COMPUTER MODELLING OF CIRCULAR CAVE PASSAGE DEFORMATIONS DEPENDENT OF THE DEPTH

RAČUNALNIŠKO MODELIRANJE DEFORMACIJ OKROGLEGA JAMSKEGA ROVA V ODVISNOSTI OD GLOBINE

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Izvleček UDK 624.121:681.3.01

Karmen Fifer-Bizjak & France Šušteršič: Računalniško modeliranje deformacij okroglega jamskega rova v odvisnosti od globine

S pomočjo računalniškega modela, ki temelji na metodi končnih razlik smo proučevali globino, na kateri se okrogel jamski kanal poruši zaradi geostatičnega tlaka. To se zgodi pri šibkih apnencih v globinah pod 750m, pri zelo trdnih pa pod 2500m.

Ključne besede: speleogeneza, mehanika hribin, računalniško modeliranje

Abstract UDC 624.121:681.3.01

Karmen Fifer-Bizjak & France Šušteršič: Computer modelling of circular cave passage deformations dependent of the depth

Using a computer model, based on the finite difference methoid we simulated the fail of circular cave channel, due to geostatic pressure. Poor limstone failed at the depth less than 750m, while very good limestone not until 2500m.

Key words: spelogenesis, rock mechanics, computer modelling

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INTRODUCTION

Present research of the early stages of the cave channel formation revealed the importance of a number controlling factors. Among them, the geomechanical properties of the rock play the key role, during the time between the inception, and the proper channel formation. In the further lines, we will discuss the control of the geomechanical properties of the rock.

The simplest and the most fundamental question is: At which depth the formation of the cave channels is impeded due to the large primary stress.

For this calculation we used program FLAC var. 3.03. It is installed at the PC computer at the Institute for Geology, Geotechnology and Geophysics in Ljubljana. As a modelling technique the program uses the finite difference method. According to this method, first, a finite different mesh is designed and in the second step the differential equation is transformed into a difference equation. The program uses Mohr-Coulomb criteria of failure. It is very effective to solve geomechanical problems because it considers the shear properties of the material, for example, angle of friction and cohesion.

Till now we have used this program for backanalyses of tunnels deformation on the motorways (for example Debeli hrib and Karavanke), for the research in Velenje coal mine and for feasibility study of underground garage in Piran.

THE MODEL

As the first step we acquired the grid of 20 elements in X direction and 20 elements in Y direction. The assumed diameter of the circular channel was set 1 mm. The calculation was simplified by considering only the upper right quarter of the channel.

In the next step we set the geomechanical properties of the limestone. The crucial problem in numerical modelling are the INPUT parameters, as the result of computations depends on the proper values of geomechanical data. At this stage we didn't use any measured field data. Rather than we made use of four general types of limestone, having taken the needed parameters from the literature, according to our previous experience with the numerical modelling. We processed the limestone of four basic groups, presented in the Table 1.

Table 1:

	label	E [MPa]	fi [°]	c[MPa]	T[MPa]
very good limestone	A1	20	42	3.0	1.5
good limestone	A2	15	35	1.0	1.0
fair limestone	A3	10	28	0.7	1.0
poor limestone	A4	7	28	0.7	0.2

In the next step we determined the primary stress field. We equalled the vertical primary stress with the geostatic pressure:

$\sigma_v = \gamma \times H$, where

σ_v ... vertical stress
γ ... specific weight

It was assumed that the horizontal and the vertical stresses are equal. In reality the relation between horizontal and vertical stress varies with depth.

We computed 18 models in total with various types of limestone at various depths. The results are summarised in

Table 2:

	DISPLACEMENT VECTORS (mm)			
	Label (type of limestone)			
DEPTH	A1	A2	A3	A4
500	5.60E-03	5.30E-03	1.00E-03	2.60E-04
600	9.60.E-03	-	-	-
750	FAIL	8.60E-03	2.40E-03	4.90E-04
1000		FAIL	4.50E-03	8.10E-04
1250			7.60E-03	1.10E-03
1500			FAIL	1.60E-03
2500				4.10E-03
3000				FAIL

As a result of our calculations we obtained for each model the maximal displacements around the channel. Our model failed for poor limestone at the depth 600 m, for the fair limestone after 750 m, for the good limestone after 1250 m and for the very good limestone after 2500 m. That means that at the listed depths formation of stable channels is not possible any more.

SOME DISCUSSION

Extremes are of our main interest because they display the limits of the results in various conditions.

In the figure of displacements showed that larger displacements appeared with the poor limestone. Displacementsare of the size order 10^{-6} m and for the good limestone 10^{-7} m. In both cases displacements have the same direction.

The largest vertical displacements occur in both cases at the top of the channel. Again, in different size orders. Displacements for the poor limestone presents Figure 1, and for very good limestone Figure 2.

In the pattern of maximum principal stresses the zone of weakness appears around the channel. After the zone of weakness, zone of higher stress occurs, which influences on the stabilisation of channel. The difference in both cases is in the dimension of the weakness zone. For the poor limestone (Fig. 3) zone of weakness is larger than for the good limestone (Fig. 4).

The zone of plasticity is larger for the poor limestone than for the very good limestone. Dimension of the plasticity zone has an influence on stabilisation of the channel. As expected, the channel in very good limestone is more stable that in poor limestone.

Though the model is rudimentary, the listed figures show the importance of the geomechanics properties of limestone for the final result of modelling.

CONCLUSIONS

According to the results of numerical modelling we can conclude that the limits of stability of circular voids in limestone are between depths of 600 to 2500 m. In the other words, in the limestones which have suffered complete diagenesis, karstification may reach approximatively four times deeper than in the nonconsolidated ones. The depth of the failure depends on geomechanical properties of the limestone. It must be pointed out that at this stage of research we didn't use any concrete field data of the geomechanical properties of the limestone, and we intended first to set the approximate limits of failure.

In the future we intend to investigate samples from selected location. With known properties of limestone and known stress field on the selected location we can make better model. Another issue that is intended to be investigated is the geometry of the primary channel, which will be approximated by ellipses of various a/b ratios.

REFERENCES

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RAČUNALNIŠKO MODELIRANJE DEFORMACIJ OKROGLEGA JAMSKEGA ROVA V ODVISNOSTI OD GLOBINE

Povzetek

Eno pomebnih vprašnj speleogeneze je, do katere globine lahko sploh nastanejo jamski kanali, ne da bi jih sproti porušil geostatični tlak. Kot prvi korak k odgovoru smo s pomočjo računalniškega programa FLAC var. 3.03, ki temelji na metodi končnih diferenc, simulirali porušitev okroglega kanale pri štirih vrstah apnenecev. Njihovo mehansko trdnost smo definirali na osnovi podatkov z literature:

Tabela 1:

		E [MPa]	fi [°]	c [MPa]	T [MPa]
zelo trden apnenec	A1	20	42	3.0	1.5
trden apnenec	A2	15	35	1.0	1.0
primeren apnenec	A3	10	28	0.7	1.0
šibak apnenec	A4	7	28	0.7	0.2

Rezultate simulacije kaže

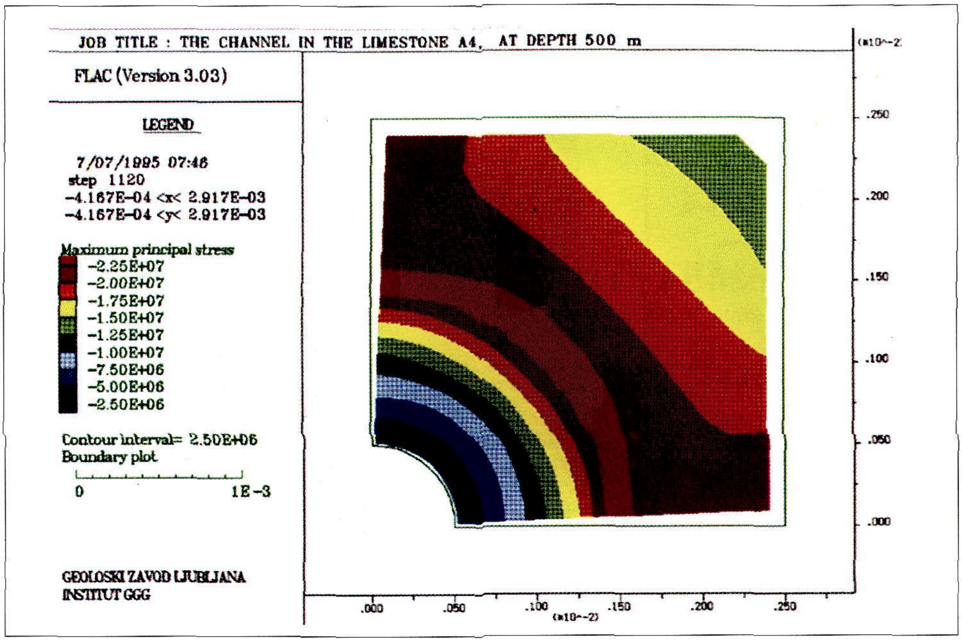
Tabela 2:

	VEKTORJI PREMIKA (mm)			
	Tip apnenca glede na Tabelo 1			
GLOBINA	A1	A2	A3	A4
500	5.60E-03	5.30E-03	1.00E-03	2.60E-04
600	9.60.E-03	-	-	-
750	PORUŠITEV	8.60E-03	2.40E-03	4.90E-04
1000		PORUŠITEV	4.50E-03	8.10E-04

1250			7.60E-03	1.10E-03
1500			PORUŠITEV	1.60E-03
2500				4.10E-03
3000				PORUŠITEV

Skupaj smo torej izračunali 18 modelov, pri čemer je za vsakega potrebnih več tisoč iteracij.

Na osnovi povedanega nastopi porušitev v globinah med 600 in 2500 metri. To pomeni, da lahko seže v trdnih apnencih, ki so prestali popolno diagenezo, zakrasevanje, štirikrat globlje, kot v tistih, kjer konsolidacija še ni končana.


JOB TITLE : THE CHANNEL IN THE LIMESTONE A4, AT DEPTH 500 m
FLAC (Version 3.03)
LEGEND
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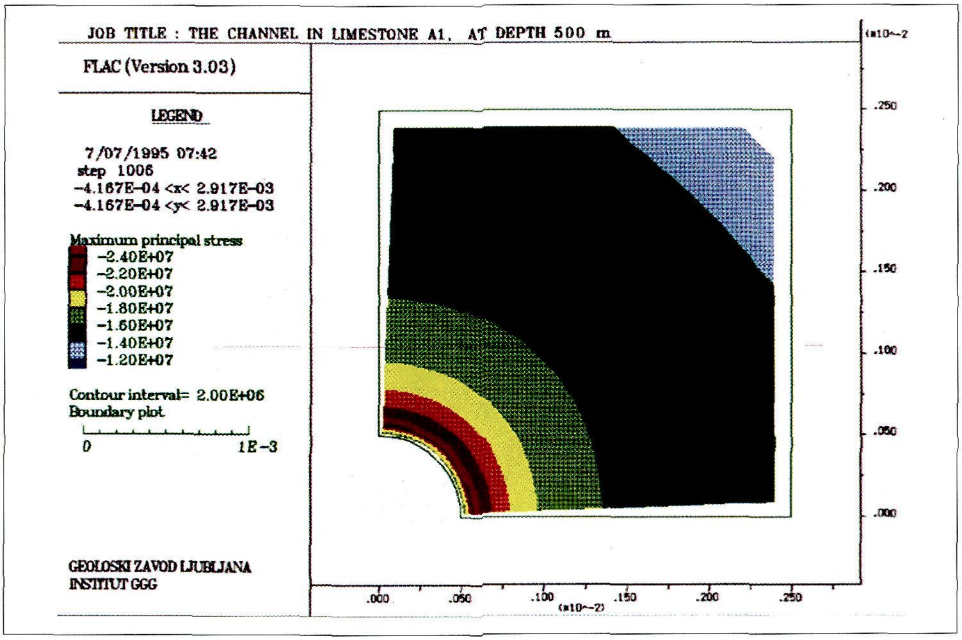
step 1120
-4.167E-04 <x< 2.917E-03
-4.167E-04 <y< 2.917E-03
Maximum principal stress
-2.25E+07
-2.00E+07
-1.75E+07
-1.50E+07
-1.25E+07
-1.00E+07
-7.50E+06
-5.00E+06
-2.50E+06
Contour interval= 2.50E+06
Boundary plot
0
1E-3
GEOLOSKI ZAVOD LJUBLJANA
INSTITUT GGG
(*10^-2)
.250
.200
.150
.100
.050
.000
.000
.050
.100
.150
.200
.250
(*10^-2)

Fig. 1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FLAC (Version 3.03)
LEGEND
7/07/1995 07:42
step 1006
-4.167E-04 <x< 2.917E-03
-4.167E-04 <y< 2.917E-03
Maximum principal stress
-2.40E+07
-2.20E+07
-2.00E+07
-1.80E+07
-1.60E+07
-1.40E+07
-1.20E+07
Contour interval= 2.00E+06
Boundary plot
0
1E-3
GEOLOSKI ZAVOD LJUBLJANA
INSTITUT GGG
(*10^-2)
.250
.200
.150
.100
.050
.000
.000
.050
.100
.150
.200
.250
(*10^-2)

Fig. 2

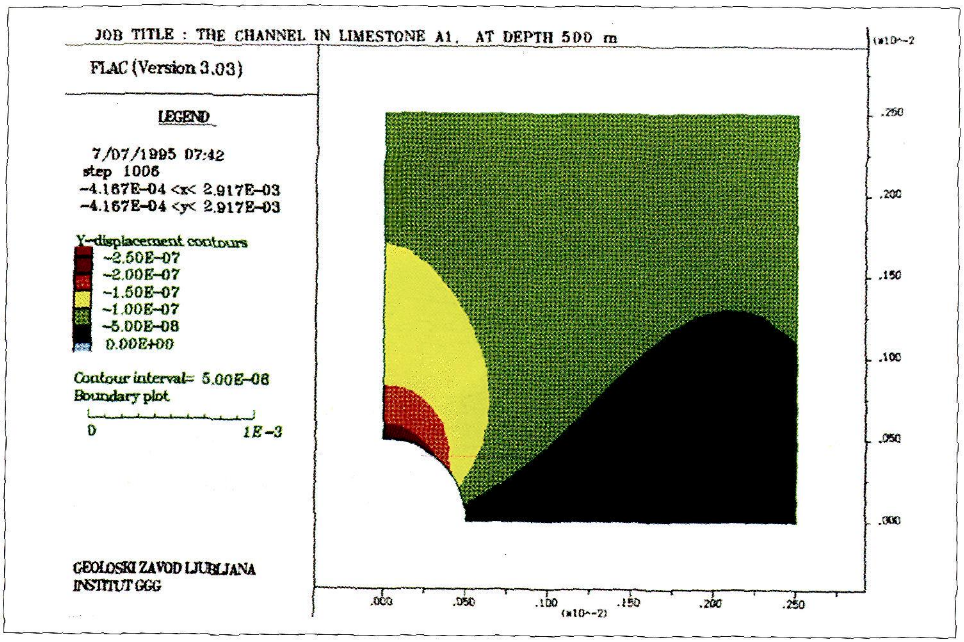
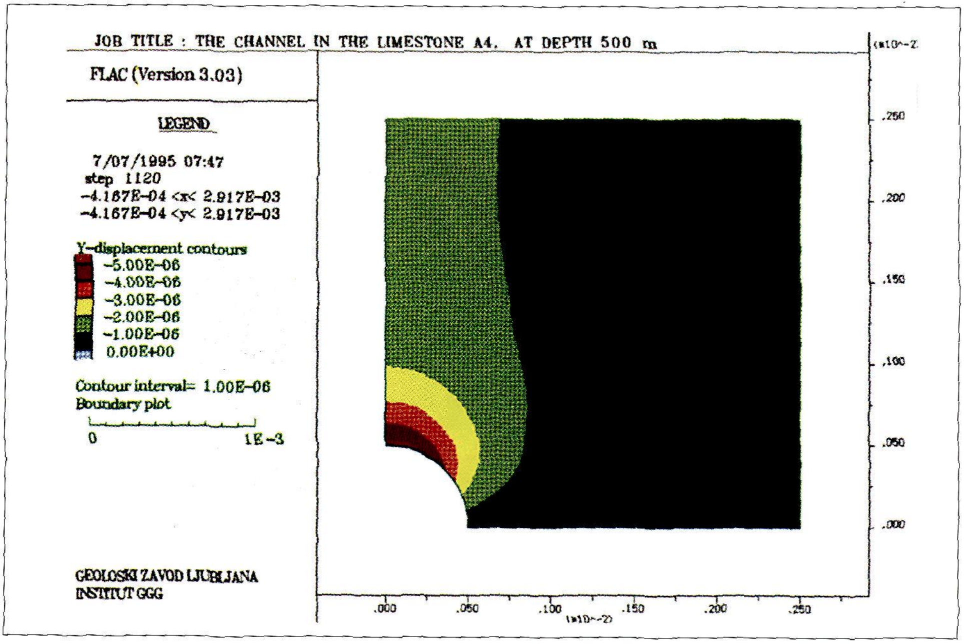

JOB TITLE : THE CHANNEL IN LIMESTONE A1. AT DEPTH 500 m
FLAC (Version 3.03)
LEGEND
7/07/1995 07:42
step 1006
-4.167E-04 <x< 2.917E-03
-4.167E-04 <y< 2.917E-03
Y-displacement contours
-2.50E-07
-2.00E-07
-1.50E-07
-1.00E-07
-5.00E-08
0.00E+00
Contour interval= 5.00E-08
Boundary plot
0
1E-3
GEOLOSKI ZAVOD LJUBLJANA
INSTITUT GGG
(x10^-2)
.250
.200
.150
.100
.050
.000
.000
.050
.100
.150
.200
.250
(x10^-2)

Fig. 3


JOB TITLE : THE CHANNEL IN THE LIMESTONE A4. AT DEPTH 500 m
FLAC (Version 3.03)
LEGEND
7/07/1995 07:47
step 1120
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-4.167E-04 <y< 2.917E-03
Y-displacement contours
-5.00E-06
-4.00E-06
-3.00E-06
-2.00E-06
-1.00E-06
0.00E+00
Contour interval= 1.00E-06
Boundary plot
0
1E-3
GEOLOSKI ZAVOD LJUBLJANA
INSTITUT GGG
(x10^-2)
.250
.200
.150
.100
.050
.000
.000
.050
.100
.150
.200
.250
(x10^-2)

Fig. 4