Rock and Ventilation Control

Chairman: Dr W. S. RAPSON

Rapporteur: Mr J. W. WILSON

Papers:

Computer applications in rock mechanics by F. H. Deist, E. Georgiadis and J. P. E. Moris

Rock mechanics in the design of mine layouts by K. Hodgson and N. G. W. Cook

Automated regulation of mine ventilation by P. Niskanen

The rock mechanics papers, because of their complementary nature, were presented in succession and discussion on both followed directly. The paper on automated ventilation control at a mine in Finland was then presented and the session was closed with several contributions to this paper.

By and large the papers and discussions which followed in this session showed how a classic tie-up had developed between the use of computing techniques in important fields of mining, and their practical application. In fact, the discussion following the rock mechanics papers showed clearly that without the aid of high-speed digital computers the rate of progress in applied research in deep-level hard-rock mines, would have been severely hindered. Furthermore, it became apparent from the comments made by several contributors that the rock mechanics techniques and computer progress described in Deist's and Cook's papers could be used to provide useful data in the solving of rock mechanics and design problems on mines other than flat dipping deep tabular deposits.

The paper by Niskanen, which described an automated ventilation control system at a mine in Finland, showed how effective computers could be in areas where the reversal of mine ventilation occurs due to severe seasonal temperature ranges. Although the system described in the paper could not be introduced easily in complex underground mines, several contributors gave examples of similar ventilation problems that could be solved mechanically.

In introducing his paper, Dr Deist said that the purpose of the paper was to give a brief account of some of the programs designed by himself and his co-authors to aid in the solution of rock mechanics problems.

The first system presented by Dr Deist was known as MINSIM in the South African mining circles. This system was designed specifically to aid in the solution of rock mechanics problems in the South African gold mining industry. It was particularly designed to handle tabular deposits at great depth but it has been used satisfactorily on a number of occasions to obtain at least approximate solutions in other mining situations. Dr Deist said that the principles embodied in the programs were easily extended and, in fact, there was a project in progress at that time which was aimed to do this. He said that the principles could easily be extended to shallow-depth mining at steep or very steep inclinations.

The author proceeded to outline the MINSIM system and said that it had been operating for about four years. The system was one of the first truly conversational systems which he and his colleagues had ever designed and facilities were available in the program to use the system on a computer terminal. At this stage, unfortunately, the system had not been used very frequently in this mode because of the limited availability of the necessary equipment. The authors had, however, foreseen this to some extent and they provided the facility for running the program in batch mode *via* card input. It was explained that it was possible to intermix the two modes by preparing the basic problem on cards, to have the problem run overnight and then to sit down at a terminal and start investigating various minor points. The basic feature of the program was that it was possible to solve large-scale gold mining configurations because most of the South African gold deposits were tabular and situated at great depth. Although the mining geometry was a three-dimensional, because the reef was largely planar, it had been possible to treat this problem as quasi-two-dimensional. The problem really amounted to using equation solution techniques to evaluate about four thousand simultaneous equations for a typical sized mining geometry. Dr Deist emphasized that there could be additional complicating factors which caused a departure from linearity. This occurred in certain mining configurations when the hangingwall and footwall actually came into contact, and since this zone of contact was not known before a solution was attempted, this complicated the solution. In other words, the determination of the zone of contact must form part of the solution, so what could initially be a linear problem, became a problem involving certain non-linearities.

The next system described in Dr Deist's paper was the *finite element* system. Dr Deist pointed out that there was nothing new about this method, although he thought that he viewed the technique in a different way from civil engineers in that he saw the finite element as essentially a finite difference procedure allowing a variable mesh. Dr Deist's system was essentially suited to handle large-scale two-dimensional continuum applications. He pointed out that while the method was in principle suitable for three-dimensional analyses, he thought that the type of applications for which he was using it would involve astronomical computer running times. For this reason only, he had never tried solving a three-dimensional problem. In his system he placed a great deal of emphasis on diagnostic capabilities as the finite element problems investigated were of such a size that he was normally dealing with what amounted to about two man-weeks of input preparation effort and, unfortunately, most of this effort had to be spent on generating the so-called 'finite element mesh'. Despite this time-consuming work the program had, and was still, enjoying wide usage – particularly because of its flexibility in handling arbitrary excavation shapes, problems involving layers of different materials, as well as a great variety of boundary conditions. In order to overcome the time-consuming job of generating this fine mesh, the authors had supplemented the finite element system with what they called a *mesh generator*. This mesh generator operated as a primary stage to the system proper and permitted the automatic generation of its mesh. Generally, it had succeeded in reducing preparation time by a factor of at least 20. In addition, it had proved to be cheaper to run because there were less re-runs prior to a solution to correct the initial input data.

The final system outlined in Dr Deist's paper was one which, he hoped, would revolutionalize the solution of truly three-dimensional problems. He thought that this would be feasible if he used an extension of the principles involved in the design of the MINSIM program. The potential advantage of this approach over a three-dimensional finite element method would be that it would manage to reduce a three-dimensional problem to a quasi-two-dimensional one by only considering the boundary surfaces. The mathematical formulation of this problem basically involved the solution of integral equations, about which little was known. As a result of this, it was necessary to rely on experimentation to assess the merit and accuracy of the system as indicated in the paper. He reaffirmed that further experiments to date had been very successful. The production version of the new three-dimensional method was being finalized and it was hoped that the program would be 'on the air' by the end of 1971.

This concluded Dr Deist's introduction to his paper and Dr N. G. W. Cook then proceeded to introduce his joint paper.

In presenting the paper on behalf of Mr Hodgson and himself, Dr Cook pointed out that during the opening session of the Symposium, the keynote speaker had expressed the view that the application of computer methods had not met with the success nor had been accepted in the mineral industry to the extent that one would have hoped and believed some time ago. Dr Cook then proceeded to relate to the delegates a case history that he believed to be a successful and well accepted application and, in doing so, he drew attention to those factors which he thought made for the success of this application. He suggested that its success could be measured in some objective terms by recognizing that today most of the 40-odd gold mines in South Africa routinely used the methods which had been evolved for planning the layout of all their future mining and excavations to make sure that there was an adequate degree of safety from the strata control and rock mechanics points of view in those excavations. Dr Cook described the structure of the method with particular reference to the part which the computer played in it, and also the limitations of the computer and the ways in which they had been overcome. In addition, he illustrated this development by running through a typical example of a solution of a rock mechanics problem.

The method involved four main factors, and Dr Cook emphasized that a complete method of computing was but a part and that the choice and proper combination of these factors were essential to the success which he mentioned earlier. This was the technical reason for success. There were, of course, psychological and personal reasons. Dr Cook said that many people assumed that because of the deep-level mining in South Africa the industry in this country was so well disposed to rock mechanics that this work was bound to succeed anyway. In a sense this was true, but at the time that his co-author Keith Hodgson and he had embarked on this work with the help of many colleagues in the industry, the climate was far from favourable. In fact, in 1963, one of the senior and most respected mining enigneers in the industry expressed the view that he would 'eat his hat' the day it was possible to design a mine along the principles which were then being considered.

The first factor in the method which needed identification was the phenomenon which led to the collapse of excavations. In general, access to the working places of a mine was through the excavation itself and collapse of an excavation impeded production and further mining – apart from constituting a serious danger hazard to persons working in the mine. From the observations of rock failure in mines over many years, several fanciful theories concerning the behaviour of rock masses had evolved and one of the most important features in these observations had been the discovery that the rock mass responded to the changes brought about by mining, in an orderly and simple fashion. These changes were so orderly that they could be described adequately and accurately by a linear relationship between force and displacement or stress and strain on the rock mass, and it could be described as Dr Deist has indicated in his paper by the geometry of the mining excavations on the plane of the reef.

Dr Cook went on to say that having established a method for computing the state of stress and displacement of the rock, it was then necessary to find out how this information could be used in design and planning. It was decided to select parameters which could be related empirically to the conditions that gave rise to rock falls, rockbursts and collapses. These parameters had to be simple and they had to have a close relationship to the problem which the authors were seeking to identify. Two related factors were selected. For the purpose of stope excavations, a factor which was called 'spatial rate of energy release' as mining proceeds, was chosen, and for the case of tunnels and other excavations that traverse the rock mass, the field stress, that is, the stress existing around these excavations neglecting the concentrations which they cause, were selected. Once this was decided, it was necessary to find the values of these parameters which distinguished between safe mining conditions and conditions under which collapse was imminent. This was done in a carefully planned series of experiments and the results subsequently confirmed by the experience gained from the use of these methods throughout the mining industry.

After completing the first part of the introduction to his paper, Dr Cook went on to illustrate with the aid of slides how use was made of the spatial energy release rate and field stress parameters in mine planning.

In the case of the use of the energy release rate concept, he showed how it was possible to predict how workings should best be laid out in a new mining area and how the best method of proceeding with mining in an existing mining layout was evaluated.

From the prediction capabilities which had emerged from the use of the spatial energy release rate parameter, it was possible to establish that more and more mines in South Africa would encounter frightening situations in terms of damage – which could be measured not only in terms of rockbursts per unit rate of area mined, but also in units of days delay per unit area mined. Investigations had shown that a delay of at least one day per month could be expected in a stope from rock bursts or rock falls due to high energy release rates, and this was equivalent to a loss of revenue of about four per cent. Because this represented a substantial part of a deep mine's profit and a very serious hazard, Dr Cook and his colleagues had set about developing techniques for maintaining safe conditions where computation forewarned them that conditions would be intolerable.

Dr Cook then described a type of rapid-yielding prop which could support a stope at a depth of about 3 km – even when an earthquake or tremor such as was common in ultra-deep-level hard-rock mines, occurred in its vicinity. He then produced evidence to indicate that with the use of rapid-yielding props it was possible to bring down the incidence of days delay in mining areas where the energy release rates were high, and where the days delay were expected to increase.

Dr Cook closed his presentation by referring to the use of computing techniques for the prediction of damage in tunnels. He said that it was very important for a mine manager to know in advance whether the location of a tunnel in a certain position in the mine would remain in good condition or whether it would collapse in the future. It was now possible to estimate on a quantitative basis from a deterministic computer calculation how many incidences of damage would occur, how serious they would be and when they would occur in relation to the mining geometry.

Dr Cook paid tribute to the work done by Mr Hodgson and colleagues such as John Wilson, Roger More O'Ferral and others in the industry and hoped that he had done them justice in this presentation because he felt that the paper really summarized all of their work.

The presentations of the rock mechanics papers by Dr Deist and Dr Cook were followed by detailed contributions by practising rock mechanics engineers from mining groups in South Africa. The first contribution offered was by Mr J. W. Wilson. He indicated that within his Group a well-established rock mechanics department had been built up to serve the gold mines in the Group. His department operated with a staff of largely non-graduate-type personnel who had previously held positions of a supervisory nature, such as production officials. These personnel had been taught the use of the programs referred to and with this knowledge and their practical mining experience, it had been possible to provide assistance with most rock mechanics problems which occurred on the mines in his Group. This department was accepted by mine management as a permanent service department which handled day-to-day problems on a routine basis, as well as providing assistance in the long-term stoping and development mine planning.

Mr Wilson made the point that, despite the fact that there were differences between the geologies of the various gold mining areas in the Witwatersrand system, it was still possible to use the parameters of energy release and field stress and the MINSIM and finite element programs in all areas. This was because of three factors common to all goldfields, namely, the mine workings were all deep, the mineable reefs were tabular in nature, and the rock was homogenous over large areas. The important point to note was that the individual magnitudes of energy release rates and field stress associated with damage in the various mining areas had different values, depending upon the nature of the rocks in the vicinity of the tunnels or stope excavations.

Mr Wilson then proceeded to describe how the MINSIM program was used in the Anglo American Corporation Rock Mechanics Department. This program was used to solve mining configurations which occurred in selected blocked-out areas of the tabular workings of their mines. All mining areas were split into discrete blocks and each block was set up on the computer using cards (batch mode) as described in Dr Deist's paper. The solution of each mining configuration was stored on a computer disc file so that when future investigations were necessary in any given area, such as the prediction of damage zones in stopes or tunnels, the design of shaft pillars or the calculation of the dimensions of mining areas to protect under or overlying tunnels or shafts, the solutions were readily available. The procedure involved recalling the relevant stored solution from the computer file, up-dating the stoping configuration, re-solving, and then calculating the relevant parameters, depending upon the type of problem under investigation. Where possible, at this stage of an investigation, the rock mechanics engineer would visit adjacent underground workings to ascertain whether the established design parameters were reliable in the area under review. Experience had shown that whenever the predicted conditions differed from the expected condition based on the established parameter values, this was usually the masked or exaggerated effects of local geological anomalies and *not* the failure of the technique.

Mr Wilson described the 'scaling' feature of the MINSIM program and how this could be used for investigating the mining sequences in a particular mining area in fine detail. He said that this feature was of great use in examining the effect of reef pillars overlying footwall tunnels or investigating the energy release rates associated with different sequences of extraction in a remnant area.

Mr Wilson went on to demonstrate the physical damage associated with high energy release rates in stopes and varying levels of field stress within tunnels, by showing a series of coloured slides of underground workings on a typical South African gold mine. These slides left no doubt as to the validity of the correlation between the design parameters mentioned in the papers given, and the physical state of damage in hard-rock mines. Reference was then made to the methods practised in the Anglo American Corporation gold mines to minimize the effects of super-critical energy release rates in stopes and high field stress levels in tunnels. It was now common practice to avoid or minimize critical areas in stopes in the planning stage before stoping commenced, and where this was not possible mining sequences were altered or improved support methods were adopted. In the case of pre-developed tunnels which could not be protected by altering nearby stoping sequences, it was now possible to predict the areas where damage could be expected and to design rockbolting patterns and ancillary support to protect the tunnels and prevent them from collapsing. Mr Wilson said that his work had shown that in deep-level hard-rock mines, timber sets, steel arches or concrete line haulages were far less effective or stable than systematic rock bolting, lacing and meshing. This finding had had a considerable influence on the economy of tunnel support as well as on the improvement in safety to workmen.

It was pointed out that other design parameters had been evaluated with the use of the MINSIM and finite element programs. One such application had been the determination of stress concentrations that were associated with bursting on unmined dykes left *in situ* on the plane of the reef. Following an historical survey of known dyke bursts over the Orange Free State and Klerksdorp goldfields, it had been possible to evaluate the maximum stresses tolerable on certain burst-prone dykes in the respective mining areas. This knowledge had been found to be of great value in the planning of mining sequences in new areas in these goldfields where the burst-prone dykes were known to exist.

Mr Wilson concluded his contribution by raising two questions for Dr Deist. He said that although a wealth of knowledge was now available for the solving of rock mechanics problems in deep-level, hard-rock mines there was still no solution to the problem of rock bursts, as experienced in the ultra-deep workings of the West Wits and East Rand goldfields. In these mines stoping was taking place at depths exceeding 10 000 ft and current plans were aimed at mining to depths of 13 000 ft and, if possible, 15 000 ft. At these depths it was not easy to control the rate of energy release, even when mining with the longwall stope configuration. The high energy release rates in these areas were a direct result of great depth, and to improve the situation in these deep mines use was now being made of waste packing in the mined-out areas to reduce the volumetric convergence which, in turn, would reduce the energy release rate and eventually help in combatting the rockburst hazard. These ultra-deep mines were also using rapid-yielding props on the stope faces, sandwich (concrete-timber) packs in stopes and also leaving reef pillars *in situ* to stabilize the workings. Despite these efforts, rock bursts were still occurring. However, it was hoped that in the long term the benefits from these techniques would be felt. One of the lines of approach that was being used at an Anglo American ultra-deep-level mine to assess or measure the effectiveness of these relatively new introductions to the mining method, was to record the seismic events that occur in the mine and to attempt to locate the epicentre of these rock bursts. Mr Wilson emphasized that there was nothing new about this technique, and in any event, it was history when the data became available. However, he said that he was now using the MINSIM program to calculate the elastic stresses, displacements, shear stresses and the other elastic parameters at the located centre of each rock burst. Attempts were being made to correlate the magnitude of these elastic parameters with the location, magnitude of the rock burst and severity of damage in the adjacent underground workings.

Mr Wilson's questions were related to the MINSIM applications referred to. He asked if there was any way in which the time for solving mining configurations involving total closure of the hangingwall and footwall could be reduced. He said that closure in stopes was extensive at ultra-deep mines and computer times could exceed three to four hours (depending on the computer model) without necessarily getting a solution at all.

Mr Wilson's second question was related to the selection of convergence factors in the MINSIM program. He wanted to know if it was possible to automate the selection of the magnitude of the convergence factor so that the optimum time for a solution could be achieved. He indicated that his department had a large number of solution times for various mining configurations using different convergence factors, and he was prepared to add this information to Dr Deist's results if there was any hope of producing an automated system.

Dr Deist pointed out that closure added a dimension of complexity to the whole solution, in that the problem became non-linear, and while there were quite a few ways in which it was possible to improve running times, one had to settle for the fact that it would never be possible to solve these configurations as quickly as those configurations that did not display total closure. Dr Deist continued by saying that as far as convergence rates were concerned, what Mr Wilson had said was quite true, but that the background of the equations that had to be solved in the MINSIM program was of such complexity that whatever was known had been found from experimental evidence from the computer, and he felt that this background had accumulated to the stage where the automatic selection of these factors was now possible. Dr Deist concluded by referring to the fact that over the last few years he had collected many other comments on the programs; however, because of limited man-power, it had not yet been possible to implement the alterations to the programs.

Mr I. Clarke described some of his experiences in the use of the programs described by Dr Deist, to aid in the solution of rock mechanics problems encountered in his Group. He said that he had found these computer programs of considerable value in assisting with the design and planning of mines, not only for tabular reef mines (such as gold mines), but also for massive type orebodies and other stability problems. Mr Clarke then proceeded to describe briefly three rock mechanics problems that he was able to solve by using the programs described by Dr Deist.

The first problem concerned a vertical elliptical orebody approximately 300 ft in length along the long axis, and between 100 to 120 ft in the short axis, extending from a depth of 1 800 ft to 2 400 ft below the surface, that is, the orebody extended about 600 ft in its vertical dimension. Situated approximately 120 to 150 ft at right angles to the long axis of the orebody was the main hoisting shaft. In order to evaluate the possibility of interaction between the orebody and the shaft, which in turn could cause damage to the latter, it was decided to use the finite element method. By modelling a two-dimensional section of a horizontal plane through the orebody void and shaft, the results showed that the shaft system would not be subjected to serious ground movement even when the shaft was used for mining at depths in excess of 3 000 ft.

The second problem also involved using the finite element technique, but this time it concerned a 600 ft reinforced chimney stack which had been constructed on ground where mining was currently taking place vertically below at a depth of 700 ft. In this area the reef was dipping at an angle of 10 degrees and the hangingwall above the reef all the way up to the surface was homogenous and without any geological faulting. A vertical two-dimensional finite element section was set up to examine the ground movement to be expected at the base of the chimney. The analysis indicated that the displacement expected would be within the design limits of the chimney as far as tilt and surface strains on the foundation were concerned. This problem was not a true two-dimensional situation because of the irregular shape of the mining configuration; however, the two-dimensional finite element solution provided the worst possible conditions so one could assume that with an irregular mining geometry actual stability conditions would be better.

Mr Clarke's third problem related to gold mining and the mining of a reef deposit at a depth of between 7 000 and 9 000 ft which was being planned at that time. The problem was peculiar to South African conditions since it involved three reefs with a total stoping width of 20 ft. These reefs would be mined within a total thickness of the reef series of 40 to 100 ft.

To overcome the rock burst problems that had been referred to by Dr Deist and Mr Wilson, it had been decided to leave *in situ* a systematic layout of reef pillars on the plane of the reefs. A combination of the MINSIM program and the finite element program had been used to design the pillar system and to enable the stability of the pillars to be examined.

In concluding his contribution Mr Clarke emphasized that the three-dimensional program which had been outlined briefly by Dr Deist was eagerly awaited as he felt that it would overcome many of the difficulties which were associated with using the approximation of a two-dimensional analysis.

A contribution similar to that made by Mr Clarke was made by Dr Jantzen. He commented that he had used the MINSIM and finite element programs to analyze a copper mining venture in Rhodesia. He said that he had been involved in the design of the workings of a copper mine in which the deposit consisted of three, and sometimes, four, uniformly dipping orebodies which were essentially tabular in nature. The original design prepared by mine management foresaw a mining system which comprised bords and barriers that would yield a 67 per cent extraction rate. Through the combined use of the MINSIM and finite element programs, Dr Jantzen had found it possible to increase the percentage extraction over the mine to a figure of not less than 80 per cent.

The last contribution made to the papers on rock mechanics was made by Prof. A. M. Starfield. He made three short comments about the work which had been discussed in this session. He said that he and his previous colleagues at the University of Minnesota had been involved in writing digital computer programs that were similar, but not quite the same in their approach as Dr Deist's MINSIM program. The first point he wanted to make was that as far as he could guess, he did not think they had a serious problem with areas in which there was complete closure and he thought that their method of solution was probably faster in that type of problem. The second point was that he and his colleagues had a computer program which handled steeply-dipping orebodies but which did not take into account the effects close to the surface. The third point he made was by way of a question to Dr Cook. He said that when Dr Cook described the ingredients for the success of the rock mechanics program in South Africa, to what extent did he, Dr Cook, attribute the success of the program to the fact that he had an analogue computer to begin with?

Dr Cook replied by saying that he felt that this question should have been addressed to members of the industry; however, as far as he was able, he would attempt to answer it. He thought that beginning with the analogue computer had had a significant effect because a large part of the misunderstood magic that seemed to pervade computing was eliminated by putting it behind a black-board which was the front of the analogue computer, and once the electronics front view was hidden, it was not frightening any more. Most people found it difficult to type, which was another problem which one had with digital computers, whereas it was really quite easy to put in pins and pull them out on an analogue computer board. The complete physical identity between a mine plan and the analogue model he thought had a substantial effect in making this a saleable product to the users, especially, as Mr Wilson pointed out, in view of the fact that many of these persons had had no extensive formal training, if any at all. Dr Cook thought that starting with the analogue computer had enabled the digital computer methods to get off to a good start because it showed first of all that the problem could be solved, and, secondly, it demonstrated that it could be solved in a finite difference but linear manner. Dr Cook said that he understood that Dr Deist's initial formulation of the MINSIM program was because he realised that he could do on a digital computer what the analogue does better.

The second part of this session commenced with the presentation of a paper by Mr P. Niskanen.

Mr Niskanen said that the Pyhäsalmi Mine was situated in Central Finland, about 500 kilometres from Helsinki, and at this mine the ore was recovered simultaneously by open pit and underground mining.

The annual temperature in Finland varied between +30°C and −30°C, which meant that natural ventilation posed a problem. They had now developed a remote-control ventilation system, and they intended to automate the control procedure as soon as possible.

With the aid of slides, Mr Niskanen described the hardware of the system and he then presented some data on air flows that had been measured in the mine.

The dimensions of the mine were given as: length 1 000 m, width and depth 500 m, and the distance between shafts approximately 500 m. For the control of the air flow they had, in addition to fans, 12 metal ventilation doors of which four could be regulated continuously. The sensing elements in the ventilation system were small hot-wire anemometers mounted about half a metre from the drift roofs. The diameter of the whole device was about 15 centimetres.

The process control desk was located in the mine office building on the surface. From this desk it was possible to regulate the doors, ascertain their positions and read the air flow rates from eight drifts in the mine. With this system, it had been possible to study the ventilation process throughout a winter season. Mr Niskanen then described the results of that research. He said that the ventilation resistances of branches and doors and the natural ventilation pressures consisted of two parts, the deterministic part and the random part. The digital computer methods for ventilation planning, on which he had also based the planning of this system, dealt with the deterministic parts of these functions. The random part was generally unknown and impossible to predict. With the system he had verified the results of the digital ventilation models, he had simulated the air flow in numerous ventilation strategies and then also measured the real flows in the mine under the same circumstances. In all cases the agreement between results had been good.

On the basis of this good correlation he claimed that the computer models for mine ventilation were now able to describe accurately the steady deterministic parts of the flow. However, he posed the question that had plagued him, 'how important was the random part of the flow?'

With the aid of slides that showed data of 'noise' level plotted against time, Mr Niskanen illustrated the variation of air flow in two drifts on a particular level. This graph showed the effects of opening and closing doors and also indicated the amplitude of the stochastic 'noise' to be of the order of about 20 per cent about the mean value under typical conditions, and a time of 2 to 5 minutes was needed to measure the mean.

This graph also showed that the flow was strongly disturbed during the period following the opening and closing of doors. It was pointed out that one source of 'noise' was the effects of hoisting. In certain ventilation conditions this kind of regular undulation in the flow was observed. When recording was carried out at night, it was shown that since less air was blown into the mine, the pressures were smaller and the lift in the shaft created the same effect as the behaviour of a transistor or an electron tube.

Mr Niskanen then gave an example of how to determine the effects on the ventilation system of an unknown variation in the natural ventilation pressures, and how long the system would take to regulate itself.

Mr Niskanen said that since his paper had been written further studies of the ventilation process had yielded many interesting results: among these the time constants of the process, the noise amplitudes and also the extent of disturbances caused by opening and closing the doors. He also said that the usefulness of the computer-simulation models was verified and concluded by saying that the results he had achieved were altogether what he had expected, and that he believed that his logic in the automatization would be the same as that given in the paper.

Mr Martinson said that Mr Niskanen's paper described an elegant and sophisticated method of automating ventilation under conditions somewhat unusual by South African standards. There were, of course, many mines in this country where underground workings connect with open pit workings and in these circumstances there was a tendency for air reversal to occur. However, Mr Martinson thought that in most of the cases he could think of, ventilation was usually sufficiently positive. In other words, in South African mines there was a tendency to put in a sufficient amount of fan power to overcome these linear aberrations caused by changes in natural ventilation pressures. He went on to point out that the extreme temperature changes that were experienced in Finland were not prevalent in South Africa and, as far as he knew, there were no automated systems of ventilation control in this country to compare with the very sophisticated system that Mr Niskanen had described.

Mr Martinson then described some instances of aberrations in the air flow which he thought would be of interest to Mr Niskanen, since they did raise problems in South Africa, but were normally solved manually. The first case that Mr Martinson described was a gold mine in the Eastern Transvaal. He thought it was now closed down but during its working life it had a very steep raise that was used as a main airway. During the rainy season a large quantity of water used to enter this steep raise and the falling water in the raise used to reverse the natural ventilation effect. This was a very small instance, but it did cause difficulties.

The second case was on a copper mine in this country where partly open cast and partly underground mining was being practised, and where a lengthy orepass system was used in the underground workings to tip ore from the upper levels into the upper tips on this orepass system. The falling ore caused a considerable rush of air down the orepass thereby creating a transient change in the ventilation of the mine. This also introduced considerable quantities of dust into the workings. The duration of this type of aberration was about 30 seconds at the most.

The third instance was somewhat similar to an example mentioned by Mr Niskanen, and that was the aberration caused by hoisting. This was normally a function of the size of the shaft in relation to the size of the cage and the speed of winding and the air velocity in the shaft. The particular gold mine shaft referred to (a relatively small circular shaft on the Central Rand) was served by two unusually large cages operating in balance, and the effect of each cage on the total resistance of the shaft was quite considerable – about 25 mm of water gauge. This would normally not have been of any great disadvantage or inconvenience to the mine; however, it so happened that the mine was already ventilated by two underground fans, situated at the bottom of this shaft. As a result of the mine being a hot deep mine, these fans were operating so close to the store zone that each time the cages pulled away the fan went into the store. The fans tolerated this for about 18 months until metal fatigue set in and the fans exploded. This example was not directly related to the subject matter of Mr Niskanen's paper, but it did have a bearing on this question of background noise. Mr Martinson imagined that one would find that the background noise in the South African mines to be very much greater than that which Mr Niskanen had described in his paper.

After Mr Martinson's contribution, Mr M. Kaas asked Mr Niskanen if he had investigated any other means for measuring the air flow and if so, what were they and what were his comments on the accuracy or reliability of the air flow measurements that he had recorded with the hot wire anemometers?

Mr Niskanen said that he had not used other types of instruments at Physälami Mine. He had been using the conventional hot-wire anemometer which was fairly reliable, but he was unable to give details on the accuracy of these anemometers because he did not have any other instrument with which to check the accuracy of the measured air flow.

Mr. Kaas asked a further question about the measuring technique used by Mr Niskanen. He asked if it was necessary to apply any particular type of digital filtering technique on the signal from these anemometers.

Mr Niskanen said that he had found that filtering was necessary. He had used digital filtering but it required such a lot of instrumentation that he was not sure that it was adequate to filter out some of the background noise from the signal that he measured from the anemometers.

Professor de Villiers Lambrechts then said that he thought he should point out that there was a printing error in the equation expressing Mr Niskanen's 'k' which was his stability coefficient. This equation, he said, should contain a plus sign in between the two fractional terms.

Professor Lambrechts then quoted Mr Niskanen's statement that the diagonal branch was stable for this ratio, if it is greater than unity. In the general case it would be stable if it was distinctly greater or less than unity, but it was at unity that it would tend to be stable. He asked whether that was correct.

Mr Niskanen said that this was so. He had taken the coefficient k from a paper given in the references to his paper, and he had found that the k value was extremely sensitive to changes in door positions and for pressures, so much so that he did not see the k value having any practical use.

Professor Lambrechts then raised a point concerning the actual numerical values of pressures in the mine, both the fan pressure and the natural ventilation pressure. He said that he could not recall that Mr Niskanen had given any figures and he wondered if he could give some figures of the order of fan pressure, either in millimetres of water or in millibars, whichever he chose to use, and natural ventilation.

Mr Niskanen said that the fan pressure at Physälami mine were usually of the order of 20 to 40 mm of water and in this case the natural ventilation pressure varied up to 18 mm of water in the worst cases.

Professor Lambrechts continued the discussion by saying that he was thinking of the rather absurd possibility of wasting a lot of power to make the convenient pressure artificially, and by putting in artificial restrictions in the mine, one could ultimately achieve, theoretically at least, the stage where the fans would dominate the picture and one would not get any air reversals. Professor Lambrechts thought that this idea was rather impractical; however, he asked Mr Niskanen if it was worth considering wasting a lot of power to make the fan pressure so high that the natural ventilation pressure would not be large enough to play a part in the matter.

Mr Niskanen replied by saying that this might well be so. However, in his case the mine did not want to do that because the natural ventilation was really most difficult at the highest levels of the mine in which it was planned that in five years' time the mine would not be working there, as the open pit workings would be exhausted. Large fan installations were not envisaged at the Physälami mine and it was felt that the system which he had described would measure the effect of natural ventilation and what it does to the air flow. He would control the fan power so that he could regulate the effect on the mine ventilation system of the natural ventilation.

Professor Lambrecht's last question dealt with a simple practical query. He asked if the automated ventilation really worked in practice. His experience with attempts to automate had only worked on paper and he wondered if this was so in Finland.

Mr Niskanen said that there had been 12 doors operating underground for about 12 months on the mine and only minor problems had arisen. The sort of problems encountered so far had been associated with weak motors that were used on the doors and minor problems of this kind. On one occasion, one of the doors did not open during blasting time as it should have done and the resulting pressure damaged the door. It was fair to say that the doors were operating satisfactorily.