9. Summary, Conclusions and Recommendation for Future Work

9.1. Summary and Conclusions

The following gives a summary of the work conducted for this dissertation and the conclusions that were drawn from it.

Field Monitoring

- Production blasts were monitored in order to measure ppv experienced in paste fill due to blasting of a secondary stope, to provide field data on the transmission of a blast through the rock/paste fill interface and to estimate the ppv at which damage occurs in paste fill.
- Site observations indicated that the once the wave entered the paste fill, it appeared to remain in the paste fill, reflecting on the paste fill/rock boundary.
- Analysis of the data on each side of the paste fill interface indicated that a large portion of the wave energy is reflected at the boundary. The ppv in the paste fill is between 55 % and 85 % of the wave in the rock.
- Fourier analysis of the waveforms indicate that the higher frequencies attenuate earlier than the lower frequencies.
- Based on observations from the field monitoring, the field tests and work by others, the ppv at which damage to paste fill begins to occur is estimated to be in the vicinity of 2.5 to 3.5 m/s.

Field Tests

- Field tests were undertaken in paste fill in order to study the transmission of a wave in paste fill without any effects of the rock or the rock/paste fill boundary.
- Peak particle velocities were obtained from the field test waveforms and used to calculate the parameters for the ppv prediction equation.
- The parameters for the ppv prediction equation are:
    - k = 1000

- $\beta = 1.02$

- The field data was used to validate the paste fill numerical model.

Laboratory Tests

- Laboratory tests were used to study the attenuation of longitudinal waves in a paste column.

- Peak particle velocity was observed to decrease with distance from the source.

- Wavelength was observed to increase with distance from the source.

- Higher frequencies were observed to attenuate faster than lower frequencies.

- The wave attenuated faster in the paste fill once it had fully cured and reached its full strength. Therefore, in order to reduce the damage observed in paste fill during blasting, the paste fill should be allowed to fully cure before it is exposed to nearby blasting.

- As the strength of the material increases, waves attenuate faster within the material.

Numerical Models

ABAQUS/Explicit was used to model effect of blasting on paste fill, using ppv as a measure of damage. Numerical models were created and calibrated against data obtained during field tests and the field monitoring.

A single blast hole in a paste fill mass was modelled with the stage 1 model. The results showed the following:

- A decrease in cement content of the paste fill results in a higher peak particle velocity in the paste fill, and in turn a larger volume of paste fill that is likely to be damaged during nearby blasting.

- A decrease in solids content of the paste fill results in a higher peak particle velocity in the paste fill, and in turn a larger volume of paste fill that is likely to be damaged during nearby blasting, when the cement content is low. For a cement content of 6 %, the results were similar for all solids contents.

- A small decrease in cement content can be partially compensated for by an increase in solid content of the paste fill. For example, a 76 % solids and 6 % cement content mixture of paste fill results in peak particle velocities in the fill of the same magnitude as an 80 % solids and 4 % cement content of paste fill.

A single blast hole in a rock mass was modelled with the stage 2 model in order to validate the loading in the rock. The results showed the following:

- The majority of rock types at Cannington Mine yielded similar results in the numerical model. The exception is the Glenholme which is the weakest rock time and for which much high peak particle velocities were predicted.

The detonation of a single borehole located adjacent to the centreline of a paste fill stope was modelled with model 3, scenario 1. The model was run for a paste fill mix of 76 % solids and 4 % cement and the broadlands rock type. The model results showed the following:

- A portion of the wave was reflected back into the rock at the rock/paste fill interface. This resulted in some high velocities being observed in the rock at the rock/paste interface as shown in Figures 8.13 to 8.16.

- The wave refracted from the rock/paste fill interface travelled through the paste fill much slower than the reflected wave travelled through the rock.

- Once the wave entered the paste fill it was observed to reflect back into the paste fill at the boundaries of the paste fill. This reflection was observed to continue until the wave attenuated within the paste fill.

- The damage to paste fill is reduced as the distance between the borehole and the paste fill is increased. For boreholes located at distances greater than 5 m from the paste fill, the thickness of the failure zone from a single borehole is predicted to be less than 0.5 m.

- The damage to paste fill is reduced as the diameter of the borehole is reduced. For boreholes located at distances greater than 2.5 m from the paste fill, the thickness of failure from a single borehole is predicted to be less than 0.5 m.

- In order to reduce the damage to paste fill, smaller diameter boreholes should be used for boreholes located within 5 m of paste fill.

The detonation of a single borehole located adjacent to a paste fill stope and offset from the centreline was modelled with model 3, scenario 2. The results showed the following:

- A single column of explosive produces a high peak particle velocity in the area near the borehole site, and produces reasonably constant peak particle velocities across the rest of the paste fill face. The constant peak particle velocity predicted across the entire paste fill face is due to the reflections which have been observed to occur within the paste fill.

The detonation of a row of boreholes was modelled with model 3, scenario 3. The results showed the following:

- The detonation of all boreholes simultaneously results in much higher peak particle velocities and damage than the detonation of multiple boreholes with small delays (100 ms to 400 ms delays were modelled). Therefore, delays are necessary to reduce damage to the nearby paste fill during blasting. Delays are typically used in mining applications to produce a more uniformly crushed product in the crushed zone.

- A comparison between results from the different blast patterns modelled showed that the order of detonation has little effect on the damage to the paste fill. The detonation order does play a large role in the resulting material in the crushed zone and should be designed accordingly.

- A comparison between the results from the same blast patterns with different delay times showed that the delay time between the detonation of boreholes has little effect on the damage to nearby paste fill. However, a delay between the detonation of multiple boreholes is necessary. Like the detonation order, the delay time between boreholes plays a large role in the resulting material in the crushed zone and should be designed accordingly.

9.2. Recommendations for Future Work

The following recommendations for future work were drawn from this study:

Monitoring

Undertake a monitoring program in which ppv are measured for blasting occurring adjacent to the section of the paste fill in which the monitoring equipment is installed in order to confirm the estimation of the ppv at which damage to paste fill occurs.

Numerical Modelling

Run the stage 3 model for an extended period of time to study how long the stress wave in the paste fill continues to reflect internally within the paste fill.