UNDERGROUND VENTILATION NETWORK ANALYSIS BY USING GRAPH THEORY

By

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ABSTRACT

Mine ventilation control is one of the most important techniques to suppress the disastrous region within a limited area, to have enough time of emergencies (ignitions, fires and so on) for underground workers.

The purpose of this paper is to introduce the simultaneous controlling of mine ventilation by using micro computer connected to various kinds of sensors.

In this study, basic of mine ventilation and graph theory are used for making computer programs when the characteristic curves of fans and temperature distribution in an underground roadway network are given.

Results considered in this paper are as follows:

1) Relation between quantity of air leakage into the gob and resistance change of each roadway branch,

2) On the ventilation quantity in relation to connected branches,

3) Relation between temperature change at surface and properties of branches in an underground roadway network, and

4) Simulation of depression and air quantity in a network at the cases of emergencies.

INTRODUCTION

Rationalization of the underground roadway network in coal mines is very important because it contributes for not only in the economical viewpoints but also at the situation of mining safety.

When some kinds of emergencies happen, on-line control of mine ventilation is one of the most available techniques for suppressing disastrous region in limited area and let the miners have enough time to escape from the dangerous district. For this purpose, software for analyzing mine ventilation using micro computer, which will probably be installed in the near future at almost all coal mines, has been developed.

In this paper, theories concerning to mine ventilation analysis and their simulation results are described.

GRAPH THEORY

For solving the problems about underground roadway network, graph theory is useful because underground roadway networks will be able to be abstracted by the sets of points and lines as in graph theory usually considered. In graph theory, a line is called a branch and both terminal points of a branch are called nodes. A branch cannot be branched away by any one except the nodes on it and one branch cannot cross itself as well as other branches.

Generally, an underground roadway network can be regarded as a set of finite number of branches and nodes, and at least, any pair of distinct nodes in the set will be connected by one chain containing a train or points and branches. So one can consider an underground roadway network a finite connected graph.

Various node and branch connection fea-

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tures are given by the coefficient of incident (D_k^a). When a branch (k) is incident to a node (a), the node (a) is called incident to a branch (k). In such a case the node (a) is a terminal node of the branch (k). Coefficent of incident D_k^a of the node (a) is given by the equation (1);

$$D_k^a = \begin{cases} 1: \text{When a branch (k) is incident to a node (a)} \\ 2: \text{When a closed branch (k) is incident to a node (a)} \\ 0: \text{When a branch (k) is not incident to a node (a)} \end{cases} \quad .... \quad (1)$$

Closed branch is a branch that both nodes are coincided each other.

Fig. 1 shows examples of D_k^a.

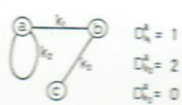

Fig. 1. Typical example of D_k^a

The degree (δa) of a node (a) is the number of branches which are incident to the node (a), and it is given by the equation (2).

$$\delta a = \sum_k D_k^a \quad .... \quad (2)$$

Where $\sum_k$ means summation for all the branches in a graph.

UNDERGROUND MINE VENTILATION THEORY

The basic laws most commonly used for analyzing underground mine ventilation problems are the Ohm's law and two Kirchoff's laws.

3 - 1. Basic law used for analyzing ventilation network

Denoting Q_k and R_k the air quantity flowing into the branch k and the resistance of the same branch having nodes (a), (b) on both ends respectivly, and H_a and H_b are depressions at the node (a) and (b) respectivly, the Ohm's law of ventilation is shown by equation (3);

$$H_a - H_b = d_{ab} R_k Q_k^P \quad .... \quad (3)$$

where $d_{ab} = 1$: when $H_a \geqq H_b$

$d_{ab} = -1$: when $H_a < H_b$

P, in the equation (3), is power of Q and its value is commonly considered from 1.9 to 2.1.

The 1st Kirchoff's law, which provides the algebraic sum of the air quantities which are flowing into and/or out each node is zero, is given by equation (4);

$$\sum_{\ell=1}^{\delta a} d_{a b_\ell} Q_{k_\ell} = 0 \quad .... \quad (4)$$

Where δa is a degree of the node (a), k_ℓ is the ℓ-th branch being incident to the node (a), and (b_ℓ) is the other side node of ℓ-th branch k_ℓ.

The 2nd Kirchoff's law, which provides also the algebraic sum of the pressure drops along the closed chain connecting a number of branches is zero, is automatically satisfied if depression is given at each node on the chain.

In this study, depressions at all the nodes are defined by repeated calculation under given depressions at boundary nodes, such as intake and outlet nodes, etc.

Calculation by computer will be executed as follows.

1) At first, being assumed 0 the values of the depressions at all nodes, except boundary ones, and the depressions at boundary ones are assigned given values as boundary conditions.

2) If the node (a) is incident to a branch k whose other side node is (b), the depression H_a could be expressed by H_{b_ℓ}, R_{ab_ℓ} and Q_{ab_ℓ}. And given that δa is a degree of the node (a) and H_{b_1} is the largest value of depression in H_{b_ℓ}, the depression H_a could be derived from the equation (3).

Therefore

$$H_a = H_{b_1} + d_{ab_1} R_{ab_1} Q_{ab_1}^{P} \quad .... \quad (5\text{-}1)$$

$$H_a = H_{b_2} + d_{ab_2} R_{ab_2} Q_{ab_2}^{P} \quad .... \quad (5\text{-}2)$$

$$\vdots$$

$$H_a = H_{b_\ell} + d_{ab_\ell} R_{ab_\ell} Q_{ab_\ell}^{P} \quad .... \quad (5\text{-}\ell)$$

$$\vdots$$

$$H_a = H_{b_{\delta a}} + d_{ab_{\delta a}} \cdot R_{ab_{\delta a}} \cdot Q_{ab_{\delta a}}^{P} \quad .... \quad (5\text{-}\delta a)$$

are approved.

3) Next equation (6) will be derived from eq.(5-1) - eq.(5-ℓ) , where $2 \leqq \ell \leqq \delta a$

$$H_{b_1} - H_{b_\ell} + d_{ab_1} \cdot R_{ab_1} \cdot Q_{ab_1}^{P} - d_{ab_\ell} \cdot R_{ab_\ell} \cdot Q_{ab_\ell}^{P} = 0 \quad .... \quad (6)$$

Solving equation (6) with respect to air quantity Q_{ab_ℓ}, following expression is obtained.

$$Q_{ab_\ell} = \left\{ (H_{b_1} - H_{b_\ell} + d_{ab_1} \cdot R_{ab_1} \cdot Q_{ab_1}^{P}) \,/\, (d_{ab_\ell} \cdot R_{ab_\ell}) \right\}^{1/P} \quad .. \quad (7)$$

4) Substituting equation (7) in equation (4), next equation containing only one unknown variable Q_{ab_1} , will be derived.

$$d_{ab_1} Q_{ab_1} + \sum_{\ell=2}^{\delta a} d_{ab_\ell} \left\{ (H_{b_1} - H_{b_\ell} + d_{ab_1} \cdot R_{ab_1} Q_{ab_1}^{P}) \,/\, (d_{ab_\ell} R_{ab_\ell}) \right\}^{1/P} = 0 \quad .... \quad (8)$$

Generally speaking, equation (8) will give a multivalued function of Q_{ab_1}. But among their roots only one can be considered to satisfy the range given by equation (9).

$$0 \leqq Q_{ab_1} \leqq \left\{ (H_{b_1} - H_{b_{Min}}) \,/\, R_{ab_1} \right\}^{1/P} \quad .... \quad (9)$$

Where $H_{b_{Min}}$ is the minimum value among H_{b_ℓ}'s.

5) Q_{ab_1} is able to be estimated by the Halfinterval iteration method, providing as lower and upper limit of the values 0 and $\left\{ (H_{b_1} - H_{b_{Min}}) \,/\, R_{ab_1} \right\}^{1/P}$ which are given initially.

6) After determing Q_{ab_1} , substituting this value into the equation (5-1), new value H_a' which is a depression at the node (a) will be obtained. Thus, the estimated depression H_a' is different from the initial value Ha, this estimated new depression value H_a^* will be adopted as new initial depression at the node (a). This procedure is applied to all the nodes except intake and outlet nodes.

Those iteration would be repeated until the difference between estimated depression and initial one becomes to the tolerance limit in relation to all the nodes.

7) After the values of depression at all nodes were converged, air quantity on each branch could be calculated from equation (7).

A flow chart for deciding depression at all nodes is illustrated in Fig. 2.

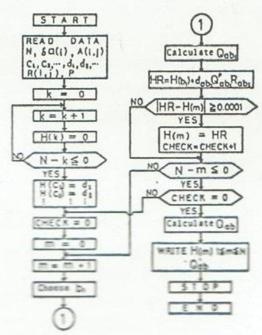

Fig. 2. A flow chart of nodal potential calculation of air ventilation network

3 - 2. Determination of operating point of fan

The method shown in article 3-1 for determination of depression at all nodes will be applied to calculate the depressions when intake and outlet node's ones are fixed.

In the mine, main fans are installed at outlet nodes and local fans are placed at the nodes in underground branches generally, and of course those fans work along the characteristic curves as shown in Fig. 3.

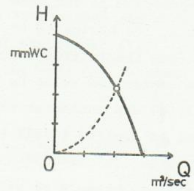

Fig 3. The characteristic curve of a fan

Operating points of fans are estimated by using next procedure.

a) Operating points of main fans that are paralleled in working

1) Firstly, assuming that the operating depression F_k of the k-th main fan takes the maximum value along its characteristic curve, and, regarded as a quadratic equation, air quantity Q_{F_k} passed through the fan will be calculated by the procedure, described in article 3-1. The resultant resistance R_{res_k} could be estimated by the following equation.

$$F_k - H_I = R_{res_k} Q_{F_k}^{p} \quad \cdots\cdots \quad (10)$$

Where H_I is the depression at the intake node.

2) Operating depression (F_k) of the main fan is decided from a crossing point of both characteristic curves of fan ($H = f_k(Q)$) and of underground roadway network ($H = R_{res_k} Q^p$). When the characteristic curve of the fan is expressed by quadratic formula, for the convenience of calculation, logarithmic coordinate is available. But if p is not integer above mentioned method may be impossible, so the Half-interval iteration method will be employed.

3) If the difference between calculated F_k and given F_k exceeds a tolerance limit, calculated F_k takes the place of F_k newly and the same procedure will be repeated until the difference reaches neglegibly small.

Fig. 4 shows a typical example.

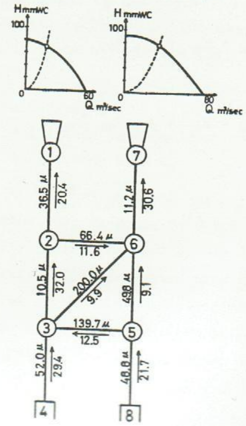

Fig. 4. An air ventilation analysis by graph theory under two fans working simultaneously

b) Operating points of a main fan combining with a local fan in series

In a mine ventilation system, one or more local fans which are combined with main fan in series are working very often at various locations in the system.

Then a local fan is set on a branch, a dummy node must be assigned for this system. The working features of local fans are dependent on main fans, and pressure gradient of them in a ventilation network must be considered as follows, i.e. before the local fan, pressures may be negative and behind it, it shows positive values.

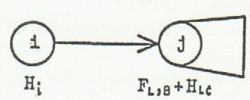

Fig. 5-1. A node which occupies the point in the negative pressure zone of a local fan

When the node (j) is considered as a dummy node of local fan, and the node (j) is in the depression zone of the system (Fig.5-1), the air quantity flowing through the branch (i, j) is defined by the following equation.

$$H_i - (F_{L,B} + H_{LC}) = d_{ij} R_{ij} Q_{ij}^{p} \quad \cdot\cdot \quad (11)$$

where H_i is depression at the node (i) and $F_{L,B} + H_{LC}$ is depression at the node (j) ($F_{L,B}$: generated depression by local fan at the front side of it, and, H_{LC} : depression borne by main fan). R_{ij} and Q_{ij} are the ventilation resistance and flowing air quantity in a branch (i, j) respectively, and p is a power of Q_{ij}. d_{ij} has a value shown under.

$$d_{ij} = \begin{cases} 1: \text{ when } H_i \geqq F_{L,B} + H_{LC} \\ -1: \text{ when } H_i < F_{L,B} + H_{LC} \end{cases}$$

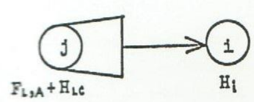

Fig. 5-2. A node (i) which occupies the point in the positive pressure zone of a local fan

In the case that node (i) is existed behind the fan, (Fig.5-2), the flowing air quantity through a branch (i,j) will be obtained by the following equation.

$$H_i - (F_{L,A} + H_{LC}) = d_{ij} R_{ij} Q_{ij}^{p} \quad \cdot\cdot \quad (12)$$

where

$$d_{ij} = \begin{cases} 1: \text{ when } H_i \geqq F_{L,A} + H_{LC} \\ -1: \text{ when } H_i < F_{L,A} + H_{LC} \end{cases}$$

and $F_{L,A}$ is generated depression by a local fan behind it.

The value of H_{LC} in equation (11) and equation (12) is defined by the following calculation.

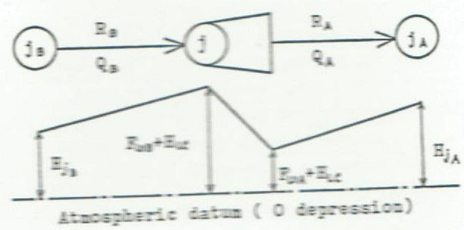

Fig. 6. Depression gratients for local fan system

Depression gradient between branches before and behind a local fan is shown in Fig.6. Imagine that air flows out from the node (j_B) and gets into the node (j) where a local fan is located, and after air passes through the local fan, it flows to reach the node (j_A). R_B and Q_B are resistance and flowing air quantity respectively at the extent (j_B, j), and R_A and Q_A are resistance and air quantity respectively at the extent (j, j_A). H_B and H_A are depression at the node (j_B) and (j_A) respectively. Thus, moreover Q_B and Q_A could be derived from equation (11) and (12).

$$\begin{aligned} Q_B^{P} = Q_A^{P} &= (F_{L,B} + H_{LC} - H_{j_B}) / R_B \\ &= (H_{j_A} - F_{L,A} - H_{LC}) / R_A \end{aligned} \quad \cdots\cdot \quad (13)$$

is also satisfied.

Solving equation (13) with respect to H_{LC}, following expression is obtained.

$$H_{LC} = \{R_B(H_{j_A} - F_{L,A}) + R_A(H_{j_B} - F_{L,B})\} / (R_A + R_B) \quad \cdots\cdot \quad (14)$$

The values of $F_{L,A}$ and $F_{L,B}$ in equations (11) ~ (14) can be decided by next procedure. At first, assuming that the initial depression $F_{L,B}$ takes a half value of the maximum one where characteristic curve of a fan shows, and the initial depression $F_{L,A}$ of local fan is also assumed 0. When operating depression F_M of main fans was determined, air quantity Q_L passed through the local fan can be calculated by the method described in article 3-2 a). Denoting $R_{B,L}$ and $R_{A,L}$ are resultant resistances (Fig.7) of before and behind branch of local fan respectively, and in addition to it taking H_{en} as a depression at the intake node, resultant resistances are estimated by following equations.

$$R_{B,L} = (F_{L,B} + H_{LC} - H_{en}) / Q_L^P \quad .. \quad (15)$$

$$R_{A,L} = (F_M - F_{L,A} - H_{LC}) / Q_L^P \quad .... \quad (16)$$

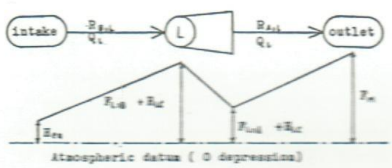

Fig. 7. Depression gradients for local and main fans system

The depression F_L of operating point of local fan is decided from a intersecting point between characteristic curve of underground roadways and the resultant characteristic curve of fans using equations (17) and (18).

$$H = (R_{B,L} + R_{A,L})\, Q^P \quad .... \quad (17)$$

$$H = f(Q) + F_M - H_{en} \quad .... \quad (18)$$

Where $f(Q)$ is a characteristic curve of a local fan.

When the difference between initial depression ($F_L = F_{L,B} - F_{L,A}$) of local fan and estimated one (F_L^*) exceed a tolerance limit, F_L^* takes place instead of F_L. And $F_{L,B}^*$ and $F_{L,A}^*$, which are derived by following equations, take place instead of $F_{L,B}$ and $F_{L,A}$ respectively in the progressive iteration.

$$F_{L,B}^* = H_{en} + R_{B,L}\, Q_L^{*P} - H_{LC} \quad .. \quad (19)$$

$$F_{L,A}^* = F_{L,B} - F_L^* \quad .... \quad (20)$$

Q_L^* is air quantity at the crossing point of equation(17) and (18).

3 - 3. Determination of direction and intensity of natural ventilation

Natural ventilation occurs due to the temperature difference among nodes connected in the train of closed chain. Natural ventilation pressures are caused by conversion of heat into mechanical energy and amount of heat converted into mechanical work per unit weight of air is indicated by equation (21).

$$h_N = -\oint V\, dP \quad .... \quad (21)$$

Where h_N, V and P are pressure head, specific volume of air and pressure respectively.

Dr. R.E. Greuer suggested that to determine the natural ventilation pressure, following equation should be applied, i.e.

$$h_N = \oint \frac{1}{T_m}\, T\, dz \quad .... \quad (22)$$

where h_N, T_m, T and z are pressure head, absolute average temperature in the closed circuit, absolute temperature of each point in the circuit and elevation, respectively.

As a matter of convenience, assuming that there governs a linear temperature change between nodes, temperature of a branch concerned is indicated by equation (23).

$$T_\ell = A_\ell z_\ell + B_\ell \quad .... \quad (23)$$

where, T_ℓ (°K) and z_ℓ(m) are absolute temperature and elevation of a branch ℓ , respectively, and A_ℓ and B_ℓ are constants for branch ℓ .

Substituting T (°K) in equation (23) into equation (22), natural ventilation pressure head h_N is approximately calculated by equation (24).

$$h_N = \frac{1}{T_m} \sum_{\ell=1}^{n} (A_\ell z_\ell + B_\ell) \quad .... \quad (24)$$

where n is the total branch number in closed circuit.

Taking up that node (i) and (j) that are incident to a branch ℓ, and $T_{\ell,i}$ and $z_{\ell,i}$ are absolute temperature and elevation at node (i), also $T_{\ell,j}$ and $z_{\ell,j}$ are absolute temperature and elevation at node (j), thus constant numbers A_ℓ and B_ℓ, in the equation (24), are decided as following expressions.

$$A_\ell = \frac{T_{\ell,i} - T_{\ell,j}}{z_{\ell,i} - z_{\ell,j}} \quad .... \quad (25)$$

$$B_\ell = \frac{T_{\ell,i}\, z_{\ell,j} - T_{\ell,j}\, z_{\ell,i}}{z_{\ell,j} - z_{\ell,i}} \quad .... \quad (26)$$

Substituting equations (25) and (26) into equation (24), equation (27) is derived.

$$h_N = \frac{1}{2T_m} \sum_{\ell=1}^{n} (T_{\ell,i}\, z_{\ell,j} - T_{\ell,j}\, z_{\ell,i}) \quad .. \quad (27)$$

Average absolute temperature T_m will be calculated as follows.

$$T_m = \frac{1}{2n} \sum_{\ell=1}^{n} (T_{\ell,i} + T_{\ell,j}) \quad .... \quad (28)$$

From equation (28) and (27), h_N could be obtained by equation (29).

$$h_N = \frac{n \sum_{\ell=1}^{n} (T_{\ell,i}\, z_{\ell,j} - T_{\ell,j}\, z_{\ell,i})}{(T_{\ell,i} + T_{\ell,j})} \quad .. \quad (29)$$

Denoting D_r as a mean density of considered circuit, natural ventilation pressure H_N (mmW.C.) is estimated as follows.

$$H_N = \frac{D_r n \sum_{\ell=1}^{n} (T_{\ell,i}\, z_{\ell,j} - T_{\ell,j}\, z_{\ell,i})}{(T_{\ell,i} + T_{\ell,j})} \quad .. \quad (30)$$

If there exist two or more closed circuit in a ventilation network, each natural ventilation pressure of each independent circuit must be considered to be taken up. In order to distinguish the independent closed circuit, all the branches in the network should be classified into tree branch and chord branch. And an independent closed circuit will be made by linking tree branches with one chord branch.

Consider that nodes (i) and (j) are terminal nodes of a chord branch. H_i and H_j indicate depressions at the node (i) and (j) respectively. R_{ij} and Q_{ij} show resistance and flowing air quantity in the chord branch respectively. And if natural ventilation pressure of a closed circuit containing a chord branch (i,j) is shown as $H_{N,ij}$, next relation could be satisfied.

$$H_i - H_j = d_{ij} R_{ij} Q_{ij}^{\rho} - S_{N,ij} H_{N,ij} \quad .. \quad (31)$$

where

$$d_{ij} = \begin{cases} 1: & \text{When the air flows from node (i) to node (j).} \\ -1: & \text{When the air flows from node (j) to node (i).} \end{cases}$$

$$S_{N,ij} = \begin{cases} 1: & \text{When a closed circuit chains are linking in the direction from the node (j) to (i).} \\ -1: & \text{In the reverse direction above described.} \end{cases}$$

When natural ventilation pressures exist in an underground roadways network, the method for deciding depression H_a at a node (a), could be modified as follows. If a node (a) is incident to a chord branch whose other side node (b) has a depression H_b, modified depression H_b' could be used for deciding depression H_a at the node (a).

$$H_b' = H_b + S_{N,ab} H_{N,ab} \quad .... \quad (32)$$

$$S_{N,ab} = \begin{cases} 1: & \text{When a closed circuit chains are linking in the direction from the node (b) to (a).} \\ -1: & \text{In the reverse direction above described.} \end{cases}$$

$H_{N,ab}$ is natural ventilation pressure of closed circuit containing chord branch (a,b).

3 - 4. Determination of ventilation quantity of regulating section resistance

Regulators are usually installed in an underground roadways network for making air quantity distribution in good conditions.

In this chapter, deciding procedure of regulator resistance will be explained. At first, depressions at all the nodes in a network without regulators should be decided by the method mentioned in previous articles. And next, using air quantity in the branch where a regulator is placed, depression between both ends of the branch and its resistance will be calculated.

In this way, repeated calculation should be executed until depression at every node and working points of main and local fans will have been converged.

EXAMPLES OF THE DEMONSTRATING APPLICATIONS

4 - 1. Arrow diagram

As an example, an underground coal mine roadway network in Japan is shown in Fig. 8. This network has 73 nodes, 121 branches, 3 main fans and 4 intake nodes. The numbers along the branches in the network are specific ventilation resistances (μ) of them and the numbers described in the parentheses show air quantities (m^3/sec) in them.

Node number has no meaning itself, but, when depressions of all the nodes in a network are already decided, node numbers should be assigned according to the values of depression in order to understand easily the direction of air flow. A flow chart for node re-numbering is illustrated in Fig. 9.

Result that all the nodes in Fig. 8 were re-numbered is shown in Fig. 10.

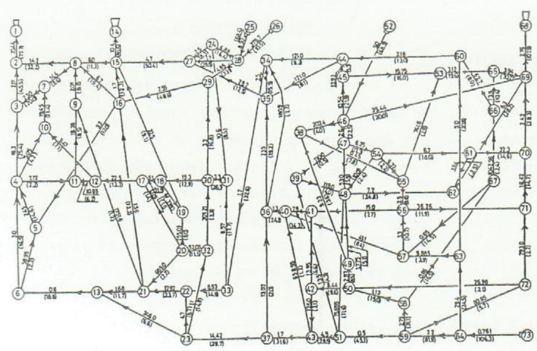

Fig. 8. An example of air ventilation network of coal mine in Japan

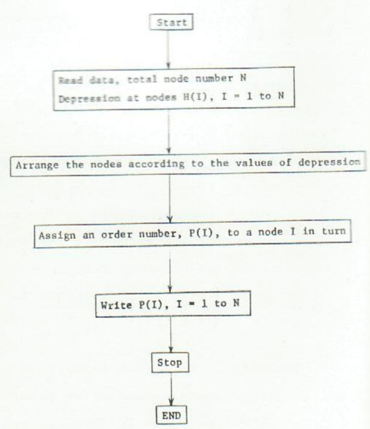

Fig. 9. A flow chart for numbering followed by the order of depression (arrow diagram)

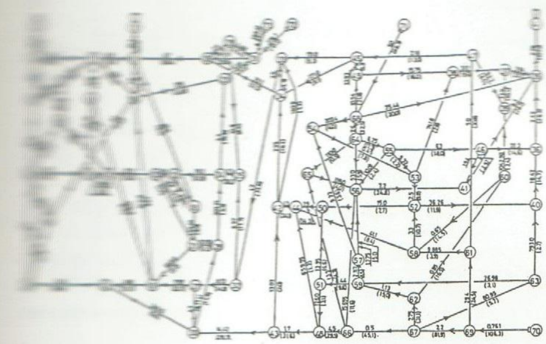

Fig. 10. An example of arrow diagram

Fig. 10. shows leakage air between node 19 and 21 is 2.2 (m^3/s) in quantity.

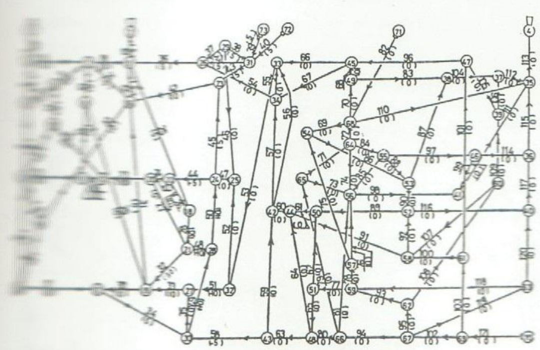

Fig. 11. Effective factor for leakage branch (node 19, node 21) influenced by each branch ventilation resistance increasing

Fig. 11 shows effect of branch resistance change on the air quantity. Numbers along branches in the figure are branch numbers. And numbers in parentheses are effective factors $A_{f\ell}$ (%) of air quantities that are changed due to the resistance R_ℓ in its branch doubled.

$$A_{f\ell,\ell} = ((\text{Leakage air quantity on the condition of } 2R_\ell - 2.2) / 2.2) \times 100 \quad ..... \quad (33)$$

From Fig. 11, it is found that effective factor of leakage branch itself is 30 (%) due to change $R_{19,21}$ into $2R_{19,21}$ and effective factor of branch 51 (node 27, node 32) is -10 (%). The latter means increased air quantity in leakage branch, due to change of branch (27, 32) from $R_{27,32}$ to $2R_{27,32}$.

Here, effective factors are estimated in the case that only one branch changed in its resistance. If resistances of branches change simultaneously, effect of leakage air quantity will be increased.

4 - 3. On the ventilation quantity in relation to connected branches

In article 4-2, effective factor of a branch ℓ was defined. By using same procedure, effective factor $A_{f m,n}$ of a branch m to other branch n can be estimated. The branch having the largest value of effective factor of $A_{f m,n}$'s is called the most effective branch of a branch m.

A flow chart for searching the most effective branch for each branch in a network is shown in Fig. 12.

Fig. 13, for negative effective factor, and Fig. 14, for positive effective factor, show the most effective branch of each branch in network given in Fig. 10 respectively.

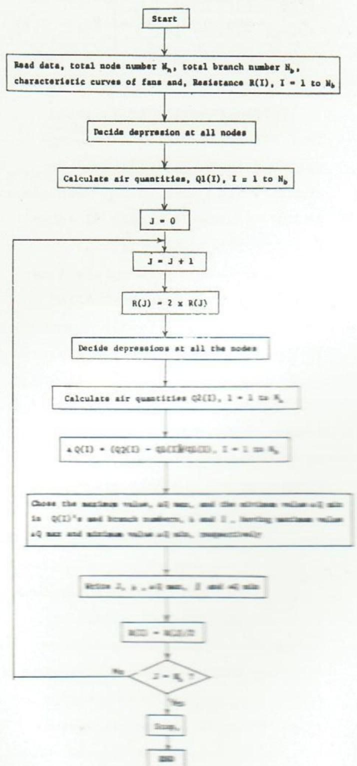

Fig. 12. A flow chart to search the branch which will have the largest effective factor

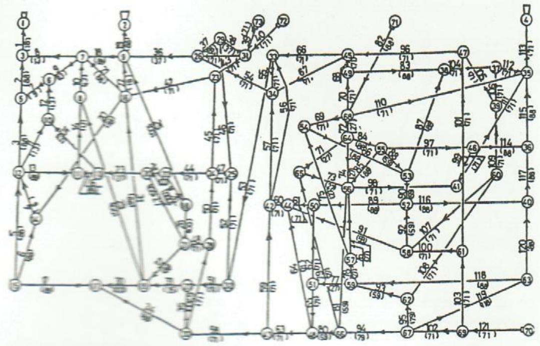

Fig. 13. Most influenced branch number (m) when the resistance of a branch makes doubled. In the case, air quantity in the branch (m) is decreased

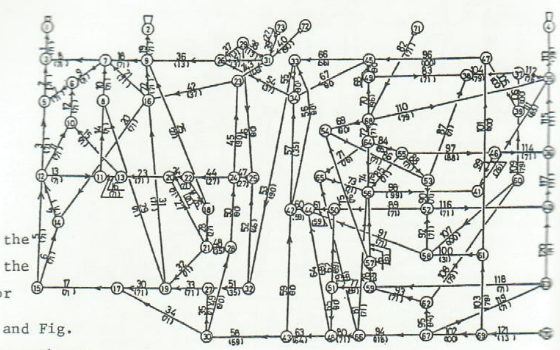

Fig. 14. Most influenced branch number (m) when the resistance of a branch ℓ makes doubled. In the case air quantity in the branch (m) is increased

Numbers along the branches in Fig. 13 and Fig. 14 are branch-numbers and numbers in parentheses in both figures are numbers of the most effective branches of the branch itself.

Considering complicated underground roadway network and characteristic curves of fan, increasing of ventilation resistance of a branch does not always yield decreasing of air quantity of the network. For this purpose, effective factor ($A_{F,mm}$) of the branch m itself would be estimated (Fig. 15). Numbers along branches and numbers in parentheses in the fig.15 are branch-numbers and effective factors ($A_{F,mm}$'s) of the branch itself. From Fig. 15, it is clear that effective factors [illegible] are generally negative, but several branches, such as branch [illegible] (node 53, node 55) and branch [illegible] (node 55, node 56) exhibit different phenomena.

Flowing direction of air in branch [illegible] will be reversed by increasing the value of ventilation resistance of [illegible]. And, increasing of ventilation resistance of branch 85 will make to increase flowing air quantity in branch 85.

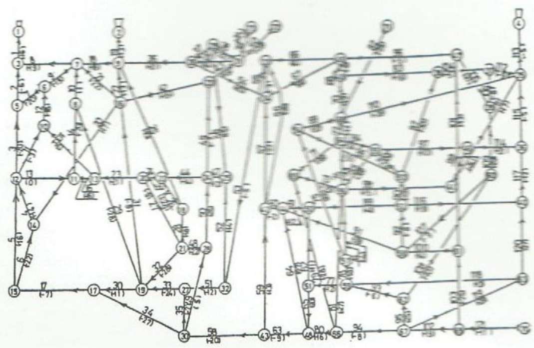

Fig. 15 Air quantity change ratio when a resistance of a branch is doubled

4 - 4. Relation between temperature change on the surface and properties (which are depression distribution and air quantity) of branches

Temperature distribution in underground roadway network can be considered to be existing in steady state except some parts which are neighbouring to intake nodes.

It is available for health safety to know how the temperature change at surface influences air quantity distribution in a network and what condition of air does happen in the case of breaking down state of main or local fans.

Simple example of temperature and depth distribution is illustrated in Fig. 16. Temperatures at intake and outlet nodes in summer as well as in winter are shown by numbers in parentheses and brackets in the Fig.16 respectively.

Natural ventilation pressures acting on chord branches (refer to Fig. 17) in a network shown in Fig. 16 are estimated in Fig. 18.

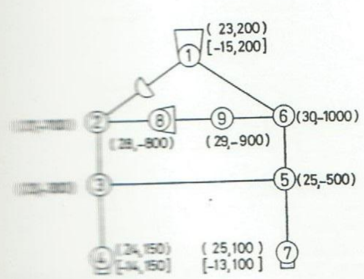

Fig. 16. Temperature (°C) and elevation (m) at each node

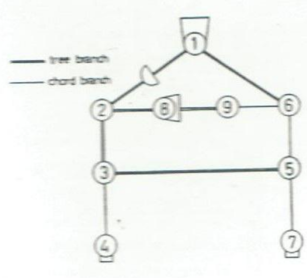

Fig. 17. An example of tree branches and chord branches

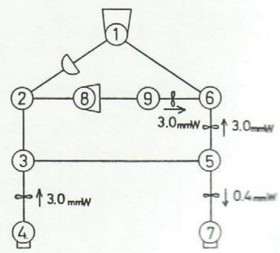

Fig. 18-1. Natural ventilation pressure in summer

Fig. 19 shows ventilation resistance of each branch, characteristic curves of fan installed at node 1 and 8, and given air quantity of the branch where the regulator is constructed.

In Fig. 20, air quantity distribution in the network is shown when no natural ventilation pressure is created. Air quantity distributions of a network in summer as well as in winter are shown in Fig. 21 and 22 respectively. It is recognized that natural ventilation pressures in winter are higher than those during summer time.

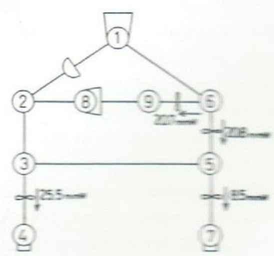

Fig. 18-2. Natural ventilation pressures in winter

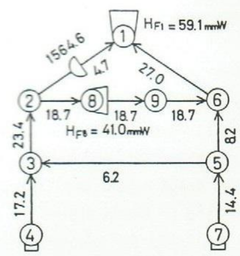

Fig. 20. Air quantity (m^3/s) distribution without natural ventilation

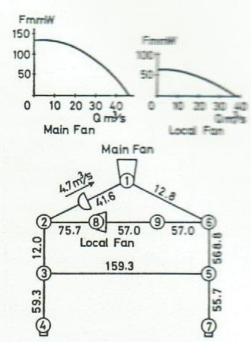

Fig. 19. Resistance (μ) on each branch, fan characteristic curve and air quantity given by a regulator

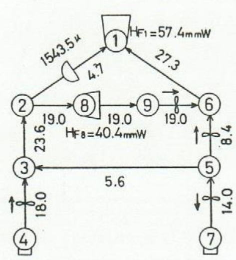

Fig. 21. Air quantity (m^3/s) distribution in summer

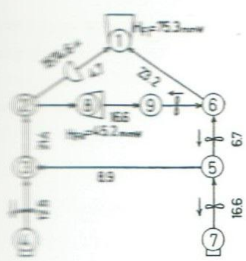

Fig. 22 Air quantity (m^3/s) distribution in winter

4 - 5. Simulation of depression and air quantity in a network at the cases of emergencies

a) Simulation for ignitions

Leakage branch in a network shown in Fig. 17 is a branch (node 5, Node 6). It is assumed that, when ignitions happen in the leakage branch, temperature at node 6 will ascend to 100 (°C) and gas explosion or other conditions that would be generated by ignitions should be neglected for simplicity.

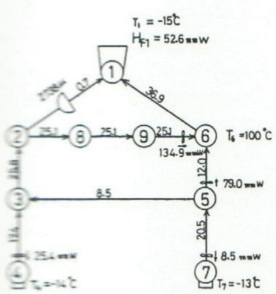

Fig. 23. An example of air quantity (m^3/s) distribution in the event of ignition in leakage branch (node 5, node 6)

Calculated results with regarding to depression of nodes and air quantities in branches using the procedure mentioned in article 3-3 are shown in Fig. 23.

b) Simulation for fires

Coal face in a network shown in Fig. 17 is a branch (node 8, node 9). It is assumed that when the fires happen in coal face branch, temperature will reach 100 (°C), and gas emission generated by fires will be estimated at 16 (m^3/s). But in this case heat transfer between rock and air or other complicated circumstances yielded by the fire should be disregarded.

Simulation result is shown in Fig.24.

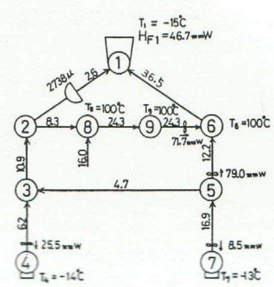

Fig. 24. An example of air quantity (m^3/s) distribution in the event of underground fire at coal face branch (node 8, node 9)

Chapter 5 CONCLUSION

The purpose of this study is on-line underground ventilation control to keep rational air quantity distribution in a network and to discover the better directions in the cases of emergencies by using micro computer.

In this paper, some fundamental programs for this purpose are shown and also several simulation results are demonstrated.

For the performance of simulation of underground ventilation network, shown in Fig. 8, having 73 nodes and 121 branches, consumed time is about 3 seconds when using Facom 230-60 computer. But, in this calculation only two branches resistances were changed and all other depression data gained by previous calculation were used as initial conditions.

It is difficult to estimate the calculating time of micro computer, but simulation by micro computer for the same network shown in Fig. 8 could be achieved within 5 minutes using depression data estimated previously. From this viewpoint, it can be considered that micro computer is available for on-line mine ventilation control. Furthermore, air quantity analysis for more complicated underground roadway network will be able to simulate by connecting a micro computer to a large computer by means of telephone cable.

On-line control of mine ventilation will be done by setting sensors for temperature, air quantity, pressure, emitted gases and so on at many important typical positions and by sending control signals from micro computer to fans and regulators.

ACKNOWLEDGEMENTS

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REFERENCES

1) Rudolf E. Greuer: Study of Mine Fires and Mine Ventilation, U.S.B.M. Contract Report No. S0241032.