CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

The work documented in this scientific note book is the continuation of the scientific note book number 388

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~~Material on pages 5 through 9 and 12 through 48 is material from the following reference:~~

~~Hadjigeorgiou, 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 for R. Chen, Center for Nuclear Waste Regulatory Analyses, San~~ Antonio, Texas. Quebec, Canada: Georock, Inc. 1999.

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9. Report #5: Dynamic DDA cases of rock falling with earth quake and thermal load.

Figure 3.1 to Figure 3.12 show the rock falling of case 1 for each two seconds of the DDA computation. In the computation, both the earth quake load and thermal load are applied.

In the case 1, the rock falling with thermal load is fewer than the rock falling without thermal load.

5. Case 2 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 2 are the following:

Table 7. Programs and input files of case 2

file description	earth quake only	with thermal load
joint forming data	dls20	dls20
joint forming code	dl0	dl0
block forming data	dcs20	dcs20
block forming code	dc0	dc0
mechanical data	dfs20	dfs21
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 4.1 shows the joints of case 2. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 2.

Figure 4.2 to Figure 4.12 show the rock falling of case 2 for each two seconds of the DDA computation. In the computation, the earth quake load is applied.

Figure 5.1 to Figure 5.12 show the rock falling of case 2 for each two seconds of the DDA computation. In the computation, both the earth quake load and thermal load are applied.

In the case 2, the rock falling with thermal load is about the same as the rock falling without thermal load. However the width of the visible joint opening is much smaller in the computation with thermal load.

6. Case 3 of Rock Falling DDA Computation

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with Earth Quake and Thermal Load

The programs and input files for the case 3 are the following:

Table 8. Programs and input files of case 3

file description	earth quake only	with thermal load
joint forming data	dls30	dls30
joint forming code	dl0	dl0
block forming data	dcs30	dcs30
block forming code	dc0	dc0
mechanical data	dfs30	dfs31
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 6.1 shows the joints of case 3. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 2.

Figure 6.2 to Figure 6.12 show the rock falling of case 3 for each two seconds of the DDA computation. In the computation, the earth quake load is applied.

Figure 7.1 to Figure 7.12 show the rock falling of case 3 for each two seconds of the DDA computation. In the computation, both the earth quake load and thermal load are applied.

In the case 3, the rock falling with thermal load is much fewer than the rock falling without thermal load. However there are visible joint opening under the thermal load. These opening joints are around the blocks which fall under the condition thermal load was not applied.

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

The programs and input files for the case 4 are the following:

Table 9. Programs and input files of case 4

file description	earth quake only	with thermal load
joint forming data	dls40	dls40
joint forming code	dl0	dl0
block forming data	dcs40	dcs40
block forming code	dc0	dc0
mechanical data	dfs40	dfs41
mechanical code	df0	df1
earth quake data	qks0	qks1

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Figure 8.1 shows the joints of case 4. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 2.

Figure 8.2 to Figure 8.12 show the rock falling of case 4 for each two seconds of the DDA computation. In the computation, the earth quake load is applied.

Figure 9.1 to Figure 9.12 show the rock falling of case 4 for each two seconds of the DDA computation. In the computation, both the earth quake load and thermal load are applied.

In the case 4, the rock falling with thermal load is about the same as the rock falling without thermal load. However the width of the visible joint opening is much smaller in the computation with thermal load.

8. Case 5 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 5 are the following:

Table 10. Programs and input files of case 5

file description	earth quake only	with thermal load
joint forming data	dls50	dls50
joint forming code	dl0	dl0
block forming data	dcs50	dcs50
block forming code	dc0	dc0
mechanical data	dfs50	dfs51
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 10.1 shows the joints of case 5. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 2.

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Figure 10.2 to Figure 10.12 show the rock falling of case 5 for each two seconds of the DDA computation. In the computation, the earth quake load is applied.

Figure 11.1 to Figure 11.12 show the rock falling of case 5 for each two seconds of the DDA computation. In the computation, both the earth quake load and thermal load are applied.

In the case 5, the rock falling with thermal load is about the same as the rock falling without thermal load.

9. Long Term Rock Falling after Tunnel Excavation

For long term rock falling, the DDA computation will be under the following basic assumptions:

[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.

This DDA computation will be conducted later.

References

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[2] Gen-hua Shi, 1993. "Block System Modeling by Discontinuous Deformation Analysis" *Computational Mechanics Publications, Southampton, UK and Boston USA*

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10. planing load combinations of the future DDA computations

Comparasion of finit block size distribution joint system No 1 is

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

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

joint system No 1 was used in previous Report #1 – #5.

Joint system No 2 is used in current Report #6

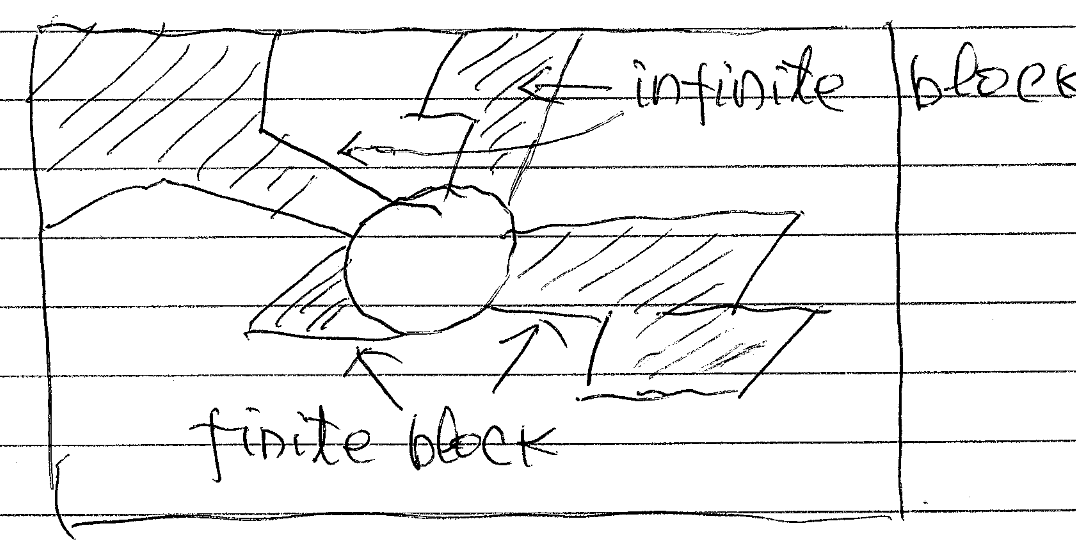
joint set	dip	dip direction
1	82°	145°
2	79°	180°
3	5°	315°

joint set	spacing: m	length: m	bridge: m
1	1.57	2.11	-.03
2	3.18	1.70	-.03
3	0.57	3.42	-.03

The sizes of finite blocks are from two dimensional cross section:

code dl0 producees the joints
code dc0 produces the blocks

finite blocks have the definition:



Boundary of finite blocks is joint and tunnel surface.

Infinite blocks connected with whole rock body. Infinite blocks are not isolated by joints and tunnel surfaces.

2. Comparasion of Finite Block Size Distribution of Joint System No 1 and Joint System No 2

The statistical joint set data of joint system No 1 and No 2 are shown in Table 3-6. Finite blocks are the divided and completely isolated blocks by joints and tunnel surface. This results of following Table 1 is from two-dimensional mesh. The following table is the finite block size distribution of joint system No 1 and No 2:

Table 1. Finite block size distribution

volume range m^2	joint system No 1	joint system No 2
$0.0m^2$—$0.2m^2$	15.2 %	13.6 %
$0.2m^2$—$0.4m^2$	37.7 %	0.6 %
$0.4m^2$—$0.6m^2$	15.9 %	0.6 %
$0.6m^2$—$0.8m^2$	10.4 %	16.0 %
$0.8m^2$—$1.0m^2$	6.4 %	15.7 %
$1.0m^2$—$1.2m^2$	4.6 %	13.3 %
$1.2m^2$—$1.4m^2$	3.3 %	12.7 %
$1.4m^2$—$1.6m^2$	3.1 %	10.2 %
$1.6m^2$—$1.8m^2$	2.2 %	5.7 %
$1.8m^2$—$2.0m^2$	1.2 %	5.7 %
$2.0m^2$—$2.2m^2$	0.0 %	3.3 %
$2.2m^2$—$2.4m^2$	0.0 %	2.6 %

Table 2. Programs and input files of finite block size

file description	forming blocks	size statistics
computation code	dc0	dv0
No 1 input of case 1	dcs10	blck
No 1 input of case 2	dcs20	blck
No 1 input of case 3	dcs30	blck
No 1 input of case 4	dcs40	blck
No 1 input of case 5	dcs50	blck
No 2 input of case 1	dcn10	blck
No 2 input of case 2	dcn20	blck
No 2 input of case 3	dcn30	blck
No 2 input of case 4	dcn40	blck
No 2 input of case 5	dcn50	blck

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Prepare joint length and spacing data of joint system #2.

3. 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 3. Joint set data of system No 1

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

Table 4. Joint set data of system No 2

joint set	dip angle	dip d.	friction angle	cohesion
joint set 1	82°	145°	39°	0 ton/m^2
joint set 2	79°	180°	39°	0 ton/m^2
joint set 3	5°	315°	39°	0 ton/m^2

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

Table 5 Statistical joint set data of system No 1

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

Table 6 Statistical joint set data of system No 2

joint set	spacing: m	length: m	bridge: m
joint set 1	1.57 m	2.11 m	-.03 m
joint set 2	3.18 m	1.70 m	-.03 m
joint set 3	0.57 m	3.42 m	-.03 m

The geometry of the tunnels are the following:

Table 7. 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 3 to Table 6, 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 8. 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 °
cohesion	0 ton /m ^{3}

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Based on the mechanical data of Table 8, the program DF0 computes the time depending block movements and block stresses. The process of block falling can be shown.

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Study seismic and thermal modeling of joint System No 2.

4. 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.

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 9. Thermal load for thermal modeling

temperature rising	150 ° c
thermal expansion rate	7.5×10^{-6} /° 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 9 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.

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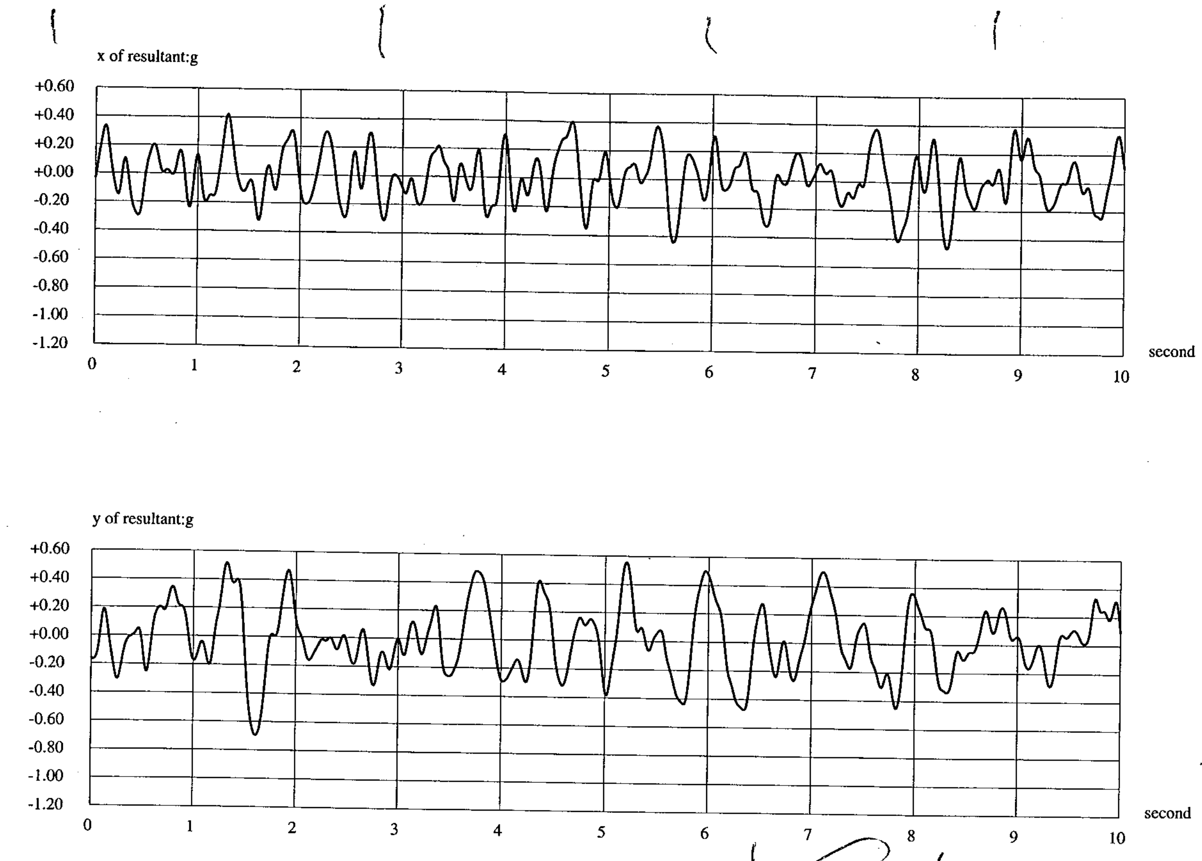

Figure 1.1 X and Y of earth quake acceleration

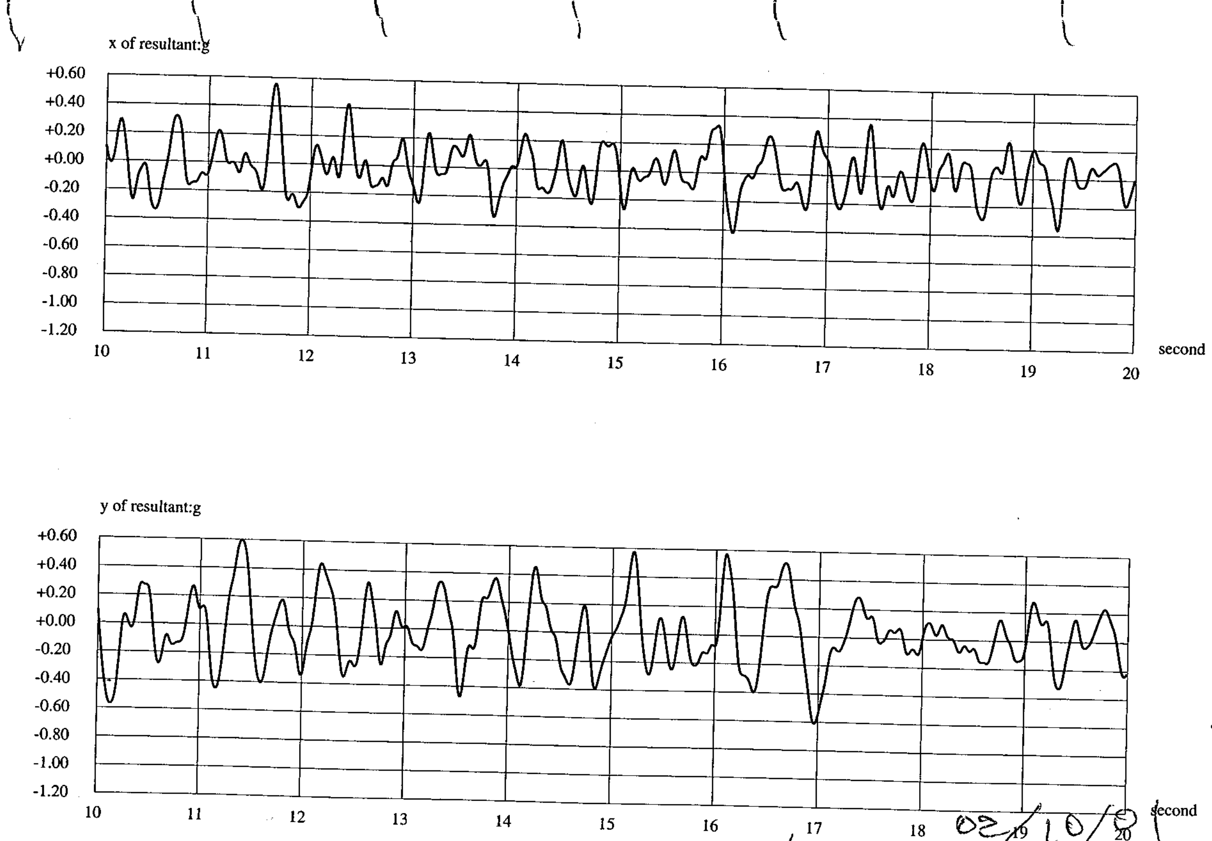

Figure 1.1 X and Y of earth quake acceleration

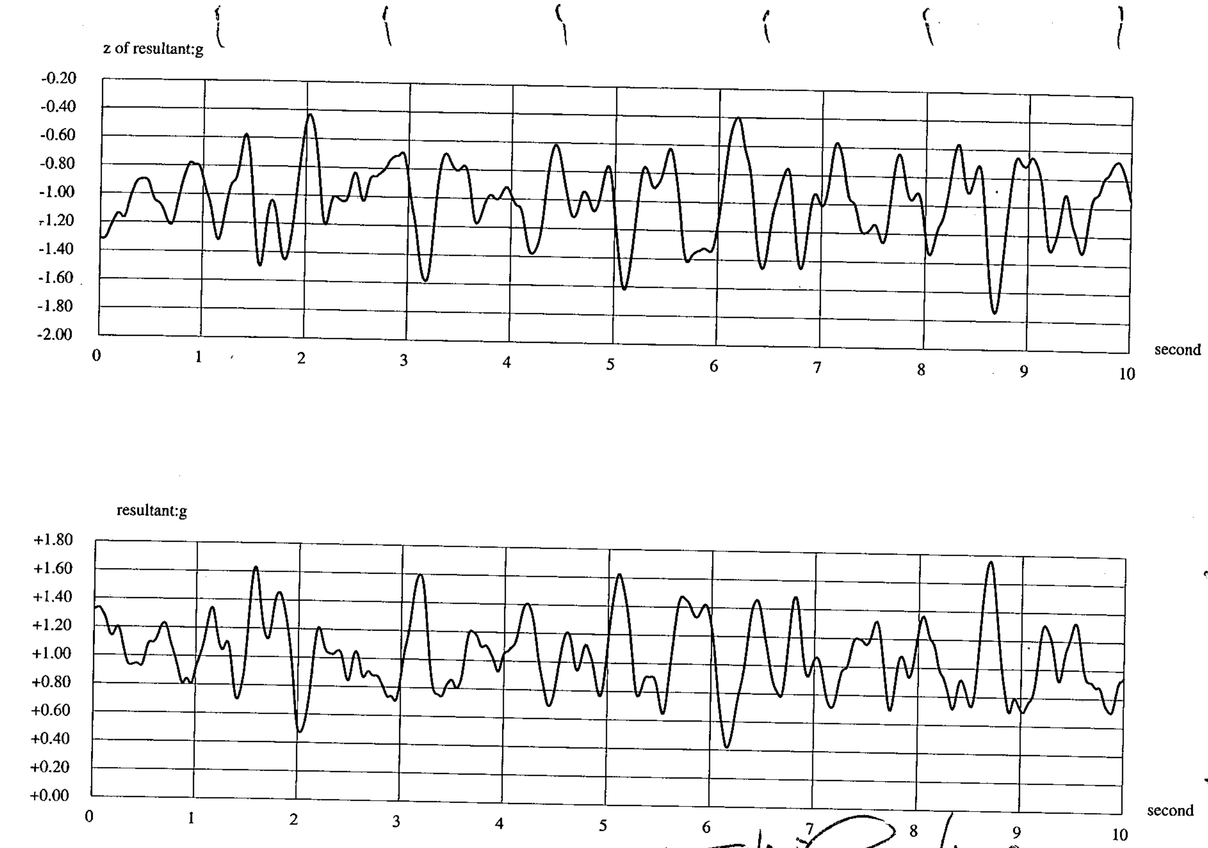

Figure 1.2 Z and resultant of earth quake accelerations

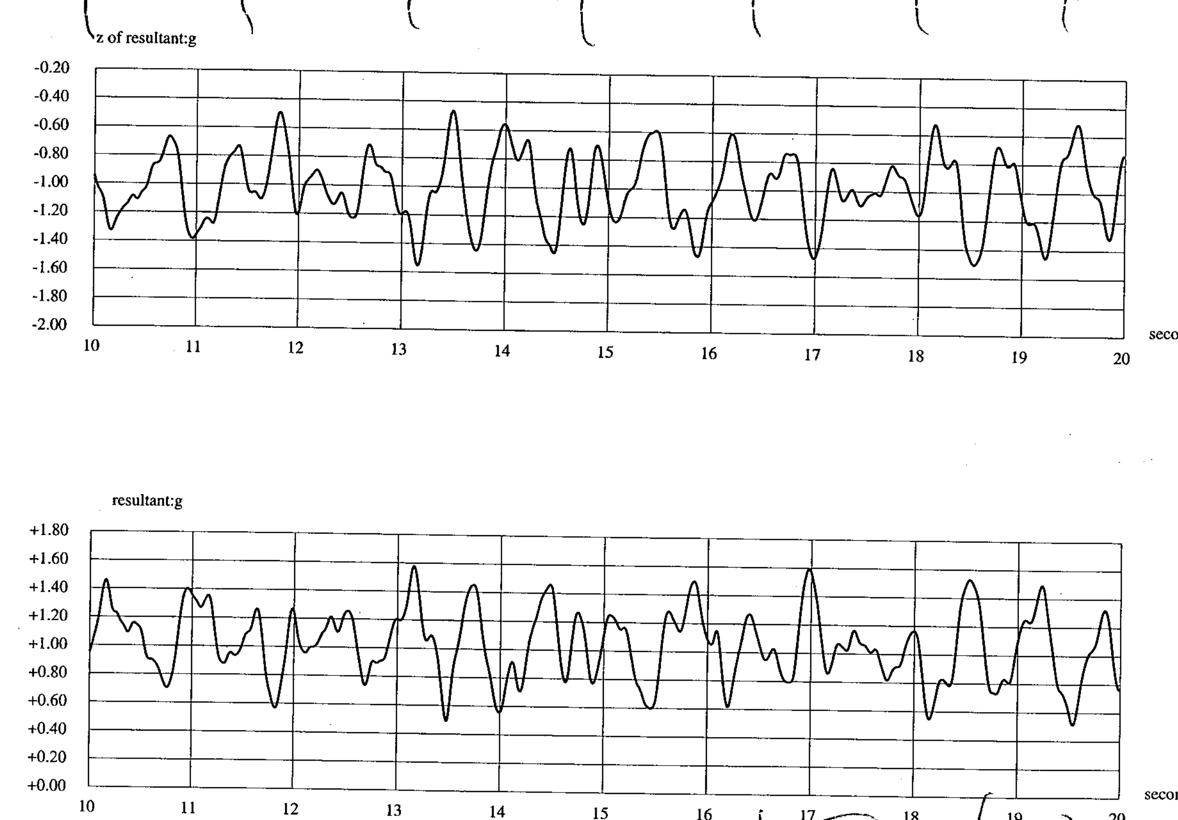

Figure 1.2 Z and resultant of earth quake accelerations

11. Rock block falling DDA computation of rock joint system No. 2 with seismic and thermal load.

there are altogether ten cases. Each case has
statistically produced joint trace map
block systems from joint trace map
rock falling under seismic loads
rock falling under seismic and thermal lodding

5. 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 10. Programs and input files of case 1

file description	earth quake only	with thermal load
joint forming data	dln10	dln10
joint forming code	dl0	dl0
block forming data	dcn10	dcn10
block forming code	dc0	dc0
mechanical data	dfn10	dfn11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 2 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 5 anf Table 6.

Figure 3 show the rock falling of the DDA computation case 1. In the computation, the earth quake load is applied.

Figure 4 show the rock falling of the DDA computation case 1. In the computation, both the earth quake load and thermal load are applied.

In the case 1, the rock falling with thermal load is fewer than the rock falling without thermal load.

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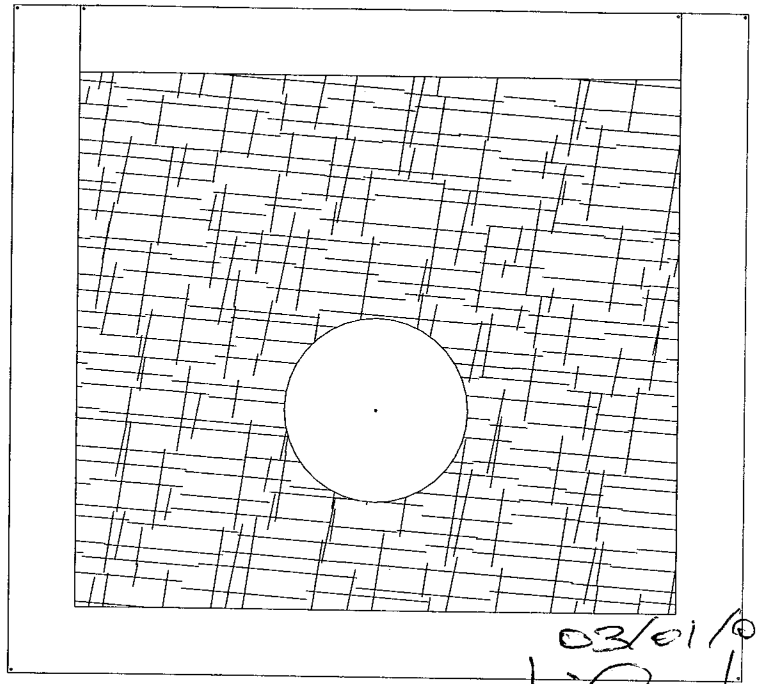

Figure 2.1 Statistically produced joints of case 1

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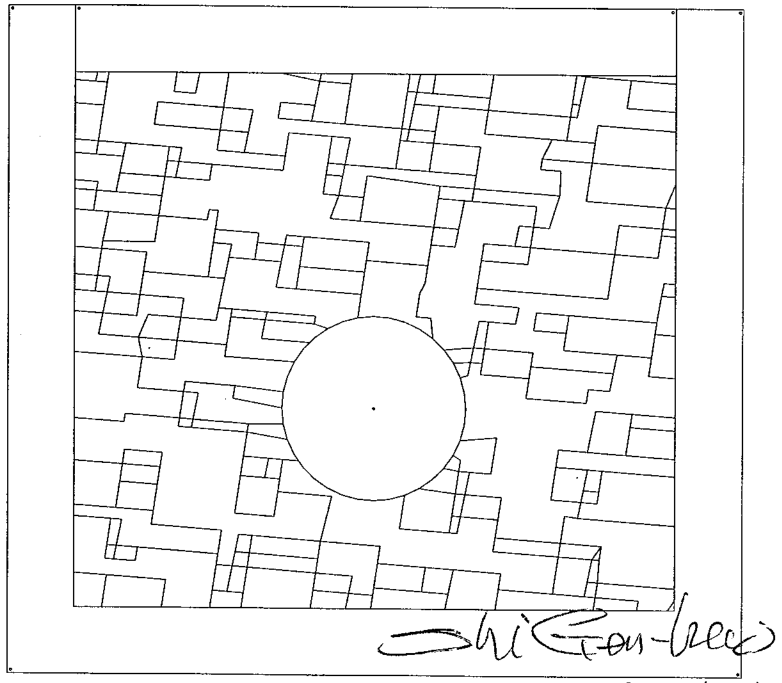

Figure 2.2 block mesh formed by joints of case 1

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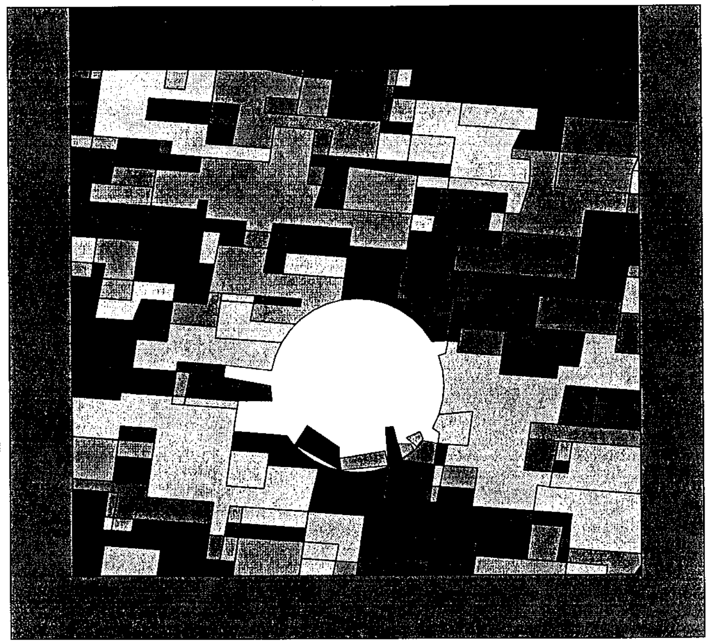

Figure 3.11 Case 1 rock falling after 20 seconds

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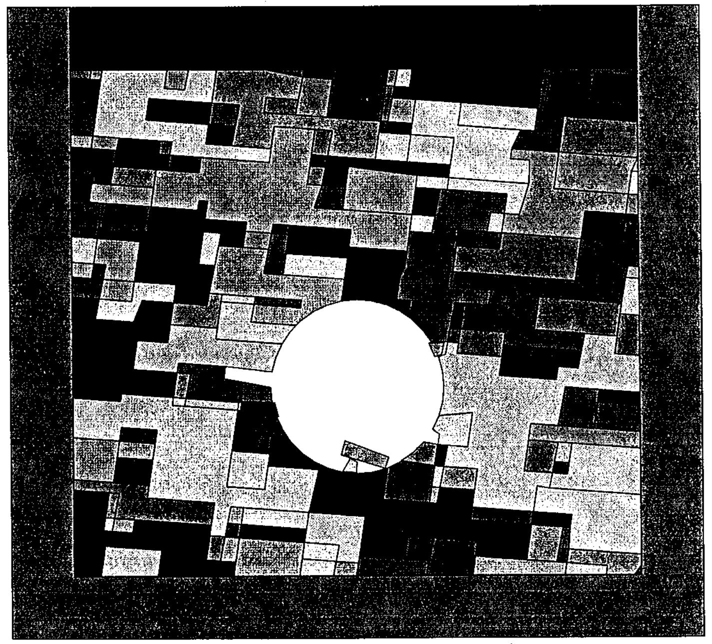

Figure 4.12 Case 1 thermal load rock falling after 22 seconds

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Case 2 of rock falling DDA computation of rock joint system No 2 with seismic and thermal loads.

6. Case 2 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 2 are the following:

Table 11. Programs and input files of case 2

file description	earth quake only	with thermal load
joint forming data	dln10	dln10
joint forming code	dl0	dl0
block forming data	dcn20	dcn20
block forming code	dc0	dc0
mechanical data	dfn10	dfn11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 5 shows the joints of case 2. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 5 anf Table 6.

Figure 6 show the rock falling of the DDA computation case 2. In the computation, the earth quake load is applied.

Figure 7 show the rock falling of the DDA computation case 2. In the computation, both the earth quake load and thermal load are applied.

In the case 2, the rock falling with thermal load is the same as the rock falling without thermal load.

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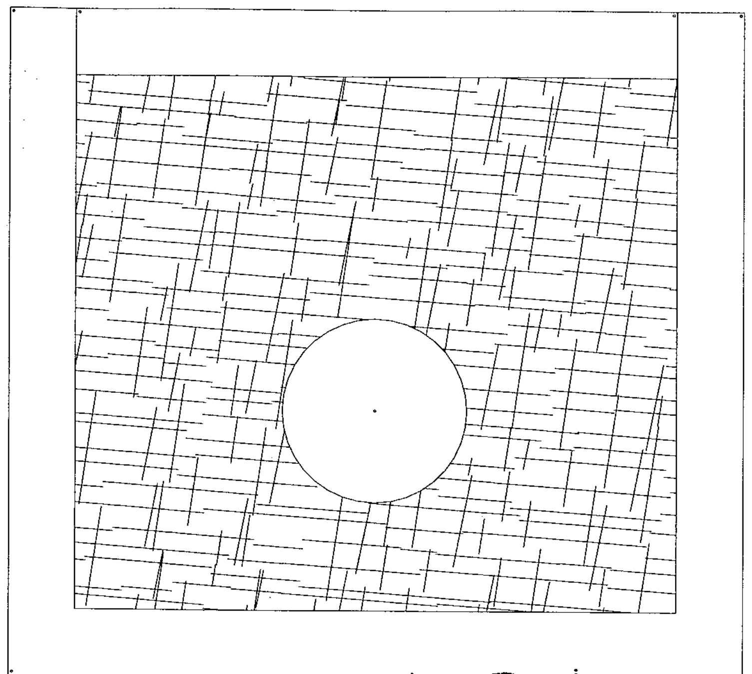

Figure 5.1 Statistically produced joints of case 2

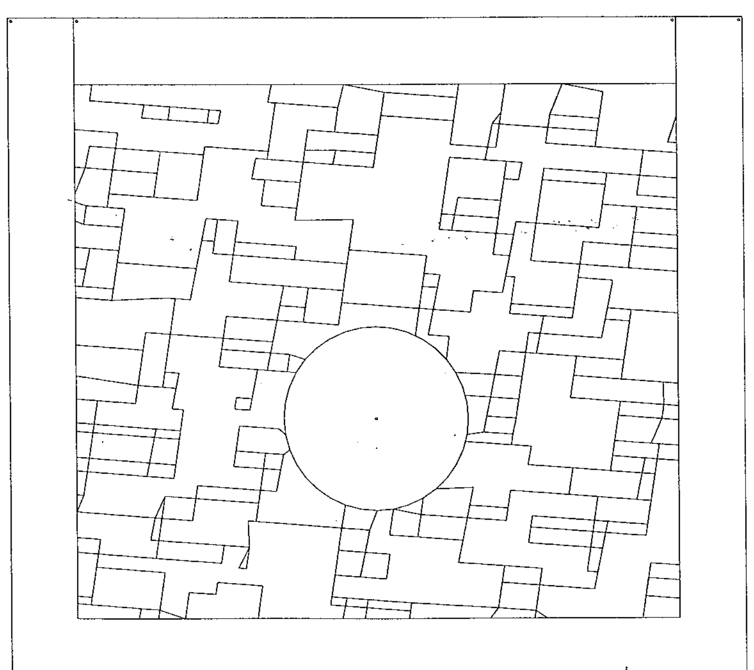

Figure 5.2 block mesh formed by joints of case 2

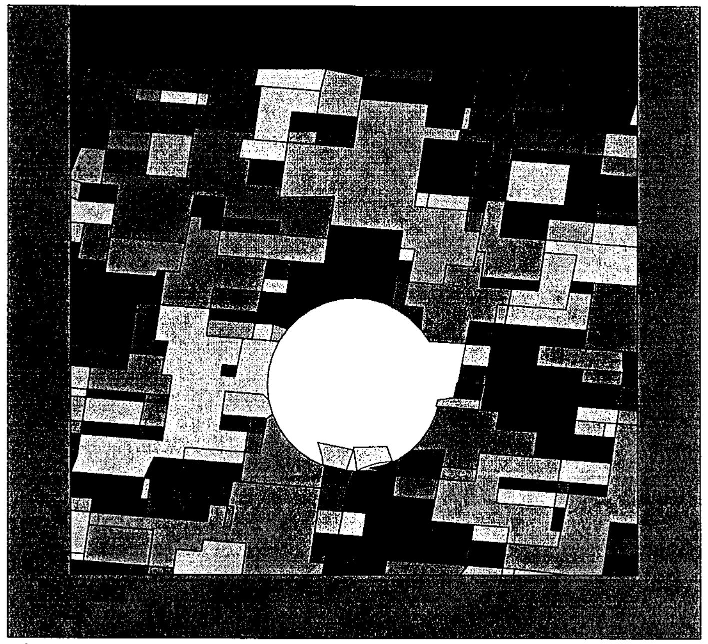

Figure 6.11 Case 2 rock falling after 20 seconds

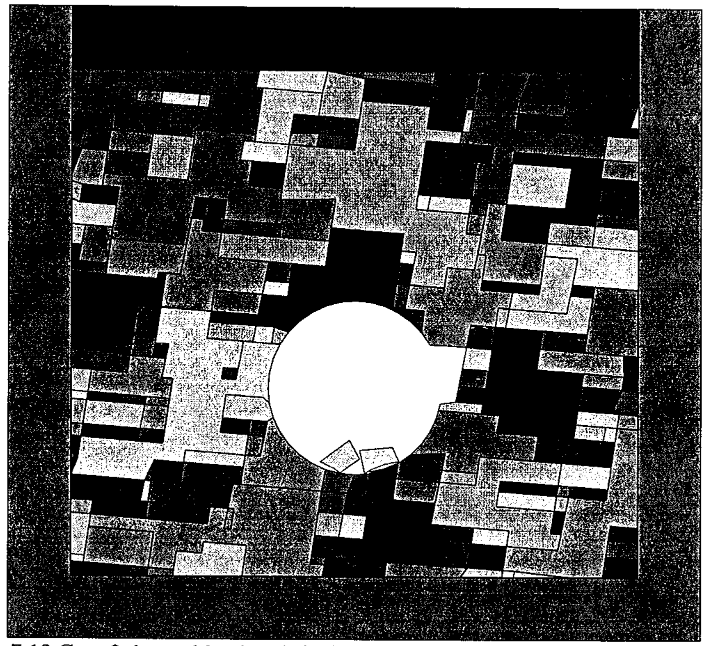

Figure 7.12 Case 2 thermal load rock falling after 22 seconds

Case 3 of rock falling DDA computation of joint system No 2 with seismic load and thermal stress loads.

7. Case 3 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 3 are the following:

Table 12. Programs and input files of case 3

file description	earth quake only	with thermal load
joint forming data	dln10	dln10
joint forming code	dl0	dl0
block forming data	dcn30	dcn30
block forming code	dc0	dc0
mechanical data	dfn10	dfn11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 8 shows the joints of case 3. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 5 anf Table 6.

Figure 9 show the rock falling of the DDA computation case 3. In the computation, the earth quake load is applied.

Figure 10 show the rock falling of the DDA computation case 3. In the computation, both the earth quake load and thermal load are applied.

In the case 3, the rock falling with thermal load is fewer than the rock falling without thermal load.

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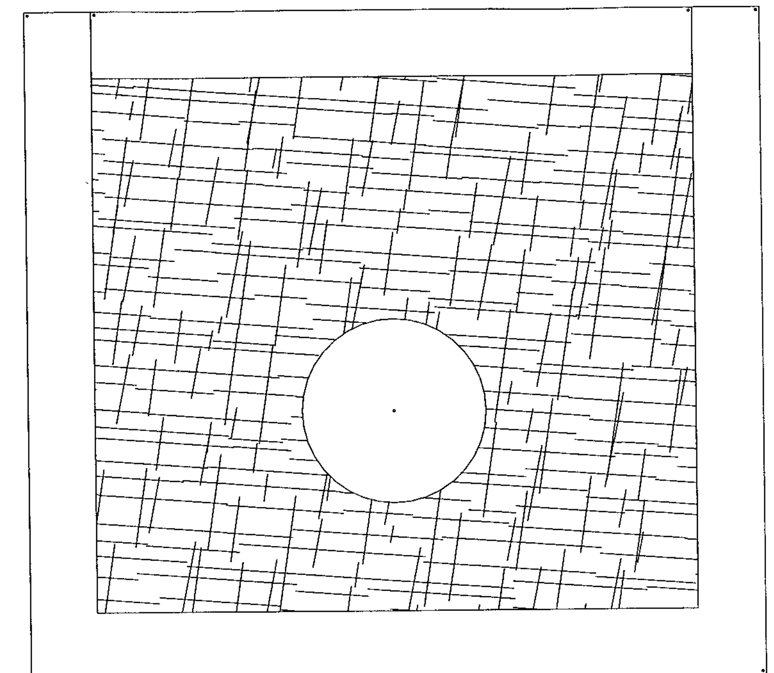

Figure 8.1 Statistically produced joints of case 3

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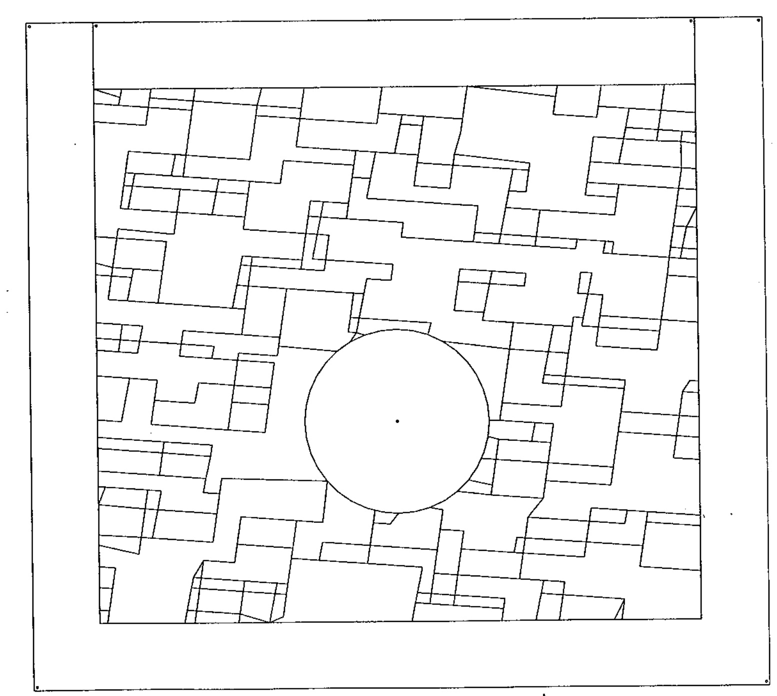

Figure 8.2 block mesh formed by joints of case 3

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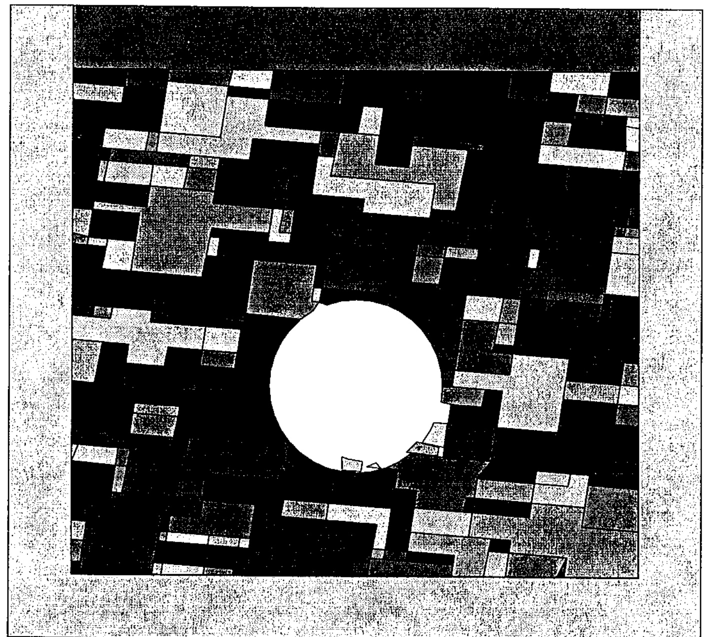

Figure 9.11 Case 3 rock falling after 20 seconds

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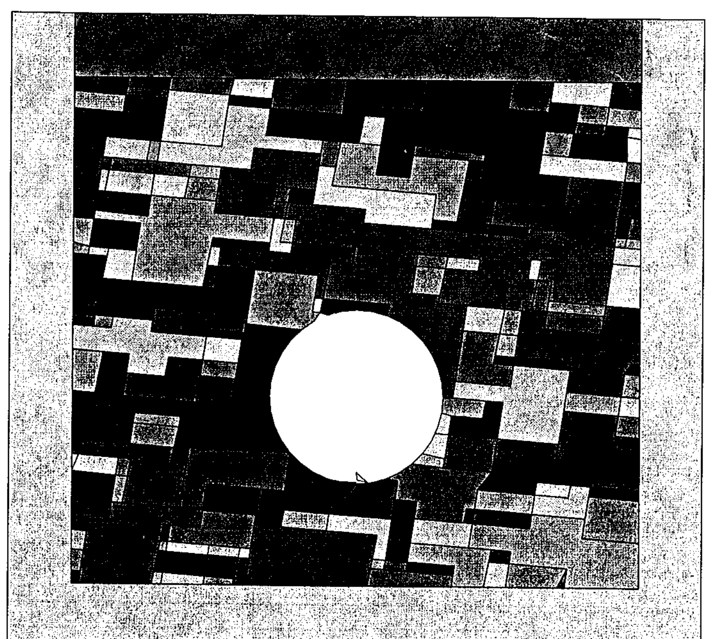

Figure 10.12 Case 3 thermal load rock falling after 22 seconds

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Case 4. of rock falling DDA computation of joint system No 2. with seismic load and thermal stress loads.

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

The programs and input files for the case 4 are the following:

Table 13. Programs and input files of case 4

file description	earth quake only	with thermal load
joint forming data	dln10	dln10
joint forming code	dl0	dl0
block forming data	dcn40	dcn40
block forming code	dc0	dc0
mechanical data	dfn10	dfn11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 11 shows the joints of case 4. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 5 anf Table 6.

Figure 12 show the rock falling of the DDA computation case 4. In the computation, the earth quake load is applied.

Figure 13 show the rock falling of the DDA computation case 4. In the computation, both the earth quake load and thermal load are applied.

In the case 4, the rock falling with thermal load is fewer than the rock falling without thermal load.

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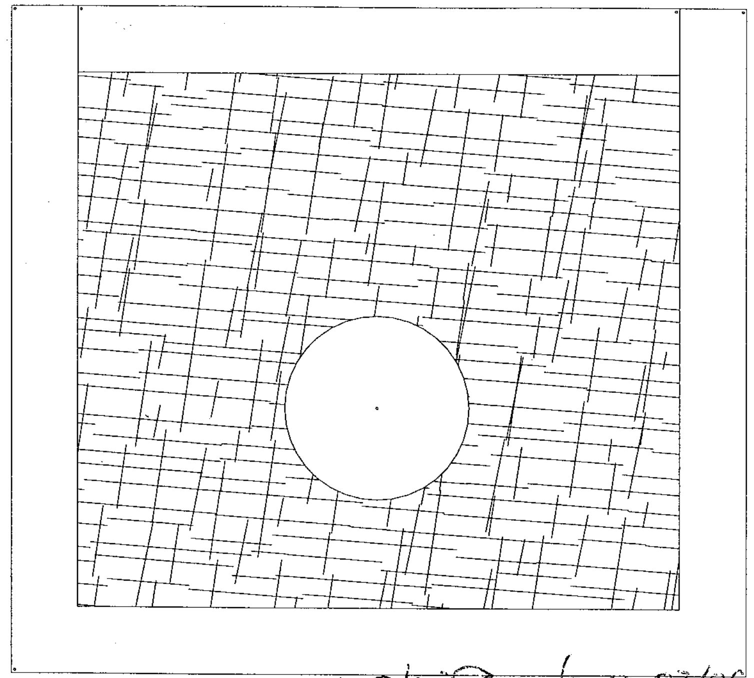

Figure 11.1 Statistically produced joints of case 4

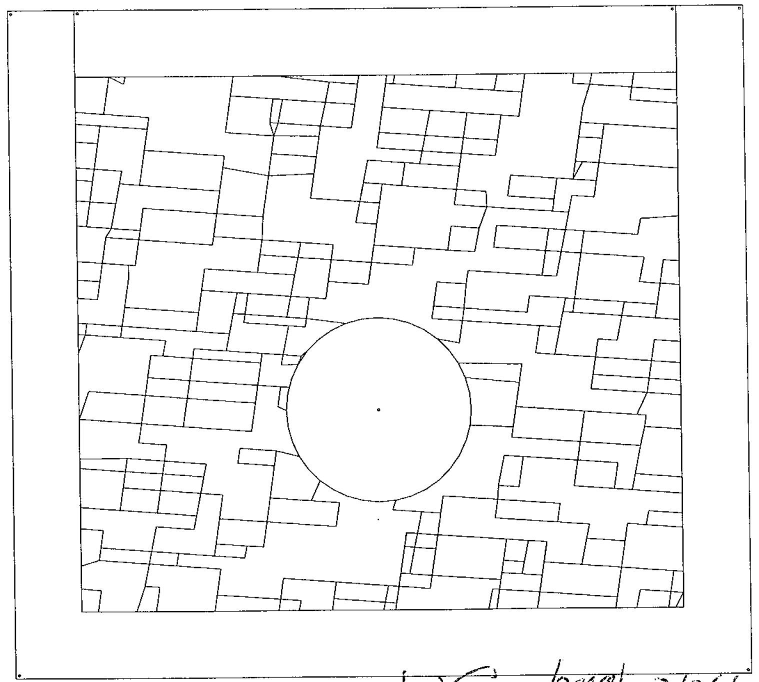

Figure 11.2 block mesh formed by joints of case 4

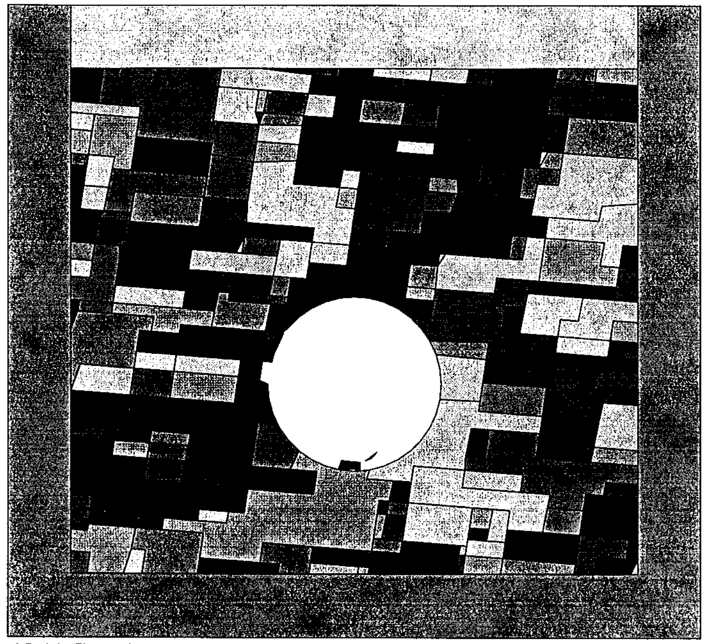

Figure 12.11 Case 4 rock falling after 20 seconds

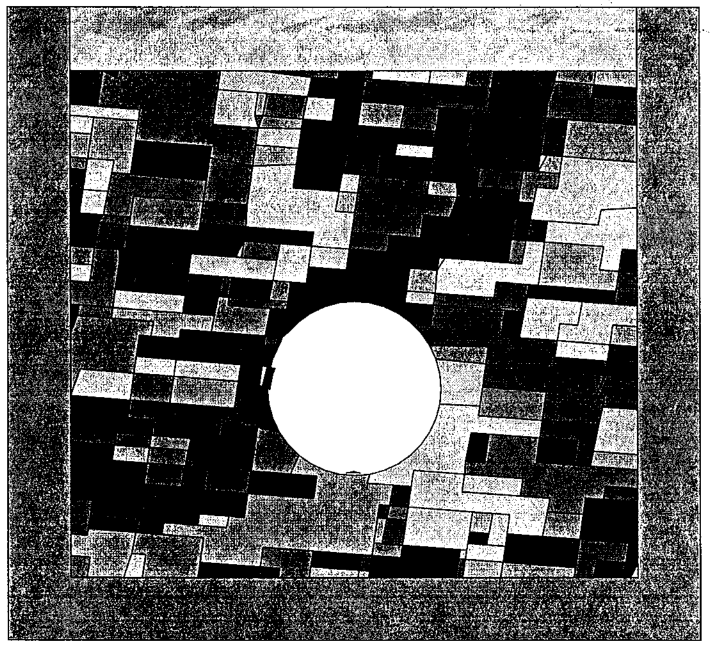

Figure 13.12 Case 4 thermal load rock falling after 22 seconds

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Case 5 of rock-falling two dimensional DDA computation of joint system No 2 with seismic load and thermal load.

9. Case 5 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 5 are the following:

Table 14. Programs and input files of case 5

file description	earth quake only	with thermal load
joint forming data	dln10	dln10
joint forming code	dl0	dl0
block forming data	dcn50	dcn50
block forming code	dc0	dc0
mechanical data	dfn10	dfn11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 14 shows the joints of case 5. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 5 anf Table 6.

Figure 15 show the rock falling of the DDA computation case 5. In the computation, the earth quake load is applied.

Figure 16 show the rock falling of the DDA computation case 5. In the computation, both the earth quake load and thermal load are applied.

In the case 5, the rock falling with thermal load is fewer than the rock falling without thermal load.

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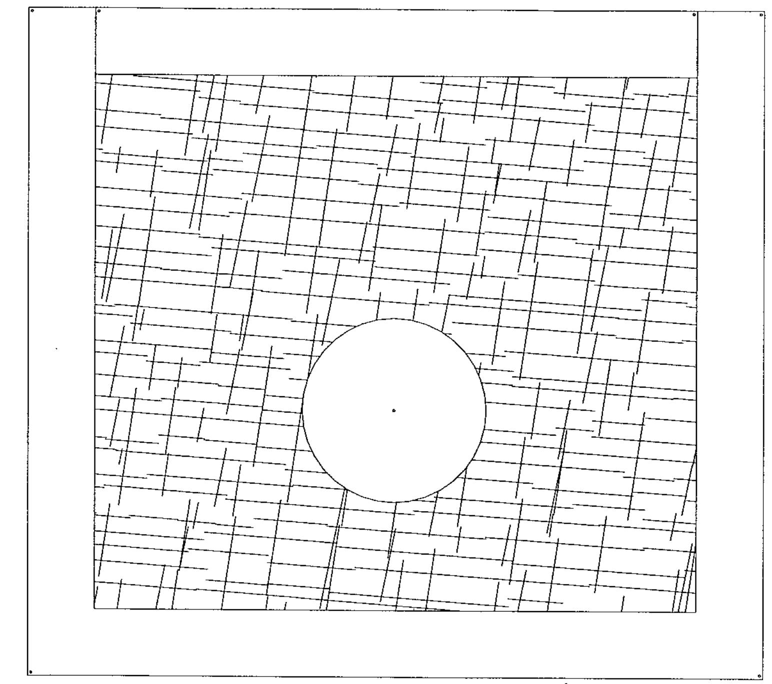

Figure 14.1 Statistically produced joints of case 5

Shi Gen-hua 03/07/01

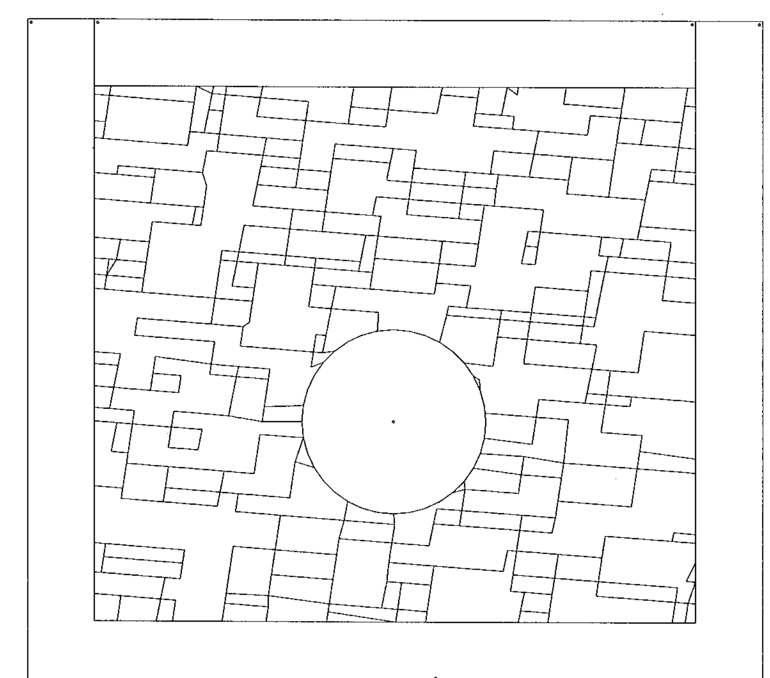

Figure 14.2 block mesh formed by joints of case 5

Shi Gen-hua 03/07/01

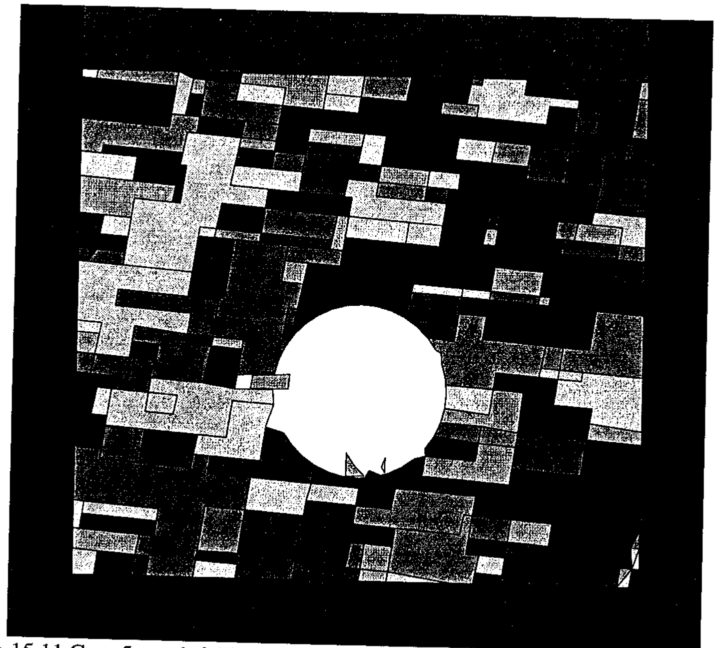

Figure 15.11 Case 5 rock falling after 20 seconds

Shi Gen-hua 03/07/01

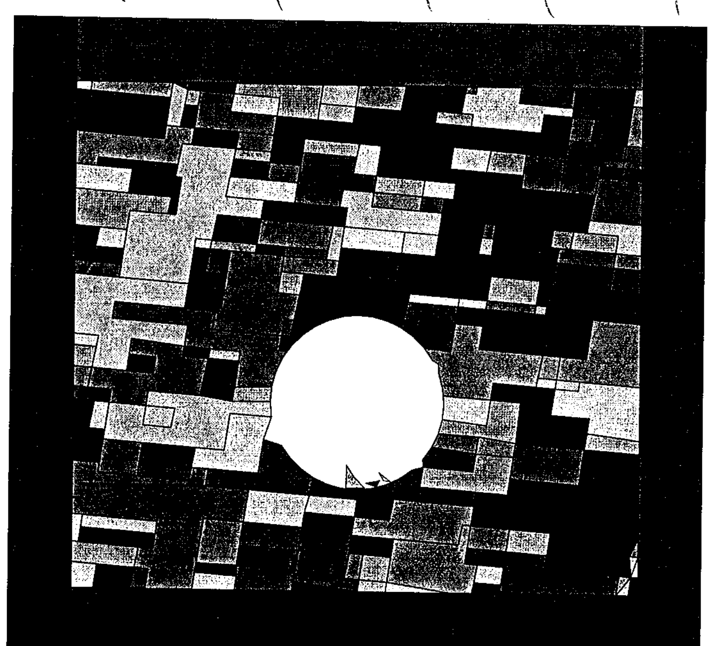

Figure 16.12 Case 5 thermal load rock falling after 22 seconds

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Shi Gen-hua 03/07/01

Case 6 two dimensional DDA computation of rock block falling under seismic and thermal loads.

10. Case 6 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 6 are the following:

Table 15. Programs and input files of case 6

file description	earth quake only	with thermal load
joint forming data	dln10	dln10
joint forming code	dl0	dl0
block forming data	dcn60	dcn60
block forming code	dc0	dc0
mechanical data	dfn10	dfn11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 17 shows the joints of case 6. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 5 anf Table 6.

Figure 18 show the rock falling of the DDA computation case 6. In the computation, the earth quake load is applied.

Figure 19 show the rock falling of the DDA computation case 6. In the computation, both the earth quake load and thermal load are applied.

In the case 6, the rock falling with thermal load is the same as the rock falling without thermal load.

Shi Gen-hua 03/09/01

4/4/2001

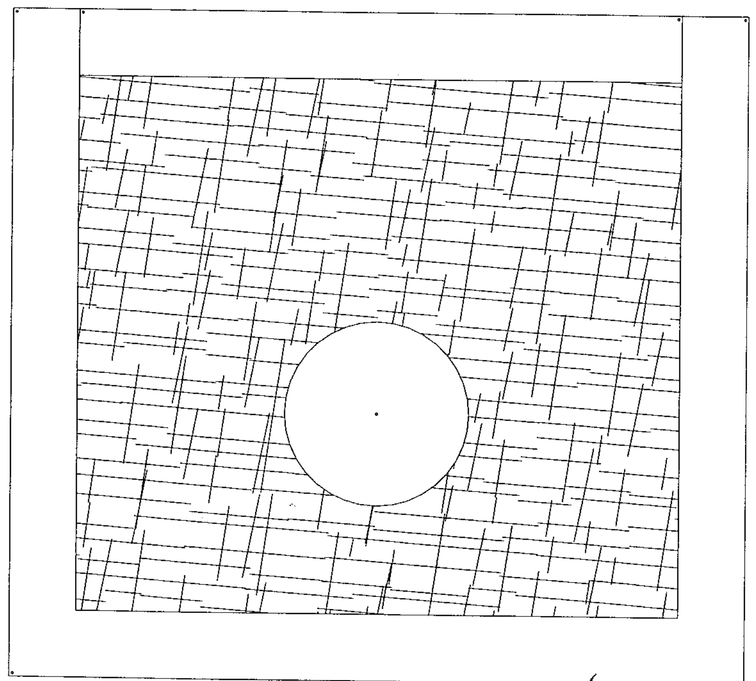

Figure 17.1 Statistically produced joints of case 6 Shi Gen-hua 03/09/01

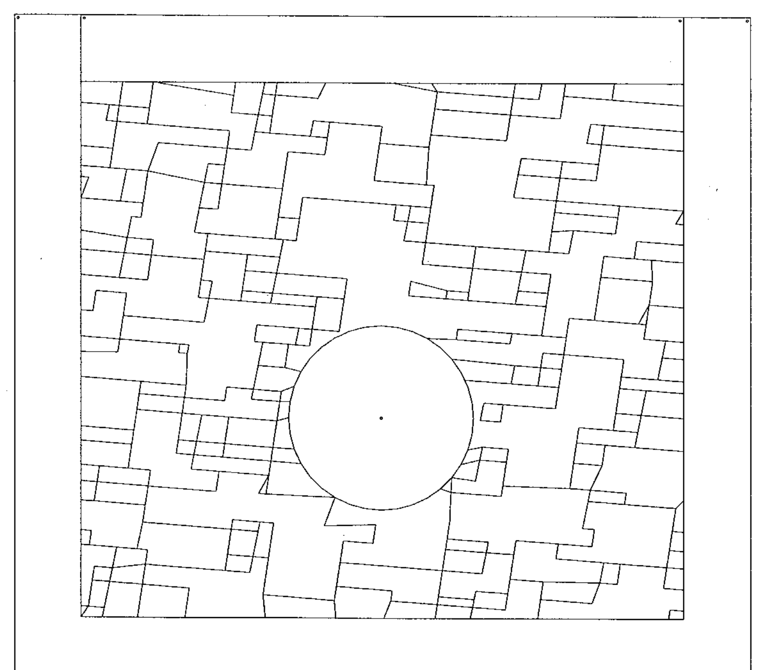

Figure 17.2 block mesh formed by joints of case 6 Shi Gen-hua 03/09/01

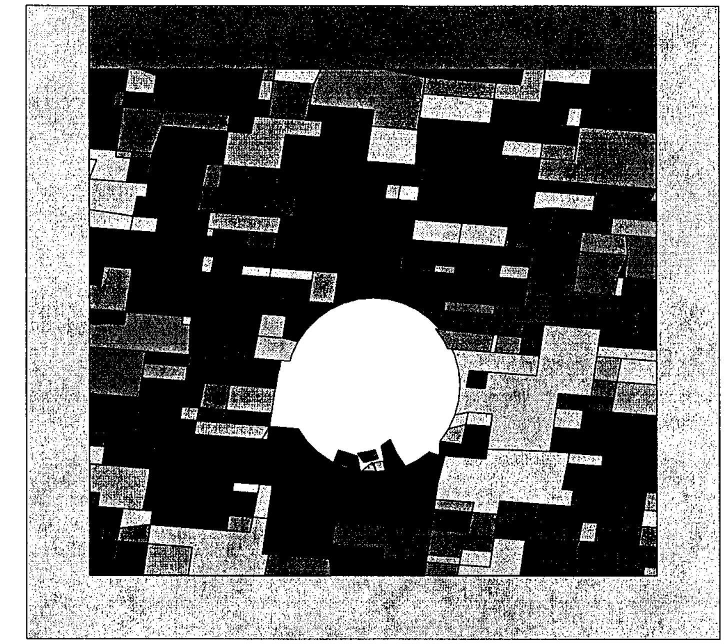

Figure 18.11 Case 6 rock falling after 20 seconds

Shi Gen-hua 03/09/01

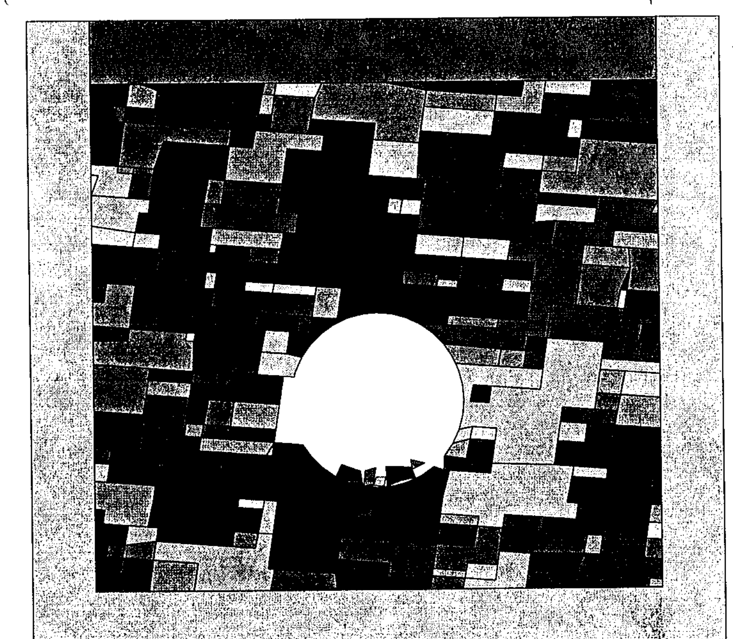

Figure 19.12 Case 6 thermal load rock falling after 22 seconds

Shi Gen-hua 03/09/01

Shi Gen-hua 03/09/01

Case 7 two dimensional DDA computation of rock block falling under seismic loads and thermal stress loads.

11. Case 7 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 7 are the following:

Table 16. Programs and input files of case 7

file description	earth quake only	with thermal load
joint forming data	dln10	dln10
joint forming code	dl0	dl0
block forming data	dcn70	dcn70
block forming code	dc0	dc0
mechanical data	dfn10	dfn11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 20 shows the joints of case 7. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 5 anf Table 6.

Figure 21 show the rock falling of the DDA computation case 7. In the computation, the earth quake load is applied.

Figure 22 show the rock falling of the DDA computation case 7. In the computation, both the earth quake load and thermal load are applied.

In the case 7, the rock falling with thermal load is fewer than the rock falling without thermal load.

Shi Gen-hua 03/12/01

4/4/2001

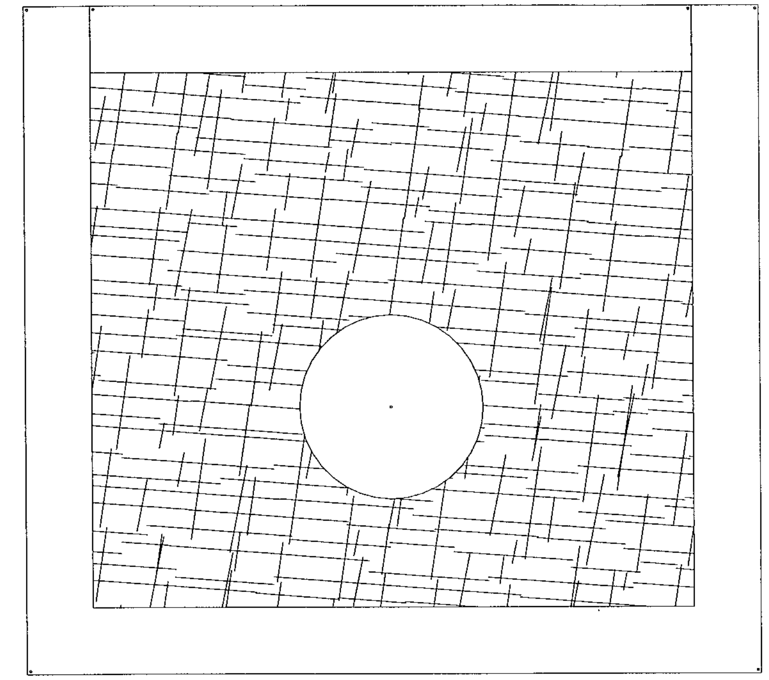

Figure 20.1 Statistically produced joints of case 7

Shi Gen-hua 03/12/01

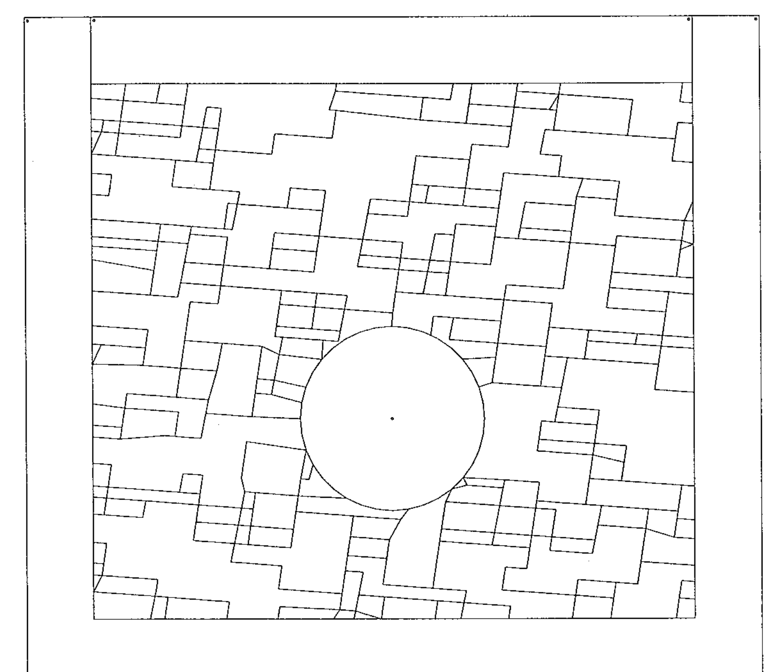

Figure 20.2 block mesh formed by joints of case 7

Shi Gen-hua 03/12/01

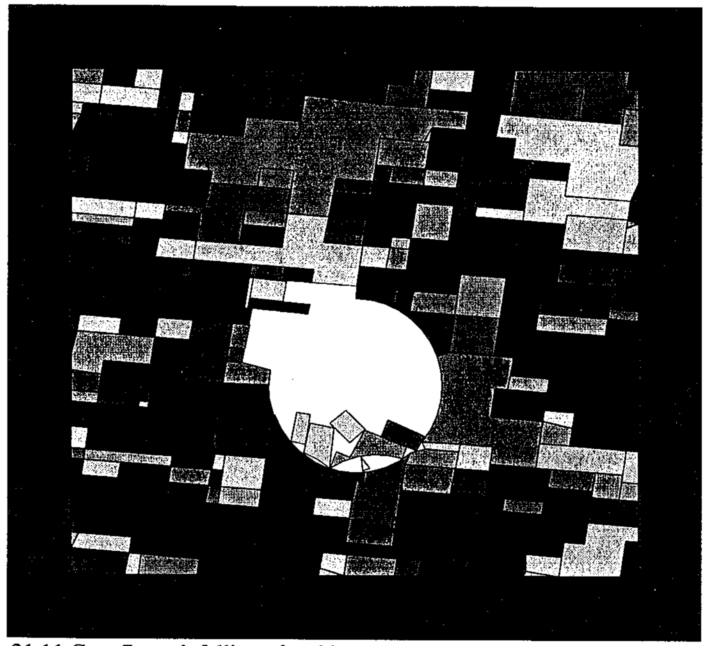

Figure 21.11 Case 7 rock falling after 20 seconds

Shi Gen-hua 03/12/01

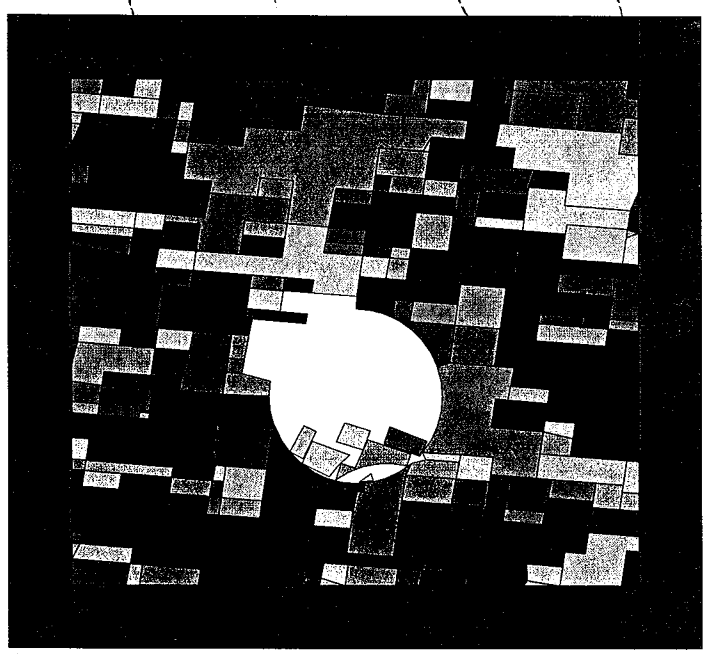

Figure 22.12 Case 7 thermal load rock falling after 22 seconds

Shi Gen-hua 03/12/01

Shi Gen-hua 03/12/01

Case 8 two dimensional computation of rock block falling of joint system No 2 under seismic loads and thermal stress loads.

12. Case 8 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 8 are the following:

Table 17. Programs and input files of case 8

file description	earth quake only	with thermal load
joint forming data	dln10	dln10
joint forming code	dl0	dl0
block forming data	dcn80	dcn80
block forming code	dc0	dc0
mechanical data	dfn10	dfn11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 23 shows the joints of case 8. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 5 anf Table 6.

Figure 24 show the rock falling of the DDA computation case 8. In the computation, the earth quake load is applied.

Figure 25 show the rock falling of the DDA computation case 8. In the computation, both the earth quake load and thermal load are applied.

In the case 8, the rock falling with thermal load is the same as the rock falling without thermal load.

Shi Gen-hua 03/13/01

4/4/2001

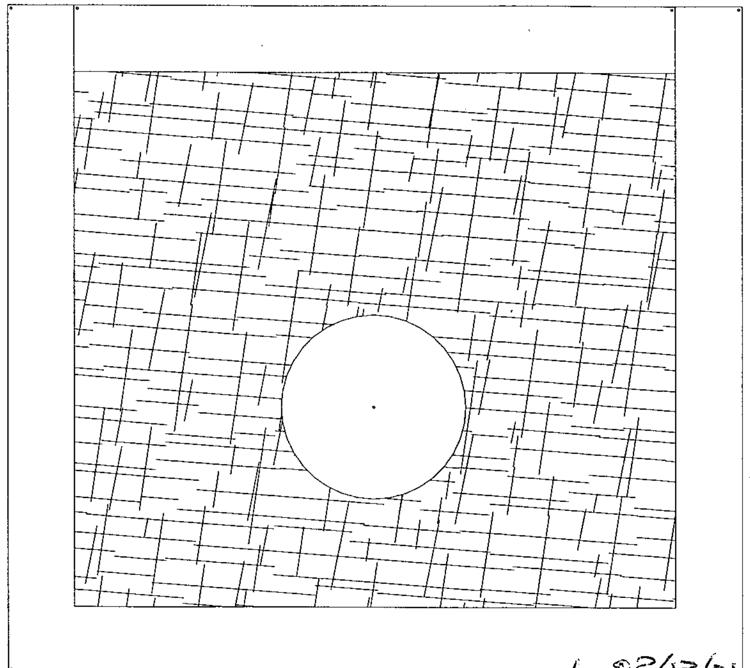

Figure 23.1 Statistically produced joints of case 8

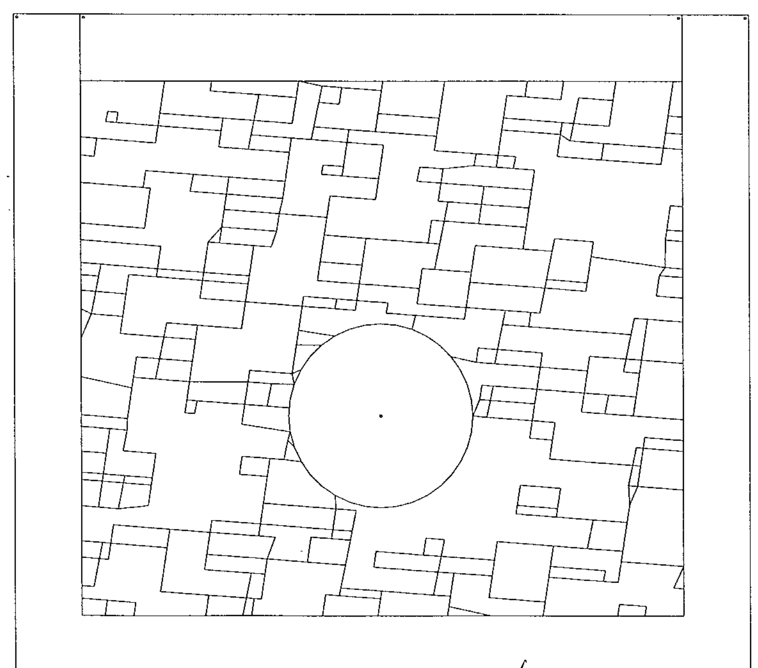

Figure 23.2 block mesh formed by joints of case 8

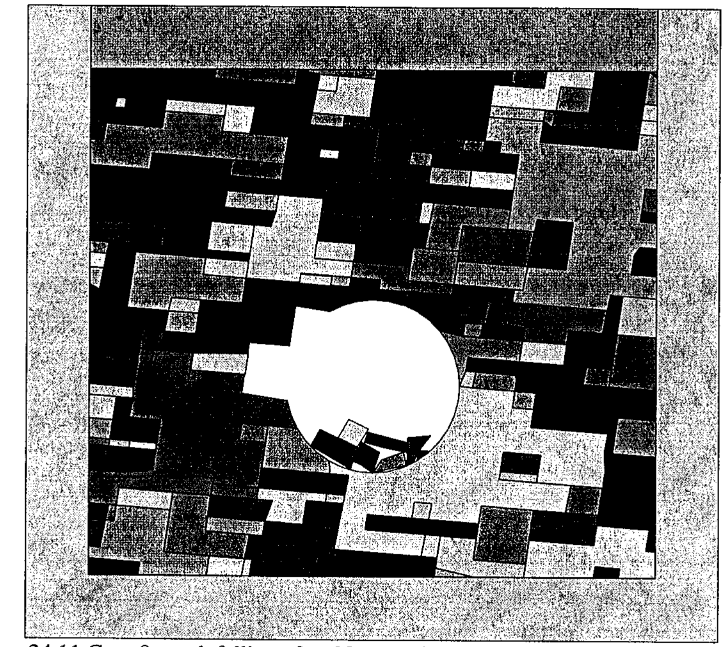

Figure 24.11 Case 8 rock falling after 20 seconds

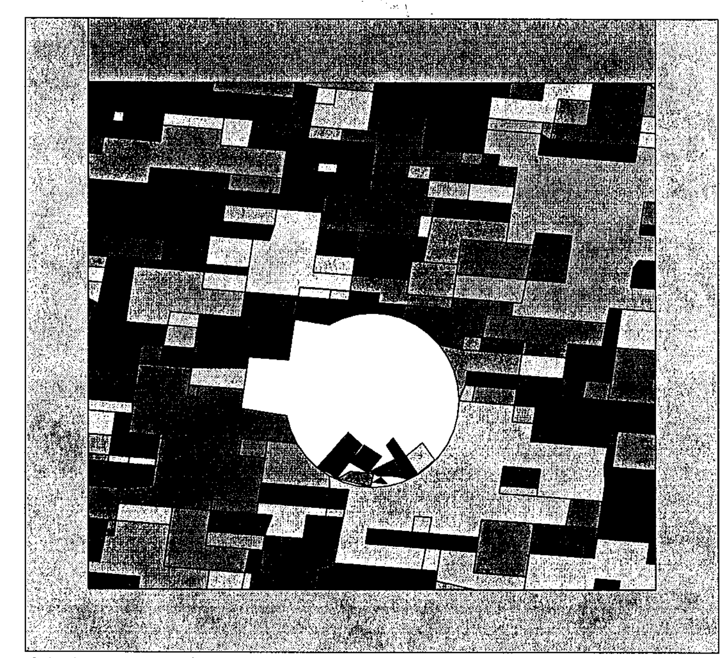

Figure 25.12 Case 8 thermal load rock falling after 22 seconds

Case 9 two dimensional DDA computation of rock block falling and seismic and thermal loads.
The computation mesh or block systems are from the joint system No 2..

13. Case 9 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 9 are the following:

Table 18. Programs and input files of case 9

file description	earth quake only	with thermal load
joint forming data	dln10	dln10
joint forming code	dl0	dl0
block forming data	dcn90	dcn90
block forming code	dc0	dc0
mechanical data	dfn10	dfn11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 26 shows the joints of case 9. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 5 anf Table 6.

Figure 27 show the rock falling of the DDA computation case 9. In the computation, the earth quake load is applied.

Figure 28 show the rock falling of the DDA computation case 9. In the computation, both the earth quake load and thermal load are applied.

In the case 9, the rock falling with thermal load is the same as the rock falling without thermal load.

Shi Gen-hua 03/14/01

4/4/2001

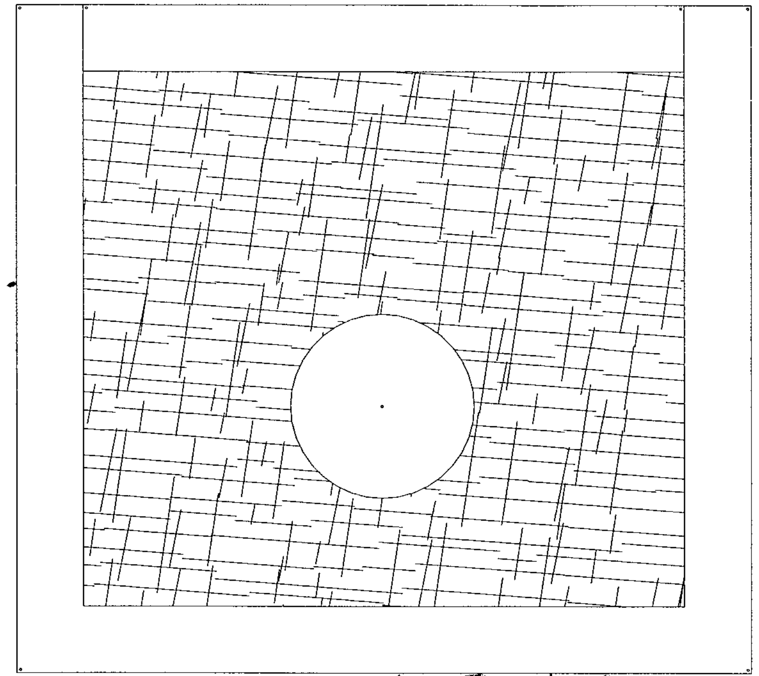

Figure 26.1 Statistically produced joints of case 9. Shi Gen-hua 03/14/01

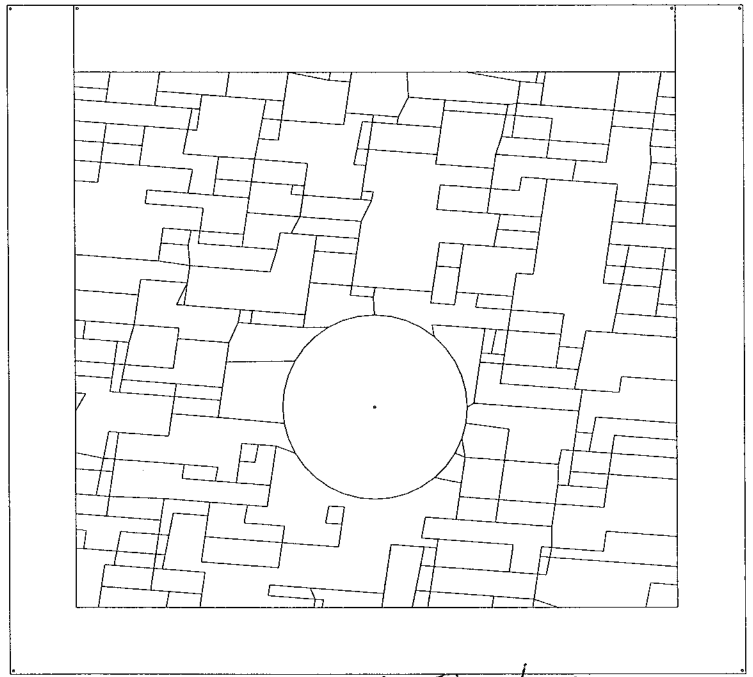

Figure 26.2 block mesh formed by joints of case 9. Shi Gen-hua 03/14/01

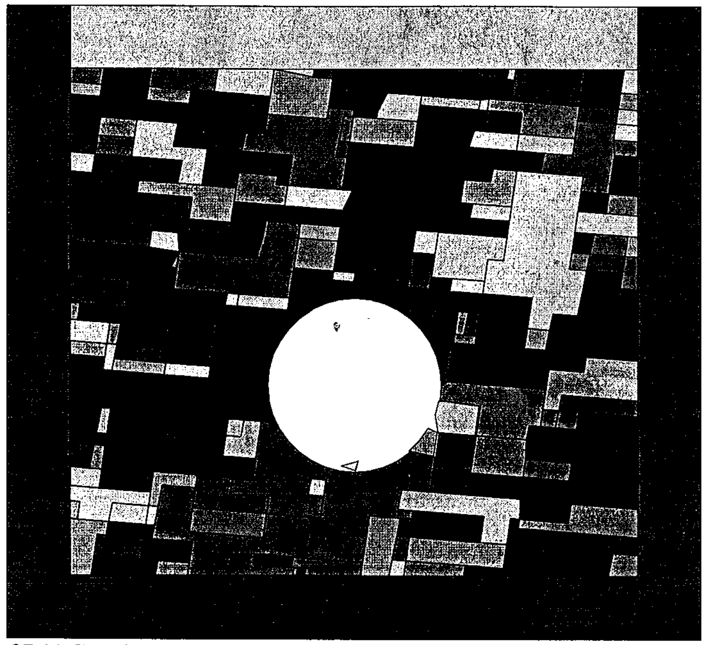

Figure 27.11 Case 9 rock falling after 20 seconds

Shi Gen-hua 03/14/01

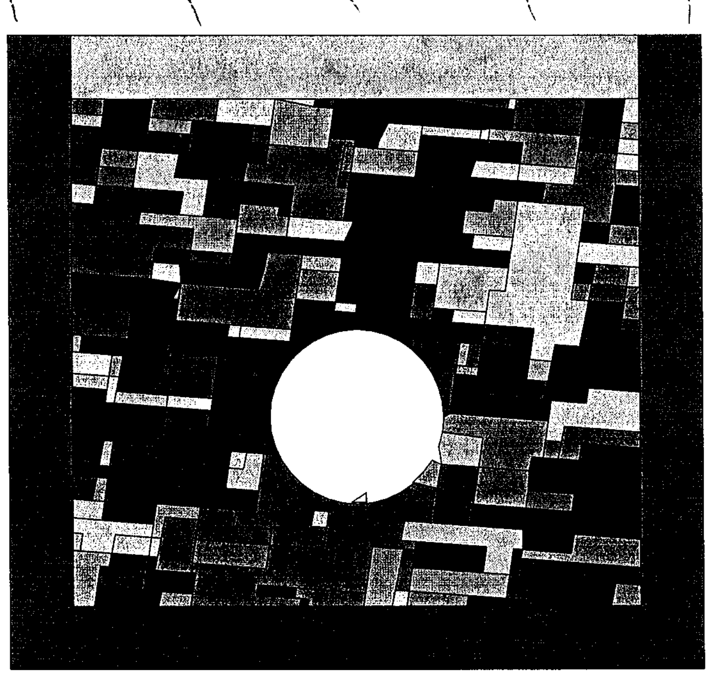

Figure 28.12 Case 9 thermal load rock falling after 22 seconds

Shi Gen-hua 03/14/01

Shi Gen-hua
03/14/01

Case 10 two dimensional DDA computation of rock block falling of joint system No 2 under seismic and thermal loads.

14. Case 10 of Rock Falling DDA Computation with Earth Quake and Thermal Load

The programs and input files for the case 10 are the following:

Table 19. Programs and input files of case 10

file description	earth quake only	with thermal load
joint forming data	dln10	dln10
joint forming code	dl0	dl0
block forming data	dcn00	dcn00
block forming code	dc0	dc0
mechanical data	dfn10	dfn11
mechanical code	df0	df1
earth quake data	qks0	qks1

Figure 29 shows the joints of case 10. The joints are statistically produced on the tunnel section plane based upon the joint length, joint spacing and joint bridge on Table 5 anf Table 6.

Figure 30 show the rock falling of the DDA computation case 10. In the computation, the earth quake load is applied.

Figure 31 show the rock falling of the DDA computation case 10. In the computation, both the earth quake load and thermal load are applied.

In the case 10, the rock falling with thermal load is fewer than the rock falling without thermal load.

Shi Gen-hua 03/15/01

DDA is reliable in the computation, this computation has very complex blocks as shown in the drawing, one large block even contains smaller blocks. each case has two runs, each run has 2000 time steps. each time step solve equation 4807 times, (open-close iteration). No problems!

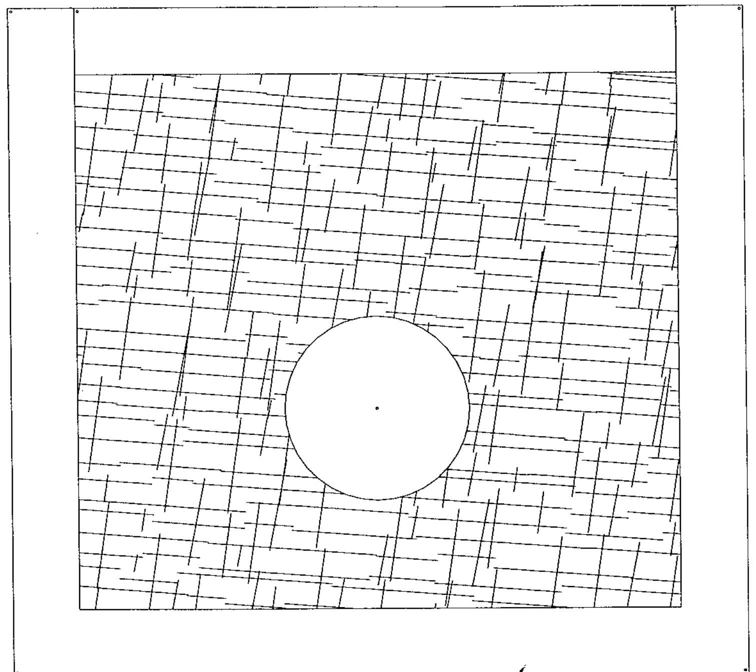

Figure 29.1 Statistically produced joints of case 10 Shi Gen-hua 03/15/01

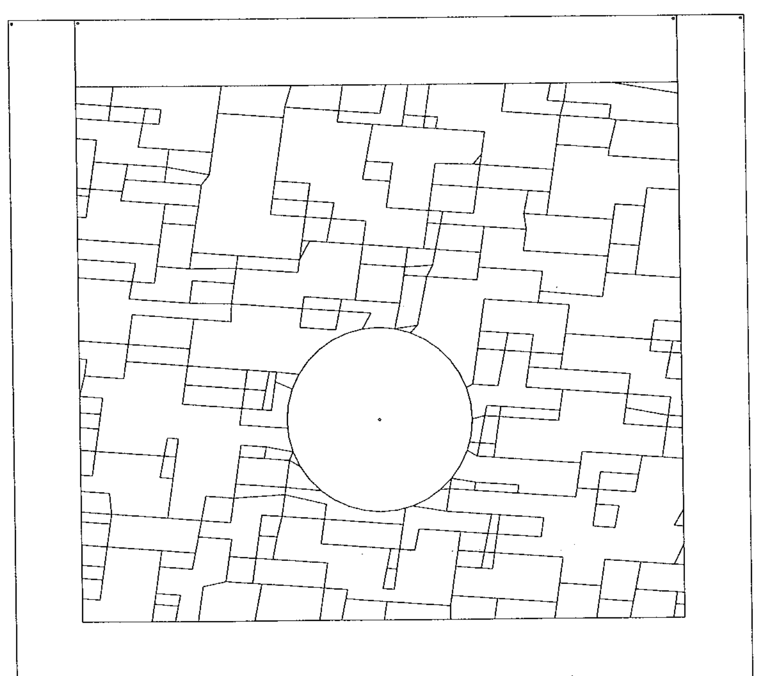

Figure 29.2 block mesh formed by joints of case 10 Shi Gen-hua 03/15/01

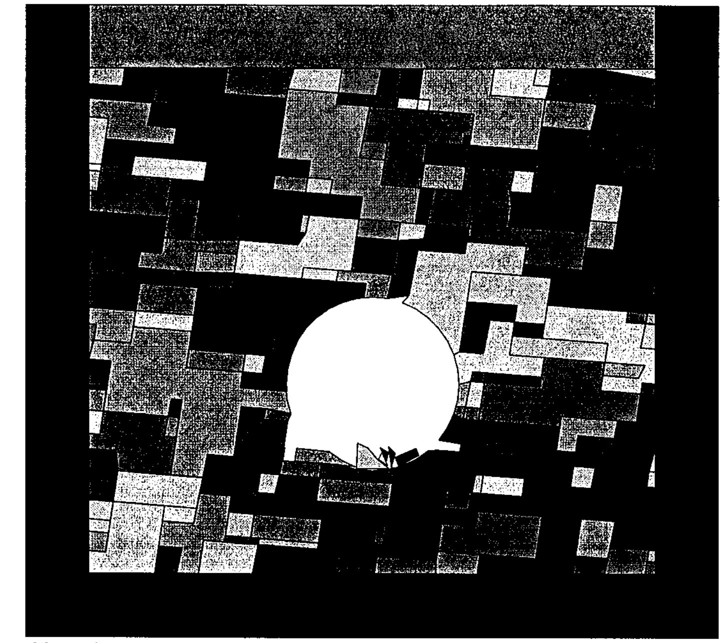

Figure 30.11 Case 10 rock falling after 20 seconds

Shi Gen-hua 03/15/01

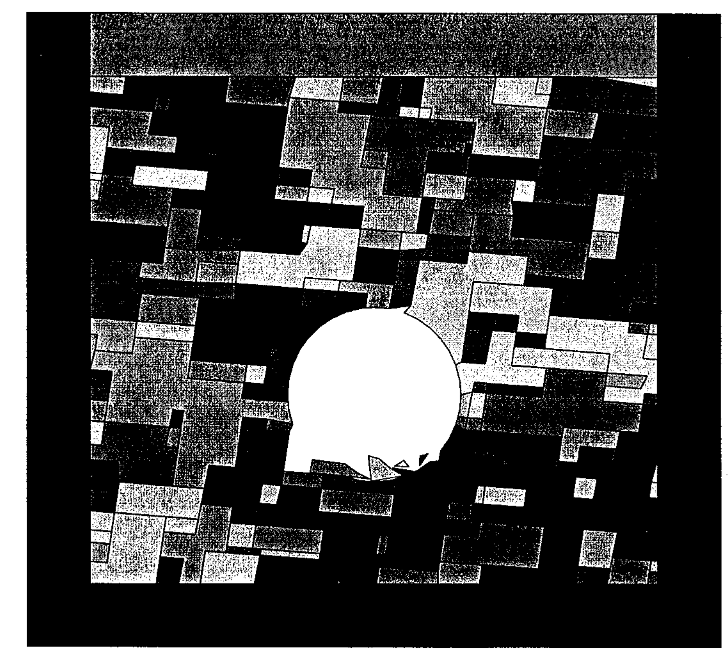

Figure 31.12 Case 10 thermal load rock falling after 22 seconds

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Shi Gen-hua 03/15/01

12. Falling rock block size distribution of joint system No 2 under seismic and thermal loads.

The statistics was made from the previous 10 cases.

Definition of falling blocks: if a block moves 0.01 times half window hieght of the mesh (0.1 m) any time in the computation, the block is falling block.

joint system No 2 has small size falling rock block than joint system No 1.

15. Falling Block Size Distribution of Joint System No 2 with Earth Quake and Thermal Load

Based on the results of rock falling computations of case 1 to case 10, the size and number are counted as following:

Table 15. Toal falling block numbers of 10 cases

volume range m^2	earth quake only	with thermal load
$0.0m^2$—$0.2m^2$	23	19
$0.2m^2$—$0.4m^2$	10	10
$0.4m^2$—$0.6m^2$	9	7
$0.6m^2$—$0.8m^2$	0	0
$0.8m^2$—$1.0m^2$	4	2
$1.0m^2$—$1.2m^2$	1	1
$1.2m^2$—$1.4m^2$	0	0
$1.4m^2$—$1.6m^2$	0	0
$1.6m^2$—$1.8m^2$	0	0
$1.8m^2$—$2.0m^2$	0	0
$2.0m^2$—$2.2m^2$	0	0
$2.2m^2$—$2.4m^2$	0	0

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The falling blocks with thermal load are fewer.

Report #6 Dynamic DDA Rock Falling Cases with Seismic and Thermal Load of Joint System No 2 of Project: 20.01402.671 Rock Fall Assessing under Seismic Load using Key Block Analysis

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DDA computation of Joint System No 2

The differences of the DDA computations between this report and the previous DDA computations of the report #2 and report #4 are the following:

[1] The joint system No 2 considers only the relatively longer joints with wider spacing. Therefore, the dip angle and dip direction of each joint set have been changed in certain extent.

[2] Since both the joint length and joint spacing of the joint system No 2 are larger than the previous joint system No 1, the finite block size distribution of joint system No 2 are different from the previous joint system No 1 in reports #1 to #4. This report will compare the finite block size distribution of both No 1 (old) and No 2 (new) joint systems.

[3] Based on the results of the dynamic DDA computation, the falling block size distribution of joint system No 2 and falling block size distribution of joint system No 1 in reports #1 to #4 will be compared.

[4] The computations of this report uses The tunnel bearing (horizontal tunnel direction) $N75°E$ same as report #4. The tunnel bearing was $N105°E$ in report #2. Therefore the joint directions in the tunnel section plan can be substantially different. The rock falling will be different.

[5] Same as the report #4, 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:

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[6] Same as the report #4, the minimum distance of nodes is 0.23, which is different from 0.25 Here, smaller blocks are allowed for this DDA computation.
[7] The bridge of the joint sets of the previous joint system No 1 of report #4 is 0.3m; the bridge of the joint sets of the current joint system No 2 of this report #5 is -0.03m.

1. Introduction of Two Dimensional Dynamic DDA with Earth Quake and Thermal Load

The two-dimensional discontinuous deformation analysis (2-d DDA) computes two-dimensional deformable block systems. In the current version, there are 6 degrees of freedom per block: displacements on X, Y directions, rotation and three strains. The block displacements are complete linear functions of the coordinates. Each block is assumed to have constant stresses and strains.
In spite of the complex shape of DDA blocks, DDA method uses analytic integrations for all of its matrices. This analytic integration is 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.
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.
When large deformation are involved, the static solution is the stabilized state from the dynamic solution due to friction or real damping. The current 2-d DDA program treats the damping in a simple manner: the dynamic computation inherits the full velocity at the end of the previous time step. The static computation inherits only a part of the velocity at the end of the previous time step as the initial velocity at the beginning of this time step. Only dynamic 2-d DDA is used in this report.
The DDA computation must satisfy following conditions at the end of each time step:
[1] Each degree of freedom of each block has an equilibrium equation. The simultaneous equilibrium equations are derived by minimizing the total potential energy at the end of each time step. All external forces acting on each block, including loads and contact forces with other blocks, reach equilibrium in X, Y directions and reach moment equilibrium for rotation. Equilibrium is also achieved between block stresses and external forces on the block. Shi Gen-hua 03/24/01

[2] Entrance theory is used to identify all possible first entrance positions. Contacts occur only on the first entrance position, interpenetrations are prevented on the first entrance positions and sliding is controlled by the friction law.
[3] Within each time step, if the tensile force from the normal contact spring exceeds the limit, this normal spring will be removed. If interpenetration occurs in a entrance position, a normal spring is applied. The global equations have to be solved repeatedly while selecting the closed entrance positions. This procedure for adding or removing springs and solving equilibrium equations is referred to as an open-close iteration. The open-close iteration will continue until all tensile force and all interpenetrations are within set limits over all the entrances.

Shi Gen-hua 03/24/01

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

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

Table 5. Programs and input files of case 1

file description	earth quake
joint forming data	dls10
joint forming code	dl0
block forming data	dcs10
block forming code	dc0
mechanical data	dfs10
mechanical code	df0
earth quake data	qkh1
graphic code	dg2
graphic files	dgq11 dgq21 dgq31 dgq41 dgq51

Figure 1.1 to Figure 1.4 show the rock falling of case 1 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 00% earth quake load is applied.

Figure 2.1 to Figure 2.4 show the rock falling of case 1 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 25% earth quake load is applied.

Figure 3.1 to Figure 3.4 show the rock falling of case 1 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 50% earth quake load is applied.

Figure 4.1 to Figure 4.4 show the rock falling of case 1 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 75% earth quake load is applied.

Figure 5.1 to Figure 5.4 show the rock falling of case 1 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 100% earth quake load is applied.

In each picture, if any vertex of any block moves more than 5 cm in any step of 20 seconds, this block is defined as a falling block. All falling blocks are in white color and with a number in it. The number is the order of falling. The block with "1" in it falls first.

The following table is the area of the falling blocks along with the falling order. The 100% earth quake load is applied. (Figure 5.1 to Figure 5.4)

Table 6. Falling rocks in time order of case 1

falling time order	block area in square meter
1	0.9795
2	0.0718
3	0.5426
4	0.0669
5	0.0961

6	0.3307
7	0.3776
8	0.7006
9	0.3424
10	0.1492
11	0.4171
12	0.4010
13	0.1177
14	0.0430
15	0.9173
16	0.0509
17	0.3252
18	0.1191
19	0.2621
20	2.3161
21	0.0787
22	0.4054
23	1.1805
24	0.1023
25	0.8978
26	0.1897
27	0.2585
28	0.9519
29	0.0518
30	0.9555

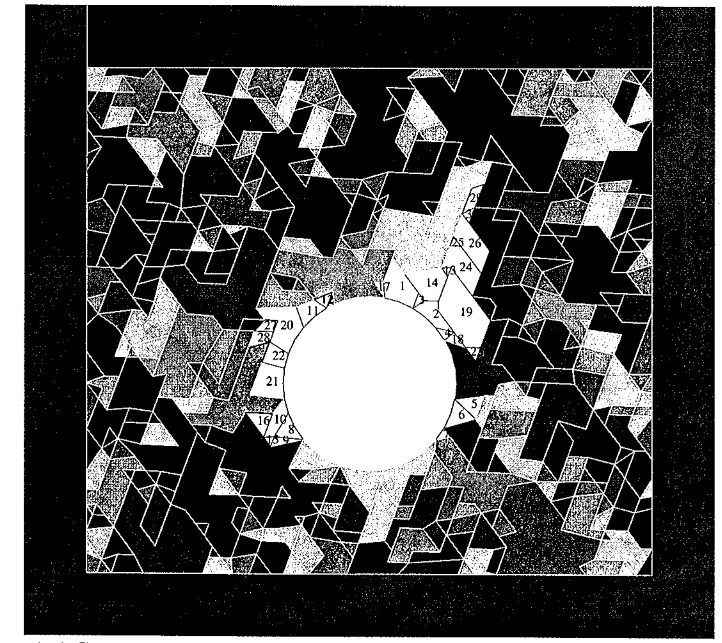

Figure 1. 1 Case 1 rock falling of .00 earth quake after 0 seconds

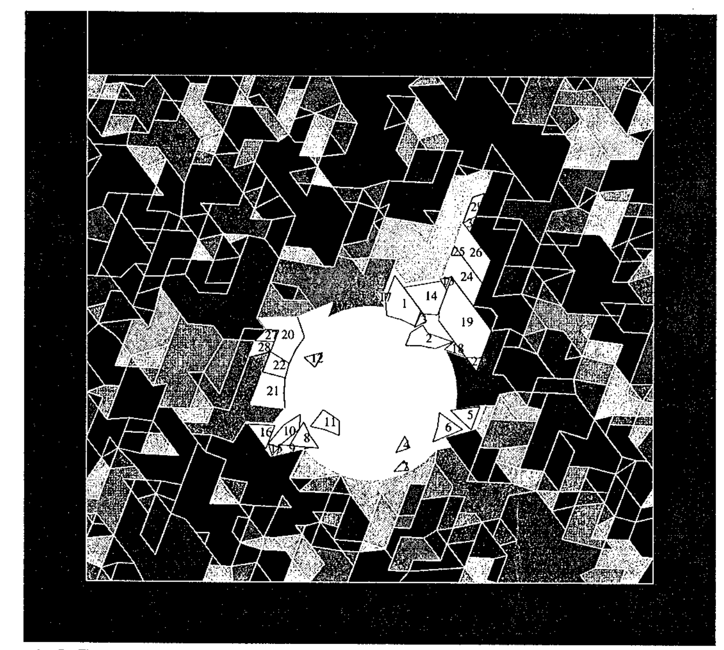

Figure 1. 2 Case 1 rock falling of .00 earth quake after 1 seconds

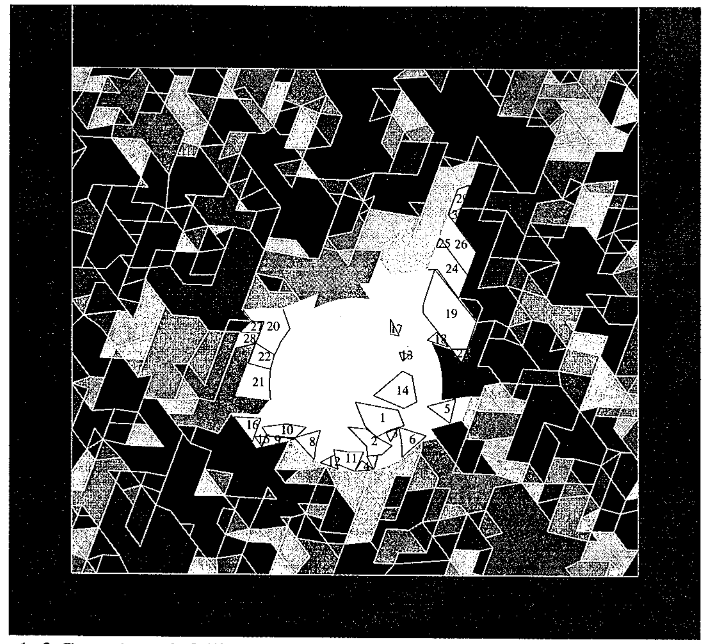

Figure 1. 3 Case 1 rock falling of .00 earth quake after 2 seconds

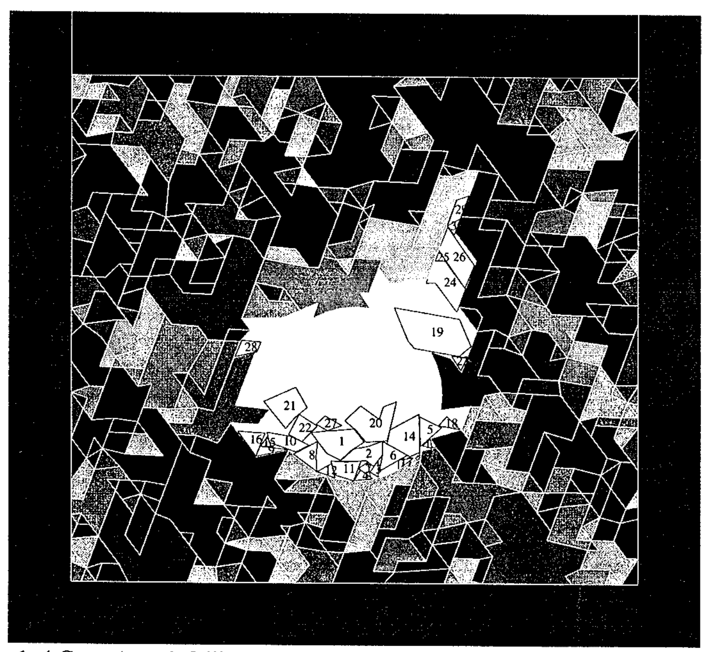

Figure 1. 4 Case 1 rock falling of .00 earth quake after 20 seconds

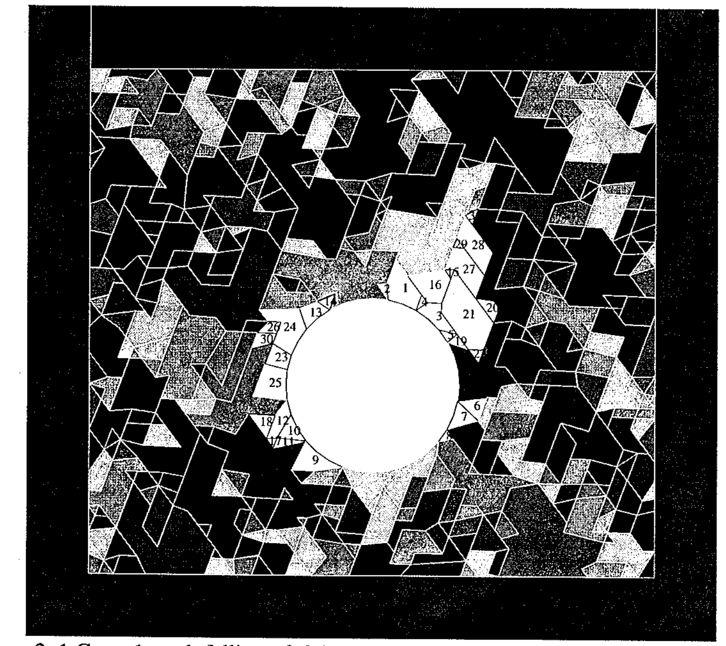

Figure 2. 1 Case 1 rock falling of .25 earth quake after 0 seconds

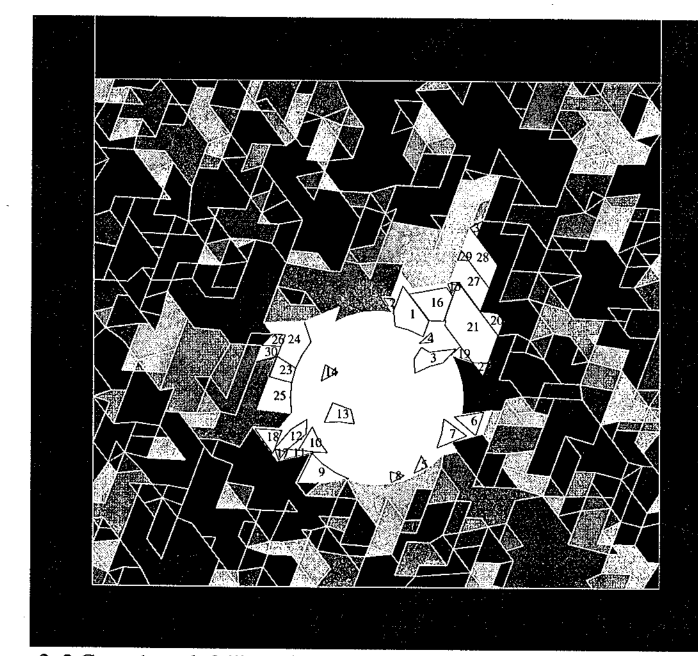

Figure 2. 2 Case 1 rock falling of .25 earth quake after 1 seconds

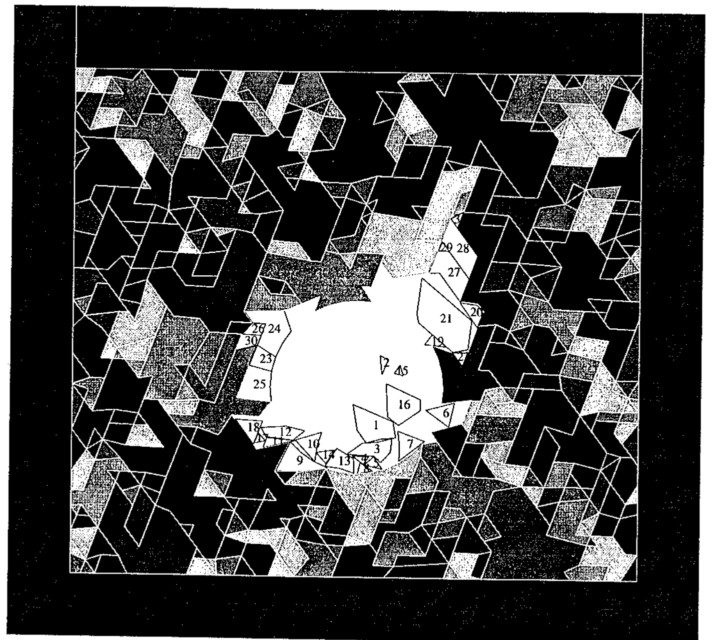

Figure 2. 3 Case 1 rock falling of .25 earth quake after 2 seconds

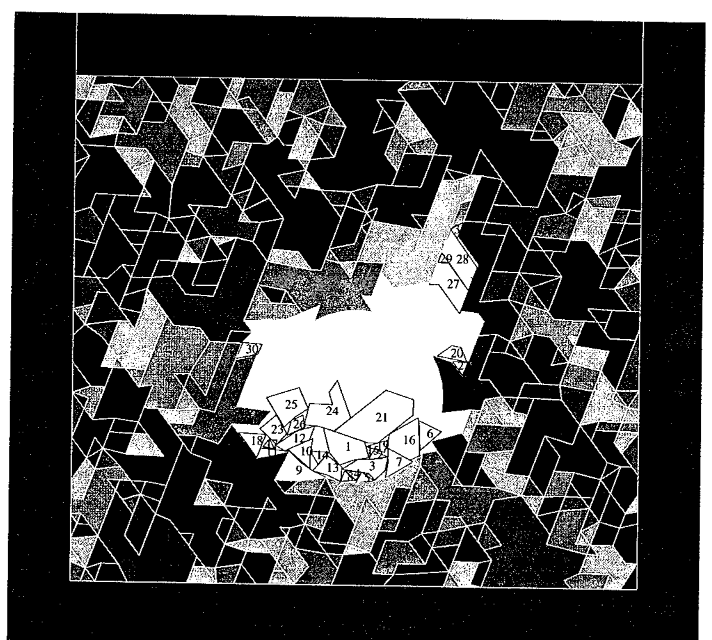

Figure 2. 4 Case 1 rock falling of .25 earth quake after 20 seconds

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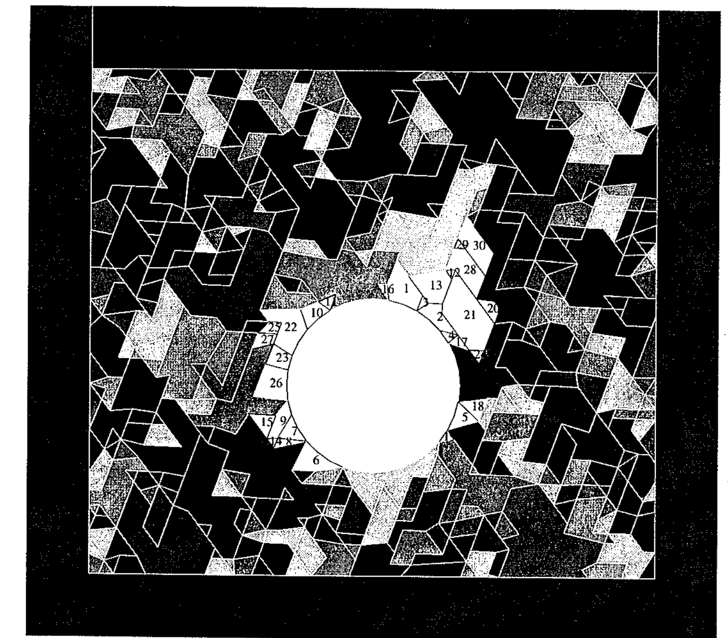

Figure 3. 1 Case 1 rock falling of .50 earth quake after 0 seconds

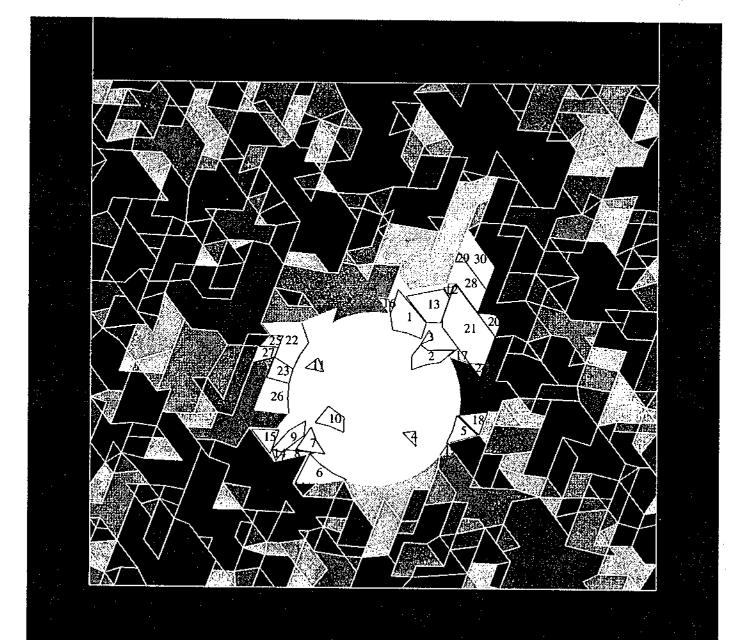

Figure 3. 2 Case 1 rock falling of .50 earth quake after 1 seconds

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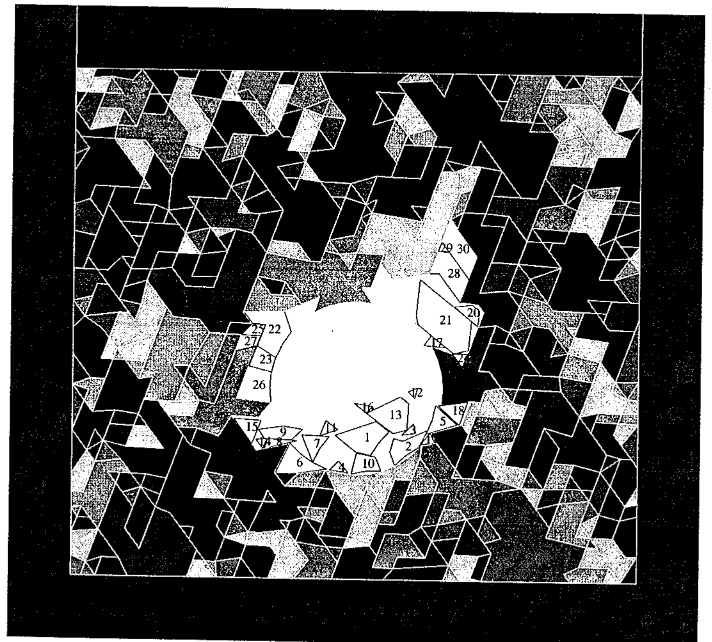

Figure 3. 3 Case 1 rock falling of .50 earth quake after 2 seconds

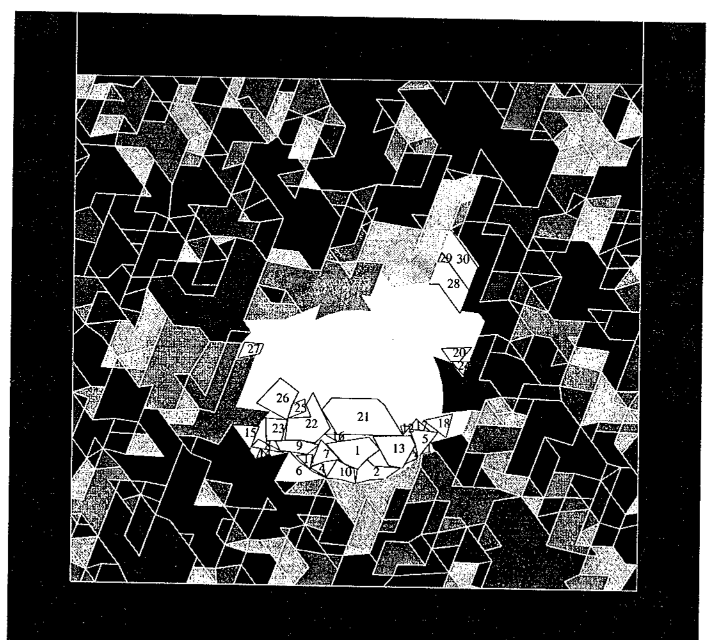

Figure 3. 4 Case 1 rock falling of .50 earth quake after 20 seconds

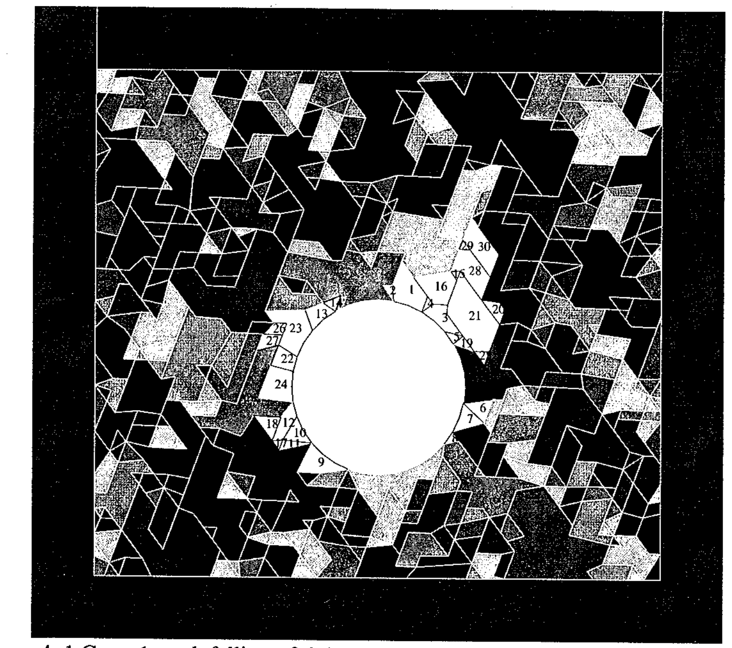

Figure 4. 1 Case 1 rock falling of .75 earth quake after 0 seconds

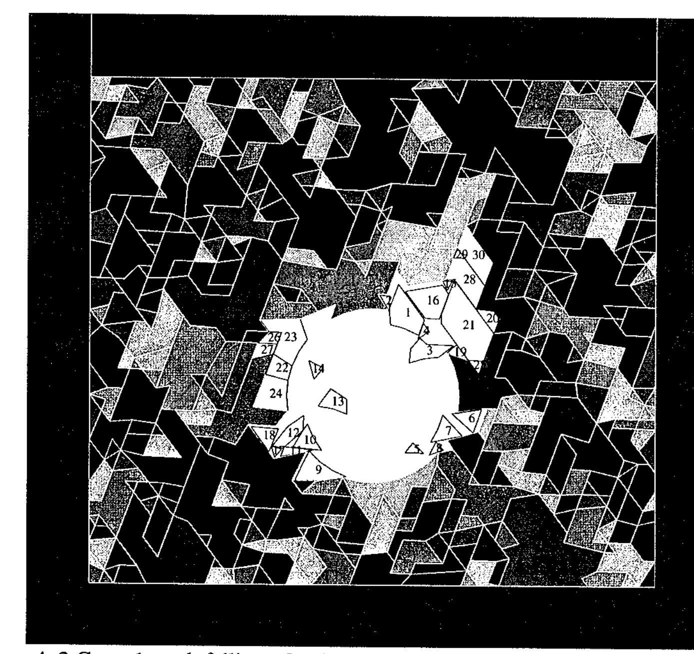

Figure 4. 2 Case 1 rock falling of .75 earth quake after 1 seconds

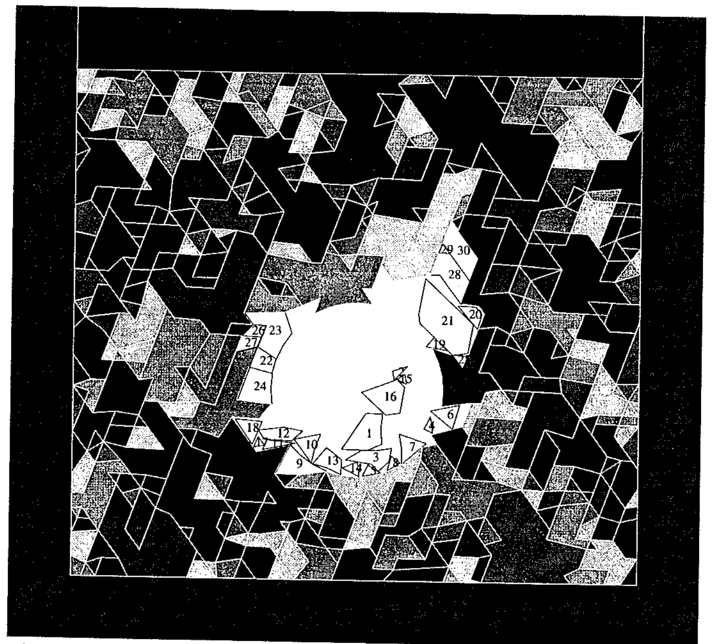

Figure 4. 3 Case 1 rock falling of .75 earth quake after 2 seconds

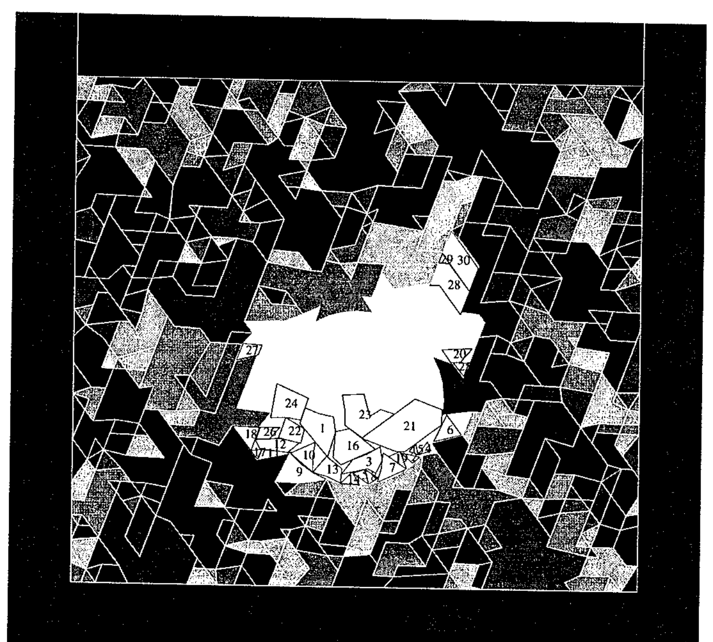

Figure 4. 4 Case 1 rock falling of .75 earth quake after 20 seconds

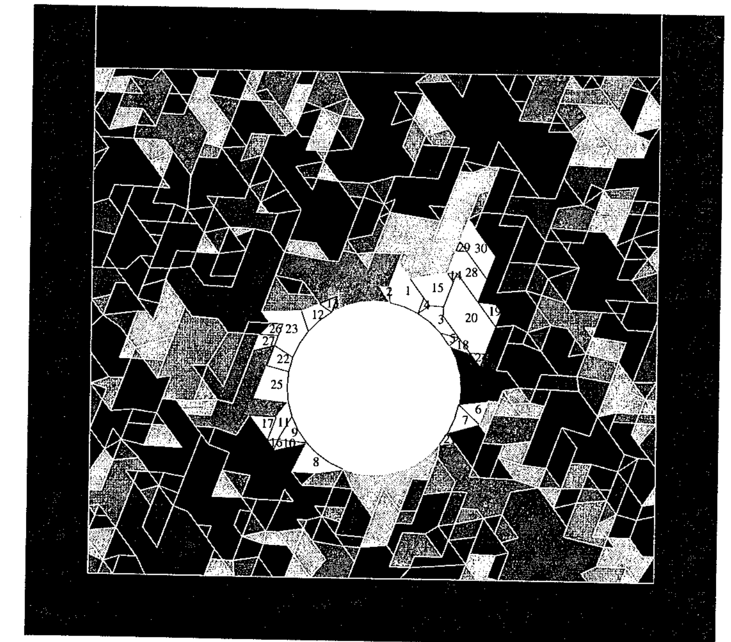

Figure 5. 1 Case 1 rock falling of 1.0 earth quake after 0 seconds

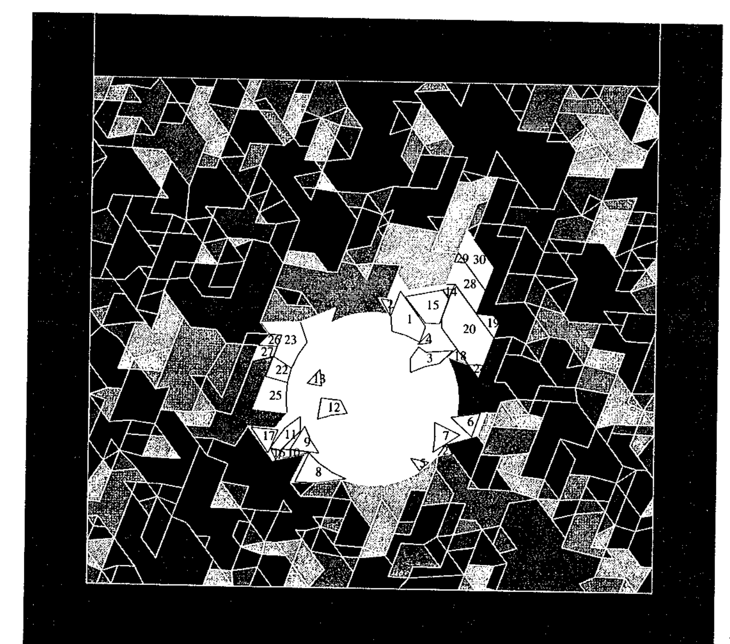

Figure 5. 2 Case 1 rock falling of 1.0 earth quake after 1 seconds

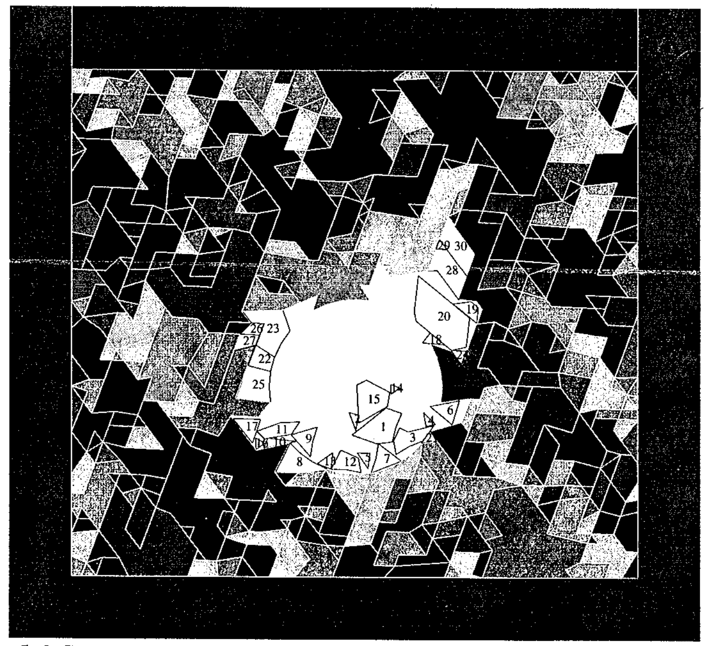

Figure 5. 3 Case 1 rock falling of 1.0 earth quake after 2 seconds

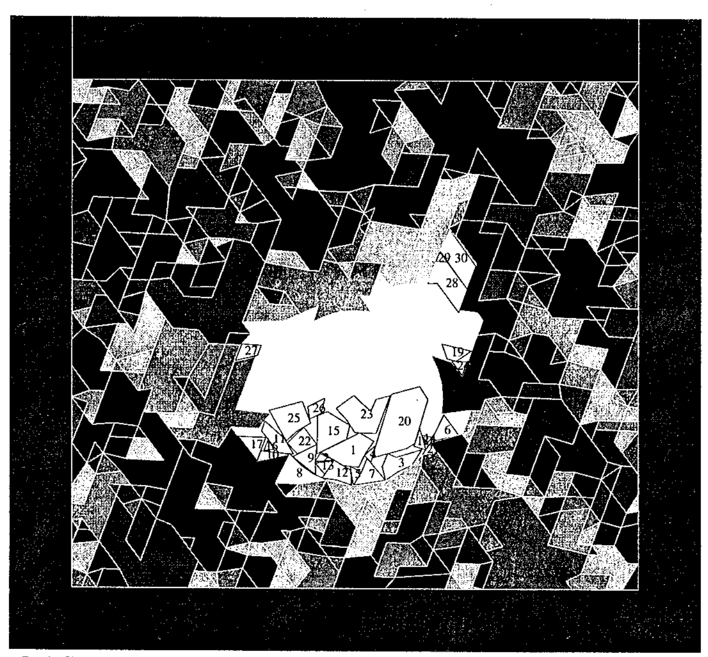

Figure 5. 4 Case 1 rock falling of 1.0 earth quake after 20 seconds

5. Case 2 of Rock Falling DDA Computation with Earth Quake Load

The programs and input files for the case 2 are the following:

Table 7. Programs and input files of case 2

file description	earth quake
joint forming data	dls20
joint forming code	dl0
block forming data	dcs20
block forming code	dc0
mechanical data	dfs20
mechanical code	df0
earth quake data	qkh1
graphic code	dg2
graphic files	dgq12 dgq22 dgq32 dgq42 dgq52

Figure 6.1 to Figure 6.4 show the rock falling of case 2 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 00% earth quake load is applied.

Figure 7.1 to Figure 7.4 show the rock falling of case 2 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 25% earth quake load is applied.

Figure 8.1 to Figure 8.4 show the rock falling of case 2 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 50% earth quake load is applied.

Figure 9.1 to Figure 9.4 show the rock falling of case 2 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 75% earth quake load is applied.

Figure 10.1 to Figure 10.4 show the rock falling of case 2 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 100% earth quake load is applied.

In each picture, if any vertex of any block moves more than 5 cm in any step of 20 seconds, this block is defined as a falling block. All falling blocks are in white color and with a number in it. The number is the order of falling. The block with "1" in it falls first.

The following table is the area of the falling blocks along with the falling order. The 100% earth quake load is applied. (Figure 10.1 to Figure 10.4)

Table 8. Falling rocks in time order of case 2

falling time order	block area in square meter
1	0.9806
2	0.2652
3	0.4219
4	0.0848
5	0.3118
6	0.2403
7	0.8517
8	0.4765
9	0.1255
10	0.4824
11	0.2709
12	0.1148
13	0.5706
14	0.3835
15	0.1248
16	0.3097
17	0.3132
18	0.3093
19	0.1798
20	0.1103
21	0.8602
22	0.2462
23	1.9715

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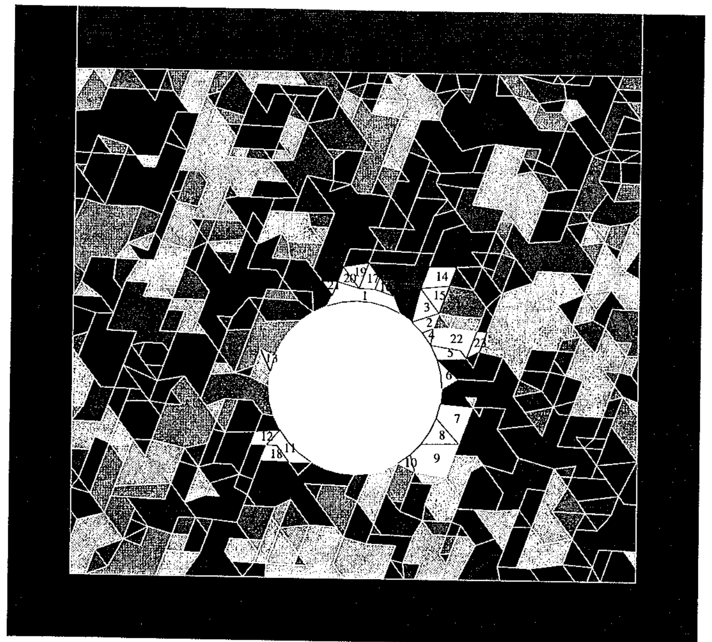

Figure 6. 1 Case 2 rock falling of .00 earth quake after 0 seconds

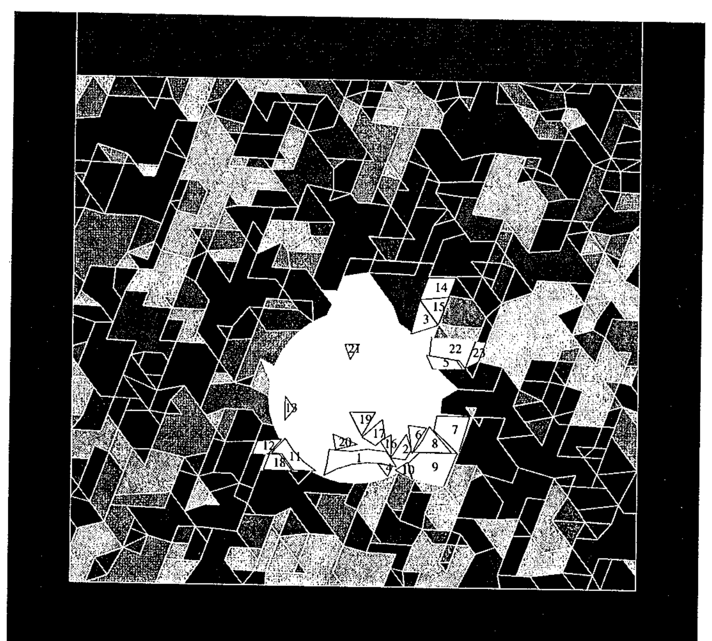

Figure 6. 2 Case 2 rock falling of .00 earth quake after 1 seconds

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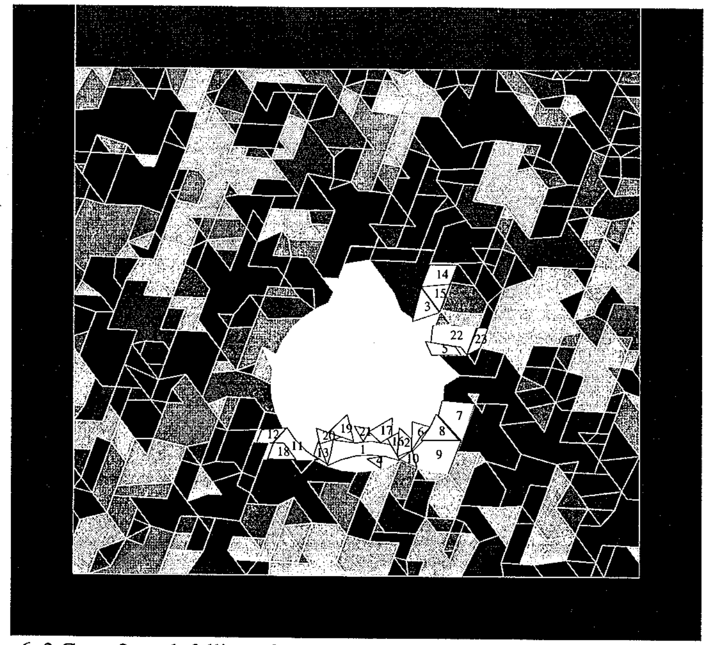

Figure 6. 3 Case 2 rock falling of .00 earth quake after 2 seconds

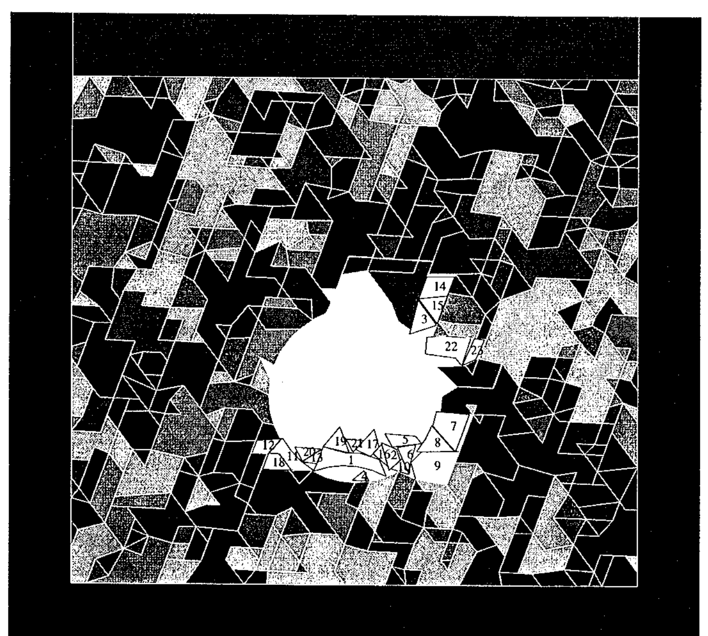

Figure 6. 4 Case 2 rock falling of .00 earth quake after 20 seconds

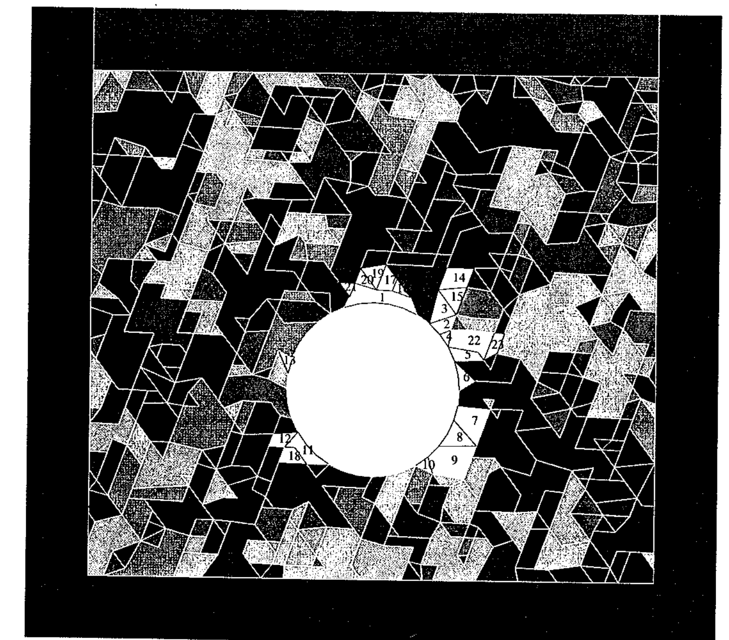

Figure 7. 1 Case 2 rock falling of .25 earth quake after 0 seconds

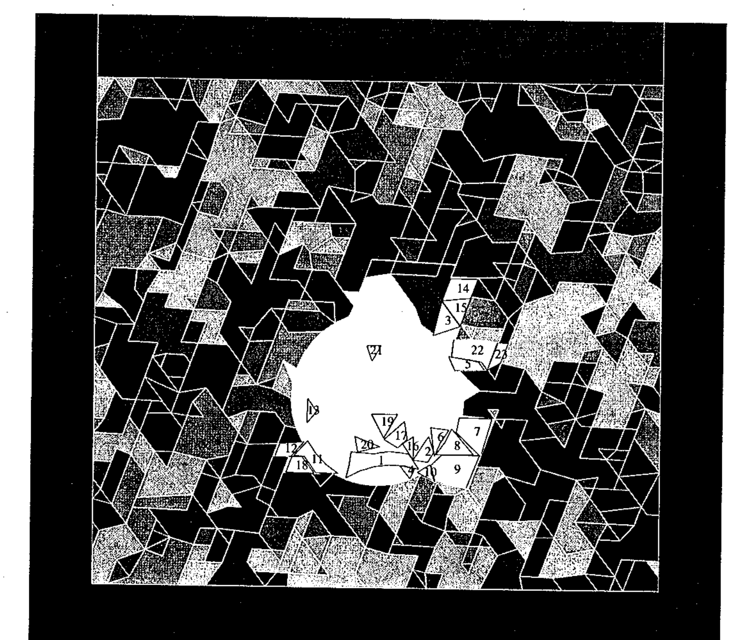

Figure 7. 2 Case 2 rock falling of .25 earth quake after 1 seconds

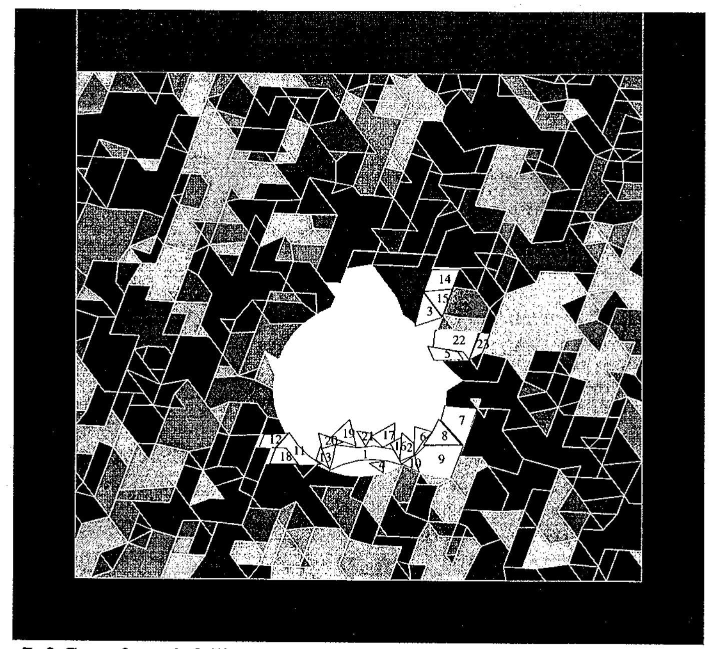

Figure 7. 3 Case 2 rock falling of .25 earth quake after 2 seconds

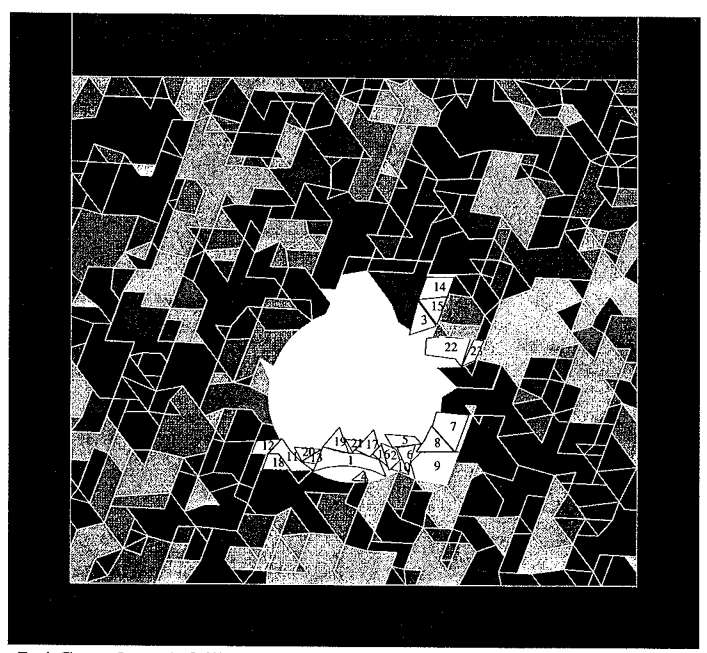

Figure 7. 4 Case 2 rock falling of .25 earth quake after 20 seconds

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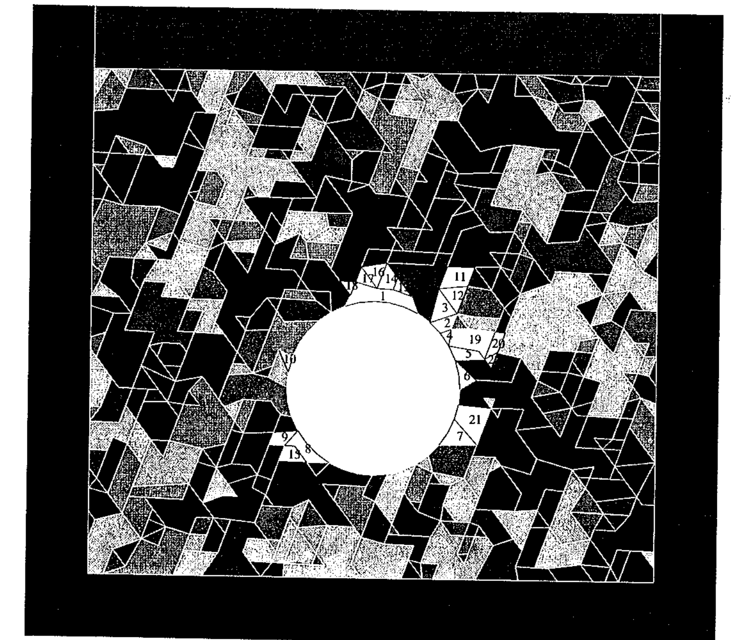

Figure 8. 1 Case 2 rock falling of .50 earth quake after 0 seconds

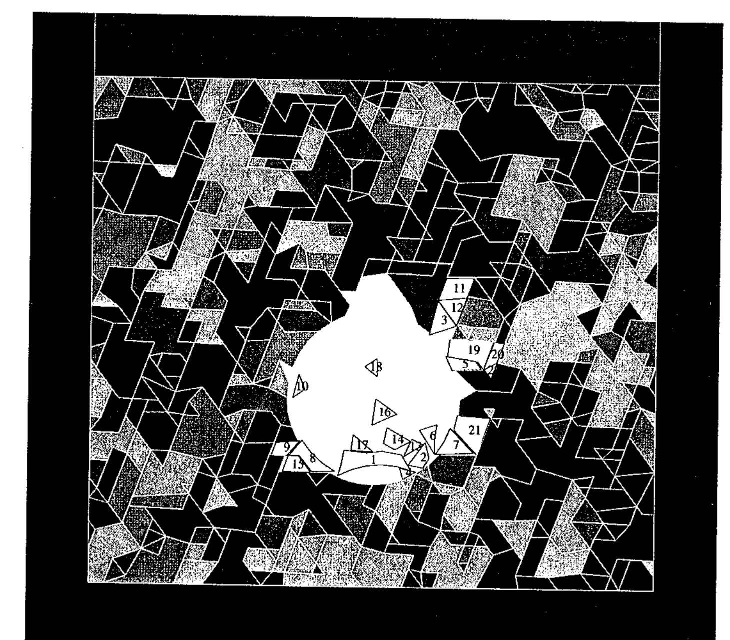

Figure 8. 2 Case 2 rock falling of .50 earth quake after 1 seconds

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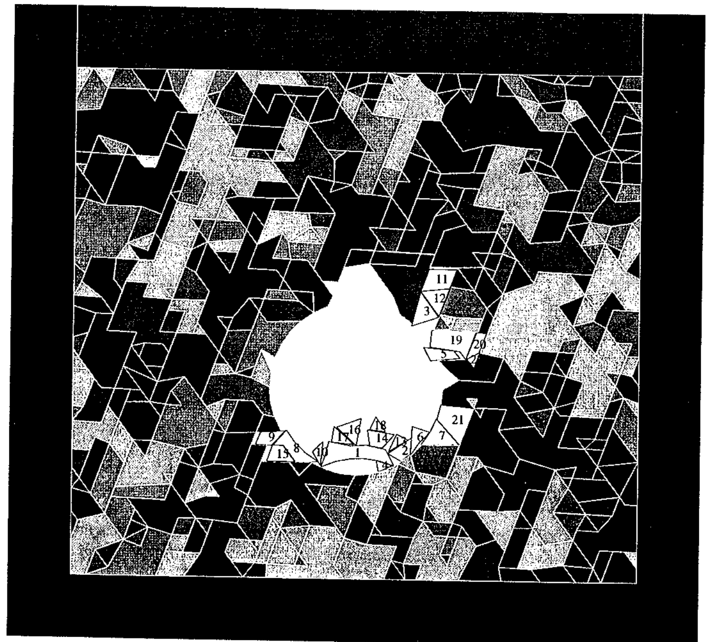

Figure 8. 3 Case 2 rock falling of .50 earth quake after 2 seconds

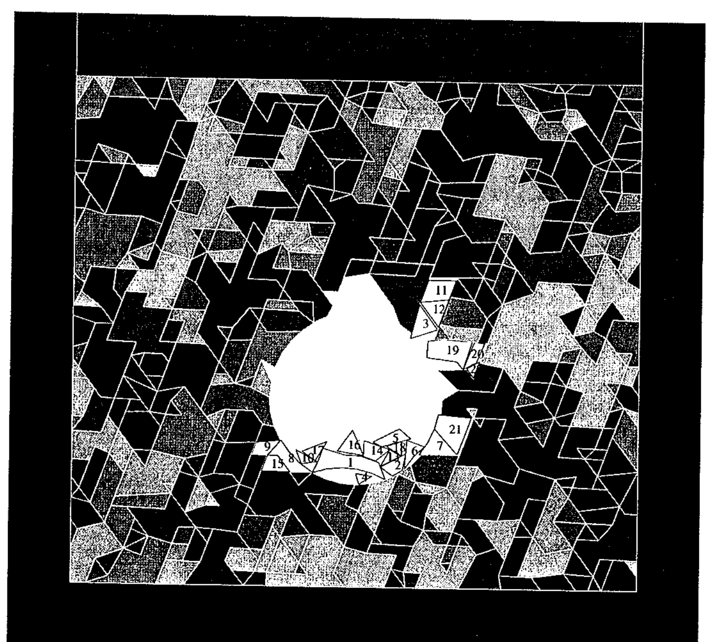

Figure 8. 4 Case 2 rock falling of .50 earth quake after 20 seconds

05/03/01

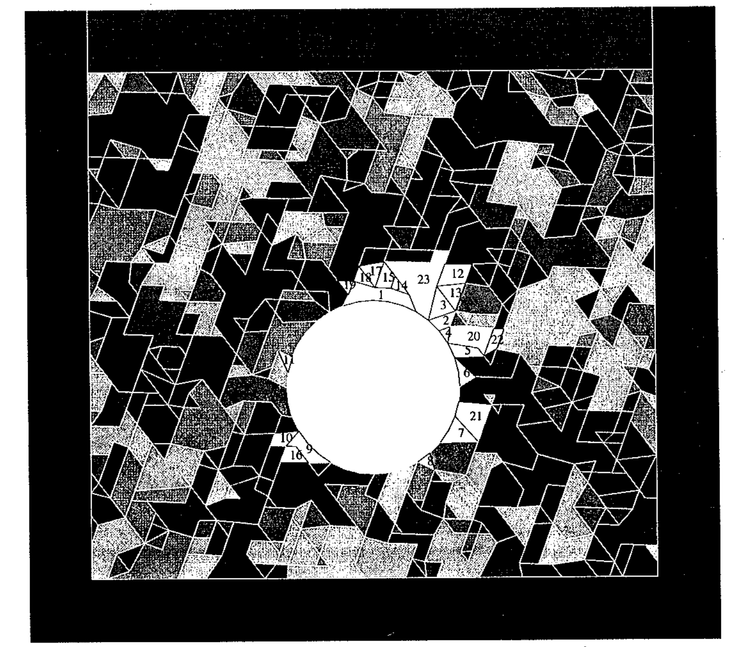

Figure 9. 1 Case 2 rock falling of .75 earth quake after 0 seconds

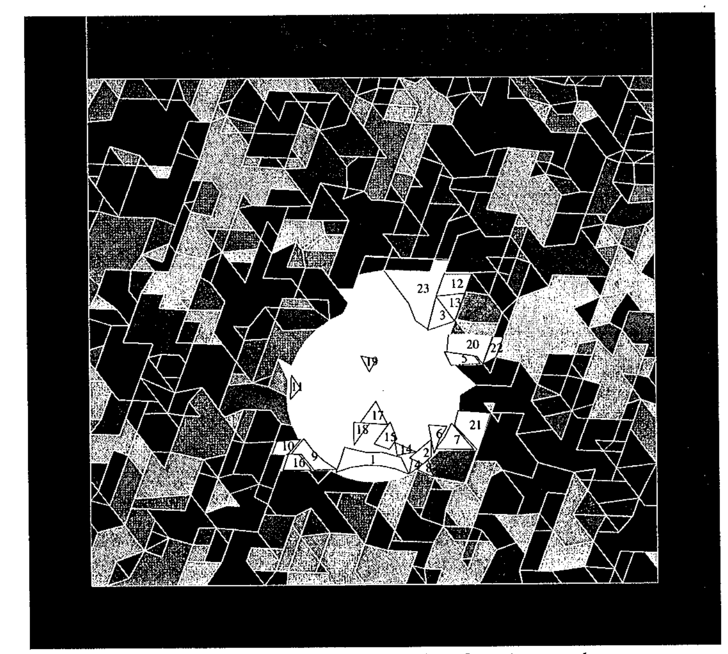

Figure 9. 2 Case 2 rock falling of .75 earth quake after 1 seconds

05/03/01

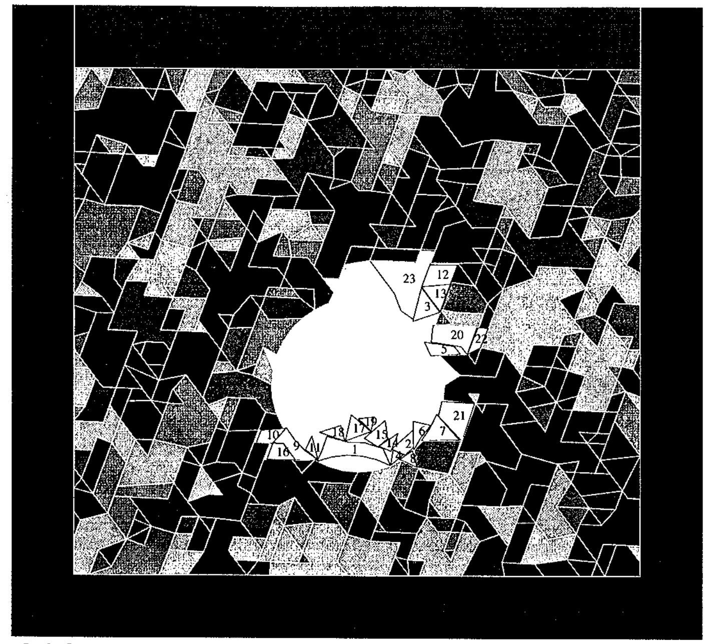
Figure 9. 3 Case 2 rock falling of .75 earth quake after 2 seconds

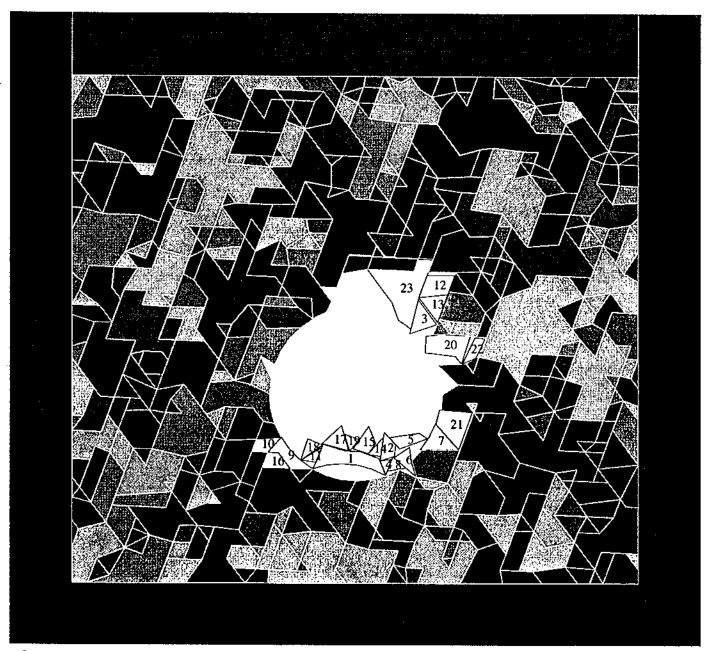
Figure 9. 4 Case 2 rock falling of .75 earth quake after 20 seconds

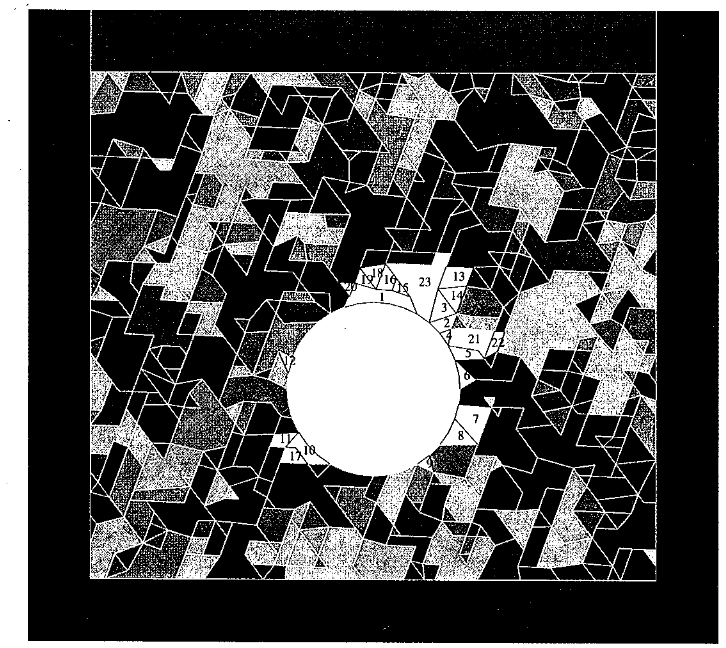
Figure 10. 1 Case 2 rock falling of 1.0 earth quake after 0 seconds

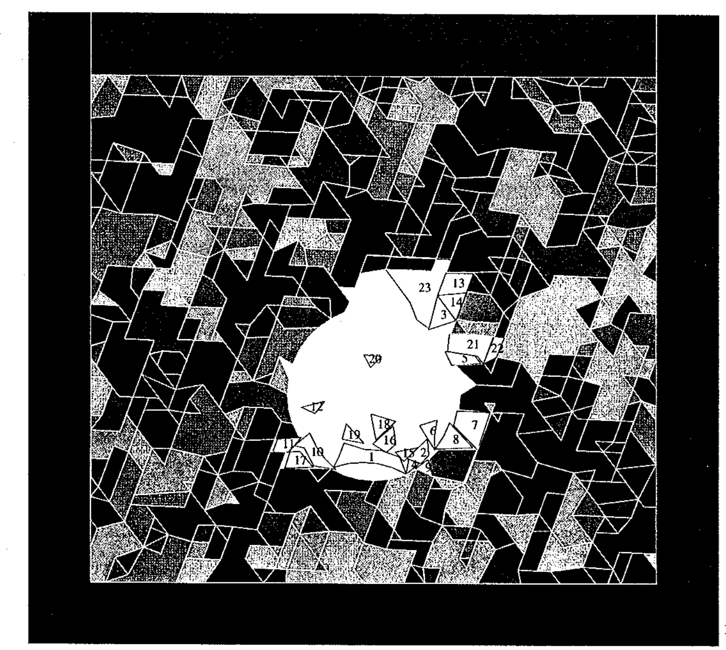
Figure 10. 2 Case 2 rock falling of 1.0 earth quake after 1 seconds

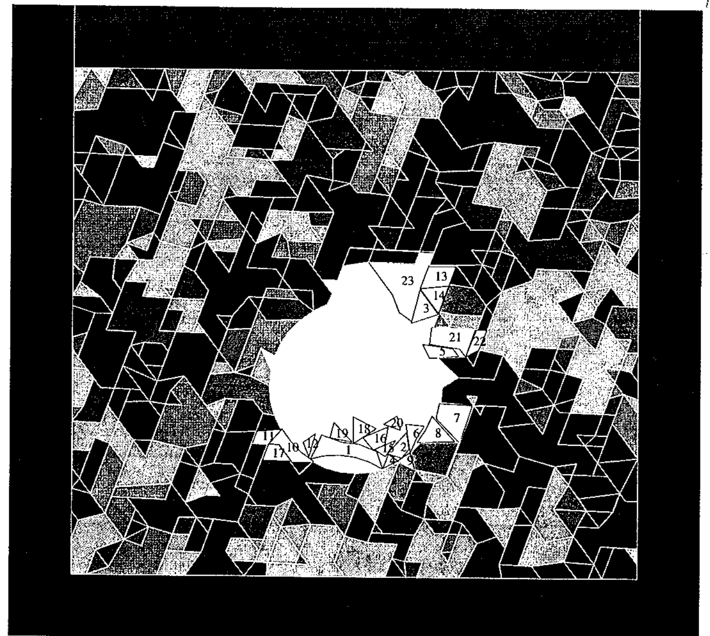

Figure 10. 3 Case 2 rock falling of 1.0 earth quake after 2 seconds

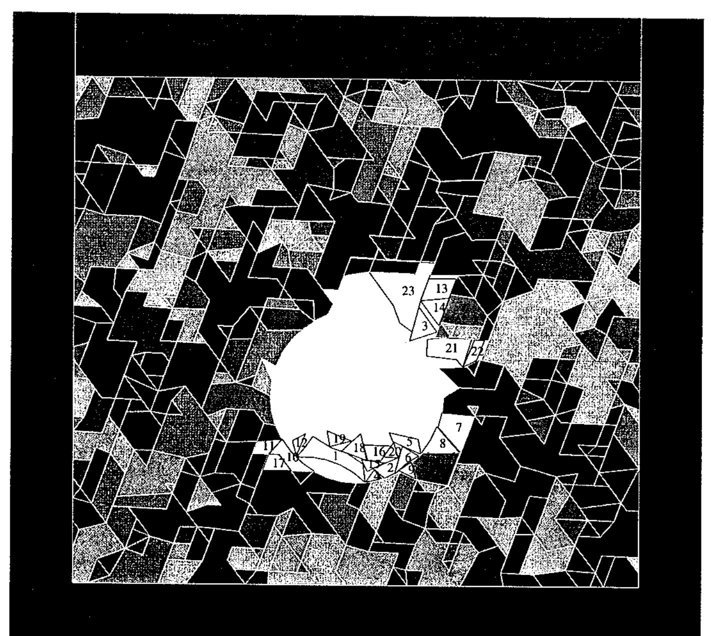

Figure 10. 4 Case 2 rock falling of 1.0 earth quake after 20 seconds

6. Case 3 of Rock Falling DDA Computation with Earth Quake Load

The programs and input files for the case 3 are the following:

Table 9. Programs and input files of case 3

file description	earth quake
joint forming data	dls30
joint forming code	dl0
block forming data	dcs30
block forming code	dc0
mechanical data	dfs30
mechanical code	df0
earth quake data	qkh1
graphic code	dg2
graphic files	dgq13 dgq23 dgq33 dgq43 dgq53

Figure 11.1 to Figure 11.4 show the rock falling of case 3 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 00% earth quake load is applied.

Figure 12.1 to Figure 12.4 show the rock falling of case 3 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 25% earth quake load is applied.

Figure 13.1 to Figure 13.4 show the rock falling of case 3 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 50% earth quake load is applied.

Figure 14.1 to Figure 14.4 show the rock falling of case 3 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 75% earth quake load is applied.

Figure 15.1 to Figure 15.4 show the rock falling of case 3 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 100% earth quake load is applied.

In each picture, if any vertex of any block moves more than 5 cm in any step of 20 seconds, this block is defined as a falling block. All falling blocks are in white color and with a number in it. The number is the order of falling. The block with "1" in it falls first.

The following table is the area of the falling blocks along with the falling order. The 100% earth quake load is applied. (Figure 15.1 to Figure 15.4)

Table 10. Falling rocks in time order of case 3

falling time order	block area in square meter
1	0.0855
2	1.4166
3	0.3503
4	0.1465
5	0.1516
6	0.2524
7	0.6278
8	0.0826
9	0.1690
10	3.1198
11	0.2497
12	1.9056
13	0.2216
14	0.2397
15	0.4006
16	0.2904
17	0.4146
18	0.1850
19	0.4042
20	1.4132
21	0.1176
22	0.2823
23	0.3445
24	0.3445
25	0.4343
26	0.0905
27	0.2721
28	0.1759
29	0.9427
30	0.0909
31	0.0973
32	0.6020
33	0.0823

34	0.3778
35	0.4446
36	0.2579
37	0.0524
38	0.0578
39	0.6136
40	0.1232
41	0.3440
42	0.0763
43	0.8839
44	0.0528
45	0.3534
46	1.7038
47	0.3704
48	0.0528
49	0.0865
50	0.1338
51	1.9218
52	0.3586
53	0.5493
54	3.3242

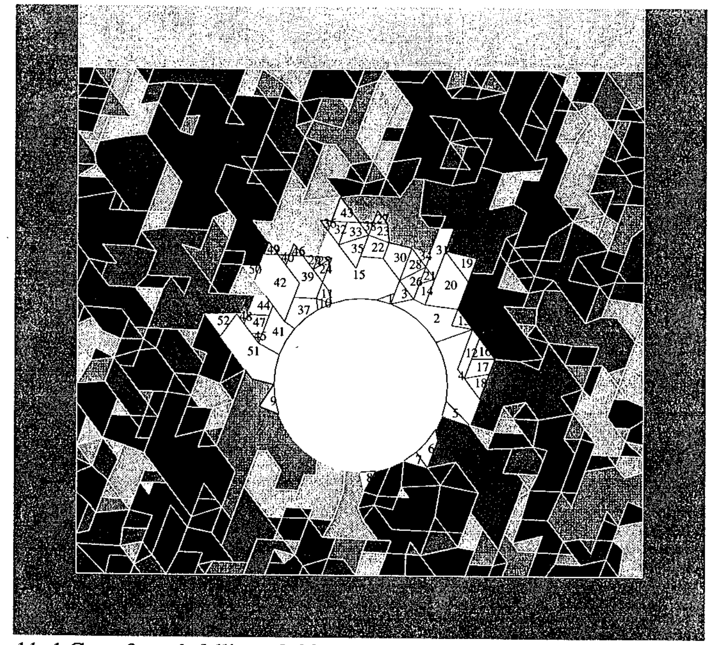

Figure 11. 1 Case 3 rock falling of .00 earth quake after 0 seconds

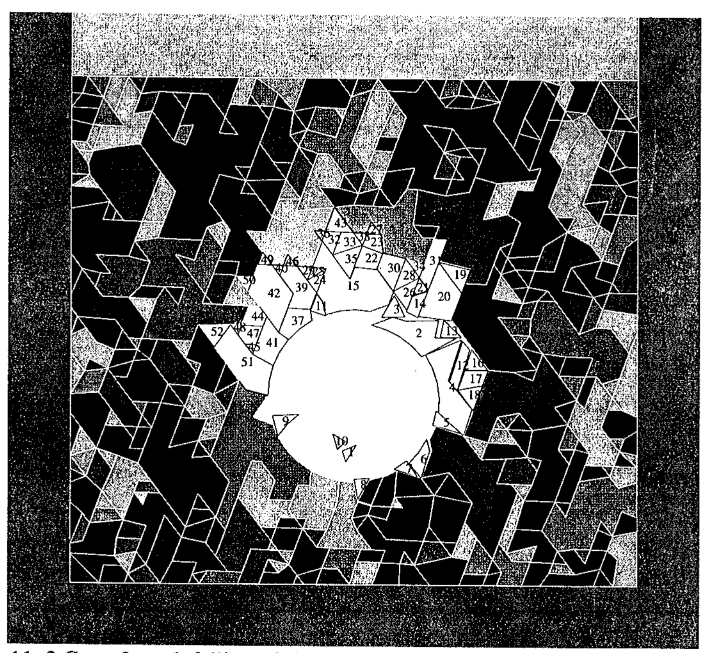

Figure 11. 2 Case 3 rock falling of .00 earth quake after 1 seconds

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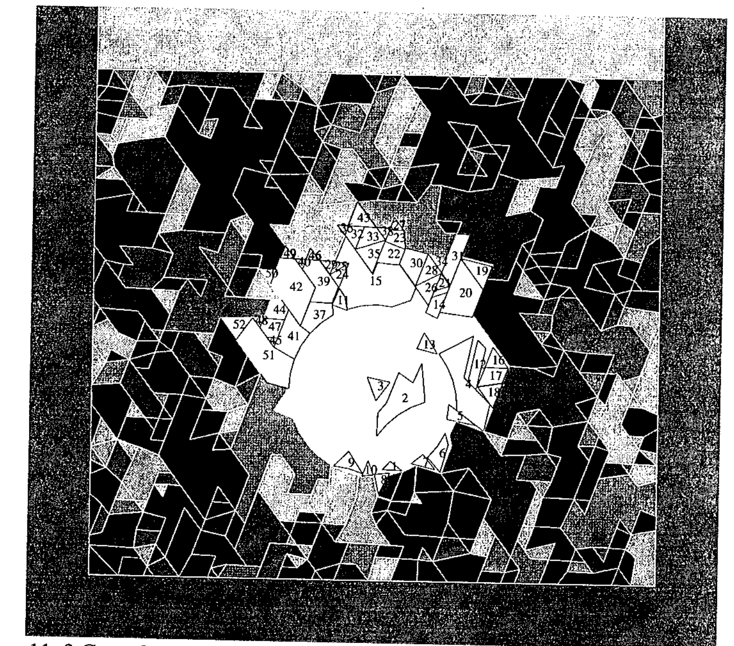

Figure 11. 3 Case 3 rock falling of .00 earth quake after 2 seconds

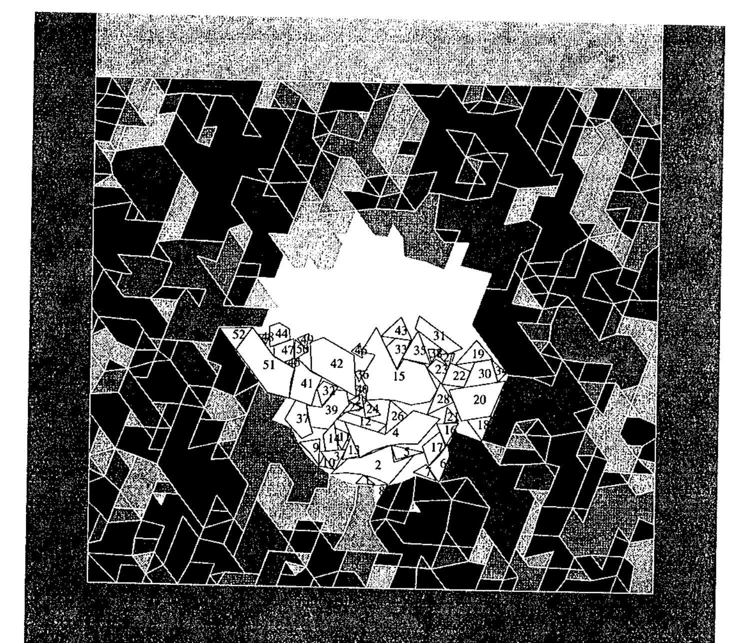

Figure 11. 4 Case 3 rock falling of .00 earth quake after 20 seconds

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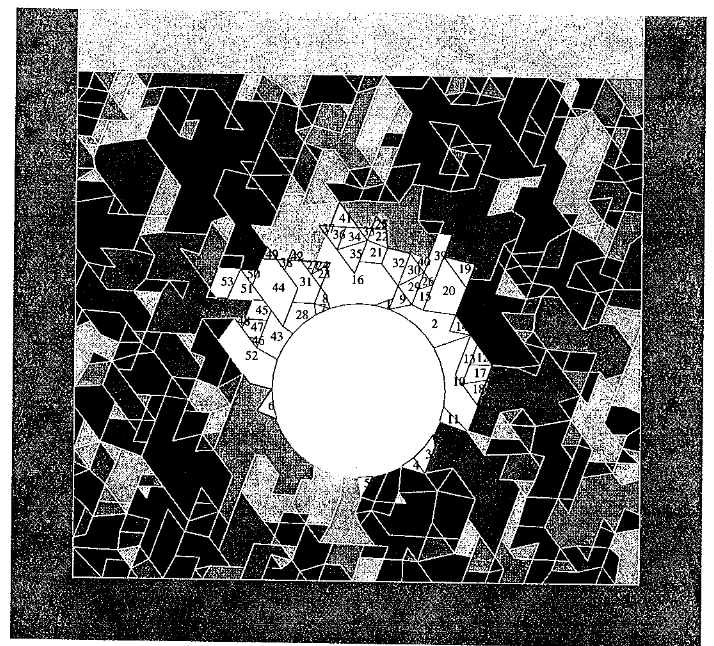

Figure 12. 1 Case 3 rock falling of .25 earth quake after 0 seconds

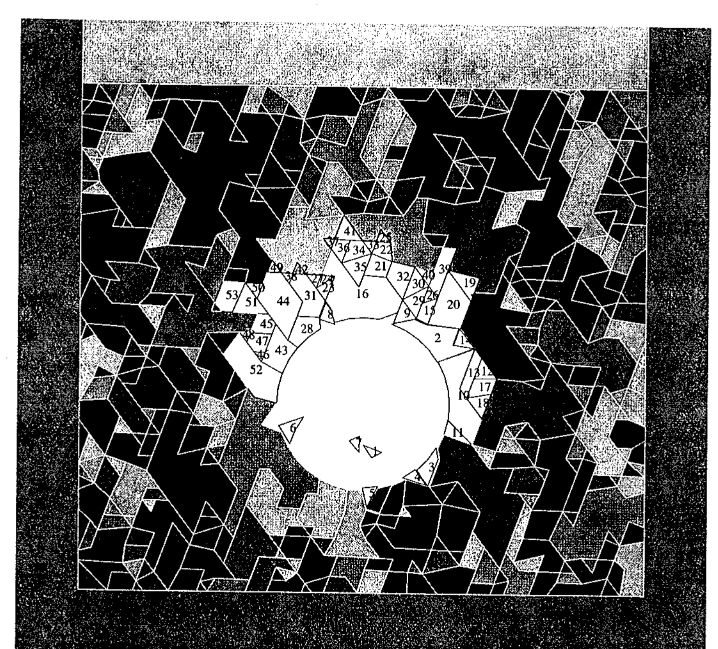

Figure 12. 2 Case 3 rock falling of .25 earth quake after 1 seconds

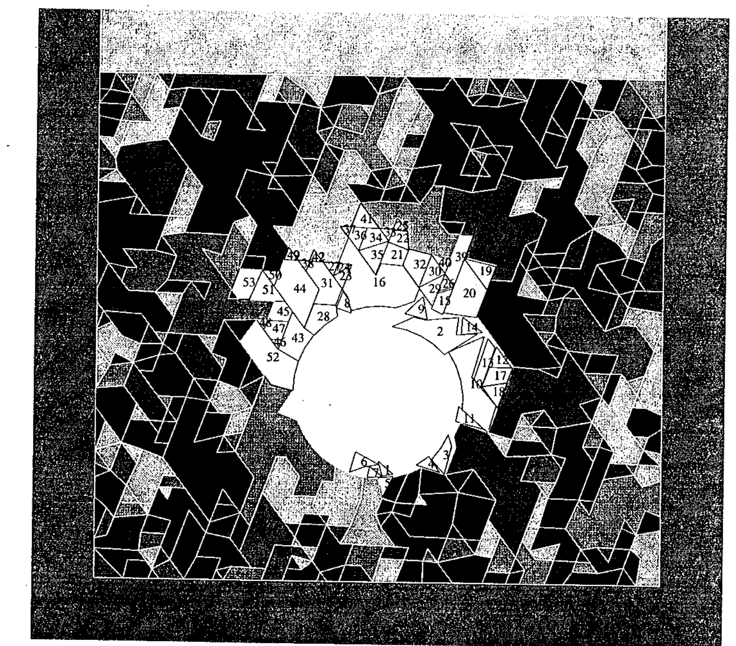

Figure 12. 3 Case 3 rock falling of .25 earth quake after 2 seconds

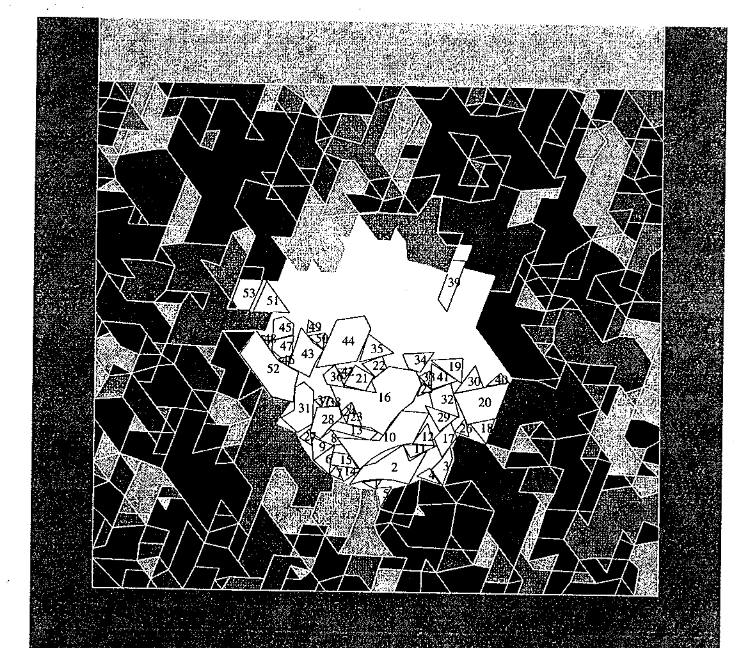

Figure 12. 4 Case 3 rock falling of .25 earth quake after 20 seconds

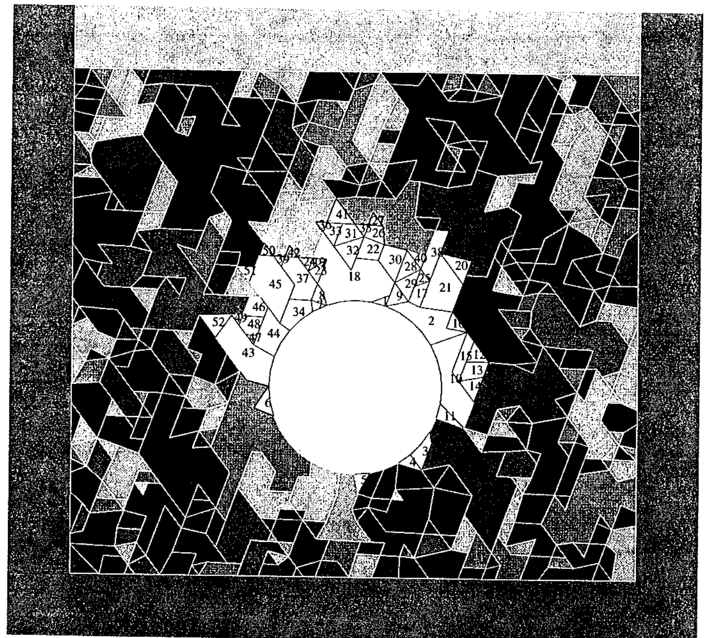

Figure 13. 1 Case 3 rock falling of .50 earth quake after 0 seconds

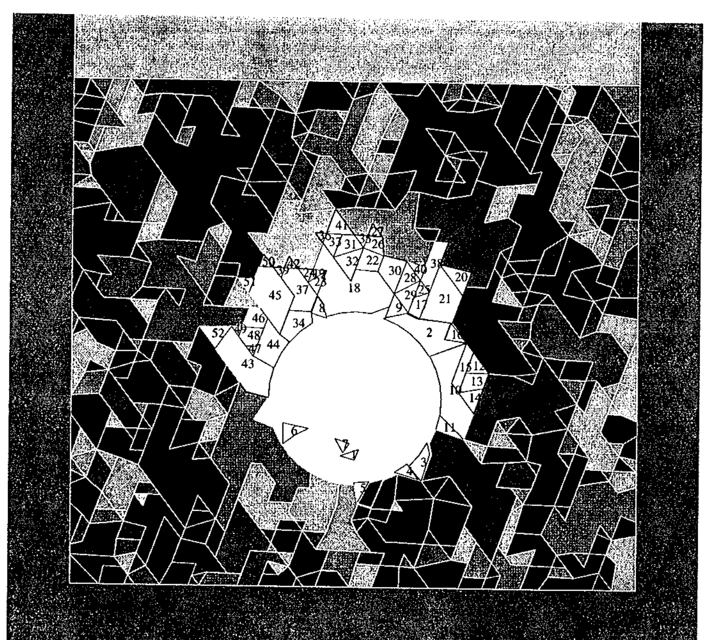

Figure 13. 2 Case 3 rock falling of .50 earth quake after 1 seconds

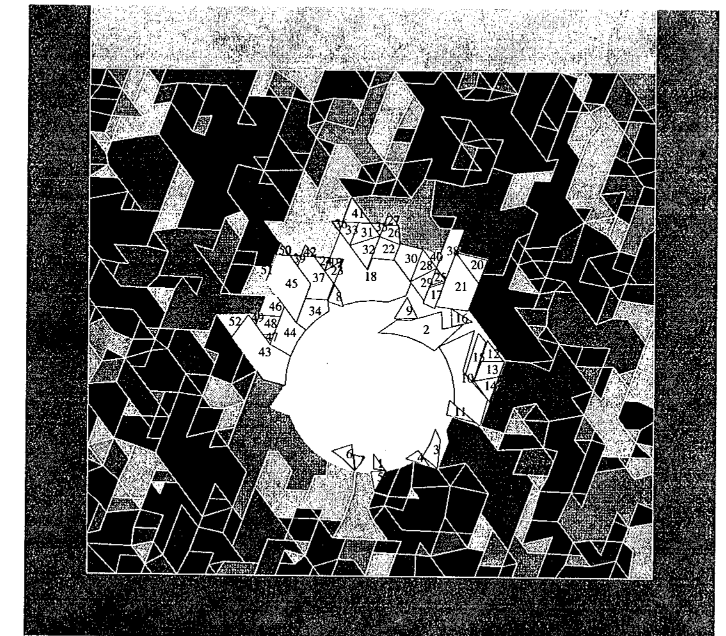

Figure 13. 3 Case 3 rock falling of .50 earth quake after 2 seconds

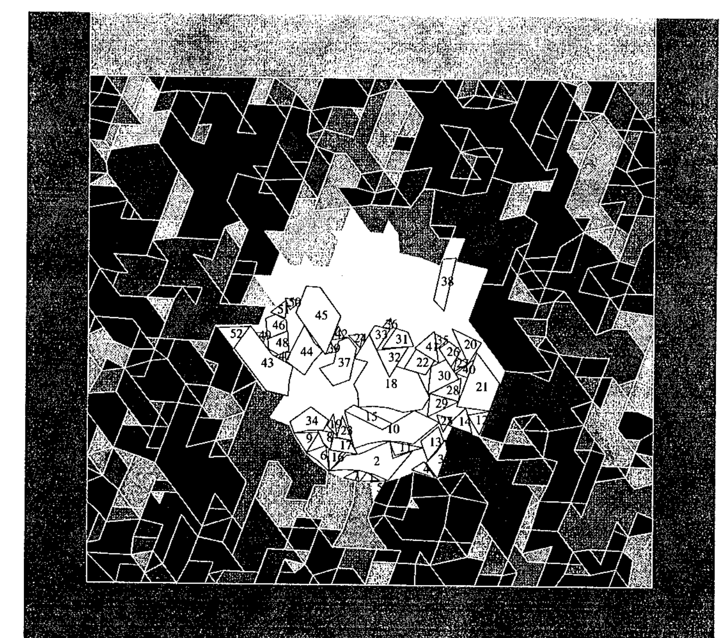

Figure 13. 4 Case 3 rock falling of .50 earth quake after 20 seconds

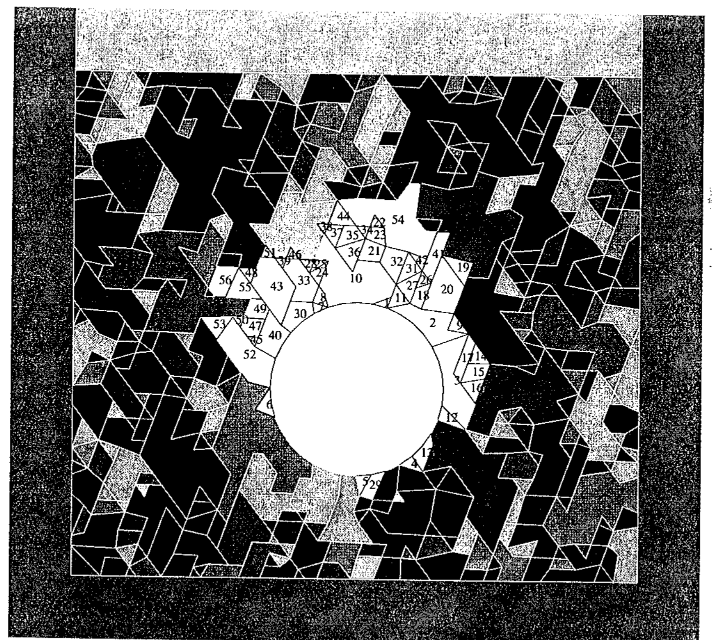

Figure 14. 1 Case 3 rock falling of .75 earth quake after 0 seconds

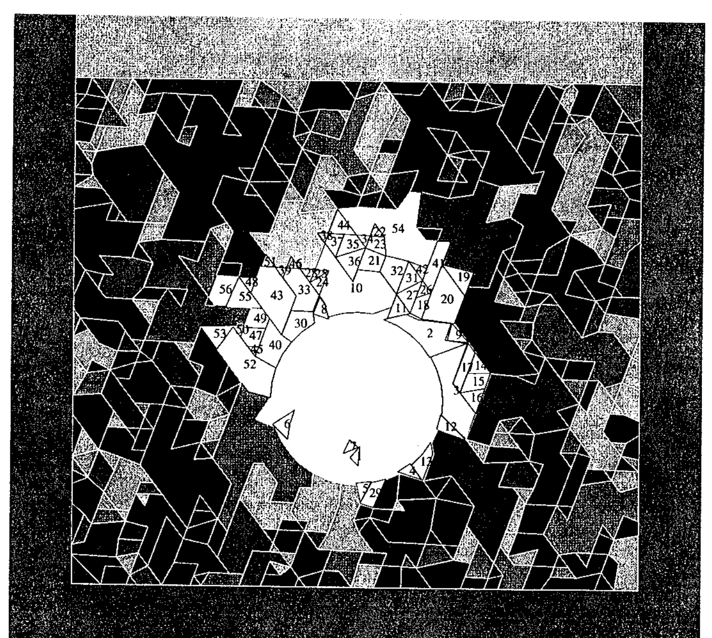

Figure 14. 2 Case 3 rock falling of .75 earth quake after 1 seconds

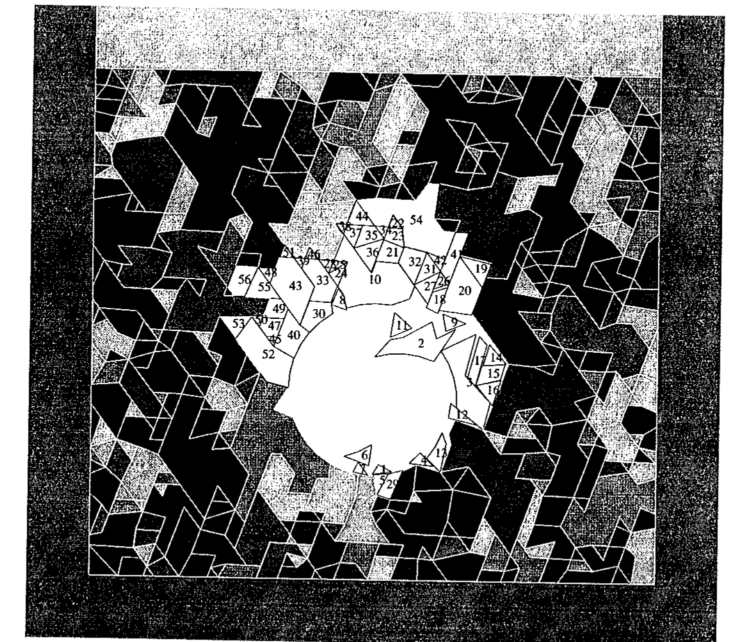

Figure 14. 3 Case 3 rock falling of .75 earth quake after 2 seconds

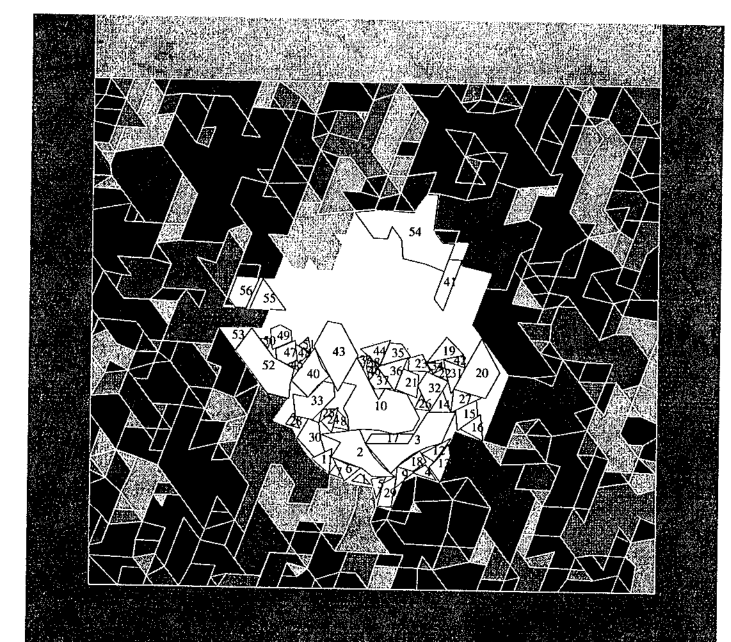

Figure 14. 4 Case 3 rock falling of .75 earth quake after 20 seconds

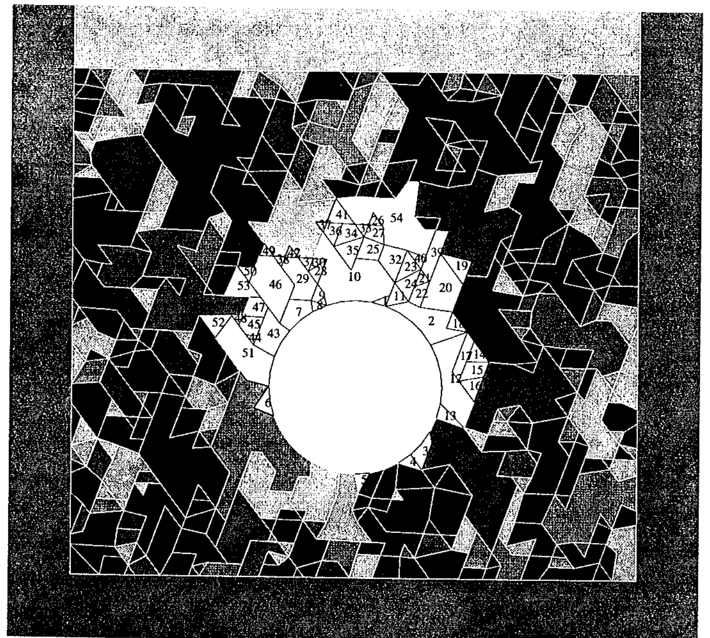

Figure 15. 1 Case 3 rock falling of 1.0 earth quake after 0 seconds

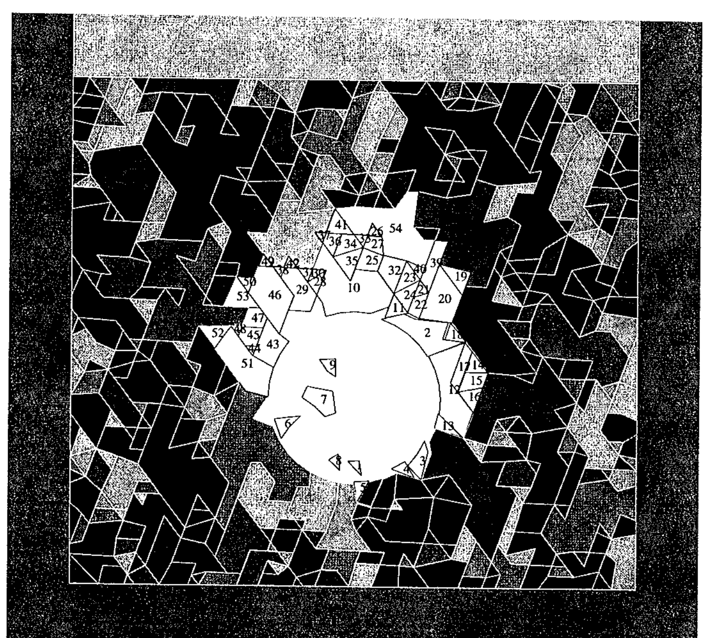

Figure 15. 2 Case 3 rock falling of 1.0 earth quake after 1 seconds

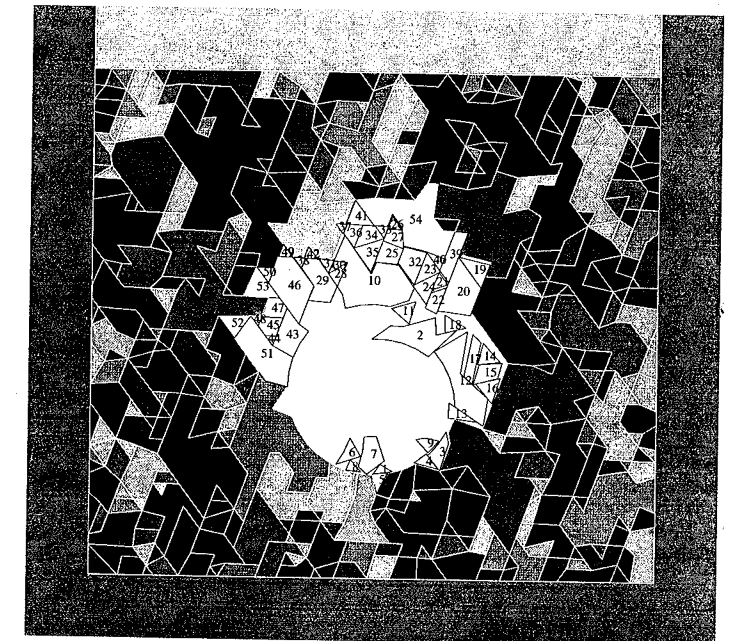

Figure 15. 3 Case 3 rock falling of 1.0 earth quake after 2 seconds

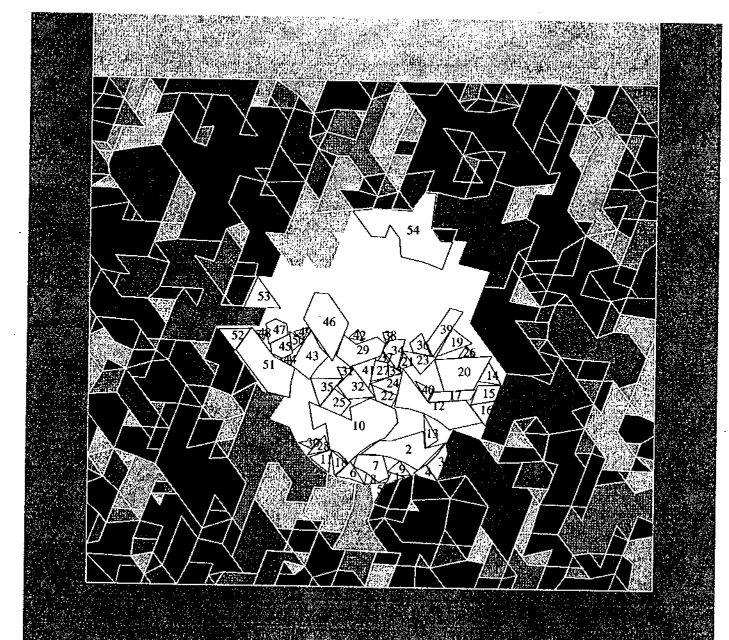

Figure 15. 4 Case 3 rock falling of 1.0 earth quake after 20 seconds

7. Case 4 of Rock Falling DDA Computation with Earth Quake Load

The programs and input files for the case 4 are the following:

Table 11. Programs and input files of case 4

file description	earth quake
joint forming data	dls40
joint forming code	dl0
block forming data	dcs40
block forming code	dc0
mechanical data	dfs40
mechanical code	df0
earth quake data	qkh1
graphic code	dg2
graphic files	dgq14 dgq24 dgq34 dgq44 dgq54

Figure 16.1 to Figure 16.4 show the rock falling of case 4 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 00% earth quake load is applied.

Figure 17.1 to Figure 17.4 show the rock falling of case 4 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 25% earth quake load is applied.

Figure 18.1 to Figure 18.4 show the rock falling of case 4 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 50% earth quake load is applied.

Figure 19.1 to Figure 19.4 show the rock falling of case 4 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 75% earth quake load is applied.

Figure 20.1 to Figure 20.4 show the rock falling of case 4 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 100% earth quake load is applied.

In each picture, if any vertex of any block moves more than 5 cm in any step of 20 seconds, this block is defined as a falling block. All falling blocks are in white color and with a number in it. The number is the order of falling. The block with "1" in it falls first.

The following table is the area of the falling blocks along with the falling order. The 100% earth quake load is applied. (Figure 20.1 to Figure 20.4)

Table 12. Falling rocks in time order of case 4

falling time order	block area in square meter
1	0.6844
2	0.2334
3	0.1906
4	0.2825
5	0.1375
6	0.2587
7	2.2046
8	0.3802
9	0.6822
10	0.1211
11	2.3715
12	0.2064
13	0.3920
14	0.4046
15	0.0942
16	0.0701
17	0.9725
18	0.0490
19	0.6554
20	0.0776
21	0.1093
22	1.2063

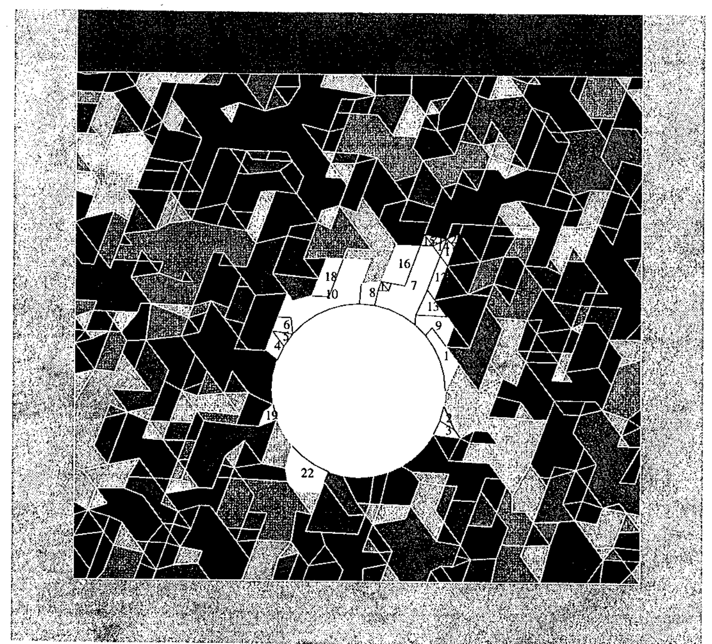

Figure 16. 1 Case 4 rock falling of .00 earth quake after 0 seconds

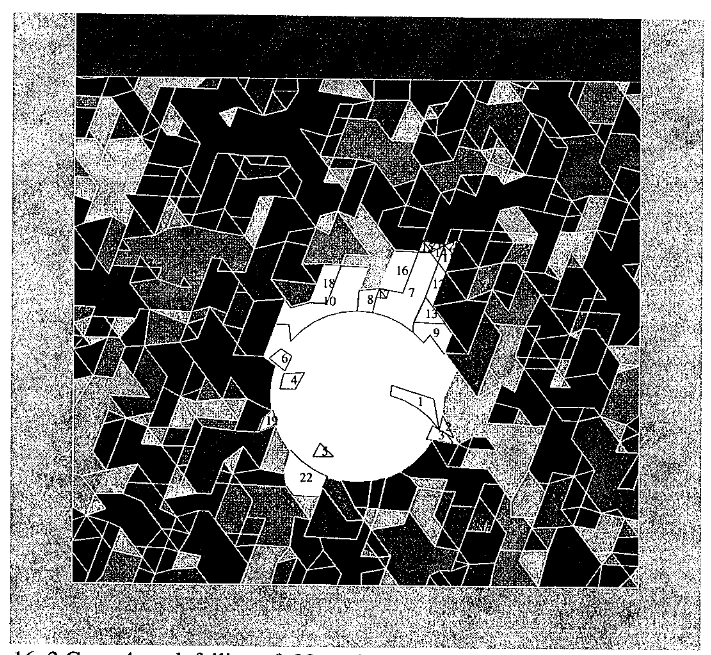

Figure 16. 2 Case 4 rock falling of .00 earth quake after 1 seconds

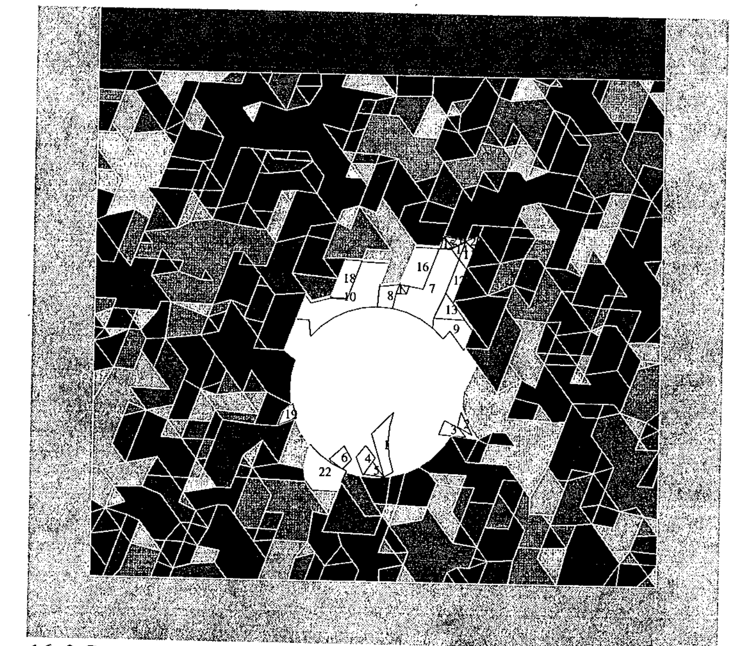

Figure 16. 3 Case 4 rock falling of .00 earth quake after 2 seconds

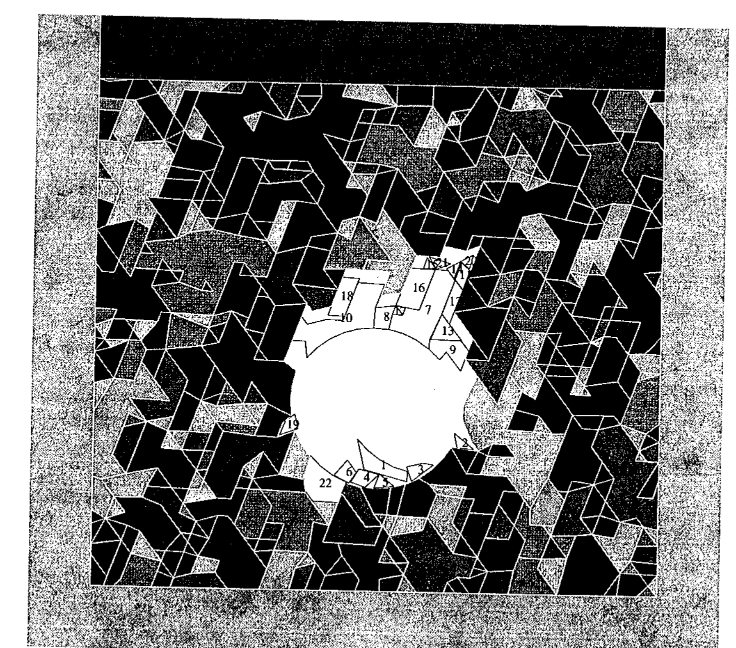

Figure 16. 4 Case 4 rock falling of .00 earth quake after 20 seconds

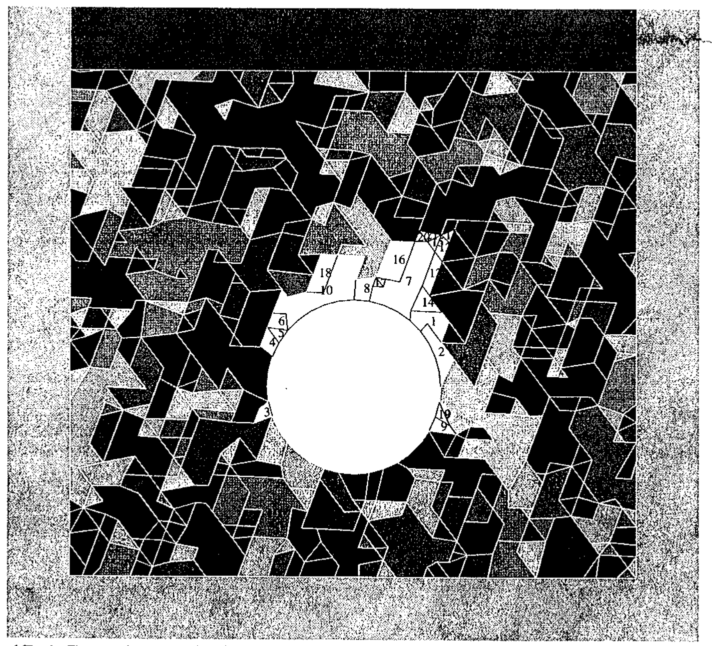

Figure 17. 1 Case 4 rock falling of .25 earth quake after 0 seconds

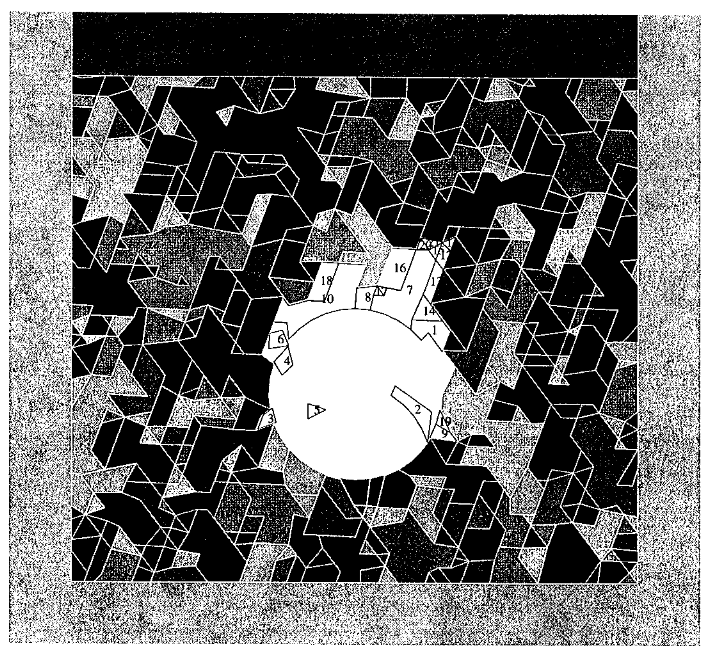

Figure 17. 2 Case 4 rock falling of .25 earth quake after 1 seconds

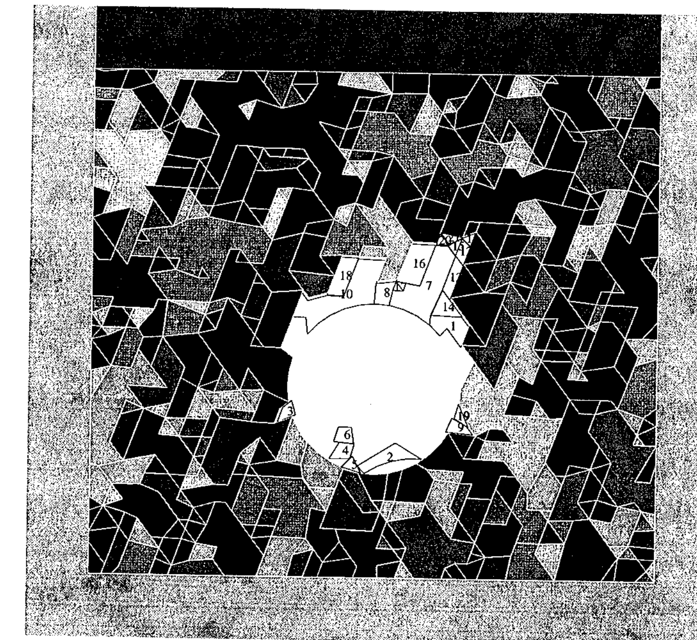

Figure 17. 3 Case 4 rock falling of .25 earth quake after 2 seconds

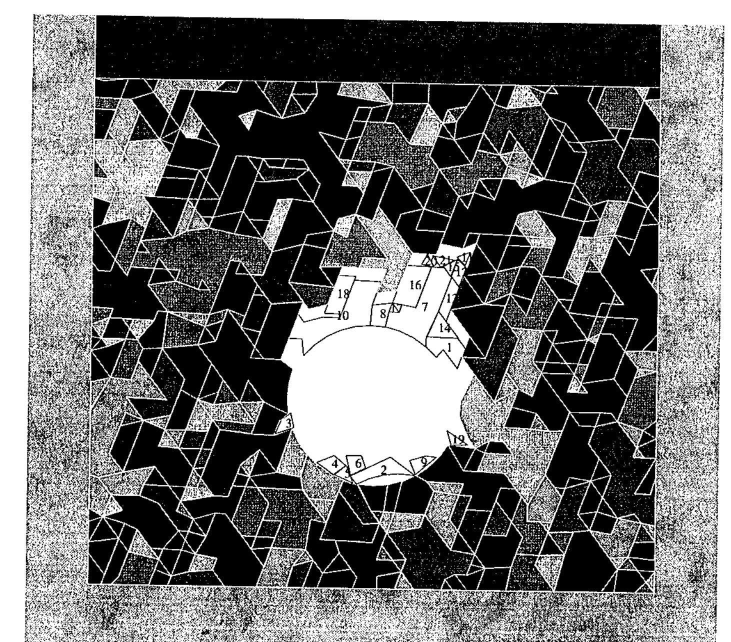

Figure 17. 4 Case 4 rock falling of .25 earth quake after 20 seconds

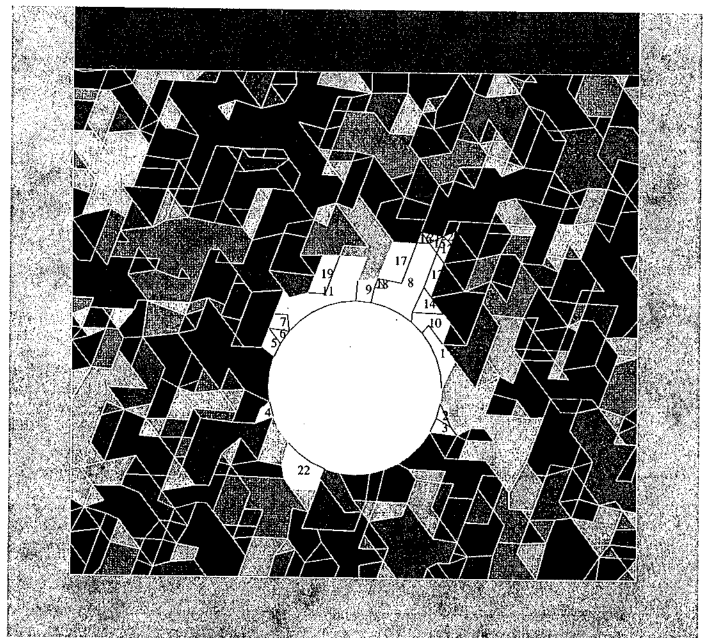

Figure 18. 1 Case 4 rock falling of .50 earth quake after 0 seconds

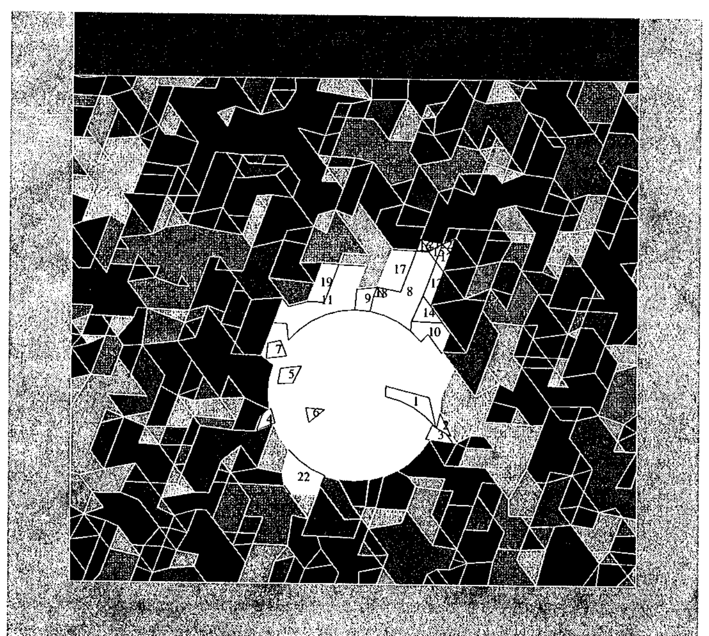

Figure 18. 2 Case 4 rock falling of .50 earth quake after 1 seconds

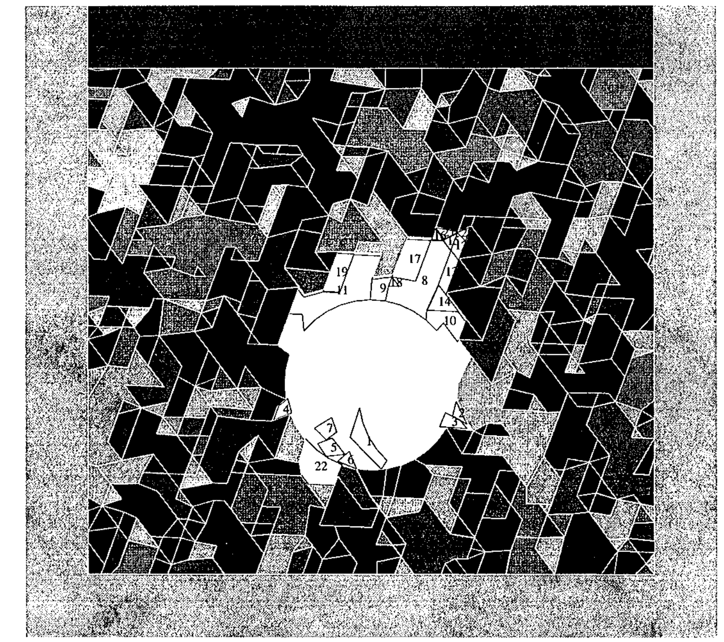

Figure 18. 3 Case 4 rock falling of .50 earth quake after 2 seconds

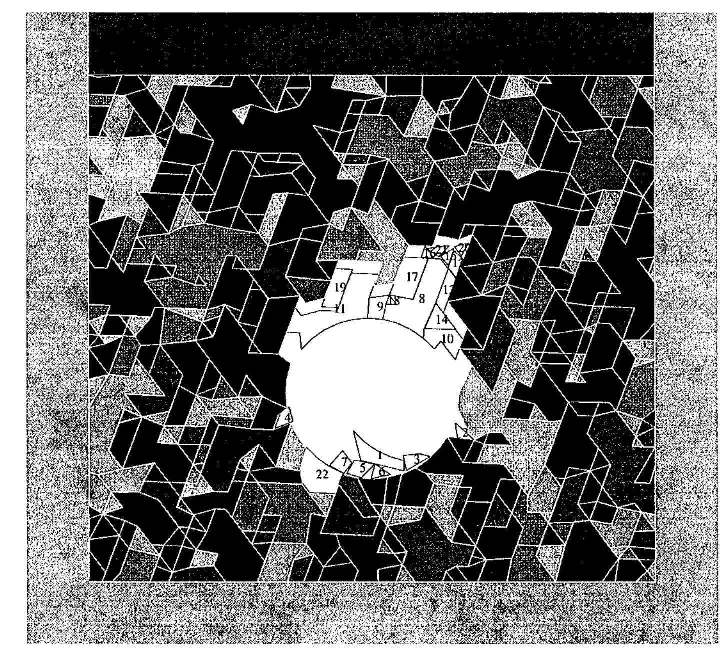

Figure 18. 4 Case 4 rock falling of .50 earth quake after 20 seconds

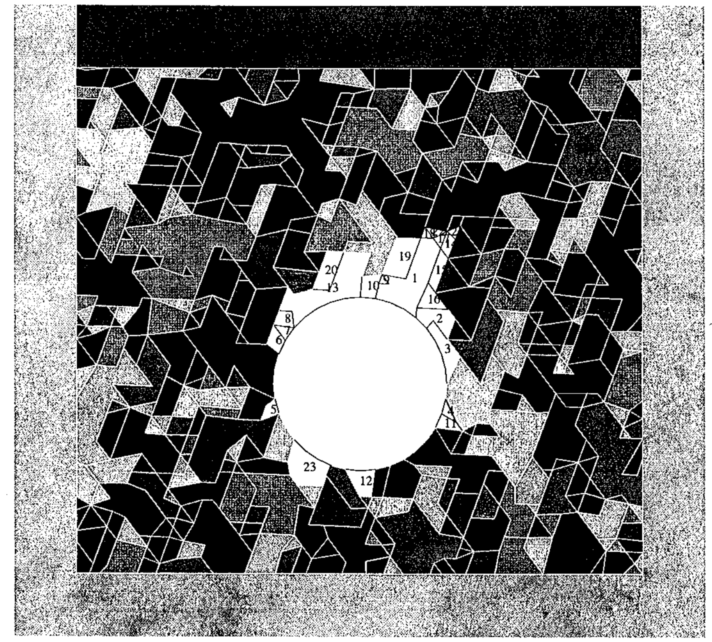

Figure 19. 1 Case 4 rock falling of .75 earth quake after 0 seconds

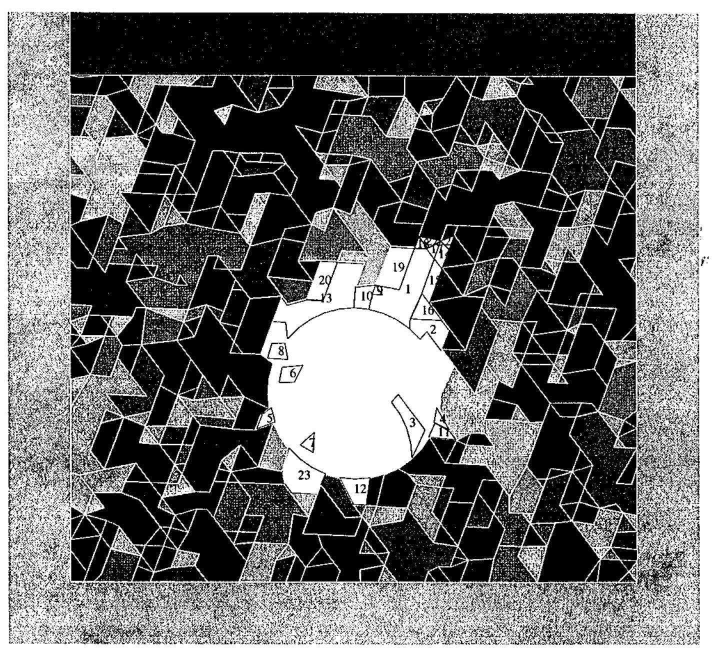

Figure 19. 2 Case 4 rock falling of .75 earth quake after 1 seconds

05/09/10

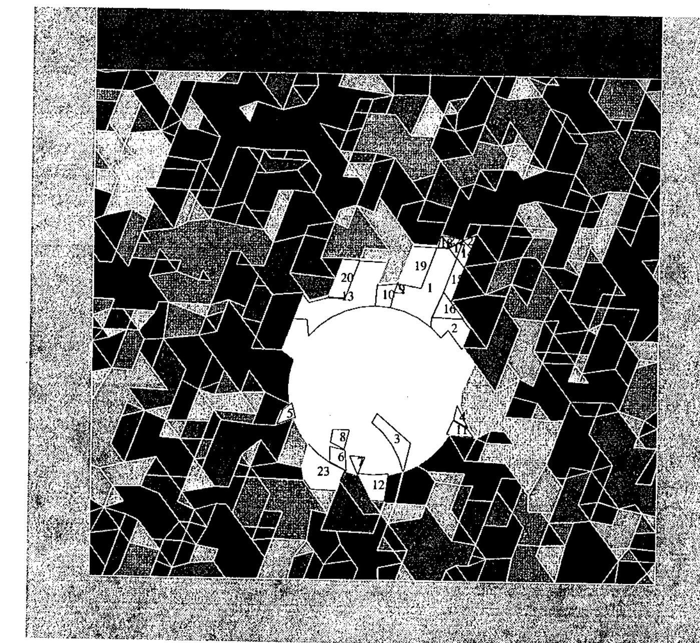

Figure 19. 3 Case 4 rock falling of .75 earth quake after 2 seconds

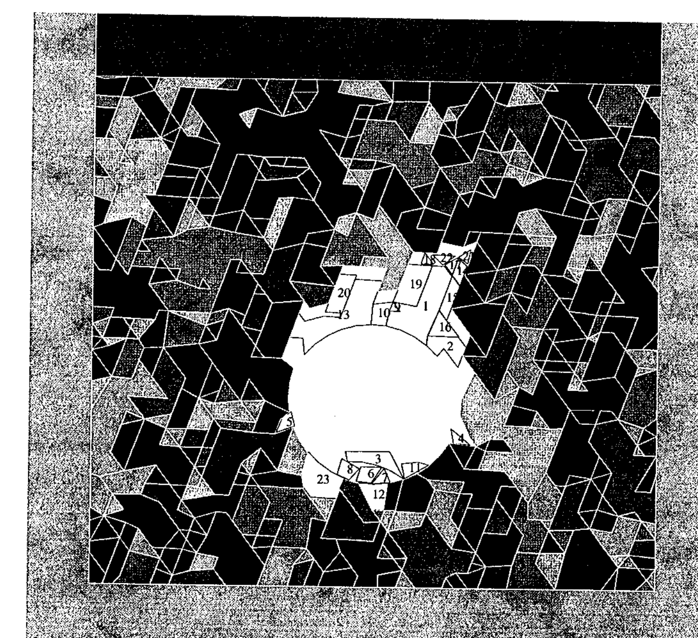

Figure 19. 4 Case 4 rock falling of .75 earth quake after 20 seconds

05/09/10

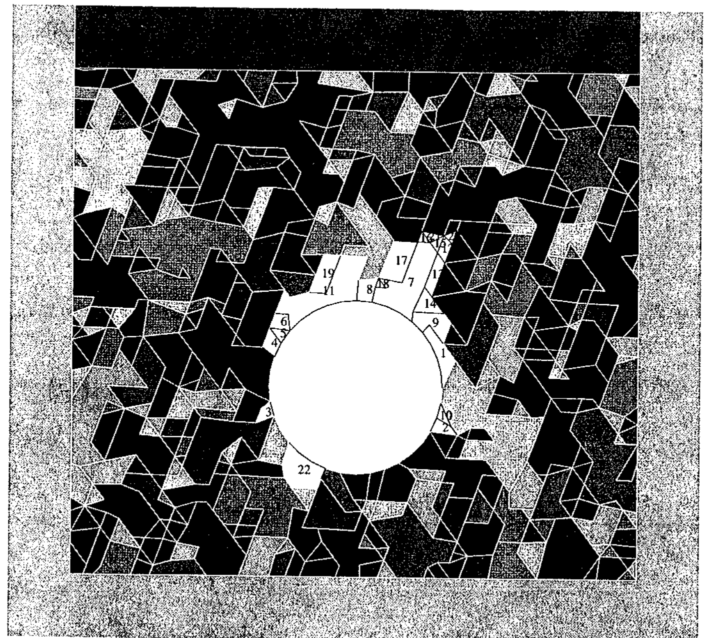

Figure 20. 1 Case 4 rock falling of 1.0 earth quake after 0 seconds

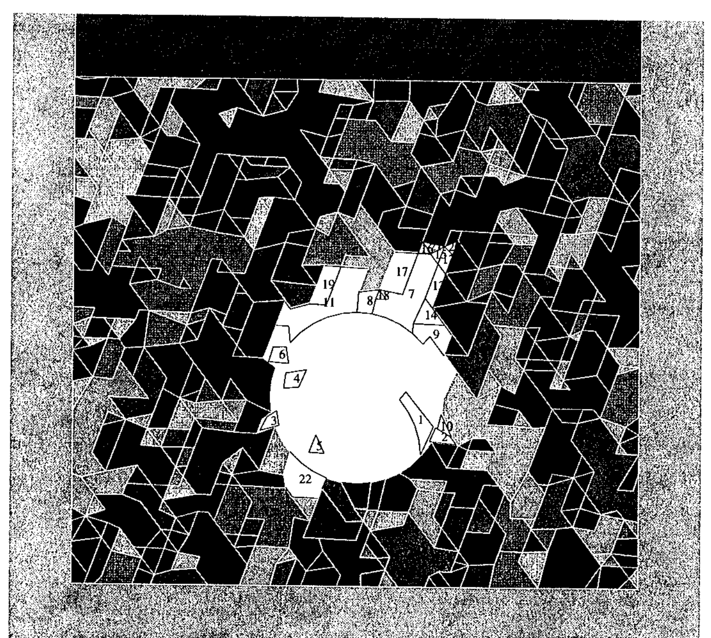

Figure 20. 2 Case 4 rock falling of 1.0 earth quake after 1 seconds

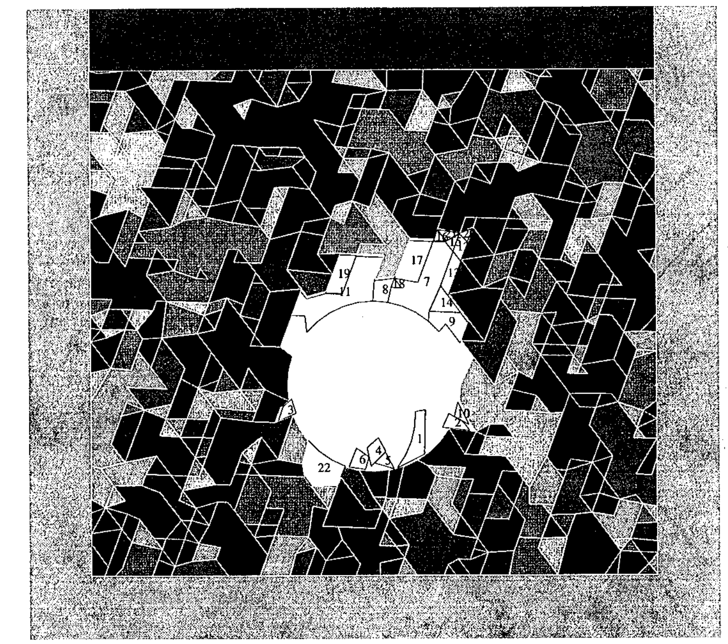

Figure 20. 3 Case 4 rock falling of 1.0 earth quake after 2 seconds

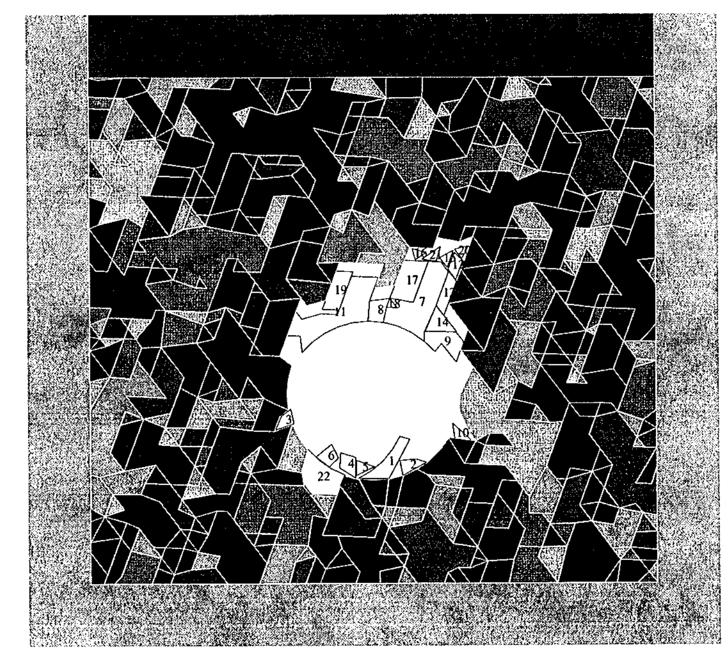

Figure 20. 4 Case 4 rock falling of 1.0 earth quake after 20 seconds

8. Case 5 of Rock Falling DDA Computation with Earth Quake Load

The programs and input files for the case 5 are the following:

Table 13. Programs and input files of case 5

file description	earth quake
joint forming data	dls50
joint forming code	dl0
block forming data	dcs50
block forming code	dc0
mechanical data	dfs50
mechanical code	df0
earth quake data	qkh1
graphic code	dg2
graphic files	dgq15 dgq25 dgq35 dgq45 dgq55

Figure 21.1 to Figure 21.4 show the rock falling of case 5 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 00% earth quake load is applied.

Figure 22.1 to Figure 22.4 show the rock falling of case 5 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 25% earth quake load is applied.

Figure 23.1 to Figure 23.4 show the rock falling of case 5 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 50% earth quake load is applied.

Figure 24.1 to Figure 24.4 show the rock falling of case 5 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 75% earth quake load is applied.

Figure 25.1 to Figure 25.4 show the rock falling of case 5 at 0, 1, 2 and 20 seconds of the DDA computation respectively. In this computation, the 100% earth quake load is applied.

In each picture, if any vertex of any block moves more than 5 cm in any step of 20 seconds, this block is defined as a falling block. All falling blocks are in white color and with a number in it. The number is the order of falling. The block with "1" in it falls first.

The following table is the area of the falling blocks along with the falling order. The 100% earth quake load is applied. (Figure 25.1 to Figure 25.4)

Table 14. Falling rocks in time order of case 5

falling time order	block area in square meter
1	0.2728
2	0.0774
3	0.3780
4	0.2444

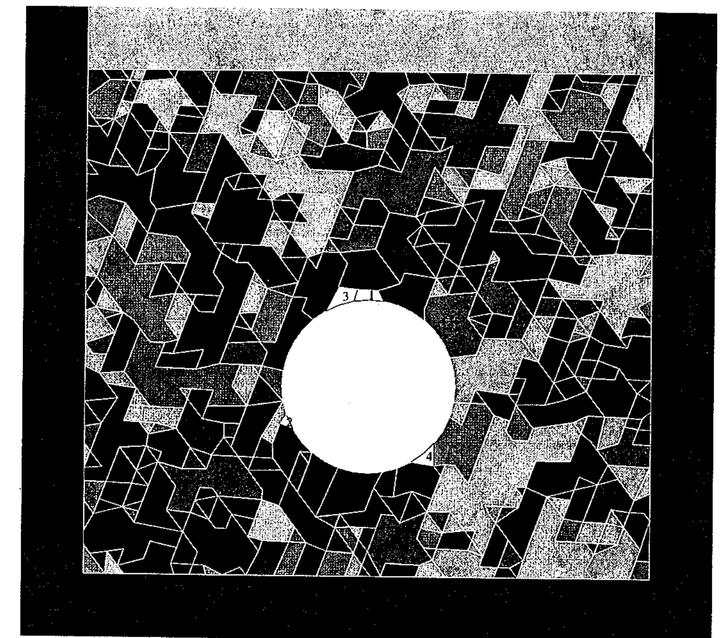

Figure 21. 1 Case 5 rock falling of .00 earth quake after 0 seconds

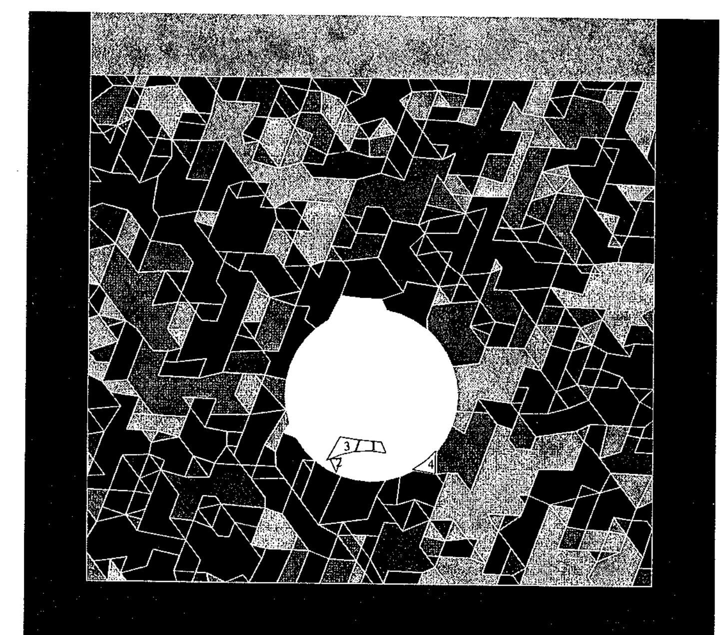

Figure 21. 2 Case 5 rock falling of .00 earth quake after 1 seconds

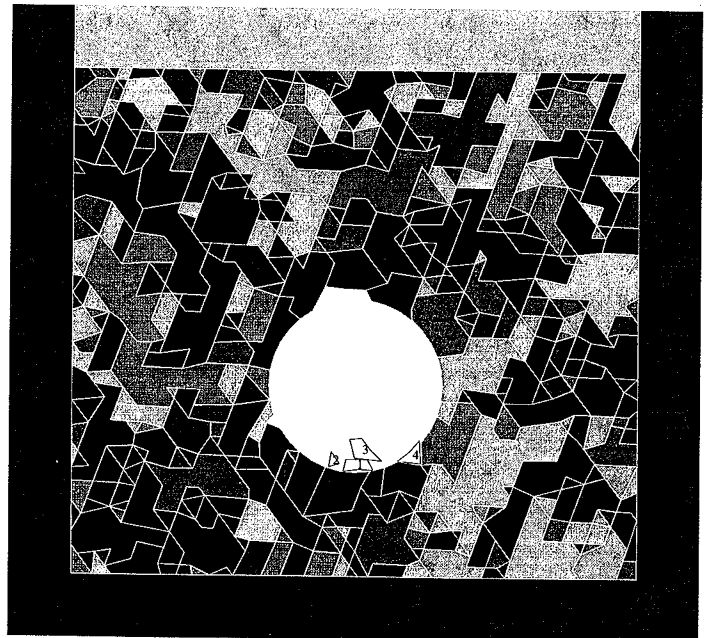

Figure 21. 3 Case 5 rock falling of .00 earth quake after 2 seconds

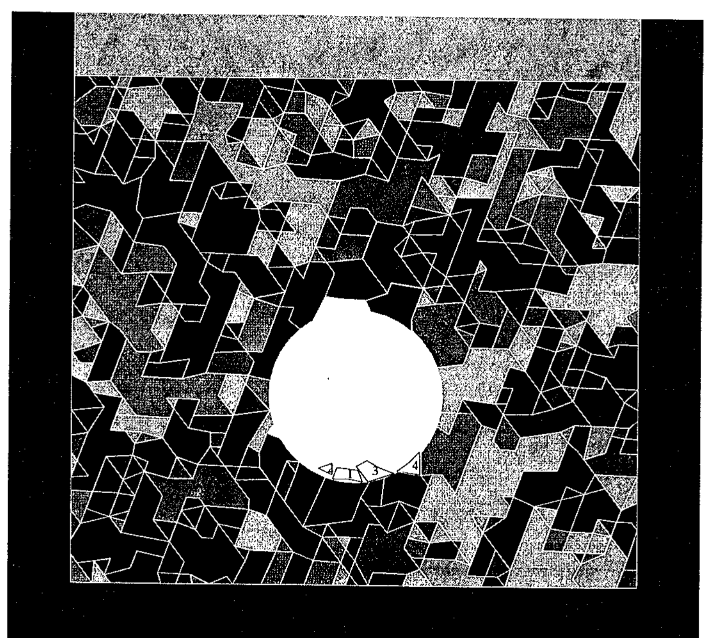

Figure 21. 4 Case 5 rock falling of .00 earth quake after 20 seconds

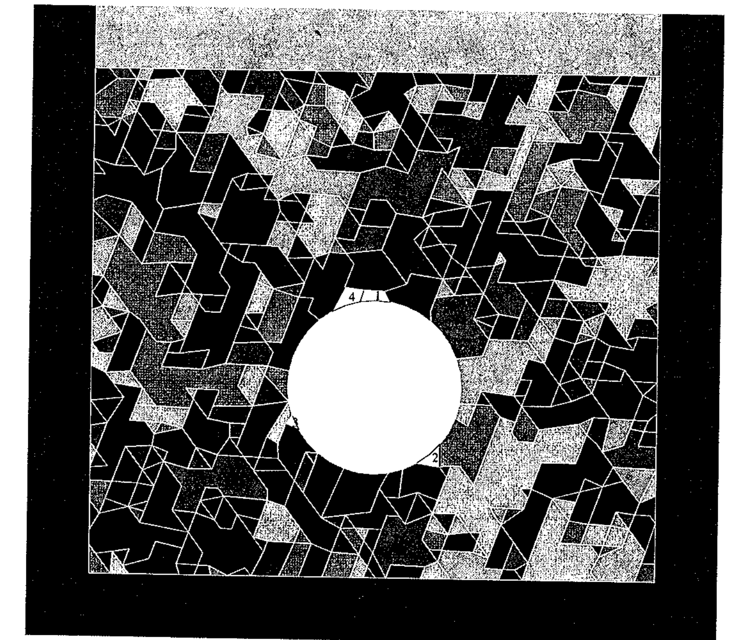

Figure 22. 1 Case 5 rock falling of .25 earth quake after 0 seconds

Figure 22. 2 Case 5 rock falling of .25 earth quake after 1 seconds

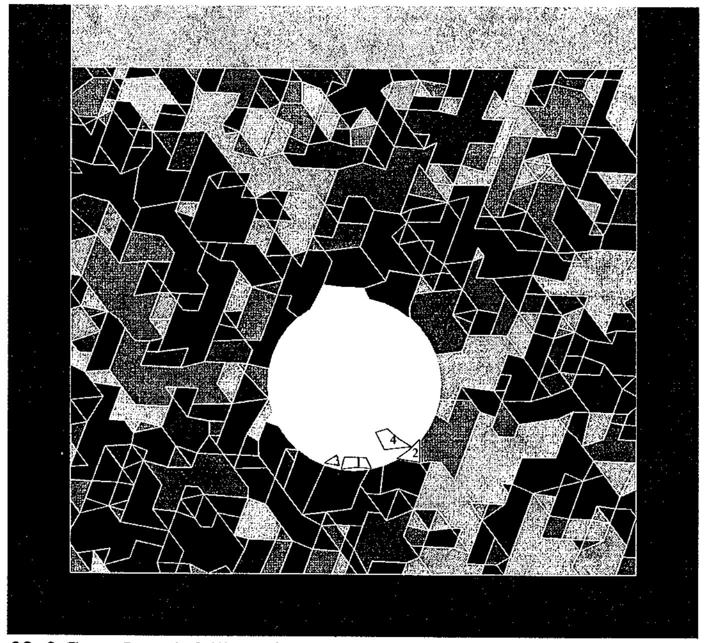

Figure 22. 3 Case 5 rock falling of .25 earth quake after 2 seconds

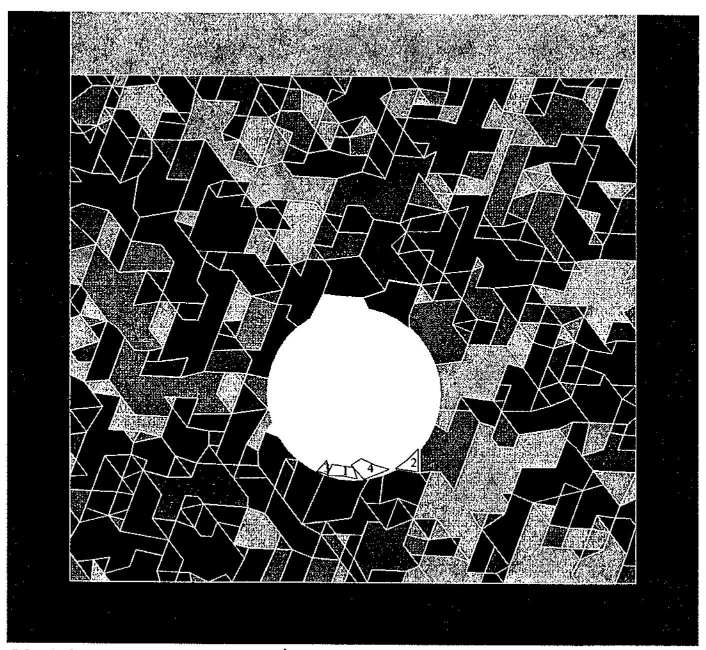

Figure 22. 4 Case 5 rock falling of .25 earth quake after 20 seconds

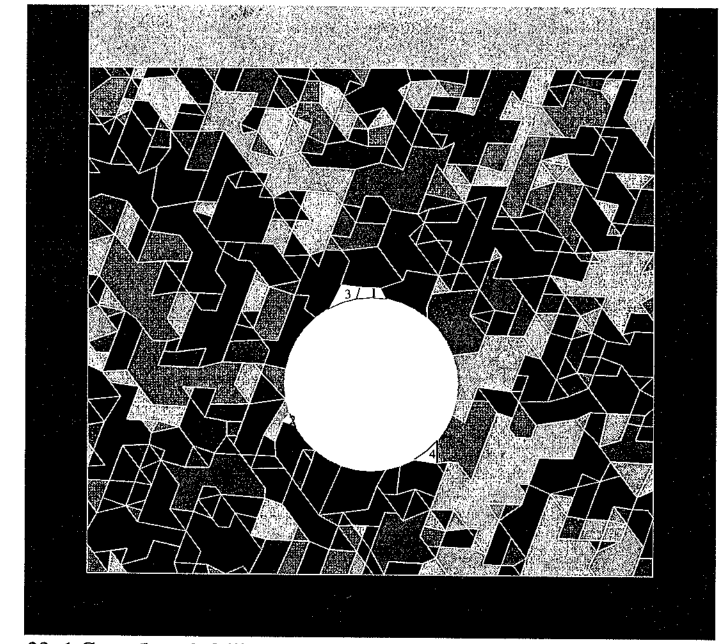

Figure 23. 1 Case 5 rock falling of .50 earth quake after 0 seconds

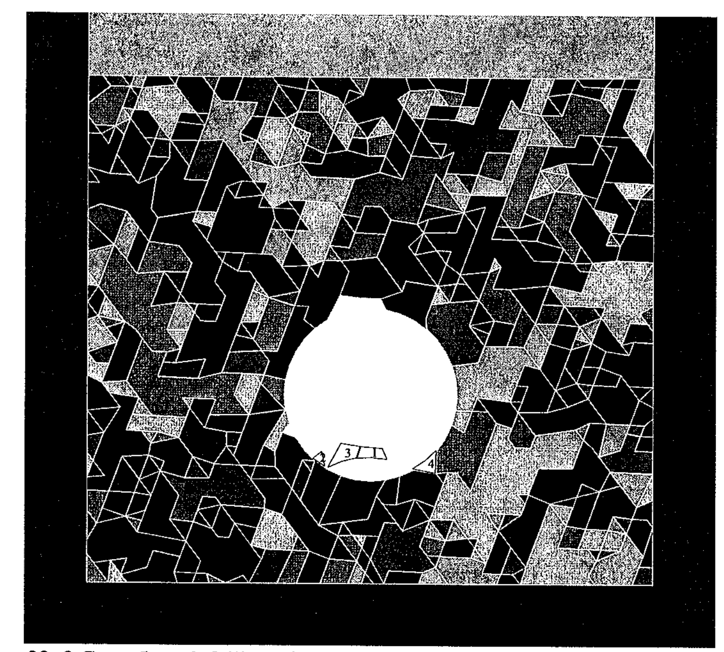

Figure 23. 2 Case 5 rock falling of .50 earth quake after 1 seconds

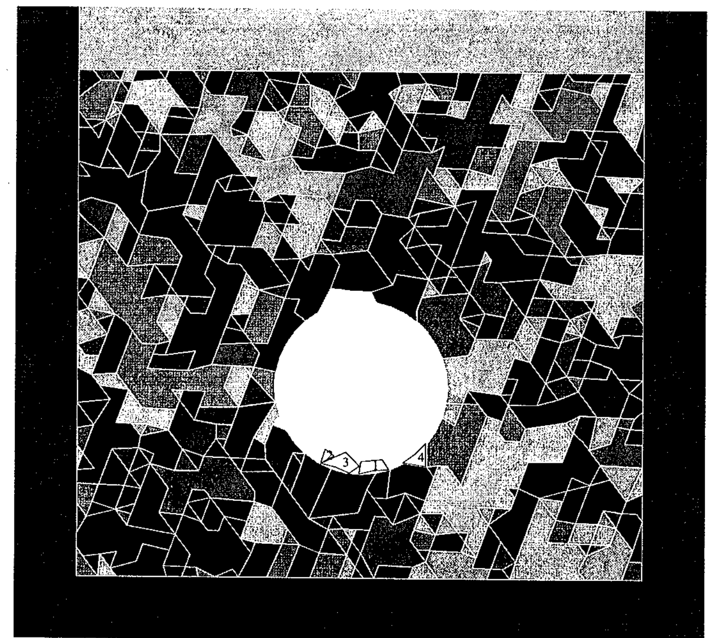

Figure 23. 3 Case 5 rock falling of .50 earth quake after 2 seconds

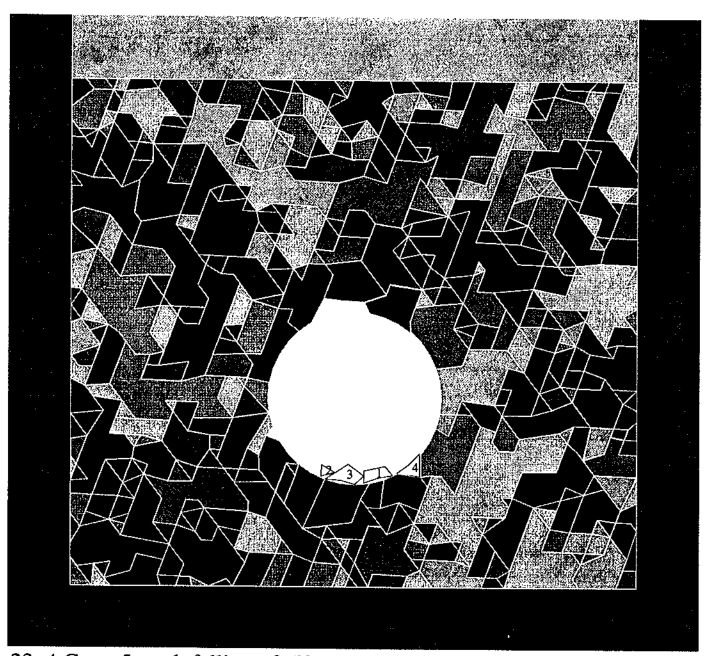

Figure 23. 4 Case 5 rock falling of .50 earth quake after 20 seconds

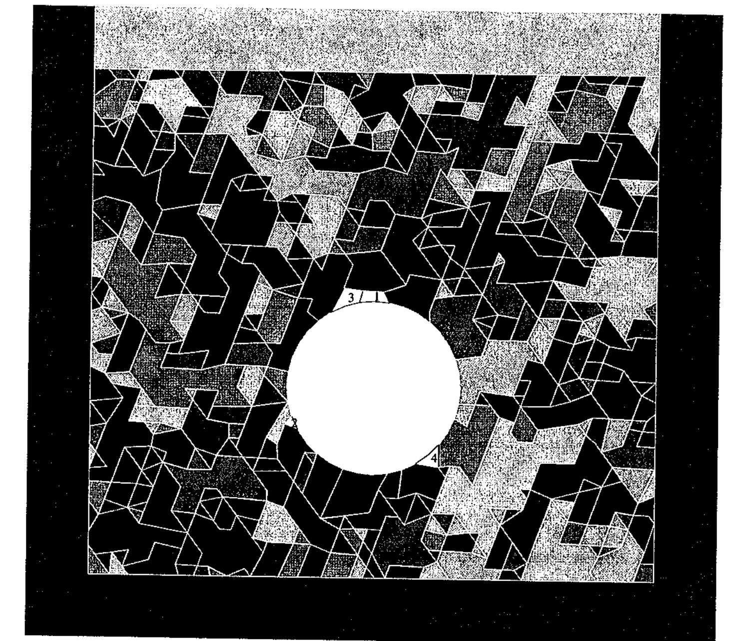

Figure 24. 1 Case 5 rock falling of .75 earth quake after 0 seconds

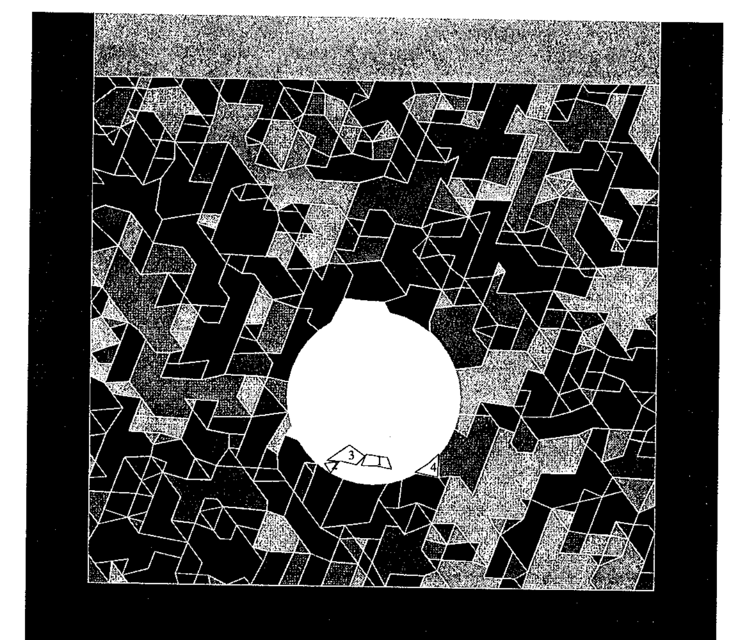

Figure 24. 2 Case 5 rock falling of .75 earth quake after 1 seconds

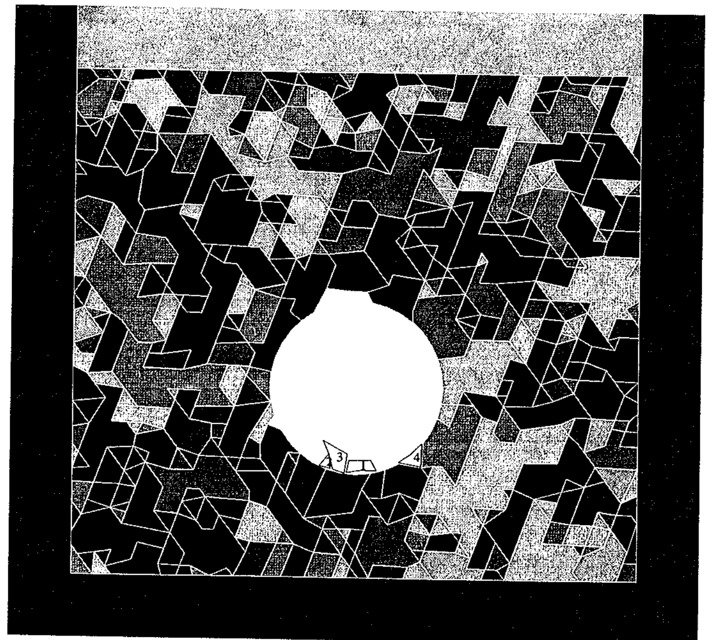

Figure 24. 3 Case 5 rock falling of .75 earth quake after 2 seconds

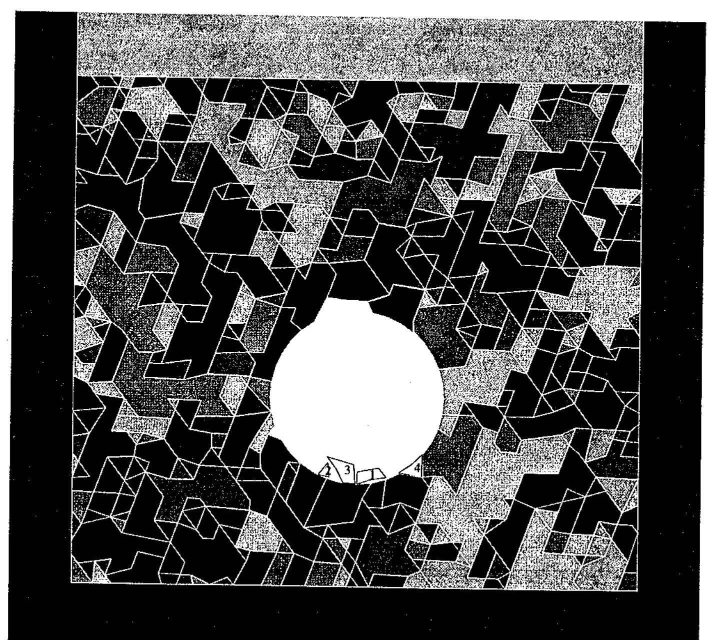

Figure 24. 4 Case 5 rock falling of .75 earth quake after 20 seconds

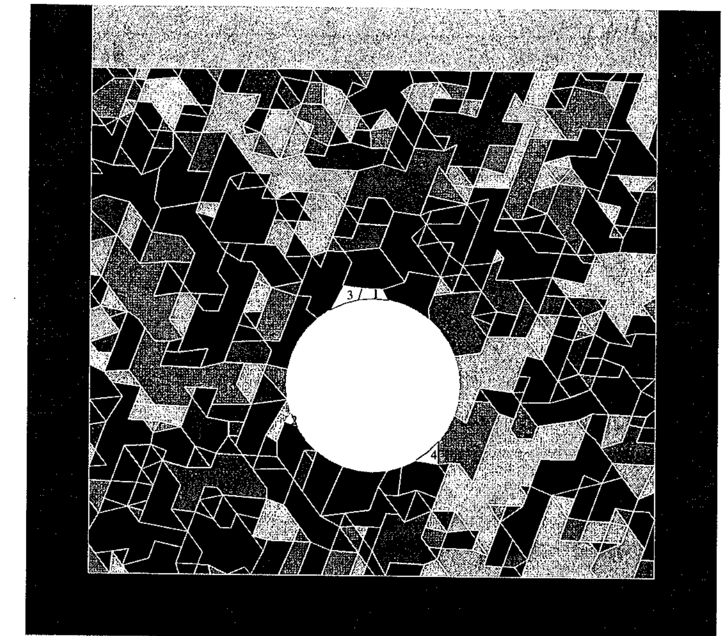

Figure 25. 1 Case 5 rock falling of 1.0 earth quake after 0 seconds

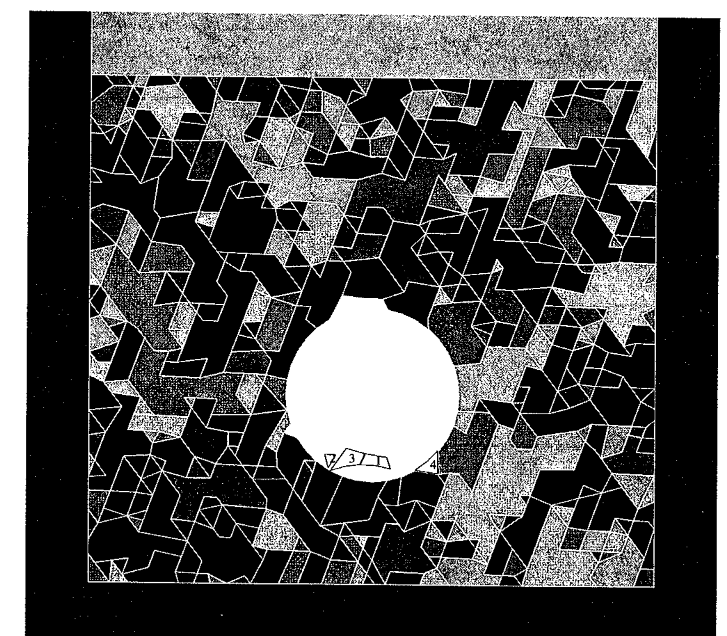

Figure 25. 2 Case 5 rock falling of 1.0 earth quake after 1 seconds

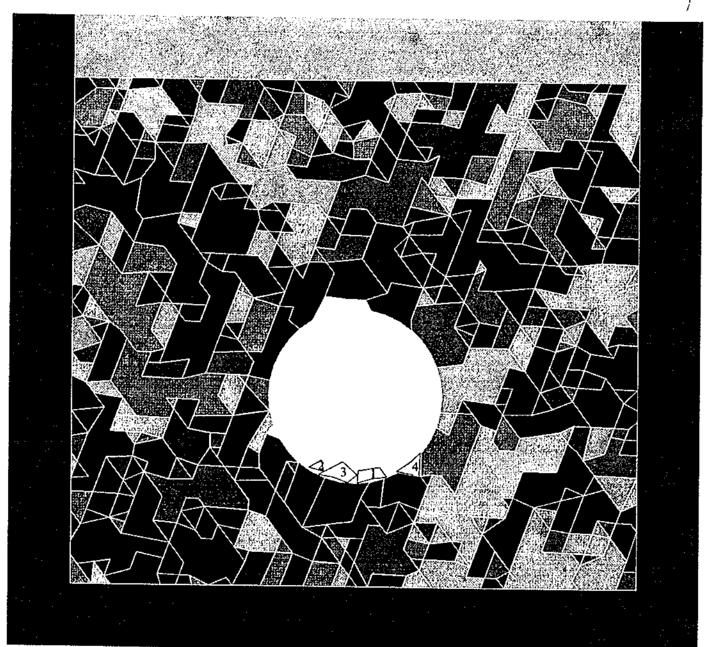

Figure 25. 3 Case 5 rock falling of 1.0 earth quake after 2 seconds

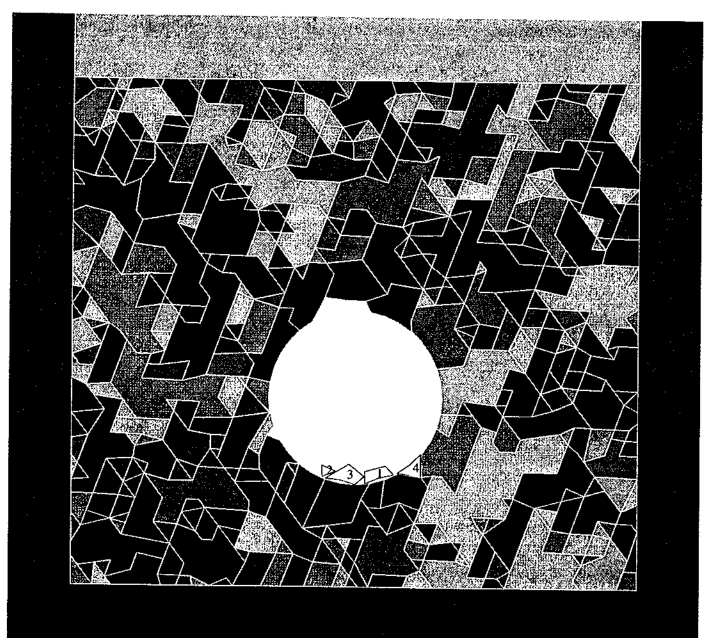

Figure 25. 4 Case 5 rock falling of 1.0 earth quake after 20 seconds

Report #7 Dynamic DDA Cases of Rock Falling under Different Earth Quake Loads of Project: 20.01402.671 Rock Fall Assessing under Seismic Load using Key Block Analysis

Prepared for:
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The Earth Quake Loads of This DDA Computation

The purpose of this DDA computation is to study the rock falling under different intensity of earth quake loads.

[1] The rock falling of joint system #2 is key block falling as shown in Report #6. The falling key blocks are individual simple convex key blocks. This individual key block falling is mainly due to the gravity and removability. Therefore key block falling is not related with earth quake loads. The rock falling of joint system #2 under earth quake load is not presented here.

[2] For the joint system #1, some of the cases have complex rock block movements. The earth quake load may cause additional rock falling. The rock falling of joint system #1 under different earth quake loads is computed.

[3] In order to do the strict comparison, the same five block meshes of joint system #1 are used.

[4] In dynamic DDA computation, 0%, 25%, 50%, 75% and 100% earth quake loads are applied.

1. Explanation of Two Dimensional Dynamic DDA

The "DDA" is the abbreviation of discontinuous deformation analysis. From mathematical point of view, DDA is block system version of original or strict 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 inside each individual block. This equilibrium is achieved between external forces and the block stresses.

Some late FEM codes use dynamic relaxation. Dynamic relaxation only can reach approximate equilibrium at end of the time step. DDA uses strict equation solver to reach the equilibrium at the end of every time step as well as at each open-close iteration in a single time step.

Based on natural contact phenomena, an "entrance theory" was developed. All of the possible entrance positions are found. The two contact sides at a entrance positions are defined: edge to edge, angle to edge or angle to angle. All possible modes of entrances are considered. There are three possible entrance modes in a entrance position: open, sliding and locking.

The "open-close" iterations ensure that no tension and no penetration occur at all entrance positions and all time steps. 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. Numerical integration is difficult to form accurate mass matrix. Mass matrices control the dynamic movement as well as the quality of the global equations. Accurate mass matrices can ensure the precise dynamic movement and the stability of the computation.

The DDA uses simplex integration. The simplex integration can solve 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.

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

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

DDA codes can perform traditional multi-block limit equilibrium analysis for whole block systems where all blocks move simultaneously, different blocks have different sliding directions, or different blocks rotates along different directions.

DDA codes are suitable to compute rock falling. Full process of rock falling involves very large movements, where the movements can be as large as many times of the diameters of the falling blocks. Rock falling computation also has

to fulfill the Newton's second law and friction law. If the block is falling without contact, it has to reach the speed of free falling. Friction law is a inequality equation system, which is hard to solve with ordinary equations. DDA is designed strictly to satisfy both Newton's law and friction law simultaneously. Therefore DDA is a method capable to compute rock falling.

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 of joint system #1 and mechanical parameters are the following:

Table 1. Angle data of joint system #1

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 length data of joint system #2

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
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. Using the random numbers, program DL0 produces five different joint meshes: dcs10, dcs20, dcs30, dcs40 and dcs50.

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

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 Loads of Dynamic DDA Computation

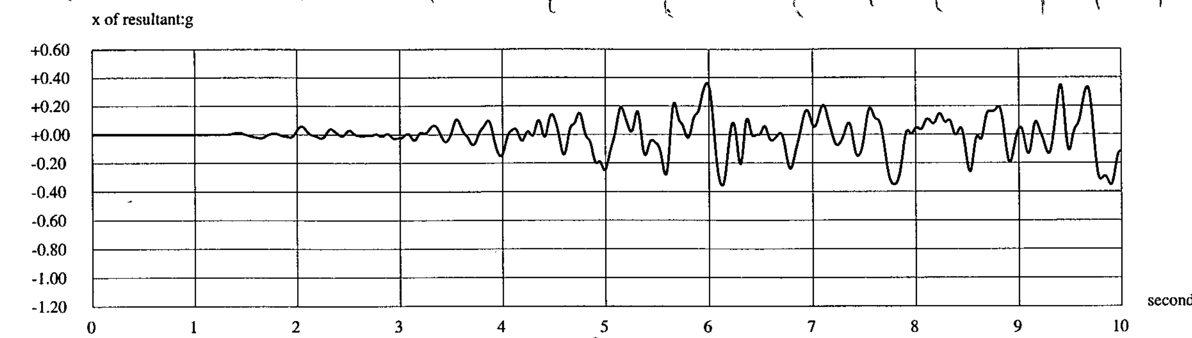
For this computation, the earth quake data of Yerba Buena island tunnel between San Francisco and Oakland are adapted. These acceleration data are from California Department of Transportation. The original data are 50 seconds, our computation only uses from 10 second to 30 second. However these 20 second 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. For the same block mesh, 0%, 25%, 50%, 75% and 100% earth quake accelerations are applied. The input earth quake file is "qkh1".

Figure 0.1 shows X and Y components of the time depending earth quake acceleration data.

Figure 0.2 shows Z components and the resultants of the time depending earth quake acceleration data.

The mechanical data of Table 4 and the data of Figure 0.1 and Figure 0.2 are the input data of the program DF0. Program DF0 computes the time depending block movements and block stresses under earth quake load of different intensity. The process of block falling can be shown.



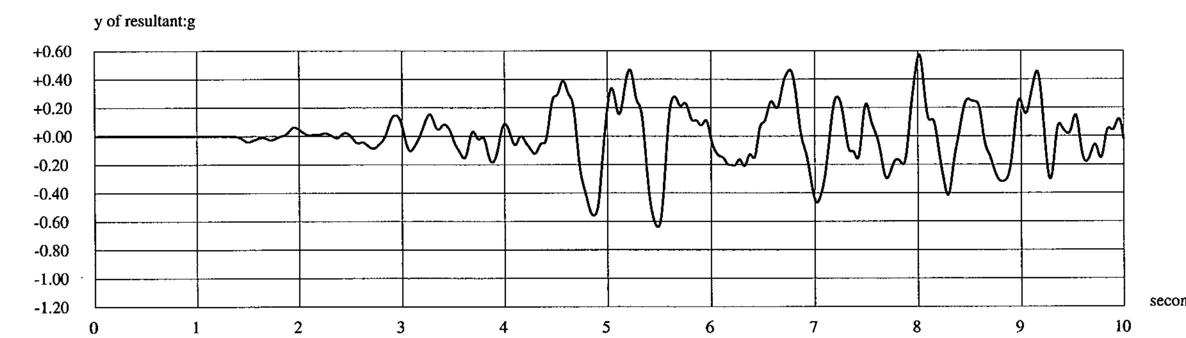
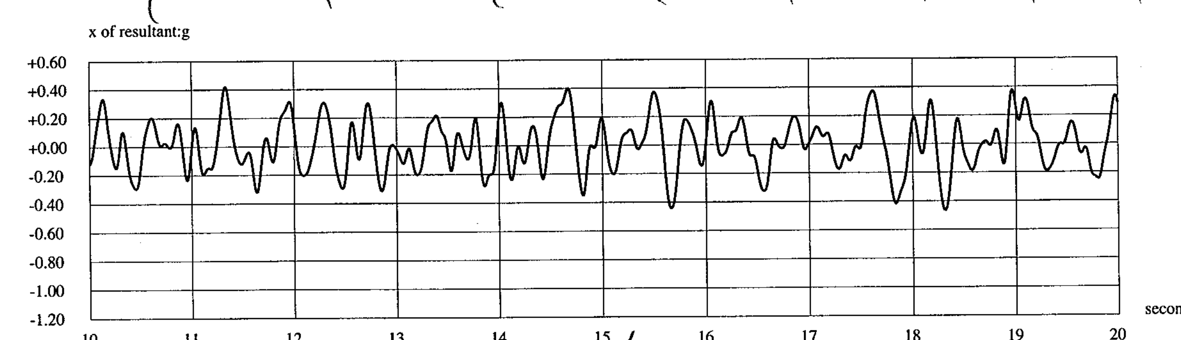


Figure 0.1 X and Y of earth quake acceleration



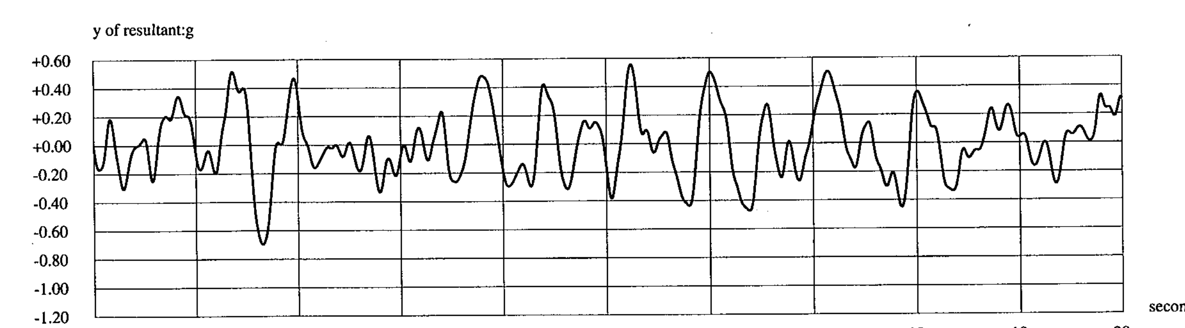


Figure 0.1 X and Y of earth quake acceleration

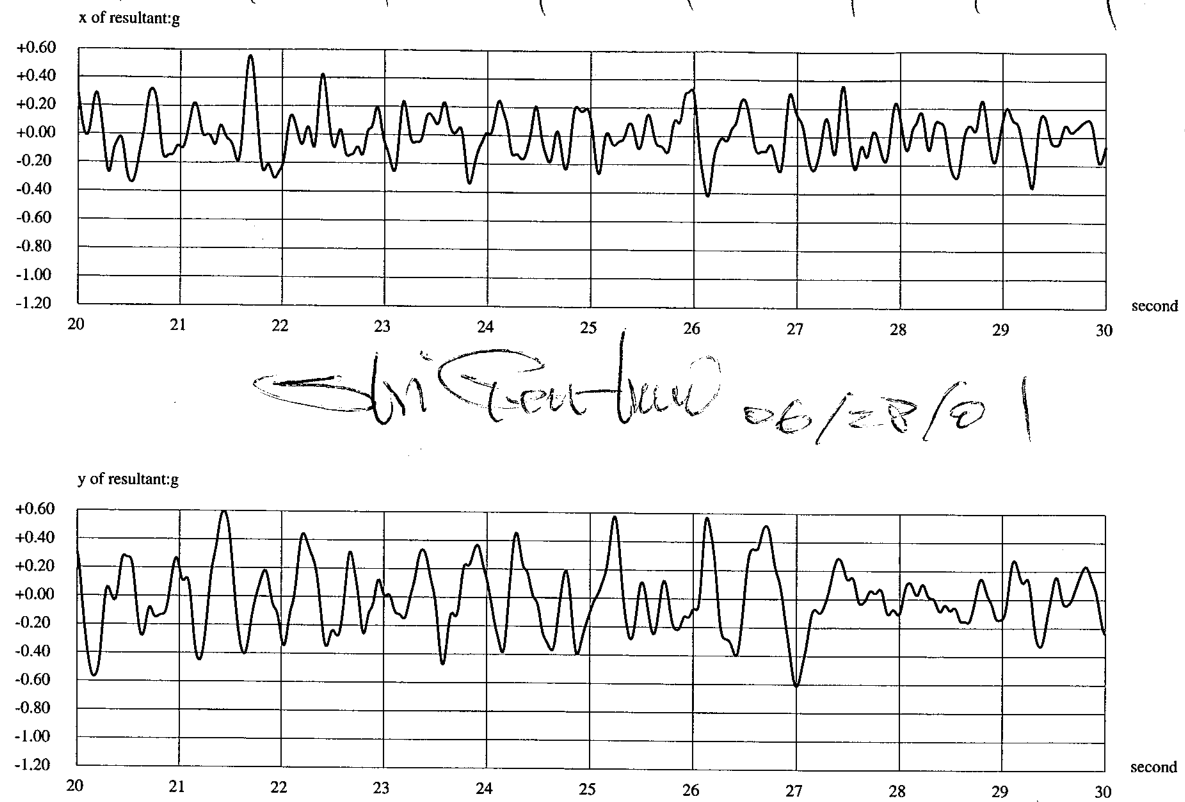


Figure 0.1 X and Y of earth quake acceleration

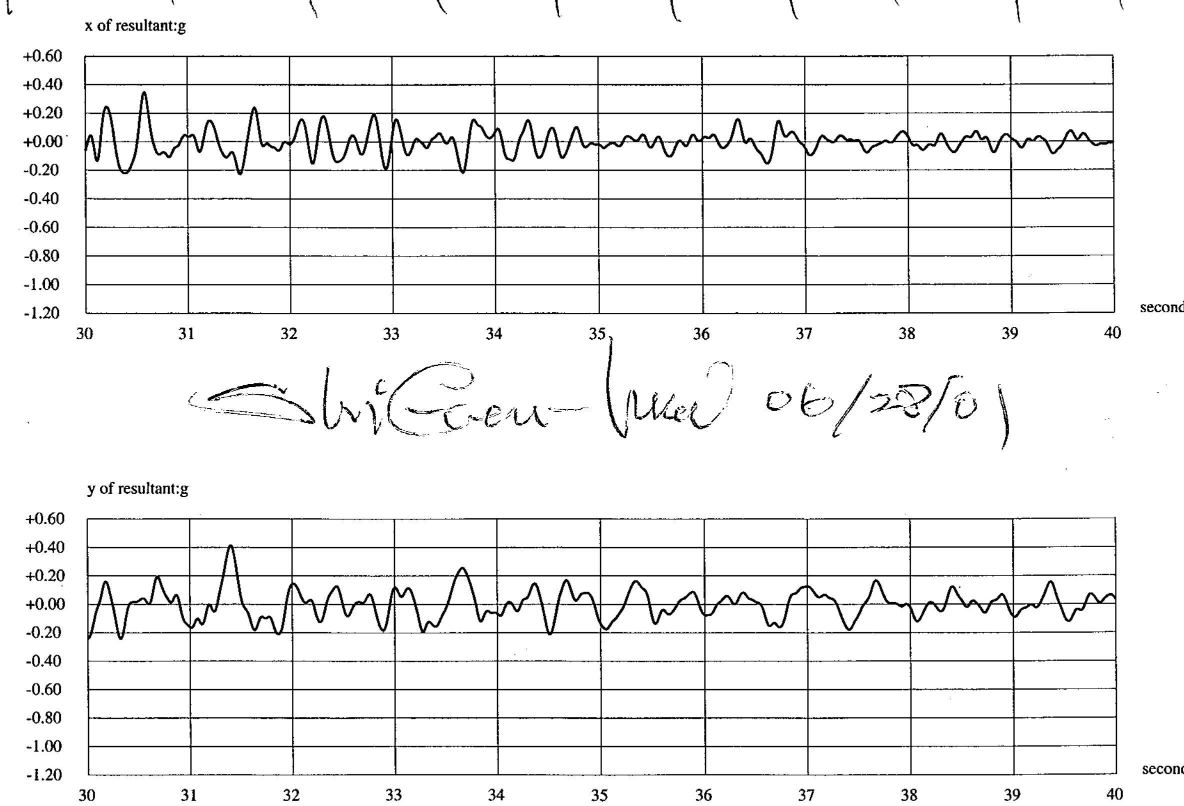


Figure 0.1 X and Y of earth quake acceleration

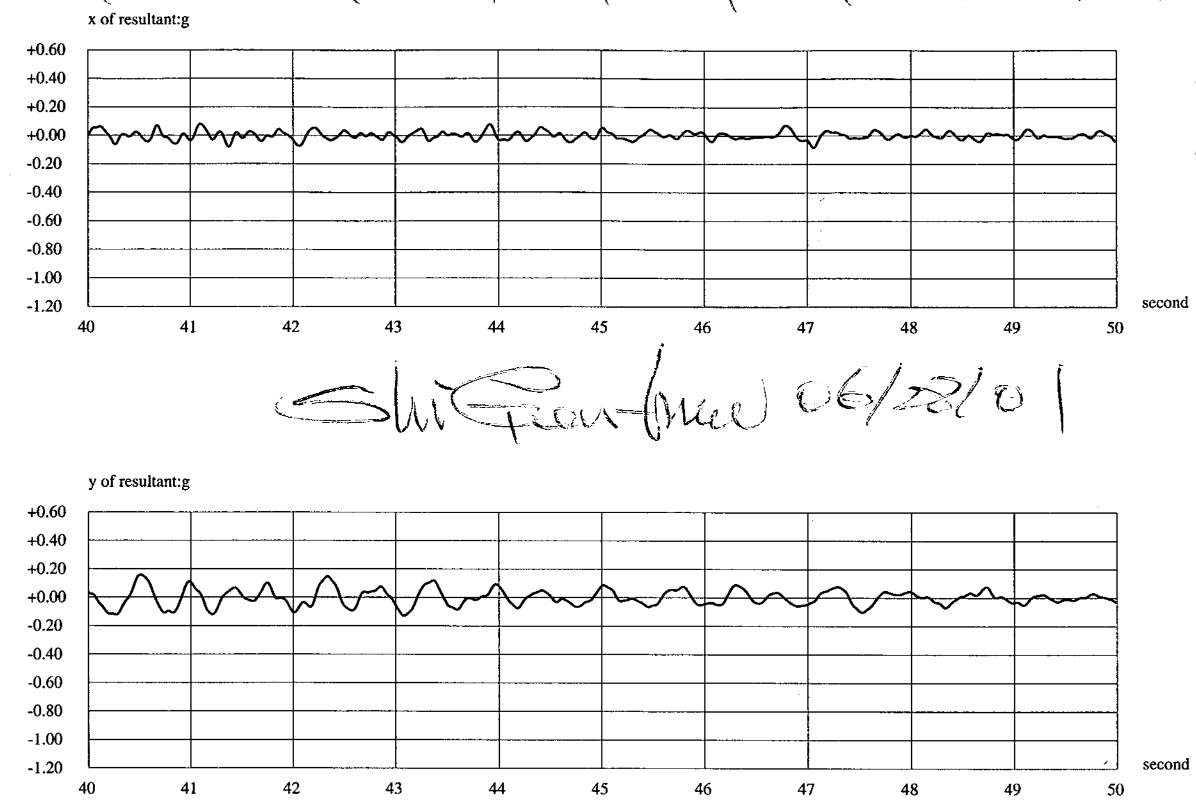


Figure 0.1 X and Y of earth quake acceleration

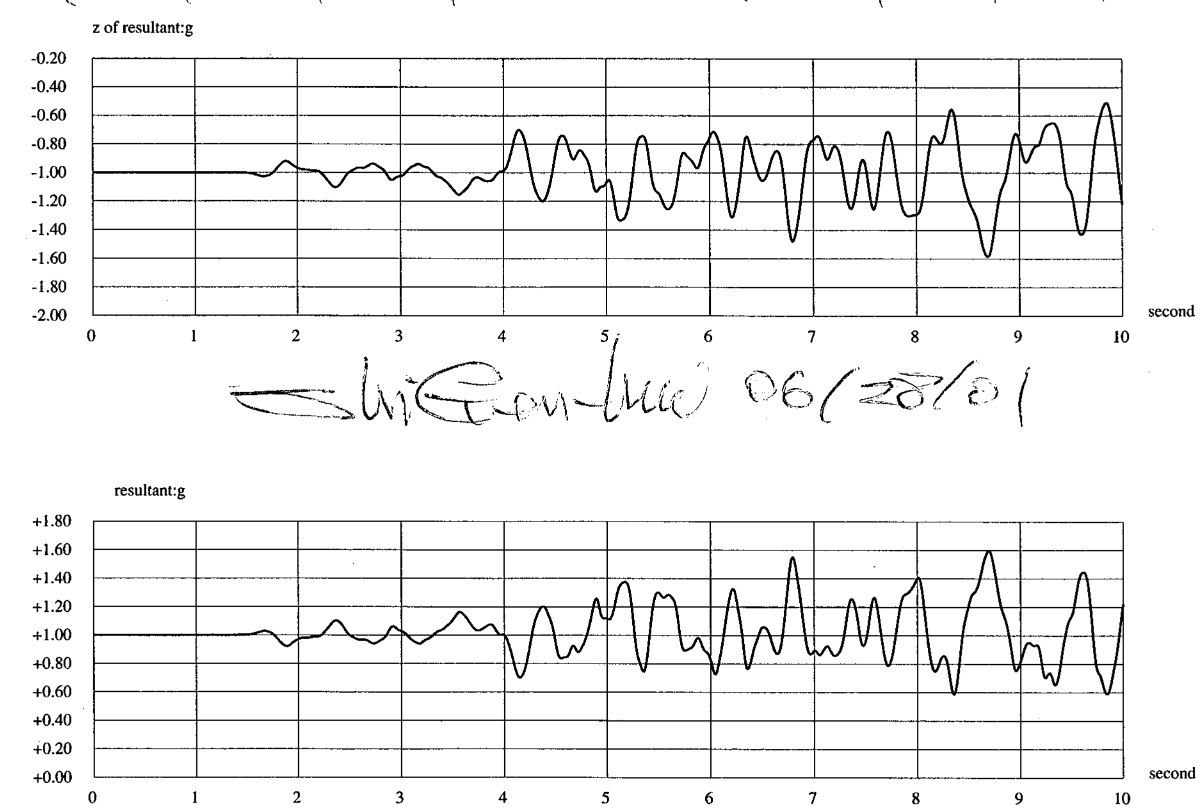


Figure 0.2 Z and resultant of earth quake acceleration

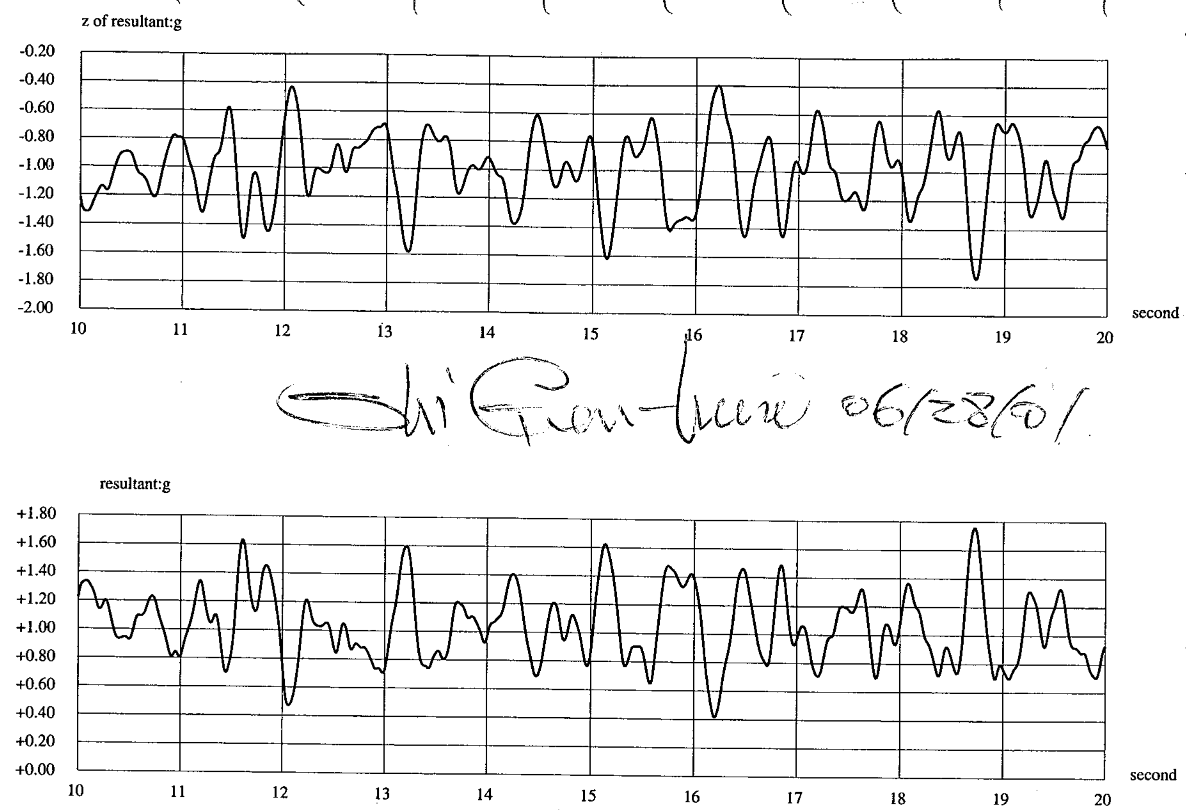


Figure 0.2 Z and resultant of earth quake acceleration

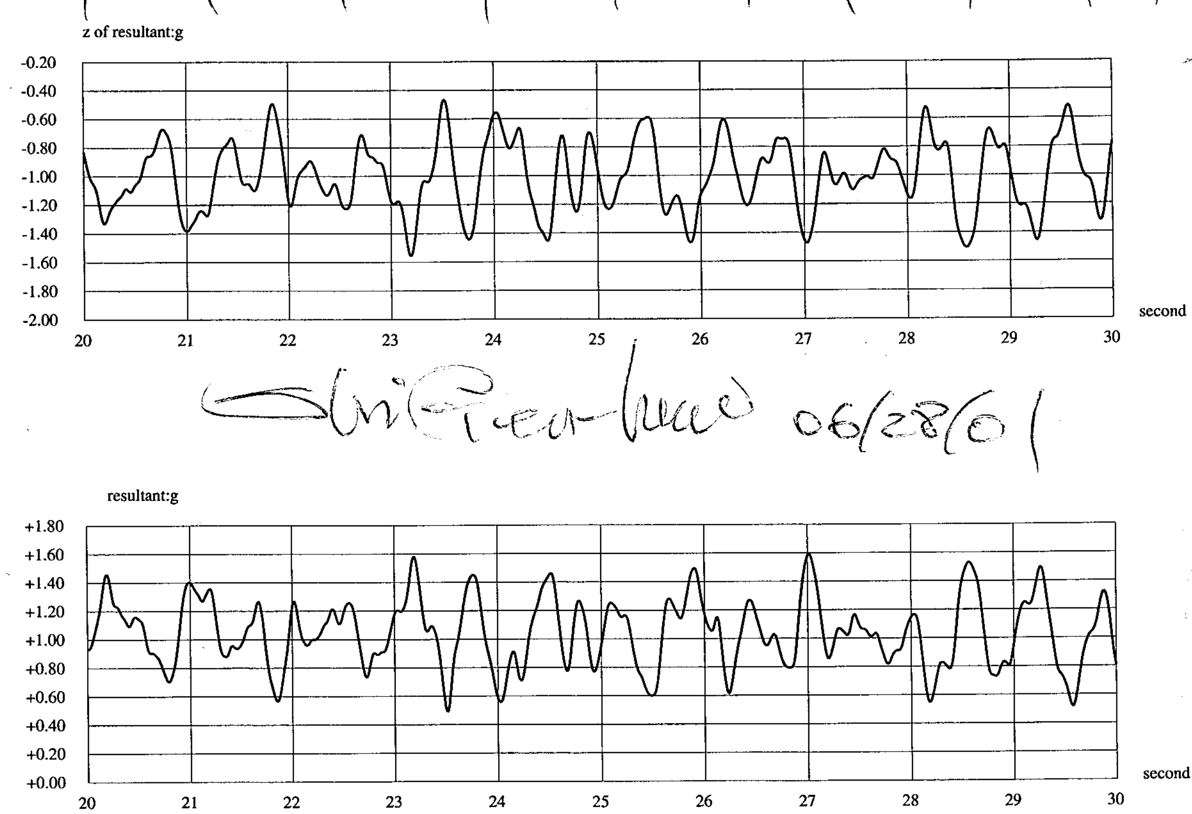


Figure 0.2 Z and resultant of earth quake acceleration

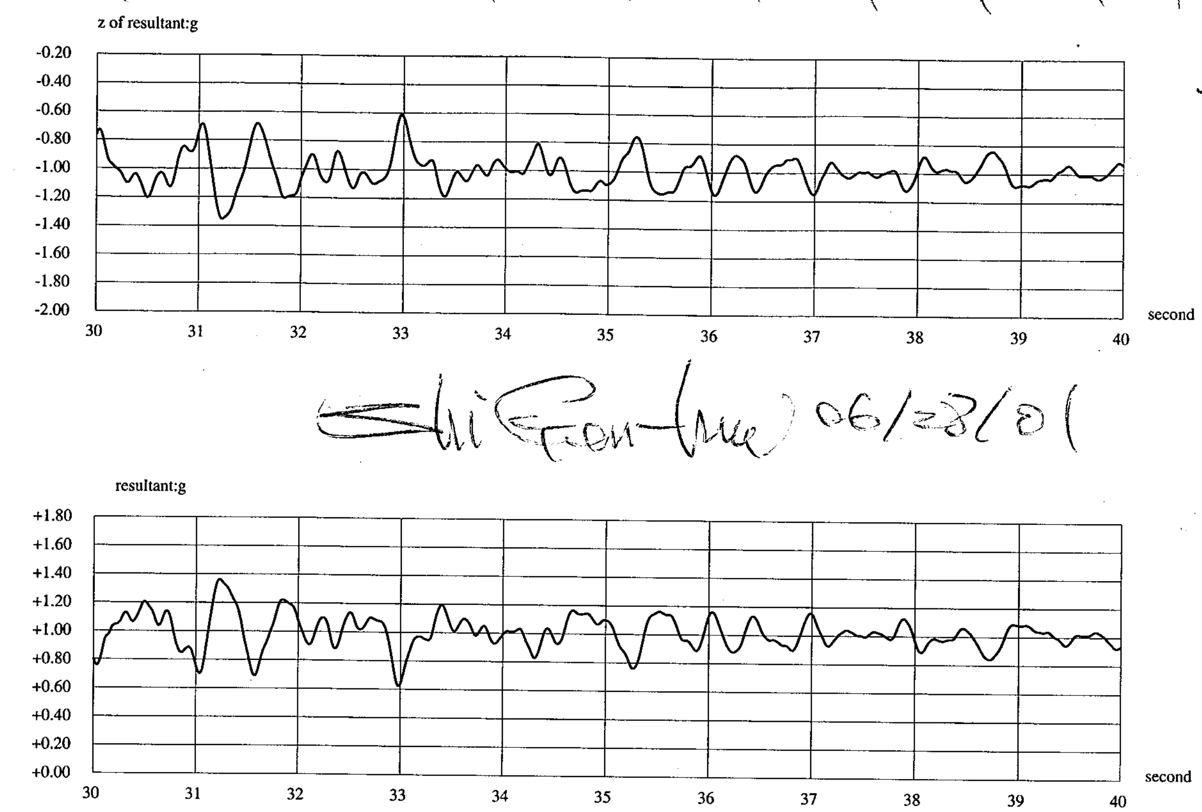


Figure 0.2 Z and resultant of earth quake acceleration

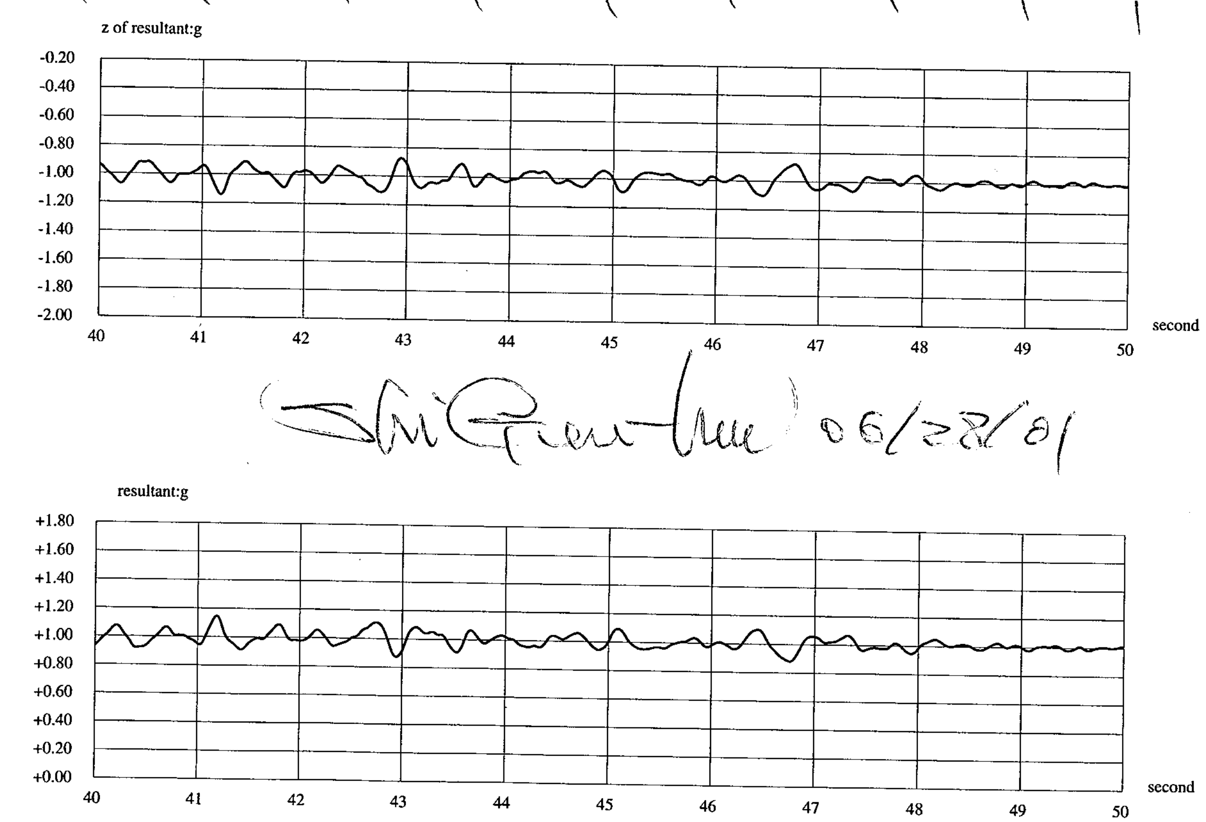


Figure 0.2 Z and resultant of earth quake acceleration

9. Falling Block Area of Different Joint Meshes Under Different Intensity of Earth Quake Load

Based on the results of rock falling computations of case 1 to case 5, the total falling block area of each earth quake load in each case are counted as following:

Table 15. Falling block area in square meters

earth quake	case 1	case 2	case 3	case 4	case 5
100 %	13.70	10.01	28.14	11.78	0.97
75 %	13.70	10.01	29.11	12.35	0.97
50 %	13.70	7.99	24.27	11.78	0.97
25 %	13.78	9.23	25.07	10.58	0.97
00 %	13.07	9.23	24.27	11.78	0.97

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01/04/02

Report #8 Static Stress Analysis of Large Number Joint Blocks Using DDA Method of Project: 20.01402.671 Rock Fall Assessing under Seismic Load using Key Block Analysis

Prepared for:
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1. Statics is Infinite Long Time and Stabilized Dynamics

For small displacement and continuous computation, the normal computation solve the equation only once. It is one time step computation. Its assumption is the single time step is very long and the inertia is 0. However this kind of simple statics computation can not compute the large displacements, large deformation and discontinuous cases.

For the large displacement, large deformation or discontinuous case, both statics and dynamics use time steps. Statics is infinite long time and stabilized dynamics. Therefore the general statics is even more difficult than dynamics.

Shi Gen-hua 02/01/02

Here in this following case, the dynamics with unit mass damping is used. The relative displacements are reduced near zero following the time steps. When the step time is 0.001 seconds, the next step uses 0.99 (normally 0.95 - 0.99) of the velocity from the end of the previous time step. If this number is 0.97, the relative displacement reduces much faster.

1	algorithm improvement for large mesh static DDA	8 Hrs.	January 31
1	algorithm improvement for large mesh static DDA	8 Hrs.	February 1
1	algorithm improvement for large mesh static DDA	8 Hrs.	February 2

Shi Gen-hua 02/01/02

Shi Gen-hua 02/02/02

2. The Geometry and Mechanical Data of Statics DDA Computation

02/03/02 Shi Gen-hua

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 of joint system #1 and mechanical parameters are the following:

Table 1. Angle data of joint system #1

joint set	dip angle	dip d.	friction angle	cohesion
joint set 1	82°	288°	39°	0 ton/m^2
joint set 2	82°	229°	39°	0 ton/m^2
joint set 3	14°	40°	39°	0 ton/m^2

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

Table 2 Statistical length data of joint system #2

joint set	spacing: m	length: m	bridge: m
joint set 1	2.6 m	16.45 m	-1.0 m
joint set 2	2.6 m	14.9 m	-1.0 m
joint set 3	2.6 m	25.8 m	.4 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
tunnel shape	circular

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

From the joint and tunnel boundary lines, program DCH produces the block system. The block system is the geometric input of program DFH.

The total block number is 3784.

Shi Gen-hua

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

02/03/02

Shi Gen-hua 02/03/02

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Table 4. Mechanical data

reduce step velocity	0.01
E of rock mass	3000000 ton /m ^{3}
contact spring	6000000 ton /m
ν of rock mass	0.21
number of time steps	20000
time step	0.0010 second
computation duration	2 second
joint friction angle	39 °
cohesion	0 ton /m ^{3}

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

3. Static DDA Computation Using Dynamics with Unit Mass Damping

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

Table 5. Programs and input files of case 1

description	file
joint forming data	dlh10
joint forming code	dlh
block forming data	dch10
block forming code	dch
mechanical data	dfh10
mechanical code	dfh
earth quake data	qks2 (null)
block graphic code	dg2
boundary drawing	dg4
static DDA text	s32.tex
joint polygon text	s33.tex

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2	damping formulation using step velocity reduction	8 Hrs.	February 3
2	damping formulation using step velocity reduction	8 Hrs.	February 4
3	large mesh DDA with 0.00 step velocity reduction	8 Hrs.	February 5

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Figure 1.1 The block mesh before the load is applied

Figure 1.2 The blocks after 100 time steps (0.1 seconds).

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Figure 1.3 The blocks after 200 time steps (0.2 seconds).

Figure 1.4 The blocks after 2000 time steps (2.0 seconds).

Figure 2.1 The block boundary before the load is applied

Figure 2.2 The block boundary after 2000 time steps (2.0 seconds).

Figure 2.2 The principle stresses of the blocks after 2000 time steps (2.0 seconds).

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Shi Gen-hua 02/09/02

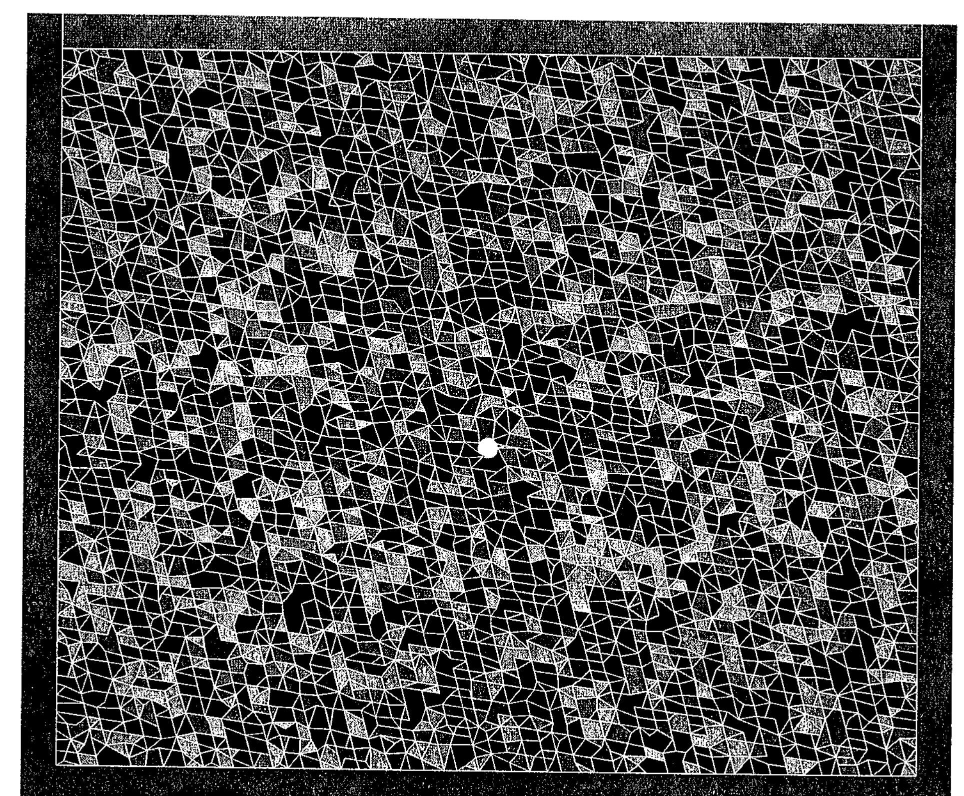

Figure 1 . 1 Case 1 rock falling after 0 steps

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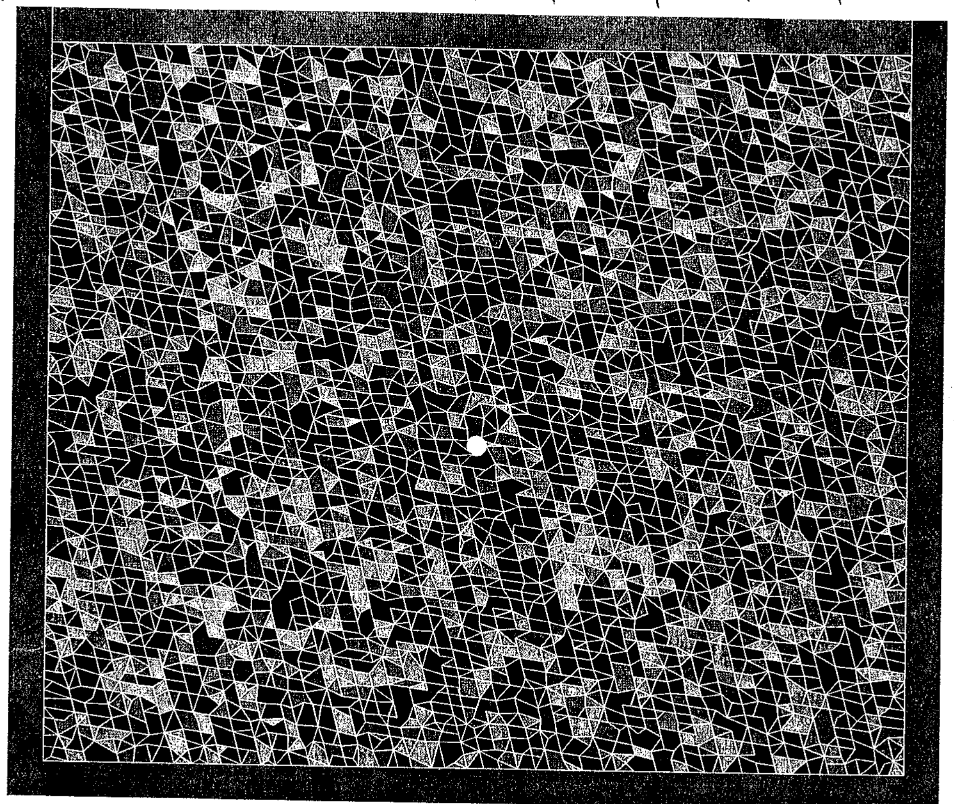

Figure 1 . 2 Case 1 rock falling after 100 steps

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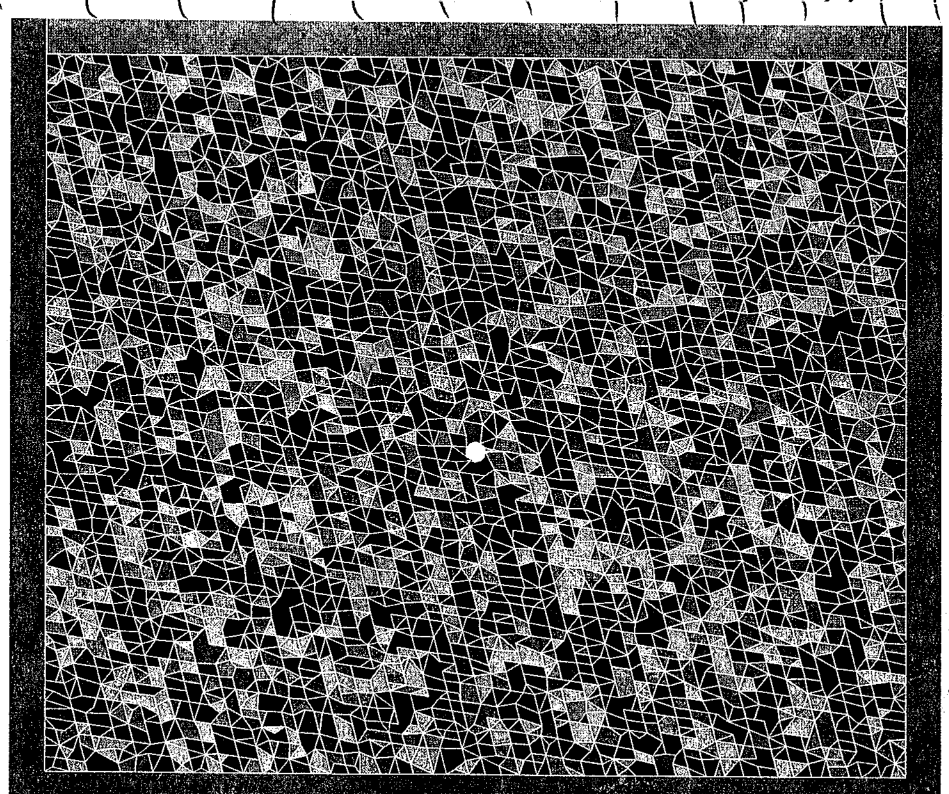

Figure 1 . 3 Case 1 rock falling after 200 steps

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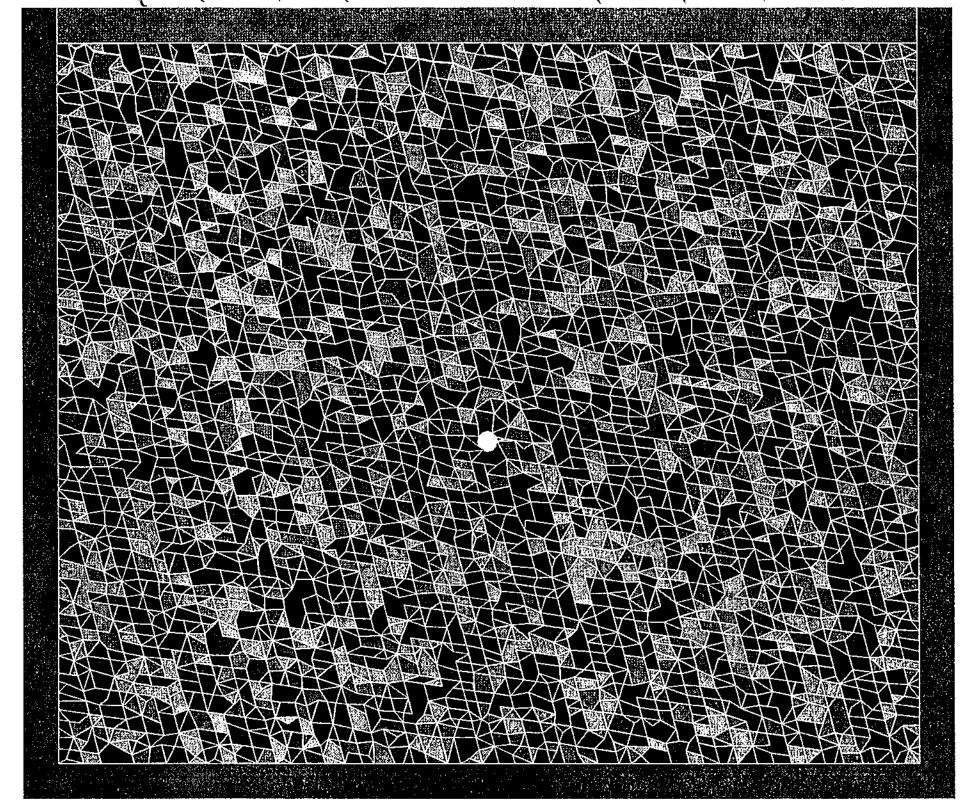

Figure 1 . 4 Case 1 rock falling after 2000 steps

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3	large mesh DDA with 0.01 step velocity reduction	8 Hrs.	February 6
3	large mesh DDA with 0.02 step velocity reduction	8 Hrs.	February 7
3	large mesh DDA with 0.03 step velocity reduction	8 Hrs.	February 8
3	large mesh DDA with 0.05 step velocity reduction	8 Hrs.	February 9
3	large mesh DDA with 0.08 step velocity reduction	8 Hrs.	February 10
3	large mesh DDA with 0.10 step velocity reduction	8 Hrs.	February 11
3	large mesh DDA with 0.15 step velocity reduction	8 Hrs.	February 12
3	large mesh DDA with 0.20 step velocity reduction	8 Hrs.	February 13

Shi Gen-hua 02/13/02

Shi Gen-hua 02/13/02

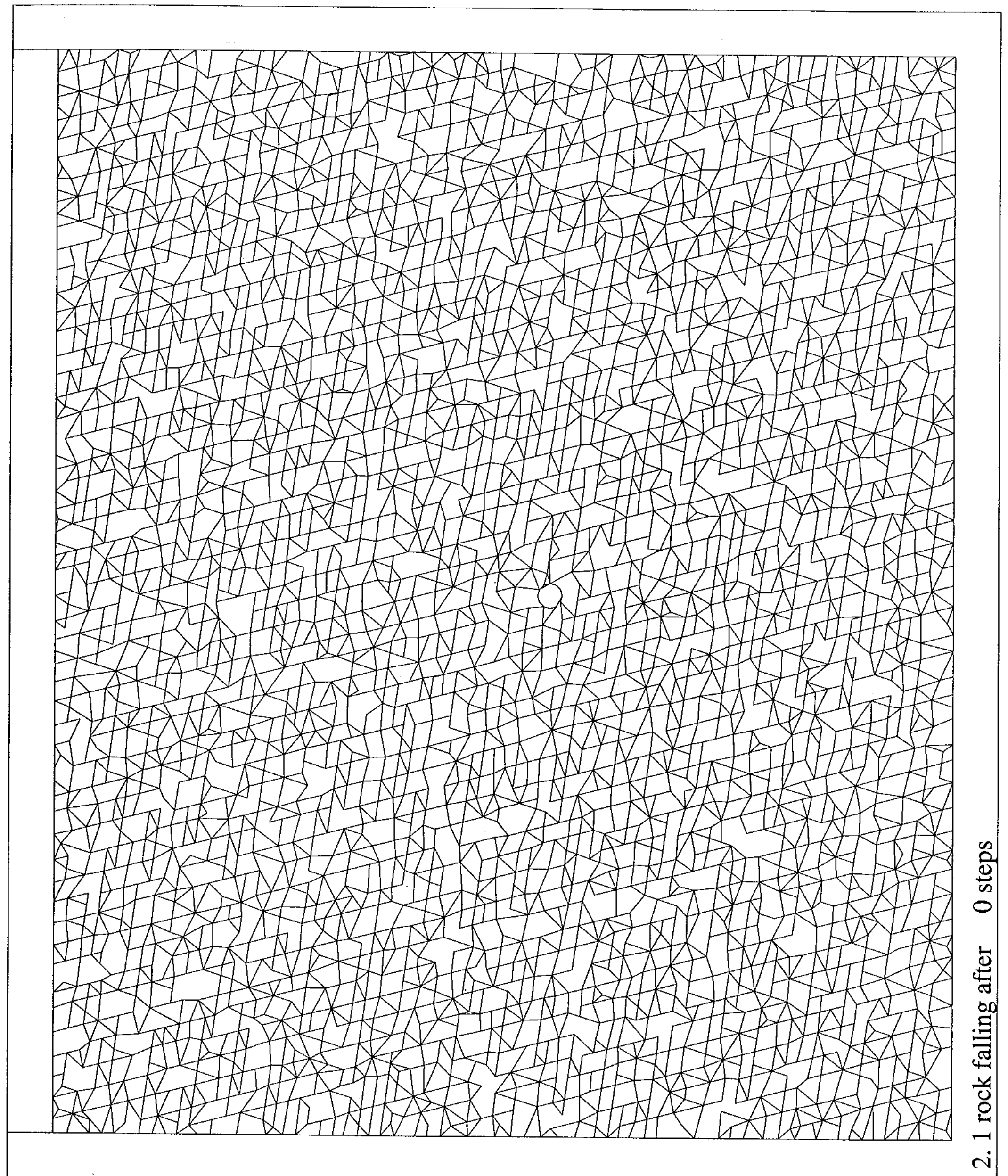

Figure 2. 1 rock falling after 0 steps

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The block boundary drawing can check the overlapping. Fig 2.1–2.2 are boundary drawing. Shi Gen-hua 02/13/02

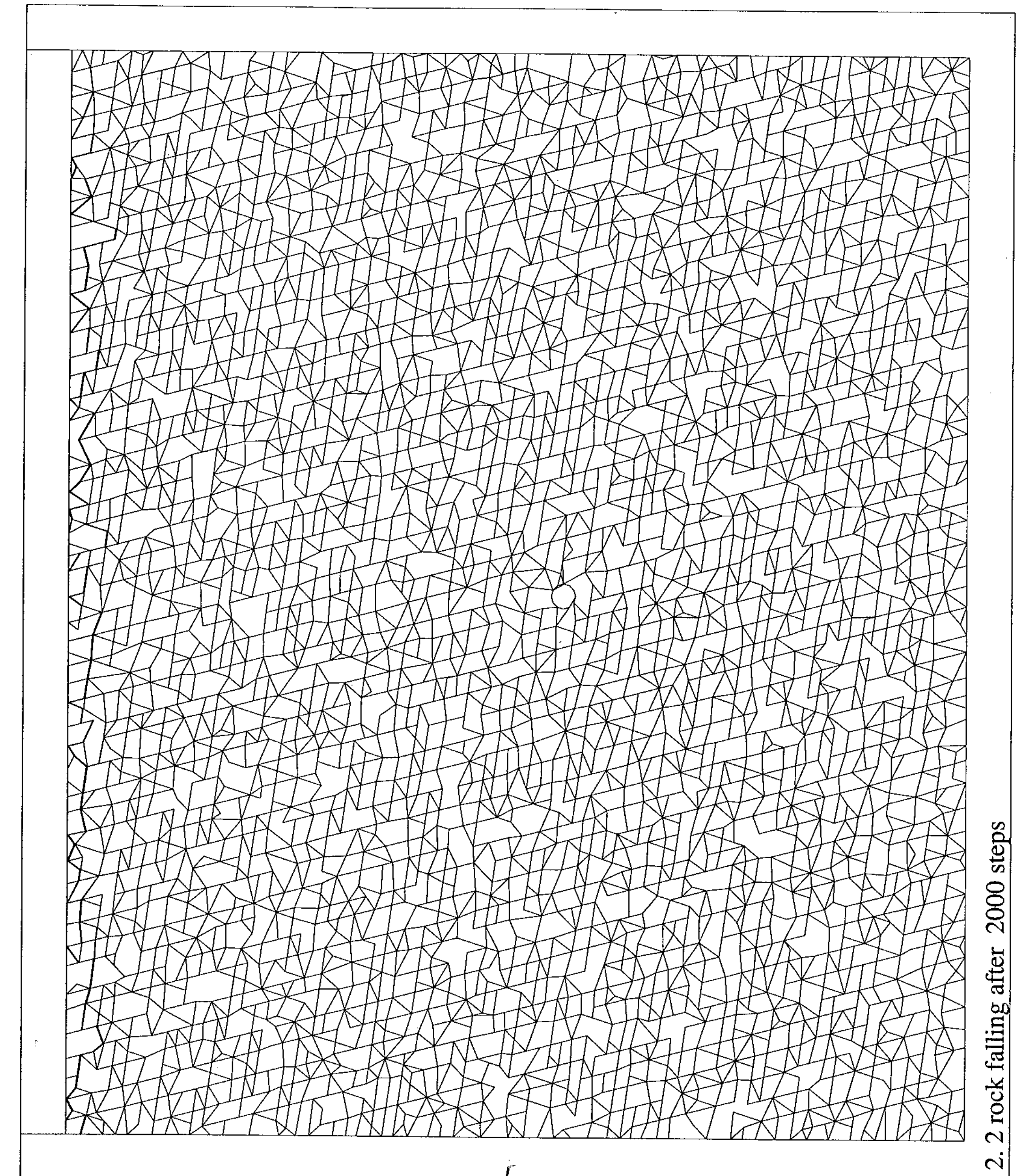

Figure 2. 2 rock falling after 2000 steps

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Fig. 2.2 shows there are no overlapping in this computation case.

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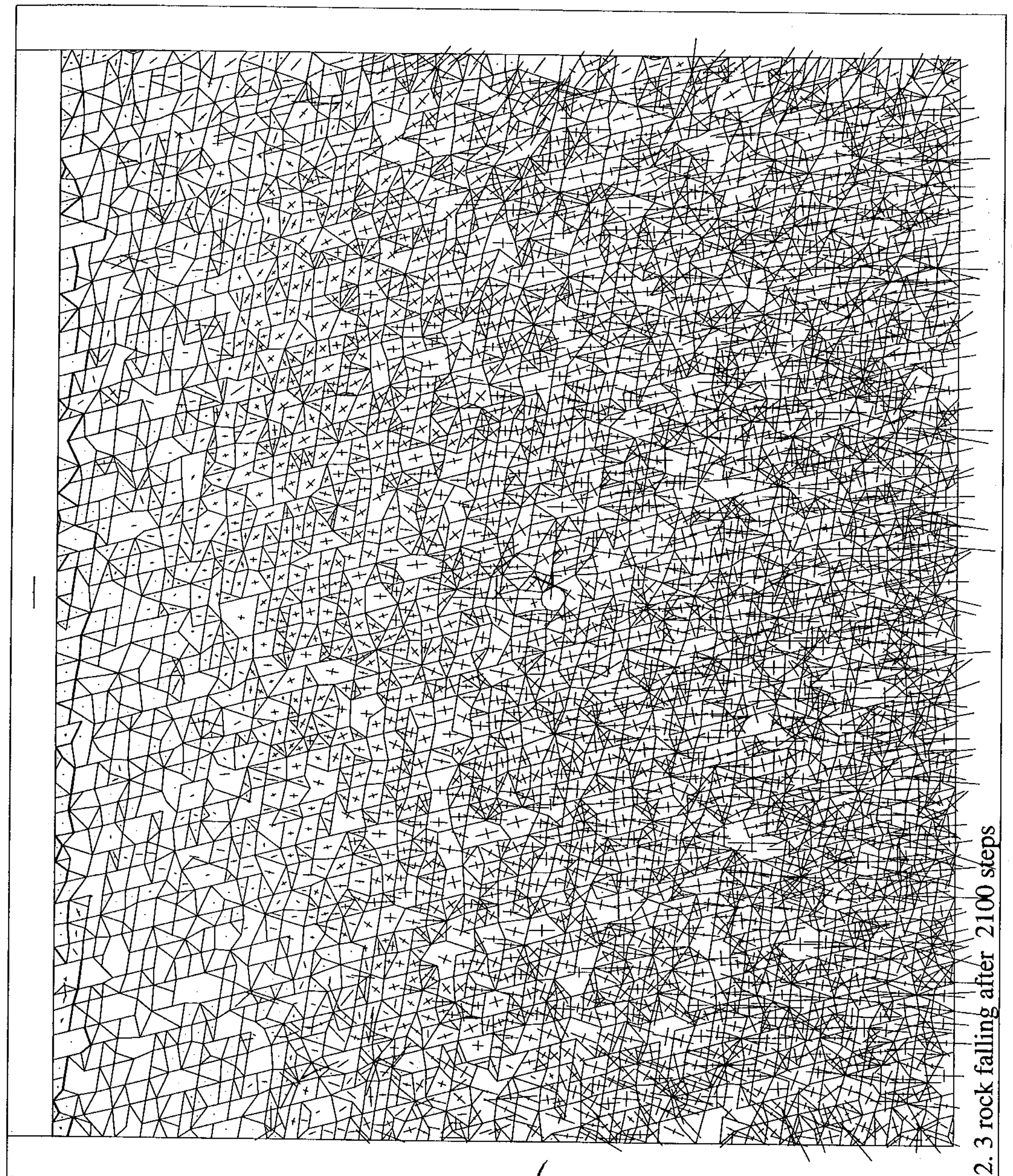

Figure 2. 3 rock falling after 2100 steps

Shi Gen-hua 02/13/02

The directions and values of the principal stresses are close to the continuous case. The author also can not find problem from discontinuous rules.

Shi Gen-hua 02/13/02

4	computing static DDA by step velocity reduction	8 Hrs.	February 14	Shi Gen-hua 02/15/02
4	computing static DDA by step velocity reduction	8 Hrs.	February 15	

The following table is the computation of the statics using dynamics. The relative displacements are reduced following the progress of the time steps. The damping is made by reducing 0.01 times of velocity after each 0.001 seconds (time interval).

Table 6. Average relative displacement

time step	relative displacement	open-close iteration
1	0.00083	9
2	0.00041	5
3	0.00032	8
4	0.00030	5
5	0.00016	5
6	0.00028	5
7	0.00038	5
8	0.00047	5
9	0.00055	5
10	0.00062	5
20	0.00103	5
30	0.00106	5
40	0.00086	4
50	0.00054	4
60	0.00023	3
70	0.00025	3
80	0.00046	2
90	0.00049	2
100	0.00039	1
150	0.00027	1

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From 100 time steps to the end of the computation, all open-close iteration just one time. It proves, from 100 step there are no contact open-or-close — no change, computation is reliable! Shi Gen-hua 02/15/02

200	0.00014	1
250	0.00005	1
300	0.00001	1
350	0.00001	1
400	0.00001	1
450	0.00000	1
500	0.00000	1
550	0.00000	1
600	0.00000	1
650	0.00000	1
700	0.00000	1
750	0.00000	1
800	0.00000	1
850	0.00000	1
900	0.00000	1
950	0.00000	1
1000	0.00000	1
1050	0.00000	1
1100	0.00000	1
1150	0.00000	1
1200	0.00000	1
1250	0.00000	1
1300	0.00000	1
1350	0.00000	1
1400	0.00000	1
1450	0.00000	1
1500	0.00000	1
1550	0.00000	1
1600	0.00000	1
1650	0.00000	1
1700	0.00000	1
1750	0.00000	1
1800	0.00000	1
1850	0.00000	1
1900	0.00000	1

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1950	0.00000	1
2000	0.00000	1

Equation solving iteration: 40 - 50

Factor of SOR: 1.25

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1	visible joint trace length and true joint length	8 Hrs.	March 4
1	visible joint trace length and true joint length	8 Hrs.	March 5
1	visible joint trace length and true joint length	8 Hrs.	March 6

Shi Gen-hua 03/06/02

Report #9 Using Statistics to Produce Joint Polygons in the Rocks Near a Tunnel of Project: 20.01402.671 Rock Fall Assessing under Seismic Load using Key Block Analysis

Prepared for:
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Submitted by Gen-hua Shi
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1. Visible Joint Trace Length and True Joint Length

Most the joint data are from the rock surface. The joint traces are the intersections of the joint polygons and the rock surfaces. The joint polygon length has to be computed from the joint trace length.

For disk shape joints:

The area is

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$$\frac{1}{4}\pi D^2$$

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The average joint trace length is

$$L_{trace} = \frac{1}{4}\pi D$$ (see Fig. 1A on p.137) 11/14/12

The joint length is D

$$D = \frac{4}{\pi}L_{trace} = 1.27L_{trace}$$

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The true joint length is 1.27 times average trace joint length.

2

For the equal lateral rectangle joint shape:

The area is

$$S^2$$

When the rock surface is parallel the rectangle diagonal, the average joint trace length is

$$L_{trace} = \frac{1}{\sqrt{2}}S$$

The true joint length is

$$\sqrt{2}S$$

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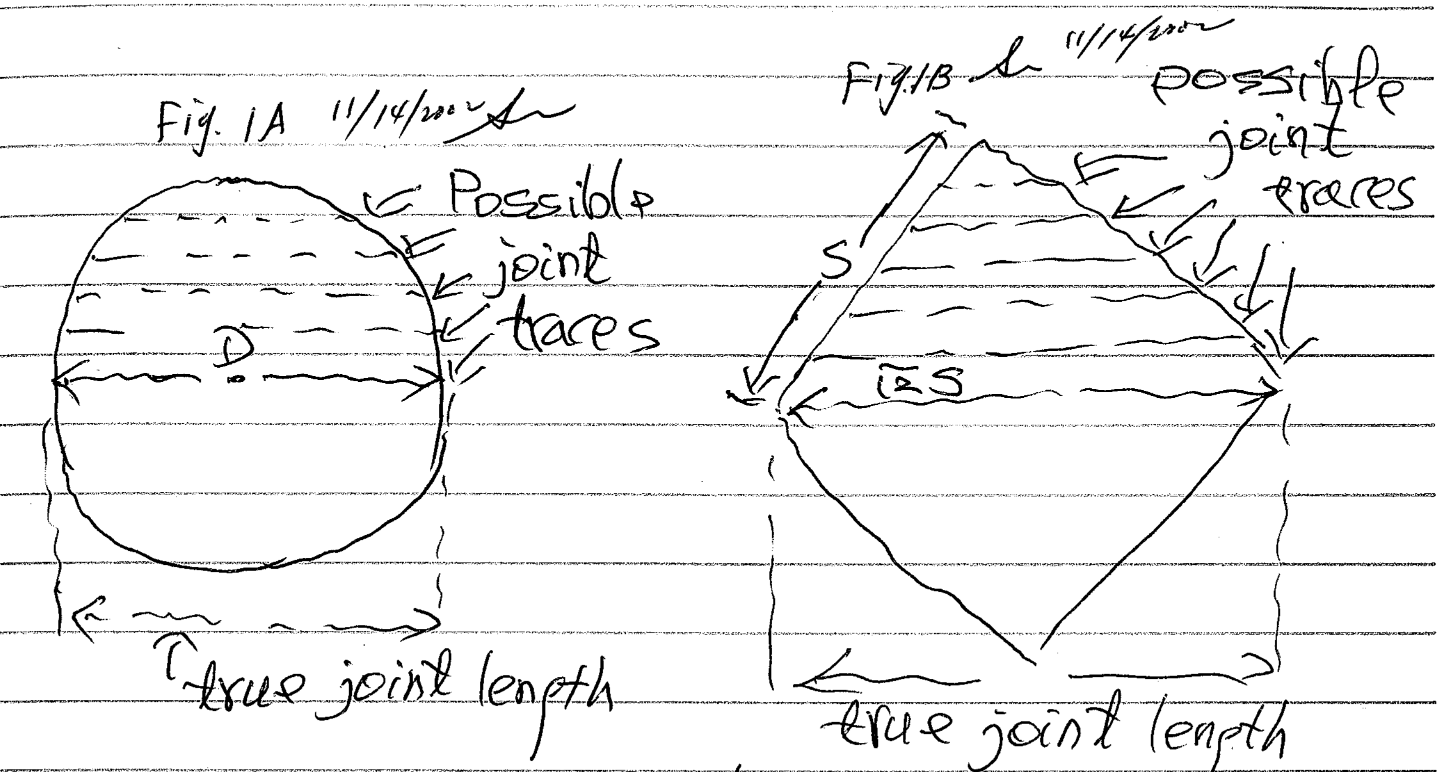
$$\sqrt{2}S = 2.0L_{trace}$$

The true joint length is 2.0 times average trace joint length.

ShiGen-hua 03/06/02



ShiGen-hua 03/06/02

2	shapes of statistically produced joint polygons	8 Hrs.	March 7
2	shapes of statistically produced joint polygons	8 Hrs.	March 8
2	shapes of statistically produced joint polygons	8 Hrs.	March 11

ShiGen-hua 03/11/02

2. Shapes of Statistically Produced Joint Polygons

The geometry of the tunnels are the following:

Table 1. Tunnel data

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

ShiGen-hua 03/11/02

The Yucca mountain rocks are jointed rock with considerable strength. The rock block are basically controlled by existing joints.

ShiGen-hua 03/11/02

The joint sets of joint system are the following:

Table 2. Angle data of joint system

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 trace parameters are the following:

Table 3 Statistical length data of joint traces

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

For the joint shape, theoretically joints are discs. However the joints are often confined by other joints. Therefore, joints practically are parallelogram. It is reasonable to assume here the joints are rectangles. One side of the rectangle is parallel to the other major joint set.

Therefore for the true joint length is 2.0 times of the average trace joint length:

ShiGen-hua 03/11/02

Table 4 Statistical length data of true joints

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

3. Algorithm of Forming Joint Polygons for Each Set

Here the joint polygons are rectangles. The algorithm of producing joint polygons are the following:

ShiGen-hua 03/14/02

1. For each joint set, produce a group of parallel planes. Each plane has the dip and dip direction angle of the given joint set. The distance between planes is equal to the joint spacing of the given joint set.

ShiGen-hua 03/14/02

2. Divide each plane to equal lateral rectangles. The edges are equal the true joint length. One pair of the edges of the rectangles are parallel to the other major joint set.

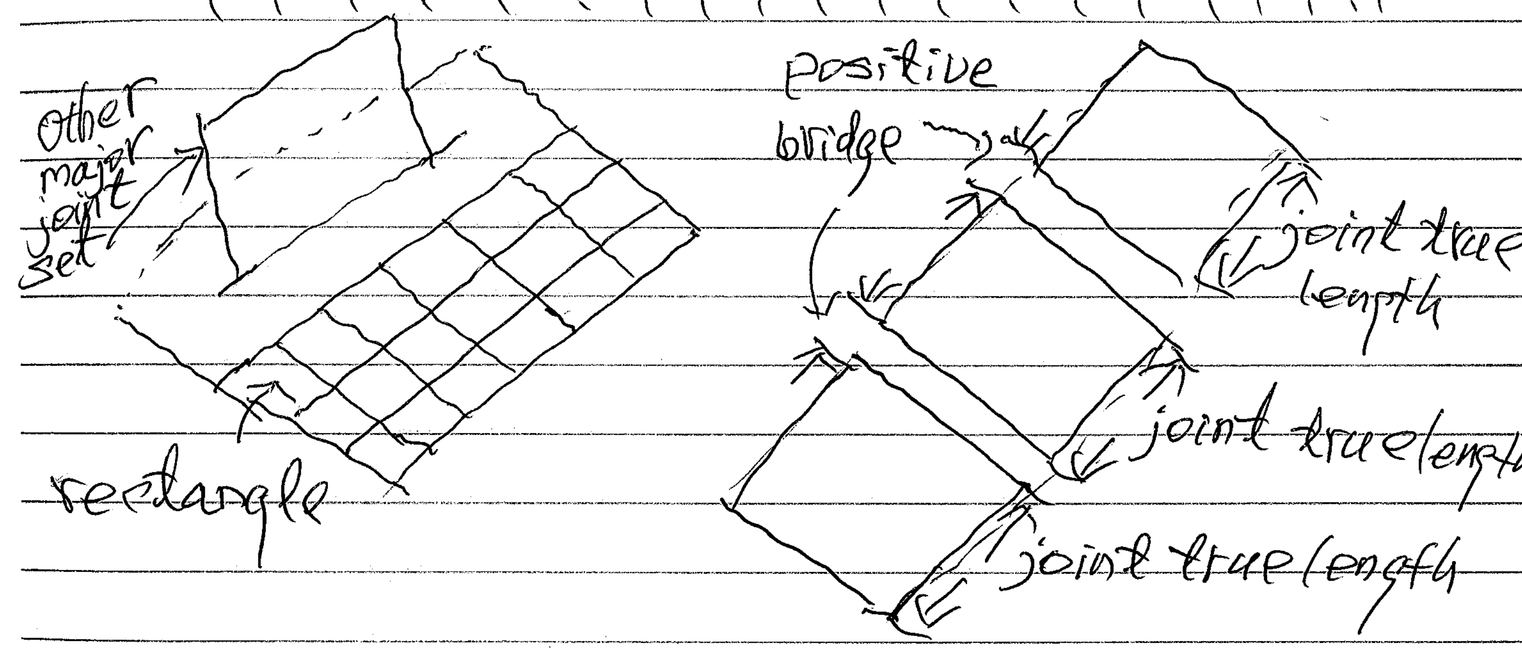
3. Reduce or extend the rectangles in according the bridge value.

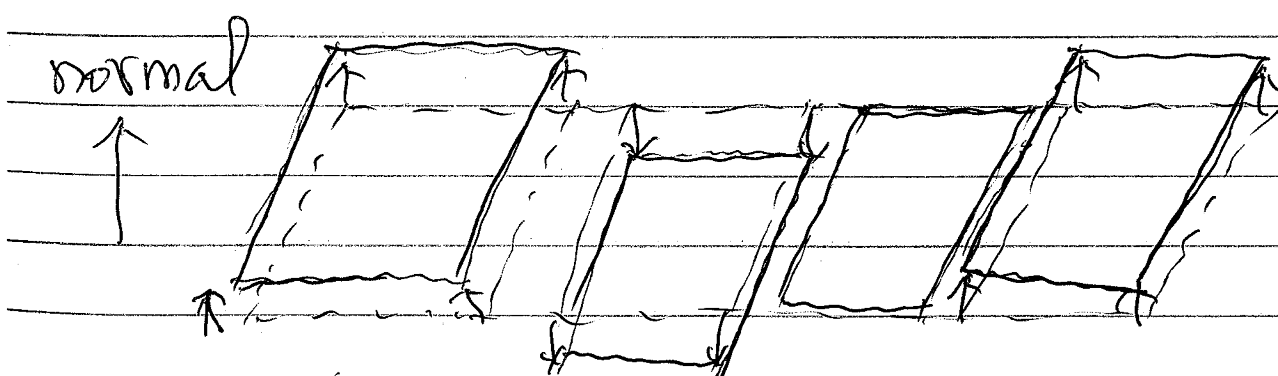
4. Using statistics to change the rectangle sizes, the distances along the normal of the rectangles.

03/14/02
ShiGen-hua

3	algorithm of forming joint polygons for each set	8 Hrs.	March 12
3	algorithm of forming joint polygons for each set	8 Hrs.	March 13
3	algorithm of forming joint polygons for each set	8 Hrs.	March 14

ShiGen-hua 03/14/02





perturbation in the normal direction by statistics.

ShiGen-hua 03/14/12

4	joint polygons with a given distance to tunnel	8 Hrs.	March 15
4	joint polygons with a given distance to tunnel	8 Hrs.	March 18
4	joint polygons with a given distance to tunnel	8 Hrs.	March 19

Shi Gen-hua 03/19/02

4. Joint Polygons with a Given Distance to Tunnel

1. All produced rectangles which are out of a defined distance from the tunnel, will be deleted.

2. The rectangles which are in a defined distance from the tunnel will be input to the block producing program TC0.

3. The tunnel surface polygons will be also input to the block producing program TC0.

4. All of the blocks inside the tunnel are deleted.

5. The finite blocks with the diameter less than half of the tunnel diameter are considered as possible falling blocks.

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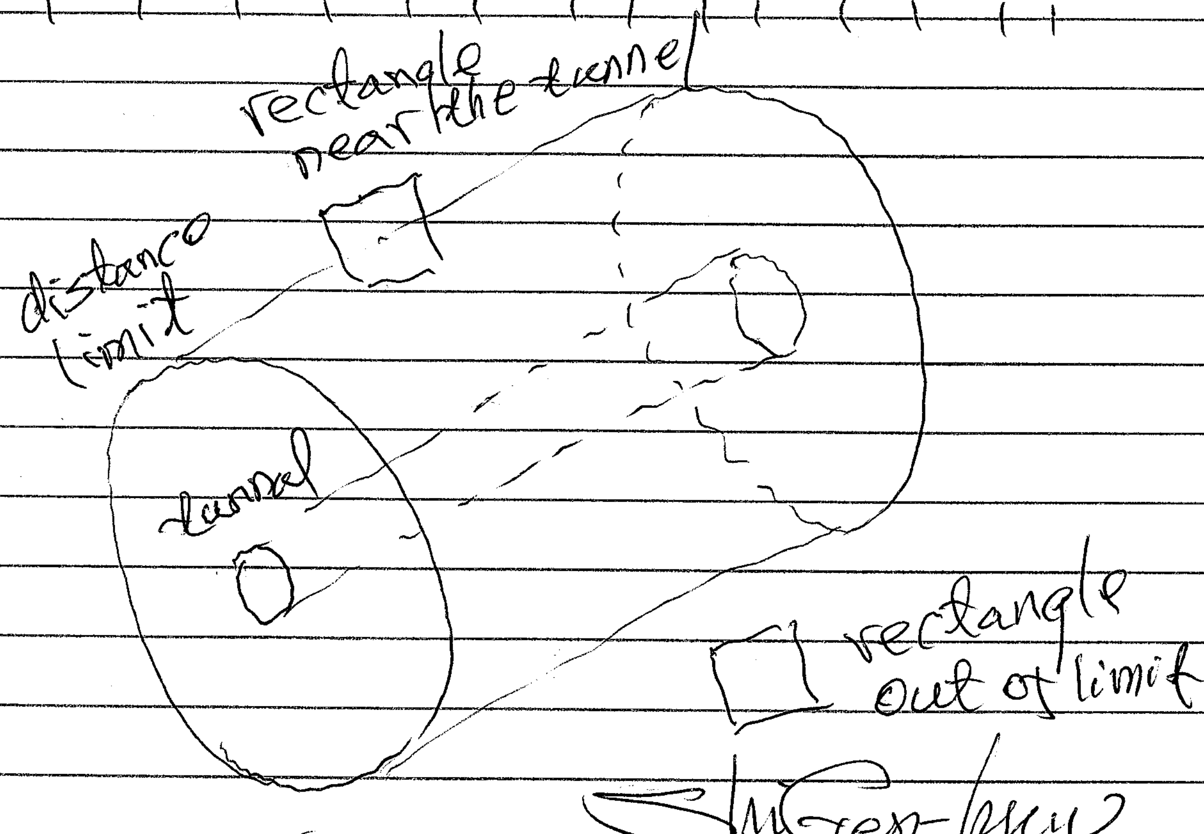
03/19/02



Shi Gen-hua
03/19/02

Forming joint polygons for each joint set:
The input joint information is dip angle and dip direction angle, these information is three-dimensional which is the same for the three-dimensional joint polygon producing.

The other group of joint set information will include joint spacing, joint length and joint bridge:

① joint spacing is the spacing along the joint normal, which is three dimensional. Therefore the same joint spacing is used in 3-dimensional joint polygon producing.

② joint length is actually the joint trace length, which is the intersection of 3-d joint polygon with the rock surface plane. The real diameter of the joint polygon is average about 1.3 times of the joint trace length. (The proof will be in latter report #(2)). The 1.3 times joint length is used for 3-d joint polygon producing.

③ joint bridge is a small positive number, 0.1m is used.

Shi 05/01/02

④ joint shape: rectangle with edge length ≈ joint length.

Shi Gen-hua 05/01/02

Report #10 Three Dimensional Joint Polygon Producing and Block Volume Statistics 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
Tel (650) 631-1804 Fax (650) 610-9505

1. Input Data of Statistically Produced Joint Polygons

The Yucca mountain rocks are jointed rock with considerable strength. The rock block are basically controlled by existing joints.

The joint sets of joint system are the following:

Table 1. Angle data of joint system

joint set	dip angle	dip d.	cohesion
joint set 1	82°	235°	0 ton/m^2
joint set 2	79°	270°	0 ton/m^2
joint set 3	5°	45°	0 ton/m^2

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

Shi Gen-hua
05/03/02

Table 2 Statistical length data of joint traces

joint set	spacing: m	length: m	bridge: m
joint set 1	3.47 m	4.56 m	.10 m
joint set 2	4.05 m	4.02 m	.10 m
joint set 3	2.94 m	7.36 m	.10 m

For the joint shape, theoretically joints are discs. However the joints are often confined by other joints. Therefore, joints practically are parallelogram. It is reasonable to assume here the joints are rectangles. One side of the rectangle is parallel to the other major joint set. 05/03/02 Shi Gen-hua

The joint producing coordinate system:
X: east Shi 05/10/02
Y: north
Z: up
the coordinate system is compatible with the joint dip dip direction measurements.

The volume to produce the joint polygon is 24 m x 24 m x 24 m for the case 1. The joint polygons are produced if it is partly or entirely in this volume.
Shi Gen-hua 05/10/02

The produced polygons need 3-d computer graphic to represent. The most popular and most capable 3-d graphic "OpenGL" is used to represent the produced joint polygons.

Shi Gen-hua
06/28/02
Shi 06/28/02

2. Polygon and Block Volume Statistics of 24 m × 24 m × 24 m Space with 1.3× Joint Length

The joint length is 1.3 times of the given average trace joint length:

Table 3 Statistical length data of true joints

joint set	spacing: m	length: m	bridge: m
joint set 1	3.47 m	5.93 m	.10 m
joint set 2	4.05 m	5.23 m	.10 m
joint set 3	2.94 m	9.57 m	.10 m

Table 4 Statistical Results of Block Producing

computation	block	intersection nodes	polygon
1	0	181	2
2	0	167	2
3	0	173	1
4	0	164	2
5	0	183	0
6	0	199	2
7	0	165	0
8	0	177	0
9	0	193	0
10	0	174	0
11	0	161	1
12	0	168	1
13	0	189	1
14	0	188	3
15	0	177	0
16	0	190	4
17	0	177	2
18	0	181	1
19	0	161	1
20	0	195	3

Shi Gen-hua 07/08/02

Shi Gen-hua 07/08/02

Shi Gen-hua 07/10/02

Science the joint spacing is large. It is better to use large volume 40m×40m×40m to produce the joint for this case 1. The following is the results. Shi Gen-hua 07/10/02

3. Polygon and Block Volume Statistics of 40 m × 40 m × 40 m Space with 1.3× Joint Length

The true joint length is 1.3 times of the given average trace joint length:

Table 5 Statistical length data of true joints

joint set	spacing: m	length: m	bridge: m
joint set 1	3.47 m	5.93 m	.10 m
joint set 2	4.05 m	5.23 m	.10 m
joint set 3	2.94 m	9.57 m	.10 m

Table 6 Statistical Results of Block Producing

computation	block	intersection nodes	polygon
1	0	850	13
2	0	738	8
3	0	761	6
4	0	785	6
5	0	788	3

Shi Gen-hua 07/10/02

4. Polygon and Block Volume Statistics of 40 m × 40 m × 40 m Space with 2.0× Joint Length

The joint length is 2.0 times of the given average trace joint length:

Table 7 Statistical length data of true joints

joint set	spacing: m	length: m	bridge: m
joint set 1	3.47 m	9.12 m	.10 m
joint set 2	4.05 m	8.04 m	.10 m
joint set 3	2.94 m	14.72 m	.10 m

Table 8 Statistical Results of Block Producing

computation	block	intersection nodes	polygon
1	0	801	27
2	1	797	34
3	0	821	38
4	0	787	26
5	0	842	43

Table 9 Block Volumes

computation	block volume m^3
2	56.02 m^3

5. Polygon and Block Volume Statistics of 40 m × 40 m × 40 m Space with 3.0× Joint Length

The joint length is 3.0 times of the given average trace joint length:

Table 10 Statistical length data of true joints

joint set	spacing: m	length: m	bridge: m
joint set 1	3.47 m	13.95 m	.10 m
joint set 2	4.05 m	12.06 m	.10 m
joint set 3	2.94 m	22.08 m	.10 m

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07/16/02

Table 11 Statistical Results of Block Producing

computation	block	intersection nodes	polygon
1	1	841	132
2	0	878	157

3	1	812	135
4	0	844	164
5	1	812	143

Table 12 Block Volumes

computation	block volume m^3	
1	66.48 m^3	0.107% of Total volume
3	67.85 m^3	0.106% of Total volume
(4	64.19 m^3	0.100% of Total volume

Shi
07/16/02

6. Polygon and Block Volume Statistics of 40 m × 40 m × 40 m Space with 4.0× Joint Length

The joint length is 4.0 times of the given average trace joint length:

Table 13 Statistical length data of true joints

joint set	spacing: m	length: m	bridge: m
joint set 1	3.47 m	18.24 m	.10 m
joint set 2	4.05 m	16.08 m	.10 m
joint set 3	2.94 m	29.44 m	.10 m

Table 14 Statistical Results of Block Producing

computation	block	intersection nodes	polygon
1	11	900	335
2	6	872	282
3	10	936	373
4	16	800	294
5	7	876	321

Table 15 Block Volumes

computation	block volume m^3
1	90.95 m^3
1	50.22 m^3

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07/16/02

1	85.71 m^3
1	86.96 m^3
1	71.58 m^3
1	93.59 m^3
1	159.64 m^3
1	63.41 m^3
1	64.19 m^3
1	88.87 m^3
1	51.37 m^3
2	62.38 m^3
2	62.53 m^3
2	161.48 m^3
2	43.26 m^3
2	54.14 m^3
2	63.43 m^3
3	56.37 m^3
3	59.97 m^3
3	65.23 m^3
3	117.25 m^3
3	44.67 m^3
3	60.99 m^3
3	59.65 m^3
3	74.96 m^3
3	47.54 m^3
3	71.91 m^3
4	64.77 m^3
4	155.11 m^3
4	91.16 m^3
4	68.66 m^3
4	69.13 m^3
4	65.45 m^3
4	88.67 m^3
4	73.33 m^3
4	57.66 m^3
4	68.69 m^3

1.42 % of total volume

0.70 % of total volume

1.03 % of total volume

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4	93.05 m^3
4	142.08 m^3
4	55.38 m^3
4	51.49 m^3
4	185.26 m^3
4	73.63 m^3
5	50.36 m^3
5	45.15 m^3
5	51.95 m^3
5	55.60 m^3
5	55.48 m^3
5	76.10 m^3
5	77.34 m^3

2.13 % of total volume

0.64 % of total volume.

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Shi 07/16/02

In case 1, due to the joint spacing there only few blocks formed. Even using the four times of the joint length, maximum 2.13 % of the block volume we can got in five computations.

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07/16/02

Item	Description	Work	Date
1	forming joint polygons for each joint set	8 Hrs.	May 1
1	forming joint polygons for each joint set	8 Hrs.	May 2
1	forming joint polygons for each joint set	8 Hrs.	May 3

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07/16/02

1	forming joint polygons for each joint set	8 Hrs.	May 6
1	forming joint polygons for each joint set	8 Hrs.	May 7
1	forming joint polygons for each joint set	8 Hrs.	May 8
1	forming joint polygons for each joint set	8 Hrs.	May 9
1	forming joint polygons for each joint set	8 Hrs.	May 10
2	drawing and checking produced joint polygons	8 Hrs.	June 25
2	drawing and checking produced joint polygons	8 Hrs.	June 26
2	drawing and checking produced joint polygons	8 Hrs.	June 27
2	drawing and checking produced joint polygons	8 Hrs.	June 28
3	checking algorithm of forming block by polygons	8 Hrs.	July 4
3	checking algorithm of forming block by polygons	8 Hrs.	July 5
3	checking algorithm of forming block by polygons	8 Hrs.	July 8
3	checking algorithm of forming block by polygons	8 Hrs.	July 9
4	compute blocks by statistically produced polygons	8 Hrs.	July 10
4	compute blocks by statistically produced polygons	8 Hrs.	July 11
4	compute blocks by statistically produced polygons	8 Hrs.	July 12
4	compute blocks by statistically produced polygons	8 Hrs.	July 15
4	compute blocks by statistically produced polygons	8 Hrs.	July 16

Shi Gen-hua
07/16/02

Case 2 computation is different. The joint spacing of case 2 is small, therefore the chance of forming blocks are much greater than case one. Due to the large number of statistically produced polygons, smaller computation volume 20m x 20m x 20m is used. The following are the results.

Shi Gen-hua
07/17/02

Report #11 Three Dimensional Joint Polygon Producing and Block Volume Statistics 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
Tel (650) 631-1804 Fax (650) 610-9505

1. Input Data of Statistically Produced Joint Polygons

The Yucca mountain rocks are jointed rock with considerable strength. The rock block are basically controlled by existing joints.

The joint sets of joint system are the following:

Table 1. Angle data of joint system

joint set	dip angle	dip d.
joint set 1	84°	221°
joint set 2	83°	299°
joint set 3	9°	59°

Shi Gen-hua
07/18/02

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

Table 2 Statistical length data of joint traces

joint set	spacing: m	length: m	bridge: m
joint set 1	0.60 m	2.54 m	.10 m

joint set 2	1.92 m	2.71 m	.10 m
joint set 3	0.56 m	3.23 m	.10 m

For the joint shape, theoretically joints are discs. However the joints are often confined by other joints. Therefore, joints practically are parallelogram. It is reasonable to assume here the joints are rectangles. One side of the rectangle is parallel to the other major joint set.

2. Polygon and Block Volume Statistics of 20 m × 20 m × 20 m Space with 1.3× Joint Length

The joint length is 1.3 times of the given average trace joint length:

Table 3 Statistical length data of true joints

joint set	spacing: m	length: m	bridge: m
joint set 1	0.60 m	3.30 m	.10 m
joint set 2	1.92 m	3.52 m	.10 m
joint set 3	0.56 m	4.20 m	.10 m

Table 4 Statistical Results of Block Producing

case	block	cutting point	polygon edge	polygon	v ratio
1	101	9761	19270	4178	1.17%
2	45	9699	17951	3849	0.65%
3	58	9812	18824	4033	0.66%
4	62	9704	18422	3983	0.77%
5	73	9709	18187	3975	0.62%
6	50	9701	18238	3885	0.61%

The block are the completely isolated blocks by joint polygons in the 20 m × 20 m × 20 m space.

The cutting points are the intersection points of three joint polygons. The intersection points have to be inside of every intersecting polygon.

The polygon edges are the line segments between two cutting points. The polygon edge have to be in the two intersecting joint polygons.

The polygons are the area delimited by edges. This area has to be totaly in the joint polygons.

The v ratio is the volume ratio. The volume ratio is the total block volume divided by the space volume = 20 m × 20 m × 20 m. Suppose this number is 0.5 or 50 %, it means only 50 per cent of the rock mass form blocks.

Table 5 Block Volumes (m^3) of Each Computation

case	0 - .25	.25 - .5	.5 - 1	1 - 2	2 - 4	4 - 8	8 - 16
1	1	13	57	24	6	0	0
2	0	5	23	12	4	1	1
3	0	9	33	13	2	1	1
4	0	14	28	14	5	1	1
5	0	20	45	8	0	0	0
6	0	7	21	19	3	0	0

3. Polygon and Block Volume Statistics of 20 m × 20 m × 20 m Space with 2.0× Joint Length

The joint length is 2.0 times of the given average trace joint length:

Table 6 Statistical length data of true joints

joint set	spacing: m	length: m	bridge: m
joint set 1	0.60 m	5.08 m	.10 m
joint set 2	1.92 m	5.42 m	.10 m
joint set 3	0.56 m	6.46 m	.10 m

Table 7 Statistical Results of Block Producing

case	block	cutting point	polygon edge	polygon	v ratio
1	711	10347	41761	8986	13.21%
2	635	10156	39465	8543	9.99%
3	773	10461	42025	9114	11.94%
4	645	10197	40351	8637	10.72%
5	716	10497	41775	9003	12.27%

The block are the completely isolated blocks by joint polygons in the 20 m × 20 m × 20 m space.

The cutting points are the intersection points of three joint polygons. The intersection points have to be inside of every intersecting polygon.

The polygon edges are the line segments between two cutting points. The polygon edge have to be in the two intersecting joint polygons.

The polygons are the area delimited by edges. This area has to be totaly in the joint polygons.

The v ratio is the volume ratio. The volume ratio is the total block volume divided by the space volume = 20 m × 20 m × 20 m. Suppose this number is 0.5 or 50 %, it means only 50 per cent of the rock mass form blocks.

Table 8 Block Volumes (m^3) of Each Computation

case	0 - .25	.25 - .5	.5 - 1	1 - 2	2 - 4	4 - 8	8 - 16
1	6	61	311	202	79	42	10
2	3	64	298	181	64	23	2
3	6	83	354	227	79	23	1
4	4	69	265	206	78	19	4
5	8	88	326	172	85	31	6

4. Polygon and Block Volume Statistics of 20 m × 20 m × 20 m Space with 3.0× Joint Length

The joint length is 3.0 times of the given average trace joint length:

Table 9 Statistical length data of true joints

joint set	spacing: m	length: m	bridge: m
joint set 1	0.60 m	7.62 m	.10 m
joint set 2	1.92 m	8.13 m	.10 m
joint set 3	0.56 m	9.69 m	.10 m

Table 10 Statistical Results of Block Producing

case	block	cutting point	polygon edge	polygon	v ratio
1	2100	10544	60982	13411	48.46%
2	2175	10579	61148	13566	44.21%
3	2415	11002	66263	14626	53.84%
4	2193	10495	60702	13435	43.50%
5	2347	10798	63831	14171	48.69%

The block are the completely isolated blocks by joint polygons in the 20 m × 20 m × 20 m space.

The cutting points are the intersection points of three joint polygons. The intersection points have to be inside of every intersecting polygon.

The polygon edges are the line segments between two cutting points. The polygon edge have to be in the two intersecting joint polygons.

The polygons are the area delimited by edges. This area has to be totaly in the joint polygons.

The v ratio is the volume ratio. The volume ratio is the total block volume divided by the space volume = 20 m × 20 m × 20 m. Suppose this number is 0.5 or 50 %, it means only 50 per cent of the rock mass form blocks.

Table 11 Block Volumes (m^3) of Each Computation

case	0 - .25	.25 - .5	.5 - 1	1 - 2	2 - 4	4 - 8	8 ¡
1	28	173	893	575	265	114	52
2	32	163	997	577	268	97	41
3	77	247	968	626	300	127	70
4	27	190	938	585	240	114	45
5	50	224	1060	604	252	100	57

5. Polygon and Block Volume Statistics of 20 m × 20 m × 20 m Space with 4.0× Joint Length

The joint length is 4.0 times of the given average trace joint length:

Table 12 Statistical length data of true joints

joint set	spacing: m	length: m	bridge: m
joint set 1	0.60 m	10.16 m	.10 m
joint set 2	1.92 m	10.84 m	.10 m
joint set 3	0.56 m	12.92 m	.10 m

Table 13 Statistical Results of Block Producing

case	block	cutting point	polygon edge	polygon	v ratio
1	3641	10940	76532	17391	64.28%
2	3484	10696	73950	16818	62.51%
3	3473	10793	74451	16877	62.52%
4	3487	10582	73866	16745	64.57%
5	3668	10899	76826	17439	65.39%

The block are the completely isolated blocks by joint polygons in the 20 m × 20 m × 20 m space.

The cutting points are the intersection points of three joint polygons. The intersection points have to be inside of every intersecting polygon.

The polygon edges are the line segments between two cutting points. The polygon edge have to be in the two intersecting joint polygons.

The polygons are the area delimited by edges. This area has to be totaly in the joint polygons.

The v ratio is the volume ratio. The volume ratio is the total block volume divided by the space volume = 20 m × 20 m × 20 m. Suppose this number is 0.5 or 50 %, it means only 50 per cent of the rock mass form blocks.

Table 14 Block Volumes (m^3) of Each Computation

case	0 - .25	.25 - .5	.5 - 1	1 - 2	2 - 4	4 - 8	8 ¡
1	112	230	1764	993	386	103	53
2	48	366	1619	952	334	119	46
3	114	235	1657	916	379	121	51
4	103	326	1640	848	372	145	53
5	116	365	1712	917	387	127	44

ShiGen-hua
09/02/02

	Item Description	Work	Date
1	compute blocks by produced polygons of case 1	8 Hrs.	July 17
1	compute blocks by produced polygons of case 1	8 Hrs.	July 18
1	compute blocks by produced polygons of case 1	8 Hrs.	July 19
1	compute blocks by produced polygons of case 1	8 Hrs.	July 22
1	compute blocks by produced polygons of case 1	8 Hrs.	July 23
1	compute blocks by produced polygons of case 1	8 Hrs.	July 24

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09/02/02

1	compute blocks by produced polygons of case 1	8 Hrs.	July 30
1	compute blocks by produced polygons of case 1	8 Hrs.	July 31
1	compute blocks by produced polygons of case 1	8 Hrs.	August 1
2	checking of 3-d block computation by topology	8 Hrs.	August 2
2	checking of 3-d block computation by topology	8 Hrs.	August 6
2	checking of 3-d block computation by topology	8 Hrs.	August 7
3	Writing report #10 block size computation case 1	8 Hrs.	August 8
3	Writing report #10 block size computation case 1	8 Hrs.	August 9
4	compute blocks and block size range of case 2	8 Hrs.	August 12
4	compute blocks and block size range of case 2	8 Hrs.	August 13
4	compute blocks and block size range of case 2	8 Hrs.	August 14
4	compute blocks and block size range of case 2	8 Hrs.	August 15
4	compute blocks and block size range of case 2	8 Hrs.	August 21
4	compute blocks and block size range of case 2	8 Hrs.	August 22
5	checking of case 2 block computation by topology	8 Hrs.	August 26
5	checking of case 2 block computation by topology	8 Hrs.	August 27
6	Writing report #11 block size computation case 2	8 Hrs.	September 2

ShiGen-hua
09/02/02

ShiGen-hua 09/02/02

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]
3-26-03

Asadul H Chowdhury