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Minto 118-Zone
– *3DEC*/DFN Analyses –

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Introduction and Background

- Itasca Consulting Group, Inc. (Itasca) has been participating in the geomechanical design of the underground 118-Zone at the Capstone Minto Mine (Minto) in the Yukon, in north-western Canada
- This presentation focuses on the *3DEC* /DFN simulations conducted to assess the stability of the roof in the chambers associated with the post-pillar cut-and-fill mining option

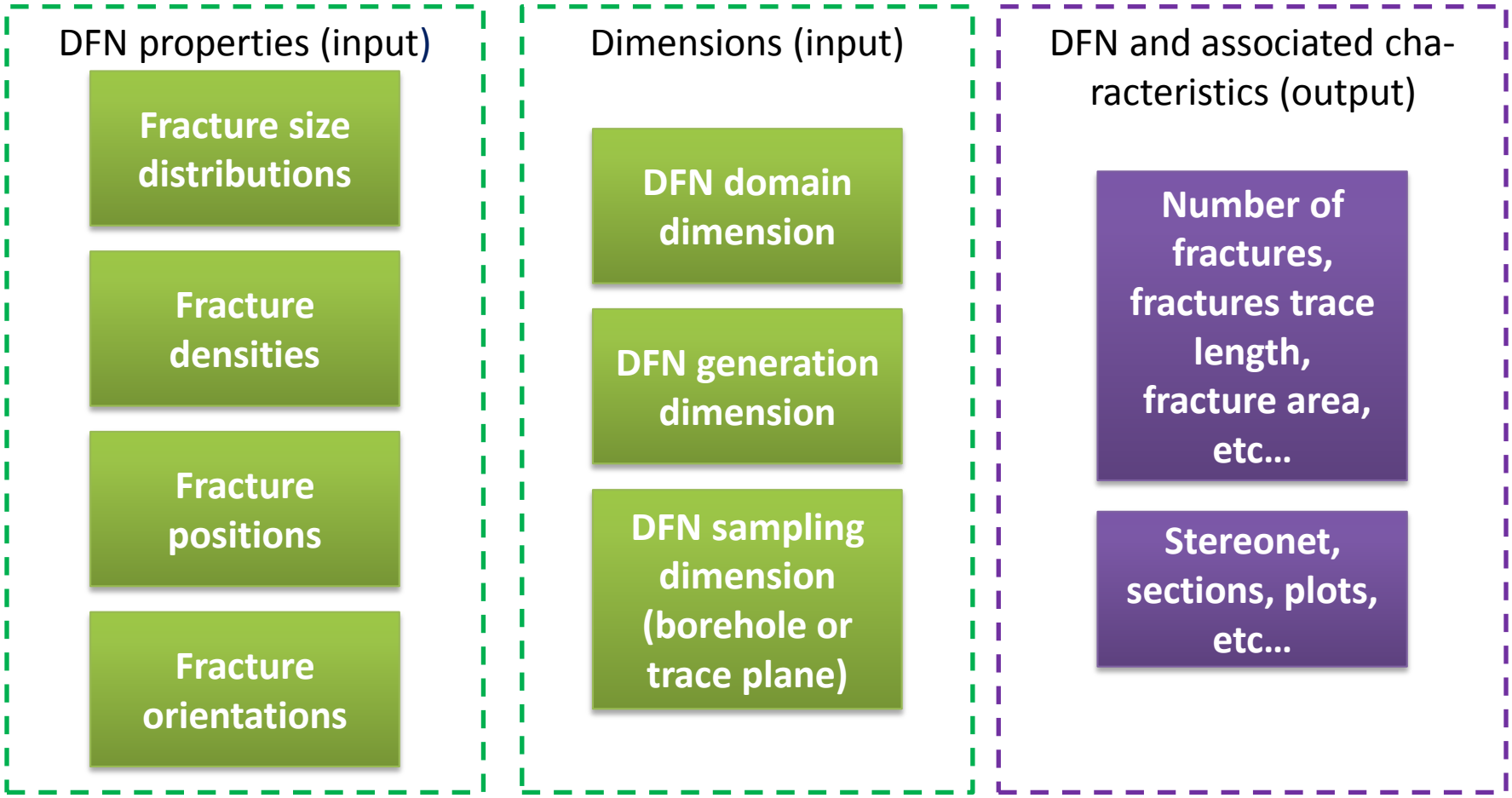
Introduction and Background

- This presentation describes discontinuum-based 3D numerical analyses conducted to assess the effects of the dominant joint sets on the structural stability of the chambers' roof, with and without ground support
- This work was done with the Itasca *3DEC* code, with which a Discrete Fracture Network (DFN) approach was implemented

3DEC Code Overview

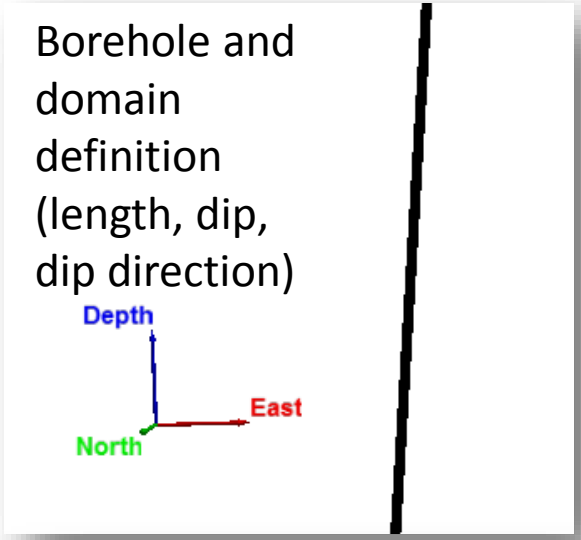
- *3DEC* simulates the response of discontinuous media that are subjected to static and/or dynamic loading
- The discontinuous media are modelled as assemblages of convex or concave polyhedra – individual blocks may be rigid or deformable, and the discontinuities are treated as boundary conditions between these blocks
- Motion along discontinuities are governed by linear and non-linear force-displacement relations for movements in both the normal and shear directions

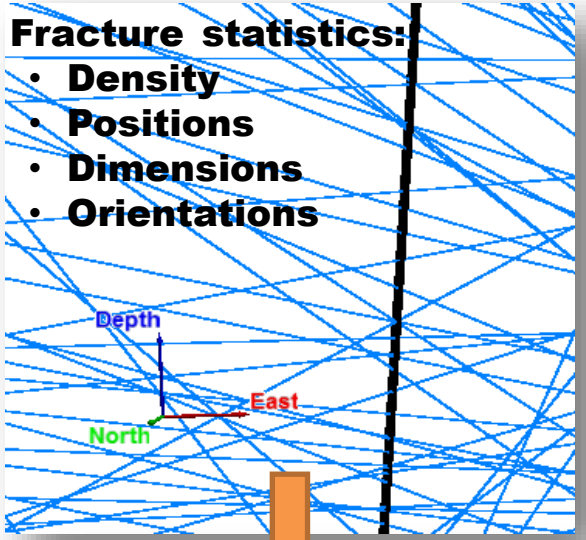
DFN Analyses General Flow Chart



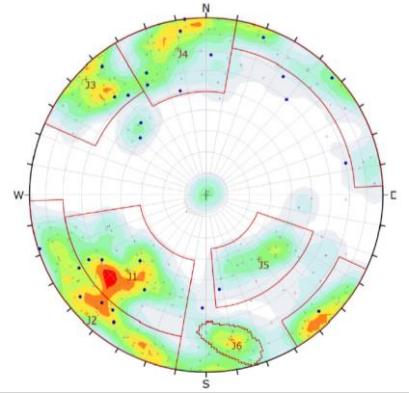
DFN Construction Overview

Borehole and domain definition (length, dip, dip direction)



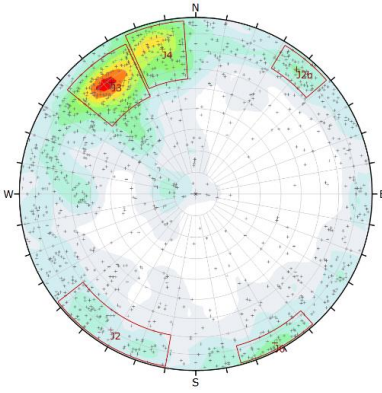


DFN Detailed Construction Process

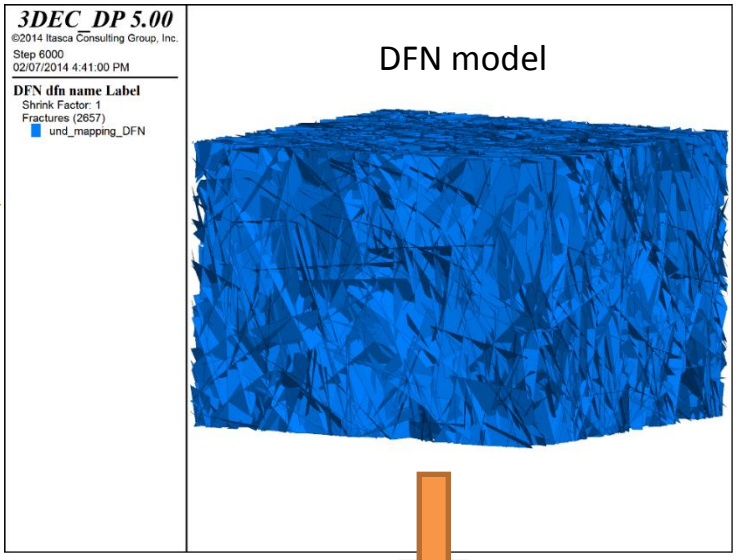


SRK Area 2 pit mapping (2013)

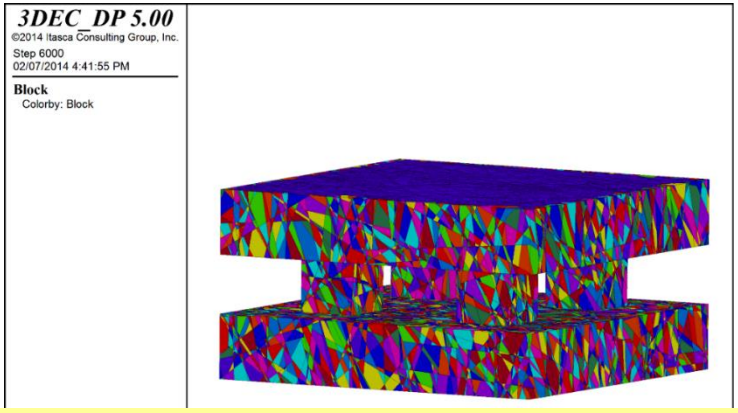
OR



All underground mapping data (zones 118 and M)



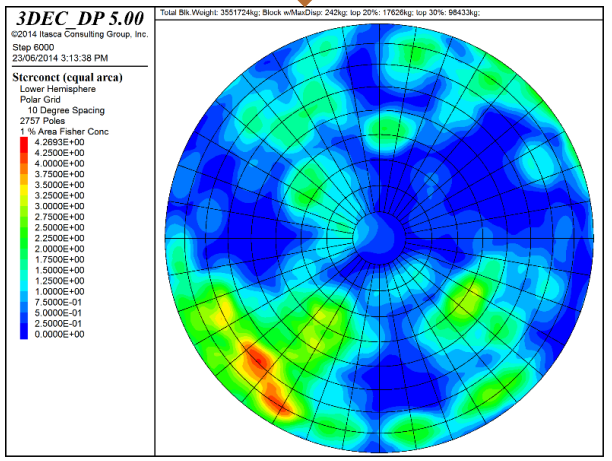
DFN model



3DEC model with excavations, for numerical stability analyses

Multiple DNF constructions ("realisations"), each one unique, are required to derive some statistical confidence in the results

Verification that the DFN matches the input stereonet data (Area 2 pit data in this example)



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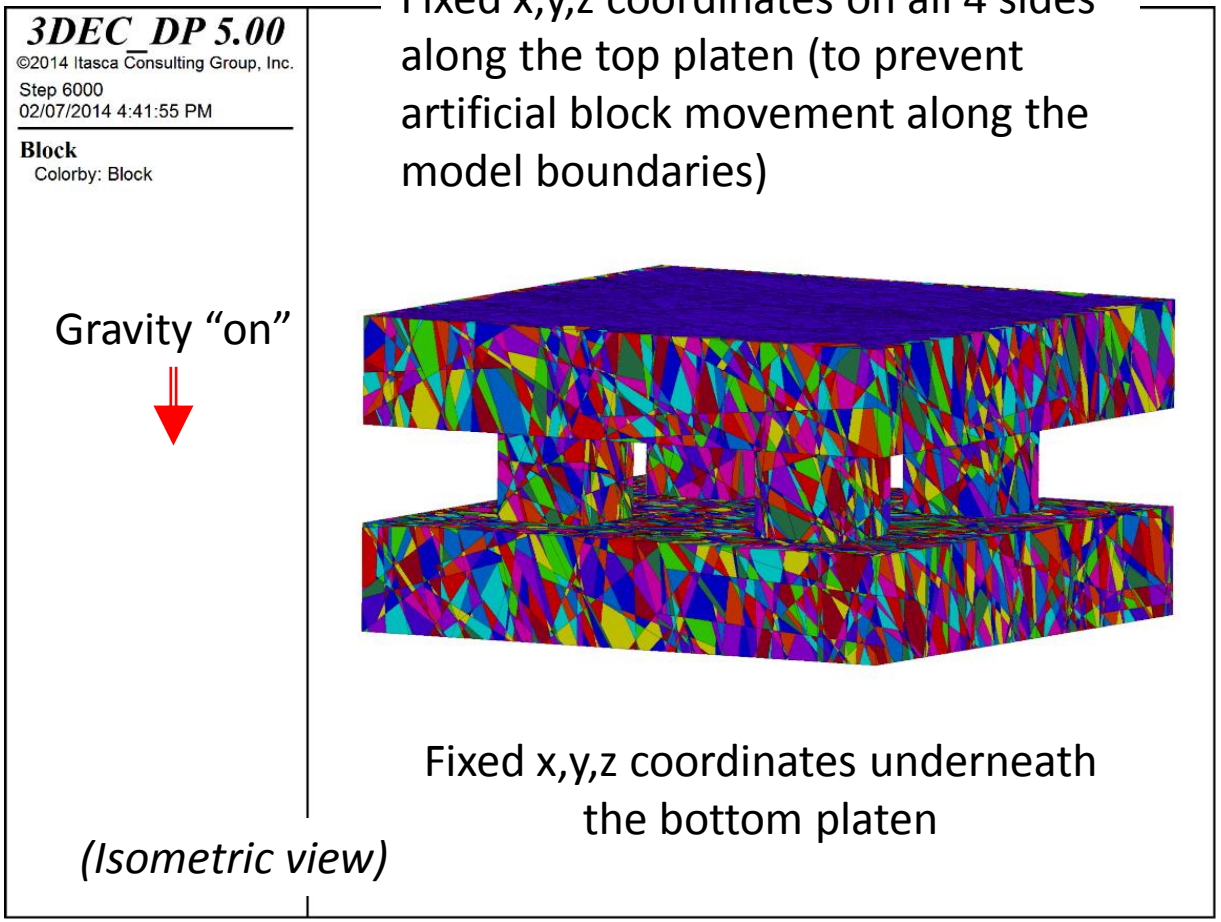
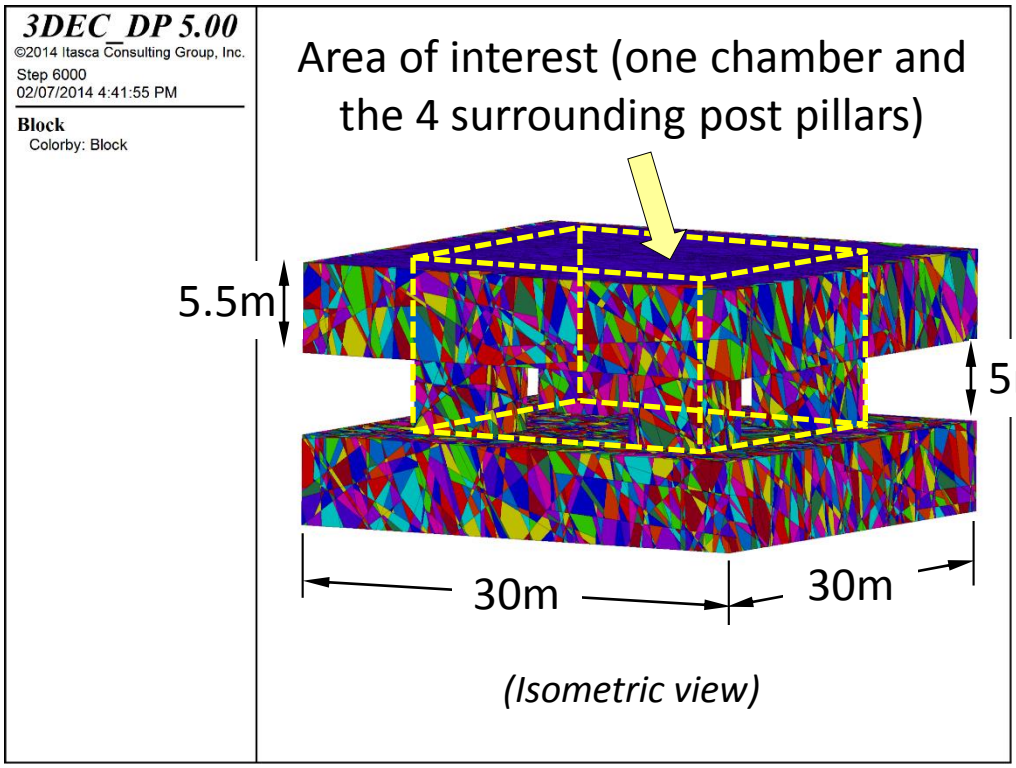
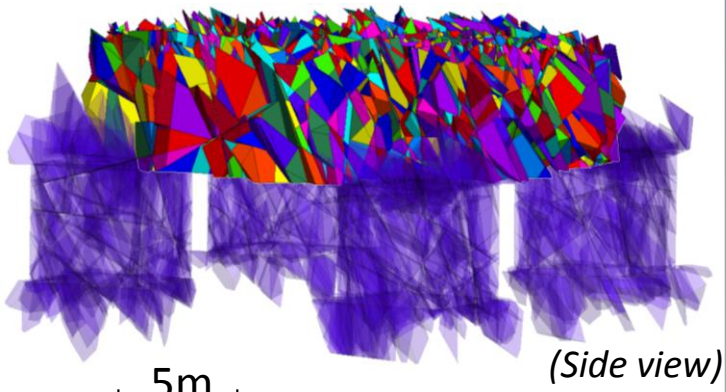
A fracture frequency of 2 joints per metre was implemented in all the simulations described in this presentation

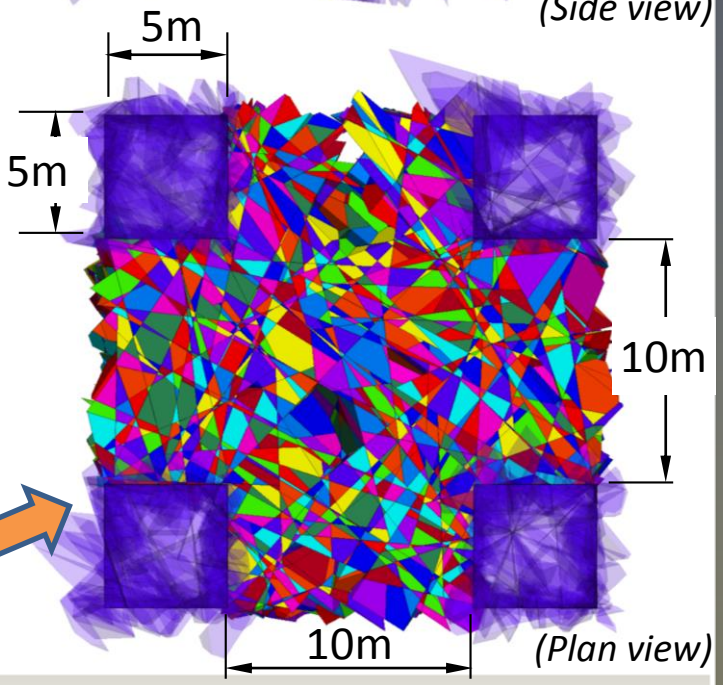
3DEC Model Boundary Conditions



3DEC Results Examination



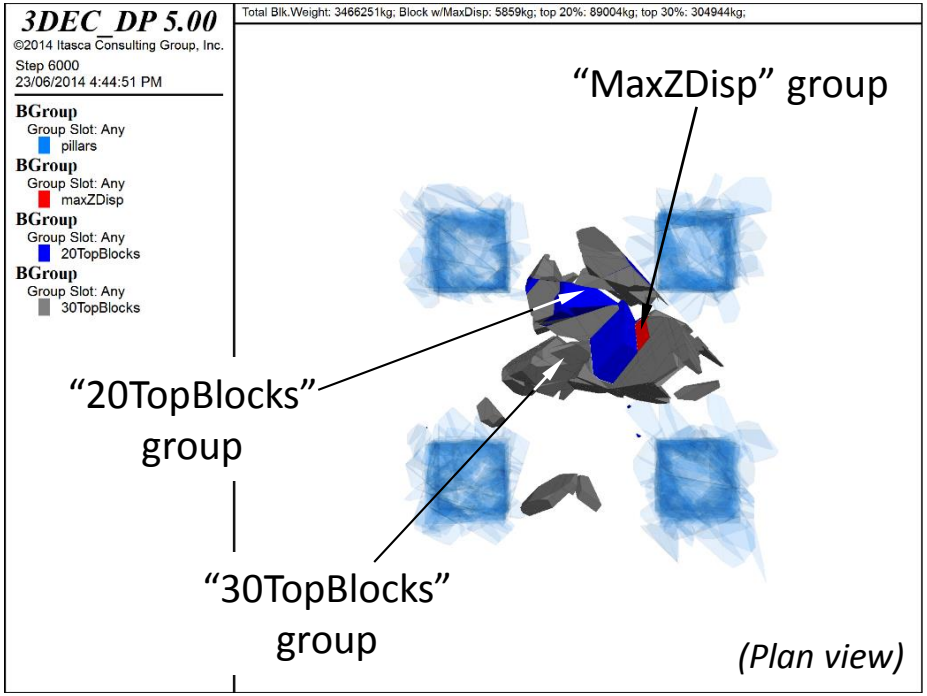




Only the blocks in the roof delineated by the four post pillars and sitting in between them have been considered in the DFN analyses

3DEC Results Interpretation

- The objective of these analyses is to identify roof blocks that are unstable due to their geometrical characteristics and kinematic freedom (the blocks themselves are not zoned, and, hence, cannot deform – they can only move relative to each other and unravel into the chamber beneath)
- All simulations were run with the same number of cycles (6,000) for comparison purposes
- The block that moves the most in a given realisation is shown in the "MaxZDisp" group (red)
- Blocks that move by more than 8 cm are shown in the "20TopBlocks" group (dark blue)
- Blocks that move by 7 to 8 cm are shown in the "30TopBlocks" group (dark grey)

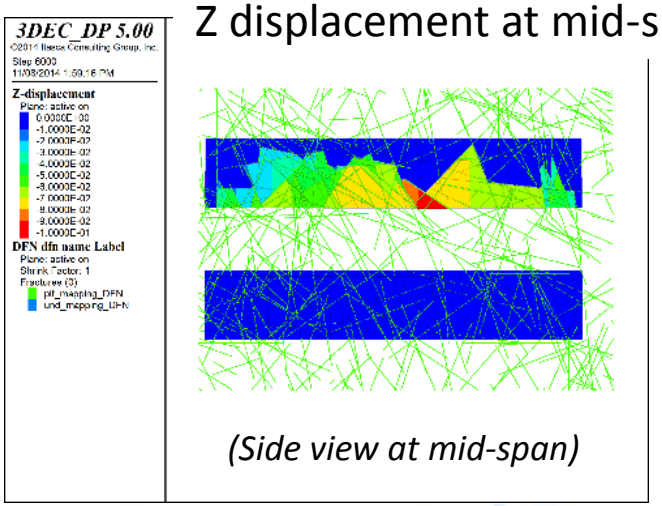


Z displacement on a mid section

Overlaid Top 20% Blocks

3DEC Results Interpretation

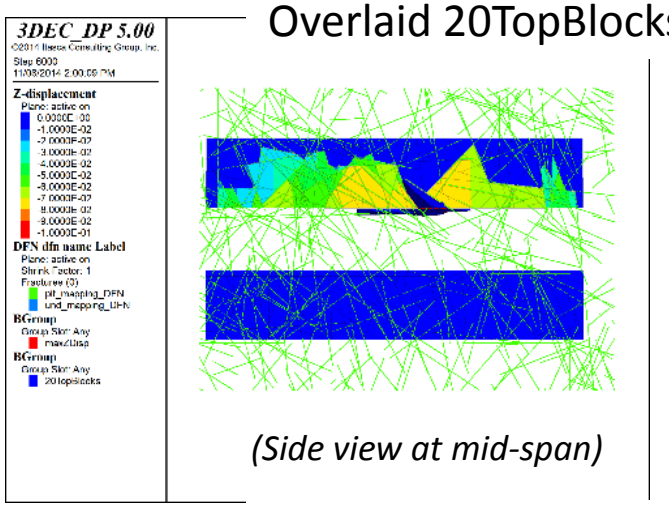
Z displacement at mid-span



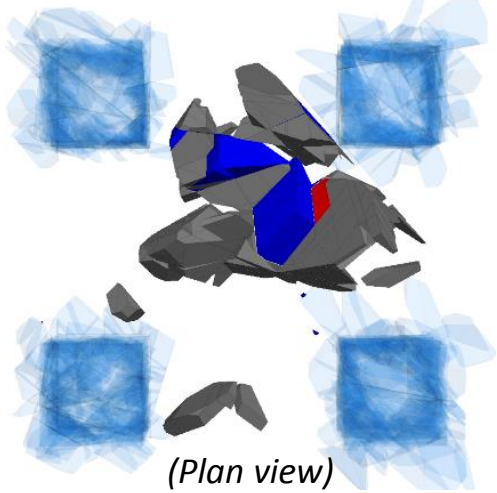
(Side view at mid-span)

All the displacement plots in this presentation have a scale in metres

Overlaid 20TopBlocks

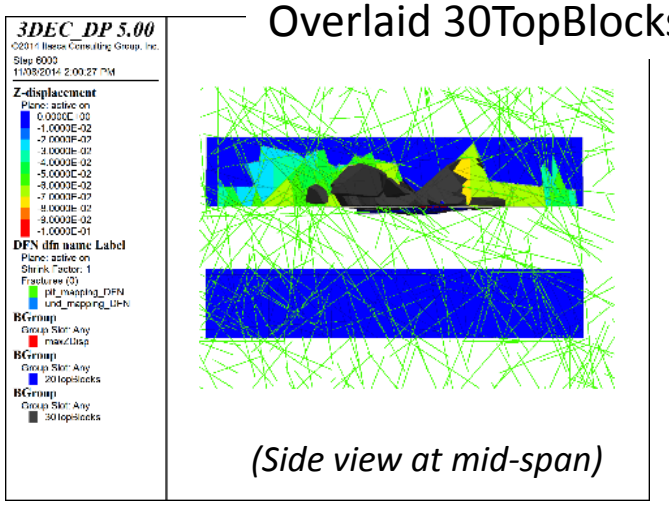


(Side view at mid-span)



(Plan view)

Overlaid 30TopBlocks



(Side view at mid-span)

First Series of Results

Based on the mapping completed by SRK in the open pit in 2013, and considering:

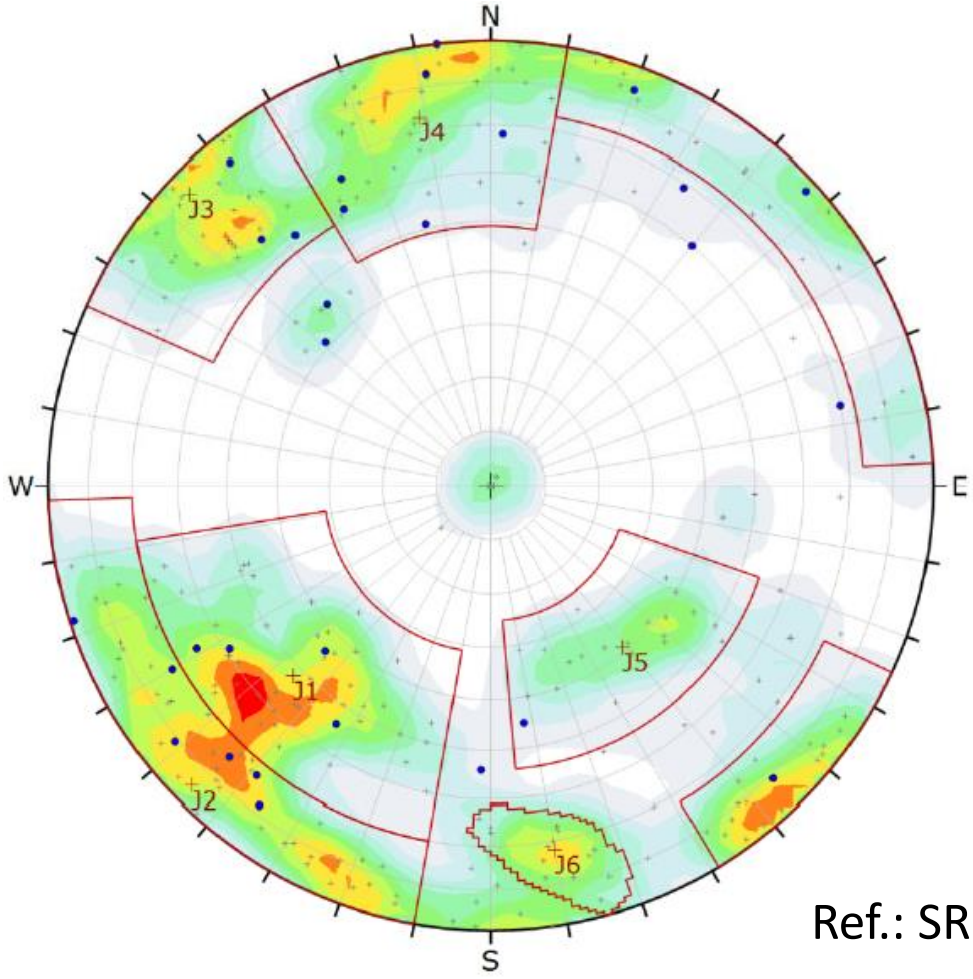
- *No ground support*
- *A joint friction angle of 25°*
- *A fracture length of 6 to 15m*

Five (5) realisations were completed with this scenario

Z displacement on a mid section

Overlaid Top 20% Blocks

Basic Mapping Data Considered



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+	Field	20
+	Field-FAI	3
+	Field-FT	4
+	Isite	223
+	Isite-FAI	5
+	Isite-FT	3
●	Isitex	29

Color	Density Concentrations
	0.00 - 0.41
	0.41 - 0.82
	0.82 - 1.23
	1.23 - 1.64
	1.64 - 2.05
	2.05 - 2.46
	2.46 - 2.87
	2.87 - 3.28
	3.28 - 3.69
	3.69 - 4.10

Maximum Density	4.01%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	287 (287 Entries)
Hemisphere	Lower
Projection	Equal Area

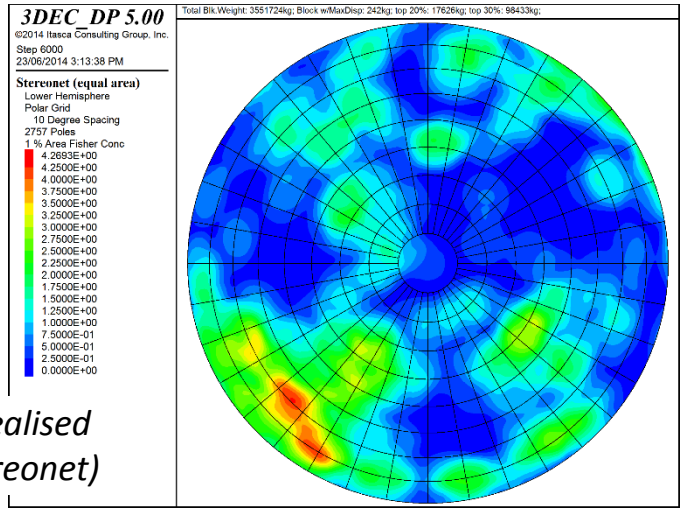
02APR2013_Update

Ref.: SRK Area 2 Pit Mapping (2013)

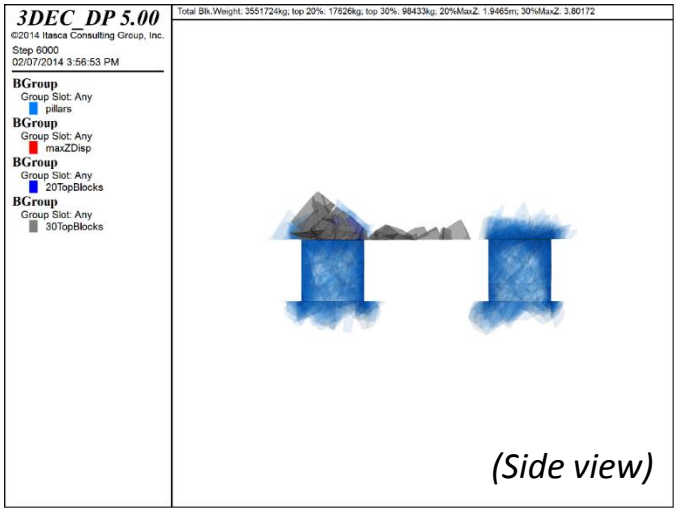
Z displacement on a mid section

Overlaid Top 20% Blocks

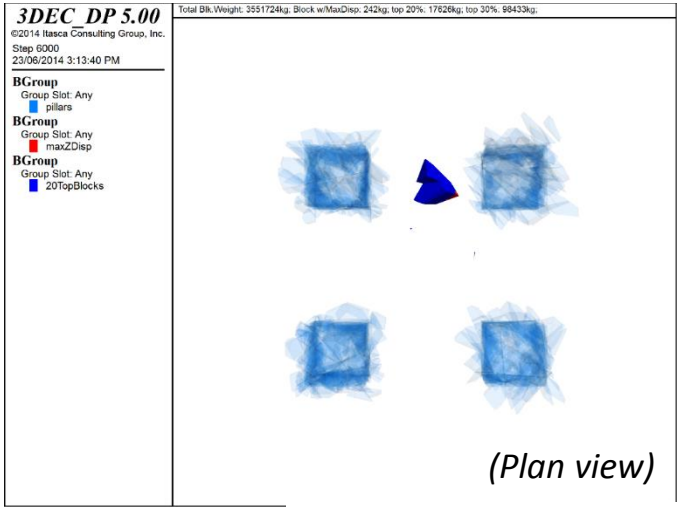
Results of Realisation #1



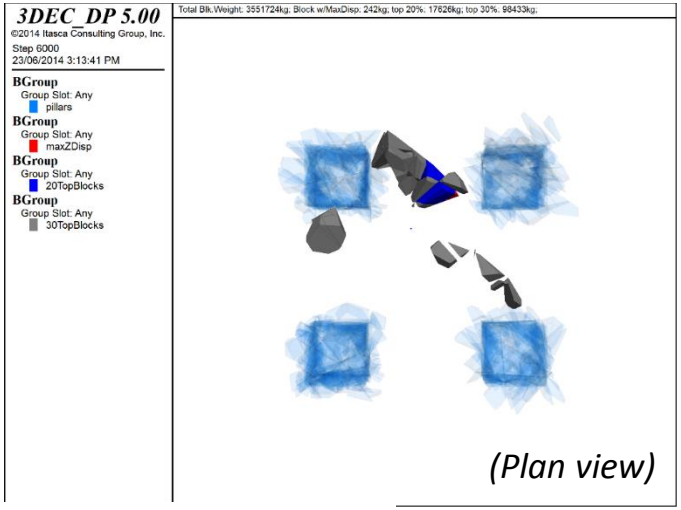
(Realised stereonet)



(Side view)



(Plan view)



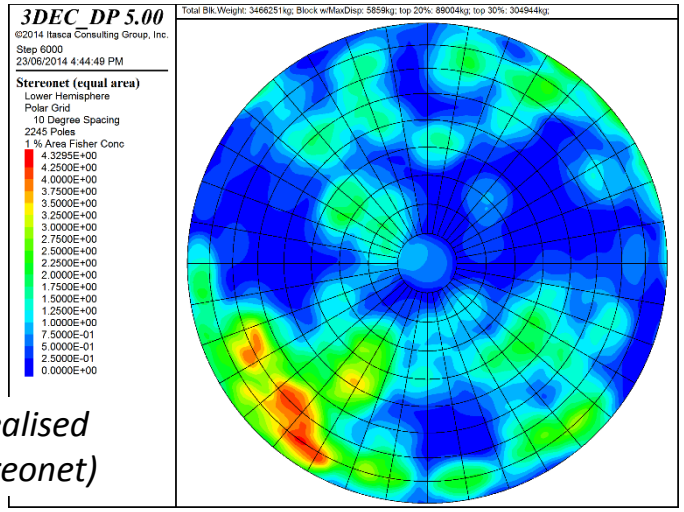
(Plan view)

Total bulk weight = 3,551.7 t, Block with MaxDisp = 242 kg
Top 20% = 17.6 t; Top 30% = 98.4 t

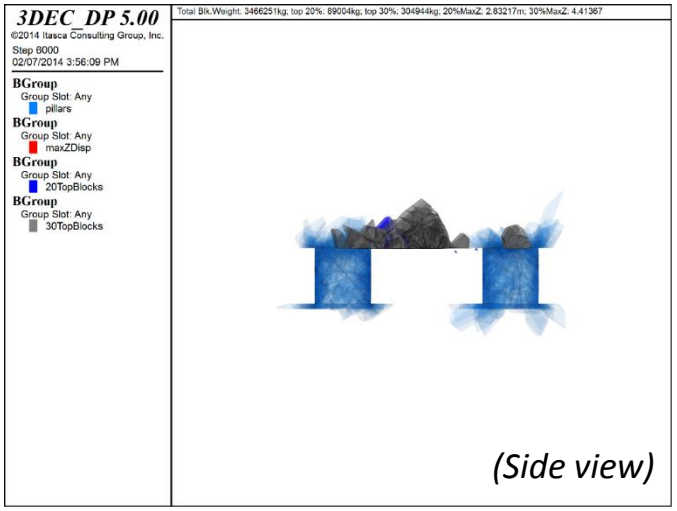
Z displacement on a mid section

Overlaid Top 20% Blocks

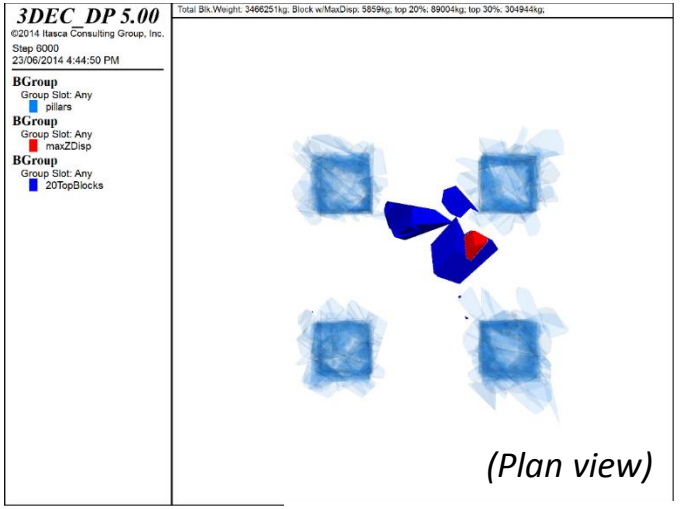
Results of Realisation #2



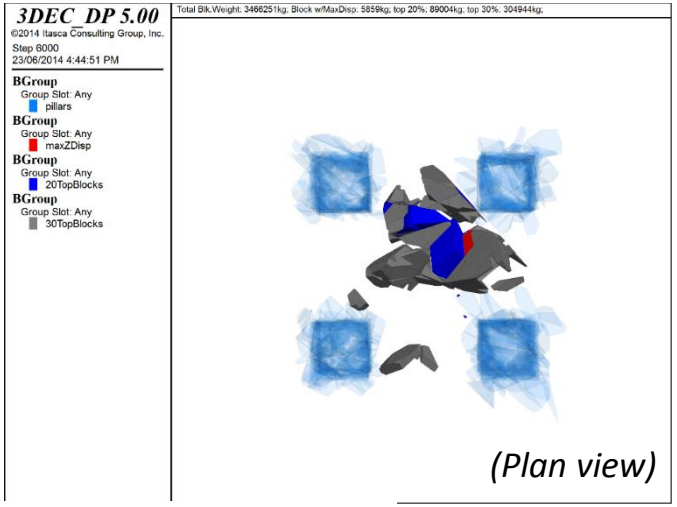
(Realised stereonet)



(Side view)



(Plan view)



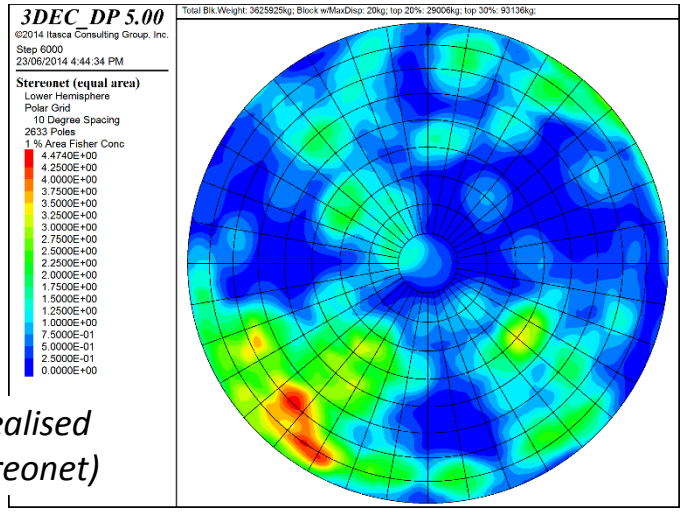
(Plan view)

Total bulk weight = 3,466.3 t, Block with MaxDisp = 5,859 kg
Top 20% = 89.0 t; Top 30% = 304.9 t

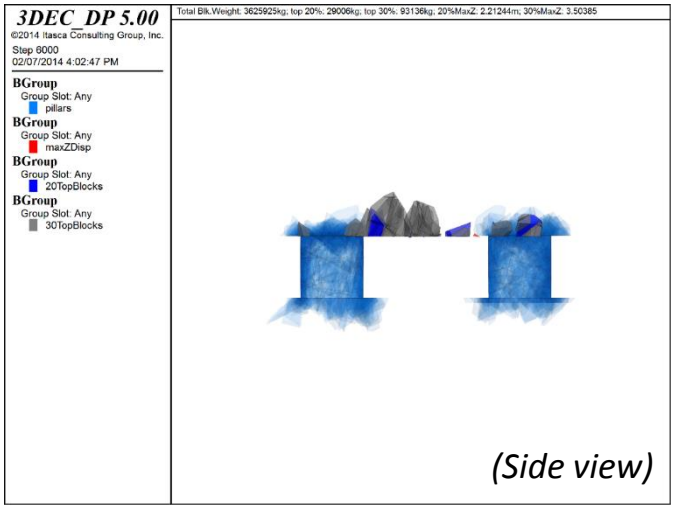
Z displacement on a mid section

Overlaid Top 20% Blocks

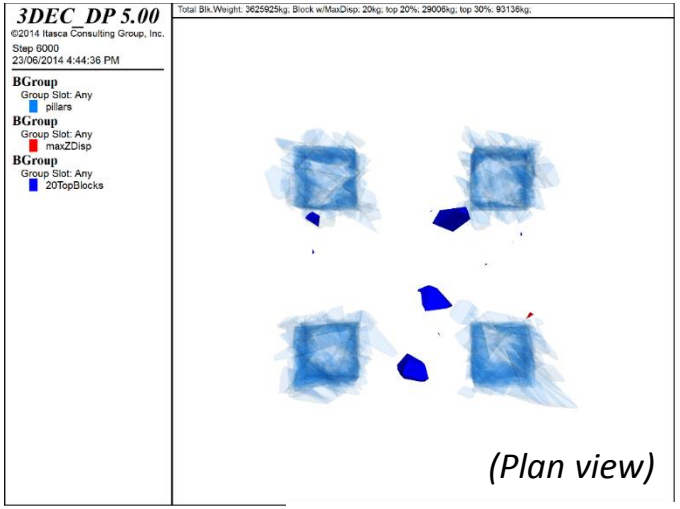
Results of Realisation #3



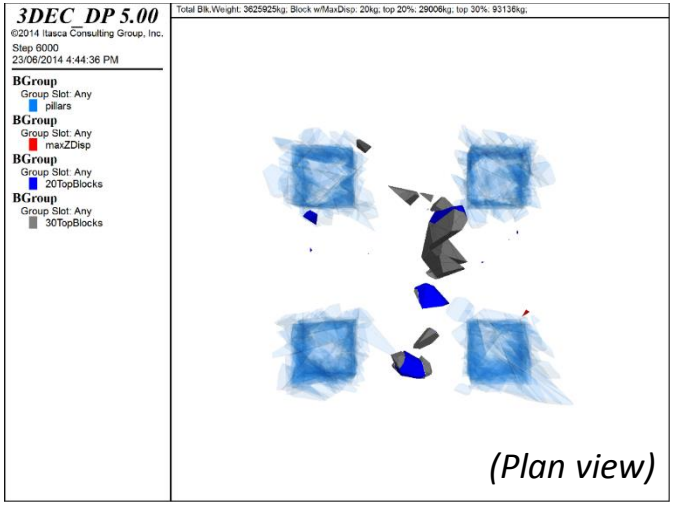
(Realised stereonet)



(Side view)



(Plan view)



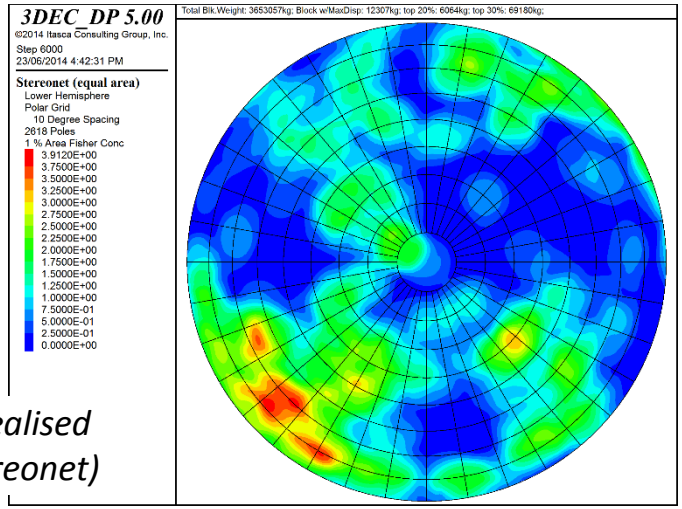
(Plan view)

Total bulk weight = 3,625.9 t, Block with MaxDisp = 20 kg
Top 20% = 29.0 t; Top 30% = 93.1 t

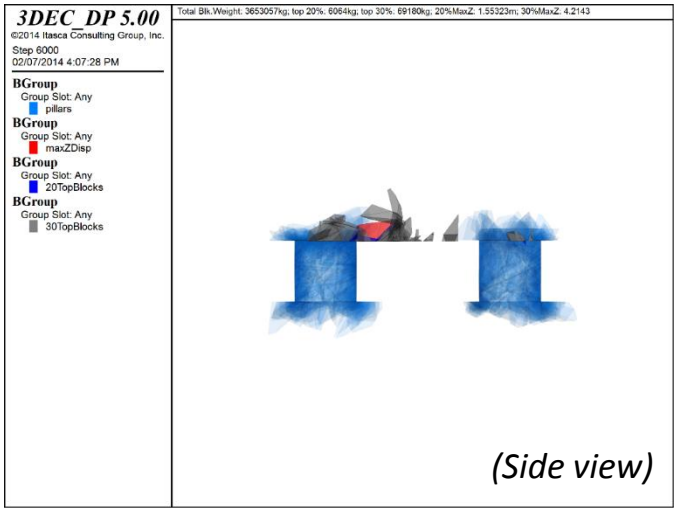
Z displacement on a mid section

Overlaid Top 20% Blocks

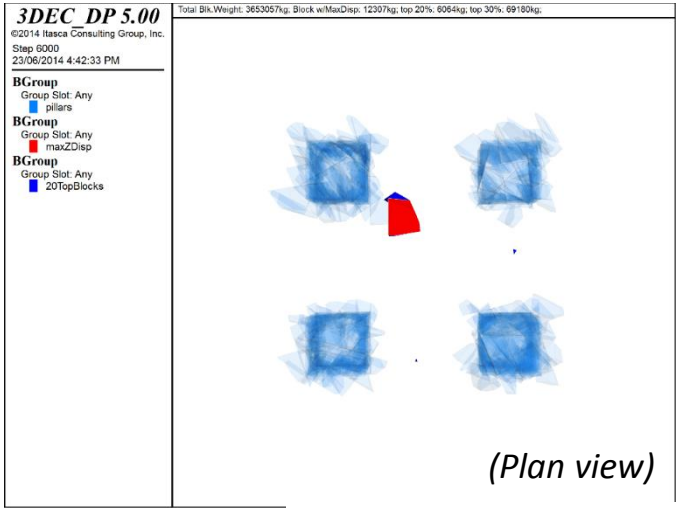
Results of Realisation #4



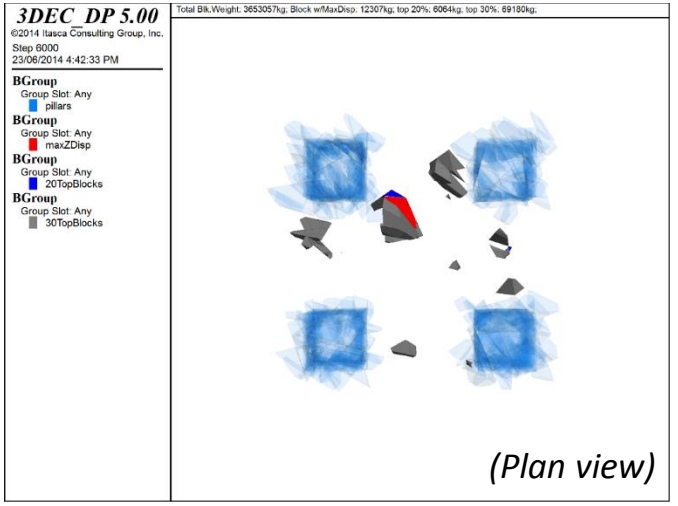
(Realised stereonet)



(Side view)



(Plan view)



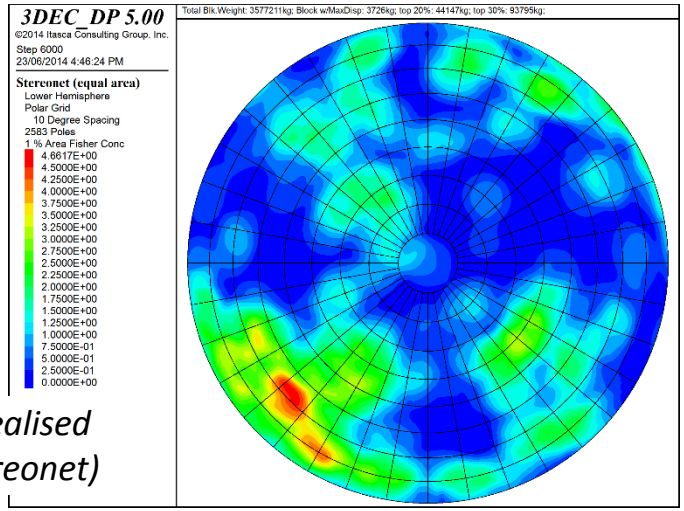
(Plan view)

Total bulk weight = 3,653.1 t, Block with MaxDisp = 12,307 kg
Top 20% = 6.1 t; Top 30% = 69.2 t

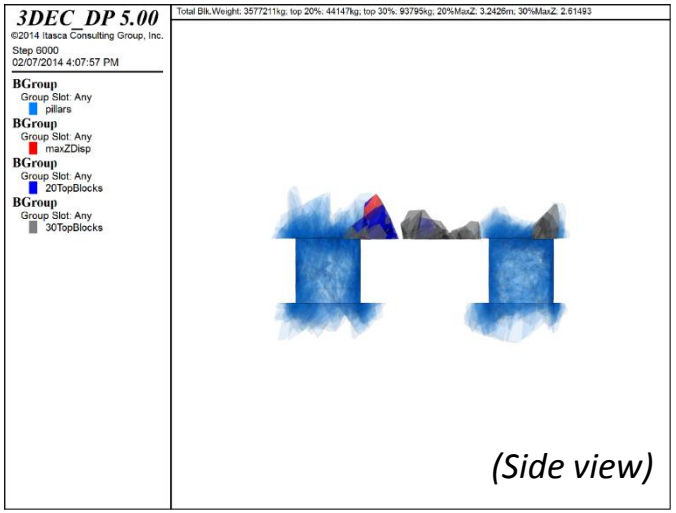
Z displacement on a mid section

Overlaid Top 20% Blocks

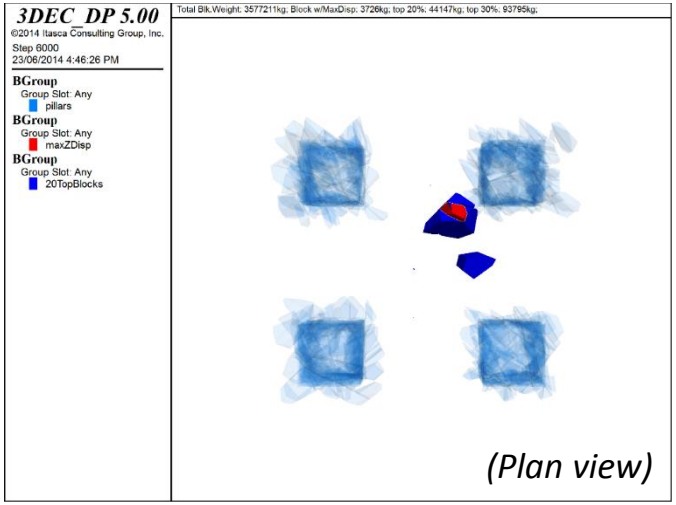
Results of Realisation #5



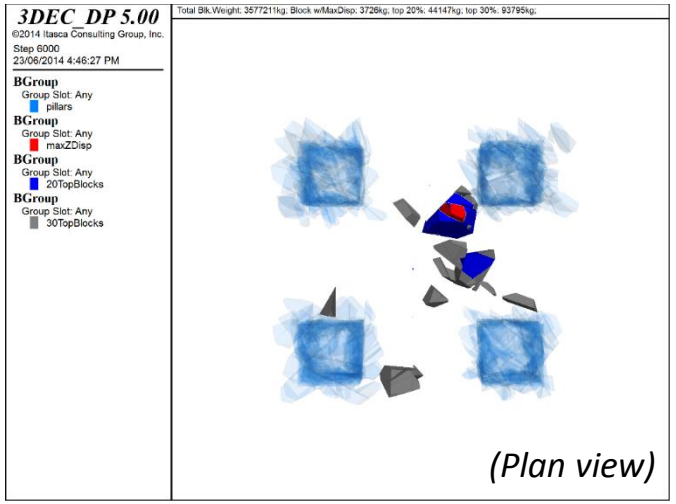
(Realised stereonet)



(Side view)



(Plan view)



(Plan view)

Total bulk weight = 3,577.2 t, Block with MaxDisp = 3,726 kg
Top 20% = 44.1 t; Top 30% = 93.8 t

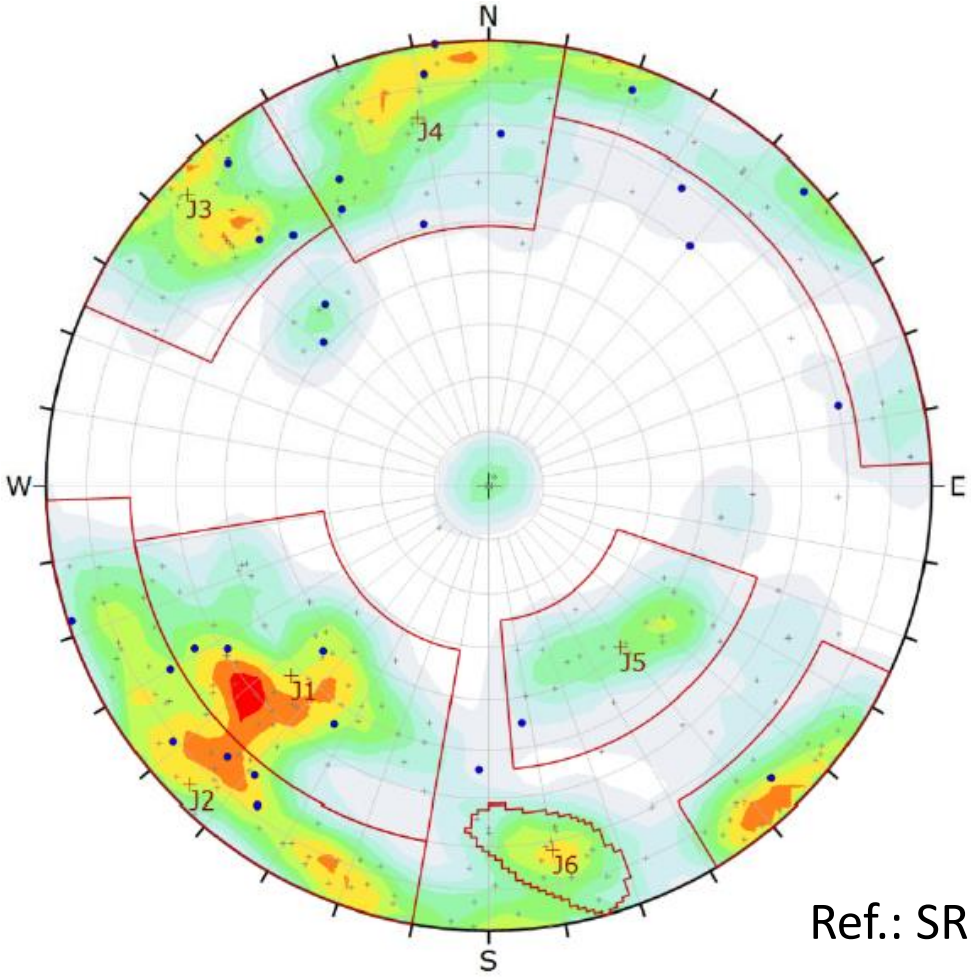
Second Series of Results

Based on the mapping completed by SRK in the open pit in 2013, and considering:

- *No ground support*
- *A joint friction angle of 30°*
- *A fracture length of 6 to 15m*

Five (5) realisations were completed with this scenario

Basic Mapping Data Considered



Symbol	SYMBOL	Quantity
+	Field	20
+	Field-FAI	3
+	Field-FT	4
+	Isite	223
+	Isite-FAI	5
+	Isite-FT	3
●	Isitex	29

Color	Density Concentrations
	0.00 - 0.41
	0.41 - 0.82
	0.82 - 1.23
	1.23 - 1.64
	1.64 - 2.05
	2.05 - 2.46
	2.46 - 2.87
	2.87 - 3.28
	3.28 - 3.69
	3.69 - 4.10

Maximum Density	4.01%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	287 (287 Entries)
Hemisphere	Lower
Projection	Equal Area

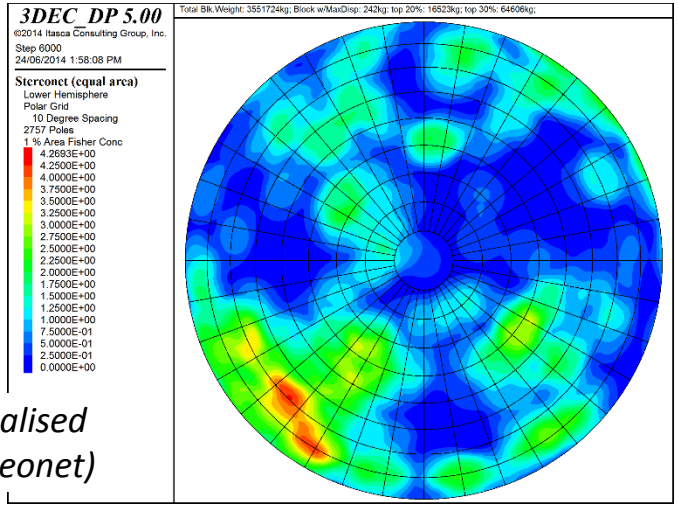
02APR2013_Update

Ref.: SRK Area 2 Pit Mapping (2013)

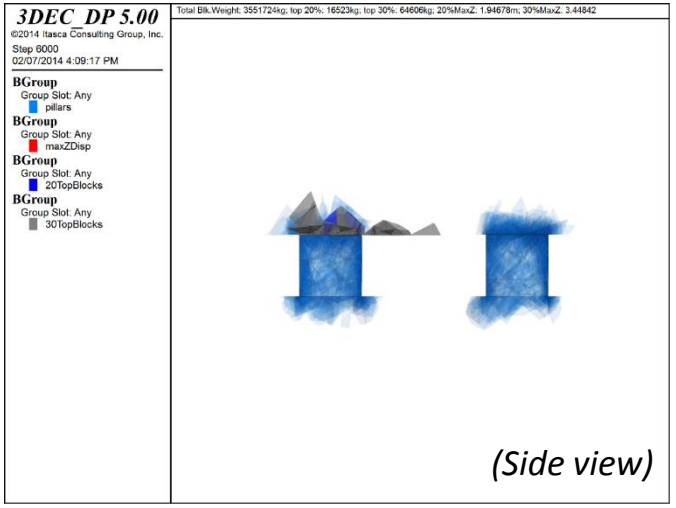
Z displacement on a mid section

Overlaid Top 20% Blocks

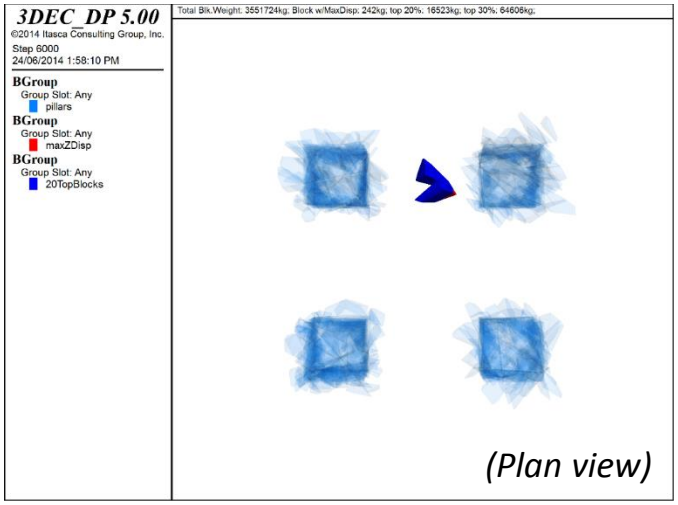
Results of Realisation #1



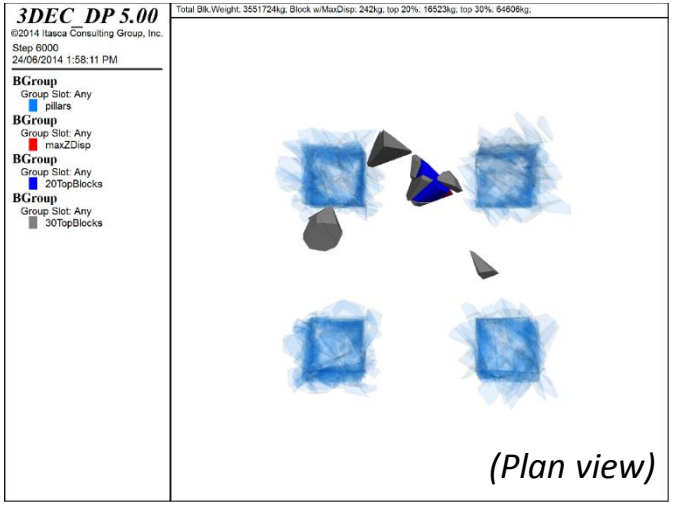
(Realised stereonet)



(Side view)



(Plan view)



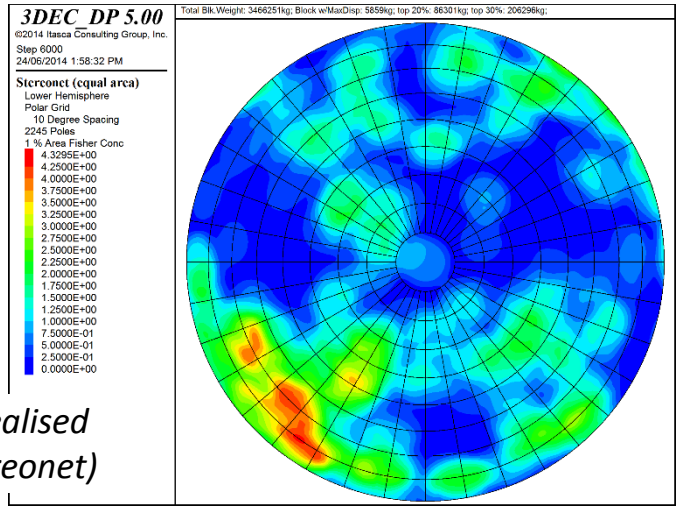
(Plan view)

Total bulk weight = 3,551.7 t, Block with MaxDisp = 242 kg
Top 20% = 16.5 t; Top 30% = 64.6 t

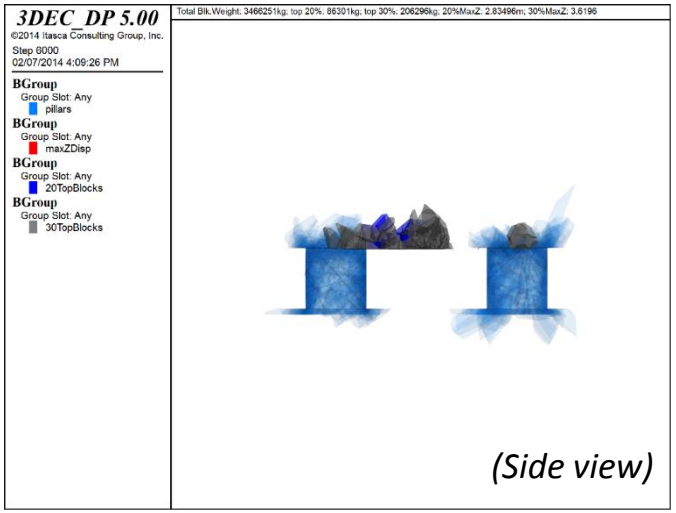
Z displacement on a mid section

Overlaid Top 20% Blocks

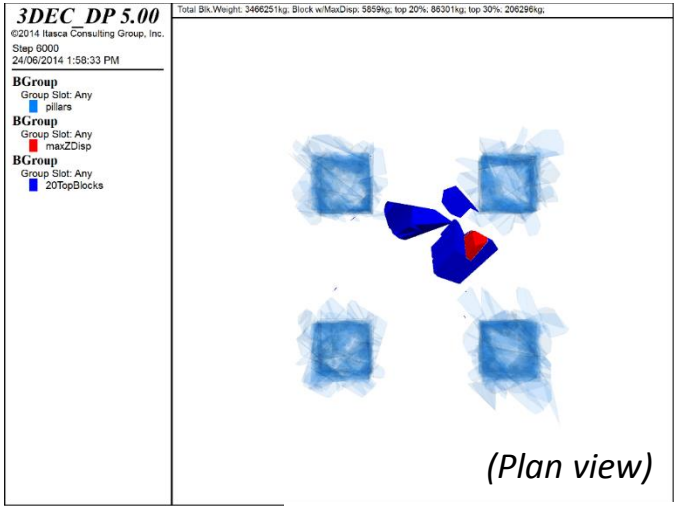
Results of Realisation #2



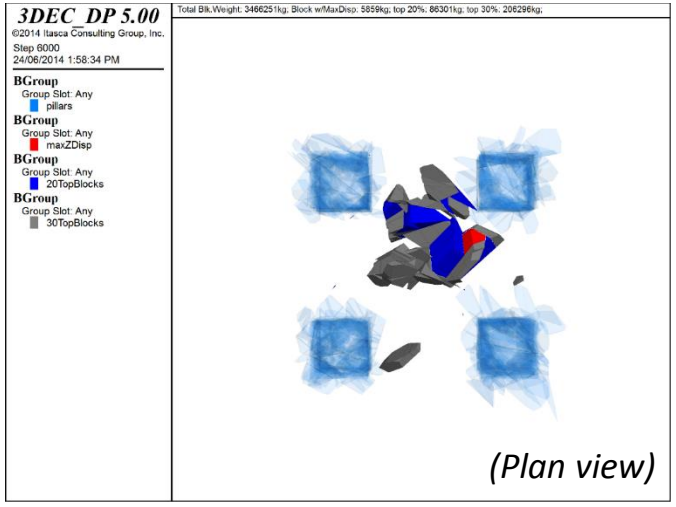
(Realised stereonet)



(Side view)



(Plan view)



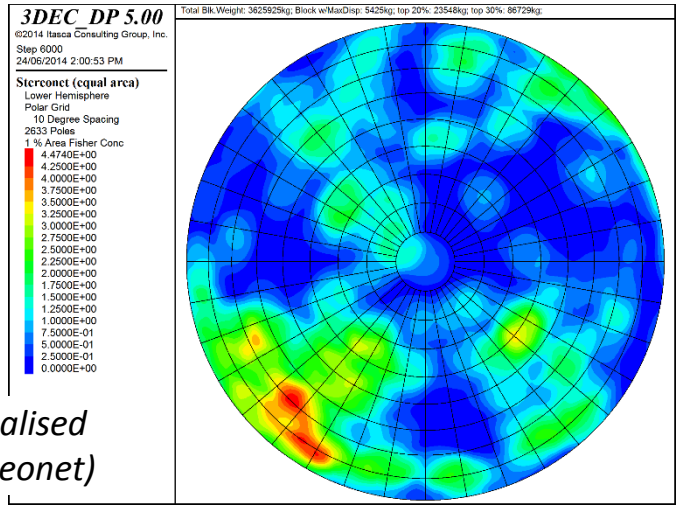
(Plan view)

Total bulk weight = 3,466.3 t, Block with MaxDisp = 5,859 kg
Top 20% = 86.3 t; Top 30% = 206.3 t

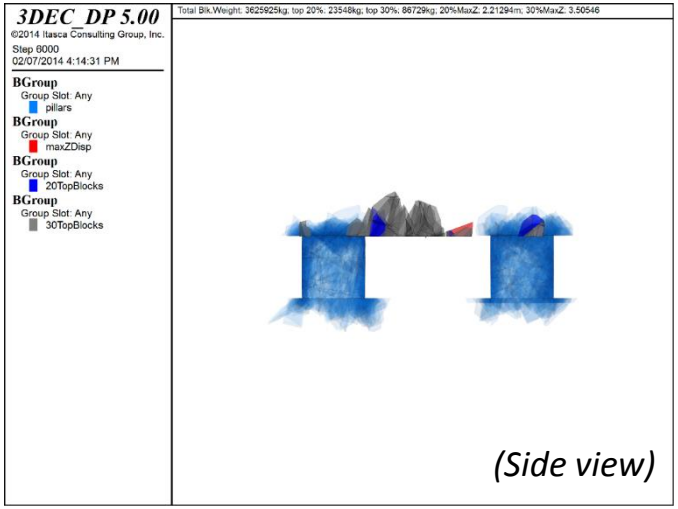
Z displacement on a mid section

Overlaid Top 20% Blocks

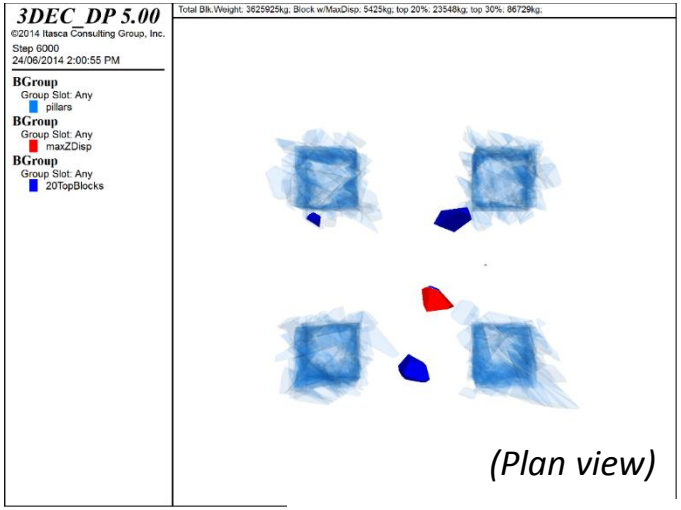
Results of Realisation #3



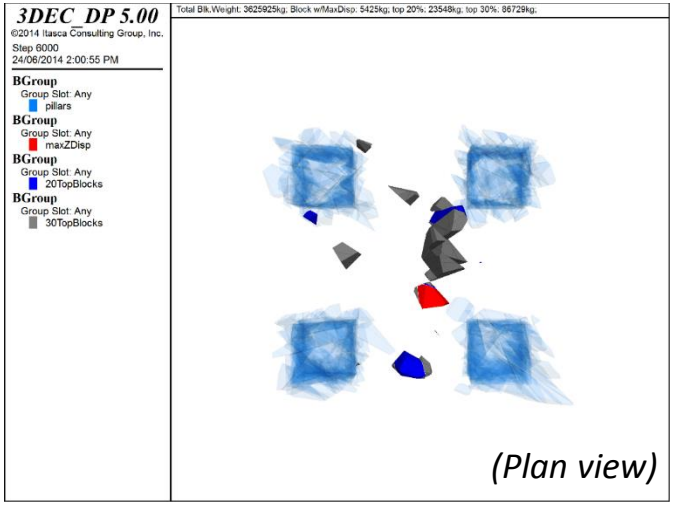
(Realised stereonet)



(Side view)



(Plan view)



(Plan view)

Total bulk weight = 3,625.9 t, Block with MaxDisp = 5,425 kg
Top 20% = 23.5 t; Top 30% = 86.7 t

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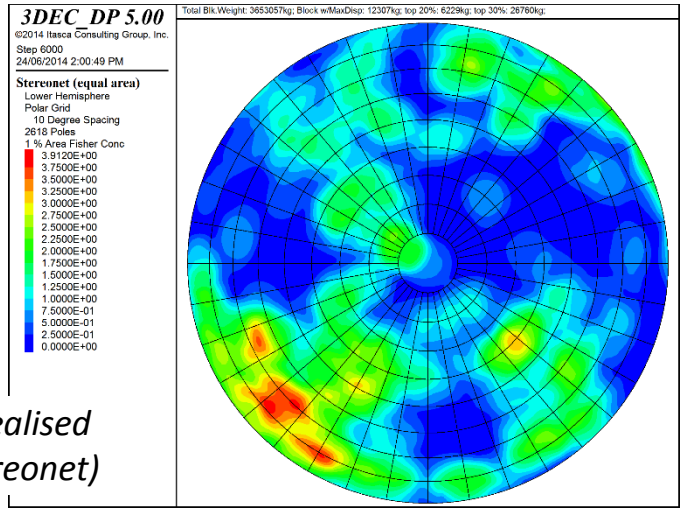
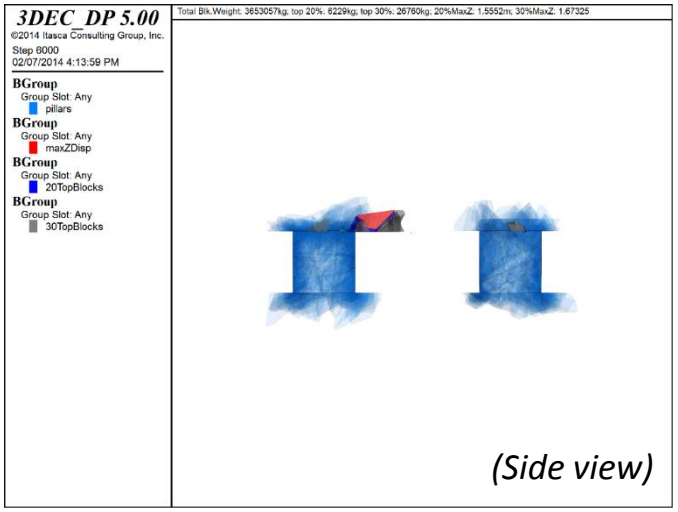
Z displacement on a mid section

Overlaid Top 20% Blocks

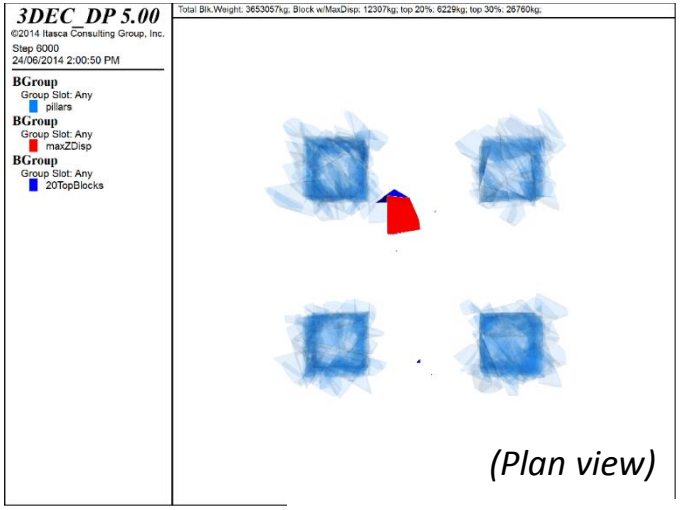
Results of Realisation #4



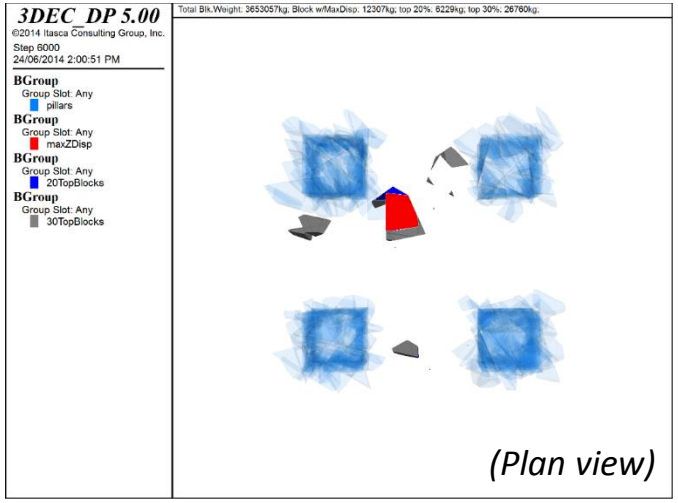
(Realised stereonet)



(Side view)



(Plan view)



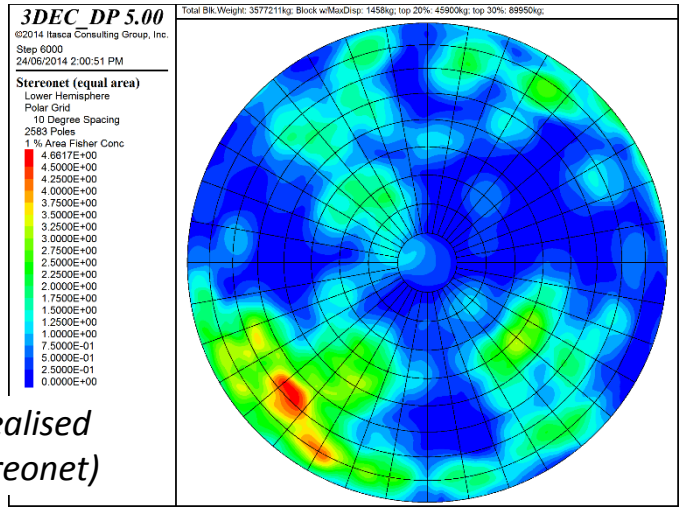
(Plan view)

Total bulk weight = 3,653.1 t, Block with MaxDisp = 12,307 kg
Top 20% = 6.3 t; Top 30% = 26.8 t

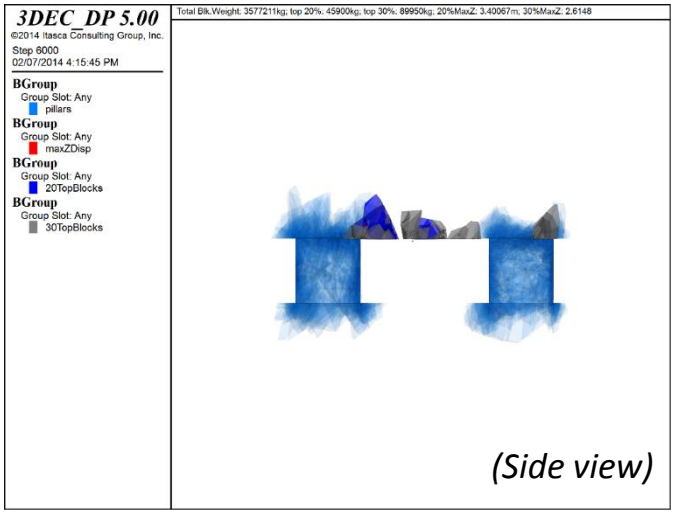
Z displacement on a mid section

Overlaid Top 20% Blocks

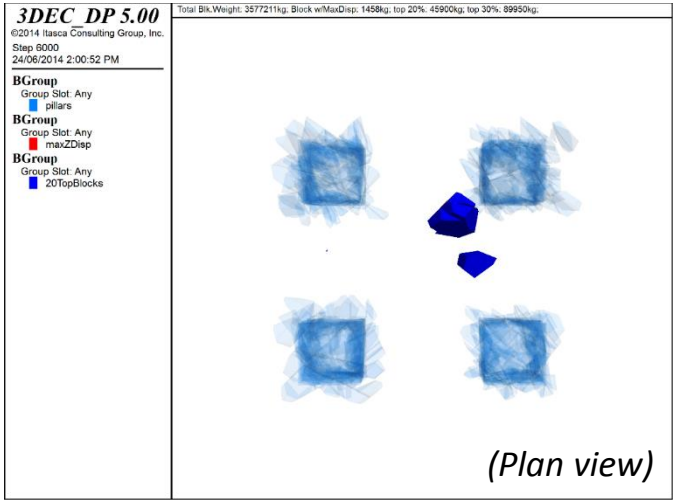
Results of Realisation #5



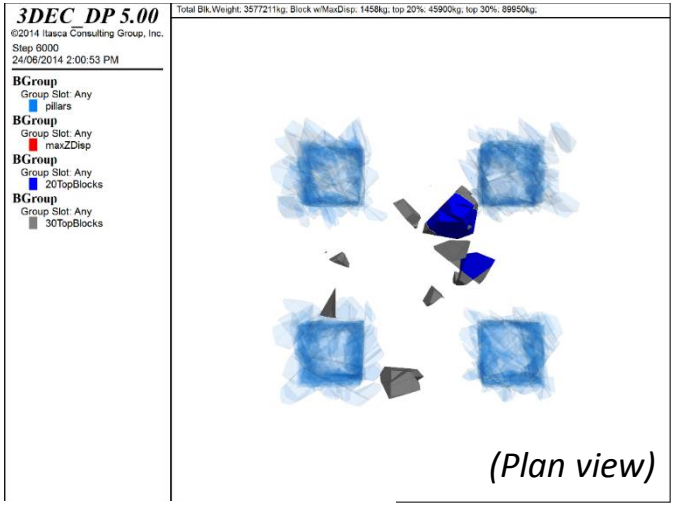
(Realised stereonet)



(Side view)



(Plan view)



(Plan view)

Total bulk weight = 3,577.2 t, Block with MaxDisp = 1,458 kg
Top 20% = 45.9 t; Top 30% = 90.0 t

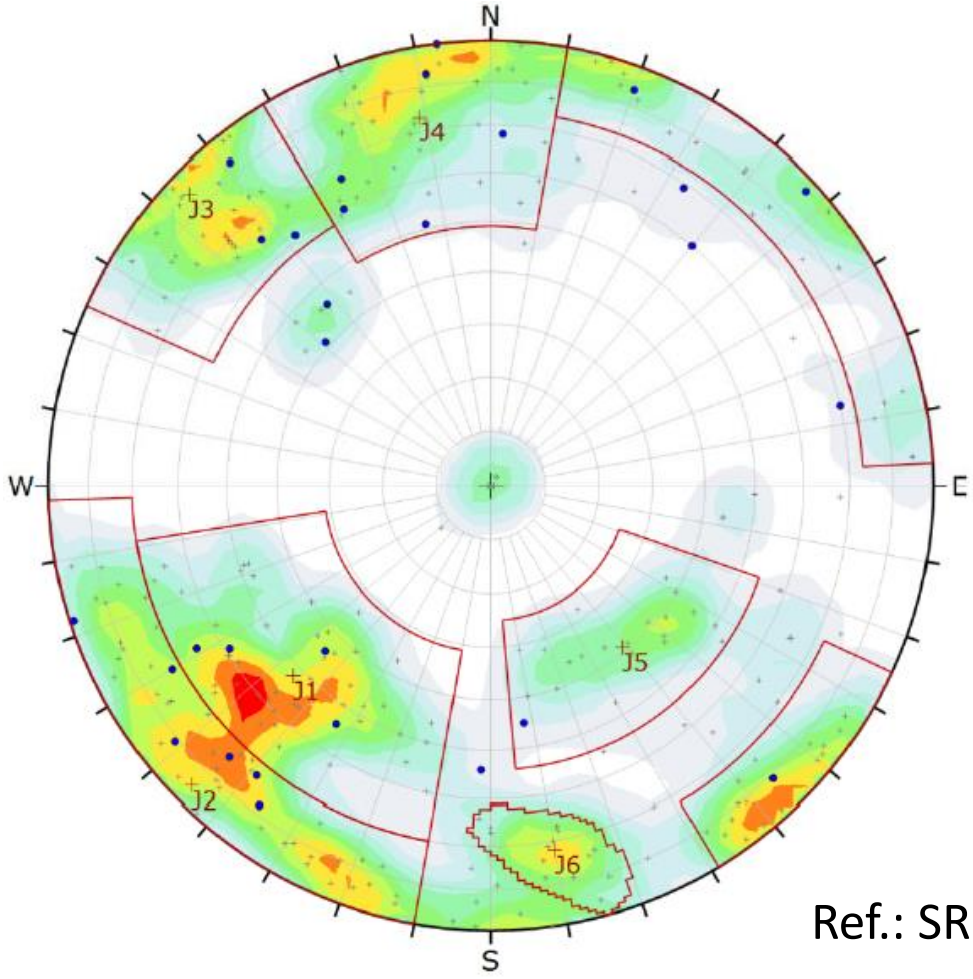
Third Series of Results

Based on the mapping completed by SRK in the open pit in 2013, and considering:

- *No ground support*
- *A joint friction angle of 25°*
- *An infinite fracture length*

Five (5) realisations were completed with this scenario

Basic Mapping Data Considered



Symbol	SYMBOL	Quantity
+	Field	20
+	Field-FAI	3
+	Field-FT	4
+	Isite	223
+	Isite-FAI	5
+	Isite-FT	3
●	Isitex	29

Color	Density Concentrations
	0.00 - 0.41
	0.41 - 0.82
	0.82 - 1.23
	1.23 - 1.64
	1.64 - 2.05
	2.05 - 2.46
	2.46 - 2.87
	2.87 - 3.28
	3.28 - 3.69
	3.69 - 4.10

Maximum Density	4.01%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	287 (287 Entries)
Hemisphere	Lower
Projection	Equal Area

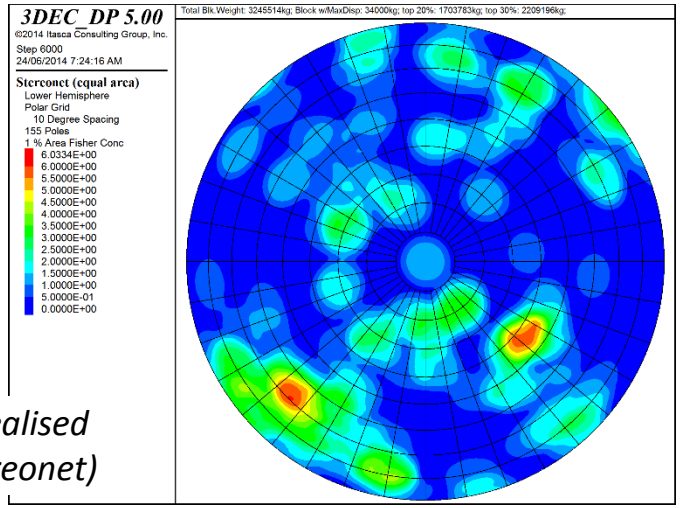
02APR2013_Update

Ref.: SRK Area 2 Pit Mapping (2013)

Z displacement on a mid section

Overlaid Top 20% Blocks

Results of Realisation #1



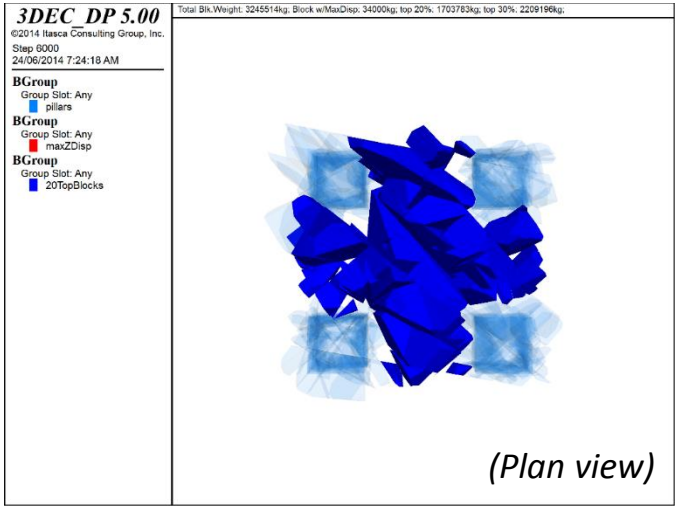
(Realised stereonet)

Total bulk weight = 3,245.5 t

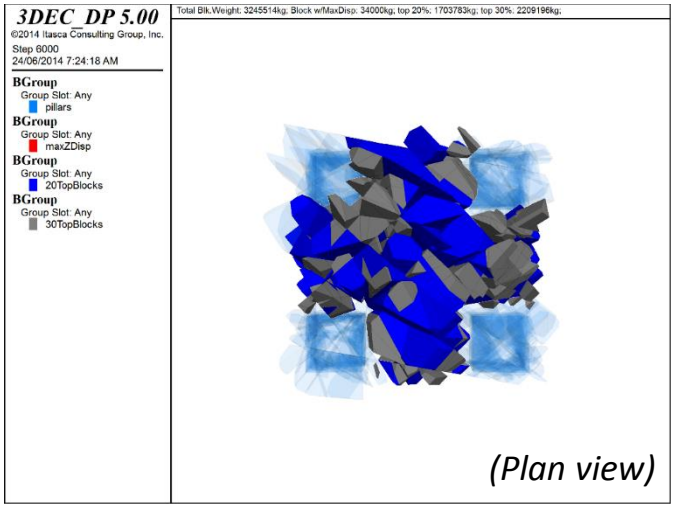
Block with MaxDisp = 34,000 kg

Top 20% = 1,703.8 t

Top 30% = 2,209.2 t



(Plan view)

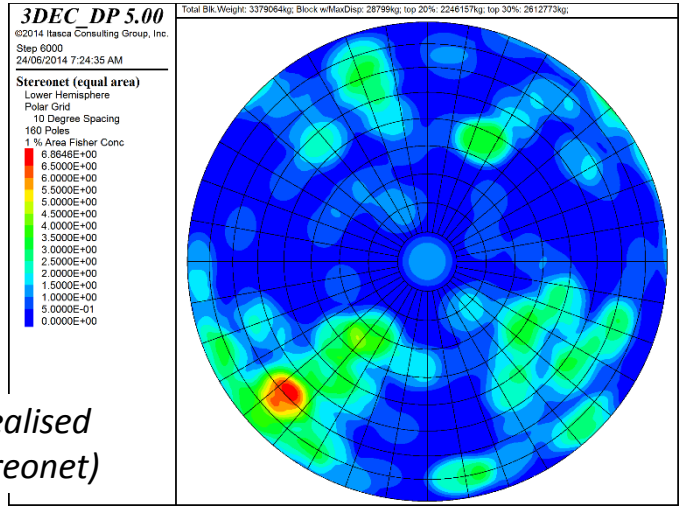


(Plan view)

Z displacement on a mid section

Overlaid Top 20% Blocks

Results of Realisation #2



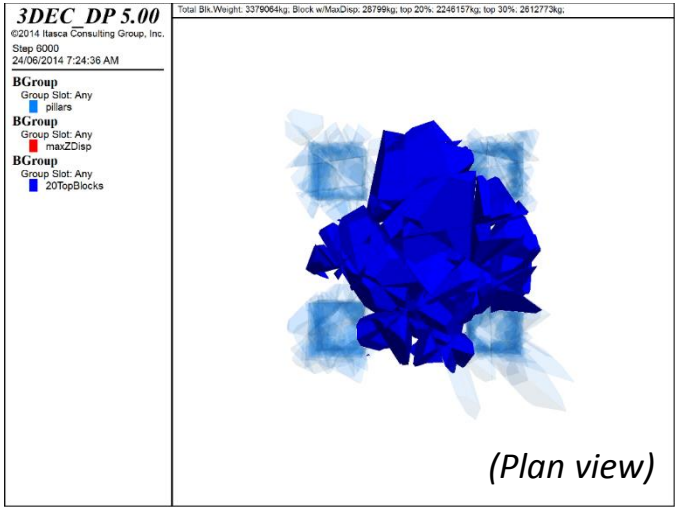
(Realised stereonet)

Total bulk weight = 3,379.1 t

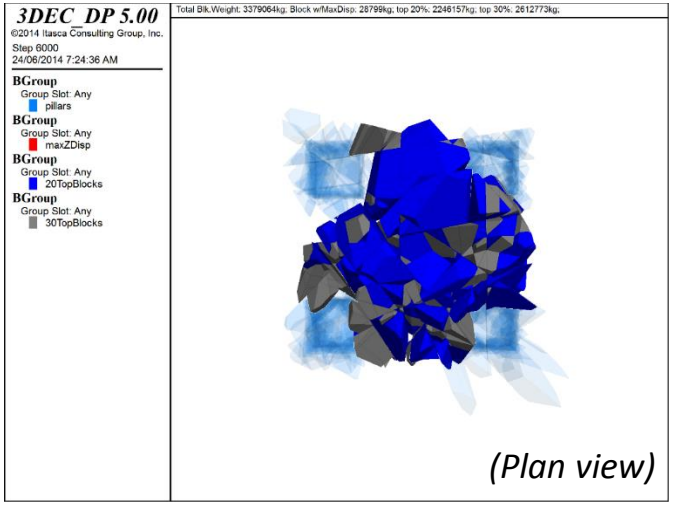
Block with MaxDisp = 28,799 kg

Top 20% = 2,246.2 t

Top 30% = 2,6128 t



(Plan view)

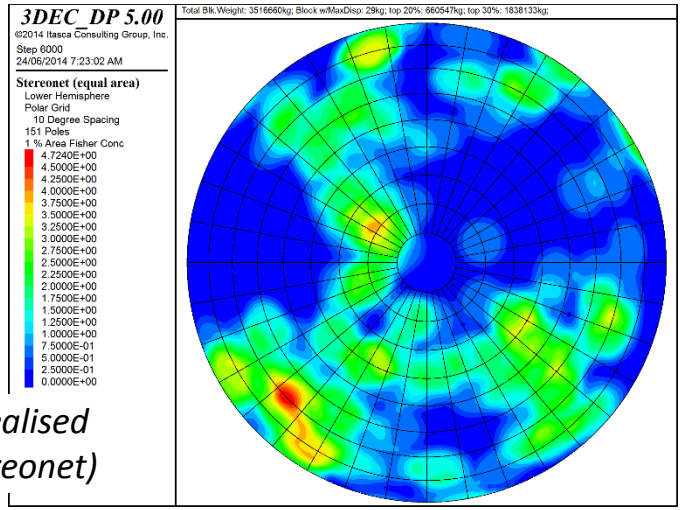


(Plan view)

Z displacement on a mid section

Overlaid Top 20% Blocks

Results of Realisation #3



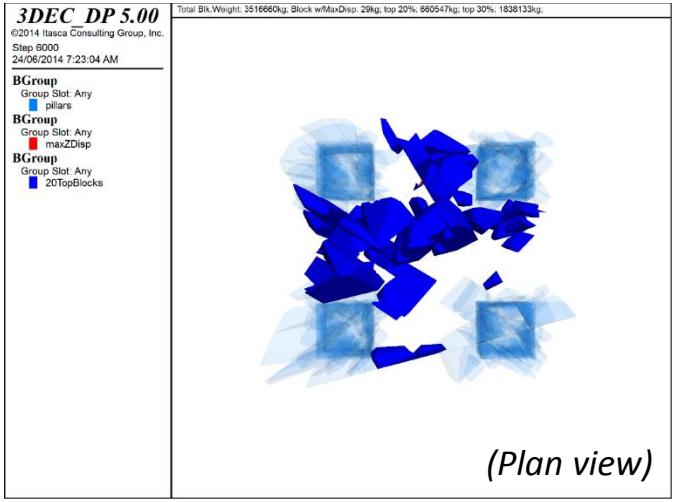
(Realised stereonet)

Total bulk weight = 3,516.7 t

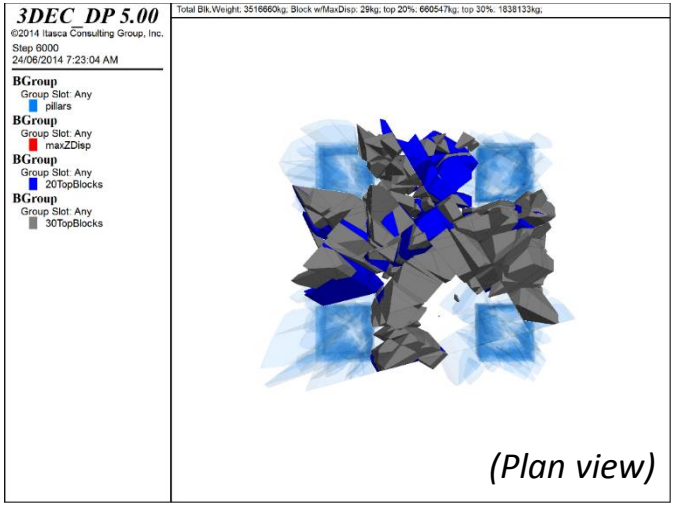
Block with MaxDisp = 29 kg

Top 20% = 660.5 t

Top 30% = 1,838.1 t



(Plan view)

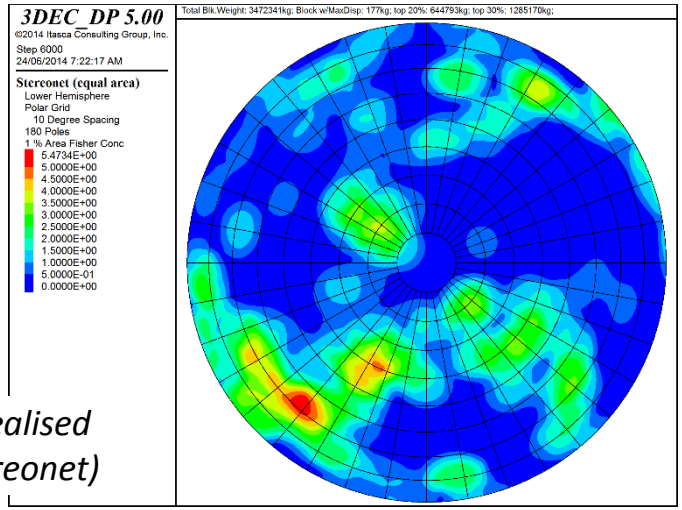


(Plan view)

Z displacement on a mid section

Overlaid Top 20% Blocks

Results of Realisation #4



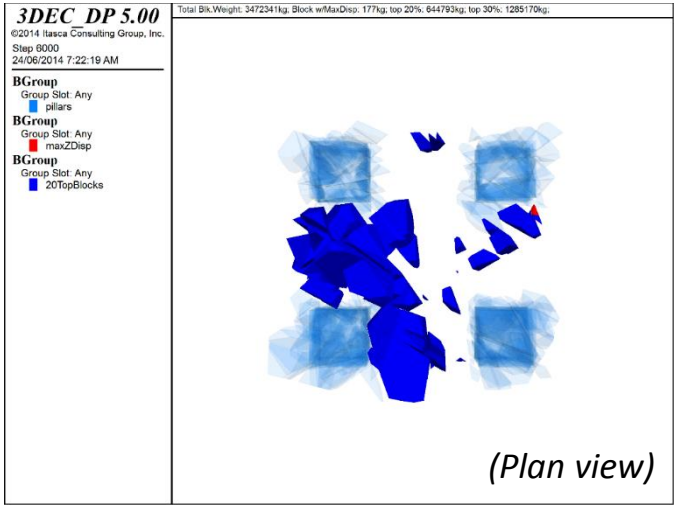
(Realised stereonet)

Total bulk weight = 3,472.3 t

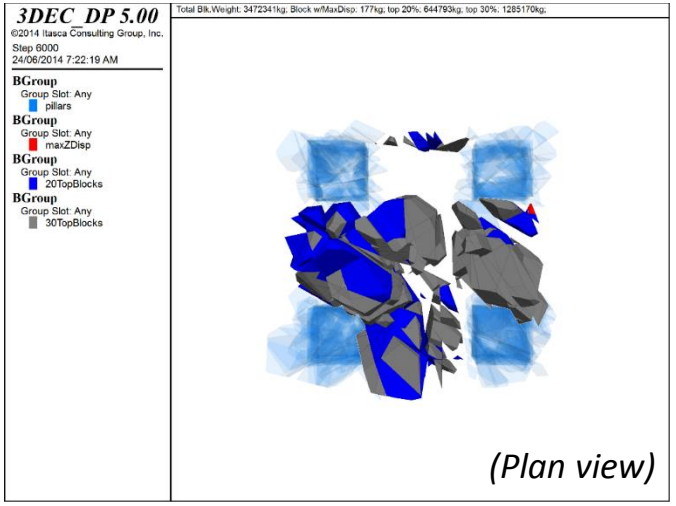
Block with MaxDisp = 177 kg

Top 20% = 644.8 t

Top 30% = 1,285.2 t



(Plan view)

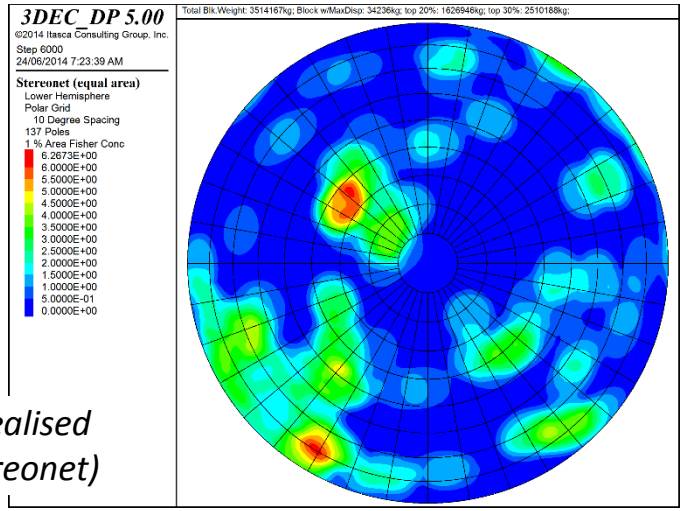


(Plan view)

Z displacement on a mid section

Overlaid Top 20% Blocks

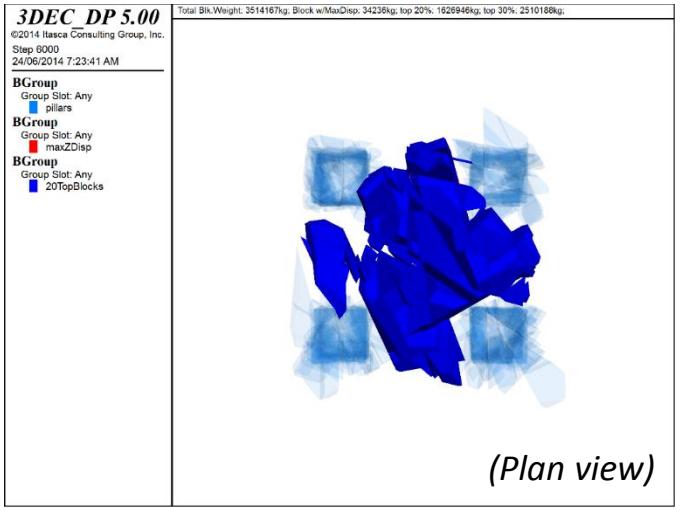
Results of Realisation #5



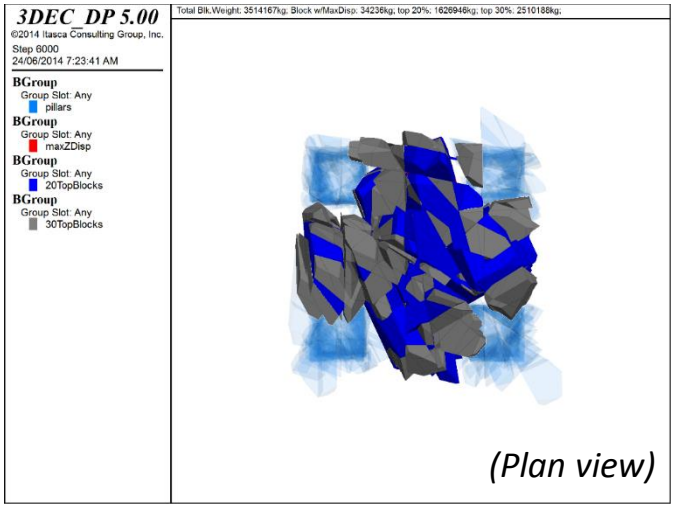
(Realised stereonet)

Total bulk weight = 3,514.2 t
Block with MaxDisp = 34,236 kg
Top 20% = 1,626.9 t
Top 30% = 2,510.2 t

Considering infinitely persistent joints (without intact rock bridges in between) results in many more and much larger unstable blocks



(Plan view)



(Plan view)

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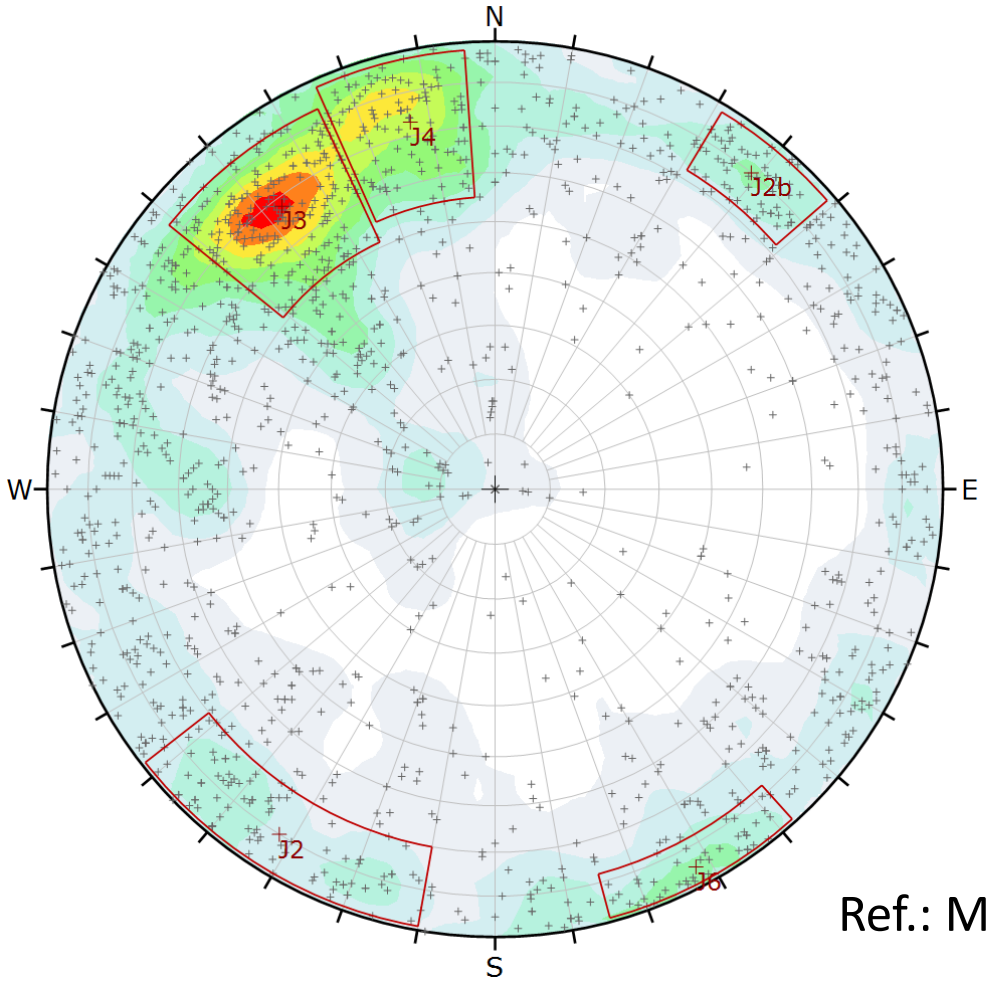
Fourth Series of Results

Based on the mapping completed underground in the 118 and M zones, and considering:

- *No ground support*
- *A joint friction angle of 25°*
- *An fracture length of 6 to 15m*

Five (5) realisations were completed with this scenario

Basic Mapping Data Considered



Symbol	Feature
+	Pole Vectors

Color	Density Concentrations
	0.00 - 0.50
	0.50 - 1.00
	1.00 - 1.50
	1.50 - 2.00
	2.00 - 2.50
	2.50 - 3.00
	3.00 - 3.50
	3.50 - 4.00
	4.00 - 4.50
	4.50 - 5.00

Maximum Density	4.78%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

	Color	Dip	Dip Direction	Label
Mean Set Planes				
1w		80	32	J2
2w		68	143	J3
3w		73	167	J4
4w		80	219	J2b
5w		85	332	J6

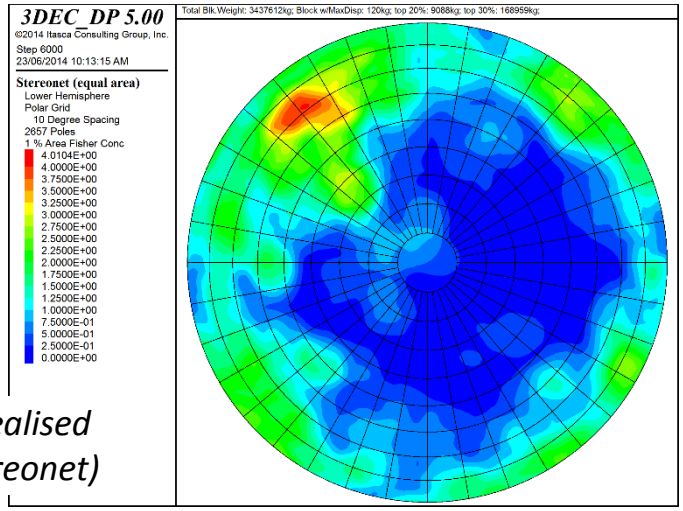
Plot Mode	Pole Vectors
Vector Count	1374 (1374 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Hemisphere	Lower
Projection	Equal Area

Ref.: Minto underground mapping

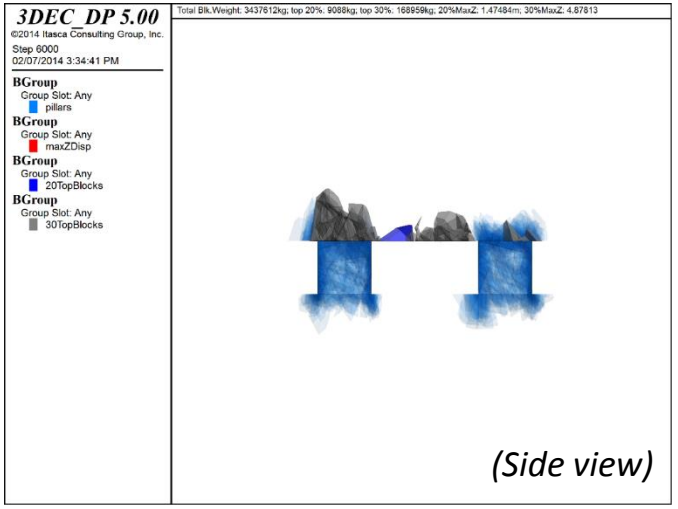
Z displacement on a mid section

Overlaid Top 20% Blocks

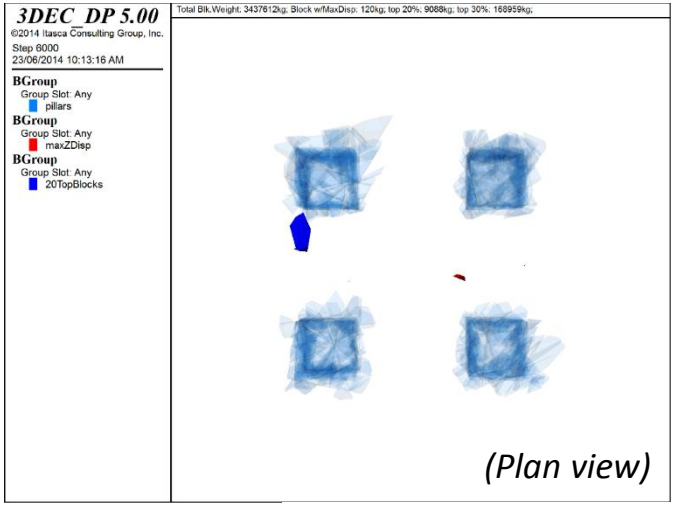
Results of Realisation #1



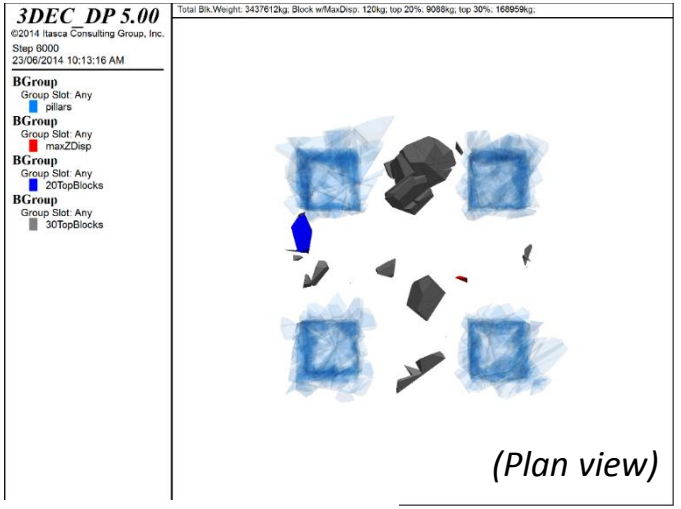
(Realised stereonet)



(Side view)



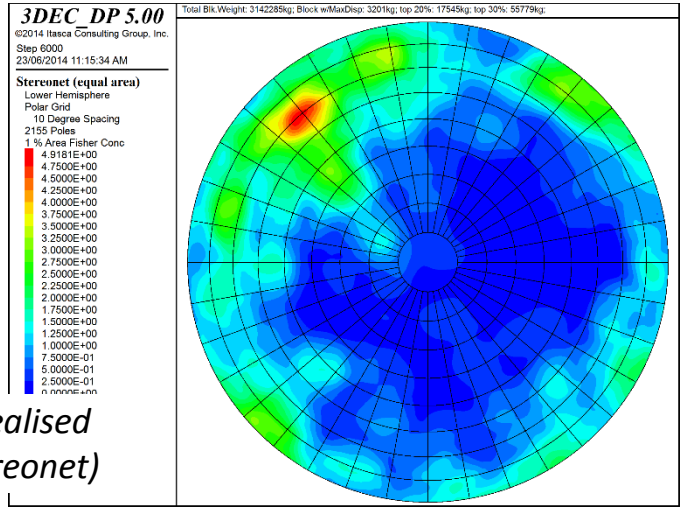
(Plan view)



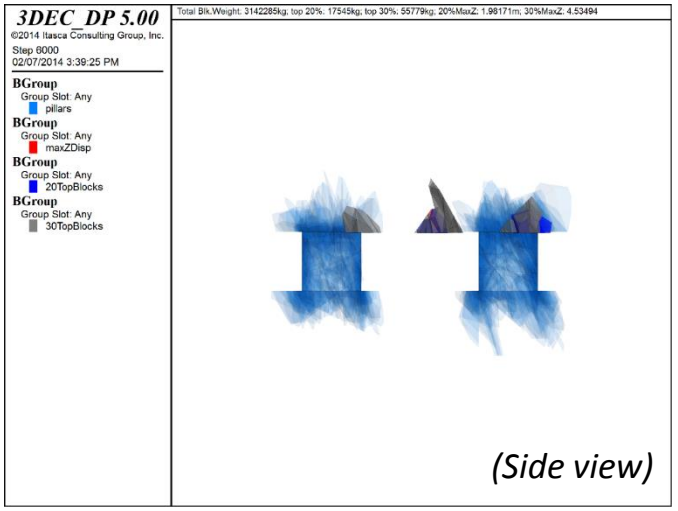
(Plan view)

Total bulk weight = 3,437.6 t, Block with MaxDisp = 120 kg
Top 20% = 9.1 t; Top 30% = 169.0 t

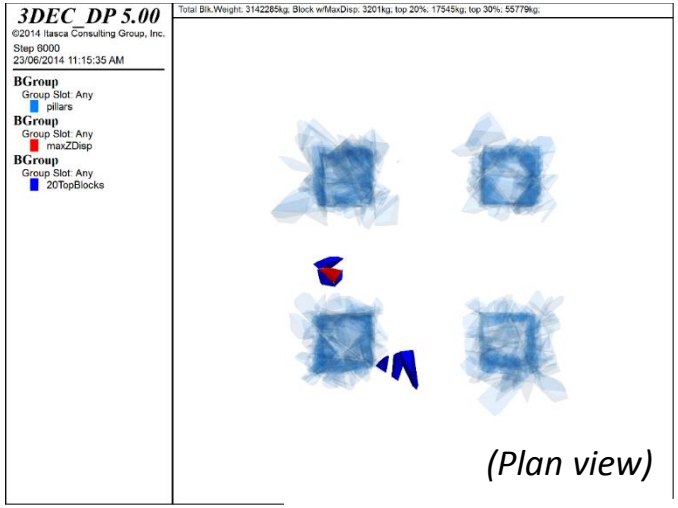
Results of Realisation #2



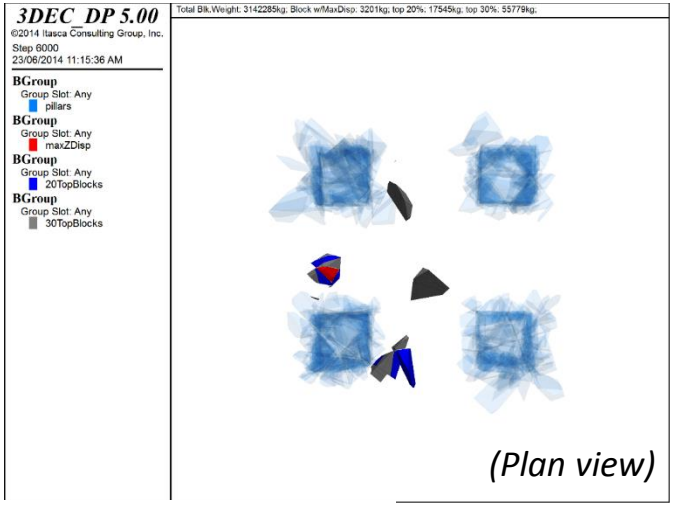
(Realised stereonet)



(Side view)



(Plan view)



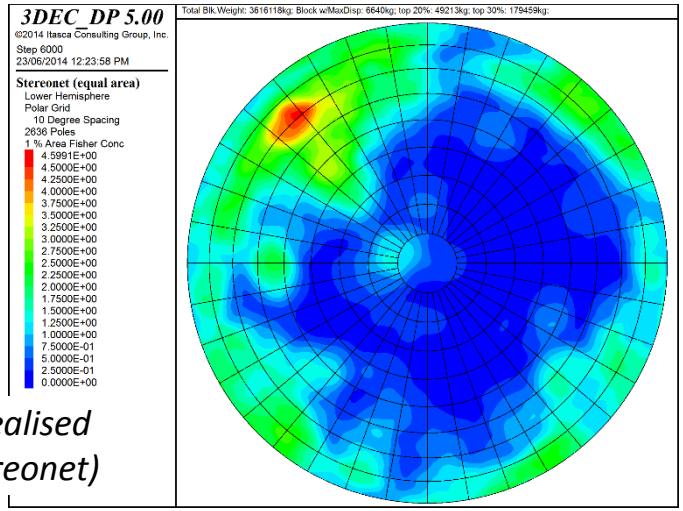
(Plan view)

Total bulk weight = 3,142.3 t, Block with MaxDisp = 3,201 kg
Top 20% = 17.5 t; Top 30% = 55.8 t

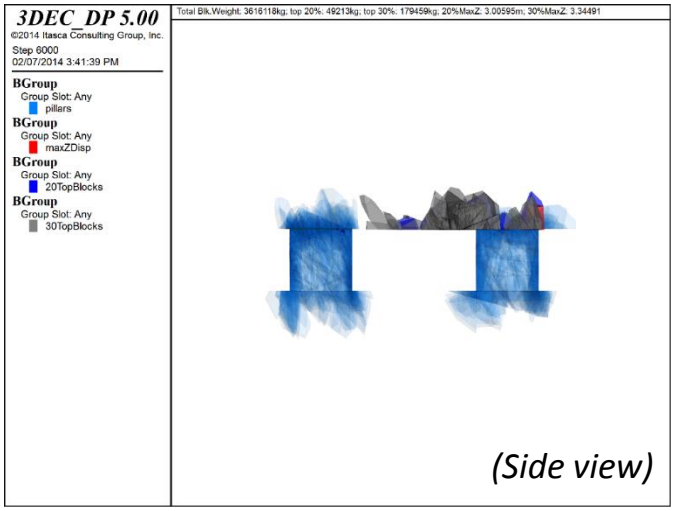
Z displacement on a mid section

Overlaid Top 20% Blocks

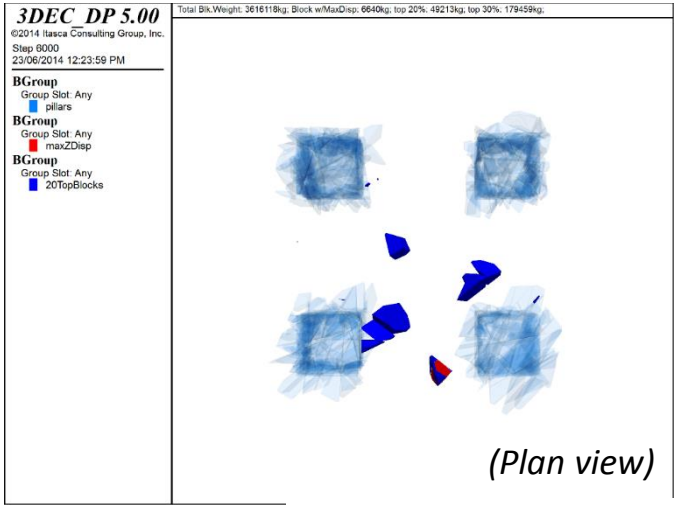
Results of Realisation #3



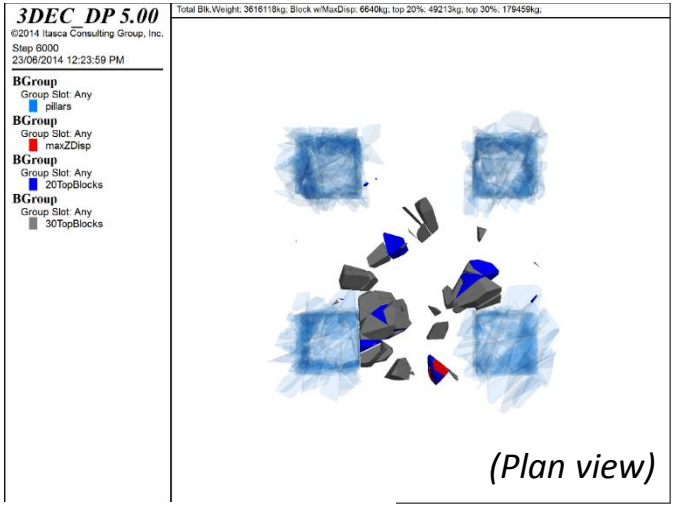
(Realised stereonet)



(Side view)



(Plan view)



(Plan view)

Total bulk weight = 3,616.2 t, Block with MaxDisp = 6,640 kg
Top 20% = 49.2 t; Top 30% = 179.5 t

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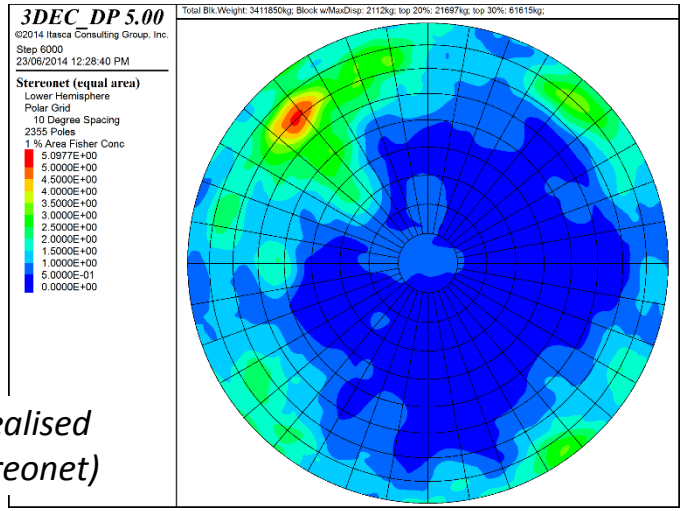
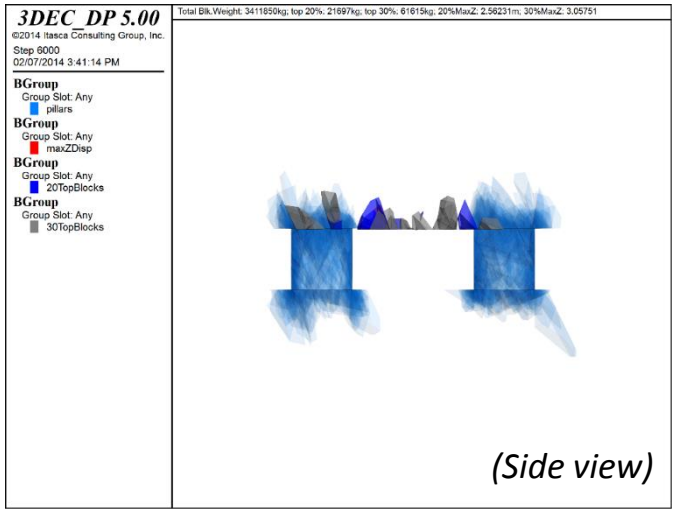
Z displacement on a mid section

Overlaid Top 20% Blocks

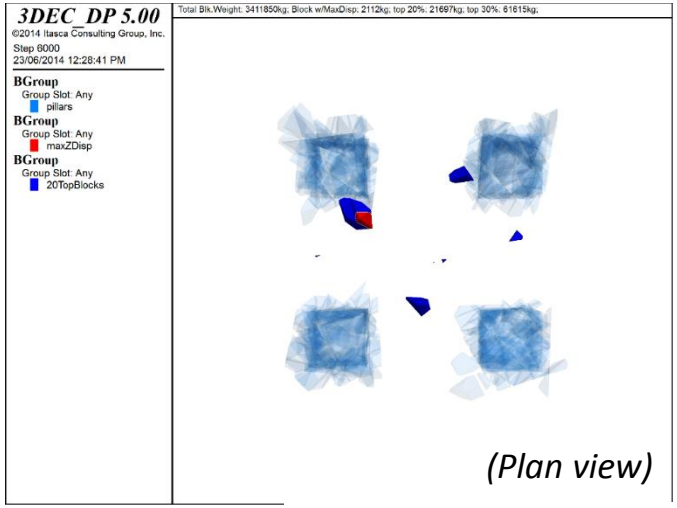
Results of Realisation #4



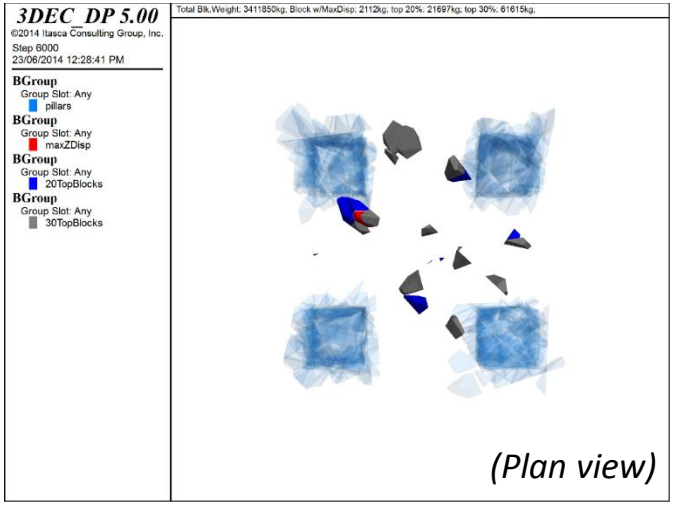
(Realised stereonet)



(Side view)



(Plan view)



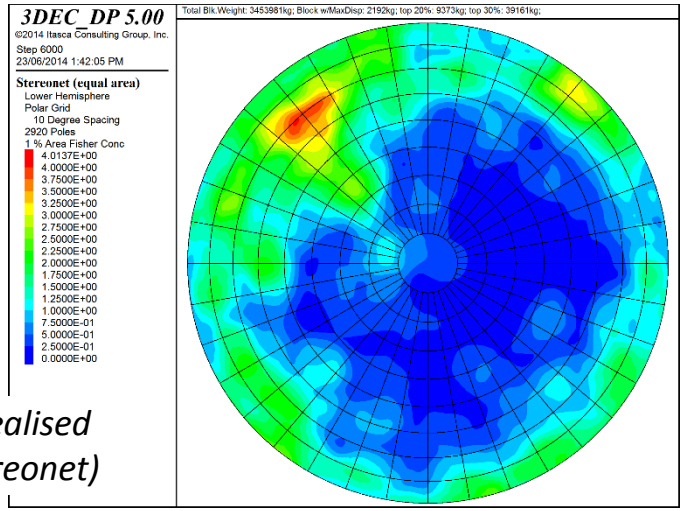
(Plan view)

Total bulk weight = 3,411.9 t, Block with MaxDisp = 2,112 kg
Top 20% = 21.7 t; Top 30% = 61.6 t

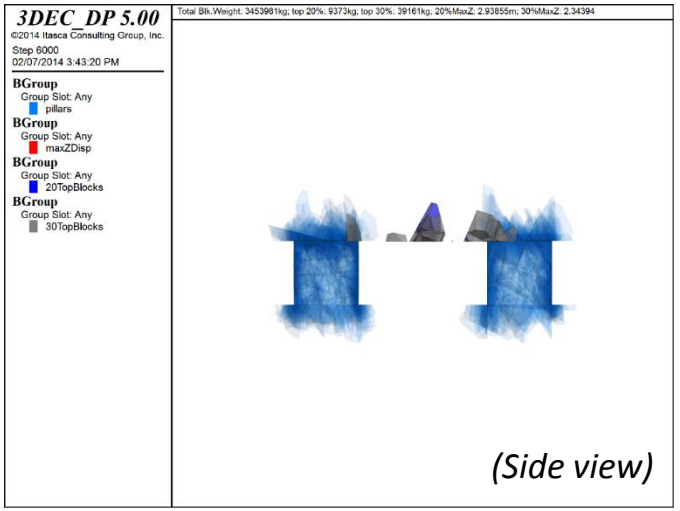
Z displacement on a mid section

Overlaid Top 20% Blocks

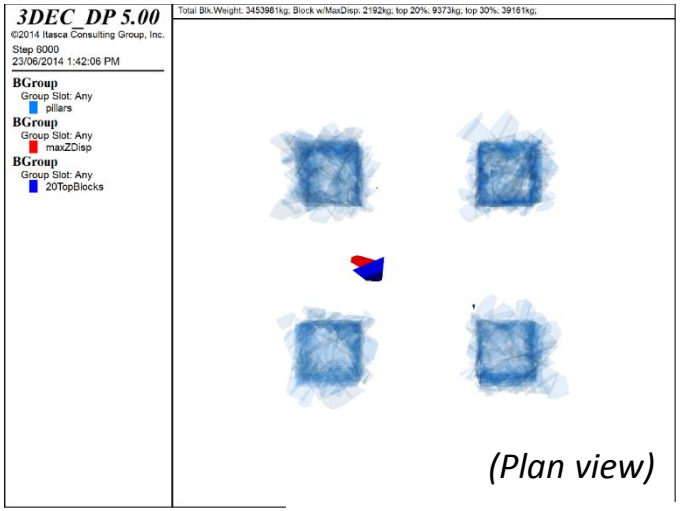
Results of Realisation #5



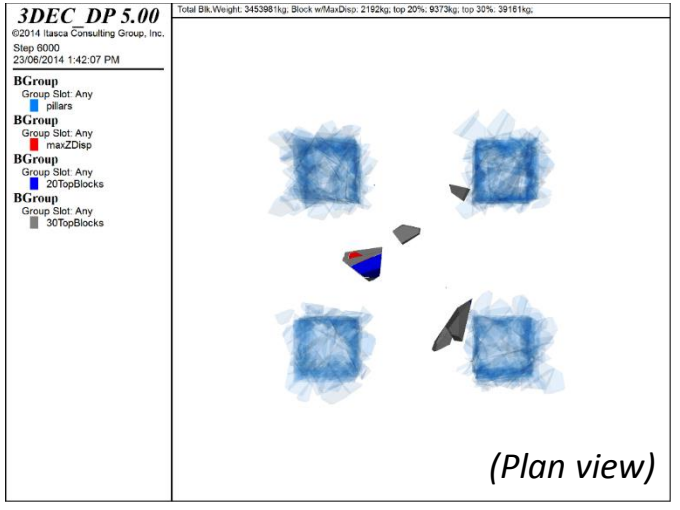
(Realised stereonet)



(Side view)



(Plan view)



(Plan view)

Total bulk weight = 3,454.0 t, Block with MaxDisp = 2,192 kg
Top 20% = 9.4 t; Top 30% = 39.2 t

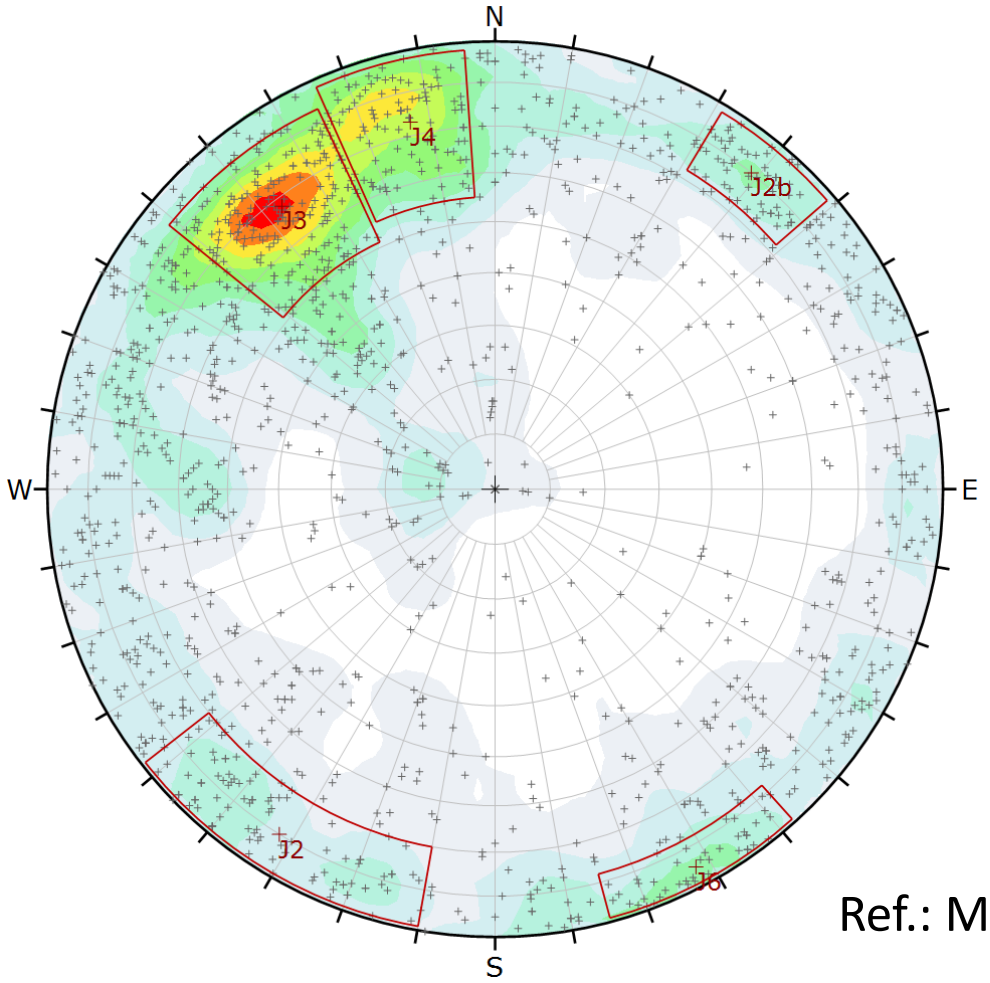
Fifth Series of Results

Based on the mapping completed underground in the 118 and M zones, and considering:

- *No ground support*
- *A joint friction angle of 30°*
- *An fracture length of 6 to 15m*

Five (5) realisations were completed with this scenario

Basic Mapping Data Considered



Symbol	Feature
+	Pole Vectors

Color	Density Concentrations
	0.00 - 0.50
	0.50 - 1.00
	1.00 - 1.50
	1.50 - 2.00
	2.00 - 2.50
	2.50 - 3.00
	3.00 - 3.50
	3.50 - 4.00
	4.00 - 4.50
	4.50 - 5.00

Maximum Density	4.78%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

	Color	Dip	Dip Direction	Label
Mean Set Planes				
1w		80	32	J2
2w		68	143	J3
3w		73	167	J4
4w		80	219	J2b
5w		85	332	J6

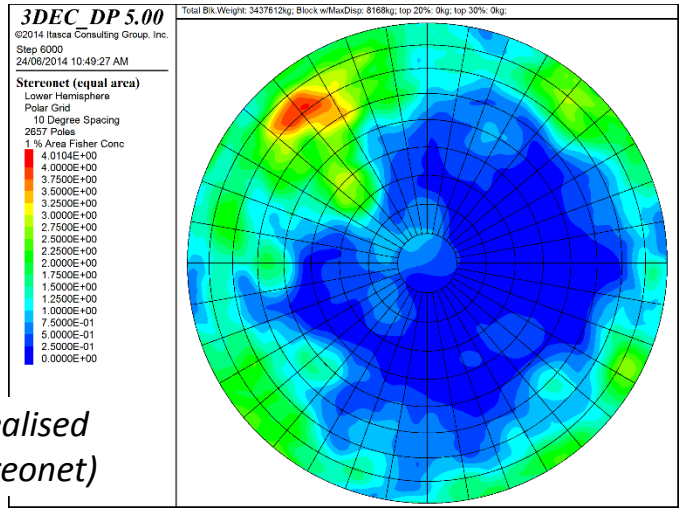
Plot Mode	Pole Vectors
Vector Count	1374 (1374 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Hemisphere	Lower
Projection	Equal Area

Ref.: Minto underground mapping

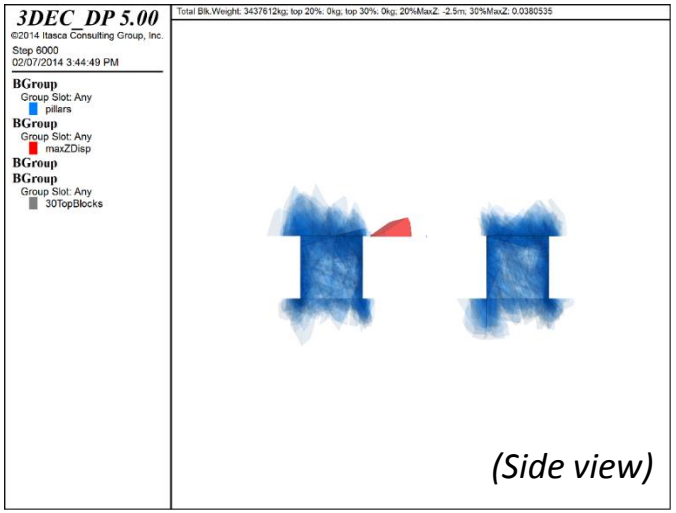
Z displacement on a mid section

Overlaid Top 20% Blocks

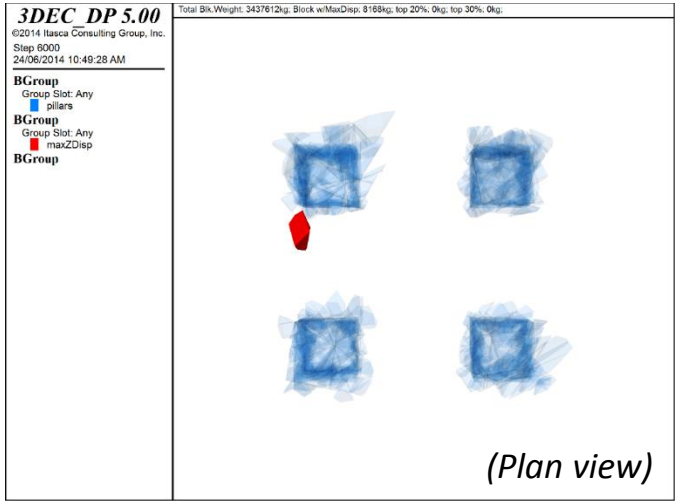
Results of Realisation #1



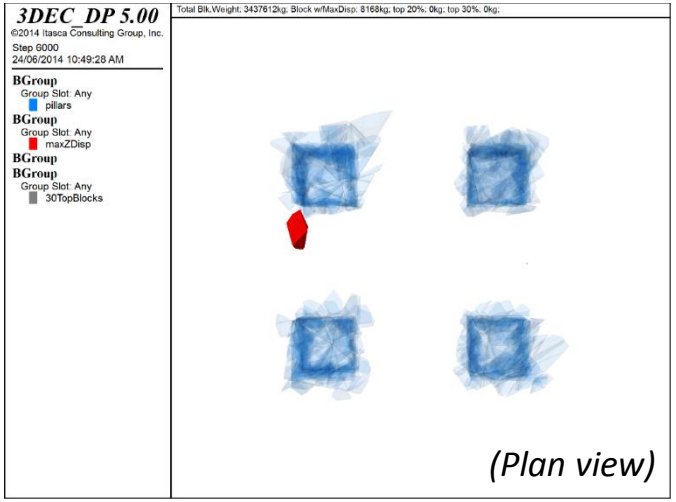
(Realised stereonet)



(Side view)



(Plan view)



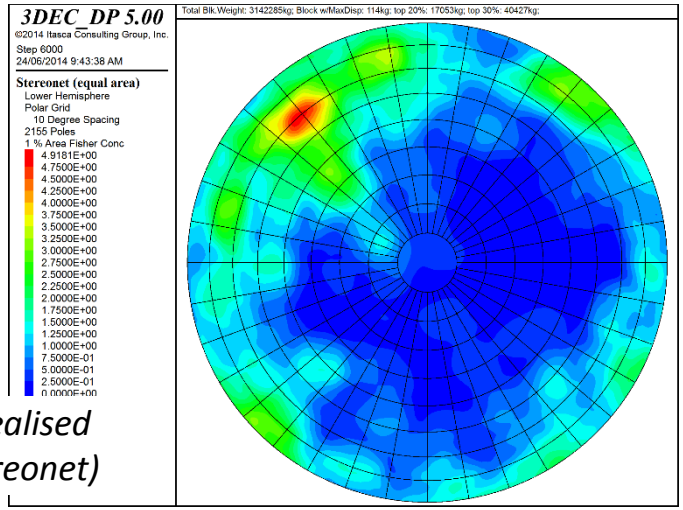
(Plan view)

Total bulk weight = 3,437.6 t, Block with MaxDisp = 8,168 kg
Top 20% = 0 t; Top 30% = 0 t

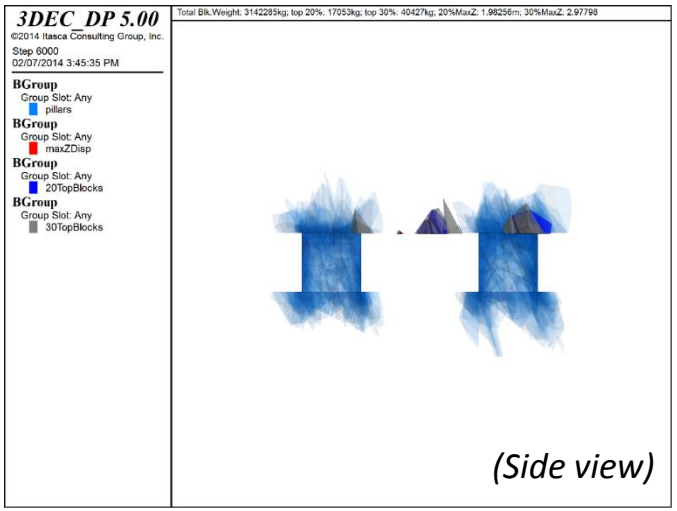
Z displacement on a mid section

Overlaid Top 20% Blocks

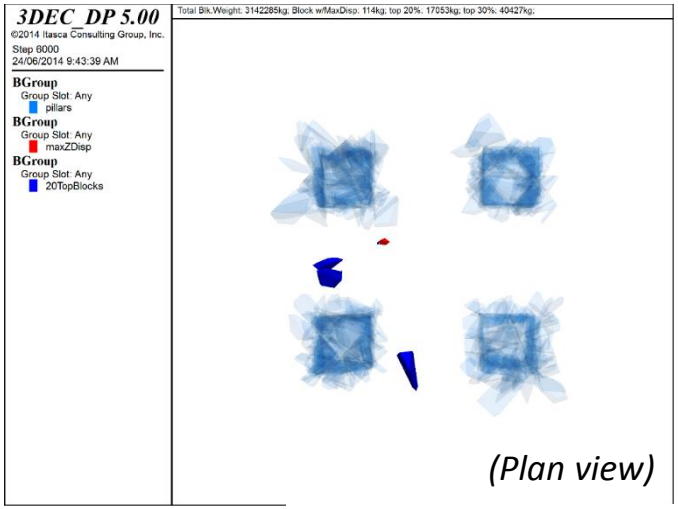
Results of Realisation #2



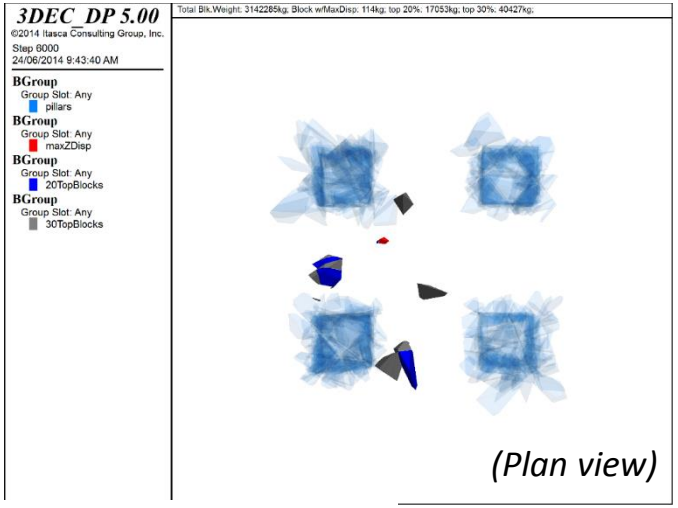
(Realised stereonet)



(Side view)



(Plan view)



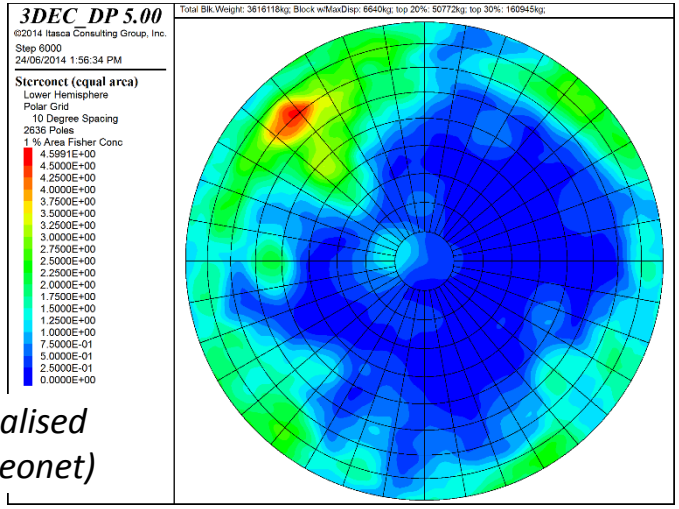
(Plan view)

Total bulk weight = 3,142.3 t, Block with MaxDisp = 114 kg
Top 20% = 17.1 t; Top 30% = 40.4 t

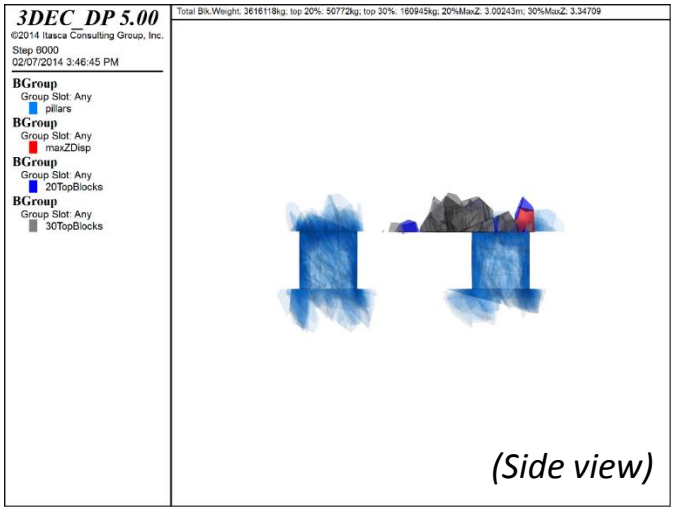
Z displacement on a mid section

Overlaid Top 20% Blocks

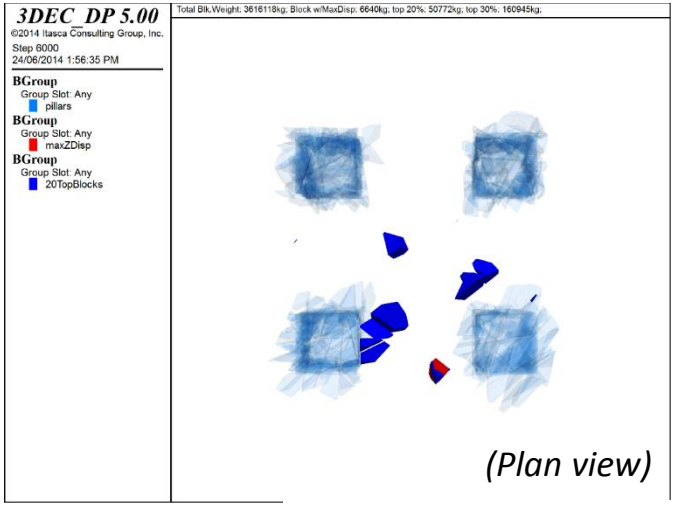
Results of Realisation #3



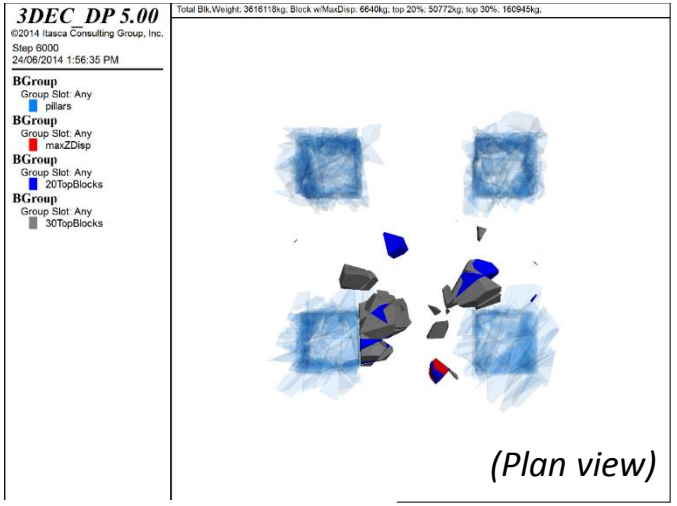
(Realised stereonet)



(Side view)



(Plan view)



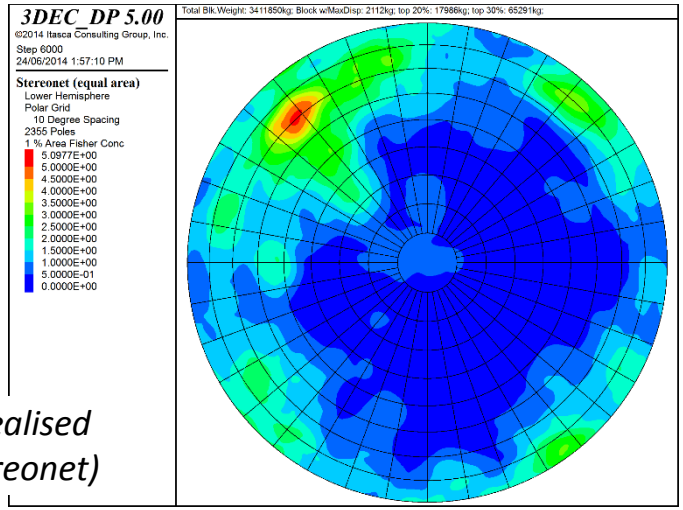
(Plan view)

Total bulk weight = 3,616.1 t, Block with MaxDisp = 6,640 kg
Top 20% = 50.8 t; Top 30% = 161.0 t

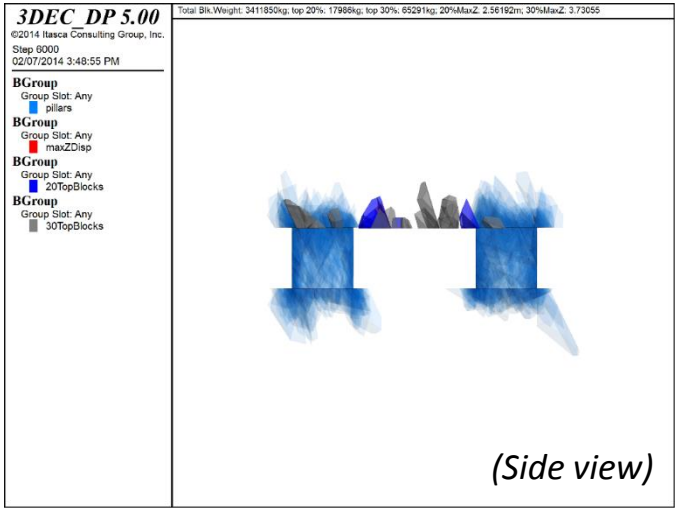
Z displacement on a mid section

Overlaid Top 20% Blocks

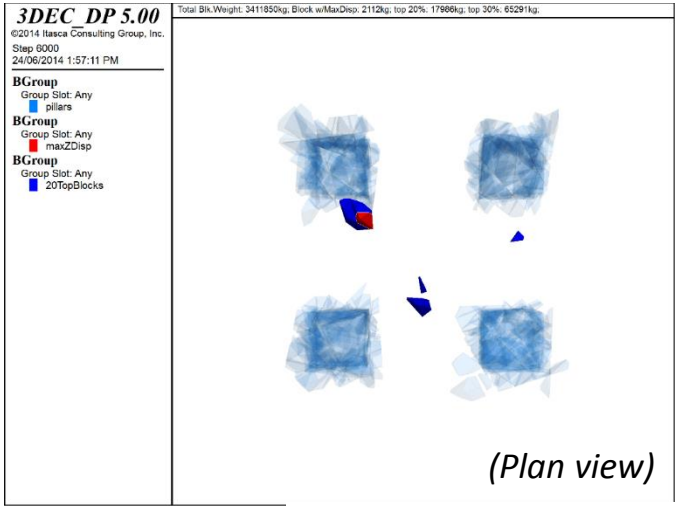
Results of Realisation #4



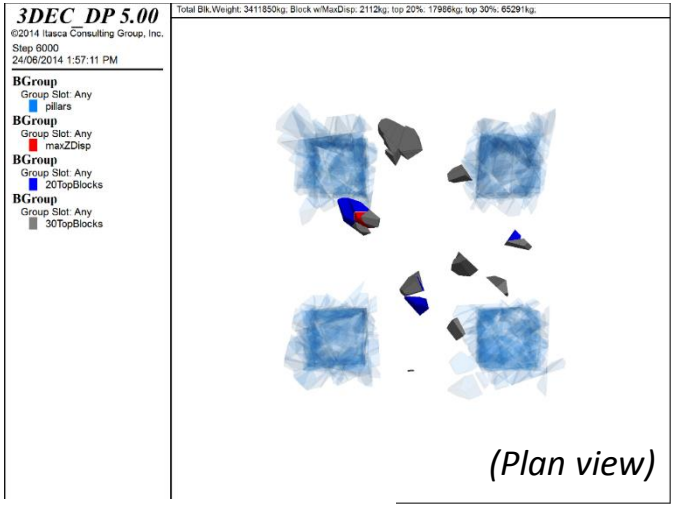
(Realised stereonet)



(Side view)



(Plan view)



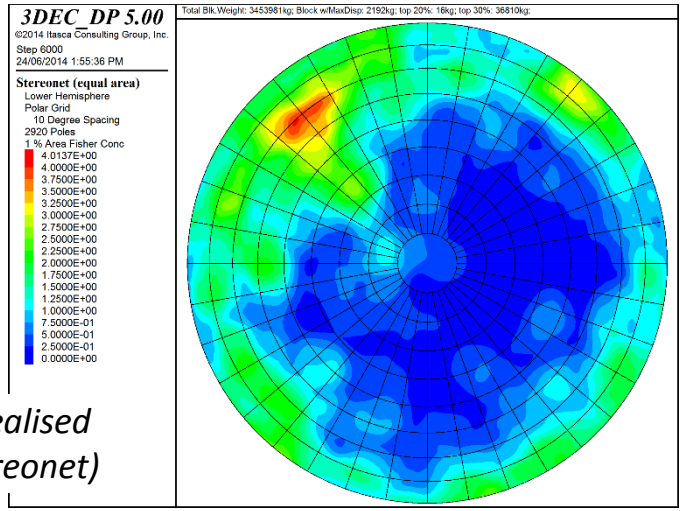
(Plan view)

Total bulk weight = 3,411.9 t, Block with MaxDisp = 2,112 kg
Top 20% = 18.0 t; Top 30% = 65.5 t

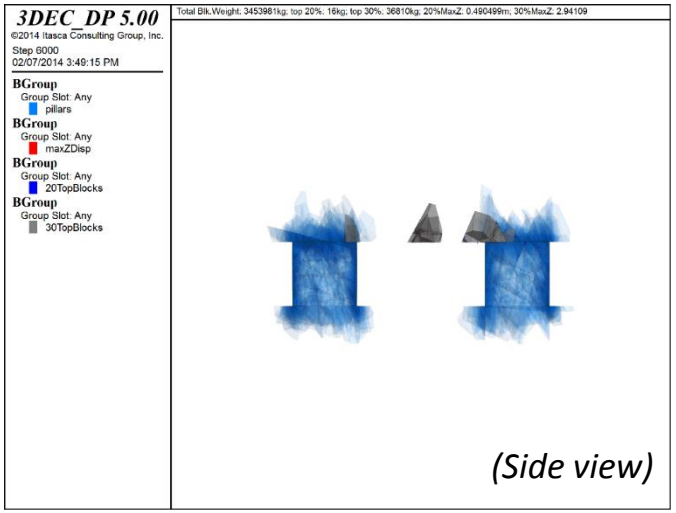
Z displacement on a mid section

Overlaid Top 20% Blocks

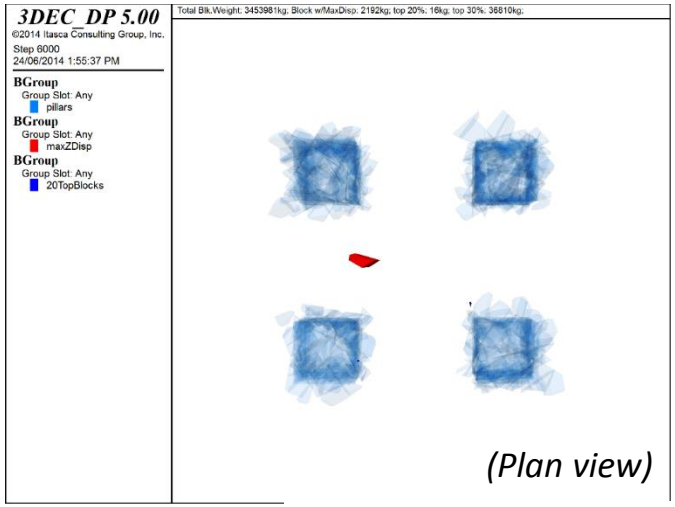
Results of Realisation #5



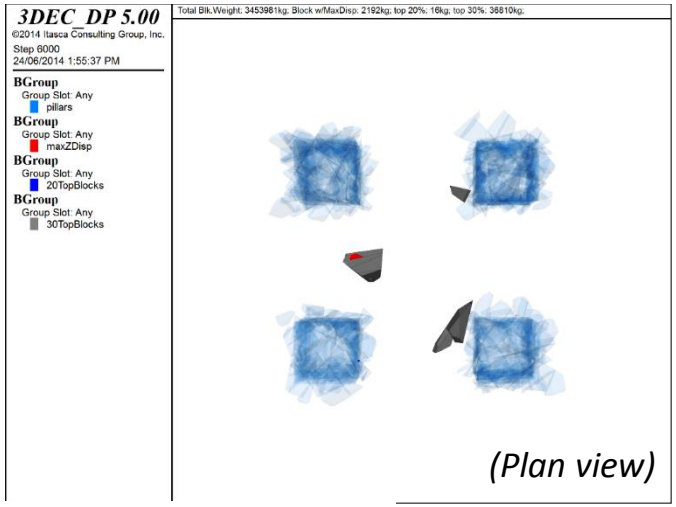
(Realised stereonet)



(Side view)



(Plan view)



(Plan view)

Total bulk weight = 3,454.0 t, Block with MaxDisp = 2,192 kg
Top 20% = 16.0 kg; Top 30% = 36.8 t

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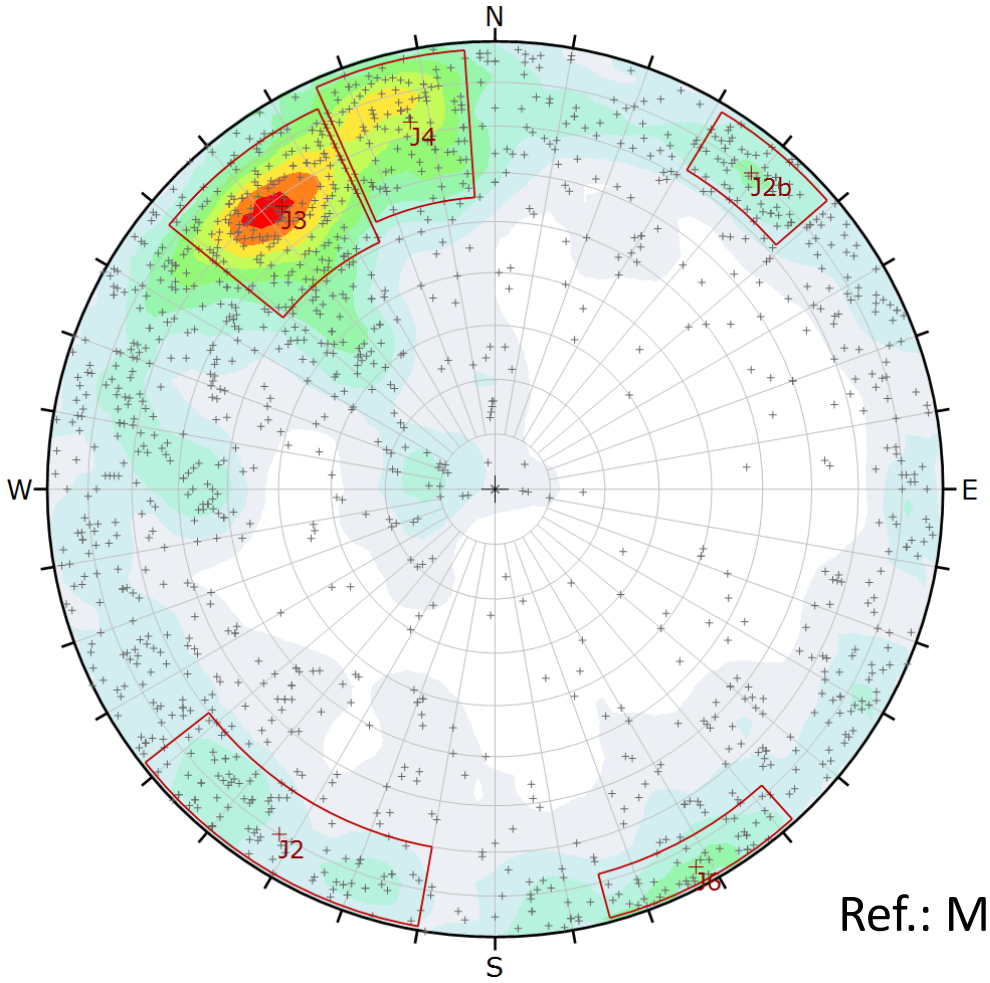
Sixth Series of Results

Based on the mapping completed underground in the 118 and M zones, and considering:

- *No ground support*
- *A joint friction angle of 25°*
- *An infinite fracture length*

Five (5) realisations were completed with this scenario

Basic Mapping Data Considered



Symbol	Feature
+	Pole Vectors

Color	Density Concentrations
	0.00 - 0.50
	0.50 - 1.00
	1.00 - 1.50
	1.50 - 2.00
	2.00 - 2.50
	2.50 - 3.00
	3.00 - 3.50
	3.50 - 4.00
	4.00 - 4.50
	4.50 - 5.00

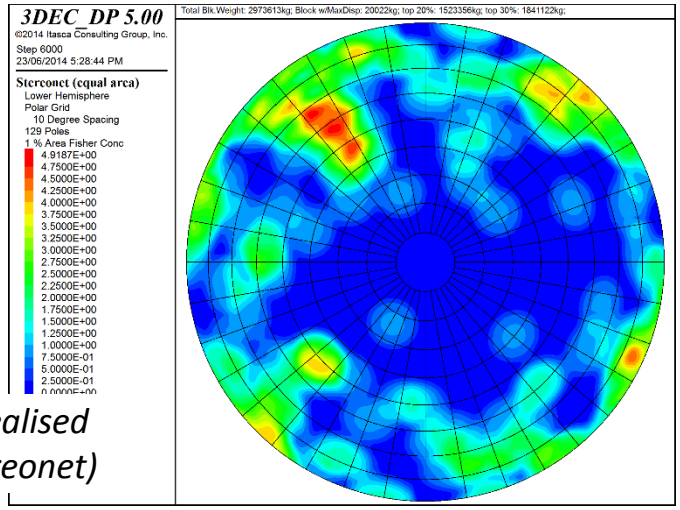
Maximum Density	4.78%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

	Color	Dip	Dip Direction	Label
Mean Set Planes				
1w		80	32	J2
2w		68	143	J3
3w		73	167	J4
4w		80	219	J2b
5w		85	332	J6

Plot Mode	Pole Vectors
Vector Count	1374 (1374 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Hemisphere	Lower
Projection	Equal Area

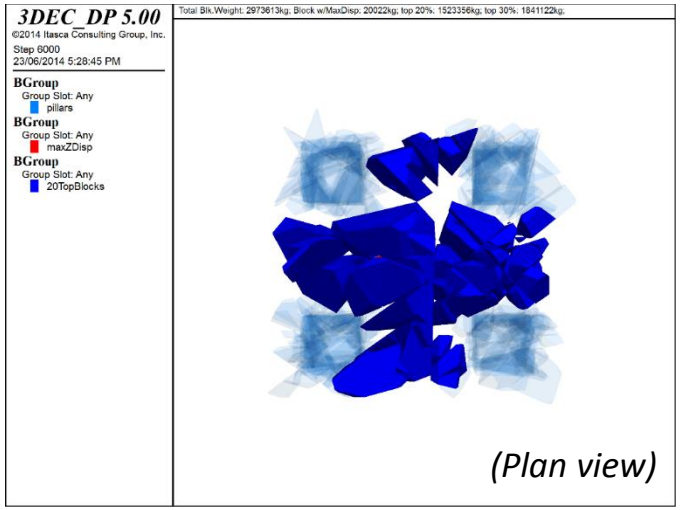
Ref.: Minto underground mapping

Results of Realisation #1

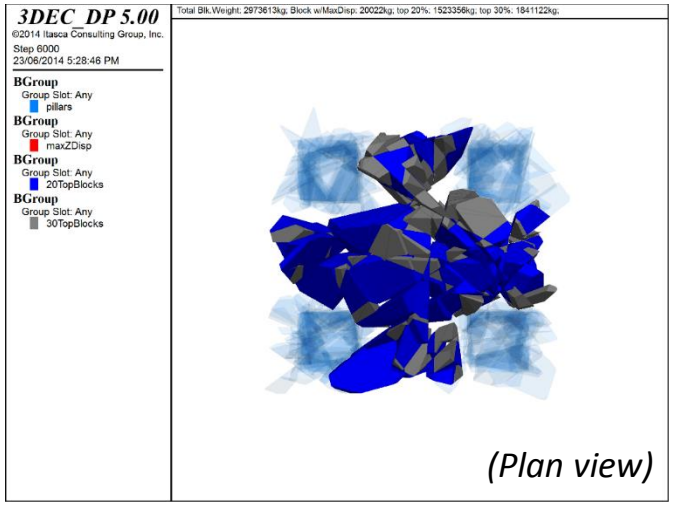


(Realised stereonet)

Total bulk weight = 2,973.6 t
Block with MaxDisp = 20,022 kg
Top 20% = 1,523.4 t
Top 30% = 1,841.1 t

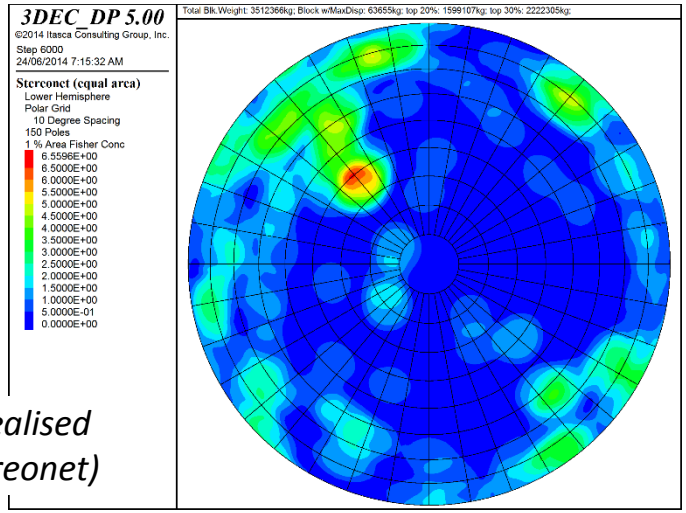


(Plan view)



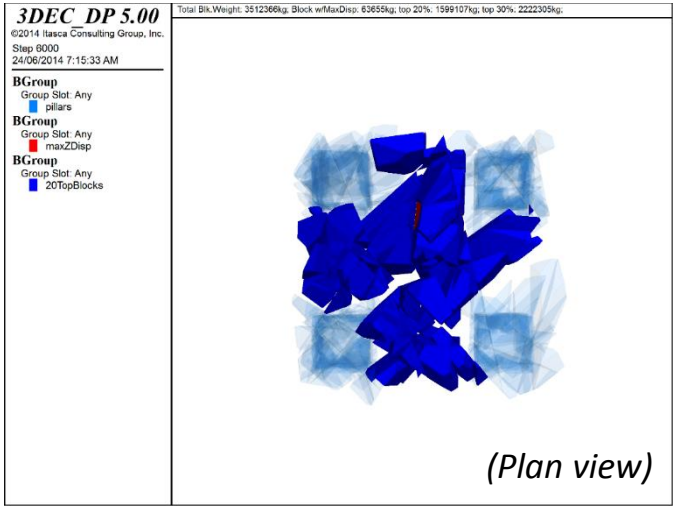
(Plan view)

Results of Realisation #2

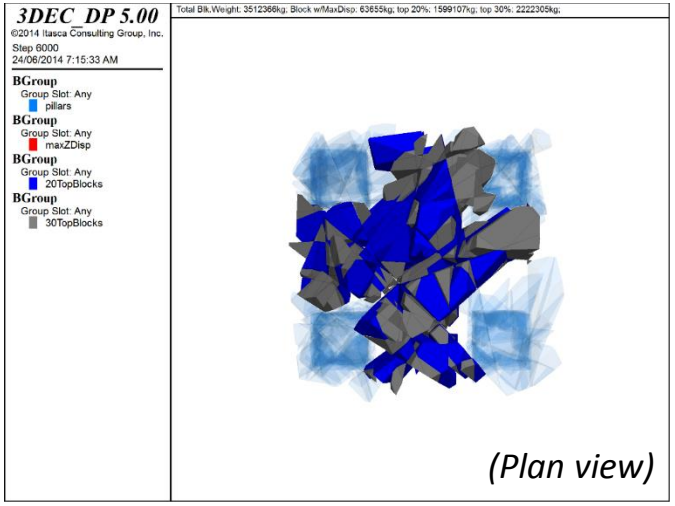


(Realised stereonet)

Total bulk weight = 3,512.4 t
Block with MaxDisp = 63,655 kg
Top 20% = 1,599.1 t
Top 30% = 2,222.3 t



(Plan view)

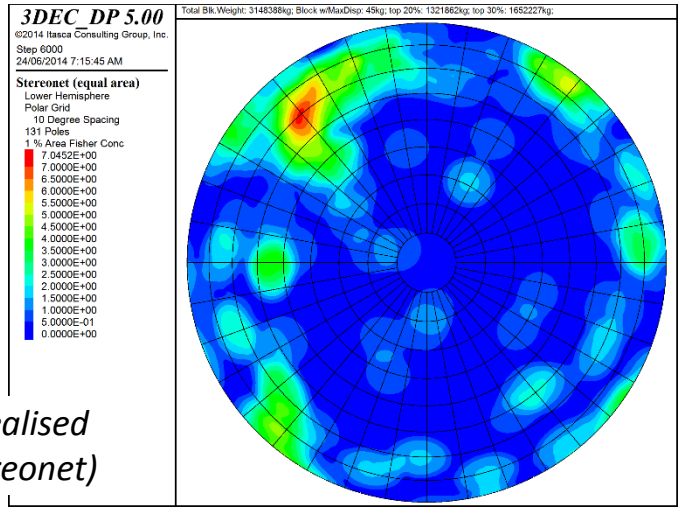


(Plan view)

Z displacement on a mid section

Overlaid Top 20% Blocks

Results of Realisation #3



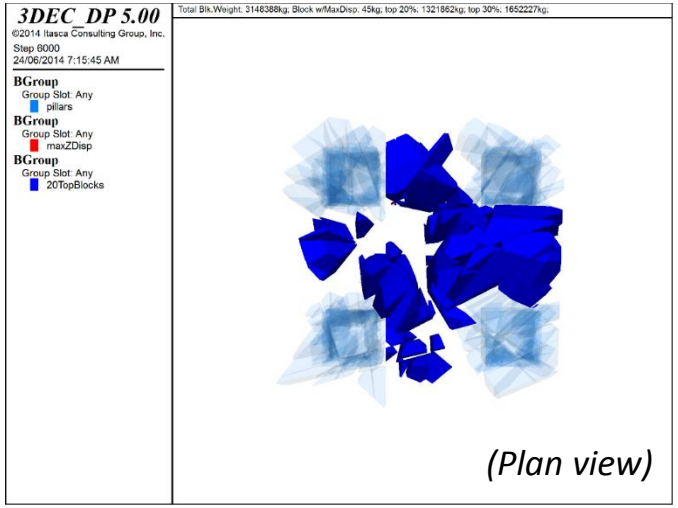
(Realised stereonet)

Total bulk weight = 3,148.4 t

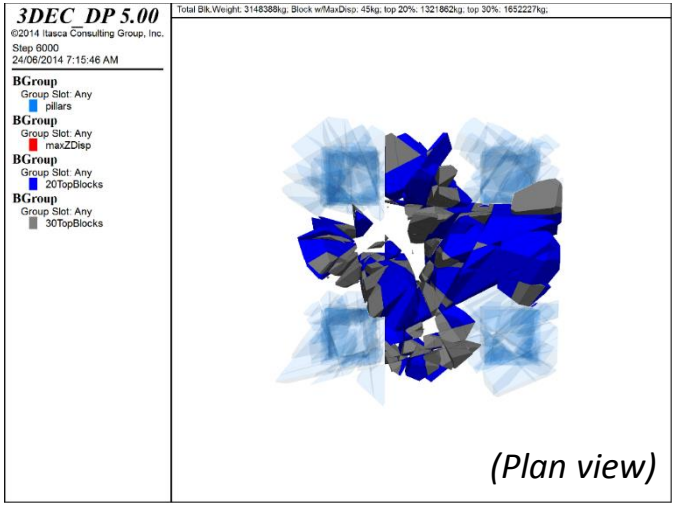
Block with MaxDisp = 45 kg

Top 20% = 1,5321.9 t

Top 30% = 1,652.2 t



(Plan view)

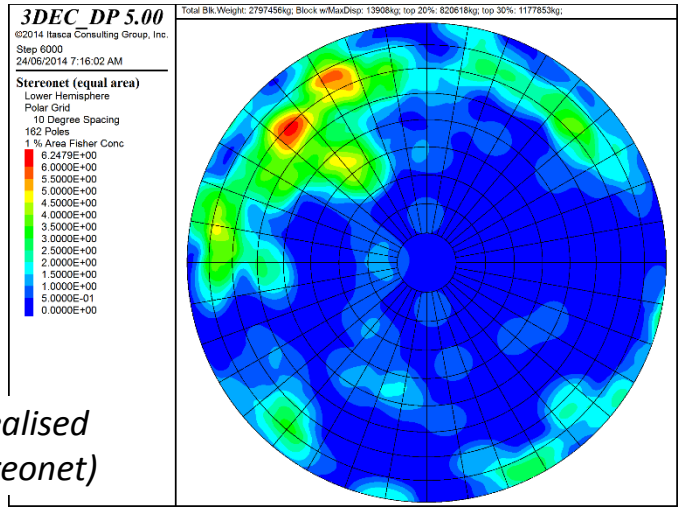


(Plan view)

Z displacement on a mid section

Overlaid Top 20% Blocks

Results of Realisation #4



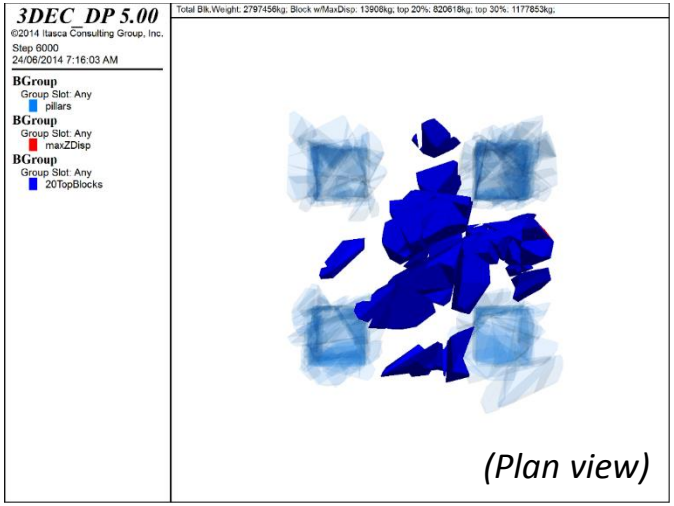
(Realised stereonet)

Total bulk weight = 2,797.5 t

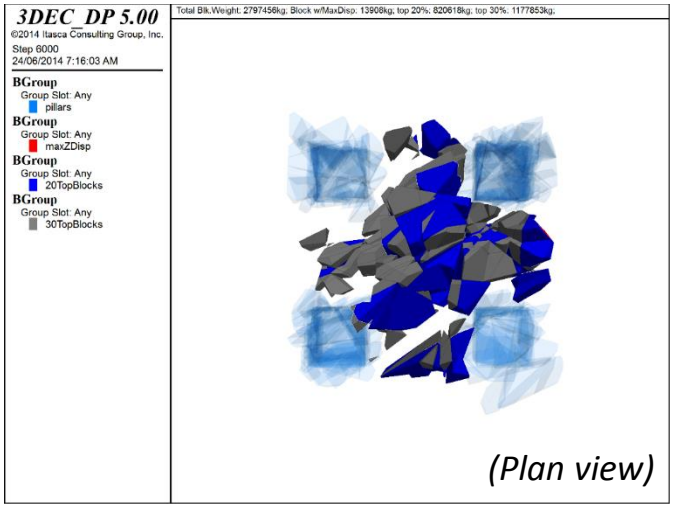
Block with MaxDisp = 13,908 kg

Top 20% = 820.6 t

Top 30% = 1,177.9 t



(Plan view)

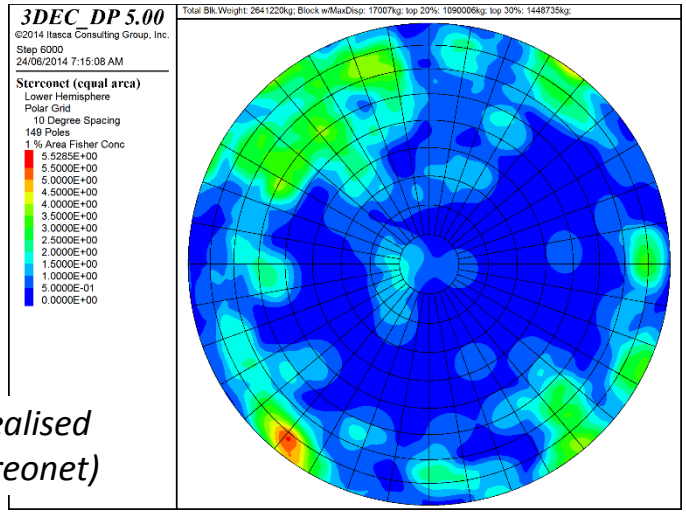


(Plan view)

Z displacement on a mid section

Overlaid Top 20% Blocks

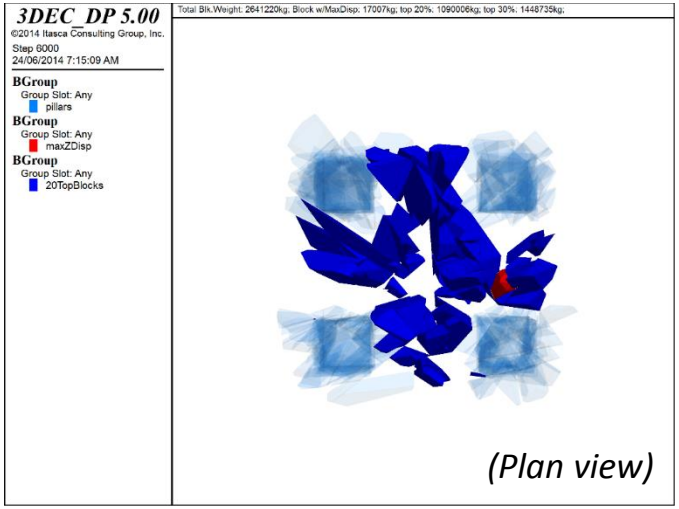
Results of Realisation #5



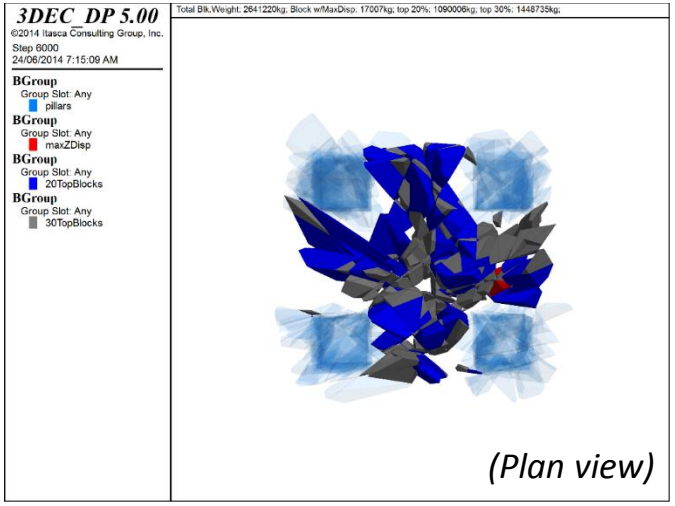
(Realised stereonet)

Total bulk weight = 2,641.2 t
Block with MaxDisp = 17,007 kg
Top 20% = 1,090.0 t
Top 30% = 1,448.7 t

Considering infinitely persistent joints (without intact rock bridges in between) results in many more and much larger unstable blocks



(Plan view)



(Plan view)

Results Comparison

Z displacement on a mid section

Overlaid Top 20% Blocks

Results Summary (Pit Mapping)

Fracture pattern	Fracture length (m)	Friction angle (deg.)	Realisa-tion (#)	Total weight of blocks in roof (t)	Top 20% blocks (t)	Top 20% max depth (m)	Top 30% blocks (t)	Top 30% max depth (m)
Pit mapping data	6 to 15	25	1	3,551.7	17.6	2.0	98.4	3.8
			2	3,466.3	89.0	2.8	304.9	4.4
			3	3,625.9	29.0	2.2	93.1	3.5
			4	3,653.1	6.1	1.6	69.2	4.2
			5	3,577.2	44.1	3.2	93.8	2.6
			Average	**3,574.8**	**37.2**	**2.4**	**131.9**	**3.7**
Pit mapping data	6 to 15	30	1	3,551.7	16.5	2.0	64.6	3.4
			2	3,466.3	86.3	2.8	206.3	3.6
			3	3,625.9	23.5	2.2	86.7	3.5
			4	3,653.1	6.3	1.6	26.8	1.7
			5	3,577.2	45.9	3.4	90.0	2.6
			Average	**3,574.8**	**35.7**	**2.4**	**94.9**	**3.0**
Pit mapping data	Infinite (200m)	25	1	3,245.5	1,703.8	5.5	2,209.2	5.5
			2	3,379.1	2,246.2	5.5	2,612.8	5.5
			3	3,516.7	660.5	5.5	1,838.1	5.5
			4	3,472.3	644.8	5.5	1,285.2	5.5
			5	3,514.2	1,626.9	5.5	2,510.2	5.5
			Average	**3,425.6**	**1,376.4**	**5.5**	**2,091.1**	**5.5**

Results Summary (U/G Mapping)

Fracture pattern	Fracture length (m)	Friction angle (deg.)	Realisa-tion (#)	Total weight of blocks in roof (t)	Top 20% blocks (t)	Top 20% max depth (m)	Top 30% blocks (t)	Top 30% max depth (m)
Underground mapping data	6 to 15	25	1	3,437.6	9.1	1.5	169.0	4.9
			2	3,142.3	17.5	2.0	55.8	4.5
			3	3,616.1	49.2	3.0	179.4	3.3
			4	3,411.9	21.7	2.6	61.6	3.1
			5	3,454.0	9.4	3.0	39.1	2.3
			Average	**3,412.4**	**21.4**	**2.4**	**101.0**	**3.6**
Underground mapping data	6 to 15	30	1	3,437.6	0.0	N/A	0.0	N/A
			2	3,142.3	17.1	2.0	40.4	3.0
			3	3,616.1	50.8	3.0	160.9	3.0
			4	3,411.9	18.0	2.6	65.3	3.7
			5	3,454.0	0.02	0.5	36.8	3.0
			Average	**3,412.4**	**17.2**	**2.0**	**60.7**	**3.2**
Underground mapping data	Infinite (200m)	25	1	2,973.6	1,523.4	5.5	1,841.1	5.5
			2	3,512.4	1,599.1	5.5	2,222.3	5.5
			3	3,148.4	1,321.9	5.5	1,652.2	5.5
			4	2,797.5	820.6	5.5	1,177.9	5.5
			5	2,641.2	1,090.0	5.5	1,448.7	5.5
			Average	**3,014.6**	**1,271.0**	**5.5**	**1,668.4**	**5.5**

Conclusions of the Unsupported Analyses

- More instability was predicted to occur when considering the mapping data from the open pit. This makes sense because this campaign identified more joint sets, resulting in more degrees of kinematic freedom the rock mass can exploit.
- Considering a higher friction angle resulted in more stability
- Considering infinitely persistent joints caused more instability to be predicted. This also makes sense as it results in no intact rock bridges remaining between joints.

Conclusions of the Unsupported Analyses

- The most conservative analyses are those with a friction angle of 25° and the joint sets mapped in the open pit. Infinitely persistent joints would be yet more conservative, but can be argued to not be overly realistic.
- As a result, the unsupported base case we retained is the one with the open pit joint mapping, 25° friction angle and 6 to 15m persistence
- Under these conditions, about 37 tonnes on average move in the roof by more than 8 cm (to a maximum depth of approximately 2.4m), and around 132 tonnes move between 7 and 8 cm (to a maximum depth of about 3.7m in the roof)

Seventh Series of Results

Based on the mapping completed by SRK in the open pit in 2013, and considering:

- *Artificial ground support*
- *A joint friction angle of 25°*
- *A fracture length of 6 to 15m*

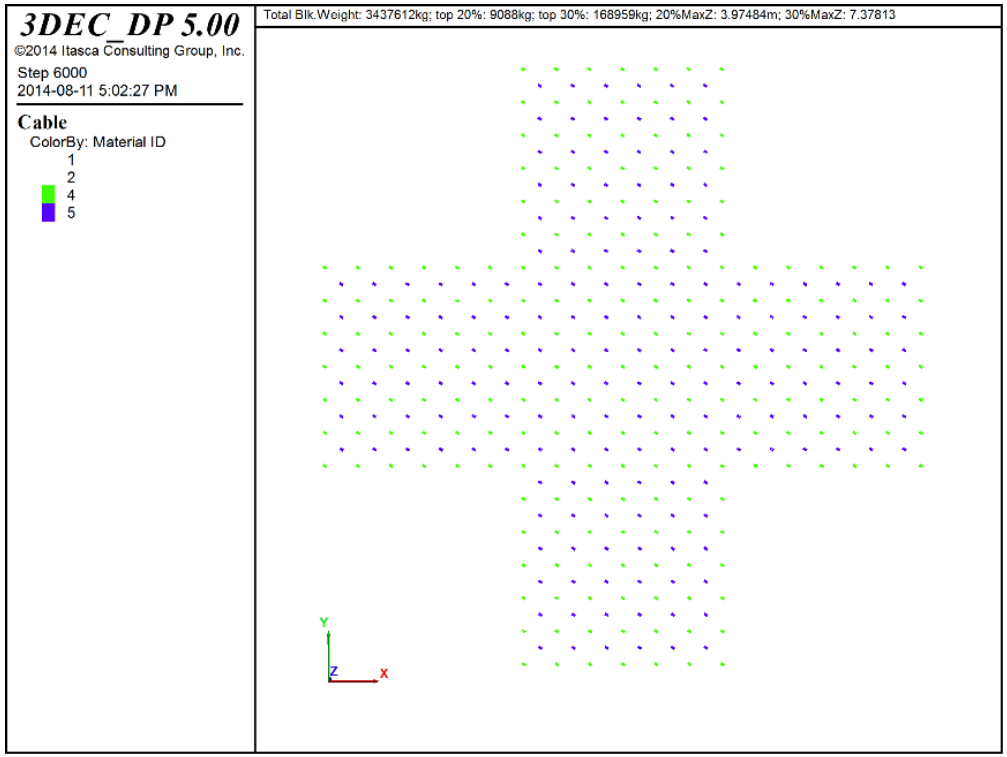
Only one (1) realisation was completed for this scenario

Ground Support Simulations

- Based upon the results of the unsupported DFN analyses, a series of additional simulations were conducted to assess the stabilising effect of artificial ground support
- Two support systems were examined:
  - The primary support alone (in the form of fully-resined rebars) – *the results of this scenario are not shown in this presentation*
  - The primary support just described, along with the secondary support (in the form of Super Swellex friction bolts)

Primary Ground Support

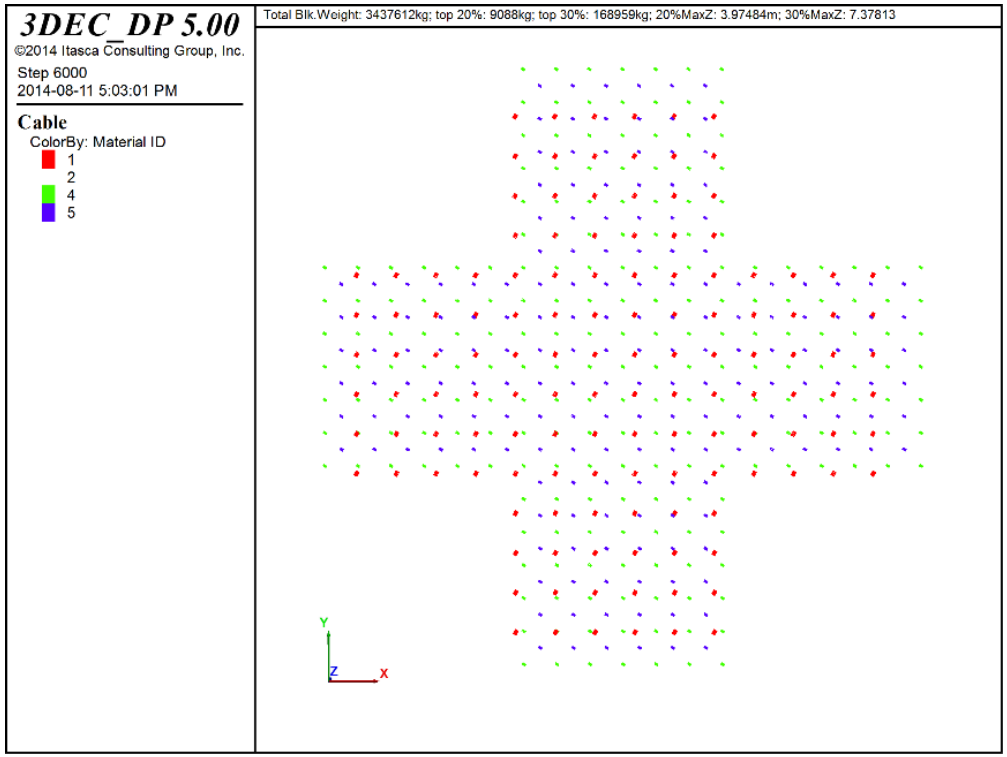
- 2.4m-long (8 ft) 12 tonne tensile capacity rebars with a 40 t/m bond strength
- Installed on a 1.5m by 1.5m pattern with an additional 1.8m-long (6 ft) rebar placed in the middle



(Plan view with bolt locations)

Secondary Ground Support

- 5.0m*-long (16.5 ft) 24 tonne tensile strength Super Swellex Pm 24 friction bolts with a 12 t/m slipping strength
- Installed on a 1.8m by 1.8m



(Plan view with bolt locations)

(Not "optimised" in between the rebars for this particular exercise)

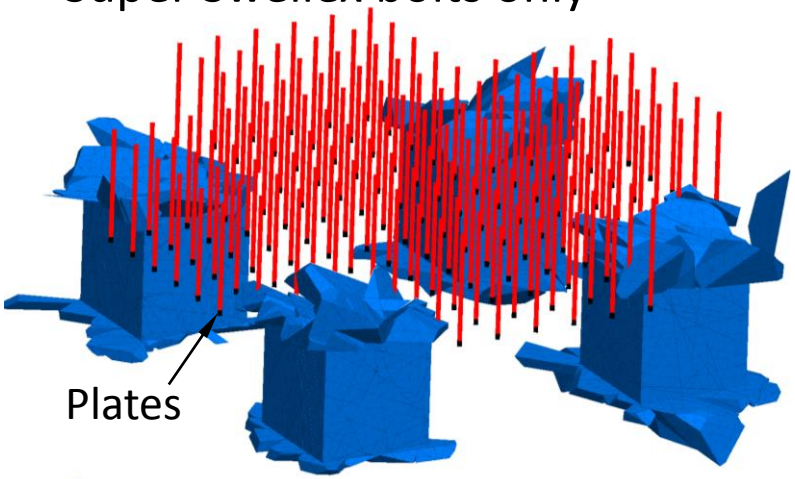
* *See note on Slide 63*

Note on Secondary Ground Support

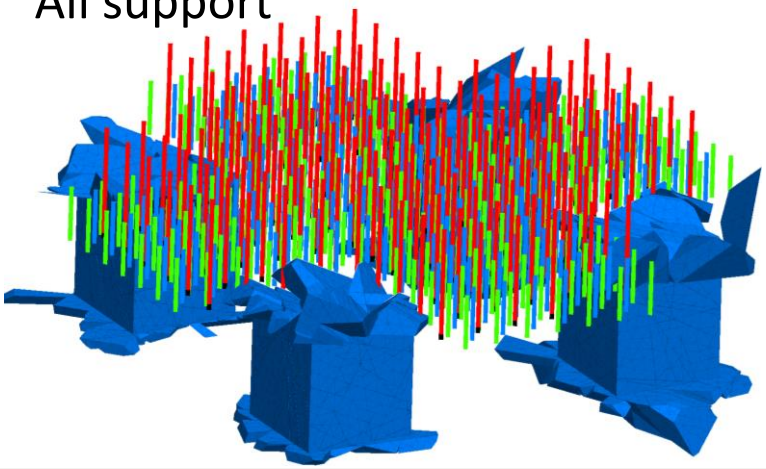
- The Super Swellex length was reduced from their actual 6.0m to 5.0m in order to fit them within the top platen of the model (i.e., to avoid them sticking out off the top of the roof platen)
- The alternative would have been to rebuild the model with a thicker (e.g., 7.0m) roof platen, but this would have made it difficult to compare with previous simulations
- The analysis with shorter Super Swellex bolts can be taken as conservative

Ground Support Plots

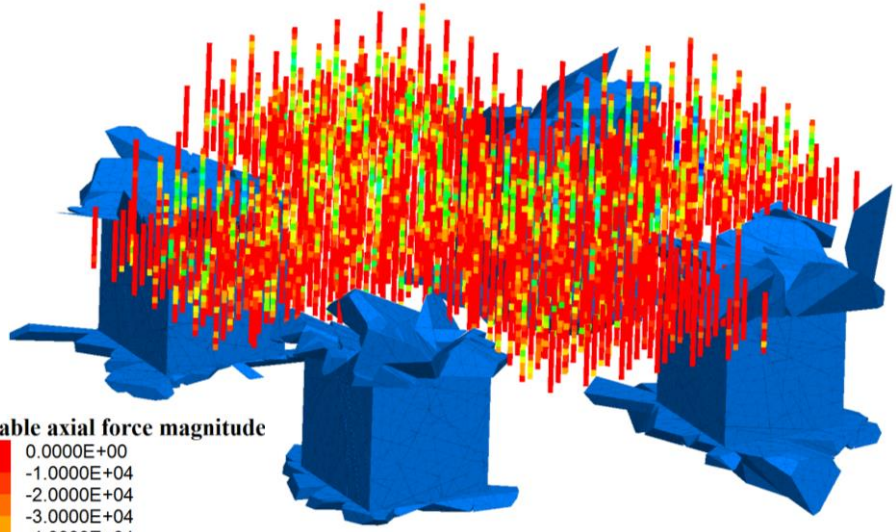
Super Swellex bolts only

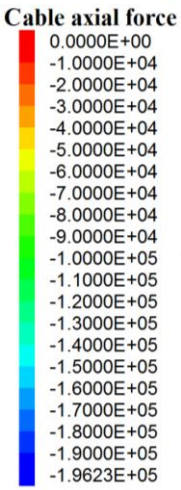


All support



Axial force magnitude in the bolts



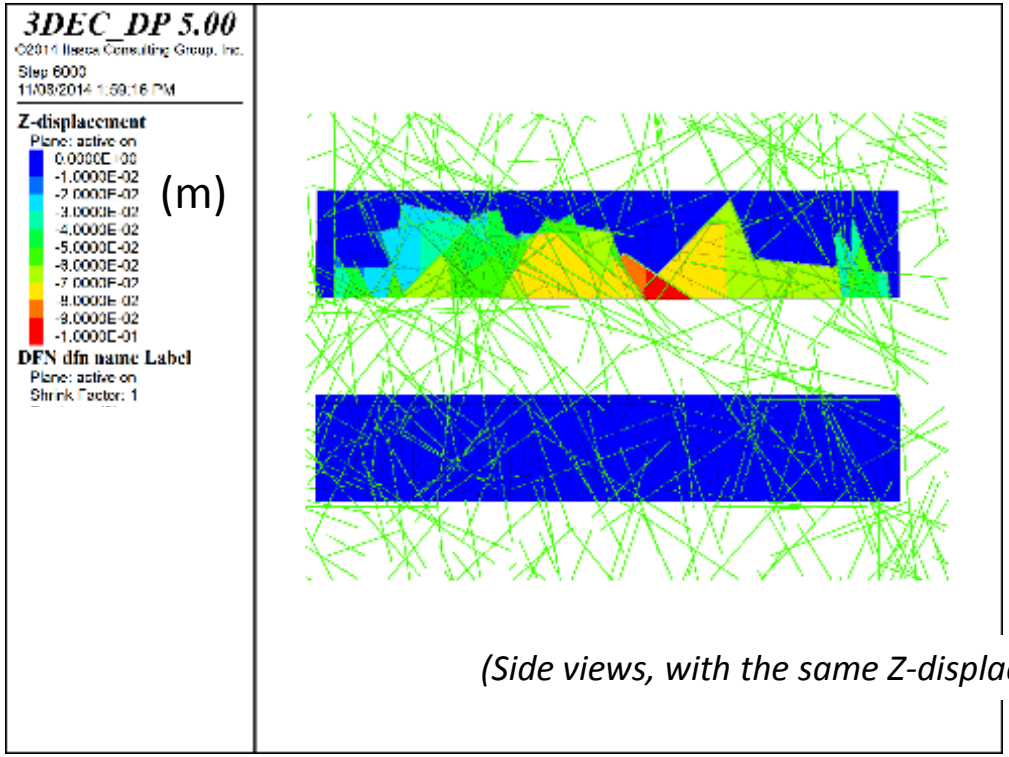


(Scale in N, with negative tension convention)

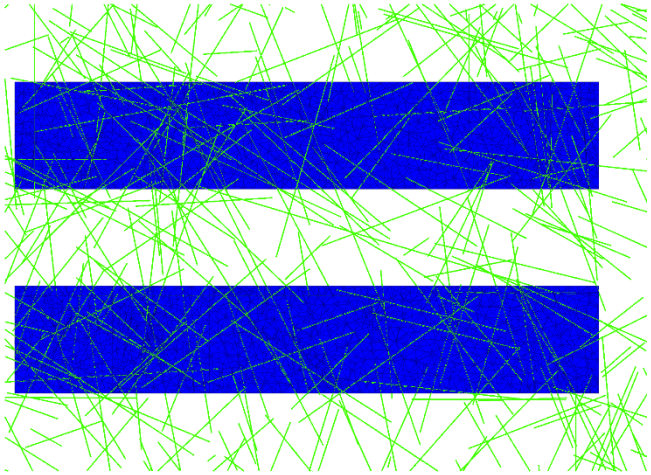
(All views isometric)

Z Displacement Plots (Both at 6,000 Cycles)

Without ground support (from Slide 11)



With full ground support (primary and secondary)



(Side views, with the same Z-displacement scale)

No significant vertical displacement was computed with the ground support in place in that one realisation, which was able to stabilise the chamber roof

Limitations of the Analyses

In reviewing these results, it is important to remember the following limitations:

1. The discrete blocks were not zoned, and, hence, unable to deform and build internal stresses. These rigid block analyses were meant to investigate the unravelling potential of the rock blocks delineated by the natural joint sets, when subjected to gravity alone. *(However, note that the roof blocks had to be converted to deformable entities in the analyses with ground support.)*
2. No potential hydrology/hydrogeology-related effects were considered