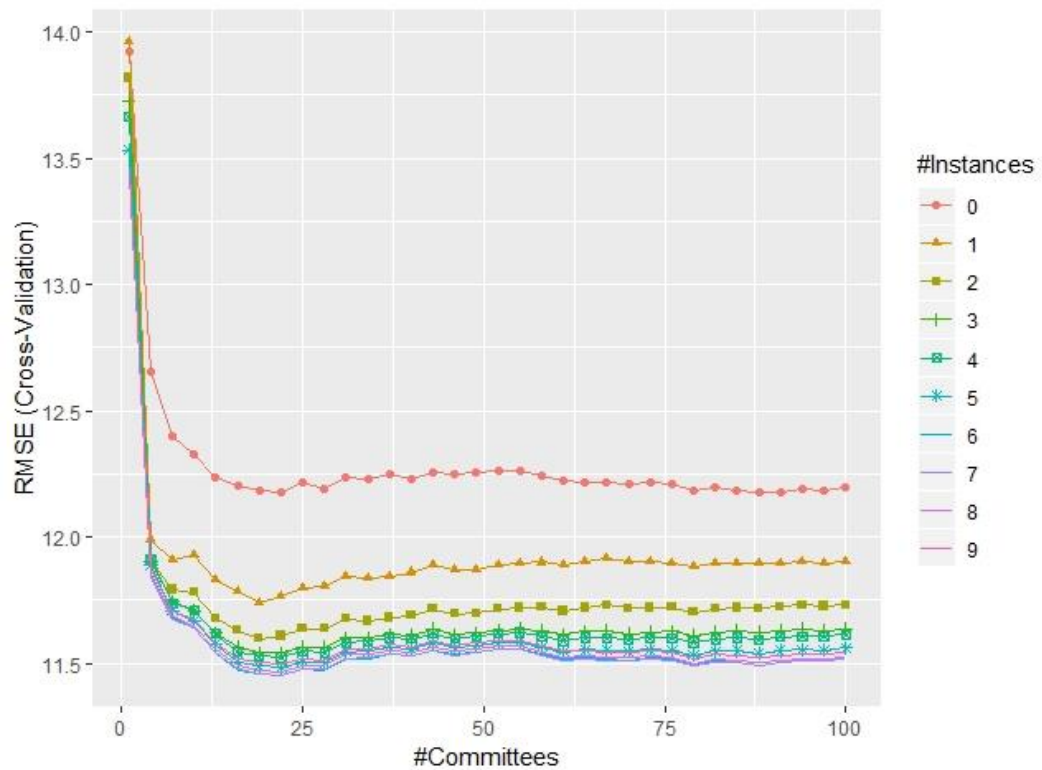


Figure 4.5: Results of grid-based hyperparameter search

22 committees were then used to train the model and six instances were used in predicting PPV from the test data. The final cubist model was developed by training it using the Cubist package. When building the model using the Cubist package directly, 90 % of the data was used to train the model and 10 % was used to evaluate its performance. The final model consisted of 22 committees, which contained their own conditional multivariate linear models. The model was limited to 14 rules per committee. This resulted in about 308 multivariate linear models. The results of training the final model are shown in Appendix I.

It is important to note that Cubist considered Distance, Max Charge per delay, charge per hole, overburden, burden, spacing and hole depth to be so important as splitting criteria. A model built with one committee is built to show how this rule based model works (Appendix J).

4.3.3 Summary

The model building stage was used to reduce the number of machine algorithms for the final test. Cubist performed better than the other seven algorithms evaluated in this section. Cubist was subsequently used along with the empirical formulae on test data to evaluate their prediction accuracy.

5 TEST RESULTS AND ANALYSIS

The purpose of this chapter is to show the test results after both models were tested. The effectiveness of a model depends on its ability to predict accurately and also to keep prediction error low. As stated in Chapter 3, the calibrated models were tested on two sets of data, which consisted of data from the population and data from a site that was not included in the training set. The models were evaluated on RMSE, MAE and R^2 . The best model generated the lowest error and the highest R^2 . The results of the test are shown 5.1 and 5.2 and include a scatter plot with a trend line that shows the correlation of the predicted PPV values to the measured PPV values. Correlation graphs are shown in Appendix K.

5.1 Prediction Results from Test 1 and Test 2

A comparison of the prediction capability of empirical formulae and machine learning algorithms was made. The two types of models were trained on Bulletin 656 data and tested on data they had previously not seen. From the eight algorithms evaluated on the training data only Cubist was chosen for the tests. The first test consisted of data that was randomly selected from the training data and thus formed part of the training data distribution. The second test was conducted with data from a site that was not included in the dataset; this data would therefore not form part of the training data distribution. These two tests, therefore, provide the interpolation and extrapolation capabilities of our dataset given historical data from various quarries.

The results from the two tests are summarised in Table 5.1. It can be seen that cubist performed better than the two empirical models on the interpolation test (Test 1), showing that it was able to produce a better approximation of the function that describes the data. However, Table 5.1 also shows that for the extrapolation test (Test 2), Cubist was outperformed by the two empirical models. The empirical model's R^2 is higher than that of Cubist and the RMSE and MAE are lower.

Table 5.1: Summary of test 1 and test 2 results

Model	R ² (%)	RMSE (mm/s)	MAE (mm/s)
Interpolation test	Test 1		
Cubist	82.39	10.64	7.30
USBM	66.78	15.43	9.30
Ambraseys and Hendron	65.61	15.41	8.88
Extrapolation test	Test 2		
Cubist	79.68	11,93	9.11
USBM	87.84	8.88	6,38
Ambraseys and Hendron	88,16	9.45	6,79

5.2 Residual Plots

According to Tukey (1993), a function represented by the observed data equals the fit obtained by a model and the residuals. A study of the residuals is therefore important because it helps describe the performance of the model more accurately. In the current study, the residuals that were evaluated are given by the equation below.

$$\text{Residuals} = \text{Observed} - \text{Predicted} \quad 5.1$$

The residual plot for the three tests is shown in Figure 5.1 and Figure 5.2. These residual plots show the residuals in mm/s on the y-axis and the test number on the x-axis. The blue dot shows the Cubist prediction residuals and the orange and grey dots show the USBM and the Ambraseys and Hendron prediction residuals, respectively. In the residual plots below a positive value represents an underestimation and a negative number represents an overestimation.

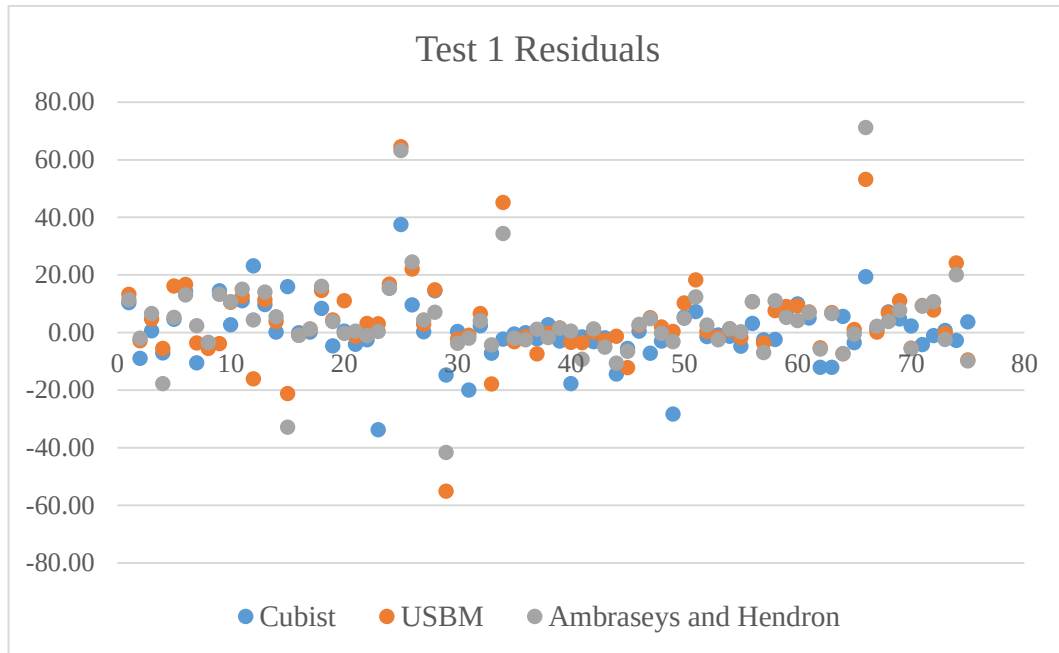


Figure 5.1: Test 1 residual plots

From the Test 1 (Figure 5.1) residual plot it is clear that Cubist model seems to be more stable as it contains fewer negative or positive residuals above 20 mm/s. The Ambraseys and Hendron model seems to have performed better than the USBM model with only two residuals above 40 mm/s as opposed to 4 residuals generated by the USBM prediction.

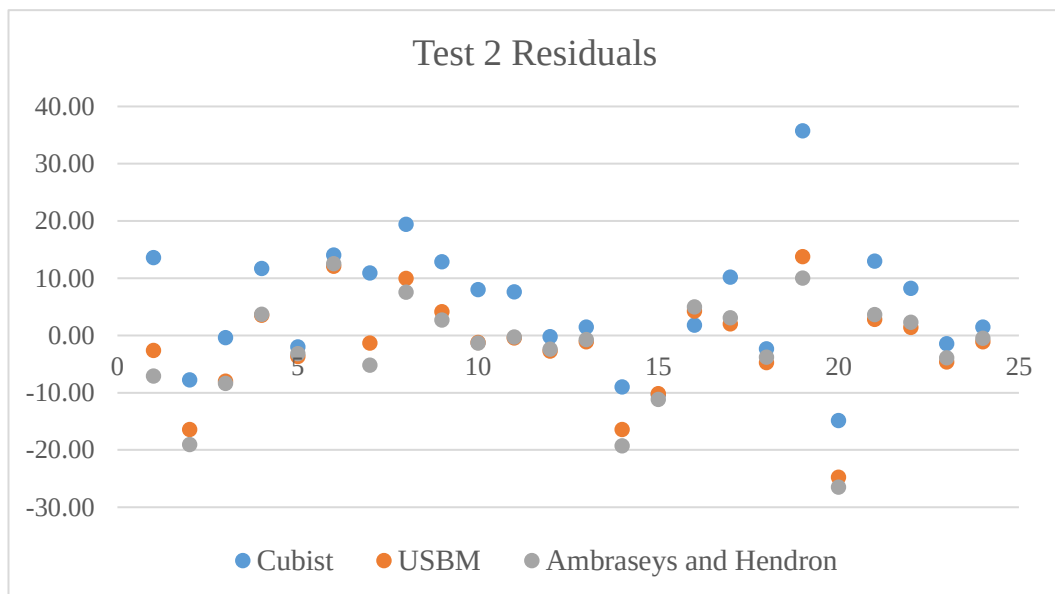


Figure 5.2: Test 2 residual plots

Most of the residuals in Figure 5.2 are between +15 mm/s and -20 mm/s. The Empirical models seem to have outperformed the Cubist model with most of the blue dots falling above the grey and orange on the positive side.

5.3 Impact of Omitted Data

The two factors that are missing from the training data is the type of explosive used along with the charging method and a proper description of the geology or a form of rock mass classification.

These two entities are important because they contribute towards the value of k and m in empirical methods. According to Ajaka and Adesida (2014), k is defined as the energy transfer coefficient and m is a specific geological constant. This definition shows the importance of geotechnical information and explosive type in the prediction of PPV. (Persson, Holmberg and Lee, 1994) suggested that the choice of an explosive for any one site will affect the ground vibrations produced.

The current form of empirical models does not allow for such an adjustment, although it is conceivable that one could be developed. (Ambraseys and Hendron 1968), suggested the use of equivalent energy parameter can be considered if blast vibration data was generated from blasts where different explosives were used. Machine learning models are more flexible and can thus be used to develop a model that can accurately predict PPV values at a new site. The addition of the explosive type and geotechnical information may improve the performance of such a model.

6 CONCLUSIONS

The current study used machine learning and empirical modelling techniques to predict PPV using historical data. Data from Bulletin 656 was used as a proxy for historical data. The prediction to accurately predict PPV may improve a mine's ability to control blast vibrations and reduce the risk of damaging structures next to the mine. Qualitative and quantitative research methods were used to evaluate machine learning algorithms that were trained using historical data. Two tests, Test 1 and Test 2, were conducted on the machine learning algorithms and empirical models. Test 1 data consisted of data that came from the same quarries as the training data and Test 2 consisted of data that came from Hi-Cone Quarry.

The data from Bulletin 656 was first cleaned, by removing missing values and non-essential columns. The cleaned data contained 941 rows of data with 16 independent variables and one dependent variable. The dataset was then split into three datasets. The first set of data was Test 1 data, which consisted of 75 rows. The second dataset was Test 2, which was made up of 24 rows. The remaining dataset was the training data and it was made up of 700. The Caret package was used to evaluate eight models and optimise Cubist, which was the best performing model, and then used to predict PPV values in Test 1 and Test 2. The training data was also used to determine k and m , for the USBM and the Ambraseys and Hendron models. The empirical models were also evaluated on Test 1 and Test 2.

In Test 1, the best performing model was the Cubist model with an R^2 of 82.39 %, an RMSE of 10.64 mm/s and a MAE of 7.30 mm/s. In Test 2, the best performing models were the USBM and Ambraseys models, which achieved an R^2 of 87.84 % and 88.16 %, an RMSE of 8.88 mm/s and 9.45 mm/s and a MAE of 6.38 mm/s and 6.79 mm/s, respectively. The two tests showed that Cubist performs better on interpolation tasks than extrapolation tasks.

Cubist did not perform according to expectations on the given data set. The results seem to indicate that the omission of explosive type and the lack of geotechnical parameters may have reduced the capability of the machine learning algorithms.

More research needs to be done on a more comprehensive data set to determine if this hypothesis is correct.

7 RECOMMENDATIONS

This research has shown that machine learning algorithms could be used to predict PPV at a new site using historical data. The USBM and Ambraseys and Hendron formulae have also been shown to be very effective at predicting PPV using historical data. The following are recommendations for further research:

- A similar study needs to be done on a data set that includes the omitted parameters in the current data set.
- A comparison between machine learning algorithms and the existing empirical models should be made using the more inclusive data set.
- New empirical models may need to be established to include important parameters that were excluded in the current data set
- There are clear differences between the USBM and Ambraseys and Hendron formulae. A study to identify the appropriate uses of each model may be useful.
- Given that the hypothesis space being searched by the different machine learning algorithms is so large, it may be better to conduct the comprehensive research with one algorithm especially those that have been shown to work. These may include MARS, ANN, RF, SVM and ANFIS. Researching with one algorithm may also allow for the use of optimization algorithms like Genetic Algorithm to find the best combination of hyperparameters to minimize the error function.

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APPENDIX A – BULLETIN 656 SHOT AND LOADING DATA

The tables in this appendix contain the shot and loading data as it appears in Appendix B of Bulletin 656.

Table A-1: Weaver Quarry, Aiden, Iowa

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
2	3	6	36	30	15	10	15	200	0	600	0	Primacord
3	3	6	36	30	15	10	15	200	2	200	17	Do.
4	1	6	36	30	15	10	0	200	0	200	0	Do.
5	7	6	36	30	15	10	15	200	6	200	17	Do.
6	3	6	36	30	15	10	15	200	2	200	34	Do.
7	7	6	36	30	15	10	15	200	6	200	34	Do.
8	7	6	36	30	15	10	15	200	0	1400	0	Do.
9	1	6	36	30	15	10	0	200	0	200	0	Do.
10	1	6	36	30	15	10	0	200	0	200	0	Do.
11	15	6	36	30	15	10	15	200	14	200	17	Do.
12	15	6	36	30	15	10	15	200	0	3000	0	Do.
13	15	6	36	30	15	10	15	200	14	3000	34	Do.

14	1	6	10	30	14-16	10	0	100	0	100	0	Do.
15	291	3	10	9	2	6	12	22	toe shot	1100	25	Do.
16	147	3	10	9	2	5	10	22	toe shot	484	25	Do.
17	60	3	14	12	2	5	10	26	toe shot	420	25	Do.
18	1	6	36	30	16	10	0	200	0	200	0	Primacord
19	3	6	36	30	16	10	15	200	2	200	9	Do.
20	7	6	36	30	16	10	15	200	6	200	9	Do.
21	15	6	36	30	16	10	15	200	14	200	9	Do.
27	13	6	36	30	16	10	15	200	3	800	17	Do.
32	21	6	36	30	16	10	14	203	3	1218	17	Do.

Table A-2: Moberly Quarry, Webster City, Iowa

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
22	490	3	12	9	2	5	9	25	3	1100	17	Primacord
25	160	3	12	9	2	5	9	25	4	400	17	Do.
26	75	3	14	10	2	5	9	30	18	120	17	Do.

Table A-3: P & M Quarry, Bradgaze, Iowa

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
23	28	3	28	24	4	8	8	40	1	560	50	Cap
24	78	3	20	18	4	8	9	25	2	625	50	Do.

Table A-4: American Merriets Quarry, Ferguson, Iowa

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
28	44	3	17	18	3	7,5	15	50	3	700	25	Cap
29	55	3	12	11	3-7,5	7,5	15	15	3	270	25	Do.

Table A-5: Marble Cliff Quarries, Shawnee, Ohio

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
30	11	6	26	25	10-12	10	12	112	4	448	25	Cap
31	11	6	26	25	10-12	10	12	125	3	500	25	Do.
81	12	5,875	25	25	10-12	10	10	102	3	612	25	Do.
82	13	5,875	30	30	12	10	10	132	3	660	25	Do.
83	1	5,875	31	30	11	10	0	132	0	132	0	Do.

Table A-6: Hamilton Quarry, Marion, Ohio

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
33	126	2,5	20	20	5-6	5	7	35	7	910	25	Cap

Table A-7: Flat Rock Quarry, Flat Rock, Ohio

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
34	12	6	56-58	53-55		11	14	450	8	886	17	Primacord
42	37	6	52	51	9	12	16	392	7	2744	17	Do.
75	36	6,25	24	23	6	12	10	182	9	1072	9	Do.
78	36	6,25	56	54	7	14	11	459	12	4620	9	Do.
79	1	6,25	56	54	4	10	0	468	0	468	0	Cap

Table A-8: France Stone Quarry Company Quarry, Belleville, Ohio

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
35	12	4	15	14		10	11	42	5	84	25	Cap
37	7	5,625	18	18		12	10	73,5	6	73,5	25	Do.
38	7	5,625	18	18		12	10	73,5	6	73,5	25	Do.
39	7	5,625	18	18		12	10	78,5	6	78,5	25	Do.
40	7	5,625	18	18		12	10	78,5	6	78,5	25	Do.

41	18	5,625	18	18		12	10	51	5	102	25	Do.
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Table A-9: France Stone Company Quarry, Bloomville, Ohio

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
36	12	6	32	32		9	14	140	2	840	25	Cap
43	41	4,75	18	18	7	10	11	77	2	1540	25	Do.
76	31	4,75	18	17	6,5	10	11	81,2	2	1218	25	Do.
77	1	4,75	18	17	6,5	11	0	80	0	80	0	Do.
80	69	4,75	18	18	6,5-7	10	11	79,8	3	2714	25	Do.

Table A-10: Theodore Roosevelt Bridge Construction Site, Washington, D.C.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
44	13	2,625	20	16		4	4	10	6	31	25	Cap
45	3	2,625	20	16		4	6	37	2	37	25	Do.
46	13	2,625	20	16		4	6,5	31	12	31	25	Do.

47	9	2,625	20	0		0	2,5	7,75	0	70	25	Do.
48	9	2,625	20	0		0	2,5	8	0	72	25	Do.
49	9	2,625	20	0		0	2,5	8	0	72	25	Do.
50	9	2,625	20	0		0	2,5	7,8	0	70	0	Primacord
51	13	2,625	20	20		4	6	31	12	31	25	Do.
52	13	2,625	20	20		4	6	26	12	26	25	Do.
53	13	2,625	20	20		4	6	21	8	42	25	Do.
54	13	2,625	18	18		4	6	25	12	25	25	Do.

*Face Height - 0 - No Face

Table A-11: New York Trap Rock Corporation, Clinton Point Quarry , Poughkeeps, N.Y.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
55	35	9	30-56	28-54	19-23	22	20	920	34	920	17-26	Primacord
56	13	9	85-106	83-104	20-22	22	20	1100- 1500	12	1522	26	Do.
57	28	9	85	80-85	20	17	23	1570	27	1570	17-26	Do.
58	30	9	55-72	53-70	20	20	16-20	1116	29	1116	17	Do.
59	48	9	17-44	15-42	12-21	20	9-21	700	47	700	17	Do.
62	20	9	61-89	59-91	12-23	23	25	1620	19	1620	26	Do.

63	18	9	69-75	67-73		23	20	1050-1249	17	1249	26	Do.
64	6	9				10-15	20	200	5	200	26	Do.
65	28	9	55-60	53-58		21	20	700-1400	27	1405	26	Do.
67	12	9	76-82	70-76		22	22	1150-1350	11	1355	26	Do.

Table A-12: New York Trap Rock Corporation, West Wyack, N.Y.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
60	10	6,5	63-68	69-74	22-29	20	15	558	9	558	26	Primacord
139	23	6,5	46	39	16-18	16-19	15	335	22	335	17-25	Primacord - Cap
140	19	6,5	52-54	47	16,5-18	16-18	15-18	360	18	400	17-25	Do.
141	31	6,5	29-51	22-44	16-18	15-16	16-18	92-300	30	303	17-25	Do.
142	16	6,5	48-50	41-43	19-22	15-16	16-18	300-325	15	325	17-25	Do.
143	23	6,5	45	38	15-19	15	16-18	308	22	308	25	Do.
144	22	6,5	46	40	17-18	16-19	15	303-393	21	393	25	Do.
145	8	6,5	51	45	19	15-18	16	303-353	7	353	25	Cap

146	15	6,5	50	43	17,5	18	16	328-350	14	350	25	Primacord - Cap
147	100		Toe Shot					1,2	0	120	0	Cap
148	27	6,5	52	45	18	15	16	303- 358,5	25	606	9-25	Primacord - Cap
149	35		Toe Shot					2,72	0	95	0	Cap
150	60		Toe Shot					0,6	0	100	0	Do.

Table A-13: Littleville Dam Construction Site, Hungtington, Mass.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
68	10	2	50	0	0	0	21,4	9,79	0	97,9	0	Primacord
69	10	2	50-52	0	0	0	21,4	10,8	0	108	0	Do.
70	21	2	50	0	0	0	22,8	9,79	0	206	0	Do.
71	14	2	50	0	0	0	20,3	5,4	0	75	0	Do.
72	52	2	10	0	0	0	Irregular	10	5	130	600-800	Do.
73	43	2	10	0	0	0	Irregular	11	6	66	600-800	Do.

74	49	2	10	0	0	0	Irregular	11	6	100	600-800	Do.
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Table A-14: Fairfax Quarries, Inc., Quarry, Centreville, Va.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
86	50	3,5	56	50	16	8	11	173	10	1384	25	Cap
87	45	3,5	36	30	12	8	10	100,5	10	703,5	25	Do.
88	28	3,5	46-50	42-46	12	8	10	110-160	10	605	25	Do.
89	45	3,5	50-56	46-52	12	8	10	160-185	10	1220	25	Do.
90	30	3,5	46-50	42-46	10	8	10	155	10	620	25	Do.
91	42	3,5	56	50	12	8	8	173,5	9	869	25	Do.
94	24	4,5	56	50	12	10	11	280	9	1120	25	Do.

Table A-15: W.E. Graham & Sons, Manasses Quarry, Manasses, Va.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
92	40	3,5	30	30	6	8	10	70	5	700	25-500	Cap
93	35	3,5	30	30	6	9	11	68,6	5	480	25-500	Do.
95	48	3,5	30	26	5	9	11	86,5	7	693	25-500	Do.
117	24	4,5	40	22	8,5	10	12	185	5	1110	25-170	Do.
118	38	3,5-4,5	45	40-46	3,5-9,5	9,0-10	11,0-12	150	6	1500	25-205	Do.
120	46	3,5-4,5	45	45	6-8	9,0-10	11,0-12	164	8	1200	25-280	Do.
121	36	2,5	16	ditch shot	8	3,5	4	15	10	60	25-5300	Do.
122	12	2,5	16	ditch shot	8	3,5	4	16,7	4	66,8	800- 4500	Do.
123	20	3,5	44	45	12	10	14	220	7	1100	25-500	Do.
124	61	2,75	45	45	5	7	5	84,9	7	905	8-150	Do.
125	16	2,5	42-50	45	3	0	2	9,5	0	150	0	Do.
126	26	3,5-4,5	40-48	37	8,0-10	7,0-10	9,0-12	186,5	7	933	25-240	Do.

Table A-16: Chemstone Corporation Quarry, Strasbury, Va.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
96	84	2,5	20	18	8,0-10	8	5	40	2	1160	5	Primacord
97	63	3,5	20	18	8,0-10	8	5	30,2	2	633	5	Do.
98	31	3,5	20	18	8,0-9	8	5	40,3	1	645	5	Do.
99	49	3,5	20	18	10	8	5	39-44	1	982	5	Do.
100	16	3,5	12,0-22	10,0-20	8	8	5	30	0	475	0	Do.
101	78	3,5	20	18	10	8	5	41	1	1600	5	Do.
102	16	3,5	10,0-20	8,0-18	8,0-10	8	5	28	1	343	5	Do.
103	59	3,5	20	18	8	8	5	36	3	589	5	Do.
104	60	3,5	15-20	15,0-20	9	8	6	40	1	1330	9	Do.
105	42	3,5	4,0-20	4,0-20	3,0-6	10	5	25-35	0	1325	0	Do.
106	61	3,5	20	18	0-4	8	5	35-45	1	1380	9	Do.
107	42	3,5	6,0-20	8,0-18	0-4	8	5	30	0	1250	0	Do.
108	60	3,5	20	18	12,0-16	10	6	33	1	1600	5	Do.
109	51	3,5	20	12,0-14	16	5	7	33	1	865	5	Do.
110	51	3,5	20	18	8,0-10	8	6	32,4	4	360	5	Do.
111	48	3,5	20	18	8,0-10	8	6	33,3	4	367	5	Do.

Table A-17: Chantilly Crushed Stone Company Quarry, Chantilly, Va.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
114	56	3,5	36	34	7-10	8	13	116	7	2090	25-240	Cap
115	42	3,5	48	46	6	8	13	157	8	1570	25-240	Do.
116	87	3,5	44-48	42-45	7	8	13	151	5	2260	25-170	Do.
119	66	3,5	46	44	6,5	8	13	166,5	8	1665	25-275	Do.

Table A-18: Culpeper Crushed Stone Company Quarry, Culpeper, Va.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
124	61	2,75	45	45	5	7	5	84,9	7	905	8-150	Cap
127	67	2,75	30-32	30-32	5	5	9	74	6	961	8-150	Do.
129	77	2,75	30-32	30-32	5	5	8	75,4	5	1206	8-125	Do.
130	57	2,75	33	33	4	6	9	69,3	8	624	8-175	Do.
132	58	2,75	30-32	30-32	2,5	6	8	71,3	8	712	25-200	Do.
133	70	2,75	30-32	30-32	3,0-4	6	8	68,6	10	686	25-300	Do.

135	87	3	10-32	30-32	3,0-6	7	9	10,5-70,8	9	630	8-250	Do.
138	59	2,75	45	46	3	6	9	93,7	6	937	8-150	Do.

Table A-19: General Crushed Stone Company Quarry, Donnel, Va.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
152	18	6	53	50	10	13	16	439-564	6	2091	25-205	Cap
153	20	6	45	42	11	13	16	354-504	6	1616	25-205	Do.
154	14	6	54	51	11,0-18	13	16	504-624	5	1837	25-170	Do.

Table A-20: Riverton Lime & Stone Company Quarry, Riverton, Va.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
137	88	3,5	18	bottom shot	8	9	9	25,6	4	666	25	Cap

Table A-21: Southern Materials Corporation, Jack Stone Quarry, Petersburg, Va.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
164	26	6	80	80	12	14	16	700	9	2965	25	Cap
165	122	3,5	45	42	7	8	8	136	7	3003	25	Do.
166	152	3,5	44	40	7	8	8	111,5	7	2565	25	Do.
167	128	3,5	45	42	7	8	8	142	7	3124	25	Do.
168	1	3,5	45	50	6	10	0	150	0	150	0	Do.

Table A-22: Superior Stone Company, Buchanan Quarry, Greensboro, N.C.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
155	49	3,5	30	27	8,0-10	7	7	60-68	8	520	17	Cap
156	44	3,5	30	27	8	7	7	80	9	565	17	Do.
157	34	3,5	30	33	10	7	7	85	6	510	17	Do.
158	11	3,5	30	27	8,0-10	7	7	86	5	173	17	Do.

159	54	3,5	33	30	8,0-10	7	7	73	7	658	17	Do.
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Table A-23: Superior Stone Company, Hi-Cone Quarry, Greensboro, N.C.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
160	42	2,75	55	59	6	5	5	115	7	690	25	Cap
161	45	2,75	55	59	6	5	5	105	7	644	25	Do.
162	33	3,5	55	59	6	7	7	172	7	857	25	Do.
163	43	2,5	58-63	60	6	6	6	136	7	816	25	Do.

Table A-24: Warner Company Quarry, Union Furnace, Pa.

Test	Total No. of Holes	Hole Size (in.)	Hole Depth (ft)	face Height (ft)	Stemming (ft)	Burden (ft)	Spacing (ft)	Charge per hole (lb)	No. of delay intervals	Max. Charge per delay (lb)	Length of Delay (msec)	Initiation
151	39	7,375	200-215	185-200	12	30	24	3910	26	7820	17	Cap
171	46	7,375	200-215	185-200	12	30	23	3925	22	19625	17	Do.

APPENDIX B – BULLETIN 656 PPV AND FREQUENCY DATA

The tables in this appendix are the vibration data as seen in Bulletin 656 Appendix C.

Table B-1: Weaver Quarry, Aiden, Iowa

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
2	8,7			1,74	50	0,789	50
	12,8	1,47	25	1,17	25	0,699	50
	12,9	0,923	20	0,68	40	0,384	30
	20,9	0,68	16	0,363	100	0,199	25
	25	0,694	20	0,324	40	0,201	20
	29,1	0,511	30	0,241	50	0,228	16
3	10,6	1,77	40	1,76	40	1,25	300
	16,3	0,721	45	1,06	35	1,51	35
	22,6	0,455	50	0,338	100	0,575	35
	28,3	0,29	50	0,201	100	0,361	16
	38,9	0,236	40	0,14	200		
	53	0,122	18	0,0966	80	0,232	24
	67,2	0,0607	50	0,0773	26	0,119	17
4	15,6	1,45	24	1,08	167	0,456	36
	21,9	0,597	26	0,418	80	0,192	42
	27,5	0,403	29	0,28	200	0,185	14
	38	0,325	21	0,144	125		
	52,2	0,15	21	0,0898	25	0,068	71
	65,9	0,0792	56	0,0502	66	0,044	20
5	11,3			3,42	28	1,7	30
	15,2	2,63	25	2,12	33	1,03	42
	20,4	1,45	27	1,02	30	0,606	31
	27,2	0,951	33	0,644	30	0,303	25

	36,4	0,637	31	0,407	31		
	48,8	0,397	22	0,328	48	0,197	38
	65,2	0,164	22	0,105	48	0,147	23
6	12,5	2,76	40	2,54	82	0,683	38
	16,2	1,03	26	0,607	100	0,458	39
	24,1	0,632	28	0,375	100	0,34	19
	33,4	0,529	17	0,289	125	0,209	19
	46,3	0,249	25	0,0959	19	0,164	18
	64,3	0,107	29	0,122	22	0,0755	19
7	13,1	1,74	27	1,24	18	0,716	33
	16,7	1,16	28	0,467	26	0,313	33
	24,7	0,566	18	0,363	28	0,269	20
	33,9	0,318	18	0,196	50	0,197	22
	46,7	0,192	20	0,106	42	0,134	23
	65,5	0,0899	23	0,092	23	0,068	23
8	3,88			8,76	15	1,65	25
	5,35	6,92	15	5,45	14	0,9	50
	7,32	4,65	14	2,27	50	0,932	20
	9,89	1,94	50	2,11	50	0,859	30
	13,4	2	50	1,2	50	0,614	50
	18	1,45	50	0,78	30	0,381	50
	24,2	0,694	28	0,35	20	0,344	18
9	11,5	1,88	37	1,79	71	0,45	17
	15,6	1,1	31	0,977	83	0,245	83
	22,8	0,475	42	0,448	71	0,269	71
	32,2	0,34	30	0,238	125	0,182	20
	45,5	0,169	36	0,157	125	0,103	20
	63,9	0,0811	23	0,071	83	0,0589	31
10	11,5	2,34	50	1,64	71	0,757	50
	15,6	1,3	38	0,892	111	0,45	36

	22,8	0,567	31	0,448	71	0,223	56
	32,2	0,386	30	0,219	31	0,182	26
	45,5	0,195	45	0,137	105	0,101	22
	63,9	0,0957	21	0,0676	83	0,05	25
11	14,7	1,17	100	1,86	62	1,54	52
	21,1	0,833	29	0,623	71	0,723	29
	26,7	0,693	69	0,398	140	0,372	38
	37,3	0,448	71	0,269	200	0,238	100
	51,5	0,179	50	0,138	44	0,117	180
	65,6	0,0939	130	0,0807	100	0,0793	50
12	4,75			4,72	25	2,41	25
	5,59	5,1	16	2,73	25	1,57	20
	6,65	4,15	12	2	25	1,24	25
	7,96	3,77	20	2,64	25	1,01	30
	9,46	3,64	20	1,65	29	1,47	25
	11,3	2,19	22	0,866	25	1,09	22
	13,4	1,49	20	0,548	20	1,25	25
	16,2	0,903	15	0,42	30		
13	20,2	1,35	24	0,884	24	0,424	35
	23,8	0,963	26	0,586	28	0,448	24
	28	0,663	24	0,397	35	0,31	24
	33	0,486	23	0,354	60	0,28	20
	38,9	0,475	22	0,26	62	0,145	21
	45,8	0,314	22	0,137	23	0,1	22
	54	0,236	24	0,131	23	0,134	22
	64,3	0,125	24	0,108	24	0,0838	26
14	54			0,094	62		
	57			0,1	30		
	61,5			0,062	50		
	68			0,064	50		
	76,5			0,049	71		

	88,8			0,043	62		
	105			0,037	20		
	126			0,02	39		
	153			0,034	17		
	187			0,012	17		
	230			0,016	18		
	291			0,00944	17		
15	18,9			0,287	63		
	20,7			0,183	22		
	22,9			0,098	29		
	25,6			0,148	36		
	29			0,0798	25		
	33,2			0,142	33		
	38,7			0,12	17		
	45,5			0,048	36		
	54			0,0896	28		
	64			0,04	26		
	77,6			0,05	17		
	96,6			0,028	13		
16	21			0,35	22		
	23			0,5	23		
	25,5			0,275	23		
	28,4			0,396	33		
	32			0,254	30		
	36,8			0,14	50		
	42			0,132	30		
	49			0,12	21		
	89,5			0,047	18		
	94,3			0,053	19		
	99,5			0,037	15		
17	34,4			0,076	50		
	36,6			0,047	18		

	39,9			0,028	36		
	43,5			0,038	31		
	46,7			0,042	31		
	51,7			0,018	18		
	57,8			0,034	20		
	65			0,035	21		
18	15,6	1,66	19	0,998	25	0,778	32
	18,9	0,713	21	0,85	56	0,696	26
	22,9	0,78	20	0,347	63	0,621	27
	29	0,634	14	0,342	25	0,279	16
	33,7	0,63	23	0,205	38	0,355	16
	40,9	0,266	24	0,105	42	0,239	18
	49,8	0,215	17	0,126	23	0,243	16
	60,3	0,131	17	0,0965	25	0,146	15
19	15,6	1,2	12	1,1	19	0,361	14
	18,9	0,99	17	1,3	62	0,391	24
	22,9	1,1	19	0,37	55	0,368	16
	29	0,88	14	0,23	33	0,321	22
	33,7	0,73	21	0,2	63	0,49	19
	40,9	0,4	15	0,15	62	0,199	18
	49,8	0,33	16	0,18	71	0,266	17
	60,3	0,17	19	0,07	55	0,112	17
20	14,4	1,69	11	1,07	82	0,984	15
	17,7	0,676	10	0,746	83	0,587	17
	21,6	0,71	23	0,685	100	0,669	16
	26,4	0,527	17	0,506	100	0,515	16
	32,2	0,408	17	0,261	132	0,368	13
	39,3	0,217	19	0,21	100	0,209	16
	48,2	0,297	16	0,192	100	0,208	14
	59	0,151	12	0,124	113	0,141	13
21	17,6	1,87	10	0,84	82	1,22	21

	21,1	1,07	28	0,71	50	0,608	19
	25,2	0,537	50	0,393	100	0,785	16
	30,2	0,924	20	0,645	62	0,759	20
	36,2	0,648	21	0,531	71	0,329	16
	43,3	0,829	19	0,386	145	0,453	18
	51,8	0,451	13	0,241	82	0,252	14
	62,1	0,181	20	0,157	14	0,237	8
27	7,57	4,48	8			1,13	22
	9,3	1,08	19	2,39	67	3,08	42
	11,3	1,8	64	1,36	45	0,859	36
	13,8	1,91	30	1,25	76	1,06	17
	16,8	1,52	20	0,744	24	0,788	15
	20,3	1,54	22	0,786	25		
	24,6	0,729	18	0,504	17	0,345	8
	29,7	0,387	19	0,228	11	0,237	8
32	7,31	4,32	9	1,13	85	1,15	134
	8,74	1,8	11			0,835	17
	10,5	1,58	98	1,15	45	1,15	20
	12,6	1,79	96	1,37	45	0,849	19
	15,2	1,28	19	0,742	25	0,988	18
	18,2	1,02	19	0,522	27	0,448	39
	21,9	1,04	15	0,406	62	0,438	19
	26,5	0,533	89	0,328	62	0,164	20

Table B-2: Moberly Quarry, Webster City, Iowa

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
22	7,36			1,36	28		
	9,84			0,63	28		
	13,2			0,39	55		

	17,9			0,506	22		
	23,9			0,31	28		
	31,8			0,22	26		
	41,6			0,219	26		
	51,6			0,128	32		
22	16,3			0,629	28		
	20,1			0,44	28		
	24,1			0,327	11		
	29,5			0,223	17		
	37,6			0,12	28		
	38,5			0,107	21		
	50,8			0,0473	10		
	60,4			0,0498	14		
25	15			0,524	33		
	17,5			0,32	28		
	21			0,345	33		
	26,5			0,253	33		
	33			0,191	24		
	41,5			0,154	31		
	52,3			0,0643	36		
	64			0,0367	33		
25	23,8			0,164	28		
	27,5			0,0962	22		
	32			0,118	20		

	37,8			0,0797	22		
	46			0,036	38		
	47,5			0,039	72		
	61			0,02	20		
	71,8			0,0255	21		
26	31,5			0,411	30		
	33,3			0,312	18		
	36,1			0,253	19		
	42			0,249	62		
	51,1			0,3	42		
	64,4			0,2	24		
	82,6			0,135	26		
	103			0,0899	62		
26	62,1			0,16	29		
	69,4			0,0857	21		
	78,5			0,11	17		
	89,5			0,0487	16		
	105			0,0465	26		
	107			0,0458	24		
	132			0,022	25		
	152			0,0266	16		

Table B-3: P & M Quarry, Bradgaze, Iowa

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
23	20,8			0,164	62		
	21,5			0,176	83		
	22,4			0,172	62		
	23,5			0,143	83		
	25,1			0,122	71		
	27			0,166	36		
23	30			0,128	36		
	33,6			0,0679	14		
	37,6			0,0731	18		
	43,3			0,039	13		
	50,3			0,036	82		
	61,3			0,02	17		
24	18,6			0,411	56		
	19,2	0,529	30	0,195	26	0,211	31
	21,4			0,156	30		
	23			0,114	23		
	25			0,114	15		
	27,4			0,384	28		
	30,8	0,252	16	0,298	18	0,191	13
	34,8			0,135	25		
	39,2			0,103	16		
	45,2			0,0712	24		
	52,2			0,0679	25		
	63,2			0,617	21		

Table B-4: American Merriets Quarry, Ferguson, Iowa

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
28	5,67			3,29	39		
	6,59			2,64	45		
	8,62			0,829	45		
	10,6			1,05	56		
	13			0,12	62		
	15,5			0,28	45		
	24,9			0,226	31		
	31			0,106	36		
	38,2			0,0596	33		
	48,1			0,0574	20		
28	6,27			1,14	55		
	8,32			0,636	35		
	11			0,546	62		
	14,6			0,234	36		
	24,1			0,233	33		
	27,8			0,119	30		
	31,9			0,0768	31		
	37,8			0,0611	22		
29	18			0,439	41		
	19,7			0,368	40		
	21,4			0,342	32		
	24,2			0,123	33		
	27,1			0,321	32		
	35,3			0,167	26		
	42,4			0,0896	23		
	49,5			0,85	40		
	59,3			0,625	13		
	71,2			0,0672	23		

	87,3			0,053	17		
29	20,6			0,42	27		
	23,7			0,326	31		
	27,7			0,29	28		
	33,3			0,181	34		
	48,4			0,137	38		
	54,2			0,171	26		
	60,7			0,14	31		
	70,2			0,119	42		

Table B-5: Marble Cliff Quarries, Shawnee, Ohio

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
30	6,66	1,02	53	1,29	45	1,64	77
	8,41			0,973	53		
	11,6	0,892	34	0,508	56	0,806	42
	15			0,207	53		
	19,6	0,549	37	0,272	59	0,179	43
	25,8			0,303	50		
	33,9	0,102	38	0,054	48	0,0569	50
30	10,5			1,1	48		
	12,6			1,32	48		
	14,9			0,527	50		
	17,2			0,473	30		
	20,5			0,375	24		
	24,2			0,232	33		
	28,8			0,314	45		
31	7,51	2,05	40	1,62	67	1,22	42
	9,44			1,06	56		
	12,5	0,783	42	0,552	50	0,736	38

	16,3			0,236	63		
	20,9	0,282	26	0,177	42	0,198	30
	27,3			0,13	19		
	34	0,175	20	0,0929	48	0,127	19
31	19,7			0,238	36		
	21,5			0,208	50		
	23,7			0,12	14		
	25,9			0,182	50		
	29,1			0,135	40		
	32,6			0,118	31		
	37			0,101	24		
	42			0,126	22		
81	9,46	1,29	42	0,733	48	0,386	71
	11,1	1,09	40	0,758	40	0,68	45
	13,9	0,488	27	0,36	38	0,301	19
	17,4	0,324	26	0,226	30	0,176	29
	22,5	0,334	21	0,265	30	0,147	29
	29,1	0,283	20	0,116	50	0,13	32
	37,8	0,212	21	0,062	40	0,0912	22
	49,6	0,0689	15	0,0545	24	0,597	18
82	6,89	1,8	48	0,99	50	0,878	48
	8,8	1,41	30	1,03	53	0,867	30
	11,4	0,743	33	0,954	50	0,668	33
	14,9	0,835	20	0,374	31	0,56	21
	19,8	0,687	20	0,244	28	0,249	21
	26,2	0,265	14	0,11	22	0,116	19
	34,5	0,204	45	0,0681	53	0,0733	91
	45,5	0,112	16	0,0468	38	0,0609	50
83	18,9	0,478	10	0,311	13	0,448	27
	23,1	0,56	32	0,461	33	0,292	33
	29	0,379	32	0,253	27	0,285	40

	36,6	0,21	26	0,223	50	0,269	23
	47,4	0,257	24	0,126	21	0,206	19
	61,4	0,17	19	0,0746	36	0,101	15
	80,2	0,116	14	0,0471	18	0,088	13
	105	0,0617	16	0,0303	16	0,0448	12

Table B-6: Hamilton Quarry, Marion, Ohio

33	14,1	0,631	23	0,359	30	0,245	14
	16,4			0,34	56		
	19,1	0,55	21	0,189	71		
	22,2			0,164	16		
	25,9	0,257	23	0,211	16	0,245	14
	30,1			0,164	16		
	35,2	0,217	25	0,11	17	0,161	11

Table B-7: Flat Rock Quarry, Flat Rock, Ohio

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
34	7,55			3,25	56	1,53	34
	9,7			3,47	42		
	12,4	2,19	19	4,26	42		
	20,7	2,08	17	0,736	30	0,637	21
	26,6			0,76	36		
	34	0,851	23	0,827	31	0,699	45
	44,4			0,28	31		
42	4,87			5,74	21	5,1	14
	6,4	5,63	15	5,14	22	2,2	12
	8,3	5,58	15	3,67	20	1,65	26
	10,9			1,94	10	1,42	36
	14,4	2,57	16	0,907	53	1,01	53
	18,8	1,68	18	0,93	26	1,21	25
	24,6	1,2	16	0,563	24	1,13	13

	32,3	0,425	26	0,672	9	0,71	26
75	7,09	2,17	25	1,79	37	2,19	36
	8,95	2,34	27	1,49	40	1,41	33
	11,4	2,19	42	1,14	48	1,68	45
	14,7	0,909	42	1,31	45	0,967	29
	19,2	0,764	34	0,896	59	0,56	33
	24,7	0,794	40	0,95	77	1,02	63
	32,7	0,407	50	0,401	40	0,418	24
	42,8	0,309	14	0,0867	11	0,348	14
78	6,77	2,06	22	2,85	22	2,32	23
	7,96	2,19	26	1,86	24	1,67	26
	9,42	2,01	24	1,31	32	1,18	11
	11,5	1,72	23	0,912	30	0,861	45
	14,2	1,47	9	0,786	17	0,834	50
	17,5	1,09	34	0,674	10	0,788	20
	22,1	0,59	43	0,373	43	0,936	63
	27,9	0,307	23	0,276	20	0,263	21
79	22,9	0,401	31	0,611	26	0,395	18
	26,7	0,384	30	0,278	25	0,334	21
	31,2	0,341	29	0,134	40	0,251	21
	37,9	0,287	26	0,147	29	0,246	21
	46,1	0,235	23	0,101	38	0,261	24
	56,7	0,152	20	0,0806	32	0,182	25
	71	0,12	18	0,0546	21	0,156	18
	89,2	0,0669	24	0,0422	17	0,0474	24

Table B-8: France Stone Quarry Company Quarry, Belleville, Ohio

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
35	19,6	1,18	20	0,66	63	0,668	71
	27,3	0,836	33	0,765	48		
	37,1	0,385	28	0,214	56	0,215	53
	50,7	0,594	25	0,185	42		
	69,8	0,19	32	0,082	50		
37	145			0,0392	42		
	162			0,0265	33		
	181			0,0248	33		
	206			0,0144	45		
	234			0,0125	25		
	270			0,00705	45		
	314			0,00634	36		
	368			0,0672	33		
37	90,1			0,0977	31		
	94,7			0,0703	39		
	102			0,0421	29		
	111			0,0317	31		
	122			0,0387	31		
	140			0,0313	33		
	161			0,0281	23		
	188			0,0186	45		
38	141			0,0309	43		
	159			0,0234	56		
	178			0,0132	77		
	203			0,0101	53		
	233			0,00818	45		
	269			0,00658	37		

	314			0,00526	42		
	369			0,00412	59		
38	84			0,0799	37		
	88,6			0,0482	42		
	96,8			0,0415	71		
	106			0,037	33		
	117			0,0368	56		
	134			0,0223	48		
	155			0,0206	42		
	183			0,0315	38		
39	74,5			0,11	36	0,135	24
	79	0,151	26	0,0541	63	0,129	36
	85,8	0,115	42				
	94,8			0,0588	71	0,12	42
	106	0,1	29	0,061	45	0,077	29
	122	0,0606	29	0,0328	48	0,075	16
	142	0,0827	25	0,0328	36	0,0638	19
	170	0,0708	14	0,0241	42	0,0416	17
40	117	0,06	26	0,0469	48	0,0608	44
	123	0,0498	29	0,0745	63	0,0746	63
	140	0,0586	50	0,0571	56	0,0438	36
	184	0,0517	42	0,0273	53	0,0444	42
	248	0,021	33			0,0185	26
	344	0,0102	50	0,00672	42	0,0157	40
41	18,3			0,888	48		
	24,8			0,97	45		
	32,2	0,444	36	0,539	67	0,292	42
	38,1	0,521	29	0,5	42	0,353	40
	53	0,415	37	0,203	59	0,171	62
	93,1	0,147	42	0,107	53	0,0899	50
	150	0,0772	56	0,0583	67	0,0492	48

	236	0,0296	50	0,0262	63	0,0381	43
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Table B-9: France Stone Company Quarry, Bloomville, Ohio

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
36	6,04	4,92	22	2,58	24	2,34	20
	8,97			1,68	22	0,81	29
	13,1	2,15	19	1,09	24	0,884	28
	19,3	1,59	28	0,613	25	0,519	36
	28,3	0,821	23	0,323	29	0,208	18
	41,4	0,426	29	0,2	31		
43	25,5			0,186	16		
	30,9			0,206	16		
	38,5			0,149	17		
	48			0,105	16		
	59,7			0,0532	20		
	73,5			0,0361	27		
	91,6			0,0268	23		
76	7,65	1,98	20	1,89	32	1,01	27
	9,68	1,97	24	1,25	33	0,651	42
	12,2	1,73	30	0,896	53	0,618	42
	15,3	1,29	24	0,549	25	0,236	40
	19,3	0,922	33	0,533	50	0,277	53
	24,4	0,926	26	0,327	26	0,259	21
	31,1	0,657	32	0,303	32	0,269	38
	42,7	0,342	32	0,143	27	0,146	33
77	28,7	0,732	30	0,493	45	0,243	45
	36,7	0,736	36	0,335	38	0,42	48
	46,6	0,534	36	0,256	63		
	58,5	0,298	29	0,127	45	0,087	56

	74,2	0,224	45	0,107	53	0,117	53
	94,2	0,199	29	0,0672	25	0,0796	42
	120	0,153	38	0,0514	33	0,042	45
	166	0,0856	43	0,0291	28	0,0194	40
80	5,55	3,16	23	3,4	67	3,61	50
	9,25	1,23	20	1,55	15	2,01	10
	10,6	0,896	29	0,539	24	1,34	14
	12	0,768	24	1,02	20	1,23	6
	12,9	0,772	24	0,794	14	1,06	23
	13,3	0,773	22	0,753	19	0,83	25
	21,4	0,265	14	0,299	17	0,382	16
	32,6	0,232	16	0,079	20	0,204	17

Table B-10: Theodore Roosevelt Bridge Construction Site, Washington, D.C.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
44	27,5			0,522	50		
	37,2			0,38	42		
	51			0,204	50		
	70,8			0,136	63		
	96,4			0,0715	83		
	125			0,0442	63		
	157			0,0319	50		
45	26,3	0,625	56	0,909	45	0,659	71
	47,7	0,415	50	0,404	36	0,251	56
	89,9	0,118	45	0,113	31	0,2	56
	116	0,114	36	0,0857	42	0,094	42
	145	0,0531	29	0,069	45	0,0339	26
46	27,7	0,426	71	0,517	31	0,398	50
	37,2	0,297	50	0,347	38	0,249	36

	50,8	0,29	63	0,207	31	0,14	63
	70,6	0,148	31	0,114	29	0,0834	83
	96,4	0,11	36	0,0685	71	0,0857	33
	125	0,0935	38	0,0425	45	0,0583	36
	157	0,294	56	0,0396	45	0,0301	31
47	16,7	0,504	45	0,269	50	0,144	45
	25,7	0,375	63	0,237	38	0,122	71
	38,8	0,101	36	0,139	125	0,0657	100
	56,1	0,079	29	0,0705	33	0,0345	63
	74,9	0,0464	38	0,0319	36	0,0382	36
	96,1	0,019	28	0,182	25	0,01	38
48	23	1,25	45	0,922	56	0,379	42
	35,8	0,413	38	0,594	45	0,158	33
	53	0,355	29	0,257	31	0,13	29
	71,8	0,153	23	0,123	38	0,144	31
	92,5	0,091	26	0,0758	24	0,0679	21
49	21,8	0,521	50	0,342	38	0,122	63
	34,8	0,181	45	0,167	100	0,0657	125
	51,9	0,103	33	0,0396	45	0,0377	63
	70,7	0,0551	36	0,0382	29	0,0404	31
	91,3	0,026	25	0,0253	26	0,0124	38
50	21	1,27	50	1,04	42	0,389	38
	34,2	0,405	38	0,465	45	0,184	36
	51,4	0,264	31	0,261	38	0,159	38
	70,4	0,155	21	0,116	36	0,137	33
	91,4	0,0689	26	0,0785	29	0,0471	29
51	27,8	0,344	50	0,373	28	0,291	36
	37,5	0,348	45	0,417	26	0,278	38
	51,4	0,373	42	0,258	38	0,17	38
	71,1	0,186	36	0,136	42	0,0966	56

	97	0,128	33	0,0804	33	0,0761	29
	126	0,101	33	0,0517	50	0,0613	42
	158	0,0366	50	0,0417	45	0,0335	26
52	34,3	0,186	50	0,418	31	0,189	29
	44,9	0,212	45	0,242	33	0,179	25
	60			0,156	28	0,0995	42
	81,6	0,0878	36	0,0803	125	0,0658	50
	110	0,0581	28	0,0726	31	0,0649	23
	141	0,0477	33	0,038	29	0,0477	31
	176	0,0253	33	0,0335	42	0,0219	15
53	28,9	0,282	83	0,361	45	0,331	26
	40,4	0,242	63	0,213	33	0,2	45
	57,6	0,113	33	0,0995	100	0,0938	28
	79,6	0,0746	25	0,0621	31	0,119	33
	104	0,0551	29	0,0332	36	0,0706	33
	131	0,0269	25	0,0286	25	0,0306	22
54	35,2	0,446	31	0,471	56	0,212	42
	50	0,466	56	0,334	38	0,271	28
	71,8	0,183	38	0,21	45	0,128	71
	100	0,126	26	0,128	63	0,0739	50
	132	0,0814	24	0,0745	31	0,0839	38
	167	0,056	25	0,0489	42	0,0309	25

Table B-11: New York Trap Rock Corporation, Clinton Point Quarry , Poughkeeps, N.Y.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
55	15,4			0,737	24		
	18,7			0,478	45		
	22,1			0,263	43		
	26,5			0,245	33		

	37,5			0,164	42		
	56,4			0,203	34		
56	27,4			0,347	27		
	49,3	0,174	16	0,0775	21	0,148	13
	52	0,0716	48	0,056	56	0,101	42
	54,6	0,0537	53	0,0457	56	0,101	42
	58,2	0,0768	23	0,0746	38	0,0891	33
	62,2	0,0582	37	0,0631	67	0,0699	48
	67,3	0,0571	32	0,0499	36	0,0953	38
	73,1	0,0439	40	0,0464	33	0,0567	29
	81,3	0,0909	34	0,0861	34	0,0862	28
57	27,1			0,27	45		
	41,6			0,139	43	0,13	27
	44,9	0,254	48	0,143	56	0,12	50
	48	0,152	42	0,125	67	0,207	48
	51,5	0,411	16	0,189	43	0,27	19
	55	0,176	28	0,123	51	0,193	30
	68,1	0,152	32	0,128	34		
58	28,7	0,618	45	0,637	14	0,48	19
	32,6	0,562	21	0,269	45	0,523	45
	37	1,12	16	0,41	40	0,676	20
	42,2	0,547	20	0,448	43	0,746	16
	47,1	0,421	43	0,61	13		
	53,6					0,225	38
	60,5					0,328	42
59	22,7			0,68	50		
	35	0,452	29	0,296	45	0,358	50
	39,7	0,27	50	0,228	50	0,439	50
	44,2	0,338	32	0,215	53	0,24	53
	49,3	0,219	53	0,913	16	0,348	17
	56,5	0,341	14	0,23	48	0,302	40

	63,5	0,265	53	0,327	16	0,215	53
	72,8	0,182	42	0,226	45	0,175	49
	82	0,123	36	0,176	42		
62	38			0,12	36		
	38			0,127	43		
	52,4	0,12	56	0,118	42	0,116	26
	55,5	0,102	38	0,0828	56	0,116	32
	65,7	0,102	32	0,0911	56	0,126	48
	73,3	0,128	29	0,139	42	0,176	37
	78	0,153	28	0,124	33	0,125	38
63	8,49	1,24	18	1,34	42		
	12	1,16	23	1,46	30		
	17	0,88	21	0,835	34		
	24,1	0,588	23	0,62	22		
	34	0,281	34	0,344	42		
	48,1	0,194	50				
63	16,1	0,459	29	0,581	56		
	21,8	0,732	29	0,618	23		
	30,8	0,228	23	0,207	31		
	38,3	0,166	25	0,245	33		
64	21,2	0,627	50	0,438	40		
	28,3	0,397	18	0,303	34		
	46	0,101	50	0,137	63		
	55,2	0,156	50	0,0818	36		
	77,1	0,106	42	0,052	20		
	106	0,0322	56	0,0357	15		
64	27,6	0,172	30	0,127	29		
	35,4			0,0517			
	48,8	0,0854	21	0,0505	37		
	60,1	0,114	16	0,0737	26		

	83,4	0,0332		0,0531			
	102	0,0194	9	0,0183	19		
65	8	0,657	40	0,705	33		
	10,7	0,658	17	0,634	40		
	17,3	0,258	29	0,202	30		
	20,8	0,258	18	0,121	26		
	29,1	0,22	25	0,124	24		
	40	0,177	36	0,0676	53		
65	8	2,08	50	1,8	36		
	16	0,966	50	0,76	38		
	20,4	0,718	26	0,358	42		
	29,1	0,207	22	0,125	27		
	36,3	0,133	28	0,105	30		
67	8	1,49	30	1,63	37	1,46	25
	9,64	1,86	9	1,33	38	1,16	20
	12	0,977	11	0,676	33	0,56	13
	14,7	0,456	9	0,518	43	0,517	11
	18,3	0,387	42	0,311	37	0,388	71
	22,7	0,311	29	0,211	38	0,269	48
	28	0,146	36	0,158	36	0,141	56
	34,8			0,128	45	0,124	50

Table B-12: New York Trap Rock Corporation, West Wyack, N.Y.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
60	13,3	4,87	45	3,86	7	3,16	33
	16,9	3,27	42				
	22	1,65	28	0,896	45	1,26	29
	36,8	1,07	50				
	49,1			0,495	71		

139	10,8	1,47	63	3,59	38	1,73	50
	13,2	2,69	33	3,45	33	1,99	25
	14,5	2,27	33	3,39	36	2,59	29
	18,1	1,64	42	0,686	36	0,837	20
	18,6	4,42	33	2,76	50	1,46	50
	26,4	0,786	45	1,05	50	1,64	45
	31,9	0,972	50	0,737	42	0,624	50
	40,5	0,631	50	0,455	63	0,558	50
	52,8	0,679	50	0,429	50	0,363	63
	77,5	0,551	45	0,372	71	0,339	56
140	13,1	2,57	31	2,31	31	1,07	28
	16	2,05	29	1,96	31	0,864	28
	22	1,07	23	1,52	42	0,742	38
	25,4	1,76	31	1,63	45	1,05	36
	28,6						
	34,8	1,27	45	0,768	25	0,49	56
	49,3	0,632	71	0,357	71	0,413	63
	60,3	0,351	83	0,239	45	0,214	71
	82,9	0,556	56	0,471	63	0,4	63
141	15,6	1,18	33	2,14	56	1,27	29
	19,4	2,07	33	3,09	42	2,29	28
	23	0,985	50	0,974	50	0,527	50
	30,2	1,09	56	1,17	38	0,797	42
	31,9	1,38	50	0,936	63	0,765	63
	37,7	1,03	45	0,697	21	0,38	50
	46,8	0,467	56	0,301	26	0,279	63
	59,6	0,339	42	0,314	45	0,212	63
	85,5	0,411	56	0,273	71	0,307	63
142	13,9	2,71	42	1,67	45	2,56	71
	19	1,54	36	1,11	45	1,07	31
	23,8	1,2	31	1,61	50	0,696	29

	27,4	2,19	31	1,4	63	0,852	28
	31	0,824	33	0,375	25	0,405	50
	31,4						
	37,7	1,43	71	0,771	45	0,837	63
	44,3						
	44,9	1,01	50	0,647	50	0,427	50
	49,9						
	53,8	0,519	56	0,253	38	0,26	45
	66,1	0,383	50	0,16	71	0,274	38
	91,1	0,677	63	0,479	56	0,453	71
143	13,1	1,57	42	2,79	63	1,64	38
	15,7	2,67	50	1,7	56	1,87	45
	18,7	2,07	50	1,62	50	4,47	66
	22,4	1,11	42	0,909	71	0,727	42
	26,7	0,794	50	0,68	50	0,707	66
	32,1	1,38	45	1,61	56	0,962	45
	37,3	0,882	45	0,806	83	0,579	63
	46	1,28	38	1,04	83	0,863	38
	54,8	1,03	56	0,949	56	0,714	50
	69,1	1,06	42	0,901	26	0,766	50
144	20,4	0,897	56	0,924	42	0,579	42
	25,3	2,17	56	1,18	50	1,17	50
	27,9	2,07	56	1,45	56	3,08	56
	27,3	1,89	42	2,21	50	1,2	56
	31,2	0,65	42	0,526	71	0,363	42
	34,8	0,974	45	0,746	42	0,761	56
	39,5	0,914	50	0,95	56	0,622	45
	44	0,593	50	0,467	63	0,352	83
	51,6	0,963	50	0,983	56	0,576	50
	59,3	0,812	38	1,07	56	0,994	42
	72	0,905	56	0,558	100	0,493	45
145	22	0,518	38	0,455	33	0,62	56

	26,8	0,517	50	0,805	63	0,538	56
	30,8	0,455	42	0,557	42	0,309	50
	35,2	1,52	38	0,797	56	0,821	38
	36,9	0,579	38	0,386	100	0,376	42
	40,5	0,303	38	0,537	36	0,437	45
	47,6	0,306	83	0,49	125	0,463	63
	55,7	0,403	31	0,351	63	0,358	56
	67,1	0,503	63	0,426	63	0,415	45
146	16,8	1,37	56	1,58	63	1	45
	19,5	0,868	56	0,659	56	0,455	83
	23,6	0,933	45	2	50	1,38	42
	27,6	1,31	56	1,18	33	1,33	63
	33,7	1,01	36	1,29	56	1,26	33
	40,5	0,986	56	0,642	50	0,869	45
	48,4	0,729	56	0,504	63	0,419	50
	57,9	0,76	63	0,869	63	0,827	45
	76,3	0,384	63	0,317	100	0,177	63
	82,8			0,0852	100	0,0644	63
147	44	0,16	63	0,163	56	0,243	63
	61,7	0,0631	50	0,0476	36	0,0631	56
	65,9	0,0995	56	0,0686	63	0,0982	42
	71,1	0,137	38	0,109	50	0,88	45
	84,1	0,0478	42	0,0498	45	0,0608	42
	92,9	0,608	50	0,04	100	0,0461	45
	115	0,0968	45	0,0608	100	0,0657	50
	129	0,056	100	0,048	56	0,0785	56
	150	0,0372	56	0,0455	71	0,0527	50
	316	0,00846	56	0,00935	58		
148	18	1,41	36	1,35	36	1,12	29
	24,2	0,731	38	0,615	38	0,765	45
	27,3	0,938	42	0,645	63	0,558	45
	29,6	1,18	38	0,909	83	0,59	42

	35,4	0,381	42	0,263	42	0,325	42
	39,4	0,61	45	0,449	63	0,229	45
	49,2	0,608	42	0,528	71	0,535	42
	55,5	0,785	38	0,686	50	0,91	38
	64,7	0,596	42	0,477	42	0,478	38
	145	0,083	67	0,0722	45	0,0848	56
	145	0,808	100	0,0604	56	0,0684	42
149	19,7	0,459	50	0,159	71	0,196	56
	36	0,143	45	0,102	45	0,0897	56
	40,6	0,162	45	0,0808	56	0,0833	36
	45	0,207	38	0,179	50	0,118	42
	60,4	0,0788	45	0,0685	56	0,035	38
	70,2	0,0496	45	0,017	33	0,0645	50
	95	0,0649	36	0,0589	50	0,0655	42
	111	0,0685	42	0,0791	56	0,0977	42
	134	0,0472	50	0,0282	50		
	322	0,0121		0,00919		0,0128	
	322	0,0121		0,00898			
150	48,8	0,0994	63	0,083	83	0,0986	56
	68,5	0,04	50	0,0328	42	0,0406	56
	73	0,032	45	0,0248	63	0,0269	42
	85,3			0,016	63	0,013	63
	92,9	0,019	45	0,0151	83	0,018	33
	103	0,23	50	0,0201	100	0,018	45
	127	0,0244	63	0,0295	56	0,0432	63
	142	0,0271	50	0,0227	63	0,0339	38
	165	0,0288	63	0,0198	83	0,0134	36
	348	0,0042		0,00219		0,00423	
	348	0,00256		0,00262		0,00314	

Table B-13: Littleville Dam Construction Site, Hungtington, Mass.

68	18,8	1,04	63	0,997	56	0,571	40
	28,5	0,607	36	0,513	48	0,49	32
	36,8	0,38	59	0,575	30	0,546	26
	51,4	0,472	28	0,475	22		
	74,1	0,102	12	0,176	67	0,0802	15
	106					0,0547	28
69	13,5	1,61	39	1,37	34	1,26	32
	20,3	0,8	59	0,97	63	0,434	38
	29,3	0,424	38	0,409	45	0,456	33
	37,2	0,31	63	0,424	33	0,444	26
	51	0,329	30	0,261	48	0,391	20
	72,7	0,0822	12	0,139	67	0,0687	14
	103			0,0621	59	0,0433	17
70	13,7	0,915	53	0,849	10	0,673	10
	20,4	0,695	42	0,56	45	0,543	30
	26,2	0,36	37	0,74	30	0,577	26
	36,2	0,481	26	0,57	42	0,59	17
	51,9	0,112	12	0,219	63	0,97	16
	73,9	0,104	20	0,0835	10	0,59	22
71	22,7	0,589	50	0,589	71	0,449	42
	33,4	0,463	45	0,341	43	0,455	34
	43,1	0,293	59	0,469	30	0,432	26
	59,7	0,353	33	0,369	40	0,493	19
	85,7	0,0849	13	0,124	67	0,0566	15
	122			0,0611	34	0,0464	22
72	18,1	0,501	53	0,368	59	0,412	48
	26,6	0,446	43	0,268	50	0,369	43
	34,1	0,208	53	0,285	40	0,283	30
	47,3	0,232	37	0,228	48	0,184	19
	67,8	0,0461	11	0,0772	63	0,0294	33

	96,7	0,0314	40	0,0414	48	0,0227	37
73	24,5	0,88	53	0,84	53	0,539	45
	35,9	0,659	38	0,448	45	0,554	31
	46,2	0,31	56	0,547	31	0,522	50
	63,9	0,483	28	0,452	38	0,582	23
	91,6	0,0982	13	0,132	13	0,0645	14
	130	0,0848	21	0,0746	59	0,0542	50
74	20,1	0,314	67			0,253	67
	29,4	0,309	67	0,147	71	0,167	45
	37,5	0,155	38	0,227	36	0,17	33
	51,9	0,107	32	0,131	43	0,116	32
	74,4	0,0328	13	0,0487	48		
	106	0,0226	19	0,032	59	0,0162	48

Table B-14: Fairfax Quarries, Inc., Quarry, Centreville, Va.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
86	21,5	0,528	33	0,204	36	0,422	30
	23,5					0,36	36
	25,9			0,421	48	0,705	40
	29	0,273	45	0,186	36	0,232	59
	31,7	0,165	37	0,152	50	0,242	36
	34,9	0,157	36	0,112	59	0,22	59
	37,6	0,204	40	0,112	48	0,172	43
87	7,54	1,14	10	2,53	43	1,38	29
	9,35	1,41	48	2,45	34	1,79	36
	11,7	2,12	30	1,64	32	2,99	33
	14,7	0,31	50	0,634	34	0,496	53
	17,9	0,518	33	0,432	83	0,346	37
	22,2			0,285	37	0,244	59

	27,9			0,235	67	0,174	33
	34,9	0,162	43	0,139	31	0,172	30
	43,4	0,114	32	0,106	29	0,121	20
	54,7	0,105	29			0,0896	29
	67,9	0,0772	11	0,045	23	0,0796	13
88	8,13	1,47	42	1,94	48	1,27	48
	9,96	1,58	34	2,11	56	1,31	50
	12,6	1,33	42	1,61	59	0,744	50
	15,8	1,14	43	0,944	77	0,937	53
	19,7	0,818	71	0,543	59	0,352	12
	31,3	0,292	59	0,288	50	0,273	50
	36,8	0,413	42	0,152	50	0,152	37
	42,9	0,347	45	0,224	59	0,235	43
	49,7	0,153	50	0,073	59	0,0796	50
	62,6	0,0597	10	0,0373	38	0,0481	42
	80,1	0,0249	91	0,0241	50	0,021	67
89	6,87	2,41	50	4,36	53	2,56	27
	8,16	1,33	31	2,46	56	1,61	27
	10	1,67	48	1,71	63	1,7	36
	12,3	0,875	43	0,909	67	1,24	37
	15,2	0,788	31				
	23,5	0,982	13	0,368	32	0,712	32
	27,8	0,474	38	0,237	43	0,214	43
	32,4	0,558	45	0,224	59	0,211	56
	47					0,155	50
	59,6	0,048	83	0,0459	63	0,0455	125
90	7,15	2,82	36	3,21	53	1,93	53
	9,04	1,61	38	1,89	53	1,06	50
	11,7	1,64	71	2,11	59	0,871	36
	14,9	1,63	43	1,06	59	0,681	63
	18,9	1,06	45	0,887	63	0,808	48
	30,5	0,585	42	0,322	40	0,365	42

	35,9	0,46	42	0,322	50	0,228	53
	42,2	0,44	45	0,17	43	0,293	43
	49	0,186	14	0,123	16	0,126	13
	61,8	0,112	12	0,0758	17	0,0827	17
	79,1			0,0295	17	0,0336	
91	6,78			4,65	26	4,83	26
	8,65	2,04	24	2,98	29	3,22	26
	10,3	1,26	29	1,61	59		53
	13,6	0,936	33	1,73	83	1,7	30
	16,5	0,773	48	1,08	56	1,48	27
	20,4			1,14	31		
	30,6	0,798	25	0,261	77	0,751	29
	37	0,24	40	0,167	53	0,386	33
	44,8	0,0932	13	0,0833	20	0,154	17
	55	0,137	50	0,148	48	0,061	53
	67	0,0673	43	0,07	59	0,0647	56
94	5,71			4,38	36	3,8	27
	7,32	3,41	56	2,48	50	2,23	31
	8,78	1,67	53	1,89	36		
	11,6	1,81	63	2,52	56	0,912	56
	14,1	1,48	36	1,14	59	1,16	50
	17,6	0,867	32	1,1	56	0,657	31
	27	0,912	24	0,511	67	0,517	30
	32,5	0,387	33	0,178	83	0,289	32

Table B-15: W.E. Graham & Sons, Manasses Quarry, Manasses, Va.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
92	7,18	2,05	71	2,37	36	1,22	77
	11	1,22	63	1,6	59	0,936	43
	17,5			0,556	23		

	26,6	0,685	10	0,508	29	0,64	10
	41,2	0,261	12	0,256	13		
	63,5	0,188	11	0,123	50	0,154	10
92	12,2	1,03	45	1,06	53	0,702	59
	16,9	1,22	31	0,676	59	0,426	34
	23,8			0,268	50	0,347	43
	32,9	0,669	19	0,621	33	0,421	36
	43,8	0,338	28	0,273	33	0,224	38
	65,2			0,143	71	0,197	67
93	9,81	1,15	77	1,22	83	0,922	50
	14,3	1,58	56	1,48	67	1,1	43
	22,2			0,781	24		
	33,1	0,431	19	0,354	22	0,337	36
	50,7	0,149	34	0,11	36	0,134	22
	77,6	0,163	22	0,0878	31	0,131	20
93	12	1,61	67	1,12	71	1,95	46
	17,8	1,44	36	1,08	43	0,781	56
	26,1			0,495	43	0,807	45
	37	0,967	26	0,486	40	0,668	83
	50,2	0,32	48	0,38	28	0,566	43
	75,8			0,166	71	0,261	50
95	10,4	1,69	59	1,41	71	0,943	71
	15,4	0,946	67	0,875	67	0,861	56
	20,8			0,55	106		
	27	0,505	83	0,647	139	0,658	105
	41,4	0,219	96	0,168	113	0,286	
	63,5	0,257	66	0,0874	148		59
95	7,11	2,2	71	2,05	59	1,83	45
	11,8	1,66	43	1,64	67	0,821	45

	18,6	1,08	37	0,729	53	0,759	48
	27,8	1,16	29	0,57	53	0,821	42
	38,8	0,504	48	0,444	56	0,456	30
	60,4	0,244	53	0,146	67	0,149	50
117	13,3	1,33	40	1,7	32	0,792	77
	16,6			0,858	40	0,863	50
	24	1,05	20	0,691	40		
	29,4	0,564	30	0,422	42	0,248	37
	38	0,487	20	0,327	27	0,245	53
	50,6	0,577	23	0,299	29	0,333	26
117	12,1	2,31	29	2,18	21	1,17	38
	18,1			0,788	33	0,77	45
	21,9	1,54	22	0,774	15	0,474	22
	26			0,455	17	0,273	24
	34	0,992	17	0,284	26	0,172	41
	45,1	0,211	36	0,267	22	0,164	41
118	10,7	1,99	21	1,93	29	1,12	50
	13,9			1,2	33	0,747	29
	20,3	1,09	30	0,625	53		
	25	0,6	33	0,73	36	0,373	37
	32,7	0,542	53	0,451	31	0,393	42
	43,1	0,373	21	0,347	27	0,487	25
118	10,5	2,74	32	2,46	34	1,46	33
	35,6			1,05	26	0,501	59
	18,9			0,648		0,682	34
	22,4			0,599		0,318	21
	29,3	0,726		0,463	24	0,348	
	39	0,318		0,273		0,17	34
120	9,87	2,92	19	1,84	50	1,06	21
	13,5	1,54	29	0,805	48	0,778	36

	20,6	0,926	36	0,538	83		
	25,8	0,673	23	0,545	56		
	34,5	0,564	21	0,365	71	0,405	33
	46,2	0,387	26	0,178	24	0,243	25
120	109	1,75	21	1,78	25	1,14	33
	15,7	1,49	25	1,1	34	0,729	30
	19,3	1,06	23				
	23,2	0,697	17	0,485	27	0,458	23
	30,9	0,711	18	0,406	30	0,401	20
	41,7	0,251	27	0,167	75	0,217	50
121	69,7					0,0807	56
	94,1	0,036	46				
	118	0,0297	40	0,0243	31	0,0334	50
	128	0,0195	32	0,0195	36		
	263			0,0526	111	0,0437	53
	321			0,0106	83		
122	68,3	0,0622	32	0,0346	59	0,026	50
	80,5	0,0439	53	0,0306	56	0,0154	48
	90,5	0,0316	45	0,0141	77	0,0117	48
	113	0,0168	34	0,00847	40	0,00797	48
	122	0,0141	36	0,0106	37		
	143	0,0142	38	0,00848	36	0,00656	38
	172	0,0139	34	0,00965	57	0,00414	43
	208	0,00599	28	0,00318	49	0,00253	68
	250	0,0025	24	0,00528	111	0,00152	59
	304			0,000922	83	0,000808	34
123	10	2,63	33	2,58	38	2,11	36
	13,3	2,18	33	1,2	29	0,889	29
	16,3	1,94	29	1,07	30	0,848	23
	22,4	0,708	33	0,963	26	0,366	28
	24,9	0,725	22	0,43	23	0,432	22

	30,2	0,758	15	0,322	20	0,536	14
	37,5					0,243	27
	46,7	0,544	21	0,239	21	0,219	43
	57,2	0,211	22	0,135	62	0,0791	26
	70,8	0,0737	31	0,0847	33	0,0656	26
125	16,1	0,833	25	1,58	50	1,12	50
	25,3	0,568	38	1,33	40	0,528	31
	28,7	0,705	48	0,901	37	0,311	42
	37,8	0,604	32	0,537	56	0,506	30
	45,1	0,487	26	0,503	56	0,386	42
	55,8	0,244		0,3		0,159	
	68,7	0,318		0,228		0,17	
	83,6	0,325		0,245		0,197	
	101	0,156	30	0,15	27	0,139	31
	128	0,149	30	0,0971	29	0,134	31
126	6,71	2,71	26	2,3	50	2,07	50
	10,4	1,17	48	1,64	48	1,44	36
	11,7	0,809	37	0,995	63	0,758	31
	15,4	0,784	29	0,731	36	1,26	36
	18,3	0,772	50	0,824	50	1,04	43
	22,6	0,606		0,374		0,481	
	27,8	0,583		0,339		0,606	
	33,8	0,518		0,298		0,453	
	40,9	0,235	26	0,196	29	0,347	32
	51,9	0,26	40	0,105	32	0,227	33

Table B-16: Chemstone Corporation Quarry, Stressbury, Va.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
96	9,4	1,46	17				
	12,1	0,962	26			0,886	24
	13,9	1,39	21	1,54	25	1,62	25
	16,4	1,03	21	0,683	25		
	20,2			0,423	19	0,9	22
	24,8	0,772	12	0,334	23	0,378	20
	30,6	0,383	16	0,314	17	0,301	16
	38,6	0,471	24	0,159	83	0,285	38
97	7,55	1,84	13	2,04	20	1,16	24
	9,18	2,07	20	1,67	21	1,2	23
	12	0,72	29	1,23	19	0,481	25
	15,4			0,999	17	0,495	28
	22,5	0,543	28	0,632	16	0,495	25
	25,6	0,936	25	0,535	26	0,446	20
	33,4	0,445	26	0,246	72	0,352	31
98	17	1,61	33	1,76	56	1,67	36
	20,2	0,679	26	0,788	31	0,794	31
	23,8	0,829	33	0,917	72	1,28	29
	28	0,55	56	0,346	42	0,692	22
	33,5	0,517	17	0,233	45	0,592	22
	39,7	0,381	14	0,142	17	0,338	17
	48	0,106	25	0,929	42	0,119	56
	56,1	0,105	26	0,991	20	0,0788	50
99	9,76					1,35	16
	12,6	1,85	29	1,67	28	1,92	21
	14,6	1,2	25	1,33	28	1,42	23
	17,3	0,861	24	0,628	50	1,53	23

	21,3			0,824	31	0,845	25
	26,3	0,692	16	0,406	20	0,472	19
	32,5	0,328	19	0,342	17	0,328	16
	41,2	0,334	28	0,215	36	0,313	25
100	15,8	1,31	36	0,529	42	0,538	56
	25,3	1,06	26	0,693	36	0,611	25
	29,2	0,328	20	0,267	25	0,38	31
	33,4	0,573	24	0,173	28	0,328	33
	38,1	0,442	20	0,23	17	0,409	25
	44,6	0,333	20	0,121	25	0,293	25
	51,8	0,258	15	0,178	19	0,204	17
	71,1	0,064	25	0,0484	17		
101	9,7	1,64	31	1,81	26	1,9	24
	11,3	1,09	20	1,14	26	1,57	22
	13,6	1,17	19	1,02	29	2,25	26
	16,8			0,714	29	0,764	16
	20,7	0,946	15	0,461	26	0,616	20
	25,8	0,938	14	0,34	17	0,434	15
	32,5	0,358	16	0,198	42	0,347	28
102	25,8	0,672	31	0,281	42	0,28	31
	30,3	0,246	33	0,185	28	0,211	36
	35,2	0,43	25	0,136	31	0,469	29
	40,9	0,196	26	0,113	20	0,261	24
	48,4	0,173	23	0,0579	23	0,153	24
	56,7	0,11	12	0,484	17	0,0681	28
	79,4	0,0306	36	0,0285	42	0,0299	31
103	11,1	2,02	7	2,61	19	1,27	10
	14,7	0,84	17	1,09	38	1,25	25
	17,2	0,773	45	0,58	26	1,09	22
	20,7	0,602	42	0,5	63	1,01	24
	25,9	0,765	26	0,243	17	0,474	21

	32,3	0,346	18	0,318	19	0,493	23
	40,5	0,223	14	0,249	17	0,232	15
	51,9	0,195	25	0,0929	72	0,353	23
104	8,5			1,24	20		
	10,3	0,558	14	1,04	23	1,89	24
	12,7	0,786	19	0,863	42	1,38	25
	16,3	2,01	22	0,456	22	1,1	29
	20,6	0,634	16	0,434	22	0,86	23
	26	0,296	11	0,285	20	0,276	16
	33,7	0,384	23	0,129	42	0,535	23
105	8,37			2,47		1,37	
	11,5			2,65		1,1	
	22,7	0,995	17	1,15	28	0,536	29
	27,5	0,873	25	0,00178	63	0,497	28
	30,2	0,581	20	0,424	36	0,421	19
	34,1	0,598	19	0,283	18	0,464	20
	38,4	0,31	14	0,217	17	0,24	18
106	7,7	2,08	15	1,4	15		
	9,42	1,98	25	1,42	25	2	21
	11,8	0,922	29	1,09	38	1,61	17
	15,2	2,6	25	0,6	33	1,58	28
	19,5	0,566	28	0,529	20	1,18	25
	24,8	0,435	13	0,384	20	0,348	19
	32,3	0,325	20	0,161	36	0,363	19
107	11,9	1,05		0,812		0,608	
	15,2	1,21		0,746			
	26,8	0,483	28	0,67	29	0,552	26
	29,1	0,253	19	0,278	28	0,248	36
	31,7	0,549	26	0,216	63	0,403	31
	34,5	0,323	22	0,257	28	0,341	23
	36,2	0,435	20	0,173	22	0,28	22

	38,5	0,347	20	0,366	20	0,235	16
	43	0,161	7	0,13	20	0,14	17
	48,9	0,171	56	0,0571	18		
108	6,25	1,42	22	1,43	17	2,17	28
	7,88	1,52	20	2,01	26	1,44	21
	10	1,13	21	0,959	42	1,41	31
	13,3	3,34	23	0,727	26	0,657	25
	15,1	1,02	20	0,977	22	1,7	21
	17,3	0,711	19	0,448	24	0,628	25
	22,2	0,387	15	0,263	12	0,338	14
	29	0,27	18	0,124	36	0,392	19
109	7,28	2,19	26	1,55	31	1,26	20
	9,45	1,09	25	1,12	25	1,85	22
	12,3	0,736	50	0,766	21	1,29	23
	16,6	2,19	24	0,373	33	0,597	25
	18,9	0,863	26	0,8	20	0,958	24
	21,9	0,387	20	0,334	23	0,628	25
	28,7	0,223	17	0,264	19	0,24	16
	38,1	0,273	25	0,105	50	0,286	24
110	11,2	1,1	24	1,06	42	1,14	29
	14,7	0,42	48	0,472	38	1,09	
	26,2	0,68	27				
	29,9	0,484	27	0,283	13	0,345	26
	34,6	0,245	11	0,144	26	0,235	33
	44,9	0,181	11	0,0847	17	0,112	48
	59,6	0,124	43	0,12	33	0,142	23
111	10,4	1,12	31	1,01	36	1,45	29
	13,8	0,465	50	0,712	50	1,23	33
	18,3	0,539	31	0,581	45	0,627	28
	25,1	0,871	30	0,518	42	0,42	28
	28,7	0,57	28	0,278	17	0,285	28

	33,4	0,29	16	0,211	24	0,328	33
	43,7	0,155	13	0,0884	15	0,143	25
	57,9	0,28	19	0,121	36	0,195	24

Table B-17: Chantilly Crushed Stone Company Quarry, Chantilly, Va.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
114	10,3	0,808		0,713		0,606	
	12,5	0,455		0,54			
	14,3	0,357		0,289			
	17,1	0,277					
	21			0,17	56	0,235	28
	28,5	0,199	36	0,118	36	0,156	19
115	23,3			0,218	42	0,364	33
	31,4	0,253	67	0,177	57	0,346	31
	45,9	0,1	33	0,0816	31	0,141	29
116	16,3	0,678	21	0,284	45	0,862	22
	21,6	0,461		0,223		0,95	
	26,8	0,258		0,17		0,253	
	32			0,151			
	37,3	0,235		0,111			
119	14,5	1,22	23	0,734	36	0,997	21
	20,6	0,789		0,443		0,705	
	26,7	0,374		0,451		0,94	
	32,8	0,378		0,134		0,434	
	39	0,267		0,174		0,334	

Table B-18: Culpeper Crushed Stone Company Quarry, Culpeper, Va.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
124	79,8	0,0879	17	0,0812	38		
	89,3	0,0862	21	0,0393	17	0,106	19
	107	0,0498	36	0,0357	63	0,0794	16
	121	0,0429	31	0,0259	56	0,078	17
127	4,94	2,49	29	2,86	28	3,06	17
	7,16	1,84	25	1,83	42	2,44	17
	10,5	1,82	36	1,26	45	1,25	17
	15,4	0,952	38	0,793	42	0,973	38
	23,1	0,385	42	0,25	45	0,579	42
	33,9	0,189	22	0,113	26	0,179	28
	45,2	0,204	26	0,205	33	0,139	28
129	5,7	2,31	22	2,18	36	3,51	18
	8,7	1,93	23	1,27	42	2,64	21
	13	0,96	38	0,758	50	0,848	20
	19,8	0,442	42	0,235	56		
	29,5	0,279	20	0,145	16	0,304	19
	39,5	0,196	21	0,0771	29	0,162	18
129	16,2	0,476		0,329		0,331	
	19,2			0,306			
	23,4	0,197		0,379			
130	8,41	2,32	24	1,76	28	1,16	18
	9,69	2,78	42	1,37	36		
	15,9	1,6	29	1,47	42	0,745	33
	20,5	1,06	23	0,667	23	0,818	25
	27,3	0,585	33	0,48	28	0,679	23
	36	0,38	18	0,196	50	0,446	23

	45,4	0,285	17	0,165	25	0,25	24
	102	0,0412	40	0,0437	56		
	126					0,0877	38
132	5,58	1,78	14	3,27	31	2,71	24
	6,75	2,18	36	2,14	29	2,71	25
	8,58	3,09	16	1,73	28	2,75	19
	12,4	1,94	31	1,29	42	1,15	45
	16,8	0,96	23	0,968	19	0,742	28
	23	0,634	28	0,731	45	0,537	26
	31,1	0,453	29	0,288	50	0,461	28
	76,5	0,0955	9	0,0413	18		
	93,1	0,0429	14	0,084	14	0,0366	18
	116	0,121	8	0,0253	9	0,0727	6
133	5,54	3	23	2,87	29	2,27	28
	6,76	3,33	50	2,14	56	2,15	45
	8,74	3,65	31	2,47	56	1,75	19
	12,7	2,48	29	1,62	56	1,47	33
	17,1	1,28	29	0,954	45	0,994	2
	23,6	1,08	38	0,701	50	0,848	45
	31,9	0,667	33	0,471	38	0,575	25
	54,9	0,111	24	0,0893	42	0,154	28
135	7,17	3,77	23	2,24	50	2,8	23
	11,2	1,71	19	1,88	45	1,67	28
	15,9	1,07	25	1,01	45	1,07	28
	19,2	1,15		0,837		0,704	
	22,6	0,771	29	0,691	50	0,745	28
	31,3	0,617	31	0,405	50	0,533	28
	43,2	0,424		0,169		0,34	
	64,1	0,109	24	0,048	42	0,187	42
138	13,8	1,27	24	0,862	36	1,11	24
	16	0,842	33	0,809	50	0,96	29

	19,3	0,727	28				
	24,3	0,308	42	0,295	36	0,535	42
	32	0,314	28	0,169	56	0,568	45
	43,1	0,118	29	0,136	33	0,298	45
	54,4	0,102	38	0,0806	56	0,238	42

Table B-19: General Crushed Stone Company Quarry, Donnel, Va.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
152	6,86	1,18	38	1,03	100		
	13,3	0,705	24	0,706	28	0,806	38
	23,4	0,3	9	0,144	17	0,281	13
	24,9	0,231	8	0,105	18	0,186	11
	26,7	0,207	10	0,187	15	0,312	13
	29	0,21	14	0,143	13	0,288	13
	32,1	0,167	6	0,132	10	0,245	10
	35,7	0,0992	13	0,105	14	0,0909	16
	41,4	0,0858	38	0,0673	16	0,127	8
	53,3	0,208	10	0,0924	9	0,167	17
	59	0,151	9	0,15	11	0,18	12
	77,7	0,0606	24	0,0515	15		
153	6,72	2,19	20	2,42	16	1,98	25
	7,71	1,19	14	1,98	17	1,31	28
	9,08	1,38	33	1,41	19	1,11	29
	10,8	1,06	25	0,942	17	0,694	25
	12,9	1,25	22	1,73	18	0,729	17
	15,5	1,17	16	1,01	17	1,07	21
	19,2	0,683	14	0,649	20	0,364	13
	23,2	0,588	19	0,353	25	0,304	20
	29,7	0,459	18	0,431	18	0,264	24
	43,3	0,313	10	0,234	23	0,523	20
	49,8	0,306	25	0,302	25	0,337	11

	71	0,206	11	0,18	14	0,115	13
154	3,97	6,14	16	5,13	36	4	13
	4,85	2,87	25	2,74	26	1,67	28
	5,95	2,27	24	1,38	23	1,39	19
	7,63	1,39	45	1,48	23	1,02	26
	9,54	1,38	12	1,34	22	1,18	18
	11,9	0,974	13	0,836	21	0,852	19
	15,3	0,478	18	0,533	20	0,354	15
	19,1	0,461	22	0,253	12	0,339	18
	25,2	0,314	16	0,46	17	0,218	19
	37,9	0,301	17	0,219	29	0,353	14
	44,1	0,357	24	0,421	24	0,322	23
	63,9	0,103	11	0,071	12		

Table B-20: Riverton Lime & Stone Company Quarry, Riverton, Va.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
137	7,56	3,54	25	3,35	24	3,79	29
	13,7	2,52	31	1,29	33	1,06	36
	19,5	3,46	22	2,53	31	1,09	29
	23,6			1,17	26		

Table B-21: Southern Materials Corporation, Jack Stone Quarry, Petersburg, Va.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
164	6,41	1,31	17	1,64	21	1,36	19
	8,58	1,26	20	1,37	17	1,4	17
	9,48	1,13	19	1,14	29		
	10,8	0,862		0,663		1,07	
	12,2	0,584	28	0,476	18	0,822	16

	15,4	0,48	15	0,4	21	0,713	15
	17,8	0,306	12	0,413	20	0,568	20
	21,3	0,372	13	0,353	20	0,558	15
	25,1	0,205		0,213		0,27	
	28,8	0,141		0,273		0,252	
	34,1	0,141	14	0,263	16	0,288	17
165	4,01	1,82	24	1,82	33	1,18	25
	5,04	2,69	23	2,41	36	1,88	21
	5,93	2,31	22	2,75	31	1,11	31
	7,3	1,67		2		1,24	
	9,03	1,1	33	1,4	20	0,964	33
	11,8	0,758	24	0,545	36	1,2	24
	14,2	0,986	28	0,779	56	0,781	33
	17,5	0,409	19	0,409	33		
	20,9	0,423		0,406		0,203	
	26,8	0,192		0,179		0,125	
	33,7	0,177	9	0,145	13	0,0909	38
166	4,66	2,67	21	1,49	26	1,38	25
	5,65	2,77	25	1,72	13	1,52	24
	6,83	1,28	13	1,11	17		
	8,39	1,26		1,04		1,14	
	10,3	1,03	25	0,909	33	1	23
	13	0,661	20	0,673	17	0,556	29
	15,4	0,496	25	0,652	22	0,473	28
	19	0,345	20	0,4	14	0,351	24
	23,1	0,305		0,426		0,319	
	29,1	0,201		0,324		0,182	
	36,4	0,12	13	0,125	13	0,155	14
167	4,29	3,58	22	2,71	23	2,63	20
	5,44	2,13	16	1,3	15	1,89	21
	6,26	2,36	20	1,91	17	1,94	18
	7,66	2,36	20	1,37	23	1,45	16

	9,48	1,44	19	0,787	22	0,248	29
	11,9	1,07	19	0,709	13	1,01	16
	14,3	1,47	20	1,43	19	1	23
	17,2	0,487		0,795		0,462	
	21,3	0,603		0,563		0,551	
	26,3	0,362		0,64		0,255	
	33,4	0,275	13	0,327	19	0,155	26
168	12,4	0,649	26	0,926		0,417	56
	17,1	0,743	36	1,1	50	0,487	50
	21,2	0,661	38	1,35	42	0,284	56
	27,1			0,613			
	35,1	0,3	42	0,32	50	0,183	56
	47,4	0,229	45	0,0942	50	0,264	72
	58	0,259	33	0,312	83	0,218	83
	72,9	0,103	38	0,186	72	0,0889	83
	90,1	0,101		0,137		0,115	
	114	0,0435		0,0551		0,03	
	145	0,0254	72	0,56	72	0,029	83

Table B-22: Superior Stone Company, Buchanan Quarry, Greensboro, N.C.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
155	18	0,595	23	1,15	25	0,484	25
	206	0,509	33	0,469	28	0,399	33
	22	0,351	29	0,346	16	0,27	29
	25,4	0,261	55	0,182	11	0,361	18
	30,3	0,17	23	0,172	18	0,2	17
	36,1	0,194	18	0,145	22	0,135	28
	43	0,188	19	0,12	25	0,245	28
	51,3	0,132	24	0,0926	31	0,0893	24
	59	0,0847	84	0,08	55	0,0621	51
	67,3	0,0475	70	0,0813	81	0,043	81

	78,9	0,0496	63	0,0702	63	0,0519	36
	88,9	0,0298	26	0,0372	14	0,036	13
156	15,1	0,714	25	0,766	33	0,321	29
	16,8	0,82	42	0,909	28	0,71	29
	19,9	0,421	25	0,41	15	0,451	38
	22,7	0,933	14	0,462	9	0,278	9
	25,6	0,16	31	0,204	22	0,12	26
	28,1	0,198	42	0,236	31	0,227	31
	40,2	0,231	28	0,244	26	0,2	21
	46,3	0,136	18	0,137	24	0,121	29
	54,2	0,092	8	0,0853	8	0,0539	19
	61,6	0,163	11	0,154	23	0,0967	13
	74	0,051	38	0,0936	71	0,0434	45
	86,2	0,0565	25	0,0588	14	0,0494	29
157	16,4	0,758	16	1,78	30	0,783	38
	19	0,607	26	0,679	14	0,406	30
	20,6	0,6	19	0,526	18	0,448	22
	23,8	0,487	91	0,283	12	0,442	58
	28,8	0,242	21	0,247	17	0,209	16
	34,8	0,198	22	0,205	26	0,0962	28
	41,3	0,175	21	0,203	23	0,143	
	47,9			0,125	19		
	56,2	0,133	64	0,115	64	0,0907	8
	64,3	0,0987	91	0,0993	58	0,0516	14
	78,8	0,0451	47	0,0936	16	0,0422	25
	89	0,0351	20	0,049	38	0,0321	17
158	31,2	0,103	33	0,822	31	0,385	36
	34,2	0,345	50	0,327	28	0,303	38
	39,5	0,172	36	0,151	15	0,152	28
	44,8	0,404	8	0,128	10	0,133	26
	54,2	0,0848	28	0,103	31	0,08	56
	64,6	0,0631	25	0,0603	33	0,0472	71

	76	0,0638	29	0,124	28	0,105	33
	86,9	0,0621	24	0,0437	24	0,0518	25
	101	0,0549	8	0,0323	10	0,0379	25
	115	0,0523	8	0,0446	14	0,0421	7
	137	0,0218	50	0,0361	63	0,0231	56
	157	0,0235	17	0,0223	13	0,0255	45
159	17	0,393	23	0,713	23	0,403	28
	19,2	0,658	33	0,321	23	0,461	31
	20,7	0,372	25	0,326	20	0,175	28
	23,5	0,273	11	0,38	64	0,245	8
	27,7	0,242	17	0,241	13	0,187	20
	32,8	0,116	23	0,147	18	0,111	23
	38,6	0,22	19	0,162	25	0,132	21
	43,6			0,115	17		
	50,6	0,109	30	0,0673	22	0,118	38
	57,5	0,124	8	0,175	18	0,076	7
	68,4	0,0621	42	0,0735	56	0,045	15
	78,6			0,0583	14	0,0481	38

Table B-23: Superior Stone Company, Hi-Cone Quarry, Greensboro, N.C.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
160	8,34	1,3	63	2,1	63	2,42	56
	10,1	1,33	45	1,22	36	1,03	45
	12,2	0,847		1,61		0,893	
	16,3	0,758	29	0,517	56	0,624	20
	22,3	0,599	33	0,558	24	0,858	50
	27,3	0,413	29	0,531	34		
	34,3	0,47		0,25		0,232	
	42,1	0,148		0,162		0,151	
	52,8	0,0788	100	0,0962	125	0,08	56
	64,9	0,109	19	0,661	19	0,1	26

161	9,73	1,63	31	1,16	45	2,02	42
	11,7	0,957	36	1,67	33	2,03	29
	13,8	0,881	50	1,49	50	1,47	33
	16,6	0,967		0,853		0,933	
	21,6	0,702	36	0,564	33	0,387	33
	26,8	0,539	28	0,381	36	0,553	31
	32	0,289	21	0,196	23		
	38,4	0,268		0,207		0,191	
	47,5	0,119		0,139		0,177	
	58,9	0,101	36	0,0535	50	0,101	45
	72,5	0,118	26	0,0439	29	0,0727	36
162	6,83	1,76	45	2,61	45	1,64	42
	8,51	1,6	50	2,06	45	1,46	45
	10,4	1,64		2,08		1,31	
	14	1,47	36	0,8	36	0,579	45
	19,5	0,933	36	0,776	31	0,696	38
	24	0,702	36	0,393	29		
	30,4	0,545		0,346		0,328	
	37,3	0,147	17	0,176	28	0,188	33
	46,9			0,0943	125	0,0729	50
	57,7	0,146		0,0833		0,124	
163	6,83	1,73	38	3,22	56	3,8	63
	8,47	1,31	45	1,4	33	1,5	50
	10,5	0,997		1,28		1,28	
	14,3			0,622	36		
	19,8	0,947	42	0,462	22	0,67	50
	24,5	0,693	36	0,652	28	0,652	45
	31	0,555		0,249		0,309	
	38,1	0,185		0,193		0,162	
	47,9	0,0897	83	0,0847	125	0,0709	100
	59,1	0,164	33	0,0776	56	0,0839	38

Table B-24: Warner Company Quarry, Union Furnace, Pa.

Test	Scaled Distance (ft/lb ^{1/2})	Radial		Vertical		Transverse	
		Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)	Particle Velocity (in/sec)	Frequency (cps)
151	3,39	4,85	11	8,73	19	6,94	12
	4,57	15	13	13,8	31	3,61	22
	6,22	6,79	10	7,46	28	5,48	14
	8,63	5,76	17	5,49	56	2,62	38
	11,9	3,68	33	2,19	71	2,68	38
	16,1	1,72	16	0,954	42	0,842	45
	20,2	1,67	14	1,04	50	0,771	38
	69	0,304		0,195		0,181	
171	3,39	6,77	10	10,2	30	6,67	
	4,4	13,2	11	20,9	16	7,47	20
	6,04	9,26	20	8,85	19	5,6	28
	8,24	5,68	25	4,4	38	4,7	71
	11,1	6,67	22	4,17	31	2,24	38
	14,9	5,15	36	2,98	29	3,05	36
	20,3	2,07	24	1,56	38	1,48	42
	66,6	0,127		0,0799		0,16	

APPENDIX C – FINAL DATASET USED IN CURRENT STUDY

Table C-1 contains the final dataset after the USBM has been cleaned.

Table C-1: Final dataset after cleaning

Site No.	Test	Total No. of Holes	Overburden (m)	Hole Size (mm)	Hole Depth (m)	Face Height (m)	Stemming (m)	Burden (m)	Spacing (m)	Charge per hole (kg)	No. of delay intervals	Max. Charge per delay (kg)	Length of Delay (msec)	Scaled Distance (m/kg ^{1/2})	Distance (m)	PPV Peak (mm/sec)
1	2	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	272,2	0,0	5,8	95,6	37,3
1	2	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	272,2	0,0	5,8	96,3	23,4
1	2	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	272,2	0,0	9,5	156,0	17,3
1	2	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	272,2	0,0	11,3	186,7	17,6
1	2	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	272,2	0,0	13,2	217,3	13,0
1	3	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	17,0	4,8	45,7	45,0
1	3	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	17,0	7,4	70,3	38,4
1	3	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	17,0	10,2	97,4	14,6
1	3	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	17,0	12,8	122,0	9,2
1	3	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	17,0	24,0	228,5	5,9
1	3	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	17,0	30,4	289,7	3,0
1	4	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	7,1	67,2	36,8
1	4	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	9,9	94,4	15,2
1	4	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	12,4	118,5	10,2
1	4	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	23,6	225,0	3,8
1	4	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	29,8	284,1	2,0
1	5	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	17,0	6,9	65,5	66,8

1	5	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	17,0	9,2	87,9	36,8
1	5	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	17,0	12,3	117,2	24,2
1	5	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	17,0	22,1	210,4	10,1
1	5	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	17,0	29,5	281,0	4,2
1	6	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	34,0	5,7	53,9	70,1
1	6	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	34,0	7,3	69,8	26,2
1	6	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	34,0	10,9	103,9	16,1
1	6	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	34,0	15,1	144,0	13,4
1	6	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	34,0	21,0	199,6	6,3
1	6	3,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	34,0	29,1	277,2	3,1
1	7	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	34,0	5,9	56,5	44,2
1	7	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	34,0	7,6	72,0	29,5
1	7	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	34,0	11,2	106,5	14,4
1	7	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	34,0	15,3	146,1	8,1
1	7	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	34,0	21,1	201,3	4,9
1	7	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	6,0	90,7	34,0	29,6	282,3	2,3
1	8	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	635,0	0,0	2,4	61,0	175,8
1	8	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	635,0	0,0	3,3	83,5	118,1
1	8	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	635,0	0,0	4,5	112,8	53,6
1	8	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	635,0	0,0	6,1	152,8	50,8
1	8	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	635,0	0,0	8,1	205,3	36,8
1	8	7,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	635,0	0,0	11,0	276,0	17,6
1	9	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	5,2	49,6	47,8
1	9	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	7,1	67,2	27,9
1	9	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	10,3	98,3	12,1
1	9	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	14,6	138,8	8,6
1	9	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	20,6	196,1	4,3
1	9	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	28,9	275,4	2,1
1	10	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	5,2	49,6	59,4

1	10	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	7,1	67,2	33,0
1	10	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	10,3	98,3	14,4
1	10	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	14,6	138,8	9,8
1	10	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	20,6	196,1	5,0
1	10	1,0	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	28,9	275,4	2,4
1	11	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	90,7	17,0	6,7	63,4	47,2
1	11	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	90,7	17,0	9,5	91,0	21,2
1	11	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	90,7	17,0	12,1	115,1	17,6
1	11	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	90,7	17,0	16,9	160,8	11,4
1	11	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	90,7	17,0	23,3	222,0	4,5
1	11	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	90,7	17,0	29,7	282,8	2,4
1	12	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	1360,8	0,0	2,5	93,3	129,5
1	12	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	1360,8	0,0	3,0	111,0	105,4
1	12	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	1360,8	0,0	3,6	132,9	95,8
1	12	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	1360,8	0,0	4,3	157,9	92,5
1	12	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	1360,8	0,0	5,1	188,6	55,6
1	12	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	0,0	1360,8	0,0	6,1	223,7	37,8
1	13	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	1360,8	34,0	9,1	337,2	34,3
1	13	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	1360,8	34,0	10,8	397,3	24,5
1	13	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	1360,8	34,0	12,7	467,4	16,8
1	13	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	1360,8	34,0	14,9	550,9	12,3
1	13	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	1360,8	34,0	17,6	649,4	12,1
1	13	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	1360,8	34,0	20,7	764,6	8,0
1	13	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	1360,8	34,0	24,4	901,5	6,0
1	13	15,0	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	1360,8	34,0	29,1	1073,5	3,2
1	18	1,0	1,8	152,4	11,0	9,1	4,9	3,0	0,0	90,7	0,0	90,7	0,0	7,1	67,2	42,2
1	18	1,0	1,8	152,4	11,0	9,1	4,9	3,0	0,0	90,7	0,0	90,7	0,0	8,6	81,5	21,6
1	18	1,0	1,8	152,4	11,0	9,1	4,9	3,0	0,0	90,7	0,0	90,7	0,0	10,4	98,7	19,8
1	18	1,0	1,8	152,4	11,0	9,1	4,9	3,0	0,0	90,7	0,0	90,7	0,0	13,1	125,0	16,1

1	18	1,0	1,8	152,4	11,0	9,1	4,9	3,0	0,0	90,7	0,0	90,7	0,0	15,3	145,3	16,0
1	18	1,0	1,8	152,4	11,0	9,1	4,9	3,0	0,0	90,7	0,0	90,7	0,0	18,5	176,3	6,8
1	18	1,0	1,8	152,4	11,0	9,1	4,9	3,0	0,0	90,7	0,0	90,7	0,0	22,5	214,7	6,2
1	18	1,0	1,8	152,4	11,0	9,1	4,9	3,0	0,0	90,7	0,0	90,7	0,0	27,3	259,9	3,7
1	19	3,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	2,0	90,7	9,0	7,1	67,2	30,5
1	19	3,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	2,0	90,7	9,0	8,6	81,5	33,0
1	19	3,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	2,0	90,7	9,0	10,4	98,7	27,9
1	19	3,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	2,0	90,7	9,0	13,1	125,0	22,4
1	19	3,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	2,0	90,7	9,0	15,3	145,3	18,5
1	19	3,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	2,0	90,7	9,0	18,5	176,3	10,2
1	19	3,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	2,0	90,7	9,0	22,5	214,7	8,4
1	19	3,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	2,0	90,7	9,0	27,3	259,9	4,3
1	20	7,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	6,0	90,7	9,0	6,5	62,1	42,9
1	20	7,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	6,0	90,7	9,0	8,0	76,3	18,9
1	20	7,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	6,0	90,7	9,0	9,8	93,1	18,0
1	20	7,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	6,0	90,7	9,0	11,9	113,8	13,4
1	20	7,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	6,0	90,7	9,0	14,6	138,8	10,4
1	20	7,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	6,0	90,7	9,0	17,8	169,4	5,5
1	20	7,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	6,0	90,7	9,0	21,8	207,8	7,5
1	20	7,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	6,0	90,7	9,0	26,7	254,3	3,8
1	21	15,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	8,0	75,9	47,5
1	21	15,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	9,5	91,0	27,2
1	21	15,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	11,4	108,6	19,9
1	21	15,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	13,7	130,2	23,5
1	21	15,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	16,4	156,0	16,5
1	21	15,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	19,6	186,6	21,1
1	21	15,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	23,4	223,3	11,5
1	21	15,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	28,1	267,7	6,0
1	27	13,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	3,0	362,9	17,0	4,2	80,2	78,2

1	27	13,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	3,0	362,9	17,0	5,1	97,4	45,7
1	27	13,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	3,0	362,9	17,0	6,2	119,0	48,5
1	27	13,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	3,0	362,9	17,0	7,6	144,8	38,6
1	27	13,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	3,0	362,9	17,0	11,1	212,1	18,5
1	27	13,0	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	3,0	362,9	17,0	13,4	256,0	9,8
1	32	21,0	1,8	152,4	11,0	9,1	4,9	3,0	4,3	92,1	3,0	552,5	17,0	3,3	77,8	109,7
1	32	21,0	1,8	152,4	11,0	9,1	4,9	3,0	4,3	92,1	3,0	552,5	17,0	4,8	111,7	40,1
1	32	21,0	1,8	152,4	11,0	9,1	4,9	3,0	4,3	92,1	3,0	552,5	17,0	5,7	134,0	45,5
1	32	21,0	1,8	152,4	11,0	9,1	4,9	3,0	4,3	92,1	3,0	552,5	17,0	6,9	161,7	32,5
1	32	21,0	1,8	152,4	11,0	9,1	4,9	3,0	4,3	92,1	3,0	552,5	17,0	8,2	193,6	25,9
1	32	21,0	1,8	152,4	11,0	9,1	4,9	3,0	4,3	92,1	3,0	552,5	17,0	9,9	233,0	26,4
1	32	21,0	1,8	152,4	11,0	9,1	4,9	3,0	4,3	92,1	3,0	552,5	17,0	12,0	281,9	13,5
3	24	78,0	2,1	76,2	6,1	5,5	1,2	2,4	2,7	11,3	2,0	283,5	50,0	8,7	146,3	13,4
3	24	78,0	2,1	76,2	6,1	5,5	1,2	2,4	2,7	11,3	2,0	283,5	50,0	13,9	234,7	7,6
5	30	11,0	4,6	152,4	7,9	7,6	3,4	3,0	3,7	50,8	4,0	203,2	25,0	3,0	43,0	41,7
5	30	11,0	4,6	152,4	7,9	7,6	3,4	3,0	3,7	50,8	4,0	203,2	25,0	5,2	74,8	22,7
5	30	11,0	4,6	152,4	7,9	7,6	3,4	3,0	3,7	50,8	4,0	203,2	25,0	8,9	126,4	13,9
5	30	11,0	4,6	152,4	7,9	7,6	3,4	3,0	3,7	50,8	4,0	203,2	25,0	15,3	218,7	2,6
5	31	11,0	4,6	152,4	7,9	7,6	3,4	3,0	3,7	56,7	3,0	226,8	25,0	3,4	51,2	52,1
5	31	11,0	4,6	152,4	7,9	7,6	3,4	3,0	3,7	56,7	3,0	226,8	25,0	5,7	85,2	19,9
5	31	11,0	4,6	152,4	7,9	7,6	3,4	3,0	3,7	56,7	3,0	226,8	25,0	9,5	142,4	7,2
5	31	11,0	4,6	152,4	7,9	7,6	3,4	3,0	3,7	56,7	3,0	226,8	25,0	15,4	231,7	4,4
5	81	12,0	4,6	149,2	7,6	7,6	3,4	3,0	3,0	46,3	3,0	277,6	25,0	4,3	71,3	32,8
5	81	12,0	4,6	149,2	7,6	7,6	3,4	3,0	3,0	46,3	3,0	277,6	25,0	5,0	83,7	27,7
5	81	12,0	4,6	149,2	7,6	7,6	3,4	3,0	3,0	46,3	3,0	277,6	25,0	6,3	104,8	12,4
5	81	12,0	4,6	149,2	7,6	7,6	3,4	3,0	3,0	46,3	3,0	277,6	25,0	7,9	131,2	8,2
5	81	12,0	4,6	149,2	7,6	7,6	3,4	3,0	3,0	46,3	3,0	277,6	25,0	10,2	169,7	8,5
5	81	12,0	4,6	149,2	7,6	7,6	3,4	3,0	3,0	46,3	3,0	277,6	25,0	13,2	219,4	7,2
5	81	12,0	4,6	149,2	7,6	7,6	3,4	3,0	3,0	46,3	3,0	277,6	25,0	17,1	285,0	5,4

5	81	12,0	4,6	149,2	7,6	7,6	3,4	3,0	3,0	46,3	3,0	277,6	25,0	22,4	374,0	15,2
5	83	1,0	4,6	149,2	9,4	9,1	3,4	3,0	0,0	59,9	0,0	59,9	0,0	8,6	66,2	12,1
5	83	1,0	4,6	149,2	9,4	9,1	3,4	3,0	0,0	59,9	0,0	59,9	0,0	10,5	80,9	14,2
5	83	1,0	4,6	149,2	9,4	9,1	3,4	3,0	0,0	59,9	0,0	59,9	0,0	13,1	101,6	9,6
5	83	1,0	4,6	149,2	9,4	9,1	3,4	3,0	0,0	59,9	0,0	59,9	0,0	16,6	128,2	6,8
5	83	1,0	4,6	149,2	9,4	9,1	3,4	3,0	0,0	59,9	0,0	59,9	0,0	21,5	166,0	6,5
5	83	1,0	4,6	149,2	9,4	9,1	3,4	3,0	0,0	59,9	0,0	59,9	0,0	27,8	215,0	4,3
5	83	1,0	4,6	149,2	9,4	9,1	3,4	3,0	0,0	59,9	0,0	59,9	0,0	36,3	280,9	2,9
5	83	1,0	4,6	149,2	9,4	9,1	3,4	3,0	0,0	59,9	0,0	59,9	0,0	47,5	367,7	1,6
5	82	13,0	4,6	149,2	9,1	9,1	3,7	3,0	3,0	59,9	3,0	299,4	25,0	3,1	54,0	45,7
5	82	13,0	4,6	149,2	9,1	9,1	3,7	3,0	3,0	59,9	3,0	299,4	25,0	4,0	68,9	35,8
5	82	13,0	4,6	149,2	9,1	9,1	3,7	3,0	3,0	59,9	3,0	299,4	25,0	5,2	89,3	24,2
5	82	13,0	4,6	149,2	9,1	9,1	3,7	3,0	3,0	59,9	3,0	299,4	25,0	6,7	116,7	21,2
5	82	13,0	4,6	149,2	9,1	9,1	3,7	3,0	3,0	59,9	3,0	299,4	25,0	9,0	155,0	17,4
5	82	13,0	4,6	149,2	9,1	9,1	3,7	3,0	3,0	59,9	3,0	299,4	25,0	11,9	205,2	6,7
5	82	13,0	4,6	149,2	9,1	9,1	3,7	3,0	3,0	59,9	3,0	299,4	25,0	15,6	270,2	5,2
5	82	13,0	4,6	149,2	9,1	9,1	3,7	3,0	3,0	59,9	3,0	299,4	25,0	20,6	356,3	2,8
6	33	126,0	3,0	63,5	6,1	6,1	1,7	1,5	2,1	15,9	7,0	412,8	25,0	6,4	129,6	16,0
6	33	126,0	3,0	63,5	6,1	6,1	1,7	1,5	2,1	15,9	7,0	412,8	25,0	11,7	238,1	6,5
6	33	126,0	3,0	63,5	6,1	6,1	1,7	1,5	2,1	15,9	7,0	412,8	25,0	15,9	323,7	5,5
7	79	1,0	2,7	158,8	17,1	16,5	1,2	3,0	0,0	212,3	0,0	212,3	0,0	10,4	151,0	15,5
7	79	1,0	2,7	158,8	17,1	16,5	1,2	3,0	0,0	212,3	0,0	212,3	0,0	12,1	176,1	9,8
7	79	1,0	2,7	158,8	17,1	16,5	1,2	3,0	0,0	212,3	0,0	212,3	0,0	14,1	205,7	8,7
7	79	1,0	2,7	158,8	17,1	16,5	1,2	3,0	0,0	212,3	0,0	212,3	0,0	17,2	249,9	7,3
7	79	1,0	2,7	158,8	17,1	16,5	1,2	3,0	0,0	212,3	0,0	212,3	0,0	20,9	304,0	6,6
7	79	1,0	2,7	158,8	17,1	16,5	1,2	3,0	0,0	212,3	0,0	212,3	0,0	25,7	373,9	4,6
7	79	1,0	2,7	158,8	17,1	16,5	1,2	3,0	0,0	212,3	0,0	212,3	0,0	32,1	468,2	4,0
7	79	1,0	2,7	158,8	17,1	16,5	1,2	3,0	0,0	212,3	0,0	212,3	0,0	40,4	588,2	1,7
7	75	36,0	2,7	158,8	7,3	7,0	1,8	3,7	3,0	82,6	9,0	486,3	9,0	3,2	70,8	55,6

7	75	36,0	2,7	158,8	7,3	7,0	1,8	3,7	3,0	82,6	9,0	486,3	9,0	4,1	89,3	59,4
7	75	36,0	2,7	158,8	7,3	7,0	1,8	3,7	3,0	82,6	9,0	486,3	9,0	5,2	113,8	55,6
7	75	36,0	2,7	158,8	7,3	7,0	1,8	3,7	3,0	82,6	9,0	486,3	9,0	6,7	146,7	33,3
7	75	36,0	2,7	158,8	7,3	7,0	1,8	3,7	3,0	82,6	9,0	486,3	9,0	8,7	191,6	22,8
7	75	36,0	2,7	158,8	7,3	7,0	1,8	3,7	3,0	82,6	9,0	486,3	9,0	11,2	246,5	25,9
7	75	36,0	2,7	158,8	7,3	7,0	1,8	3,7	3,0	82,6	9,0	486,3	9,0	14,8	326,3	10,6
7	75	36,0	2,7	158,8	7,3	7,0	1,8	3,7	3,0	82,6	9,0	486,3	9,0	19,4	427,1	8,8
7	78	36,0	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12,0	2095,6	9,0	3,1	140,3	72,4
7	78	36,0	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12,0	2095,6	9,0	3,6	164,9	55,6
7	78	36,0	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12,0	2095,6	9,0	4,3	195,2	51,1
7	78	36,0	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12,0	2095,6	9,0	5,2	238,3	43,7
7	78	36,0	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12,0	2095,6	9,0	6,4	294,2	37,3
7	78	36,0	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12,0	2095,6	9,0	7,9	362,6	27,7
7	78	36,0	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12,0	2095,6	9,0	10,0	457,9	23,8
7	78	36,0	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12,0	2095,6	9,0	12,6	578,0	7,8
7	42	37,0	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7,0	1244,7	17,0	2,9	102,2	143,0
7	42	37,0	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7,0	1244,7	17,0	3,8	132,5	141,7
7	42	37,0	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7,0	1244,7	17,0	6,5	229,9	65,3
7	42	37,0	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7,0	1244,7	17,0	8,5	300,2	42,7
7	42	37,0	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7,0	1244,7	17,0	11,1	392,8	30,5
7	42	37,0	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7,0	1244,7	17,0	14,6	515,7	18,0
9	36	12,0	5,2	152,4	9,8	9,8	5,5	2,7	4,3	63,5	2,0	381,0	25,0	2,7	53,4	125,0
9	36	12,0	5,2	152,4	9,8	9,8	5,5	2,7	4,3	63,5	2,0	381,0	25,0	5,9	115,7	54,6
9	36	12,0	5,2	152,4	9,8	9,8	5,5	2,7	4,3	63,5	2,0	381,0	25,0	8,7	170,5	40,4
9	36	12,0	5,2	152,4	9,8	9,8	5,5	2,7	4,3	63,5	2,0	381,0	25,0	12,8	250,0	20,9
9	76	31,0	8,4	120,7	5,5	5,2	2,0	3,0	3,4	36,8	2,0	552,5	25,0	3,5	81,4	50,3
9	76	31,0	8,4	120,7	5,5	5,2	2,0	3,0	3,4	36,8	2,0	552,5	25,0	4,4	103,0	50,0
9	76	31,0	8,4	120,7	5,5	5,2	2,0	3,0	3,4	36,8	2,0	552,5	25,0	5,5	129,8	43,9
9	76	31,0	8,4	120,7	5,5	5,2	2,0	3,0	3,4	36,8	2,0	552,5	25,0	6,9	162,8	32,8

9	76	31,0	8,4	120,7	5,5	5,2	2,0	3,0	3,4	36,8	2,0	552,5	25,0	8,7	205,3	23,4
9	76	31,0	8,4	120,7	5,5	5,2	2,0	3,0	3,4	36,8	2,0	552,5	25,0	11,0	259,6	23,5
9	76	31,0	8,4	120,7	5,5	5,2	2,0	3,0	3,4	36,8	2,0	552,5	25,0	14,1	330,8	16,7
9	76	31,0	8,4	120,7	5,5	5,2	2,0	3,0	3,4	36,8	2,0	552,5	25,0	19,3	454,2	8,7
9	77	1,0	8,4	120,7	5,5	5,2	2,0	3,4	0,0	36,3	0,0	36,3	0,0	13,0	78,2	18,6
9	77	1,0	8,4	120,7	5,5	5,2	2,0	3,4	0,0	36,3	0,0	36,3	0,0	16,6	100,1	18,7
9	77	1,0	8,4	120,7	5,5	5,2	2,0	3,4	0,0	36,3	0,0	36,3	0,0	26,5	159,5	7,6
9	77	1,0	8,4	120,7	5,5	5,2	2,0	3,4	0,0	36,3	0,0	36,3	0,0	33,6	202,3	5,7
9	77	1,0	8,4	120,7	5,5	5,2	2,0	3,4	0,0	36,3	0,0	36,3	0,0	42,6	256,8	5,1
9	77	1,0	8,4	120,7	5,5	5,2	2,0	3,4	0,0	36,3	0,0	36,3	0,0	54,3	327,1	3,9
9	77	1,0	8,4	120,7	5,5	5,2	2,0	3,4	0,0	36,3	0,0	36,3	0,0	75,1	452,6	2,2
9	80	69,0	8,4	120,7	5,5	5,5	2,4	3,0	3,4	36,2	3,0	1231,0	25,0	2,5	88,1	91,7
9	80	69,0	8,4	120,7	5,5	5,5	2,4	3,0	3,4	36,2	3,0	1231,0	25,0	4,2	146,9	51,1
9	80	69,0	8,4	120,7	5,5	5,5	2,4	3,0	3,4	36,2	3,0	1231,0	25,0	4,8	168,3	34,0
9	80	69,0	8,4	120,7	5,5	5,5	2,4	3,0	3,4	36,2	3,0	1231,0	25,0	5,4	190,5	31,2
9	80	69,0	8,4	120,7	5,5	5,5	2,4	3,0	3,4	36,2	3,0	1231,0	25,0	5,8	204,8	26,9
9	80	69,0	8,4	120,7	5,5	5,5	2,4	3,0	3,4	36,2	3,0	1231,0	25,0	6,0	211,2	21,1
9	80	69,0	8,4	120,7	5,5	5,5	2,4	3,0	3,4	36,2	3,0	1231,0	25,0	9,7	339,8	9,7
9	80	69,0	8,4	120,7	5,5	5,5	2,4	3,0	3,4	36,2	3,0	1231,0	25,0	14,8	517,7	5,9
10	47	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	25,0	7,6	42,6	12,8
10	47	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	25,0	11,6	65,5	9,5
10	47	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	25,0	17,6	98,9	3,5
10	47	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	25,0	25,4	143,1	2,0
10	47	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	25,0	33,9	191,0	1,2
10	47	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	25,0	43,5	245,1	4,6
10	48	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	10,4	59,5	31,8
10	48	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	16,2	92,6	15,1
10	48	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	24,0	137,1	9,0
10	48	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	32,5	185,7	3,9

10	48	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	41,9	239,2	2,3
10	49	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	9,9	56,4	13,2
10	49	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	15,7	90,0	4,6
10	49	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	23,5	134,2	2,6
10	49	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	32,0	182,9	1,4
10	49	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	41,3	236,1	0,7
10	50	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	0,0	9,5	53,6	32,3
10	50	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	0,0	15,5	87,2	11,8
10	50	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	0,0	23,3	131,1	6,7
10	50	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	0,0	31,9	179,5	3,9
10	50	9,0	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	0,0	41,4	233,1	2,0
11	59	48,0	7,9	228,6	9,3	8,7	5,0	6,1	4,6	317,5	47,0	317,5	17,0	15,8	282,2	11,5
11	59	48,0	7,9	228,6	9,3	8,7	5,0	6,1	4,6	317,5	47,0	317,5	17,0	18,0	320,2	11,2
11	59	48,0	7,9	228,6	9,3	8,7	5,0	6,1	4,6	317,5	47,0	317,5	17,0	20,0	356,4	8,6
11	59	48,0	7,9	228,6	9,3	8,7	5,0	6,1	4,6	317,5	47,0	317,5	17,0	22,3	397,6	23,2
11	59	48,0	7,9	228,6	9,3	8,7	5,0	6,1	4,6	317,5	47,0	317,5	17,0	25,6	455,6	8,7
11	59	48,0	7,9	228,6	9,3	8,7	5,0	6,1	4,6	317,5	47,0	317,5	17,0	28,7	512,1	8,3
11	59	48,0	7,9	228,6	9,3	8,7	5,0	6,1	4,6	317,5	47,0	317,5	17,0	32,9	587,1	5,7
11	62	20,0	7,9	228,6	22,9	22,9	5,3	7,0	7,6	734,8	19,0	734,8	26,0	23,7	642,8	3,0
11	62	20,0	7,9	228,6	22,9	22,9	5,3	7,0	7,6	734,8	19,0	734,8	26,0	25,1	680,9	2,9
11	62	20,0	7,9	228,6	22,9	22,9	5,3	7,0	7,6	734,8	19,0	734,8	26,0	29,7	806,0	3,2
11	62	20,0	7,9	228,6	22,9	22,9	5,3	7,0	7,6	734,8	19,0	734,8	26,0	33,2	899,2	4,5
11	62	20,0	7,9	228,6	22,9	22,9	5,3	7,0	7,6	734,8	19,0	734,8	26,0	35,3	956,9	3,9
11	57	28,0	7,9	228,6	25,9	25,1	6,1	5,2	7,0	712,1	27,0	712,1	21,5	20,3	542,3	6,5
11	57	28,0	7,9	228,6	25,9	25,1	6,1	5,2	7,0	712,1	27,0	712,1	21,5	21,7	579,7	5,3
11	57	28,0	7,9	228,6	25,9	25,1	6,1	5,2	7,0	712,1	27,0	712,1	21,5	23,3	622,0	10,4
11	57	28,0	7,9	228,6	25,9	25,1	6,1	5,2	7,0	712,1	27,0	712,1	21,5	24,9	664,2	4,9
11	58	30,0	7,9	228,6	19,4	18,7	6,1	6,1	5,5	506,2	29,0	506,2	17,0	13,0	292,2	16,2
11	58	30,0	7,9	228,6	19,4	18,7	6,1	6,1	5,5	506,2	29,0	506,2	17,0	14,8	331,9	14,3

11	58	30,0	7,9	228,6	19,4	18,7	6,1	6,1	5,5	506,2	29,0	506,2	17,0	16,7	376,7	28,4
11	58	30,0	7,9	228,6	19,4	18,7	6,1	6,1	5,5	506,2	29,0	506,2	17,0	19,1	429,7	18,9
11	56	13,0	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12,0	690,4	26,0	22,3	586,2	4,4
11	56	13,0	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12,0	690,4	26,0	23,5	618,3	2,6
11	56	13,0	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12,0	690,4	26,0	24,7	649,3	2,6
11	56	13,0	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12,0	690,4	26,0	26,3	692,1	2,3
11	56	13,0	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12,0	690,4	26,0	28,1	739,6	1,8
11	56	13,0	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12,0	690,4	26,0	30,5	800,3	2,4
11	56	13,0	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12,0	690,4	26,0	33,1	869,2	1,4
11	56	13,0	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12,0	690,4	26,0	36,8	966,7	2,3
12	139	23,0	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	4,9	60,3	91,2
12	139	23,0	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	6,0	73,6	87,6
12	139	23,0	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	6,6	80,9	86,1
12	139	23,0	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	8,2	101,0	41,7
12	139	23,0	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	8,4	103,8	112,3
12	139	23,0	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	11,9	147,3	41,7
12	139	23,0	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	14,4	178,0	24,7
12	139	23,0	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	18,3	225,9	16,0
12	139	23,0	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	23,9	294,6	17,2
12	139	23,0	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	35,1	432,4	14,0
12	141	31,0	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	7,1	82,8	54,4
12	141	31,0	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	8,8	102,9	78,5
12	141	31,0	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	10,4	122,0	25,0
12	141	31,0	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	13,7	160,2	29,7
12	141	31,0	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	14,4	169,2	35,1
12	141	31,0	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	17,1	200,0	26,2
12	141	31,0	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	21,2	248,3	11,9
12	141	31,0	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	27,0	316,2	8,6
12	141	31,0	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	38,7	453,6	10,4

12	143	23,0	0,0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22,0	139,7	25,0	5,9	70,1	70,9
12	143	23,0	0,0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22,0	139,7	25,0	7,1	84,0	67,8
12	143	23,0	0,0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22,0	139,7	25,0	8,5	100,0	113,5
12	143	23,0	0,0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22,0	139,7	25,0	10,1	119,8	28,2
12	143	23,0	0,0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22,0	139,7	25,0	12,1	142,8	20,2
12	143	23,0	0,0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22,0	139,7	25,0	14,5	171,7	40,9
12	143	23,0	0,0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22,0	139,7	25,0	16,9	199,5	22,4
12	143	23,0	0,0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22,0	139,7	25,0	20,8	246,1	32,5
12	143	23,0	0,0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22,0	139,7	25,0	24,8	293,1	26,2
12	143	23,0	0,0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22,0	139,7	25,0	31,3	369,6	26,9
12	140	19,0	0,0	165,1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	5,9	79,9	65,3
12	140	19,0	0,0	165,1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	7,2	97,5	52,1
12	140	19,0	0,0	165,1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	10,0	134,1	38,6
12	140	19,0	0,0	165,1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	11,5	154,8	44,7
12	140	19,0	0,0	165,1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	15,7	212,1	32,3
12	140	19,0	0,0	165,1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	22,3	300,5	16,1
12	140	19,0	0,0	165,1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	27,3	367,6	8,9
12	140	19,0	0,0	165,1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	37,5	505,4	14,1
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	9,2	123,3	23,5
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	11,4	152,9	55,1
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	12,6	168,6	78,2
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	12,4	165,0	56,1
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	14,1	188,5	16,5
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	15,7	210,3	24,7
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	17,9	238,7	24,1
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	19,9	265,9	15,1
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	23,4	311,8	25,0
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	26,8	358,3	27,2
12	144	22,0	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	32,6	435,1	23,0

12	146	15,0	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	7,6	95,8	40,1
12	146	15,0	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	8,8	111,2	22,0
12	146	15,0	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	10,7	134,6	50,8
12	146	15,0	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	12,5	157,4	33,8
12	146	15,0	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	15,3	192,2	32,8
12	146	15,0	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	18,3	230,9	25,0
12	146	15,0	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	21,9	276,0	18,5
12	146	15,0	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	26,2	330,2	22,1
12	146	15,0	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	34,5	435,1	9,8
12	146	15,0	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	37,5	472,1	2,2
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	8,1	135,1	35,8
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	11,0	181,6	19,4
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	12,4	204,8	23,8
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	13,4	222,1	30,0
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	16,0	265,6	9,7
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	17,8	295,6	15,5
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	22,3	369,2	15,4
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	25,1	416,4	23,1
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	29,3	485,5	15,1
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	65,6	1088,0	2,2
12	148	27,0	0,0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25,0	274,9	16,0	65,6	1088,0	20,5
12	145	8,0	0,0	165,1	15,5	13,7	5,8	5,0	4,9	148,8	7,0	160,1	25,0	10,0	126,0	15,7
12	145	8,0	0,0	165,1	15,5	13,7	5,8	5,0	4,9	148,8	7,0	160,1	25,0	12,1	153,5	20,4
12	145	8,0	0,0	165,1	15,5	13,7	5,8	5,0	4,9	148,8	7,0	160,1	25,0	13,9	176,4	14,1
12	145	8,0	0,0	165,1	15,5	13,7	5,8	5,0	4,9	148,8	7,0	160,1	25,0	15,9	201,6	38,6
12	145	8,0	0,0	165,1	15,5	13,7	5,8	5,0	4,9	148,8	7,0	160,1	25,0	16,7	211,3	14,7
12	145	8,0	0,0	165,1	15,5	13,7	5,8	5,0	4,9	148,8	7,0	160,1	25,0	18,3	231,9	13,6
12	145	8,0	0,0	165,1	15,5	13,7	5,8	5,0	4,9	148,8	7,0	160,1	25,0	21,5	272,6	12,4
12	145	8,0	0,0	165,1	15,5	13,7	5,8	5,0	4,9	148,8	7,0	160,1	25,0	25,2	319,0	10,2

12	145	8,0	0,0	165,1	15,5	13,7	5,8	5,0	4,9	148,8	7,0	160,1	25,0	30,4	384,3	12,8
12	142	16,0	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	6,3	76,4	68,8
12	142	16,0	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	8,6	104,4	39,1
12	142	16,0	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	10,8	130,8	40,9
12	142	16,0	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	12,4	150,6	55,6
12	142	16,0	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	14,0	170,3	20,9
12	142	16,0	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	17,1	207,2	36,3
12	142	16,0	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	20,3	246,7	25,7
12	142	16,0	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	24,3	295,6	13,2
12	142	16,0	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	29,9	363,2	9,7
12	142	16,0	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	41,2	500,6	17,2
12	60	10,0	0,0	165,1	20,0	21,8	7,8	6,1	4,6	253,1	9,0	253,1	26,0	6,0	95,8	123,7
12	60	10,0	0,0	165,1	20,0	21,8	7,8	6,1	4,6	253,1	9,0	253,1	26,0	10,0	158,4	41,9
14	90	30,0	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	3,2	54,3	81,5
14	90	30,0	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	4,1	68,6	48,0
14	90	30,0	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	5,3	88,8	53,6
14	90	30,0	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	6,7	113,1	41,4
14	90	30,0	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	8,6	143,4	26,9
14	90	30,0	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	13,8	231,5	14,9
14	90	30,0	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	16,2	272,5	11,7
14	90	30,0	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	19,1	320,3	11,2
14	90	30,0	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	22,2	371,9	4,7
14	90	30,0	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	28,0	469,0	2,8
14	87	45,0	3,0	88,9	11,0	9,1	3,7	2,4	3,0	45,6	10,0	319,1	25,0	3,4	61,0	64,3
14	87	45,0	3,0	88,9	11,0	9,1	3,7	2,4	3,0	45,6	10,0	319,1	25,0	4,2	75,6	62,2
14	87	45,0	3,0	88,9	11,0	9,1	3,7	2,4	3,0	45,6	10,0	319,1	25,0	5,3	94,6	75,9
14	87	45,0	3,0	88,9	11,0	9,1	3,7	2,4	3,0	45,6	10,0	319,1	25,0	6,7	118,8	16,1
14	87	45,0	3,0	88,9	11,0	9,1	3,7	2,4	3,0	45,6	10,0	319,1	25,0	8,1	144,7	13,2
14	87	45,0	3,0	88,9	11,0	9,1	3,7	2,4	3,0	45,6	10,0	319,1	25,0	15,8	282,1	4,4

14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	21,2	350,9	3,1
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	33,1	548,9	2,0
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	3,7	61,0	49,3
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	4,5	74,7	53,6
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	5,7	94,5	40,9
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	7,2	118,5	29,0
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	8,9	147,7	20,8
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	14,2	234,7	7,4
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	16,7	275,9	10,5
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	19,4	321,6	8,8
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	22,5	372,6	3,9
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	28,3	469,3	1,5
14	88	28,0	3,0	88,9	14,6	13,4	3,7	2,4	3,0	61,2	10,0	274,4	25,0	36,3	600,5	0,6
14	89	45,0	3,0	88,9	16,2	14,9	3,7	2,4	3,0	78,2	10,0	553,4	25,0	3,1	73,1	110,7
14	89	45,0	3,0	88,9	16,2	14,9	3,7	2,4	3,0	78,2	10,0	553,4	25,0	3,7	86,9	62,5
14	89	45,0	3,0	88,9	16,2	14,9	3,7	2,4	3,0	78,2	10,0	553,4	25,0	4,5	106,5	43,4
14	89	45,0	3,0	88,9	16,2	14,9	3,7	2,4	3,0	78,2	10,0	553,4	25,0	5,6	130,9	31,5
14	89	45,0	3,0	88,9	16,2	14,9	3,7	2,4	3,0	78,2	10,0	553,4	25,0	10,6	250,2	24,9
14	89	45,0	3,0	88,9	16,2	14,9	3,7	2,4	3,0	78,2	10,0	553,4	25,0	12,6	296,0	12,0
14	89	45,0	3,0	88,9	16,2	14,9	3,7	2,4	3,0	78,2	10,0	553,4	25,0	14,7	344,9	14,2
14	89	45,0	3,0	88,9	16,2	14,9	3,7	2,4	3,0	78,2	10,0	553,4	25,0	27,0	634,5	1,2
14	91	42,0	3,0	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9,0	394,2	25,0	3,1	60,9	122,7
14	91	42,0	3,0	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9,0	394,2	25,0	3,9	77,7	81,8
14	91	42,0	3,0	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9,0	394,2	25,0	6,2	122,2	43,9
14	91	42,0	3,0	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9,0	394,2	25,0	7,5	148,3	37,6
14	91	42,0	3,0	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9,0	394,2	25,0	13,8	274,9	20,3
14	91	42,0	3,0	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9,0	394,2	25,0	16,7	332,5	9,8
14	91	42,0	3,0	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9,0	394,2	25,0	20,3	402,5	3,9
14	91	42,0	3,0	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9,0	394,2	25,0	24,9	494,2	3,8

14	91	42,0	3,0	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9,0	394,2	25,0	30,3	602,0	1,8
14	94	24,0	3,0	114,3	17,1	15,2	3,7	3,0	3,4	127,0	9,0	508,0	25,0	3,3	74,7	86,6
14	94	24,0	3,0	114,3	17,1	15,2	3,7	3,0	3,4	127,0	9,0	508,0	25,0	5,2	118,3	64,0
14	94	24,0	3,0	114,3	17,1	15,2	3,7	3,0	3,4	127,0	9,0	508,0	25,0	6,4	143,8	37,6
14	94	24,0	3,0	114,3	17,1	15,2	3,7	3,0	3,4	127,0	9,0	508,0	25,0	8,0	179,5	27,9
14	94	24,0	3,0	114,3	17,1	15,2	3,7	3,0	3,4	127,0	9,0	508,0	25,0	12,2	275,4	23,2
14	94	24,0	3,0	114,3	17,1	15,2	3,7	3,0	3,4	127,0	9,0	508,0	25,0	14,7	331,5	9,8
14	86	50,0	3,0	88,9	17,1	15,2	4,9	2,4	3,4	78,5	10,0	627,8	25,0	9,7	243,8	13,4
14	86	50,0	3,0	88,9	17,1	15,2	4,9	2,4	3,4	78,5	10,0	627,8	25,0	13,1	328,8	6,9
14	86	50,0	3,0	88,9	17,1	15,2	4,9	2,4	3,4	78,5	10,0	627,8	25,0	14,3	359,5	6,1
14	86	50,0	3,0	88,9	17,1	15,2	4,9	2,4	3,4	78,5	10,0	627,8	25,0	15,8	395,7	5,6
14	86	50,0	3,0	88,9	17,1	15,2	4,9	2,4	3,4	78,5	10,0	627,8	25,0	17,0	426,4	5,2
15	125	16,0	1,8	63,5	14,0	13,7	0,9	0,0	0,6	4,3	0,0	68,0	0,0	7,3	60,1	40,1
15	125	16,0	1,8	63,5	14,0	13,7	0,9	0,0	0,6	4,3	0,0	68,0	0,0	11,4	94,4	33,8
15	125	16,0	1,8	63,5	14,0	13,7	0,9	0,0	0,6	4,3	0,0	68,0	0,0	13,0	107,1	22,9
15	125	16,0	1,8	63,5	14,0	13,7	0,9	0,0	0,6	4,3	0,0	68,0	0,0	17,1	141,1	15,3
15	125	16,0	1,8	63,5	14,0	13,7	0,9	0,0	0,6	4,3	0,0	68,0	0,0	20,4	168,4	12,8
15	125	16,0	1,8	63,5	14,0	13,7	0,9	0,0	0,6	4,3	0,0	68,0	0,0	45,7	377,0	4,0
15	125	16,0	1,8	63,5	14,0	13,7	0,9	0,0	0,6	4,3	0,0	68,0	0,0	57,9	477,8	3,8
15	95	48,0	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	4,7	83,4	42,9
15	95	48,0	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	7,0	123,6	24,0
15	95	48,0	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	12,2	216,6	16,7
15	95	48,0	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	3,2	57,0	55,9
15	95	48,0	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	5,3	94,7	42,2
15	95	48,0	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	8,4	149,2	27,4
15	95	48,0	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	12,6	223,1	29,5
15	95	48,0	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	17,6	311,3	12,8
15	95	48,0	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	27,3	484,6	6,2
15	92	40,0	1,8	88,9	9,1	9,1	1,8	2,4	3,0	31,8	5,0	317,5	25,0	3,2	57,9	60,2

15	92	40,0	1,8	88,9	9,1	9,1	1,8	2,4	3,0	31,8	5,0	317,5	25,0	5,0	88,7	40,6
15	92	40,0	1,8	88,9	9,1	9,1	1,8	2,4	3,0	31,8	5,0	317,5	25,0	12,0	214,5	17,4
15	92	40,0	1,8	88,9	9,1	9,1	1,8	2,4	3,0	31,8	5,0	317,5	25,0	28,7	512,1	4,8
15	92	40,0	1,8	88,9	9,1	9,1	1,8	2,4	3,0	31,8	5,0	317,5	25,0	5,5	98,4	26,9
15	92	40,0	1,8	88,9	9,1	9,1	1,8	2,4	3,0	31,8	5,0	317,5	25,0	7,6	136,3	31,0
15	92	40,0	1,8	88,9	9,1	9,1	1,8	2,4	3,0	31,8	5,0	317,5	25,0	14,9	265,3	17,0
15	92	40,0	1,8	88,9	9,1	9,1	1,8	2,4	3,0	31,8	5,0	317,5	25,0	19,8	353,2	8,6
15	93	35,0	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5,0	217,7	25,0	4,4	65,5	31,0
15	93	35,0	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5,0	217,7	25,0	6,5	95,5	40,1
15	93	35,0	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5,0	217,7	25,0	15,0	221,0	10,9
15	93	35,0	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5,0	217,7	25,0	22,9	338,6	3,8
15	93	35,0	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5,0	217,7	25,0	35,1	518,2	4,1
15	93	35,0	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5,0	217,7	25,0	5,4	80,1	49,5
15	93	35,0	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5,0	217,7	25,0	8,1	118,9	36,6
15	93	35,0	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5,0	217,7	25,0	16,7	247,1	24,6
15	93	35,0	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5,0	217,7	25,0	22,7	335,2	14,4
15	118	38,0	1,8	101,6	13,7	13,1	1,8	2,9	3,5	68,0	6,0	680,4	25,0	4,8	126,3	50,5
15	118	38,0	1,8	101,6	13,7	13,1	1,8	2,9	3,5	68,0	6,0	680,4	25,0	11,3	295,1	18,5
15	118	38,0	1,8	101,6	13,7	13,1	1,8	2,9	3,5	68,0	6,0	680,4	25,0	14,8	386,0	13,8
15	118	38,0	1,8	101,6	13,7	13,1	1,8	2,9	3,5	68,0	6,0	680,4	25,0	19,5	508,8	12,4
15	118	38,0	1,8	101,6	13,7	13,1	1,8	2,9	3,5	68,0	6,0	680,4	25,0	4,8	124,0	69,6
15	120	46,0	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	4,5	104,2	74,2
15	120	46,0	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	6,1	142,5	39,1
15	120	46,0	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	15,6	364,3	14,3
15	120	46,0	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	20,9	487,8	9,8
15	120	46,0	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	49,3	1150,9	45,2
15	120	46,0	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	7,1	165,8	37,8
15	120	46,0	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	10,5	245,0	17,7
15	120	46,0	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	14,0	326,3	18,1

15	120	46,0	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	18,9	440,3	6,4
15	122	12,0	1,8	63,5	4,9	0,0	2,4	1,1	1,2	7,6	4,0	30,3	800,0	30,9	170,1	1,6
15	122	12,0	1,8	63,5	4,9	0,0	2,4	1,1	1,2	7,6	4,0	30,3	800,0	36,4	200,5	1,1
15	122	12,0	1,8	63,5	4,9	0,0	2,4	1,1	1,2	7,6	4,0	30,3	800,0	41,0	225,5	0,8
15	122	12,0	1,8	63,5	4,9	0,0	2,4	1,1	1,2	7,6	4,0	30,3	800,0	51,1	281,5	0,4
15	122	12,0	1,8	63,5	4,9	0,0	2,4	1,1	1,2	7,6	4,0	30,3	800,0	64,7	356,2	0,4
15	122	12,0	1,8	63,5	4,9	0,0	2,4	1,1	1,2	7,6	4,0	30,3	800,0	77,8	428,5	0,4
15	122	12,0	1,8	63,5	4,9	0,0	2,4	1,1	1,2	7,6	4,0	30,3	800,0	94,1	518,2	0,2
15	122	12,0	1,8	63,5	4,9	0,0	2,4	1,1	1,2	7,6	4,0	30,3	800,0	113,1	622,8	0,1
15	117	24,0	1,8	114,3	12,2	6,7	2,6	3,0	3,7	83,9	5,0	503,5	25,0	6,0	135,1	43,2
15	117	24,0	1,8	114,3	12,2	6,7	2,6	3,0	3,7	83,9	5,0	503,5	25,0	13,3	298,6	14,3
15	117	24,0	1,8	114,3	12,2	6,7	2,6	3,0	3,7	83,9	5,0	503,5	25,0	17,2	385,9	12,4
15	117	24,0	1,8	114,3	12,2	6,7	2,6	3,0	3,7	83,9	5,0	503,5	25,0	22,9	513,8	14,7
15	117	24,0	1,8	114,3	12,2	6,7	2,6	3,0	3,7	83,9	5,0	503,5	25,0	5,5	122,9	58,7
15	117	24,0	1,8	114,3	12,2	6,7	2,6	3,0	3,7	83,9	5,0	503,5	25,0	9,9	222,4	39,1
15	117	24,0	1,8	114,3	12,2	6,7	2,6	3,0	3,7	83,9	5,0	503,5	25,0	15,4	345,3	25,2
15	117	24,0	1,8	114,3	12,2	6,7	2,6	3,0	3,7	83,9	5,0	503,5	25,0	20,4	458,0	6,8
15	126	26,0	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7,0	423,2	25,0	3,0	62,5	68,8
15	126	26,0	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7,0	423,2	25,0	4,7	96,8	41,7
15	126	26,0	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7,0	423,2	25,0	5,3	108,9	25,3
15	126	26,0	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7,0	423,2	25,0	7,0	143,4	32,0
15	126	26,0	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7,0	423,2	25,0	8,3	170,4	26,4
15	126	26,0	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7,0	423,2	25,0	18,5	380,8	8,8
15	126	26,0	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7,0	423,2	25,0	23,5	483,2	6,6
15	123	20,0	1,8	88,9	13,4	13,7	3,7	3,0	4,3	99,8	7,0	499,0	25,0	4,5	101,1	66,8
15	123	20,0	1,8	88,9	13,4	13,7	3,7	3,0	4,3	99,8	7,0	499,0	25,0	6,0	134,5	55,4
15	123	20,0	1,8	88,9	13,4	13,7	3,7	3,0	4,3	99,8	7,0	499,0	25,0	7,4	164,8	49,3
15	123	20,0	1,8	88,9	13,4	13,7	3,7	3,0	4,3	99,8	7,0	499,0	25,0	10,1	226,4	24,5
15	123	20,0	1,8	88,9	13,4	13,7	3,7	3,0	4,3	99,8	7,0	499,0	25,0	11,3	251,7	18,4

15	123	20,0	1,8	88,9	13,4	13,7	3,7	3,0	4,3	99,8	7,0	499,0	25,0	13,7	305,3	19,3
15	123	20,0	1,8	88,9	13,4	13,7	3,7	3,0	4,3	99,8	7,0	499,0	25,0	21,1	472,1	13,8
15	123	20,0	1,8	88,9	13,4	13,7	3,7	3,0	4,3	99,8	7,0	499,0	25,0	25,9	578,2	5,4
15	123	20,0	1,8	88,9	13,4	13,7	3,7	3,0	4,3	99,8	7,0	499,0	25,0	32,0	715,7	2,2
16	106	61,0	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1,0	626,0	9,0	4,3	106,7	50,8
16	106	61,0	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1,0	626,0	9,0	5,3	133,6	40,9
16	106	61,0	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1,0	626,0	9,0	6,9	172,1	66,0
16	106	61,0	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1,0	626,0	9,0	8,8	220,8	30,0
16	106	61,0	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1,0	626,0	9,0	11,2	280,8	11,0
16	106	61,0	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1,0	626,0	9,0	14,6	365,7	9,2
16	107	42,0	1,8	88,9	4,0	4,0	0,6	2,4	1,5	13,6	0,0	567,0	0,0	12,1	288,8	17,0
16	107	42,0	1,8	88,9	4,0	4,0	0,6	2,4	1,5	13,6	0,0	567,0	0,0	13,2	313,6	7,1
16	107	42,0	1,8	88,9	4,0	4,0	0,6	2,4	1,5	13,6	0,0	567,0	0,0	14,3	341,6	13,9
16	107	42,0	1,8	88,9	4,0	4,0	0,6	2,4	1,5	13,6	0,0	567,0	0,0	15,6	371,8	8,7
16	107	42,0	1,8	88,9	4,0	4,0	0,6	2,4	1,5	13,6	0,0	567,0	0,0	16,4	390,1	11,0
16	107	42,0	1,8	88,9	4,0	4,0	0,6	2,4	1,5	13,6	0,0	567,0	0,0	17,4	414,9	9,3
16	107	42,0	1,8	88,9	4,0	4,0	0,6	2,4	1,5	13,6	0,0	567,0	0,0	19,5	463,4	4,1
16	105	42,0	1,8	88,9	3,7	3,7	1,4	3,0	1,5	13,6	0,0	601,0	0,0	10,3	251,9	29,2
16	105	42,0	1,8	88,9	3,7	3,7	1,4	3,0	1,5	13,6	0,0	601,0	0,0	12,4	305,1	22,2
16	105	42,0	1,8	88,9	3,7	3,7	1,4	3,0	1,5	13,6	0,0	601,0	0,0	13,7	335,1	14,8
16	105	42,0	1,8	88,9	3,7	3,7	1,4	3,0	1,5	13,6	0,0	601,0	0,0	15,4	378,3	15,2
16	105	42,0	1,8	88,9	3,7	3,7	1,4	3,0	1,5	13,6	0,0	601,0	0,0	17,4	426,0	7,9
16	100	16,0	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0,0	215,5	0,0	7,2	105,0	33,3
16	100	16,0	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0,0	215,5	0,0	11,4	168,1	26,9
16	100	16,0	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0,0	215,5	0,0	13,2	194,0	9,7
16	100	16,0	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0,0	215,5	0,0	15,1	221,9	14,6
16	100	16,0	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0,0	215,5	0,0	17,2	253,1	11,2
16	100	16,0	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0,0	215,5	0,0	20,2	296,3	8,5
16	100	16,0	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0,0	215,5	0,0	23,4	344,1	6,6

16	103	59,0	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3,0	267,2	5,0	5,0	82,1	66,3
16	103	59,0	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3,0	267,2	5,0	6,7	108,7	31,8
16	103	59,0	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3,0	267,2	5,0	7,8	127,2	27,7
16	103	59,0	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3,0	267,2	5,0	9,4	153,1	25,7
16	103	59,0	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3,0	267,2	5,0	11,7	191,6	19,4
16	103	59,0	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3,0	267,2	5,0	14,6	238,9	12,5
16	103	59,0	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3,0	267,2	5,0	18,3	299,6	6,3
16	103	59,0	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3,0	267,2	5,0	23,5	383,9	9,0
16	98	31,0	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1,0	292,6	5,0	7,7	131,6	44,7
16	98	31,0	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1,0	292,6	5,0	9,1	156,4	20,2
16	98	31,0	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1,0	292,6	5,0	10,8	184,2	32,5
16	98	31,0	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1,0	292,6	5,0	12,7	216,7	17,6
16	98	31,0	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1,0	292,6	5,0	15,2	259,3	15,0
16	98	31,0	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1,0	292,6	5,0	18,0	307,3	9,7
16	98	31,0	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1,0	292,6	5,0	21,7	371,6	23,6
16	98	31,0	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1,0	292,6	5,0	25,4	434,3	25,2
16	96	84,0	1,8	63,5	6,1	5,5	2,7	2,4	1,5	18,1	2,0	526,2	5,0	6,3	144,3	41,1
16	96	84,0	1,8	63,5	6,1	5,5	2,7	2,4	1,5	18,1	2,0	526,2	5,0	11,2	257,5	19,6
16	96	84,0	1,8	63,5	6,1	5,5	2,7	2,4	1,5	18,1	2,0	526,2	5,0	13,8	317,7	9,7
16	96	84,0	1,8	63,5	6,1	5,5	2,7	2,4	1,5	18,1	2,0	526,2	5,0	17,5	400,7	12,0
16	97	63,0	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2,0	287,1	5,0	3,4	57,9	51,8
16	97	63,0	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2,0	287,1	5,0	4,2	70,4	52,6
16	97	63,0	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2,0	287,1	5,0	5,4	92,0	31,2
16	97	63,0	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2,0	287,1	5,0	10,2	172,5	16,1
16	97	63,0	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2,0	287,1	5,0	11,6	196,3	23,8
16	97	63,0	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2,0	287,1	5,0	15,1	256,1	11,3
16	102	16,0	1,8	88,9	4,6	4,0	2,7	2,4	1,5	12,7	1,0	155,6	5,0	11,7	145,6	17,1
16	102	16,0	1,8	88,9	4,6	4,0	2,7	2,4	1,5	12,7	1,0	155,6	5,0	13,7	171,0	6,2
16	102	16,0	1,8	88,9	4,6	4,0	2,7	2,4	1,5	12,7	1,0	155,6	5,0	15,9	198,7	11,9

16	102	16,0	1,8	88,9	4,6	4,0	2,7	2,4	1,5	12,7	1,0	155,6	5,0	18,5	230,9	6,6
16	102	16,0	1,8	88,9	4,6	4,0	2,7	2,4	1,5	12,7	1,0	155,6	5,0	21,9	273,2	4,4
16	102	16,0	1,8	88,9	4,6	4,0	2,7	2,4	1,5	12,7	1,0	155,6	5,0	25,7	320,1	12,3
16	102	16,0	1,8	88,9	4,6	4,0	2,7	2,4	1,5	12,7	1,0	155,6	5,0	35,9	448,2	0,8
16	104	60,0	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1,0	603,3	9,0	4,7	114,5	48,0
16	104	60,0	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1,0	603,3	9,0	5,7	141,2	35,1
16	104	60,0	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1,0	603,3	9,0	7,4	181,2	51,1
16	104	60,0	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1,0	603,3	9,0	9,3	229,0	21,8
16	104	60,0	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1,0	603,3	9,0	11,8	289,0	7,5
16	104	60,0	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1,0	603,3	9,0	15,3	374,6	13,6
16	110	51,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	14,7	4,0	163,3	5,0	5,1	64,8	29,0
16	110	51,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	14,7	4,0	163,3	5,0	13,5	172,9	12,3
16	110	51,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	14,7	4,0	163,3	5,0	15,7	200,1	6,2
16	110	51,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	14,7	4,0	163,3	5,0	20,3	259,7	4,6
16	110	51,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	14,7	4,0	163,3	5,0	27,0	344,7	3,6
16	111	48,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4,0	166,5	5,0	4,7	60,7	36,8
16	111	48,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4,0	166,5	5,0	6,2	80,6	31,2
16	111	48,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4,0	166,5	5,0	8,3	106,9	15,9
16	111	48,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4,0	166,5	5,0	11,4	146,6	22,1
16	111	48,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4,0	166,5	5,0	13,0	167,6	14,5
16	111	48,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4,0	166,5	5,0	15,1	195,0	8,3
16	111	48,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4,0	166,5	5,0	19,8	255,2	3,9
16	111	48,0	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4,0	166,5	5,0	26,2	338,1	7,1
16	99	49,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,8	1,0	445,4	5,0	5,7	120,3	48,8
16	99	49,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,8	1,0	445,4	5,0	6,6	139,5	36,1
16	99	49,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,8	1,0	445,4	5,0	7,8	165,2	38,9
16	99	49,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,8	1,0	445,4	5,0	11,9	251,2	17,6
16	99	49,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,8	1,0	445,4	5,0	14,7	310,4	8,7
16	99	49,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,8	1,0	445,4	5,0	18,6	393,5	8,5

16	101	78,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,6	1,0	725,7	5,0	4,4	118,3	48,3
16	101	78,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,6	1,0	725,7	5,0	5,1	137,8	39,9
16	101	78,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,6	1,0	725,7	5,0	6,2	165,8	57,2
16	101	78,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,6	1,0	725,7	5,0	9,4	252,4	24,0
16	101	78,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,6	1,0	725,7	5,0	11,7	314,6	23,8
16	101	78,0	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,6	1,0	725,7	5,0	14,7	396,2	9,1
16	108	60,0	1,8	88,9	6,1	5,5	4,3	3,0	1,8	15,0	1,0	725,7	5,0	2,8	76,2	55,1
16	108	60,0	1,8	88,9	6,1	5,5	4,3	3,0	1,8	15,0	1,0	725,7	5,0	3,6	96,1	51,1
16	108	60,0	1,8	88,9	6,1	5,5	4,3	3,0	1,8	15,0	1,0	725,7	5,0	4,5	121,9	35,8
16	108	60,0	1,8	88,9	6,1	5,5	4,3	3,0	1,8	15,0	1,0	725,7	5,0	6,0	162,2	84,8
16	108	60,0	1,8	88,9	6,1	5,5	4,3	3,0	1,8	15,0	1,0	725,7	5,0	6,8	184,1	43,2
16	108	60,0	1,8	88,9	6,1	5,5	4,3	3,0	1,8	15,0	1,0	725,7	5,0	7,8	210,9	18,1
16	108	60,0	1,8	88,9	6,1	5,5	4,3	3,0	1,8	15,0	1,0	725,7	5,0	10,0	270,7	9,8
16	108	60,0	1,8	88,9	6,1	5,5	4,3	3,0	1,8	15,0	1,0	725,7	5,0	13,1	353,6	10,0
16	109	51,0	1,8	88,9	6,1	4,0	4,9	1,5	2,1	15,0	1,0	392,4	5,0	3,3	65,3	55,6
16	109	51,0	1,8	88,9	6,1	4,0	4,9	1,5	2,1	15,0	1,0	392,4	5,0	4,3	84,7	47,0
16	109	51,0	1,8	88,9	6,1	4,0	4,9	1,5	2,1	15,0	1,0	392,4	5,0	5,6	110,3	32,8
16	109	51,0	1,8	88,9	6,1	4,0	4,9	1,5	2,1	15,0	1,0	392,4	5,0	7,5	148,8	55,6
16	109	51,0	1,8	88,9	6,1	4,0	4,9	1,5	2,1	15,0	1,0	392,4	5,0	8,6	169,4	24,3
16	109	51,0	1,8	88,9	6,1	4,0	4,9	1,5	2,1	15,0	1,0	392,4	5,0	9,9	196,3	16,0
16	109	51,0	1,8	88,9	6,1	4,0	4,9	1,5	2,1	15,0	1,0	392,4	5,0	13,0	257,3	6,7
16	109	51,0	1,8	88,9	6,1	4,0	4,9	1,5	2,1	15,0	1,0	392,4	5,0	17,2	341,5	7,3
17	115	42,0	1,2	88,9	14,6	14,0	1,8	2,4	4,0	71,2	8,0	712,1	25,0	10,5	281,4	9,2
17	115	42,0	1,2	88,9	14,6	14,0	1,8	2,4	4,0	71,2	8,0	712,1	25,0	14,2	379,2	8,8
17	115	42,0	1,2	88,9	14,6	14,0	1,8	2,4	4,0	71,2	8,0	712,1	25,0	20,8	554,3	3,6
17	119	66,0	1,2	88,9	14,0	13,4	2,0	2,4	4,0	75,5	8,0	755,2	25,0	6,6	180,3	31,0
17	116	87,0	1,2	88,9	13,9	13,3	2,1	2,4	4,0	68,5	5,0	1025,1	25,0	7,4	236,2	21,9
17	114	56,0	1,2	88,9	11,0	10,4	2,6	2,4	4,0	52,6	7,0	948,0	25,0	8,5	261,3	5,1
18	132	58,0	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8,0	323,0	25,0	2,5	45,4	83,1

18	132	58,0	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8,0	323,0	25,0	3,1	54,9	68,8
18	132	58,0	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8,0	323,0	25,0	3,9	69,8	78,5
18	132	58,0	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8,0	323,0	25,0	5,6	100,9	49,3
18	132	58,0	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8,0	323,0	25,0	7,6	136,6	24,6
18	132	58,0	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8,0	323,0	25,0	10,4	187,1	18,6
18	132	58,0	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8,0	323,0	25,0	14,1	252,9	11,7
18	132	58,0	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8,0	323,0	25,0	42,1	757,2	2,1
18	132	58,0	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8,0	323,0	25,0	52,5	943,4	3,1
18	138	59,0	7,6	69,9	13,7	14,0	0,9	1,8	2,7	42,5	6,0	425,0	8,0	6,2	128,8	32,3
18	138	59,0	7,6	69,9	13,7	14,0	0,9	1,8	2,7	42,5	6,0	425,0	8,0	7,2	149,3	24,4
18	138	59,0	7,6	69,9	13,7	14,0	0,9	1,8	2,7	42,5	6,0	425,0	8,0	11,0	226,7	13,6
18	138	59,0	7,6	69,9	13,7	14,0	0,9	1,8	2,7	42,5	6,0	425,0	8,0	14,5	298,6	14,4
18	138	59,0	7,6	69,9	13,7	14,0	0,9	1,8	2,7	42,5	6,0	425,0	8,0	19,5	402,1	7,6
18	138	59,0	7,6	69,9	13,7	14,0	0,9	1,8	2,7	42,5	6,0	425,0	8,0	24,6	507,6	6,0
18	133	70,0	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10,0	311,2	25,0	2,5	44,2	76,2
18	133	70,0	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10,0	311,2	25,0	3,1	54,0	84,6
18	133	70,0	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10,0	311,2	25,0	4,0	69,8	92,7
18	133	70,0	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10,0	311,2	25,0	5,7	101,4	63,0
18	133	70,0	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10,0	311,2	25,0	7,7	136,5	32,5
18	133	70,0	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10,0	311,2	25,0	10,7	188,4	27,4
18	133	70,0	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10,0	311,2	25,0	14,4	254,7	16,9
18	133	70,0	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10,0	311,2	25,0	24,8	438,3	3,9
18	130	57,0	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8,0	283,0	8,0	3,8	64,0	58,9
18	130	57,0	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8,0	283,0	8,0	7,2	121,1	40,6
18	130	57,0	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8,0	283,0	8,0	9,3	156,1	26,9
18	130	57,0	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8,0	283,0	8,0	12,4	207,9	17,2
18	130	57,0	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8,0	283,0	8,0	16,3	274,1	11,3
18	130	57,0	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8,0	283,0	8,0	20,5	345,7	7,2
18	135	87,0	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9,0	285,8	8,0	3,2	54,9	95,8

18	135	87,0	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9,0	285,8	8,0	5,1	85,7	47,8
18	135	87,0	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9,0	285,8	8,0	7,2	121,6	27,2
18	135	87,0	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9,0	285,8	8,0	10,2	172,9	19,6
18	135	87,0	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9,0	285,8	8,0	14,2	239,5	15,7
18	135	87,0	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9,0	285,8	8,0	29,0	490,4	4,7
18	124	61,0	7,6	69,9	13,7	13,7	1,5	2,1	1,5	38,5	7,0	410,5	8,0	40,4	818,8	2,7
18	124	61,0	7,6	69,9	13,7	13,7	1,5	2,1	1,5	38,5	7,0	410,5	8,0	48,4	981,1	2,0
18	124	61,0	7,6	69,9	13,7	13,7	1,5	2,1	1,5	38,5	7,0	410,5	8,0	54,8	1109,5	2,0
18	127	67,0	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6,0	435,9	8,0	2,2	46,7	77,7
18	127	67,0	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6,0	435,9	8,0	3,2	67,7	62,0
18	127	67,0	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6,0	435,9	8,0	4,8	99,2	46,2
18	127	67,0	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6,0	435,9	8,0	7,0	145,5	24,7
18	127	67,0	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6,0	435,9	8,0	10,5	218,3	14,7
18	127	67,0	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6,0	435,9	8,0	15,3	320,3	4,8
18	127	67,0	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6,0	435,9	8,0	20,5	427,1	5,2
18	129	77,0	7,6	69,9	9,4	9,4	1,5	1,5	2,4	34,2	5,0	547,0	8,0	2,6	60,3	89,2
18	129	77,0	7,6	69,9	9,4	9,4	1,5	1,5	2,4	34,2	5,0	547,0	8,0	3,9	92,1	67,1
18	129	77,0	7,6	69,9	9,4	9,4	1,5	1,5	2,4	34,2	5,0	547,0	8,0	5,9	137,6	24,4
18	129	77,0	7,6	69,9	9,4	9,4	1,5	1,5	2,4	34,2	5,0	547,0	8,0	13,4	312,3	7,7
18	129	77,0	7,6	69,9	9,4	9,4	1,5	1,5	2,4	34,2	5,0	547,0	8,0	17,9	418,1	5,0
19	152	18,0	1,1	152,4	16,2	15,2	3,0	4,0	4,9	222,3	6,0	948,5	25,0	6,0	185,4	20,5
19	152	18,0	1,1	152,4	16,2	15,2	3,0	4,0	4,9	222,3	6,0	948,5	25,0	10,6	326,1	7,6
19	152	18,0	1,1	152,4	16,2	15,2	3,0	4,0	4,9	222,3	6,0	948,5	25,0	11,3	347,0	5,9
19	152	18,0	1,1	152,4	16,2	15,2	3,0	4,0	4,9	222,3	6,0	948,5	25,0	12,1	372,1	7,9
19	152	18,0	1,1	152,4	16,2	15,2	3,0	4,0	4,9	222,3	6,0	948,5	25,0	13,1	404,2	7,3
19	152	18,0	1,1	152,4	16,2	15,2	3,0	4,0	4,9	222,3	6,0	948,5	25,0	14,5	447,4	6,2
19	152	18,0	1,1	152,4	16,2	15,2	3,0	4,0	4,9	222,3	6,0	948,5	25,0	16,2	497,6	2,7
19	152	18,0	1,1	152,4	16,2	15,2	3,0	4,0	4,9	222,3	6,0	948,5	25,0	18,7	577,0	3,2
19	152	18,0	1,1	152,4	16,2	15,2	3,0	4,0	4,9	222,3	6,0	948,5	25,0	24,1	742,9	5,3

19	152	18,0	1,1	152,4	16,2	15,2	3,0	4,0	4,9	222,3	6,0	948,5	25,0	26,7	822,3	4,6
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	3,0	82,3	61,5
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	3,5	94,5	50,3
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	4,1	111,3	35,8
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	4,9	132,3	26,9
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	5,8	158,1	43,9
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	7,0	189,9	29,7
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	8,7	235,3	17,3
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	10,5	284,3	14,9
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	13,4	363,9	11,7
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	19,6	530,5	13,3
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	22,5	610,2	8,6
19	153	20,0	1,1	152,4	13,7	12,8	3,4	4,0	4,9	195,5	6,0	733,0	25,0	32,1	869,9	5,2
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	1,8	51,9	156,0
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	2,2	63,4	72,9
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	2,7	77,7	57,7
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	3,5	99,7	37,6
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	4,3	124,6	35,1
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	5,4	155,5	24,7
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	6,9	199,9	13,5
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	8,6	249,5	11,7
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	11,4	329,2	11,7
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	17,2	495,1	9,0
19	154	14,0	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	20,0	576,1	10,7
20	137	88,0	0,0	88,9	5,5	0,0	2,4	2,7	2,7	11,6	4,0	302,1	25,0	3,4	59,5	96,3
20	137	88,0	0,0	88,9	5,5	0,0	2,4	2,7	2,7	11,6	4,0	302,1	25,0	6,2	107,8	64,0
20	137	88,0	0,0	88,9	5,5	0,0	2,4	2,7	2,7	11,6	4,0	302,1	25,0	8,8	153,4	87,9
21	168	1,0	9,1	88,9	13,7	15,2	1,8	3,0	0,0	68,0	0,0	68,0	0,0	5,6	46,3	23,5
21	168	1,0	9,1	88,9	13,7	15,2	1,8	3,0	0,0	68,0	0,0	68,0	0,0	7,7	63,8	27,9

21	168	1,0	9,1	88,9	13,7	15,2	1,8	3,0	0,0	68,0	0,0	68,0	0,0	9,6	79,1	34,3
21	168	1,0	9,1	88,9	13,7	15,2	1,8	3,0	0,0	68,0	0,0	68,0	0,0	15,9	131,0	8,1
21	168	1,0	9,1	88,9	13,7	15,2	1,8	3,0	0,0	68,0	0,0	68,0	0,0	21,5	176,9	6,7
21	168	1,0	9,1	88,9	13,7	15,2	1,8	3,0	0,0	68,0	0,0	68,0	0,0	26,2	216,5	7,9
21	168	1,0	9,1	88,9	13,7	15,2	1,8	3,0	0,0	68,0	0,0	68,0	0,0	33,0	272,1	4,7
21	168	1,0	9,1	88,9	13,7	15,2	1,8	3,0	0,0	68,0	0,0	68,0	0,0	65,6	541,3	14,2
21	165	122,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7,0	1362,1	25,0	1,8	67,0	46,2
21	165	122,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7,0	1362,1	25,0	2,3	84,2	68,3
21	165	122,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7,0	1362,1	25,0	2,7	99,0	69,9
21	165	122,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7,0	1362,1	25,0	4,1	150,8	35,6
21	165	122,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7,0	1362,1	25,0	5,3	197,1	30,5
21	165	122,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7,0	1362,1	25,0	6,4	237,2	25,0
21	165	122,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7,0	1362,1	25,0	15,3	562,9	4,5
21	166	152,0	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7,0	1163,5	25,0	2,1	71,9	67,8
21	166	152,0	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7,0	1163,5	25,0	2,6	87,2	70,4
21	166	152,0	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7,0	1163,5	25,0	4,7	159,0	26,2
21	166	152,0	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7,0	1163,5	25,0	5,9	200,7	17,1
21	166	152,0	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7,0	1163,5	25,0	7,0	237,7	16,6
21	166	152,0	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7,0	1163,5	25,0	8,6	293,3	10,2
21	166	152,0	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7,0	1163,5	25,0	16,5	561,9	3,9
21	167	128,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7,0	1417,0	25,0	1,9	73,1	90,9
21	167	128,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7,0	1417,0	25,0	2,5	92,7	54,1
21	167	128,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7,0	1417,0	25,0	2,8	106,6	59,9
21	167	128,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7,0	1417,0	25,0	3,5	130,5	59,9
21	167	128,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7,0	1417,0	25,0	4,3	161,5	36,6
21	167	128,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7,0	1417,0	25,0	5,4	202,7	27,2
21	167	128,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7,0	1417,0	25,0	6,5	243,6	37,3
21	167	128,0	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7,0	1417,0	25,0	15,1	569,0	8,3
21	164	26,0	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9,0	1344,9	25,0	2,9	106,4	41,7

21	164	26,0	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9,0	1344,9	25,0	3,9	142,4	35,6
21	164	26,0	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9,0	1344,9	25,0	5,5	202,5	20,9
21	164	26,0	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9,0	1344,9	25,0	7,0	255,6	18,1
21	164	26,0	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9,0	1344,9	25,0	8,1	295,4	14,4
21	164	26,0	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9,0	1344,9	25,0	9,6	353,5	14,2
21	164	26,0	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9,0	1344,9	25,0	15,4	566,0	7,3
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	6,8	109,4	19,5
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	7,6	121,7	23,1
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	9,0	144,2	11,5
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	10,3	164,5	23,7
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	11,6	185,5	5,2
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	12,7	203,6	6,0
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	18,2	291,2	6,2
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	21,0	335,4	3,5
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	24,5	392,7	2,3
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	27,9	446,3	4,1
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	33,5	536,1	2,4
22	156	44,0	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9,0	256,3	17,0	39,0	624,5	1,5
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	8,1	125,1	29,2
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	93,2	1431,8	12,9
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	10,0	152,9	8,9
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	11,5	176,5	9,2
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	13,7	210,6	5,1
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	16,3	250,9	4,9
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	19,5	298,9	6,2
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	23,2	356,6	3,4
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	26,7	410,1	2,2
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	30,5	467,8	2,1
22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	35,7	548,4	1,8

22	155	49,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29,0	8,0	235,9	17,0	40,2	617,9	0,9
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	14,1	125,1	20,9
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	15,5	137,1	8,8
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	17,9	158,4	4,4
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	20,3	179,6	10,3
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	24,5	217,3	2,6
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	29,2	259,0	1,6
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	34,4	304,7	3,1
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	39,3	348,4	1,6
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	45,7	404,9	1,4
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	52,0	461,0	1,3
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	62,0	549,2	0,9
22	158	11,0	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	71,1	629,4	0,6
22	159	54,0	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	7,7	132,9	18,1
22	159	54,0	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	8,7	150,1	16,7
22	159	54,0	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	9,4	161,8	9,4
22	159	54,0	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	10,6	183,7	9,7
22	159	54,0	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	12,5	216,6	6,1
22	159	54,0	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	14,8	256,4	3,7
22	159	54,0	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	17,5	301,8	5,6
22	159	54,0	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	22,9	395,6	3,0
22	159	54,0	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	26,0	449,6	4,4
22	159	54,0	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	31,0	534,8	1,9
22	157	34,0	9,1	88,9	9,1	10,1	3,0	2,1	2,1	38,6	6,0	231,3	17,0	7,4	112,9	45,2
22	157	34,0	9,1	88,9	9,1	10,1	3,0	2,1	2,1	38,6	6,0	231,3	17,0	8,6	130,8	17,2
22	157	34,0	9,1	88,9	9,1	10,1	3,0	2,1	2,1	38,6	6,0	231,3	17,0	9,3	141,8	15,2
22	157	34,0	9,1	88,9	9,1	10,1	3,0	2,1	2,1	38,6	6,0	231,3	17,0	10,8	163,8	12,4
22	157	34,0	9,1	88,9	9,1	10,1	3,0	2,1	2,1	38,6	6,0	231,3	17,0	13,0	198,2	6,3
22	157	34,0	9,1	88,9	9,1	10,1	3,0	2,1	2,1	38,6	6,0	231,3	17,0	15,7	239,5	5,2

22	157	34,0	9,1	88,9	9,1	10,1	3,0	2,1	2,1	38,6	6,0	231,3	17,0	25,4	386,8	3,4
22	157	34,0	9,1	88,9	9,1	10,1	3,0	2,1	2,1	38,6	6,0	231,3	17,0	29,1	442,6	2,5
22	157	34,0	9,1	88,9	9,1	10,1	3,0	2,1	2,1	38,6	6,0	231,3	17,0	35,7	542,4	2,4
22	157	34,0	9,1	88,9	9,1	10,1	3,0	2,1	2,1	38,6	6,0	231,3	17,0	40,3	612,6	1,2
23	160	42,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	3,8	66,8	61,5
23	160	42,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	4,6	80,9	33,8
23	160	42,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	7,4	130,5	19,3
23	160	42,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	10,1	178,5	21,8
23	160	42,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	23,9	422,7	2,4
23	160	42,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	29,4	519,6	16,8
23	161	45,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	4,4	75,3	51,3
23	161	45,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	5,3	90,5	51,6
23	161	45,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	6,2	106,7	37,8
23	161	45,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	9,8	167,1	17,8
23	161	45,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	12,1	207,3	14,0
23	161	45,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	26,7	455,6	2,6
23	161	45,0	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	32,8	560,8	3,0
23	162	33,0	9,1	88,9	16,8	18,0	1,8	2,1	2,1	78,0	7,0	388,7	25,0	3,1	60,9	66,3
23	162	33,0	9,1	88,9	16,8	18,0	1,8	2,1	2,1	78,0	7,0	388,7	25,0	3,9	75,9	52,3
23	162	33,0	9,1	88,9	16,8	18,0	1,8	2,1	2,1	78,0	7,0	388,7	25,0	6,3	124,9	37,3
23	162	33,0	9,1	88,9	16,8	18,0	1,8	2,1	2,1	78,0	7,0	388,7	25,0	8,8	174,0	23,7
23	162	33,0	9,1	88,9	16,8	18,0	1,8	2,1	2,1	78,0	7,0	388,7	25,0	16,9	332,8	4,8
23	163	43,0	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	3,1	59,5	96,5
23	163	43,0	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	3,8	73,7	38,1
23	163	43,0	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	9,0	172,4	24,1
23	163	43,0	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	11,1	213,3	17,6
23	163	43,0	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	21,7	417,1	2,3
23	163	43,0	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	26,7	514,6	4,2

APPENDIX D – TRAINING AND TESTING DATA

Table D-1 contains the training data. Table D-2 contains Test 1 data and Table D-3 contains Test 2 data.

Table D-1: Training Data

Ran d	Sit e No.	Tes t	Total No. of Hole s	Overburde n (m)	Hole Size (mm)	Hole Dept h (m)	Face Heigh t (m)	Stemmin g (m)	Burde n (m)	Spacin g (m)	Charg e per hole (kg)	No. of delay interval s	Max. Charg e per delay (kg)	Lengt h of Delay (msec)	Scaled Distance (m/kg ^{1/2})	Distanc e (m)	PPV Peak (mm/sec)
0	10	47	9	8,4	66,7	6,1	0	0	0	0,8	3,5	0	31,8	25	7,6	42,6	12,8
0	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	26,7	410,1	2,2
0	18	127	67	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6	435,9	8	2,2	46,7	77,7
0	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	8,7	235,3	17,3
0	18	127	67	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6	435,9	8	15,3	320,3	4,8
0	15	93	35	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5	217,7	25	22,7	335,2	14,4
0	16	109	51	1,8	88,9	6,1	4	4,9	1,5	2,1	15	1	392,4	5	8,6	169,4	24,3
0	14	87	45	3	88,9	11	9,1	3,7	2,4	3	45,6	10	319,1	25	15,8	282,1	4,4
0	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	28,3	469,3	1,5
0	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	13,4	222,1	30
0	15	92	40	1,8	88,9	9,1	9,1	1,8	2,4	3	31,8	5	317,5	25	28,7	512,1	4,8
0	15	126	26	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7	423,2	25	4,7	96,8	41,7
0	21	165	122	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7	1362,1	25	1,8	67	46,2
0	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	71,1	629,4	0,6
0	12	146	15	0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14	158,8	25	34,5	435,1	9,8
0	16	109	51	1,8	88,9	6,1	4	4,9	1,5	2,1	15	1	392,4	5	4,3	84,7	47
0	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	6,8	109,4	19,5
0	5	83	1	4,6	149,2	9,4	9,1	3,4	3	0	59,9	0	59,9	0	36,3	280,9	2,9

0	14	89	45	3	88,9	16,2	14,9	3,7	2,4	3	78,2	10	553,4	25	3,1	73,1	110,7
0	11	59	48	7,9	228,6	9,3	8,7	5	6,1	4,6	317,5	47	317,5	17	15,8	282,2	11,5
0	12	141	31	0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30	137,4	21	8,8	102,9	78,5
0	16	108	60	1,8	88,9	6,1	5,5	4,3	3	1,8	15	1	725,7	5	3,6	96,1	51,1
0	7	75	36	2,7	158,8	7,3	7	1,8	3,7	3	82,6	9	486,3	9	19,4	427,1	8,8
0	1	10	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	28,9	275,4	2,4
0	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	35,7	548,4	1,8
0	1	4	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	29,8	284,1	2
0	1	2	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	272,2	0	5,8	95,6	37,3
0	18	135	87	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9	285,8	8	5,1	85,7	47,8
0	10	48	9	8,4	66,7	6,1	0	0	0	0,8	3,6	0	32,7	25	24	137,1	9
0	16	103	59	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3	267,2	5	9,4	153,1	25,7
0	21	166	152	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7	1163,5	25	4,7	159	26,2
0	12	145	8	0	165,1	15,5	13,7	5,8	5	4,9	148,8	7	160,1	25	18,3	231,9	13,6
0	15	117	24	1,8	114,3	12,2	6,7	2,6	3	3,7	83,9	5	503,5	25	20,4	458	6,8
0	12	142	16	0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15	147,4	21	41,2	500,6	17,2
0	12	146	15	0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14	158,8	25	21,9	276	18,5
0	15	117	24	1,8	114,3	12,2	6,7	2,6	3	3,7	83,9	5	503,5	25	5,5	122,9	58,7
0	7	75	36	2,7	158,8	7,3	7	1,8	3,7	3	82,6	9	486,3	9	6,7	146,7	33,3
0	14	91	42	3	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9	394,2	25	6,2	122,2	43,9
0	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	3,5	94,5	50,3
0	21	165	122	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7	1362,1	25	15,3	562,9	4,5
0	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	5,8	158,1	43,9
0	15	122	12	1,8	63,5	4,9	0	2,4	1,1	1,2	7,6	4	30,3	800	113,1	622,8	0,1
0	16	100	16	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0	215,5	0	7,2	105	33,3
0,1	16	96	84	1,8	63,5	6,1	5,5	2,7	2,4	1,5	18,1	2	526,2	5	11,2	257,5	19,6

0,1	18	130	57	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8	283	8	20,5	345,7	7,2
0,1	15	93	35	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5	217,7	25	8,1	118,9	36,6
0,1	21	168	1	9,1	88,9	13,7	15,2	1,8	3	0	68	0	68	0	7,7	63,8	27,9
0,1	16	109	51	1,8	88,9	6,1	4	4,9	1,5	2,1	15	1	392,4	5	7,5	148,8	55,6
0,1	9	80	69	8,4	120,7	5,5	5,5	2,4	3	3,4	36,2	3	1231	25	5,8	204,8	26,9
0,1	1	8	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	635	0	4,5	112,8	53,6
0,1	22	157	34	9,1	88,9	9,1	10,1	3	2,1	2,1	38,6	6	231,3	17	15,7	239,5	5,2
0,1	16	110	51	1,8	88,9	6,1	5,5	2,7	2,4	1,8	14,7	4	163,3	5	20,3	259,7	4,6
0,1	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	16,7	275,9	10,5
0,1	12	145	8	0	165,1	15,5	13,7	5,8	5	4,9	148,8	7	160,1	25	16,7	211,3	14,7
0,1	15	118	38	1,8	101,6	13,7	13,1	1,8	2,9	3,5	68	6	680,4	25	19,5	508,8	12,4
0,1	21	166	152	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7	1163,5	25	2,1	71,9	67,8
0,1	16	97	63	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2	287,1	5	15,1	256,1	11,3
0,1	1	12	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	1360,8	0	6,1	223,7	37,8
0,1	16	101	78	1,8	88,9	6,1	5,5	3	2,4	1,5	18,6	1	725,7	5	6,2	165,8	57,2
0,1	17	115	42	1,2	88,9	14,6	14	1,8	2,4	4	71,2	8	712,1	25	14,2	379,2	8,8
0,1	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	25,1	416,4	23,1
0,1	7	79	1	2,7	158,8	17,1	16,5	1,2	3	0	212,3	0	212,3	0	40,4	588,2	1,7
0,1	5	82	13	4,6	149,2	9,1	9,1	3,7	3	3	59,9	3	299,4	25	6,7	116,7	21,2
0,1	16	100	16	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0	215,5	0	11,4	168,1	26,9
0,1	22	159	54	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7	298,5	17	9,4	161,8	9,4
0,1	14	91	42	3	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9	394,2	25	3,1	60,9	122,7
0,1	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	29,3	485,5	15,1
0,1	12	145	8	0	165,1	15,5	13,7	5,8	5	4,9	148,8	7	160,1	25	30,4	384,3	12,8
0,1	18	127	67	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6	435,9	8	20,5	427,1	5,2
0,1	1	9	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	5,2	49,6	47,8

0,1	21	168	1	9,1	88,9	13,7	15,2	1,8	3	0	68	0	68	0	21,5	176,9	6,7
0,1	1	9	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	7,1	67,2	27,9
0,1	15	92	40	1,8	88,9	9,1	9,1	1,8	2,4	3	31,8	5	317,5	25	5	88,7	40,6
0,1	15	122	12	1,8	63,5	4,9	0	2,4	1,1	1,2	7,6	4	30,3	800	41	225,5	0,8
0,1	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	33,5	536,1	2,4
0,1	11	59	48	7,9	228,6	9,3	8,7	5	6,1	4,6	317,5	47	317,5	17	22,3	397,6	23,2
0,1	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	29,2	259	1,6
0,1	12	142	16	0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15	147,4	21	20,3	246,7	25,7
0,1	12	146	15	0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14	158,8	25	18,3	230,9	25
0,1	5	31	11	4,6	152,4	7,9	7,6	3,4	3	3,7	56,7	3	226,8	25	5,7	85,2	19,9
0,1	6	33	126	3	63,5	6,1	6,1	1,7	1,5	2,1	15,9	7	412,8	25	6,4	129,6	16
0,1	15	92	40	1,8	88,9	9,1	9,1	1,8	2,4	3	31,8	5	317,5	25	12	214,5	17,4
0,1	9	80	69	8,4	120,7	5,5	5,5	2,4	3	3,4	36,2	3	1231	25	6	211,2	21,1
0,1	14	91	42	3	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9	394,2	25	3,9	77,7	81,8
0,1	1	5	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	17	29,5	281	4,2
0,1	15	122	12	1,8	63,5	4,9	0	2,4	1,1	1,2	7,6	4	30,3	800	51,1	281,5	0,4
0,1	11	59	48	7,9	228,6	9,3	8,7	5	6,1	4,6	317,5	47	317,5	17	18	320,2	11,2
0,1	10	49	9	8,4	66,7	6,1	0	0	0	0,8	3,6	0	32,7	25	15,7	90	4,6
0,1	7	75	36	2,7	158,8	7,3	7	1,8	3,7	3	82,6	9	486,3	9	11,2	246,5	25,9
0,1	7	42	37	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7	1244,7	17	6,5	229,9	65,3
0,1	9	36	12	5,2	152,4	9,8	9,8	5,5	2,7	4,3	63,5	2	381	25	2,7	53,4	125
0,1	15	93	35	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5	217,7	25	35,1	518,2	4,1
0,1	21	164	26	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9	1344,9	25	5,5	202,5	20,9
0,1	1	19	3	1,8	152,4	11	9,1	4,9	3	4,6	90,7	2	90,7	9	18,5	176,3	10,2
0,1	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	36,3	600,5	0,6
0,1	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	93,2	1431,8	12,9

0,1	16	107	42	1,8	88,9	4	4	0,6	2,4	1,5	13,6	0	567	0	19,5	463,4	4,1
0,1	16	111	48	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4	166,5	5	6,2	80,6	31,2
0,1	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	4,1	111,3	35,8
0,1	18	135	87	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9	285,8	8	3,2	54,9	95,8
0,1	1	5	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	17	12,3	117,2	24,2
0,1	15	125	16	1,8	63,5	14	13,7	0,9	0	0,6	4,3	0	68	0	57,9	477,8	3,8
0,1	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	21,2	350,9	3,1
0,1	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	8,9	147,7	20,8
0,1	12	143	23	0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22	139,7	25	7,1	84	67,8
0,1	1	3	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	2	90,7	17	10,2	97,4	14,6
0,1	15	126	26	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7	423,2	25	8,3	170,4	26,4
0,1	16	100	16	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0	215,5	0	23,4	344,1	6,6
0,1	12	143	23	0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22	139,7	25	16,9	199,5	22,4
0,1	16	104	60	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1	603,3	9	11,8	289	7,5
0,1	9	76	31	8,4	120,7	5,5	5,2	2	3	3,4	36,8	2	552,5	25	4,4	103	50
0,1	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	5,7	94,5	40,9
0,1	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	11	181,6	19,4
0,1	16	103	59	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3	267,2	5	18,3	299,6	6,3
0,1	17	114	56	1,2	88,9	11	10,4	2,6	2,4	4	52,6	7	948	25	8,5	261,3	5,1
0,1	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	18,2	291,2	6,2
0,1	15	93	35	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5	217,7	25	4,4	65,5	31
0,1	21	165	122	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7	1362,1	25	2,7	99	69,9
0,1	1	8	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	635	0	6,1	152,8	50,8
0,1	16	111	48	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4	166,5	5	13	167,6	14,5
0,1	21	167	128	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7	1417	25	2,5	92,7	54,1
0,1	11	56	13	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12	690,4	26	23,5	618,3	2,6

0,1	5	82	13	4,6	149,2	9,1	9,1	3,7	3	3	59,9	3	299,4	25	20,6	356,3	2,8
0,1	16	102	16	1,8	88,9	4,6	4	2,7	2,4	1,5	12,7	1	155,6	5	21,9	273,2	4,4
0,1	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	65,6	1088	2,2
0,1	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	32,1	869,9	5,2
0,1	5	83	1	4,6	149,2	9,4	9,1	3,4	3	0	59,9	0	59,9	0	13,1	101,6	9,6
0,1	5	30	11	4,6	152,4	7,9	7,6	3,4	3	3,7	50,8	4	203,2	25	3	43	41,7
0,2	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	27,9	446,3	4,1
0,2	18	138	59	7,6	69,9	13,7	14	0,9	1,8	2,7	42,5	6	425	8	11	226,7	13,6
0,2	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	8,1	125,1	29,2
0,2	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	16,3	250,9	4,9
0,2	1	12	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	1360,8	0	5,1	188,6	55,6
0,2	15	118	38	1,8	101,6	13,7	13,1	1,8	2,9	3,5	68	6	680,4	25	4,8	124	69,6
0,2	11	58	30	7,9	228,6	19,4	18,7	6,1	6,1	5,5	506,2	29	506,2	17	16,7	376,7	28,4
0,2	11	57	28	7,9	228,6	25,9	25,1	6,1	5,2	7	712,1	27	712,1	21,5	24,9	664,2	4,9
0,2	1	21	15	1,8	152,4	11	9,1	4,9	3	4,6	90,7	14	90,7	9	23,4	223,3	11,5
0,2	16	102	16	1,8	88,9	4,6	4	2,7	2,4	1,5	12,7	1	155,6	5	18,5	230,9	6,6
0,2	11	56	13	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12	690,4	26	33,1	869,2	1,4
0,2	15	95	48	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7	314,3	25	27,3	484,6	6,2
0,2	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	19,6	530,5	13,3
0,2	15	120	46	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8	544,3	25	18,9	440,3	6,4
0,2	16	108	60	1,8	88,9	6,1	5,5	4,3	3	1,8	15	1	725,7	5	2,8	76,2	55,1
0,2	16	108	60	1,8	88,9	6,1	5,5	4,3	3	1,8	15	1	725,7	5	7,8	210,9	18,1
0,2	15	123	20	1,8	88,9	13,4	13,7	3,7	3	4,3	99,8	7	499	25	6	134,5	55,4
0,2	12	143	23	0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22	139,7	25	14,5	171,7	40,9
0,2	16	103	59	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3	267,2	5	6,7	108,7	31,8
0,2	16	106	61	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1	626	9	5,3	133,6	40,9

0,2	12	144	22	0	165,1	14	12,2	5,3	5,3	4,6	157,9	21	178,3	25	23,4	311,8	25
0,2	15	125	16	1,8	63,5	14	13,7	0,9	0	0,6	4,3	0	68	0	20,4	168,4	12,8
0,2	14	90	30	3	88,9	14,6	13,4	3	2,4	3	70,3	10	281,2	25	16,2	272,5	11,7
0,2	1	10	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	7,1	67,2	33
0,2	15	125	16	1,8	63,5	14	13,7	0,9	0	0,6	4,3	0	68	0	13	107,1	22,9
0,2	21	166	152	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7	1163,5	25	7	237,7	16,6
0,2	12	139	23	0	165,1	14	11,9	5,2	5,3	4,6	152	22	152	21	23,9	294,6	17,2
0,2	5	83	1	4,6	149,2	9,4	9,1	3,4	3	0	59,9	0	59,9	0	27,8	215	4,3
0,2	1	4	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	12,4	118,5	10,2
0,2	1	32	21	1,8	152,4	11	9,1	4,9	3	4,3	92,1	3	552,5	17	12	281,9	13,5
0,2	12	145	8	0	165,1	15,5	13,7	5,8	5	4,9	148,8	7	160,1	25	10	126	15,7
0,2	19	154	14	1,1	152,4	16,5	15,5	4,4	4	4,9	255,8	5	833,2	25	3,5	99,7	37,6
0,2	16	110	51	1,8	88,9	6,1	5,5	2,7	2,4	1,8	14,7	4	163,3	5	5,1	64,8	29
0,2	5	83	1	4,6	149,2	9,4	9,1	3,4	3	0	59,9	0	59,9	0	47,5	367,7	1,6
0,2	18	138	59	7,6	69,9	13,7	14	0,9	1,8	2,7	42,5	6	425	8	19,5	402,1	7,6
0,2	16	102	16	1,8	88,9	4,6	4	2,7	2,4	1,5	12,7	1	155,6	5	35,9	448,2	0,8
0,2	5	30	11	4,6	152,4	7,9	7,6	3,4	3	3,7	50,8	4	203,2	25	15,3	218,7	2,6
0,2	14	89	45	3	88,9	16,2	14,9	3,7	2,4	3	78,2	10	553,4	25	4,5	106,5	43,4
0,2	17	119	66	1,2	88,9	14	13,4	2	2,4	4	75,5	8	755,2	25	6,6	180,3	31
0,2	14	94	24	3	114,3	17,1	15,2	3,7	3	3,4	127	9	508	25	6,4	143,8	37,6
0,2	14	94	24	3	114,3	17,1	15,2	3,7	3	3,4	127	9	508	25	3,3	74,7	86,6
0,2	22	157	34	9,1	88,9	9,1	10,1	3	2,1	2,1	38,6	6	231,3	17	7,4	112,9	45,2
0,2	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	19,5	298,9	6,2
0,2	16	106	61	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1	626	9	8,8	220,8	30
0,2	22	157	34	9,1	88,9	9,1	10,1	3	2,1	2,1	38,6	6	231,3	17	25,4	386,8	3,4
0,2	14	89	45	3	88,9	16,2	14,9	3,7	2,4	3	78,2	10	553,4	25	27	634,5	1,2

0,2	16	108	60	1,8	88,9	6,1	5,5	4,3	3	1,8	15	1	725,7	5	6,8	184,1	43,2
0,2	1	7	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	34	7,6	72	29,5
0,2	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	10	152,9	8,9
0,2	7	42	37	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7	1244,7	17	11,1	392,8	30,5
0,2	14	90	30	3	88,9	14,6	13,4	3	2,4	3	70,3	10	281,2	25	13,8	231,5	14,9
0,2	18	133	70	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10	311,2	25	5,7	101,4	63
0,2	11	62	20	7,9	228,6	22,9	22,9	5,3	7	7,6	734,8	19	734,8	26	23,7	642,8	3
0,2	12	143	23	0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22	139,7	25	10,1	119,8	28,2
0,2	18	130	57	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8	283	8	3,8	64	58,9
0,2	16	97	63	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2	287,1	5	11,6	196,3	23,8
0,2	15	122	12	1,8	63,5	4,9	0	2,4	1,1	1,2	7,6	4	30,3	800	77,8	428,5	0,4
0,2	18	132	58	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8	323	25	5,6	100,9	49,3
0,2	18	130	57	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8	283	8	7,2	121,1	40,6
0,2	3	24	78	2,1	76,2	6,1	5,5	1,2	2,4	2,7	11,3	2	283,5	50	8,7	146,3	13,4
0,2	22	159	54	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7	298,5	17	26	449,6	4,4
0,2	16	110	51	1,8	88,9	6,1	5,5	2,7	2,4	1,8	14,7	4	163,3	5	15,7	200,1	6,2
0,2	12	146	15	0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14	158,8	25	7,6	95,8	40,1
0,2	1	18	1	1,8	152,4	11	9,1	4,9	3	0	90,7	0	90,7	0	18,5	176,3	6,8
0,2	16	103	59	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3	267,2	5	7,8	127,2	27,7
0,2	5	83	1	4,6	149,2	9,4	9,1	3,4	3	0	59,9	0	59,9	0	10,5	80,9	14,2
0,2	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	62	549,2	0,9
0,2	12	139	23	0	165,1	14	11,9	5,2	5,3	4,6	152	22	152	21	8,4	103,8	112,3
0,2	16	110	51	1,8	88,9	6,1	5,5	2,7	2,4	1,8	14,7	4	163,3	5	27	344,7	3,6
0,2	1	32	21	1,8	152,4	11	9,1	4,9	3	4,3	92,1	3	552,5	17	8,2	193,6	25,9
0,2	12	143	23	0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22	139,7	25	12,1	142,8	20,2
0,2	1	8	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	635	0	8,1	205,3	36,8

0,2	15	123	20	1,8	88,9	13,4	13,7	3,7	3	4,3	99,8	7	499	25	13,7	305,3	19,3
0,2	12	140	19	0	165,1	16,2	14,3	5,3	5,2	5	163,3	18	181,4	21	5,9	79,9	65,3
0,3	16	97	63	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2	287,1	5	5,4	92	31,2
0,3	15	92	40	1,8	88,9	9,1	9,1	1,8	2,4	3	31,8	5	317,5	25	14,9	265,3	17
0,3	15	126	26	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7	423,2	25	23,5	483,2	6,6
0,3	11	59	48	7,9	228,6	9,3	8,7	5	6,1	4,6	317,5	47	317,5	17	32,9	587,1	5,7
0,3	5	83	1	4,6	149,2	9,4	9,1	3,4	3	0	59,9	0	59,9	0	8,6	66,2	12,1
0,3	11	58	30	7,9	228,6	19,4	18,7	6,1	6,1	5,5	506,2	29	506,2	17	14,8	331,9	14,3
0,3	12	141	31	0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30	137,4	21	13,7	160,2	29,7
0,3	1	18	1	1,8	152,4	11	9,1	4,9	3	0	90,7	0	90,7	0	10,4	98,7	19,8
0,3	18	130	57	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8	283	8	9,3	156,1	26,9
0,3	5	82	13	4,6	149,2	9,1	9,1	3,7	3	3	59,9	3	299,4	25	15,6	270,2	5,2
0,3	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	11,5	176,5	9,2
0,3	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	7	189,9	29,7
0,3	18	127	67	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6	435,9	8	4,8	99,2	46,2
0,3	12	142	16	0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15	147,4	21	14	170,3	20,9
0,3	11	59	48	7,9	228,6	9,3	8,7	5	6,1	4,6	317,5	47	317,5	17	28,7	512,1	8,3
0,3	22	159	54	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7	298,5	17	17,5	301,8	5,6
0,3	1	19	3	1,8	152,4	11	9,1	4,9	3	4,6	90,7	2	90,7	9	22,5	214,7	8,4
0,3	1	6	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	2	90,7	34	21	199,6	6,3
0,3	7	75	36	2,7	158,8	7,3	7	1,8	3,7	3	82,6	9	486,3	9	14,8	326,3	10,6
0,3	22	159	54	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7	298,5	17	12,5	216,6	6,1
0,3	1	10	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	5,2	49,6	59,4
0,3	18	132	58	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8	323	25	10,4	187,1	18,6
0,3	10	50	9	8,4	66,7	6,1	0	0	0	0,8	3,5	0	31,8	0	41,4	233,1	2
0,3	16	98	31	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1	292,6	5	25,4	434,3	25,2

0,3	15	118	38	1,8	101,6	13,7	13,1	1,8	2,9	3,5	68	6	680,4	25	4,8	126,3	50,5
0,3	19	152	18	1,1	152,4	16,2	15,2	3	4	4,9	222,3	6	948,5	25	10,6	326,1	7,6
0,3	19	154	14	1,1	152,4	16,5	15,5	4,4	4	4,9	255,8	5	833,2	25	11,4	329,2	11,7
0,3	16	98	31	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1	292,6	5	7,7	131,6	44,7
0,3	1	6	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	2	90,7	34	15,1	144	13,4
0,3	16	99	49	1,8	88,9	6,1	5,5	3	2,4	1,5	18,8	1	445,4	5	5,7	120,3	48,8
0,3	16	103	59	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3	267,2	5	23,5	383,9	9
0,3	15	125	16	1,8	63,5	14	13,7	0,9	0	0,6	4,3	0	68	0	45,7	377	4
0,3	11	58	30	7,9	228,6	19,4	18,7	6,1	6,1	5,5	506,2	29	506,2	17	13	292,2	16,2
0,3	1	2	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	272,2	0	5,8	96,3	23,4
0,3	14	91	42	3	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9	394,2	25	16,7	332,5	9,8
0,3	5	82	13	4,6	149,2	9,1	9,1	3,7	3	3	59,9	3	299,4	25	3,1	54	45,7
0,3	16	107	42	1,8	88,9	4	4	0,6	2,4	1,5	13,6	0	567	0	12,1	288,8	17
0,3	9	77	1	8,4	120,7	5,5	5,2	2	3,4	0	36,3	0	36,3	0	26,5	159,5	7,6
0,3	16	111	48	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4	166,5	5	15,1	195	8,3
0,3	9	77	1	8,4	120,7	5,5	5,2	2	3,4	0	36,3	0	36,3	0	42,6	256,8	5,1
0,3	16	100	16	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0	215,5	0	17,2	253,1	11,2
0,3	1	8	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	635	0	3,3	83,5	118,1
0,3	16	100	16	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0	215,5	0	15,1	221,9	14,6
0,3	22	157	34	9,1	88,9	9,1	10,1	3	2,1	2,1	38,6	6	231,3	17	8,6	130,8	17,2
0,3	1	7	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	34	21,1	201,3	4,9
0,3	1	27	13	1,8	152,4	11	9,1	4,9	3	4,6	90,7	3	362,9	17	6,2	119	48,5
0,3	15	95	48	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7	314,3	25	17,6	311,3	12,8
0,3	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	52	461	1,3
0,3	15	92	40	1,8	88,9	9,1	9,1	1,8	2,4	3	31,8	5	317,5	25	3,2	57,9	60,2
0,3	22	159	54	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7	298,5	17	22,9	395,6	3

0,3	1	18	1	1,8	152,4	11	9,1	4,9	3	0	90,7	0	90,7	0	13,1	125	16,1
0,3	18	127	67	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6	435,9	8	10,5	218,3	14,7
0,3	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	33,1	548,9	2
0,3	18	127	67	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6	435,9	8	3,2	67,7	62
0,3	1	18	1	1,8	152,4	11	9,1	4,9	3	0	90,7	0	90,7	0	22,5	214,7	6,2
0,3	18	133	70	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10	311,2	25	14,4	254,7	16,9
0,3	14	91	42	3	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9	394,2	25	13,8	274,9	20,3
0,3	20	137	88	0	88,9	5,5	0	2,4	2,7	2,7	11,6	4	302,1	25	3,4	59,5	96,3
0,3	15	122	12	1,8	63,5	4,9	0	2,4	1,1	1,2	7,6	4	30,3	800	36,4	200,5	1,1
0,3	12	60	10	0	165,1	20	21,8	7,8	6,1	4,6	253,1	9	253,1	26	10	158,4	41,9
0,3	12	144	22	0	165,1	14	12,2	5,3	5,3	4,6	157,9	21	178,3	25	17,9	238,7	24,1
0,3	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	34,4	304,7	3,1
0,3	16	102	16	1,8	88,9	4,6	4	2,7	2,4	1,5	12,7	1	155,6	5	15,9	198,7	11,9
0,3	18	135	87	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9	285,8	8	14,2	239,5	15,7
0,3	18	138	59	7,6	69,9	13,7	14	0,9	1,8	2,7	42,5	6	425	8	6,2	128,8	32,3
0,3	16	106	61	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1	626	9	11,2	280,8	11
0,3	1	6	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	2	90,7	34	10,9	103,9	16,1
0,3	9	76	31	8,4	120,7	5,5	5,2	2	3	3,4	36,8	2	552,5	25	19,3	454,2	8,7
0,3	18	129	77	7,6	69,9	9,4	9,4	1,5	1,5	2,4	34,2	5	547	8	3,9	92,1	67,1
0,3	1	13	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	1360,8	34	29,1	1073,5	3,2
0,3	1	5	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	17	22,1	210,4	10,1
0,3	15	92	40	1,8	88,9	9,1	9,1	1,8	2,4	3	31,8	5	317,5	25	5,5	98,4	26,9
0,3	15	117	24	1,8	114,3	12,2	6,7	2,6	3	3,7	83,9	5	503,5	25	17,2	385,9	12,4
0,3	12	139	23	0	165,1	14	11,9	5,2	5,3	4,6	152	22	152	21	6,6	80,9	86,1
0,3	10	47	9	8,4	66,7	6,1	0	0	0	0,8	3,5	0	31,8	25	33,9	191	1,2
0,3	15	123	20	1,8	88,9	13,4	13,7	3,7	3	4,3	99,8	7	499	25	10,1	226,4	24,5

0,3	21	165	122	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7	1362,1	25	4,1	150,8	35,6
0,3	18	130	57	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8	283	8	16,3	274,1	11,3
0,4	18	130	57	7,6	69,9	10,1	10,1	1,2	1,8	2,7	31,4	8	283	8	12,4	207,9	17,2
0,4	11	62	20	7,9	228,6	22,9	22,9	5,3	7	7,6	734,8	19	734,8	26	29,7	806	3,2
0,4	21	164	26	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9	1344,9	25	9,6	353,5	14,2
0,4	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	13,7	210,6	5,1
0,4	7	78	36	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12	2095,6	9	3,1	140,3	72,4
0,4	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	12,7	203,6	6
0,4	18	132	58	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8	323	25	7,6	136,6	24,6
0,4	6	33	126	3	63,5	6,1	6,1	1,7	1,5	2,1	15,9	7	412,8	25	15,9	323,7	5,5
0,4	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	16	265,6	9,7
0,4	21	167	128	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7	1417	25	3,5	130,5	59,9
0,4	1	10	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	10,3	98,3	14,4
0,4	1	7	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	34	5,9	56,5	44,2
0,4	16	101	78	1,8	88,9	6,1	5,5	3	2,4	1,5	18,6	1	725,7	5	4,4	118,3	48,3
0,4	11	59	48	7,9	228,6	9,3	8,7	5	6,1	4,6	317,5	47	317,5	17	25,6	455,6	8,7
0,4	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	23,2	356,6	3,4
0,4	16	99	49	1,8	88,9	6,1	5,5	3	2,4	1,5	18,8	1	445,4	5	7,8	165,2	38,9
0,4	16	105	42	1,8	88,9	3,7	3,7	1,4	3	1,5	13,6	0	601	0	13,7	335,1	14,8
0,4	15	95	48	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7	314,3	25	3,2	57	55,9
0,4	1	21	15	1,8	152,4	11	9,1	4,9	3	4,6	90,7	14	90,7	9	9,5	91	27,2
0,4	15	123	20	1,8	88,9	13,4	13,7	3,7	3	4,3	99,8	7	499	25	11,3	251,7	18,4
0,4	1	2	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	272,2	0	13,2	217,3	13
0,4	14	90	30	3	88,9	14,6	13,4	3	2,4	3	70,3	10	281,2	25	3,2	54,3	81,5
0,4	16	99	49	1,8	88,9	6,1	5,5	3	2,4	1,5	18,8	1	445,4	5	14,7	310,4	8,7
0,4	11	57	28	7,9	228,6	25,9	25,1	6,1	5,2	7	712,1	27	712,1	21,5	21,7	579,7	5,3

0,4	1	18	1	1,8	152,4	11	9,1	4,9	3	0	90,7	0	90,7	0	8,6	81,5	21,6
0,4	15	123	20	1,8	88,9	13,4	13,7	3,7	3	4,3	99,8	7	499	25	21,1	472,1	13,8
0,4	1	3	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	2	90,7	17	30,4	289,7	3
0,4	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	24,5	392,7	2,3
0,4	16	96	84	1,8	63,5	6,1	5,5	2,7	2,4	1,5	18,1	2	526,2	5	13,8	317,7	9,7
0,4	21	166	152	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7	1163,5	25	16,5	561,9	3,9
0,4	12	144	22	0	165,1	14	12,2	5,3	5,3	4,6	157,9	21	178,3	25	15,7	210,3	24,7
0,4	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	13,4	363,9	11,7
0,4	18	132	58	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8	323	25	2,5	45,4	83,1
0,4	5	81	12	4,6	149,2	7,6	7,6	3,4	3	3	46,3	3	277,6	25	6,3	104,8	12,4
0,4	15	123	20	1,8	88,9	13,4	13,7	3,7	3	4,3	99,8	7	499	25	32	715,7	2,2
0,4	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	4,5	74,7	53,6
0,4	1	21	15	1,8	152,4	11	9,1	4,9	3	4,6	90,7	14	90,7	9	8	75,9	47,5
0,4	18	129	77	7,6	69,9	9,4	9,4	1,5	1,5	2,4	34,2	5	547	8	5,9	137,6	24,4
0,4	22	157	34	9,1	88,9	9,1	10,1	3	2,1	2,1	38,6	6	231,3	17	40,3	612,6	1,2
0,4	1	5	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	17	9,2	87,9	36,8
0,4	1	12	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	1360,8	0	3,6	132,9	95,8
0,4	16	108	60	1,8	88,9	6,1	5,5	4,3	3	1,8	15	1	725,7	5	6	162,2	84,8
0,4	14	86	50	3	88,9	17,1	15,2	4,9	2,4	3,4	78,5	10	627,8	25	15,8	395,7	5,6
0,4	19	152	18	1,1	152,4	16,2	15,2	3	4	4,9	222,3	6	948,5	25	13,1	404,2	7,3
0,4	18	135	87	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9	285,8	8	29	490,4	4,7
0,4	1	21	15	1,8	152,4	11	9,1	4,9	3	4,6	90,7	14	90,7	9	28,1	267,7	6
0,4	21	168	1	9,1	88,9	13,7	15,2	1,8	3	0	68	0	68	0	33	272,1	4,7
0,4	1	3	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	2	90,7	17	4,8	45,7	45
0,4	12	145	8	0	165,1	15,5	13,7	5,8	5	4,9	148,8	7	160,1	25	21,5	272,6	12,4
0,4	10	49	9	8,4	66,7	6,1	0	0	0	0,8	3,6	0	32,7	25	41,3	236,1	0,7

0,4	11	57	28	7,9	228,6	25,9	25,1	6,1	5,2	7	712,1	27	712,1	21,5	20,3	542,3	6,5
0,4	1	7	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	34	11,2	106,5	14,4
0,4	12	143	23	0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22	139,7	25	24,8	293,1	26,2
0,4	14	91	42	3	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9	394,2	25	7,5	148,3	37,6
0,4	14	94	24	3	114,3	17,1	15,2	3,7	3	3,4	127	9	508	25	5,2	118,3	64
0,4	11	59	48	7,9	228,6	9,3	8,7	5	6,1	4,6	317,5	47	317,5	17	20	356,4	8,6
0,4	5	81	12	4,6	149,2	7,6	7,6	3,4	3	3	46,3	3	277,6	25	22,4	374	15,2
0,4	1	13	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	1360,8	34	14,9	550,9	12,3
0,4	7	79	1	2,7	158,8	17,1	16,5	1,2	3	0	212,3	0	212,3	0	12,1	176,1	9,8
0,4	12	140	19	0	165,1	16,2	14,3	5,3	5,2	5	163,3	18	181,4	21	15,7	212,1	32,3
0,4	9	77	1	8,4	120,7	5,5	5,2	2	3,4	0	36,3	0	36,3	0	54,3	327,1	3,9
0,4	18	132	58	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8	323	25	52,5	943,4	3,1
0,4	16	106	61	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1	626	9	14,6	365,7	9,2
0,4	9	77	1	8,4	120,7	5,5	5,2	2	3,4	0	36,3	0	36,3	0	16,6	100,1	18,7
0,4	7	78	36	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12	2095,6	9	5,2	238,3	43,7
0,4	9	80	69	8,4	120,7	5,5	5,5	2,4	3	3,4	36,2	3	1231	25	4,2	146,9	51,1
0,4	12	141	31	0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30	137,4	21	14,4	169,2	35,1
0,4	12	144	22	0	165,1	14	12,2	5,3	5,3	4,6	157,9	21	178,3	25	12,4	165	56,1
0,4	15	93	35	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5	217,7	25	6,5	95,5	40,1
0,4	12	143	23	0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22	139,7	25	8,5	100	113,5
0,4	1	20	7	1,8	152,4	11	9,1	4,9	3	4,6	90,7	6	90,7	9	9,8	93,1	18
0,4	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	17,8	295,6	15,5
0,4	5	83	1	4,6	149,2	9,4	9,1	3,4	3	0	59,9	0	59,9	0	16,6	128,2	6,8
0,4	17	116	87	1,2	88,9	13,9	13,3	2,1	2,4	4	68,5	5	1025,1	25	7,4	236,2	21,9
0,4	16	107	42	1,8	88,9	4	4	0,6	2,4	1,5	13,6	0	567	0	14,3	341,6	13,9
0,4	15	125	16	1,8	63,5	14	13,7	0,9	0	0,6	4,3	0	68	0	17,1	141,1	15,3

0,4	16	107	42	1,8	88,9	4	4	0,6	2,4	1,5	13,6	0	567	0	15,6	371,8	8,7
0,5	22	157	34	9,1	88,9	9,1	10,1	3	2,1	2,1	38,6	6	231,3	17	13	198,2	6,3
0,5	1	5	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	17	6,9	65,5	66,8
0,5	1	3	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	2	90,7	17	24	228,5	5,9
0,5	12	139	23	0	165,1	14	11,9	5,2	5,3	4,6	152	22	152	21	8,2	101	41,7
0,5	9	77	1	8,4	120,7	5,5	5,2	2	3,4	0	36,3	0	36,3	0	13	78,2	18,6
0,5	9	76	31	8,4	120,7	5,5	5,2	2	3	3,4	36,8	2	552,5	25	8,7	205,3	23,4
0,5	16	107	42	1,8	88,9	4	4	0,6	2,4	1,5	13,6	0	567	0	17,4	414,9	9,3
0,5	16	109	51	1,8	88,9	6,1	4	4,9	1,5	2,1	15	1	392,4	5	17,2	341,5	7,3
0,5	10	48	9	8,4	66,7	6,1	0	0	0	0,8	3,6	0	32,7	25	41,9	239,2	2,3
0,5	1	19	3	1,8	152,4	11	9,1	4,9	3	4,6	90,7	2	90,7	9	15,3	145,3	18,5
0,5	10	47	9	8,4	66,7	6,1	0	0	0	0,8	3,5	0	31,8	25	25,4	143,1	2
0,5	19	154	14	1,1	152,4	16,5	15,5	4,4	4	4,9	255,8	5	833,2	25	17,2	495,1	9
0,5	12	142	16	0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15	147,4	21	10,8	130,8	40,9
0,5	1	13	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	1360,8	34	12,7	467,4	16,8
0,5	7	78	36	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12	2095,6	9	7,9	362,6	27,7
0,5	19	154	14	1,1	152,4	16,5	15,5	4,4	4	4,9	255,8	5	833,2	25	2,7	77,7	57,7
0,5	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	40,2	617,9	0,9
0,5	9	80	69	8,4	120,7	5,5	5,5	2,4	3	3,4	36,2	3	1231	25	14,8	517,7	5,9
0,5	7	78	36	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12	2095,6	9	3,6	164,9	55,6
0,5	19	154	14	1,1	152,4	16,5	15,5	4,4	4	4,9	255,8	5	833,2	25	5,4	155,5	24,7
0,5	5	83	1	4,6	149,2	9,4	9,1	3,4	3	0	59,9	0	59,9	0	21,5	166	6,5
0,5	15	123	20	1,8	88,9	13,4	13,7	3,7	3	4,3	99,8	7	499	25	4,5	101,1	66,8
0,5	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	3	82,3	61,5
0,5	1	10	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	14,6	138,8	9,8
0,5	22	157	34	9,1	88,9	9,1	10,1	3	2,1	2,1	38,6	6	231,3	17	9,3	141,8	15,2

0,5	5	30	11	4,6	152,4	7,9	7,6	3,4	3	3,7	50,8	4	203,2	25	5,2	74,8	22,7
0,5	5	82	13	4,6	149,2	9,1	9,1	3,7	3	3	59,9	3	299,4	25	9	155	17,4
0,5	1	32	21	1,8	152,4	11	9,1	4,9	3	4,3	92,1	3	552,5	17	9,9	233	26,4
0,5	18	133	70	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10	311,2	25	2,5	44,2	76,2
0,5	5	82	13	4,6	149,2	9,1	9,1	3,7	3	3	59,9	3	299,4	25	4	68,9	35,8
0,5	21	167	128	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7	1417	25	1,9	73,1	90,9
0,5	9	76	31	8,4	120,7	5,5	5,2	2	3	3,4	36,8	2	552,5	25	6,9	162,8	32,8
0,5	12	145	8	0	165,1	15,5	13,7	5,8	5	4,9	148,8	7	160,1	25	15,9	201,6	38,6
0,5	1	18	1	1,8	152,4	11	9,1	4,9	3	0	90,7	0	90,7	0	7,1	67,2	42,2
0,5	1	19	3	1,8	152,4	11	9,1	4,9	3	4,6	90,7	2	90,7	9	27,3	259,9	4,3
0,5	7	75	36	2,7	158,8	7,3	7	1,8	3,7	3	82,6	9	486,3	9	3,2	70,8	55,6
0,5	11	56	13	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12	690,4	26	36,8	966,7	2,3
0,5	12	144	22	0	165,1	14	12,2	5,3	5,3	4,6	157,9	21	178,3	25	26,8	358,3	27,2
0,5	18	138	59	7,6	69,9	13,7	14	0,9	1,8	2,7	42,5	6	425	8	14,5	298,6	14,4
0,5	15	122	12	1,8	63,5	4,9	0	2,4	1,1	1,2	7,6	4	30,3	800	94,1	518,2	0,2
0,5	14	87	45	3	88,9	11	9,1	3,7	2,4	3	45,6	10	319,1	25	8,1	144,7	13,2
0,5	16	97	63	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2	287,1	5	3,4	57,9	51,8
0,5	15	120	46	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8	544,3	25	6,1	142,5	39,1
0,5	21	167	128	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7	1417	25	15,1	569	8,3
0,5	7	42	37	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7	1244,7	17	14,6	515,7	18
0,5	21	166	152	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7	1163,5	25	2,6	87,2	70,4
0,5	9	76	31	8,4	120,7	5,5	5,2	2	3	3,4	36,8	2	552,5	25	11	259,6	23,5
0,5	1	20	7	1,8	152,4	11	9,1	4,9	3	4,6	90,7	6	90,7	9	11,9	113,8	13,4
0,5	7	42	37	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7	1244,7	17	8,5	300,2	42,7
0,5	15	95	48	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7	314,3	25	8,4	149,2	27,4
0,5	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	39	624,5	1,5

0,5	10	50	9	8,4	66,7	6,1	0	0	0	0,8	3,5	0	31,8	0	15,5	87,2	11,8
0,5	16	98	31	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1	292,6	5	21,7	371,6	23,6
0,5	16	111	48	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4	166,5	5	11,4	146,6	22,1
0,5	16	108	60	1,8	88,9	6,1	5,5	4,3	3	1,8	15	1	725,7	5	10	270,7	9,8
0,5	16	98	31	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1	292,6	5	10,8	184,2	32,5
0,5	1	21	15	1,8	152,4	11	9,1	4,9	3	4,6	90,7	14	90,7	9	11,4	108,6	19,9
0,5	1	10	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	20,6	196,1	5
0,5	1	18	1	1,8	152,4	11	9,1	4,9	3	0	90,7	0	90,7	0	27,3	259,9	3,7
0,5	16	109	51	1,8	88,9	6,1	4	4,9	1,5	2,1	15	1	392,4	5	9,9	196,3	16
0,5	16	107	42	1,8	88,9	4	4	0,6	2,4	1,5	13,6	0	567	0	16,4	390,1	11
0,5	22	159	54	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7	298,5	17	14,8	256,4	3,7
0,5	1	6	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	2	90,7	34	5,7	53,9	70,1
0,5	12	145	8	0	165,1	15,5	13,7	5,8	5	4,9	148,8	7	160,1	25	13,9	176,4	14,1
0,5	12	142	16	0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15	147,4	21	6,3	76,4	68,8
0,5	14	89	45	3	88,9	16,2	14,9	3,7	2,4	3	78,2	10	553,4	25	5,6	130,9	31,5
0,5	12	144	22	0	165,1	14	12,2	5,3	5,3	4,6	157,9	21	178,3	25	14,1	188,5	16,5
0,5	16	111	48	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4	166,5	5	8,3	106,9	15,9
0,6	10	48	9	8,4	66,7	6,1	0	0	0	0,8	3,6	0	32,7	25	32,5	185,7	3,9
0,6	7	78	36	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12	2095,6	9	6,4	294,2	37,3
0,6	16	106	61	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1	626	9	6,9	172,1	66
0,6	11	62	20	7,9	228,6	22,9	22,9	5,3	7	7,6	734,8	19	734,8	26	33,2	899,2	4,5
0,6	15	93	35	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5	217,7	25	16,7	247,1	24,6
0,6	11	56	13	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12	690,4	26	26,3	692,1	2,3
0,6	1	20	7	1,8	152,4	11	9,1	4,9	3	4,6	90,7	6	90,7	9	21,8	207,8	7,5
0,6	21	164	26	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9	1344,9	25	3,9	142,4	35,6
0,6	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	22,5	372,6	3,9

0,6	17	115	42	1,2	88,9	14,6	14	1,8	2,4	4	71,2	8	712,1	25	10,5	281,4	9,2
0,6	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	10,5	284,3	14,9
0,6	9	36	12	5,2	152,4	9,8	9,8	5,5	2,7	4,3	63,5	2	381	25	5,9	115,7	54,6
0,6	15	126	26	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7	423,2	25	18,5	380,8	8,8
0,6	10	48	9	8,4	66,7	6,1	0	0	0	0,8	3,6	0	32,7	25	10,4	59,5	31,8
0,6	1	12	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	1360,8	0	2,5	93,3	129,5
0,6	12	143	23	0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22	139,7	25	31,3	369,6	26,9
0,6	10	50	9	8,4	66,7	6,1	0	0	0	0,8	3,5	0	31,8	0	9,5	53,6	32,3
0,6	18	132	58	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8	323	25	3,1	54,9	68,8
0,6	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	17,9	158,4	4,4
0,6	11	57	28	7,9	228,6	25,9	25,1	6,1	5,2	7	712,1	27	712,1	21,5	23,3	622	10,4
0,6	11	56	13	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12	690,4	26	24,7	649,3	2,6
0,6	7	78	36	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12	2095,6	9	10	457,9	23,8
0,6	15	120	46	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8	544,3	25	14	326,3	18,1
0,6	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	19,4	321,6	8,8
0,6	14	90	30	3	88,9	14,6	13,4	3	2,4	3	70,3	10	281,2	25	6,7	113,1	41,4
0,6	22	157	34	9,1	88,9	9,1	10,1	3	2,1	2,1	38,6	6	231,3	17	10,8	163,8	12,4
0,6	15	117	24	1,8	114,3	12,2	6,7	2,6	3	3,7	83,9	5	503,5	25	9,9	222,4	39,1
0,6	14	86	50	3	88,9	17,1	15,2	4,9	2,4	3,4	78,5	10	627,8	25	17	426,4	5,2
0,6	12	143	23	0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22	139,7	25	5,9	70,1	70,9
0,6	16	109	51	1,8	88,9	6,1	4	4,9	1,5	2,1	15	1	392,4	5	13	257,3	6,7
0,6	16	111	48	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4	166,5	5	26,2	338,1	7,1
0,6	19	154	14	1,1	152,4	16,5	15,5	4,4	4	4,9	255,8	5	833,2	25	1,8	51,9	156
0,6	1	9	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	14,6	138,8	8,6
0,6	22	159	54	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7	298,5	17	31	534,8	1,9
0,6	16	104	60	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1	603,3	9	5,7	141,2	35,1

0,6	6	33	126	3	63,5	6,1	6,1	1,7	1,5	2,1	15,9	7	412,8	25	11,7	238,1	6,5
0,6	16	97	63	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2	287,1	5	10,2	172,5	16,1
0,6	1	3	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	2	90,7	17	12,8	122	9,2
0,6	11	56	13	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12	690,4	26	30,5	800,3	2,4
0,6	16	98	31	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1	292,6	5	15,2	259,3	15
0,6	1	27	13	1,8	152,4	11	9,1	4,9	3	4,6	90,7	3	362,9	17	7,6	144,8	38,6
0,6	15	117	24	1,8	114,3	12,2	6,7	2,6	3	3,7	83,9	5	503,5	25	13,3	298,6	14,3
0,6	1	9	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	20,6	196,1	4,3
0,6	14	90	30	3	88,9	14,6	13,4	3	2,4	3	70,3	10	281,2	25	4,1	68,6	48
0,6	19	152	18	1,1	152,4	16,2	15,2	3	4	4,9	222,3	6	948,5	25	18,7	577	3,2
0,6	1	2	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	272,2	0	9,5	156	17,3
0,6	21	166	152	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7	1163,5	25	5,9	200,7	17,1
0,6	1	11	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	90,7	17	16,9	160,8	11,4
0,6	22	157	34	9,1	88,9	9,1	10,1	3	2,1	2,1	38,6	6	231,3	17	35,7	542,4	2,4
0,6	18	124	61	7,6	69,9	13,7	13,7	1,5	2,1	1,5	38,5	7	410,5	8	40,4	818,8	2,7
0,6	18	133	70	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10	311,2	25	3,1	54	84,6
0,6	21	164	26	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9	1344,9	25	2,9	106,4	41,7
0,6	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	12,4	204,8	23,8
0,6	12	141	31	0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30	137,4	21	7,1	82,8	54,4
0,6	10	50	9	8,4	66,7	6,1	0	0	0	0,8	3,5	0	31,8	0	23,3	131,1	6,7
0,6	11	62	20	7,9	228,6	22,9	22,9	5,3	7	7,6	734,8	19	734,8	26	25,1	680,9	2,9
0,6	16	98	31	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1	292,6	5	9,1	156,4	20,2
0,6	16	97	63	1,8	88,9	6,1	5,5	2,7	2,4	1,5	13,7	2	287,1	5	4,2	70,4	52,6
0,6	16	108	60	1,8	88,9	6,1	5,5	4,3	3	1,8	15	1	725,7	5	13,1	353,6	10
0,6	12	146	15	0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14	158,8	25	37,5	472,1	2,2
0,6	19	154	14	1,1	152,4	16,5	15,5	4,4	4	4,9	255,8	5	833,2	25	6,9	199,9	13,5

0,6	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	10,3	164,5	23,7
0,6	1	13	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	1360,8	34	10,8	397,3	24,5
0,6	18	138	59	7,6	69,9	13,7	14	0,9	1,8	2,7	42,5	6	425	8	24,6	507,6	6
0,6	21	168	1	9,1	88,9	13,7	15,2	1,8	3	0	68	0	68	0	15,9	131	8,1
0,6	15	126	26	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7	423,2	25	3	62,5	68,8
0,6	22	157	34	9,1	88,9	9,1	10,1	3	2,1	2,1	38,6	6	231,3	17	29,1	442,6	2,5
0,6	7	79	1	2,7	158,8	17,1	16,5	1,2	3	0	212,3	0	212,3	0	32,1	468,2	4
0,6	16	104	60	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1	603,3	9	9,3	229	21,8
0,6	19	152	18	1,1	152,4	16,2	15,2	3	4	4,9	222,3	6	948,5	25	26,7	822,3	4,6
0,6	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	39,3	348,4	1,6
0,6	12	144	22	0	165,1	14	12,2	5,3	5,3	4,6	157,9	21	178,3	25	11,4	152,9	55,1
0,6	12	146	15	0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14	158,8	25	10,7	134,6	50,8
0,6	15	120	46	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8	544,3	25	4,5	104,2	74,2
0,6	14	86	50	3	88,9	17,1	15,2	4,9	2,4	3,4	78,5	10	627,8	25	13,1	328,8	6,9
0,6	14	91	42	3	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9	394,2	25	24,9	494,2	3,8
0,6	10	47	9	8,4	66,7	6,1	0	0	0	0,8	3,5	0	31,8	25	43,5	245,1	4,6
0,6	21	167	128	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7	1417	25	5,4	202,7	27,2
0,6	18	132	58	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8	323	25	14,1	252,9	11,7
0,6	14	89	45	3	88,9	16,2	14,9	3,7	2,4	3	78,2	10	553,4	25	14,7	344,9	14,2
0,6	5	81	12	4,6	149,2	7,6	7,6	3,4	3	3	46,3	3	277,6	25	5	83,7	27,7
0,6	12	144	22	0	165,1	14	12,2	5,3	5,3	4,6	157,9	21	178,3	25	32,6	435,1	23
0,6	12	146	15	0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14	158,8	25	15,3	192,2	32,8
0,6	14	90	30	3	88,9	14,6	13,4	3	2,4	3	70,3	10	281,2	25	28	469	2,8
0,6	1	4	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	7,1	67,2	36,8
0,6	20	137	88	0	88,9	5,5	0	2,4	2,7	2,7	11,6	4	302,1	25	8,8	153,4	87,9
0,6	16	101	78	1,8	88,9	6,1	5,5	3	2,4	1,5	18,6	1	725,7	5	9,4	252,4	24

0,6	12	60	10	0	165,1	20	21,8	7,8	6,1	4,6	253,1	9	253,1	26	6	95,8	123,7
0,7	14	90	30	3	88,9	14,6	13,4	3	2,4	3	70,3	10	281,2	25	5,3	88,8	53,6
0,7	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	11,6	185,5	5,2
0,7	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	3,7	61	49,3
0,7	1	12	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	1360,8	0	4,3	157,9	92,5
0,7	21	165	122	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7	1362,1	25	2,3	84,2	68,3
0,7	12	139	23	0	165,1	14	11,9	5,2	5,3	4,6	152	22	152	21	11,9	147,3	41,7
0,7	15	93	35	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5	217,7	25	15	221	10,9
0,7	1	9	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	28,9	275,4	2,1
0,7	16	111	48	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4	166,5	5	4,7	60,7	36,8
0,7	14	87	45	3	88,9	11	9,1	3,7	2,4	3	45,6	10	319,1	25	6,7	118,8	16,1
0,7	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	22,3	369,2	15,4
0,7	19	152	18	1,1	152,4	16,2	15,2	3	4	4,9	222,3	6	948,5	25	6	185,4	20,5
0,7	14	91	42	3	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9	394,2	25	20,3	402,5	3,9
0,7	9	76	31	8,4	120,7	5,5	5,2	2	3	3,4	36,8	2	552,5	25	3,5	81,4	50,3
0,7	16	99	49	1,8	88,9	6,1	5,5	3	2,4	1,5	18,8	1	445,4	5	6,6	139,5	36,1
0,7	1	3	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	2	90,7	17	7,4	70,3	38,4
0,7	12	140	19	0	165,1	16,2	14,3	5,3	5,2	5	163,3	18	181,4	21	10	134,1	38,6
0,7	16	98	31	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1	292,6	5	12,7	216,7	17,6
0,7	19	154	14	1,1	152,4	16,5	15,5	4,4	4	4,9	255,8	5	833,2	25	20	576,1	10,7
0,7	22	159	54	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7	298,5	17	7,7	132,9	18,1
0,7	5	82	13	4,6	149,2	9,1	9,1	3,7	3	3	59,9	3	299,4	25	5,2	89,3	24,2
0,7	14	87	45	3	88,9	11	9,1	3,7	2,4	3	45,6	10	319,1	25	3,4	61	64,3
0,7	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	8,1	135,1	35,8
0,7	19	154	14	1,1	152,4	16,5	15,5	4,4	4	4,9	255,8	5	833,2	25	8,6	249,5	11,7
0,7	15	126	26	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7	423,2	25	7	143,4	32

0,7	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	20,3	179,6	10,3
0,7	15	125	16	1,8	63,5	14	13,7	0,9	0	0,6	4,3	0	68	0	7,3	60,1	40,1
0,7	12	139	23	0	165,1	14	11,9	5,2	5,3	4,6	152	22	152	21	18,3	225,9	16
0,7	1	18	1	1,8	152,4	11	9,1	4,9	3	0	90,7	0	90,7	0	15,3	145,3	16
0,7	7	79	1	2,7	158,8	17,1	16,5	1,2	3	0	212,3	0	212,3	0	14,1	205,7	8,7
0,7	16	105	42	1,8	88,9	3,7	3,7	1,4	3	1,5	13,6	0	601	0	12,4	305,1	22,2
0,7	21	165	122	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7	1362,1	25	5,3	197,1	30,5
0,7	21	164	26	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9	1344,9	25	7	255,6	18,1
0,7	9	80	69	8,4	120,7	5,5	5,5	2,4	3	3,4	36,2	3	1231	25	4,8	168,3	34
0,7	14	90	30	3	88,9	14,6	13,4	3	2,4	3	70,3	10	281,2	25	22,2	371,9	4,7
0,7	15	123	20	1,8	88,9	13,4	13,7	3,7	3	4,3	99,8	7	499	25	25,9	578,2	5,4
0,7	5	82	13	4,6	149,2	9,1	9,1	3,7	3	3	59,9	3	299,4	25	11,9	205,2	6,7
0,7	18	132	58	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8	323	25	42,1	757,2	2,1
0,7	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	4,9	132,3	26,9
0,7	15	117	24	1,8	114,3	12,2	6,7	2,6	3	3,7	83,9	5	503,5	25	6	135,1	43,2
0,7	18	138	59	7,6	69,9	13,7	14	0,9	1,8	2,7	42,5	6	425	8	7,2	149,3	24,4
0,7	18	129	77	7,6	69,9	9,4	9,4	1,5	1,5	2,4	34,2	5	547	8	17,9	418,1	5
0,7	16	103	59	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3	267,2	5	5	82,1	66,3
0,7	16	104	60	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1	603,3	9	15,3	374,6	13,6
0,7	15	95	48	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7	314,3	25	4,7	83,4	42,9
0,7	21	167	128	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7	1417	25	6,5	243,6	37,3
0,7	1	19	3	1,8	152,4	11	9,1	4,9	3	4,6	90,7	2	90,7	9	8,6	81,5	33
0,7	1	20	7	1,8	152,4	11	9,1	4,9	3	4,6	90,7	6	90,7	9	17,8	169,4	5,5
0,7	16	104	60	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1	603,3	9	4,7	114,5	48
0,7	19	153	20	1,1	152,4	13,7	12,8	3,4	4	4,9	195,5	6	733	25	22,5	610,2	8,6
0,7	12	143	23	0	165,1	13,7	11,6	5,2	4,6	5,2	139,7	22	139,7	25	20,8	246,1	32,5

0,7	14	94	24	3	114,3	17,1	15,2	3,7	3	3,4	127	9	508	25	14,7	331,5	9,8
0,7	16	109	51	1,8	88,9	6,1	4	4,9	1,5	2,1	15	1	392,4	5	3,3	65,3	55,6
0,7	1	9	1	1,8	152,4	11	9,1	4,6	3	0	90,7	0	90,7	0	10,3	98,3	12,1
0,7	5	81	12	4,6	149,2	7,6	7,6	3,4	3	3	46,3	3	277,6	25	4,3	71,3	32,8
0,7	18	129	77	7,6	69,9	9,4	9,4	1,5	1,5	2,4	34,2	5	547	8	13,4	312,3	7,7
0,7	20	137	88	0	88,9	5,5	0	2,4	2,7	2,7	11,6	4	302,1	25	6,2	107,8	64
0,7	14	86	50	3	88,9	17,1	15,2	4,9	2,4	3,4	78,5	10	627,8	25	9,7	243,8	13,4
0,7	12	139	23	0	165,1	14	11,9	5,2	5,3	4,6	152	22	152	21	14,4	178	24,7
0,7	5	81	12	4,6	149,2	7,6	7,6	3,4	3	3	46,3	3	277,6	25	17,1	285	5,4
0,7	5	30	11	4,6	152,4	7,9	7,6	3,4	3	3,7	50,8	4	203,2	25	8,9	126,4	13,9
0,7	19	152	18	1,1	152,4	16,2	15,2	3	4	4,9	222,3	6	948,5	25	14,5	447,4	6,2
0,7	1	11	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	90,7	17	23,3	222	4,5
0,7	1	32	21	1,8	152,4	11	9,1	4,9	3	4,3	92,1	3	552,5	17	3,3	77,8	109,7
0,7	16	107	42	1,8	88,9	4	4	0,6	2,4	1,5	13,6	0	567	0	13,2	313,6	7,1
0,7	1	27	13	1,8	152,4	11	9,1	4,9	3	4,6	90,7	3	362,9	17	5,1	97,4	45,7
0,7	16	102	16	1,8	88,9	4,6	4	2,7	2,4	1,5	12,7	1	155,6	5	25,7	320,1	12,3
0,7	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	21	335,4	3,5
0,7	5	81	12	4,6	149,2	7,6	7,6	3,4	3	3	46,3	3	277,6	25	7,9	131,2	8,2
0,7	18	127	67	7,6	69,9	9,4	9,4	1,5	1,5	2,7	33,6	6	435,9	8	7	145,5	24,7
0,7	15	93	35	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5	217,7	25	22,9	338,6	3,8
0,7	7	79	1	2,7	158,8	17,1	16,5	1,2	3	0	212,3	0	212,3	0	17,2	249,9	7,3
0,7	10	48	9	8,4	66,7	6,1	0	0	0	0,8	3,6	0	32,7	25	16,2	92,6	15,1
0,7	12	144	22	0	165,1	14	12,2	5,3	5,3	4,6	157,9	21	178,3	25	19,9	265,9	15,1
0,8	5	31	11	4,6	152,4	7,9	7,6	3,4	3	3,7	56,7	3	226,8	25	15,4	231,7	4,4
0,8	19	154	14	1,1	152,4	16,5	15,5	4,4	4	4,9	255,8	5	833,2	25	4,3	124,6	35,1
0,8	12	141	31	0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30	137,4	21	27	316,2	8,6

0,8	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	7,6	121,7	23,1
0,8	21	164	26	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9	1344,9	25	8,1	295,4	14,4
0,8	1	7	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	34	29,6	282,3	2,3
0,8	21	168	1	9,1	88,9	13,7	15,2	1,8	3	0	68	0	68	0	26,2	216,5	7,9
0,8	1	27	13	1,8	152,4	11	9,1	4,9	3	4,6	90,7	3	362,9	17	11,1	212,1	18,5
0,8	10	47	9	8,4	66,7	6,1	0	0	0	0,8	3,5	0	31,8	25	17,6	98,9	3,5
0,8	1	11	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	90,7	17	9,5	91	21,2
0,8	15	120	46	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8	544,3	25	49,3	1150,9	45,2
0,8	16	103	59	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3	267,2	5	11,7	191,6	19,4
0,8	21	164	26	9,1	152,4	24,4	24,4	3,7	4,3	4,9	317,5	9	1344,9	25	15,4	566	7,3
0,8	1	32	21	1,8	152,4	11	9,1	4,9	3	4,3	92,1	3	552,5	17	6,9	161,7	32,5
0,8	18	124	61	7,6	69,9	13,7	13,7	1,5	2,1	1,5	38,5	7	410,5	8	48,4	981,1	2
0,8	15	126	26	1,8	101,6	13,4	11,3	2,7	2,6	3,2	84,6	7	423,2	25	5,3	108,9	25,3
0,8	7	75	36	2,7	158,8	7,3	7	1,8	3,7	3	82,6	9	486,3	9	8,7	191,6	22,8
0,8	14	89	45	3	88,9	16,2	14,9	3,7	2,4	3	78,2	10	553,4	25	10,6	250,2	24,9
0,8	1	20	7	1,8	152,4	11	9,1	4,9	3	4,6	90,7	6	90,7	9	14,6	138,8	10,4
0,8	12	142	16	0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15	147,4	21	17,1	207,2	36,3
0,8	3	24	78	2,1	76,2	6,1	5,5	1,2	2,4	2,7	11,3	2	283,5	50	13,9	234,7	7,6
0,8	14	94	24	3	114,3	17,1	15,2	3,7	3	3,4	127	9	508	25	8	179,5	27,9
0,8	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	14,2	234,7	7,4
0,8	16	109	51	1,8	88,9	6,1	4	4,9	1,5	2,1	15	1	392,4	5	5,6	110,3	32,8
0,8	19	152	18	1,1	152,4	16,2	15,2	3	4	4,9	222,3	6	948,5	25	16,2	497,6	2,7
0,8	14	88	28	3	88,9	14,6	13,4	3,7	2,4	3	61,2	10	274,4	25	7,2	118,5	29
0,8	16	100	16	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0	215,5	0	13,2	194	9,7
0,8	12	142	16	0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15	147,4	21	12,4	150,6	55,6
0,8	1	11	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	90,7	17	29,7	282,8	2,4

0,8	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	24,5	217,3	2,6
0,8	12	139	23	0	165,1	14	11,9	5,2	5,3	4,6	152	22	152	21	6	73,6	87,6
0,8	1	13	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	1360,8	34	9,1	337,2	34,3
0,8	12	146	15	0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14	158,8	25	26,2	330,2	22,1
0,8	15	117	24	1,8	114,3	12,2	6,7	2,6	3	3,7	83,9	5	503,5	25	22,9	513,8	14,7
0,8	12	142	16	0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15	147,4	21	24,3	295,6	13,2
0,8	12	148	27	0	165,1	15,8	13,7	5,5	4,6	4,9	149,7	25	274,9	16	65,6	1088	20,5
0,8	19	152	18	1,1	152,4	16,2	15,2	3	4	4,9	222,3	6	948,5	25	11,3	347	5,9
0,8	9	77	1	8,4	120,7	5,5	5,2	2	3,4	0	36,3	0	36,3	0	75,1	452,6	2,2
0,8	14	91	42	3	88,9	17,1	15,2	3,7	2,4	2,4	78,7	9	394,2	25	30,3	602	1,8
0,8	9	36	12	5,2	152,4	9,8	9,8	5,5	2,7	4,3	63,5	2	381	25	8,7	170,5	40,4
0,8	1	13	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	1360,8	34	20,7	764,6	8
0,8	16	99	49	1,8	88,9	6,1	5,5	3	2,4	1,5	18,8	1	445,4	5	11,9	251,2	17,6
0,8	12	145	8	0	165,1	15,5	13,7	5,8	5	4,9	148,8	7	160,1	25	25,2	319	10,2
0,8	16	101	78	1,8	88,9	6,1	5,5	3	2,4	1,5	18,6	1	725,7	5	11,7	314,6	23,8
0,8	9	76	31	8,4	120,7	5,5	5,2	2	3	3,4	36,8	2	552,5	25	5,5	129,8	43,9
0,8	19	152	18	1,1	152,4	16,2	15,2	3	4	4,9	222,3	6	948,5	25	12,1	372,1	7,9
0,8	11	56	13	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12	690,4	26	22,3	586,2	4,4
0,8	7	42	37	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7	1244,7	17	3,8	132,5	141,7
0,8	12	142	16	0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15	147,4	21	8,6	104,4	39,1
0,8	12	139	23	0	165,1	14	11,9	5,2	5,3	4,6	152	22	152	21	35,1	432,4	14
0,8	15	120	46	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8	544,3	25	7,1	165,8	37,8
0,8	15	95	48	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7	314,3	25	12,6	223,1	29,5
0,8	7	79	1	2,7	158,8	17,1	16,5	1,2	3	0	212,3	0	212,3	0	20,9	304	6,6
0,8	9	36	12	5,2	152,4	9,8	9,8	5,5	2,7	4,3	63,5	2	381	25	12,8	250	20,9
0,8	7	79	1	2,7	158,8	17,1	16,5	1,2	3	0	212,3	0	212,3	0	10,4	151	15,5

0,8	16	102	16	1,8	88,9	4,6	4	2,7	2,4	1,5	12,7	1	155,6	5	13,7	171	6,2
0,8	7	75	36	2,7	158,8	7,3	7	1,8	3,7	3	82,6	9	486,3	9	4,1	89,3	59,4
0,8	12	141	31	0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30	137,4	21	21,2	248,3	11,9
0,8	16	106	61	1,8	88,9	6,1	5,5	0,6	2,4	1,5	18,1	1	626	9	4,3	106,7	50,8
0,8	14	94	24	3	114,3	17,1	15,2	3,7	3	3,4	127	9	508	25	12,2	275,4	23,2
0,8	1	8	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	635	0	2,4	61	175,8
0,8	10	49	9	8,4	66,7	6,1	0	0	0	0,8	3,6	0	32,7	25	32	182,9	1,4
0,8	10	47	9	8,4	66,7	6,1	0	0	0	0,8	3,5	0	31,8	25	11,6	65,5	9,5
0,8	1	2	3	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	272,2	0	11,3	186,7	17,6
0,8	12	146	15	0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14	158,8	25	12,5	157,4	33,8
0,8	1	19	3	1,8	152,4	11	9,1	4,9	3	4,6	90,7	2	90,7	9	7,1	67,2	30,5
0,8	15	118	38	1,8	101,6	13,7	13,1	1,8	2,9	3,5	68	6	680,4	25	14,8	386	13,8
0,8	22	156	44	9,1	88,9	9,1	8,2	2,4	2,1	2,1	36,3	9	256,3	17	9	144,2	11,5
0,8	18	124	61	7,6	69,9	13,7	13,7	1,5	2,1	1,5	38,5	7	410,5	8	54,8	1109,5	2
0,8	1	27	13	1,8	152,4	11	9,1	4,9	3	4,6	90,7	3	362,9	17	4,2	80,2	78,2
0,9	1	8	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	635	0	11	276	17,6
0,9	16	101	78	1,8	88,9	6,1	5,5	3	2,4	1,5	18,6	1	725,7	5	14,7	396,2	9,1
0,9	1	32	21	1,8	152,4	11	9,1	4,9	3	4,3	92,1	3	552,5	17	4,8	111,7	40,1
0,9	18	133	70	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10	311,2	25	24,8	438,3	3,9
0,9	12	140	19	0	165,1	16,2	14,3	5,3	5,2	5	163,3	18	181,4	21	27,3	367,6	8,9
0,9	9	80	69	8,4	120,7	5,5	5,5	2,4	3	3,4	36,2	3	1231	25	5,4	190,5	31,2
0,9	16	105	42	1,8	88,9	3,7	3,7	1,4	3	1,5	13,6	0	601	0	15,4	378,3	15,2
0,9	15	120	46	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8	544,3	25	20,9	487,8	9,8
0,9	5	31	11	4,6	152,4	7,9	7,6	3,4	3	3,7	56,7	3	226,8	25	9,5	142,4	7,2
0,9	21	167	128	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7	1417	25	2,8	106,6	59,9
0,9	21	168	1	9,1	88,9	13,7	15,2	1,8	3	0	68	0	68	0	5,6	46,3	23,5

0,9	1	20	7	1,8	152,4	11	9,1	4,9	3	4,6	90,7	6	90,7	9	8	76,3	18,9
0,9	12	140	19	0	165,1	16,2	14,3	5,3	5,2	5	163,3	18	181,4	21	11,5	154,8	44,7
0,9	1	12	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	0	1360,8	0	3	111	105,4
0,9	9	77	1	8,4	120,7	5,5	5,2	2	3,4	0	36,3	0	36,3	0	33,6	202,3	5,7
0,9	15	122	12	1,8	63,5	4,9	0	2,4	1,1	1,2	7,6	4	30,3	800	64,7	356,2	0,4
0,9	16	100	16	1,8	88,9	5,2	4,6	2,4	2,4	1,5	13,6	0	215,5	0	20,2	296,3	8,5
0,9	16	98	31	1,8	88,9	6,1	5,5	2,6	2,4	1,5	18,3	1	292,6	5	18	307,3	9,7
0,9	15	92	40	1,8	88,9	9,1	9,1	1,8	2,4	3	31,8	5	317,5	25	7,6	136,3	31
0,9	11	58	30	7,9	228,6	19,4	18,7	6,1	6,1	5,5	506,2	29	506,2	17	19,1	429,7	18,9
0,9	21	168	1	9,1	88,9	13,7	15,2	1,8	3	0	68	0	68	0	65,6	541,3	14,2
0,9	17	115	42	1,2	88,9	14,6	14	1,8	2,4	4	71,2	8	712,1	25	20,8	554,3	3,6
0,9	16	111	48	1,8	88,9	6,1	5,5	2,7	2,4	1,8	15,1	4	166,5	5	19,8	255,2	3,9
0,9	14	90	30	3	88,9	14,6	13,4	3	2,4	3	70,3	10	281,2	25	19,1	320,3	11,2
0,9	16	104	60	1,8	88,9	5,3	5,3	2,7	2,4	1,8	18,1	1	603,3	9	7,4	181,2	51,1
0,9	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	15,5	137,1	8,8
0,9	12	145	8	0	165,1	15,5	13,7	5,8	5	4,9	148,8	7	160,1	25	12,1	153,5	20,4
0,9	22	155	49	9,1	88,9	9,1	8,2	2,7	2,1	2,1	29	8	235,9	17	30,5	467,8	2,1
0,9	1	13	15	1,8	152,4	11	9,1	4,6	3	4,6	90,7	14	1360,8	34	17,6	649,4	12,1
0,9	18	129	77	7,6	69,9	9,4	9,4	1,5	1,5	2,4	34,2	5	547	8	2,6	60,3	89,2
0,9	5	81	12	4,6	149,2	7,6	7,6	3,4	3	3	46,3	3	277,6	25	13,2	219,4	7,2
0,9	1	7	7	1,8	152,4	11	9,1	4,6	3	4,6	90,7	6	90,7	34	15,3	146,1	8,1
0,9	1	19	3	1,8	152,4	11	9,1	4,9	3	4,6	90,7	2	90,7	9	13,1	125	22,4
0,9	14	87	45	3	88,9	11	9,1	3,7	2,4	3	45,6	10	319,1	25	5,3	94,6	75,9
0,9	19	152	18	1,1	152,4	16,2	15,2	3	4	4,9	222,3	6	948,5	25	24,1	742,9	5,3
0,9	16	108	60	1,8	88,9	6,1	5,5	4,3	3	1,8	15	1	725,7	5	4,5	121,9	35,8
0,9	18	133	70	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10	311,2	25	4	69,8	92,7

0,9	9	80	69	8,4	120,7	5,5	5,5	2,4	3	3,4	36,2	3	1231	25	9,7	339,8	9,7
0,9	22	158	11	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39	5	78,5	17	45,7	404,9	1,4
0,9	11	62	20	7,9	228,6	22,9	22,9	5,3	7	7,6	734,8	19	734,8	26	35,3	956,9	3,9
0,9	15	118	38	1,8	101,6	13,7	13,1	1,8	2,9	3,5	68	6	680,4	25	11,3	295,1	18,5
0,9	12	141	31	0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30	137,4	21	10,4	122	25
0,9	7	78	36	2,7	158,8	17,1	16,5	2,1	4,3	3,4	208,2	12	2095,6	9	12,6	578	7,8

Table D-2: Test 1 – Randomly Selected Data

Rando m	Sit e No.	Tes t	Total No. of Holes	Overburde n (m)	Hole Size (mm)	Hole Dept h (m)	Face Heigh t (m)	Stemmin g (m)	Burde n (m)	Spacin g (m)	Charg e per hole (kg)	No. of delay interval s	Max. Charg e per delay (kg)	Lengt h of Delay (msec)	Scaled Distance (m/kg^{1/2})	Distanc e (m)	PPV Peak (mm/sec)
0,90	1	21	15,00	1,8	152, 4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	19,6	186,6	21,1
0,91	1	27	13,00	1,8	152, 4	11,0	9,1	4,9	3,0	4,6	90,7	3,0	362,9	17,0	13,4	256,0	9,8
0,91	9	76	31,00	8,4	120, 7	5,5	5,2	2,0	3,0	3,4	36,8	2,0	552,5	25,0	14,1	330,8	16,7
0,91	10	49	9,00	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	9,9	56,4	13,2
0,91	1	11	15,00	1,8	152, 4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	90,7	17,0	6,7	63,4	47,2
0,91	18	132	58,00	7,6	69,9	9,4	9,4	0,8	1,8	2,4	32,3	8,0	323,0	25,0	3,9	69,8	78,5
0,91	16	101	78,00	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,6	1,0	725,7	5,0	5,1	137,8	39,9
0,92	14	86	50,00	3,0	88,9	17,1	15,2	4,9	2,4	3,4	78,5	10,0	627,8	25,0	14,3	359,5	6,1
0,92	7	78	36,00	2,7	158, 8	17,1	16,5	2,1	4,3	3,4	208,2	12,0	2095,6	9,0	4,3	195,2	51,1
0,92	18	133	70,00	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10,0	311,2	25,0	10,7	188,4	27,4
0,92	7	75	36,00	2,7	158, 8	7,3	7,0	1,8	3,7	3,0	82,6	9,0	486,3	9,0	5,2	113,8	55,6
0,92	9	80	69,00	8,4	120, 7	5,5	5,5	2,4	3,0	3,4	36,2	3,0	1231,0	25,0	2,5	88,1	91,7
0,92	16	105	42,00	1,8	88,9	3,7	3,7	1,4	3,0	1,5	13,6	0,0	601,0	0,0	10,3	251,9	29,2
0,92	15	120	46,00	1,8	101, 6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	15,6	364,3	14,3
0,92	5	31	11,00	4,6	152, 4	7,9	7,6	3,4	3,0	3,7	56,7	3,0	226,8	25,0	3,4	51,2	52,1
0,92	7	79	1,00	2,7	158, 8	17,1	16,5	1,2	3,0	0,0	212,3	0,0	212,3	0,0	25,7	373,9	4,6
0,92	16	103	59,00	1,8	88,9	6,1	5,5	2,4	2,4	1,5	16,3	3,0	267,2	5,0	14,6	238,9	12,5
0,92	15	117	24,00	1,8	114, 3	12,2	6,7	2,6	3,0	3,7	83,9	5,0	503,5	25,0	15,4	345,3	25,2

0,93	14	90	30,00	3,0	88,9	14,6	13,4	3,0	2,4	3,0	70,3	10,0	281,2	25,0	8,6	143,4	26,9
0,93	1	20	7,00	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	6,0	90,7	9,0	6,5	62,1	42,9
0,93	16	105	42,00	1,8	88,9	3,7	3,7	1,4	3,0	1,5	13,6	0,0	601,0	0,0	17,4	426,0	7,9
0,93	1	11	15,00	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	90,7	17,0	12,1	115,1	17,6
0,93	12	144	22,00	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	9,2	123,3	23,5
0,93	12	141	31,00	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	17,1	200,0	26,2
0,93	12	144	22,00	0,0	165,1	14,0	12,2	5,3	5,3	4,6	157,9	21,0	178,3	25,0	12,6	168,6	78,2
0,93	15	123	20,00	1,8	88,9	13,4	13,7	3,7	3,0	4,3	99,8	7,0	499,0	25,0	7,4	164,8	49,3
0,93	16	96	84,00	1,8	63,5	6,1	5,5	2,7	2,4	1,5	18,1	2,0	526,2	5,0	17,5	400,7	12,0
0,93	21	168	1,00	9,1	88,9	13,7	15,2	1,8	3,0	0,0	68,0	0,0	68,0	0,0	9,6	79,1	34,3
0,93	19	154	14,00	1,1	152,4	16,5	15,5	4,4	4,0	4,9	255,8	5,0	833,2	25,0	2,2	63,4	72,9
0,94	1	4	1,00	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	23,6	225,0	3,8
0,94	18	135	87,00	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9,0	285,8	8,0	7,2	121,6	27,2
0,94	1	21	15,00	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	16,4	156,0	16,5
0,94	21	167	128,00	9,1	88,9	13,7	12,8	2,1	2,4	2,4	64,4	7,0	1417,0	25,0	4,3	161,5	36,6
0,94	12	139	23,00	0,0	165,1	14,0	11,9	5,2	5,3	4,6	152,0	22,0	152,0	21,0	4,9	60,3	91,2
0,94	11	56	13,00	7,9	228,6	29,1	28,5	6,4	6,7	6,1	589,7	12,0	690,4	26,0	28,1	739,6	1,8
0,94	1	20	7,00	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	6,0	90,7	9,0	26,7	254,3	3,8
0,94	21	165	122,00	9,1	88,9	13,7	12,8	2,1	2,4	2,4	61,7	7,0	1362,1	25,0	6,4	237,2	25,0
0,94	16	110	51,00	1,8	88,9	6,1	5,5	2,7	2,4	1,8	14,7	4,0	163,3	5,0	13,5	172,9	12,3
0,95	18	135	87,00	7,6	76,2	6,4	9,4	1,4	2,1	2,7	18,1	9,0	285,8	8,0	10,2	172,9	19,6
0,95	14	89	45,00	3,0	88,9	16,2	14,9	3,7	2,4	3,0	78,2	10,0	553,4	25,0	3,7	86,9	62,5
0,95	1	4	1,00	1,8	152,4	11,0	9,1	4,6	3,0	0,0	90,7	0,0	90,7	0,0	9,9	94,4	15,2

0,95	16	99	49,00	1,8	88,9	6,1	5,5	3,0	2,4	1,5	18,8	1,0	445,4	5,0	18,6	393,5	8,5
0,95	15	122	12,00	1,8	63,5	4,9	0,0	2,4	1,1	1,2	7,6	4,0	30,3	800,0	30,9	170,1	1,6
0,95	1	6	3,00	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	34,0	7,3	69,8	26,2
0,95	21	166	152,00	9,1	88,9	13,4	12,2	2,1	2,4	2,4	50,6	7,0	1163,5	25,0	8,6	293,3	10,2
0,96	15	95	48,00	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	12,2	216,6	16,7
0,96	12	142	16,00	0,0	165,1	14,9	12,8	6,6	4,7	5,2	141,7	15,0	147,4	21,0	29,9	363,2	9,7
0,96	16	102	16,00	1,8	88,9	4,6	4,0	2,7	2,4	1,5	12,7	1,0	155,6	5,0	11,7	145,6	17,1
0,96	12	146	15,00	0,0	165,1	15,2	13,1	5,3	5,5	4,9	153,8	14,0	158,8	25,0	8,8	111,2	22,0
0,96	1	19	3,00	1,8	152,4	11,0	9,1	4,9	3,0	4,6	90,7	2,0	90,7	9,0	10,4	98,7	27,9
0,96	15	125	16,00	1,8	63,5	14,0	13,7	0,9	0,0	0,6	4,3	0,0	68,0	0,0	11,4	94,4	33,8
0,97	15	120	46,00	1,8	101,6	13,7	13,7	2,1	2,9	3,5	74,4	8,0	544,3	25,0	10,5	245,0	17,7
0,97	1	6	3,00	1,8	152,4	11,0	9,1	4,6	3,0	4,6	90,7	2,0	90,7	34,0	29,1	277,2	3,1
0,97	15	92	40,00	1,8	88,9	9,1	9,1	1,8	2,4	3,0	31,8	5,0	317,5	25,0	19,8	353,2	8,6
0,97	14	89	45,00	3,0	88,9	16,2	14,9	3,7	2,4	3,0	78,2	10,0	553,4	25,0	12,6	296,0	12,0
0,97	12	140	19,00	0,0	165,1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	37,5	505,4	14,1
0,97	10	49	9,00	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,6	0,0	32,7	25,0	23,5	134,2	2,6
0,97	1	32	21,00	1,8	152,4	11,0	9,1	4,9	3,0	4,3	92,1	3,0	552,5	17,0	5,7	134,0	45,5
0,97	22	158	11,00	9,1	88,9	9,1	8,2	2,7	2,1	2,1	39,0	5,0	78,5	17,0	14,1	125,1	20,9
0,97	15	93	35,00	1,8	88,9	9,1	9,1	1,8	2,7	3,4	31,1	5,0	217,7	25,0	5,4	80,1	49,5
0,97	12	141	31,00	0,0	165,1	12,2	10,1	5,2	4,7	5,2	136,1	30,0	137,4	21,0	38,7	453,6	10,4
0,97	15	95	48,00	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	7,0	123,6	24,0
0,98	18	133	70,00	7,6	69,9	9,4	9,4	1,1	1,8	2,4	31,1	10,0	311,2	25,0	7,7	136,5	32,5
0,98	22	159	54,00	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	10,6	183,7	9,7
0,98	15	95	48,00	1,8	88,9	9,1	7,9	1,5	2,7	3,4	39,2	7,0	314,3	25,0	5,3	94,7	42,2
0,98	7	42	37,00	2,7	152,4	15,8	15,5	2,7	3,7	4,9	177,8	7,0	1244,7	17,0	2,9	102,2	143,0

0,98	1	13	15,00	1,8	152, 4	11,0	9,1	4,6	3,0	4,6	90,7	14,0	1360,8	34,0	24,4	901,5	6,0
0,98	14	87	45,00	3,0	88,9	11,0	9,1	3,7	2,4	3,0	45,6	10,0	319,1	25,0	4,2	75,6	62,2
0,98	1	21	15,00	1,8	152, 4	11,0	9,1	4,9	3,0	4,6	90,7	14,0	90,7	9,0	13,7	130,2	23,5
0,99	22	159	54,00	9,1	88,9	10,1	9,1	2,7	2,1	2,1	33,1	7,0	298,5	17,0	8,7	150,1	16,7
0,99	12	140	19,00	0,0	165, 1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	22,3	300,5	16,1
0,99	16	96	84,00	1,8	63,5	6,1	5,5	2,7	2,4	1,5	18,1	2,0	526,2	5,0	6,3	144,3	41,1
1,00	10	50	9,00	8,4	66,7	6,1	0,0	0,0	0,0	0,8	3,5	0,0	31,8	0,0	31,9	179,5	3,9
1,00	12	140	19,00	0,0	165, 1	16,2	14,3	5,3	5,2	5,0	163,3	18,0	181,4	21,0	7,2	97,5	52,1
1,00	5	81	12,00	4,6	149, 2	7,6	7,6	3,4	3,0	3,0	46,3	3,0	277,6	25,0	10,2	169,7	8,5

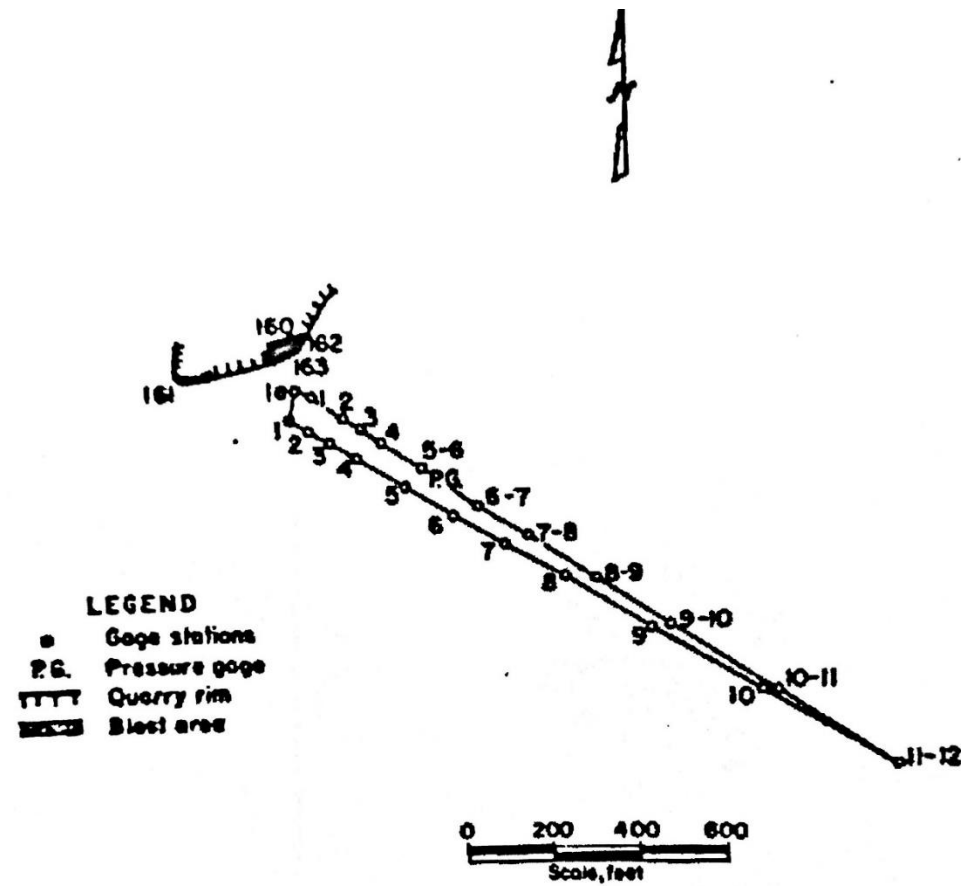
Table D-3: Test 2 – Superior Stone Company Data from Hi-Cone Quarry

Sit e No.	Tes t	Tota l No. of Hole s	Overburde n (m)	Hole Size (mm)	Hole Dept h (m)	Face Heigh t (m)	Stemmin g (m)	Burde n (m)	Spacin g (m)	Charg e per hole (kg)	No. of delay interval s	Max. Charg e per delay (kg)	Lengt h of Delay (msec)	Scaled Distance (m/kg ^{1/2})	Distanc e (m)	PPV Peak (mm/sec)
23	160	42	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	3,8	66,8	61,5
23	160	42	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	4,6	80,9	33,8
23	160	42	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	7,4	130,5	19,3
23	160	42	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	10,1	178,5	21,8
23	160	42	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	23,9	422,7	2,4
23	160	42	9,1	69,9	16,8	18,0	1,8	1,5	1,5	52,2	7,0	313,0	25,0	29,4	519,6	16,8
23	161	45	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	4,4	75,3	51,3
23	161	45	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	5,3	90,5	51,6
23	161	45	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	6,2	106,7	37,8
23	161	45	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	9,8	167,1	17,8
23	161	45	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	12,1	207,3	14,0
23	161	45	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	26,7	455,6	2,6
23	161	45	9,1	69,9	16,8	18,0	1,8	1,5	1,5	47,6	7,0	292,1	25,0	32,8	560,8	3,0
23	162	33	9,1	88,9	16,8	18,0	1,8	2,1	2,1	78,0	7,0	388,7	25,0	3,1	60,9	66,3
23	162	33	9,1	88,9	16,8	18,0	1,8	2,1	2,1	78,0	7,0	388,7	25,0	3,9	75,9	52,3
23	162	33	9,1	88,9	16,8	18,0	1,8	2,1	2,1	78,0	7,0	388,7	25,0	6,3	124,9	37,3
23	162	33	9,1	88,9	16,8	18,0	1,8	2,1	2,1	78,0	7,0	388,7	25,0	8,8	174,0	23,7
23	162	33	9,1	88,9	16,8	18,0	1,8	2,1	2,1	78,0	7,0	388,7	25,0	16,9	332,8	4,8
23	163	43	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	3,1	59,5	96,5
23	163	43	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	3,8	73,7	38,1
23	163	43	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	9,0	172,4	24,1
23	163	43	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	11,1	213,3	17,6
23	163	43	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	21,7	417,1	2,3

23	163	43	9,1	63,5	18,4	18,3	1,8	1,8	1,8	61,7	7,0	370,1	25,0	26,7	514,6	4,2
----	-----	----	-----	------	------	------	-----	-----	-----	------	-----	-------	------	------	-------	-----

APPENDIX E – HI-CONE QUARRY MAP

This is a map of the Hi-Cone Quarry (Nicholls, Johnson and Duvall, 1971). The vibration measurements from this quarry were used in Test 2.



APPENDIX F – R CODE USED IN THE CURRENT STUDY

The code in this appendix was used in the current research and it was adapted from Kuhn and Johnson (2013) and Kuhn (2018).

```
# ***** Caret Libraries *****
# Loading Required Libraries
library(lattice)
library(ggplot2)
library(caret)
library(kernlab)
library(earth)
library(party)
library(Cubist)

# ***** Importing Data *****
# Import Training Data
# Import Excel Data Library
library(readxl)
library(rio)

# Import Training Data
train <- read_excel("C:/Users/A0003534/Desktop/WITS/Learning/My MSc/Final MSc Report/Report/Print Data
                  Folder/PPV-Data-Train.xlsx",
                  col_types = c("skip", "skip", "skip", "numeric", "numeric", "numeric", "numeric",
                              "numeric", "numeric", "numeric", "numeric", "numeric", "numeric",
                              "numeric", "numeric", "skip", "numeric", "numeric"))

View(train)
str(train)
summary(train)
# ***** Check correlation *****
library(corrplot)
# load library

# Correlation of each independent variable with the dependent variable
cor(train, train[,1:14])

# Check corelation between features
```

```

#calculate correlations
correlations <- cor(train[,1:14])

# Calculate near zero variance
nzv <- nearZeroVar(train, saveMetrics = TRUE)
sum(nzv$nzv)

# ***** Global Parameters *****
# Setting Default Seed
seed <- 1963

# 10-fold cross validation repeated 5 times
control <- trainControl(method="repeatedcv", number=10, repeats=5, search = "random")

# ***** MODELLING *****
# ***** Modelling with Tune using 'CARET' package and Random Search *****

## Linear
set.seed(seed)
lmModel <- train(PPV ~ .,
  data = train,
  method = "lm",
  preProc = c("center", "scale"),
  tuneLength = 15,
  trControl = control)

lmModel
varImp(lmModel)

## KNN
set.seed(seed)
knnModel <- train(PPV ~ .,
  data = train,
  method = "knn",
  preProc = c("center", "scale"),
  tuneLength = 15,
  trControl = control)

knnModel
plot(knnModel)

```

```

ggplot(knnModel)

## MARS
set.seed(seed)
MARSMoDel <- train(PPV ~ .,
  data = train,
  method = "earth",
  preProc = c("center", "scale"),
  tuneLength = 15,
  trControl = control)

MARSMoDel
plot(MARSMoDel)
ggplot(MARSMoDel)
varImp(MARSMoDel)

# SVM
set.seed(seed)
svmRModel <- train(PPV ~ .,
  data = train,
  method = "svmRadial",
  tuneLength = 15,
  preProc = c("center", "scale"),
  trControl = control)

svmRModel
plot(svmRModel)
ggplot(svmRModel)

# NNet
set.seed(seed)
NNetModel <- train(PPV ~ .,
  data = train,
  method = "nnet",
  tuneLength = 15,
  preProc = c("center", "scale"),
  linout = TRUE,
  trace = FALSE,
  maxit = 1000,
  trControl = control)

```

```

NNetModel
plot(NNetModel)
ggplot(NNetModel)
varImp(NNetModel)

# RF
set.seed(seed)
rfModel <- train(PPV ~ .,
                 data = train,
                 method = "rf",
                 tuneLength = 15,
                 ntrees = 1000,
                 importance = TRUE,
                 trControl = control)

rfModel
plot(rfModel)
ggplot(rfModel)
varImp(rfModel)

# cTree
set.seed(seed)
ctreeModel <- train(PPV ~ .,
                   data = train,
                   method = "ctree",
                   tuneLength = 15,
                   trControl = control)

ctreeModel
plot(ctreeModel)
ggplot(ctreeModel)

# Cubist
set.seed(seed)
cbModel <- train(PPV ~ .,
                 data = train,
                 method = "cubist",
                 tuneLength = 15,
                 trControl = control)

cbModel

```

```

plot(cbModel)
ggplot(cbModel)

# ***** Evaluate resampling results *****
# Compare the results of these algorithms
ppv.results <- resamples(list(LM=lmModel, KNN=knnModel, MARS=MARSModel,
                             SVM=svmRModel, NNet=NNetModel, RF=rfModel,
                             CTREE=ctreeModel, CUBIST=cbModel))

# Summary and Plot of Results
summary(ppv.results)

scales <- list(x=list(relation="free"), y=list(relation="free"))
dotplot(ppv.results, scales=scales)

# ***** Tune Chosen Model - Cubist *****
# Hyper parameter optimisation -Check the hyper parameters that can be optimised
cbModel
ggplot(cbModel)
# Hyper parameters to be optimised are number of "committees" and "instances"
# neighbors can't be optimised here. They can only be tested in the predict function

# Optimisation with Grid Search *****

# Tune Cubist
# Set Validation Parameters
set.seed(1968)
trainControl <- trainControl(method="cv", number=10)
metric <- "RMSE"
cubistGrid <- expand.grid(committees=seq(1, 100, by=3),
                        neighbors = c(0:9))

fit.cubist_Grid <- train(PPV~., data=train, method="cubist",
                        preProc=c("center", "scale"), metric=metric, tuneGrid=cubistGrid,
                        trControl=trainControl)

fit.cubist_Grid
plot(fit.cubist_Grid)
ggplot(fit.cubist_Grid)

```

```

# Train Caret Tuned Model
set.seed(1980)
caretcontrol <- cubistControl(unbiased = TRUE, rules = 14, extrapolation = 100,
                             sample = 90, seed = 1980, label = "Predicted PPV(mm/s)")
Finalmodel <- cubist(x = train[,-14], y = train$PPV, control=caretcontrol, committees = 22)
summary(Finalmodel)

# ***** Final Model Testing *****
# Save Final Cubist Model
save(Finalmodel, file = "Finalmodel.RData")

#*****
# Import Testing Data - Interpolation
PPV.Test1 <- read_excel("C:/Users/A0003534/Desktop/WITS/Learning/My MSc/Final MSc Report/Report/Print Data
                        Folder/PPV-Data-Test1.xlsx",
                        col_types = c("skip", "skip", "skip", "numeric", "numeric", "numeric", "numeric",
                                     "numeric", "numeric", "numeric", "numeric", "numeric", "numeric",
                                     "numeric", "numeric", "skip", "numeric", "numeric"))

# Import Testing Data - Extrapolation
PPV.Test2 <- read_excel("C:/Users/A0003534/Desktop/WITS/Learning/My MSc/Final MSc Report/Report/Print Data
                        Folder/PPV-Data-Test2.xlsx",
                        col_types = c("skip", "skip", "numeric", "numeric", "numeric", "numeric", "numeric",
                                     "numeric", "numeric", "numeric", "numeric", "numeric",
                                     "numeric",
                                     "numeric", "skip", "numeric", "numeric"))

View(PPV.Test1)
str(PPV.Test1)
View(PPV.Test2)
str(PPV.Test2)

# Test 1 features
test1 <- PPV.Test1[, -14]
View(test1)

```

```

# Test 2 features
test2 <- PPV.Test2[ , -14]
View(test2)

# Prediction
pred.Finalmodel_1 <- predict(Finalmodel, newdata = test1, neighbors = 6)
View(pred.Finalmodel_1)
pred.Finalmodel_2 <- predict(Finalmodel, newdata = test2, neighbors = 6)
View(pred.Finalmodel_2)

## Export Prediction Results
export(as.matrix(pred.Finalmodel_1), "PPV_Prediction_1.csv")
export(as.matrix(pred.Finalmodel_2), "PPV_Prediction1_2.csv")

## All other Model Evaluations Conducted in Excel Along with Empirical Model Evaluations ##
# ***** END *****
## EXTRA - to show as an example

set.seed(1971)
caretcontrol <- cubistControl(unbiased = TRUE, rules = 14, extrapolation = 100,
                             sample = 90, seed = 1971, label = "Predicted PPV(mm/s)")
TenRuleModel <- cubist(x = train[,-14], y = train$PPV, control=caretcontrol, committees = 1)
summary(TenRuleModel)

```

APPENDIX G – CROSS-VALIDATION RESULTS

This appendix contains RStudio outputs of the cross-validation process along with the graphs depicting the results obtained from each resample. The outputs also show which model was selected.

G-1 – Linear Model

Summary

```
> lmModel
```

```
Linear Regression
```

```
700 samples
```

```
13 predictors
```

```
Pre-processing: centred (13), scaled (13)
```

```
Resampling: Cross-Validated (10-fold, repeated 5 times)
```

```
Summary of sample sizes: 629, 630, 630, 630, 630, 630, ...
```

```
Resampling results:
```

RMSE	Rsquared	MAE
19.31172	0.4325591	13.31186

```
Tuning parameter 'intercept' was held constant at a value of TRUE
```

G-2 – K-Nearest Neighbour

Summary

```
> knnModel
```

```
k-Nearest Neighbors
```

```
700 samples
```

```
13 predictors
```

```
Pre-processing: centred (13), scaled (13)
```

```
Resampling: Cross-Validated (10-fold, repeated 5 times)
```

```
Summary of sample sizes: 629, 630, 630, 630, 630, 630, ...
```

```
Resampling results across tuning parameters:
```

k	RMSE	Rsquared	MAE
5	16.33239	0.5813706	10.24006
13	17.02295	0.5538582	11.11196
37	19.33078	0.4566030	13.32434
48	20.20700	0.3991113	14.24803
60	21.11208	0.3359245	15.11520
63	21.23700	0.3302880	15.24164
74	21.55916	0.3222489	15.56868
101	22.14285	0.2970832	16.15303

131	22.21282	0.3255624	16.34904
193	22.40196	0.3539828	16.54316
198	22.42691	0.3542943	16.56227
205	22.45998	0.3533311	16.59039
227	22.63649	0.3352808	16.75207
233	22.68786	0.3286359	16.79988

RMSE was used to select the optimal model using the smallest value.
The final value used for the model was $k = 5$.

Graph

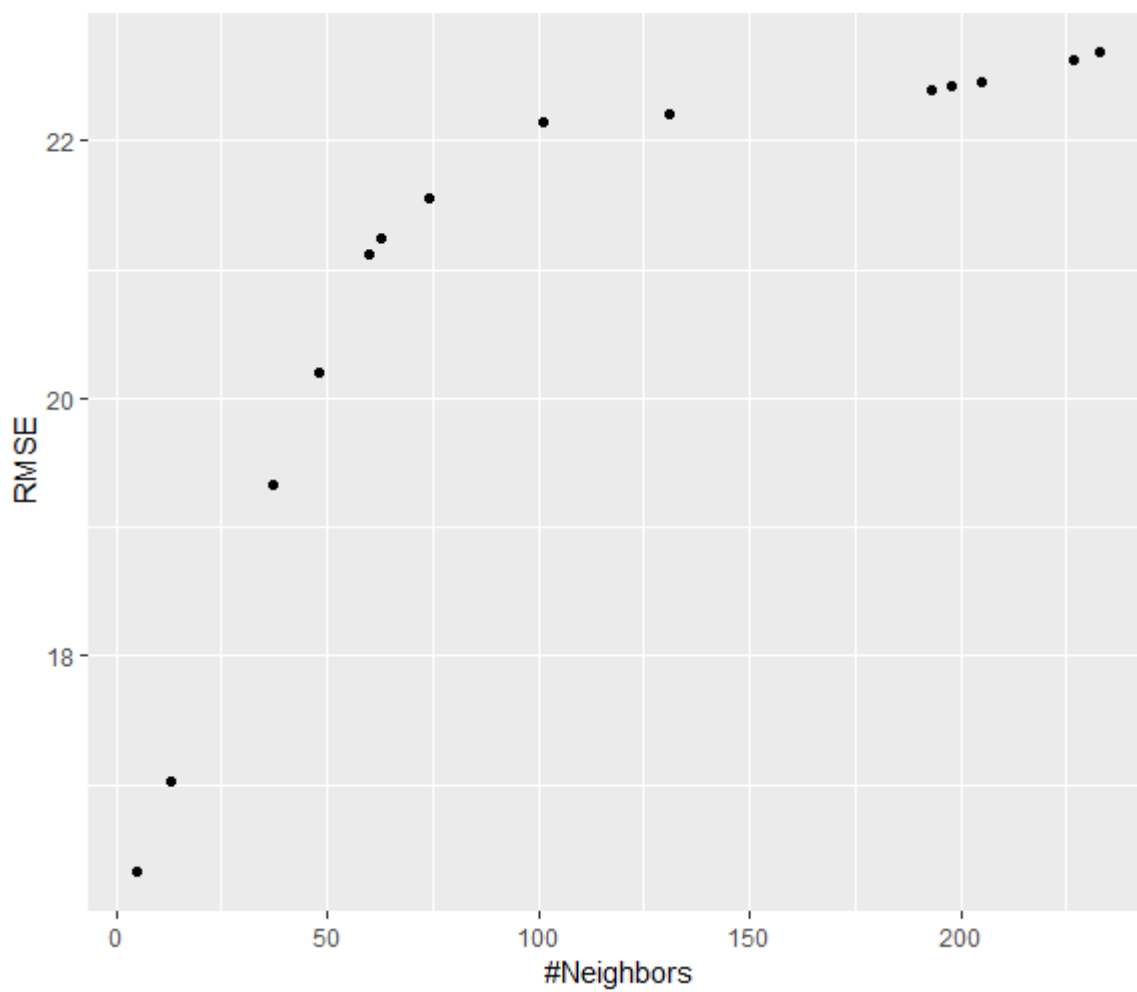


Figure G-1: KNN cross-validation results

G-3 – Multivariate Adaptive Regression Splines

Summary

```
> MARSmodel
```

```
Multivariate Adaptive Regression Spline
```

```
700 samples
```

```
13 predictors
```

```
Pre-processing: centred (13), scaled (13)
```

```
Resampling: Cross-validated (10-fold, repeated 5 times)
```

```
Summary of sample sizes: 629, 630, 630, 630, 630, 630, ...
```

```
Resampling results across tuning parameters:
```

degree	nprune	RMSE	Rsquared	MAE
1	2	19.46856	0.3967449	13.652572
1	6	14.91837	0.6549989	10.403222
1	9	14.82904	0.6608316	10.192176
1	12	14.83804	0.6620400	10.149599
1	16	14.59276	0.6728079	10.027360
1	17	14.57727	0.6739574	10.029767
1	19	14.56182	0.6747941	10.014339
2	2	18.43237	0.4624053	12.743861
2	4	15.10203	0.6443202	10.443997
2	5	14.71398	0.6614556	10.083524
2	7	14.11343	0.6896972	9.491755
2	17	12.60181	0.7586180	8.251704
2	19	12.62651	0.7581229	8.219138

RMSE was used to select the optimal model using the smallest value.
The final values used for the model were nprune = 17 and degree = 2.

Graph

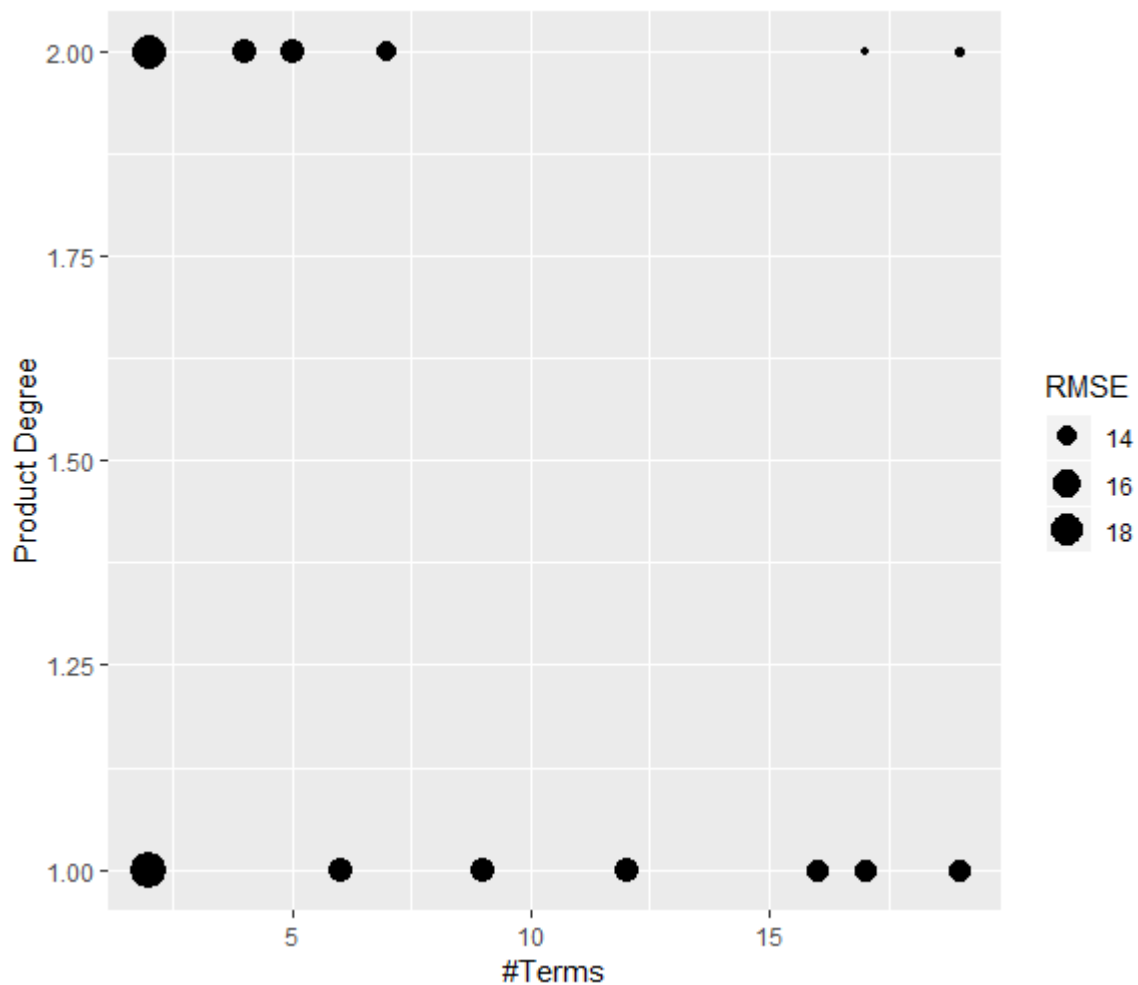


Figure G-2: MARS cross-validation results

G-4 – Support Vector Machines

Summary

```
> svmRModel
```

Support Vector Machines with Radial Basis Function Kernel

700 samples

13 predictors

Pre-processing: centred (13), scaled (13)

Resampling: Cross-Validated (10-fold, repeated 5 times)

Summary of sample sizes: 629, 630, 630, 630, 630, 630, ...

Resampling results across tuning parameters:

sigma	C	RMSE	Rsquared	MAE
0.004444153	95.26722857	15.80834	0.6387870	9.541913
0.008521474	0.10536820	21.77126	0.4461762	13.244981
0.009427301	0.04979539	23.06139	0.4198095	14.177845

0.010649553	29.64758800	15.15405	0.6701780	9.171187
0.011855326	88.07454053	13.98783	0.7167680	8.535069
0.019365883	2.97806272	15.97297	0.6490876	9.581781
0.031719265	0.12686613	19.50979	0.5406395	11.614516
0.063618424	2.91664780	14.15459	0.7167631	8.478460
0.145457603	0.20282623	17.45554	0.6264388	10.064821
0.406568244	1.27247776	13.94760	0.7235601	8.233082
0.412509878	0.71664084	14.70060	0.7090903	8.520863
0.439505613	0.10578440	19.75225	0.5635355	11.368513
0.715215927	1.19023902	14.28644	0.7070625	8.521269
0.820270105	249.02552530	16.24231	0.6248480	10.686777
0.852377984	0.12394942	20.01192	0.5636346	11.552881

RMSE was used to select the optimal model using the smallest value.
The final values used for the model were sigma= 0.4065682 and C= 1.272478.

Graph

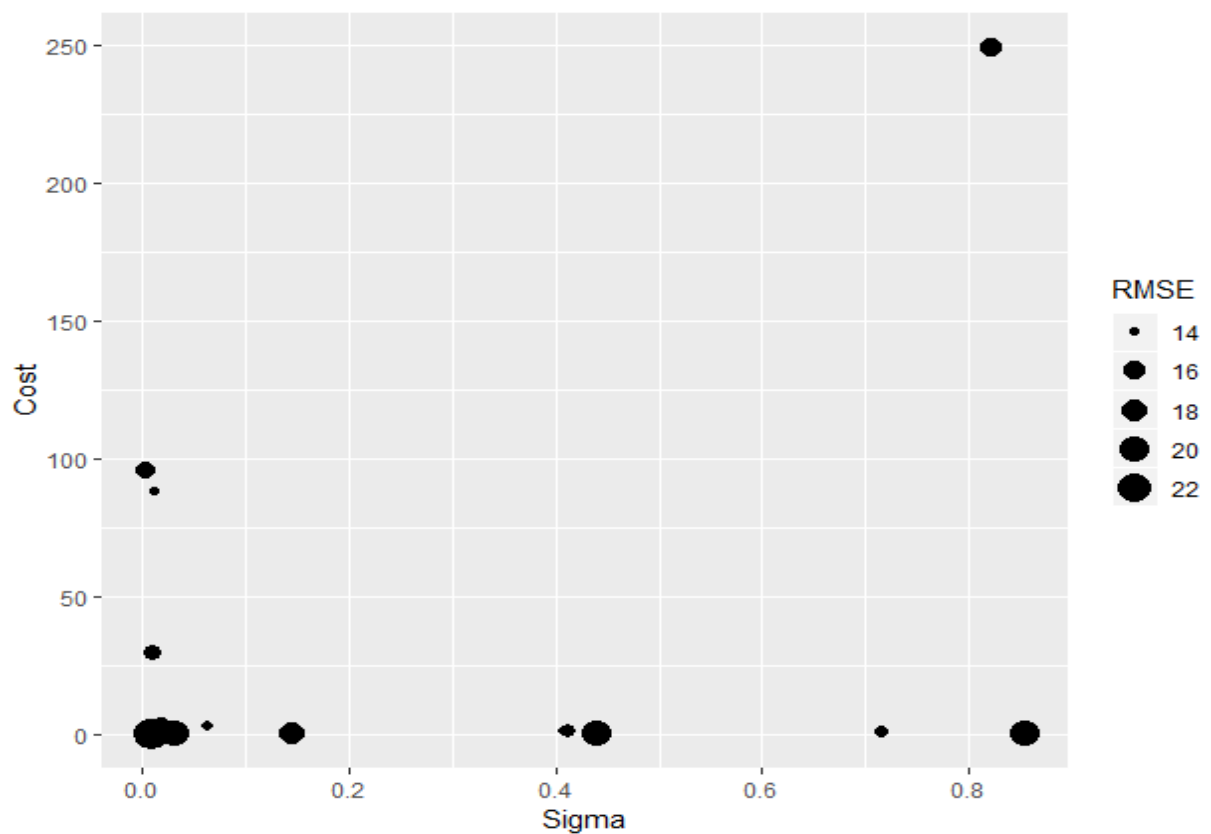


Figure G-3: SVM cross-validation

G-5 – Artificial Neural Networks

Summary

```
> NNetModel
```

```
Neural Network
```

```
700 samples
```

```
13 predictors
```

```
Pre-processing: centred (13), scaled (13)
```

```
Resampling: Cross-validated (10-fold, repeated 5 times)
```

```
Summary of sample sizes: 629, 630, 630, 630, 630, 630, ...
```

```
Resampling results across tuning parameters:
```

size	decay	RMSE	Rsquared	MAE
1	8.041103e-05	14.53628	0.6762115	9.481372
2	4.270987e-01	14.64402	0.6718814	9.724569
4	3.213052e-01	14.25375	0.6919579	9.413575
5	6.872799e+00	13.00355	0.7402283	8.348147
6	3.532676e-04	14.63915	0.6786574	9.784425
6	1.158318e-03	14.93711	0.6703898	9.818431
7	9.377728e-02	13.63341	0.7161942	9.142639
9	2.247144e-04	14.16799	0.7015304	9.532140
12	2.482175e-03	14.43891	0.6947709	9.676623
17	2.717948e-05	16.08449	0.6430582	10.824374
17	4.036617e-05	15.49998	0.6667868	10.634806
18	3.096664e-01	13.90675	0.7136157	9.319174
20	3.977231e-05	15.71503	0.6507526	10.927704
20	4.039101e-04	15.26437	0.6748711	10.632451
20	1.716402e-02	14.77881	0.6820551	10.134137

RMSE was used to select the optimal model using the smallest value.
The final values used for the model were size = 5 and decay = 6.872799.

Graph

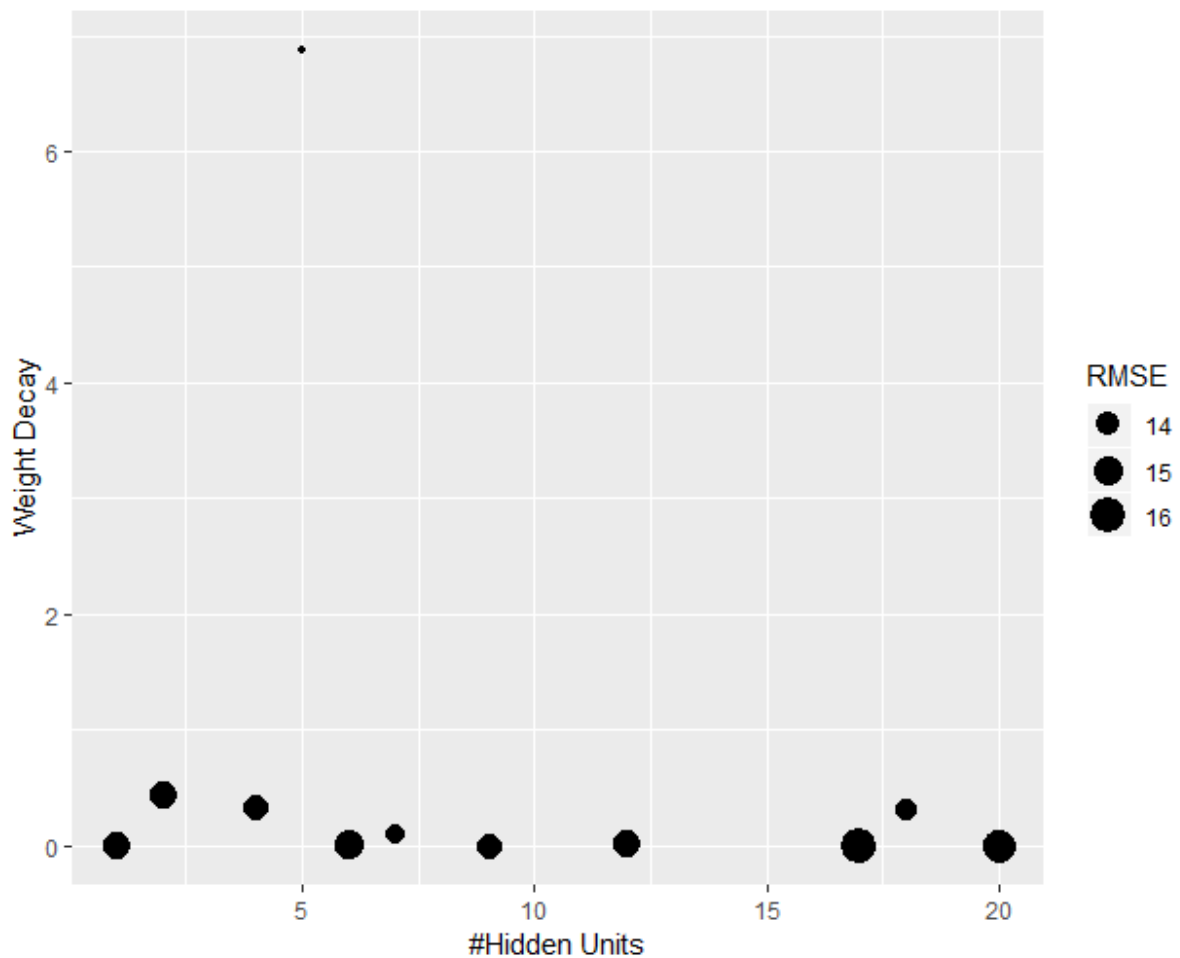


Figure G-4: ANN cross-validation results

G-6 – Random Forests

Summary

```
> rfModel
```

```
Random Forest
```

```
700 samples
```

```
13 predictors
```

```
No pre-processing
```

```
Resampling: Cross-Validated (10-fold, repeated 5 times)
```

```
Summary of sample sizes: 629, 630, 630, 630, 630, 630, ...
```

```
Resampling results across tuning parameters:
```

mtry	RMSE	Rsquared	MAE
1	16.56483	0.6107050	11.082778
3	12.64763	0.7678950	7.840532
4	12.21208	0.7787475	7.449596
5	12.02514	0.7826648	7.271505

6	11.98125	0.7828840	7.220612
8	11.98042	0.7809822	7.228282
11	12.10288	0.7760623	7.353024
12	12.10947	0.7756968	7.382202
13	12.19754	0.7721441	7.438869

RMSE was used to select the optimal model using the smallest value.
The final value used for the model was mtry = 8.

Graph

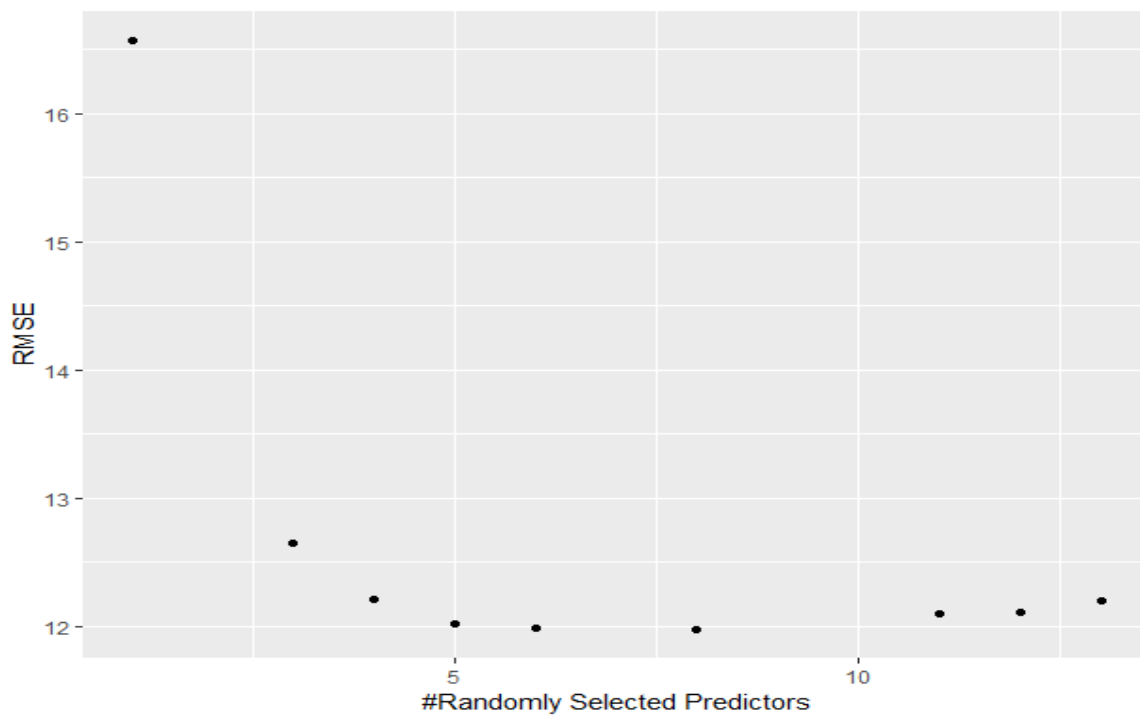


Figure G-5: RF cross-validation results

G-7 – Conditional Inference Trees

Summary

```
> ctreeModel
```

Conditional Inference Tree

700 samples

13 predictors

No pre-processing

Resampling: Cross-validated (10-fold, repeated 5 times)

Summary of sample sizes: 629, 630, 630, 630, 630, 630, ...

Resampling results across tuning parameters:

mincriterion	RMSE	Rsquared	MAE
0.01891035	14.82152	0.6730540	9.176580
0.05175354	14.81996	0.6731281	9.166566
0.15677142	14.82391	0.6728953	9.163469
0.20484349	14.81885	0.6732110	9.150672

0.25511998	14.81970	0.6729885	9.179685
0.26634884	14.82006	0.6730065	9.181521
0.31561165	14.82764	0.6722049	9.194888
0.43269275	14.86070	0.6707652	9.236111
0.56205380	14.87747	0.6684822	9.282981
0.82828801	15.16526	0.6561386	9.482165
0.84834967	15.21338	0.6535076	9.510666
0.87617322	15.24697	0.6517401	9.515168
0.97329851	15.45333	0.6415642	9.748507
0.99686132	15.73666	0.6237937	10.103430
0.99911876	15.91885	0.6156484	10.229557

RMSE was used to select the optimal model using the smallest value.
The final value used for the model was mincriterion = 0.2048435.
*Mincriterion = 1- p

Graph

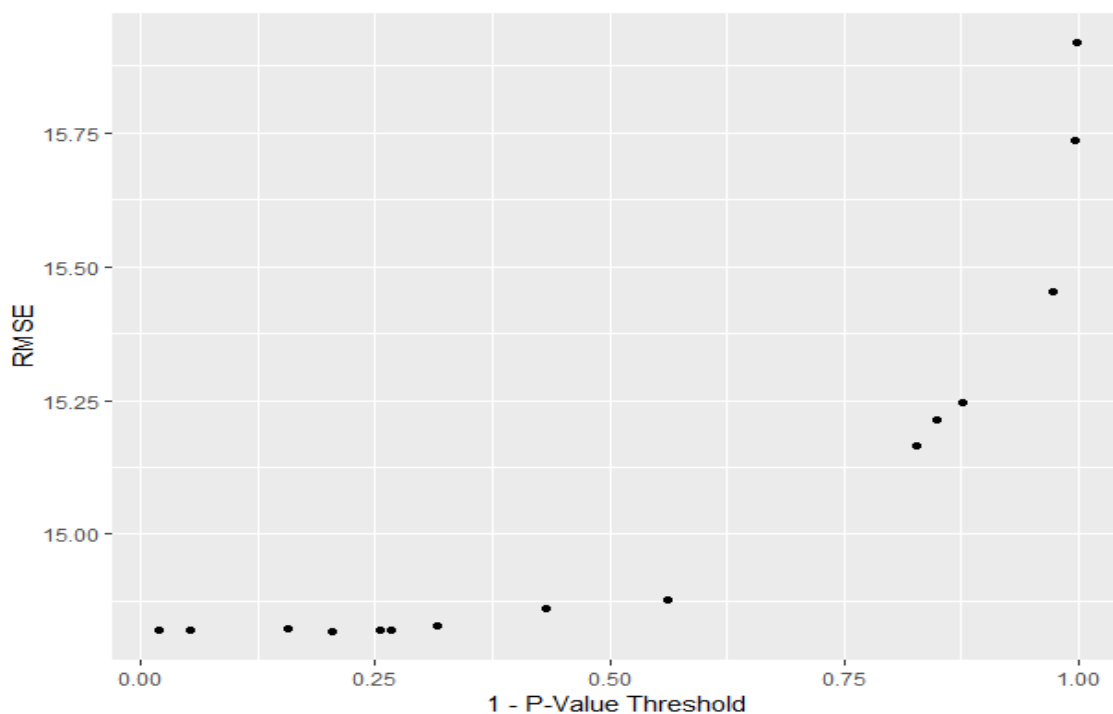


Figure G-6: CTree cross-validation

G-8 – Cubist

Summary

```
> cbModel
```

Cubist

700 samples

13 predictors

No pre-processing

Resampling: Cross-validated (10-fold, repeated 5 times)

Summary of sample sizes: 629, 630, 630, 630, 630, 630, ...

Resampling results across tuning parameters:

committees	neighbors	RMSE	Rsquared	MAE
8	8	11.93495	0.7811302	7.153077
10	9	11.88463	0.7823659	7.140858
11	8	11.83952	0.7843474	7.103796
16	0	12.25700	0.7761318	7.399425
23	4	11.63243	0.7904435	7.059304
26	2	11.92970	0.7811374	7.192326
27	9	11.56674	0.7938901	6.967895
35	2	11.88442	0.7827069	7.171224
40	5	11.49423	0.7962914	6.959871
54	9	11.42962	0.7989791	6.914533
67	3	11.59604	0.7922211	7.042782
75	8	11.40809	0.7999452	6.886458
76	1	12.01118	0.7785921	7.349161
78	0	12.00039	0.7861409	7.240209
98	2	11.80517	0.7858388	7.125661

RMSE was used to select the optimal model using the smallest value.

The final values used for the model were committees= 75 and neighbors= 8.

APPENDIX H – CROSS-VALIDATION SUMMARY

This appendix contains a summary of the final training and testing of the models that were chosen (as seen in appendix G).

```
> summary(ppv.results)
```

```
call:
```

```
summary.resamples(object = ppv.results)
```

```
Models: LM, KNN, MARS, SVM, NNet, RF, CTREE, CUBIST
```

```
Number of resamples: 50
```

MAE

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	NA's
LM	10.017712	12.398439	13.248323	13.311860	14.113962	17.406361	0
KNN	7.306960	9.406460	10.200440	10.240057	11.093072	14.322251	0
MARS	6.398032	7.518657	8.197717	8.251704	8.832194	11.690784	0
SVM	5.575721	7.283202	8.264835	8.233082	8.925443	12.229107	0
NNet	6.088222	7.834066	8.402128	8.348147	8.886893	9.906986	0
RF	5.330914	6.709648	7.190127	7.228282	7.868281	9.791970	0
CTREE	7.412239	8.274961	9.152237	9.150672	9.849856	12.020710	0
CUBIST	5.174020	6.407021	7.029621	6.886458	7.350547	9.024295	0

RMSE

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	NA's
LM	12.922559	17.284312	19.84969	19.31172	20.97720	28.68393	0
KNN	10.500804	13.739086	15.37678	16.33239	18.70768	25.07669	0
MARS	8.965725	10.939602	12.32223	12.60181	13.64036	20.09302	0
SVM	7.380678	10.958410	13.38319	13.94760	16.61631	23.48958	0
NNet	8.727172	11.719852	12.78786	13.00355	14.31918	19.05383	0
RF	7.455977	10.133724	11.59446	11.98042	13.68483	19.18605	0
CTREE	10.896006	12.783753	14.60393	14.81885	16.34783	21.50403	0
CUBIST	7.569341	9.703801	11.33242	11.40809	13.31060	16.69452	0

Rsquared

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	NA's
LM	0.2328055	0.3801523	0.4330962	0.4325591	0.4978362	0.5979927	0
KNN	0.3475782	0.5313834	0.5939685	0.5813706	0.6457596	0.7976607	0
MARS	0.6225452	0.7077495	0.7608181	0.7586180	0.7945458	0.8718478	0
SVM	0.5327508	0.6943190	0.7332007	0.7235601	0.7799616	0.8490801	0
NNet	0.6294730	0.6996204	0.7328190	0.7402283	0.7827754	0.8537516	0
RF	0.6793900	0.7386551	0.7812548	0.7809822	0.8327822	0.8814371	0
CTREE	0.4908278	0.6306797	0.6766264	0.6732110	0.7310864	0.8143873	0
CUBIST	0.7064164	0.7633116	0.8031850	0.7999452	0.8464353	0.9144893	0

APPENDIX I - CUBIST OPTIMISATION

The RStudio output in this appendix shows the results of resampling during the optimization process of Cubist.

```
> fit.cubist_Grid
```

```
Cubist
```

```
700 samples
```

```
13 predictors
```

```
Pre-processing: centred (13), scaled (13)
```

```
Resampling: Cross-validated (10-fold)
```

```
Summary of sample sizes: 629, 628, 630, 631, 632, 631, ...
```

```
Resampling results across tuning parameters:
```

committees	neighbors	RMSE	Rsquared	MAE
1	0	13.92382	0.7115463	8.278672
1	1	13.96162	0.7186749	8.330163
1	2	13.81753	0.7231990	8.142123
1	3	13.72936	0.7243433	8.118538
1	4	13.66233	0.7240095	8.016888
1	5	13.53308	0.7274474	7.927169
1	6	13.47530	0.7299456	7.824590
1	7	13.45662	0.7306635	7.809833
1	8	13.44206	0.7310901	7.808336
1	9	13.44165	0.7307514	7.824959
4	0	12.65364	0.7529852	7.631088
4	1	11.99079	0.7728605	7.484982
4	2	11.91146	0.7735193	7.294340
4	3	11.90039	0.7732402	7.296203
4	4	11.91276	0.7727946	7.212281
4	5	11.88943	0.7738984	7.141316
4	6	11.85396	0.7758286	7.084494
4	7	11.84451	0.7763649	7.075254
4	8	11.84697	0.7763680	7.105260
4	9	11.87114	0.7755352	7.121512
7	0	12.39753	0.7647598	7.455847
7	1	11.91149	0.7764181	7.342789
7	2	11.79169	0.7787946	7.188914
7	3	11.74330	0.7799200	7.186429
7	4	11.73749	0.7799245	7.099354
7	5	11.70763	0.7814458	7.018171
7	6	11.68331	0.7831391	6.958499
7	7	11.67462	0.7836914	6.931054
7	8	11.68486	0.7833874	6.966843
7	9	11.70905	0.7824303	6.996122
10	0	12.32673	0.7701660	7.398913
10	1	11.92927	0.7760149	7.356881
10	2	11.78009	0.7800018	7.167138
10	3	11.70807	0.7818299	7.140813
10	4	11.71026	0.7814488	7.062206
10	5	11.66814	0.7835800	6.976909
10	6	11.63889	0.7856670	6.934242
10	7	11.63869	0.7860024	6.930328
10	8	11.64925	0.7857452	6.960808
10	9	11.67349	0.7848426	6.980344
13	0	12.23651	0.7735605	7.351507
13	1	11.83024	0.7789293	7.309833
13	2	11.67779	0.7832084	7.103381

13	3	11.61929	0.7848303	7.060424
13	4	11.61691	0.7847491	6.993554
13	5	11.57562	0.7868986	6.924646
13	6	11.54460	0.7890585	6.882354
13	7	11.54549	0.7893943	6.884189
13	8	11.55674	0.7891964	6.911689
13	9	11.58478	0.7882201	6.940382
16	0	12.20507	0.7746628	7.330219
16	1	11.78406	0.7800415	7.290568
16	2	11.62964	0.7845129	7.085131
16	3	11.56196	0.7867337	7.042944
16	4	11.54642	0.7872215	6.966502
16	5	11.50489	0.7893964	6.903356
16	6	11.47375	0.7915697	6.856236
16	7	11.47834	0.7917622	6.861641
16	8	11.48964	0.7915611	6.892167
16	9	11.51850	0.7905270	6.919514
19	0	12.18529	0.7759540	7.312814
19	1	11.73855	0.7822882	7.265685
19	2	11.59618	0.7861777	7.078867
19	3	11.54040	0.7879628	7.035844
19	4	11.52721	0.7884063	6.969984
19	5	11.48982	0.7904003	6.911282
19	6	11.45834	0.7925273	6.858982
19	7	11.45981	0.7928184	6.862694
19	8	11.47371	0.7925056	6.897417
19	9	11.50316	0.7914543	6.923944
22	0	12.17591	0.7772778	7.310831
22	1	11.76500	0.7818518	7.289407
22	2	11.60854	0.7863129	7.085472
22	3	11.54173	0.7883931	7.041295
22	4	11.52288	0.7890035	6.965915
22	5	11.48232	0.7911422	6.902313
22	6	11.45313	0.7931801	6.851647
22	7	11.45491	0.7934694	6.855399
22	8	11.46749	0.7932112	6.894209
22	9	11.49415	0.7922618	6.917634
25	0	12.21526	0.7760638	7.329683
25	1	11.79823	0.7811208	7.305729
25	2	11.63568	0.7857343	7.090800
25	3	11.56393	0.7879024	7.047559
25	4	11.54798	0.7883656	6.970419
25	5	11.50592	0.7905457	6.902713
25	6	11.47760	0.7925329	6.859722
25	7	11.48015	0.7927756	6.863902
25	8	11.49373	0.7924589	6.902717
25	9	11.51900	0.7915505	6.927925
28	0	12.19003	0.7771873	7.288893
28	1	11.80548	0.7813096	7.309774
28	2	11.63639	0.7861466	7.073312
28	3	11.56204	0.7882672	7.029545
28	4	11.54379	0.7887076	6.945631
28	5	11.50263	0.7908403	6.878869
28	6	11.47322	0.7928675	6.833027
28	7	11.47599	0.7931067	6.836427
28	8	11.48923	0.7927989	6.869010
28	9	11.51282	0.7919345	6.890902
31	0	12.23500	0.7755233	7.282850
31	1	11.84656	0.7799370	7.321764
31	2	11.67615	0.7848459	7.083080
31	3	11.60062	0.7869362	7.035984
31	4	11.58066	0.7874712	6.958299

31	5	11.54471	0.7894149	6.891842
31	6	11.51809	0.7913508	6.846079
31	7	11.52024	0.7916270	6.845053
31	8	11.53368	0.7913130	6.875827
31	9	11.55698	0.7904680	6.898460
34	0	12.22850	0.7748356	7.277793
34	1	11.83517	0.7799339	7.313528
34	2	11.66782	0.7846787	7.078565
34	3	11.60077	0.7864351	7.051863
34	4	11.58664	0.7867056	6.977410
34	5	11.54783	0.7886803	6.905639
34	6	11.51977	0.7906199	6.863235
34	7	11.52113	0.7908791	6.858258
34	8	11.53448	0.7905479	6.887982
34	9	11.55756	0.7897078	6.910539
37	0	12.25046	0.7742553	7.273118
37	1	11.84156	0.7796549	7.305370
37	2	11.68112	0.7842567	7.068968
37	3	11.61246	0.7861709	7.031808
37	4	11.60182	0.7863696	6.963926
37	5	11.56388	0.7883484	6.898797
37	6	11.53630	0.7902872	6.861638
37	7	11.53651	0.7905683	6.857208
37	8	11.54999	0.7902064	6.886164
37	9	11.57269	0.7893725	6.907200
40	0	12.23115	0.7747057	7.255914
40	1	11.85988	0.7788675	7.310049
40	2	11.68937	0.7838053	7.069434
40	3	11.61078	0.7860272	7.025478
40	4	11.59652	0.7863531	6.955703
40	5	11.55634	0.7883751	6.887882
40	6	11.52820	0.7903297	6.851099
40	7	11.52704	0.7906885	6.847719
40	8	11.54029	0.7903559	6.874865
40	9	11.56154	0.7895904	6.894387
43	0	12.25679	0.7737942	7.261399
43	1	11.88858	0.7778516	7.317579
43	2	11.71623	0.7830016	7.071956
43	3	11.63451	0.7853313	7.030522
43	4	11.61756	0.7857366	6.958161
43	5	11.57983	0.7876719	6.887933
43	6	11.55212	0.7896315	6.849439
43	7	11.55130	0.7899820	6.846271
43	8	11.56504	0.7896363	6.873582
43	9	11.58623	0.7888700	6.889497
46	0	12.24880	0.7744416	7.249585
46	1	11.87034	0.7785429	7.306977
46	2	11.69493	0.7837327	7.059180
46	3	11.61341	0.7860528	7.017179
46	4	11.59858	0.7864199	6.938389
46	5	11.56173	0.7883627	6.867461
46	6	11.53361	0.7903487	6.827732
46	7	11.53331	0.7906968	6.826729
46	8	11.54706	0.7903635	6.854336
46	9	11.56860	0.7896036	6.872508
49	0	12.25661	0.7740729	7.254069
49	1	11.87107	0.7785978	7.307016
49	2	11.69772	0.7837603	7.059741
49	3	11.61989	0.7859408	7.020769
49	4	11.60656	0.7862256	6.944496
49	5	11.57107	0.7881064	6.872541
49	6	11.54444	0.7900404	6.830457

49	7	11.54408	0.7903824	6.827971
49	8	11.55804	0.7900254	6.856965
49	9	11.57989	0.7892524	6.874368
52	0	12.26407	0.7738400	7.250788
52	1	11.89147	0.7778846	7.314777
52	2	11.71513	0.7831979	7.057290
52	3	11.63140	0.7855496	7.008541
52	4	11.61833	0.7858125	6.934892
52	5	11.58151	0.7877369	6.865494
52	6	11.55537	0.7896534	6.822569
52	7	11.55492	0.7899908	6.821167
52	8	11.56880	0.7896308	6.849413
52	9	11.59063	0.7888519	6.868199
55	0	12.26447	0.7737459	7.249092
55	1	11.89495	0.7777249	7.307890
55	2	11.71958	0.7829484	7.055237
55	3	11.63594	0.7852879	7.004215
55	4	11.62188	0.7855783	6.930827
55	5	11.58400	0.7875521	6.860137
55	6	11.55493	0.7895678	6.813016
55	7	11.55347	0.7899409	6.809848
55	8	11.56656	0.7896060	6.842192
55	9	11.58820	0.7888360	6.861629
58	0	12.24199	0.7745305	7.237538
58	1	11.89945	0.7776899	7.316941
58	2	11.72292	0.7828973	7.062818
58	3	11.62963	0.7855695	7.007781
58	4	11.60783	0.7861217	6.928576
58	5	11.56599	0.7882396	6.858416
58	6	11.53462	0.7903628	6.810586
58	7	11.53308	0.7907423	6.809144
58	8	11.54619	0.7904167	6.839467
58	9	11.56764	0.7896553	6.860086

[reached getOption("max.print") -- omitted 140 rows]

RMSE was used to select the optimal model using the smallest value.
The final values used for the model were committees =22 and neighbors= 6.

The rest of the results were omitted by RStudio, because they were longer than the console window size.

APPENDIX J – SIMPLE CUBIST MODEL

The output in this section is a ten rule Cubist model that shows how Cubist model works. The model generated by the optimization process shown in Appendix I could not be shown because it was too long to fit on the RStudio console screen.

```
> summary(TenRuleModel)
```

```
Call:
cubist.default(x = train[, -14], y = train$PPV, committees = 1, control
 = caretcontrol)
```

```
Cubist [Release 2.07 GPL Edition] Sun Feb 24 13:16:49 2019
-----
```

```
Target attribute `Predicted PPV(mm/s)'
```

```
Read 630 cases (14 attributes) from undefined.data
```

```
Model:
```

```
Rule 1: [17 cases, mean 7.4000659, range 1.44018 to 45.212, est err 7.4381661]
```

```
if
  Distance (m) > 715.7224
then
  Predicted PPV(mm/s) = -5.082787 + 0.013 Distance (m)
```

```
Rule 2: [99 cases, mean 8.6923599, range 0.134112 to 36.83, est err 3.7614913]
```

```
if
  Max. Charge per delay (kg) <= 90.71848
  Distance (m) > 75.8652
then
  Predicted PPV(mm/s) = 32.224783 - 0.152 Distance (m)
                        + 0.0557 Max. Charge per delay (kg)
                        - 0.034 Length of Delay (msec)
                        - 0.017 Charge per hole (kg) + 1 Spacing (m)
                        - 0.46 Overburden (m)
                        + 0.18 No. of delay intervals
                        - 0.033 Hole Size (mm) + 0.9 Burden (m)
                        + 0.03 Total No. of Holes + 0.11 Hole Depth (m)
```

```
Rule 3: [91 cases, mean 9.7947617, range 0.134112 to 38.608, est err 4.6932993]
```

```
if
  Max. Charge per delay (kg) <= 181.437
  Distance (m) > 189.9185
then
  Predicted PPV(mm/s) = 13.4796906 + 0.0415 Max. Charge per delay (kg)
                        + 0.125 Charge per hole (kg)
                        - 0.124 Hole Size (mm) - 0.026 Distance (m)
                        + 1 Burden (m) + 0.4 Spacing (m)
                        - 0.16 Overburden (m) + 0.09 Hole Depth (m)
                        + 0.05 No. of delay intervals
                        - 0.08 Face Height (m) + 0.012 Total No. of Holes
```

```
Rule 4: [45 cases, mean 11.2268000, range 1.69926 to 43.688, est err 4.6982222]
```

```

if
  Charge per hole (kg) > 177.8082
  Distance (m) > 189.9185
  Distance (m) <= 715.7224
then
  Predicted PPV(mm/s) = 8.818371 - 0.343 Length of Delay (msec)
                        - 0.029 Distance (m)
                        + 0.0117 Max. Charge per delay (kg)
                        + 2.5 Burden (m) - 0.24 Face Height (m)
                        + 0.23 Hole Depth (m) + 0.5 Spacing (m)
                        - 0.005 Charge per hole (kg)

```

Rule 5: [191 cases, mean 12.3404770, range 0.63246 to 65.278, est err 4.5872421]

```

if
  Charge per hole (kg) <= 177.8082
  Max. Charge per delay (kg) > 181.437
  Distance (m) > 189.9185
  Distance (m) <= 715.7224
then
  Predicted PPV(mm/s) = 30.1208716 + 0.219 Charge per hole (kg)
                        - 0.041 Distance (m) - 1.13 Hole Depth (m)
                        + 0.011 Max. Charge per delay (kg)
                        - 0.092 Hole Size (mm)
                        - 0.031 Length of Delay (msec)
                        - 0.13 Face Height (m) + 0.3 Spacing (m)
                        + 0.3 Burden (m)

```

Rule 6: [52 cases, mean 28.4343224, range 5.1816 to 95.758, est err 8.0999842]

```

if
  Charge per hole (kg) <= 61.68856
  Max. Charge per delay (kg) > 90.71848
  Max. Charge per delay (kg) <= 299.371
  Distance (m) <= 189.9185
then
  Predicted PPV(mm/s) = 36.2596477 - 0.876 Charge per hole (kg)
                        - 0.304 Distance (m)
                        + 0.1074 Max. Charge per delay (kg)
                        + 4.49 Face Height (m) - 0.177 Total No. of Holes
                        - 0.029 Length of Delay (msec)
                        + 0.1 No. of delay intervals - 0.19 Overburden (m)
                        + 0.3 Spacing (m) + 0.1 Hole Depth (m)

```

Rule 7: [116 cases, mean 35.5006599, range 5.1816 to 141.732, est err 11.3494225]

```

if
  Max. Charge per delay (kg) > 90.71848
  Distance (m) > 111.2555
  Distance (m) <= 189.9185
then
  Predicted PPV(mm/s) = 59.1508703 - 0.317 Distance (m)
                        + 0.0365 Max. Charge per delay (kg)
                        - 0.111 Charge per hole (kg)
                        - 0.151 Length of Delay (msec)
                        + 0.59 No. of delay intervals
                        - 1.17 Overburden (m) + 1.9 Stemming (m)
                        + 1.5 Spacing (m) + 0.5 Hole Depth (m)

```

Rule 8: [20 cases, mean 37.5831108, range 9.525 to 70.104, est err 10.9076471]

```

if
  Max. Charge per delay (kg) <= 90.71848
  Distance (m) <= 75.8652
then
  Predicted PPV(mm/s) = 26.7801903 + 0.2802 Max. Charge per delay (kg)
                        - 0.151 Distance (m)
                        - 0.119 Length of Delay (msec)
                        - 0.059 Charge per hole (kg)
                        + 0.39 No. of delay intervals
                        - 0.69 Overburden (m) + 1.2 Spacing (m)
                        + 0.4 Hole Depth (m)

```

Rule 9: [12 cases, mean 43.1355515, range 18.5674 to 84.836, est err 15.0082407]

```

if
  Charge per hole (kg) <= 61.68856
  Max. Charge per delay (kg) > 299.371
  Distance (m) > 146.1267
  Distance (m) <= 189.9185
then
  Predicted PPV(mm/s) = 75.6954379 - 0.43 Charge per hole (kg)
                        - 0.215 Distance (m)
                        + 0.0164 Max. Charge per delay (kg)
                        + 0.36 Hole Depth (m) - 0.26 Overburden (m)
                        + 0.08 No. of delay intervals + 0.4 Stemming (m)

```

Rule 10: [46 cases, mean 51.2715569, range 13.1572 to 96.266, est err 10.9670401]

```

if
  Charge per hole (kg) <= 61.68856
  Max. Charge per delay (kg) > 299.371
  Distance (m) <= 146.1267
then
  Predicted PPV(mm/s) = 91.5362292 - 0.499 Distance (m)
                        - 0.031 Charge per hole (kg)
                        + 0.11 Total No. of Holes
                        + 0.0019 Max. Charge per delay (kg)
                        + 0.08 Hole Depth (m)

```

Rule 11: [15 cases, mean 57.3786011, range 25.273 to 90.932, est err 11.0015278]

```

if
  Stemming (m) <= 3.3528
  Charge per hole (kg) > 61.68856
  Max. Charge per delay (kg) > 90.71848
  Distance (m) <= 111.2555
then
  Predicted PPV(mm/s) = 71.4173786 - 0.484 Distance (m)
                        - 0.104 Charge per hole (kg)
                        + 0.0333 Max. Charge per delay (kg)
                        - 0.109 Length of Delay (msec) + 4.5 Stemming (m)
                        + 0.38 No. of delay intervals
                        - 0.71 Overburden (m) + 1.1 Spacing (m)
                        + 0.36 Hole Depth (m) - 0.046 Total No. of Holes

```

Rule 12: [29 cases, mean 81.6242142, range 23.4442 to 175.768, est err 25.2144108]

```

if
  Stemming (m) > 3.3528
  Charge per hole (kg) > 61.68856
  Max. Charge per delay (kg) > 90.71848

```

```

Distance (m) <= 111.2555
then
  Predicted PPV(mm/s) = 132.5103118 - 1.686 Distance (m)
                        + 18.9 Stemming (m)
                        + 0.0665 Max. Charge per delay (kg)
                        - 0.2 Charge per hole (kg)
                        - 0.005 Length of Delay (msec)

```

Evaluation on training data (630 cases):

Average error	7.0609824
Relative error	0.39
Correlation coefficient	0.89

Attribute usage:

Conds	Model	
100%	100%	Distance (m)
92%	98%	Max. Charge per delay (kg)
53%	98%	Charge per hole (kg)
6%	23%	Stemming (m)
	94%	Hole Depth (m)
	86%	Spacing (m)
	77%	Length of Delay (msec)
	58%	Burden (m)
	55%	Overburden (m)
	55%	No. of delay intervals
	52%	Hole Size (mm)
	52%	Face Height (m)
	41%	Total No. of Holes

Evaluation on test data (70 cases):

Average error	9.1541431
Relative error	0.47
Correlation coefficient	0.85

Time: 0.0 secs

APPENDIX K – REGRESSION PLOTS FOR TEST 1 AND TEST 2

The graphs in this appendix are regression graphs that show the prediction performance of the three models tested in the current study.

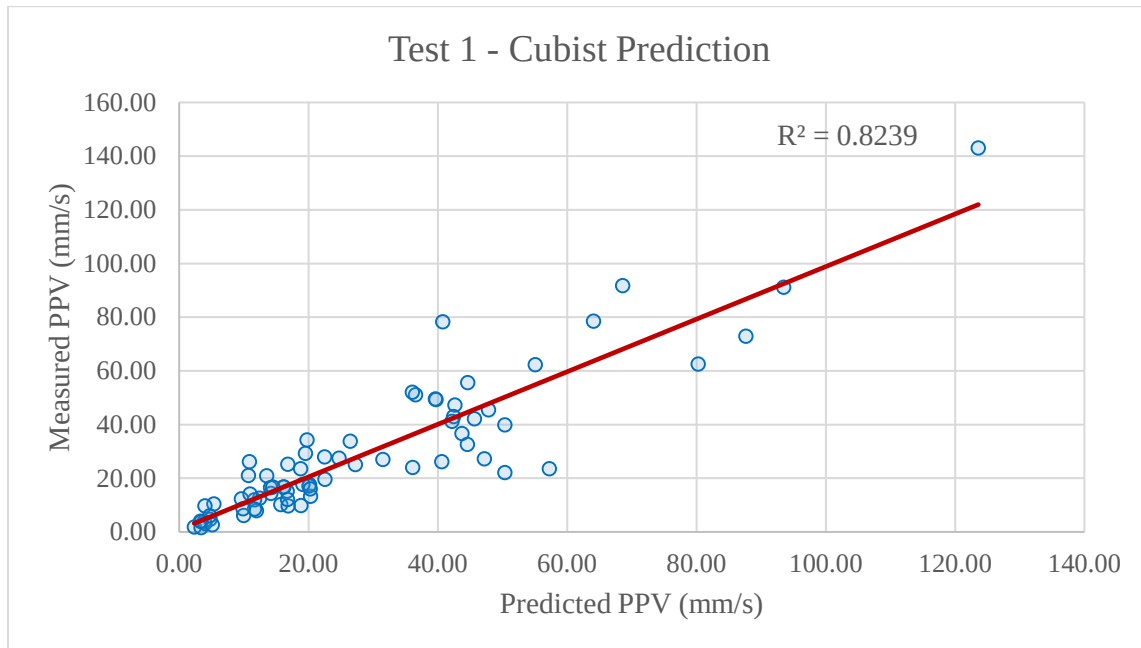


Figure K-1: Test 1 Cubist Prediction Performance

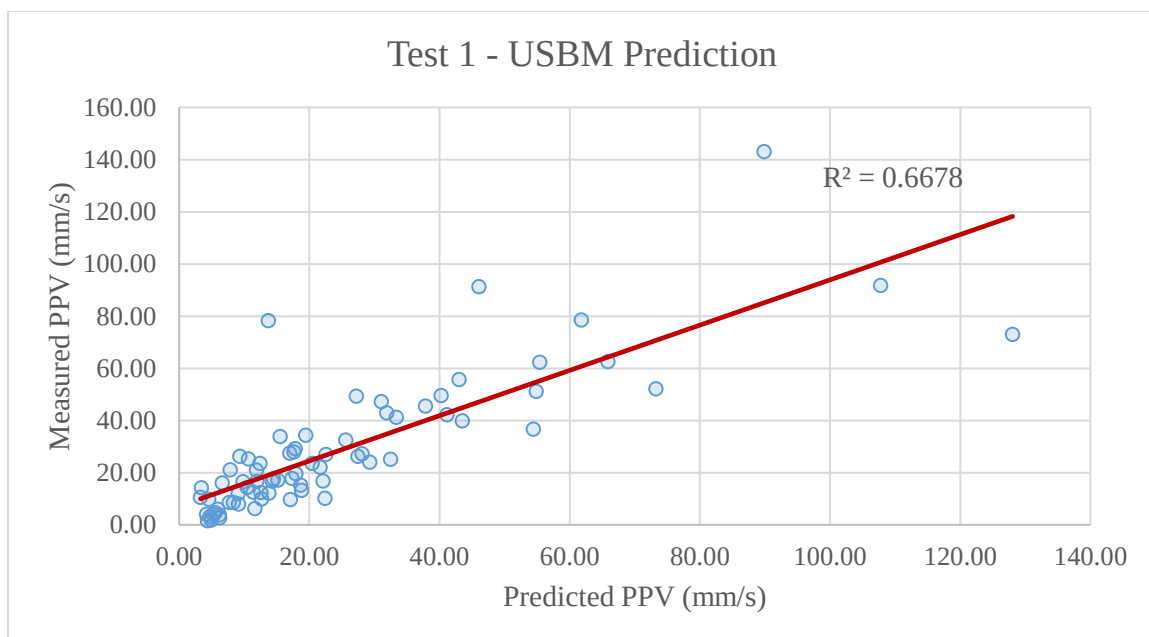


Figure K-2: Test 1 USBM Prediction Performance

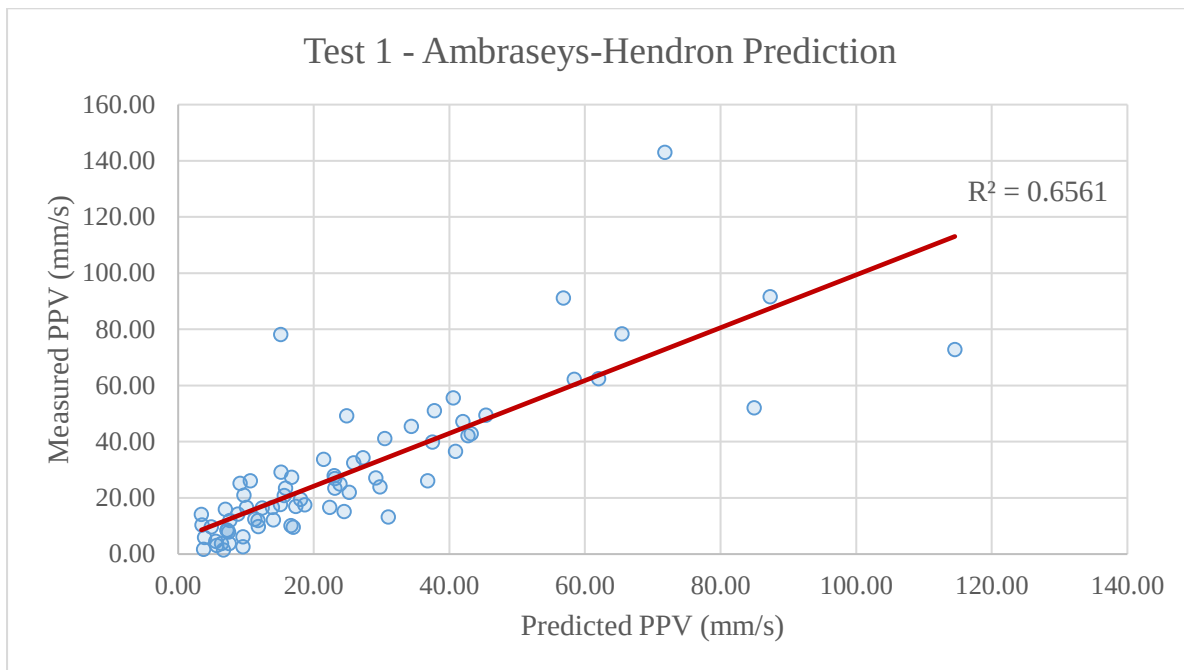


Figure K-3: Test 1 Ambraseys-Hendron Prediction Performance

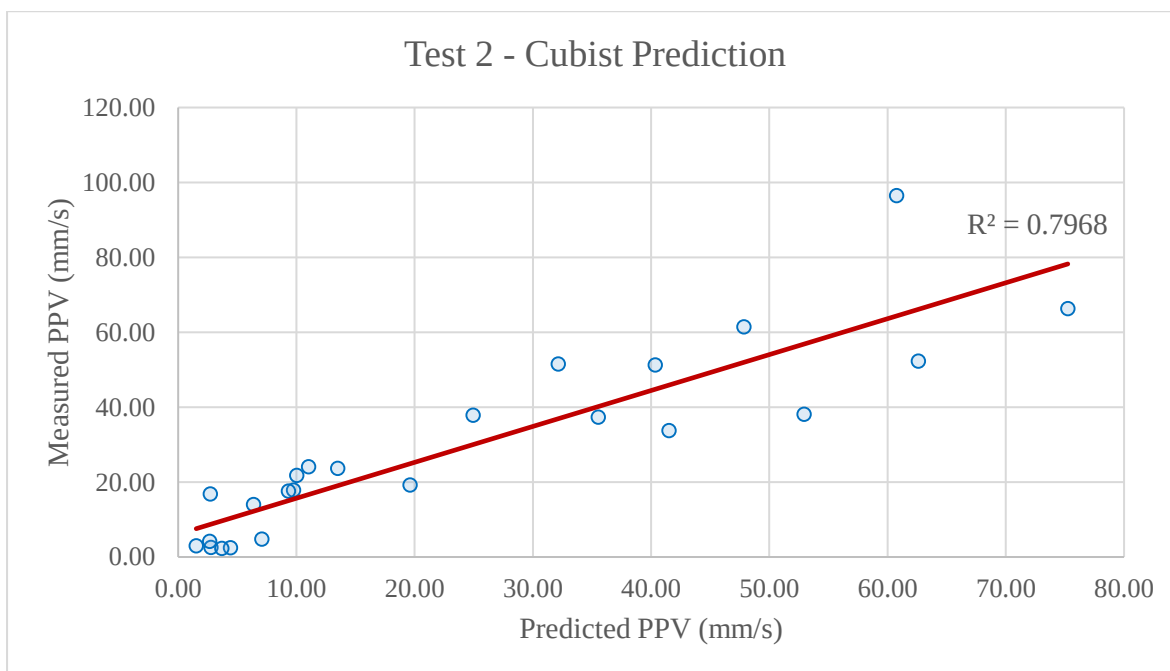


Figure K-4: Test 2 Cubist Prediction Performance

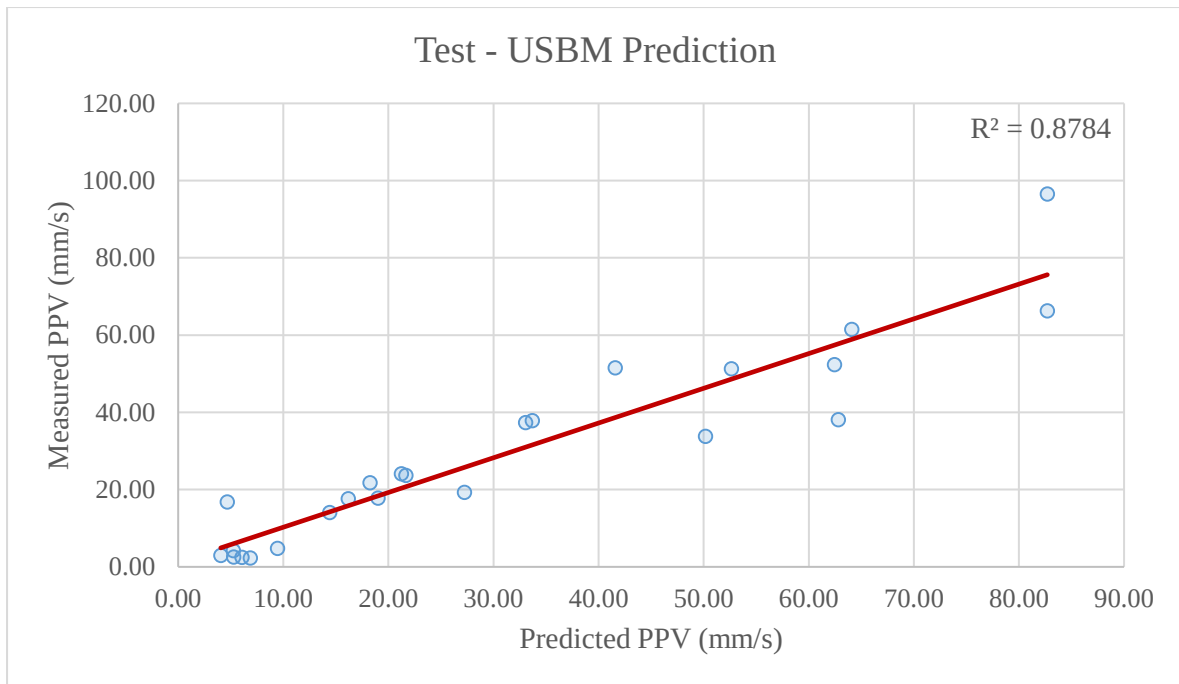


Figure K-5: Test 2 USBM Prediction Performance

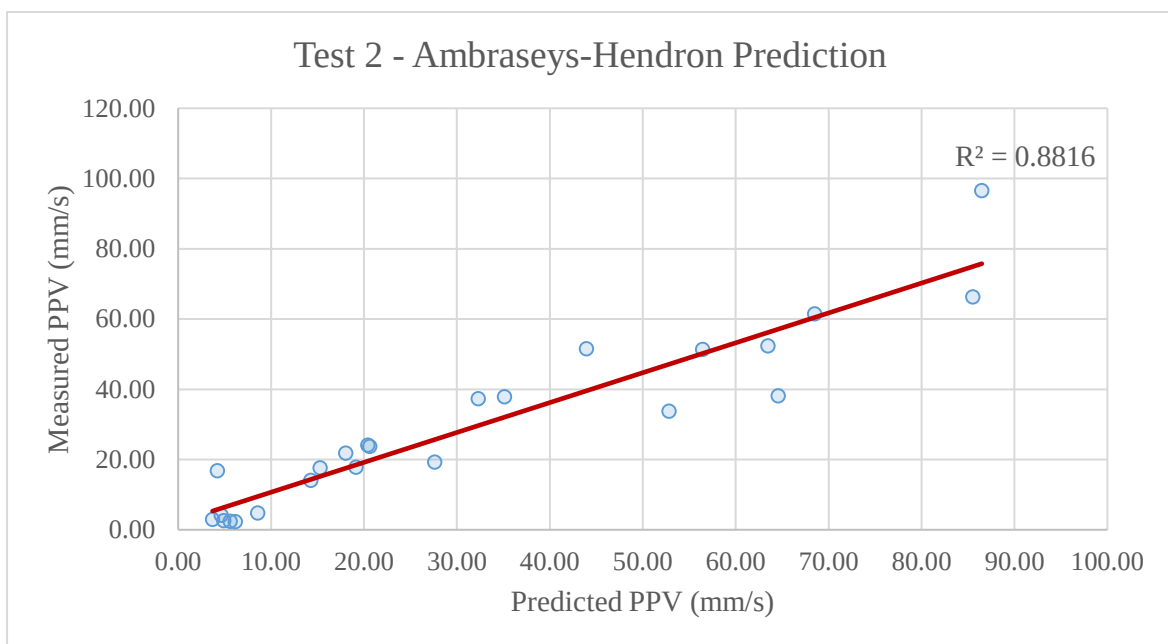


Figure K-6: Test 2 Ambraseys-Hendron Prediction Performance