INTERNATIONAL JOURNAL OF RESEARCH SCIENCE & MANAGEMENT

RADAR SLOPE MANAGEMENT AT NCHANGA OPEN PIT MINE ZAMBIA: FOOTWALL FAILURE OF NOVEMBER 2014

S Silwamba C[1*],Chileshe P R K[2]
Correspondence Author: kross.silwamba@gmail.com

Keywords: Nchanga, SSR®, Near Real time,two–phaseslope failure, Deformation, Failure and Footwall

Abstract

Since 10 fatalities due to one slope failure in April 2001, pit slope management strategy at KCM Nchanga Open Pit [NOP] has been based on slope stability radar for generation of slope performance indicators for management response.The radar for near 'real time' data capturing capability wasfirst acquired and implemented at NOP in 2002 and has been successfully used at the mine site to predict slope failures with high potential impact on both economy and safety of life.However,at about 23:15 hours on the 14th November, 2014a major slope failure of about nine hundred thousand tonnes of back fill material occurred from the footwall side resulting in three 240t Komatsu 830E trucks being partially buried. This failure was against the background that the latest recorded radar deformation rates monitored at 09:00hours on the same day of failure indicated that deformation rates were within normally acceptable limits.

The main objectives of this paper were to:

1. Understandthe failure mechanism for the 14th November, 2014 footwall slough.
2. Suggest a secondary slope failure prediction philosophy at the mine site using alternative methodologies to the Slope Stability Radar (SSR) ®.
3. Identify options for maximum impact on water management strategies.

The pattern of deformation rates showed a lesser degree of deformation in the upper portions of the slope while a larger degree of movement was taking placein the mid-slope and at the toe, which suggested a two phase failure mechanism. The toe of the slope moving first, followed by the mid-slope and upper portions of the slope is the failure mechanism which took place on the November, 2014 slope failure at Nchanga mine.

Introduction

Nchanga Open Pit [NOP] mine has been in existence since 1955 and at one point was the second largest open cast mine in the world. Due to the slope instabilities associated with the foot wall side of this open pit, the mine has been back filled with fine material over time. Mining strategy was that of leaving a 'skin' of competent mineralized Feldspathic Quartzite [TFQ] of not less than 50m thick in some sections before intersecting the Pink Quartzite [PQ] rock mass on the foot wall side. As the mine approaches end of life and slope monitoring strategies and technologies improve i.e. with the usage of SSR technology for slope management, the coping strategy to extend life of mine was to optimise resource utilization by mining out the back fill material to take advantage of the 'skinof copper and cobalt in the TFQ'and designing the slopes to remain in the PQ. Between TFQ and PQ is a thin layer of very weak micaceous Banded Sandstone Upper [BSSU] material.

The footwall slope failure of the Nchanga Open Pit of 14 November, 2014, NOP CUT-II, occurred between section lines 32East and 35East, covering a strike length of about 360m and affected benches from 135mb to 210mb. Approximately nine hundred thousand tonnes of sloughed back fill material of the footwall came down on the extreme eastern side of the pit and resulted in three 240t Komatsu 830E trucks being partially buried. There were no personal injuries although the incident had the potential to affect quality of life and was declared by the company, Konkola Copper Mines Plc (KCM), as a HIPO, i.e. high potential with ability to affect quality of life. Figure 1 shows the slough zone, while Figure 2 shows the partially trapped Komatsu trucks after the slough.

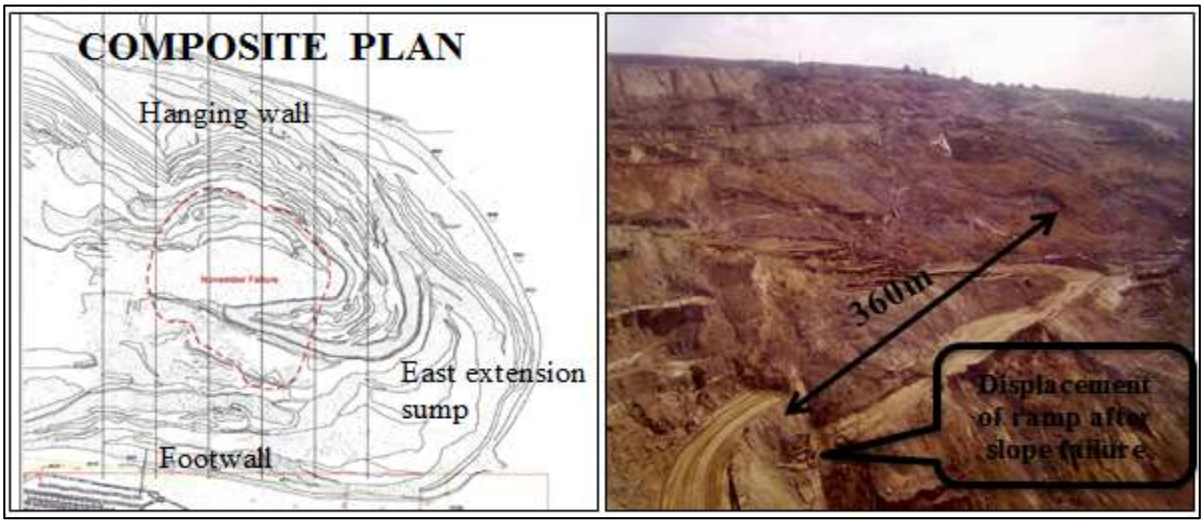


Figure 1: Plan and pictorial view of Nchanga Open Pit Slough zone of November 2014

Prior to this failure and as far back as April, 2014, instability in this section of the mine was detected by the SSR® in which the 'The Feldspathic Quartzite' (TFQ) was observed to be sliding down on its contact with the underlying weak Banded SandstoneUpper (BSSU) rock formations. However, over time, the slope was observed to have settled and deformation rates reduced to normal, though monitoring of the slope continued.

Figure 2: Three 240t Komatsu 830E trucks partially buried after the slough at Nchanga Open Pit

Background

Nchanga Open Pit mine which derives its name from the Nchanga stream which initially ran across the current location of the pit and was diverted further south in a stream diversion tunnel called WD3 in 1972, to pave way for mining as shown in Figure 3 (KCM Survey Department, 1999). Over the years, this tunnel had not been inspected to check the integrity of the concrete lining walls. Recent attempts to gain access into the tunnel proved futile. Indications are, however, that deposition of silt accumulation has reduced the tunnel initial opening of about 5m to approximately0.6m.

On the day of the slough at about 16:30hrs, a blast was conducted at the bottom of the pit on the access ramp to re-profile the western access. This was to ensure natural flow of rain water into the prepared sump for the rain season, which meant that the second access route into the pit was temporarily closed because of the blasted material (Figure17).

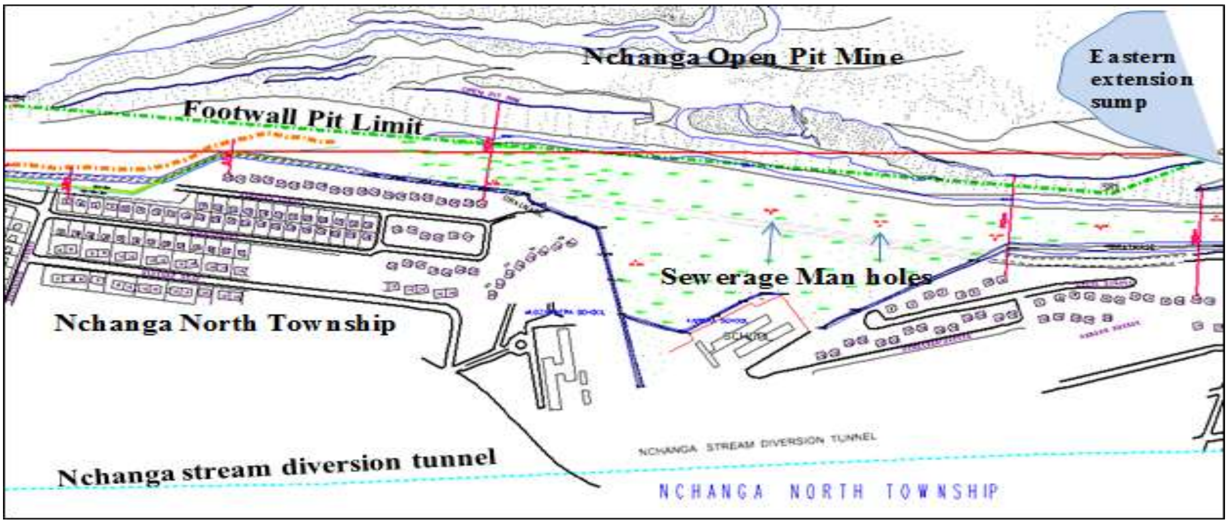


Figure 3: Nchanga stream diversion tunnel (KCMSurvey Department,2014)

A few metres from the stream diversion are a complex of sewage drains and man holes which service the township adjacent to the mine. The majority of these infrastructures has not been maintained over a long period of time and is blocked in manycases.

On the extreme eastern portion of the pit lies an old cobalt pit called the east extension. With the passage of time, this has been used as a collection point for storm and incidental waterfrom the mine which is eventually pumped out. The silt which has accumulated in the east extension sump is in excess of 30mdeep and therefore creates the potential of trapping water inside the silt. The water would then eventually percolate to the adjacent active pit through cracks and fissures. Moreover, the east extension sump has remained at a higher elevation while mining has gone below it. Migration of water down dip has been made easier.

From past experience, it has been observed that water is the core root cause or triggerfor slope failuresexperienced from the footwall side of Nchanga Open Pit (Silwamba and Chileshe, 2015).

Objectives

Slopeinstability is normal in open cut mining operations, mainly caused by excavation response and blasting(Bates, 2009).Movement of the ground can be acceptable provided it is not unexpected and catastrophic.As stated by Hoek and Bray (1981), '…… slopes seldom fail without giving adequate warning'.Terzaghi (1950) made a similar observation that, "… if a landslide comes as a surprise to the eye-witnesses, it would be more accurate to say that the observers failed to detect the phenomena which preceded the slide." The Nchanga Open Pit slope failure of November 2014 occurred unexpectedly, and partially buried three parked 240t trucks, though it did not cause personnel injuries.

Against the background stated above, the main objectives of this paper were to:

1. Establish the failure mechanism for the 14th November, 2014, footwall slough.
2. Establishing a secondary slope failure prediction philosophy at the mine site using he alternative methodologies to the SSR®.
3. Identify the options for maximum impact on water management strategies at Nchanga Open Pit CUTII footwall slopes.

Methodology

Slope stability management at Nchanga Open Pits hinges on the optimal utilisation of the real time data capturing capacity provided by the SSR® since the 2001 fatal slope failure. Therefore, data obtained from the SSR®, other additional slope monitoring strategies like survey monitored pegs, using back analysis and empirical guidelines established at the mine site, prior to the failure and during the failure of 14th November, 2014 will be evaluated.

A root cause analysis (RCA) into why the latest deformation rates picked from the radar did not give enough warning of the impending failure of the slope as per mine site guide linesand expected norms was conducted as well as a gap analysis.The water transport system in the footwall rock mass of NOP was studied for identification of effective water management mitigation options.

A review of previous slope failures wasalso carried out in order to assess the time dependency of the slope movement rates at NOP CUTII. This was supplemented by the examination of the impact of external factors on slope deformation rate acceleration (Martin, 1993).

Sullivan (2007) highlighted some short comings in the existing time dependent slope models.The two most important criticisms were that the models did not indicate the large time periods over which displacement occurred and the second one was the assumption that the models implied that slopes record large deformation rates over long periods prior to failure.

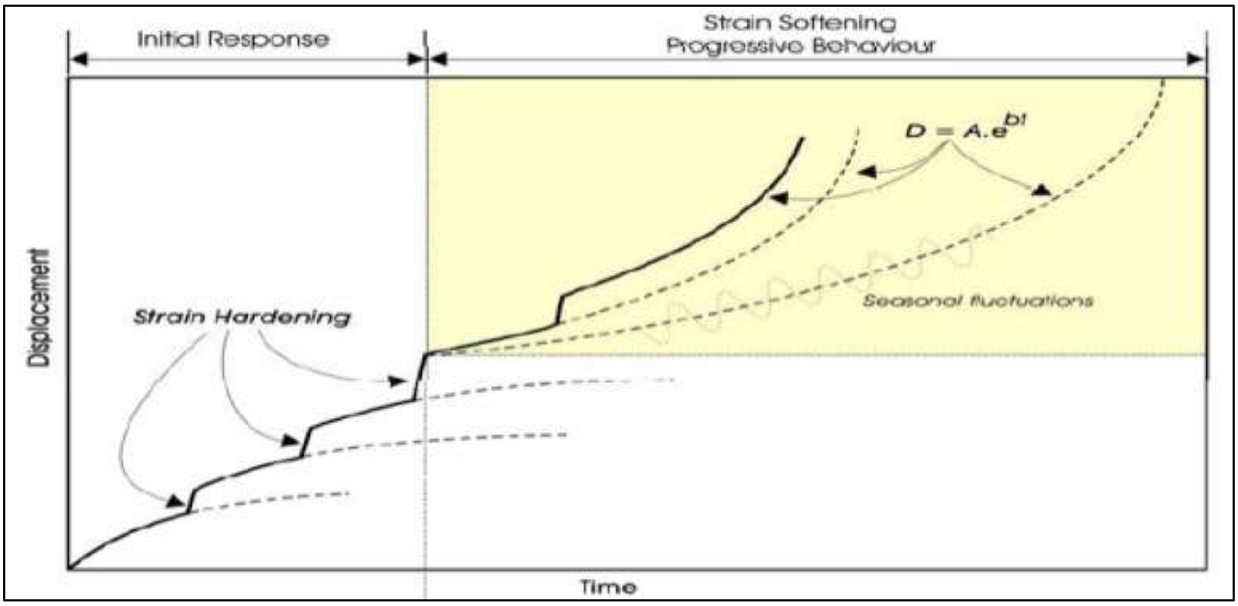


Figure 4: Model for time dependent deformation behavior(Martin, 1993)

Data collection and analysis

Management trigger action response plan to slope instability at Nchanga Open Pit mines have been summarised as indicated in Table I below based on past experience and time dependency of slope deformation rates. Prior to the failure of 14th November, 2014, the deformation rates captured before the 'information black out' happened at 09:00 hrs as result of a catastrophic failure in the normal operation of the slope scanning radarare shown in Table II.

Table I: Trigger levels derived from the 21E Failure (Wessels, 2009)

Trigger Level	Response	Activity
< 3mm/hr	Normal Monitoring, frequency of deformation rate calculations every hour	Continue mining
3mm - 5mm/hr	Increase frequency of rate calculation to 30 minute.	Continue mining. Enhance visual inspections.
5mm-10mm/hr	Increase frequency of rate calculation to 15 minute. Inform control room.	Continue mining. Enhance visual inspections. Restrict access to area
> 10mm/hr	Evacuation from area of concern	Evacuate

As per mine site empirical guidelines based on back analysis of previous failures, the deformation rates on the day of failure were within normal acceptable limits and could not result in a slope failure, of the magnitude that occurred.

Table II: Nchanga Open Pit south wall deformation rates on the day of failure (14th November 2014)

NCHANGA OPEN PIT SOUTH WALL DEFORMATION RATES[mm/hour]-day of failure

Date	Time	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
11/15/2014	1:00	SLUMPED MATERIAL-900,000t									
		MATERIAL MOVEMENT DETECTION-PHYSICAL METHODS									
11/14/2014	23:15										
11/14/2014	21:15	RADAR SCANNING-HAMONIC DRIVE DEFECTIVE [NO DATA GENERATION]									
	9:00										
11/14/2014	9:00	0.5	5.2	4.3	5	3.1	1.8	4.1	0.5	1.6	0.3
	8:00	0.3	4	4.9	3.4	2.8	1.2	2.5	0.3	0	-0.3
11/14/2014	2:30	-0.5	3.2	4.1	3.4	2.7	0.7	3.2	-1.6	-3	-3.3
	1:00	1.1	3.5	4.3	3.9	2.6	1.3	2.7	1.6	-0.6	-0.6
11/13/2014	23:00	1.3	4.1	3.4	4.6	2	1.3	1.2	1	0.7	0.7
	22:00	0.4	3.8	3.2	4.7	2.1	1.1	2.5	1.9	-0.4	-0.5
11/13/2014	20:00	0.5	3.5	4.2	3.9	2.3	1.3	2.4	0.2	-1	-1
	18:00	-0.1	3	3.7	-4.1	1.3	0.2	0.2	0.8	-0.7	-1.4
11/13/2014	16:00	0.8	3.4	3.3	3.7	1.6	0.8	1.4	-0.1	0.1	0.1
	14:00	0.4	4	2.7	3.9	1.7	0.6	0.7	0.1	0.2	0.1
11/13/2014	12:00	0.3	3.6	3.9	2.8	1.1	0.5	1.1	0.3	-0.2	-0.3
	10:00	-0.8	3.2	3.8	2.9	1.8	0.3	0.9	0.2	0	-0.1
11/13/2014	8:00	-0.2	2.8	3.4	2.2	0.4	0.3	0.2	0.2	-0.6	-0.8
	6:00	0	3.2	4.1	2.7	0	0	0.6	-0.7	-0.5	-0.7

Deformation rates data, month by month, five months prior to the failure was further collected and analysed for indications of slope instabilities. A summary of these rates by pictorial views are shown in Figure 5 while location points were shown in Figure 6 prior to failure

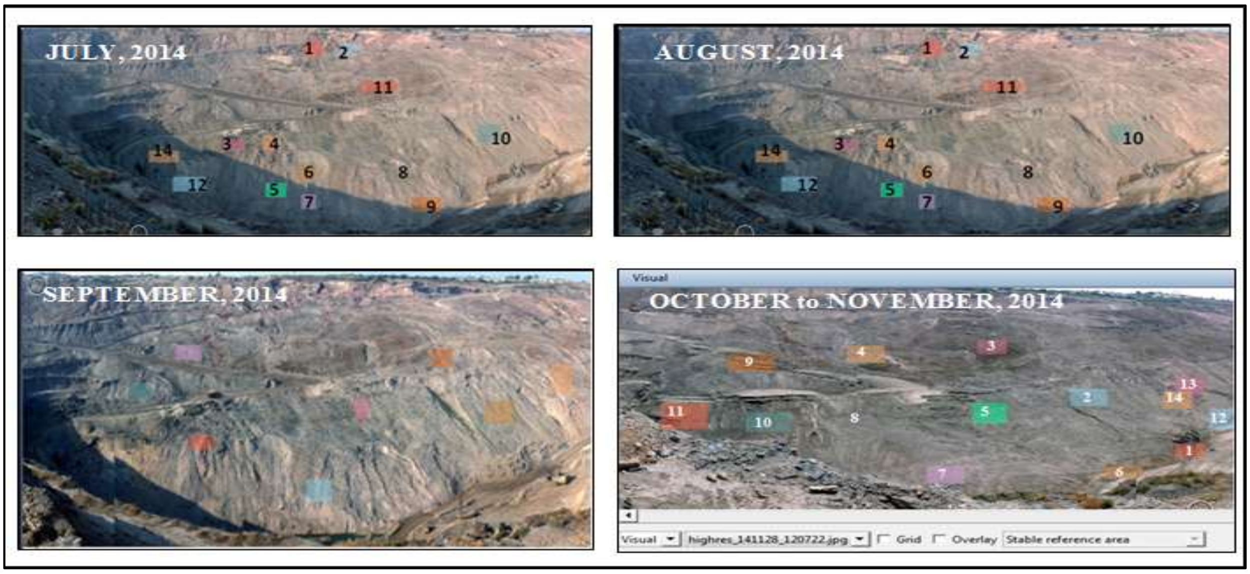


Figure 5: Pictorial view of deformation rates locations points –July to November 2014

From Figure 6, it was noted that in the period July to September 2014, monitoring points in the toe and the mid-slope were very active, compared to the upper slope. July 2014 had the highest activity while August 2014 saw a decline which continued through September 2014

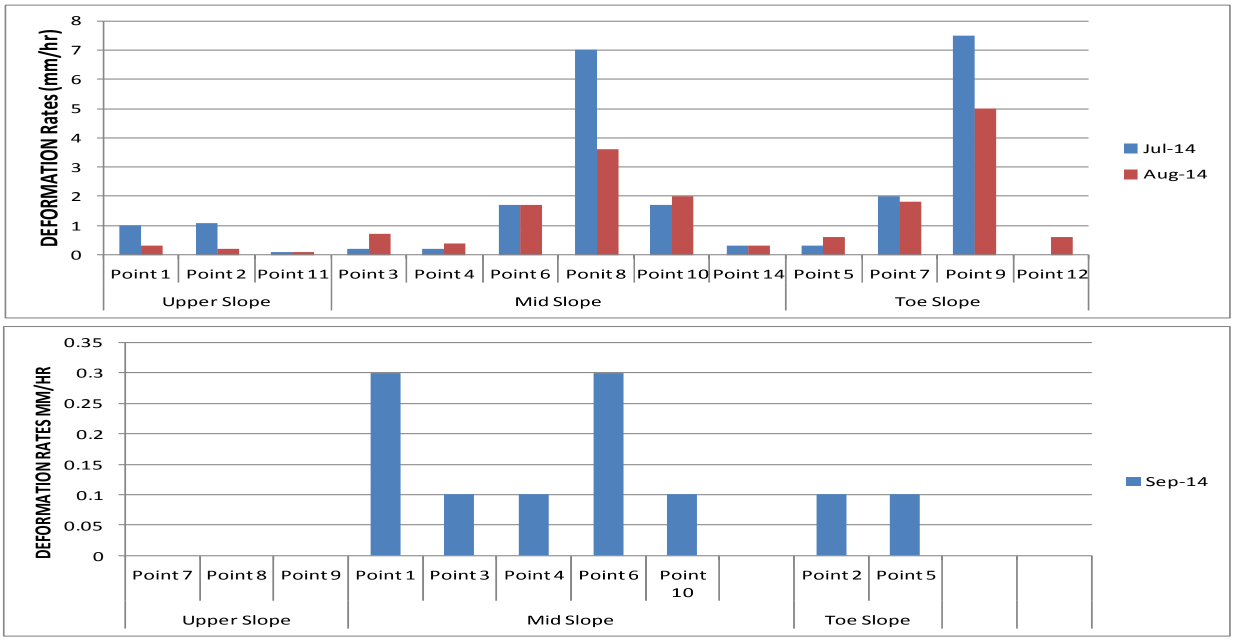


Figure 6: Deformation rates on the south footwall slope at Cut II Nchanga Open Pit July – September 2014

In October and November 2014, the activity was insignificant (Figure 7) across the upper, mid and toe slopes, but interestingly there was a perceptible increment from October to November 2014 in the toe deformation rates in the month of the slough.

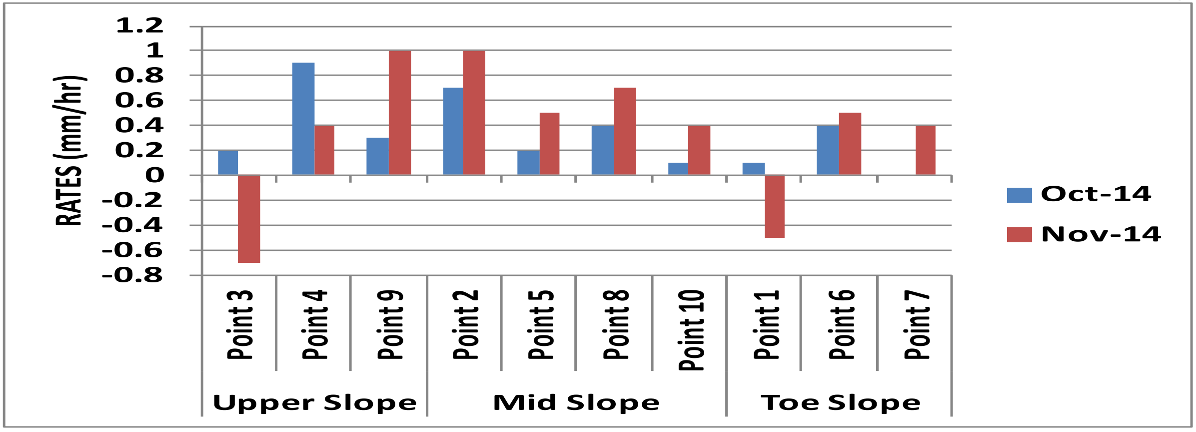


Figure 7: Deformation rates on the south footwall slope at Cut II Nchanga Open Pit October – November 2014, just before the failure

Proposed slope failure mechanism

The pattern of deformation showed a lesser degree of deformation in the upper portion of the slope while a larger degree of movementwas taking place at the toe and the mid-slope, suggesting a **two phase failure mechanism (Figure 8).**Overall ground movement rates across the whole slope, were relatively small, less than 1 mm/hr, in the two months before the failure (Figure 7). The toe of the slope went first followed by the mid and upper portions of the slope as postulated in Figure 8.The low deformation rates in the period of October and November before the slough seems to indicate a stick-slip scenario, whereby the slope had experienced intense activity in July and August 2014 (Figure 6), and then stuck, leading to a quiet period. This same pattern had been observed earlier on in the year in April 2014, when there was a lot of activity followed by quiescence.On the day of the slough, 14th November 2014, a trigger of some kind, possibly the early rain seepage as shown in the appendix (Table VII) and Table V, little as it may seem, or blasting furtheraccelerated the massive ground movement over just a few hours, which coincidedwith theSSR®'information blackout'. The slope movement then stuck again, as found after the slough, whereby the trucks at the toe could even be rescued, and were notcompletely buried (Figure 2). The folded nature of the rock formations at the bottom of Nchanga Open Pit enhanced this failure mechanism due to the fact that the rock strata after being exposed 'day lighted' in the face as shown in Figure9.

The SSR® which works by principle of line of sight could not capture the excessive displacements at the toe of the slope with increase in depth of the pit (210mb). This is attributed to the fact that the mine site relies on the instantaneous 2-D deformation rates component of the SSR®. A 3-D analysis of the deformation vectors with the application of survey monitored pegs as shown by the example of survey prism in Figure 15 and associated prism location plan in Figure16 could be used to predict and mitigate slope failures at NOP.

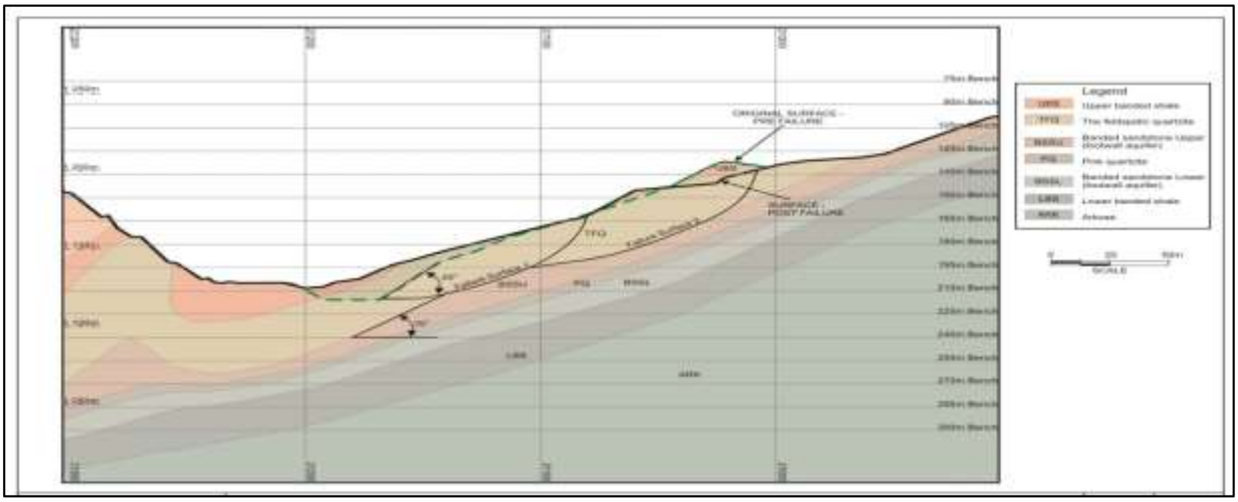


Figure 8: Two phase failure mechanism of Nchanga Open Pit Foot wall slope (Terbrugge, 2015)

Figure 9 illustrates the zones outside the radar coverage for deformation calculations and geological folded nature of section 33E.

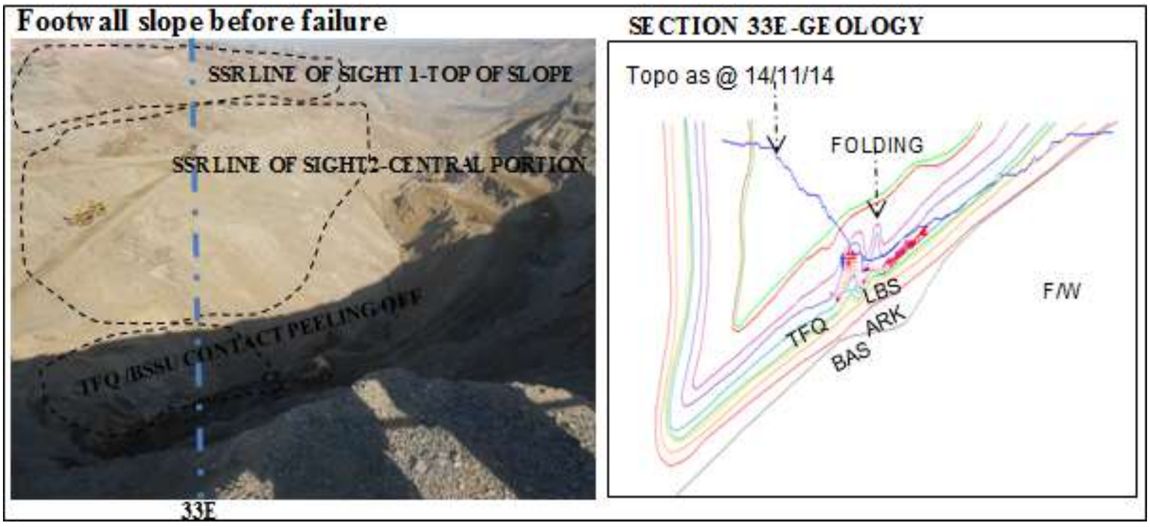


Figure 9: Footwall slope and geological nature of section 33E before failure

Surface/ground water management

Surface water management

From the surface of the south wall pit limit to about 30mb of the Nchanga Open Pit mine slopes, there was a continuous ingress of surface water as shown in Figure 10.From inception of Nchanga open pit mine, rock slope instability of the foot wall side of the mine has been as a result of the 20% effect of the water causing 80% effect on the slope instability. The source of this water isfrom three perspectives:

1. Unmaintained Nchanga stream diversion channel;
2. Theunmaintained man hole and sewerage drains servicing the nearby Nchanga North Township; and
3. Rain water accumulating in the fine rock mass and acting as a lubricant.

Figure 10: Sub - surface water percolating through the NOP Foot wall slopes (top) and the Eastern Extension sump

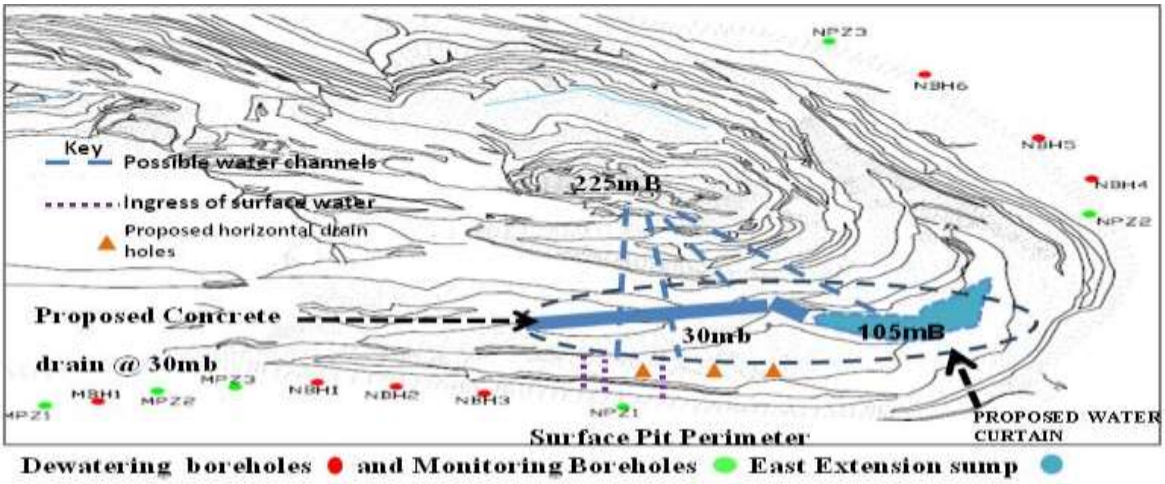


Figure 11: Pit layout and boreholes in the East of Nchanga Open Pit

From the practical point of view, creating a 'water curtain' (Figure 11) for the sub - surface water would have a huge impact on the stability of south wall at NchangaOpen Pit foot wall compared to the complementary options of resolving the primary root causes of the water from the diversion stream. SRK Consulting was key in assisting with the formulation of a strategy (Terbrugge, 2015). The fatal slope failure of 2001 established clearly the influence of water on slope stability at Nchanga.

The water curtain would involve but not limited to the following activities:

1. Mining out all the weak BSSU to the PQ plane to enable tracing of the water transportation causing slope instability.
2. Creating a deep concrete lined curtain drain along the foot wall with the objective of capturing all the water and directing it to controlled sumps.
3. Drilling of horizontal de-pressurizing boreholes from the foot wall into the concrete drain.

The alternative would beto de-silting the stream diversion channel and inspecting the integrity of the channel lining for mitigation measures. It must however be noted that ensuring continuity in the flow of water inside the diversion tunnel was unquestionable, as otherwise the mine would flood.

The maintenance of the sewerage drains is an easy but key aspect as well to resolve the mystery of the source of surface water which plays havoc with slope stability at the mine site.

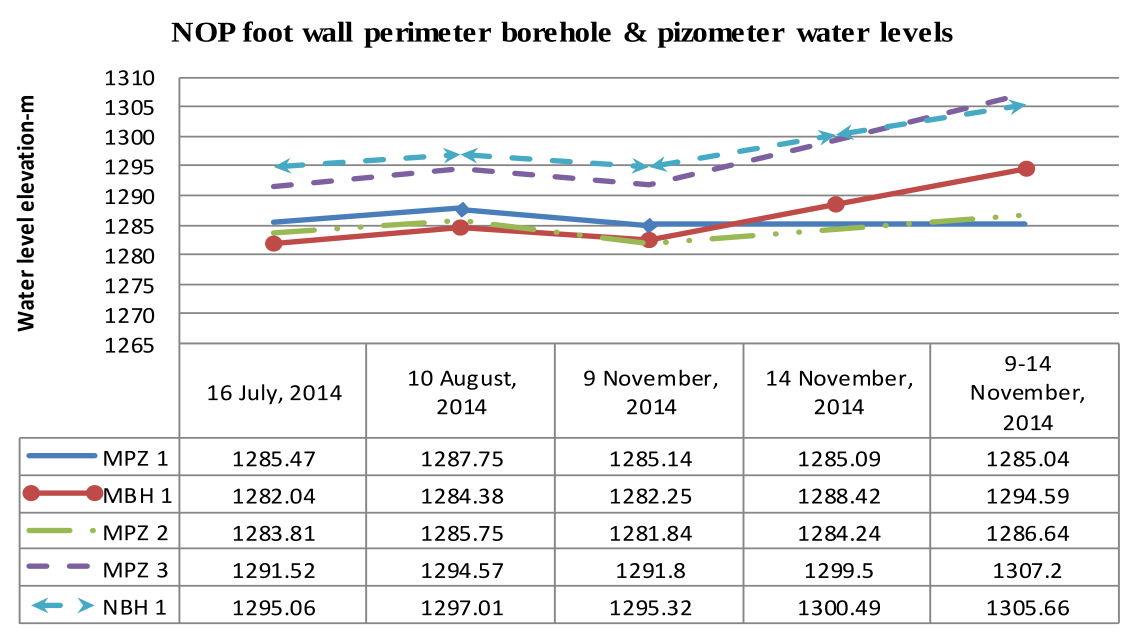
Ground water management

The rate of ground water recharge from the aquifers at Nchanga Open Pit is very slow. However, continuous pumping from the drilled boreholes along the pit perimeter is very critical as any rise in water levels from the perched aquifers can cause inflow of water through the fractured rock mass as evidenced in the month of November prior to the foot wall slope failure in borehole number MPZ3 which recorded 7.7m of water rise (Table III).

Table III: Ground water piezometer readings at the foot wall

	16 July, 2014	10 August, 2014	9 November, 2014	14 November, 2014	9-14 November, 2014
MPZ 1	1285.47	1287.75	1285.14	1285.09	1285.04
MBH 1	1282.04	1284.38	1282.25	1288.42	1294.59
MPZ 2	1283.81	1285.75	1281.84	1284.24	1286.64
MPZ 3	1291.52	1294.57	1291.8	1299.5	1307.2
NBH 1	1295.06	1297.01	1295.32	1300.49	1305.66

A trend analysis of the monthly water levels of the south wall pit limit bore holes was carried out as shown in Figure 12.



	16 July, 2014	10 August, 2014	9 November, 2014	14 November, 2014	9-14 November, 2014
MPZ 1	1285.47	1287.75	1285.14	1285.09	1285.04
MBH 1	1282.04	1284.38	1282.25	1288.42	1294.59
MPZ 2	1283.81	1285.75	1281.84	1284.24	1286.64
MPZ 3	1291.52	1294.57	1291.8	1299.5	1307.2
NBH 1	1295.06	1297.01	1295.32	1300.49	1305.66

Figure 12: NOP calculated South wall water profile

Impact of groundwater on the foot wall slopes of NOP-Back analysis [slide version 6.0]
Table IVillustrates the rain fall patterns at the mine site seven months prior to failure. From this table it could be seen that there was rain water accumulation in the fine back fill material of the foot wall.

Table IV: Monthly rain fall (mm) prior to failure (2013 - 2014)

MONTHLY RAINFALL PRIOR TO FAILURE (mm)

	MONTH	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	TOTAL
YEAR											
2013-2014			14.8	160.7	341	227	282.9	170.9	82.7		1280.0
2014-2015		12.7	9.9	3.7							26.3

When this water wastransported into the weak BSSU between TFQ and PQ, this resulted in creating a probability of failures of slopes as illustrated in the slide version 6.0 stability analysis results of table V.

Table V: NOP Foot wall stability analysis results using slide 6.0

SECTIONS	WATER [Hu] CONDITION	NOP FOOT WALL	
		FOS	POF [%]
31E	Hu=10%	1.106	0
	Hu=20%	1.008	0
	Hu=30%	0.911	100
	Hu=40%	0.795	100
	Hu=50%	0.68	100
32E	Hu=10%	1.225	0
	Hu=20%	1.134	0
	Hu=30%	1.043	0
	Hu=40%	0.846	100
	Hu=50%	0.692	100
33E	Hu=10%	1.258	0
	Hu=20%	1.134	0
	Hu=30%	1.009	0
	Hu=40%	0.885	100
	Hu=50%	0.762	100
33.5E	Hu=10%	1.42	0
	Hu=20%	1.272	0
	Hu=30%	1.123	0
	Hu=40%	0.976	100
	Hu=50%	0.824	100

Impact of geology on the failure

A 15 to 20m middling between the top of the mined TFQ rock mass horizon and the BSSU contact at the bottom of the pit compared to a 50m middling higher up on the western side of the failure was left to anchor the foot wall slope. This is coupled with an increase in the dip angle of the mined slope from 30° to 35° on the TFQ/BSSU contact near the 33E section and the folded nature of the rock mass accelerated the slope failure in a two phase mechanism as depicted in Figure13.

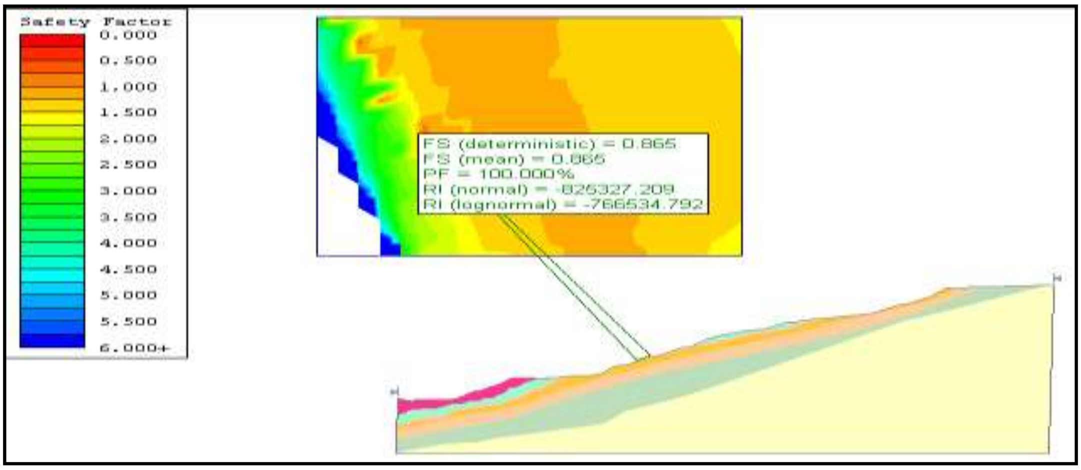


Figure 13: Impact of water on foot wall slope on Section Line 33.5 @ Hu = 0.4

Pit slope early warning strategy of slope failure management at Nchanga open pit mine

Nchanga Open Pit mine utilizes an accelerating creep theory which is time dependent and uses deformation rates from the near real time SSR® to predict slope failure.In an event of catastrophic failure on the SSR machine, theinverse velocity (Fukuno, 1985) method of tracking changes in the areas of movement as it progressively accelerate over period of time to predict slope failure time as illustrated in Figure14could enhance slope failure management strategy at the mine site.

With this tool, management of slope risks can be achieved and a focused approach to tracking slope movement from start to end and implementation of mitigation measures to reduce the risks of slope failure.

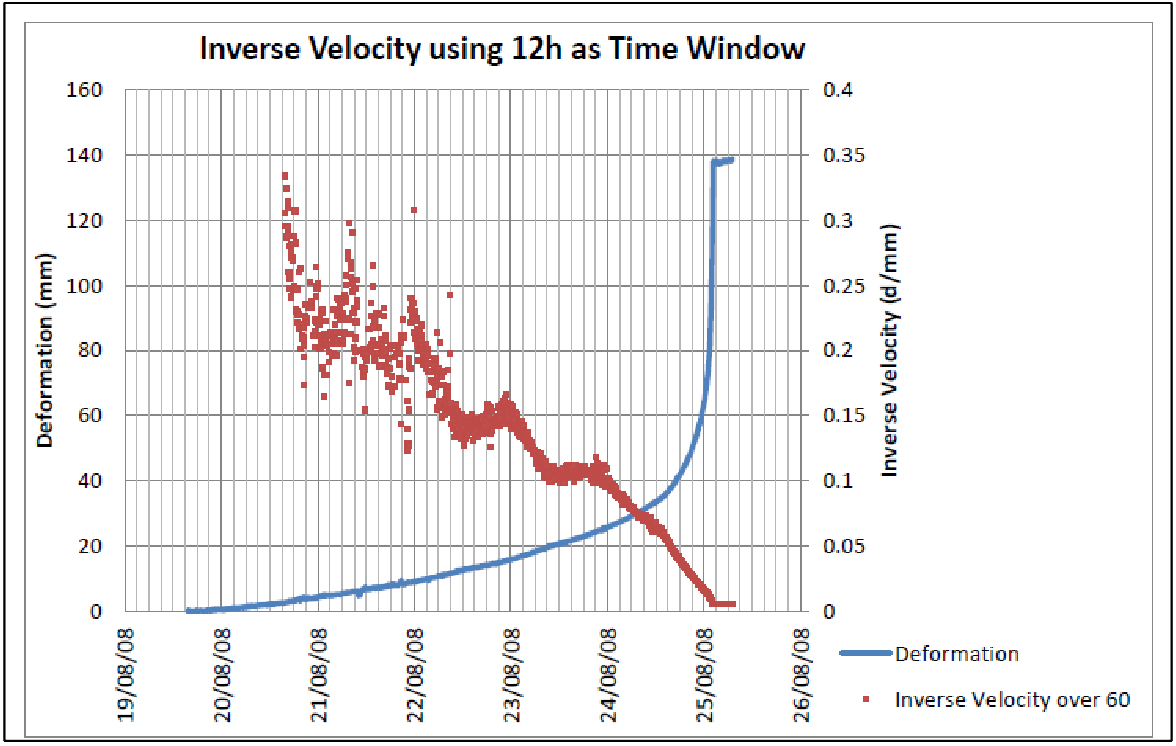


Figure14: Inverse velocity concept for prediction of time of failure of slope

The second back up data capturing mechanism was the re-introduction of traditional practice at the mine of installing target prisms (Figure 15) on the slope face of the south wall.

Figure15: Illustration of target and prism used at NOP foot wall slope

Figure 16 illustrates the proposed location of the target prism monitoring points for displacement calculations.

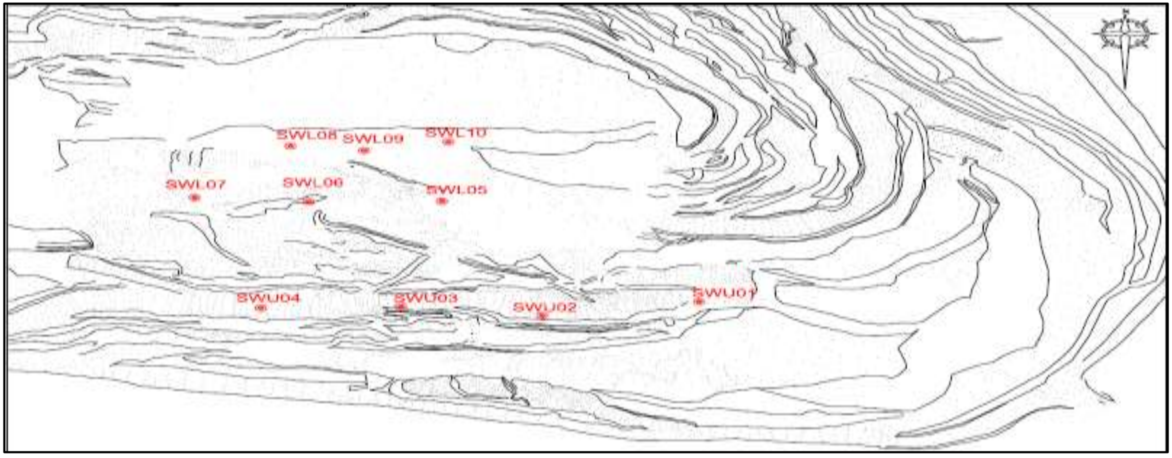


Fig 16: NOP CUTII Foot wall slope location of prisms for survey monitoring of deformations

Figure 17 illustrates the relationship of the slope zone to the area blasted before failure.

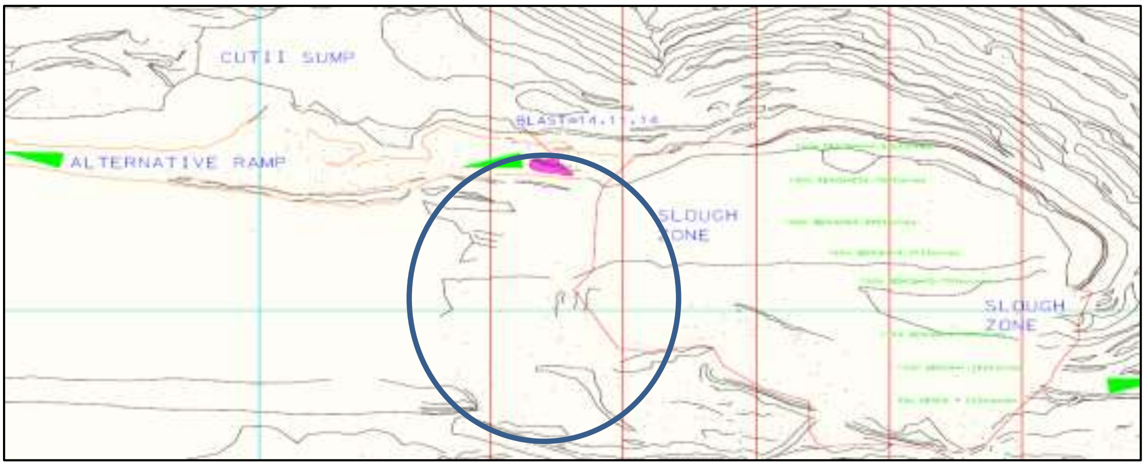


Figure17: Blast of 14th November 2014 in relation to Failure zone (circled)

INTERNATIONAL JOURNAL OF RESEARCH SCIENCE & MANAGEMENT

Conclusions

1. The pattern of displacement which showed a lesser degree of deformation in the upper portions of the slope while a larger degree of movement was taking place in the mid-slope and at the toe, suggested a two phase failure mechanism. The toe of the slope moved first followed by the mid-slope and upper portions of the slope was the failure mechanism which took place on the November 2014 slope failure at Nchanga mine.
2. Using a combination of slope failure early warning strategies such as the inverse velocity of slope failure time prediction together with the use of SSR® would enhance safety and productivity of the mine site.
3. From practical point of view, creating a ‘water curtain’ for this sub - surface water could have an impact on the stability of south wall at Nchanga open pit foot wall.De-silting the stream diversion channel and inspecting the integrity of the channel lining has practicality limitations.
4. The maintenance of the sewerage drains is an easy but key aspect to resolve the mystery of the source of surface water playing havoc to slope stability at the mine site.
5. Moreover, it could be concluded that though the blast on the day of failure happened720m away from the failure zone, it might have played a role in accelerating the deformation of the slopes which eventually ended up failing on the 14th November2014 in combination with other factors such the ingress of sub - surface water**.**

Acknowledgements

The authors wish to thank the Copperbelt University, Kitwe, Zambia and Konkola Copper Mines plc Zambia management, technical staff and consultants for their many inputs into this research too numerous to itemise individually. Any errors fully belong to the authors.

References

1. Brox, D. and Newcomen, W. (2003).Utilising strain criteria to predict high wallStability performance,ISRM 2003 – Technology roadmap for rock mechanics, SouthAfrican Institute of Mining and Metallurgy.
2. Bates, D.P.G. (2009).Case study of use of SSR system at Thompson Creek Mine in Idaho, USA.
3. Fukuno, T. (1985). A new method for predicting the failure time of a slope. Procs. 4th Int. Conf. and Field Workshop on Landslides, Tokyo, 145-150.
4. Hoek, E. and Bray J.W. (1981) Rock Slope Engineering. 4th ed. London: The Institute of Mining andMetallurgy.
5. KCM. (1999). Internal report. Survey Department, Nchanga Mine. KCM archives.
6. KCM. (2014). Internal report. Mine Safety Department, Nchanga Mine. KCM archives.
7. Martin, D.C. (1993). Time dependent deformation of rock slopes. PhD Thesis, University of London.
8. Silwamba, C. and Chileshe, P.R.K. (2015). Open pit water control safety: A Case of Nchanga Open Pit Mine, Zambia. International Journal of scientific and Technology Research Volume 4, Issue 08, August 2015. www.ijstr.org
9. Sullivan, T.D. (2007).Hydromechanical coupling and pit slope movements.Proceedings, 2007 International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering, ed Y Potvin, Perth, September 2007, pp 3 - 43.
10. Sullivan, T.D. (1993).Understanding pit slope movements. Proceedings of the Australian Conference on Geotechnical Instrumentation and Monitoring in Open Pit and Underground Mining, (Szwedzicki Ed.) Kalgoorlie, Balkema, pp.435-445.
11. Terbrugge, P. (2015). Two phase failure mechanism. Personal communication. (10 January 2015).
12. Terzaghi, K. (1950).Mechanism of landslides. Application of geology to engineering practice, Berkley Volume, Geol. Soc Am., pp 83 - 123.
13. Wessels, S.D.N. (2009).Monitoring and management of a large open pit failure. Master’s Thesis, University of Witwatersrand, Johannesburg