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Validation of the Slope Monitoring Programme at Nchanga Open Pit Mine, Zambia

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Abstract: Nchanga Open Pit (NOP) mine, where this research was carried out, is the second largest underground copper mine in Africa. Of late, NOP facing geotechnical problems such as pit-wall instability that resulting in wall failure, disruption to normal operations, loss of assets and increasing mining cost. Above all, any such incidence severely affects the moral of the workers.To validate existing safety programme at NOP a two year research programme was contracted to the University of Zambia, School of Mines. The articles reports on outcome of the research modifying the existing pit wall angle which is found promising.

Keywords: factors, risk analysis geotechnical parameters, validation, pitslope, safety

1. Introduction

Zambia has a long history of surface mining. This has created geotechnical problems such as slope failure in both soil and rock has presented a lot of challenges over the past. The Nchanga Open Pit (NOP), where the research was carried out is the second largest in Africa. Mining from this pit has presented a lot of challenges over the past. Safety of slopes had been the biggest challenge of the pit and its surrounding satellite pits that caused extensive damage to equipment and loss of production. Since then, increased awareness towards determination of safe slope angle, high level of slope monitoring technology and new management strategies.

The paper reports on the methodology used in this research mainly based on geotechnical parameters for safe design of the slope pit.The Nchanga – Chingola region Open Pit F and COP F/D Phase III was thestudy area where this research was carried out.

Figure 1 research site location

Figure 2. Nchanga-Chingola aerial view

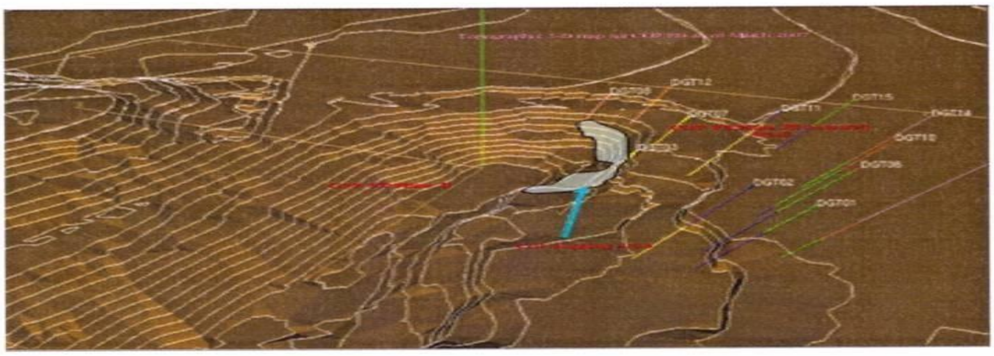

Figure 3 3-D model of COP (FD)

Figures 1, 2, and 3 shows the physical location of Nchanga Open Pit Mine Research Site aerial view of the same and 3-D model of the same

The present practice of NOP is that:A routine mapping of accessible pit slopes and remote mapping of the sites was carried out. Although this information is contained in EXCEL spreadsheet database but not always fully presented on contour plans and sections. Hence it was thought to have a better database system needs to be set up for better presentation on contour plans and section. The stability of the designed slopes requires to be determined through detailed analysis, may be using kinematic principles to determine whether the given relative orientation of major discontinuities and pit walls failure will occur. If so, what will be the most likely mode of failure? The earlier studies have indicated that most likely mode of failure is plane sliding and to a less extent, wedge failure. Having established the kinematic feasibility of the designed slopes the next step should be to establish the factor of safety or probability of failure and also the mechanism of failure.

2. The Latest Trend (At Cop F.D)

To maintain the stability of the rock slope a constant check is necessary. The current management has introduced a number of measures and operating instructions to provide for safety of men and equipment. These include:

- The management has deployed the ground probe slope stability radar (SSR) imported from Brisbane, Australia to monitor 24-hour slope movement with a very high degree of precision. The SSR is able to record displacements at over 3000 points on the slope at approximately 15 minute intervals. This provides the ability to identify and trace movements with such intensity to management as to whether mining operations should continue or be suspended. The SSR system is fully self-contained, hence it can be installed at any site without difficulty. This equipment is not affected by darkness, rain or dust.

The main objectives for slope monitoring strategy are;

- Maintaining safe operational systems and procedures to protect personnel and equipment
- To provide notice of potentially unstable ground so that mine plans can be modified to minimize the impact of slope displacement
- To provide geotechnical information for analyzing any slope instability failure mechanisms, including the design of an appropriate remedial action plan and conducting future slope designs
- Assessing the performance of implemented slope design; and
- Building up a history of information to determine different rock behaviors over a long period of time of monitoring.

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- The pictures scanned by SSR are sent to a computer in the control room through a radio link. The control room has the system to raise an alarm automatically should there be a sign ofexcessive slope. This enables the workers and equipment to be quickly removed to a safe site. This has given the improved productivity, reduction in down time and improved understanding of time related effect of blasting on the slope stability
- Several monitoring points were established and daily survey is carried out to give 3-D co-ordinates of all points.
- Control towers were built at few sites and the person in-charge were provided with radio communication system so that they can inform the geotechnical office and other senior officials immediately in case they notice any movement in the slope.
- Front – end – shovels (rubber tyred) were introduced in place of ordinary shovels so that in case of emergency, they can be quickly moved to a safe place.
- “Movement rate trigger level” guidelines were drawn (based on past experience of failures) and this is being regularly revised and made known to relevant personnel.
- Water drainage systems around the open pit were improved to stop water logging at any point.
- Strict checks on under-cutting of the slope were severely dealt with. This has generally helped in maintaining the slope stability.

- Estimating the safety factor, based on height to slope ratio, using software has become a part of the planning for production.
- The use of rock bolts were encouraged at the weak section of the rock slope.
- Whenever there is a temporary stoppage of production, mainly due to severe weather conditions (storm or rain) it was made necessary to obtain approval of the senior geotechnical officials to resume the work.
- The frequency of inspections and the review of procedure are reviewed periodically.
- A high resolution digital camera has been set to record images regularly.

3. Research Methodology

The approach of this study has included field visits, laboratory work and desk analyses. In addition, field observation of pit slopes and the trends of smaller failures provided helpful information on the general characteristics and behaviour of the rock slopes.
Site investigations formed the largest part of the research activities as raw data was collected on which this whole study depended.

Geotechnical core logging

Geotechnical core logging was the first activity in data collection method for this study. Physical inspections of the rock cores were done at the time of drilling up to the core storage shade. Logging was also conducted on cores that had been drilled a long time before the onset of this study. This gave an opportunity to compare the particular parameters of core from various places but belonging to the same area formations.

Slope cracks monitoring

Tension cracks presented a geotechnical challenge in slope management. Site inspections were conducted at almost all slopes to identify and locate tension cracks. Extensometers were used to monitor the progress of these cracks. Electrical triggers in the extensometers were helpful in giving early warning signs for the evacuation of workers in case of a slop failure. Also other cracks were buried to prevent soaking the infill (especially kaolinitic) which would reduce the shear strength of the discontinuities.

Study of potential slip surfaces

The cell mapping was conducted to obtain information on the geologic structures characterizing the site under investigation. Mapping was carried out in cells. The slope faces in the pit were demarcated and the coordinates were picked for areas of maximum horizontal distances of 30m. photographs of these cells were taken for later analysis. Physical investigations fo the area were then carried out by inspecting the ground for various geological structures, with emphasis on the discontinuities. During the cell mapping the discontinuities were classified according to the way the infiling was found and they were rated towards the strength of in-situ conditions.The mapping information was recorded on mapping sheets specifically designed to capture as much information as possible on the pit slope faces. From this designed database, initial rock characterization was done to get rock mass parameters for rock classification by Bieniawski$_{89}$ and Laubscher$_{90.}$

The rock characteristics analysed by geotechnical cell mapping were compared to those determined in geotechnical core logging. This helped to close up gaps of incongruence and reduce descriptive errors.

Table 1 Software Used In the Analysis of Various Parameters

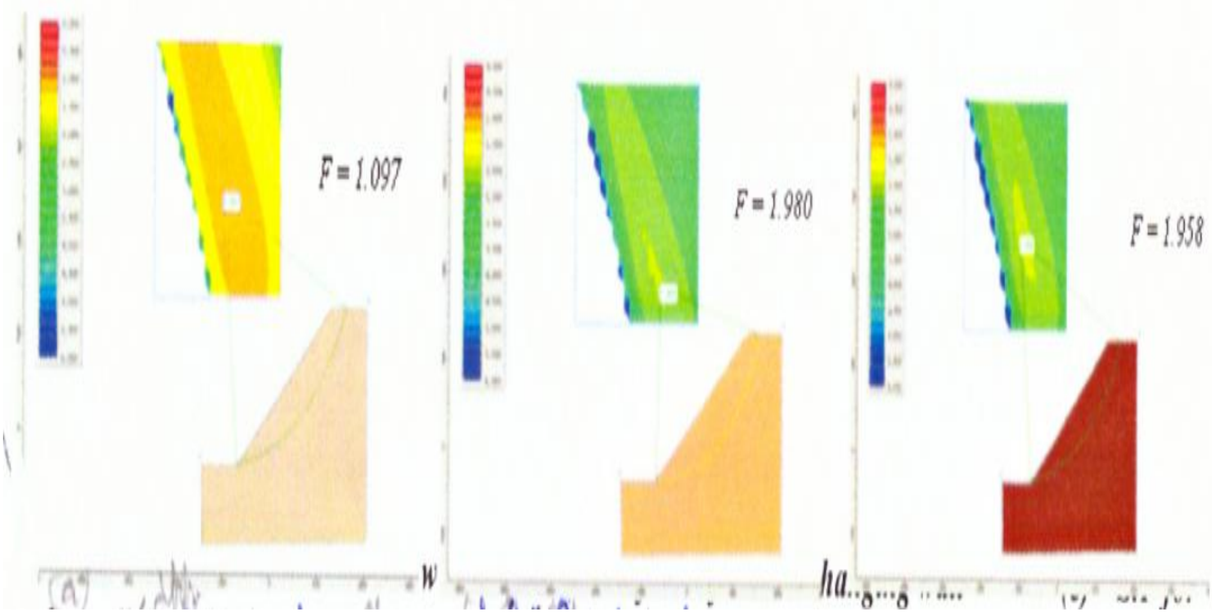
Software	**Data input**	**Key variables**	**Expected data output**	**Comment**
Datamine	Borehole ID (e.g. x,y,z coordinates). Geological data optional info. (e.g. weathered zones , weak spots, etc)	Survey data (hole identifiers) geological formations and contact points / depths	Colour coded 3-D models of 'desurveyed' bore holes, digital terrain models (DTMs), zones of influence	Very useful in graphical visualization of important aspects of the pit during design stages.
DIPS	Discontinuity setting, type, material descriptions (e.g. strength, weathering, etc)	Dip angles Dip direction/trends Coordinates and major and controlling discontinuities	Stereographs, discontinuity density and their trends dips Comparison of various planes	Is useful in itself for plane failure analysis

RocLab	Field cell mapping data observed blasting effects rock mass characteristics (e.g. field strength values and surface qualities)	Rock strength values Rock quality designational data (e.g. surface quality, cracks and jointing) petrologic data	Shear strength data (cohesion, frictional angles, hoek brown failure criteria parameters)	Useful in determination of field estimated design parameters especially in the absence of triaxial test data
SLIDE	X,y,z coordinated of sectional slices. Shear/material properties from Roclab Cracks and ground water models	Cohesion and frictional angles from RocLab Orientation and dip of tension cracks	Safety factors Indication of slip surfaces	Analysis of failure along a failure plane.
SWEDGE	Orientations of discontinuities form DIPS (mapping) Slope heights and shear parameters from RocLab	Cohesion and frictional angles Dips and trends of joints and slope surfaces	Safety factor and its distribution for deterministic and probability of failure analyses for wedges Orientation of the line of intersection of the planes	Useful for modeling wedges at various locations Useful also in a risk analysis (probabilities)

Table 2 Results obtained from software used in the analysis of various slope design parameters

Stack	Rock formations	Stack Height (m)	Stack RMR		Density (MN/m^3)	Internal friction angle (Deg)	Cohesion (c) (MPa)	Overall slope angle (Deg)	Pit Design	
			Bieniawski	laubscher					Berm width (m)	Slope face (Deg)
Upper hanging wall stack	URD, SWG, CDOL, DOLSCH	60 - 200	37	32	0.026	32.46	0.226	30-35	10	65
Lower hanging wall stack	UBS, TFQ, TFQT, BSSU, PQ/SM, BSSL, LBS, TR	30 - 70	39	36	0.025	40.01	0.29	37 - 42	10	70
Footwall stack	ARK, BAS	40 – 80	57	53	0.027	41.91	0.419	39 - 45	10	70

Other information was collected by observational visits in the field. As the research period was stretched over different seasons, care was taken to determine the effects of seasonal during the rainy season, observations were made on water seepage rates in various positions. Areas where tension cracks were suspected were found to be very susceptible to failures in the rainy season much more than they were in dry seasons.



(a) Upper hanging wall (b)Lower hanging wall(c) Footwall

Figure 4: Factors of safety for three different sections

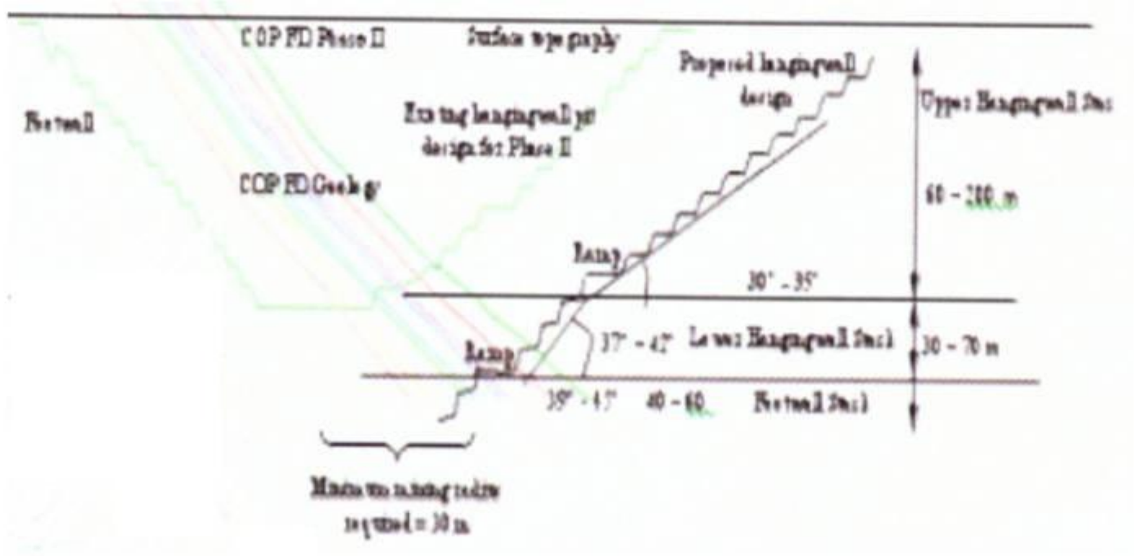


Figure 5: Proposed pit design slope angles for the above S.F

4. Risk Assessment

The greater incidences of major slope failures in open pit mines has increased the need for risk assessment. For qualitative evaluation, risk is defined as the product of the "probability" and "consequences of events" i.e. risk = (event) (consequence).

Reliability of a rock assessment process is a function of harnessing all valuable information source and is compiled from most reliable data to be faced into the risk analysis process.

During the research, comprehensive risk assessments were done for few production open pit faces and the results from some faces are given in Table 5 and 6 which show cost analysis for the same.

Table 4: Risk assessment for a few production faces

SLOPE SITE	RISK LEVEL SAFETY/ECONOMIC	MITIGATION	SUMMARY
Ramp slope, western wall. COP F-D Phase III	E: Needs constant monitoring to prevent undercutting of ramp	• Detailed monitoring in place to be maintained. • Anchor load testing on a regular basis	• Acceptable low risk, but implications of failure that would destroy ramp are high
Upper slope western wall	S: Upper slope – low. Latter stages, mining may undercut BSS. E: Moderate to high depending upon accepted design	• Requires a detailed design and crack monitoring • Detailed monitoring if BSS is to be undercut in lower slop	• Potential high risk in lower slope. • Detailed design/review required before mining design can be completed. • Possible revised mining plan.
Eastern wall OB 5 (dump area)	S: High on OB (dump) situated on footwall. Probable local mobilization of failure debris. E: Low provided geotechnical design accepted		• Acceptable (moderate to low) risk levels provided mining carefully controlled and detailed monitoring in place. • Field modification design to be expected

5. Results and Discussions

This section describes the results, their analysis and discussion of the findings. This approach has been adopted to aid the reader in following the findings and discussions of on objective without disruptions. A brief summary of the major findings are then presented and the chapter ends with a short reflection or the data analysis tools for the study.

The results of the study on slope design parameters for COP future development phase III are presented in this section. These results were determined from various stages of data collection and are analysed concurrently.

Methods of data collection such as drill core logging and geotechnical mapping were given special attention because they have a great bearing on the quality of designs that they will give, which stems from the quality of data collection.

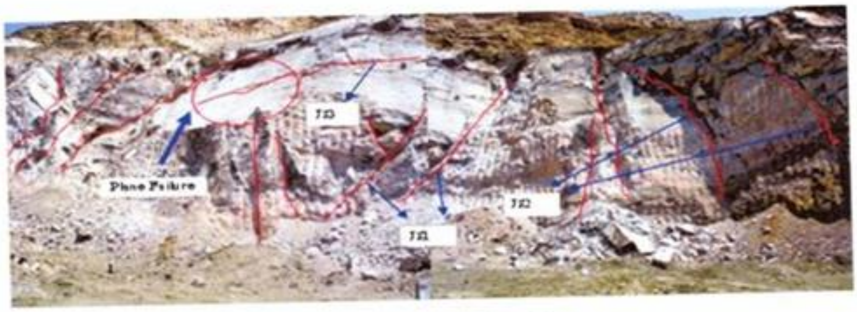
Detailed core logging of geotechnical drill holes was carried out to determine rock mass characteristics which were critical factors fo the geotechnical zones of the study site. The Nchanga Open Pits uses the rock mass classification system devised by Laubscher (1990) while the Bieniawski classification is used as a reference system to check the accuracy of the Laubscher classification.

Table shows the rock mass ratings that were determined from drill core logging. It can be seen from the table that the Laubscher rating isconservative (lower values) as compared to the Bieniawski rating. This is due to the adjustments that have been included in the Laubscher rating for mining.

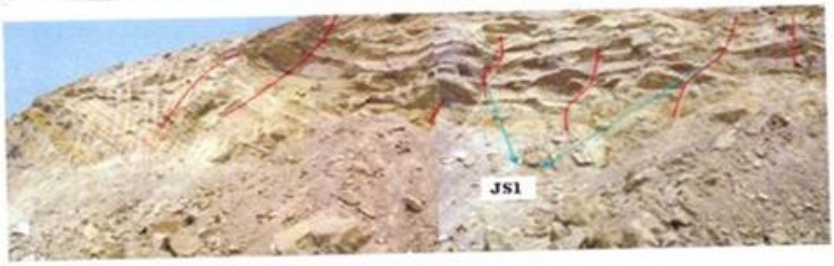
Cell mapping (field mapping) at COP F/D phase II, where in-depth information on the rock units was obtained. Face mapping was carried out on the western wall based on benches in phase II adjacent to phase III. As in core logging, mapping was a source of design information used for rock mass characterization and geotechnical zones identification.

Face mapping was carried out in benches starting from the newly mined 105mb. This bench was found to be characterized by the Feldspathic Quartzites (TFQ) to some extent and Arkose (ARK) to Lower Banded Shales (LBS) to a larger extent. The mineralsiation at this depth is of high grade copper. The rock mass in this locality is leached and highly weathered due to a shallow water table. Table 4 shows the face mapping information collected at this bench.

Photograph 1. 105 meter bench mapping site



Photograph 2. 90 meter bench shows area of mapping site



Photograph 3. 75 meter- bench mapping site

Photographs 1, 2 and 3 are mapping sites

Table 3 Results from mapping for various slope faces. COP F/D Phase II

Discontinuity type	**Dip**	**Dip direction**	**Comments**
JS1	**60**	**70**	Highly persistent jointing, hard in-filing in some places, highly weathered generally, groundwater conditions determined from an independent study of the hydrology of the area.
JS2	**78**	**127**	
JS3	**88**	**175**	
B	**53**	**258**	
Discontinuity type	**Dip**	**Dip direction**	
JS_1	**76**	**147**	HW, hard, leached, moist, smooth and stepped joints. Highly broken, dark grey, micaceous, flaky
JS_2	**74**	**60**	
B	**55**	**260**	

Photograph 1 indicates areas where the information in Table 4 was picked, from which stereo plots were constructed. It shows at least two joint sets while photograph 2 shows the possibility of wage failure and indicating the presence of at least two joint sets. The bedding here dips into the face thereby improving stability. Whereas photograph 3 shows highly weathered sediment structures due to atmospheric conditions.

Fig. 6 describes stereographic projections showing both bedding and joint orientations. The planes presented are the slope face, bedding and joint planes. The general slope face designed was to plunge at 70 degrees eastwards (i.e. 70 deg dip, 90 degree dip direction).

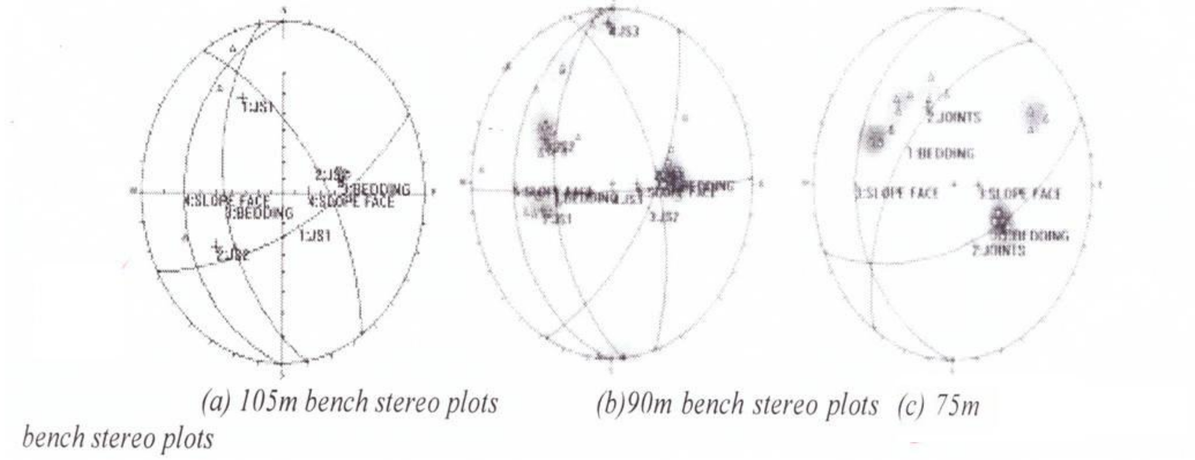


Figure 6 The 105m, 90m and 75m bench stereo plots

The 90m bench had various geotechnical structures. There were several planes of discontinuities oriented in different directions. However, the overall conditions of the rock mass (generally weak and highly weathered, leached and sheared) gave it a different rock mass behaviour in failure propagation which was inclined towards planar or semi-circular failure.

6. Conclusion

Drill core examined during core logging comprised of newly drilled core and that left from previous analyses and activities. Logging of the previously drilled core provided the ‘missing’ information for various areas of the study site. A total of 3000m of core was logged in this exercise, which formed an important basis for information collection for the research.

Geotechnical mapping done in cells was successfully carried out with over $13000m^2$ of the area mapped. A challenge arose in mapping inaccessible areas, a few of these areas had been mapped before and so a simple photography-assisted mapping was done. The information from mapping and core logging provided a vast array of information for the geotechnical zoning of COP FD. These zones were designed by considering rock mass behaviour and the slope designs in this research have been compared with those used in phase I and II. Two geotechnical zones have been suggested in this study for the hanging wall in phase III while only one zone exists in the hanging wall for phase II. An increase of up to 35% in the cost of mining at the slope of 30^o in the hanging wall and 3% in the footwall at the angle of 39^o.

A risk assessment was carried out and three risk areas were identified (during this research) that needed extra attention. These risks were either economic or safety related. Risks were compounded by seasonal rainfall which was responsible for major slope instability of pit slopes. With annual rainfall of 194mm many slopes were found to be highly saturated due to which tension cracks were weakened and sliding was unavoidable in weak formations.

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