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1 Initial Entries:

Rock fall assessing under Seismic load using Key Block analysis and DDA.

Project number 20.01402.671

PI: Simon Hsiung

1.1 Objectives:

the rock block falling imidiate after the excavations

the rockfall due to the earth quake.

1.2 Technical Approaches:

The rockfall after excavation is assessed by Key Block analysis.

The earth quake rock block falling will be done by DDA.

1.3 Computer codes

- proje: draw stereo-graphic projection of joint sets
- trmo: maximum key block zones for all joint combinations or joint pyramids
- tblo: maximum 3-d key block

Material on the following pages are from: Hadjigerorgiou, J. and M. Grenon. "Preliminary Analysis Aiming to Develop Block Size Distributions That Can Be Used as Input for a Distinct Element Analysis: Sample Data From Yucca Mountain." Prepared by R. Chen, Center for Nuclear Waste Regulatory Analyses, San Antonio, Texas. Quebec, Canada: Georock Inc. 1999.

of a given joint pyramid

· ujto: produce joint trace overall map on the tunnel walls by statistics. on the joint trace map, key block area are delimited

· dl0: produce joint trace map by statistics on the tunnel section plane.

· dc0: forming blocks from the joint lines

· df0: perform the mechanical analysis and compute the the rock falling under earthquake loads

1.4 Data Sources

· dip angles and dip directions of joint from page ~~40~~ 30 of Report ANL-EBS-MD-000027 REV 00 also from Geo Rock: preliminary analysis for block size distributions and UDEC input page 2

the statistical data of joint length and joint spacing are from page 2 of Georock Report: preliminary analysis for block size distributions and UDEC input: Yucca Mountain Analysis.

the length of #2 joint set are larger the reason is on the chart of Georock report Total (2) vs Total set 2 Discontinuity Trace Length (m).

The friction angle from report ANL-EBS-MD-000027 REV 00 page 17, also from page 4-5 the input data for UDEC computation.

Table 1.1 Joint set data of Tptpll case

joint set	dip angle	dip d.	friction angle	cohesion
joint set 1	79°	270°	39°	0
joint set 2	81°	230°	39°	0
joint set 3	5°	45°	39°	0

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Table 1.2 Joint set data of Tptpul case

joint set	dip angle	dip d.	friction angle	cohesion
joint set 1	82°	288°	39°	0
joint set 2	82°	228°	39°	0
joint set 3	14°	39°	39°	0

Table 4.1 Statistical joint set data of Tptpll case

joint set	spacing: m	length: m	bridge: m
joint set 1	.30	1.8	.1
joint set 2	.30	2.4	.1
joint set 3	.50	1.8	.1

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Table 4.2 Statistical joint set data of Tptpul case

joint set	spacing: m	length: m	bridge: m
joint set 1	.30	1.8	.1
joint set 2	.30	2.4	.1
joint set 3	.50	1.8	.1

For elastic modulus E and
Poisson's Ratio μ
rock Mass Density,
the data are from ANL-EBS-MD-000027 REV 00, page V-5

Table 6. Tptpll rock falling using DDA programs

unit weight	2.27 tons/m ^{3}
E of rock mass	3000000 tons/m ^{2}
ν of rock mass	0.21

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Tunnel diameter: 5.5 m

Tunnel Shape Circular

Tunnel direction (drift trending) 105° (tunnel axis is 105° from north clockwise)

From Report ANL-EBS-MD-000027 REV 00

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~~2 Computation input files~~ 08/28/00

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Table 2.1 Tunnel data

bearing angle of tunnel axis	105°
rise angle of tunnel axis	0°
tunnel diameter	5.5 meter
tunnel shape	circular

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2. computation codes and files

2.1 Computation input files:

Key Block program: IBM RS-6000

program prejo:
input file prjs1, prjs2

program trmo
input file trms1, trms2

Program tblo
input file tbls1, tbls2, tbls3, tbls4

Program ujto
input file ujts1, ujts2, ujts3, ujts4

DDA program: PC

program dlo
input file dls1, dls2, dls3

Program dco
input file dcs1, dcs2, dcs3

Program dfo
input file dfs1, dfs2, dfs3

earth quak file: (20 seconds) qks1.

For this computation, the earth quake data of Yerba Buena Island Tunnel between San Francisco and Oakland are considered. The acceleration data are from California Department of Transportation. The ariginal data are 50 seconds, our computation only use from 10 second to 30 second. However the 20 second data are the main part of the strong earth quake.

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For the graphic post-processor:
dg0: (program)
input file: dgs1, dgs2, dgs3

2.2 data preparation and computation time table:

Description	Work	Date
Read field, laboratory and statistical data	8 Hrs.	Jan 24
Working on basic theory of tunnel rockfalls	16 Hrs.	Jan 27-28
Working on basic theory of seismic rockfalls	16 Hrs.	Feb 3-4
Checking Key Block computer codes	16 Hrs.	Feb 8-9
Chosing time-acceleration data	8 Hrs.	Mar 3
Chosing model of long term stability analysis	8 Hrs.	Mar 6

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3. data preparation and computation time table

Description	Work	Date
stereographic projection of joint sets	6 Hrs.	March 7
computation of all maximum key block zones	3 Hrs.	March 7
computation of all maximum key block zones	8 Hrs.	March 8
3-d view of maximum tunnel key blocks	4 Hrs.	March 9
sliding force contours of all tunnel directions	5 Hrs.	March 9
writing the first report	8 Hrs.	March 10
writing the first report	5 Hrs.	March 11
chosing joint statistical data for key block codes	5 Hrs.	March 11
finding key blocks on unrolled joint trace map	9 Hrs.	March 13
finding key blocks on unrolled joint trace map	8 Hrs.	March 14
checking DDA code for rock falling computation	8 Hrs.	March 15
checking DDA code for rock falling computation	8 Hrs.	March 16
chosing joint statistical data for DDA mesh	8 Hrs.	March 17
producing block mesh for DDA computation	8 Hrs.	March 18
checking block mesh for DDA computation	5 Hrs.	March 22
chosing time-acceleration data for DDA computation	4 Hrs.	March 22
rock falling computation under seismic load	8 Hrs.	March 23
rock falling computation under seismic load	8 Hrs.	March 24
rock falling computation under seismic load	10 Hrs.	March 25
printing graphics for the second report	8 Hrs.	March 26
writing the second report	8 Hrs.	March 27

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Data preparation and computation time table

Description	Work	Date
rock falling computation under seismic load, case 2	8 Hrs.	March 28
rock falling computation under seismic load, case 3	8 Hrs.	March 29
writing progress report	8 Hrs.	April 10
writing progress report	8 Hrs.	April 11
review progress report	4 Hrs.	April 12
to prepare graphic files	4 Hrs.	April 12
review progress report	4 Hrs.	April 14
preparation of earth quake displacement input	8 Hrs.	April 17
review progress report	4 Hrs.	April 18

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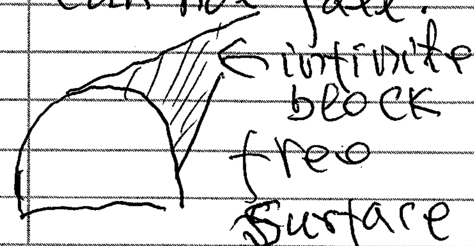
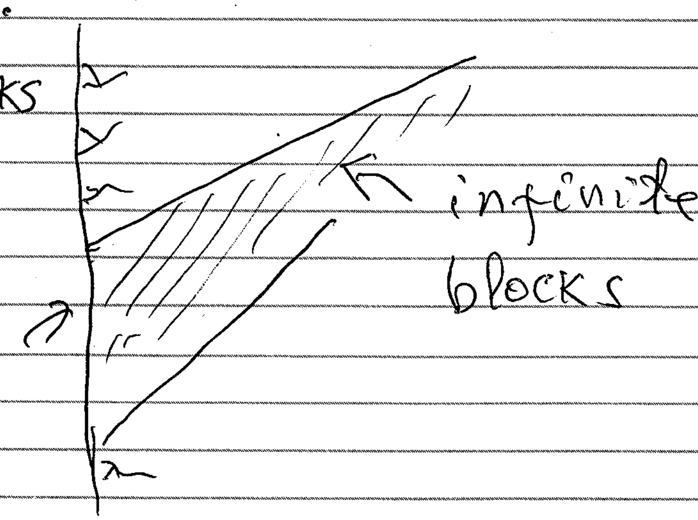
G. 4 Key Block Theory and Method:

All of the rock falling are block falling. There are four different kinds of rock blocks

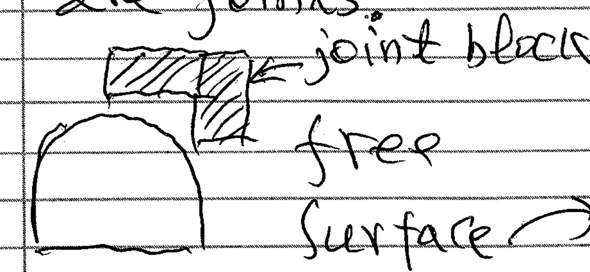
① Infinite blocks, which are not isolated and connected with the whole rock mass.

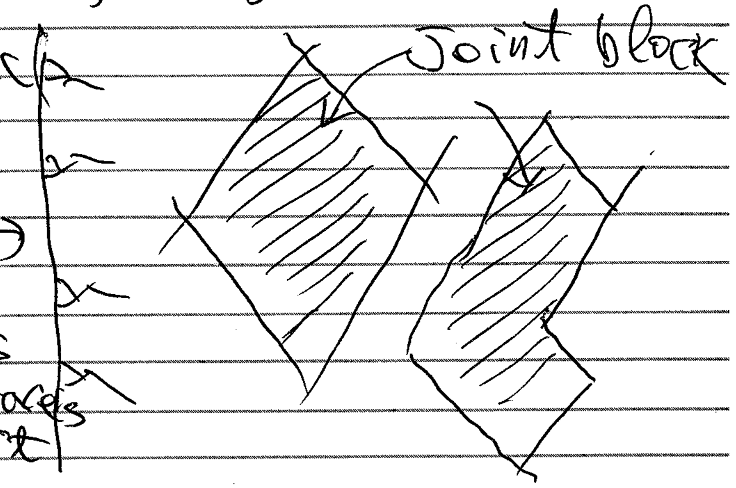
Infinite blocks are safe and can not fall.





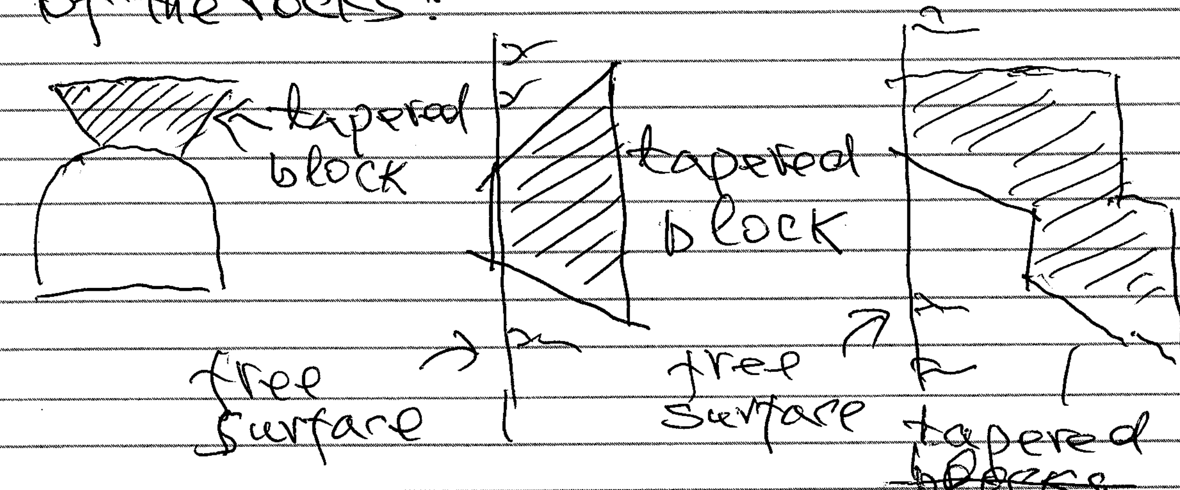
② Joint blocks, which are finite or isolated due to the joints. All of the boundary faces of the joint blocks are joints.





Since joint blocks has no free surfaces as their faces, it is impossible for joint blocks to fall

③ Tapered blocks, which are finite or isolated due to the joints and free surfaces. However tapered blocks can not fall due to the constrain of the rocks:



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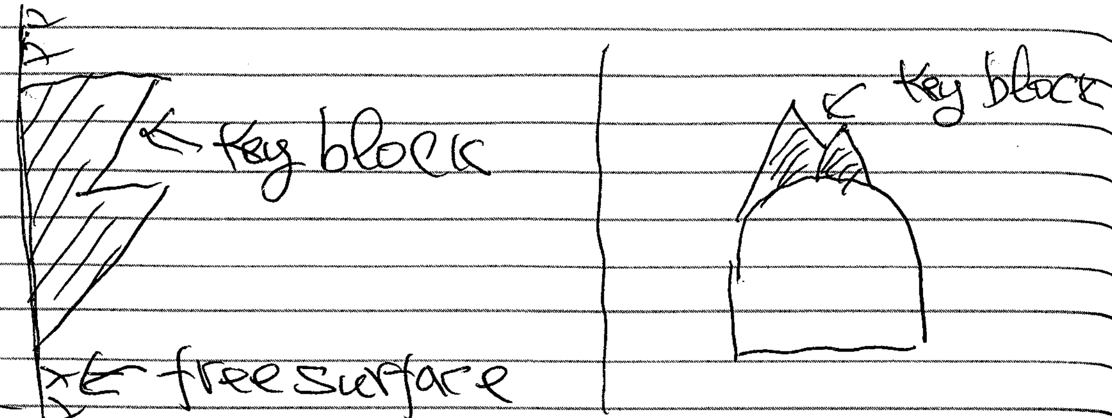
④ Key blocks are the only type of rock blocks which can fall. The Definition of key blocks are the following:



[1] Finiteness: The faces of key blocks are the existing joints. The joint polygons isolated the block from all directions.

[2] Integrity: All blocks of a united key block have the same displacement along the same straight line.

[3] Removability: The united key block can do parallel translation toward the free space without invade into the rocks outside of the united key block.

Based on the joint sets, there are several types of key blocks called JP (joint pyramid). Key blocks of the same JP are in the same side of joints of each joint set. All key blocks of a JP can form a maximum key block.

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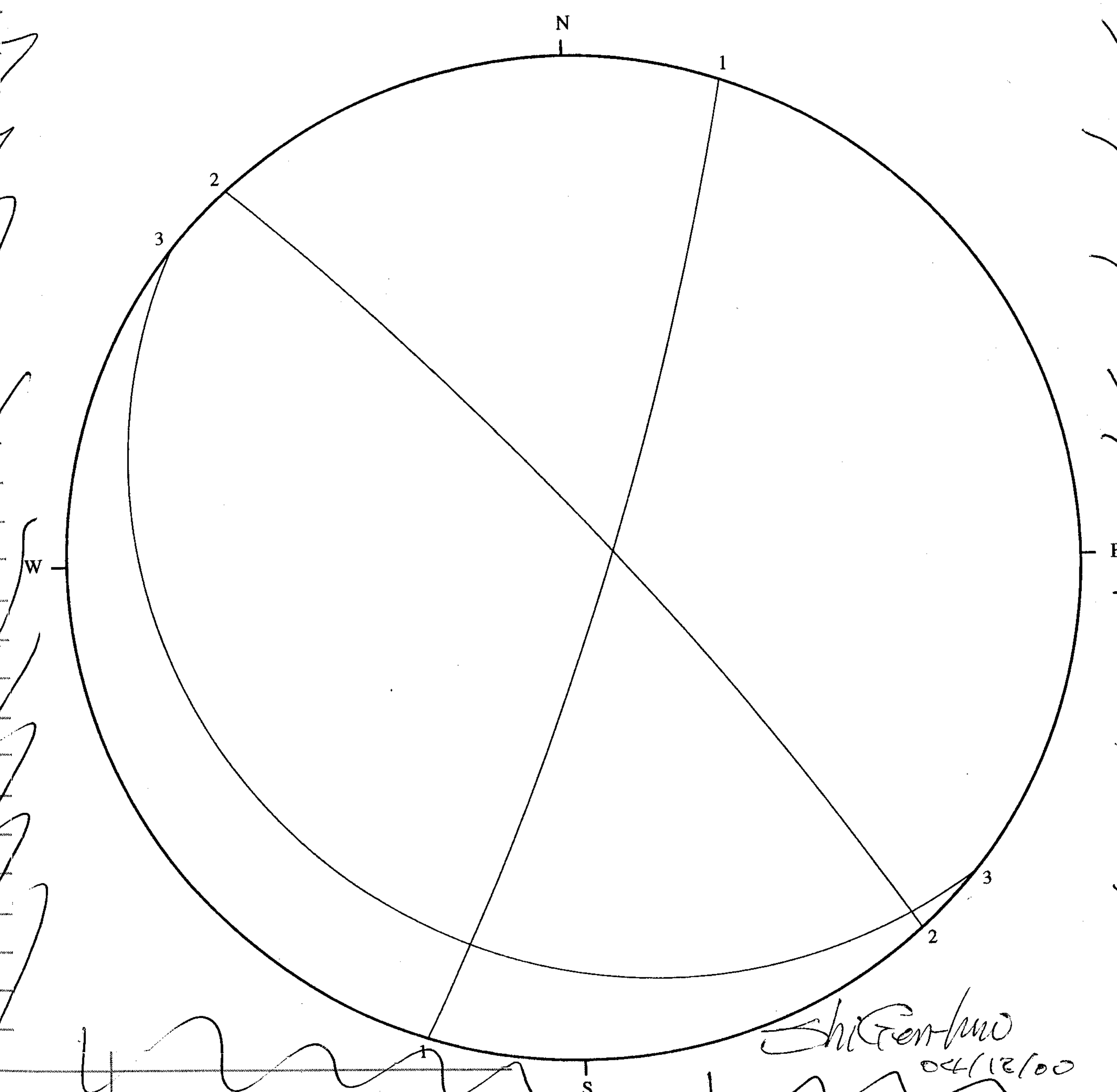
There are many finite joint blocks around the tunnel. The key blocks are the first to fall. Other blocks can fall only after the falling of key blocks which create more moving space. Therefore, if the all maximum key blocks are supported, all other blocks can not fall.

Finding key blocks: Key blocks can contain othe key blocks. Simple key blocks can form complex key blocks. The number of key blocks can be very large. the joint behind the excavation surface can not be found. Therefore Key blocks are also indefincle.

However key blocks depend on joint

sets: the joint sets can be represented by stereographic projections:



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The stereographic projection has the

following advantages:

equal angle projection, the angle between ~~two~~ projection arcs is the true intersection angle between the two joint set planes.

this simple diagram shows all of the angular relations between joint sets.

All of the key block types can be found based uppon the joint sets.

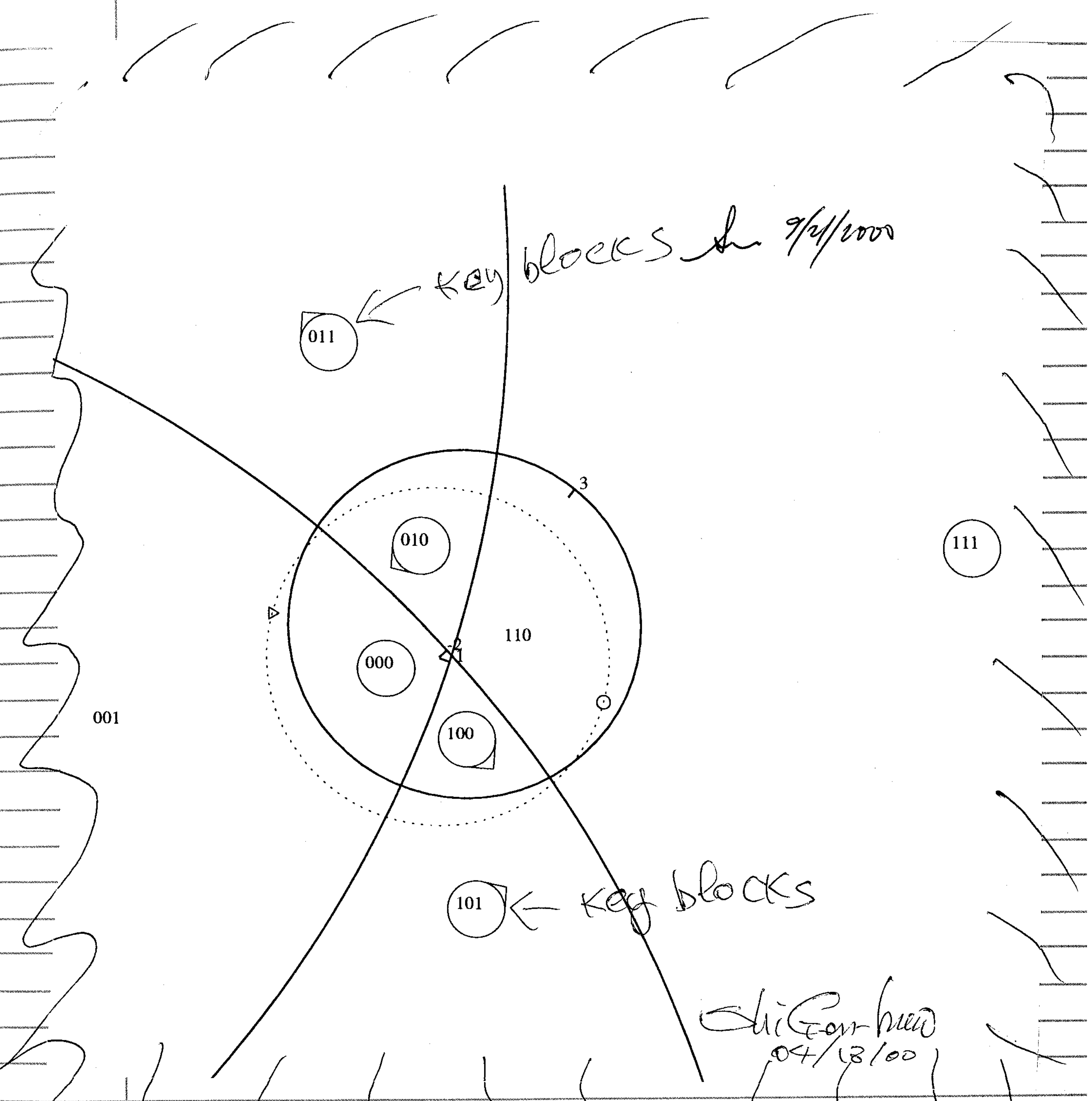
All key blocks can be diveded into several groups called "joint pyramid" (JP). For example, key blocks of JP=101 means the blocks on the lower side of joint set 1, upper side of joint set 2 and lower side of joint set 3. ("1" means lower side of a joint set; "0" means upper side of joint set.

The combinations of all key blocks of the same joint pyramid JP are still the key blocks of the same JP. therefore, there is a maximum key block in each JP.

The drawing of the opposite page is the maximum key blocks for each joint pyramid (JP). the big circles on the drawing are the stereographic projection of the three joint sets.

The numbers are the JP codes

Only JP=011, JP=101 have key blocks. JP=011 and JP=101 may have positive sliding force. Other JP can not slide



even they may be removable.

JP=010 and JP=100 have removable blocks. The sliding directions of JP=010 and JP=100 are too ~~plat~~ flat, can not slide even under very small friction angles.

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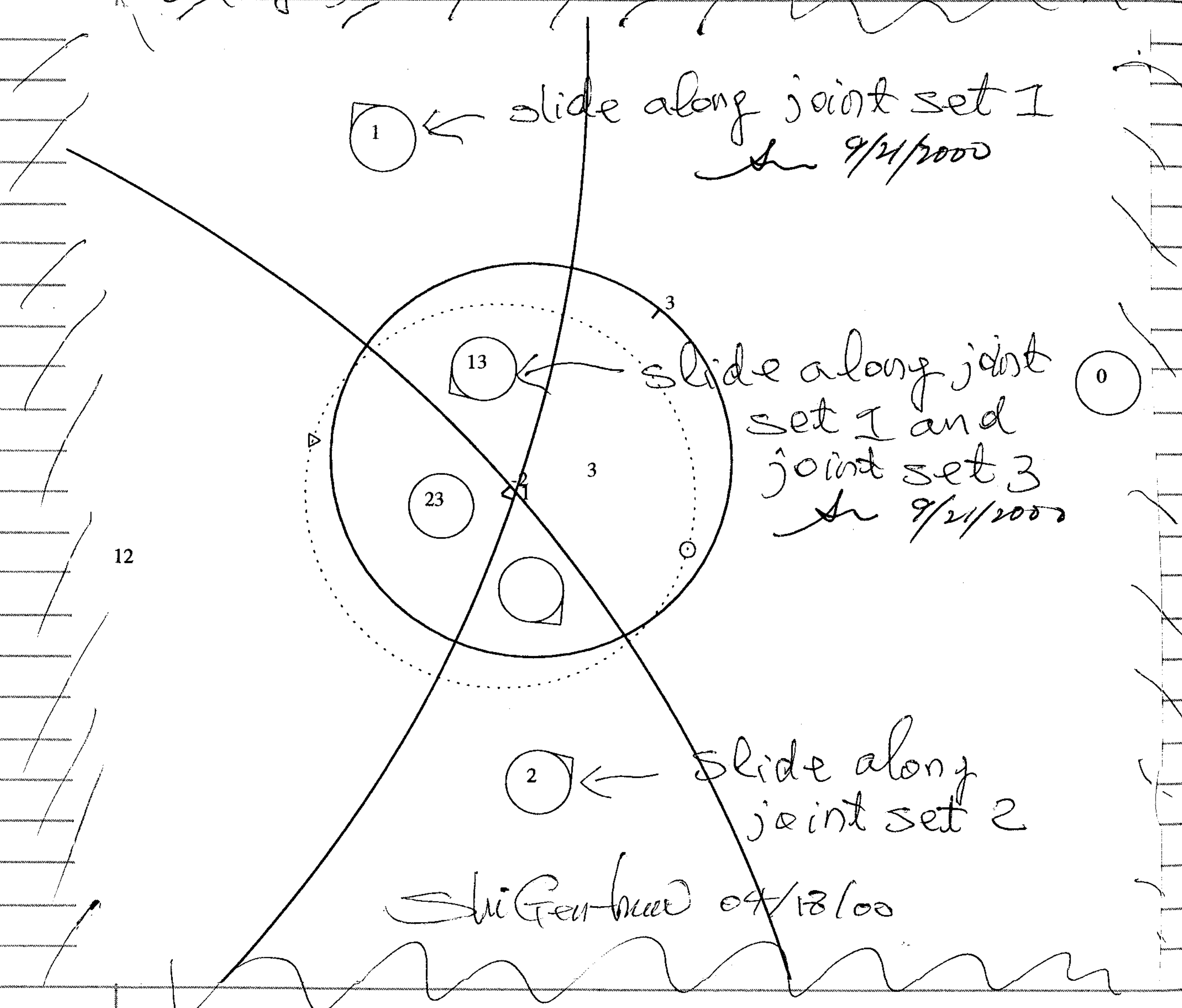
The drawing of the same stereographic projections of all three joint sets also shows the maximum key blocks of each JP.

The difference of this figure is that, the numbers are the sliding directions instead of JP codes.

number "I" means the key blocks slide along joint set "I"

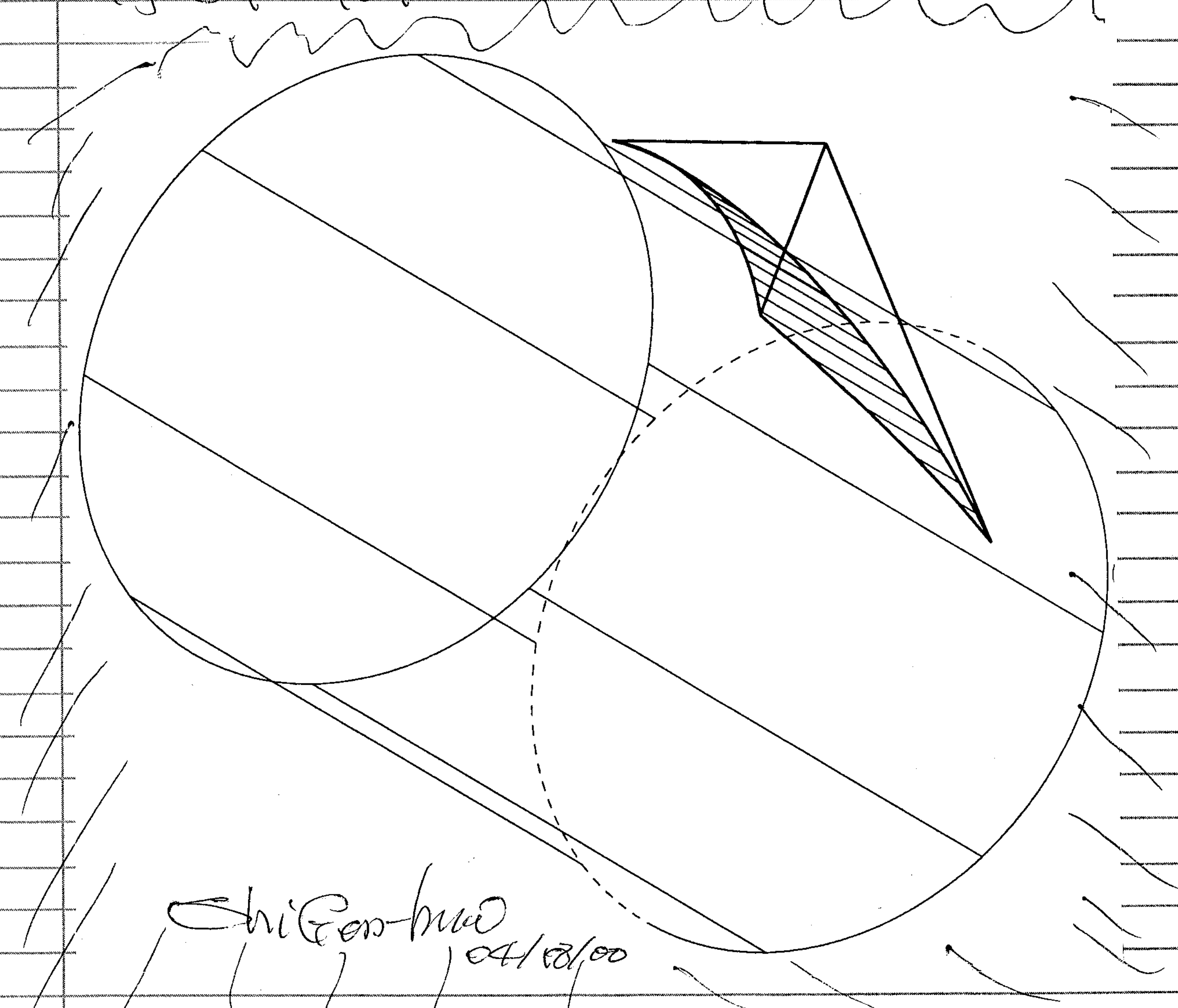


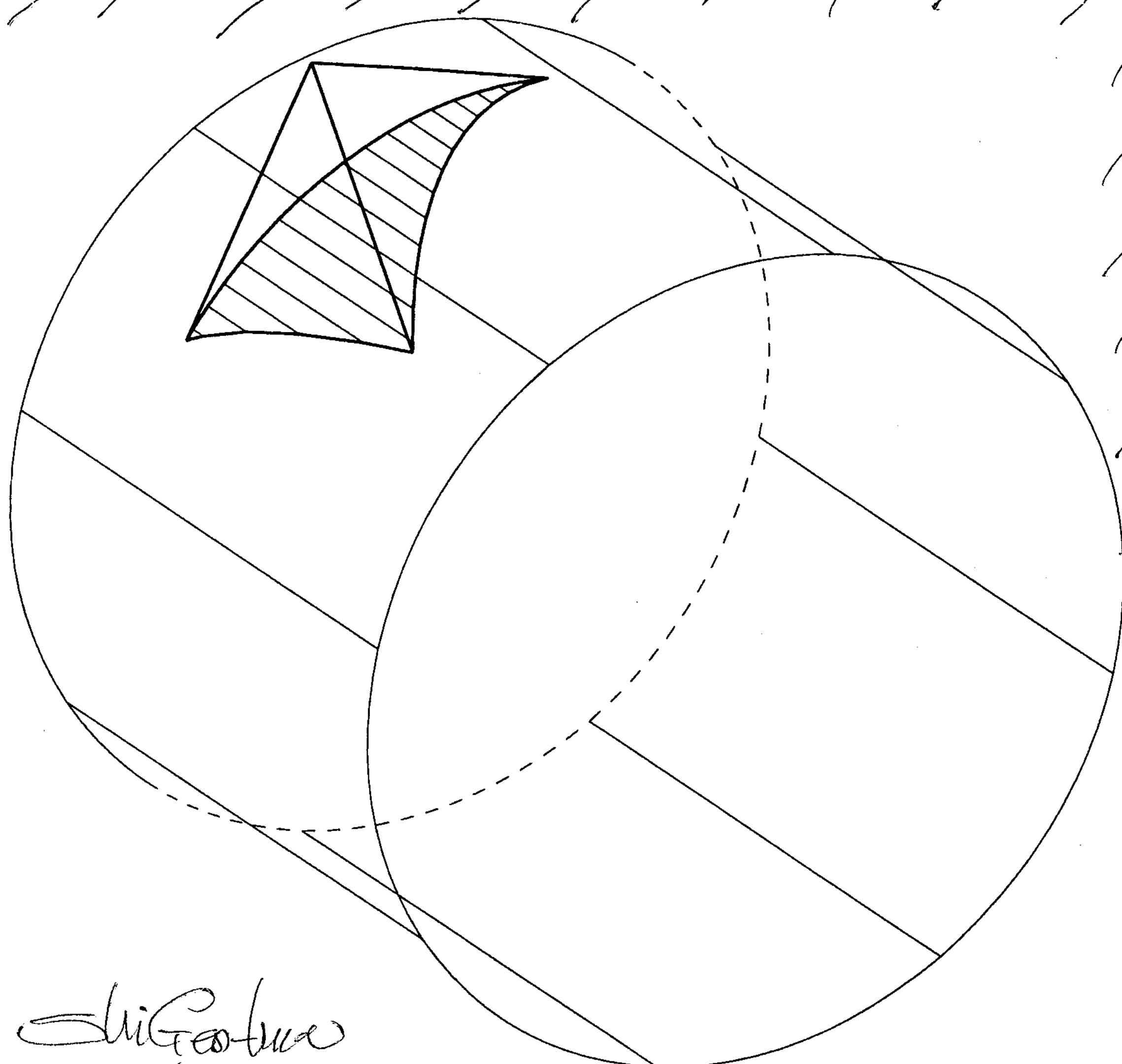
The number "13" means the key blocks slide along the intersection line of joint set I and joint set 3.

The number "0" means the corresponding JP has no sliding direction.

In the following the first drawing shows the maximum key block of JP=011.

The second drawing shows the three dimensional view of the maximum key block of JP=101.





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The volumes of the maximum key blocks are computed by "Simplex Integration". "Simplex Integration" is a accurate integration for complex shapes.

The volumes of the maximum key blocks are one cubic meter or less, even if the joint can be infinite long and infinite dense ← dense

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The assumptions are: the joint length in each joint set is sufficiently large and the joint spacing in each joint set is sufficiently small. Under these extreme assumptions, the maximum key blocks are drawn. Any actual key block can not be larger than these maximum key blocks. The actual key blocks could be much smaller due to the limited length and substantial spacing.

Table 3.1 Maximum key block JP=011

key block JP code	011
key block volume	1.06 cubic meter
area in tunnel surface	3.39 square meter
sliding direction	joint set 1

Table 3.2 Maximum key block JP=101

key block JP code	101
key block volume	0.61 cubic meter
area in tunnel surface	2.53 square meter
sliding direction	joint set 2

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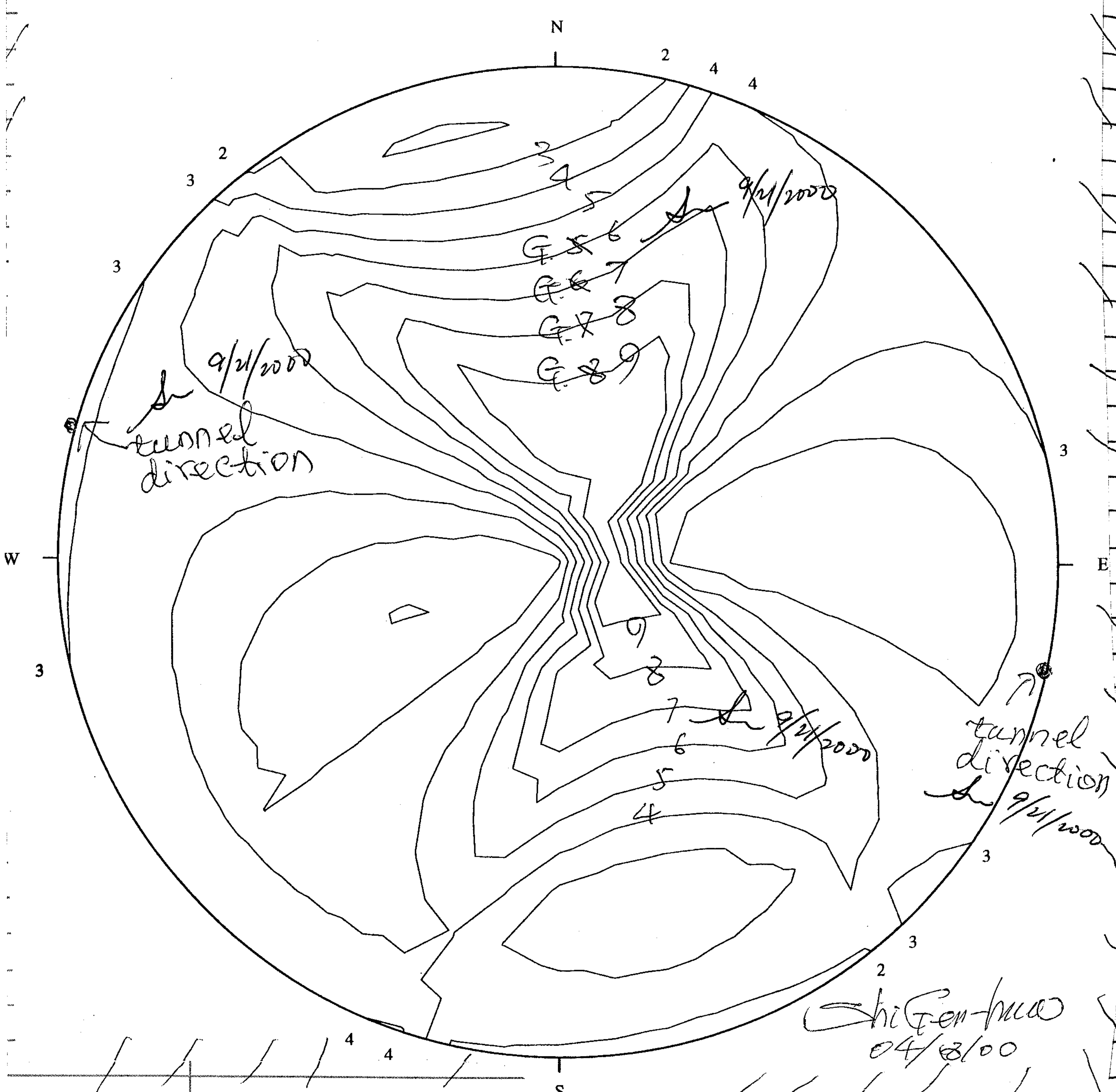
The tunnel diameter is 5.5m, the maximum key blocks are 1 m³ or less. This means the tunnel is fairly safe during the excavation.

The key blocks will fall immidiately after the excavation.

The sizes of maximum key blocks will change if the tunnel direction changes. For the same joint sets or the same rock mass, different tunnel directions can have different size of maximum key blocks.

Some times different tunnel directions can cause 30 times difference of maximum

tunnel key block volumes. The tunnel Direction is N105°E, maximum sliding force of this direction is about 3/9 of the sliding force of the worst tunnel direction.

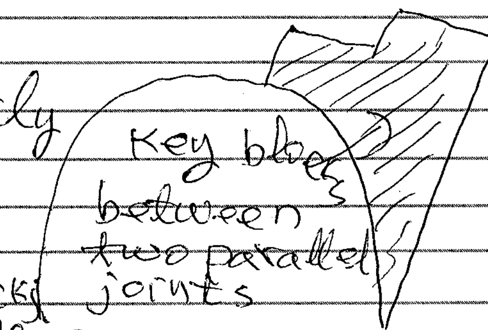


So far the key block computation is to find the maximum key block for each joint pyramid JP. The computations are under the following assumptions:

a) the joint are very long and the spacing are very small

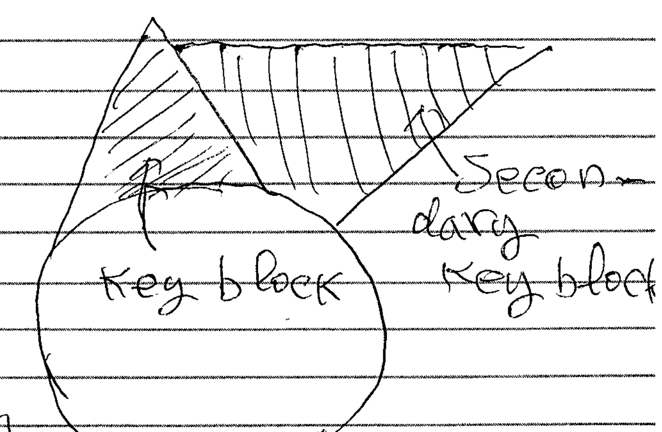
b) The joint sets are different in different locations, only one location is studied.

c) The key blocks in between two parallel joints are not considered, therefore the results only can estimate the rock falling imidietly after the tunnel excavation



d) after the key block fall, new space will be created, than the larger space will have secondary key blocks. the secondary key block are not considered in this computation.

e) Earth quake was not considered in this computation



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5. statistical key block theory

In this case, the joint length and joint spacing of each joint set are considered. Also, the joint bridge is considered.

Based on the joint length, joint spacing and joint bridge of each joint set, the joint trace map on the tunnel surface is produced by statistical method even before the tunnel excavation. The input data are the two following tables:

Joint set data:

joint set	dip angle	dip direction	friction angle
1	79°	270°	39°
2	81°	230°	89°
3	5°	45°	39°

Statistical joint set data

joint set	spacing: m	length: m	bridge: m
1	0.30m	1.8m	0.1m
2	0.30m	2.4m	0.1m
3	0.50m	1.8m	0.1m

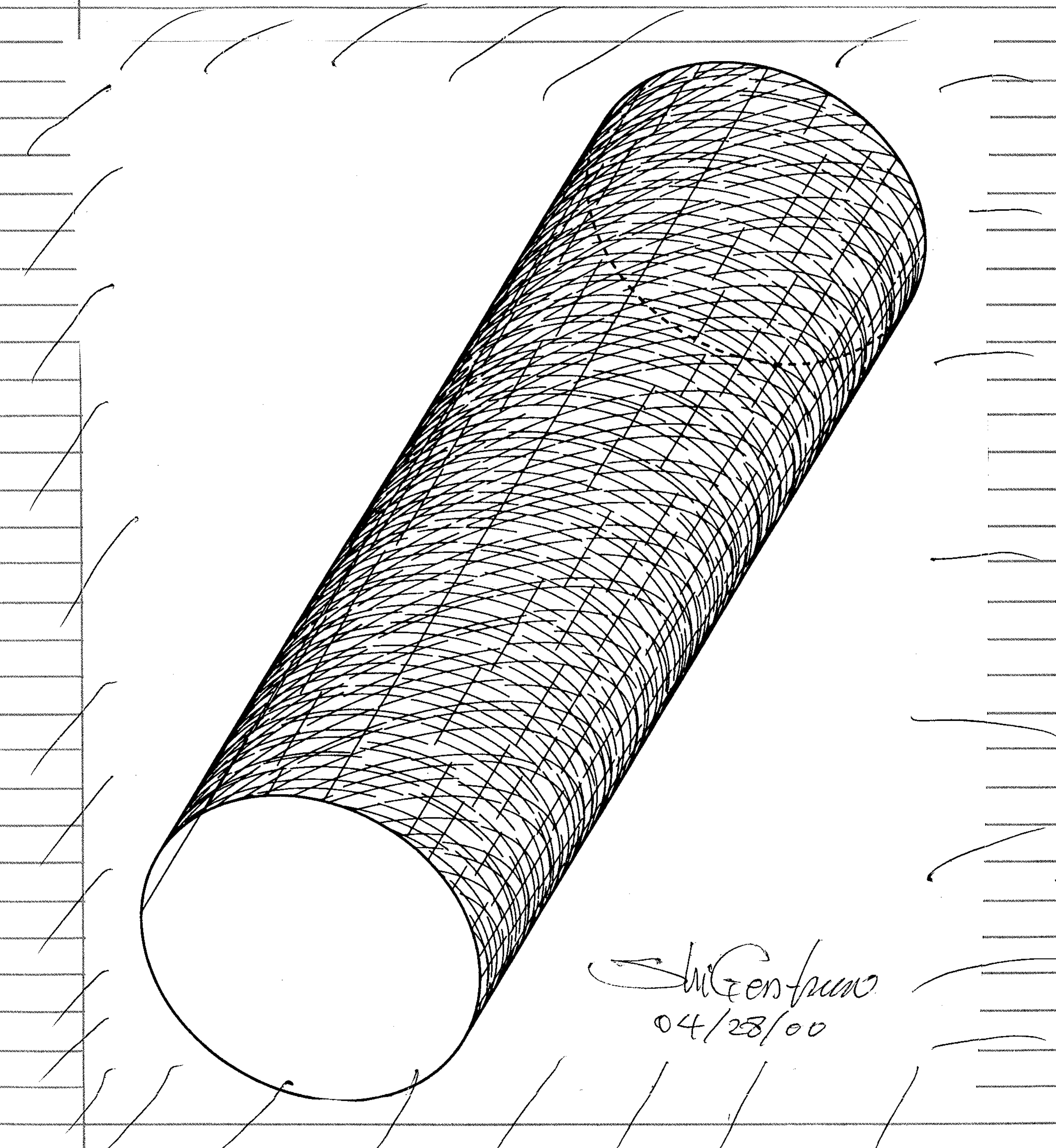
The tunnel information is the following:

Tunnel data:

bearing angle of tunnel axis	N 105°E
rise angle of tunnel axis	0°
tunnel diameter	5.5 meter
tunnel shape	circular

The advantage of this computation is that, the joint trace map of the tunnel wall can be made befor the excavation.

After the excavation, this joint map can be corrected. The following drawing is the 3-dimensional view of the produced joint trace map on the tunnel walls.



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On the joint trace map on the tunnel surface, the key block areas of each joint pyramid can be delinited. There are ~~otG.~~ only two joint pyramids which have key blocks: JP=011, JP=101. The results are in the following tables:

Table 5.1 Tptpll key block zones JP=011

key block JP code	011
key block area in tunnel surface	from 1.37% to 2.23%
sliding direction	joint set 1
Program UJT0 file	UJTS1

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Table 5.2 Tptpll key block zones JP=101

key block JP code	101
key block area in tunnel surface	from 1.57% to 1.64%
sliding direction	joint set 2
Program UJT0 file	UJTS2

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Table 6.1 Tptpul key block zones JP=011

key block JP code	011
key block area in tunnel surface	from 2.25% to 2.41%
sliding direction	joint set 1
Program UJT0 file	UJTS3

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Table 6.2 Tptpul key block zones JP=101

key block JP code	101
key block area in tunnel surface	from 1.75% to 2.04%
sliding direction	joint set 2
Program UJT0 file	UJTS4

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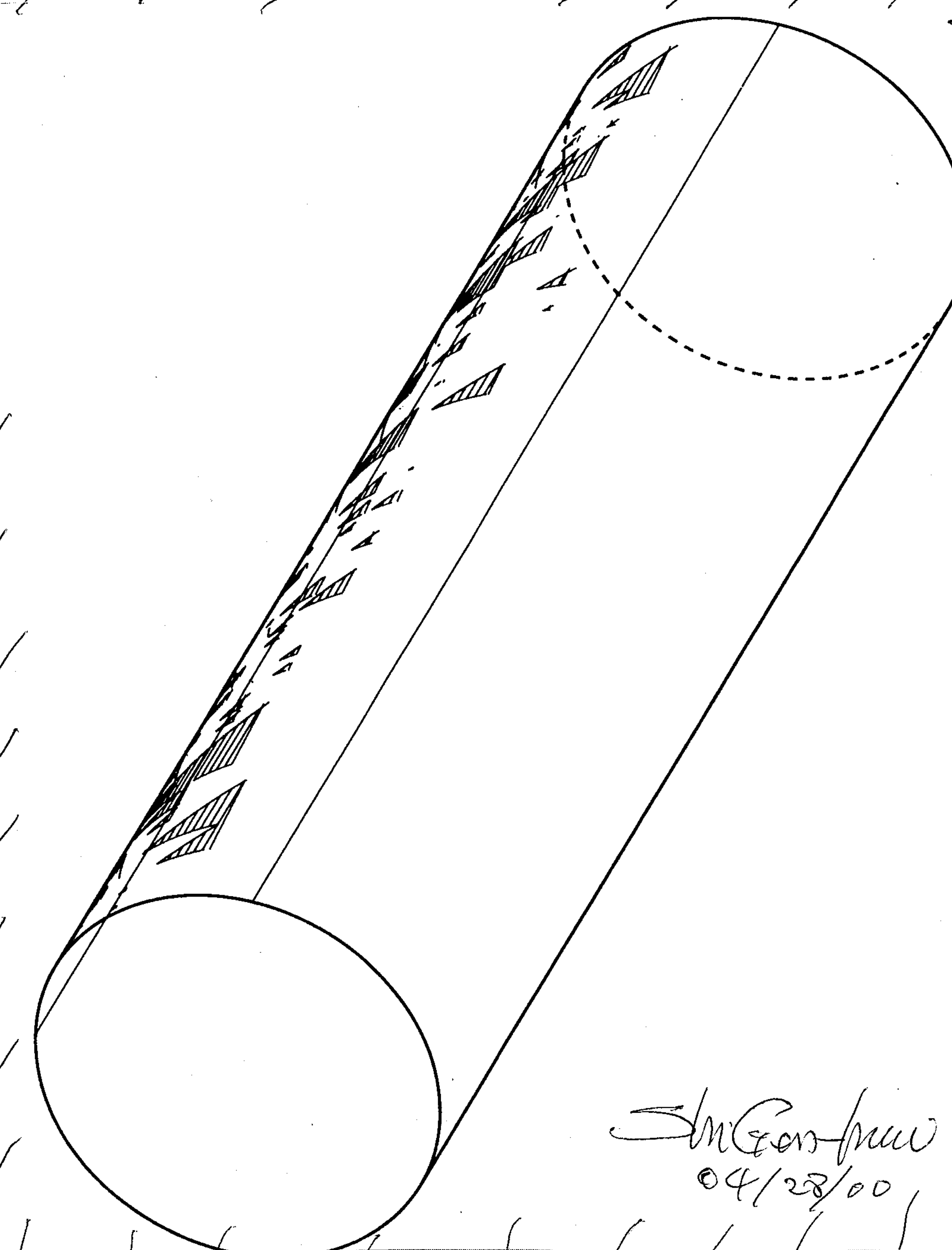
The key block area on the tunnel walls are form 2.94% to 4.45% of the whole tunnel surface. These key blocks can fall shortly after the tunnel excavation.

The following drawing is the key block areas of JP=011. The assumption is the joints behind the tunnel walls are long enough to form the key blocks. The real key block areas are smaller.



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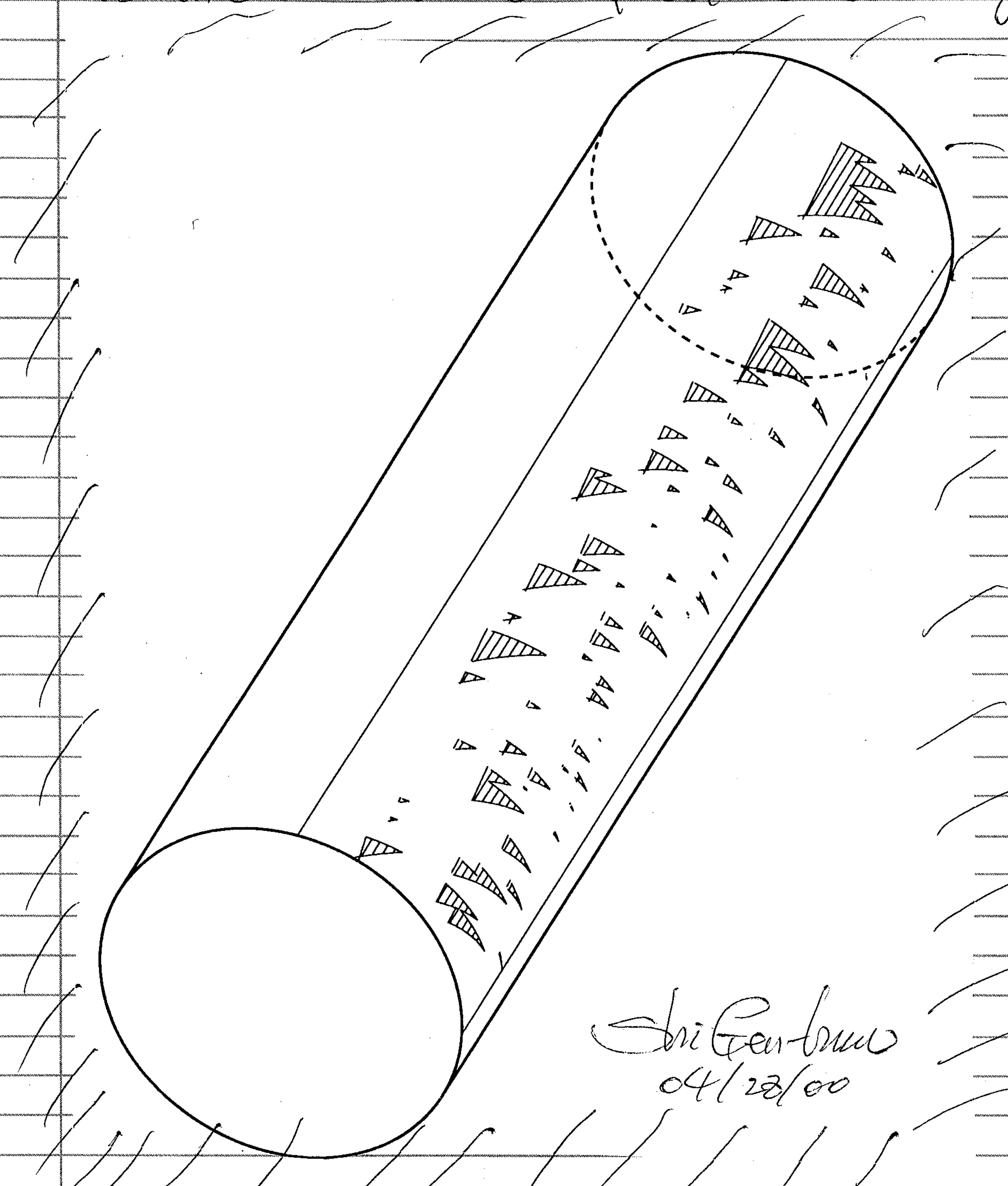
The following drawing is the key block areas of JP=101. The projection direction is the same as two previous drawing.



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6. Preliminary Rock Fall Assessing under Seismic Load using DDA Analysis.

The differences of DDA and Key Block are the following

a) Key block is 3-dimensional, DDA is 2-d
b) DDA can directly input earth quake data.
c) DDA can consider the falling of key blocks in between two parallel joints
d) DDA can compute the secondary key blocks. After the movements of the key blocks, more space are created. Then, the secondary key blocks can move toward the space of the key blocks
e) DDA considers rotation and deformation.

The working schedules are:

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Item	Description	Work	Date
1	checking and improving tunnel key block program	4 Hrs.	April 27
1	checking and improving tunnel key block program	4 Hrs.	April 28
2	analizing tunnel key block size on joint trace map	8 Hrs.	May 1
2	analizing tunnel key block size on joint trace map	8 Hrs.	May 2
3	review block size distribution by Georock	8 Hrs.	May 4
3	review block analysis ANL-EBS-MD-000027 REV 00	8 Hrs.	May 5
4	prepare joint lenth and bridge data for case 4	8 Hrs.	May 8
5	rock falling computation under seismic load, case 4	8 Hrs.	May 30
5	rock falling computation under seismic load, case 4	8 Hrs.	May 31
6	block size distribution computation	8 Hrs.	June 1

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Discontinuous deformation analysis (DDA) also has the advantages:

a) equilibrium between blocks
b) equilibrium between forces and stresses for each individual block.
c) large step-by-step displacements and deformations
d) complete block system ~~kinematics~~ kinematics
e) friction law is satisfied
f) no damping is used, accurate dynamics.

DDA Dynamic Computation for Long Term Earth Quake Stability

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From mathematics, DDA is block system version of FEM. The DDA uses time steps. At the end of each time step, the equilibrium is reached by minimizing the total potential energy.

Based on natural contact phenomena, an "entrance theory" was developed. The "open-close" iterations ensure that no tension and no penetration occur at all entrance positions and all time steps. There are three entrance modes: open, sliding and locking. Coloumb's Law is also fulfilled at all entrance modes, all entrance positions and all time steps.

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DDA computation offers the movements, stresses and strains of each block. The computed block displacements are often large enough to be visible, the modes of failure and the final damage can be seen directly.

On the other side, the DDA codes can perform traditional limit equilibrium analysis for whole block systems. The discontinuous deformation analysis (DDA) has to fulfill physical laws of both inside a block or between blocks.

For long term analysis, massive rock collapsing often are block system movements: all blocks move simultaneously, different blocks have different sliding directions. The multi-block rotation such as toppling or buckling can be computed by DDA method.

The input data of DDA computations include the time depending earth quake accelerations, block geometry and mechanical parameters.

DDA code include:

a) DL0: produce the joint lines by statistics. the inpute data are same as key block theory:

dip and dip direction angle of each joint set; and

sh 9/21/2000 spacing ~~Spacing~~, Length ~~and~~ bridge of each joint set sh 9/21/2000

b) DC0: produce blocks from joint and boundary lines.
c) DF0: Mechanical computation. The material parameters of blocks are required. The mechanical parameters are same as FEM method
d) DG0: graphic post-processor, whic produce PostScript graphic files for print the graphic results.

The following are the input data of DF0

unit weight	2.27 tons/m ^{3}
E of rock mass	3000000 tons/m ^{3}
ν of rock mass	0.21
number of time steps	20000
time step	0.0020 seconds
Program DL0 file	DLS1: producing joints
Program DC0 file	DCS1: producing blocks
Program DF0 file	DFS1: mechanical computations
Earth quake file	QKS1: 20 seconds earth quake

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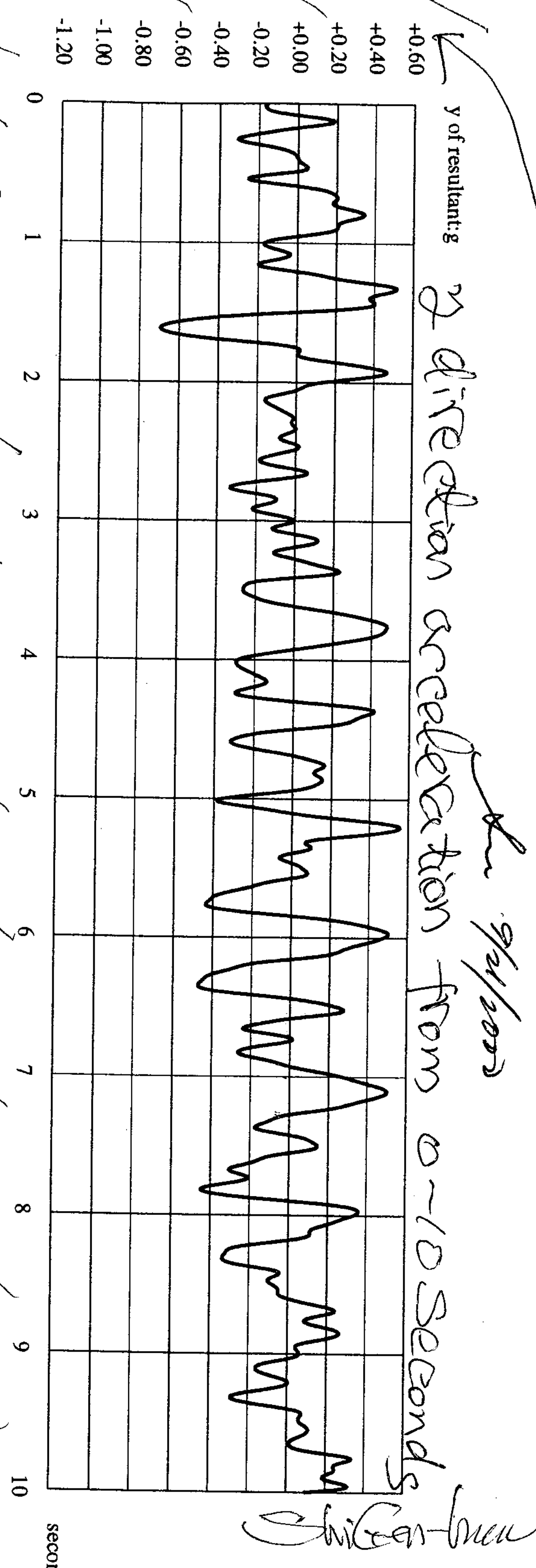
For this computation, the earth quake data of Yerba Buena Island Tunnel between San Francisco and Oakland are considered. The acceleration data are from California Department of Transportation. The ariginal data are 50 seconds, our computation only use from 10 second to 30 second. However the 20 second data are the main part of the strong earth quake.


y of resultant:g
second
y direction acceleration from 0~10 seconds
unit: g
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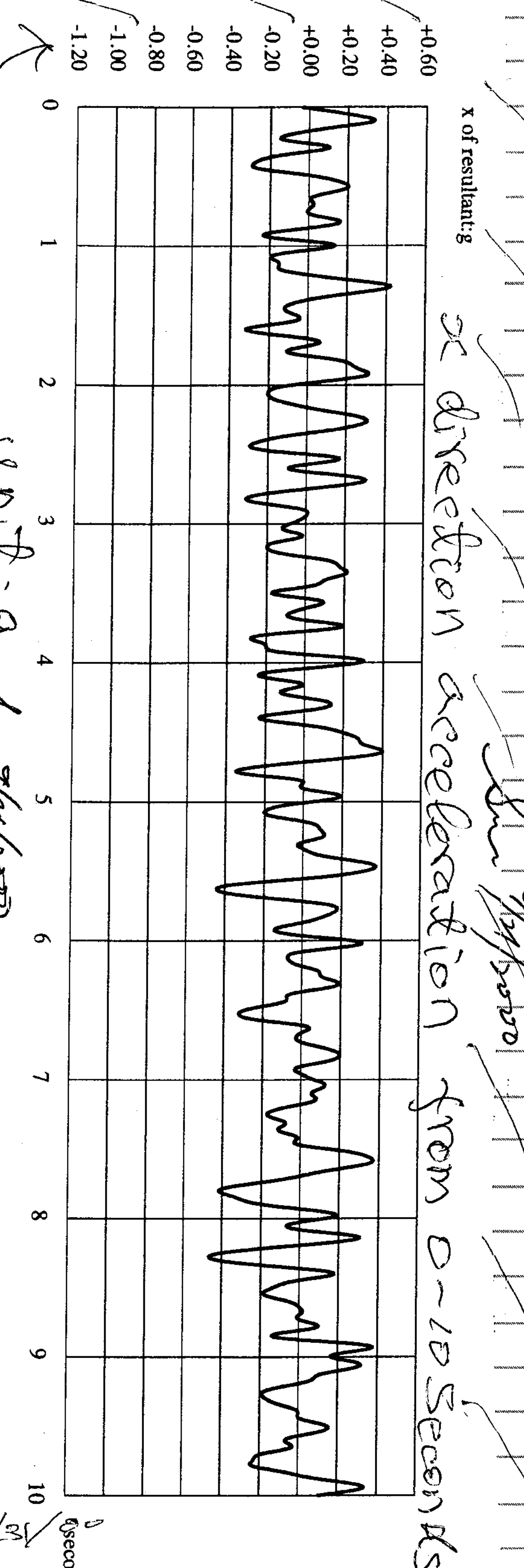
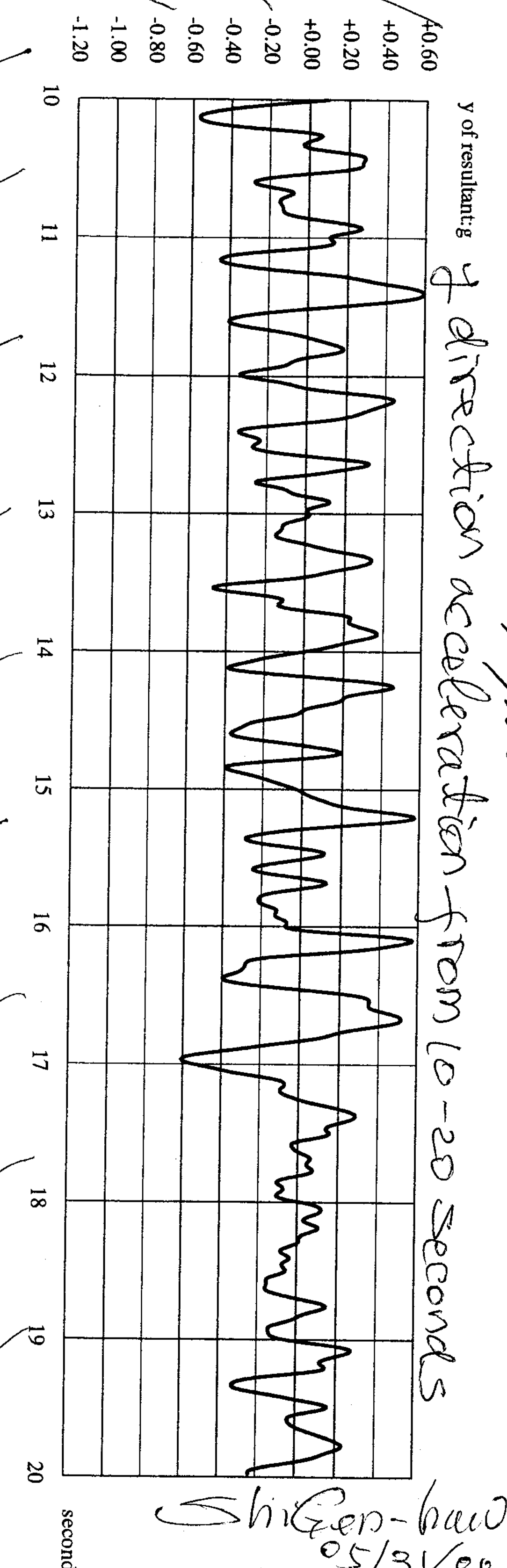

x of resultant:g
second
x direction acceleration from 0~10 seconds


y of resultant:g
second
y direction acceleration from 10-20 seconds
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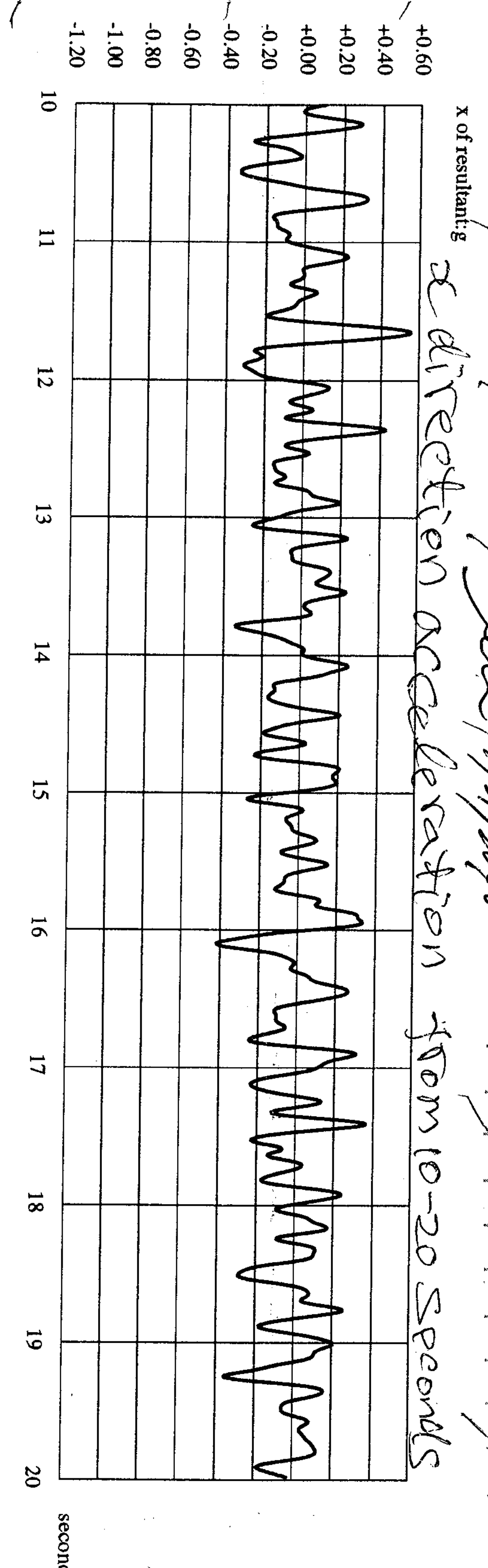
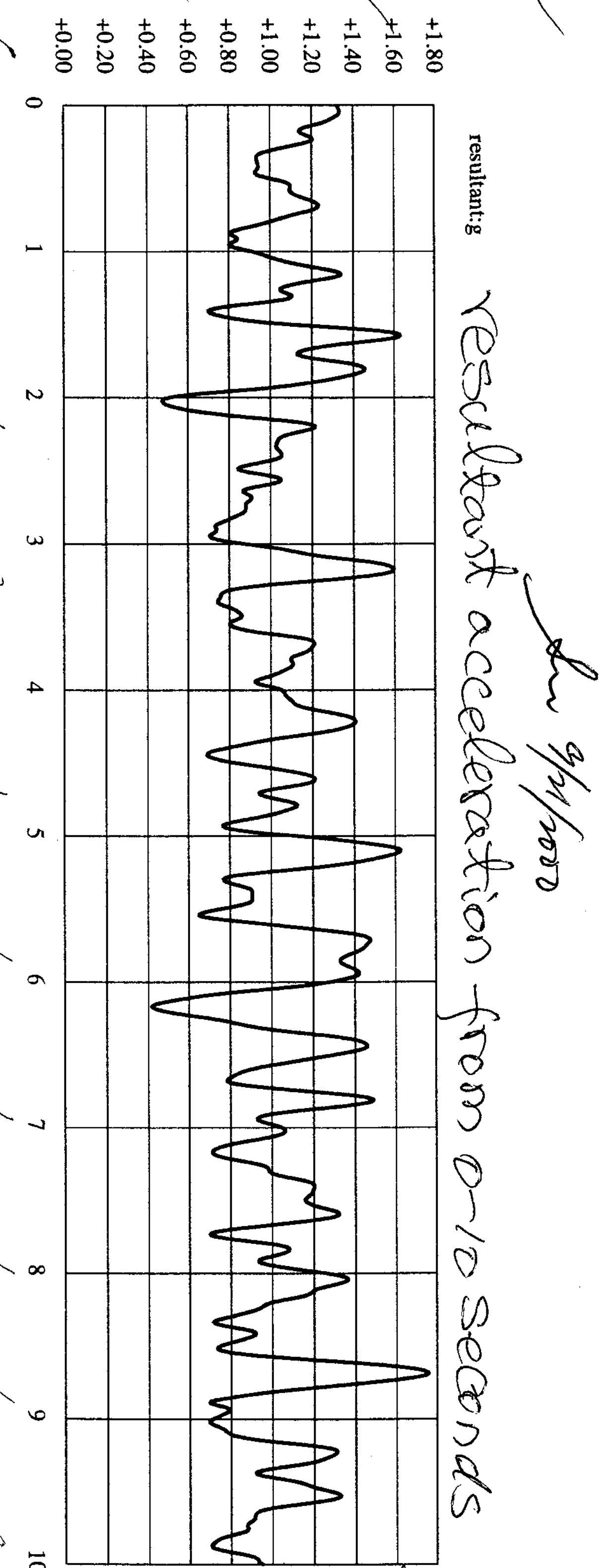
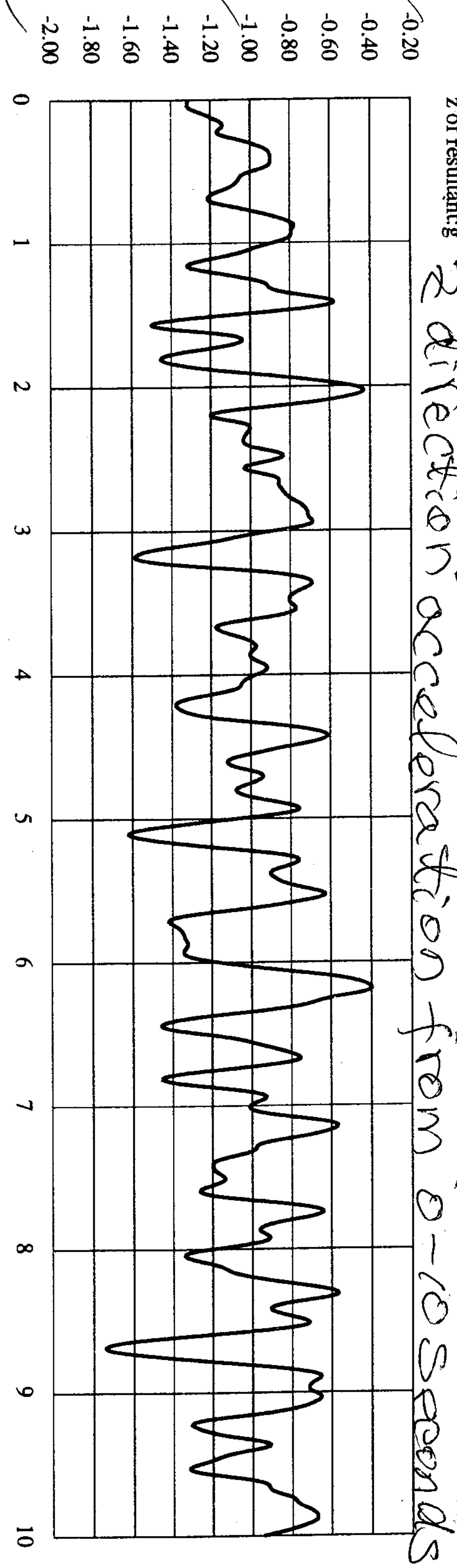
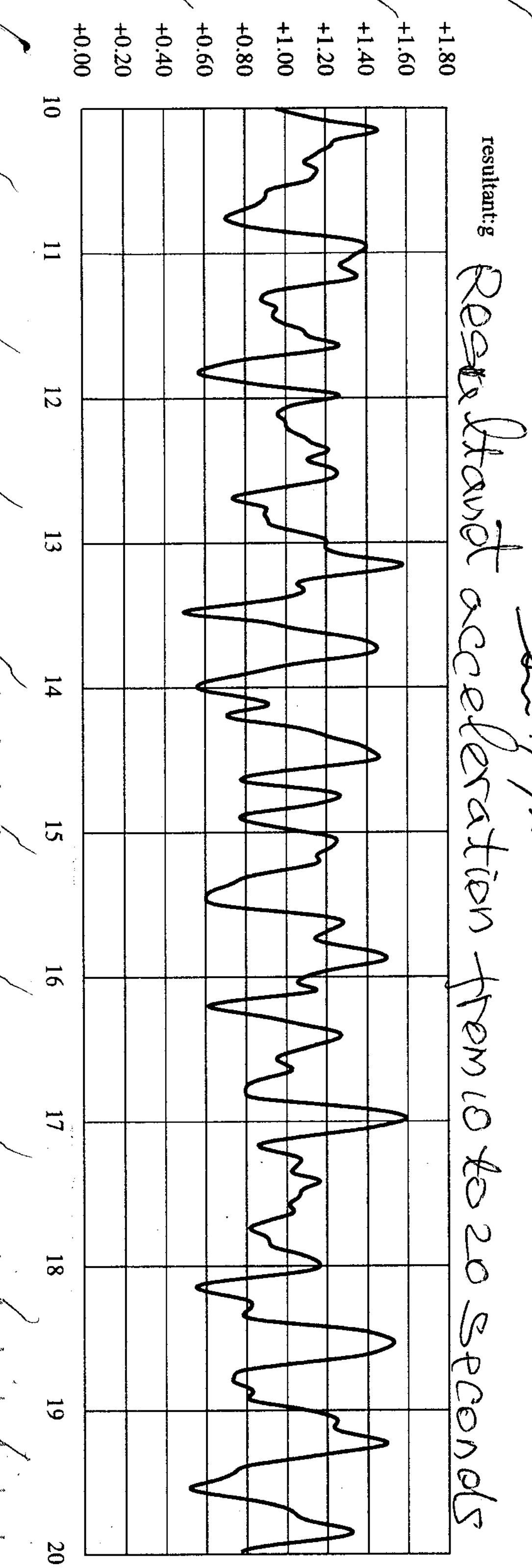
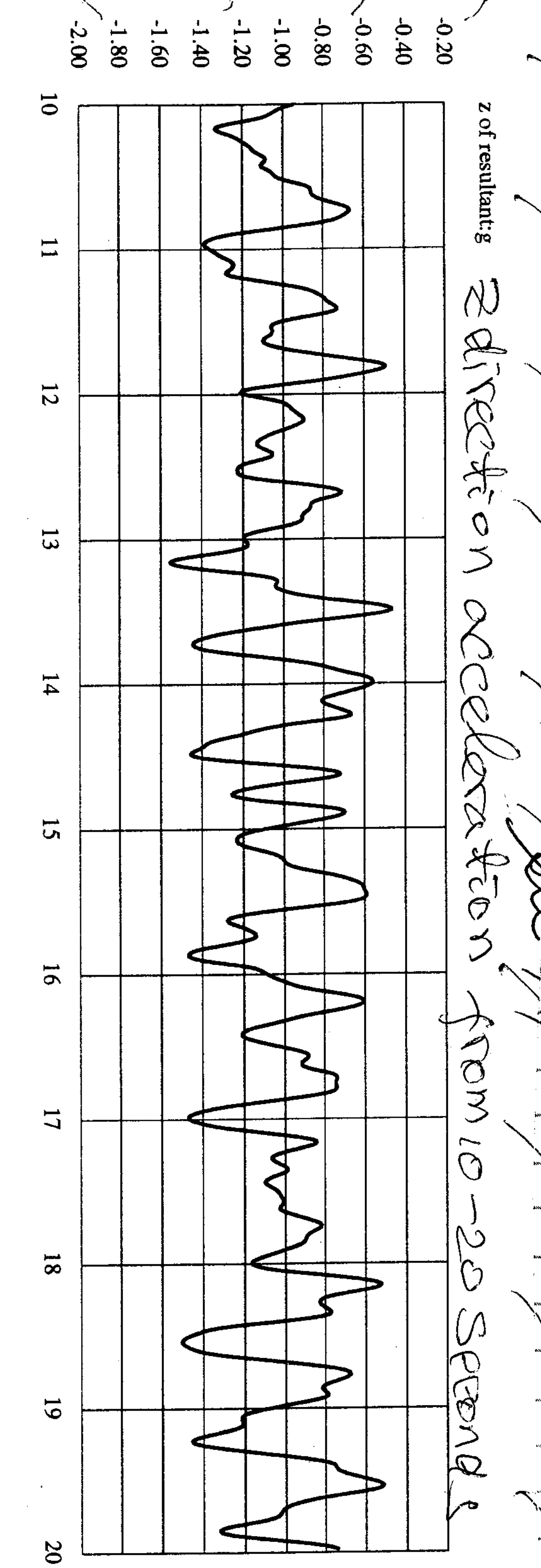

x of resultant:g
second
x direction acceleration from 10-20 seconds





Shi'Cen-huu 05/31/00





Shi'Cen-huu 05/31/00

The code DLO produces the joint mesh, which is the drawing of the opposite page.

The joint set data are the same as key block computations accept the bridge is 0.3m instead of 0.1m. the reason is this is two dimesional computation. The joint mesh is only two dimensional section of the three dimensional joint polygons.

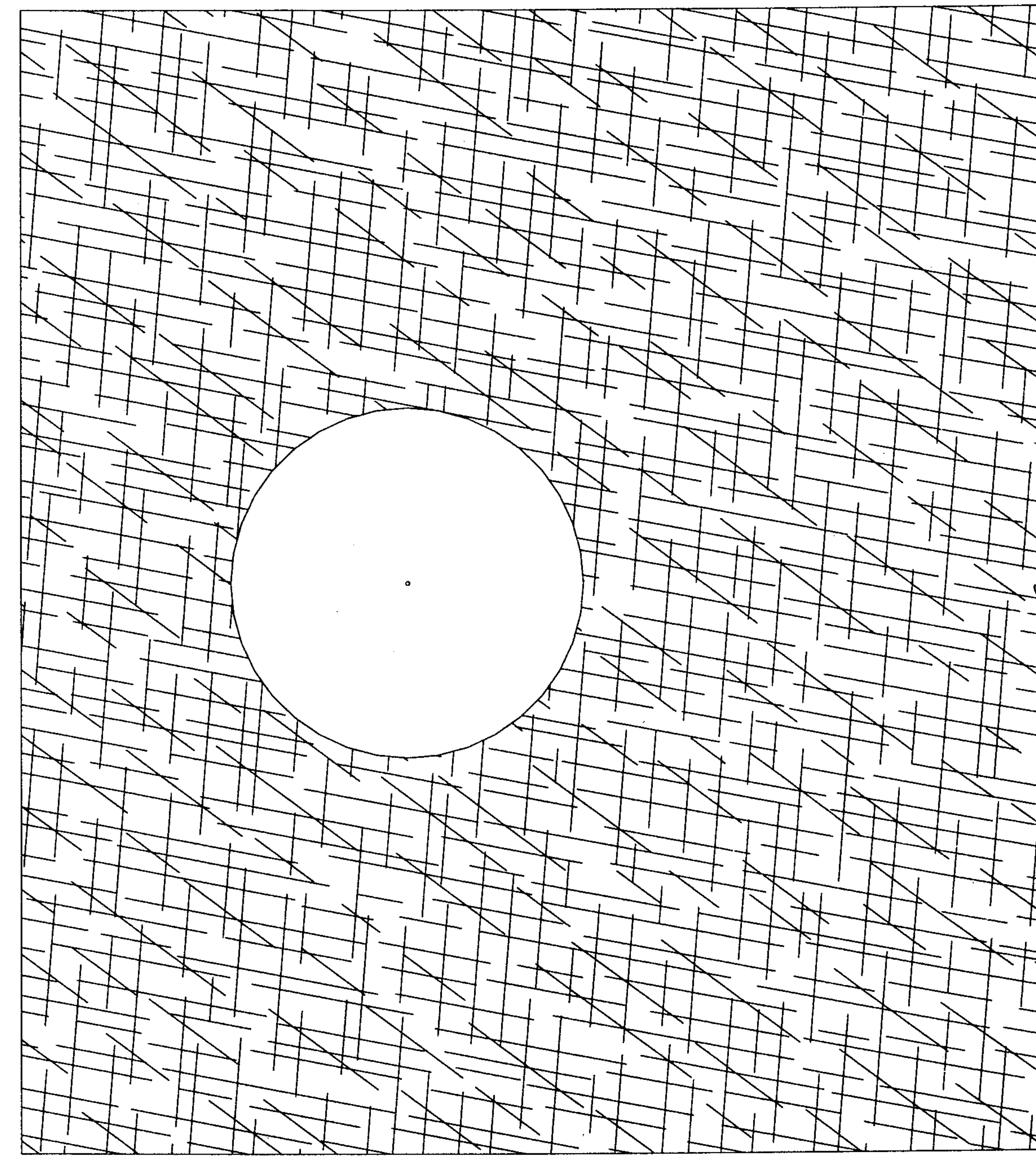
This computation assumes non connection on the direction of third dimension. therefore the bridges are increased as joint spacing.

joint set	dip angle	dip direction	friction
1	79°	270°	39°
2	81°	230°	39°
3	5°	45°	39°

joint set	spacing: m	length: m	bridge: m
1	0.3m	1.8m	0.3m
2	0.3m	2.4m	0.3m
3	0.5m	1.8m	0.5m

tunnel direction: N105°E
cohesions of all joint sets are 0. If real cohesions are input, the volume of rock falling can be reduced in a great deal.

In the computation no damping is used so the earth quake damage is not under estimated.



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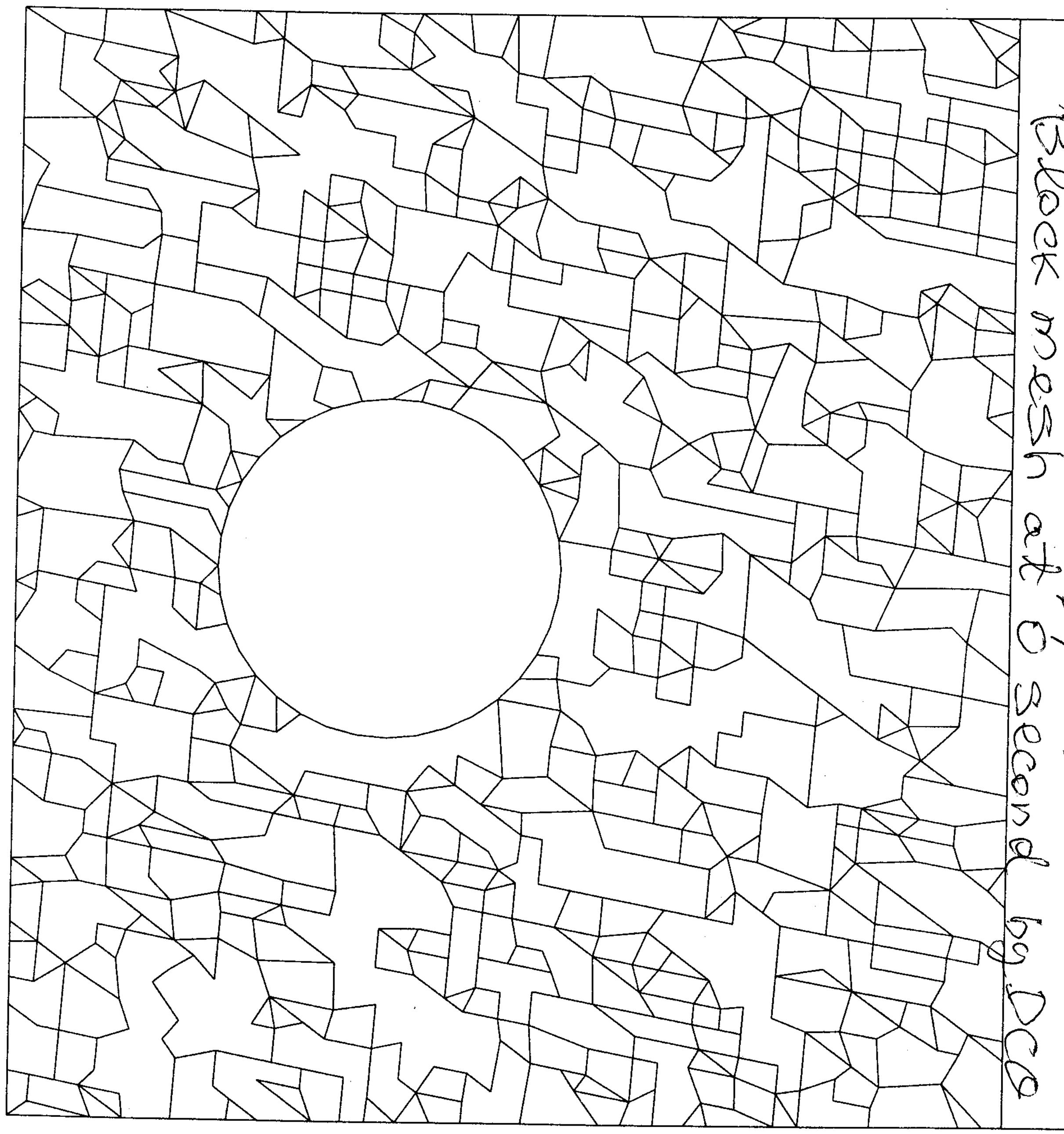
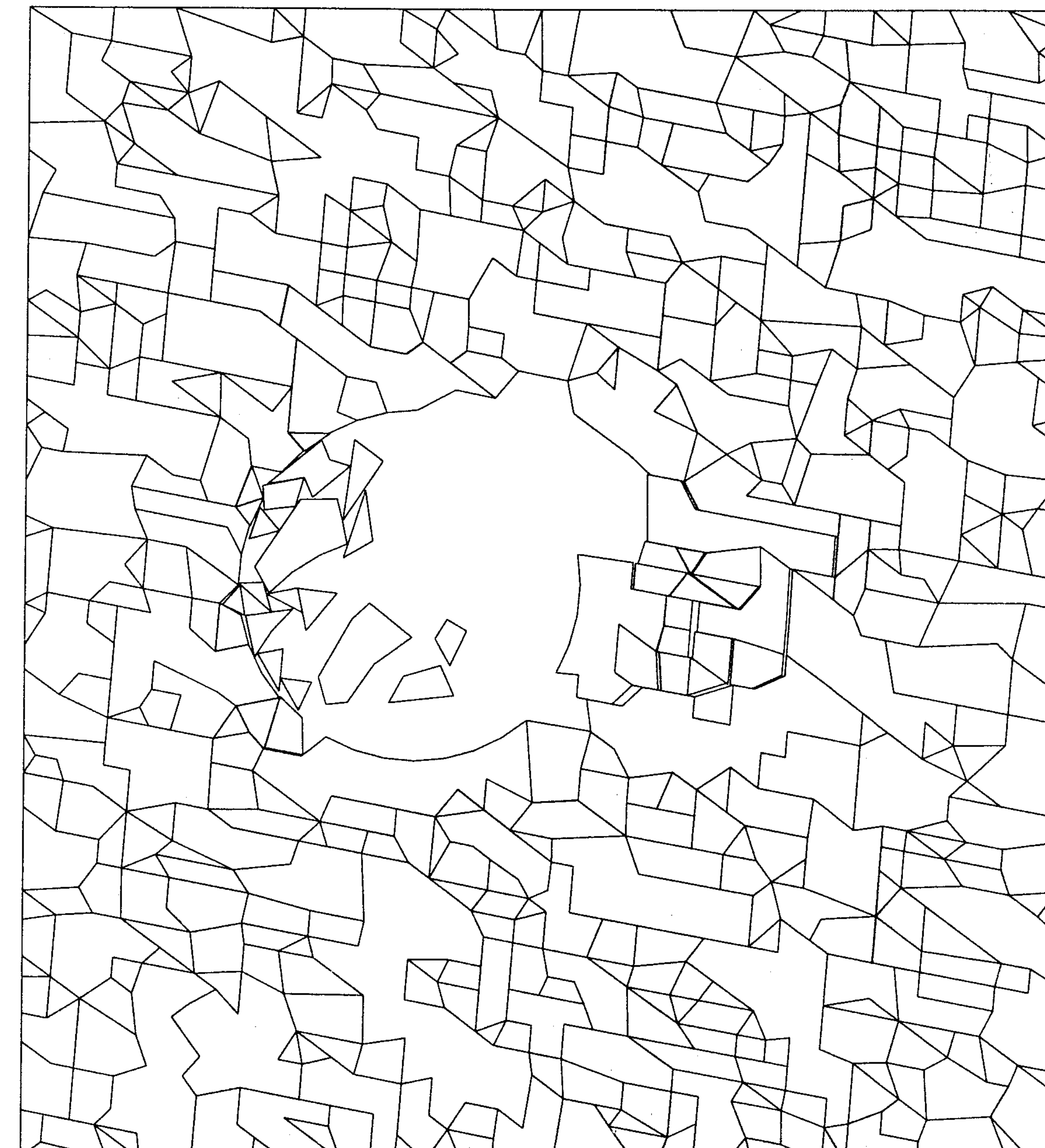


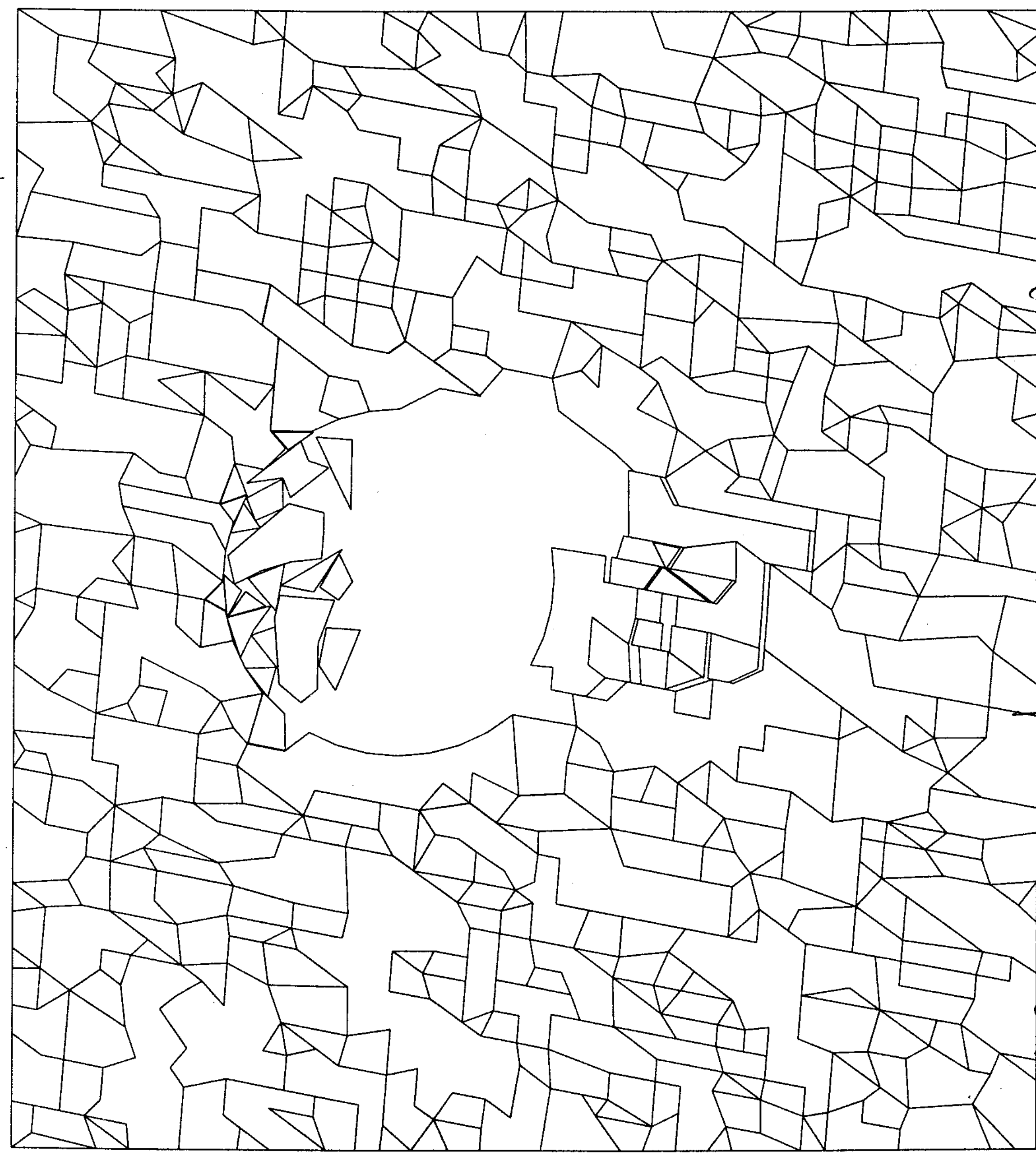
Block mesh at 0 second by DDA 9/11/2000

Shi Gen-hua 05/31/00



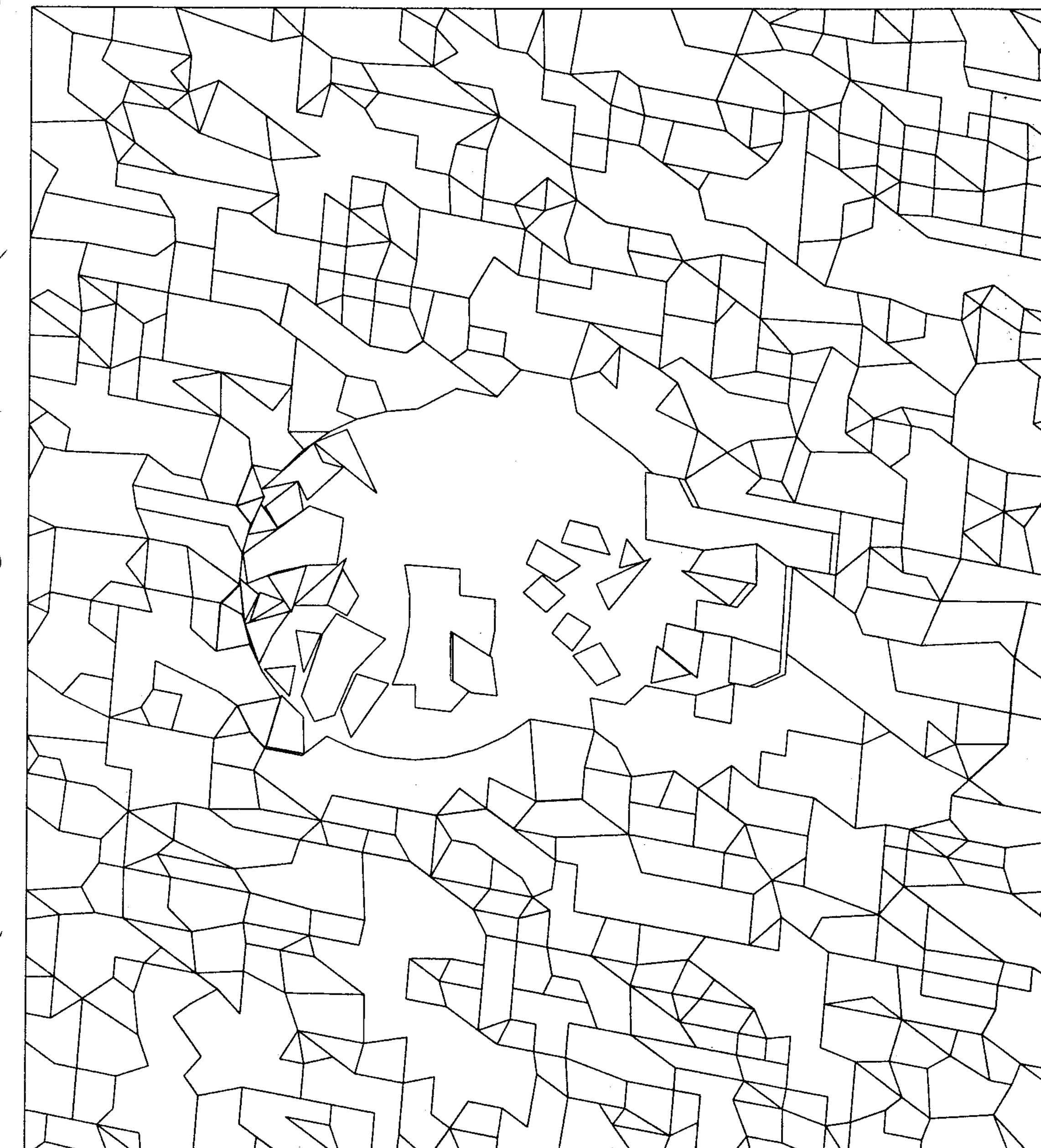
Block displacement and deformation at 2 seconds by DDA 9/11/2000

Shi Gen-hua 05/31/00



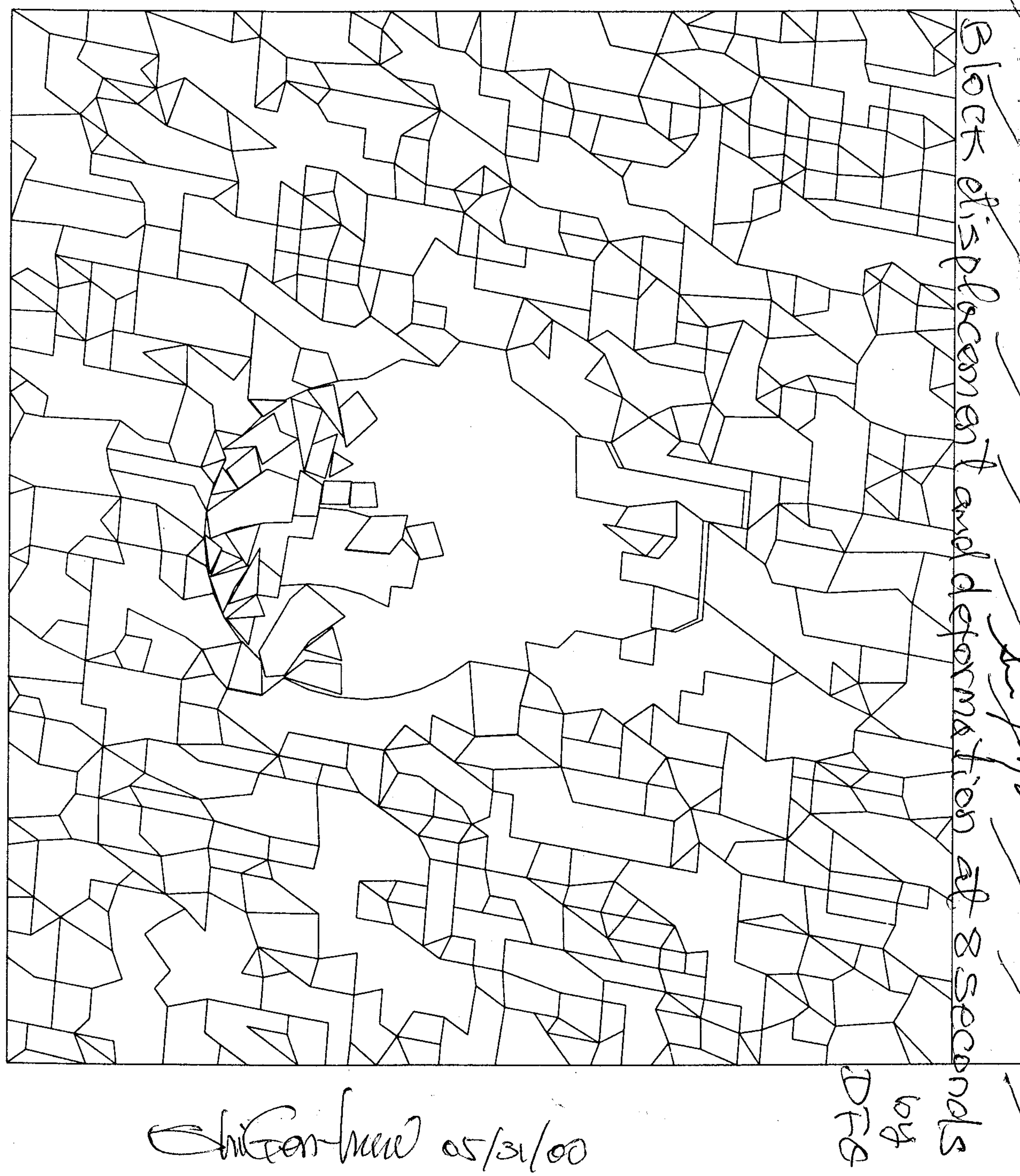
Block displacement and deformation at 4 seconds

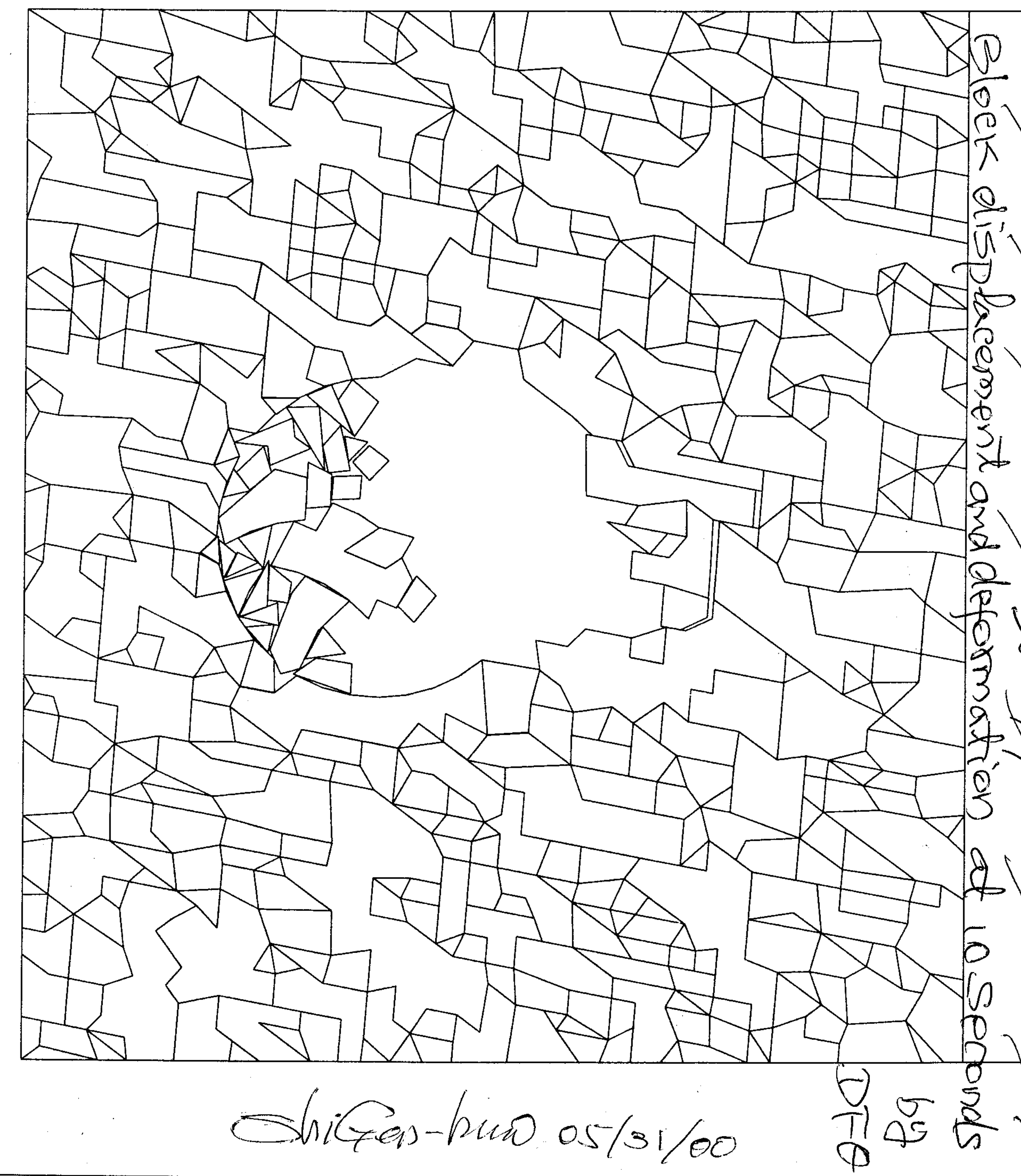
05/31/00



Block displacement and deformation at 6 seconds

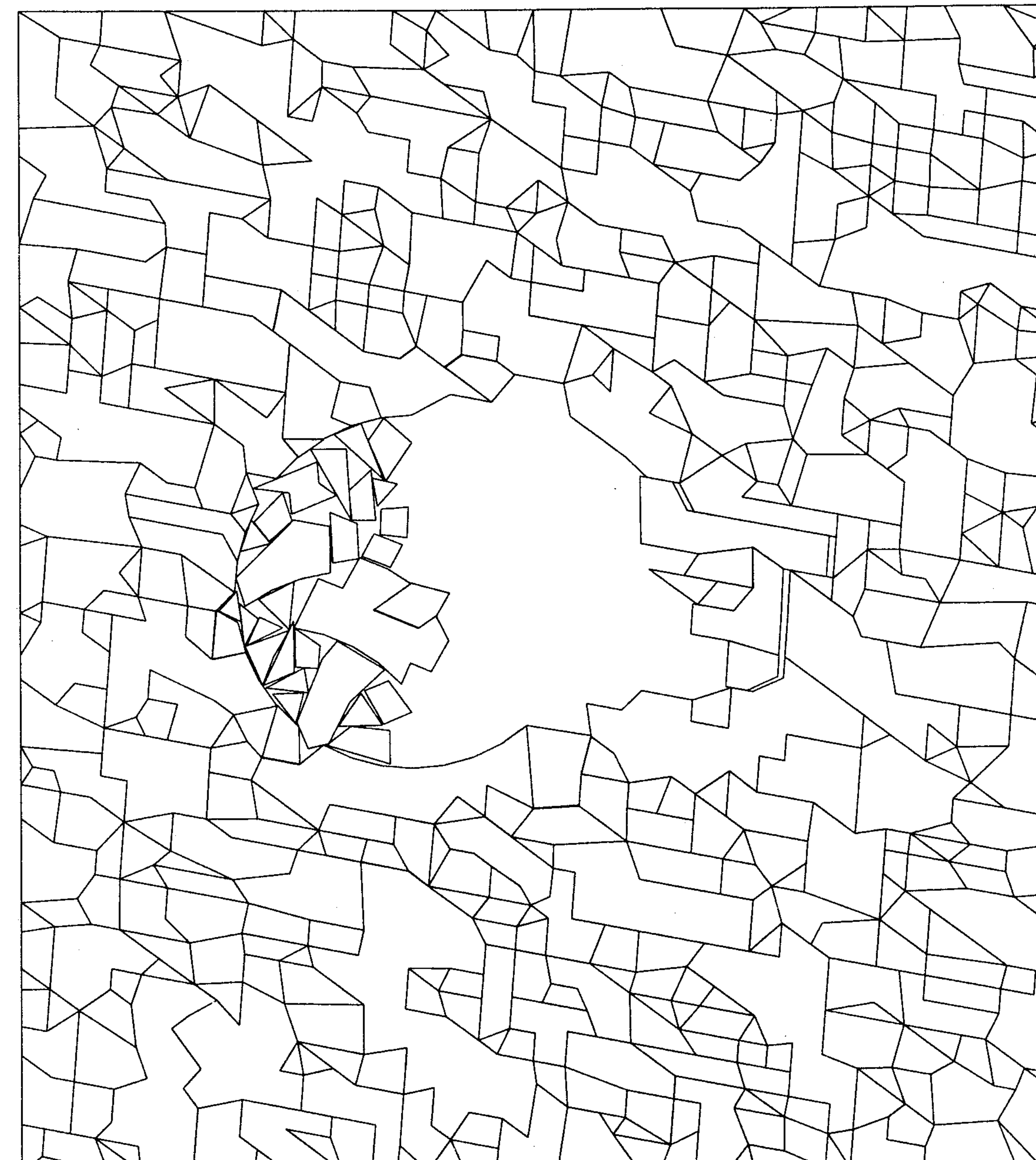
05/31/00


Block displacement and deformation at 8 seconds
ShiGen-huo 05/31/00


Block displacement and deformation at 10 seconds
ShiGen-huo 05/31/00

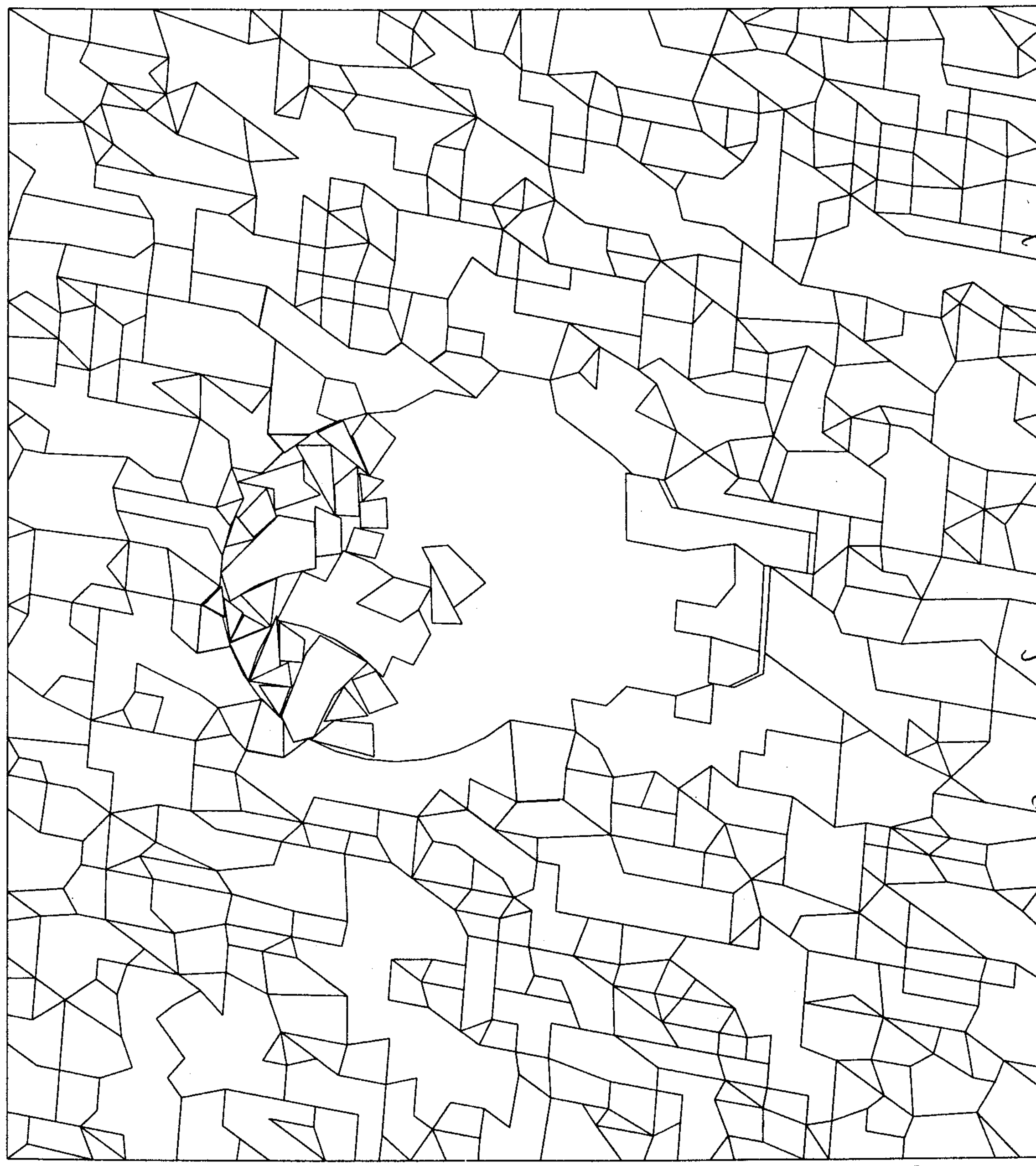
Block displacement and deformation at 12 seconds

Shi Gen-hua 05/31/00



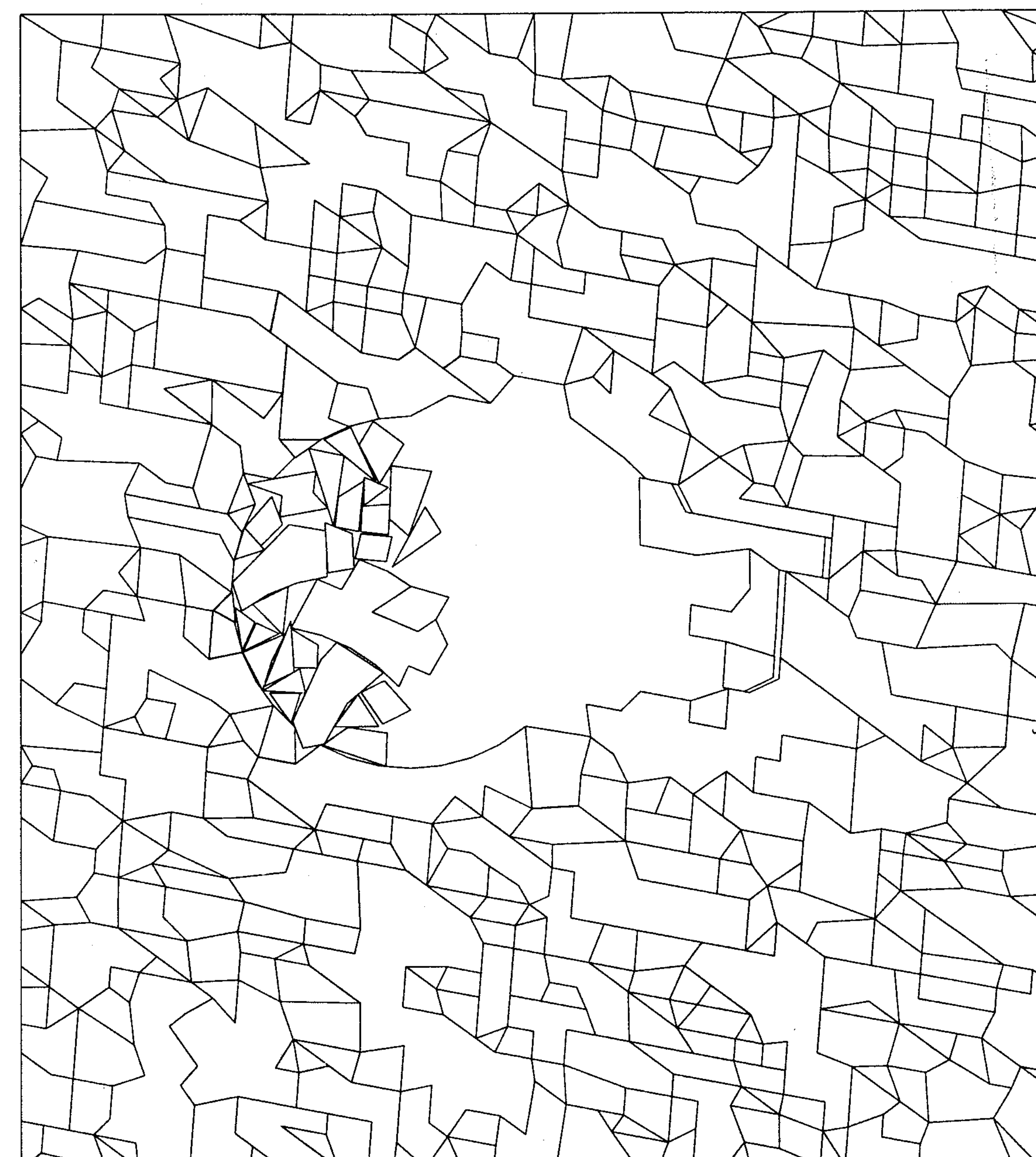
Block displacement and deformation at 14 seconds

Shi Gen-hua 05/31/00



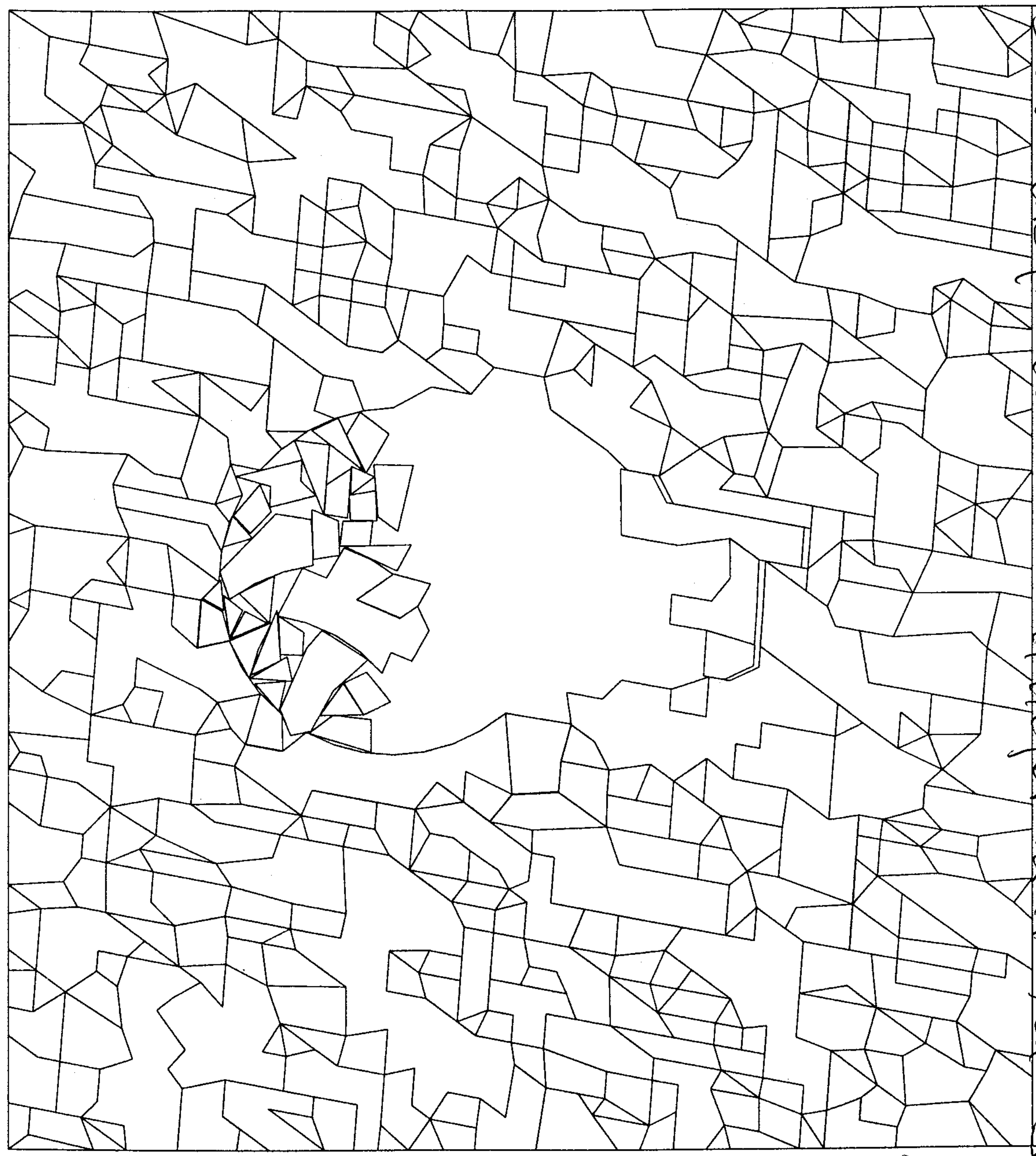
Block displacement and deformation at 16 seconds

Shi Genhua 05/31/00 by DDA



Block displacement and deformation at 13 seconds

Shi Genhua 05/31/00 by DDA



Block displacement and deformation at 20 seconds

DFO 5

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The previous 10 drawings are the DFO code results. The computation is

for 20 seconds. Both gravity and initial stress are considered. The loading of the earth quake accelerations is time depending volume force.

The earth quake computation results shows the strong influence of the earth quake ~~loading~~: strong G. ... 9/21/2000

a) the mesh is the state of 0 second.

b) the drawing of 2 second shows many blocks fall to the bottom. Since the tunnel diameter is 5.5m, 2 seconds are enough time for block to fall to the bottom

$$S = \frac{1}{2} g t^2$$

$g = 9.8\,m/s^2$, $t = 1$ second, $S = 4.9\,m$

c) At the fourth second, there are blocks which move down-ward but not fall yet. These movements are obviously due to the earth quake load.

d) At sixth second, large ment of blocks fall down-ward. Those blocks are the blocks which move downward at the end of fourth second but have not separated from the main rock mass.

e) from 8 seconds to 20 seconds, no blocks fall even the earth quake was very strong. The remaining blocks are inter-locked kinematically.

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7. Block Size Distribution under Different ~~Joint~~ Length
joint [initials] 9/1/2000

Different joint length can produce different block sizes. Under different joint length, the block mesh can be very different, the rock falling can be different.

The following works are the results of the block size distributions under different joint length.

If the joint lengths are 2~4 times of the original and the bridge ≈ 0, will the tunnel be "OK" under strong earth quake?
The following is work list

Item	Description	Work	Date
1	to prepare advanced tunnel key block computation	8 Hrs.	June 28
1	to prepare advanced tunnel key block computation	8 Hrs.	June 29
2	writing the ideas of tunnel Key Block computation	8 Hrs.	July 2
3	writing scientific note book about DDA computation	8 Hrs.	July 3

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The geometry of the tunnels are the following:

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Table 2 Tunnel data

bearing angle of tunnel axis	105°
rise angle of tunnel axis	0°
tunnel diameter	5.5 meter
tunnel shape	circular

The following are the input data of the code DL0 and the results. The produced joints and blocks are shown by the next two figures

Block Size Distribution
Based on Extended Joint Length

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The following are the joint set data with extended joint length and zero joint bridge.

Table 3 Statistical joint set data with extended length

joint set	spacing: m	length: m	bridge: m
joint set 1	.30	3.6	.0001
joint set 2	.30	4.8	.0001
joint set 3	.50	3.6	.0001

Since the joints are long and the joint set 1 is almost perpenticular to the tunnel axis, joint set 1 can be considered as cross section plane. Therefore only joint set 2 and joint set 3 are used to produce the joints on the tunnel section. The joint set 1 serves as the side cutting.

The 2-d DDA code DL0 and DC0 are used to produce the joints and blocks. The block volume distribution is shown by the following Table 4:

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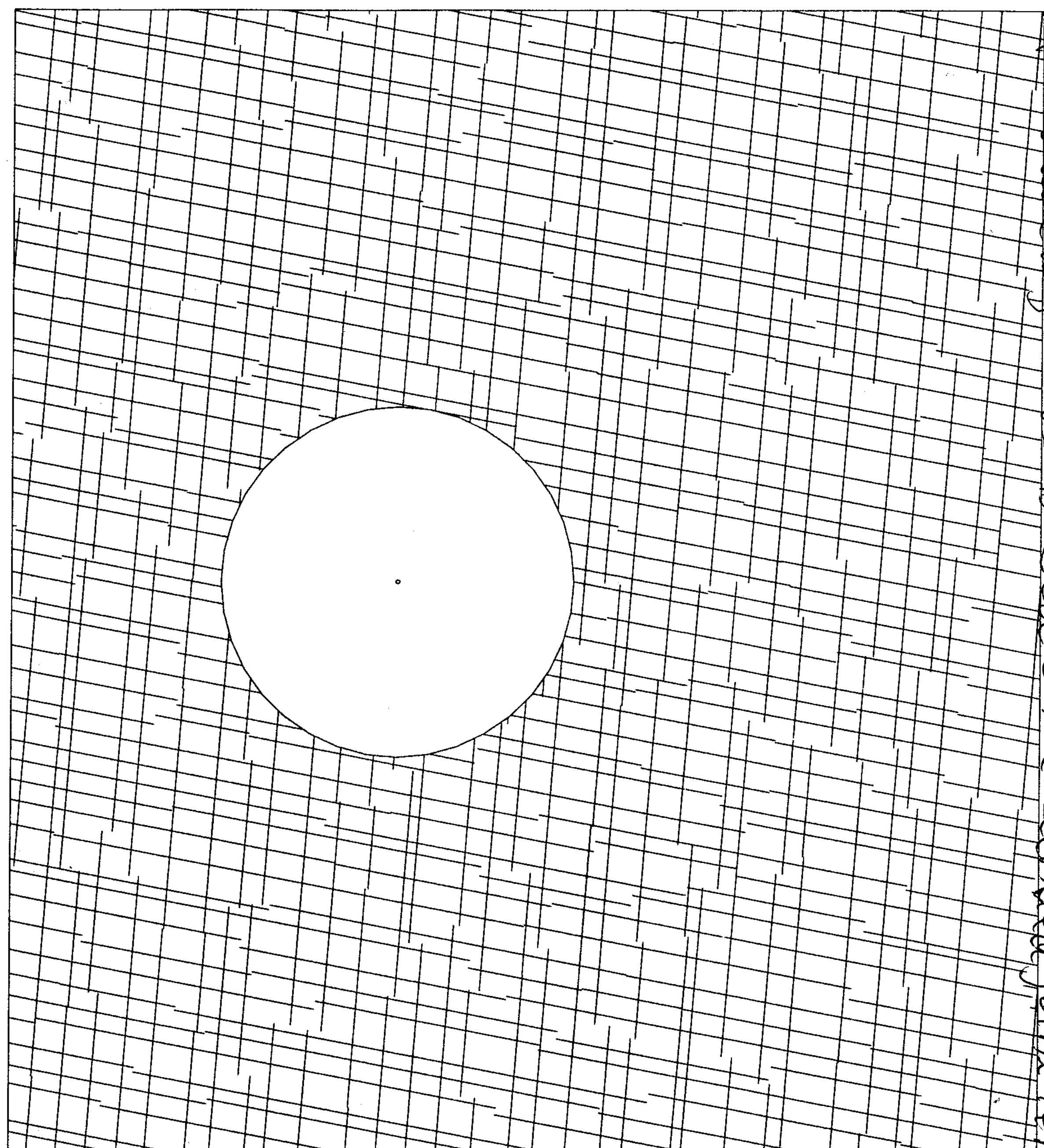
Table 4 Block volumes with extended joint length

volume range m^3	per cent %
0.0 to 0.2	61.6 %
0.2 to 0.4	30.1 %
0.4 to 0.6	6.51 %
0.6 to 0.8	1.26 %
0.8 to 1.0	0.34 %
1.0 to 1.2	0.11 %

The total block number is 876. The maximum block volume is 1.05m^3



Produced joints based on extended joint length by DCQ

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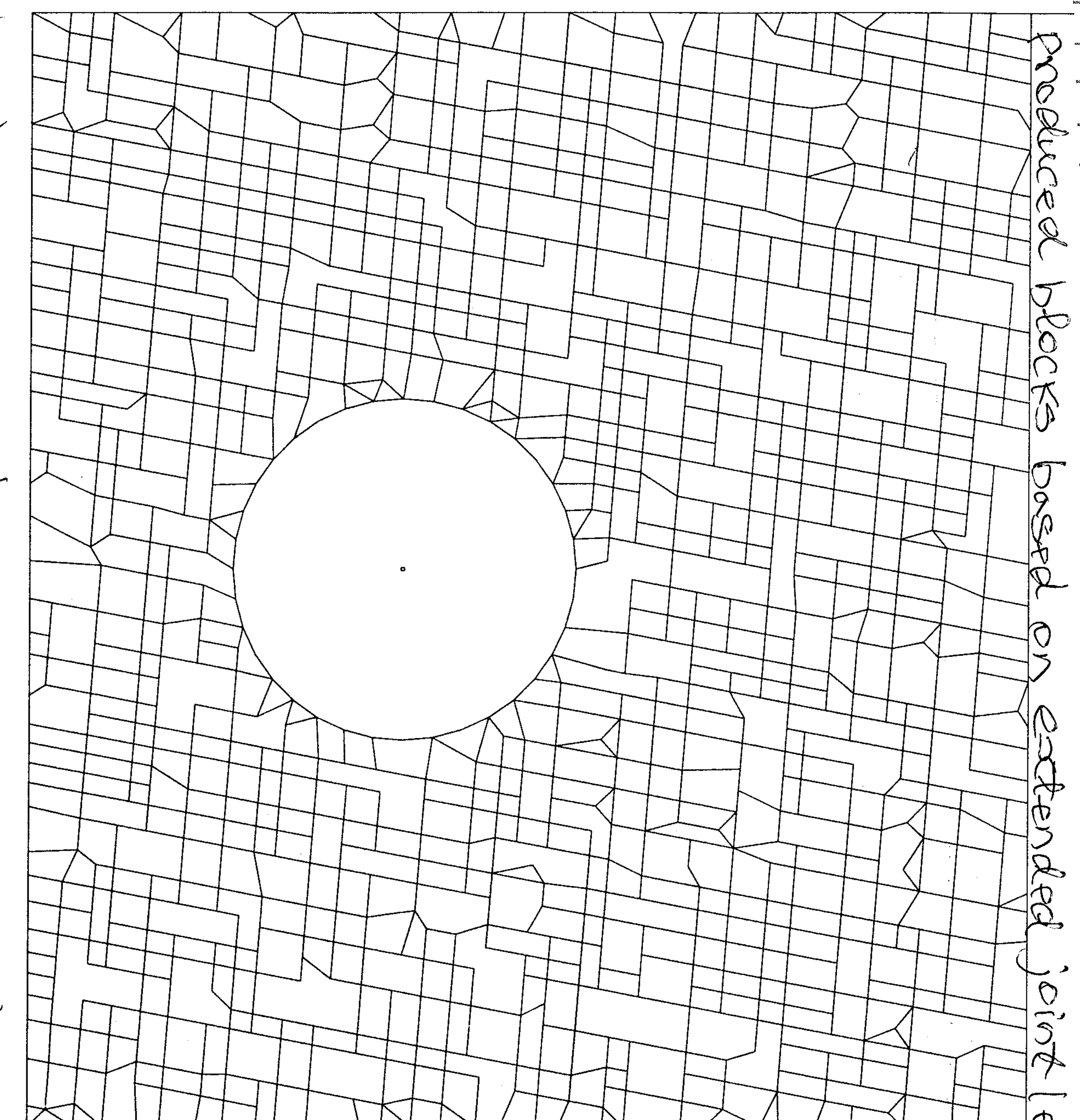

Produced blocks based on extended joint length by DCQ

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The following are the input data and the results of code DL0. The joint length is original but the joint bridges are zero.

The maximum block volume are larger than the volume of previous case.

Block Size Distribution
Based on Original Joint Length

The following are the joint set data with original joint length and zero joint bridge.

Table 5 Statistical joint set data with original length

joint set	spacing: m	length: m	bridge: m
joint set 1	.30	1.8	.0001
joint set 2	.30	2.4	.0001
joint set 3	.50	1.8	.0001

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In this case, all three joint sets are used to produce the joints.

The 2-d DDA code DL0 and DC0 are used to produce the joints and blocks. The block volume distribution is shown by the following Table 6:

Table 6 Block volumes with original joint length

volume range m^3	per cent %
0.0 to 0.2	66.2 %
0.2 to 0.4	21.8 %
0.4 to 0.6	7.26 %
0.6 to 0.8	2.65 %
0.8 to 1.0	0.92 %
1.0 to 2.0	1.15 %

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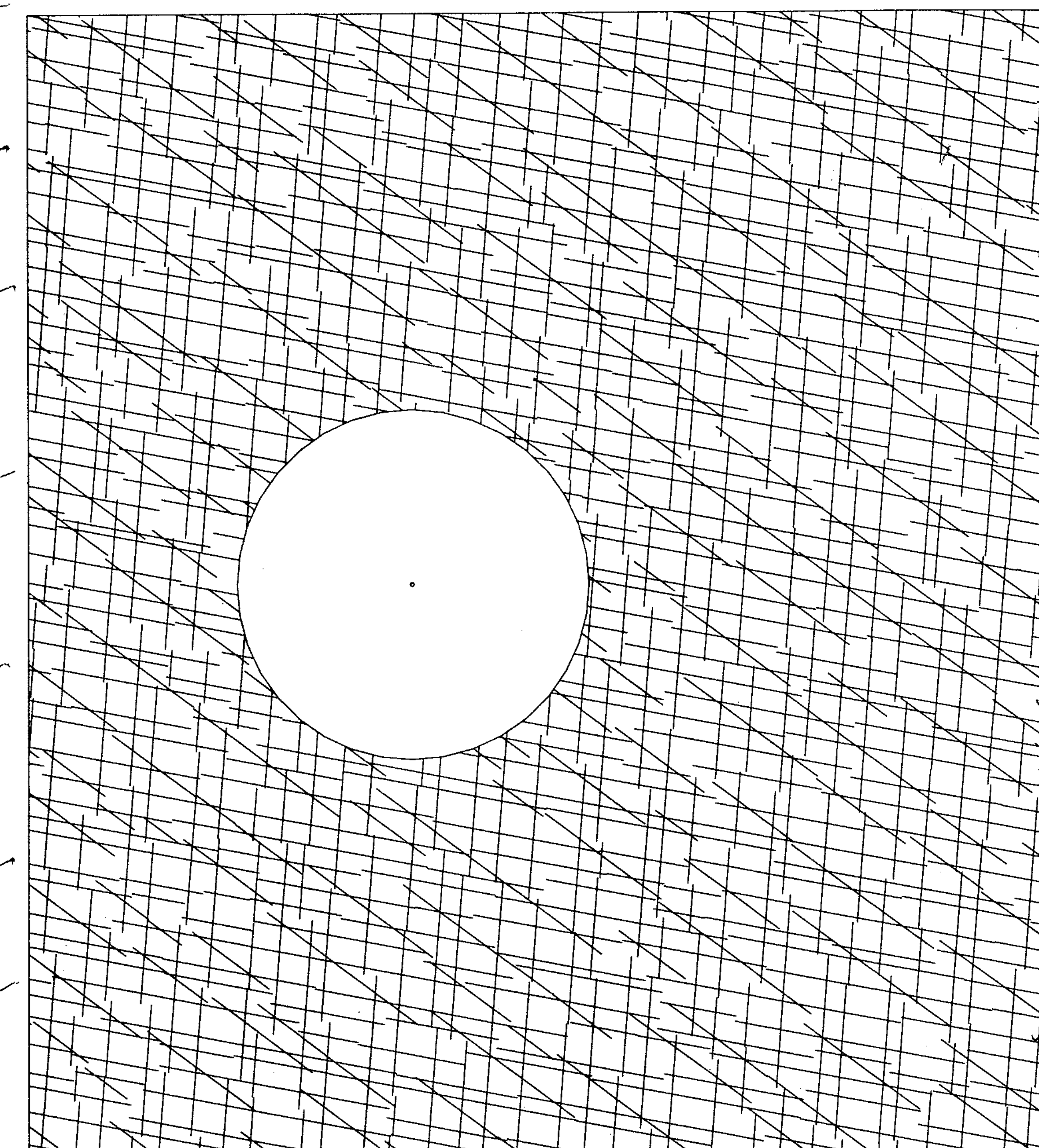
The total block number is 867. The maximum block volume is $1.68m^3$.



Produced joint based on original joint length and 0 bridge by DL0

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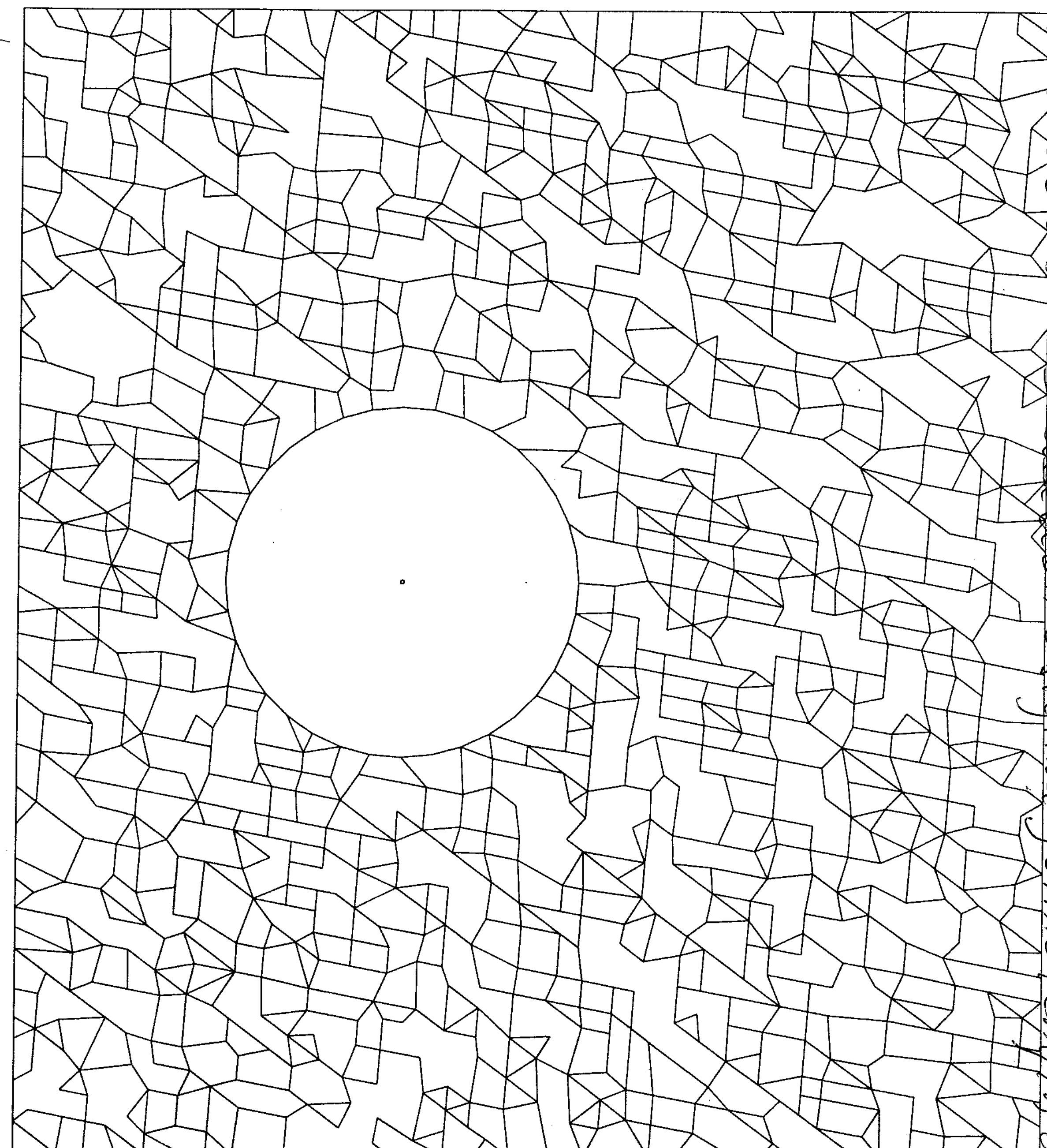

Produced blocks based on original joint length and 0 bridge by DC0

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The following are the joint set data with original joint length and normal joint bridge.

Table 7 Statistical joint set data with normal bridge

joint set	spacing: m	length: m	bridge: m
joint set 1	.30	1.8	.1
joint set 2	.30	2.4	.1
joint set 3	.50	1.8	.1

In this case, all three joint sets are used to produce the joints.

The 2-d DDA code DL0 and DC0 are used to produce the joints and blocks. The block volume distribution is shown by the following Table 6:

Table 8 Block volumes with original joint length

volume range m^3	per cent %
0.0 to 0.2	55.6 %
0.2 to 0.4	25.1 %
0.4 to 0.6	9.46 %
0.6 to 0.8	3.70 %
0.8 to 1.0	2.05 %
1.0 to 2.0	3.43 %
2.0 to 3.0	0.27 %

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The total block number is 729. The maximum block volume is $2.10m^3$

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8. Results of 2-d DDA Earth Quake Computation Based on Extended Joint Length

The following tables listed the actual DDA input data:

Table 9. Tptpll rock falling using DDA programs

unit weight	2.27 tons/m ^{3}
E of rock mass	3000000 tons/m ^{3}
ν of rock mass	0.21
number of time steps	20000
time step	0.0010 seconds
Program DL0 file	DLS4: producing joints
Program DC0 file	DCS4: producing blocks
Program DF0 file	DFS4: mechanical computations
Earth quake file	QKS1: 20 seconds earth quake

For this computation, the earth quake data of Yerba Buena Island Tunnel between San Francisco and Oakland are considered. The acceleration data are from California Department of Transportation. The ariginal data are 50 seconds, our computation only use from 10 second to 30 second. However the 20 second data are the main part of the strong earth quake.

In DDA computation, as a extension of Mewmark method from one block to multi-blocks, the earth quake accelerations are applied as body forces.

The extended joint length is used and the joint bridge is 0 for all joint sets. This should be the worst case of tunnel stability. The computation shows the rock falling in the 20 seconds strong earth quake.

Assumption of 2-d DDA Dynamic Computation for Earth Quake Stability

The Yucca mountain rocks are suitable for the applications of DDA method. The joint sets are the following:

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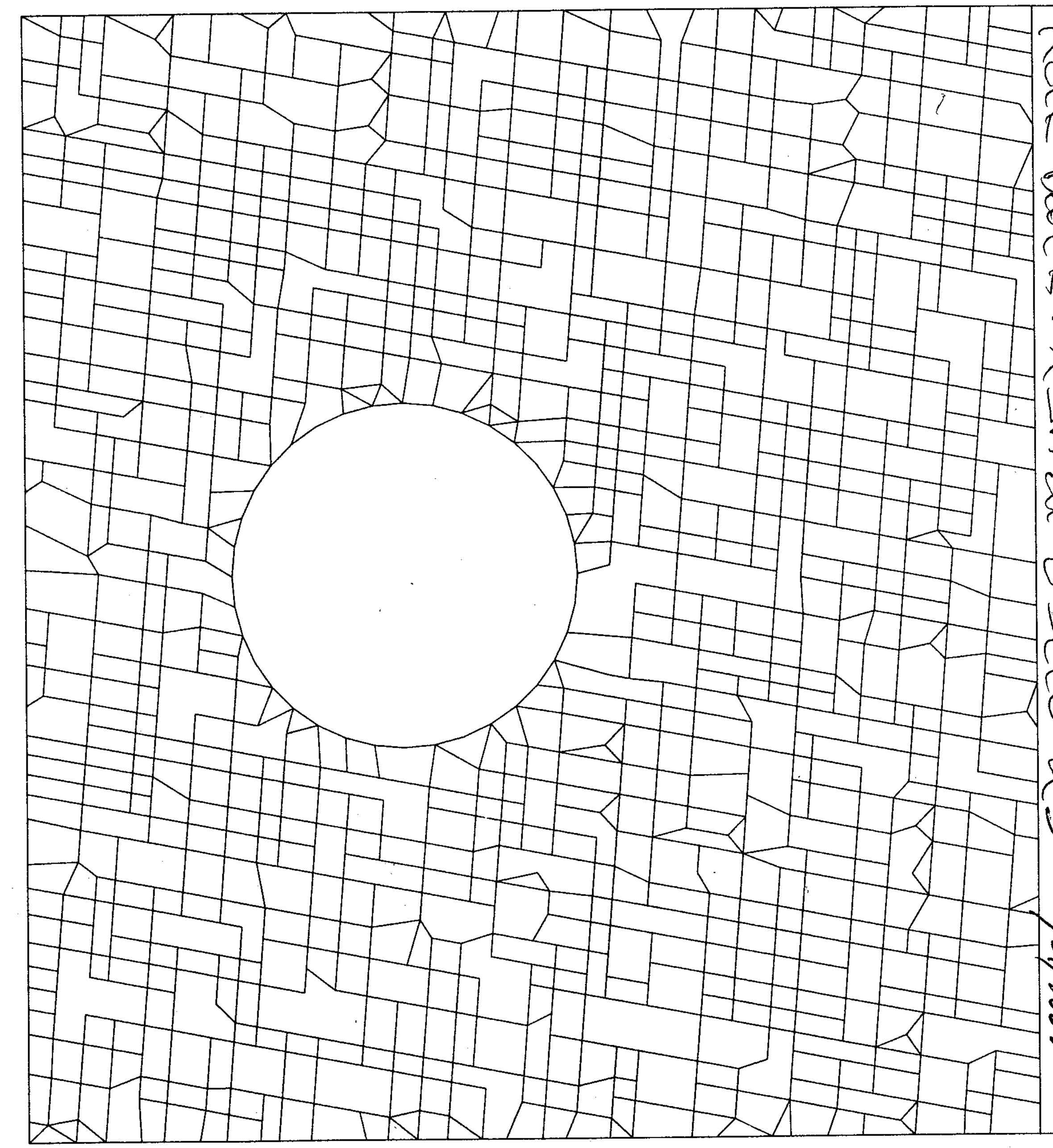
Table 1 Joint set data

joint set	dip angle	dip d.	friction angle	cohesion
joint set 1	79°	270°	39°	10 T/m^2
joint set 2	81°	230°	39°	10 T/m^2
joint set 3	5°	45°	39°	10 T/m^2



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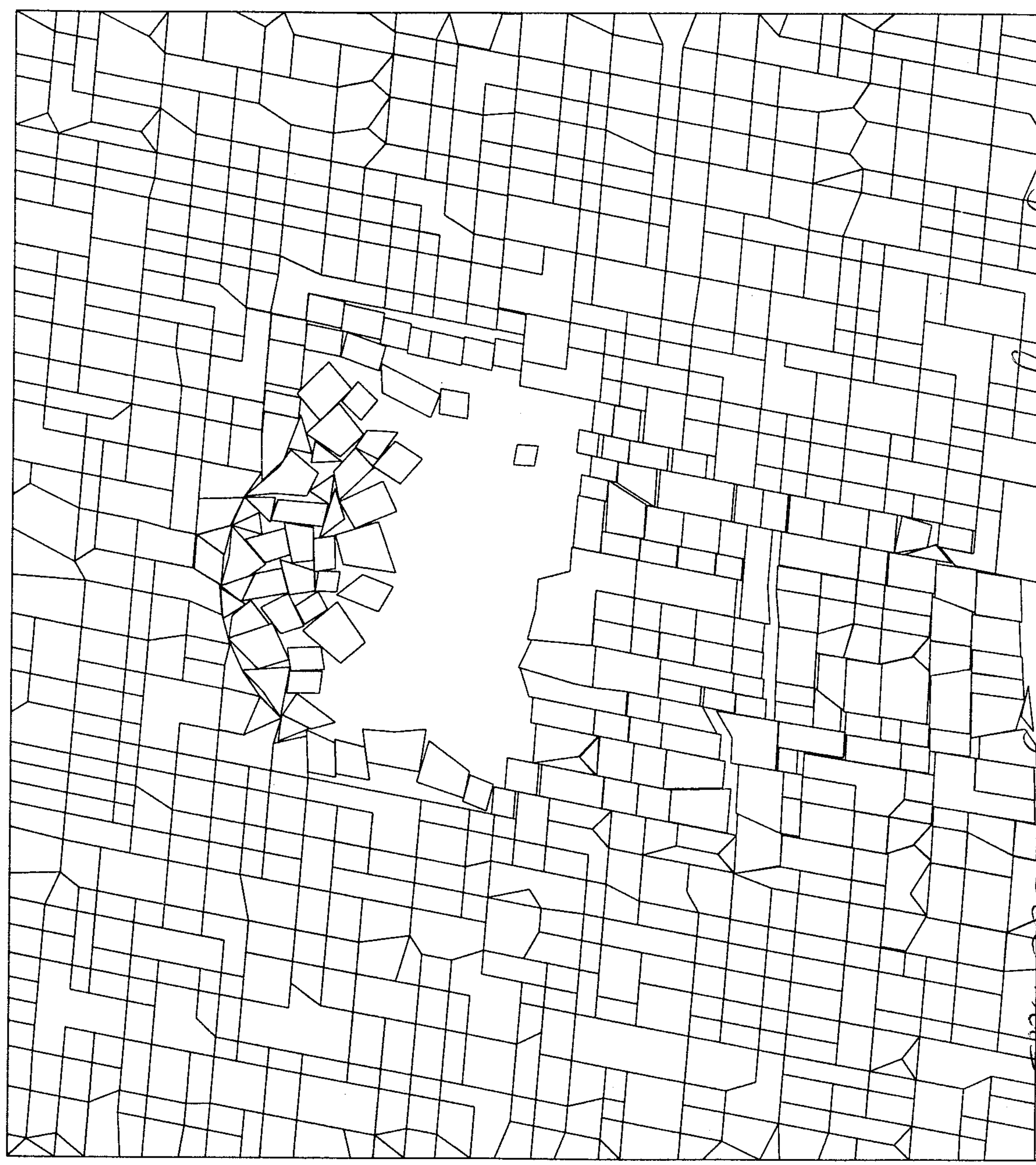

Rock falling at the end of 3 seconds 9/1/2000

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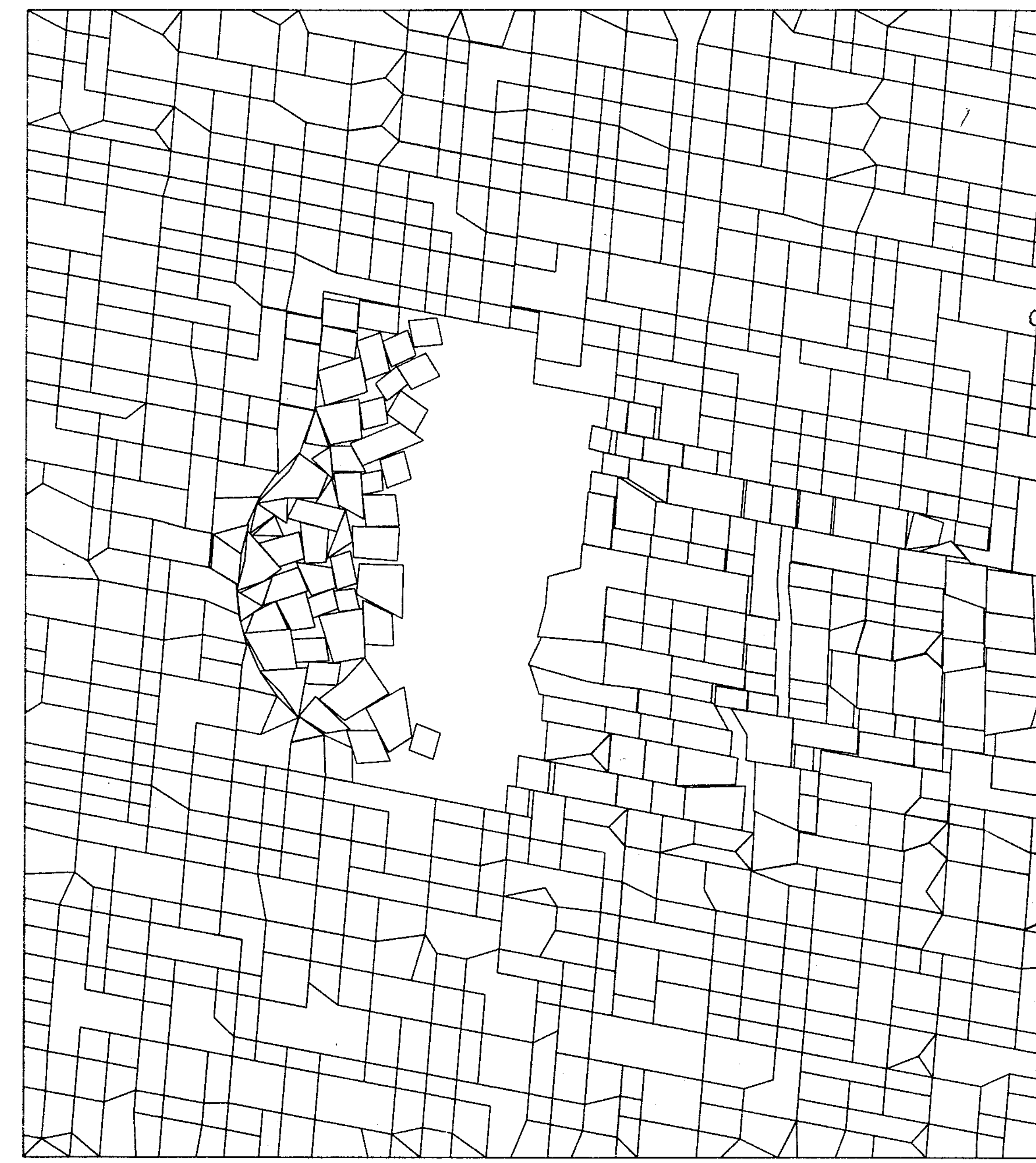

Rock falling at the end of 4 seconds 9/1/2000

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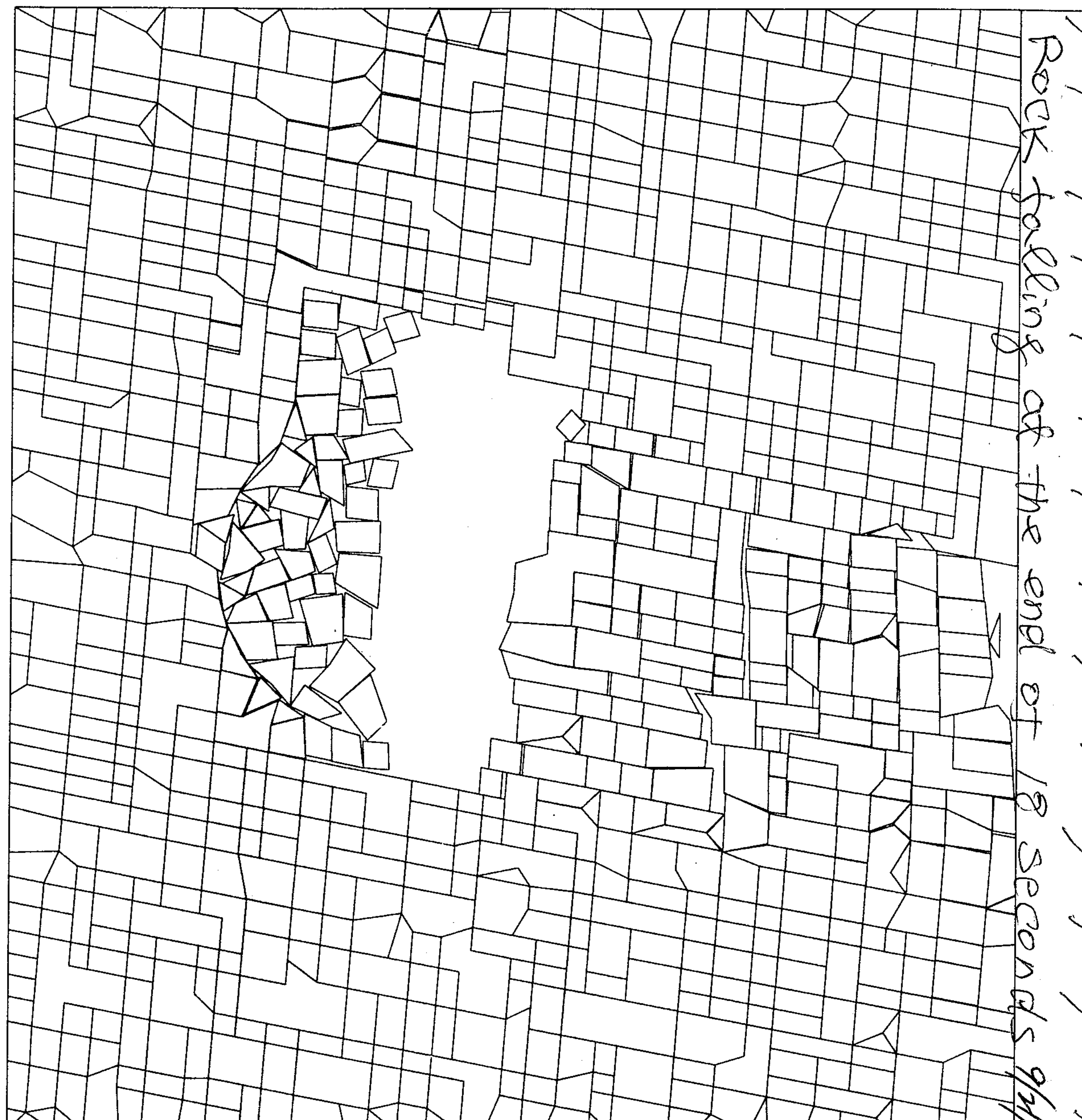
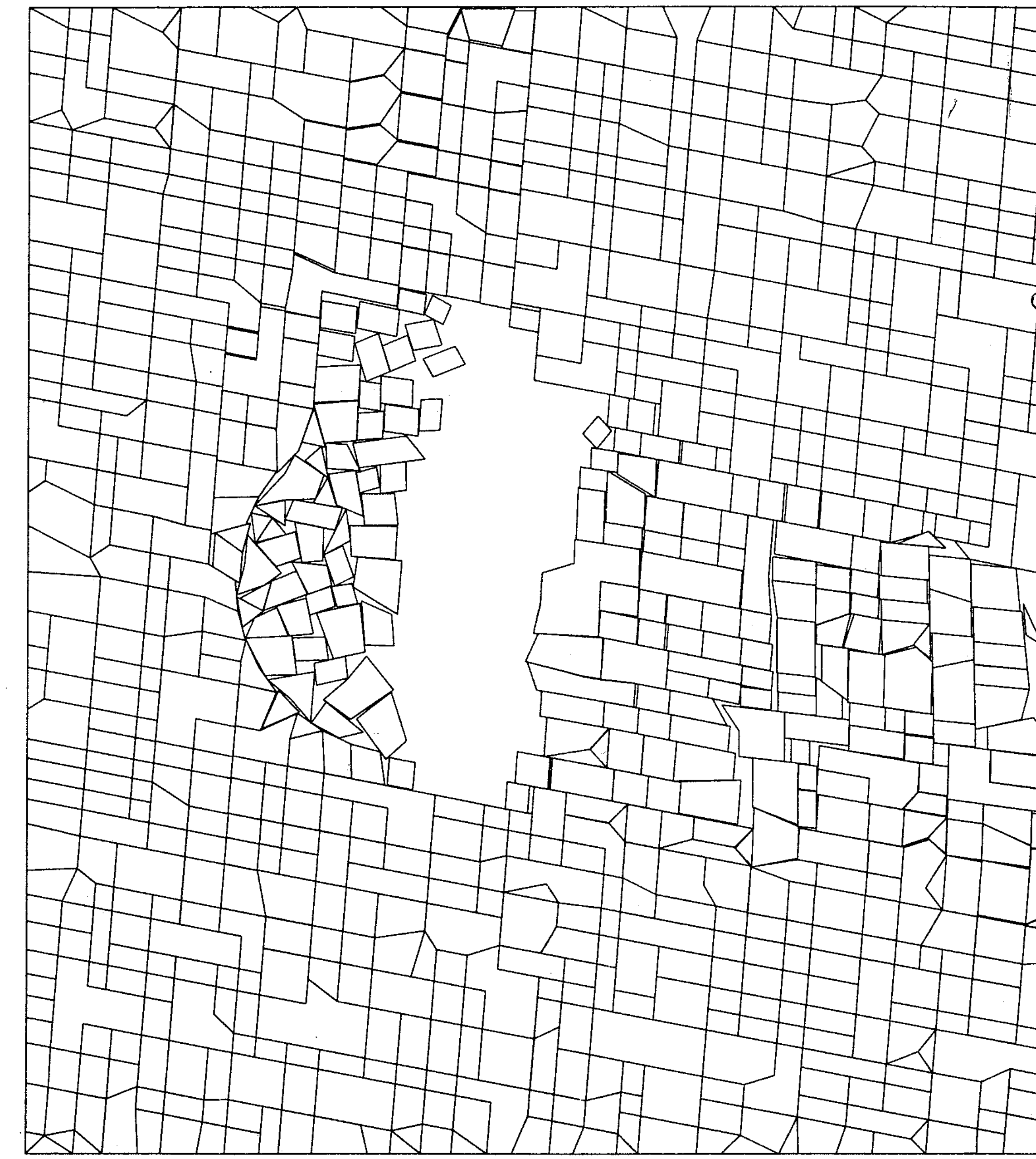


Shi Gen-hua 07/26/00



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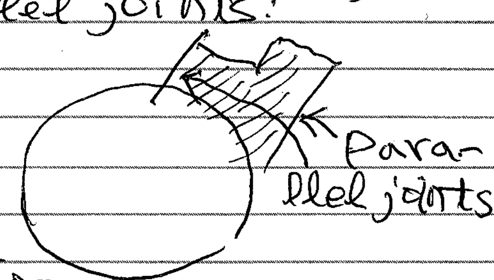
9. The plan for next stage of computation:

Since the tunnel direction was changed from N105°E to N75°E, all of the key block computation and DDA computation data have to be readjusted. The computation results may be similiar:

Tunnel direction change causes all key block results to change:
a) JP joint pyramid with maximum key blocks
b) 3-d maximum key blocks
c) key block zones on the tunnel walls based uppon the statistically produced joint trace map
d) the contour of maximum key block volumes for different tunnel directions. (the contour numbers of inner loops have to be print out, This is today's work.)

work of today:
a) try to find the way to print the inner loop contour number for the max. key block valume for different tunnel directions

b) try the code of key block zones on the tunnel walls from the produceede joint trace map. The case is the key block between two parallel joints:



a) and b) will be continued tomorrow.

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10. The plan for next DDA computation

Since the tunnel direction has changed from N105°E to N75°E, the joint lines in different tunnel direction have different direction. The joint mesh in the cross-section of the tunnel will change. All of the rock falling DDA analysis should perform based on the new tunnel direction:

a) DDA analysis basid on new tunnel direction N75°E
b) The joint material parameter were
   Friction angle = 30°
   cohesion = 0 — Shi 07/28/00
   if the cohesion is not 0, will the rock falling chages much? we need many runs of the code to find out.
c) The earth quake load of the former DDA computation is about 1.0 g. The real earth quake acceleration would be much smaller the computation will consider the reduced accelerations by 0.3, 0.6 times of the original acceleration.
d) It is also possible to do second order DDA analysis where the x, y direction displacements are

$$u = a_0 + a_1 x + a_2 y + a_{11} x^2 + a_{12} xy + a_{22} y^2$$
$$v = b_0 + b_1 x + b_2 y + b_{11} x^2 + b_{12} xy + b_{22} y^2$$

how much chages will occur?

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11. maximum sliding force of key blocks for all tunnel directions

the differences of this computation from Figure 4.1 and 4.2 of report #2 is

a) the contour numbers are printed along x=0 and y=0 two directions the inner contour loops have the contour number

b) the tunnel direction is projected as small circle on the equal area projection

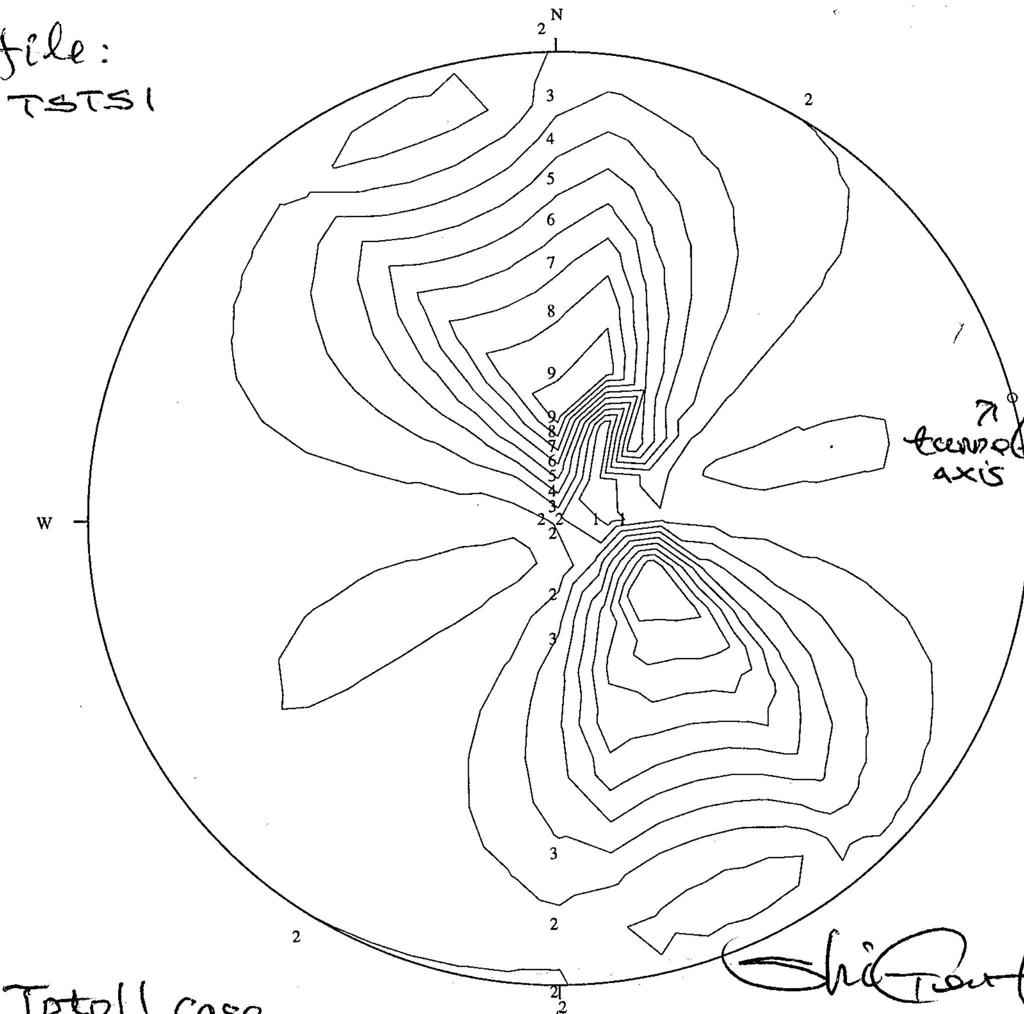
c) the total steps of contours from 9 increase to ten, if the tunnel axis projection is on contour 3, it means, the maximum sliding force of key block is 0.3 of the maximum key block sliding force for all tunnel directions.

file TSTS1: case of Tptpll
file has been changed:
contour → ~~contour~~ number 10
add tunnel direction
[initials] 9/21/2000

file TSTS2: case of Tptpul
file hase been changed:
contour number 10
add tunnel direction

Results: For the Tptpll case the new tunnel direction is N75°E, bearing 25° rise 0°

file:
TSTS1



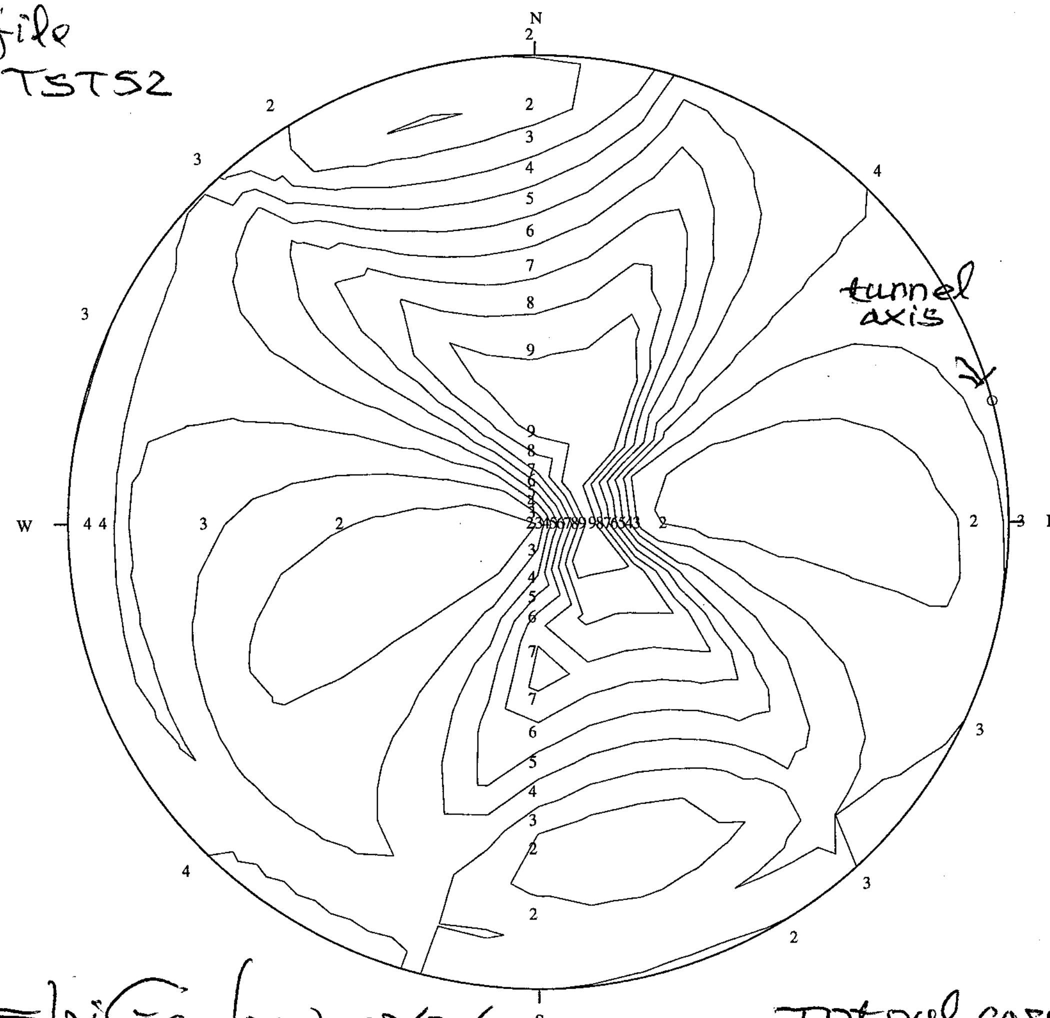
Tptpll case

[signature]
07/31/00

From this drawing:
the sliding force of the key blocks of the new tunnel direction is about 0.2 of the sliding force of the ~~old~~ maximum (G) [initials] 9/21/2000 ~~tunnel~~ old [initials] 9/21/2000 directions.
The new tunnel direction is N75°E
The old tunnel direction is N105°E
Both directions have approximat the same sliding force

In the Tptul case, (See drawing of next page)

file
TSTS2



Shi Gen-huo 07/31/00 Tetpul case

The key block sliding force is ~~0.25~~ 0.35 of the maximum sliding force. 9/2/2000

For the old tunnel direction N10°E, the number is 0.3.

the program is TST.

Shi Gen-huo 07/31/00

12 All possible removable blocks of the new tunnel direction.

Under the new tunnel direction, all of the removable blocks can be different. the computation of the tunnel removable JP are computed.

The source code TRM.C was checked. The new computation will include
sliding force of each JP
factor of safety of each JP

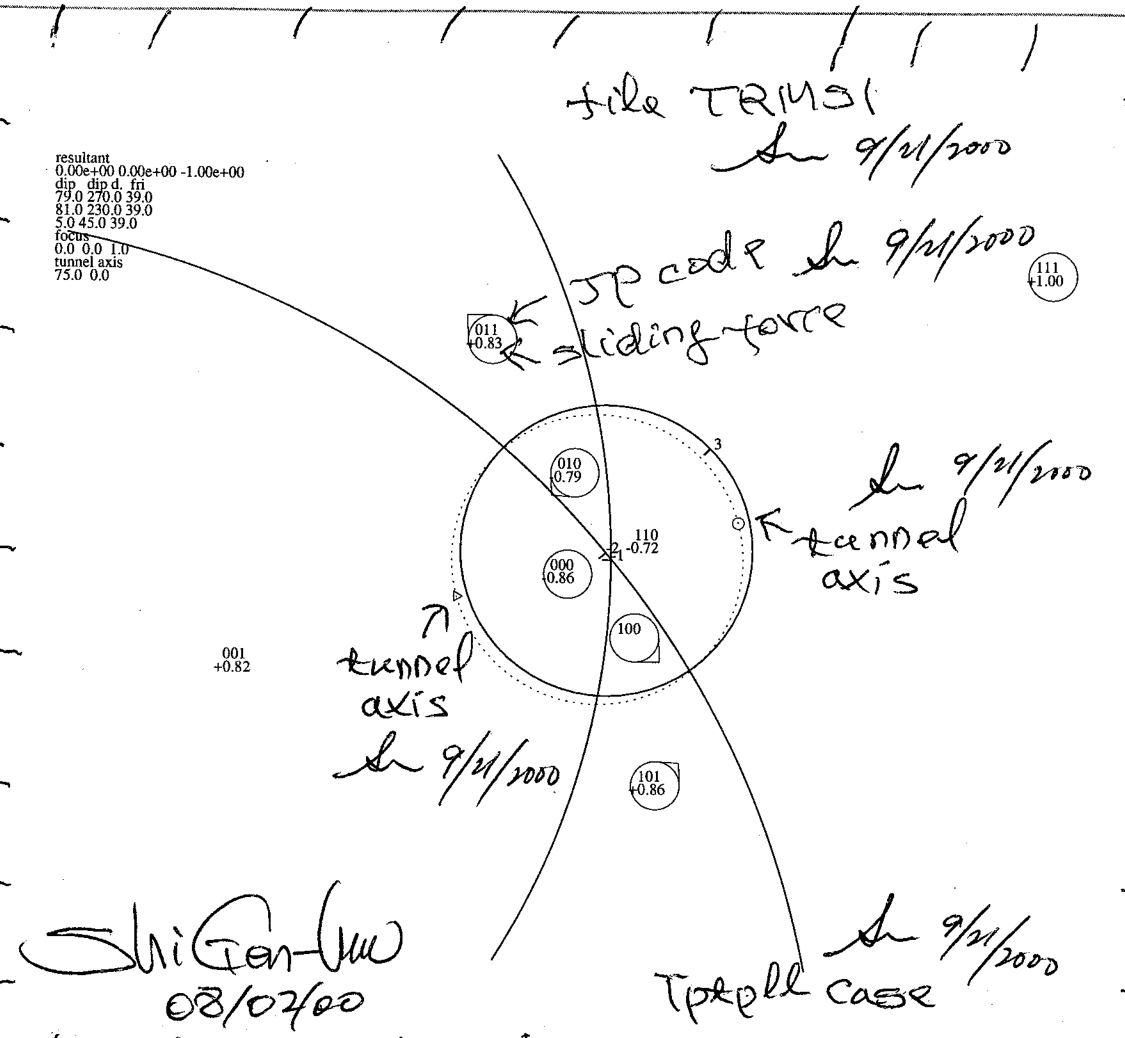
The sliding force of JP and factor of safety of JP (cohesion=0) are checked

The input file TRMS1 and TRMS2 have been changed:
tunnel bearing angle N75°E
tunnel rise angle 0° (same)
friction angle of each joint set:

Joint set	friction angle
1	39°
2	39°
3	39°

Other input data on files TRMS1 and TRMS2 are remain the same.

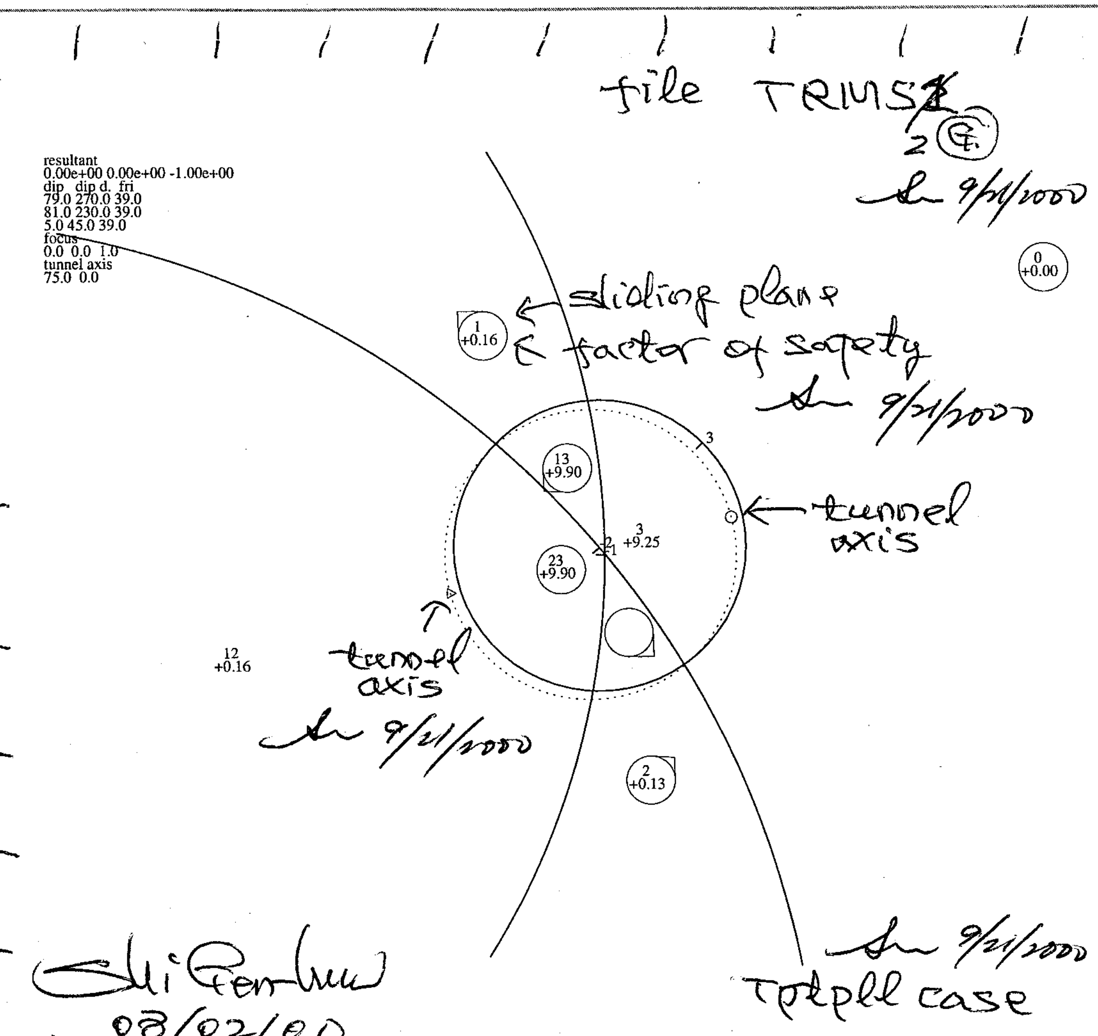
This kind of blocks (key blocks) will fall imidietly after the excavation. Removable blocks with sliding direction are key blocks



The drawing are the maximum key block zones for different joint pyramids.
the first number: JP code
the second number: sliding force with unit g
if the sliding force is minus, no sliding
if no sliding force printed, no sliding direction which is safe even if friction angle is 0°.

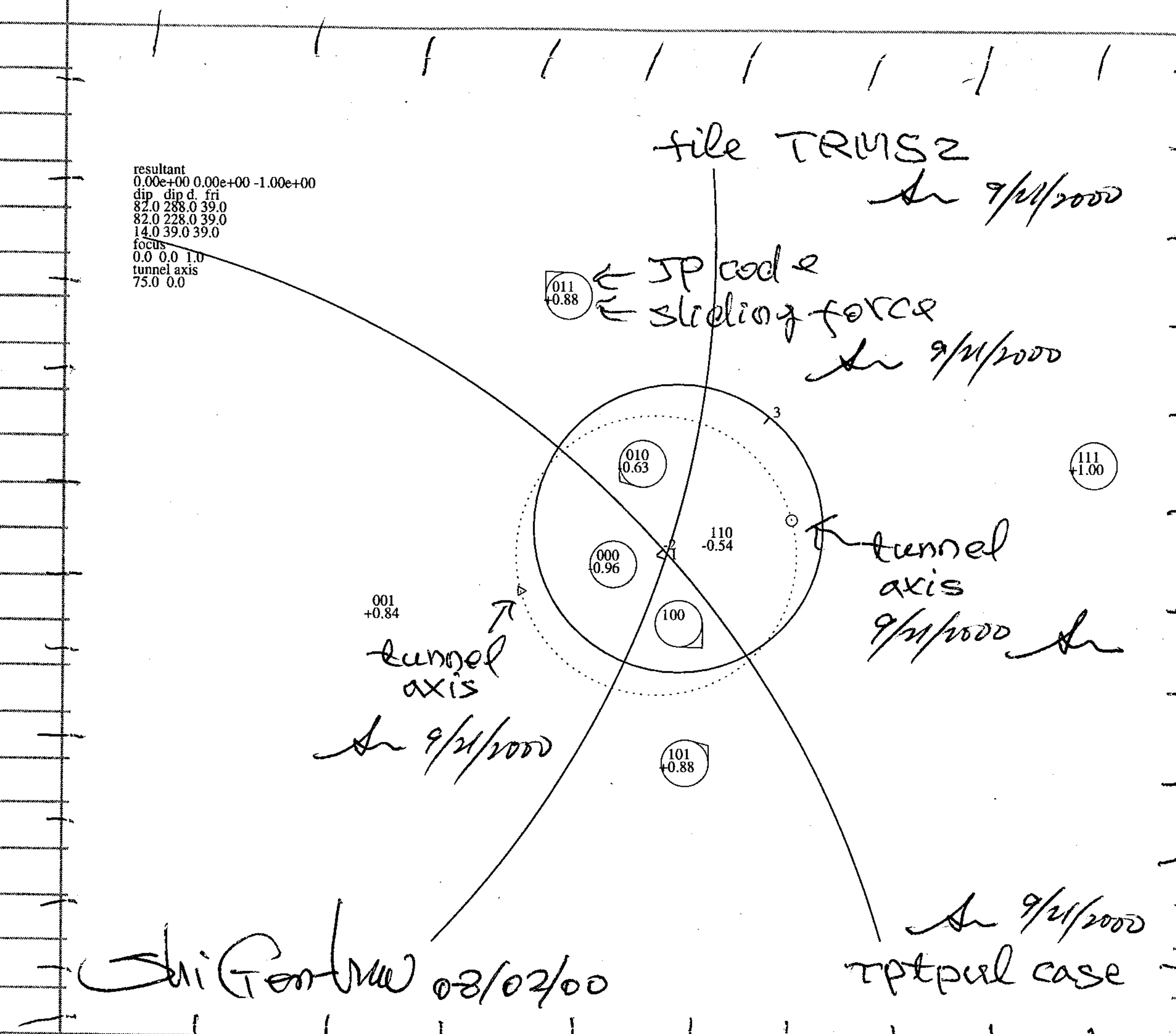
only two JP has key blocks:

JP code	sliding force:
011	0.83 g
101	0.86 g



The drawing is same as the previous drawing except.
The first number is sliding plane:
0: no sliding plane, direct falling
1: sliding along joint set 1
13: sliding along joint set 1 and 3, the sliding direction is intersection of joint set 1 and 3.
the second number is factor of safty
only two JP have key block

JP code	sliding plane	factor of safety
011	1	0.16
101	2	0.13



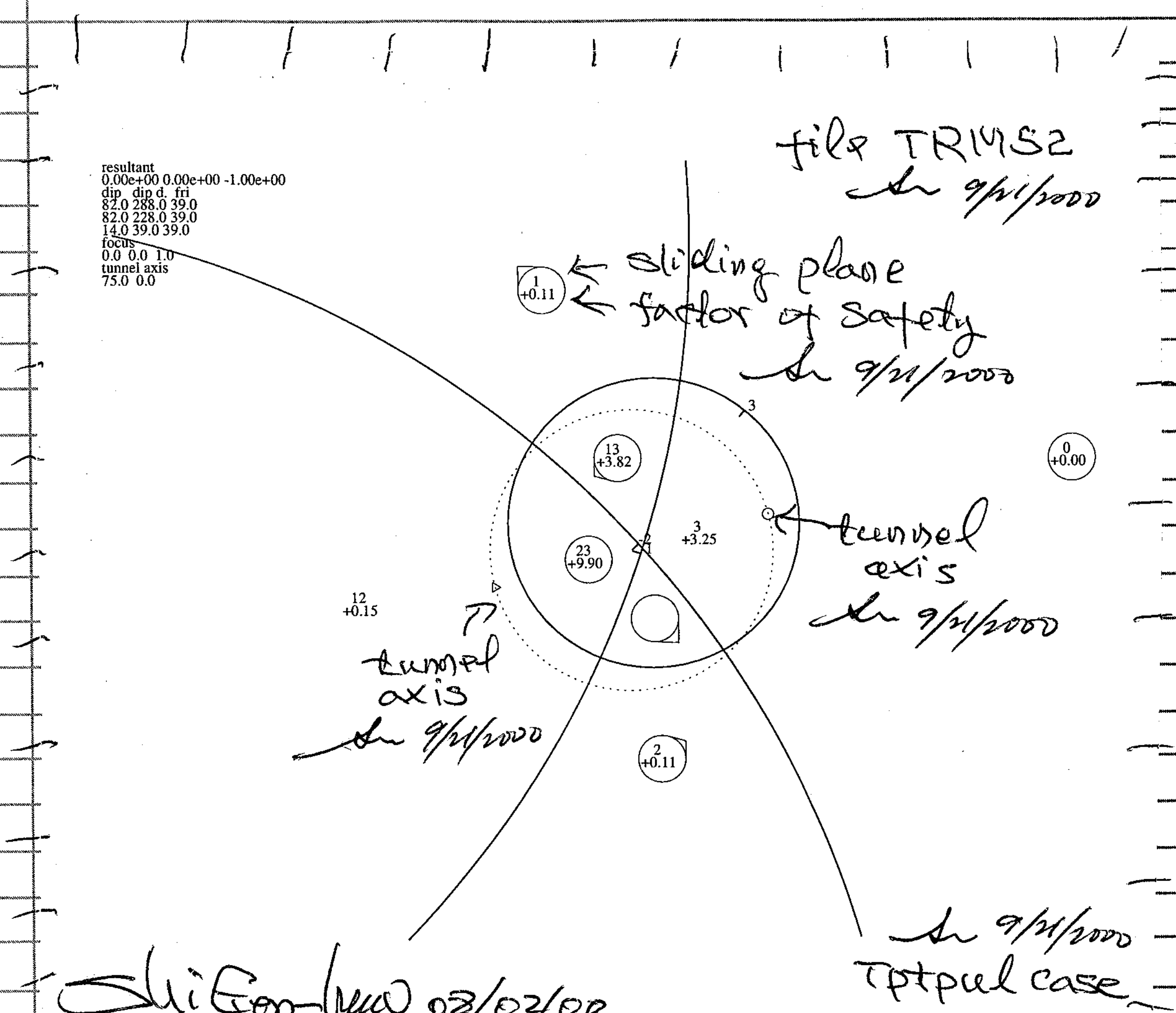
The drawing in this page are the maximum key block zones for Different joint pyramids (JP).

The first number: JP code

JP=011 meas the key blocks on
upper side of joint set 1
lower side of joint set 2
lower side of joint set 3

the second number: sliding force with unit g. only two JP have key block:

JP code	sliding force
011	0.88g
101	0.88g



the drawing is the same as previous drawing except
the first number is sliding plane
the second number is factor of safety

The two JP have key block:

JP code	sliding plane	factor of safety
011	1	0.11
101	2	0.11

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13. Three Dimensional Drawing of all maximum key blocks under the New Tunnel Direction:

The results of the previous drawing shows the JP with large size of the maximum key block zone and positive sliding force.

The other JP are neglected with the following reasons:
a) the maximum key block zone is not large enough to have the visible key blocks. ⓔ 9/21/2000
b) the sliding force of the JP is negative, therefore this kind of block can not slide even if it is removable

The Tptpll case has two JP
011 and 101
which have noticeable key blocks

The Tptpul case has two JP
011 and 101
which have noticeble key blocks.

The following drawing are the cases:
a) Tptpll case JP=011
b) Tptpll case JP=101
c) Tptpul case JP=011
d) Tptpul case JP=101

The real key blocks would be smaller than the one with maximum side but with similar shapes.

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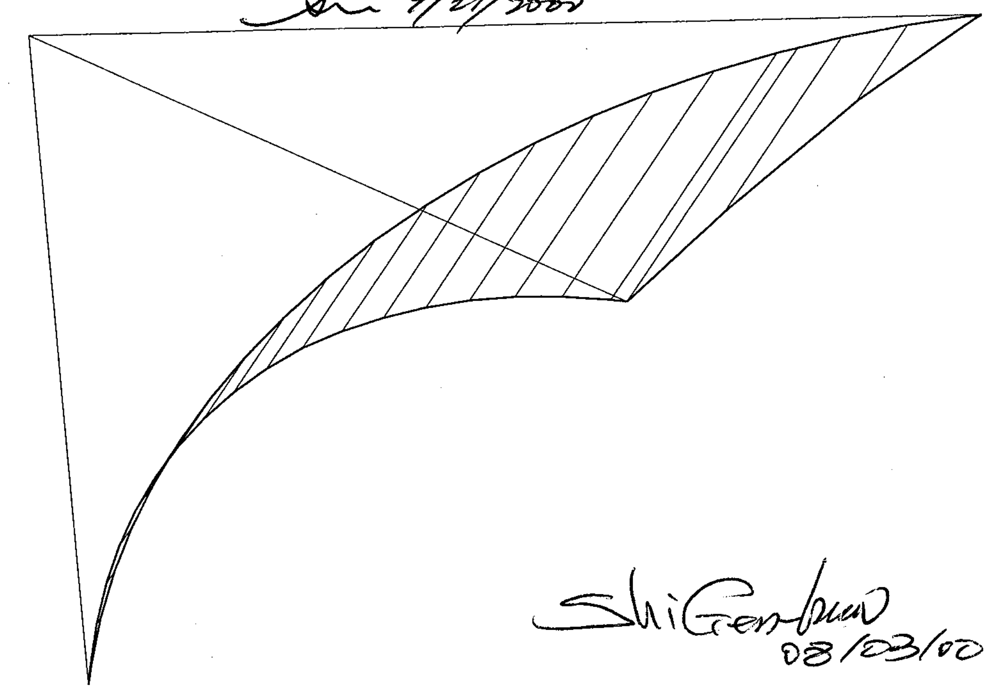
Tptpllcase JP=011 file: TBLS1

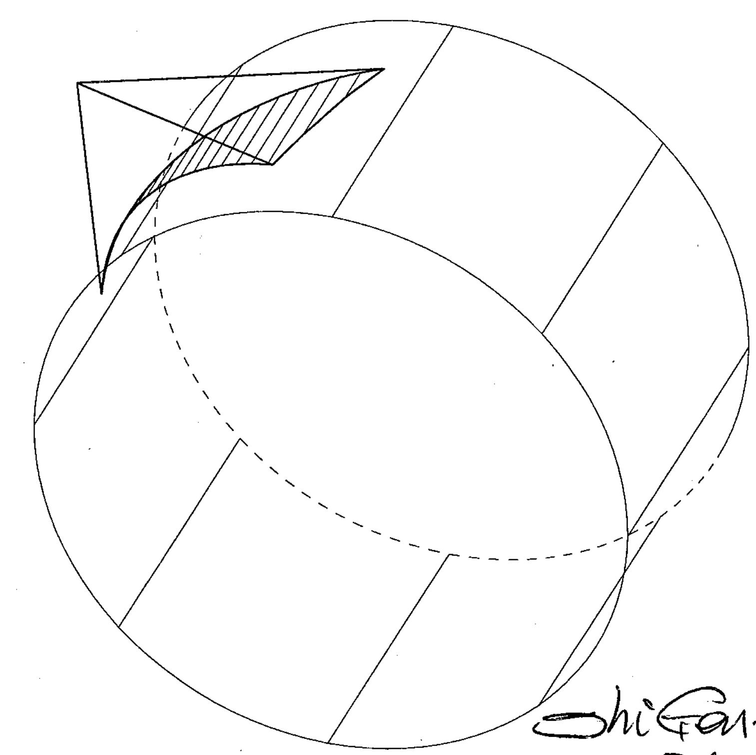
9/21/2000

top vertex
-2.85e+00 2.77e+00
dip dip d.
79.0 270.0
81.0 230.0
5.0 45.0
tunnel dir.
75.0 0.0
angle interval
267.93 0.48
011



Shi Gen-hua 08/03/00

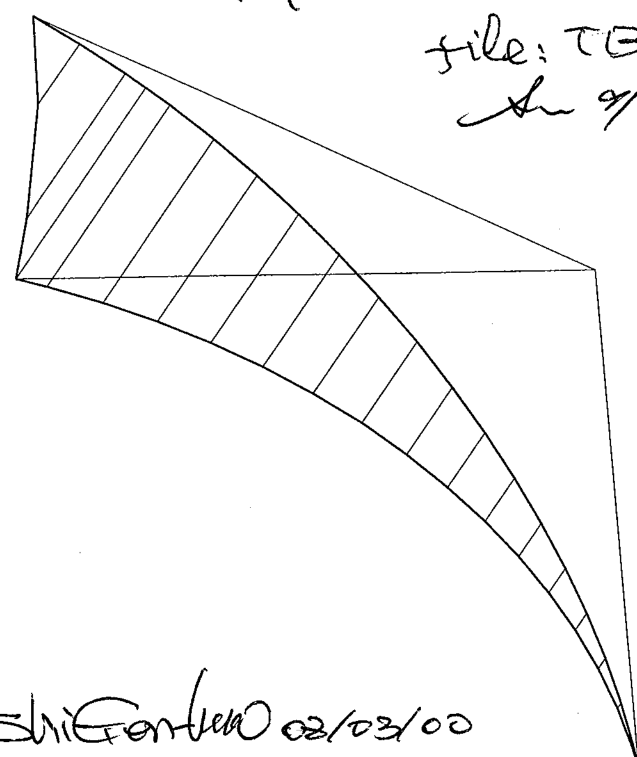
tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
0.00e+00
0.00e+00
0.00e+00
top distance
0.00e+00
011



Shi Gen-hua 08/03/00

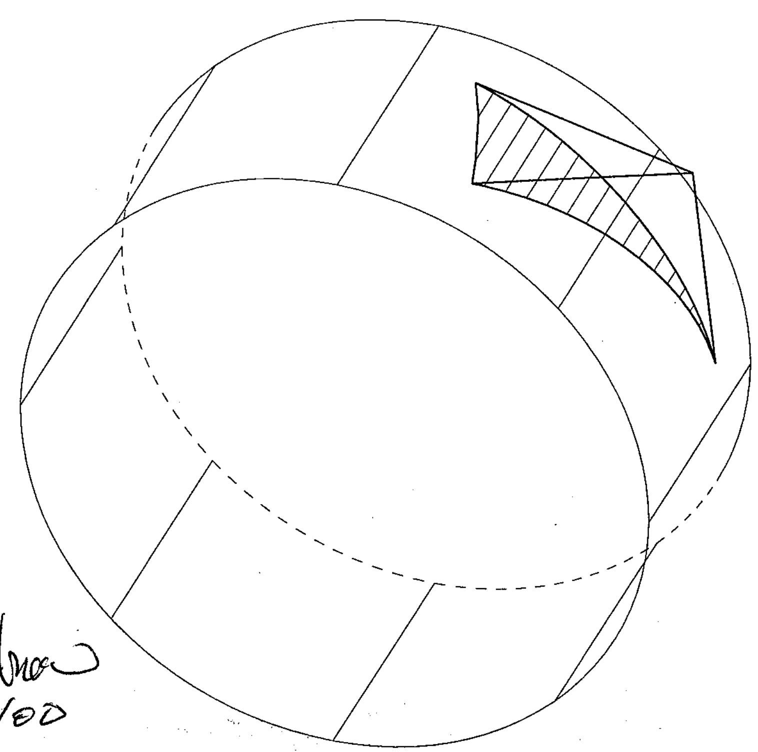
top vertex
2.66e+00 2.59e+00
dip dip d.
79.0 270.0
81.0 230.0
5.0 45.0
tunnel dir.
75.0 0.0
angle interval
3.61 87.93
101

Tptpll case JP=101
file: TBLS2
9/21/2000



02/03/00

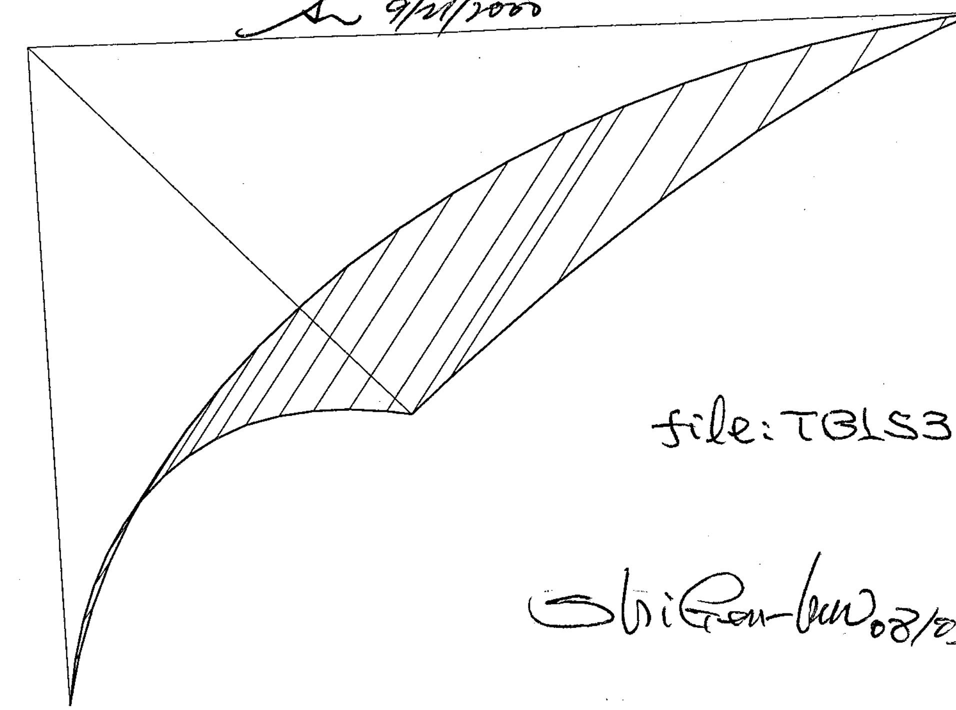
tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
0.00e+00
0.00e+00
0.00e+00
top distance
0.00e+00
101



08/03/00

top vertex
-2.77e+00 2.87e+00
dip dip d.
82.0 288.0
82.0 228.0
14.0 39.0
tunnel dir.
75.0 0.0
angle interval
269.51 2.43
011

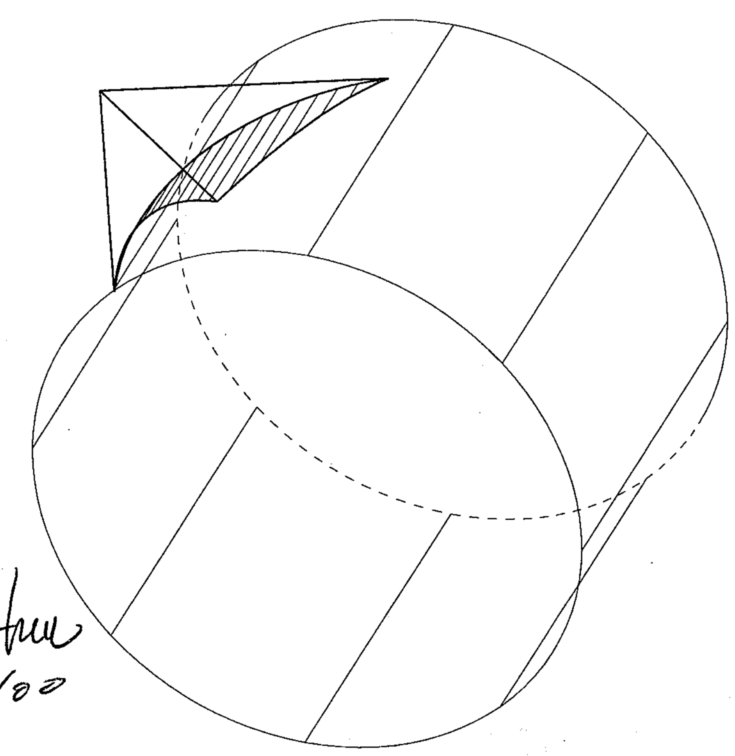
Tptpul case JP=011
9/21/2000



file: TBLS3

08/03/00

tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
0.00e+00
0.00e+00
0.00e+00
top distance
0.00e+00
011



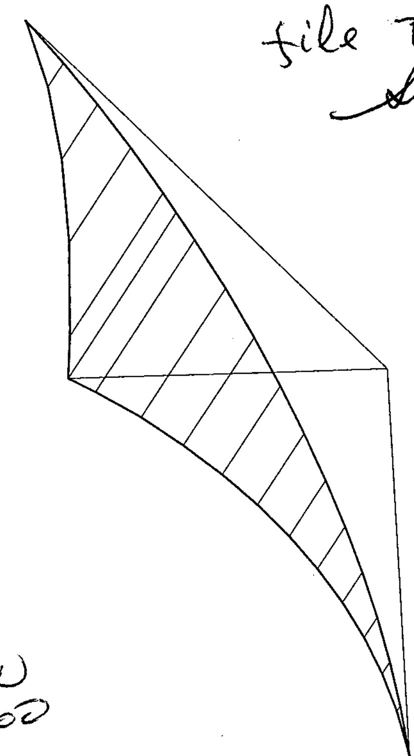
08/03/00

top vertex
2.73e+00 2.11e+00
dip dip d.
82.0 288.0
82.0 228.0
14.0 39.0
tunnel dir.
75.0 0.0
angle interval
15.03 89.51
101

Tptpul case JP=101

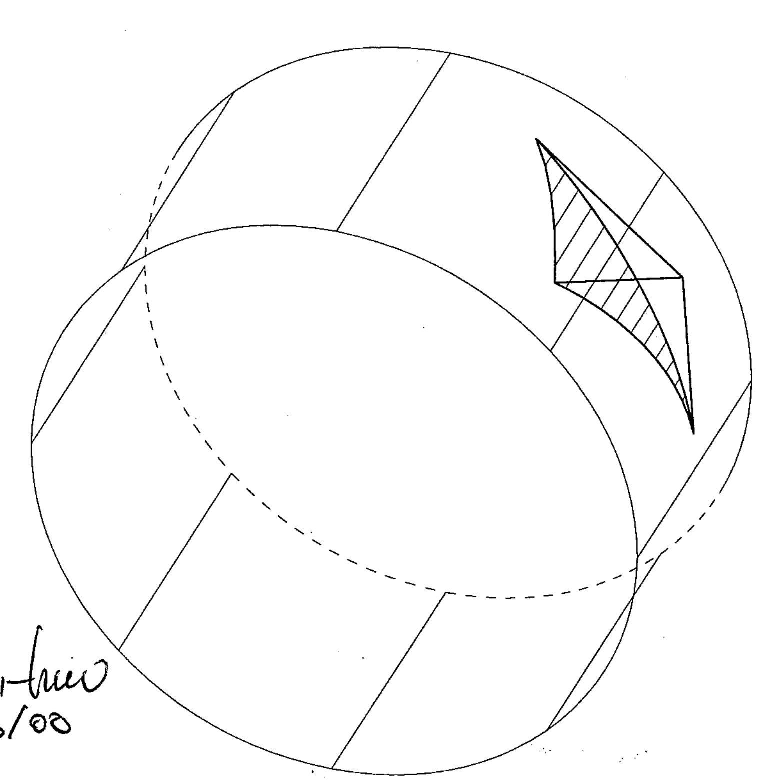
file TBLS4

[initials] 9/21/2000



Shi Genhua
08/03/00

tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
0.00e+00
0.00e+00
0.00e+00
top distance
0.00e+00
101



Shi Genhua
08/03/00

14 Key blocks on statistically produced joint trace map of tunnel walls

The difference of this computation and the previous computation is

a) the new tunnel direction is N75E, the joint trace map should be different. The joint trace map should be re-produced.

b) the key blocks in between two parallel joints are considered. The key block area of the joint trace map should be larger

parallel — [initials] 9/21/2000

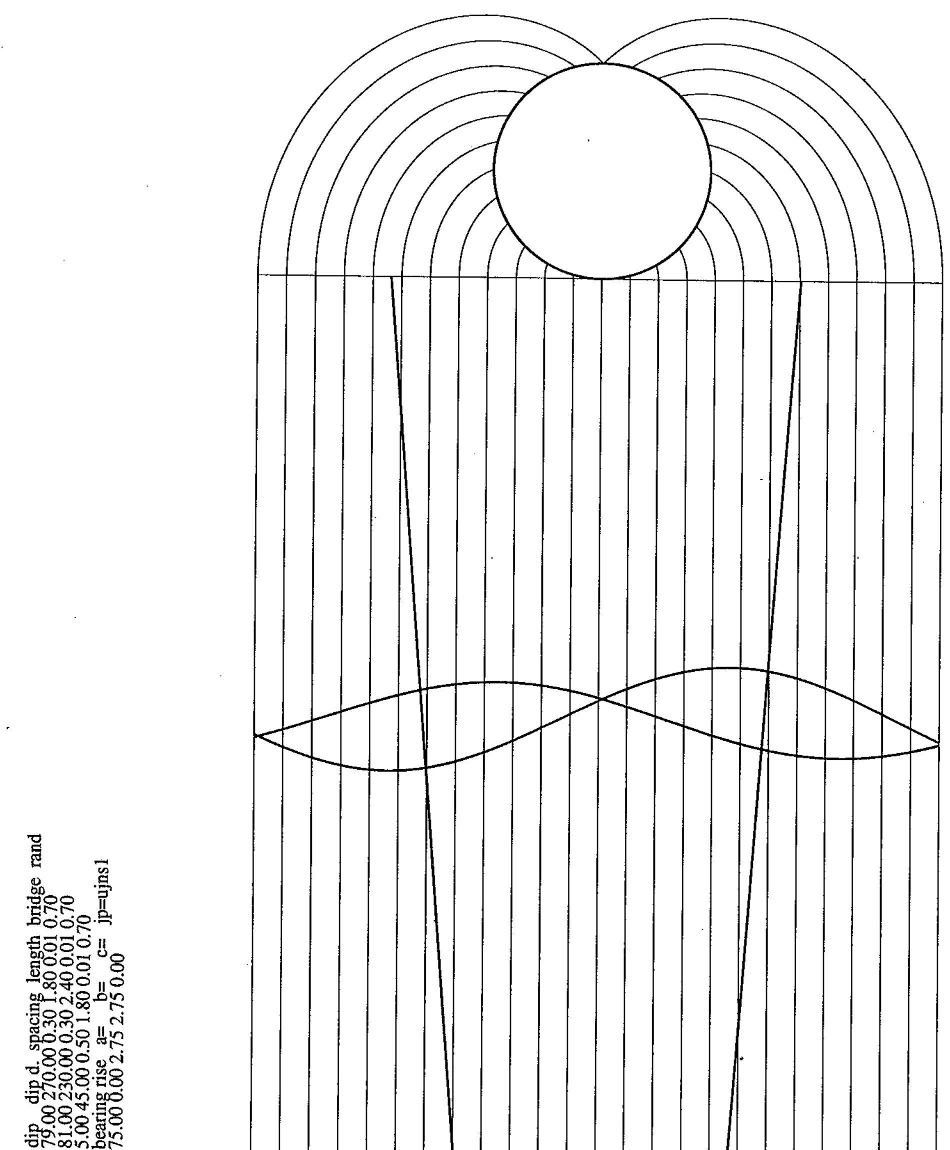
c) the key block area of all JP can be in the same key block drawing of both unrolled and 3-dimensional projection. All of the area of block falling are on the same drawing. The unrolled and 3-dimensional drawing are the view of all block falling.

d) The correctness of this key block analysis can be checked by eyes: just simply put the joint map and key block area map together, one can find out the errors if there is any. Therefore the user can check without go through the complicated logic.

e) In both Tpxpll and Tptpul cases, the set (joint set) one and two are long, therefore the key blocks in between the parallel joints are considered (e) [initials] 9/21/2000 for joint set 1 and joint set 2

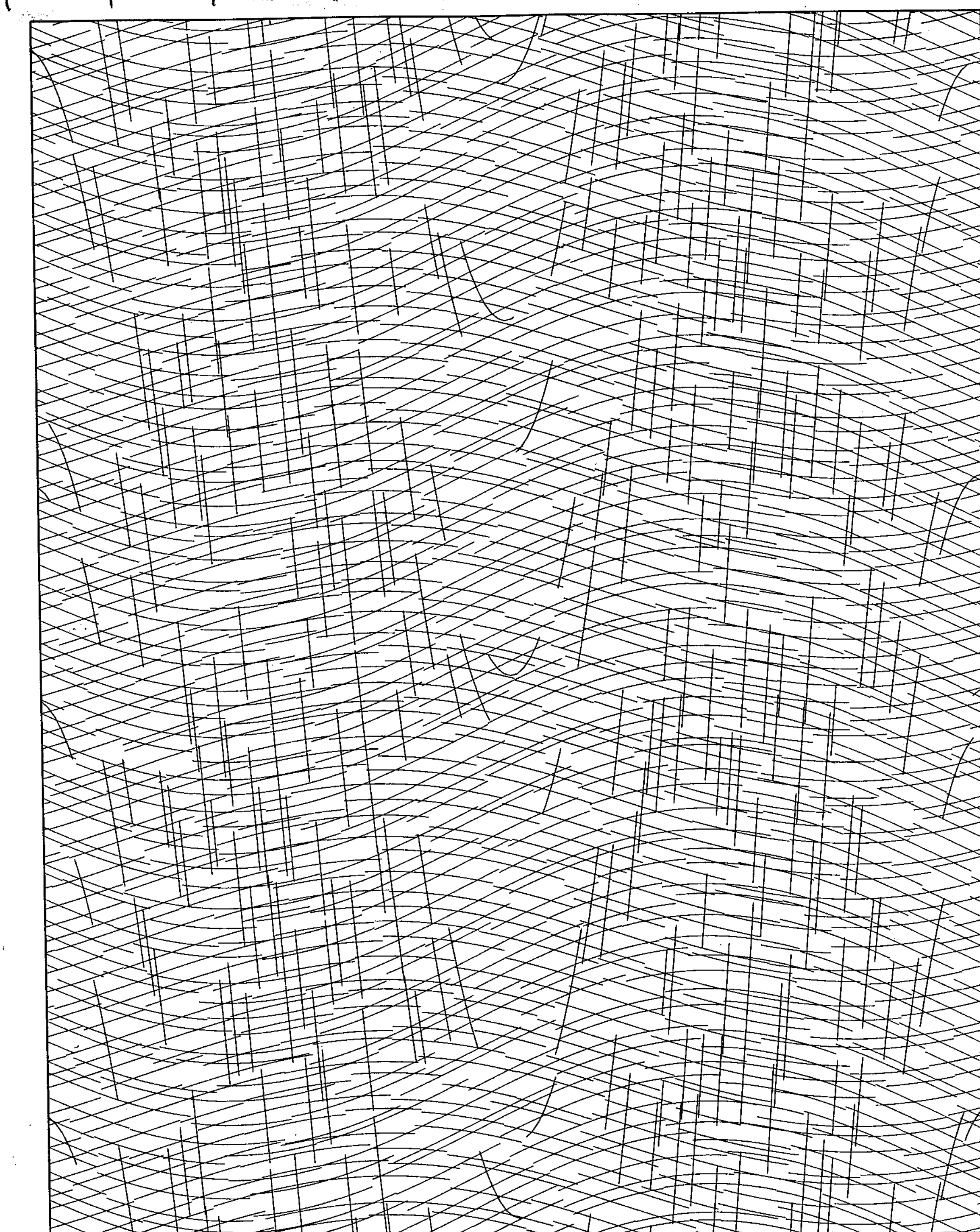
Tptpllcase file: UJNS1

Sh 9/21/2000



ShiGen-huw 08/06/00

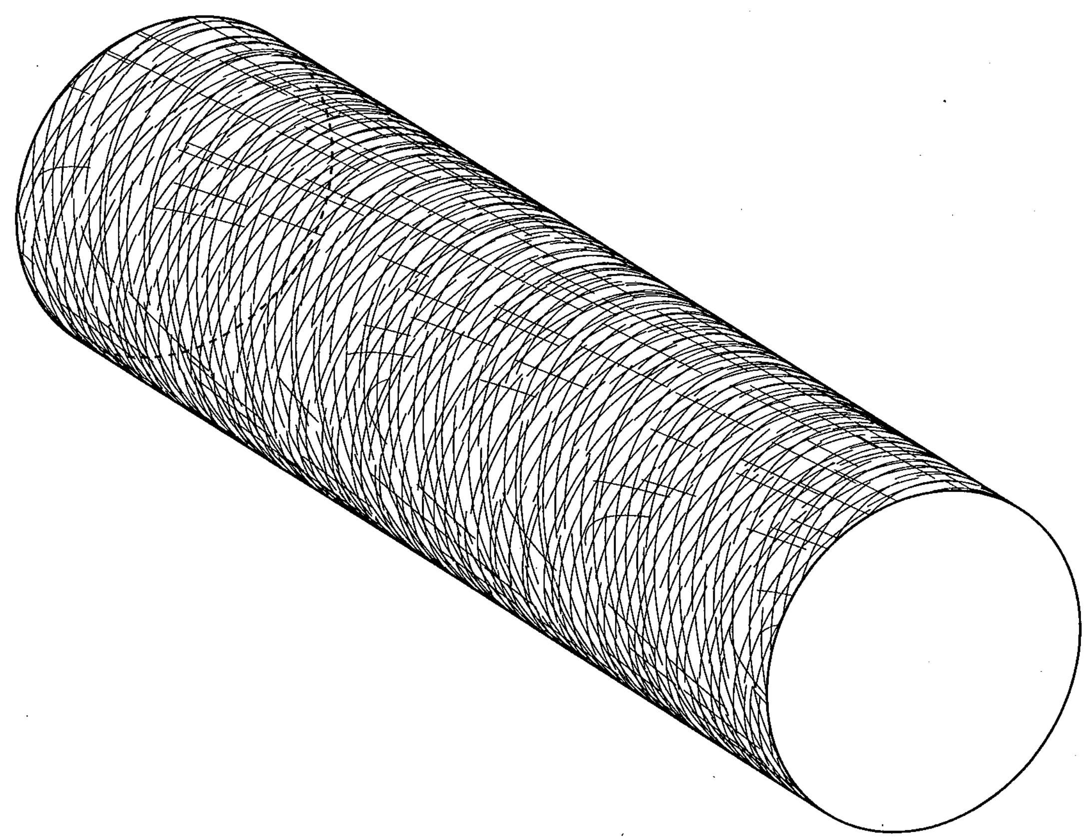
This is for Tptpllcase. this drawing shows the way of the unrolling of the joint sets.



Tptpllcase file: UJNS1 ShiGen-huw 08/06/00

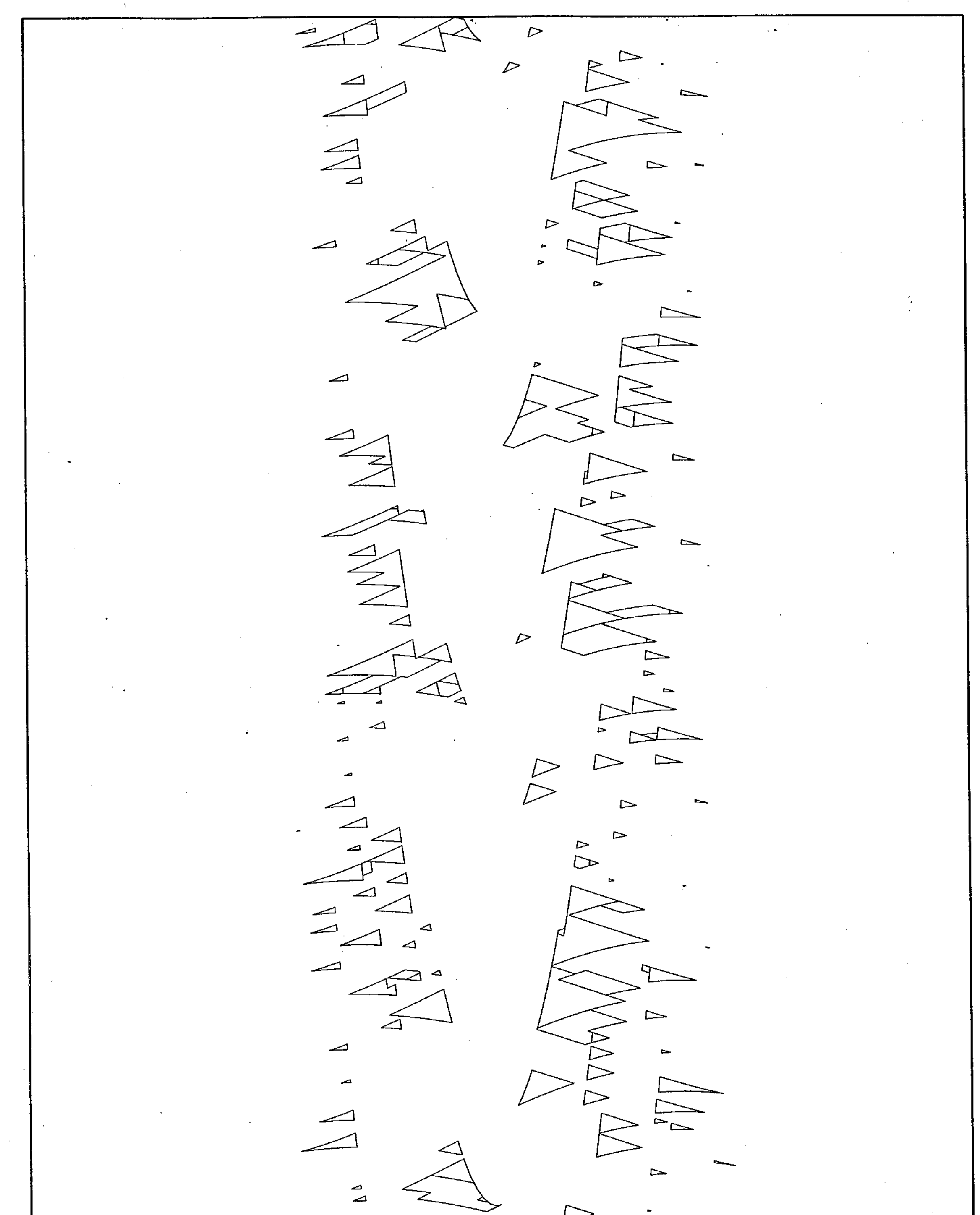
This is Tptpll case. this drawing is the unrolled map of statistically produced joint traces on the tunnel walls.

Tptpll case file: UJNS1
sh 9/21/2000



Shi Gen-hua
08/06/00

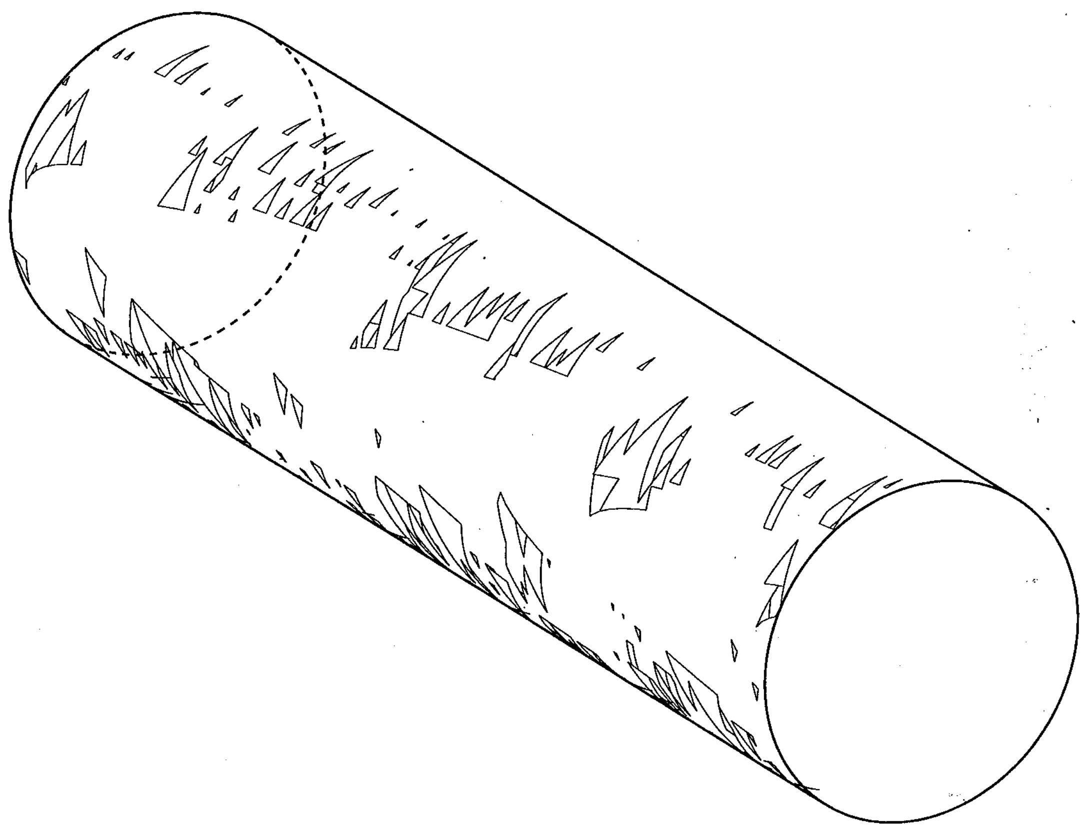
This is Tptpll case. This drawing is the three dimensional view of the previous joint trace map on the tunnel walls



Tptpll case file: UJNS1 Shi Gen-hua 08/06/00

This is Tptpllcase. This drawing is the key block areas of the unrolled joint trace map; Key blocks JPcodes: 311, 301, 031, 131

Tptpll case file: UJNS1
Shi 9/21/2000



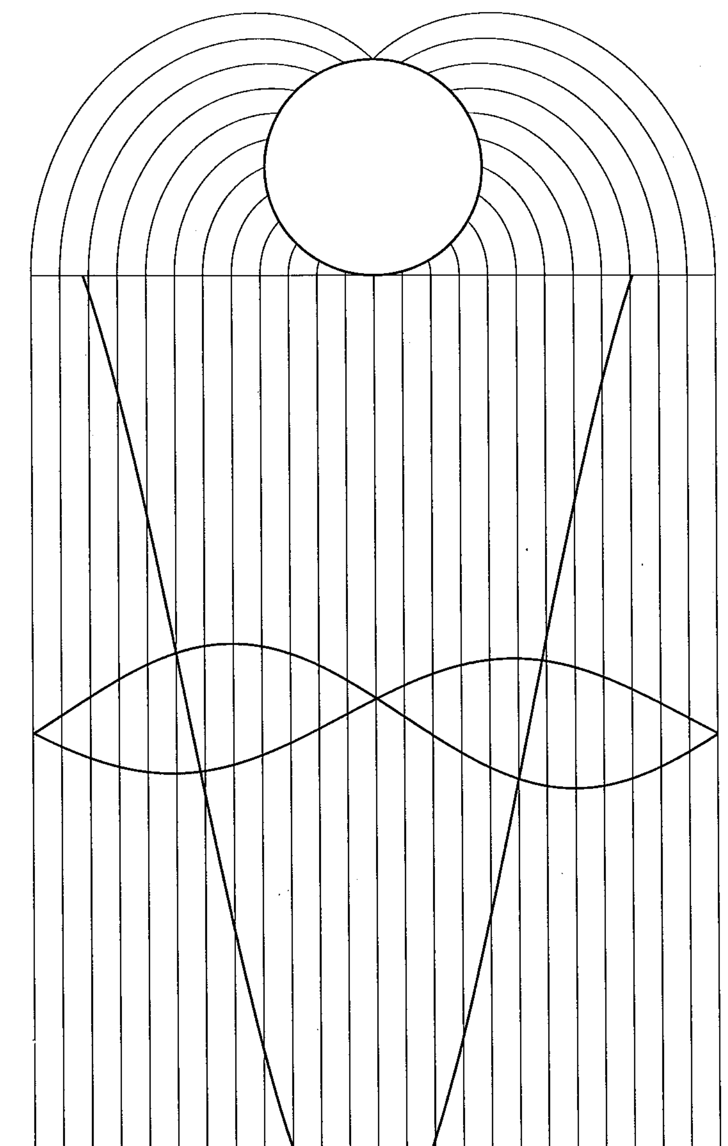
Shi Gen-hua
08/06/00

This is the 3-dimentional view of the previous key block areas.
JP = 311, 301, 031, 131: "3" means both sides.

Tptpul case file: UJNS2
Shi 9/21/2000

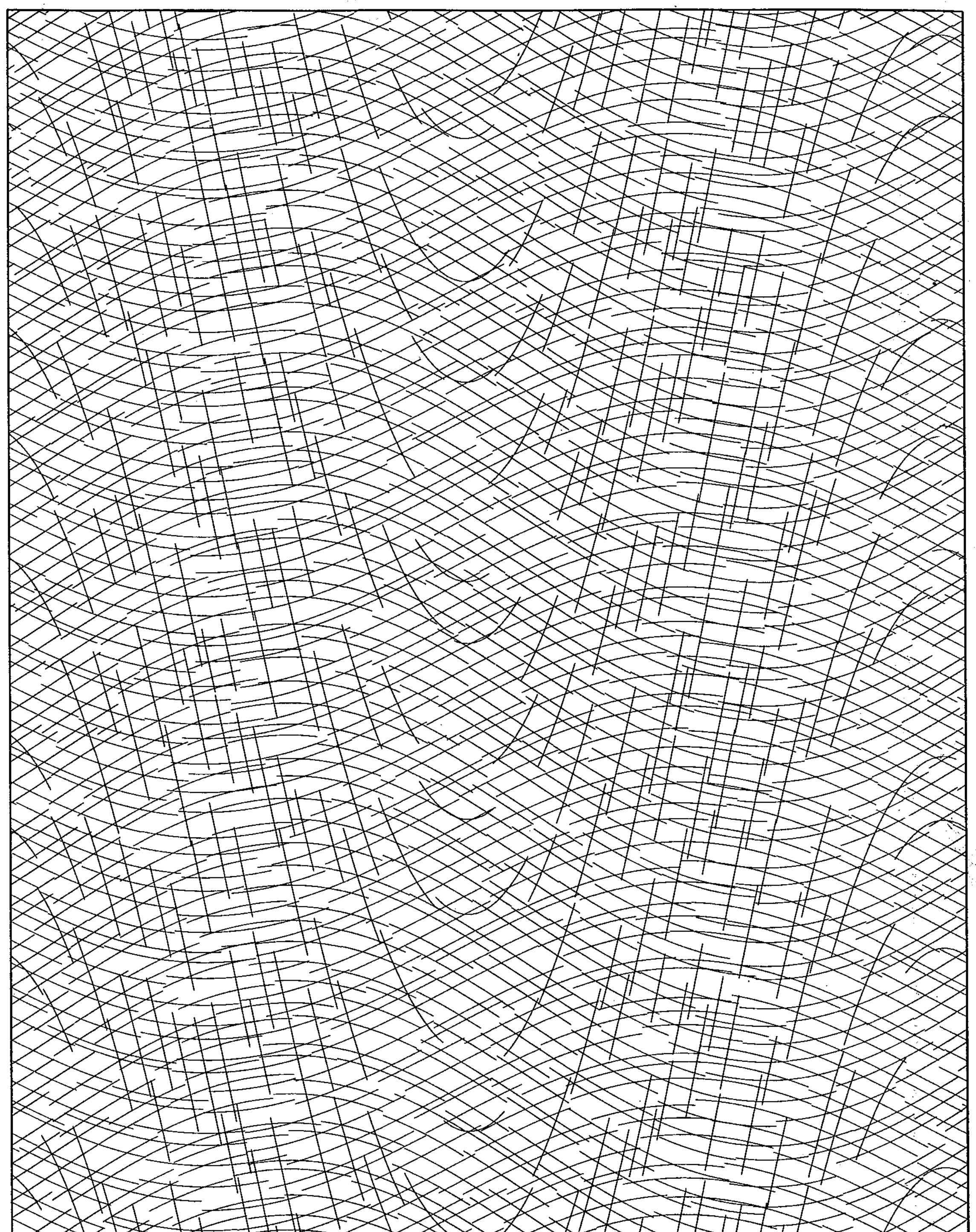
dip	dip d.	spacing	length	bridge	rand
82.00	288.00	0.30	1.80	0.01	0.70
82.00	228.00	0.30	2.40	0.01	0.70
14.00	39.00	0.50	1.80	0.01	0.70

bearing	rise	a=	b=	c=	jp=ujns2
75.00	0.00	2.75	2.75	0.00	



Shi Gen-hua 08/06/00

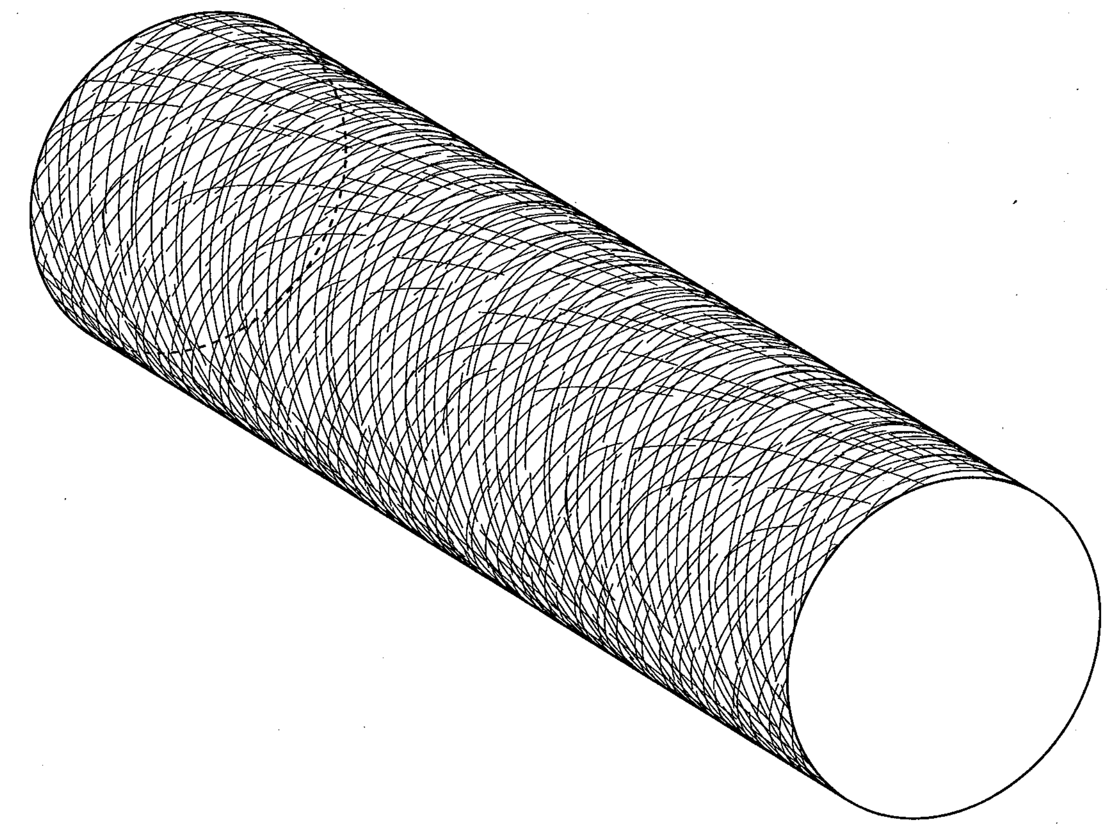
This is for Tptpll case. This drawing shows the way of the unrolling of the three joint sets.



Tptpul case file: UJNS2 ShiGen-huw 08/06/00

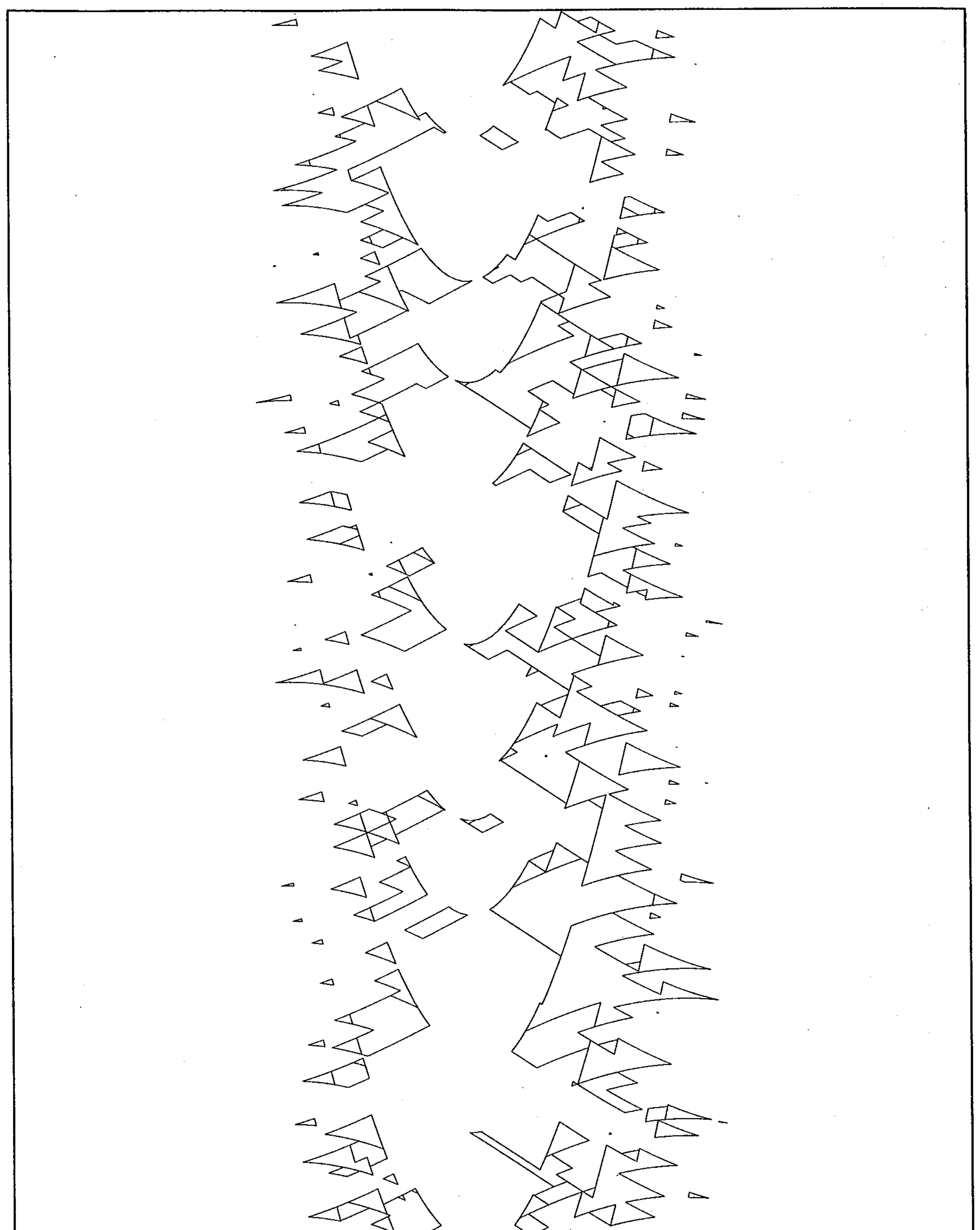
This is Tptpul case. This drawing is the unrolled map of statistically produced joint traces on the tunnel walls.

Tptpul case file: UJNS2
[signature] 9/21/2000



ShiGen-huw
08/06/00

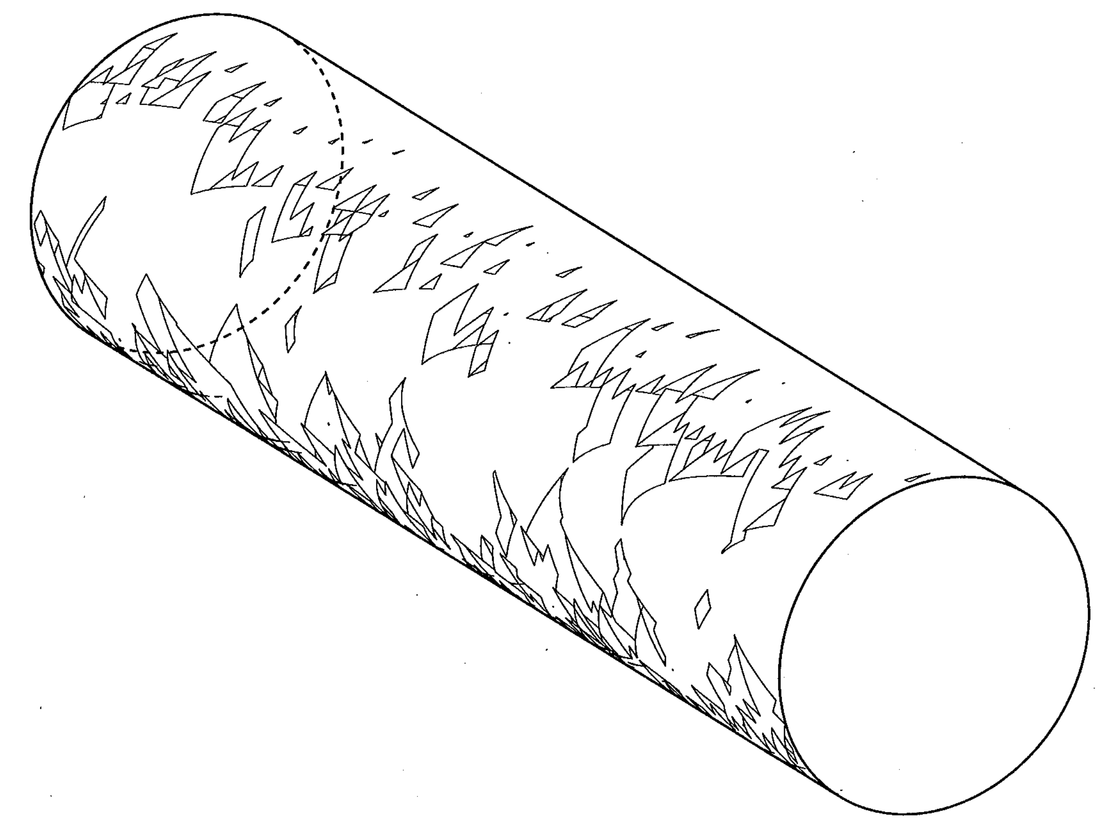
This is Tptpul case. This drawing is the three dimensional view of the previous joint trace map on the tunnel walls.



Tptpul case file: UJNS2 Shi Gen-hua 08/06/00

This is Tptpul case. This drawing is the key block areas of the unrolled joint trace map. Key block JP codes: 311, 301, 031, 131.

Tptpul case file: UJNS2
9/21/2000



Shi Gen-hua
08/06/00

This is the three dimensional view of the previous key block areas. Shi Gen-hua
08/06/00

1.5. DDA computations of the rock falling under the new tunnel direction;
Case I.
previous tunnel direction N105°E
New tunnel direction N75°E

DL file: DLS5, Change from DLS1
a) maximum distance of nodes
from 0.025 to 0.023 (1st number)
b) bridge of 1st jointset
from 0.4 to 0.3 same as spacing
c) tunnel bearing
from 105° to 75°

DC file: DCS5, produced by DL

DF file: DFS5 (copy of DFS1)

(G.)
~~Renamed:~~ Renamed: [initials] 9/21/2000

DC file DCS10, produced by DL
DF file DFS10 (copy of DFS1)

output 10 figures, 2 second per Figure, Duration of the earth quake is 20 Seconds.

Case I: next seven pictures are the out put of Case 2.
The rock falling time 0-6 seconds
The rock displacement time 0-10 Seconds.
The rock stable time 10-20 Seconds.

Case 1 0 second [initials] 9/21/2000

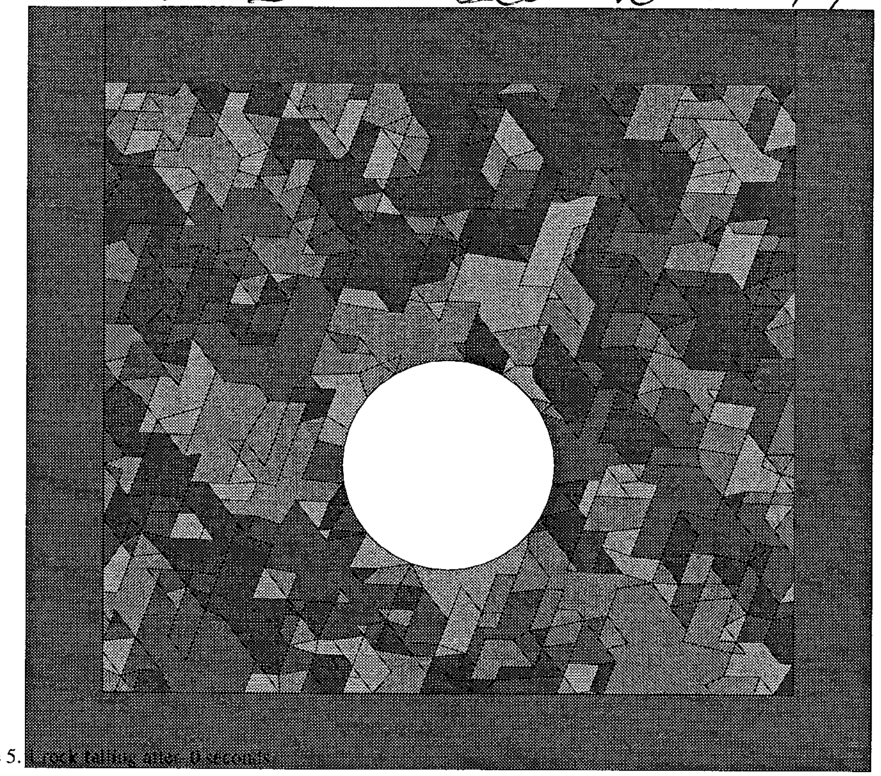


Figure 5.1 rock falling after 0 seconds

Shi Gen-hua 08/28/00

Case 1 2 second

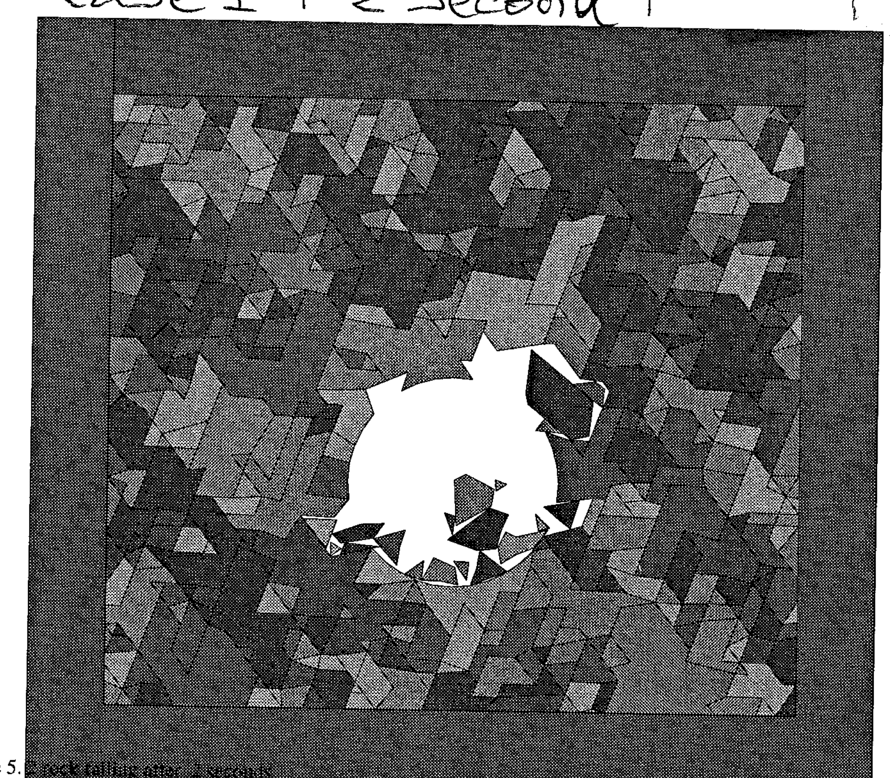


Figure 5.2 rock falling after 2 seconds

Shi Gen-hua 08/28/00

case 1 4 seconds [initials] 9/21/2000

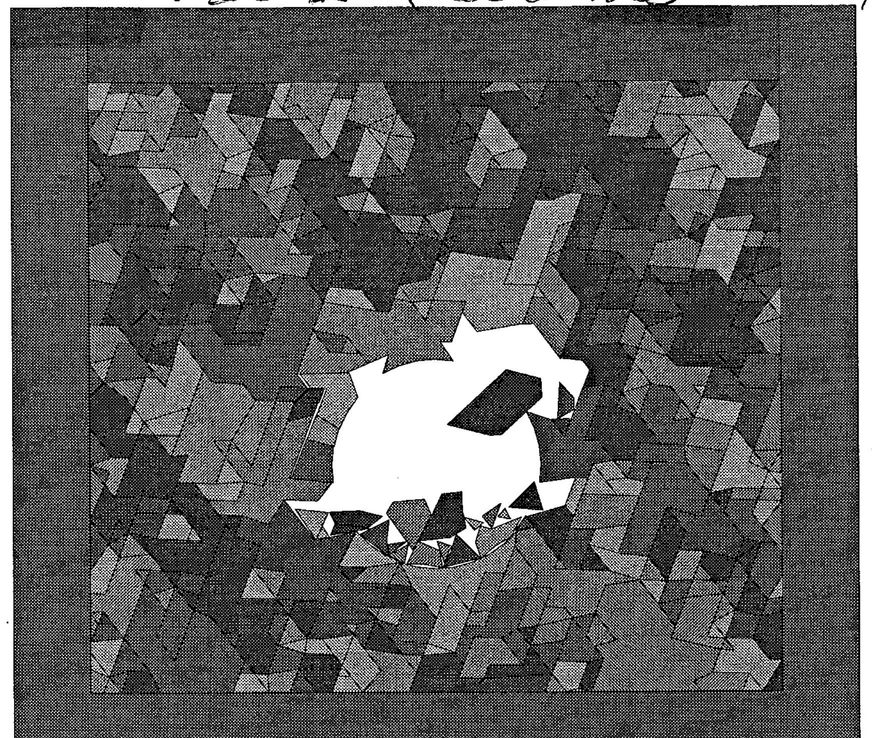


Figure 5.3 rock falling after 4 seconds

ShiGen-hua 08/08/00

case 1 6 Seconds

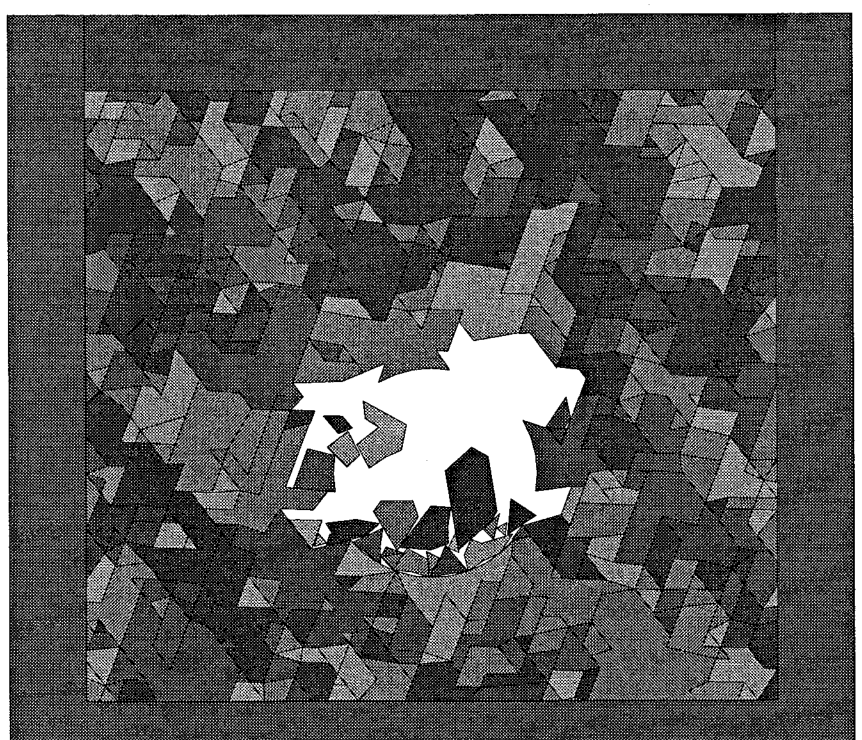


Figure 5.4 rock falling after 6 seconds

ShiGen-hua 08/08/00

case 1 8 seconds [initials] 9/21/2000

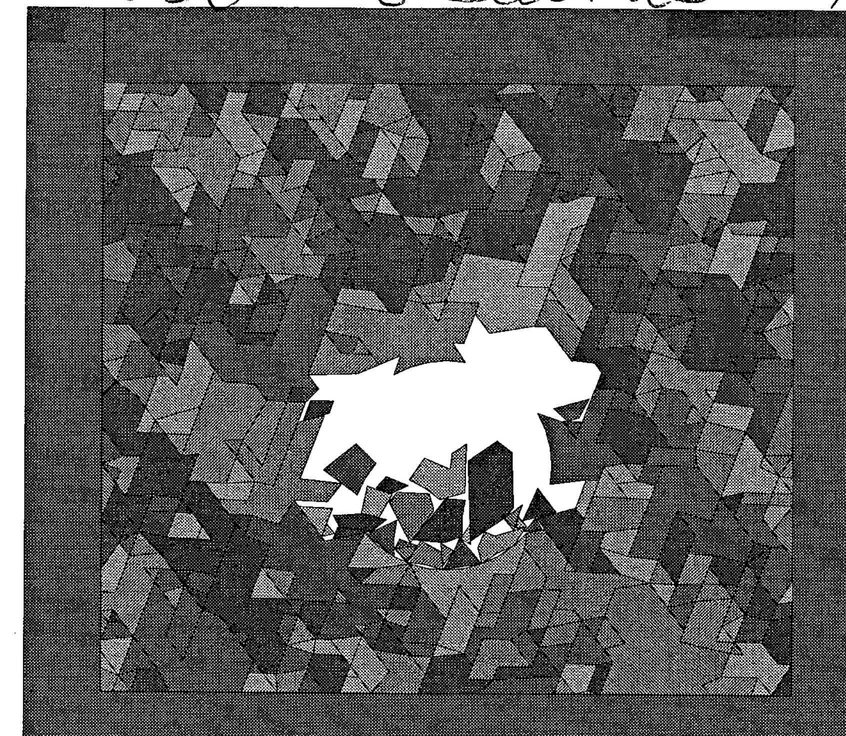


Figure 5.5 rock falling after 8 seconds

ShiGen-hua 08/08/00

case 1 10 Seconds

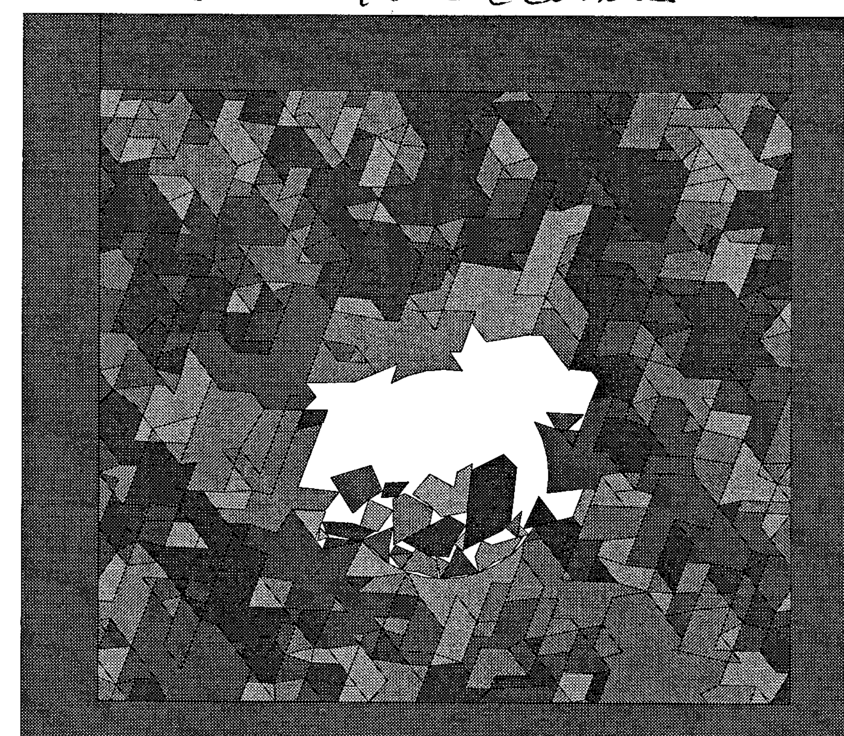


Figure 5.6 rock falling after 10 seconds

ShiGen-hua 08/08/00

case 1 20 seconds [initials] 9/21/2000

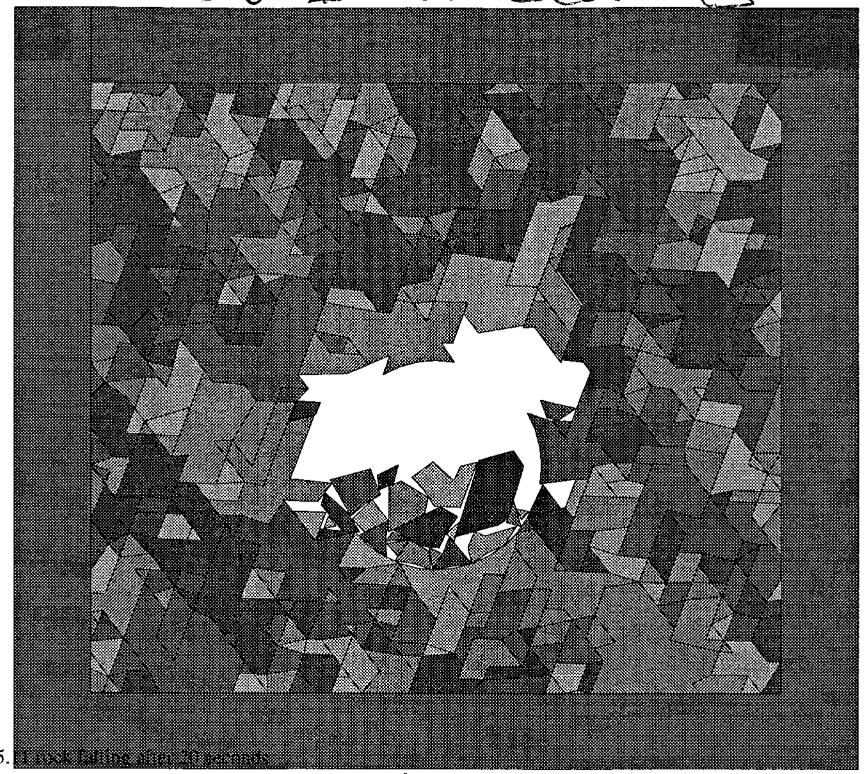


Figure 5. 1 rock falling after 20 seconds

Shi Genhua 08/08/00

From 2 second drawing, many blocks are in the tunnel bottom. Shince the tunnel diameter is 5.5 m, free falling

$$S = \frac{1}{2} g t^2, \quad g = 9.8\,m, \quad t = 1\,sec$$

$$S = 0.49\,m \times 10 = 4.9\,m$$

So the 1 second rock block can fall 4.9 m maximum.

Therefore the computation is reasonable.

Shi Genhua 08/08/00

16. DDA computation of rock falling case 2.

a) maximum distance of nodes from 0.025 change to 0.023

b) bridge of 1st joint set changes from 0.4 to 0.3 (same as the joint spacing)

c) tunnel bearing changes from 105° to 75°

DC file DCS20

DF file DFS20

The results are the following

case 2 0 second [initials] 9/21/2000

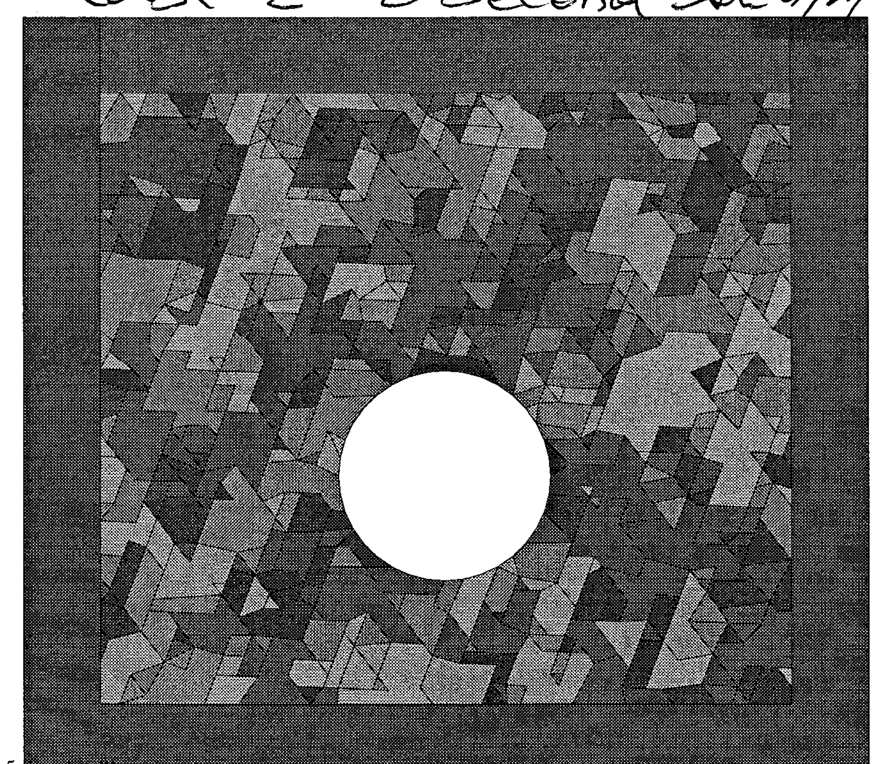


Figure 5. 1 rock falling after 0 seconds

Shi Genhua 08/08/00

case 2 2 seconds [illegible] 9/21/2000

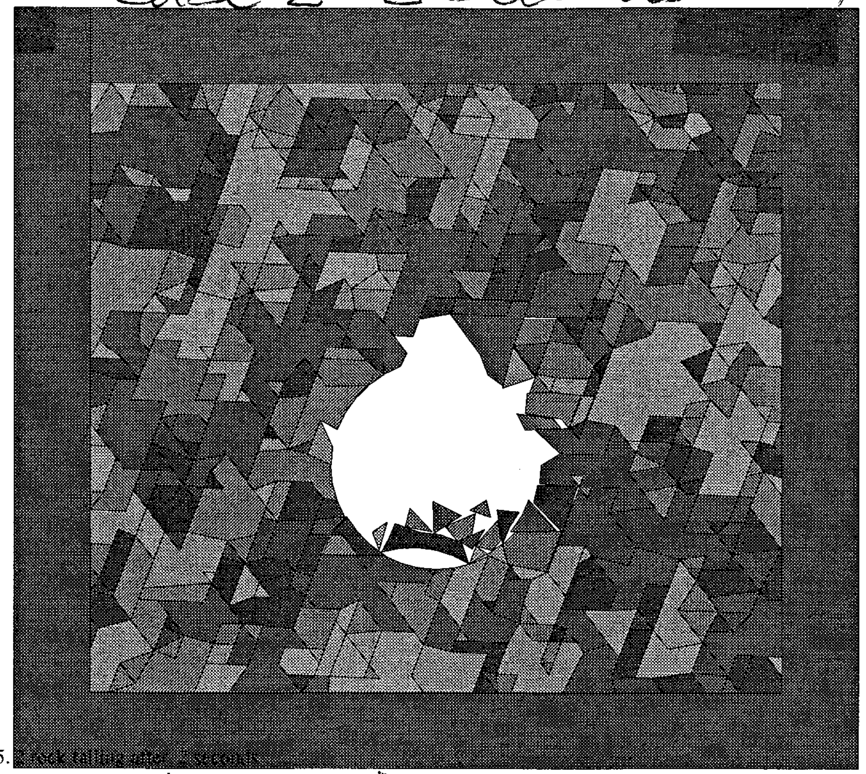


Figure 5.[illegible] rock falling after [illegible] seconds

Shi Gen-hua, 08/10/00

case 2 4 Seconds

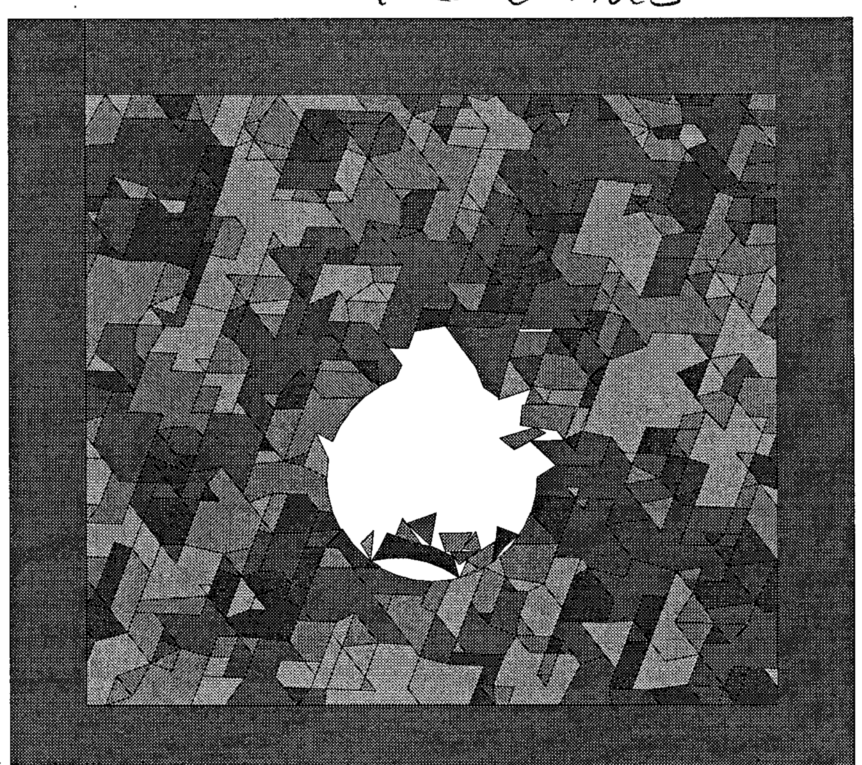


Figure 5.[illegible] rock falling after [illegible] seconds

Shi Gen-hua, 08/10/00

case 2 6 seconds [illegible] 9/21/2000

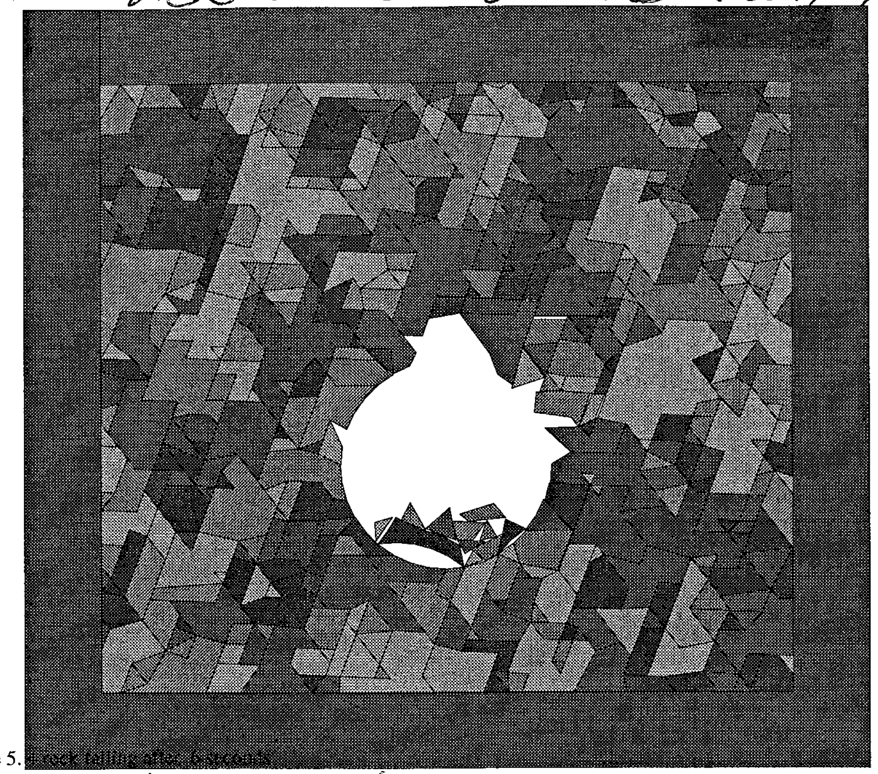


Figure 5.[illegible] rock falling after 6 seconds

Shi Gen-hua 08/10/00

case 2 8 seconds

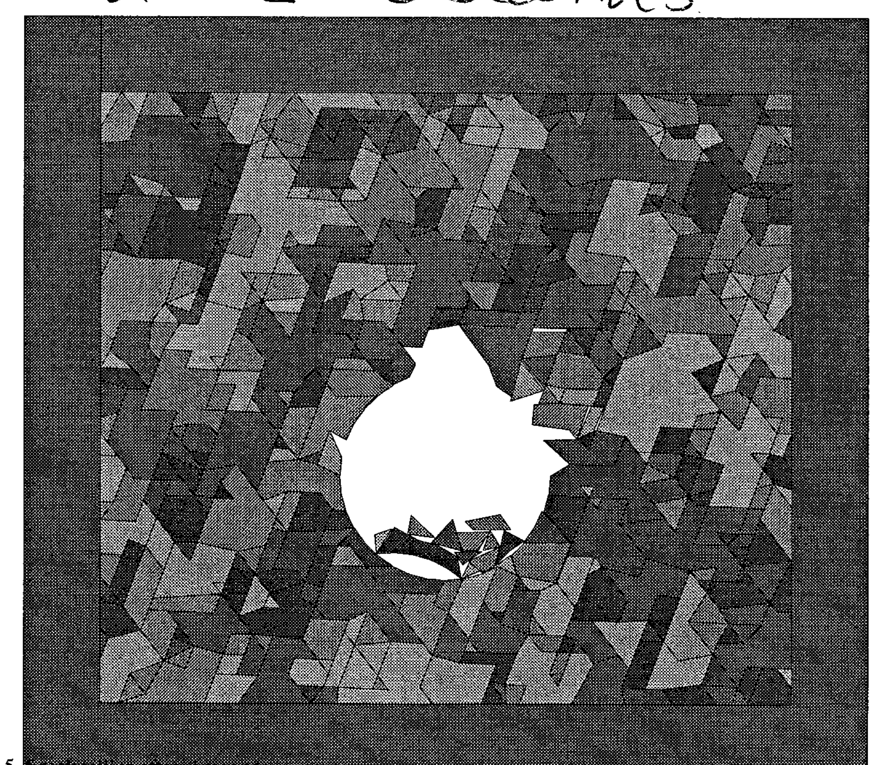


Figure 5.[illegible] rock falling after [illegible] seconds

Shi Gen-hua 08/10/00

case 2 20 seconds Sh 9/21/2000

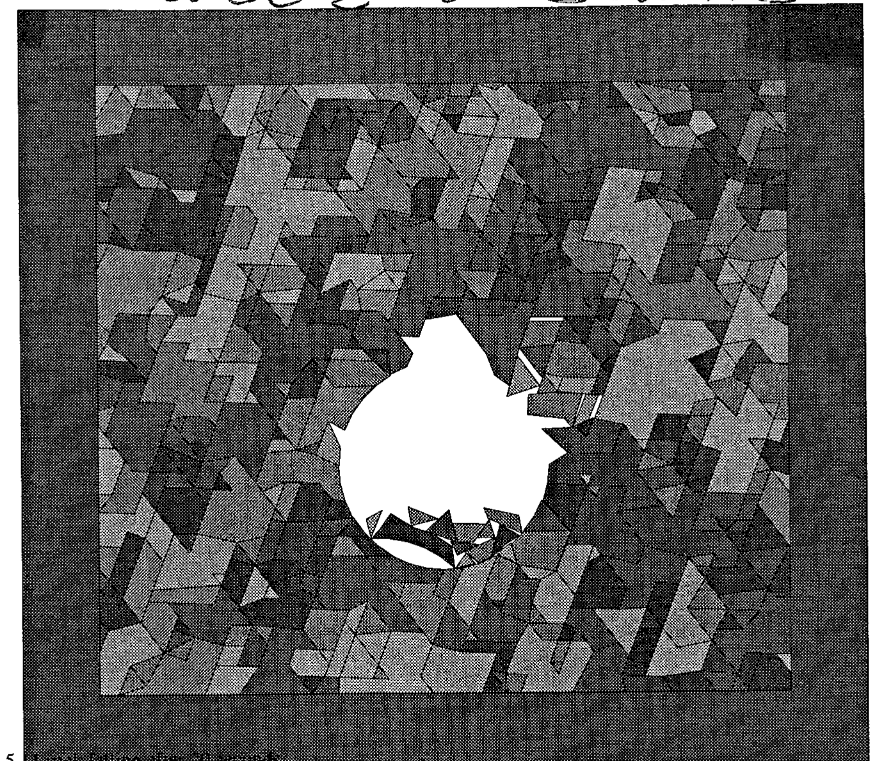


Figure 5.1 rock falling after 20 seconds

Shi Gen-hua 08/10/00

In the case 2 the fallowing movements or rock falling take place:

a) in 2 second, all of the falling blocks move to the tunnel bottom.

b) from 2-8 seconds only one small block falls.

c) untill 20 seconds, some joint opens.

Shi Gen-hua 08/10/00

17 DDA computation of rock falling case 3:

a) maximum distance of nodes changes from 0.25 to 0.23

b) bridge of 1st joint set changes from ~~0.4~~ to 0.3 (same as the joint ~~spacing~~ spacing. G. Sh 9/21/2000

c) tunnel bearing changes from 105° to 75°

DC file: DCS30
DF file: DFS30
the results are the following

case 3 0 second Sh 9/21/2000

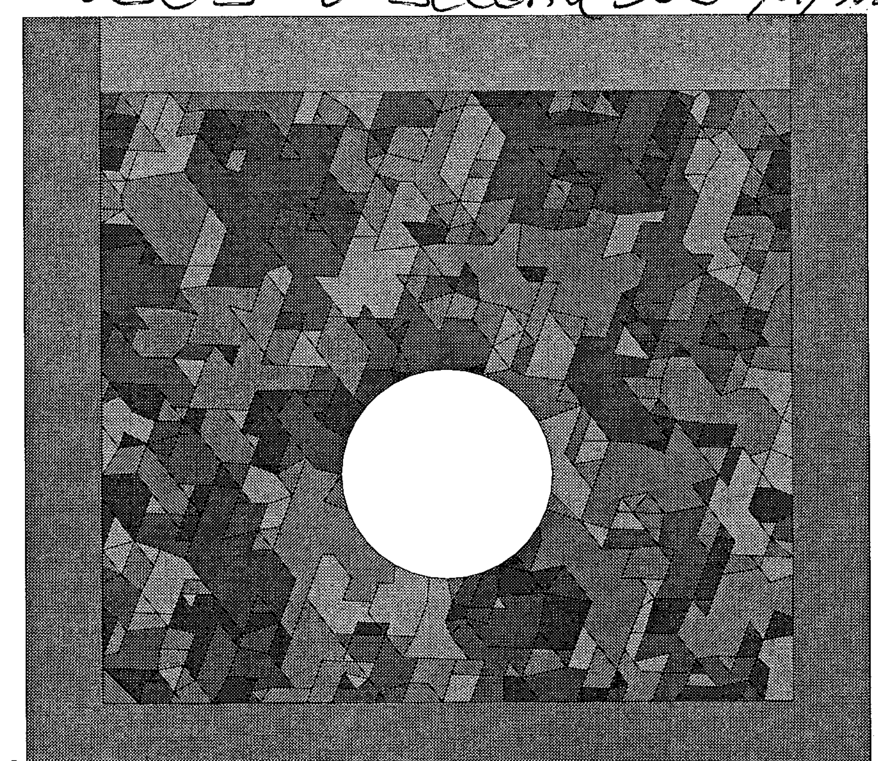


Figure 5.1 rock falling after 0 seconds

Shi Gen-hua, 08/12/00

case 3 2 seconds Shi 9/21/2000

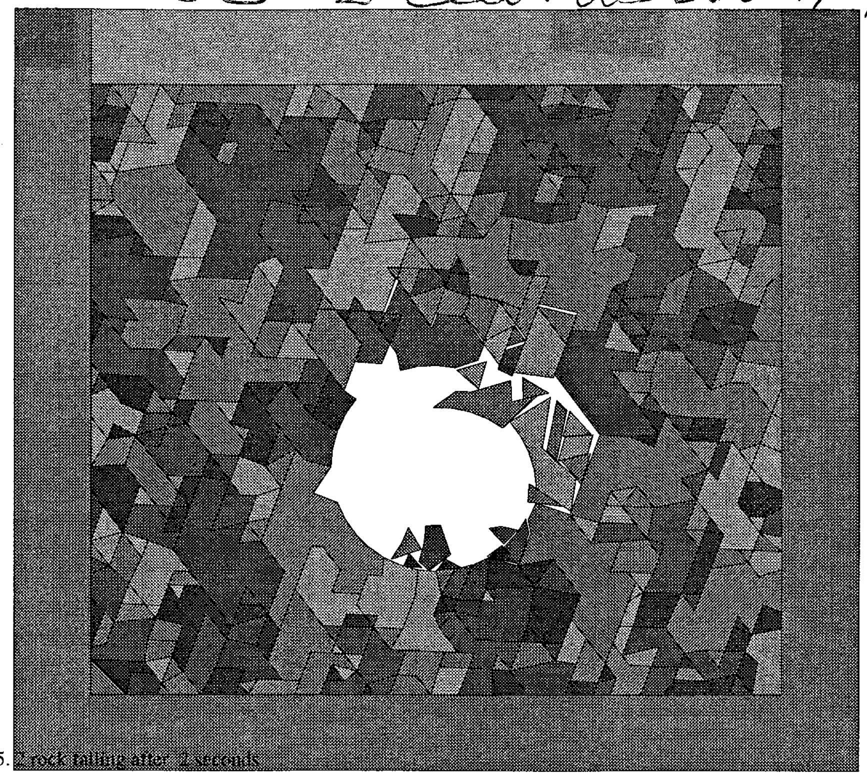


Figure 5.2 rock falling after 2 seconds

Shi Gen-hua 08/12/00

case 3 4 seconds

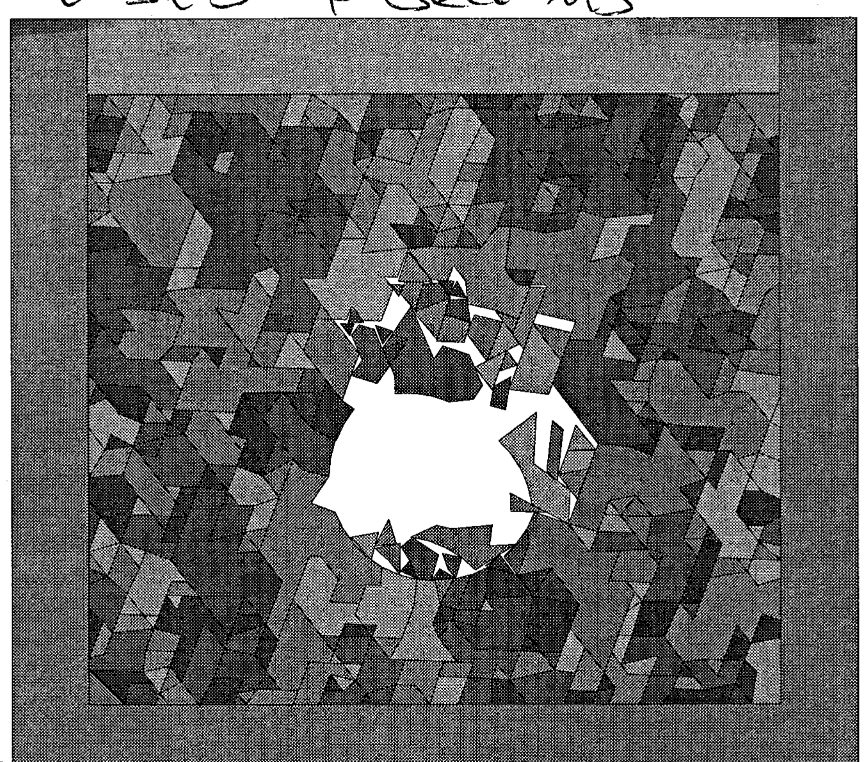


Figure 5.3 rock falling after 4 seconds

Shi Gen-hua 08/12/00

case 3 6 seconds Shi 9/21/2000

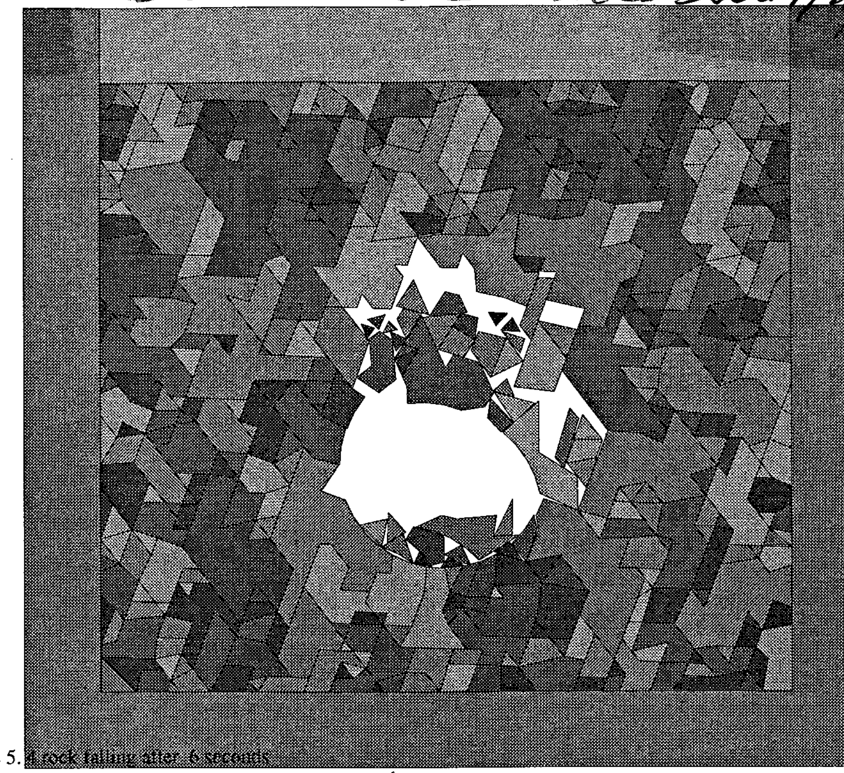


Figure 5.4 rock falling after 6 seconds

Shi Gen-hua 08/12/00

case 3 8 seconds

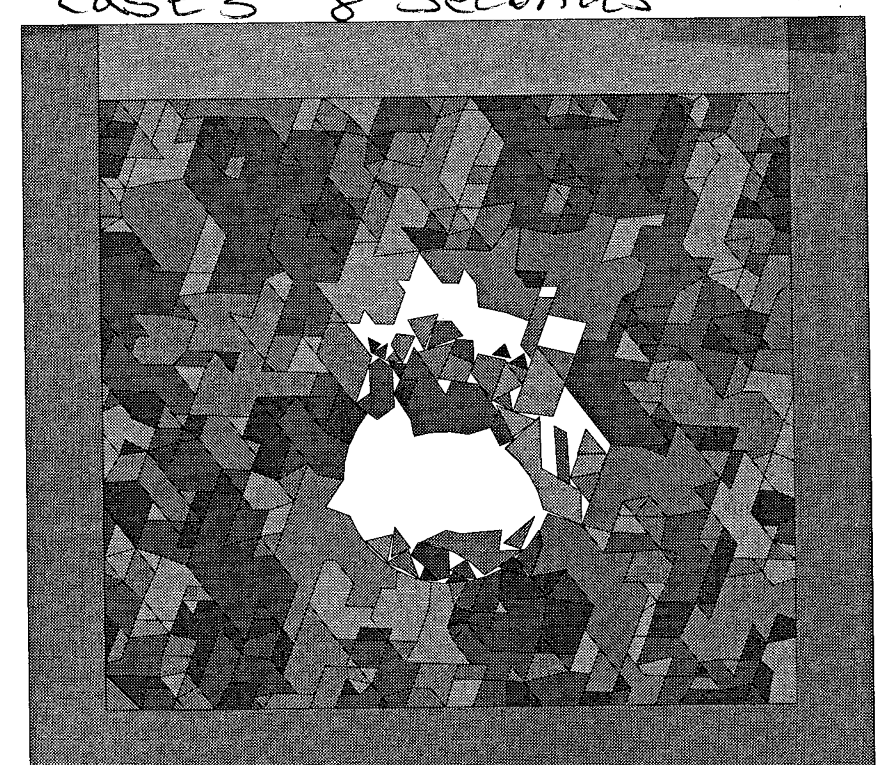


Figure 5.5 rock falling after 8 seconds

Shi Gen-hua 08/12/00

case 3 10 seconds Sh 9/21/2000

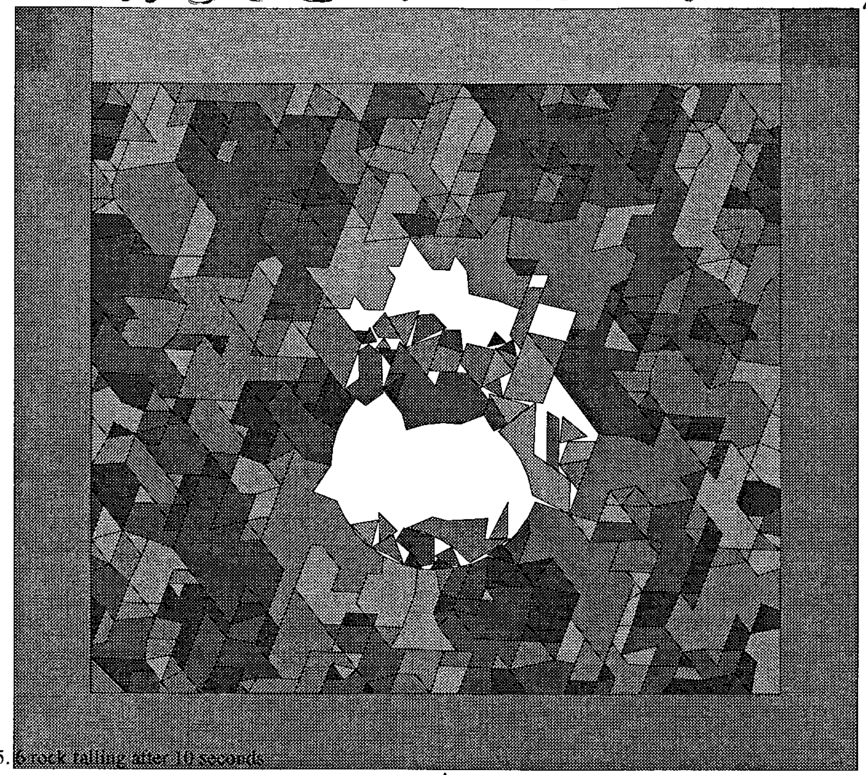


Figure 5.6 rock falling after 10 seconds

Shi Gen-hua 08/12/00

case 3 12 seconds

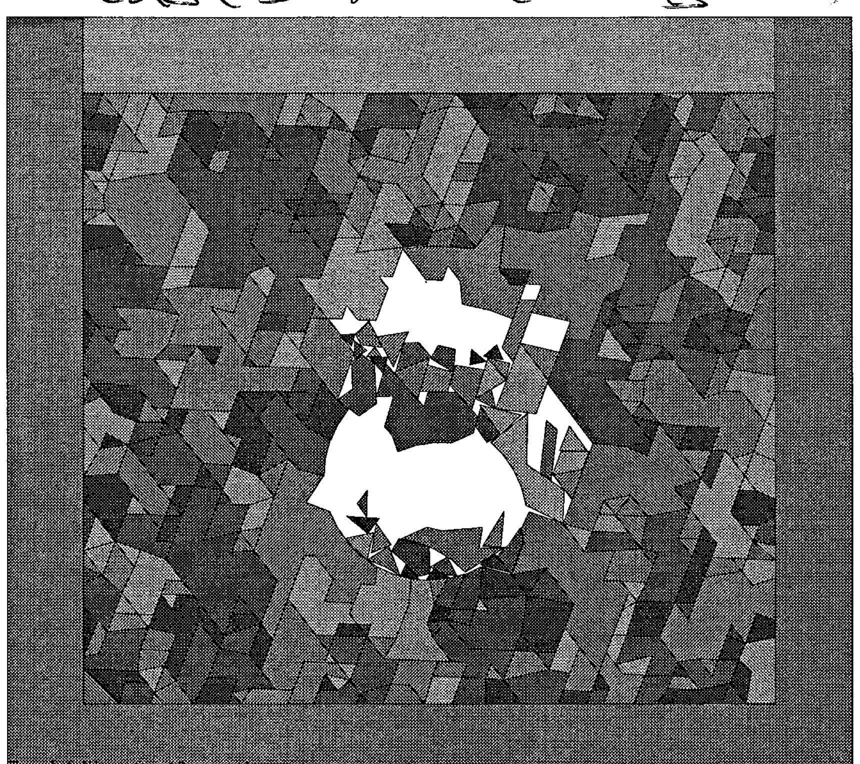


Figure 5.7 rock falling after 12 seconds

Shi Gen-hua 08/12/00

case 3 14 seconds Sh 9/21/2000

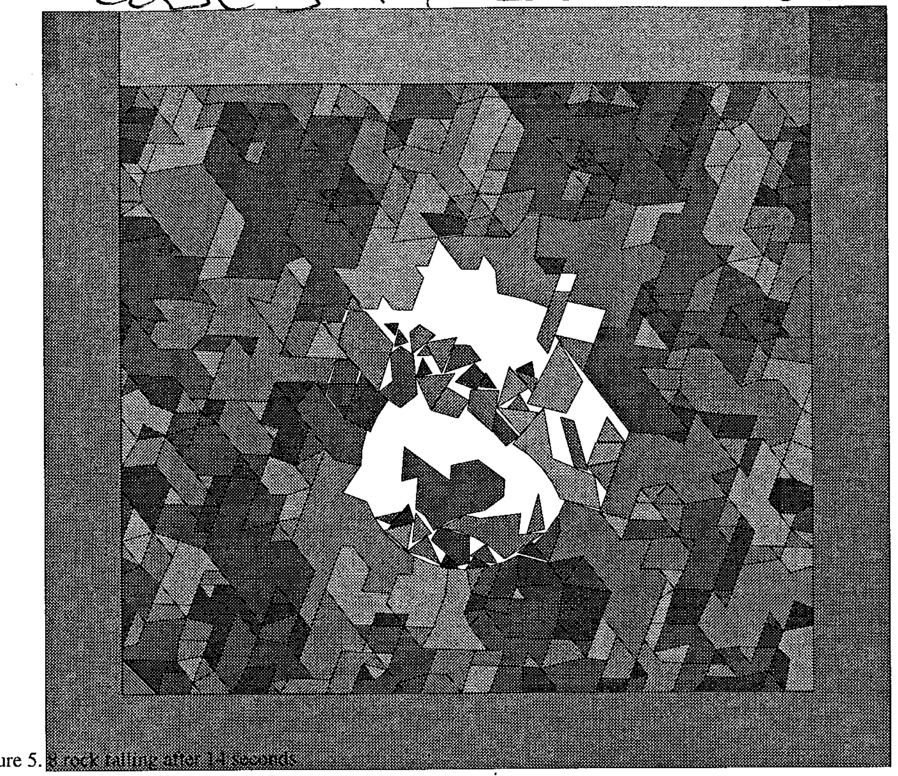


Figure 5.8 rock falling after 14 seconds

Shi Gen-hua 08/12/00

case 3 16 seconds

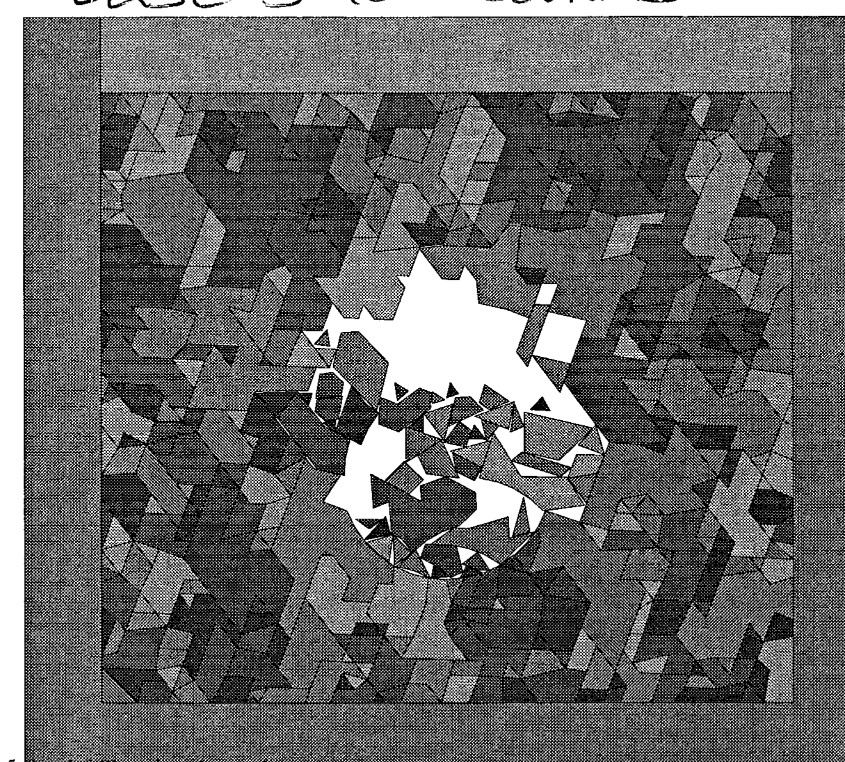


Figure 5.9 rock falling after 16 seconds

Shi Gen-hua 08/12/00

case 3 | 18 seconds Shi 9/21/2000

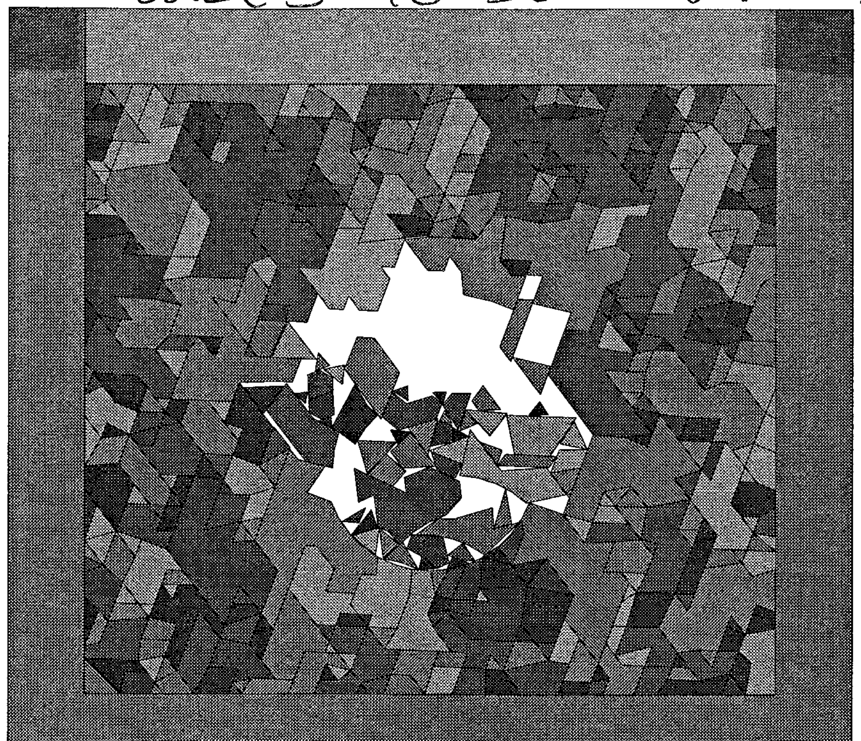


Figure 5.10 rock falling after 18 seconds

Shi Gen-hua 08/12/00

case 3 | 20 | seconds

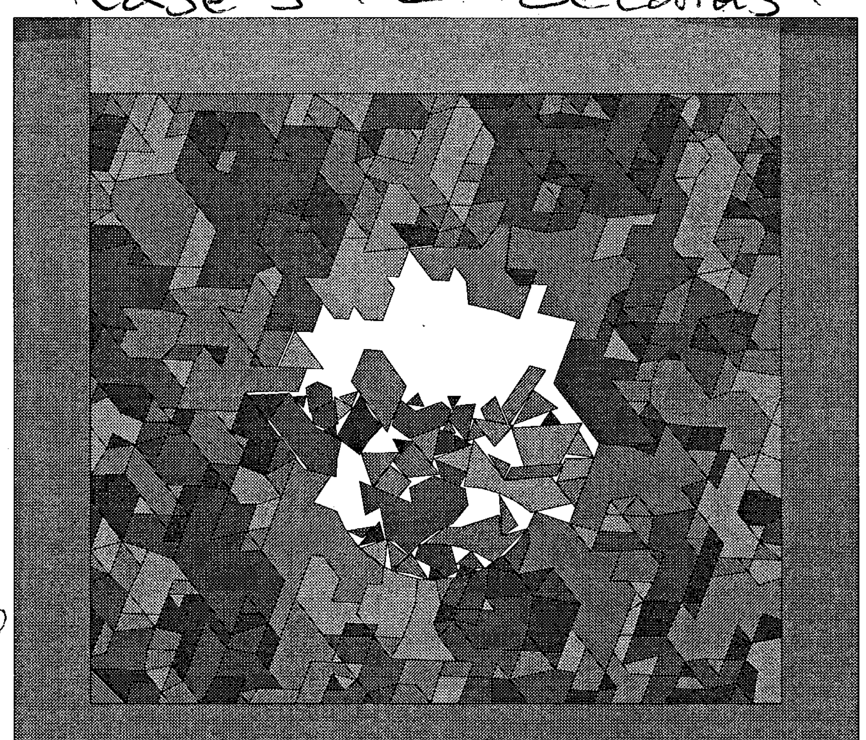


Figure 5.11 rock falling after 20 seconds

Shi Gen-hua 08/12/00

Shi Gen-hua 08/12/00

18 DDA computation of rock falling case 4:

a) maximum distance of nodes changes from 0.25 to 0.23

b) bridge of 1st joint set changes from 0.4 to 0.3 (same as the joint spacing)

c) tunnel bearing changes from 105° to 75°

DC file DCS40
DF file DFS40

The results are the following:

case 4 0 second Shi 9/21/2000

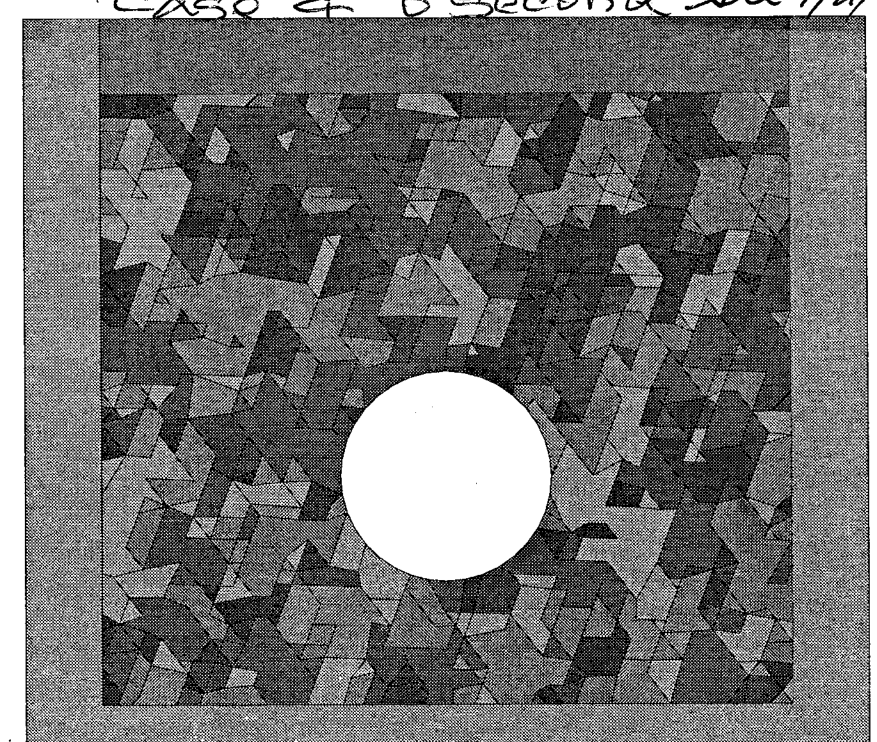


Figure 5.1 rock falling after 0 seconds

Shi Gen-hua 08/14/00

case 4 2 second Sh 9/21/2000

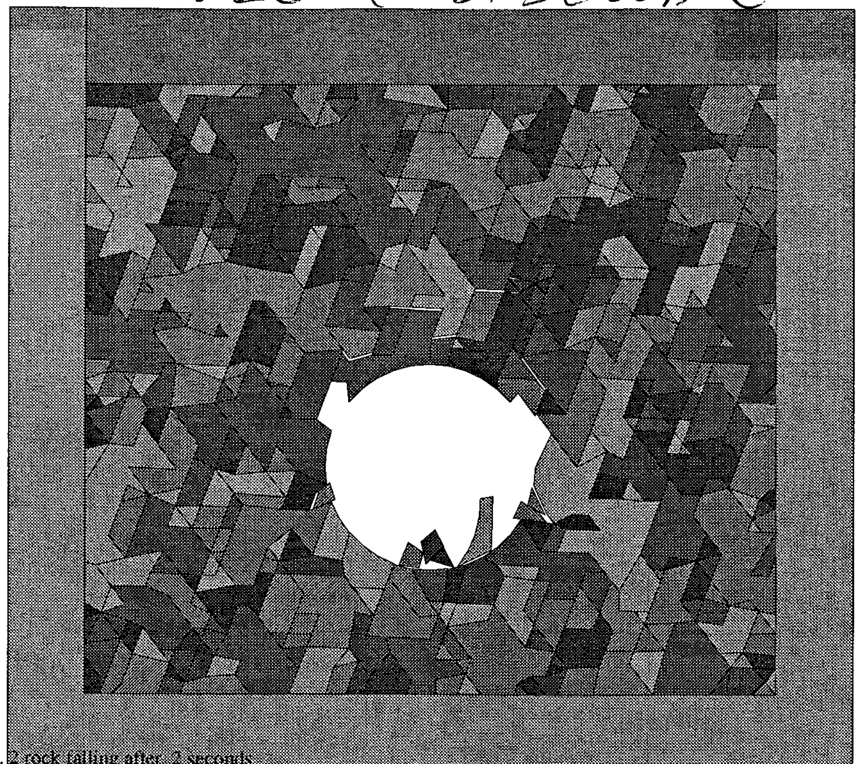


Figure 5. 2 rock falling after 2 seconds

Shi Gen-hua 08/14/00

case 4 4 seconds

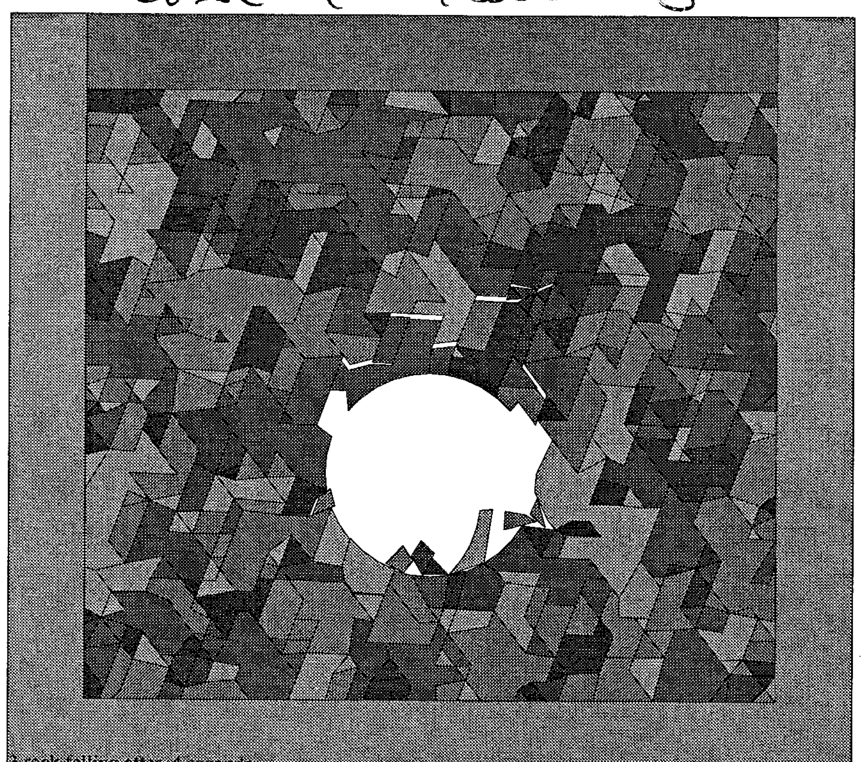


Figure 5. 3 rock falling after 4 seconds

Shi Gen-hua 08/14/00

case 4 6 seconds Sh 9/21/2000

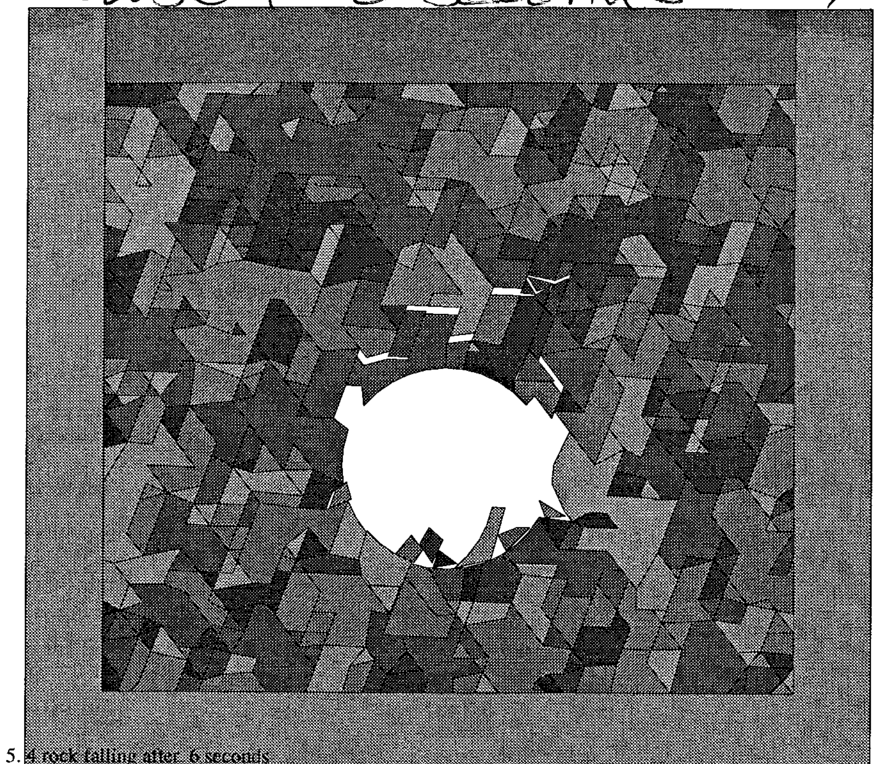


Figure 5. 4 rock falling after 6 seconds

Shi Gen-hua 08/14/00

case 4 8 seconds

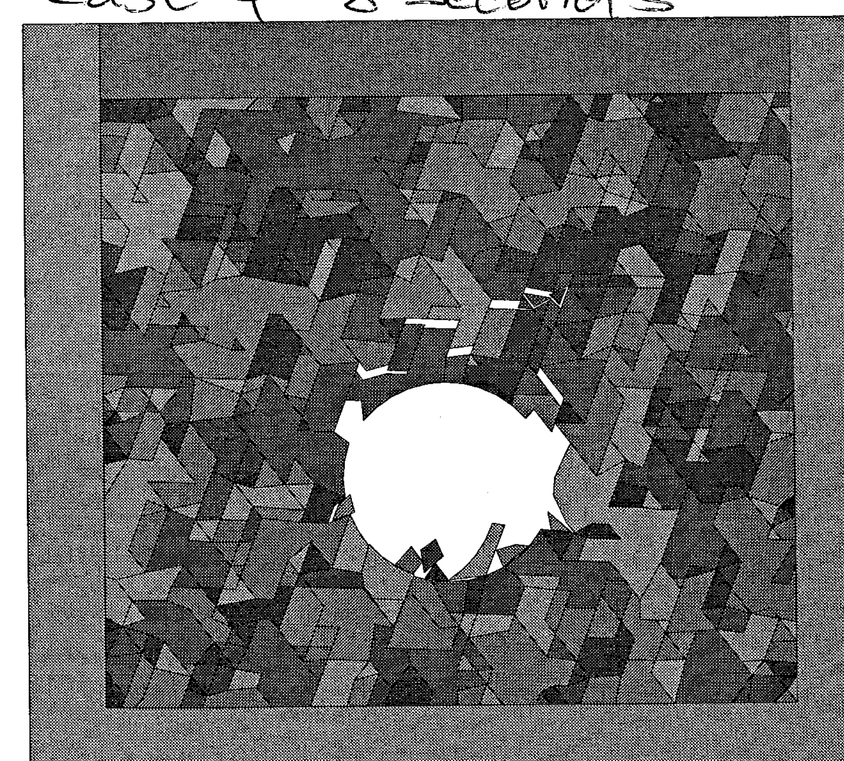


Figure 5. 5 rock falling after 8 seconds

Shi Gen-hua 08/14/00

case 4 10 seconds 9/21/2000

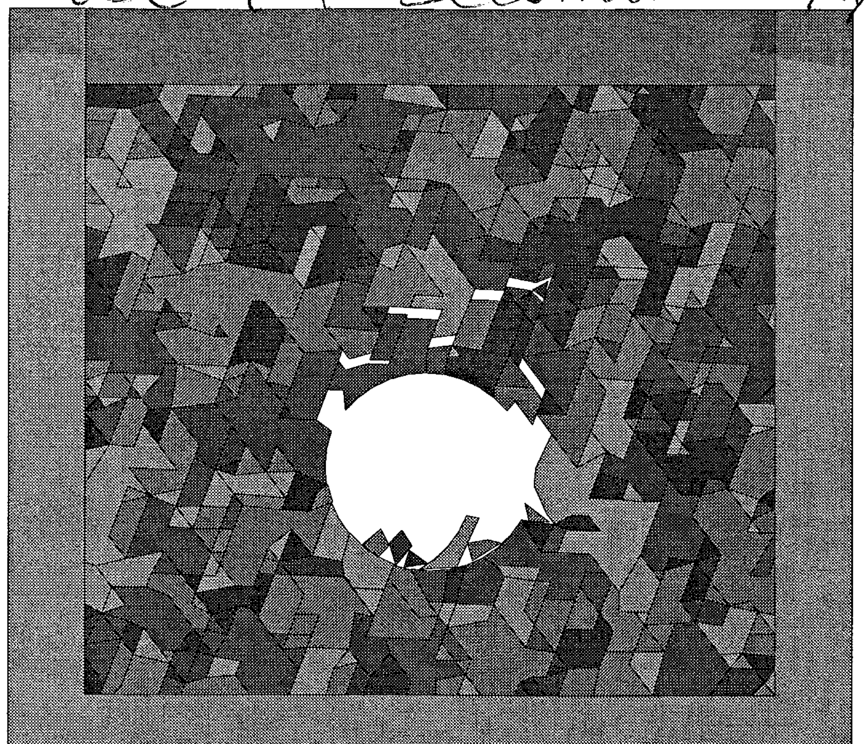


Figure 5.6 rock falling after 10 seconds

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case 4 12 seconds

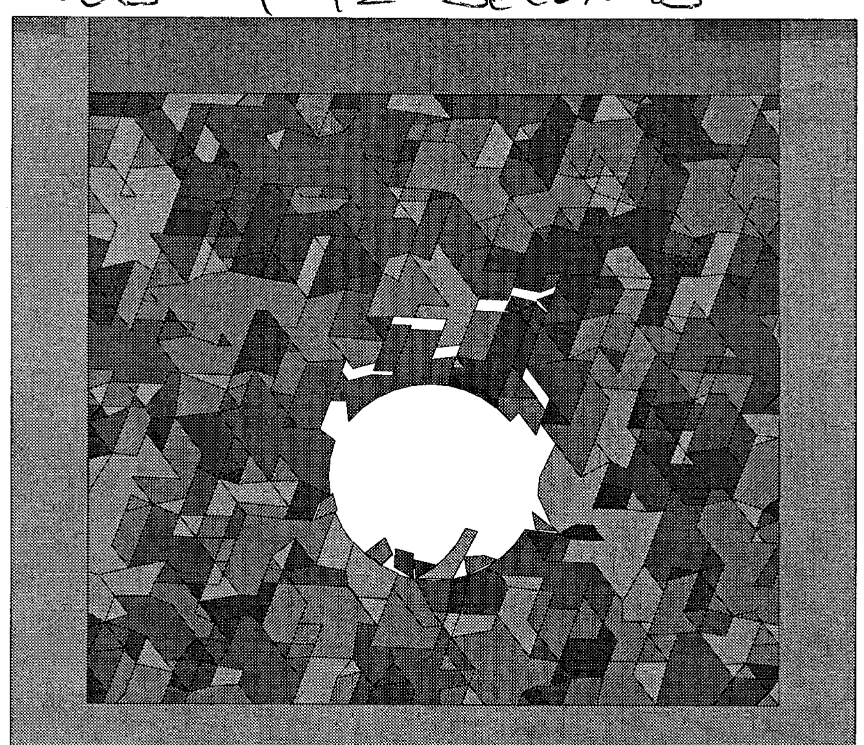

Figure 5.7 rock falling after 12 seconds

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case 4 20 seconds 9/21/2000

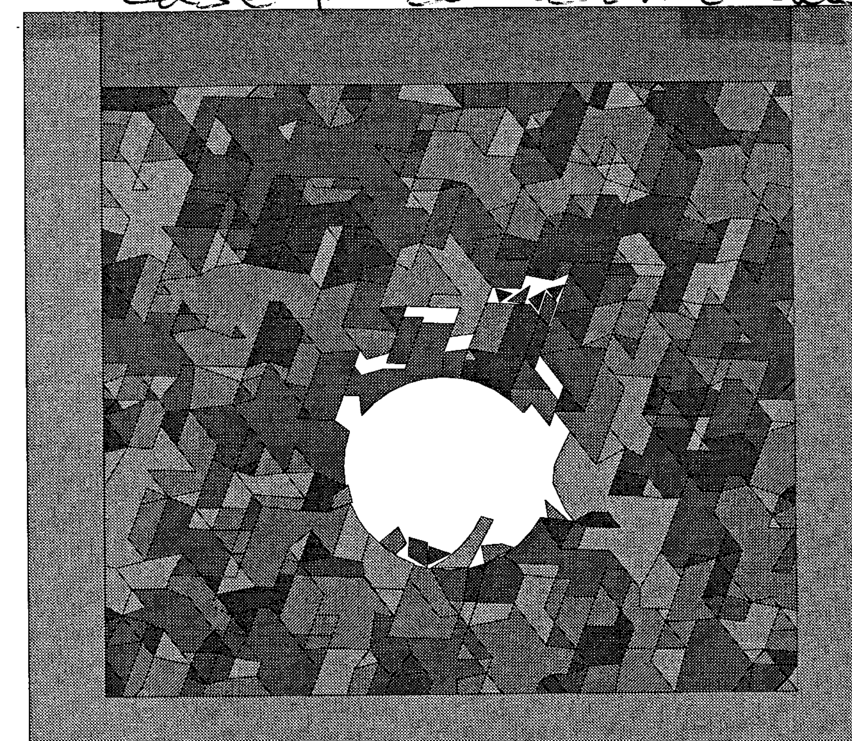

Figure 5.11 rock falling after 20 seconds

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The out put drawing shows

a) from 0-2 seconds, all 5 falling blocks move to the tunnel bottom.

b) from 2-20 seconds, many joints on top of the tunnel still open.

c) there are many blocks on the top of tunnel, which move but not falling.

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19. DDA computation of rock falling, case 5:

a) Maximum distance of the nodes changes from 0.25 to 0.23

b) Bridge of the 1st joint set changes from 0.4 to 0.3 (0.3 is the joint spacing)

c) tunnel bearing changes from 105° to 75°

DC file DC550
DF file DF550

The results are the following

case 5 0 second [initials] 9/21/2000

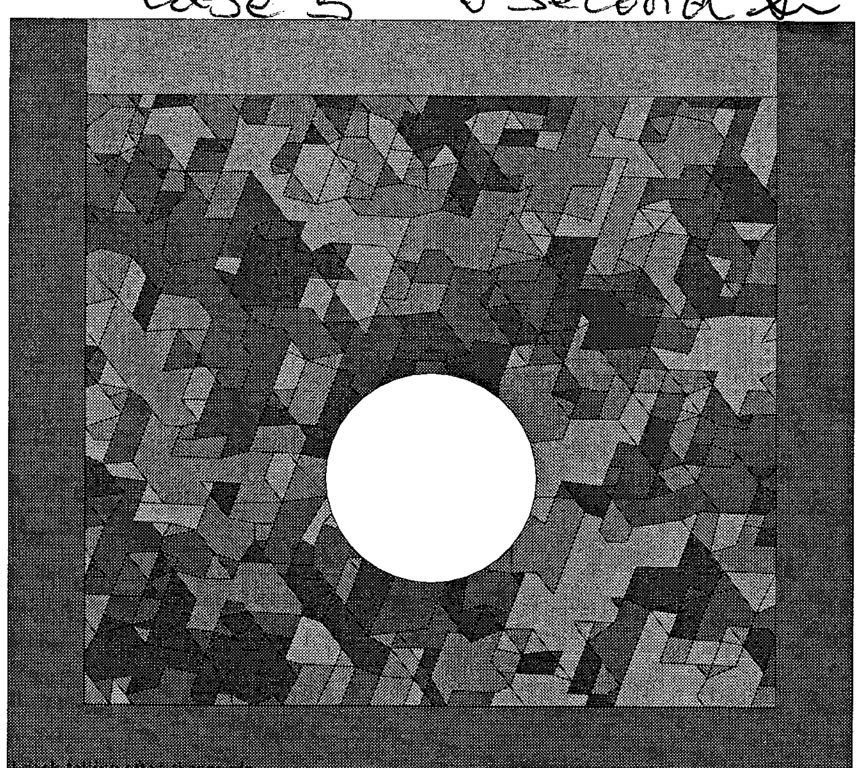

Figure 5.1 rock falling after 0 seconds

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case 5 2 seconds [initials] 9/21/2000

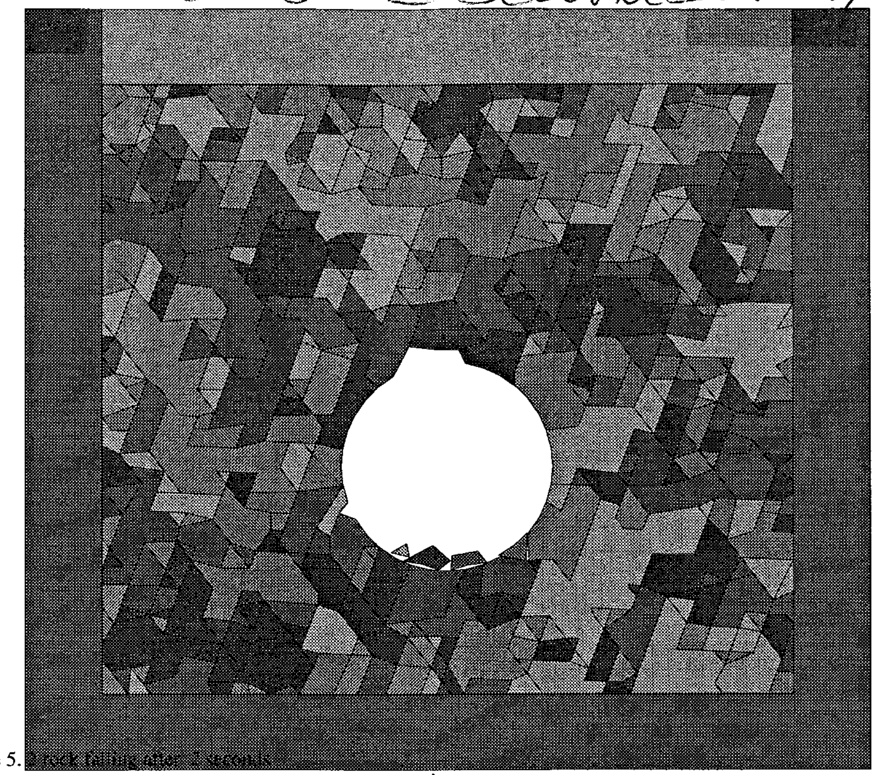

Figure 5.2 rock falling after 2 seconds

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case 5 (4.) ~~4.20~~ seconds

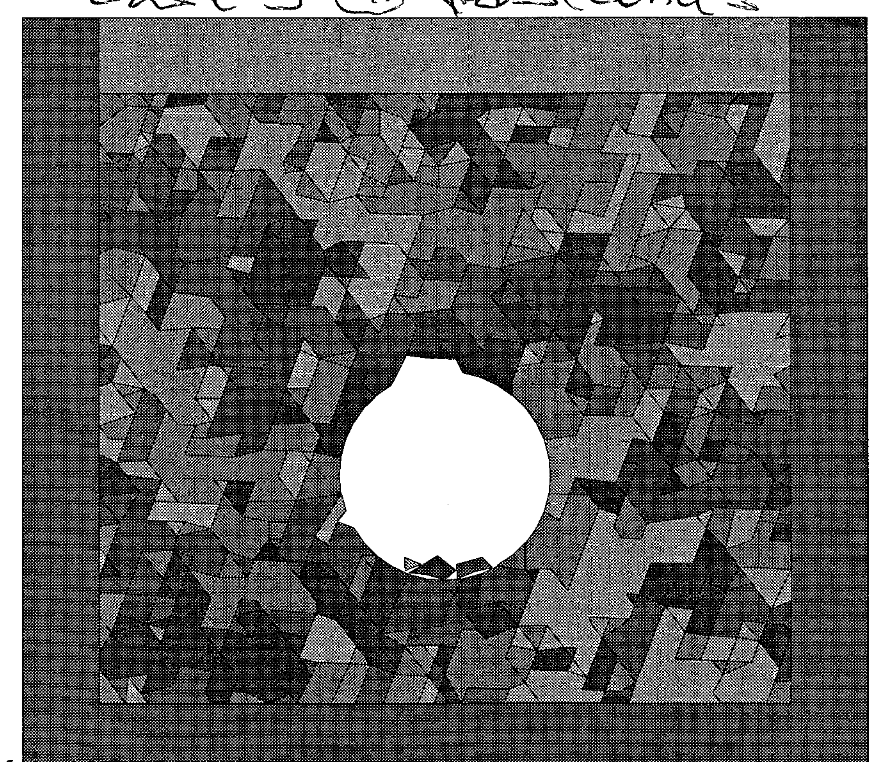

Figure 5.3 rock falling after 20 seconds

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20. Three dimensional improved drawing of general maximum key blocks.

Tptpll case. the JP=011 has key blocks. It has been considered when the key block located in between paralled joints of joint set 1.

JP=011 changes to JP=311

JP=011 changes to JP=031

Tptpul case:

JP=011 changes to JP=311

JP=011 changes to JP=031

Tptpll case

JP=101 changes to JP=301

JP=101 changes to JP=131

Tptpul case

JP=101 changes to JP=301

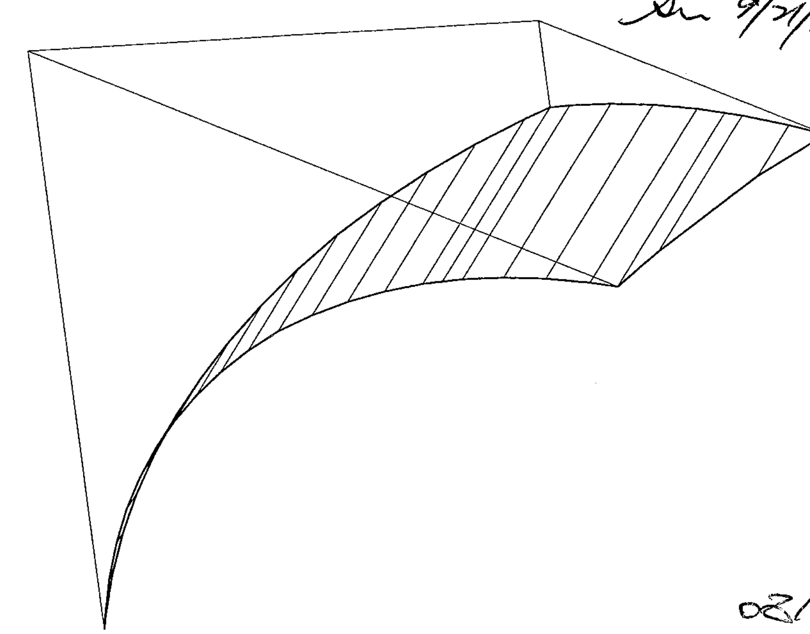
JP=101 changes to JP=131

All of the eight combinations have the fallowing Results.
The drawing is block and tunnel.

Tptpll case JP= 311

Shi 9/21/2000

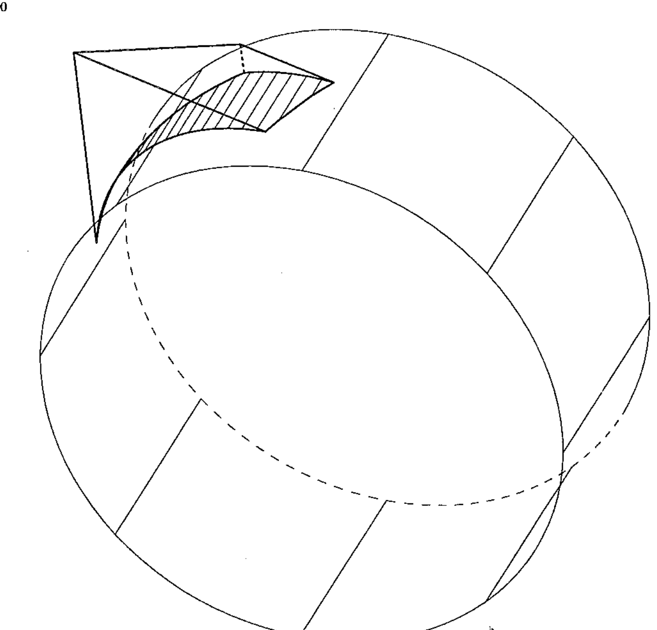
top vertex
-2.86e+00 2.93e+00
dip dip d.
79.0 270.0
81.0 230.0
5.0 45.0
tunnel dir.
75.0 0.0
angle interval
267.93 3.61
311



08/18/00
Shi Gen-hua

tbls11

tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
0.00e+00
0.00e+00
0.00e+00
0.00e+00
top distance
1.11e+00
311

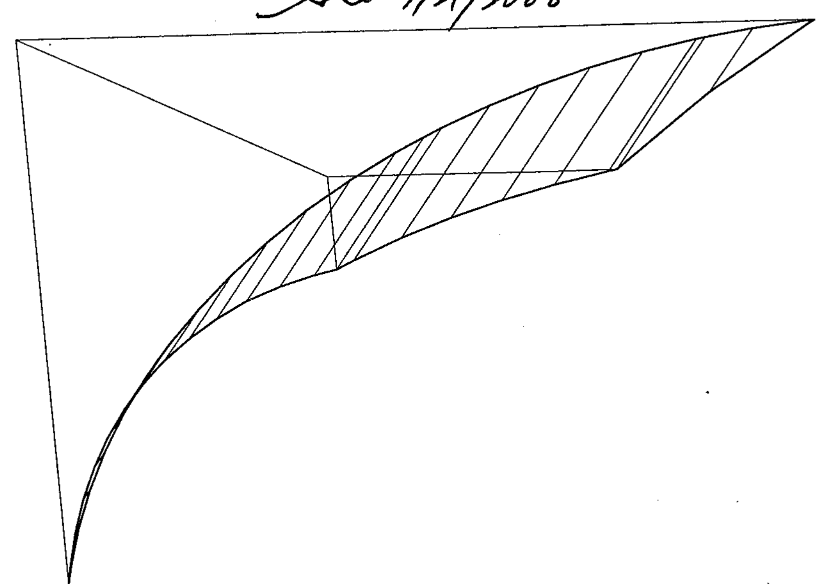


tbls11

Shi Gen-hua
08/18/00

top vertex
-2.85e+00 2.77e+00
dip dip d.
79.0 270.0
81.0 230.0
5.0 45.0
tunnel dir.
75.0 0.0
angle interval
267.93 0.48
031

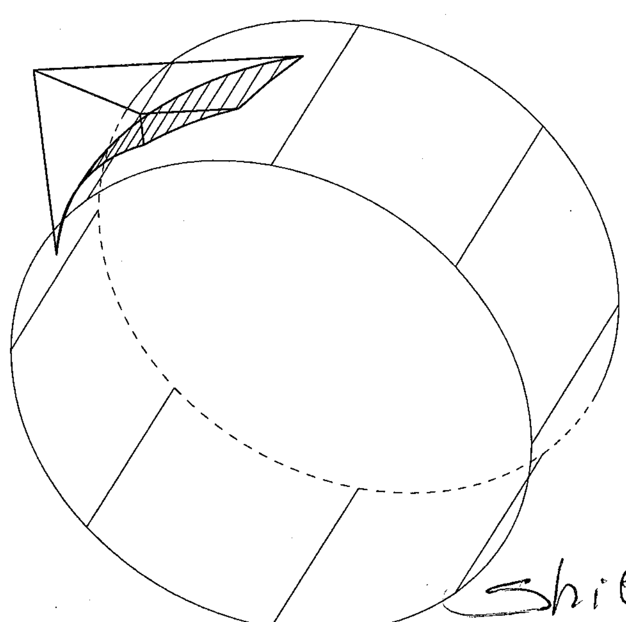
Tptpll case JP=031
9/21/2000



tbls12

08/18/00
Shi Gen-hua

tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
0.00e+00
8.08e-01
0.00e+00
0.00e+00
top distance
0.00e+00
031

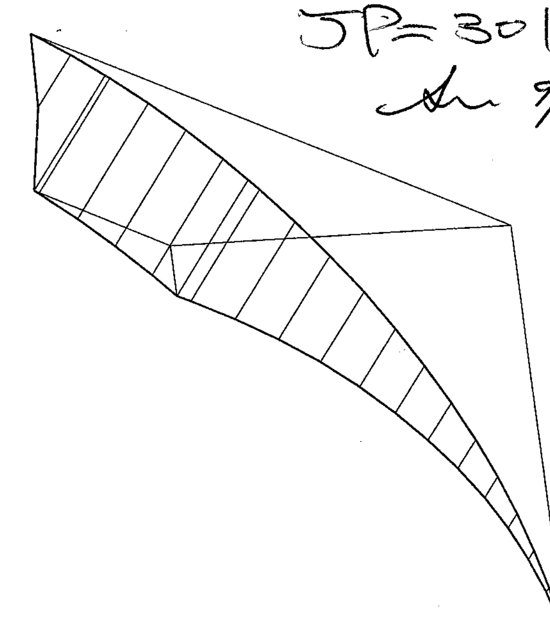


Shi Gen-hua
08/18/00

tbls12

top vertex
2.66e+00 2.59e+00
dip dip d.
79.0 270.0
81.0 230.0
5.0 45.0
tunnel dir.
75.0 0.0
angle interval
3.61 87.93
301

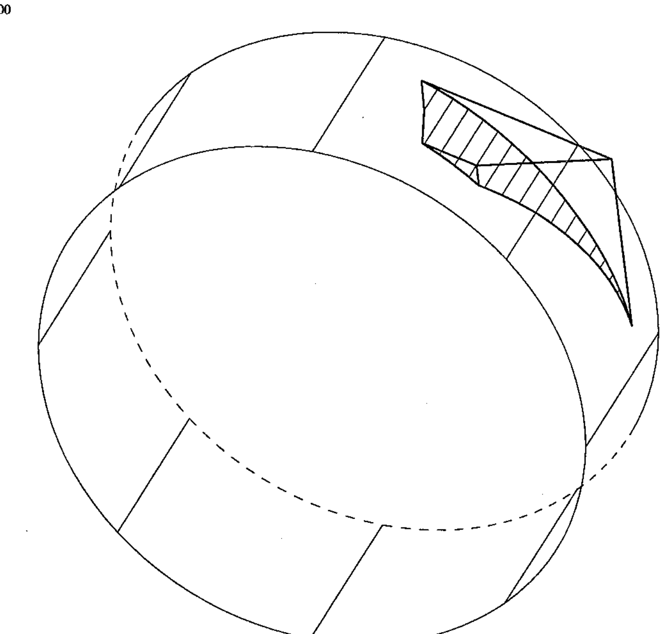
Tptpll case
JP=301
9/21/2000



tbls13

Shi Gen-hua
08/18/00

tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
8.14e-01
0.00e+00
0.00e+00
0.00e+00
top distance
0.00e+00
301

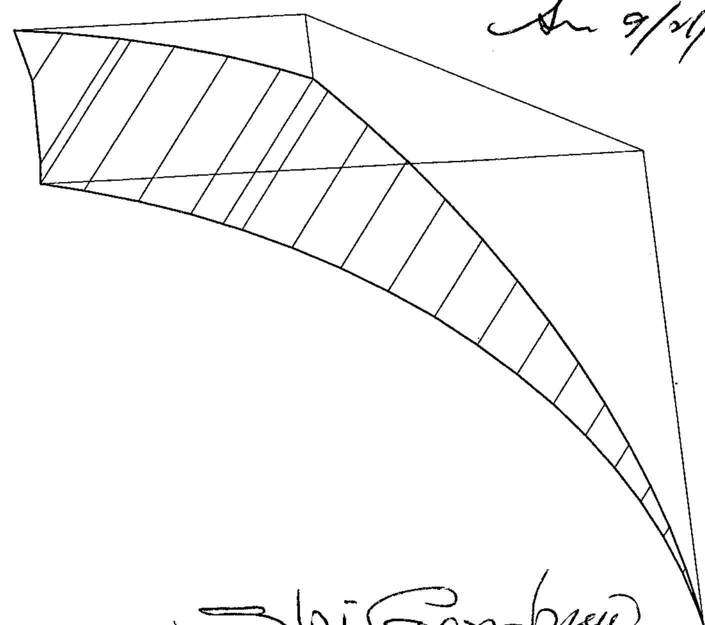


tbls13

Shi Gen-hua
08/18/00

Tptpll case JP=131
Sh 9/21/2000

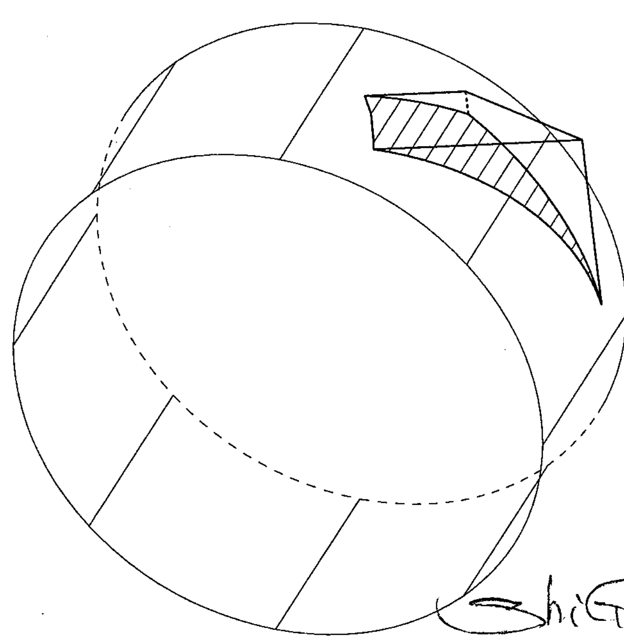
top vertex
2.65e+00 2.73e+00
dip dip d.
79.0 270.0
81.0 230.0
5.0 45.0
tunnel dir.
75.0 0.0
angle interval
0.48 87.93
131



ShiGen-hua
08/18/00

tbks14

tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
0.00e+00
0.00e+00
0.00e+00
0.00e+00
top distance
-9.73e-01
131

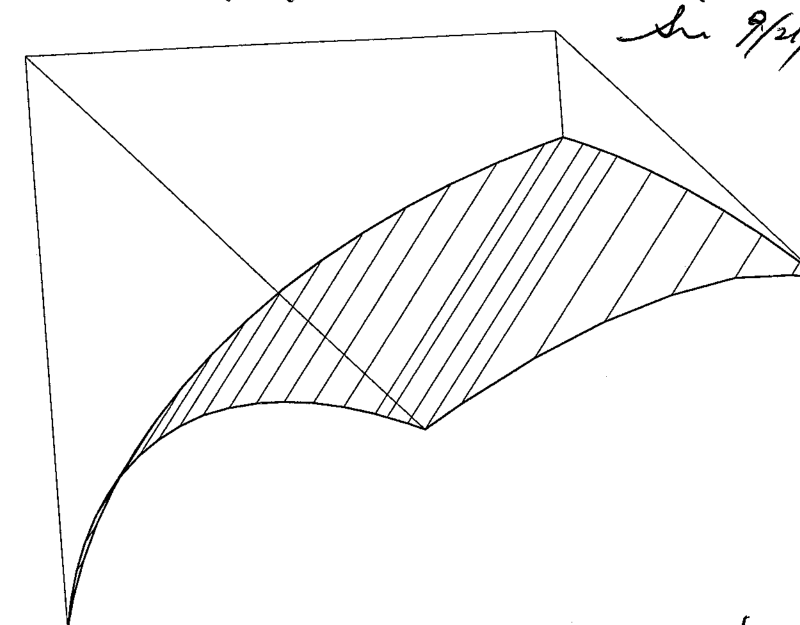


ShiGen-hua
08/18/00

tbks14

tptpul case JP=311
Sh 9/21/2000

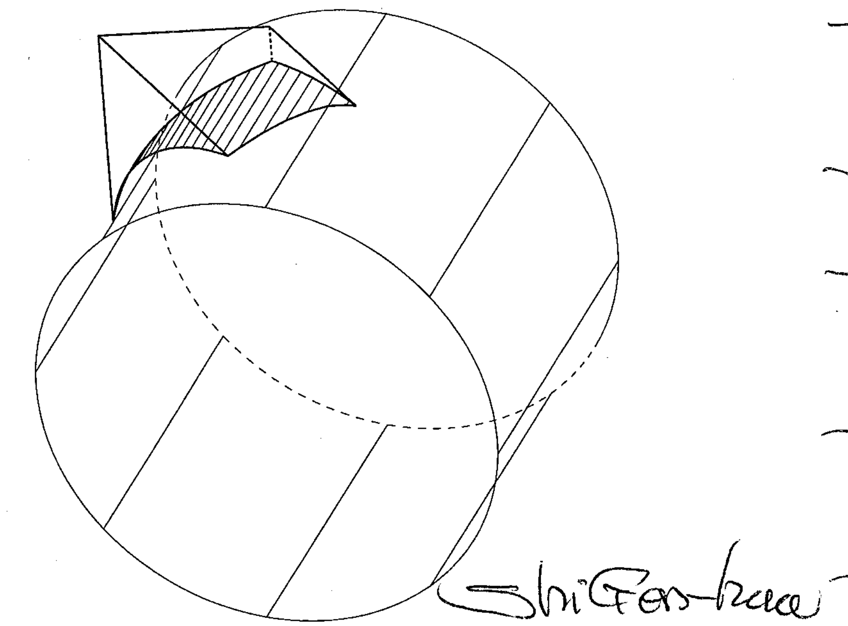
top vertex
-2.78e+00 3.59e+00
dip dip d.
82.0 288.0
82.0 228.0
14.0 39.0
tunnel dir.
75.0 0.0
angle interval
269.51 15.03
311



ShiGen-hua
08/18/00

tbls21

tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
0.00e+00
0.00e+00
0.00e+00
0.00e+00
top distance
2.02e+00
311



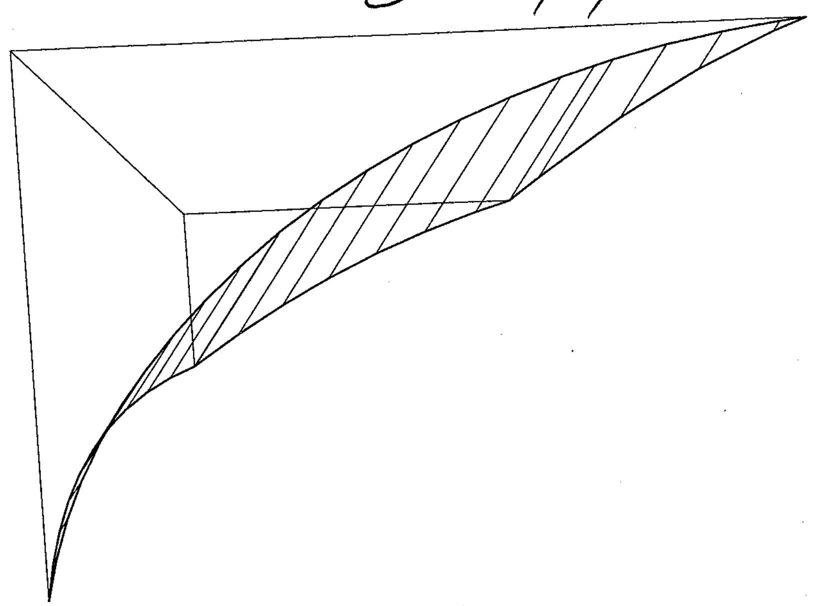
ShiGen-hua
08/18/00

tbls21

Tetpul case JP=031

9/21/2000

top vertex
-2.77e+00 2.87e+00
dip dip d.
82.0 288.0
82.0 228.0
14.0 39.0
tunnel dir.
75.0 0.0
angle interval
269.51 2.43
031

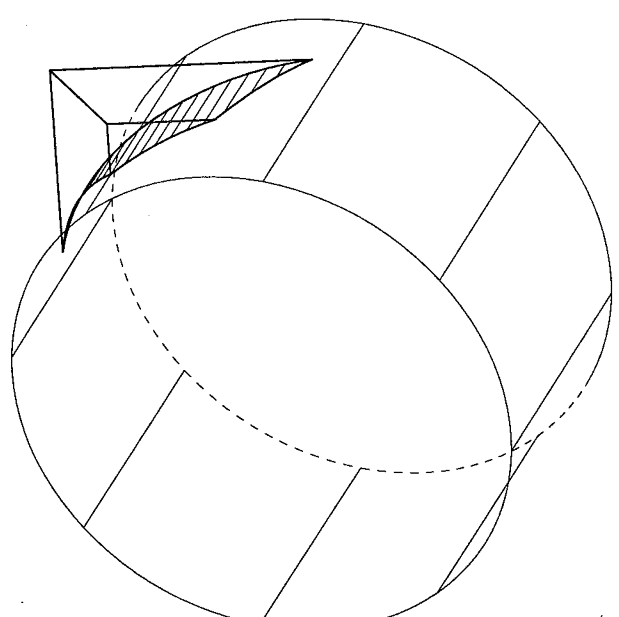


tbls22

08/18/00

Tetpul case JP=031

tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
0.00e+00
8.08e-01
0.00e+00
0.00e+00
top distance
0.00e+00
031



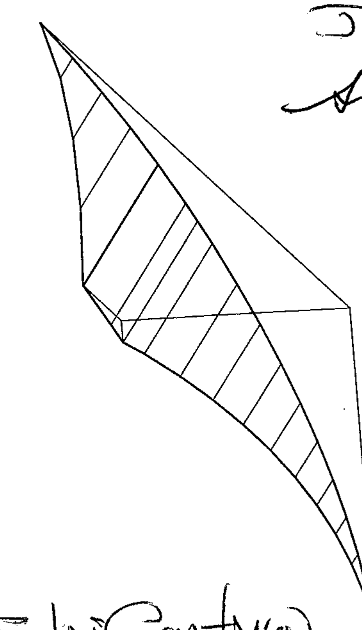
tbls22

08/18/00

Tetpul case JP=301

9/21/2000

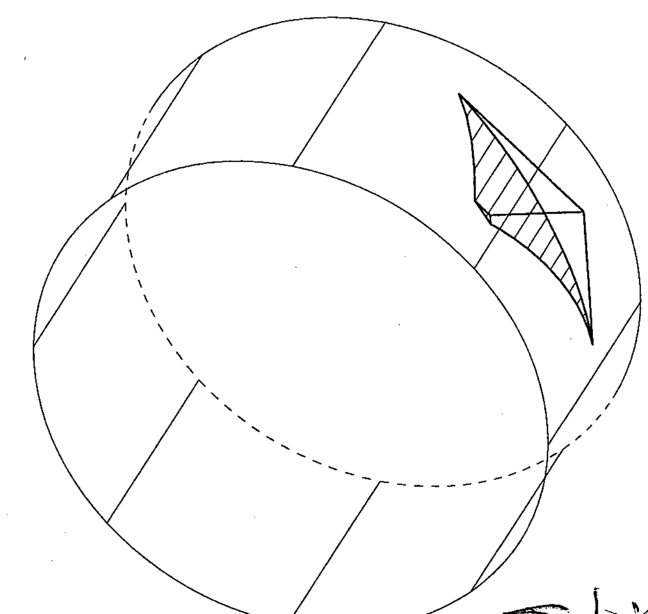
top vertex
2.73e+00 2.11e+00
dip dip d.
82.0 288.0
82.0 228.0
14.0 39.0
tunnel dir.
75.0 0.0
angle interval
15.03 89.51
301



tbls23

08/18/00

tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
8.12e-01
0.00e+00
0.00e+00
0.00e+00
top distance
0.00e+00
301

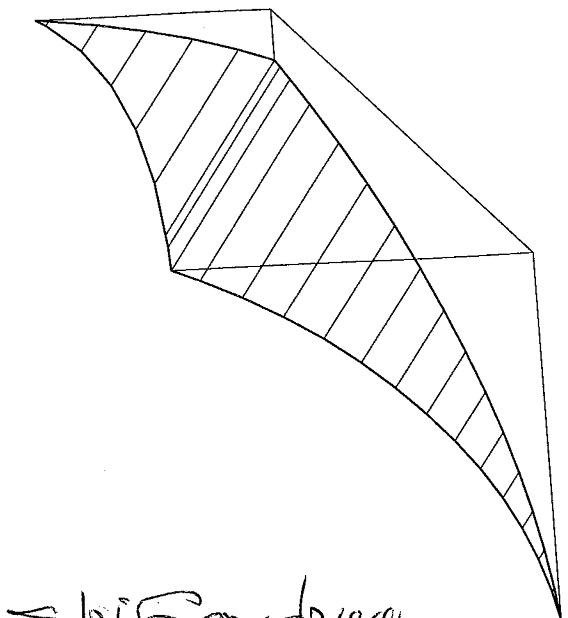


tbls23

08/18/00

Tptpul case Jp=131

top vertex
2.73e+00 2.63e+00
dip dip d.
82.0 288.0
82.0 228.0
14.0 39.0
tunnel dir.
75.0 0.0
angle interval
2.43 89.51
131



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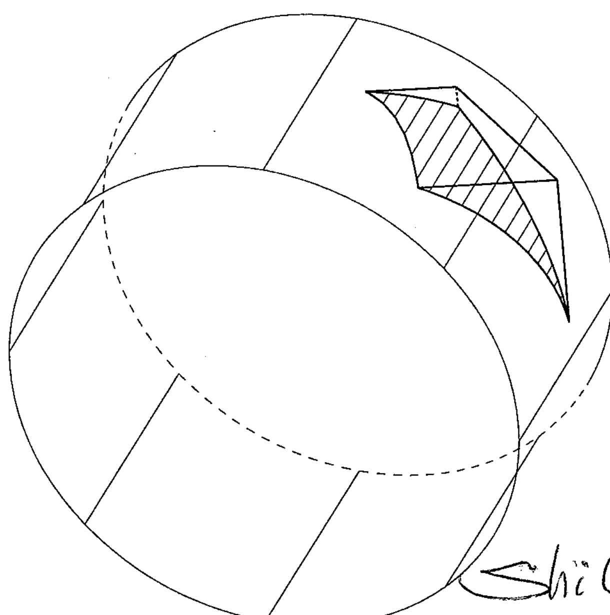
tbls24

tunnel shape
2.75e+00 2.75e+00 0.00e+00
projective dir.
1.00e+00 2.00e+00 3.00e+00
top vertix dis.
0.00e+00
0.00e+00
0.00e+00
0.00e+00
top distance
-1.58e+00
131



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Shi Gen-hua
08/18/00

tbls24

21. General three dimensional drawing of both joint traces and key blocks on tunnel surface.

This new drawing shows 3-d projection of joint traces on the tunnel surface. The key blocks on the tunnel surface are drawed in the same fram and same projection.

Consider the joints traces are very dense in both Tptpll and Tptpul cases, the hidden curved joint traces are not shown.

Therefore we show the following combinations (4).

Tptpll case:

far side view of joint trace map.
far side view of key blocks

near side view of joint trace map
near side view of key blocks

Tptpul case:

far side view of joint trace map
far side view of key blocks

near side view of joint trace map
near side view of key block

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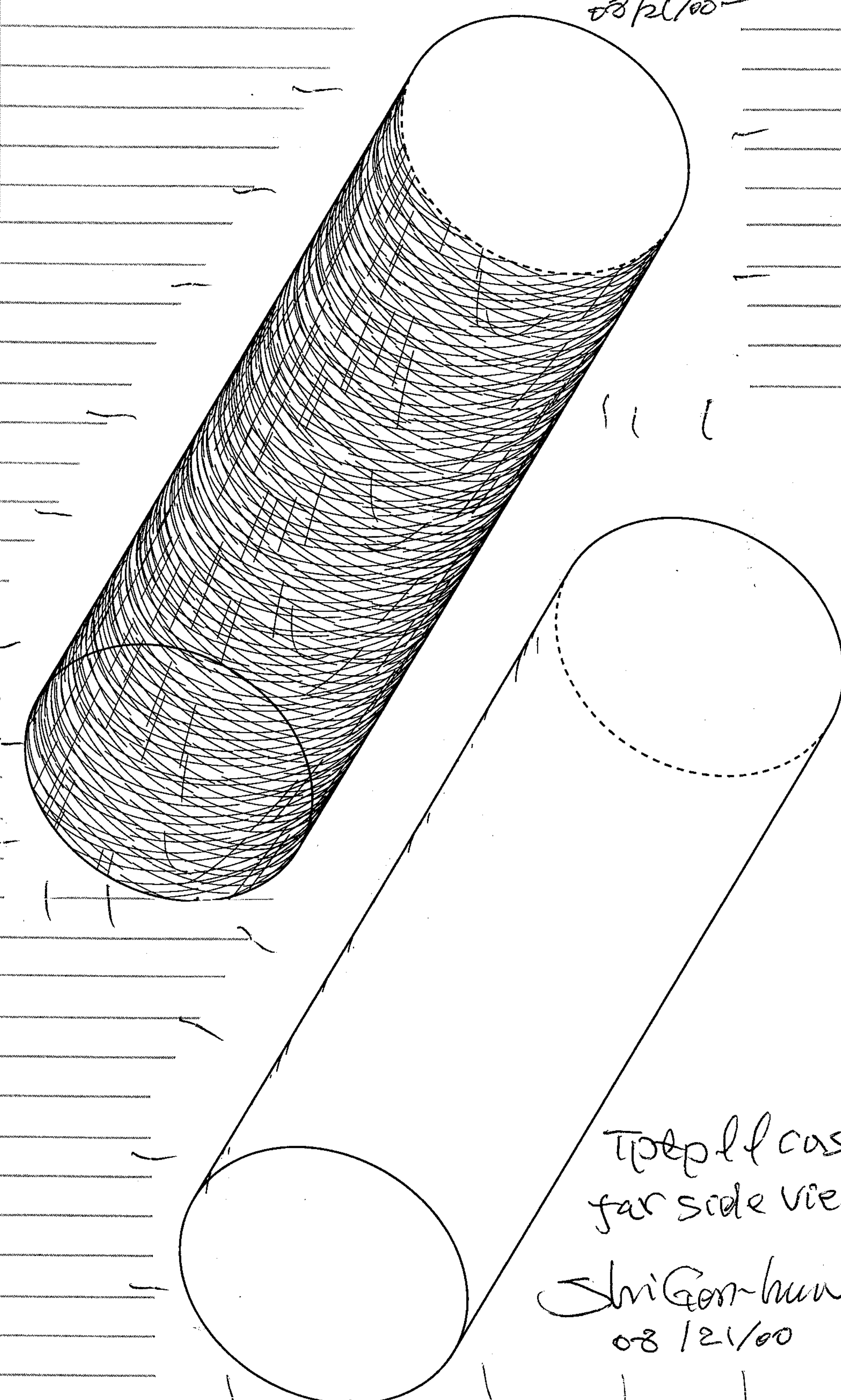
08/21/00



Tpepll case
far side view

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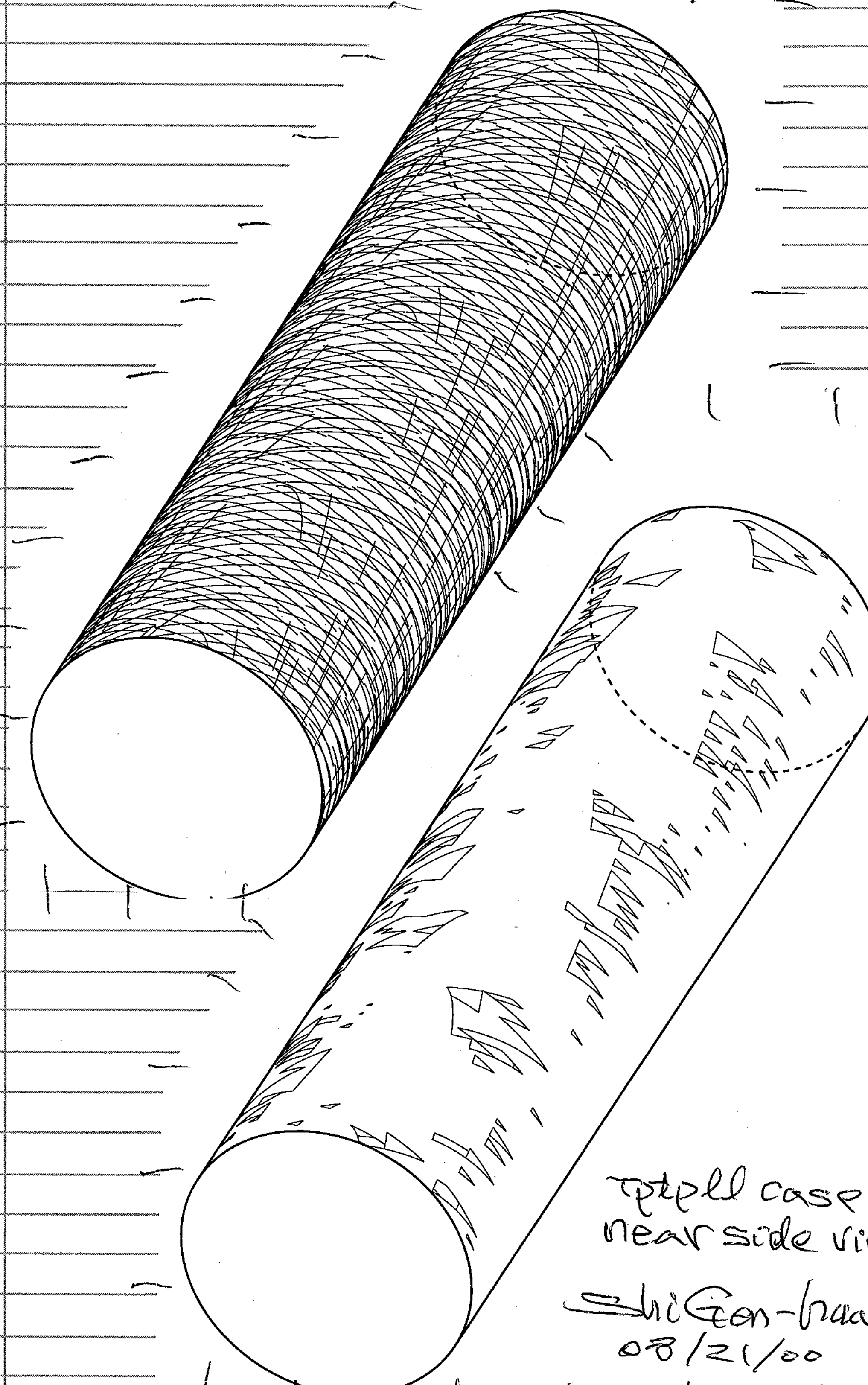
08/21/00

ShiGon-hun
08/21/00



Tpepll case
near side view

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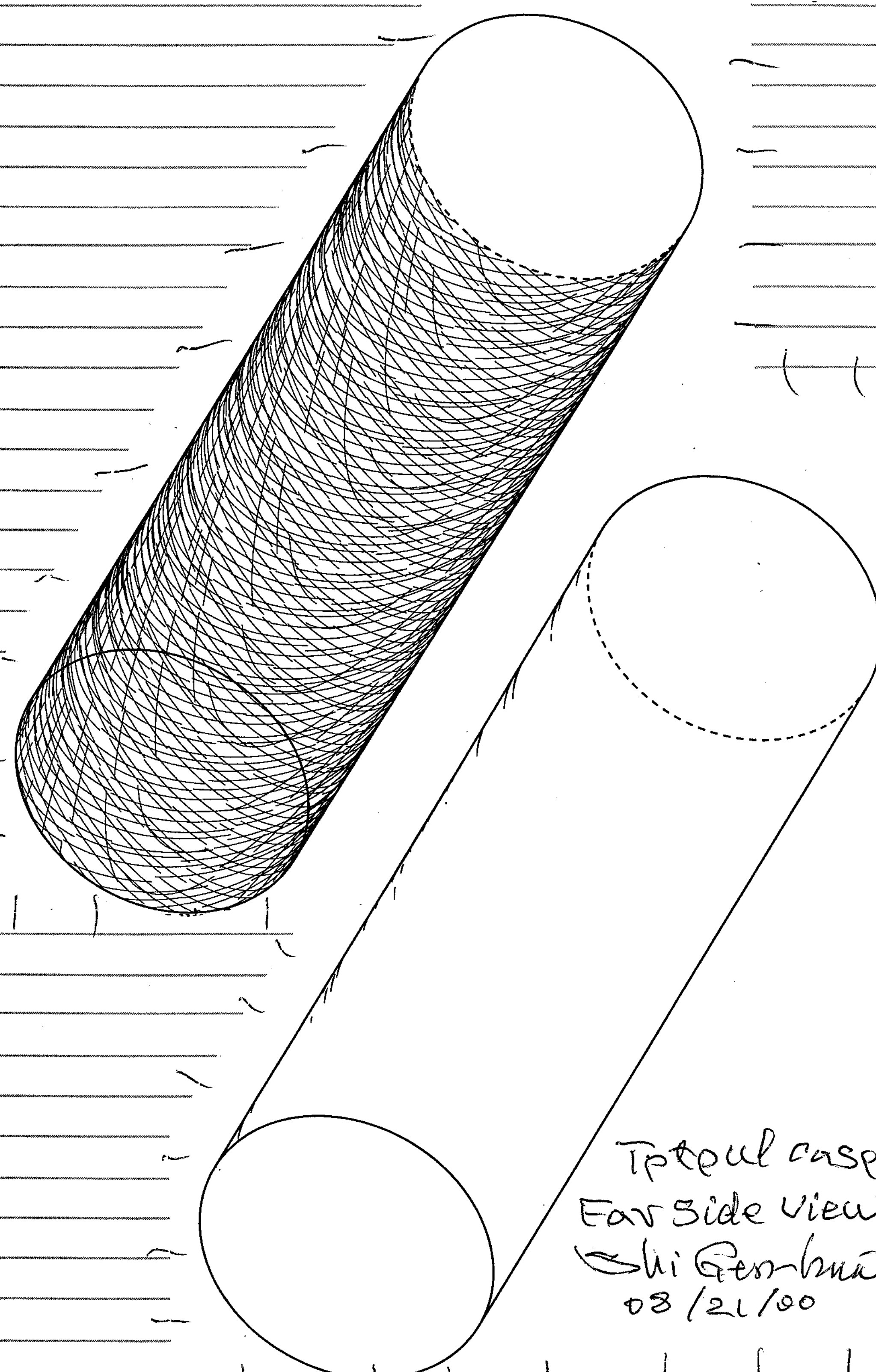
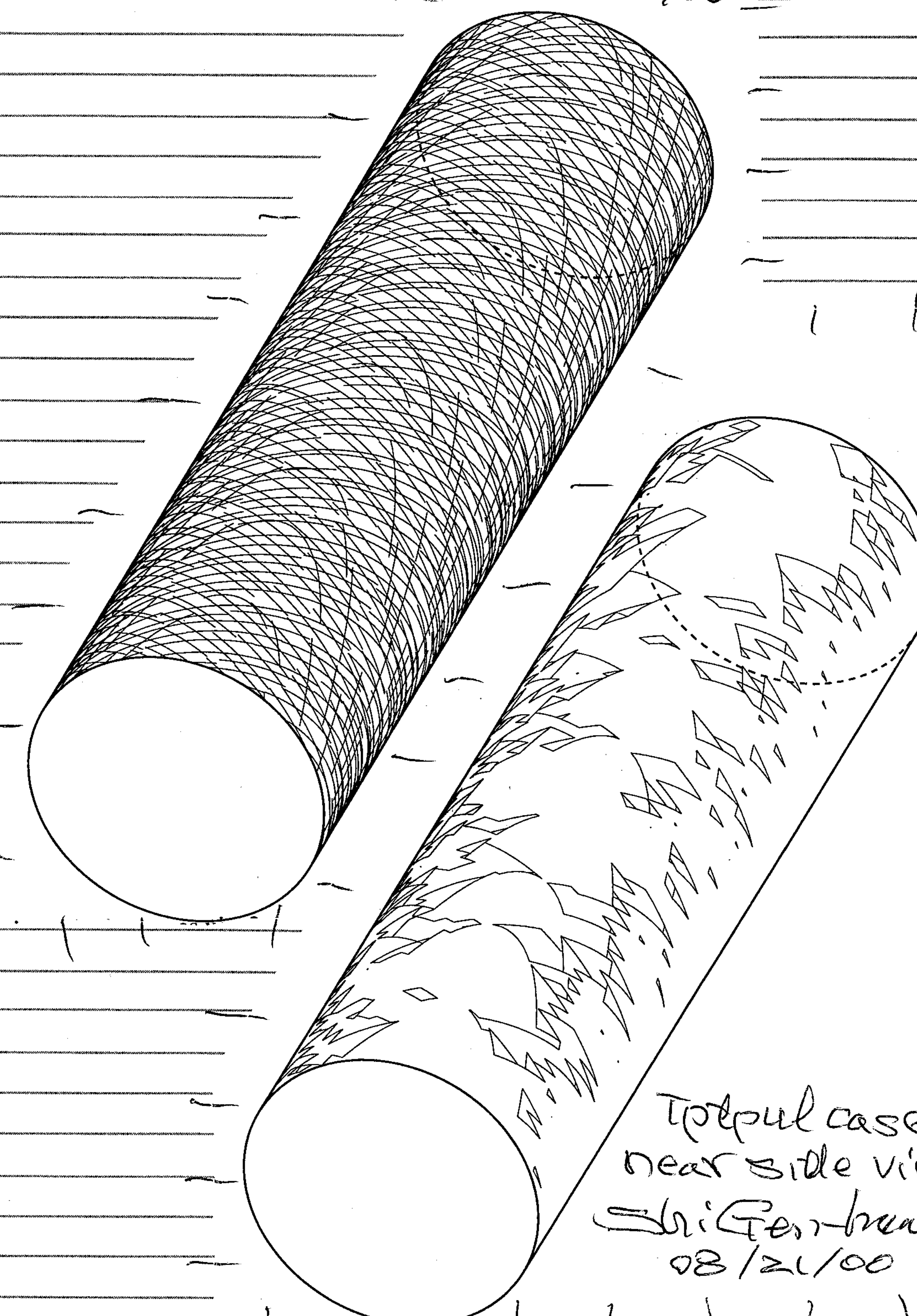
08/21/00

Shi Gen-hua
08/21/00



Tetpul case
Far side view
Shi Gen-hua
08/21/00

Shi Gen-hua
08/21/00



Tetpul case
near side view
Shi Gen-hua
08/21/00

22. Report #4: Key block results of rock falling.

Report #4 Key Block Results of Rock Falling of Project: 20.01402.671 Rock Fall Assessing under Seismic Load using Key Block Analysis

Prepared for:
CNWRA, Southwest Research Institute
Submitted by Gen-hua Shi
1746 Terrace Drive, Belmont, CA 94002
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Key Block Theory of Rock Falling and Tunnel Support

All of the rock falling is block falling. In the process of tunnel or other underground excavations, there are four different kind of rock blocks:

[1] Infinite blocks: Infinite blocks are connected with the whole rock mass and not isolated by joints. Infinite blocks are safe and can not fall.

[2] Tapered blocks: Tapered blocks are finite or isolated by the joint cutting. Tapered blocks can not fall due to the constrain of the outside rocks.

[3] The rock blocks can fall only if other blocks fall first to create the space for the given blocks to fall.

[4] The rock blocks can fall directly toward the excavated space. The falling can takes place without the previous falling of other blocks. These blocks are called key blocks.

Key block theory only focus on the 4th kind of blocks or key blocks. The reason is if the key blocks are supported, all of other blocks can not fall any more. The DDA can find both 3rd and 4th kind of blocks.

The key block is defined by the following criteria:

[1] Finiteness: The faces of key blocks are the existing joints or free surfaces. The joint polygons and free surfaces isolate the block from all directions.

[2] Integrity: All blocks of a united key block have the same displacement along the same straight line.

[3] Removability: The united key block can do parallel translation toward the free space without invade into the rocks outside of the united key block. The key blocks are surface blocks, they are on the natural or the excavated surfaces.

Finding key blocks: A large key block can contain other small key blocks. Simple convex key blocks can form complex non-convex key blocks. The number of key blocks can be very large. Also the real joints behind the excavation surface can not be located. Therefore the key blocks are indefinite.

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Based on the joint sets, there are several types of key blocks called JP (joint pyramid). Key blocks of the same JP are in the same side of joints of each joint set. All key blocks of a JP can form a maximum key block.

There are many finite joint blocks around the tunnel. The key blocks are the first to fall. Other blocks can fall only after the falling of key blocks which create more moving space. Therefore, if all maximum key blocks are supported, all other blocks can not fall.

1. Stereographic Projection of Joint Sets

The Yucca mountain rocks are suitable for the applications of key block theory. The joint sets of the Tptpll case are the following:

Table 1.1 Joint set data of Tptpll Case

joint set	dip angle	dip d.	friction angle	cohesion
joint set 1	79°	270°	39°	0
joint set 2	81°	230°	39°	0
joint set 3	5°	45°	39°	0

The joint sets of the Tptpul case are the following:

Table 1.2 Joint set data of Tptpul case

joint set	dip angle	dip d.	friction angle	cohesion
joint set 1	82°	288°	39°	0
joint set 2	82°	228°	39°	0
joint set 3	14°	39°	39°	0

Figure 1.1 is the upper hemisphere equal angle stereographic projection of Tptpll joint sets.

Figure 1.2 is the upper hemisphere equal angle stereographic projection of Tptpul joint sets.

The input files of stereographic projection are the following:

Table 1.3 Input files of stereographic projection

Program PRJ0 file	PRJS1 for Tptpll
Program PRJ0 file	PRJS2 for Tptpul

The equal angle stereographic projection has the following three advantages:

[1] The projection of any plane is a arc or a segment of a circle.

[2] The intersection angle between two projection arcs is the true intersection angle between the two joint set planes.

[3] This simple diagram shows all of the angular relationship between joint sets.

The joint sets for both Tptpll and Tptpul are similar. Two nearly vertical joint sets and one nearly horizontal joint set. The dip directions of joint set 1 for both Tptpll and Tptpul cases are 18 degree different.

2. Total Sliding Forces for All Tunnel Directions

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The volume and sliding forces of key blocks are sensitive to the tunnel directions. The following is the study: If the given tunnel direction is safe in terms of the key block sliding force. This tunnel direction study only based on the tunnel directions and the joint set directions.

The assumptions are:

[1] The joints are very long.

[2] The joint spacing are very small.

[3] The key blocks in between two parallel joints are not considered.

Figure 2.1 shows the contours of the sliding forces of maximum key blocks for all tunnel directions. The Tptpll joint sets are input. The contours is equal area projection of the tunnel axis inside of the reference circle.

In this Tptpll case, the tunnel direction $N75°E$ is marked as a small circle in the drawing. The maximum sliding force of this direction is about 20% to 30% of the over all largest sliding force for all tunnel directions.

Due to the two vertical joint sets, the tunnels with nearly 90 degrees rise angle or shafts have relatively large key block sliding force.

Figure 2.2 shows the contours of the sliding forces of maximum key blocks for all tunnel directions. The Tptpul joint sets are input.

In this Tptpul case, the tunnel direction $N75°E$ is marked as a small circle in the drawing. The maximum sliding force of this direction is about 30% to 40% of the over all largest sliding force for all tunnel directions.

The input files of sliding force contours are the following:

Table 2.1 Input files of total sliding force computations

Program TST0 file	TSTS1 for Tptpll
Program TST0 file	TSTS2 for Tptpul

The geometry of the tunnels are the following:

Table 2.2 Tunnel data

bearing angle of tunnel axis	75°
rise angle of tunnel axis	0°
tunnel diameter	5.5 meter
tunnel shape	circular

Based on the diagrams of Figure 1.1 and 1.2, the maximum key block sliding forces of different tunnel directions can be compared. The conclusion of the tunnel direction study is:

Since this tunnel is horizontal, the projection of the tunnel axis is on the boundary of the reference circle. The location is 75 degree clockwise from north on the reference circle. The tunnel have the average maximum sliding force among the horizontal tunnels.

The differences of maximum sliding forces among the horizontal tunnel directions are not very much since the set 1 and 2 are nearly vertical and set 3 are nearly horizontal.

3. Key Block Zones of Each JP under a Tunnel Direction

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08/24/00

Figure 3.1 shows the zones of maximum Tptpll key blocks for each Joint Pyramid. The maximum key block zones are the projections of the maximum 3 dimensional key block on the tunnel section plane. Also all the key blocks of the same joint pyramid (JP) are in the corresponding key block zone. The numbers under the JP codes are the sliding forces with unit g.

The zone marked "011" means JP=011, where "0" means upper side of the joint set and "1" means lower side of the joint set. All key blocks of JP=011 are in the upper side of joint set 1, lower side of joint set 2 and lower side of joint set 3. Under the number "011" is "+0.83". The sliding force of the JP=011 key blocks is 0.83 times the key block weight.

Figure 3.2 shows the sliding joint sets of the related maximum Tptpll key blocks. The zone marked "1" means all of the key blocks of this JP slide along joint set 1. The zone marked "13" means all of the key blocks of this JP slide along the intersection line of joint set 1 and joint set 3. The second number under the sliding joint set number is the factor of safety of all the key blocks of the corresponding JP. The factor of safety of JP=011 key blocks is 0.16. If the factor of safety is greater than 9.99, 9.99 is printed.

Figure 3.3 shows the zones of maximum Tptpul key blocks for each Joint Pyramid. The maximum key block zones are the projections of the maximum 3 dimensional key block on the tunnel section plane. Also all the key blocks of the same joint pyramid (JP) are in the corresponding key block zone.

Figure 3.4 shows the sliding joint sets of the related maximum Tptpul key blocks.

The input files of Figure 3.1 to 3.4 are the following:

Table 3.1 Input files of all key block zone computations

Program TRM0 file	TRMS1 for Tptpll
Program TRM0 file	TRMS2 for Tptpul

If the joints have limited lengths and wide spacing, the key blocks can occupy only a part of the maximum key block zone. Most of the real key blocks will lie near the tunnel surface.Therefore, relatively smaller key block region can be considered in the stability analysis.

From Figure 3.1 to 3.4, for both Tptpll and Tptpul cases, only key blocks of JP=011 and JP=101 can fall.

Key blocks of JP=011 means the block is on the upper side of joint set 1, lower side of joint set 2 and lower side of joint set 3. From Figure 3.2 and Figure 3.4 key blocks of JP=011 slide along the joints of joint set 1.

Key blocks of JP=101 means the key blocks are on the lower side of joint set 1, upper side of joint set 2 and lower side of joint set 3. From Figure 3.2 and Figure 3.4, key blocks of JP=101 slide along the joints of joint set 2.

Table 3.2 Tunnel key blocks

case	JP	sliding plane	sliding force	factor of safety
Tptpll	011	1	+0.83 g	0.16
Tptpll	101	2	+0.86 g	0.13
Tptpul	011	1	+0.88 g	0.11
Tptpul	101	2	+0.88 g	0.11

4. Three Dimensional View of Maximum Key Blocks

Table 4.1 Input files of 3-D maximum key blocks

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Program TBL0 file	TBLS11 for Tptpll
Program TBL0 file	TBLS12 for Tptpll
Program TBL0 file	TBLS13 for Tptpll
Program TBL0 file	TBLS14 for Tptpll
Program TBL0 file	TBLS21 for Tptpul
Program TBL0 file	TBLS22 for Tptpul
Program TBL0 file	TBLS23 for Tptpul
Program TBL0 file	TBLS24 for Tptpul

Figure 4.1 shows the three dimensional view of the maximum Tptpll key block JP=011. Here the key block can be in between two parallel joints of joint set 1 or JP=311.

Figure 4.2 shows the three dimensional view of the maximum Tptpll key block JP=011. Here the key block can be in between two parallel joints of joint set 2 or JP=031.

Figure 4.3 shows the three dimensional view of the maximum Tptpll key block JP=101. Here the key block can be in between two parallel joints of joint set 1 or JP=301.

Figure 4.4 shows the three dimensional view of the maximum Tptpll key block JP=101. Here the key block can be in between two parallel joints of joint set 2 or JP=131.

Figure 4.5 shows the three dimensional view of the maximum Tptpul key block JP=011. Here the key block can be in between two parallel joints of joint set 1 or JP=311.

Figure 4.6 shows the three dimensional view of the maximum Tptpul key block JP=011. Here the key block can be in between two parallel joints of joint set 2 or JP=031.

Figure 4.7 shows the three dimensional view of the maximum Tptpul key block JP=101. Here the key block can be in between two parallel joints of joint set 1 or JP=301.

Figure 4.8 shows the three dimensional view of the maximum Tptpul key block JP=101. Here the key block can be in between two parallel joints of joint set 2 or JP=131.

For the maximum three dimensional key blocks, the assumptions are: the joint length in each joint set is sufficiently large and the joint spacing in each joint set is sufficiently small. Under these extreme assumptions, the maximum key blocks are drawn. Any actual key block can not be larger than these maximum key blocks. The actual key blocks could be much smaller due to the limited length and substantial spacing.

The results of the three dimensional maximum key blocks are the following:

Table 4.2 Maximum key block JP=311 of Tptpll

key block JP code	011 or 311
key block volume	0.77 cubic meter
area in tunnel surface	2.16 square meter
sliding direction	joint set 1

Table 4.3 Maximum key block JP=031 of Tptpll

key block JP code	011 or 031
key block volume	0.64 cubic meter
area in tunnel surface	1.84 square meter
sliding direction	joint set 1

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Table 4.4 Maximum key block JP=301 of Tptpll

key block JP code	101 or 301
key block volume	0.39 cubic meter
area in tunnel surface	1.47 square meter
sliding direction	joint set 2

Table 4.5 Maximum key block JP=131 of Tptpll

key block JP code	101 or 131
key block volume	0.47 cubic meter
area in tunnel surface	1.68 square meter
sliding direction	joint set 2

Table 4.6 Maximum key block JP=311 of Tptpul

key block JP code	011 or 311
key block volume	1.59 cubic meter
area in tunnel surface	3.62 square meter
sliding direction	joint set 1

Table 4.7 Maximum key block JP=031 of Tptpul

key block JP code	011 or 031
key block volume	0.79 cubic meter
area in tunnel surface	2.01 square meter
sliding direction	joint set 1

Table 4.8 Maximum key block JP=301 of Tptpul

key block JP code	101 or 301
key block volume	0.26 cubic meter
area in tunnel surface	1.28 square meter
sliding direction	joint set 2

Table 4.9 Maximum key block JP=131 of Tptpul

key block JP code	101 or 131
key block volume	0.49 cubic meter
area in tunnel surface	2.03 square meter
sliding direction	joint set 2

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5. Key Block Areas on Tunnel Surface Joint Trace Map

For the rock falling, key block analysis is under the following basic assumptions:

[1] The joint length of fresh rock masses from the excavated tunnels is used as input data.

[2] The joint strength of fresh rock masses from the excavated tunnels is used as input data.

[3] The key blocks only lie in one side of each joint set. However, the key blocks located in two sides of only one given joint set are considered.

Based on the joint spacing, joint length and joint bridge, the joint traces on the curved tunnel surface are produced statistically.

Table 5.1 Statistical joint set data of Tptpll case

joint set	spacing: m	length: m	bridge: m
joint set 1	.30	1.8	.1
joint set 2	.30	2.4	.1
joint set 3	.50	1.8	.1

Table 5.2 Statistical joint set data of Tptpul case

joint set	spacing: m	length: m	bridge: m
joint set 1	.30	1.8	.1
joint set 2	.30	2.4	.1
joint set 3	.50	1.8	.1

The input files and results of Figure 5.1 to 5.14 are the following:

Table 5.3 Input files of tunnel joint trace map

Program UJN0 file	UJNS1 for Tptpll
Program UJN0 file	UJNS2 for Tptpul

It has been assumed here that the joints having traces in the tunnel surface extend sufficiently far behind the tunnel surface as to form blocks by their mutual intersections. It has been proved that if the joints do thus extend behind the tunnel surface, the three dimensional key blocks of the tunnel can be delimited by operating only with the joint traces exposed on the tunnel surface.

Then using key block theory, the key block zones are delimited from the curved polygons of the unrolled joint trace map.

Figure 5.1 is the diagram which shows the way the tunnel, including the Tptpll joint sets, is unrolled.

Figure 5.2 is the statistically produced unrolled joint trace map of the whole tunnel for the Tptpll case.

Figure 5.3 is the key blocks on the unrolled joint trace map of the whole tunnel for the Tptpll case.

Figure 5.4 is the three dimensional far side view of statistically produced joint traces for the Tptpll case.

Figure 5.5 is the three dimensional far side view of key blocks for the Tptpll case.

Figure 5.6 is the three dimensional near side view of statistically produced joint traces for the Tptpll case.

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Figure 5.7 is the three dimensional near side view of key blocks for the Tptpll case.

Figure 5.8 is the diagram which shows the way the tunnel, including the Tptpul joint sets, is unrolled.

Figure 5.9 is the statistically produced unrolled joint trace map of the whole tunnel for the Tptpul case.

Figure 5.10 is the key blocks on the unrolled joint trace map of the whole tunnel for the Tptpul case.

Figure 5.11 is the three dimensional far side view of statistically produced joint traces for the Tptpul case.

Figure 5.12 is the three dimensional far side view of key blocks for the Tptpul case.

Figure 5.13 is the three dimensional near side view of statistically produced joint traces for the Tptpul case.

Figure 5.14 is the three dimensional near side view of key blocks for the Tptpul case.

Table 5.4 Tptpll key block zones

JP code	key block area	sliding joint set
311	9.81 m^2	1
031	7.70 m^2	1
301	11.19 m^2	2
131	5.88 m^2	2

Table 5.5 Tptpul key block zones

JP code	key block area	sliding joint set
311	17.03 m^2	1
031	13.82 m^2	1
301	26.29 m^2	2
131	5.42 m^2	2

Table 5.6 Total key block area

case	total key block area	percentage with tunnel surface
Tptpll	34.58 m^2	8.91 %
Tptpul	62.56 m^2	16.12 %

The key block area on the tunnel walls are form 8.91% to 16.12% of the whole tunnel surface. These key blocks can fall shortly after the tunnel excavation.

6. Long Term Rock Falls after Tunnel Excavation

For long term rock falling, key block analysis will be under the following basic assumptions:

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[1] Joint length will increase with time. The surface joint length from nearby long time weathered natural rock can be used.

[2] Joint strength will decrease with time. The surface joint strength from nearby long time weathered natural rock can also be used.

[3] The key blocks between the joints of the same joint set may fall. The key blocks located in two sides of the same joint set have to be found from the tunnel joint trace map. Therefore, the additional key blocks due to the direction variation of the joints in the same set have to be estimated. Using the key block theory, the surface area of all possible additional key blocks will be computed.

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study thermal load from thermal modeling

The intention of this computation is to estimate the rock falling when the temprature of rock masses rises.

The temprature rising will increase the stresses of the rock blocks. the continuous methods such like FEM can give the condition of rock masses, how the yielding zones expand.

The DDA computation is different in the following items

(1). DDA will compute the rock falling after thermal load is applied.

(2). The joint stiffness is lower then the rock mass or rock block stiffness. under the thermal stresses the joint will have more deformations than the rock blocks. DDA can do this kind of computation. The reason is DDA solve equilibrium equations, the joint stiffness is transfered into the contact spring stiffness. The DDA results will be reliable.

(3) In the begining of each time step, DDA can input the additional stresses as a load. Therefore the thermal load can be applied.

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2. checking dda codes with thermal stresses

The intention of this computation is to compare the rock falling results under following two different conditions:

condition 1. 20 second earth quake load.

condition 2. 0 ~ 2 second rise temprature 150°C. 2 - 22 second the 20 seconds earth quake is applied. from 17 to 22 second, the temprature drop 150°C.

The comparasion is under the following choices:

(1) Both cases use the same joint mesh and the same block mesh.

(2) Both cases are under the same boundary condition

(3) Both cases are under the same loading condition accept the second case has the thermal load.

(4) Both cases use the same material parameters, time steps and contact stiffness.

This is the computation, how the temprature influence the rock falling.

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3 Rock falling DDA Case 1, with thermal load.

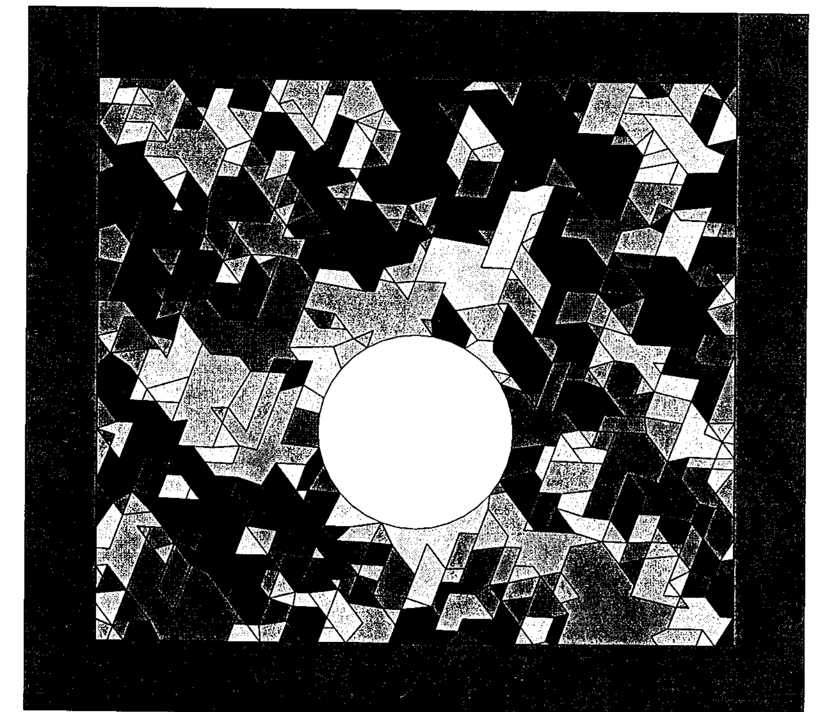

Figure 3. 1 Case 1 thermal load rock falling after 0 seconds

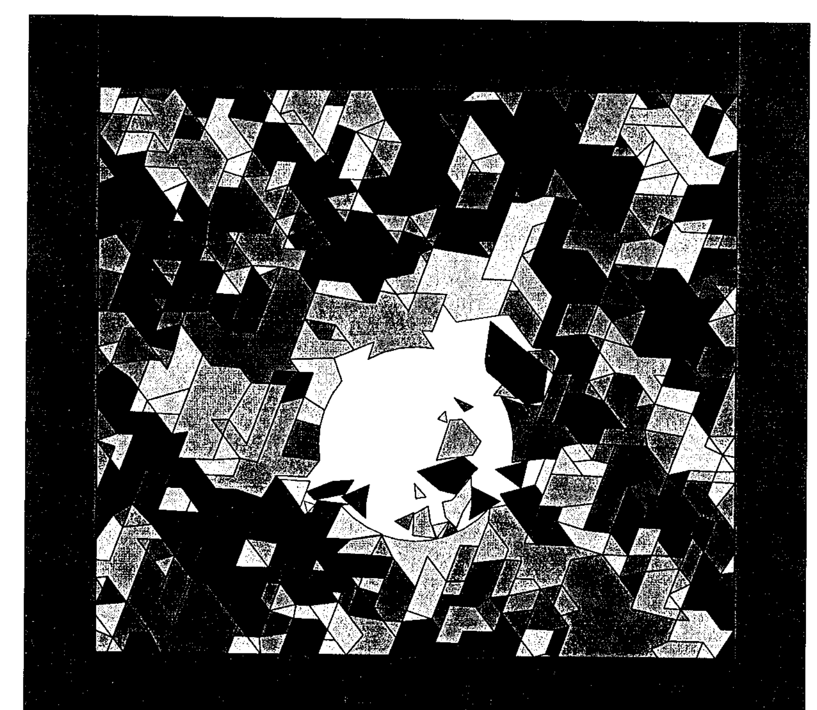

Figure 3. 2 Case 1 thermal load rock falling after 2 seconds

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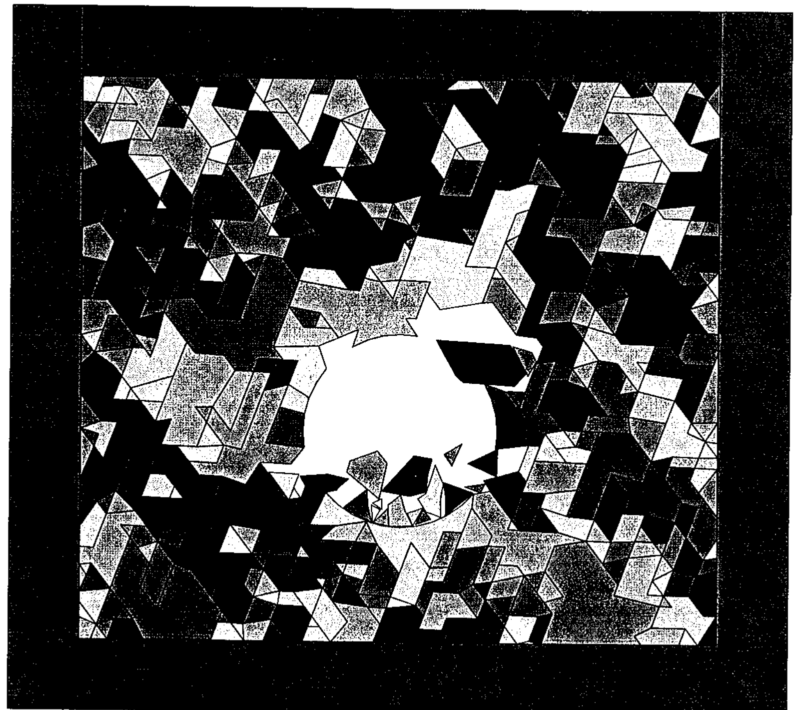

Figure 3. 3 Case 1 thermal load rock falling after 4 seconds

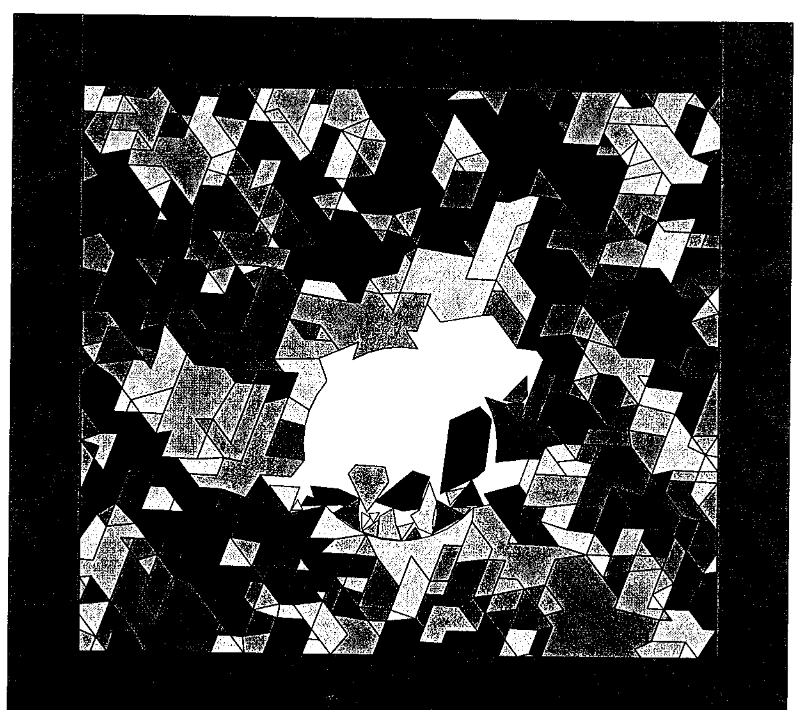

Figure 3. 4 Case 1 thermal load rock falling after 6 seconds

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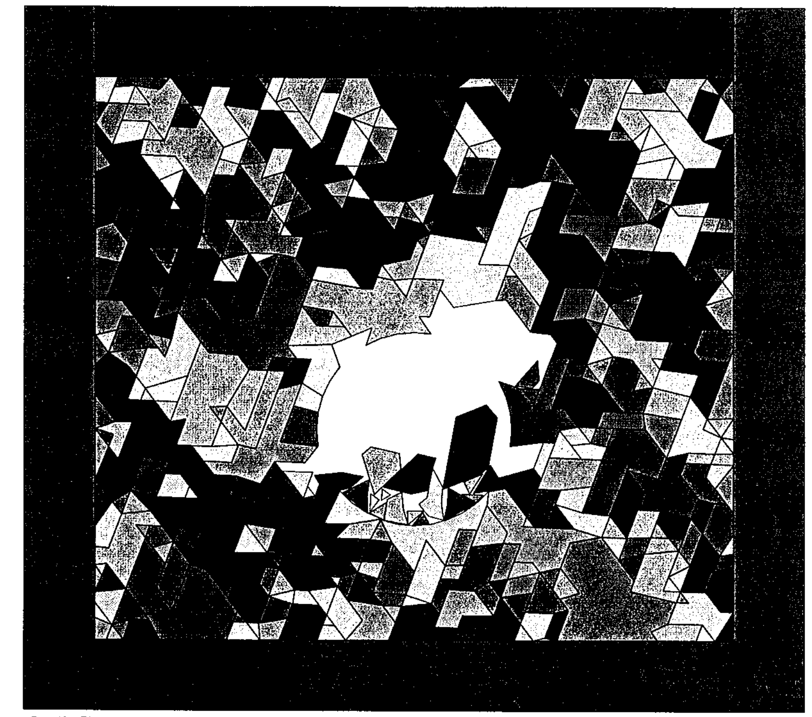

Figure 3. 5 Case 1 thermal load rock falling after 8 seconds

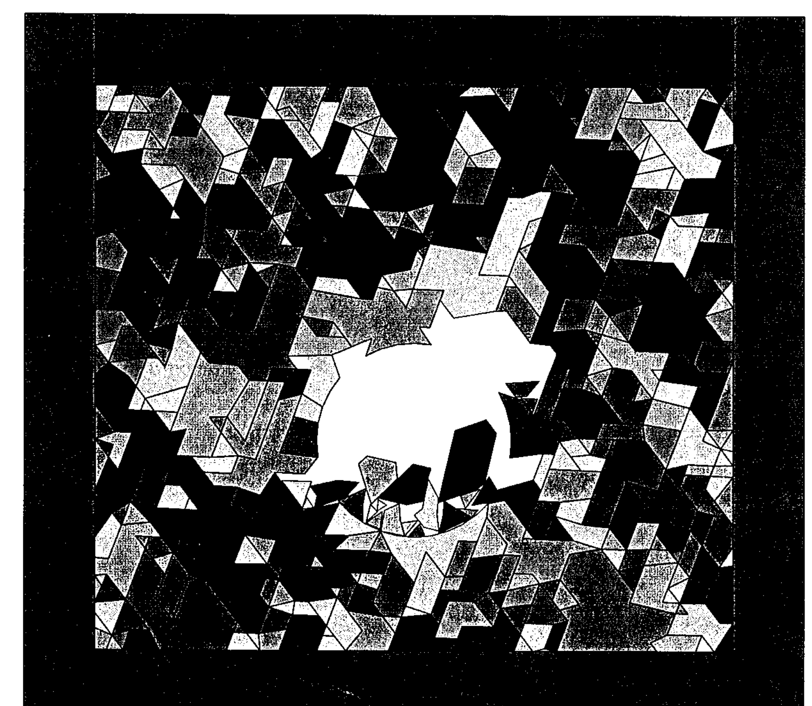

Figure 3. 6 Case 1 thermal load rock falling after 10 seconds

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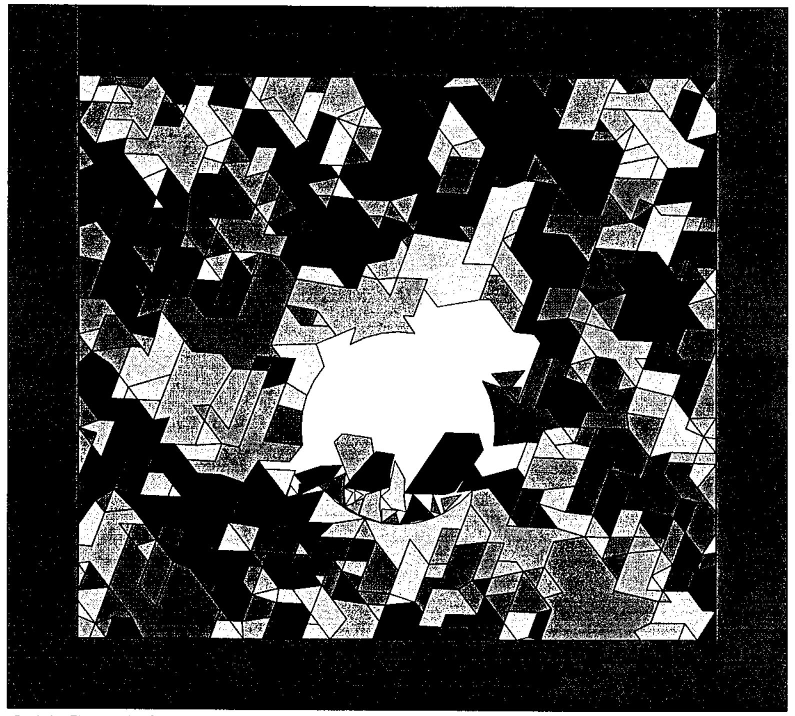

Figure 3.11 Case 1 thermal load rock falling after 20 seconds

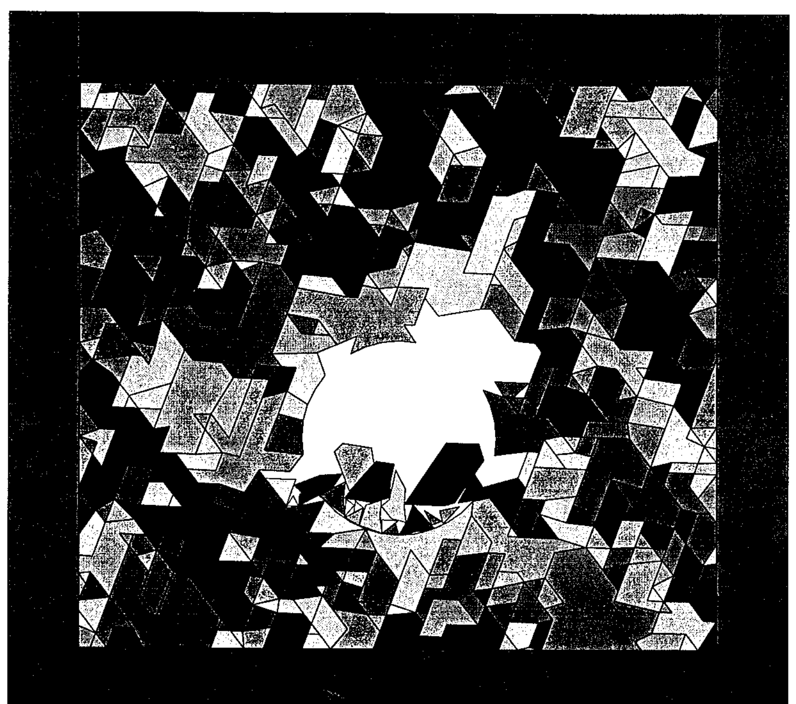

Figure 3.12 Case 1 thermal load rock falling after 22 seconds

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4 Rock falling DDA case 2 with thermal load

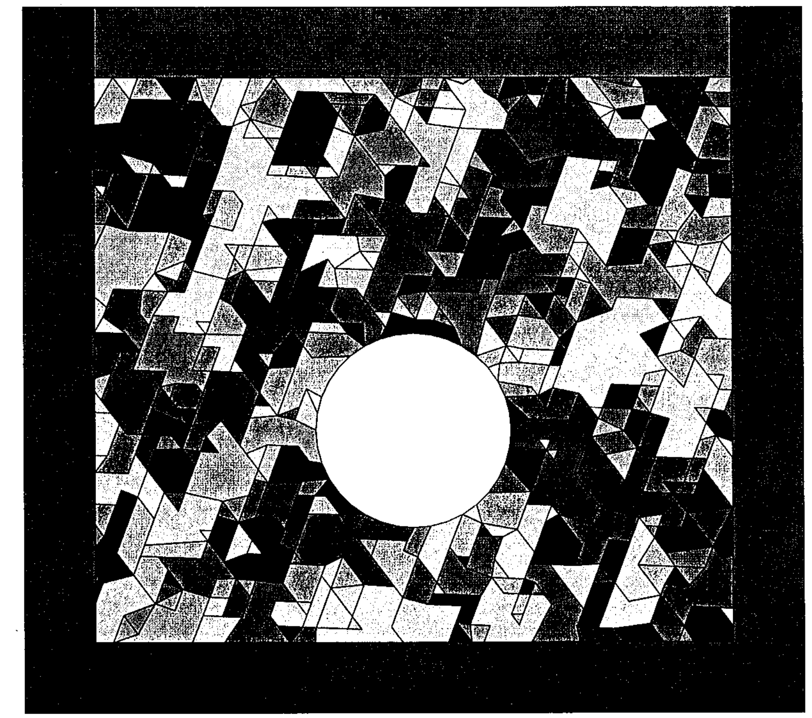

Figure 5. 1 Case 2 thermal load rock falling after 0 seconds

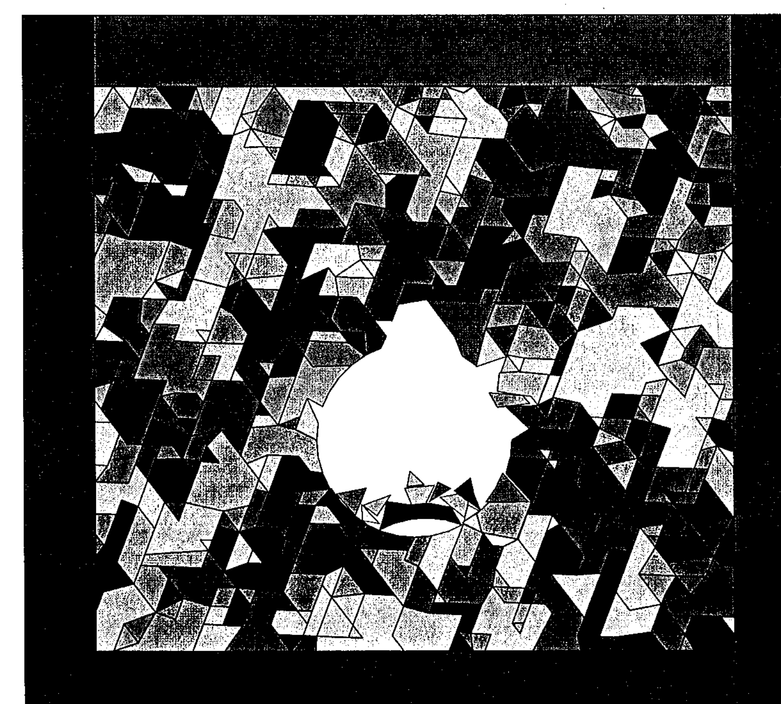

Figure 5. 2 Case 2 thermal load rock falling after 2 seconds

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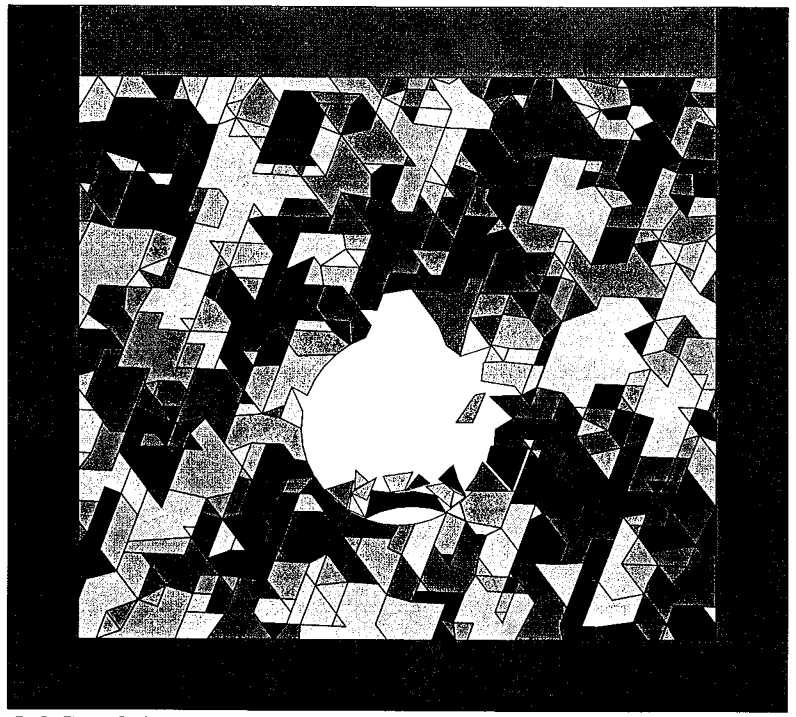

Figure 5. 3 Case 2 thermal load rock falling after 4 seconds

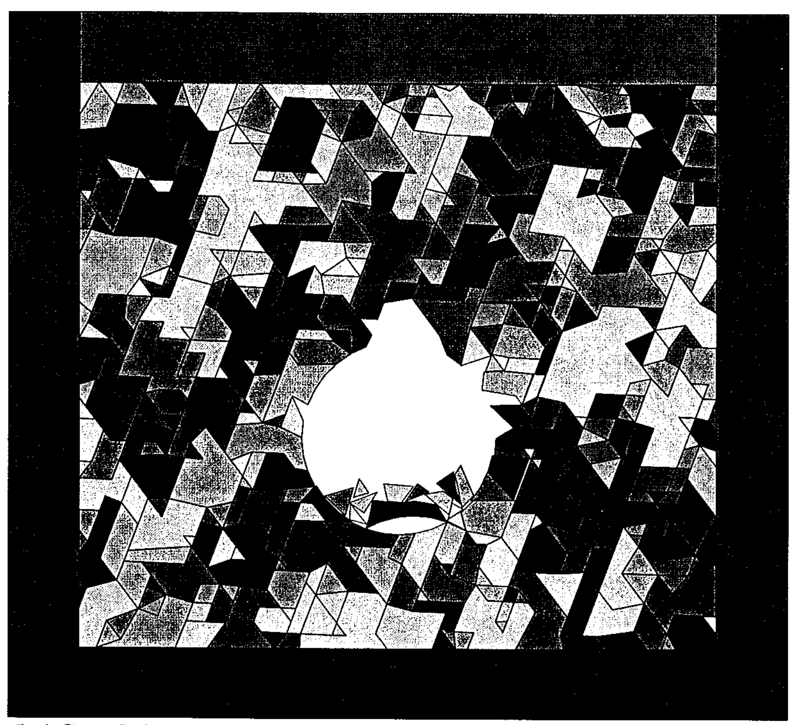

Figure 5. 4 Case 2 thermal load rock falling after 6 seconds

8/31/00

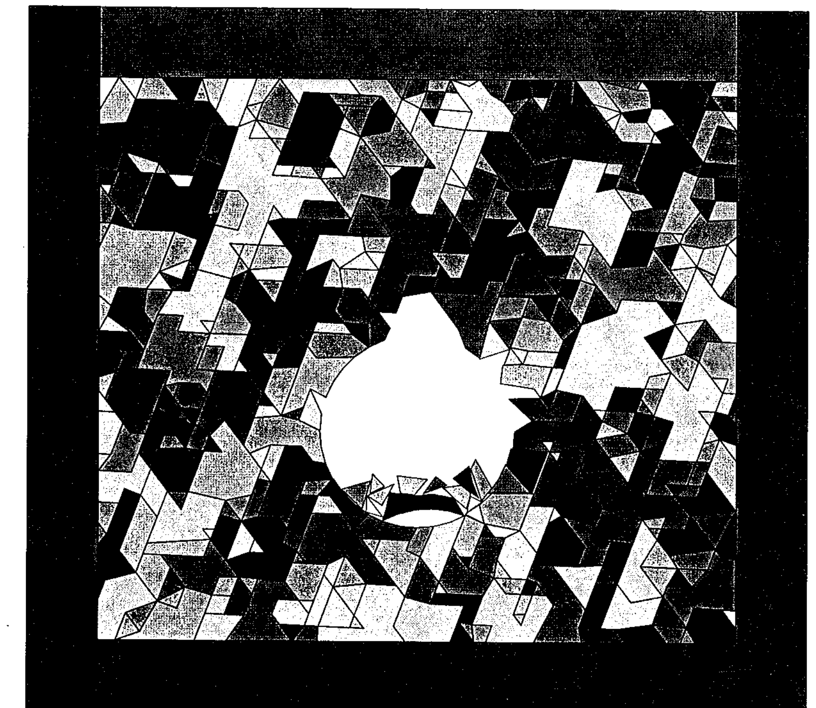

Figure 5. 5 Case 2 thermal load rock falling after 8 seconds

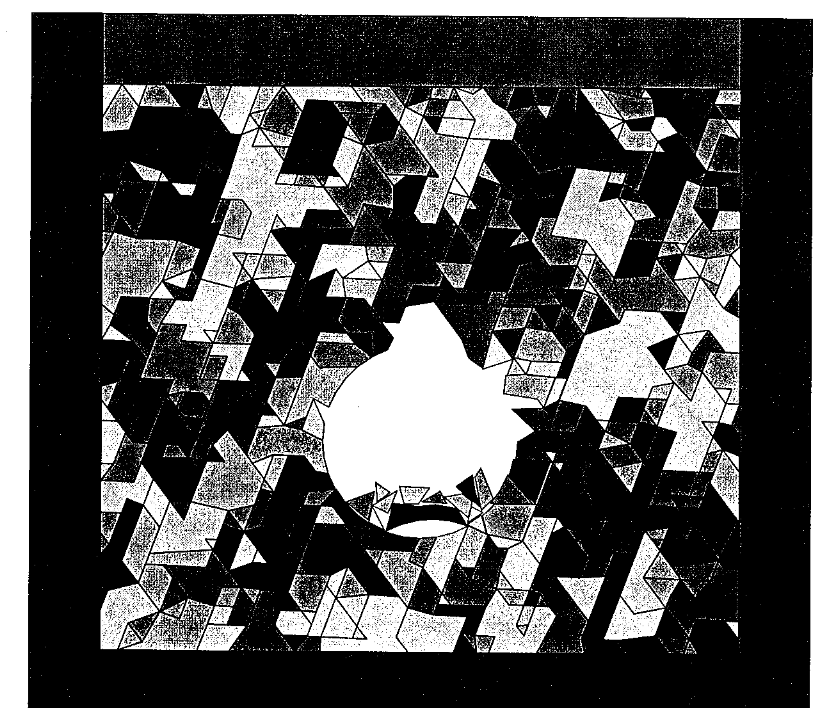

Figure 5. 6 Case 2 thermal load rock falling after 10 seconds

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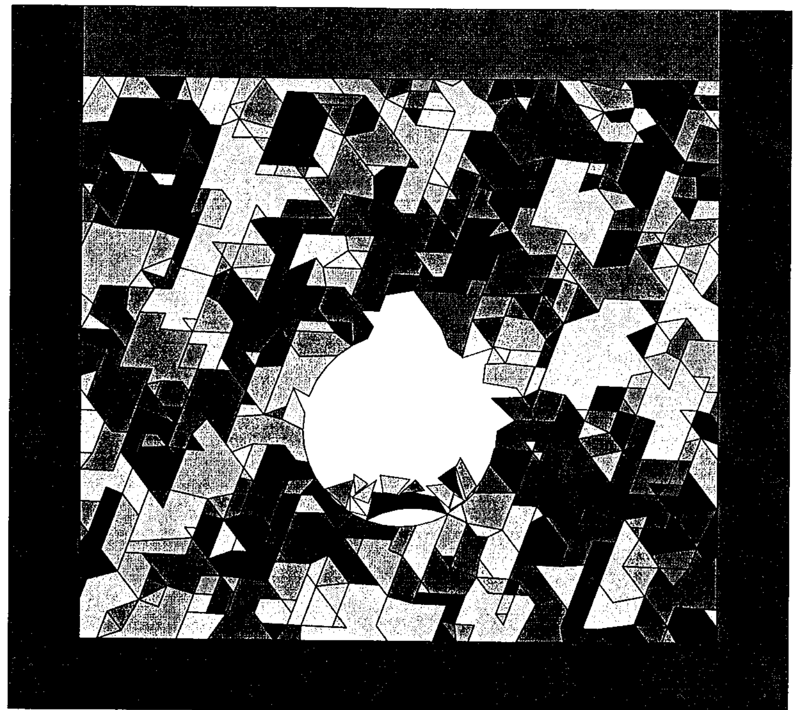

Figure 5.11 Case 2 thermal load rock falling after 20 seconds

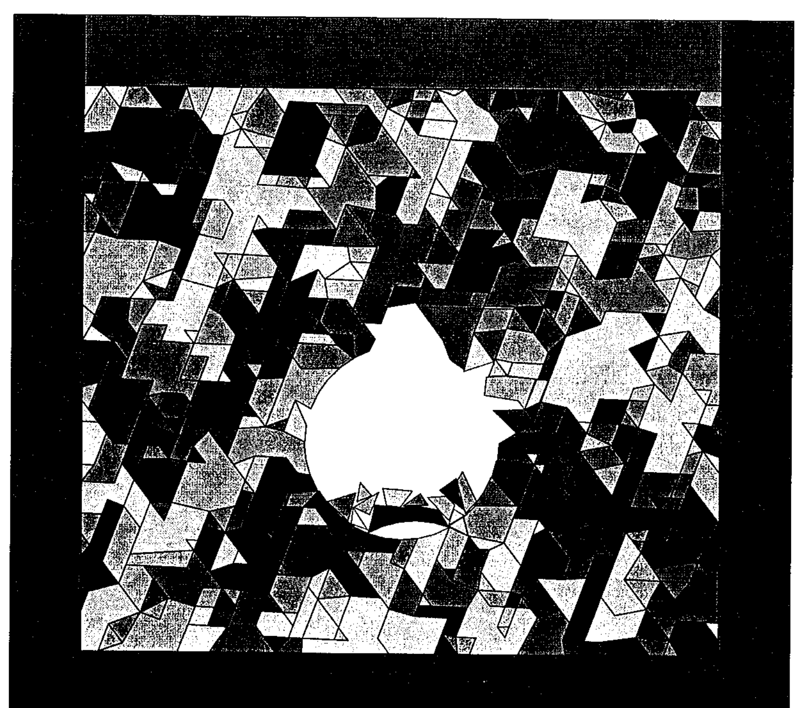

Figure 5.12 Case 2 thermal load rock falling after 22 seconds

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5.8. Rock falling DDA case, 3 (thermal, load)

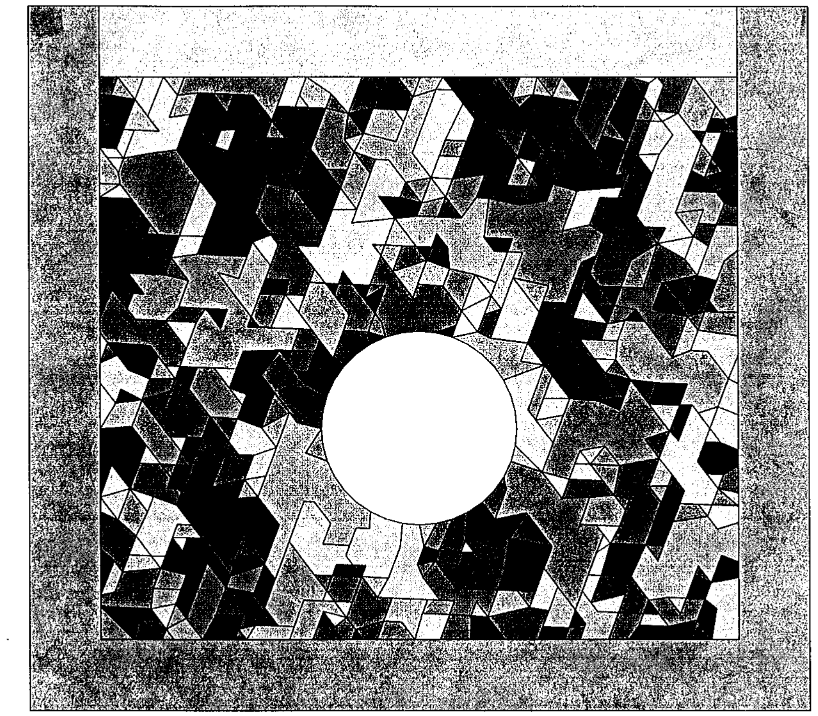

Figure 7. 1 Case 3 thermal load rock falling after 0 seconds

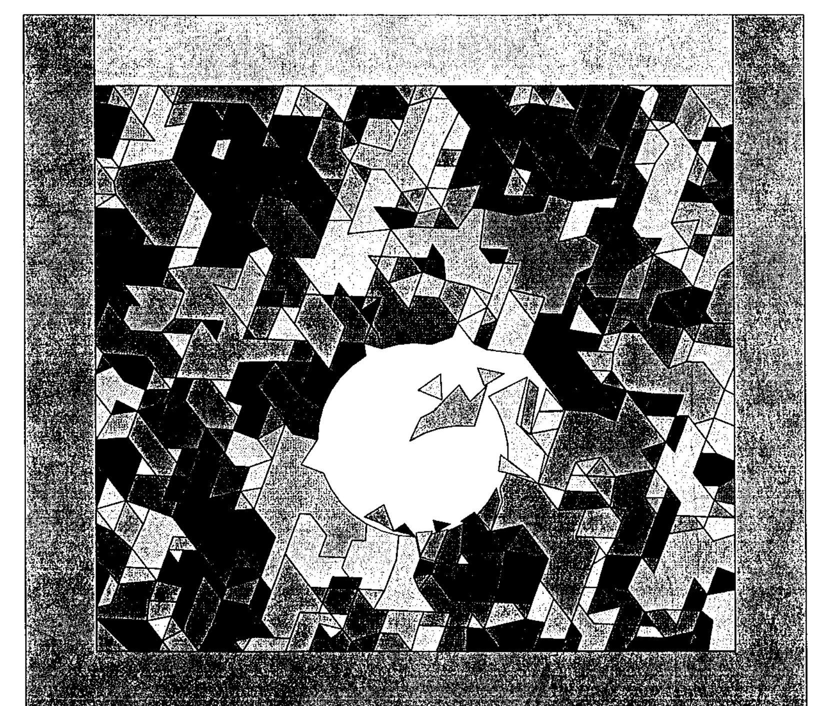

Figure 7. 2 Case 3 thermal load rock falling after 2 seconds

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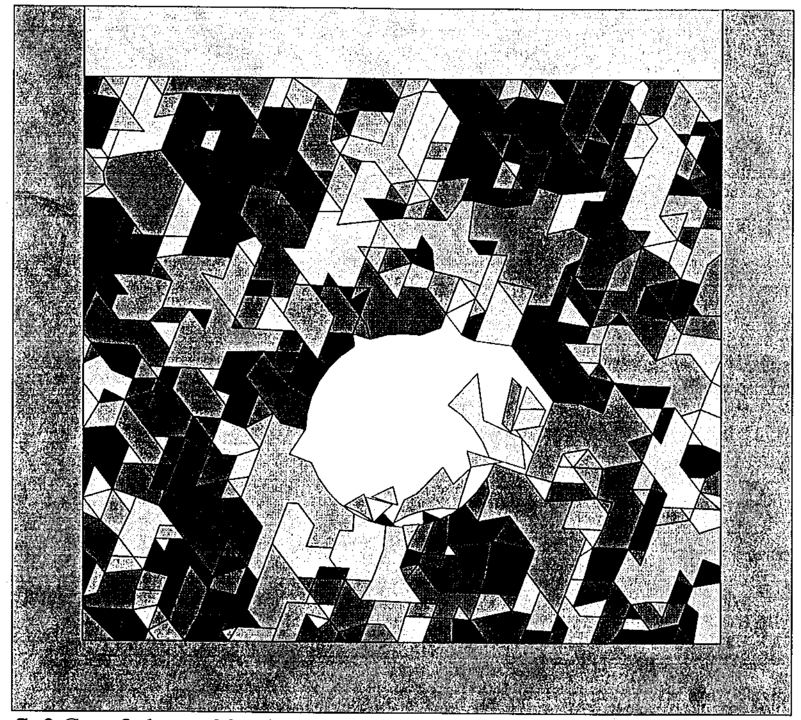

Figure 7. 3 Case 3 thermal load rock falling after 4 seconds

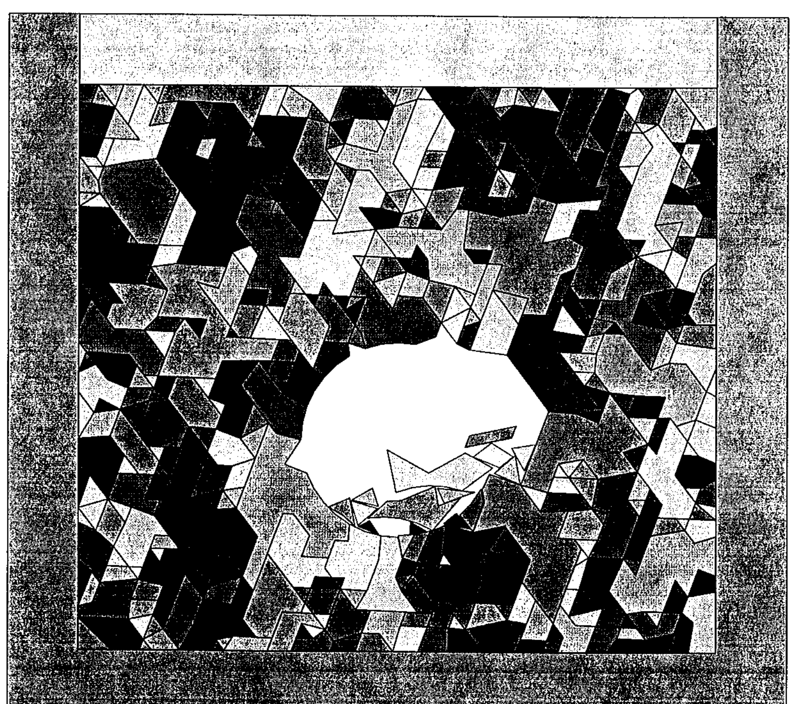

Figure 7. 4 Case 3 thermal load rock falling after 6 seconds

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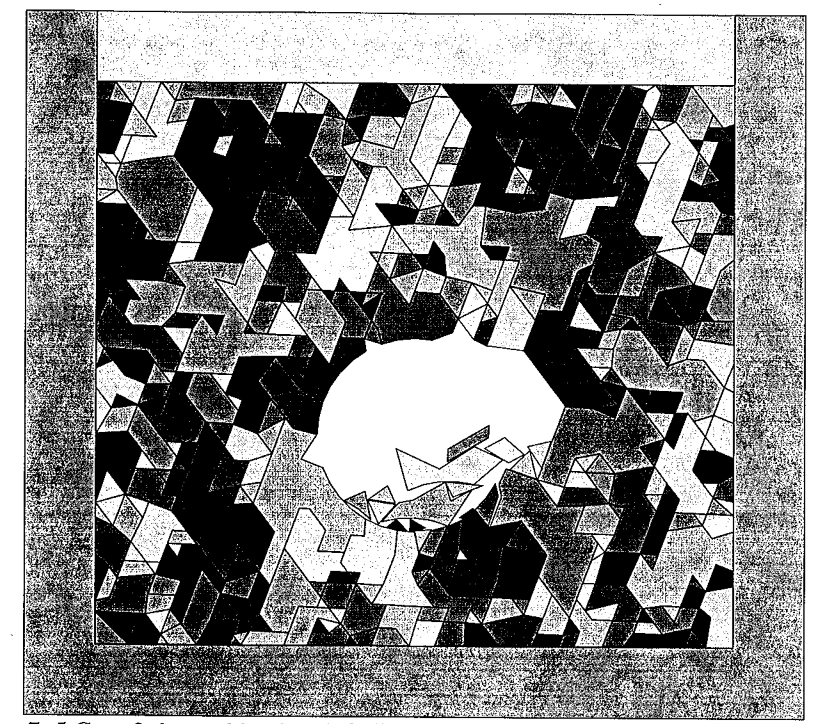

Figure 7. 5 Case 3 thermal load rock falling after 8 seconds

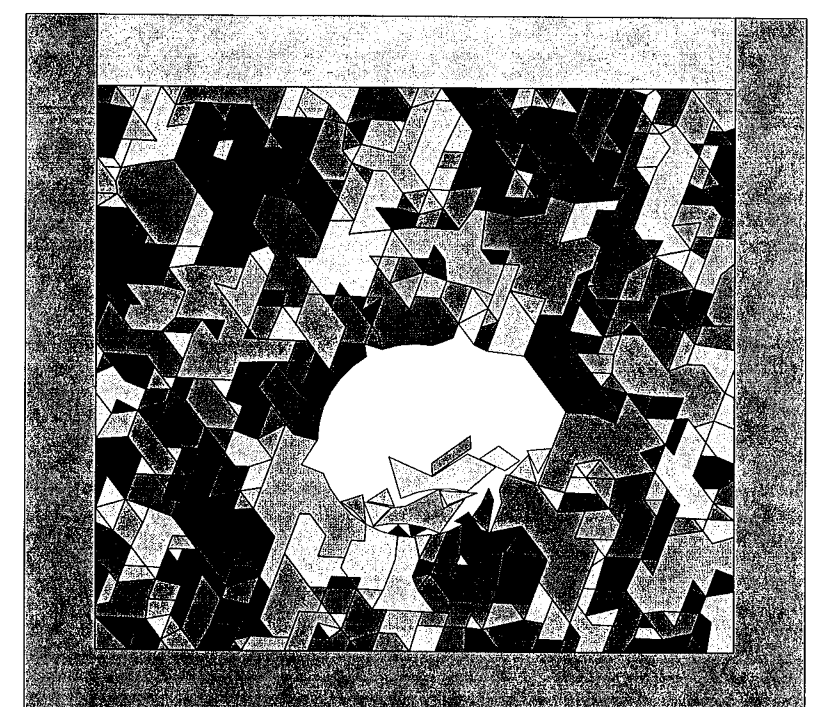

Figure 7. 6 Case 3 thermal load rock falling after 10 seconds

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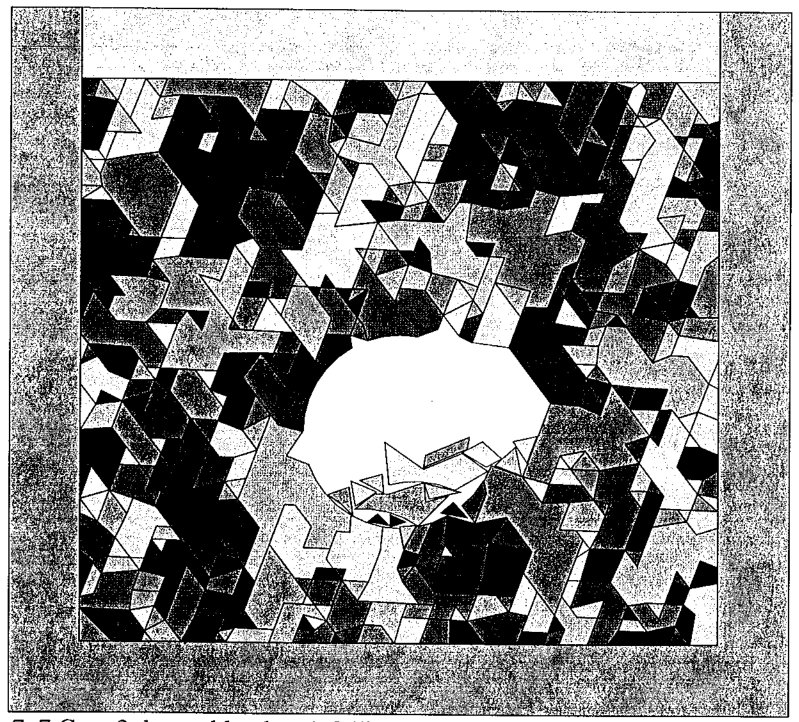

Figure 7. 7 Case 3 thermal load rock falling after 12 seconds

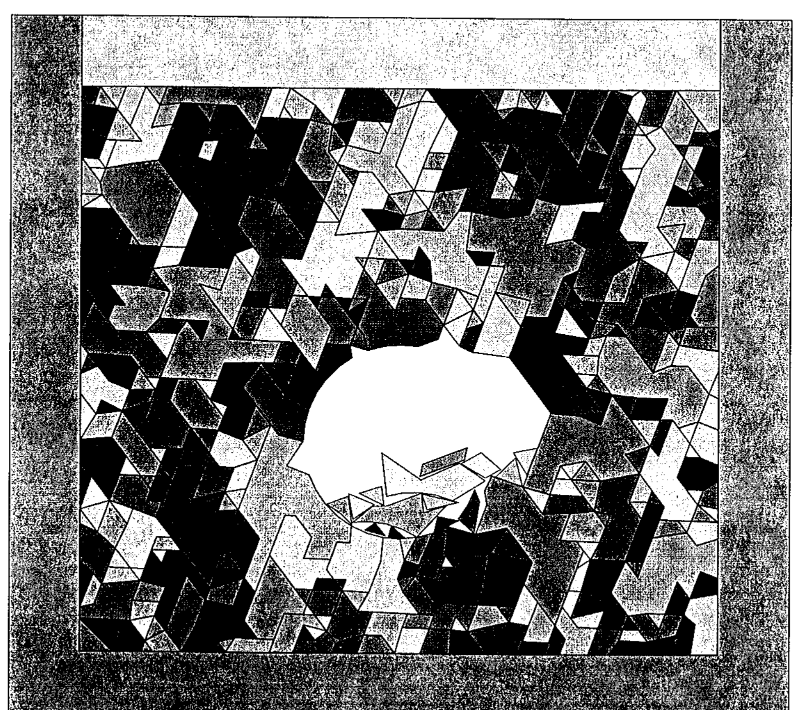

Figure 7. 8 Case 3 thermal load rock falling after 14 seconds

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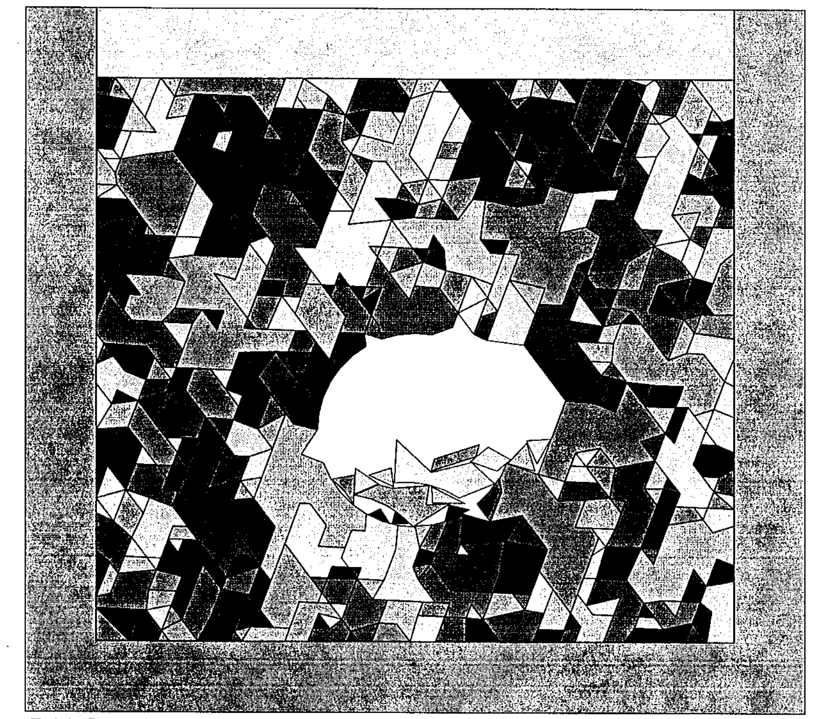

Figure 7.11 Case 3 thermal load rock falling after 20 seconds

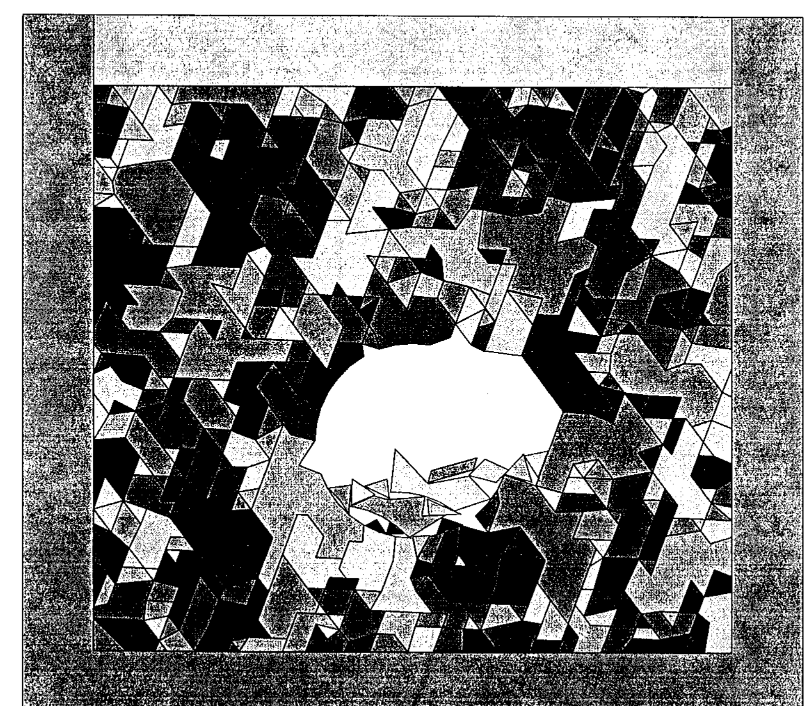

Figure 7.12 Case 3 thermal load rock falling after 22 seconds

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6 Rock falling DDA Case 4 with thermal load

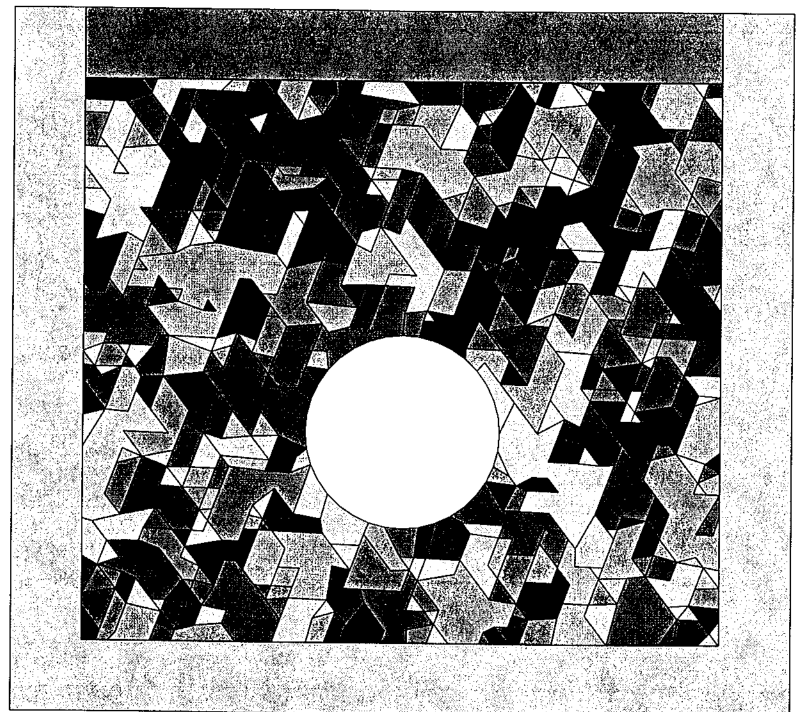

Figure 9. 1 Case 4 thermal load rock falling after 0 seconds

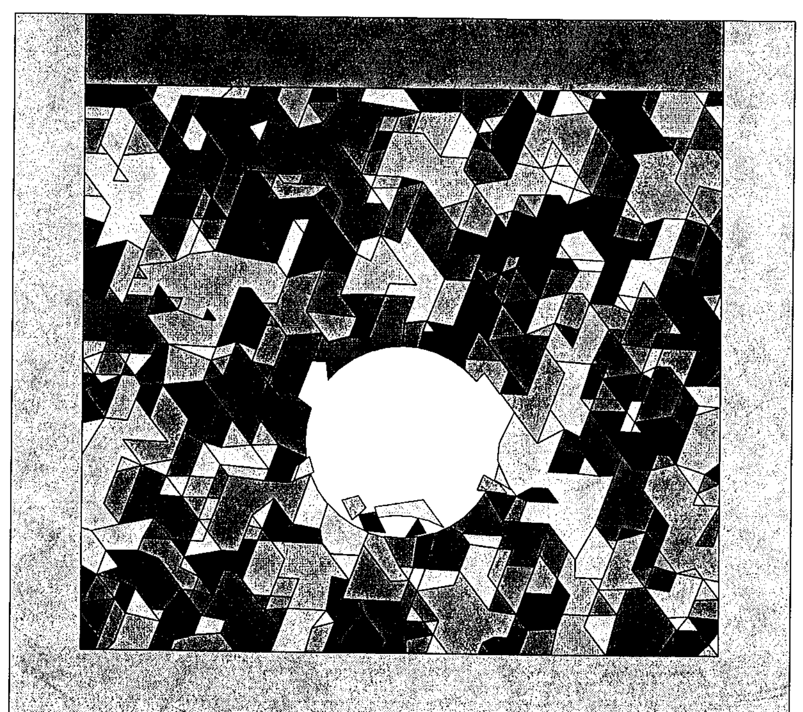

Figure 9. 2 Case 4 thermal load rock falling after 2 seconds

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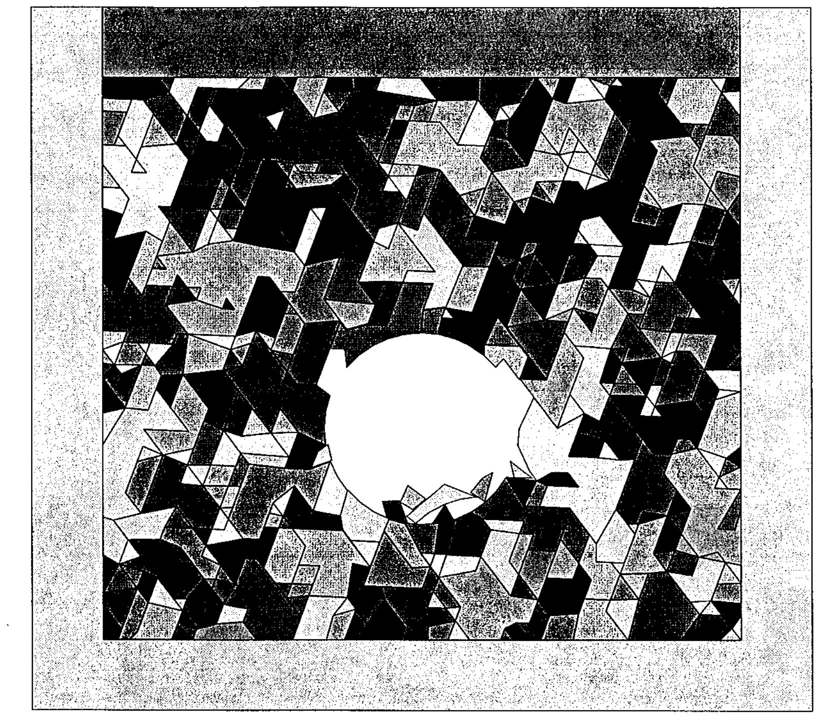

Figure 9. 3 Case 4 thermal load rock falling after 4 seconds

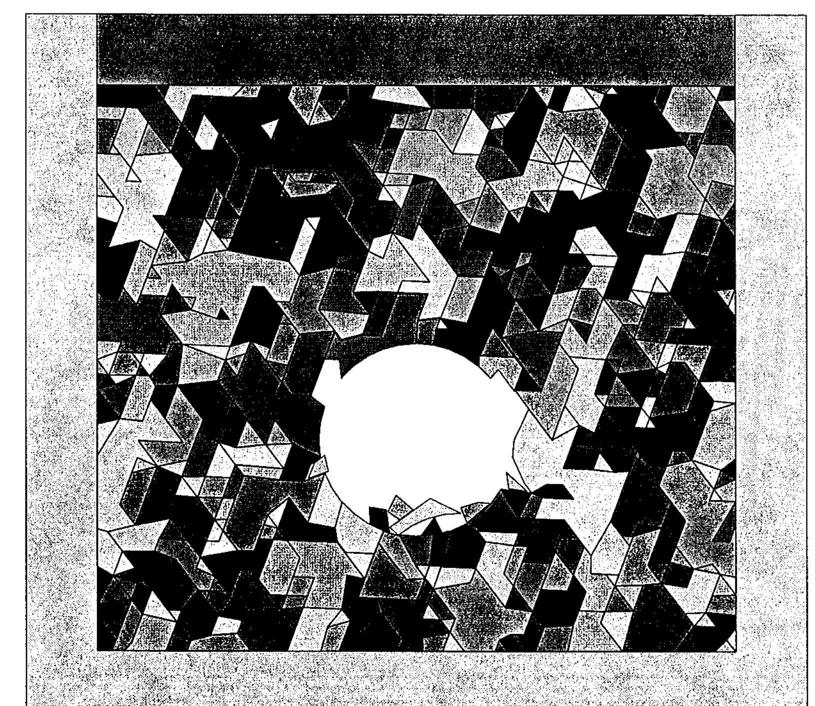

Figure 9. 4 Case 4 thermal load rock falling after 6 seconds

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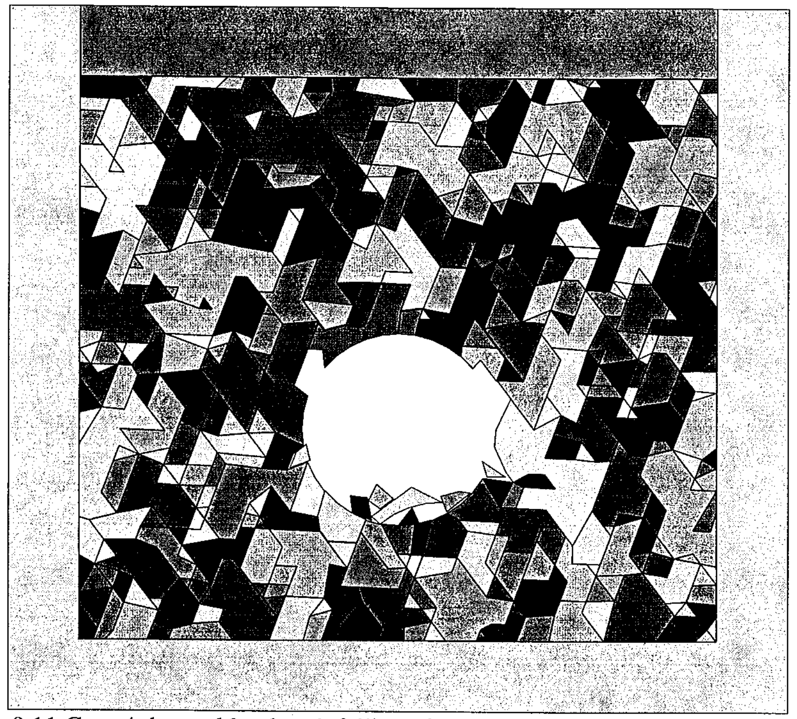

Figure 9.11 Case 4 thermal load rock falling after 20 seconds

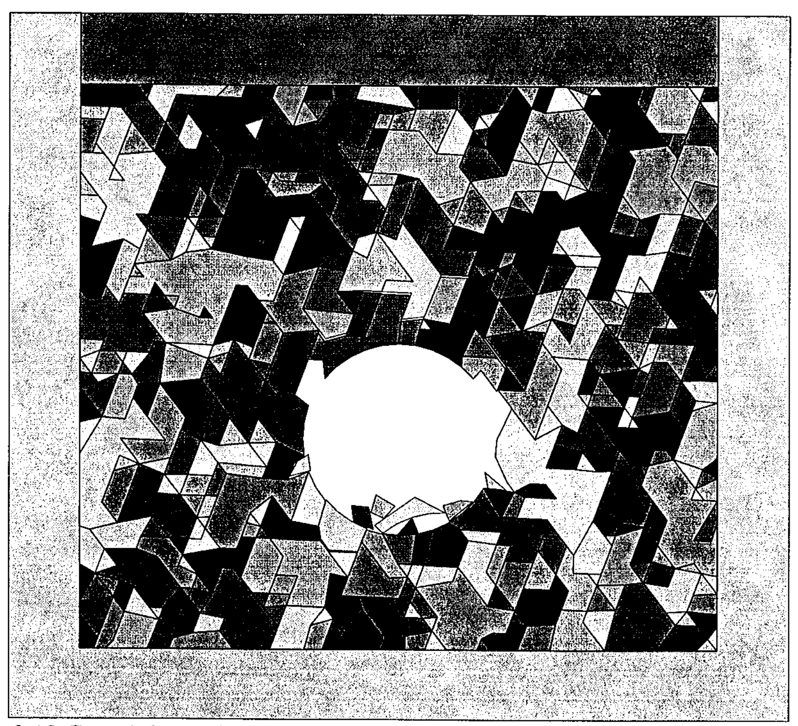

Figure 9.12 Case 4 thermal load rock falling after 22 seconds

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7. Rock falling DDA case 5 with thermal load.

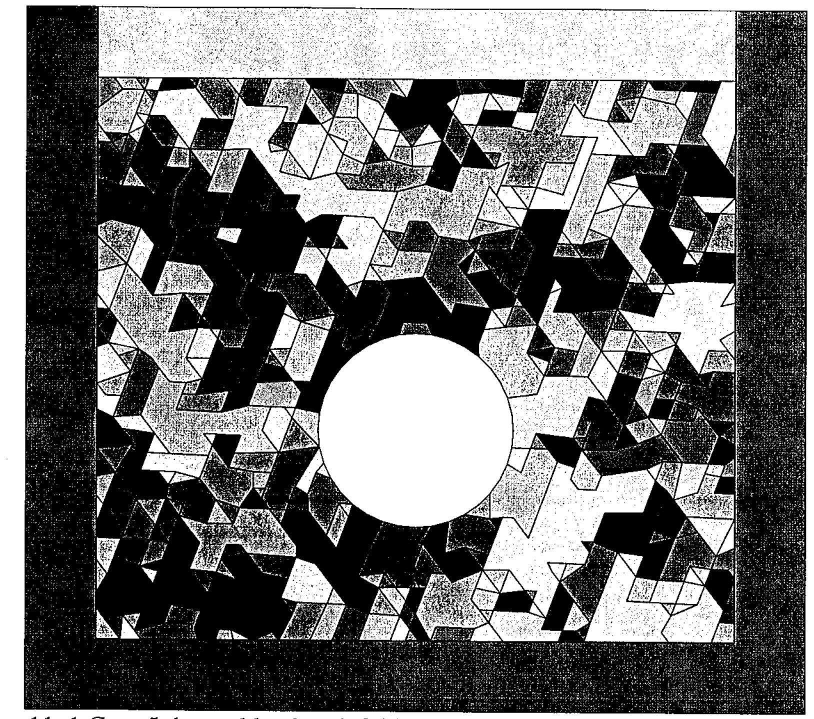

Figure 11. 1 Case 5 thermal load rock falling after 0 seconds

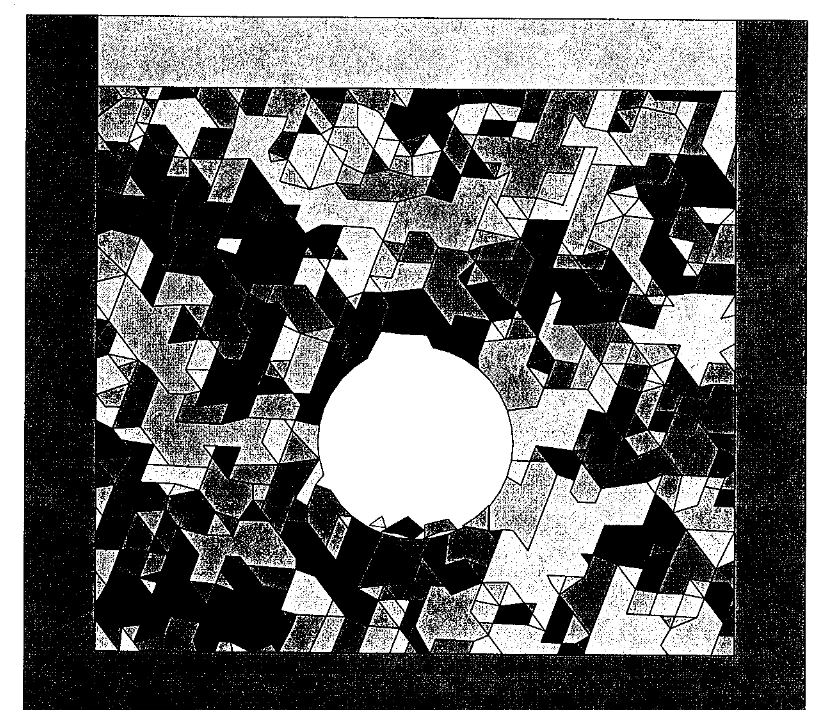

Figure 11. 2 Case 5 thermal load rock falling after 2 seconds

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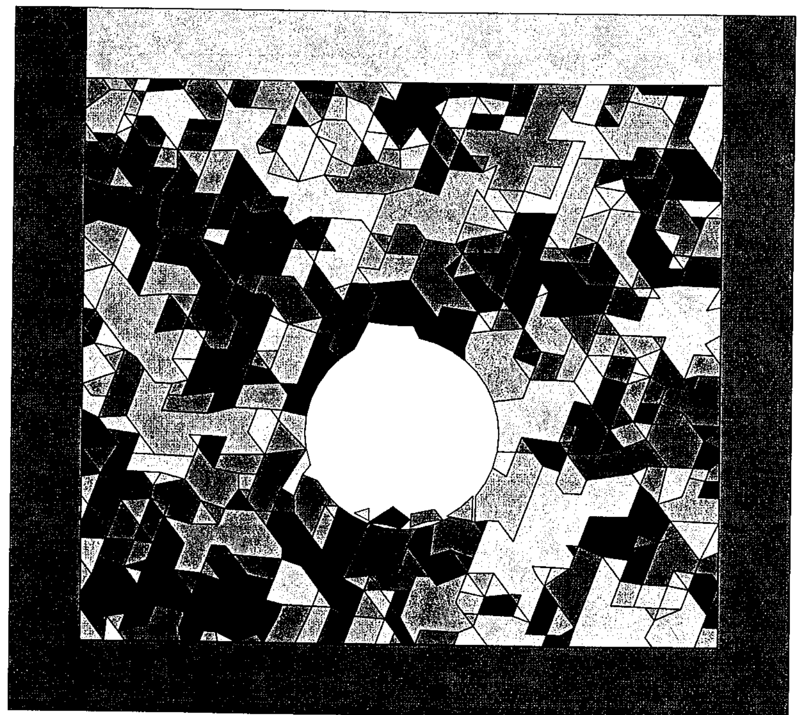

Figure 11. 3 Case 5 thermal load rock falling after 4 seconds

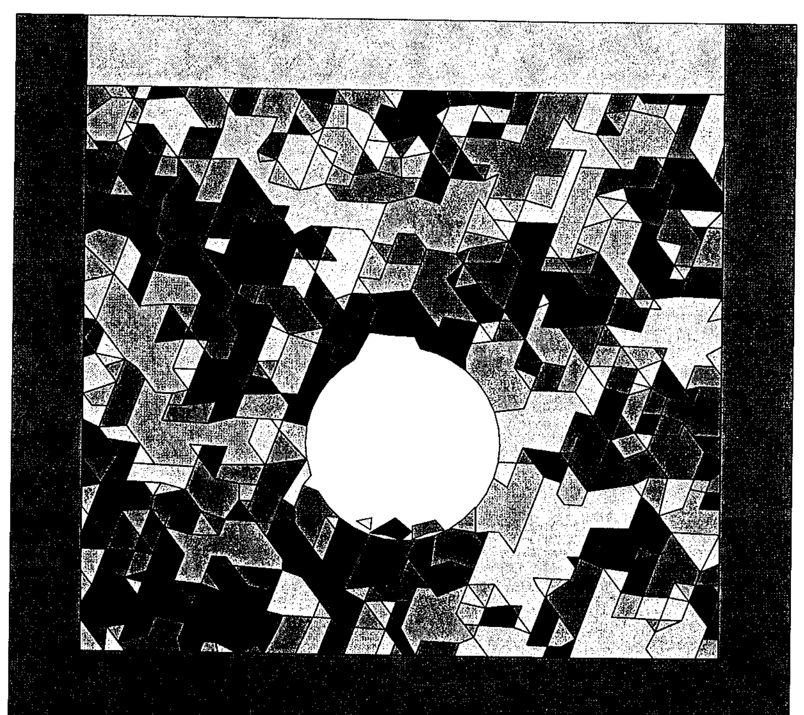

Figure 11. 4 Case 5 thermal load rock falling after 6 seconds

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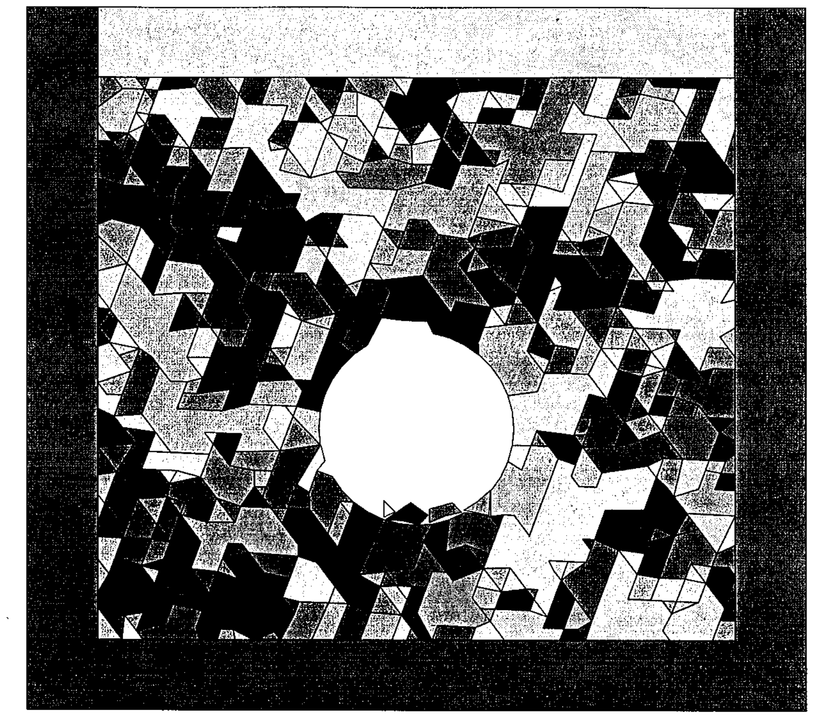

Figure 11.11 Case 5 thermal load rock falling after 20 seconds

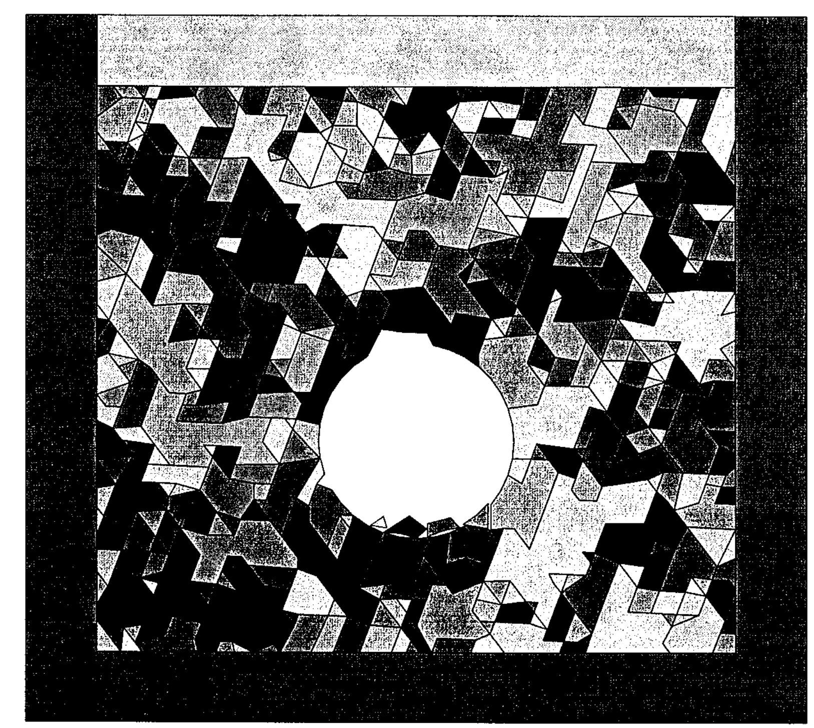

Figure 11.12 Case 5 thermal load rock falling after 22 seconds

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8 checking computed rock falling under thermal load.

The results of the comparasion is clear. this results mean the influence of the thermal load in block systems.

(1). In all five cases both computations were complete. five cases under two different load all have results.

(2) In all five cases, ten load combinations the falling rocks are equal or fewer in the condition with thermal load.

(3). Some cases have visible joint opening. The visible joint opening are smaller in the thermal loading condition.

(4) The rock falling after the temprature go back to the original still fewer or equal to the results of constant ~~temprature~~ condition.
Temperature Sh 9/11/2000

(5) In all five meshes, there are no blocks that fall in thermal load and stay without thermal load.

conclusion: when the temprature rises, the rock falling is fewer, There are no additional rock falling.

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9. Report #5

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Report #5 Dynamic DDA Cases of Rock Falling with Earth Quake and Thermal Load of Project: 20.01402.671 Rock Fall Assessing under Seismic Load using Key Block Analysis

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Introduction of the DDA computation

The differences of the DDA computations between this report and the previous DDA computations of the report #2 are the following:

[1] The tunnel bearing (horizontal tunnel direction) changes from N 105 ° E to N 75 ° E. Therefore the joint directions in the tunnel section plan can be substantially different. The rock falling will be different.

[2] The thermal load has been applied in this DDA computation. The rock falling without thermal load is compared with the rock falling with thermal load.

Also there are two miner changes, which may not influence the resulting rock falling at all:

[3] The minimum distance of nodes changes from 0.25 to 0.23. Smaller blocks are allowed for this DDA computation.

[4] The bridge of the first joint set changes from 0.4m to 0.3m. Here the joint bridge is the same as the joint spacing.

1. Explanation of Two Dimensional Dynamic DDA with Earth Quake Load

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The "DDA" is the abbreviation of discontinuous deformation analysis. From mathematical point of view, DDA is block system version of FEM. It is also true that DDA is discontinuous version of FEM. The DDA is for the computation of discontinuous block systems. The DDA blocks can be convex, concave or complex blocks with any number of edges.

The DDA uses time steps for statics, pseudo-statics, pseudo-dynamics and dynamics. At the end of each time step, two different kinds of equilibrium are reached by minimizing the total potential energy.

The first equilibrium is the equilibrium between blocks. The forces acting on each block, from external loads or contacts with other blocks, satisfy the equilibrium equations.

The second equilibrium is the equilibrium is for each individual block. This equilibrium is achieved between external forces and the block stresses.

Based on natural contact phenomena, an "entrance theory" was developed. The "open-close" iterations ensure that no tension and no penetration occur at all entrance positions and all time steps. There are three entrance modes: open, sliding and locking. Coloumb's Law is also fulfilled at all entrance modes, all entrance positions and all time steps.

In spite of the complex shape of DDA blocks. DDA method uses analytic integrations for all of its matrices. This is another difference from FEM. FEM basically uses numerical integrations inside of each element.

The DDA uses simplex integration. The simplex integration can compute ordinary integrations without subdividing 2-d domains to triangles. Using simplex integration, the integration of any n-dimensional polynomials can be represented by the coordinates of boundary vertices of generally shaped blocks.

The current version of DDA is first order. The displacements of each point inside a block is linear function of coordinates (x, y). Therefore the stresses and strains inside of each block are constant.

DDA computation offers the movements, stresses and strains of each block. The computed block displacements are often large enough to be visible, the modes of failure and the final damage can be seen directly.

On the other side, the DDA codes can perform traditional limit equilibrium analysis

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for whole block systems. The discontinuous deformation analysis (DDA) has to fulfill physical laws of both inside a block or between blocks.

For long term analysis, massive rock collapsing often are block system movements: all blocks move simultaneously, different blocks have different sliding directions. The multi-block rotation such as toppling or buckling can be computed by DDA method.

2. The Geometry and Mechanical Data of Dynamic DDA Computation

The Yucca mountain rocks are jointed rock with considerable strength. The rock falling is basically controlled by existing joints. Therefore the Yucca mountain rocks are suitable for the applications of DDA method.

The joint sets and mechanical parameters are the following:

Table 1. Joint set data

joint set	dip angle	dip d.	friction angle	cohesion
joint set 1	79 °	270°	39 °	0 ton/m^2
joint set 2	81 °	230°	39 °	0 ton/m^2
joint set 3	5 °	45°	39 °	0 ton/m^2

Based upon the statistics, the joint geometric parameters are the following:

Table 2 Statistical joint set data

joint set	spacing: m	length: m	bridge: m
joint set 1	.30 m	1.8 m	.30 m
joint set 2	.30 m	2.4 m	.30 m
joint set 3	.50 m	1.8 m	.50 m

The geometry of the tunnels are the following:

Table 3. Tunnel data

bearing angle of tunnel axis	75 °
rise angle of tunnel axis	0 °
tunnel diameter	5.5 meter

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tunnel shape circular

Based on the geometric data of Table 1, Table 2 and Table 3, program DL0 produces the joints and tunnel boundary lines.

From the joint and tunnel boundary lines, program DC0 produces the block system. The block system is the geometric input of program DF0 and DF1.

The mechanical parameters of both rock masses and joints are the following:

Table 4. Mechanical data

unit weight	2.27 ton /m ^{3}
E of rock mass	3000000 ton /m ^{3}
ν of rock mass	0.21
number of time steps	20000
time step	0.0010 second
earth quake duration	20 second
joint friction angle	39 $^\circ$
cohesion	0 ton /m ^{3}

Based on the mechanical data of Table 4, the program DF0 computes the time depending block movements and block stresses. The process of block falling can be shown.

3. The Earth Quake and Thermal Load of Dynamic DDA Computation

For this computation, the earth quake data of Yerba Buena island tunnel between San Francisco and Oakland are adapted. These acceleration data are from California Department of Transportation. The original data are 50 seconds, our computation only uses from 10 second to 30 second. However these 20 second data are the main part of the strong earth quake.

In DDA computation, as a extension of Mewmark method from one block to multi-blocks, the earth quake accelerations are applied as body forces.

Figure 1.1 shows X and Y components of the time depending earth quake acceleration data.

Figure 1.2 shows Z components and the resultants of the time depending earth quake acceleration data.

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Program DF1 transfers thermal load to initial stresses. The thermal initial stresses are applied gradually following time steps. The thermal load data are the following:

Table 5. Thermal load for thermal modeling

temperature rising	150 $^\circ$ c
thermal expansion rate	7.5×10^{-6} /$^\circ$ c
temperature rising time	from 0 second to 2 second
earth quake time	from 2 second to 22 second
temperature falling time	from 17 second to 22 second

The mechanical data of Table 5 and the data of Figure 1.1 and Figure 1.2 are the input data of the programs DF0 and DF1. Programs DF0 and DF1 compute the time depending block movements and block stresses under earth quake and thermal load. The process of block falling can be shown.

4. Case 1 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 1 are the following:

Table 6. Programs and input files of case 1

file description	earth quake only	with thermal load
joint forming data	dls10	dls10
joint forming code	dl0	dl0
block forming data	dcs10	dcs10
block forming code	dc0	dc0
mechanical data	dfs10	dfs11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 2.1 shows the joints of case 1. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 2.

Figure 2.2 to Figure 2.12 show the rock falling of case 1 for each two seconds of the DDA computation. In the computation, the earth quake load is applied.

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This scientific note book will be continued in scientific note book number 422

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I have reviewed this scientific notebook and find it in compliance with QAP-001. There is sufficient information regarding procedures used for conducting tests, acquiring and analyzing data so that another qualified individual could repeat the activity.

[signature]

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