SANJAY PRASAD DUBEY
MANISH D. UTTARWAR
and
M.S. TIWARI

Reliability study of 42 cum rope shovel under diverse geo-mining parameters: a case study

Today's mining industry demand large-capacity shovels and dumpers for mega production and low-cost operations. While increased mechanization and automation make considerable contribution to mine productivity, unexpected equipment failure prohibit the maximum possible utilization of sophisticated mining equipment and require significant amount of extra capital investment. With regard to productivity, till date reviewed literature does not indicate any bench mark nor it could be established for the shovel-dumper based production equipment system in Indian mines due to varied working conditions, different geo-mining profiles and deployment methodology. High equipment reliability is a choice of globalised competition. High equipment reliability is achieved by ensuring the minimum chance of incidents that cause failures of equipment. To maintain remarkably long and trouble-free equipment lives, it becomes dire necessity to keep parts and components at comparatively low stress levels and within suitable operating geo-mining conditions prevailing inside the mines.

On the other hand, technological changes, market depressions, increasing labour and maintenance costs and the uneven operating environments have driven the economies of scale towards low-cost bulk production method. The natural environments of surface mining operations create different challenging conditions which include limitation of space, weak overburden material, weathered soils and rocks, drainage, weather conditions etc. Thus, the industry faces enormous challenges in the selection of appropriate mining equipment to meet technical, operating, safety, environmental and economic requirements. The need for understanding the real issues that affect the real choices for bulk surface mining operations is critical for achieving economies of scale. Thus it has become eminent to study the reliability of machinery under the given geo-mining conditions in order to keep down time to a minimum.

In this paper reliability analysis of 42 cum shovels and its prediction under different geo-mining parameters with an emphasis on compressive strength of overburden material is presented with a case study of Gevra mine, being the largest coal mine of Asia. Availability and reliability of HEMM are the functions of geo-mining conditions, so there is a need to study and formulate a guideline in this regard. In this study failure data of 42 cum shovel has been correlated with compressive strength of overburden material as one of the prime parameter of prevailing geo-mining conditions. The reliability is evaluated using Weibull Analysis method.

Keywords: *Geo-mining conditions, shovel-dumper, reliability, rel. evaluation, Weibull analysis.*

I. Introduction

Global competition requires demand for reliable technology and equipment for optimum utilization. Operational reliability analysis is an important research area, specifically in the early operating phase of the equipment to verify whether the reliability of the sub-systems of the equipment meets the required bench marks. Its correlation with different geo-mining conditions in the mines will be helpful in planning maintenance schedules, inventory management and thus improving the overall availability.

In this study, an operational reliability-based methodology is developed for electromechanical systems. It overcomes the drawbacks of other reliability evaluation approaches which are not suitable for complex geo-mining production systems with limited failure data. This methodology is integrated with distributions and evaluates the equipment reliability at different operating time. Uncontrolled interactions between machine and environment negatively affect operational performance. In this paper, failure data and geo-mining parameters are studied together to establish machine-environment interaction where the system has the highest failure rate among all conditions of machine operations.

Gevra opencast mine was established in the year 1981 and has sanctioned capacity of 40 million tonnes production per annum with an average stripping ratio of 1.3 cum per tonne. There are 4 major coal seams with average thickness ranging from 117 m to 174 m and gradient ranging from 1 in 6 to 1 in

Mr. Sanjay Prasad Dubey, Senior Manager Gevra OCP, SECL Bilaspur, Chhattisgarh, Email: sanjaydubey806@yahoo.com, Dr. Manish D. Uttarwar, Professor and Head, Dept. of Mining, RCERT, Chandrapur, Maharashtra, Email: udmanish@gmail.com and Prof. M.S. Tiwari, Associate Professor, Ramdeobaba College of Engg & Management Nagpur, Maharashtra, Email: Ms.tiwari@yahoo.co.in

12. The depth of the mine is 160-300 m. As the thickness of coal seam is high and seam gradient is smooth, surface miners are used for coal production. The width and height of coal bench is approximately 30 m and 10 m respectively with slope of 60^0 to 75^0. Overburden removal is carried out by shovel-dumper combinations with large diametric deep hole drills. The width of overburden bench varies from 30 to 35 m and height is about 20-21 m for the 42 cum shovel.

Gevra opencast project is one of the prominent mines of S.E.C.L with annual coal and overburden production targets for the year 2014-2015 slated at 40 million tonnes and 49 million cubic meters respectively. The project is planned to produce 70 million tonnes of coal in the near future. Gevra OCP possesses an array of mining equipment which are more complex, sophisticated and capital intensive. To meet the prevailing targets, the project thus demands not only for better but increased equipment reliability [12].

II. Mechanism of 42 cum shovel

Electrical rope shovel (ERS) is mining excavator which is used for removal of overburden material. These shovels are classified in accordance with their bucket sizes. The total machine is divided into three major structures namely lower structure, upper structure and attachment. The major components of lower structure are car body and crawler frame; upper structure has revolving frame, machinery house and the operator cabin; attachments include boom, dipper handle and the dipper.

The power utilized is three phase 6.6 kV. The recommended power is supplied from the substation to the feeder breaker. From feeder breaker it is supplied to the field switch of the particular shovel. From the field switch it goes to high voltage collector shoes through coupler. These HV collector shoes are spring loaded which is connected to the high voltage collector rings (HV rings). HV rings pass the electricity to high voltage cabinet (ZHV). In this ZHV there are current transformers which calculate the current in the particular phase and potential transformers which calculate the voltage in the particular phase. From this ZHV electricity is passed to main disconnect switch (MDS). From the MDS; two secondary are connected; one is auxiliary power transformer (APT) and the other is drive power transformer (DPT). APT is connected for all the auxiliary components like lighting, blowers, motor control center (MCC), breakers, PLC etc. DPT is connected to the insulated gate bipolar transistor (IGBT). In IGBT the AC current is converted to DC current and again this DC current to AC current in order to stabilize the high fluctuation of the current. From this IGBT, the final AC current is connected to the motors.

There are a total of six main motors for the major machine motions like hoist motor, crowd motor, two swing motors and two propel motors. All these motors are attached with a blower motor for maintaining the temperature of the bearings.

III. Reliability assessment for of 42 cum shovel

As stated earlier, 42 cum shovel is considered in this case study for evaluating the reliability. System modelling has been done by Weibull and exponential distribution procedure. Reliability block diagram (RBD) is the method chosen for reliability modelling of the system and is shown in the Fig.1.

IV. Methodology

The reliability evaluation of electromechanical system of the 42 cum shovel under different geo-mining conditions is as shown in the Fig.2.

The above flow chart involves six steps for the case study of reliability evaluation of 42 cum shovel under different geo-mining parameter with particular emphasis on compressive strength of OB material using Weibull analysis method. Sub-systems and components of the given system are identified as they determine their functional relationships. Failure data of the components under the given geo-mining condition have been collected from equipment log book at field for the period 26-08-2010 to 25-08-2014. This method is applicable in early operating phase when limited failure data is available. OEM generic data of components which specifies life of the

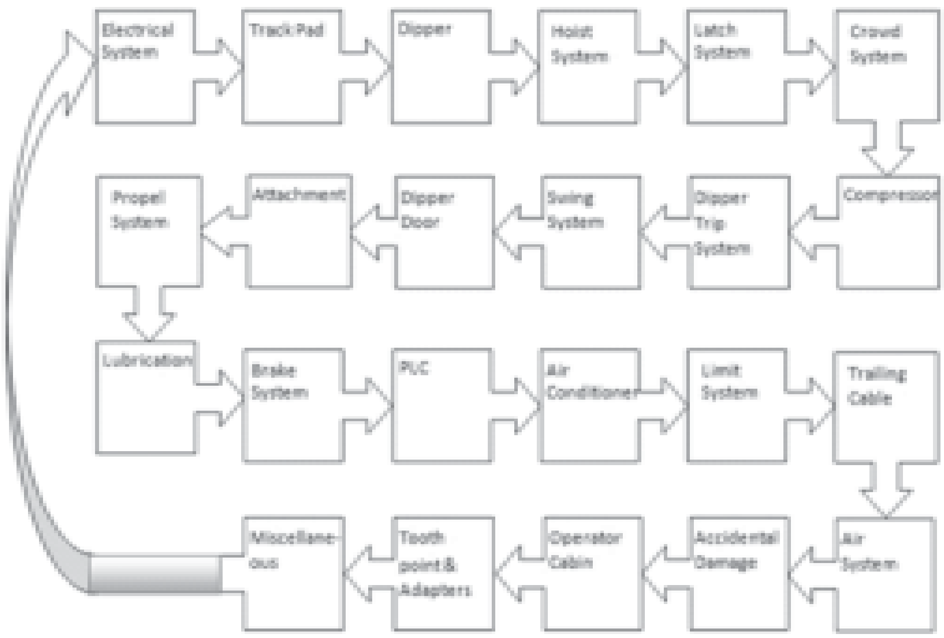


Fig.1 Block diagram for reliability evaluation of electromechanical system of shovel

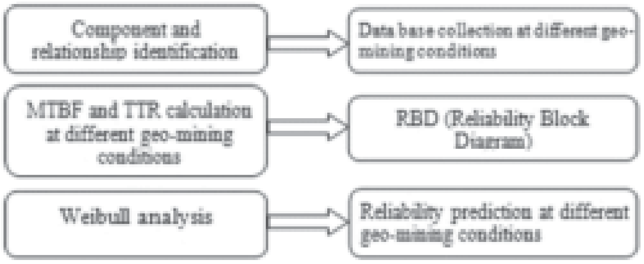


Fig.2 Flow chart for reliability evaluation method of 42 cum shovel Ref: [12]

particular components has also been considered. The failure of the selected components (even a simple light) leads to system failure and system operation breakdown.

A. Geo-mining parameters of Gevra OCP

The entire block of Gevra project is capped with thick soil cover. The general strike of the strata is NW-SE to E-W in major part of the block. Generally the dip direction is south and SW in the major part of the block. The existence of three well defined coal seams has been proved and is named as lower Kusmunda, upper Kusmunda and E&F in ascending order [1].

The geo-mining parameters like compressive strength, tensile strength, shear strength etc. of OB material to be handled affecting equipment reliability are considered in the analyses. Initially, the compressive strength of four different locations has been correlated with failure data of machine in respect of machine locations for assessing the equipment reliability.

From the obtained borehole logs, geological and litho-logical details were studied for the particular selected locations. The average compressive strength of the strata for the selected locations is computed and is depicted in the Tables (1-4).

The face length, height and width were almost equal for three different locations. Component failure data of shovel for these locations was collected for the period from 26-08-2010 to 25-08-2014.

Table 1: Location 1 (Year-2011); With courtesy [2]

Litho logy	Thickness (Mts.)	Compressive strength	Avg.compressive strength, kg/cm^2
Soil sandy	4	310	
Sand stone (fine grained)	4.5	227	
Sand stone (coarse grained)	108.77	127	
Coal	1.0	206	
Shaly coal	0.11	162	154.42
Carb. shale	0.56	337	
Sandy shale	5.16	297	
Shale	3.51	147	
Intercalation	8.93	252	
Sandstone pebbly	1.7	330	

Table 2: Location 2 (Year-2012); With courtesy [2]

Lithology	Thickness (Mts.)	Compressive strength	Avg.compressive strength, kg/cm^2
Soil sandy	6.23	261	
Sand stone (fine grained)	8.6	55	
Sand stone (medium grained)	29.93	75	
Sand stone (coarse grained)	36.48	96	124.30
Carb. Shale	0.97	259	
Sandy shale	12.27	266	
Intercalation	13.87	156	

Table 3: Location 3 (Year-2013); With courtesy [2]

Lithology	Thickness (Mts.)	Compressive strength	Avg.compressive strength,kg/cm^2
Soil sandy	4.85	238	
Sand stone (fine grained)	9	110	
Sand stone (medium grained)	32.9	43	
Sand stone (coarse grained)	37.15	52	89.94
Carb. Shale	1.02	152	
Sandy shale	13.19	241	

Table 4: Location 4 (Year-2014); With courtesy [2]

Lithology	Thickness (Mts.)	Compressive strength	Avg.compressive strength, kg/cm^2
Soil sandy	4.5	276	
Sand stone (fine grained)	19.21	200	
Sand stone (medium grained)	19.46	150	
Sand stone (coarse grained)	55.44	110	142.26
Coal	0.55	133	
Shaly coal	0.76	158	
Carb. Shale	2.35	205	
Shale	8.4	104.5	
Intercalation	6.88	155.5	

B. Reliability Assessment

The reliability analysis has been done by using Weibull analysis. Weibull analysis is a method for modelling data sets containing values greater than zero, such as failure data [4]. Weibull analysis can make prediction about a products life, compare the reliability of competing product designs, statistically establish machine life with respect to mining parameter or proactively manage spare parts inventories. Frequent breakdowns, types of breakdowns, interval between breakdowns etc. are the main data used here. The formula for reliability assuming a two parameter Weibull distribution is as follows:

$$R(x) = e^{(-(x/\text{á})\ \hat{}\ \text{â})} \text{ ; for } x > 0 \qquad \ldots \ldots (1)$$

Where "â" is the shape parameter,

"á" is the characteristics life and

"x" is the time to failure.

The most important process is to analyze and compute the collected data by calculating the median rank and performing a simple linear regression to obtain the parameter estimate that help to infer the reliabilities of the machine and systems.

The median rank is approximated by using Bernard's approximation using the formula

F (t) = (i-0.3)/(n+0.4) ... ... (2)

Where "i" is the corresponding rank of the data and "n" is the total number of breakdown samples.

C. Weibull Analysis

The type of Weibull distribution used in this paper is called, "Two parameter Weibull distributions". This simple form is adequate for majority of Weibull analysis scenarios. The main benefits of Weibull analysis is to forecast the failure probability with extremely small samples and also to provide reasonable accurate failure analysis. Using Weibull analysis, the problems can be predicted in the earlier stage and accordingly can be solved. The primary advantage of Weibull analysis is graphical line fit plots of failure data which are useful in understanding the failure characteristics. In the Weibull graphical line fit plot, the horizontal scale represents the measure of life or operating time and the vertical scale represents the cumulative failure percentage. The two defining parameters of the Weibull line are the shape parameter â, and the characteristic life á.

The main scope of work within the ambit of Weibull analysis are plotting the data and making interpretations from the plot, failure forecasting and prediction, evolving corrective action plans, substantiation for new designs with minimum cost, maintenance planning, cost effective replacement strategies, spare parts forecasting etc.

D. Use of Microsoft excel for Weibull analysis

The Weibull distribution's strength is its versatility. Depending on the parameters' values, the Weibull distribution can approximate an exponential, a normal or a skewed distribution [4].

The Weibull distribution's virtually limitless versatility is matched by excel's countless capabilities. An astute data analyst who understands the theory behind a given analysis can often get results from excel that others might require specialized statistical software [4]. With excel, Weibull analysis stays well within reach for most engineers with a statistical background. Hence quite often Weibull distribution is used to predict failure behaviour of equipment and to estimate reliability.

E. Analysis methodology

- Create a new Microsoft excel sheet and in cell A1 give a label as "Break down cycles".
- Enter the failure data of break down cycles into cells A2 to Ax (where "x" is the number of break down cycles).
- Select the cells A2 to Ax and select "Sort Ascending" option so as to arrange the data in lowest to highest format.
- Select the cell B1 and give a label as "Rank".
- Type the integers 1 to x in the cells B2 through Bx.
- Type "Median rank" in cell C1.
- In cell C2 enter the formula "= ((B2-0.3)/(x+0.4))".
- Copy cell C2 down through cell Cx in order to enter the same formula in cell C3 to Cx.
- Label D1 as "1/(1-Median Rank)".
- Enter the formula "=1/(1-C2)" in cell D2 and copy it down through Dx.
- Label "In (In (1/(1-Median Rank)))" in cell E1.
- Enter the formula "=LN (LN (D2))" in cell E2 and copy it down through Ex.
- Label "In (Break down cycles)" in cell F2.
- Enter the formula "=LN (A2)" in cell F2 and copy it down through Fx.
- Open data bar from menu bar and select data analysis.
- From data analysis option highlight "Regression" option and then click "ok".
- A pop up box asking to select some parameters arises.
- Type "$E$1:Ex" for "Input Y range" and "$F$1:Fx" for "Input X range".
- Select "labels" option by clicking on the checkbox beside it.
- Select "New worksheet ply" by selecting the button beside it.
- Select "line fit plots" by clicking the checkbox beside it.
- A new excel sheet with some data and a graph is obtained.
- Select the columns A to I and click on any of the column label in order to align the data.
- Click once on the graph and stretch it as much as required for better view.
- Type the label "Beta" in the cell A19.
- Type the formula "=B18" in the cell B19.
- Type the label "Alpha" in the cell A20.
- Type the formula "=EXP(-B17/B18)"
- Now copy the cells A19, A20, B19, B20 and paste in a new work sheet in the cell A1 by editing the cell selecting the "paste special" option and from that selecting the option "values".
- Type the label "cycles" in the cell D1.
- Type the cycle values in column D
- Type the label "survival probability" in the cell E1.

- Type the formula "=Weibull (D2,$B$1,$B$2, true)" in the cell E2.
- Copy the cell E2 down through last.
- Type the label "reliability" in cell F1.
- Type the formula "=1-E2" in the cell F2.
- Copy the cell F2 down through last.

V. Output of Weibull analysis

For the graphical plot pertaining to year 2011, the average compressive strength of overburden strata is 154.42 kg/cm^2, the reliability of the shovel comes to 0.81743. Here it is observed that the reliability is high during initial period but shows decreasing trend after 2000 hours.

By observing graphical plot for the location no 2 where shovel was deployed in the year 2012 and where the average compressive strength of overburden strata was 124.30 kg/cm^2, the reliability of the shovel comes out to 0.99939. It is observed in the case that the reliability is high up in initial 500 working hours and later has decreasing trend.

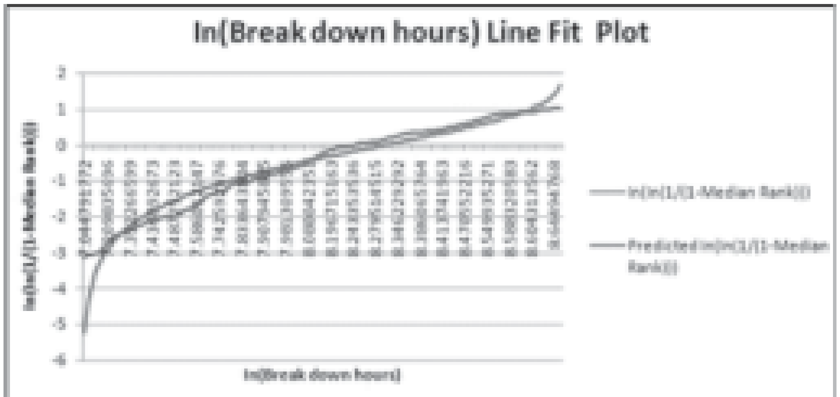
The graphical plot for the location no 3 where shovel was deployed in the year 2013 and where the average compressive strength of overburden strata was 89.43 kg/cm^2, the reliability of the shovel is found to be 0.99999. Here it can be seen that the reliability is high up to 1500 working hours and later on it shows decreasing trend.

The final graphical plot for the location no 4 where shovel was deployed in the year 2014 and where the average compressive strength of overburden strata is 142.26 kg/cm^2, the reliability of the shovel is found to be 0.81743014. It is observed here that the reliability is showing slightly decreasing trend from the initial period of deployment.

A. Reliability Evaluation

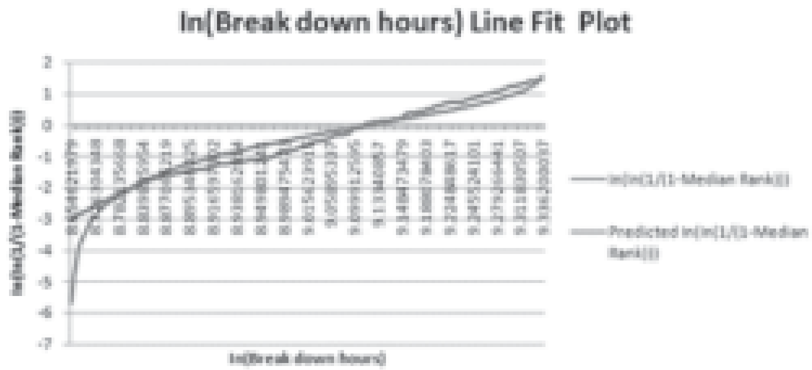
This section tabulates selected locations of deployment of 42 cum shovel along with compressive strength of OB material to be handled and associated reliability estimates. The Figs. 3 and 4 establish to correlate the two parameters under consideration.

From the comparative analysis of the reliability graphical plots of the 42 cum shovel with the compressive strength for selected four locations during the given period of deployment, it can be primarily established that the reliability of the shovel decreases after a certain initial hours of deployment with the increasing compressive strength of the OB material to be handled.



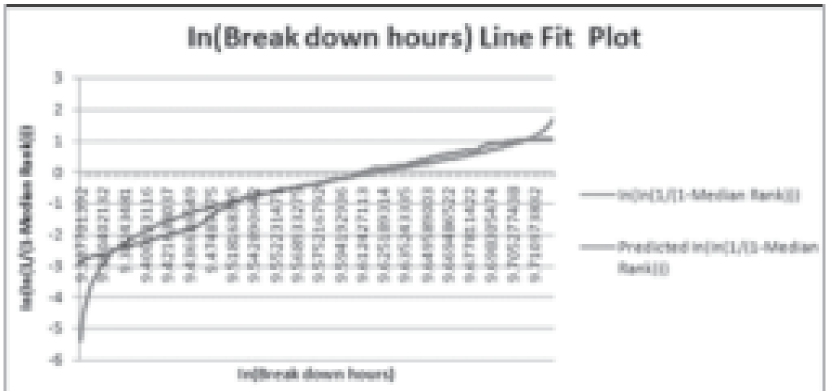
	A	B	C	D	E	F
1	Beta	2.590841		cycles	Survival probability	Reliability
2	Alpha	3846.958		100	7.8198E-05	0.9999218
3				200	0.000471011	0.999529
4				300	0.001346063	0.9986539
5				400	0.00283425	0.9971657
6				500	0.005047015	0.994953
7				1000	0.030022803	0.9699772
8				1500	0.083462367	0.9165376
9				2000	0.167767188	0.8322328
10				2500	0.279190651	0.7208093
11				3000	0.408472995	0.591527
12				3500	0.542872953	0.457127
13				4000	0.669238326	0.3307617

Fig.3 Year: 2011; Location: 1 (Compressive Strength = 154.42)



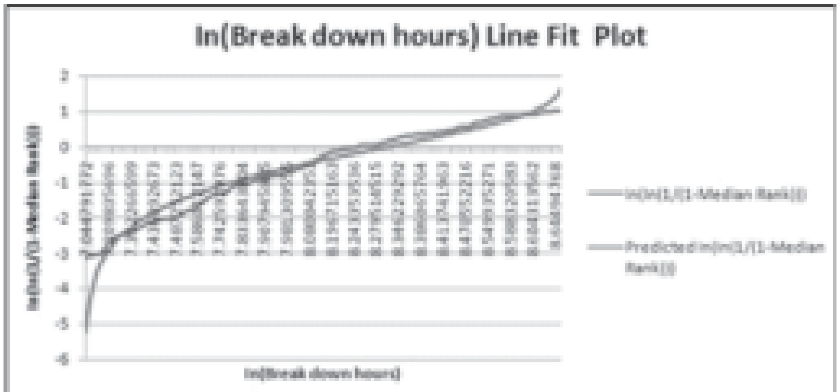
	A	B	C	D	E	F
1	Beta	6.550757		cycles	Survival probability	Reliability
2	Alpha	9135.402		100	1.43108E-13	1
3				200	1.34192E-11	1
4				300	1.91097E-10	1
5				400	1.25805E-09	1
6				500	5.42665E-09	1
7				1000	5.08752E-07	0.9999995
8				1500	7.24496E-06	0.9999928
9				2000	4.76947E-05	0.9999523
10				2500	0.000205717	0.9997943
11				3000	0.000678992	0.999321
12				3500	0.00186277	0.9981372
13				4000	0.004461538	0.9955385

Fig.4 Year: 2012; Location: 2 (Compressive Strength = 124.30)



	A	B	C	D	E	F
1	Alpha	10.50856216		cycles	Survival probability	Reliability
2	Beta	14986.14958		100	0	1
3				200	0	1
4				300	0	1
5				400	0	1
6				500	3.33067E-16	1
7				1000	4.41758E-13	1
8				1500	3.13078E-11	1
9				2000	6.43547E-10	0.999999999
10				2500	6.71175E-09	0.999999993
11				3000	4.56085E-08	0.999999954
12				3500	2.30842E-07	0.99999977
13				4000	9.37503E-07	0.999999062

Fig.5 Year: 2013; Location: 3 (Compressive Strength = 89.43)



	A	B	C	D	E	F
1	Alpha	2.590841		cycles	Survival probability	Reliability
2	Beta	3846.958		100	7.8198E-05	0.999921802
3				200	0.000471011	0.999528989
4				300	0.001346063	0.998653937
5				400	0.00283425	0.99716575
6				500	0.005047015	0.994952985
7				1000	0.030022803	0.969977197
8				1500	0.083462367	0.916537633
9				2000	0.167767188	0.832232812
10				2500	0.279190651	0.720809349
11				3000	0.408472995	0.591527005
12				3500	0.542872953	0.457127047
13				4000	0.669238326	0.330761674

Fig.6 Year: 2014; Location: 4 (Compressive Strength = 142.26)

VI. Conclusion

- Reliability assessment methodology for electromechanical systems with consideration of compressive strength is developed to overcome the drawbacks of other reliability evaluation approaches which are not suitable for complex mechanical systems having varied geo-mining conditions.
- There is no significant change in the equipment reliability till certain limited variation of compressive strength. For example in location 1 and 4, the difference in compressive strength is 12.16 but then the reliability is almost same. Similarly for location 2 and 3, the difference in compressive strength is 34.87 and again the reliability is almost same.
- As the compressive strength increases, the equipment reliability decreases after a particular range. For example in consideration with location 3 and 2, the difference between the compressive strength is 34.87 and the difference of equipment reliability is 0.0006 which shows there is no significant change in equipment reliability; but in location 3 and 1, the difference between the compressive strength is 64.99 and the difference of equipment reliability is 0.18256 which shows there is significant change in equipment reliability.
- With the calculation of the overall reliability of the shovel, it can be concluded that with increase in the compressive strength, the reliability of the equipment decreases and finally after particular working hours, the reliability becomes zero. Here it is suggested that preventive maintenance schedules should be planned for the kind of situation.
- The findings of this study can prove to be a benchmark for similar projects indicating the effectiveness and performance of presented method for reliability evaluation of systems existing in planning and design phase with limited failure data for its component.

VII. Future scope

- The future scope of this study includes reliability study of other mining equipments like 240 te dumpers and supporting drill equipment.
- This kind of study can be made more comprehensive by correlating failure data with other geo-mining parameters of the pit.

	Location/ year	Average compressive Strength, kg/cm^2	Reliability
1	1/2011	154.42	0.81743
2	2/2012	124.30	0.99939
3	3/2013	89.43	0.99999
4	4/2014	142.26	0.81743014

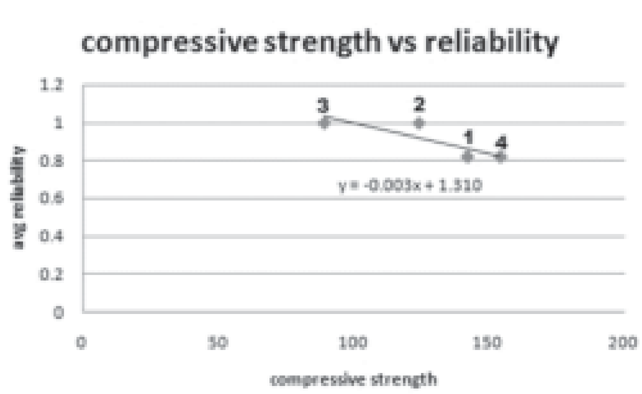


Fig.7 Compressive strength vs reliability at 2000 hours at different locations

	Location/ year	Average compressive Strength, kg/cm^2	Reliability
1	1/2011	154.42	0.3307617
2	2/2012	124.30	0.9955385
3	3/2013	89.43	0.9999906
4	4/2014	142.26	0.3307616

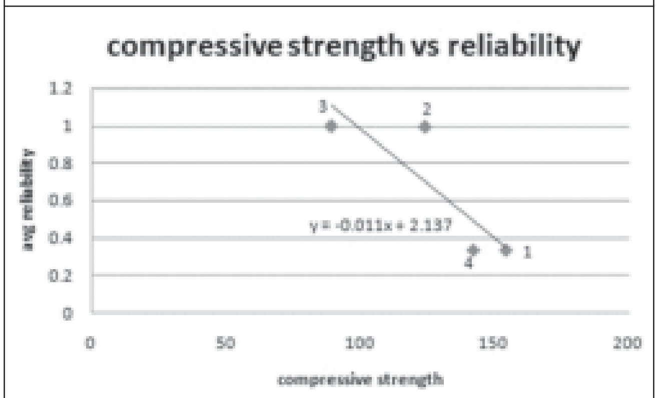


Fig.8 Compressive strength vs reliability at 4000 hours at different locations

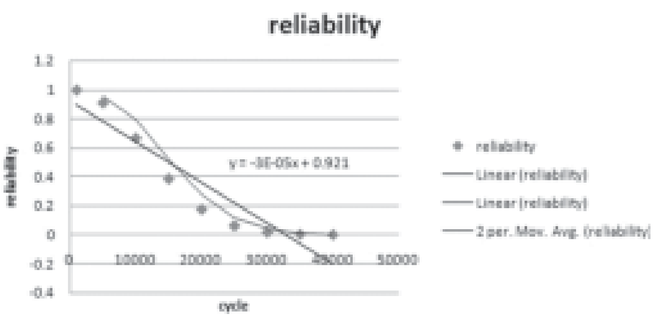


Fig.9 Predicted graph of overall shovel reliability

VIII. Acknowledgments

The work presented in this paper forms a part of the Post Graduate Study of the first author. The author expresses his thankfulness towards the supervisor of the study and Department of Mining Engineering, RCERT, Chandrapur for providing varied facilities due to which this research paper could take present shape. The permission and subsequent field support from Gevra OCP of SECL, Bilaspur, selected for the study is deeply acknowledged with thanks. The views expressed in this paper are those of authors and not necessarily of the organizations they represent nor of the sector under study

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