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Risk Assessment in Constructing Horseshoe Vault Tunnels using Fuzzy Technique

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ABSTRACT

Risk assessment is one of the projects' important issues and by applying fuzzy method, subsidence possibility can be investigated. In this paper, subsidence has been examined using fuzzy method and investigating 81 and then 6000 soil samples in order to obtain subsidence possibility of soils those which have these features. Results of fuzzy rules in this dissertation have been analyzed about tunnel vault height, the height of the soil, modulus as well as density which can be used in applicable matters. According to the results obtained from this study deformation modulus has the greatest impact on subsidence so that when it is less than 100, soil is not usable more. The higher the slag soil is, the more subsidence is so that from a height of 6 m, the retaining structures must be used. The higher the tunnel vault is, the more the subsidence is and the more the soil density is increasing, subsidence is also increasing. When deformation modulus becomes 100, fuzzy digit is reducing and it stands between 3.8 and 4.2. When slag soil height is increasing, subsidence is more likely to go up. When tunnel vault is from 1 to 4, fuzzy digit stands from 0 to 2.5 and when slag soil density stands between 2200 and 2400, fuzzy digit is between 5 and 6. Risk assessment carried out in fuzzy logic indicates that whenever slag soil height, slag soil density and tunnel vault is increasing, subsidence rate is also going up and whenever deformation modulus is decreasing, subsidence rate is increasing.

Keywords
Tunnel, Horseshoe, Fuzzy logic, Subsidence.

1. INTRODUCTION

Tunnel projects are always along with high percentage of risks due to uncertainties related to them. Accurate and proper management of these risks and predicting them is reducing their possibility or negative consequences. In a global scrolling about tunnel projects, 30 to 50 percent increase in time and costs has been reported due too partial and fault management. Risk assessment has been one of the fundamental bases of risk management and anticipating risk will offer a great aid to the experts to cover risk better. The main aim of risk assessment is to measure risk based on various indices such as effect of occurrence. Risk anticipation especially in civil projects can prevent from financial consequences. Predicting cases such as tunnel vault impact, soil density and soil subsidence rate are the cases that predicting them is very important not only in theoretical view, but also in scientific and logical view. On the other hand, there are many algorithms which can take risk prediction into consideration. Fuzzy method is one of them which can appropriately predict risks by forming learning networks. Hence, in this paper we have approached prognosticating rate of soil subsidence using various variables such as modulus vault, density, and soil height and so on. It is expected that by performing this study, rate of subsidence is anticipated and also rules affecting on subsidence are obtained which can be considerably helpful with accurate comprehension of risks and how they are occurred [1].

2. Literature review

Najjar and Zaman (1993) have proposed a numerical method based on Non-linear finite elements for a mine in Oklahoma. They have tried different percentage of adhesion and elasticity for linear and non-linear condition of soil and have come to this conclusion that decrease in adhesion of soil and also elasticity modulus will cause reduction in soil linear behavior [2].

Selby (1999) has modeled some tunnel in England using finite element method. In his analysis, 2 techniques of linear elastic and Varangian finite difference have been applied. Eventually, he compared these 2 methods with theoretical results and came to this conclusion that subsidence estimation in ground surface by aforementioned methods will cause subsidence to be shallower and wider than the real prediction rate [3].

Want et al (2000) offered surface ground curve caused by soft ground tunneling using Modified Gaussian model which has been carried out based on FLAC software and finite difference method and then generalized subsidence equations derived from one tunnel to two parallel tunnels [4].

Pachen and Brasinga (2003) in a report related to drilling two tunnels with a diameter of 5.6 m and a length of 4.2 km by savers in Rotterdam, Netherland in the sand ground showed that elastic solution is ensured. Calculations of this report have been done using Plaxis software and Centrifuges model [5].

Glossop et al (1976) have carried out some researches about short-term subsidence s in Balfast tunnel in 2 different times. Respective tunnel has 2.7 m diameter and it is in 4.8 depth and soil feature is saturated silt. They arrived to this conclusion that subsidence s derived from soil consolidation over the time form considerable part of the total soil subsidence derived from tunnel [6].

Etol et al (1986) have done researches in the context of soil subsidence derived from tunnel drilling. In these papers, subsidence s derived from tunneling have been categorized into two parts, short-term subsidence s and long-term ones. Short-term subsidence s is those which are happening by tunnel drilling and long-term subsidence s are occurring caused by impacts such as consolidation in saturated environment around tunnel. In this study, they showed that soil long-term subsidence impact is transparently clear in subsidence depth curve and cause short-term depth subsidence curve to be wider and shallower and might cause damages in surrounding areas and surface structures. These researchers have found 2 factors affecting on accelerating consolidation phenomenon in underground water drainage from the tunnel and water drainage from slots created inside the soil around tunnel. Both factors are causing to create very powerful drainage areas around tunnel and to cause accelerating consolidation in the soil [7].

Krisha et al (1999) has done some researches about tunnel drilling in consolidation clay soil. They showed that by tunnel drilling in soft adhesive grounds, subsidence in surrounding soils by consolidation includes a considerable percentage of total soil subsidence. They have used 3-D consolidation in their studies. Krisha showed that permeability coefficient is the main factor of the pore water pressure control. He also showed that the soil lateral coefficient at rest (K) determines the excess pore pressure distribution form around the tunnel. Plus, pore water pressure and the time that is disappeared is dependent on soil surrounding layers and permeability of area around the tunnel and also tunnel position [8].

Chou and Bodet (2001) have done a number of researches about soil subsidence in several cases of tunnel drilling in saturated clay soil. This dissertation has been applied in plane strain condition. Researchers have achieved the following results based on analyses done in undetermined condition:

1- The main parameter in determining subsidence rate is the gap with allowable displacement.
2- The most displacements have been happened at a distance of about 4 to 5 times the radius around the tunnel.
3- Vertical displacement of the layer under the tunnel about twice the tunnel diameter from the tunnel center is equal to zero. Of course, in the condition that there is a layer of stone under the tunnel, vertical displacement would be zero.

4- Horizontal displacement in the area around the tunnel compared to vertical displacement is trivial.

Huang and Zhang (2004) have considered calculating long-term subsidence in soft ground in Shanghai metro tunnels into account and investigated impact of excavation during coating for tunnels on ground subsidence expansion and compared this subsidence s to numerical modeling by finite difference method and have found out the following results:

1- Tunnel manufacturing methodology has a very crucial effect on tunnels' long-term subsidence in clay soils or grounds.
2- Tunnels' long-term subsidence in Shanghai metro is too much.

3. Fuzzy Logic

In 1965, Professor Lotfi Zade has published a paper entitled "Fuzzy set" in control and information journal. In this paper, what have been called << ambiguity >> or << multi-valued >> by Bertrand Russell, John Albion, Max Black and others was named "Fuzzy". Fuzzy set was introduced with an example of human tallness set. This case was the first set introduced by Lotfi Zade. Fuzzy digits are a fuzzy subset of the real numbers which proposes a spectrum of confidence interval of opinions and beliefs. [9]

Triangular fuzzy numbers:

Triangular fuzzy numbers A or simplicity triangular number with membership function of $\mu_A(x)$ over R is defined as the following:

$$A \underline{\underline{\Delta}} \mu_A(x) = \begin{cases} \dfrac{x-a_1}{a_M - a_1} & a_1 \le x \le a_M \\ \dfrac{x-a_2}{a_M - a_2} & a_M \le x \le a_2 \end{cases}$$

In aforementioned relation, $[a_1, a_2]$ is an abutment interval and $(a_M, 1)$ is the top point,

Triangular numbers are mostly used in applications such as (Fuzzy controllers, management, commercial and financial affairs, social science decision making). They have a membership function which includes 2 linear sections A^l (left) and A^r (right) and in the top, they are connected in $(a_M, 1)$ which causes graphic display and operation of triangular numbers is very easy. [9]

Calculative operation with triangular numbers:

Fuzzy number sum:

It can be proved that sum of 2 triangular number of $A_1 = (a_1^{(1)}, a_M^{(1)}, a_2^{(1)})$ and $A_2 = (a_1^{(2)}, a_M^{(2)}, a_2^{(2)})$ is also a triangular number.

$$A_1 + A_2 = (a_1^{(1)}, a_M^{(1)}, a_2^{(1)}) + A_2 = (a_1^{(2)}, a_M^{(2)}, a_2^{(2)})$$

$$= (a_1^{(1)} + a_1^{(2)}, a_M^{(1)} + a_M^{(2)}, a_2^{(1)} + a_2^{(2)})$$

Multiplying a triangular number into a real number:

Multiplying a triangular number, An into a real number r is also a triangular number:

$$Ar = rA = r(a_1, a_M, a_2) = (ra_1, ra_M, ra_2)$$

Dividing a triangular number by a real number:

This process is defined as multiplying A into $1/r$, provided that $r \neq 0$. Therefore, this relation shows that: [10]

$$\frac{A}{r} = \frac{1}{r}(a_1, a_M, a_2) = \left(\frac{a_1}{r}, \frac{a_M}{r}, \frac{a_2}{r}\right)$$

Defuzzification:

Since, in most of the time, we are forced to defuzzificate to eventually obtain answer and compared two fuzzy numbers, the following relation is often used in defuzzification [11].

T=(L+2M+U)/4

4. METHODOLOGY

4.1 determining variables

In this section, research variables have been introduced. In this dissertation, 4 variables have been employed which have been displayed in table 1: [9]

Table 1: Research variables

Subsidence possibility (Summit)			
High	**Average**	**Low**	**Variables**
High [53] 12 to 7	[53] **Average** 7 to 4	**Low** [53] 4 to1	Size of slag soil 12 to 1 (m)
Low [25] 2200 to 2000	[25] **Average** 2400 to 2200	**High** [25] 2600 to 2400	Density of slag soil 2600 to 2000 (kg/m^3)
High [53] 18×10^{3} to 1000	**Average** [53] 5×10^{4} to 18×10^{3}	**Low** [53] 5×10^{4} to 8×10^{4}	Deformation modulus 80000 to 1000 (kpa)
High [53] 13 to 10	**Average** [53] 10 to 5	**Low** [53] 5 to 2	Size of horseshoe vault 13 to 2 (m)

4.2 calculating tunnel subsidence using theoretical method

In this paper, landfall which is directly influencing tunneling is regarded and excess subsidence s related to underground waters due to their importance is included in this discussion. Subsidence parameters in theoretical calculations have been exhibited as the figure 1.

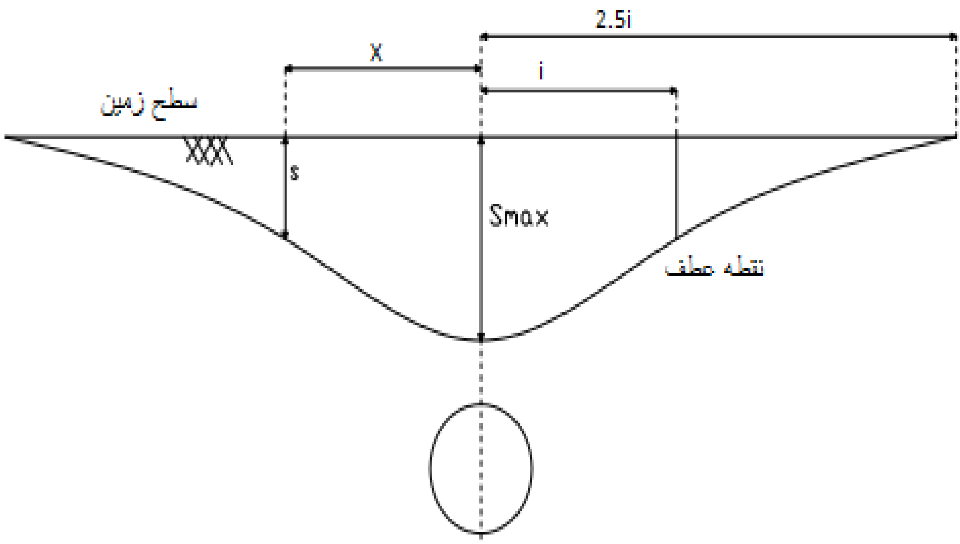

Figure 1: Subsidence parameters

Hypotheses used for estimating subsidence have been brought as follows:

- Tunnel cross section is horseshoe.
- Tunnel has been examining din all depths.
- The tunnel passes through the clay.
- NATM is tunneling method.
- Prediction is acceptable for the initiative protection.
- After drilling tunnel to 35 m depth, subsidence reaction is ignored.
- Long-term consolidation subsidence is ignored.

Equations used to estimate subsidence have been indicated in appendix 1 and in appendix 2 also equations symbol are introduced. [12]

4.3 Transforming theoretical method to the fuzzy method

A fuzzy model contributes 3 sections, fuzzification, fuzzy inference system and defuzzification. Owing to the most of applications, fuzzy system's input and output are the real numbers. [12]

We have to create mediators between fuzzy inference engine and environment. These mediators are fuzzificator and defuzzificators. Fuzzification is being done using membership functions. Membership function specifies fuzzy value of a quantity and in fact shows membership degree of different elements to a set. This determines an amount that is awarded to a set with the number between zero and one. In this paper, fuzzy logic has been employed to analyze data. Fuzzy logic was raised versus classic logic.it is accounted as a powerful tool to solve problems related to complicated systems in which their comprehension is hard or issues which are dependent on reasoning, decision-making and human perception. [13] Choosing an appropriate method and view for modeling a system is entirely depending on complexity of that system and it has reverse relationship with the extent of our knowledge or perception from that system.

Fuzzy logic toolbox consists of a set of fuzzy functions in the form of MATLAB calculative environment. This toolbox provides facilities to infer fuzzy systems in the MATLAB framework. Also, in regard with simulation of fuzzy systems, there is a possibility to integrate them in Simulink Software framework. You can use functions related to this toolbox in other applications (for example in C programing). This toolbox exploits a Graphic User Interface to aid user, but if you wish, you can relative functions in MATLAB.

In this dissertation, Fuzarith Function from MATLAB toolbox is used which means applying mathematic in fuzzy in which zmf function indicates low amount and smf indicates high amount and trimf expresses average value. [14]

5. Discussion

A) Results of theoretical examination of soil sample experiments

81 soil samples have been examined using theoretical method. In figure 1, subsidence of 81 soil samples has been depicted, for example studied soil samples in the case of 10 first theoretical methods have been calculated in table 2.

Table 2: Soil samples of 10 first case studies

Studied soil sample	Slag soil size (m)	Slag soil density $(\frac{kg}{m^3})$	Deformation modulus (kpa)	Horseshoe vault size (m)	Subsidence (cm)
1	3	2500	700	4	0/0256
2	3	2500	700	8	0/0958
3	3	2500	700	12	0/2060
4	3	2500	150	4	0/1197
5	3	2500	150	8	0/4469
6	3	2500	150	12	0/9615
7	3	2500	100	4	0/1795
8	3	2500	100	8	0/6703

9	3	2500	100	12	1/4423
10	3	2300	700	4	0/0236

For example, in the first sampling, as it is observed in table 3, when slag soil size is equal to 3 meters and slag soil density is equal to 2500 kg/ M^3 and deformation modulus is 700 Kpa and horseshoe vault size is equal to 4meters, subsidence rate will be 0.0256 cm.

As it is seen in table 3, in the case of the forth study, when slag soil size is equal to 3 meters and slag soil density is equal to 2500 kg/ M^3 and deformation modulus is 150 Kpa and horseshoe vault size is equal to 4meters, subsidence rate will be 0.1197 cm. This value compared with 3 first samples due to lowering vault size to 4 meters and changing deformation modulus from 700 Kpa to 150 Kpa, subsidence rate compared to two first cases is more and compared to the third sample is less which indicates importance of deformation modulus parameter.

Changes in subsidence rate about all studies have been depicted in figure 2.

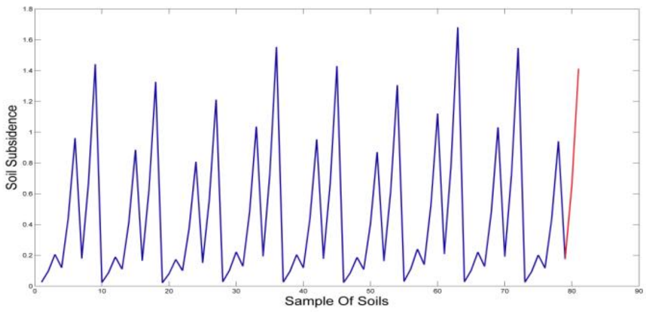

Figure 2: Changes in studies

In figure 3, subsidence in more than 6000 soil samples has been calculated by theoretical method which is the most one is 25 cm soil subsidence. In investigations, it was determined when deformation modulus parameter is increasing, subsidence is lowered. As it is detailed in figure 1, when deformation modulus is moving from low interval toward high interval, by widening vault, subsidence rate is increasing and in fig 2 according to subsidence occurrence, deformation modulus is moving from high interval toward low interval. By lowering vault, subsidence value is decreasing, respectively.

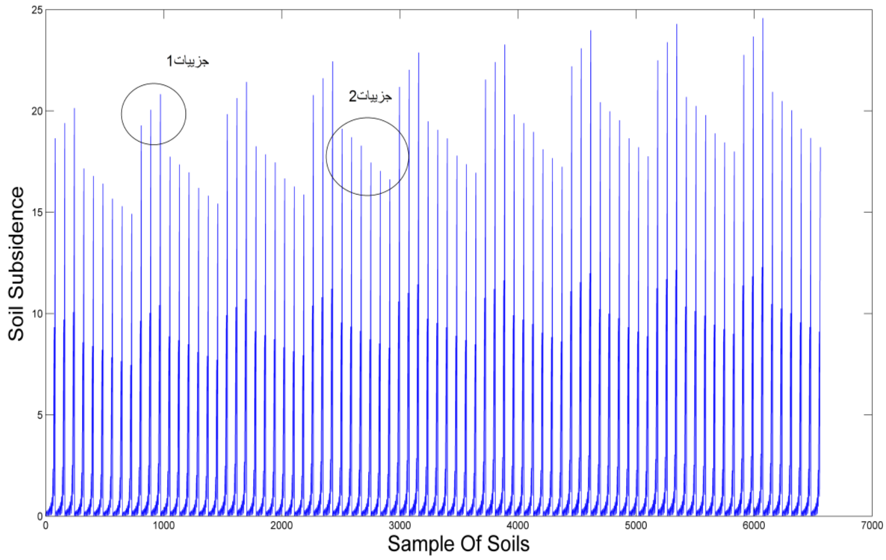

Figure 3: 6000 samples

B) Studying effect of soil size, tunnel vault, modulus and density on soil subsidence

In figure 4, impact of slag soil size parameter on soil subsidence in the tunnel has been investigated. It can be concluded from fig 4 that the higher the slag soil height is, the more the subsidence is.

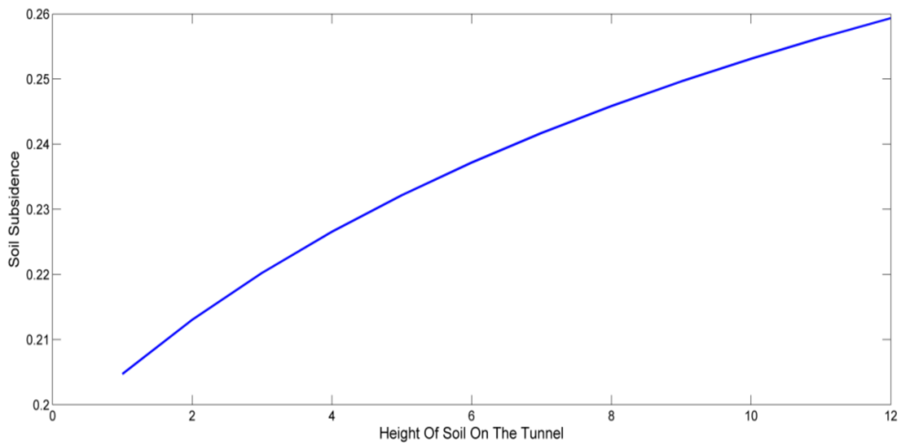

Figure 4: Impact of slag soil size

In figure 5, impact of tunnel vault on soil subsidence in the tunnel has been investigated. It can be concluded from fig 5 that the wider the tunnel vault is, the more the subsidence is.

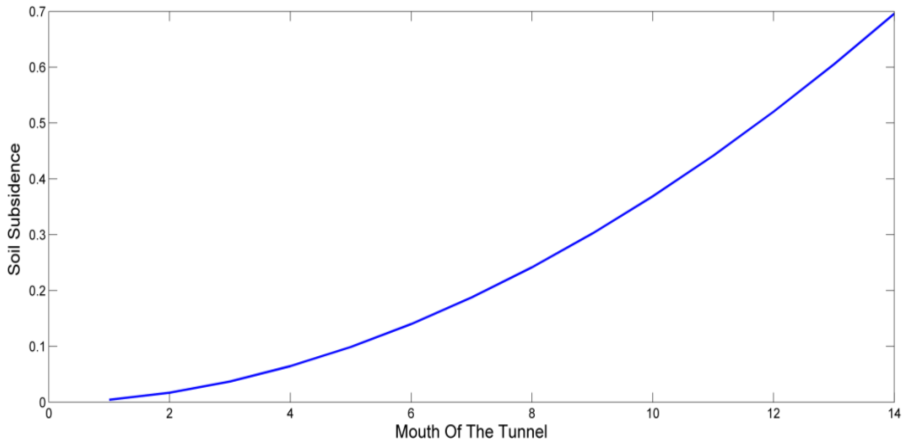

Figure 5: Impact of tunnel vault

In figure 6, impact of deformation modulus on soil subsidence in the tunnel has been investigated. It can be concluded from fig 6 that the more the deformation modulus is, the less the subsidence is, but as it is transparent, since then the rate of subsidence is approximately constant and it passes a linear path.

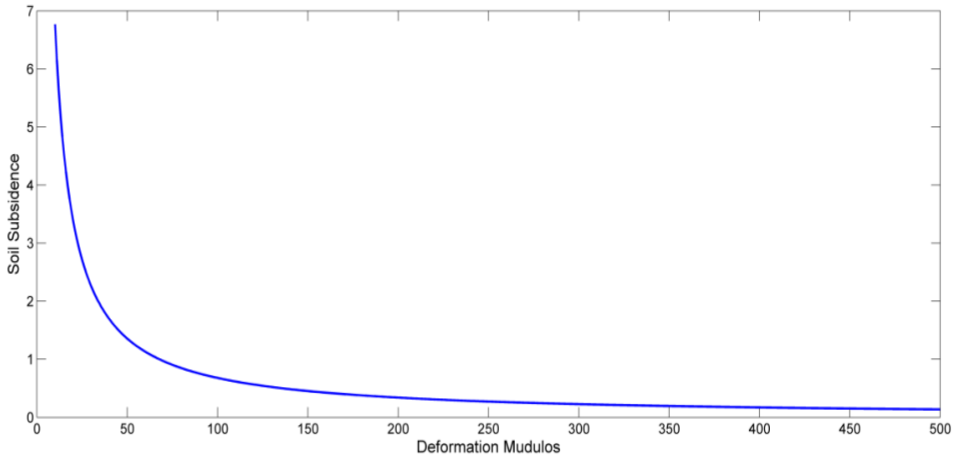

Figure 6: Impact of deformation modulus

In figure 7, effect of slag soil density parameter on soil subsidence in the tunnel has been examined. It can be concluded from fig 7 that the higher the slag soil density is, the more the subsidence is.

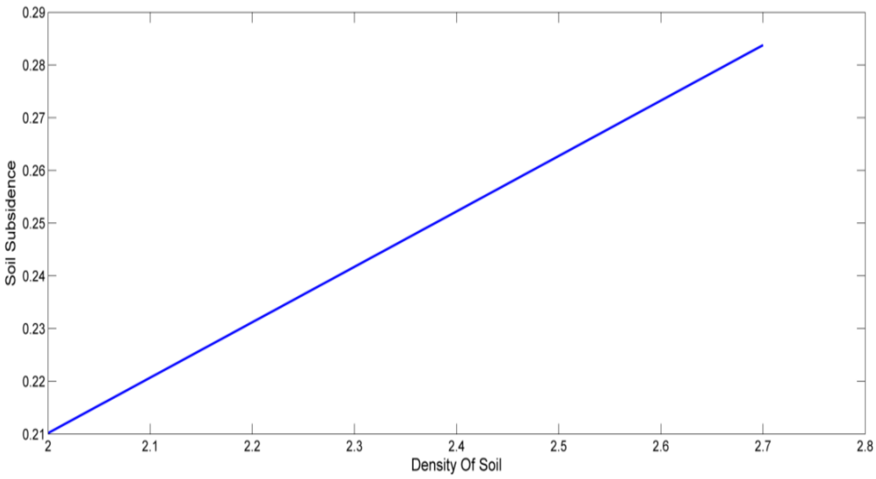

Figure 7: Impact of slag soil density

C) Soil subsidence analysis using fuzzy logic

In this step, 81 soil samples were transformed to fuzzy form. As a sample, 6 charts have been proposed which due to soil subsidence, fuzzy number has been proposed.

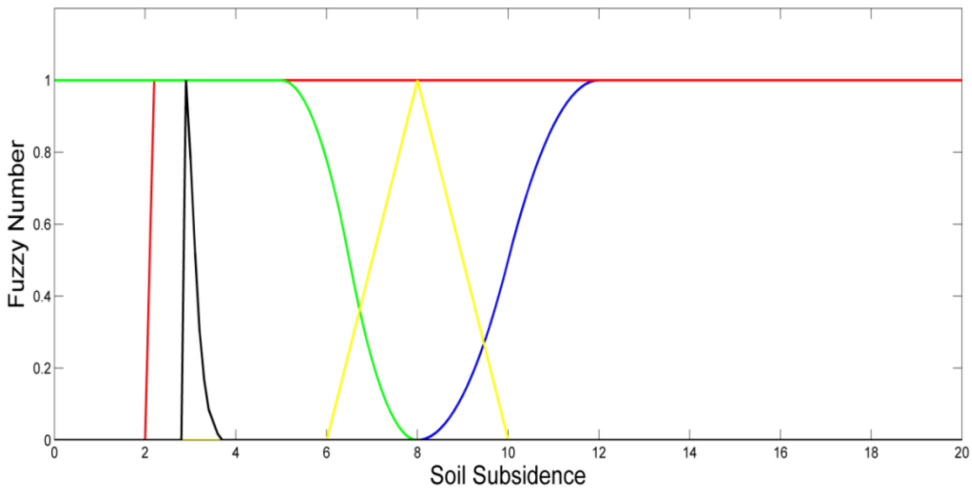

Figure 8: Changing to fuzzy

Table 3: Changing to the first fuzzy

Horseshoes vault size	Deformation modulus	Slag soil density	Slag soil size	Variables
High	Low	High	High	Quantity
Yellow	Green	Red	Blue	Color

In the figure 8, as it is transparent from table 3, red color indicates slag soil density and yellow color indicates horseshoe vault and blue color shows slag soil size and green indicates deformation modulus and black color represents fuzzy results.

Therefore, if slag soil size is average, slag soil density is average and deformation modulus is low and horseshoe vault size is high, as a result, subsidence is between 3 and 4. Owing to this issue that subsidence rate in theoretical method is 1.4 and when it is transformed to fuzzy value, this value is reduced to 3 or 4, shows that when this value is changed to fuzzy value, soil subsidence is investigated with higher risk possible percentage.

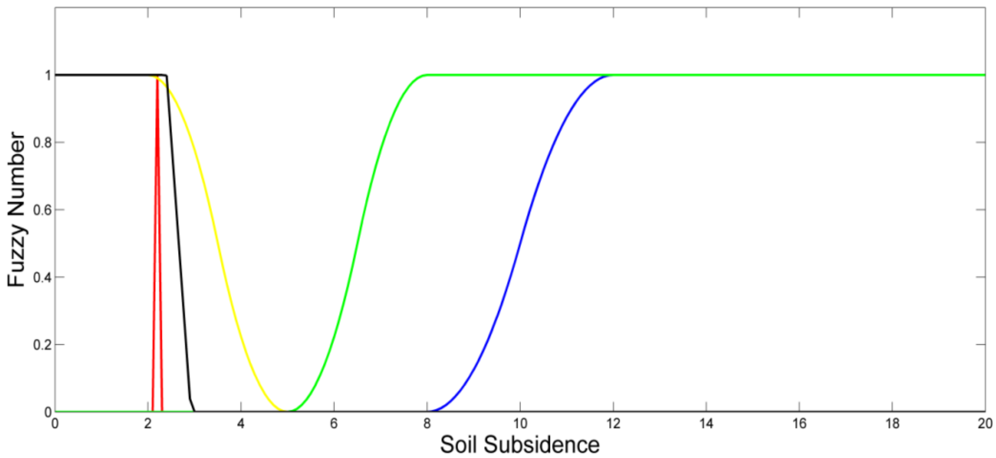

Figure 9: Changing to fuzzy

Table 4: Changing to the second fuzzy

Horseshoes vault size	Deformation modulus	Slag soil density	Slag soil size	Variables
Low	High	Average	High	Quantity
Yellow	Green	Red	Blue	Color

In the figure 9, as it is transparent from table 4, red color indicates slag soil density and yellow color indicates horseshoe vault and blue color shows slag soil size and green indicates deformation modulus and black color represents fuzzy results.

Therefore, if slag soil size is high, slag soil density is average and deformation modulus is high and horseshoe vault size is low, as a result, subsidence is between 0 and 3. Owing to this issue that subsidence rate in theoretical method is 0.02 and when it is transformed to fuzzy value, this value is reduced to 0 or 3, shows that when this value is changed to fuzzy value, soil subsidence is investigated with higher risk possible percentage.

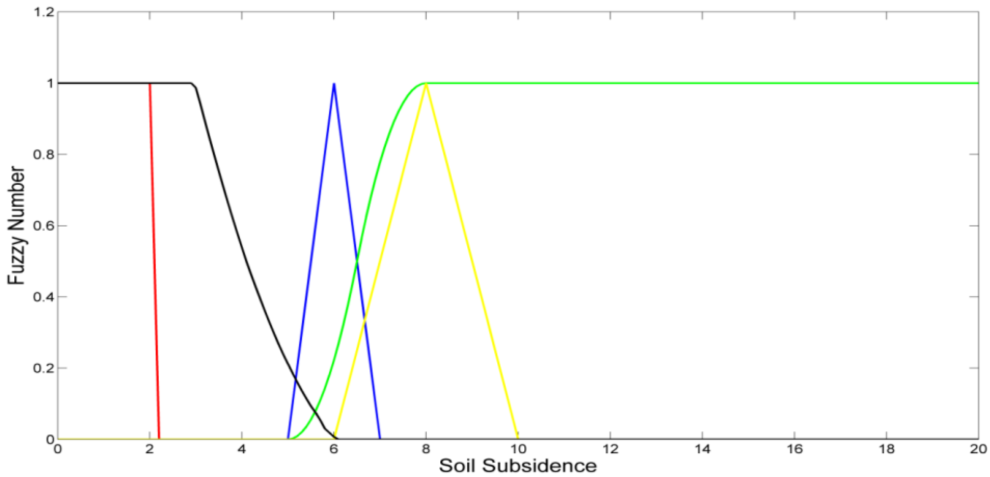

Figure 10: Changing to fuzzy

Table 5: Changing to the third fuzzy

Horseshoes vault size	Deformation modulus	Slag soil density	Slag soil size	Variables
Average	High	Low	Average	Quantity
Yellow	Green	Red	Blue	Color

In the figure 10, as it is clear from table 5, in above chart red color indicates slag soil density and yellow color indicates horseshoe vault and blue color shows slag soil size and green indicates deformation modulus and black color represents fuzzy results.

Thus, if slag soil size is average, slag soil density is high and deformation modulus is high and horseshoe vault size is average, as a result, subsidence is between 0 and 6. Due to this issue that subsidence rate in theoretical method is 0.01 and when it is transformed to fuzzy value, this value is reduced to 0 or 6, shows that when this value is changed to fuzzy value, soil subsidence is investigated with higher risk possible percentage.

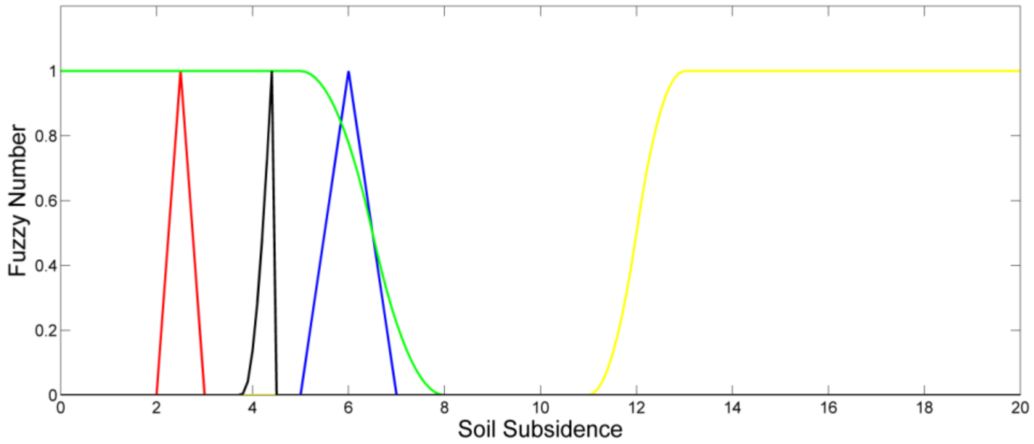

Figure 11: Changing to fuzzy

Table 6: Changing to the forth fuzzy

Horseshoes vault size	Deformation modulus	Slag soil density	Slag soil size	Variables
High	Low	Low	Average	Quantity
Yellow	Green	Red	Blue	Color

In the figure 11, as it is clear from table 6, in above chart red color indicates slag soil density and yellow color indicates horseshoe vault and blue color shows slag soil size and green indicates deformation modulus and black color represents fuzzy results.

Thus, if slag soil size is high, slag soil density is low and deformation modulus is low and horseshoe vault size is average, as a result, subsidence is between 3.7 and 4.2. Due to this issue that subsidence rate in theoretical method is 0.07 and when it is transformed to fuzzy value, this value is reduced to 3.7 or 4.2, shows that when this value is changed to fuzzy value, soil subsidence is investigated with higher risk possible percentage.

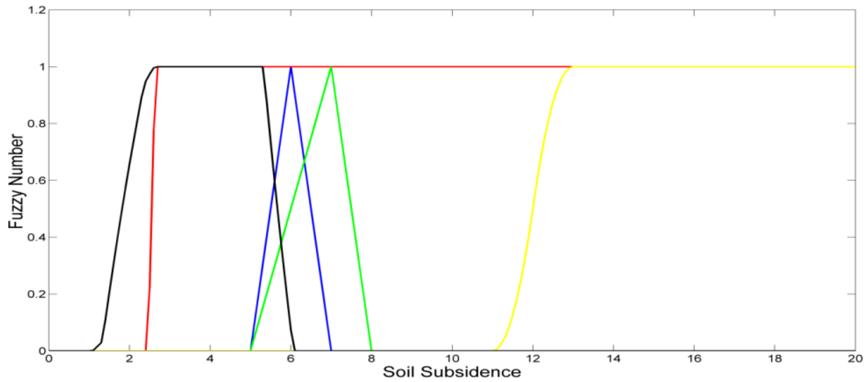

Figure 12: Changing to fuzzy

Table 7: Changing to the fifth fuzzy

Horseshoes vault size	Deformation modulus	Slag soil density	Slag soil size	Variables
High	Average	Low	Average	Quantity
Yellow	Green	Red	Blue	Color

In the figure 12, as it is clear from table 7, in above chart red color indicates slag soil density and yellow color indicates horseshoe vault and blue color shows slag soil size and green indicates deformation modulus and black color represents fuzzy results.

So, if slag soil size is average, slag soil density is low and deformation modulus is average and horseshoe vault size is high, as a result, subsidence is between 1.5 and 6. Due to this issue that subsidence rate in theoretical method is 0.95 and when it is transformed to fuzzy value, this value is reduced to 1.5 or 6, shows that when this value is changed to fuzzy value, soil subsidence is investigated with higher risk possible percentage.

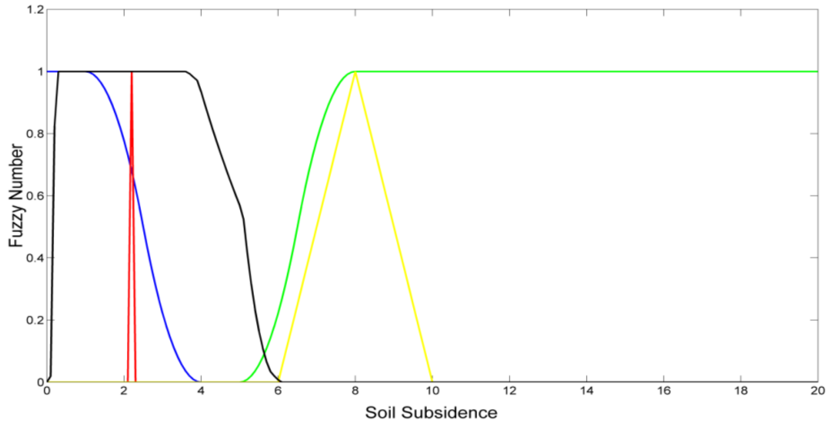

Figure 13: Changing to fuzzy

Table 8: Changing to the sixth fuzzy

Horseshoes vault size	Deformation modulus	Slag soil density	Slag soil size	Variables
Average	High	Average	Low	Quantity
Yellow	Green	Red	Blue	Color

In the figure 13, as it is clear from table 8, in above chart red color indicates slag soil density and yellow color indicates horseshoe vault and blue color shows slag soil size and green indicates deformation modulus and black color represents fuzzy results.

Therefore, if slag soil size is low, slag soil density is average and deformation modulus is high and horseshoe vault size is average, as a result, subsidence is between 0 and 6. Due to this issue that subsidence rate in theoretical method is 0.09 and when it is transformed to fuzzy value, this value is reduced to 0 or 0.09, shows that when this value is changed to fuzzy value, soil subsidence is investigated with higher risk possible percentage.

6. CONCLUSIONS

In this research, we have considered risk assessment in constructing horseshoe vault tunnels. Accordingly, variables affecting on soil subsidence have been examined by determining appropriate criteria and tunnel risk analysis was done over 81 samples. Thus, the following applicable results can be observed in this dissertation:

1) Deformation modulus has the highest effect on soil subsidence, whatever the numerical value of the deformation modulus is low;

subsidence value is increasing so that when it is lessen to 100 Kpa, soil is not more useable.

2) The higher the slag soil height is, the more the subsidence is so that from the height 6 meters, retaining wall and structures have to applied.
3) The higher the slag soil density is, the more the subsidence is.
4) The higher the tunnel vault is, the more the subsidence is so that from the height 8 meters, especial strategies have to be taken.
5) In fuzzy logic also, the less the deformation modulus is, subsidence rate is increased by higher risk possibility. When deformation modulus is 100 Kpa, fuzzy number is also decreasing and will stand between 3.8 and 4.2.
6) In fuzzy logic, the higher the slag soil is, subsidence rate is increased by higher risk possibility. When slag soil height is between 8 and 12 meters, its fuzzy number is also between 0 and 3.
7) In fuzzy logic, the more the slag soil density is, subsidence rate is increased by higher risk possibility. When slag soil density is between 2200 and 2400 kg/m^3, fuzzy number is between 5 and 6.
8) In fuzzy logic, the wider the tunnel vault is, subsidence is increased by higher risk possibility. When tunnel vault is between 1 and 4 m, fuzzy number stands between 0 and 2.5.
9) Risk assessment carried out by fuzzy method shows that in the subsidence rate results, slag soil height, slag soil density and tunnel vault is increased. Subsidence rate is also increasing and the lower the deformation modulus is, the higher the subsidence is.

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