J. S. Afr. Inst. Min. Metall., vol. 85, no. 7.
Jul. 1985. pp. 217-220

A note on the simulation of seismic activity in the Klerksdorp area

by **R.W.O. KERSTEN***

SYNOPSIS

The note describes an exercise on the simulation of the frequency and size of seismic events on the basis of the frequency distribution of the events and their inter-arrival times (i.e. the frequency distribution of the time elapsed between events). From the suite of available results, those of one simulation for a period of three months are included.

The tentative conclusions drawn from the exercise indicate that the overall seismic activity in an area can be predicted for a time period, that structurally complex areas will have a higher incidence of seismic events than other areas, and that the position and time of an event cannot be predicted by the use of a wide-spread system such as that used at present.

SAMEVATTING

Hierdie opmerkings handel oor 'n studie van die simulering van die frekwensie en grootte van seismiese gebeurtenisse op grond van die frekwensieverdeling van die gebeurtenisse en hul tussenaankomstye (d.w.s. die frekwensieverdeling van die tyd wat tussen gebeurtenisse verloop). Uit die stel beskikbare resultate word dié van een simulasie vir 'n tydperk van drie maande ingesluit.

Die tentatiewe gevolgtrekkings wat uit die studie gemaak word, dui daarop dat die totale seismiese aktiwiteit in 'n gebied vir 'n tydbestek voorspel kan word, dat struktureel komplekse gebiede 'n hoër voorkoms van seismiese gebeurtenisse as ander gebiede sal hê, en dat die posisie en tyd van 'n gebeurtenis nie met gebruik van 'n wydverspreide stelsel soos dié wat op die oomblik gebruik word, voorspel kan word nie.

Introduction

The seismicity in the Klerksdorp area appears to be associated mainly with geological features on the brink of unstable equilibrium due to tectonic forces. Minor changes in stress induced by mining may therefore trigger off seismic events.

According to Salamon[1], seismicity appears to be a statistically predictable, rather than a deterministically foreseeable, phenomenon. The process resulting in a mining geometry that will cause a seismic event is a variable that consists of a deterministic and a random component. The random component is based on the presence of unstable equilibria in the rock, and is usually associated with pre-existing 'cracks'. The origin, size, attitude, and distribution of these cracks are varied, and this variability constitutes the statistical element in seismicity.

Salamon concludes that the frequency of seismic events increases

(i) if the number of unstable equilibria in a given volume of rock increases, and
(ii) if the volume of rock exposed to a given level of disturbance becomes larger.

With mining spread evenly over the entire area of the Klerksdorp Gold Field, an equal amount of tectonically unstable features could be triggered at random anywhere in the rock mass that is affected by mining.

If the above is true then it should be possible to simulate the frequency and size of the events for various periods on the basis of the frequency distribution of the events and their inter-arrival times.

Frequency Distribution

The frequency distribution of the seismic events referred to here is the generally accepted relationship between size of event and relative frequency. Fig. 1 is a typical example showing that most of the events are small. In addition, the slope of this curve appears to be constant for an extended period in the Klerksdorp area.

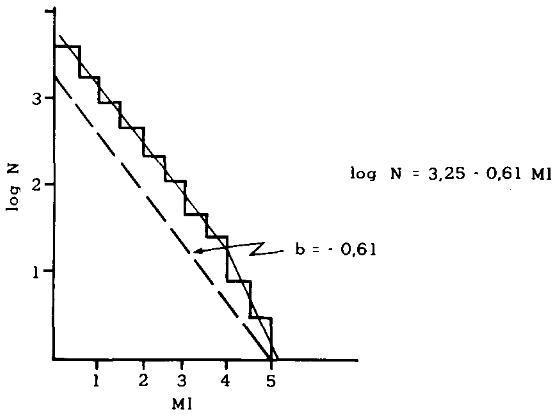

Fig. 1—Frequency of various magnitudes of events

This distribution is given by

$$\log N = 3{,}25 - 0{,}61\ \mathrm{Ml}. \quad (1)$$

Inter-arrival Time

The frequency distribution of the time elapsed between events, the inter-arrival time, is shown in Fig. 2, which again indicates an exponential type of distribution. The equation for this is

$$f(t) = k\,\lambda e^{-\lambda t}, \quad (2)$$

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* Group Rock Mechanics Engineer, Anglovaal Limited, P.O. Box 62379, Marshalltown, 2107 Transvaal.

SA ISSN 0038-223X/$3.00 + 0.00. Note received 18th Oct., 1984.

where $k = 260$ and
$\lambda = 0{,}1$.

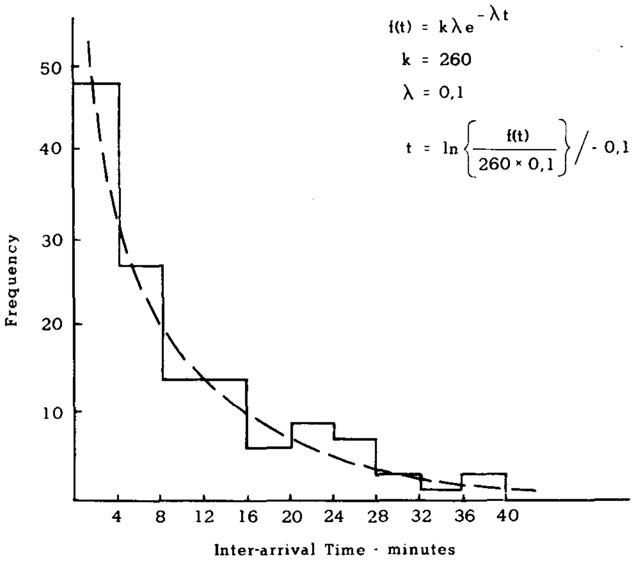

Fig. 2—Frequency of inter-arrival times

Simulation of Events

With the relationships given in equations (1) and (2), seismic activity can be simulated on a random basis. When numbers 1 to 1000 are assigned to the size of the event, and 1 to 100 to the inter-arrival times, random numbers are used and allotted to their respective size and time slots.

The programme listed in Table I gives a printout of the total number of events, time interval, cumulative time, size of event, and cumulative seismic energy radiated.

Results

Table II is a printout for one simulation for a period of three months selected at random from the whole suite that was available. At first glance the printout can easily be confused with the actual printout given in Table III (excluding locations).

The apparent random nature of the frequency is well simulated, as shown in Fig. 3. In addition, the apparent increase over extended periods was also simulated as indicated. A similar erratic sequence emerges to that observed, although the limits of the actual sequence are slightly wider apart.

Where the size distribution is concerned, a plot of the cumulative energy is identical in character to that generally obtained in nature (Fig. 4).

Conclusions

From the above it appears that the following tentative conclusions can be drawn for the seismic activity in the Klerksdorp area.

(1) The triggering effect of a mine 'sweeps' through a medium in which a number of unstable equilibria of various magnitudes are present. As soon as the mining effect 'sweeps' across, the event is triggered.
(2) The frequency distribution may be a function of the frequency distribution of size of faults in the area affected (Van den Heever[2]).
(3) The number of events would be a function of the frequency of faults, i.e. structural complexity, and the

TABLE I
SIMULATION PROGRAM*

```
 100  REM
 200  REM      Rudi's seismic sim.
 300  REM      Array so will contain
 400  REM      The size parameters
 500  REM      And array to will
 550  REM      Contain the inter-arrival time
 600  REM
 700  REM
 900  REM
1000  DIM      SO(10), TO(25)
1100  Data 526, 763, 882, 943, 974, 987, 994, 998, 999
1200  Data 17, 32, 44, 53, 59, 65, 70, 74, 78, 81, 84, 87, 90, 91,
        92, 93, 94, 95, 96, 97, 98, 99
1300  For I = 1 to 9
1400  Read SO(I)
1500  Next I
1600  For I = 1 to 22
1700  Read TO(I)
1800  Next I
1900  REM
2000  REM
2100  Randomize
2200  Print "No time Time (MJ) Size"
2300  TO = 0
2400  EO = 0
2500  N = 0
2600  T1 = 1P (RND*100)
2700  REM
2800  REM arrival time distr.
2900  REM
3000  T = 0
3100  For I1 = 1 to 22
3200  I2 = I1
3300  If T1 = T and T1 = T0(I1) the N GOTO 3800
3400  T = T0(I1) + 1
3500  Next I1
3600  Print "Error–RND outside 100 limits"
3700  Stop
3800  T2 = RBD*2
3900  T3 = (I2 - 1)*2 + T2
4000  REM
4100  REM
4200  REM size distribution
4300  REM
4400  NO = IP (RND*1000)
4500  S = O
4600  For I7 = 1 to 9
4700  I2 = I1
4800  If NO = S and NO = SO(I1) the N GOTO 5300
4900  S = SO(I1) + 1
5000  Next I1
5100  Print "Error — RND outside 1000 limits"
5200  Stop
5300  S1 = RND
5400  TF S1 4 then S1 = (A1 - 2)/2
5500  S2 = 5*I2 + 1 + S1
5600  E1 = 10 (11 4 + 1 5*S2)/10 ^ 13
5700  TO = TO + T3
5800  EO = EO + E1
5900  N = N + 1
6000  If N = 1000 then N = 1
6100  Print using 6200, N, T3, TO, EO, S2
6200  Image DDD, 1X,DD.D,1X,DDDDD.D,1X,DDDDDDDDDD,
        2X,D.D
6300  If TO = 17250 then GOTO 2600
6400  Print "end of run"
6500  Stop
6600  End
```

*Program written by M. van Aswegen

volumes affected by mining.

(4) The findings bear out the basic statement made by Salamon about the random component of such events.

Practical Significance

The practical significance of the above conclusions can be summed up as follows.

(a) The overall seismic activity in an area can be predicted for a time period, and structurally complex areas will have a higher incidence of seismic events.
(b) The position and time of events cannot be predicted by the use of a wide-spread system such as is used at present.
(c) Mining remnants will affect large areas, and hence result in greater seismic activity.

TABLE II
SIMULATED EVENTS FOR THREE MONTHS

No.	Time	Accumulated time	Accumulated (MJ)	Size
1	12,0	12,0		0,7
2	5,8	17,8	1	0,8
3	9,5	27,3	2	1,0
4	2,4	29,8	2	0,7
5	8	30,5	2	0,7
6	40,5	71,0	5	1,3
7	6	71,6	9	1,5
8	3,6	75,2	21	1,8
9	1,7	76,9	44	2,0
10	4,3	81,2	46	1,2
11	6,9	88,0	57	1,8
12	3,0	91,0	61	1,5
13	41,7	132,7	61	0,8
14	15,3	147,9	62	0,8
15	26,0	173,9	62	1,0
16	5,0	170,0	63	0,9
17	1,9	180,9	63	0,9
18	13,3	194,2	64	1,0
19	1,2	195,4	64	0,7
20	1,1	196,5	65	0,9
21	21,4	217,9	67	1,3
22	1,1	219,0	4252	3,5
23	1,1	220,1	4253	0,8
24	5,7	225,8	4253	0,6
25	4,2	230,0	4254	1,0
26	7	230,6	4258	1,5
27	4,0	234,7	4271	1,8
28	8,6	243,3	4273	1,3
29	14,3	257,6	4274	0,9
30	3	257,9	4274	0,8
31	2,4	260,3	4312	2,1
32	14,7	275,0	4313	0,9
33	2.0	277,0	4313	0,7
34	25,0	302,0	4314	1,0
35	8,2	310,1	4314	0,9
36	2,5	312,6	4315	0,8
37	19,2	332,3	4315	0,8
38	12,0	344,3	4317	1,2
39	11,3	355,6	4317	0,9
40	1,9	357,6	4340	2,0
41	20,4	377,9	4353	1,8
42	4,9	382,9	4356	1,4
43	13,8	396,6	4358	1,3
44	5,5	402,2	4358	0,7
45	27,9	430,1	18834	3,8
46	7,8	437,9	18835	0,9
47	1,5	439,4	18837	1,3
48	12,0	451,3	18837	0,9
49	34,7	486,0	18854	1,9
50	12,3	498,4	18855	0,9

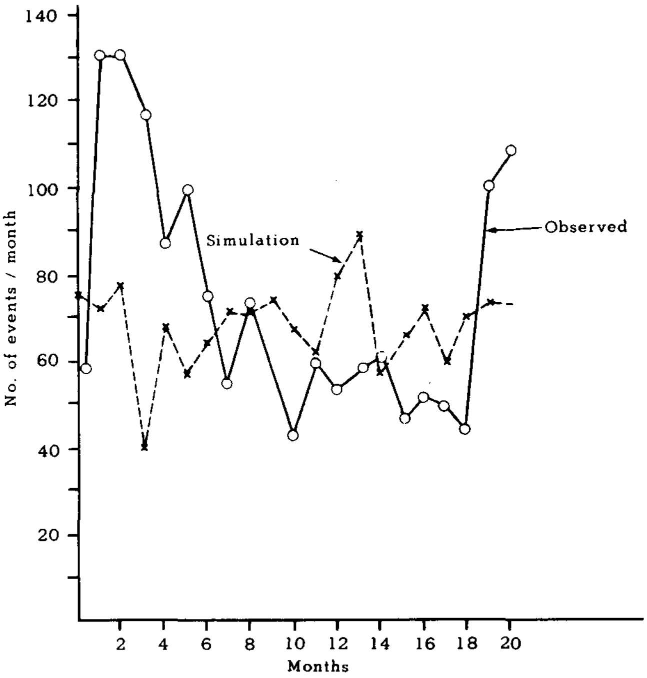

Fig. 3—Total number of events per month as measured and as obtained from simulation

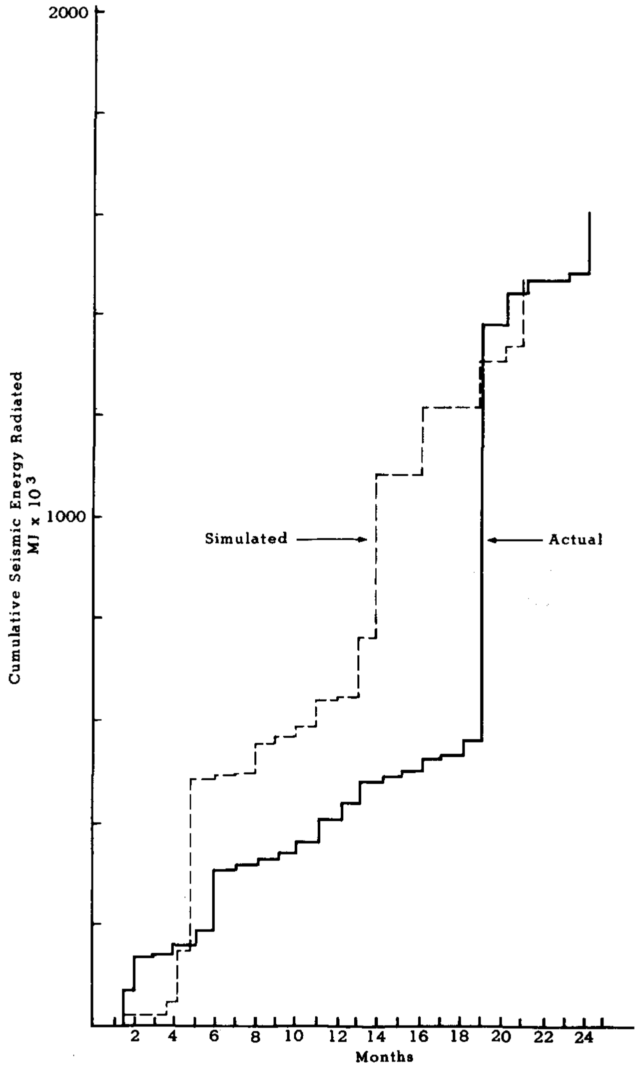

Fig. 4—Cumulative seismic energy radiated, shown as radiated and as simulated

TABLE III
TIMES AND MAGNITUDES OF OBSERVED EVENTS

Seq. no.	Date no.	Time	Mag.	accuracy
351	840101	024246	2,4	22m
352	840101	104428	0,7	19m
353	840101	113419	1,0	27m
354	840101	210218	3,2	44m
355	840102	165219	1,0	28m
356	840103	013135	2,5	55m
357	840103	022506	1,5	25m
358	840103	080615	1.5	32m
359	840104	001804	0,8	32m
360	840104	030515	2,0	17m
361	840104	060434	2,5	51m
362	840104	061343	1,0	150m
363	840104	112211	0,4	67m
364	840104	152117	0,5	48m
365	840104	162638	1,3	23m
366	840105	172514	0,5	33m
367	840106	084613	0,7	33m
368	840106	233722	0,9	44m
369	840107	000646	1,0	31m
370	840107	105929	0,6	91m
371	840108	034204	0,5	12m
372	840108	083511	1,2	35m
373	840108	083512	2,7	31m
374	840108	143527	2,2	64m
375	840109	150720	1,1	39m
376	840110	234025	1,7	35m
377	840111	115447	2,4	50m
378	840111	154938	0,9	84m
379	840111	171525	1,2	15m
380	840112	082242	2,4	19m
381	840112	082643	1,0	18m
382	840112	091738	0,8	105m
383	840112	154824	1,2	67m
384	840112	223411	0,5	20m
385	840113	112222	1,2	23m
386	840113	162031	2,2	150m
387	840113	195105	2,1	32m
388	840114	130348	2,0	150m
389	840114	231242	2,0	123m
390	840116	153152	1,5	59m
391	840117	152713	1,5	89m
392	840117	195245	0,8	35m
393	840118	104048	2,5	2m
394	840118	153213	0,4	21m
395	840120	034234	3,6	89m
396	840121	111120	1,2	76m
397	840123	011355	1,3	17m
398	840123	113223	4,2	8m
399	840123	141218	1,1	52m
400	840124	054342	1,2	20m
401	840124	092752	2,1	150m
402	840125	003843	0,8	89m
403	840125	010143	2,6	7m
404	840125	010240	3,2	15m
405	840125	052444	0,5	98m
406	840125	101455	2,6	53m
407	840125	102345	0,5	38m
408	840125	170424	0,6	43m
409	840125	233111	1,8	81m
410	840126	001102	3,5	74m
411	840126	151514	0,4	10m
412	840126	171949	1,6	50m
413	840127	171949	2,2	45m
414	840128	113733	0,8	21m
415	840128	151336	0,7	140m
416	840128	151709	4,7	44m
417	840128	164116	4,7	17m
418	840128	190918	0,8	23m
419	840128	233358	0,5	22m
420	840129	034507	0,4	108m
421	840129	111129	0,4	35m
422	840129	150716	2,3	24m
423	840130	145834	1,1	35m
424	840130	195108	0,9	50m
425	840131	052957	1,9	50m
426	840131	053210	0,8	42m
427	840131	154444	2,8	27m

(d) It is problematical whether seismic events will ever be predicted accurately.

It is clear that, for practical purposes, the support used must be able to cope with this type of disturbance.

Acknowledgement

The author thanks the management of Anglovaal for permission to publish this note.

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2. Van den Heever, P. The influence of geological structure on seismicity and rockbursts in the Klerksdorp Goldfield. Johannesburg, Rand Afrikaans University, M.Sc. dissertation, Dec. 1982.