

# STATISTICAL WEIGHT ANALYSIS ON THE PARAMETERS FOR GEOMECHANICS CLASSIFICATION OF TUNNELLING

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A statistical reconsideration on the parameters for geomechanics classification of rock mass has been carried out to apply them in the Japanese geological conditions.

Procedure to produce the parameters from the data base collected in conjunction with tunnel deformation and geomechanical rock conditions is reported.

Analysed results of 152 examples of tunnel excavation in the Japanese geology so far collected are compared with the weighting of classifications by Wickham, Bieniawski and Barton.

The authors concluded that the greatest weight should be placed on the thickness of tunnel overburden presented by the sectional area of tunnelling, whereas the RQD and joint condition constitute the greatest factor in the aforesaid researchers.

## 1. INTRODUCTION

In recent years, much importance has been attached to new engineering classification of rock masses related to tunnel and cavern excavation as a method of assesment.

As old examples of rock mass classification related to tunnelling works, there are some ideas proposed by Terzaghi (1946), Lauffer (1958) and others.

In Japan, some types of classifications made by respective authorities are also being used.

These are applied mainly to the criteria in the planning stage for determining the method of excavation and support system.

Though quantitative arrangement such as seismic wave velocity, interval of cracks, core recovery rate, etc. is made partially, the most part is assessed qualitatively and the data relating to the behaviour of rock mass after excavation are not provided.

In the 1970's, techniques were developed in which factors governing rock behaviors after tunnel excavation were analyzed from past execution data and quantitative evaluation was made with weighted factors in relation with the modern tunnelling techniques.

These techniques included those of Wickham *et al.*<sup>7)</sup> (1972), Bieniawski *et al.*<sup>3)</sup> (1979) and Barton *et al.*<sup>2)</sup> (1975) were applied to actual tunnel excavation for verification purposes by Houghton *et al.*<sup>4)</sup> (1976) and Rutledge *et al.*<sup>6)</sup> (1978).

As the results of their studies, several problems were posed in the use of their evaluation methods and the authors already reported the present situation of these problems in Japan at the ISRM symposium<sup>8),9)</sup> (Aachen 1982, Melbourne 1983).

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The evaluation methods proposed by above mentioned researchers were developed on geomechanically stable hard rocks in South Africa, America and Scandinavia, and were considered improper when their methods were to be used for classifying and evaluating rock mass in Japan where tunnels were excavated at soft rock portions having complicated geological structures.

These assessment techniques are composed of the selection, weighting and rating of parameters for the classification.

Weighting of these parameters, however, was determined personally by the proposing workers taking into consideration preceding execution of excavation, but mutual correlations between the parameters were not quantitatively determined.

This is considered attributable to difficulties encountered at that time in preparing data to which proper statistical techniques were applicable when the above mentioned determinations were made.

For this reason, the authors collected data concerning the geology, deformation and excavation techniques of tunnels executed by the authors since 1980 and, after statistical processing of the data, re-considered on the parameters for rock evaluation in order to prepare a rock classification which was suited for geological structures of Japan and capable of correlating it to the evaluation techniques of above mentioned researchers.

As a result, it is considered that parameters which have been taken into consideration by the previous evaluation method can be effectively applied to the geological condition of Japan, but mutual weighting of parameters should be newly made which reflects the geological conditions of Japan.

Thus, when their evaluation techniques are to be applied to geological structure of Japan, it may be necessary to correct the weighting of parameters.

## 2. CURRENT QUANTITATIVE GEOMECHANICAL CLASSIFICATION

The objective of rock mass classification used in tunnelling is to forecast the magnitude and the mode of acting earth pressure generating in the ground through which a tunnel is excavated, and to determine safe, effective and economical method of excavation, support system and thickness of lining.

For this purpose, geomechanics classification have to be equipped with quantitative parameters which are weighted according to the degree of influence to the behaviour of rock mass.

The parameters that control behaviour of rocks can be classified into those related to geology and those related to excavation methods.

As geological factors, there are ;

- (1) Condition of rocks, stratification (rock types, anisotropy)
- (2) Mechanical properties of rocks
- (3) Discontinuity of rock mass (strike, dip, frequency of discontinuity, cohesion on the surface of discontinuity, characteristics of filling materials.)
- (4) Geologic structure (fault, folding, fracture zone, etc.)
- (5) Initial stress of the ground
- (6) Conditions of groundwater and inflow of water into the tunnel

As factors related to excavation method, there are ;

- (1) Demension and shape of the tunnel
- (2) Direction of the tunnel in relation to the geological structure (discontinuity, anisotropy, etc.) of the ground
- (3) Method of excavation (techniques of blasting, excavation system, excavation steps and speed of excavation, etc.)
- (4) Type of support system (timing of support work, etc.)

These factors are interrelated mutually. Therefore, if classification is made on the basis of one parameter only, classified rock mass is assessed with a large aberration.

When assessment is made by combining some of these factors, it becomes possible to fractionize properties of the ground from mechanical and engineering aspects. Since it is very difficult to design support system and lining of the tunnels on the basis of design calculation properly modelling the ground, the procedure that determines the design empirically and corrects it according to the condition of geology is considered to be most reasonable at present.

Studies on the methods of quantitative classification of rock masses basing on the accumulated data of excavation and geology were made by Wickham, Bieniawski, Barton and others in recent years, and were presented as RSR (Rock Structure Rating) concept, RMR (Rock Mass Rating) concept and  $Q$  system.

These classification method were used experimentally in a part of tunnel construction in Japan.

Comparative studies were executed mutually on each of the three conceptions by those who applied them and can be summerized as below :

Barton compared the  $Q$  system with RMR concept and described the difference qualitatively. He pointed out that the stress condition seen in the  $Q$  system was not considered in the parameter taken up in RMR. On the other hand, for the criticism that parameters of interval and direction of joint which were taken in RMR were omitted in his  $Q$  system, Barton said that this causes no pblem as coarseness (Jr) and degree of alteration (Ja) were determined by selecting joint or surface of discontinuity which was likely to collapse first.

Bieniawski compared RMR and  $Q$  value on 111 examples of caverns excavation and obtained the following relation.

$$\text{RMR} = 9 \log_e Q + 44$$

Houghton also used these three classification methods at the Kielder tunnel and pointed out the followings

(1) Coincidence and discordance in estimation of necessary scale of support system according to each method reflect difference in parameters used by respective author rather than difference in interpretation of behaviour of rocks.

(2) When applying the method of classification in the field, geomechanics classification by Bieniawski is easier to apply compared with Barton's  $Q$  system.

(3) Bieniawski's classification is more adequately applicable to jointed rocks in South Africa while Barton's classification was developed for massive rocks in the Scandinavian shield.

A unified system that enable assessment of rocks in the whole world is necessary.

On the other hand, Rutledge et al. used the three methods of classification in New Zealand correlating them mutually and obtained following formula as mutual relation.

$$\text{RSR} = 0.77 \text{RMR} + 12.4$$

$$\text{RSR} = 13.3 \log Q + 46.5$$

$$\text{RMR} = 13.5 \log Q + 43.0$$

According to his study, the most important parameter is the work method including technique of excavation adopted, kind of support, time from the excavation to installation of supports, etc. Further, he stated that when using geomechanics classifications, all methods should be utilized instead of depending on one classification method and should be corrected through monitoring by experimentation, stress analysis and measuring during excavation work since rock classification alone would not provide sufficient reliability.

Meayens<sup>9)</sup> compared predictions according to Barton's and Bieniawski's classification with the condition of tunnel rocks after excavation.

As the results, he found that Barton's  $Q$ -system showed a tendency to give lower assessment of rock mass by about one rank compared with that of Bieniawski's, consequently requiring greater supports.

The same tendency was also observed in Barton's  $Q$  system experimentally used in Japan and the re-

sult obtained was quite different from existing geomechanics classification standard in Japan. However, Maeyens concluded that the two classifications could provide realistic assessment to geotechnologists and result of higher reliability for various grounds could be obtained by using the both together.

### 3. METHOD OF STATISTICAL PROCESSING AND ANALYSIS

#### 3.1 Selection of Parameters

In order to select parameters required for rock evaluation, necessary survey items at site were set up and rock conditions were classified according to the following consideration.

(1) Items used for observation record of underground geology are such that even a non-specialist in geology can make correct description after training for two to three days, and can generate significant differences as parameters.

(2) Considering the importance of correlation between geological data and that of work methods, the data of excavation are to be recorded in detail. Especially, the records are to be made to enable analysis of influences exerted by excavation speed (speed of advance of the face and time of installation of support), type of support, auxiliary working method, etc. on the behaviour of rock mass after tunnel excavation.

(3) Quantitative assessment is to be made for confirmation of stabilization of the ground and for deformation of support after tunnel excavation. For this purpose, convergence measurement is to be made without fail on the section for which geological data are recorded. The standard measurement to be made is for deformation of tunnel section, rock bolts, shotcrete and rock mass. The measured

Table 1 Example of data sheet.

| ① Name of tunnel                              |                                       | ② Excavated date               |                                    |                                       |                               |                                  |   |                       |
|---|---------------------------------------|--------------------------------|------------------------------------|---------------------------------------|-------------------------------|----------------------------------|---|-----------------------|
|   |                                       | year                           |                                    | month                                 |                               | day                              |   |                       |
| ③ Distance from entrance                      |                                       | k                              | m                                  | Tunnel dimension                      | ④ Width m                     | ⑤ Height m                       | ⑥ Section m <sup>2</sup>                        |                       |
| ⑦ Rock type ( )                               |                                       | 1 Plutonics                    | 2 Metamorphics                     | 3 Sedimentaries                       | 4 Volcanics                   | 5 Others                         |   |                       |
| ⑧ Hardness of rock (MPa)                      |                                       | 1 Hard (>80)                   | 2 Medium hard (80-20)              | 3 Soft (20-8)                         | 4 Residuals, Clay, Sand, etc. |                                  |   |                       |
| Condition of joints and cracks                | joint interval d (cm)                 | ⑨ Horizontal direction on face | 1 $100 \leq d$                     | 2 $50 \leq d < 100$                   | 3 $20 \leq d < 50$            | 4 $5 \leq d < 20$                | 5 $0 \leq d < 5$                                |                       |
|   |                                       | ⑩ Vertical direction on face   | 1 $100 \leq d$                     | 2 $50 \leq d < 100$                   | 3 $20 \leq d < 50$            | 4 $5 \leq d < 20$                | 5 $0 \leq d < 5$                                |                       |
|   |                                       | ⑪ Axial direction of tunnel    | 1 $100 \leq d$                     | 2 $50 \leq d < 100$                   | 3 $5 \leq d < 20$             | 4 $5 \leq d < 20$                | 5 $0 \leq d < 5$                                |                       |
|   | ⑫ Joint dip to the direction of drive | 1 Favourable                   | 2 Fair                             | 3 Untavourable                        |                               |                                  |   |                       |
|   | ⑬ Condition of opening                | 1 No separation, unweathered.  | 2 Slightly separated and weathered | 3 Partly separated and weathered      | 4 Separated and weathered     |                                  |   |                       |
| ⑭ Water inflow from face                      |                                       | 1 None, completely dry         | 2 Wet condition on surface         | 3 Partial seepage from joint          | 4 Seepage from whole joint    | 5 Partial gushing out from joint |   |                       |
| ⑮ Quantity of water inflow (at the entrance)  |                                       |                                |                                    |                                       |                               | l/min                            | 6 Gushing out from whole joint                  | 7 Special case, flood |
| ⑯ Tunnel orientation to the strike of stratum |                                       | 1 Nearly parallel              | 2 Nearly right angle               | 3 Oblique                             |                               |                                  |   |                       |
| ⑰ Velocity of P-wave in surrounding rock mass |                                       | m/sec                          |                                    | ⑱ Velocity of P-wave in rock specimen | m/sec                         |                                  | ⑲ Uni-axial strength                            | Mpa                   |
| ⑳ Weight                                      |                                       | t/m <sup>3</sup>               |                                    | ㉑ Overburden                          | m                             |                                  | ㉒ Ratio of uni-axial strength to the overburden |                       |
| ㉓ Coefficient of joint                        |                                       | ㉔ Place of observation         |                                    |                                       |                               |                                  |   |                       |
|   |                                       | 1 full face                    | 2 arch portion                     | 3 central drift                       | 4 right drift                 | 5 left drift                     |   |                       |
| ㉕ Remarks                                     |                                       | 1 Yes                          | 0 No                               |                                       |                               |                                  |   |                       |

Table 2 Correlation of parameters.

|            | Classification  |  |  | Considered Parameters in Table-1  |
|------------|---|--|--|---|
|            | Wickham's   | Bieniawski's   | Barton's   |   |
| Parameters | <ul style="list-style-type: none"> <li>○ Rock Type</li> <li>○ Geological Structure</li> <li>○ Joint Orientation</li> <li>○ Joint Spacing</li> <li>○ Water Inflow</li> </ul> | <ul style="list-style-type: none"> <li>○ Rock Strength</li> <li>○ R.Q.D.</li> <li>○ Condition of Joint</li> <li>○ Joint Spacing</li> <li>○ Water Inflow</li> </ul> | <ul style="list-style-type: none"> <li>○ Geological Condition</li> <li>○ R.Q.D.</li> <li>○ Joint Roughness</li> <li>○ Joint Spacing</li> <li>○ Joint Alteration</li> <li>○ Water Inflow</li> </ul> | <ul style="list-style-type: none"> <li>○ Rock Type</li> <li>○ Rock Strength</li> <li>○ Joint Orientation</li> <li>○ Joint Spacing</li> <li>○ Joint Alteration</li> <li>○ Water Inflow</li> <li>○ Thickness of Overburden</li> <li>○ Sectional area of tunnel</li> </ul> |

values represent the behaviour of rock mass after excavation and are created by combination of rock classification and work methods. Those values are used to judge the quality of adopted excavation techniques.

(4) The form should be such that allows retrieval easily as data base.

The form of data sheet is shown in Table 1.

This data sheet was prepared by referring to the parameters shown in Table 2 which were previously presented by Wickham, Bieniawski and Barton.

For the deformation measurement after tunnel excavation which was used as reference for selecting parameters, data measured by the latest convergence meter was adopted and analysis was made by using 152 examples in which the data sheet and measured results showed satisfactory correspondence. Numbers of surveyed tunnels are shown in Fig.1 classified by rock type and excavated sectional area of the tunnel.

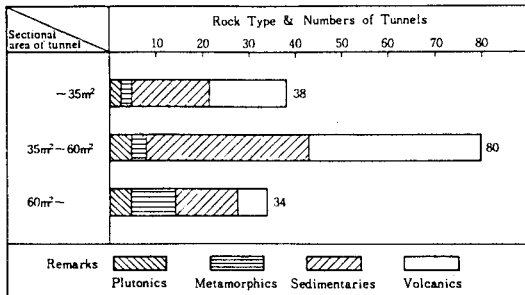


Fig.1 Number of surveyed tunnels.

As shown in the figure, most of surveyed tunnels were drilled into volcanics and sedimentaries which reflect the characteristics of Japanese geology.

The reasons for not taking R. Q. D into consideration as a parameter in this study were that only a few data of core boring were available at the locations of tunnel deformation measurement and that R. Q. D was considered to be indicated by the spacing and degeneration degree of the joint.

In combination with the above mentioned parameters, the authors collected data concerning the sectional area of tunnel excavation, excavation techniques and support techniques, and examined the correlation between the abovementioned parameters and data items.

In obtaining the correlation, statistical processing to be described below was made and the mutual relations were quantitatively calculated.

### 3.2 Outline of Analytical Procedure

Data which had been investigated at site were given statistical processing on the bases of the flow chart of analysis shown in Fig. 2.

Analysis theory used in this procedure is called "quantification theory model II" of multivariate analysis, and is possible to perform examination of attribution and factor in the total number of groups T.

Supposing that it is represented by a linear equation of the quantity of each category of each factor for a sample *i*

$$\alpha_i = \sum_j^R \sum_k^{k_j} \delta_i(jk) x_{jk} \quad (i=1 \cdots N)$$

where

$\delta_i(jk)=1(0)$  : when the sample  $i$  reacts (does not react) to factor  $j$ , category  $k$ .

$x_{jk}$  : quantity given to category  $k$  by factor  $j$ .

Here, when classification into some groups is made,  $x_{jk}$  that makes internal variance small and external variance large is to be found.

That means,  $x_{jk}$  that makes the correlation ratio  $\eta^2 = \sigma_b^2 / \sigma^2$  maximum is to be found.

where,

$$\text{total variance} \quad \sigma^2 = \frac{1}{n} \sum_{i=1}^n \alpha_i^2 - \bar{\alpha}^2$$

$$\text{external variance} \quad \sigma_b^2 = \sum_{t=1}^T \frac{n_t}{n} (\bar{\alpha}_t - \bar{\alpha})^2$$

$$n_{jk}(t) = \sum_{i(t)=1}^{n_i} \delta_{i(t)}(jk)$$

$$\bar{\alpha}_t = \frac{1}{n_t} \sum_{i(t)=1}^{n_i} \alpha_i(t) = \frac{1}{n_t} \sum_j \sum_k n_{jk}(t) x_{jk}$$

$t$  : group number

$T$  : total number of groups

$n_{jk}(t)$  : number that reacts to factor  $j$ , category  $k$  in group  $t$ .

$n$  : total number of samples

$n_t$  : number of sample corresponding to  $t$

To obtain  $x_{jk}$  that make  $\eta^2$  maximum,

$$\frac{\partial \eta^2}{\partial x_{uv}} = 0 \quad (u=1, \dots, R; \nu=1, \dots, \nu_u)$$

This is

$$\frac{\sigma^2 \frac{\partial \sigma_b^2}{\partial x_{uv}} - \sigma_b^2 \frac{\partial \sigma^2}{\partial x_{uv}}}{(\sigma^2)^2} = 0$$

or

$$\frac{\partial \sigma_b^2}{\partial x_{uv}} = \eta^2 \frac{\partial \sigma^2}{\partial x_{uv}} \quad (u=1, \dots, R; \nu=1, \dots, \nu_u)$$

According to above mentioned theory, first, collected data items were subjected to simple and cross tabulations at step-2 in the flow chart to find out the data characteristics.

Then, the classification range of each category and deviation of sampling were examined.

In step-3, all of those items were analysed by employing the quantification theory and correlation coefficients between various items were investigated. Items affecting the deformation quantity of the tunnel were also selected.

This operation was performed on the trial-and-error basis, and the parameter group having the best correlation was selected. If the analysis results of this parameter group are satisfactory, prediction of the deformation quantity of the tunnel to be newly excavated becomes possible at step-4.

#### 4. DISCUSSION ON MUTUAL CORRELATION OF PARAMETERS

Through the analysis by the quantification theory, correlation coefficients between various para-

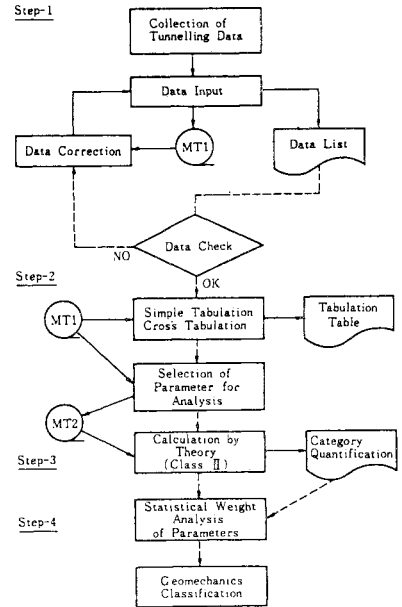


Fig.2 Flowchart of data processing and analysis.

Table 3 Classification range.

| Parameters               | Range  |
|--------------------------|--|
| Sectional area of tunnel | 1. Under 35 m <sup>2</sup><br>2. 35 m <sup>2</sup> ~60 m <sup>2</sup><br>3. Over 60 m <sup>2</sup> |
| Rock Type                | 1. Plutonics & Metamorphics<br>2. Sedimentaries<br>3. Volcanics                                    |
| Hardness of Rock         | 1. Hard<br>2. Medium Hard<br>3. Soft, Residuals, Clay, Sand  |
| Joint Spacing            | 1. 20 cm ≤ d<br>2. 5 cm ≤ d < 20 cm<br>3. 0 ≤ d < 5 cm   |
| Conditions of Opening    | 1. No Separation<br>2. Slightly Separated<br>3. Partly Weathered<br>4. Weathered                   |

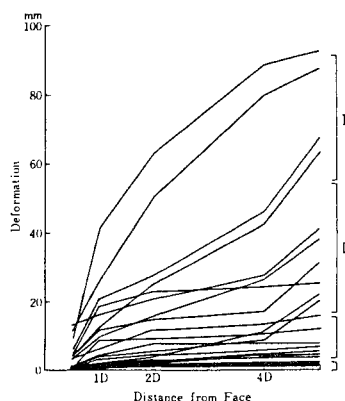


Fig. 3 Classification range of tunnel deformation.

meters were calculated and the classification range of categories of various parameters were rearranged as shown in Table 3.

On the tunnel deformation which is to be discussed with the correlation to parameters, the convergence displacement (final quantity) is classified into four groups (1 mm–10 mm, 10 mm–50 mm, 50 mm over) as shown in Fig. 3.

The final deformation of the tunnel was measured when the face advanced to the equivalent distance of 5 times of diameter, and was measured at the top of the sidewall of the tunnel which was executed by using standard bolts and shotcrete method.

During the rearrangement work of those parameters, various results mentioned below were referred

(1) Correlation coefficients of joint spacing and tunnel deformations in the horizontal, vertical and axial direction on the tunnel face were of the same degree, but only the joint spacing and tunnel deformation in the axial direction were used because of their high mutual internal relation.

(2) The dip of the joint was omitted, because it has high correlation with the sectional area of the tunnel and the rock type which have high correlation with tunnel deformation.

(3) Water inflow was omitted, because it has a high correlation with the rock type and a low correlation with tunnel deformation.

(4) The thickness of overburden has a very high correlation with the sectional area but has no high correlation with other parameters. This means there was no need of adopting it.

(5) Rock type was adopted because it had high correlation with water inflow and tunnel deformation

(6) Hardness of rock was adopted because it had high correlation with the orientation of the joint and tunnel deformation.

(7) Condition of opening was adopted because it had high correlation with all parameters.

(8) Sectional area of excavation of the tunnel was adopted because it had high correlation with most of parameters.

Results of the quantification analysis made by using the rearranged parameters are shown in Table 4 as simple correlation matrix.

The quantity of categories of various parameters are shown in Table 5. The correlation ratio at this time was 0.68.

Frequency distribution in which the sample quantity was obtained on the basis of this quantity of categories is shown in Fig. 4, which clearly indicated that classification by tunnel deformation is

Table 4 Simple correlation matrix.

| Parameterers             | Tunnel Section | Rock Type | Hardness of Rock | Joint Spacing | Condition of Opening | Tunnel Deformation |
|--------------------------|----------------|-----------|------------------|---------------|----------------------|--------------------|
| Sectional area of tunnel | 1.0000         | 0.3677    | 0.4998           | -0.0358       | 0.3030               | 0.6267             |
| Rock Type                | 0.3677         | 1.0000    | 0.2393           | 0.3121        | 0.4011               | 0.6047             |
| Hardness of Rock         | 0.4998         | 0.2393    | 1.0000           | 0.3644        | 0.3470               | 0.5298             |
| Joint Spacing            | -0.0358        | 0.3121    | 0.3644           | 1.0000        | 0.3252               | 0.3896             |
| Condition of Opening     | 0.3030         | 0.4011    | 0.3470           | 0.3252        | 1.0000               | 0.5786             |
| Tunnel Deformation       | 0.6267         | 0.6047    | 0.5298           | 0.3896        | 0.5786               | 1.0000             |

Table 5 Result of category quantification.

| Parameter                | Category                           | Quantity | Partial Correlation Coefficient, Range |          |
|--------------------------|------------------------------------|----------|--|----------|
|                          |                                    |          |  |          |
| Sectional area of tunnel | (1) 0~35 m <sup>2</sup>            | 0.0000   | 0.49 ①                                 | 0.7978 ① |
|                          | (2) 35~60 m <sup>2</sup>           | 0.2898   |  |          |
|                          | (3) 60 m <sup>2</sup>              | -0.5080  |  |          |
| Rock Type                | (1) Metamorphics                   | 0.0000   | 0.37 ②                                 | 0.4340 ③ |
|                          | (2) Sedimentaries                  | 0.0531   |  |          |
|                          | (3) Volcanics                      | 0.4340   |  |          |
| Hardness of Rock         | (1) Hard                           | 0.0000   | 0.13 ⑤                                 | 0.2084 ⑤ |
|                          | (2) Medium hard                    | -0.1509  |  |          |
|                          | (3) Soft, Clay, Sand               | -0.2084  |  |          |
| Joint Spacing            | (1) 20 ≤ d                         | 0.0000   | 0.29 ④                                 | 0.3012 ④ |
|                          | (2) 5 ≤ d < 20                     | -0.3012  |  |          |
|                          | (3) 0 ≤ d < 5                      | -0.1553  |  |          |
| Condition of Opening     | (1) No separation                  | 0.0000   | 0.35 ③                                 | 0.7002 ② |
|                          | (2) Slightly Separated             | 0.2230   |  |          |
|                          | (3) Partly Separated and Weathered | 0.0912   |  |          |
|                          | (4) Separated and Weathered        | -0.4772  |  |          |

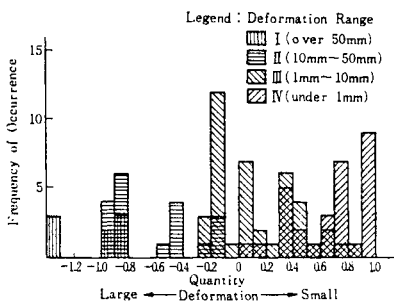


Fig. 4 Histogram of sample quantification.

possible.

The above results clarify that effective contributions were made to classification by the tunnel section, opening condition of the joint, rock type, joint spacing and hardness of rock as factors affecting the tunnel deformation.

## 5. FINAL COMMENTS

The analysis results of 152 examples of tunnel excavation in the geological condition of Japan so far collected are compared with the weighting of classi-

fications by the three aforesaid researchers in Table 6.

As shown in the analysis results, various parameters used in all of the RSR Concept, RMR Concept and *Q*-System seem to effectively applicable to the geological classification of Japan. Particularly the rating of the analysis results virtually agrees with that of the RMR Concept.

The only difference lies in that the greatest weight is placed on RQD and the joint condition in their classifications, whereas in the Japanese classification, sectioned area of tunnel affected by the thickness of tunnel overburden constitutes the greatest factor.

The above indicates that most of the geology of Japan belong to the so-called "fault zone," that is, the rock body has turned into debris and many joints have occurred, thereby making classification by joint spacing difficult.



Table 6 Correlation of parameter weight.

|   | Rating<br>good+poor<br>(Range) | Weight of Parameters        |
|---|--------------------------------|-----------------------------|
| RSR<br>Concept  | 45 - 9 (34)                    | Sectional area of tunnel    |
|   | 6 - 30 (23)                    | Geological Structure        |
|   | 25 - 6 (19)                    | Water Inflow                |
|   | 1 - 4                          | Rock Type                   |
| RMR<br>Concept  | 30 - 0 (30)                    | Joint Condition             |
|   | 20 - 3 (5) (17)                | RQD, Joint Spacing          |
|   | 15 - 0 (15)                    | Rock Strength               |
|   | 15 - 0 (15)                    | Water Inflow                |
| Q-System  | 100 - 0 (100)                  | R, Q, D.                    |
|   | 0.5 - 20 (19.5)                | Joint Spacing               |
|   | 0.5 - 20 (19.5)                | Geological Condition        |
|   | 4 - 0.05 (19.5)                | Joint Condition             |
|   | 1 - 0.005 (0.95)               | Water Inflow                |
| Result of<br>Analysis<br>(Coefficient<br>range x 100) | -51 - 29 (78)                  | Tunnel Section or Thickness |
|   | -48 - 22 (74)                  | Joint Condition             |
|   | 0 - 43 (43)                    | Rock Type                   |
|   | -30 - 0 (30)                   | Joint Spacing               |
|   | -21 - 0 (21)                   | Rock Strength               |
|   | 0                              | Water Inflow                |

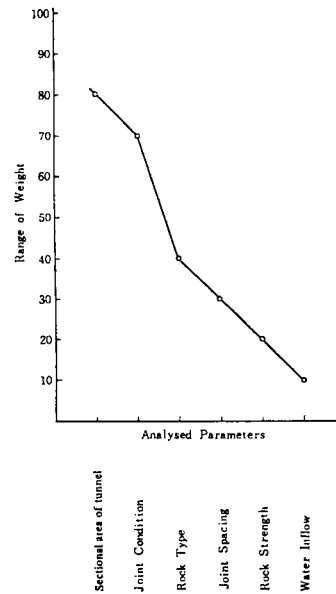


Fig. 5 Rounded numbers of weight.

For this reason it is necessary to consider, in classifying the rock mass for tunnelling of Japan, that the strength ratio which is determined by the strength of rock specimens comprising the mass and thickness of the overburden has become the factor governing the stability of the tunnel. In connection with this, the size of the tunnel to be excavated also should require full consideration in evaluation of the geology.

The results for the trial use of classification is shown in Fig. 5 as rounded numbers of weight.

In the future, analyzed weight of parameters is expected to try in the RMR-concept or Q-system comparing their established weight applied in Japanese geology. After those trial use and assessment, it is considered that a new classification could be framed up taking account of tunnelling method and geological parameters, also it is expected that the weight of parameter will make a contribution to the reliability analysis of tunnelling.

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