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POSSIBILITY OF APPLICATION OF FUZZY LOGIC FOR STABILITY ASSESSMENT OF UNDERGROUND FACILITIES

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Abstract: *A proper assessment of the stability of underground facilities leads to proactive decision making for the choice of method of construction, the shape and size of the cross-section of the facility and the adequate type and dimensions of the support system. The stability is directly dependent on the characteristics of the rock mass. To ease the process for the early phase of design, a certain mathematical model should be developed that could assess the stability of the underground facilities in the design phase. Fuzzy logic proved to be a good choice to describe and solve various problems in mining engineering, also ambiguity in mining engineering, particularly within the design phase, directs the development of the model using a fuzzy logic system and fuzzy "if-then" rules.*

Keywords: *Stability, assessment, underground construction, fuzzy logic*

1. INTRODUCTION

The increasing need for the global construction of underground facilities is due to the rapid expansion of urban zones –e.g. underground passages, parking spaces, underground tunnels for road traffic, the development of a network of underground city railways, metros, a larger number of communal tunnels, as well as underground mining roadways and facilities. These underground facilities that are necessary for the utilization of mineral resource, however, lie deep within the earth's depths, due to a long exploitation period of mineral resource deposits within surface mining. Furthermore, the high standards set within the field of environmental protection either do not allow disturbances of the terrain or require the re-cultivation of the degraded terrain (created in the midst of mining activities). These have, consequently, led to an increase in ore prices.

Moreover, the underground construction of these facilities presents a very complex problem, primarily because of the working environment (e.g. rock mass) which consists of rocks with different physical and chemical compositions and sometimes with great structural differences in very small areas. Its chemical composition, as well as genesis, mineral composition, structural, texture and hydrological characteristics and tectonicism, thus influence the physical, mechanical and technical characteristics of the rock mass. This leads to the conclusion that, with the application of fuzzy sets, the parameters of the rock mass can be classified in much more detail.

Underground constructions must be stable and to ensure this stability, it is sometimes necessary to install a support system. The shape and dimensions of underground facilities are conditioned by the characteristics of the rock mass, as well as the shape and dimensions of the support system –which depend on the stability of the underground space.

The traditional assessment-based methods used to determine the stability of underground facilities are based on the experience gained from previously-constructed underground facilities, while the mathematical model for predicting the stability of underground facilities, is almost non-existent. This experience can then be used to define linguistic variables that would be brought into the fuzzy logic relationship through appropriate membership functions.

The fuzzy model, used for assessing the stability of underground facilities, would facilitate the construction of these facilities as it provides better perspective on very scarce data. With the implementation of the fuzzy model, comes the need for a properly-selected support system and an accurate dimensions of the cross-section of these underground facilities.

2. STABILITY ASSESMENT OF UNDERGROUND FACILITIES

The selection of an appropriate support system is one of the most complex tasks in the process of underground construction since the support systems serve to stabilize the underground facilities during the process of production and its period of exploitation. Furthermore, in the design phase, there is lack of data on the rock mass (through which the underground facilities are constructed).

The type of support system depends partially on the shape and dimensions of the underground facilities as well as on the value of the underground pressure and the estimated stability of the contours of the underground facilities. It is necessary to adopt an adequate support system that can resist all the loads and will preserve the designed shape and dimensions of the underground facility [1] so that, ultimately, the shape and dimensions are directly dependent on the type of support system chosen and its level of stability.

Stability is very important in terms of its construction and exploitation. There is the notion that stability is associated with a particular feature of rock mass which serves to preserve the shape and dimensions of the constructed facility, i.e. the deformations of the rock mass surrounding the underground facility do not go beyond the area of the elasticity of the material [2]. The rock mass (i.e. working environment) with this feature is considered stable and therefore does not often require a support system. Some rock masses however are easily deformed, resulting in cracks in, and the eventual collapse of, the material; and in such cases these underground facilities require the installation of support systems in order to maintain stability.

The possibility of a collapse in the contour of the underground facilities is related to the petrographic composition and strength of the rock mass, the macrostructure, the density, the orientation of the cracks in the rock mass, the depth of the facility, the size of the cross-section of the facility, the construction technology, etc. Stability also depends on material flow characteristics as well as on the atmospheric influences that prevail in underground facilities –e.g. air, humidity, temperature changes, etc. [3].The research, that is necessary for fully understanding the values of all factors influencing the stability of underground facilities, would be very expensive and time consuming. The solution is, therefore, to rely on the information gathered through the monitoring of underground objects' behavioural patterns within different working conditions [4].

The stability of the rock mass is determined and classified by different criteria. The most commonly-used criteria for assessing stability [5] are:

- The general criterion of stability based on the ratio of the pressure values and the carrying capacity of the rock mass,

$$k \cdot \gamma \cdot H \leq \xi \cdot n \cdot R \quad (1)$$

where:

γ – unit weight of overburden; k – stress concentration coefficient; H – object depth; ξ – flow coefficient; n – coefficient of damage to the rock mass and R – uniaxial compressive strength of rock mass.

The stability criterion, according to Ju. Z. Zaslavsky, representing the ratio of hydrostatic load and uniaxial compressive strength of the rock mass

$$S = \frac{\gamma \cdot H}{R} \quad (2)$$

where:

γ – unit weight of overburden; H – object depth and R – uniaxial compressive strength of rock mass.

The criterion of stability by F. Mor

$$s = C \cdot \frac{(1+\sin\varphi)^2}{\gamma \cdot H \cdot (1-\sin\varphi)} \quad (3)$$

where:

C – cohesion; γ – unit weight of overburden; H – object depth and φ – angle of internal friction.

All above mentioned criteria are applicable in estimating the stability of the rock mass when the underground facility is constructed in solid and weak (fragile) rock mass. On the other side, for stability assessment of rock mass in case of underground construction in rock mass with the plastic behaviour criteria for stability assessment are a bit different [2]. These criteria are shown in eq. (4) and eq. (5).

- The general criterion of stability based on the ratio of the pressure values and the carrying capacity of the rock mass with plastic behaviour:

$$k \cdot \gamma \cdot H \le \xi \cdot n \cdot R \cdot K_s \quad (4)$$

where:

γ – unit weight of overburden; k – stress concentration coefficient; H – object depth; ξ – flow coefficient; n – coefficient of damage to the rock mass and R – uniaxial compressive strength of rock mass and K_s – a coefficient characterized by an increase in the stability of the rock mass capable of plastic deformation (see eq. 4.1.).

$$K_s = \frac{P^{\frac{\alpha}{2}} - 1}{\sin\varphi} \quad (4.1.)$$

where:

P – an indicator of the plastic behaviour of the rock mass; φ – angle of internal friction and α is represented with eq. 4.2.

$$\alpha = \frac{2\sin\varphi}{1-\sin\varphi} \quad (4.2.)$$

where:

φ – angle of internal friction.

According to Ju. Z. Zaslavsky, floor of horizontal underground facility is stable if the heaving doesn't have larger value than 200mm. This requirement is met when:

$$2a = A \cdot \frac{R}{\gamma \cdot H} \quad (5)$$

where:
2a – width of the underground facility; γ – unit weight of overburden; H – object depth and R – uniaxial compressive strength of rock mass and A – coefficient which takes into account the position of the underground facility in relation to the mineral deposit (A=1,6 for transversal hallways, A=1,22 for all other positions of hallways).

3. BASIS FOR THE FUZZY MODEL

The widespread implementation of fuzzy logic in engineering is a result of approximate determination rather than the reliance on more precise data (which is generally absent from engineering-related problem solving approaches, especially at the design stage). Given that man's thought process/pattern is governed by nature, fuzzy logic, therefore, serves as a familiar tool. The creator of fuzzy logic, L. Zadeh [6], concluded, in his analysis of complex systems, that as the complexity of the system increases, our possibilities of precise observation and behaviour of the system, decrease [7].

As part of the solution process in mining engineering, fuzzy logic, as in other engineering branches, has found its purpose and application. Thus, the fuzzy logic approach was applied to the classification of rock mass [8-10], serving to assess the stability of the slopes [11], the predicted rate of penetration in rotary drilling [7], tunnel construction [12], the use of rational technology for the construction of underground facilities [13], the management process in mineral processing [14] and production planning in bauxite mines [15]. In above mentioned researches fuzzy sets and fuzzy logic gave satisfactory results from engineering point of view.

As previously mentioned, set theory and fuzzy logic have been integral tools for resolving problems in mining engineering. In fact, the fuzzy set theory and fuzzy logic approach could serve as a solution to one of the largest underground mining engineering problems, stability assessment.

The decision-making algorithm for applying the appropriate criteria for assessing stability is shown in the graph below (Figure 1.)

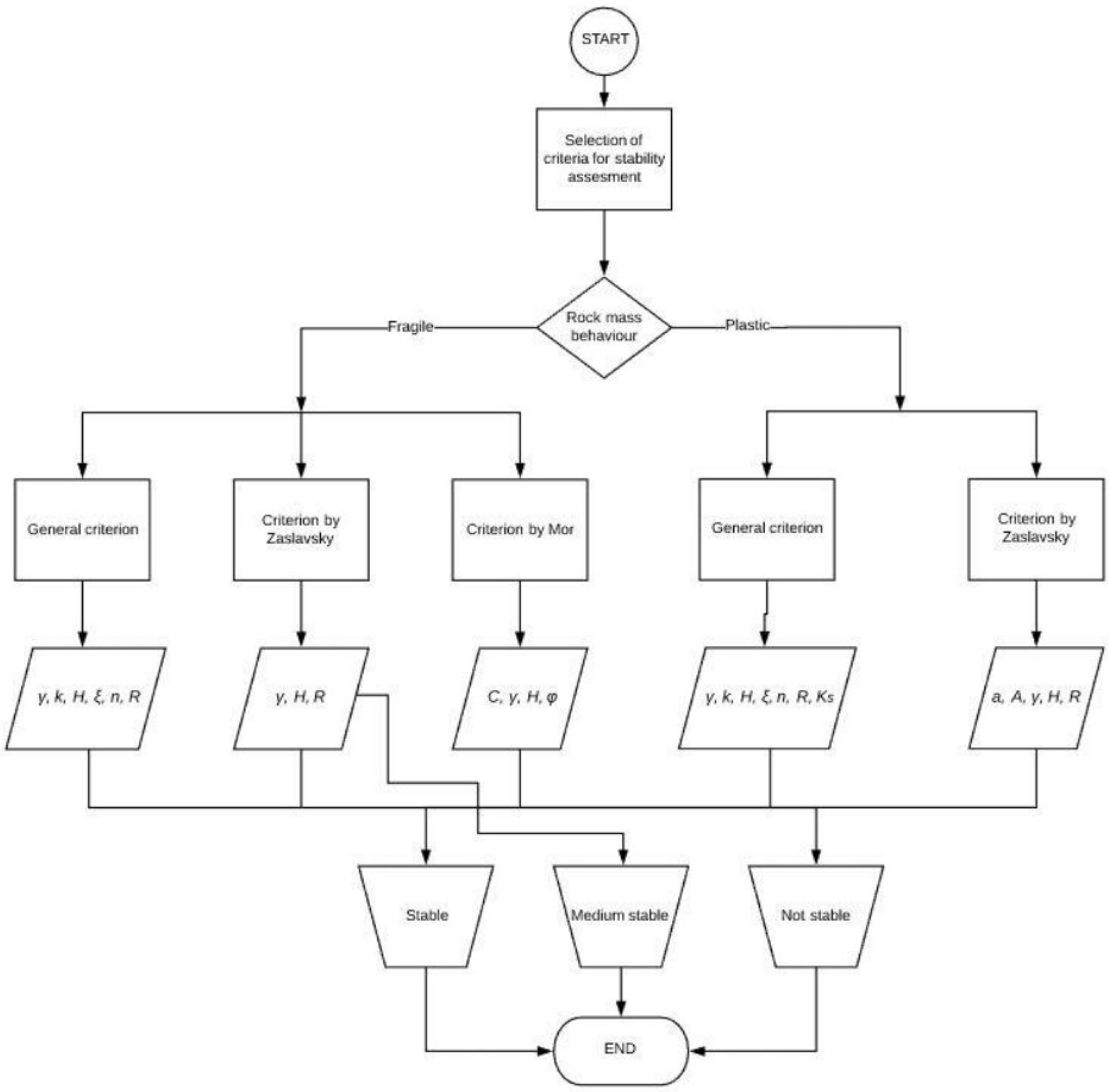

Figure 1. Decision-making algorithm for applying the appropriate criteria for assessing stability

The model will be based on an assessment of stability of rock masses with a fragile behaviour. The stability assessment according to criteria by Zaslavsky is based on the smallest number of input parameters (3), and as a result, the most of the output data is obtained (3), therefore, the rock mass is categorized as stable, medium stable and unstable. Based on this, we conclude that the fuzzy logical model for stability assessment of underground premises should initially rely on the same input data that is determined by Zaslavsky's criteria, which are: unit weight, uniaxial compressive strength of the rock mass and the depth of the underground object with corresponding number of membership functions which belong to each of the input data. Based on the calculation, the output will be obtained (the degree of stability of the rock mass) defined by three membership functions (stable, medium-stable and unstable rock mass).

By placing the linguistic value of the input and output variables into the relation between the "if-then" rules, the fuzzification of the same and the processing of the Mamdani algorithm, and finally by defuzzification, we obtain the value of the degree of stability on the basis of which it is possible to classify the rock mass as stable, medium-stable or unstable. It's necessary to compare the obtained results

based on a certain number of data to be processed by the model, with the values obtained by the Zaslavsky's form. By comparing the data, a model check will be performed. If the model produces satisfactory results, it can be used as a submodel for selecting the shape and dimensions of the cross-section of the underground premises, selecting the method of excavation, the appropriate type of support construction as well as other parameters related to the design of underground premises.
The fuzzy model, used for estimating the stability of underground facilities, should be based on input parameters from the equation (i.e. Eq. 2) –which was originally proposed by Ju. Z. Zaslavsky [17] (who also classified rock mass by stability – which is shown in table 1). The model could be made using the Mamdani algorithm [16] in the MATLAB fuzzy logic toolbox.

Table 1. Classification of rock mass by stability

Stability degree	Coefficient of stability, depending on the fall angle of rock mass		Type of support to be used
	Slightly sloping rock	Steep rock	
Stable rock	0 – 0.25	0-0.30	Protective lightweight support
Medium stable rock	0.25-0.40	0.30-0.45	Incomplete frame support
Unstable rock	0.40 – 0.65	0.45-0.65	Full frame support

The model would consist of three input variables (uniaxial compressive strength of the rock mass, object depth and unit weight of overburden) and one output variable (coefficient of stability) –all of which are linguistically described and defined by appropriate membership functions and numerical parameters. Putting variables in adequate "if-then" relation in a software such as MATLAB and running them through Mamdani algorithm it would be possible to get the 3D surface relations between variables. For the model validation, eq. 2 could be used because it is the result of field research conducted in numerous mines. As each of input variables would be consist of five membership functions (linguistic values Very low, Low, Medium, High, Very high) and there would be one output variable defined by 3 membership functions (Stable, Medium stable, Unstable) a model would have total number of 125 rules. An example of one fuzzy rule that should be in the model for stability assessment is "If (Uniaxial compressive strength is High) and (Object depth is Very high) and (Unit weight is Very high) then (Coefficient of stability is Medium)." Figure 2. shows fuzzy logic designer in MATLAB software.

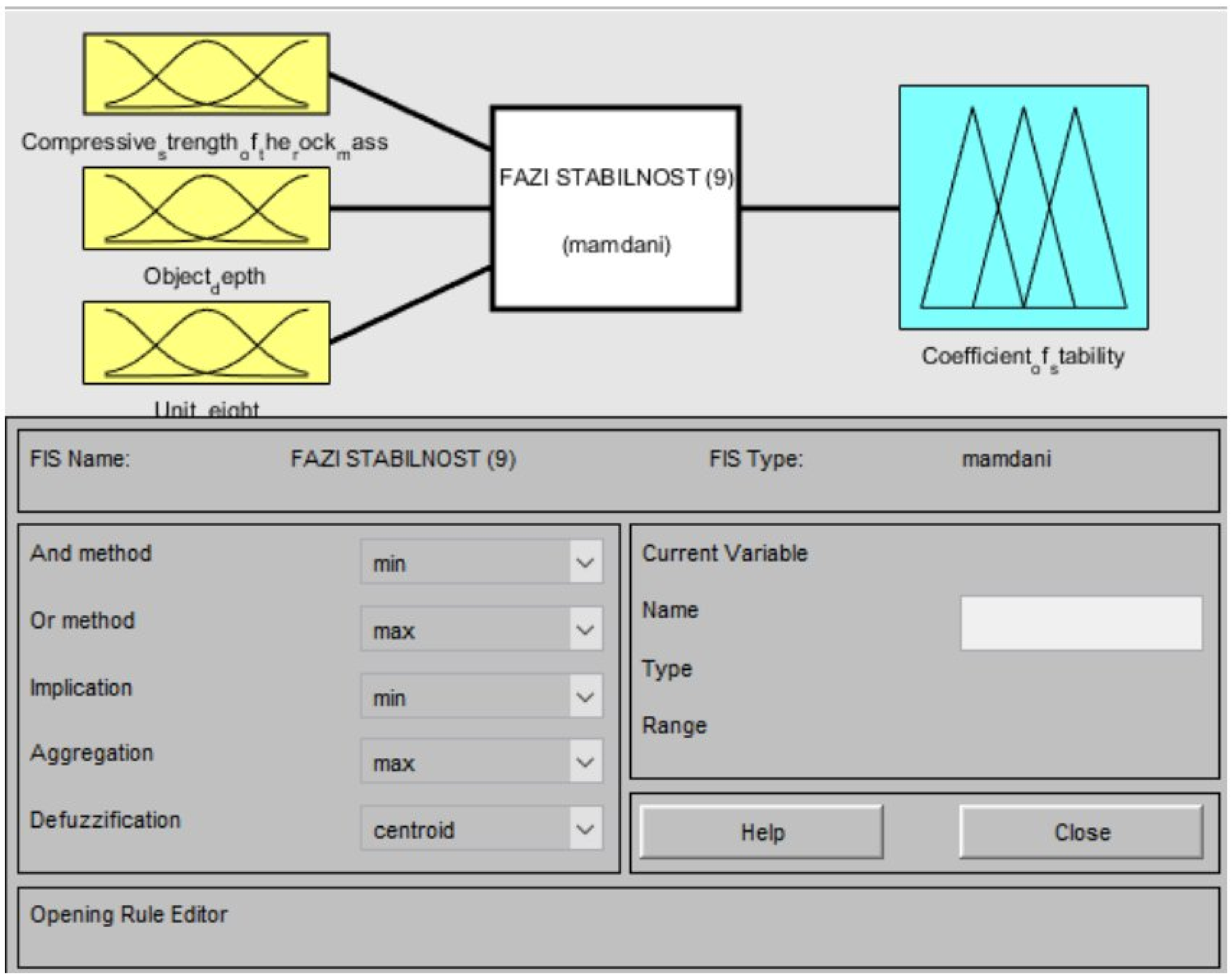

Figure 2. Display of MATLAB fuzzy logic designer application

4. CONCLUSION

Based on a literature review from which it can be noted that the fuzzy logic models have already been used for solving various problems in mining engineering, one can conclude that there is a possibility as well as the need for developing an appropriate model for assessing the stability of underground facilities.

The paper presents the basis for the development of the fuzzy logic model for estimating the stability of underground facilities. The quality of a model can be verified by a simple comparative analysis of the obtained results from the model and the results given by the traditional method for estimating the stability proposed by Ju. Z. Zaslavsky, which came from extensive field research.

The significance of the model would be reflected in its integration (as a submodule) into a more comprehensive model related to the proper assessment of underground facilities excavation method, the choice of the appropriate support construction, the choice of the shape and dimensions of the cross-section, or the fuzzy logic management of the processes in underground construction. The model would also give appropriate graphs of the dependence of clamp factors on the stability of the underground facilities, ie the three-dimensional graphics of the dependence of the compressive strength, unit weight and depth of the underground facilities with the coefficient of strength.

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MULTI-CRITERIA ANALYSIS OF THE SELECTION OF ROADHEADER TYPE FOR DEVELOPMENT OF ROADWAYS IN SERBIAN UNDERGROUND COAL MINES

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Abstract: *The mines with underground exploitation of coal in the Republic of Serbia are part of the Public Enterprise for Underground Exploitation of Coal Resavica (JP PEU). In the mines of the company JP PEU, underground rooms are presently being construction by the technology of drilling and blasting works. This method which is used in Serbian coal mines, has shown with its speed, performance, costs and other elements that it is not acceptable anymore. Classical method of construction of underground rooms does not allow satisfying performance, because technological operations of this method, drilling and blasting are performing manually and require unacceptably big time consuming. Regarding this fact and also earlier delays of openning and preparing new production capacities, present method of their preparation guides to stagnation in spreading room system in mines and does not allow increasing of coal production. In order to increase coal production and opening of new pits and mining fields, it is necessary to consider the application of more productive methods of construction of underground rooms, i.e. application of machines for construction of underground rooms. Procurement of new equipment requires large investments, therefore it is necessary to carry out a detailed examination of the technological process of pit production and to select a machine for the construction of underground rooms that will meet the specified conditions. In order to properly select the machine for construction of underground rooms for the conditions of coal mines in Serbia, a multi-criteria analysis was used, as given in this paper.*

Keywords: *Analysis, underground room, mechanized building, mine.*

1. INTRODUCTION

In JP PEU, openings of new mine fields are in progress in mines „Soko", „Lubnica", „Rembas" – mine „Strmosten" and mine „Ravna reka IV blok". In these mines are projected 26.000 m of underground rooms. Such large length of the rooms if was produced using conventional methods, has led to long delays in preparation and to creation of new underground production capacity, and prevented the increase in coal production. Therefore, in order of faster mines and production shaft openings, it is necessery to consider applying mechanized construction of underground rooms in the mines of JP PEU. In order to access mechanized construction of the basic rooms and detailed preparation, it is necessery to purchase machines for construction of underground rooms which will meet the requirements of Serbian mines.

2. CONDITIONS FOR CONSTRUCTION OF UNDERGROUND ROOMS IN MINES

Underground rooms in mines of JP PEU are built in coal and associated rocks (trailings). Uniaxial compressive strenght of coal ranges from 8 to 38 MPa, and for trailings from 14 to 66 MPa. The most common working environment in which underground rooms are built is coal, and average compressive strenght of working environment for considered mines is 22,9 MPa.