Categorizing the tunnel excavation in karst

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THE PAPER ANALYSES THE RELATIONSHIP between forecasted and achieved categories of excavation of certain tunnels in Croatia. A relationship is given in the natural and financial sense. Based on the analyzed relationship of forecasted and achieved categories of excavated tunnel, various approaches to this categorization are analyzed from the point of view of the designer, investor and contractor, depending on their approach to the goals of the construction as an investment project. Based on previous analyses, risk in categorization of tunnel excavations is explained as a key technological and key design risk in construction, especially for long tunnels in karst. At the end, a model for managing risk in categorization of tunnel excavations between investor and contractor is given.

Keywords

long tunnel, tunnel excavation in karst, risk of categorization of tunnel excavation

INTRODUCTION

There are three basic systems in tunneling, which, with their interaction, enable the creation of the safe and useful underground hole as the main excavation goal for any kind of tunnel (*Linarić, 1984, 1987, 1993)*:

- *natural system* which constitutes the underground rock massif through which the tunnel passes *(Figure 1.)*,
- *support system* which as the construction in interaction with the surrounding rock massif in every way enables the stable (safe) underground hollow space, performed by
- *technological system,* expanded based on the techniques and technology of excavation with supporting tunnel (which means that the natural and support systems make the integral parts of the technological system).

The natural system of the rock massif has the key space in the tunneling, usually defined as the tunnel geology (Linarić, 1993). The geology has the significant impact on the choice and planning of the tunnel excavation technology and at the same time it influences the planning and progress of the tunnel excavation or defining the total time of the tunnel construction. The problems of the choice and planning of the tunnel excavation technology is the result of the tunnel geology probability (Linarić, 1987, 1993). The tunnel geology probability results from the characteristics of the forecasted geological section as the underground rock massif through which the tunnel passes geology (Linarić, 1994, 1996, 1999). This tunnel model is the result of the previous geological, geophysical, engineering-geological and other geotechnical researches. In fact, it presents the graphical static model of the dynamic natural system

Figure 1. **The natural system of the rock massif by tunneling in croatian karst (Source: Žderić et al, 2005)**

of the underground in which the tunnel is excavated geology (Linarić, 2002). It represents the main elements, which structure of the natural system model. In this connection, it defines more the elements characteristics than their relations and interactions. Since the model system is natural and dynamical, in its behavior it is stochastically in relation to its model. The result is the mentioned probability as the basic characteristic of the forecasted section of the tunnel.

The model itself is the *longitudinal geological section of the tunnel* and the *surrounding underground* with the description of the estimated engineering-geological and geotechnical parameters. The purpose of these parameters, defined as the *geotechnical indicators* is, among other things, the selection and planning of the excavation method and the supporting of the tunnel. *Geological section of the tunnel* based on the connection and the homogenization of the estimated geotechnical indicators and the classification of the underground rock massif enables the *categorization of the tunnel excavation*, including the division of the tunnel in terms of its length into some "categories of the tunnel excavation". In this matter, the tunnel categorization has the triple purpose:

- notional establishment of characteristics and scales which define the certain category of the tunnel excavation - these categorizations of the tunnel excavation are different and they are prescribed or recommended by the technical regulations,
- forecast schedule and length of certain category of the tunnel excavation per total tunnel length,
- definition of the underground rock massif real characteristics during or after the excavation and the realized schedule of certain categories per total tunnel length.

In the case of forecasted and achieved categorization, the definition of the schedule and the length of the certain categories of the tunnel excavation per tunnel length are evaluated by the person who works on this categorization. In the process, these two categorizations are independent and mutually temporarily separated. Different persons make these categorizations, giving them the mark of their particular knowledge, approach and interest. Each person gives the particular importance to the forecasted or the achieved categorization of the tunnel excavation. This represents one of the basic causes and sources of the *problem area of the tunnel excavation categorization* and as the consequence of this situation – the other problems related to the planning and construction of the tunnel.

This problem area of the tunnel excavation categorization could be shown in the best way as the example or the base for the future analysis of this paper, using the facts of the forecast and the achievement of the categories of tunnel excavation of six tunnels in Croatia on the semi-highway in the direction of the town of Rijeka via Gorski Kotar (Jašarević et al, 1998; Linarić 2000). The tunnels in their total length of about 5 km have been excavated in the rock massifs of the high karst in the lias and doger limestone. The achieved categories of the tunnel excavation in terms of their length are considerably different from the forecated categories. Some of four forecasted tunnel categories did not surpass in their achievement 40 % of their individually forecasted lengths inspire of the use of the most modern methods of the engineering-geological research. For the longest tunnel "Tuhobić" (2.087 m) the relation between the forecasted and the achieved category of the tunnel excavation was as it is shown in the Table I. The total length of the achieved category in relation to the total length on the forecasted category is shown in percentage in the Table 2.

The above shown results of the categorization of the tunnel "Tuhobić" could be differently interpreted. In the first place, we could come to the conclusion that the achieved results were quite risky in a business sense for the contractor. The achievement

			Achieved lengths of the individual categories of the tunnel excavation (% & “m”)						
Excav. category	Forecasted length		II	III		IV		V	
II	2	35	-	(1)	28	-	-	(1)	7
III	50	1050	-	15	314	21	443	14	293
IV	15	316	-	6	134	6	127	3	55
V	33	686	-	15	308	10	198	8	180
Total	100 %	2087 m		37 %	784 m	37 %	768 m	26%	535 m

Table 1. **Forecasted and achieved categories of the excavation of the tunnel Tuhobić[1]**

Category done as (in %)	II	III	IV	V
II.	-	80	-	20
III.	-	30	42	28
IV.	-	43	40	17
V.	-	45	29	26

Table 2. **Achieved categories in the framework of the forecasted categories for the tunnel Tuhobić[2]**

of the lengths of some more “productive” categories were smaller than the forecasted lengths (II Category does not exist in the achievement, III Category achieves about 75 % of the forecast) which means that the contractor should achieve a considerably smaller profit than it was planned. The risk for the investor is also possible because the achievement of some “more expensive” category was bigger than it was forecasted (IV Category was twice longer than it was forecasted). However, are only these conclusions acceptable? We could also ask the following questions :

- other possible intentions related to the categorization of the achieved excavation of some parts of the tunnel in question,
- categorization of the areas of caverns and caves – these areas should be out of five foreseen categories of the tunnel excavation.

Category II. has not been done, because “more valuable” categories have been done. In IV Category, about 22 % bigger achievement brings a possibly bigger profit in relation to the decrease of profit for the reasons of about 13% smaller achievement of III Category. In V Category the achievement was about 7 % smaller which presents the decrease of profits for the value of the excavation of this category, but it could also mean the increase of profit for the shorter term of the excavation of this category for the reasons of smaller indirect expenses which are proportional to the duration of the tunnel excavation.

These questions could be considered if the mentioned forecasted and achieved lengths are estimated on the basis of some defined (objective) price and (real) quantity of progress for each category of the tunnel excavation (excavation category / excavation price / progress): *II./ 2.687 US$ /m1 tunnel / 9,00 m/day; III. / 3.560 US$ /m1 tunnel / 4,50 m/day; IV. /4.668 US$ /m1 tunnel / 2,25 m/day; V. /8.415 US$ /m1tunnel / 1,50 m/day*. In this case for the forecasted (contracted) categorization of the tunnel excavation, the expenses and the duration of the excavation would be as it is shown in the Table 3, and in the case of the achieved (paid) categorization, it would be as it is shown in the Table 4.

In the comparison of the above shown costs evaluation of the forecasted and achieved categorization, we could come to the conclusion that neither the “contractor has achieved smaller profit”, nor the investor has realized the better financial result. If this is the case, it could also mean that the achieved categorization was the result of some form of the more or less targeted approach of the investor towards this categorization? The above mentioned results also show one intention of the investor, as the unwritten rule of the tunnel construction practice, which is conditionally defined as “the rule of the invariability of the previously defined value of works for the tunnel excavation and supporting”. Based on this rule, with his decisions the investor intends to “achieve” this categorization of the tunnel excavation, which allows the smaller invariability of the total contracted price of the works for the tunnel excavation and supporting.

The mentioned facts of the probabilism of the forecasted geological sec-

Tunnel category	Category length (m)	Value of works Per category (US$)	Duration of works Per category (days)
II	35.00	94.045	3,89
III		3.738.000	233,33
IV	315.50	1.472.754	140,22
V	686.25	5.774.794	457,50
total	2086.75	11.079.593	~ 835
average		5.309 US$/m1	2,50 m/day

Table 3. **Value and duration of works for the tunnel excavation per forecasted categories**

Tunnel category	Category length (m)	Value of works Per category (US$)	Duration of works Per category (days)
III	785,10	2.794.956	174,47
IV	767,80	3.584.090	341,24
V	533,85	4.492.348	355,90
Total	2086.75	10.871.394	~ 872
average		5.209 US$/m1	2,40 m/day

Table 4. **Value and duration of works for the tunnel excavation per achieved categories**

tion of the tunnel and the probabilism of the forecasted categorization of the tunnel excavation (which is founded on the probabilistic geological indicators) – in relation to the possible achievement of the categorization – indicate that the decisions relative to the choice and planning of works and progress (as well as the costs evaluation) of the technology of the tunnel excavation, especially in the conditions of the geology of karst, are if fact quite risky decisions. Therefore, the categorization of the tunnel excavation is one of the main sources of the technological risks for the case of the excavation of the long tunnels in karst which represent the integral part of the project or business risks related to the complete tunnel construction.

Technological risks in case of the excavation of the long tunnels in karst

The mentioned process of decision making in the conditions of risks is one of the causes of the technological risks in the case of the excavation of the long tunnels in karst. Other causes of the mentioned risks are different hazards and *states of risk* relative to the expectations of the functionning of the considered systems. There are different sources of these causes, for example:

- *natural system of the underground rock massif* in which the tunnel has been excavated in two ways: as the natural source of risks coming from the area of the technological system and as the work subject inside of technological system,
- structure of the project organization and the *management subjects* of the tunnel construction project and its technological sub-system, organized for the purpose of the tunnel excavation,
- *information and communications* inside the technological system and its surrounding area,
- *technological system and its functioning through the excavation and supporting process at the beginning of the tunnel excavation*, based on which this system has been organized,
- *organization of the tunnel excavation techniques and technology* or the organization of the technological system in form of three structurally different, but connected technological and logistical subsystems (outside preparation, transport of resources through tunnel from the preparation to the face of the excavation, face of the tunnel excavation with heading crew),
- *supporting system* on the basis of its interaction with the rock massif around the excavated tunnel profile and as the supporting process,
- *(in)security of persons and goods* inside the organization and the technology of works for the tunnel excavation.

A certain research geology (Linarić, 2000) based on the consideration of the causes and sources of seven *key technological risks* which affect the achievement or the lack of achievement of the technological aims of the project relative to the expenses, progress, quality of the excavation and supporting works of the long tunnels in karst, has estimated the following facts:

1. situation of the project documentation (especially the situation of the bill of expenses) – *risk of tunnel excavation bill of expenses*,
2. expectations evaluation of the natural hazards resulting from the macrostructure characteristics of the geological phenomenon of karst – *risk of geological phenomenon of karst*,
3. evaluation of the tunnel excavation progress – *risk of tunnel excavation progress*,
4. evaluation method and the calculation of the overprofiled tunnel excavation – *risk of overprofiled (overbreak) tunnel excavation*,
5. inefficiency of the supporting system – *risk of tunnel supporting*,
6. method of calculating the expenses and costs of work for the tunnel excavation and supporting – *risk of expenses calculation for the tunnel excavation*,
7. supervision of the achievement of works for the tunnel excavation – *risk of supervision of the tunnel excavation*.

Risk of tunnel excavation bill of expenses

Bill of expenses is the starting information basis, based on which the communication process between the tunnel construction participants has been founded. Mostly, it is the first business «meeting» of the potential contractor with the tunnel construction project. On the basis of the bill of expenses, the contractor decides whether he will participate in this construction in order to achieve his business goals. He also estimates his further relation with this construction. Structure method of works description as well as the correlation of some works quantities strongly influences the quality and the realization of the mentioned decisions of the potential contractor. In this process, *the risk of tunnel excavation bill of expenses* especially results from the probabilism of the work quantities for the tunnel excavation and supporting in the bill of expenses, and the bill of expenses results from the probabilism of the forecasted tunnel excavation categorization .

Figure 2. **Bigg cave in croatian highway tunnel Učka**
(Source: http://pticica.gorila.hr/slike/velika-spilja/572719)

Risk of geological phenomenons of karst

Geological "phenomenons" of karst as the manifestation of the natural hazards include cavernous fault line areas and their filling, as well as the areas of bigger or smaller caves *[Figure 2.]*. The fault lines are especially important if they are followed by the shattered condition of the rock massifs and the bigger or smaller caverns or caves. They also enable the subterraneous water flows and different ways of filling of these shattered hollow zones with the layers of clay glina, mixed clay with karst, breccia and similar lithostratigraphic formations. However, although these forms usually appear, they cannot be foreseen in terms of their size, form, way and time of their manifestation during the tunnel construction. That's why the estimate of the risk of geological phenomenon of karst as the consequence of the mentioned phenomenons causes the problems in terms of the realization of the technological aims and the progress, costs and quality of the tunnel excavation works. It isn't simple also to establish the influence of this risk to the technological aims of the project. In this respect, the heuristic approach could help, on the basis of the consideration of some indicators, gathered from the previous practice of the excavation of the long tunnels in karst.

Risk of tunnel excavation progress

The "variability" of the estimate for the tunnel excavation *progress* presents the source of many project (business) risks in the process of tunnel construction, especially for the technological risk of the excavation of the long tunnels in karst, defined as the *risk of tunnel excavation progress*. The planned progress rate of the tunnel excavation is mostly determined by the probabilism of the tunnel excavation categorization, then the estimate of the manifestation of the geological phenomenons of karst and the hypothesis of the adaptability of the technological system to the statistical conditions of the natural environment. Therefore, the tunnel excavation progress, in its characteristics and value, represents *the accidental variable*. Double consideration of the tunnel excavation progress – once as the forecasted value and the other time as the achieved value realized during the tunnel excavation – represents is the basis characteristic, which points to the general probabilism of the estimate of the tunnel excavation progress. There is a big difference in terms of value of these two situations (forecasted achieved).

Risk of calculation of the tunnel excavation expenses

The riskiness of the calculation of the unit prices of the tunnel excavation and supporting is defined as the *risk of calculation of tunnel excavation expenses*. The bill of expenses for the works on tunnel excavation and supporting includes a considerably small number of expense items, which represent a very big total value of these works. Therefore, even a small change of unit prices could cause the big changes of the works total value. The mentioned "variability" of the excavation unit prices is possible in one part of the "variability" of the estimated value of the tunnel excavation progress. A considerable "riskiness" of the calculation of the tunnel excavation and supporting expenses is the result of the "philosophy" itself of this calculation. This is the case of the approach to the calculation of the tunnel excavation and supporting expenses in the calculation structure of the unit prices and the analysis structure of the prices of the "direct" and "indirect" expenses (costs). It is important to point out the correlation of the calculation structure of the mentioned excavation expenses with the calculation structure for the tunnel supporting expenses.

Risk of the overprofiled (owerbreak) tunnel excavation

The excavation of the overprofiled (theoretical) tunnel excavation profiles *[Figure 3.]* considerably influences the total expenses of the excavation and the supporting, as well as total lining expenses. Therefore, the problem area of the overprofiled excavation represents one of the key technological risks, defined as the *risk of the overprofiled (owerbreak) tunnel excavation*. The overprofiled excavation could be necessary or foreseeable and unforeseeable or accidental. The technological overprofiled excavation is mostly necessary and foreseeable. A part of this overprofiled excavation could be accidental as the consequence of the uncareful work or if the «inappropriate» mining activities have not been adjusted to the rock characteristics. Geological overprofiled excavation, as a natural phenomenon, is accidental and unforeseeable in terms of size, form and time of its manifestation. Total overprofiled excavation in its manifestation is neither uncertain, nor undetermined. The probability of the manifestation of the total overprofiled excavation is obvious. This is the reason why the total overprofiled tunnel excavation is considered as the technological and natural hazard. In addition to this, there are also some other "natural events" as the bigger caving in and detachments, which help even more in the notional determination of the overprofiled excavation as the hazard.

Risk of tunnel supporting

The designed situation of the supporting system (shotcrete, different sorts of roof or rock bolts, metal nets, steel tunnel archs, liner plates, elements of water drainage) is determined by the decisions relative to the supporting conception and construction per some categories of the tunnel excavation *[Figure 3.]*. These decisions are risky because they are based on the probabilism of the tunnel excavation categorization. This is the condition for the definition of one of the key technological risks which is determined as the *risk of tunnel supporting*. The probabilism of the dimension of the supporting construction influences the probabilism of the quantities of the supporting system elements in the bill of expenses. The concept of the supporting construction is also influenced by the mutually determined corbel length per individual cycle and the "stand-up time" of the rock which has been supported. This time is also an accidental variable, so this "variability" is one of the sources of this risk. In contrast to the planned situation, the achieved situation of the supporting system will be determined by :

- real length of the tunnel , per individual excavation cycle
- real geotechnical rock characteristics around the excavated tunnel profile,
- real "stand-up time" of the rock,
- achieved *overprofiled (owerbreak) tunnel excavation*,
- manifestation of *the geological phenomenons of karst,*
- situation relative to the supporting system during its stabilization with the surrounding rock massif, the balancing of which results with the termination of the supporting construction deformation,
- adaptability of the technological system to the natural surrounding area or to the current situation during the excavation of the surrounding rock massif.

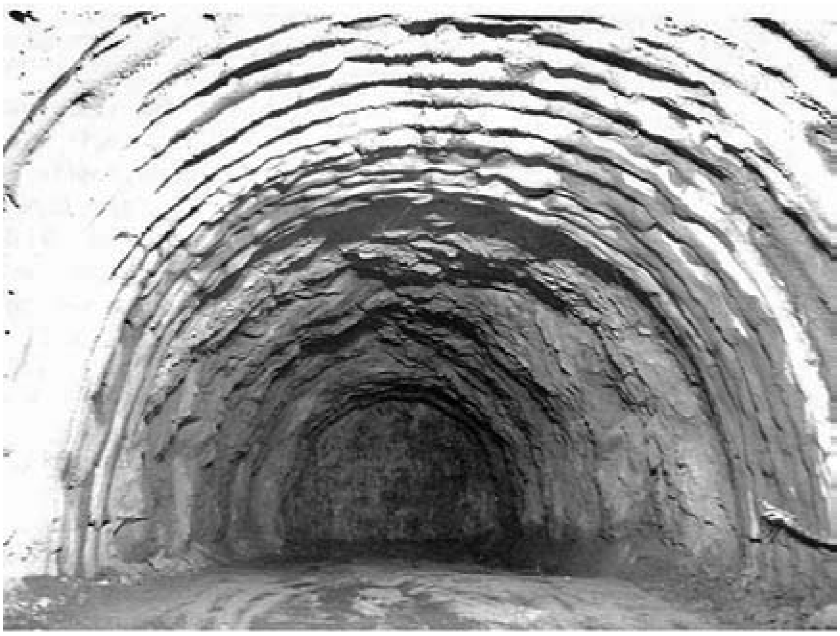

Figure 3. **Overprofiled (overbreak) tunnel excavation and tunnel supporting by tunneling in karst** (Source: TUNEL MALA KAPELA – NAJDUŽI TUNEL U HRVATSKOJ, GRAĐEVINAR 56 (2004) 1)

Therefore, the achieved quantity and the corresponding tunnel supporting value in its important characterization could only be the accidental variable. The risk of the tunnel supporting could be also caused by the hazards of the tunnel supporting construction. The cases of the deformation of the supporting system and the possible hazards of its fracture or caving in mostly appear in the tunnel excavation categories in the rocks classified as the rocks with thrust. The hazards of fracture or caving in of the supporting system during the excavation and the supporting of the long tunnels could be expected with the big probability, based on the data of the total number of tunnel constructions with the example of the partial or complete supporting system caving in..

Risk of tunnel excavation supervision

The problem area of the tunnel excavation and supporting supervision is the possible source of the risk in the technology of the construction of the long tunnels, defined as the *risk of tunnel excavation supervision*. The decisions about the methods of the initial supporting of the excavated part of the tunnel are made on the spot, on the basis of mostly subjective evaluation and estimate of the situation of the rock massif in the area surrounding the excavated tunnel profile. The solution must be quick and efficient, because there is not enough time for the evaluation and the estimate of the parameters which could allow the best solution for the supporting construction, depending on the achieved category of the tunnel excavation. The conclusion is that the solutions of the supporting construction are mostly "satisfactory" in terms of reliability, and they are rarely optimal in terms of total technoeconomical unstintingness. The experience shows that the subsequent reinforcement of the supporting system rarely occurs after the measurement of its convergence and other characteristics of its situation in terms of bearing power. It could mostly mean that the supporting is "well dimensioned" or more precisely, based on the personal experience of the author, it is mostly "over-dimensioned" in relation to the designed supporting in the individual tunnel category.

Management of the technological risks

As we have already seen, the technological risk in question could have more causes and sources, or it can be compositional. However, it is a fact that one of the main sources of the above mentioned risks is the relation between the forecasted and achieved tunnel excavation categorization or, generally speaking, the probabilism of the tunnel excavation categorizations. The solutions for this problem area are possible only with the optimal division of the risks and their consequences between the major participants in the realization of the tunnel construction (investor or owner, designer, contractor etc.) and with the method of risk management. This division should include the following elements, as follows:

1. in the first place, the initial avoiding of risks is possible,
2. secondly, the attenuation of risks is possible,
3. thirdly, it is possible to keep (the attenuated) risk as the form of the oriented division of risks in relation to the person who makes this division,
4. fourthly, it is possible to transfer the risks towards the other as the form of the oriented division from the person who makes this division, but at the same time, avoids the risks
5. fifthly, it is possible to mutually divide the risks.

The distribution or the division of the mentioned key technological risks should be performed only between two main participants in the tunnel construction project - investor and contractor (in spite of other opinions and attitudes that all the main participants in the tunnel construction should participate in the distribution of the mentioned risks and their positive or negative consequences (designers, engineers, investigators, etc...).

The involvement and the responsibility of the designer to manage or supervise the mentioned risks are theoretically possible, but it is difficult to put it into practice. The value of some tunnel design is too small in relation to the total value of the budget for some long tunnel so that the designer could participate in the responsibility for the expenses of some project technological risks. This financial "lack of power" of the designer is in fact his protection from the consequences of the probable risks, but the designer could be the cause or the source of these risks for the reasons of his decisions he has made and the project documentation that he "produces". In the case of the construction of long tunnels, the task and aim of the "performer" of the geotechnical research works is the "forecasted longitudinal tunnel section". And this forecast, by the nature of its name and notion, represents nothing specified, more or less probable in its certainty and it is sometimes even uncertain. The mentioned "investigators", in terms of the obvious probabilism of the forecast that they produce, are not completely determined to bear the consequences of the project risks, which occur from their "research" in the tunnel construction.

It could be concluded that only the investor and contractor are able to manage, divide or supervise the mentioned technological risks. Their source is mostly the probabilism of the tunnel geology or the tunnel excavation categorization, and the management of these risks is efficiently directed towards the minimization of the risk expenses. However, it is an undoubtful fact that the total expenses (which means the price or the value) of the tunnel excavation and supporting, as well as the project business risks should be beard mostly only by the investor, especially when the contractor is able and competent to contract and perform the underground works. Therefore, the investor is the bearer of all the project investments and expenses and he is involved in the project development from the beginning until its end. The investor is also the only person who makes the risks distribution among him and the other work contractors - and in this case, this distribution refers to the key technological risks of the tunnel excavation and supporting.

Distribution of the technological risks

There are two groups of the mentioned technological risks. One group consists of the *absolute risks*, which are undoubtful in their existence and distribution. They involve *the risk of bill of expenses in terms of tunnel excavation quantity and its costs, the risk of geological phenomenons of karst and its costs, the risk of geological overprofiled (owerbreak) excavation and its costs and the risk of tunnel supporting and its costs.* The risk of the tunnel excavation supervision is included in the risk of bill of expenses for the tunnel excavation and supporting. The absolute risks occur with certainty, but it is uncertain to estimate the size of their action and the consequences of this action. These risks could be proven in terms of expenses, and they can be individually measured in their realization and in the compensation towards the expense contractor, as defined by the contract distribution. The investor should completely keep (assign himself) the supervision, and the corresponding obligations and consequences, related to the absolute risks because it is in his interest to keep the expenses minimal. The contractor's interest, regardless of the quantity of these expenses, is that he receives the complete (fair) compensation.

The other group is the group of the *relative risks, which cause the direct "variability",* or "the riskiness" of the unit or the complete prices of the tunnel excavation or the supporting. The expenses of these risks are included in the total expenses, and in the individual expenses of each group of works for the tunnel excavation. These "variable" expenses or prices include the expenses of the *risk of description and estimate of the quantities in the bill of expenses for the project of tunnel excavation, risk of tunnel excavation progress, risk of technological overprofiled tunnel excavation and the risk of the tunnel supporting in the part which is relative to the fill estimate of the overprofiled excavation with the shortcrete.* These risks are defined "this way or another". They could be included "this way or another" in the price of works. For the reasons of this proportional relativism of these risks, we could speak about the risky price of the tunnel excavation, which, in its complicated structure, involves the mentioned risks and their expenses. Generally speaking, these expenses could not be separated from the price of works, but they are mutually dependant and determined by the other expenses which form this price. The supervision, obligations and consequences connected to these relative risks should be transferred towards the contractor, because they are included in the "risky" (possibly "variable") price of the tunnel excavation and supporting. The technological overprofiled excavation with its size determines the method of its filling with the shotcrete or the lining concrete, and therefore, this sort of supporting system risk, in terms of this estimate, is assigned to the contractor.

This distribution, as keeping and assigning of key technological risks by the investor does not mean that all the mentioned risks completely fit to the scope of interest of the contractor to whom they had been assigned or to the investor who had kept them. This especially concerns the relative risks, which, in terms of their expenses, form an integral part of expenses as the completely contracted price and the unit prices for the tunnel excavation and supporting. Among them, the risk of tunnel excavation progress is quite important. This risk, as the majority of the key technological risks is a compositional one, so it cannot be avoided, as well as the involvement of both sides in bearing the possible consequence of the occurrence of this risk.

Attenuation of the technological risks

In general, the absolute risks cannot be "minimized", "maximized" or "optimized" because they are the consequence of mostly the probabilism of this tunnel excavation categorization. In their achievement, they are certain, but it is difficult to foresee the scope of their action and consequences. Therefore, they cannot be avoided, but just attenuated in some way. In contrast to this, it is possible to "minimize" and "optimize" the relative risks and their expenses, but also to "maximize" them with the possible incompetence and the lack of the necessary knowledge. They are mostly the consequence of the approach to the choice, planning and evaluation of the techniques and technology of the tunnel excavation and supporting, on the basis of the probabilism of this tunnel excavation categorization. Their achievement is also certain, and the scope of action and their consequences could be also foreseen. They cannot be avoided, but they can be attenuated in some way.

One of the elementary ways of attenuation of the mentioned key technological risks is the application of the appropriate *„lasifikation"* of rocks and the tunnel excavation categorization. Such categorization should include three basic components (as the parts or the chapters with the description of contents for each category of the tunnel excavation):

- definition of the characteristics (especially the quality and structure) of the underground rock massif in which the tunnel has been excavated, based on some classification,
- definition of the quantity and the quality of the "average" supporting system, as the result of the calculation on the basis of the parameters from the rock characteristics after the classification has been applied - we could also add to it a further expectation of the deformations and the acceptable deformations of the supporting construction, because of which they should be additionally reinforced;
- definition of the techniques and technology of the tunnel excavation and supporting, in terms of
- tunnel excavation after the previous rock mining in a mechanical or a combined way,
- length of excavation progress cycle (length of excavation round), length and possible or acceptable duration of unsupporting excavated tunnel profile;
- tunnel excavation in its parts on several levels,
- other difficulties, relative to the organization of the technological tunnel excavation (water penetration, subterraneous gases, etc.).

The mentioned risks could be attenuated in the following ways:

- for a starter, the geological manifestations of karst have to be foreseen and determined on the basis of their key characteristics, as for example approximate length of the tunnel areas in which the probability of the occurrence of these manifestations is big, the form and scope of these manifestations, geotechnical characteristics of these manifestations, sort and scope of these areas etc.
- later on, the certain typical solutions of the supporting system and the final lining for the particular number of possible forms and sorts of tunnel tubes with the morphology of the geologic phenomenons in the project documentation, on the basis of the forecast of the manifestations of the karst phenomenon and the definition of the approximate characteristics of these manifestations,
- based on what has been mentioned above, the appropriate bill of expense items should be shown in the bill of expenses for the works of excavation and supporting including the works and their planned expenses for example, for the "recovery" of caves and caverns etc.

It is logical that all the risk cases, resulted as the consequence of the possible forms of the geological karats, can be solved this way neither in the constructive way, nor in terms of expenses. However, there is a request for any form of forecast of the activities on the tunnel excavation through the areas of caverns and caves that the contractor has a certain preparation for this kind of works. For solving this problem area of the attenuation of the risks relative to the geological phenomenons of karst, the investor's investment into the research of these manifestations would be of help in terms of form and the methods of solving the construction of the tunnel tube passage in the past scope of tunnel excavation in karst.

SUMMARY

Not enough importance has been given to the forecasted tunnel excavation categorizations in terms of their punctuality and practical acceptability, as it should be, because they define the basic (and key) level of the starting "business" relations between the main participants in the tunnel construction. The simplified tunnel excavation categorizations and the corresponding sophisticated formulations have to be a valuable "tool" for the evaluation of the future situation about the underground rock massif in which the tunnel has been excavated. However, in some cases, they become inappropriate from the point of view of the limitation of their hypothesis and the applicability on some rock massif. As the consequence of that, the contractors mostly stick to their own experience and criteria in the utilization of these categorizations. There is even one opinion that this is what gives the riskiness to the entrepreneur's spirit in the tunnel construction or what brings the advantage to the experienced tunnel constructors in comparison to the inexperienced beginners. As the tunnel excavations categories cannot include all the factors important for decision making in terms of choice and planning of the effects of tunnel excavation technology, the experienced contractors often use some other methods in order to define in every way the expected efficiency of the selected excavation method especially for the long tunnels.

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Notes

[1] Explanation of the Table 1.: on the length of 443 m (21 %) III Category has been designed, and IV Category has been achieved and it was forecasted total of 1050 m (50%) of III Category;

[2] Explanation of the Table 2.: On the basis of 42 % forecasted III Category, IV category has been achieved;

[3] The notion "tunnel category" is used to mark the group of combinations of the geotechnical indicators requesting almost the same supporting system, same excavation method in the technological sense and as the elaboration of the tunnel transversal section, and the same length of each tunnel izboj.

[4] One of the common defects of all the used "categorizations" of the tunnel excavations is the description or the designation of the rocks ranging from good to very bad. We could ask ourselves a question in which way some rocks are good or bad for the tunnel excavations - geotechnical, technological, constructive and technoeconomical. Are they good or bad in terms of support, linning ?. For whom - cotractor or investor?.

[5] Explanation of the Table 1.: on the length of 443 m (21 %) III Category has been designed, and IV Category has been achieved and it was forecasted total of 1050 m (50%) of III Category;

[6] Explanation of the Table 2.: On the basis of 42 % forecasted III Category, IV category has been achieved;

[7] For the needs of underground works in karst, the acceptable information about fault or fault lines, cavernes and caves is missing, which could present the main additional parameters for any excavation categorization in the karst rock massifs. The tunnel excavation through the engineering-geological phenomenons of karst with the geotechnical characteristics should be certainly defined out of the usual descriptions of the other tunnel categories. The fault or the cave cannot be very good or very bad in terms of usually used descriptions of the underground rock massifs in particular categories of the tunnel excavation. If the occurrence of the foult or the cave is previously foreseen, they must be separately described in terms of their basic characteristics, filling size and form, but also in terms of possible constructive and technological intervention on their bridging over and passages.

[8] Hazards are accidental (or risky) events and the risks are their measurable consequences.

[9] State of dynamical situations (consisting of natural, supporting and technological systems) is defined by the systems motion and performance. System's performance is characterized by the system's output, as the consequence of the processes in this system. The process is determined by the situation of the system's input. The dependence between the system's performance and the performance of its environment influences the motion and the development of the dynamical system.

[10] It has to be point out that the "variability" of the values of the planned progress per categories of the tunnel excavation, which results with sone planned average daily progress, does not have to result with the big "variability" of the achieved average progress, if there is the "variability" of the achieved progress per particular excavation categories. This relation of the "variability" of the planned progress values for the tunnel excavation with the achieved progress results depends mostly on the achieved categories in relation to the planned excavation categories. This way, the mutual dependance of the probabilisms of the tunnel excavation categorizations and the riskiness of the estimate of the works progress (tunnel excavation and supporting) are quite obvious.

[11] As the ilustration, we can mention the cases of caving in of the constructed and subsequently reinforced supporting system in the road tunnel Karavanke and the railway tunnel in the northern Germany, etc. However, it is very difficult and almost impossible to estimate the objective probability and the intensity of the occurrence of hazard or the caving in of the supporting system in some long tunnels.

[12] Based on the experience of the engineer-geologists in the estimate or the interpretation of the results of the engineering-geological research, as well as his expertness in "geology" of the extensive scope of tunnel construction with the necessity to obligatorily consult the experts in morphology of the extensive range of the tunnel construction.