Golder Associates

OPG'S DEEP GEOLOGIC REPOSITORY FOR LOW & INTERMEDIATE LEVEL WASTE – 3D Detailed Analysis of Selected Areas

Authorization

Prepared by:	<signature removed> Joe Carvalho, Ph. D., P. Eng. WP2-7 Task Leader, Golder	Date:	October 16, 2012
Reviewed by:	<signature removed> C. M. Steed, P. Eng. Project Manager, Golder	Date:	October 16, 2012
Approved by:	<signature removed> C. M. Steed, P. Eng. Project Manager, Golder	Date:	October 16, 2012
Approved by:	<signature removed> Serge Clement, P. Eng. Project Manager, Tetra Tech	Date:	Oct 16, 2012
Accepted by:	<signature removed> Richard Heystee Area Package 2 Lead, NWMO	Date:	21 NOV 12

Revision Summary		
Revision Number	**Date**	**Description of Changes/Improvements**
00	October 16, 2012	First Issue

October 2012

TECHNICAL MEMORANDUM

OPG'S DEEP GEOLOGIC REPOSITORY FOR LOW & INTERMEDIATE LEVEL WASTE

3D Detailed Analysis of Selected Areas

Submitted to:
Nuclear Waste Management Organization
22 St. Clair Avenue East, 6th Floor
Toronto, Ontario
M4T 2S3

Report Number: 1011170042-TM-G2070-0007-00

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Table of Contents

1.0 INTRODUCTION

This Technical Memorandum describes the three-dimensional numerical modelling undertaken to assess the stability and the support requirements for areas identified for detailed analyses as a result of the repository-wide modelling. In the numerical analyses of the full repository (1011170042-TM-G2070-0002-01[1]), the intersections of the emplacement rooms with the access tunnels and the return air tunnels, as well as the intersections of the shafts with the shaft stations and loading pocket, and the shop (largest underground opening) were identified for detailed analyses.

These areas have geometries which are three-dimensional in nature and promote stress concentrations (or stress relaxation) and as such require a more detailed analysis. Both the full repository analysis and the two-dimensional analyses of the emplacement rooms and access tunnels indicated that the rock surrounding the openings remains in the elastic state for the most part. Therefore, the three-dimensional analyses were undertaken with the boundary element code Examine3D. This choice allows for finer meshes and a more accurate representation of complex geometry typical of intersections.

While the emplacement rooms, access and return air tunnels, and the shop are entirely contained in the Lower Member of the Cobourg Formation (all references to Cobourg Formation or simply Cobourg throughout this document mean the argillaceous limestone of the Cobourg Formation Lower Member), the main shaft extends down into the Sherman Fall Formation and the ventilation shaft extends even deeper into the Kirkfield Formation.

The properties of these formations for the purpose of analyses are presented first.

2.0 CONSTITUTIVE MODELS AND PARAMETERS

2.1 Generalised Hoek-Brown Constitutive Model

The Generalized Hoek-Brown constitutive model[2] was used in the analyses for all formations in question. In the case of the Cobourg Formation, a back-analysis of the shaft was undertaken with several constitutive models to determine which one was the most applicable[3]. That analysis concluded that the Generalized Hoek-Brown was then constitutive model that best represented the field observations. The Generalised Hoek-Brown criterion is mathematically described as follows[2]:

$$\sigma_1 = \sigma_3 + \sigma_c \left(m_b \frac{\sigma_3}{\sigma_c} + s \right)^a$$

2.1.1 Generalised Hoek-Brown Parameters for the Intact Rock

The intact Hoek-Brown Parameters for the three formations, based on Brazilian, Uniaxial Compression and Triaxial Compression testing (where available), are shown in Table 2-1 (1011170042-REP-G2050-0001-01[4]). It should be noted that additional testing from samples from borehole DGR8[5] have been completed at the CANMET laboratory but no final report was available at the time of completion of this Technical Memorandum. However, preliminary results were made available to Golder Associates and have been incorporated in the estimation of the rock properties for the three-dimensional analyses.

Table 2-1: Intact Rock Properties

Property	Cobourg Formation	Sherman Fall Formation	Kirkfield Formation
σ_c (MPa)	119.3	74.4	60.3
m_i	11.39	15.03	11.00*
E_i (GPa)	41.7	38.8	25.4

* – suggested value

These intact parameters include results of the most recent laboratory testing on samples from Borehole DGR8. Figure 2-1 shows the intact Hoek-Brown envelopes for the three formations.

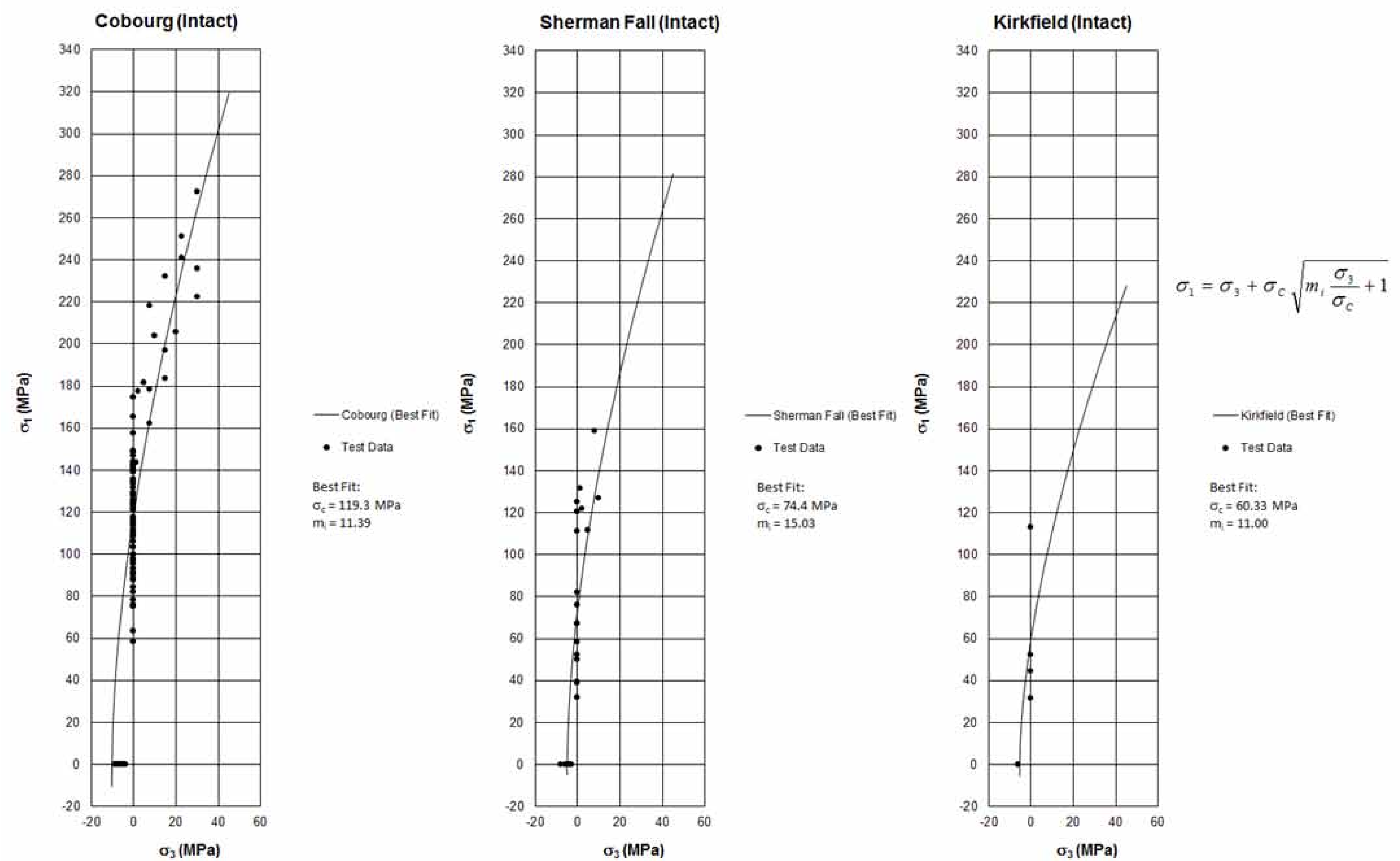

Figure 2-1: Intact failure envelopes for the Cobourg Formation Lower Member, Sherman Fall Formation and the Kirkfield Formation.

2.1.2 Generalised Hoek-Brown Parameters for the Rock Mass

The rock mass parameters are estimated by downgrading the intact (laboratory) strength to a field strength according to the rock mass quality (GSI or RMR). The rock mass quality in borehole DGR8 for the Lower Member of the Cobourg Formation, the Sherman Fall Formation and the Kirkfield Formation is generally better than that estimated from the previous investigations (1011170042-REP-G2040-0005-00[6]); however, the average rock mass quality from all the boreholes (DGR1 through DGR8), which cover a larger area than the repository itself and potentially are more representative of the formations, was used in the analyses. The relationships between the intact strength and the field strength as a function of GSI are as follows[6]:

$$m_b = m_i \times e^{\left(\frac{\mathrm{GSI}-100}{28-14D}\right)}$$

$$s = e^{\left(\frac{\mathrm{GSI}-100}{9-3D}\right)}$$

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-\mathrm{GSI}/15} - e^{-20/3}\right)$$

where m_i is the intact rock Hoek-Brown m parameter; GSI is the Geological strength Index; and D is the disturbance factor. Therefore, the rock mass strength envelopes for the Lower Member of the Cobourg Formation, the Sherman Fall Formation and the Kirkfield Formation are defined as follows:

Table 2-2: Rock Mass Properties

Property	Cobourg Formation	Sherman Fall Formation	Kirkfield Formation
σ_c (MPa)	119.3	74.4	60.33
GSI	90	83	84
D	0	0	0
m_b	7.967	8.190	6.212*
s	0.3292	0.1512	0.1690
a	0.500	0.500	0.500
E_{rm} (GPa)	39.75	35.35	23.31

* – suggested value

Figure 2-2 shows the rock mass Hoek-Brown envelopes for the Lower Member of the Cobourg Formation, Sherman Fall Formation and the Kirkfield Formation.

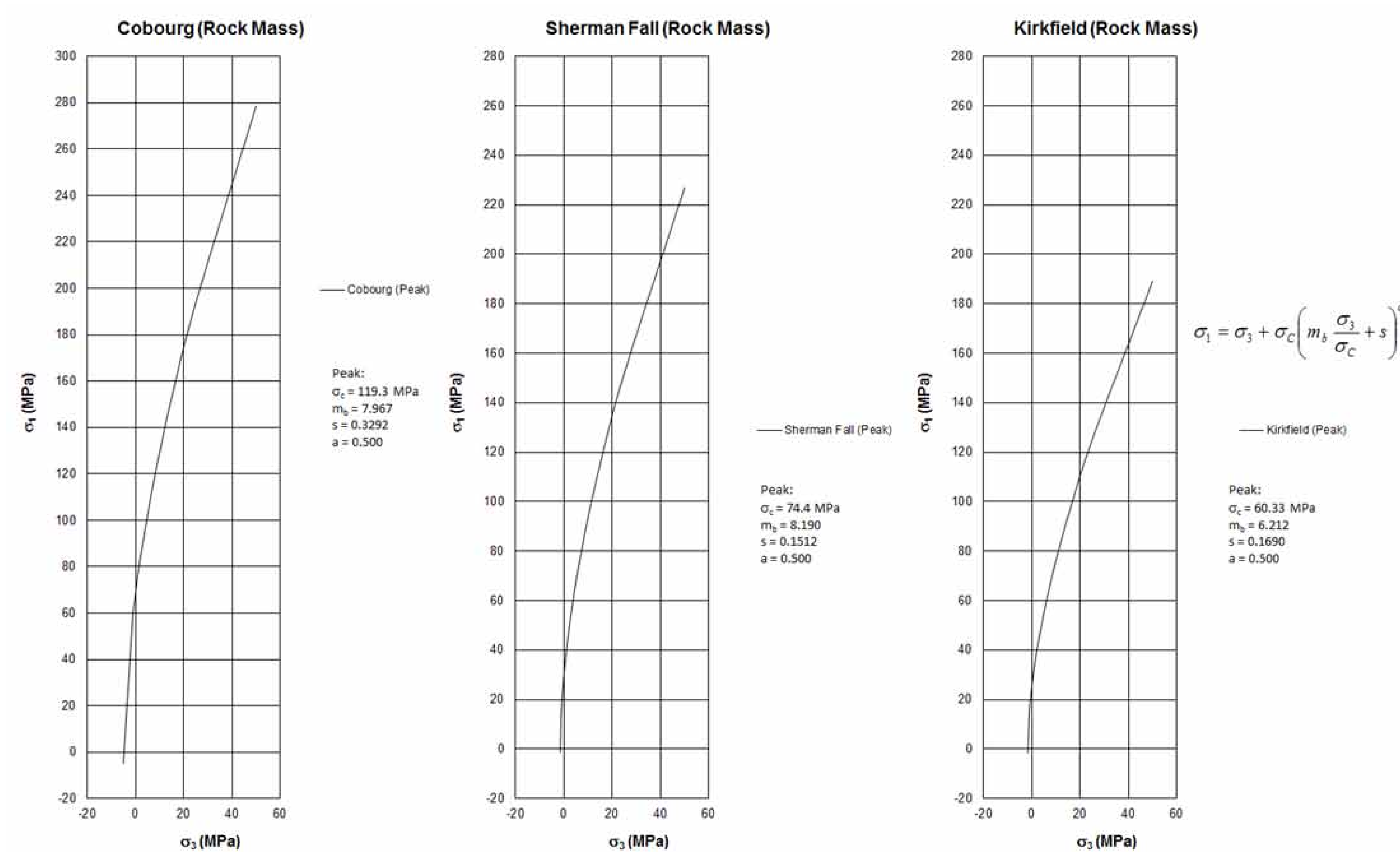

Figure 2-2: Rock mass strength envelopes for the Cobourg Formation Lower Member, Sherman Fall Formation and the Kirkfield Formation.

3.0 IN SITU STRESSES

The in situ stress estimates have taken into account the relative stiffness of the stratigraphic units at the DGR site when strained horizontally with constant displacement over the vertical profile in both horizontal directions to simulate the tectonic forces.

The following *in situ* stress state was used in the model (Geotechnical Interpretative Report [4]):

3.1 Lower Member of the Cobourg Formation

Vertical stress: σ_v (MPa) = 0.0263 (MN/m^3) * depth below surface (m)

Major horizontal stress: $\sigma_H = 2.05 * \sigma_v$

Minor horizontal stress: $\sigma_h = 1.65 * \sigma_v$

3.2 Sherman Fall Formation

Vertical stress: σ_v (MPa) = 0.0263 (MN/m^3) * depth below surface (m)

Major horizontal stress: $\sigma_H = 1.41 * \sigma_v$

Minor horizontal stress: $\sigma_h = 1.13 * \sigma_v$

3.3 Kirkfield Formation

Vertical stress: σ_v (MPa) = 0.0263 (MN/m^3) * depth below surface (m)

Major horizontal stress: $\sigma_H = 1.06 * \sigma_v$

Minor horizontal stress: $\sigma_h = 0.81 * \sigma_v$

At the repository level (Lower Member of the Cobourg Formation) the major and minor horizontal stresses are estimated at $\sigma_H = 36.85\ MPa$ and $\sigma_h = 29.71\ MPa$. In the formations below the repository the magnitude of the horizontal stresses is considerably lower (between 55 and 70% of those in the Cobourg Formation).

4.0 MODELLING RESULTS

The following sections describe the results of detailed modelling for selected areas in the underground repository. The general arrangement of the underground repository is shown in Tetra Tech Drawing 1088240200-DWG-R0001, Rev. H[7], This drawing should be used to identify locations of the six areas selected for detailed 3D analysis. Portions of the Ventilation Shaft and Loading Pocket are shown in drawings 1088240200-DWG-R0035, Rev. C[8] and 1088240200-DWG-R0029, Rev. D[9]; the Main Shaft Station is shown in drawing 1088240200-DWG-R0027, Rev. C[10]. The dimensions of the Emplacement Rooms, Access Tunnels and Return Air Tunnels are shown in drawings 1088240200-DWG-R0006, Rev. D[11], 1088240200-DWG-R0015, Rev. D[12], 1088240200-DWG-R0018, Rev. D[13], and 1088240200-DWG-R0019, Rev. C[14].

4.1 Access Tunnel – Emplacement Room Intersection

The boundary element mesh for the intersection of the Access Tunnel and an Emplacement Room is shown in Figure 4-1. The areas of interest are the stability of the roof at the intersection, the brow at the emplacement room entrance and the triangular pillar created by the intersection.

Figure 4-2 shows isosurfaces for a factor of safety of 1. These isosurfaces include zones of overstress around the excavation as well as zones where the tensile strength has been exceeded. The analysis confirms the observations from the 2-dimensional analyses, namely that the zones of overstress are only surficial (damage shallower than 5 cm is considered surficial) and are limited to the corners of the rooms. There are no indications of overstress in the pillar or stress relaxation at the brow of the entrance to the emplacement rooms. Figure 4-3 shows only the zones where the tensile strength has been exceeded; it can be seen that the tensile stresses are lower than the tensile strength. The depth of disturbance in all cases is less than the expected depth of damage from the blasting. Depth of blast damage, given the specified careful blasting, should be limited to 0.5 m or less.

The recommended support for the intersections of the emplacement rooms and the panel access tunnels consists of 3.5 m long rockbolts (25mm dia.) on a 1.8 m × 1.8 m pattern and screening or shotcrete as per the standard requirements of the emplacement rooms and access tunnels. The length and spacing are mainly dictated by the maximum span of the intersections.

4.2 Return Air Tunnel – Emplacement Room Intersection – North Panel

The boundary element mesh for the intersection of the Return Air Tunnel and an Emplacement Room in the North panel is shown in Figure 4-4. The areas of interest are the stability of the roof at the intersection, the brow at the emplacement room entrance and the triangular pillar created by the intersection.

Figure 4-5 shows isosurfaces for a factor of safety of 1. These isosurfaces include zones of overstress around the excavation as well as zones where the tensile strength has been exceeded. The analysis confirms the observations from the 2-dimensional analyses, namely that the zones of overstress are only surficial and are limited to the corners of the rooms and the corners of the connecting tunnels between the emplacement room and the return air tunnel. There are no indications of overstress in the pillar or stress relaxation at the brow of the entrance to the emplacement rooms. Figure 4-6 shows only the zones where the tensile strength has been exceeded. It can be seen that the only zone where the tensile strength is exceeded is a localized zone in the east wall of the connecting tunnel; this is due to a combination of the tunnel orientation with respect to the in situ stresses and the aspect ratio of the tunnel. The depth of disturbance in all cases is less than the expected depth of damage from the blasting.

The recommended support for the intersections of the return air tunnels and the tunnels connecting to the emplacement rooms consists of 2.4 m long rockbolts (25mm dia.) on a 1.5 m × 1.5 m pattern and screening or shotcrete as per the standard requirements of the emplacement rooms and access tunnels. The length and spacing are mainly dictated by the maximum span of the intersections.

4.3 Return Air Tunnel – Emplacement Room Intersection – South Panel

The boundary element mesh for the intersection of the Return Air Tunnel and an Emplacement Room in the South panel is shown in Figure 4-7. The areas of interest are the stability of the roof at the intersection, the brow at the emplacement room entrance and the triangular pillar created by the intersection.

Figure 4-8 shows isosurfaces for a factor of safety of 1. These isosurfaces include zones of overstress around the excavation as well as zones where the tensile strength has been exceeded. The analysis confirms the observations from the 2-dimensional analyses, namely that the zones of overstress are only surficial and are limited to the corners of the rooms and the corners of the connecting tunnels between the emplacement room and the return air tunnel. There are no indications of overstress in the pillar or stress relaxation at the brow of the entrance to the emplacement rooms. Figure 4-9 shows only the zones where the tensile strength has been exceeded. It can be seen that the only zone where the tensile strength is exceeded is a localized zone in the west wall of the connecting tunnel; this is due to a combination of the tunnel orientation with respect to the in situ stresses and the aspect ratio of the tunnel. It should be noted that the location of the tensile zone is on the opposite side of that in the connection tunnel in the North panel. The depth of disturbance in all cases is less than the expected depth of damage from the blasting (< 50 cm).

The recommended support for the intersections of the return air tunnels and the tunnels connecting to the emplacement rooms consists of 2.4 m long rockbolts (25mm dia.) on a 1.5 m × 1.5 m pattern and screening or shotcrete as per the standard requirements of the emplacement rooms and access tunnels. The length and spacing are mainly dictated by the maximum span of the intersections.

4.4 Shop Area

The boundary element mesh for the Shop and the intersection of the tunnels on either end of the Shop is shown in Figure 4-10. The areas of interest are the stability of Shop roof and walls, the roof and brows at the intersection with the tunnels at both ends, and the triangular pillar created by the intersection at the NE corner.

Figure 4-11 shows isosurfaces for a factor of safety of 1. These isosurfaces include zones of overstress around the excavation as well as zones where the tensile strength has been exceeded. The analysis shows that the zones of overstress are only surficial and are limited to the corners of the shop and the corners of the brows. There are no indications of overstress in the pillar or stress relaxation at the brows. Figure 4-9 shows only the zones where the tensile strength has been exceeded. It can be seen that the only zones where the tensile strength is exceeded are localized zones in the walls of the electrical room and the office in the shop area. The depth of disturbance in all cases is less than the expected depth of damage from the blasting (< 50 cm).

The recommended support for the roof consists of 4.0 m long rockbolts (25mm dia.) on a 2.0 m × 2.0 m pattern and screening or shotcrete as per the standard requirements of the emplacement rooms and access tunnels . The length and spacing are mainly dictated by the span of the room. This support can be extended to the intersection with the west return air tunnel. The recommended support for the intersection of the shop with the service area access tunnel consists of 6 m long cable bolts on a 2.0 m × 2.0 m pattern, including the brow, and screening or shotcrete as per the standard requirements of the emplacement rooms and access tunnels.

4.5 Main Shaft Station

The boundary element mesh for the main shaft, shaft station and adjacent rooms, and the chairing system below the station is shown in Figures 4-13 and 4-14; Figure 4-13 also shows the excavation sequence. The areas of interest are the shaft station, the chairing system floor and the layout area (large span).

Figure 4-15 shows isosurfaces for a factor of safety of 1. These isosurfaces include zones of overstress around the excavation as well as zones where the tensile strength has been exceeded. The analysis shows that the zones of overstress are only surficial around the shaft and the shaft station. The chairing system floor is located in the Sherman Fall Formation and shows a slightly deeper overstress zone (approx. 1.2 m), which is consistent with the two-dimensional analysis results for the shaft. Figure 4-16 shows that the intersection of the shaft and the shaft station has tensile stresses which exceed the tensile strength of the rock. Elsewhere, the tensile zones are limited to the rock surface.

The main shaft above the shaft station and the brow of the intersection with the shaft station should be bolted with 3 m rockbolts (25mm dia.) at a spacing of 1.8 m and the shaft station should be bolted with 4 m long rockbolts (25mm dia.) on a 2.0 m × 2.0 m pattern and screening or shotcrete as per the standard requirements of the emplacement rooms and access tunnels. The floor of the chairing system maintenance floor should be bolted with vertical dowels 3 m long (25mm dia.) at spacing of 1.8 m.

The layout area adjacent to the shaft station is the room with the largest span in the repository. It has dimensions of 19 m × 15 m. Figure 4-17 shows the isosurface for a factor of safety of 1 and the areas under tension. Although the zones exceeding the tensile strength of the rock are very limited, the large span and the flat roof are a concern due to the potential presence of horizontal weakness planes.

This room should be supported by 3 m rockbolts (25mm dia.) on a 1.5 m × 1.5 m pattern, complemented by 7 m long double cable bolts (2 per hole) on a 3.0 m × 3.0 m pattern and screening or shotcrete as per the standard requirements of the emplacement rooms and access tunnels.

4.6 Ventilation Shaft Station and Loading Pocket

The boundary element mesh for the ventilation shaft, shaft station and adjacent rooms, and the loading pocket below the station is shown in Figures 4-18 and 4-19; Figure 4-18 also shows the excavation sequence. The areas of interest are the shaft station, the loading pocket and the conveyor tunnel.

Figures 4-20 through 4-22 show several views of the isosurfaces for a factor of safety of 1. These isosurfaces include zones of overstress around the excavation as well as zones where the tensile strength has been exceeded. The analysis shows that the zones of overstress are only surficial around the shaft and the shaft station (Cobourg formation). The loading pocket and the conveyor tunnel are located in the Sherman Fall formation and show a slightly deeper overstress zone (< 0.8 m in the walls of the conveyor tunnel and < 1 m in the roof; relaxation of the intersection of the shaft and the loading pocket up to 1 m), which is consistent with the two-dimensional analysis results for the shaft. The bottom of the loading pocket and the portion below the loading pocket are located in the Kirkfield Formation, which is slightly weaker than the Sherman Fall Formation and shows a similar level of overstress.

Figures 4-23 through 4-25 show several views of the tensile zones. Tension is limited to localized zones with the intersection of the shaft and the loading pocket showing the largest extent.

The shaft station and the access at the bottom of the loading pocket should be bolted with 3 m long rockbolts (25mm dia.) at a spacing of 1.8 m and screening or shotcrete as per the standard requirements of the emplacement rooms and access tunnels. The roof and sidewalls of the conveyor tunnel and the walls of the loading pocket should be bolted with 2.4 m long bolts (25mm dia.) on a 1.5 m × 1.5 m pattern and screening or shotcrete as per the standard requirements of the emplacement rooms and access tunnels.

5.0 RECOMMENDATIONS

Based on the results of the three-dimensional detailed analyses, the following are recommendations for rock support:

Location	Type	Length (m)	Diameter (mm)	Spacing (m x m)
Access Tunnel – Emplacement Room Intersection	Hollow-core groutable rockbolt	3.5	25	1.8 x 1.8
Return Air Tunnel – Emplacement Room Intersection (N Panel)	Hollow-core groutable rockbolt	2.4	25	1.5 x 1.5
Return Air Tunnel – Emplacement Room Intersection (S Panel)	Hollow-core groutable rockbolt	2.4	25	1.5 x 1.5
Shop Area – Roof and Intersection with West Return Air Tunnel	Hollow-core groutable rockbolt	4.0	25	2.0 x 2.0
Shop Area – Service Area Access Tunnel Intersection	Cable Bolt	6.0	15.2	2.0 x 2.0
Main Shaft (above shaft station) and brow of intersection with shaft station	Hollow-core groutable rockbolt	3.0	25	2.0 x 2.0
Main Shaft Station	Hollow-core groutable rockbolt	4.0	25	2.0 x 2.0
Main Shaft chairing system floor	Rebar dowel	3.0	25	1.8 x 1.8
Main Shaft Layout Area	Hollow-core groutable rockbolt	3.0	25	1.5 x 1.5
	Double Cable Bolts	7.0	15.2 (ea)	3.0 x 3.0
Ventilation Shaft Station and Loading Pocket Access	Hollow-core groutable rockbolt	3.0	25	1.8 x 1.8
Conveyor Tunnel and Sidewalls and Loading Pocket Sidewalls	Hollow-core groutable rockbolt	2.4	25	1.5 x 1.5

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[14] Tetra Tech, 2012. Underground Facility Tunnelling Dimensions Return Air Tunnels, Drawing No. 1088240200-DWG-R0019, Rev. C

Report Signature Page

GOLDER ASSOCIATES LTD.

J.L. Carvalho, Ph.D., P.Eng.
Principal

C.M. Steed, M.Sc., P.Eng.
Principal

JLC/CMS/co

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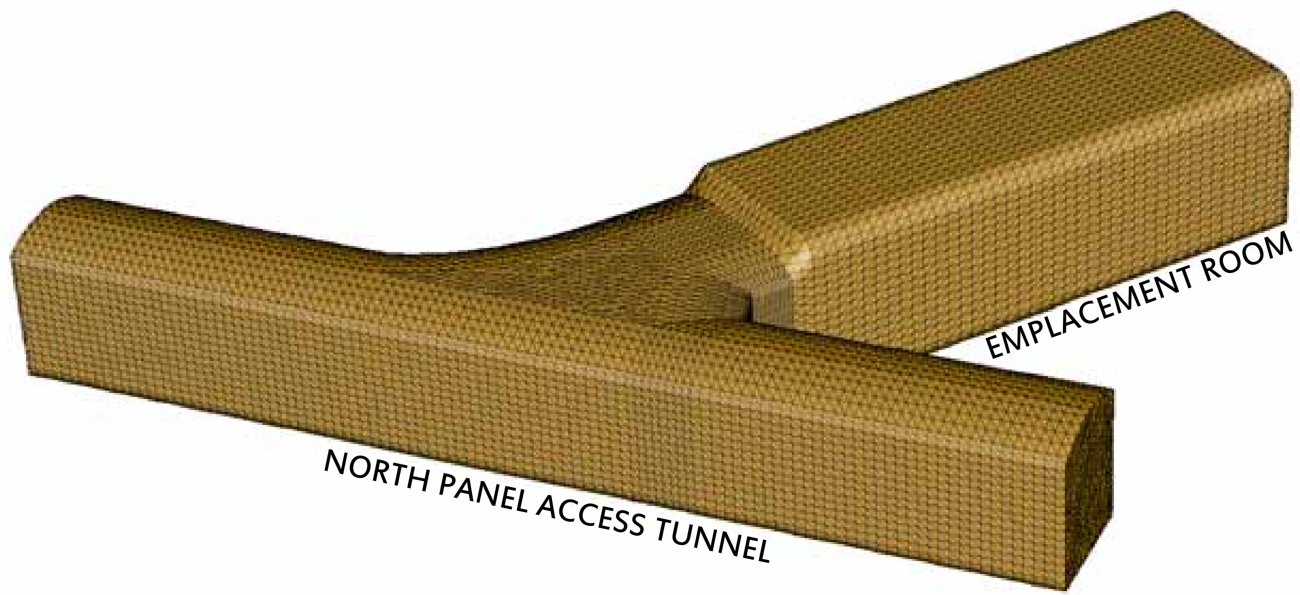
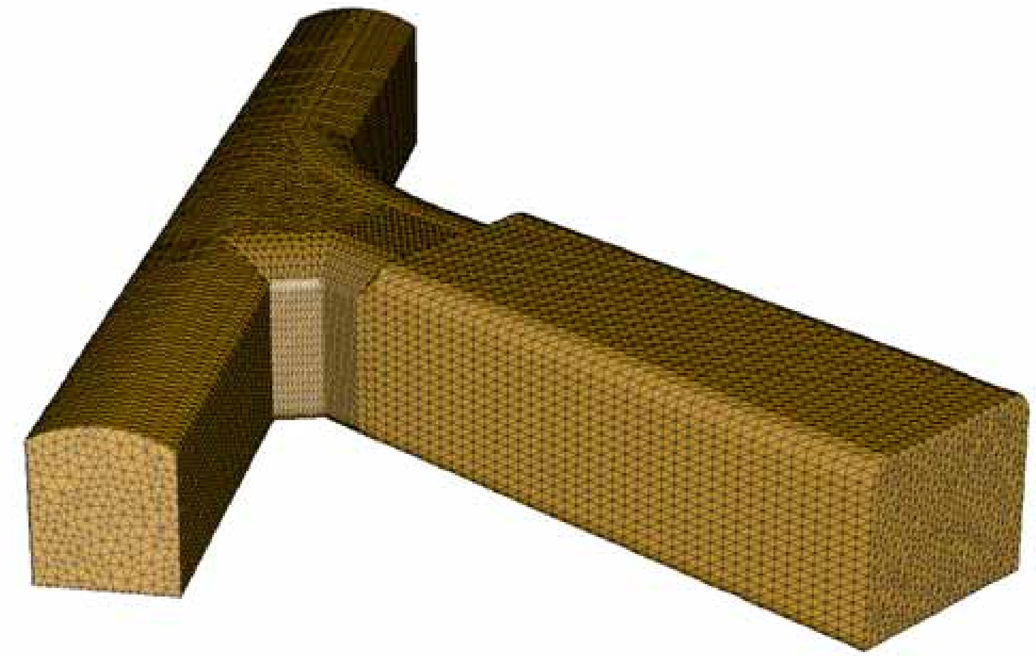
FIGURES

MODEL GEOMETRY AND MESH
ACCESS TUNNEL
DGR FOR L&ILW

FIGURE 4-1



VIEW LOOKING NW (DPG COORD SYSTEM)



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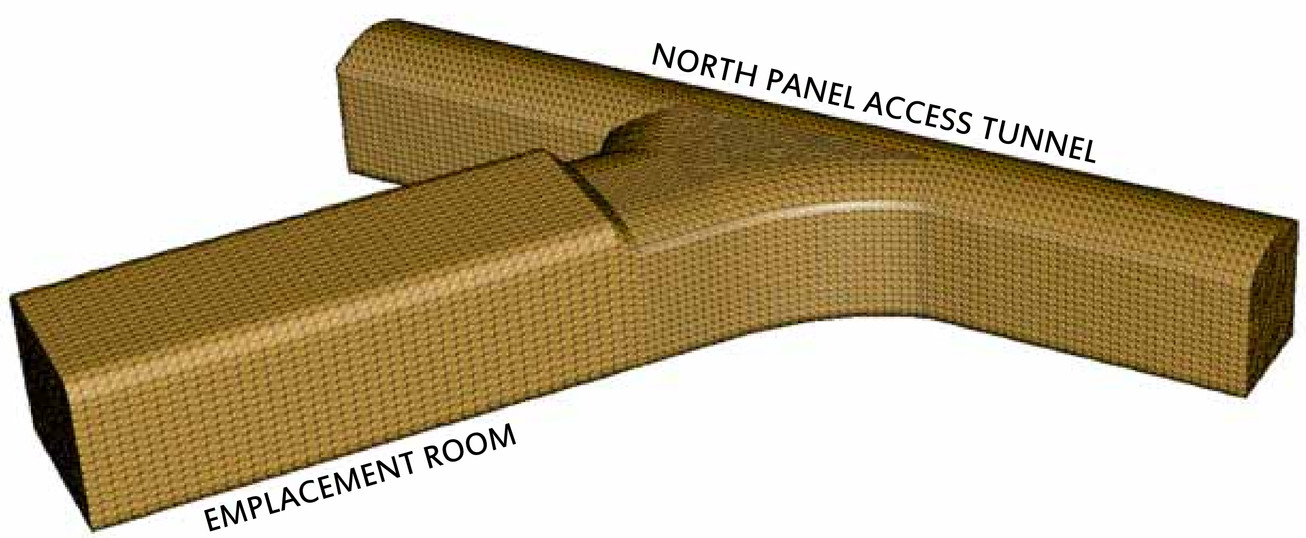

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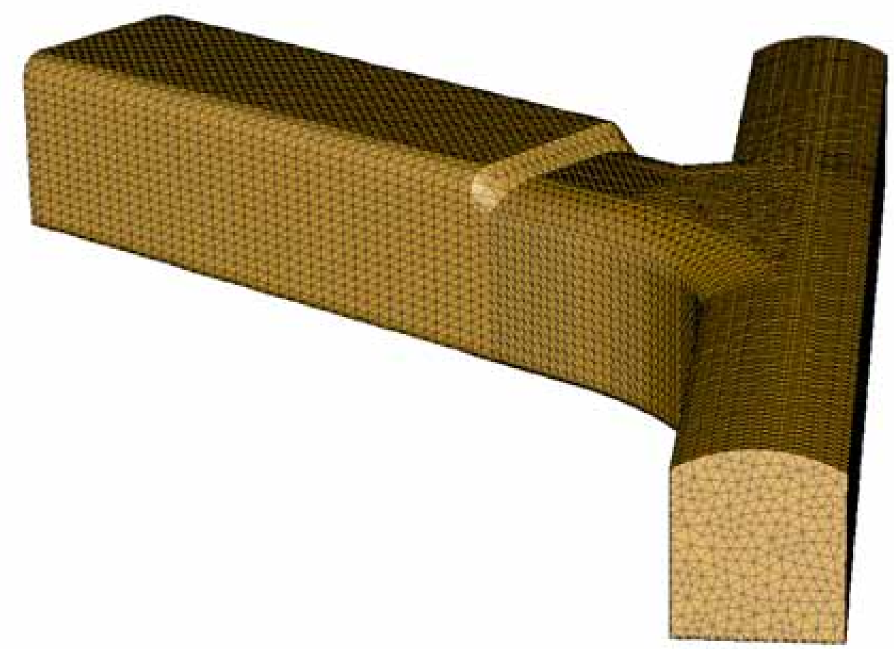

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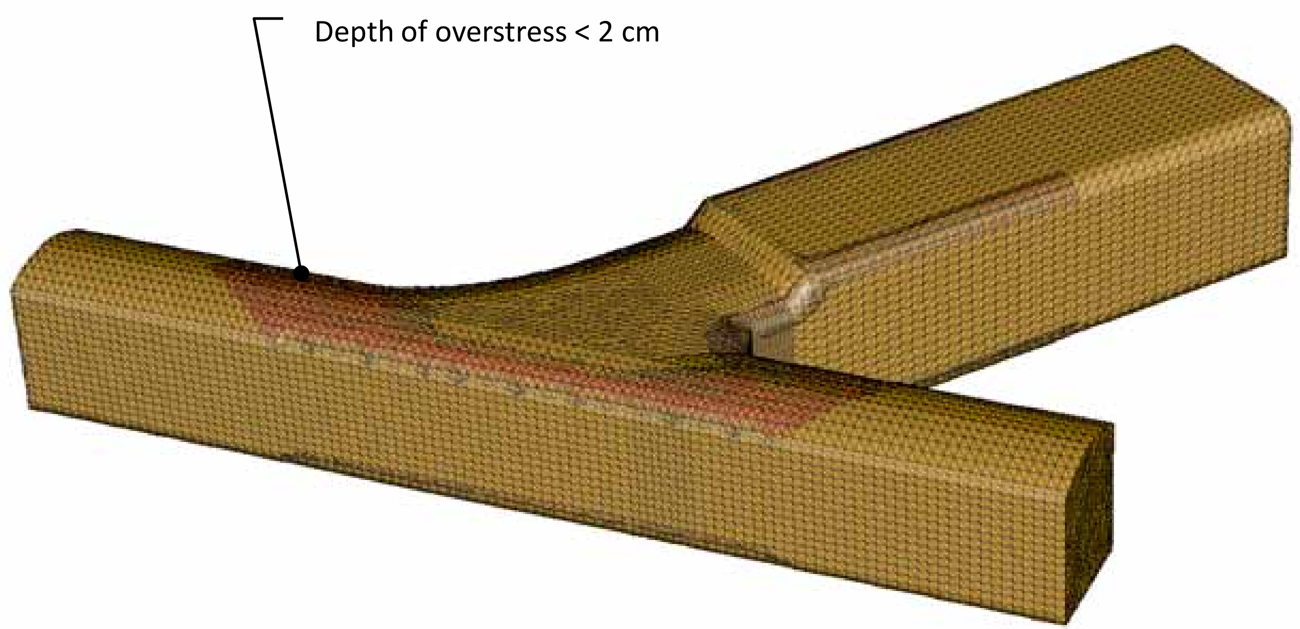
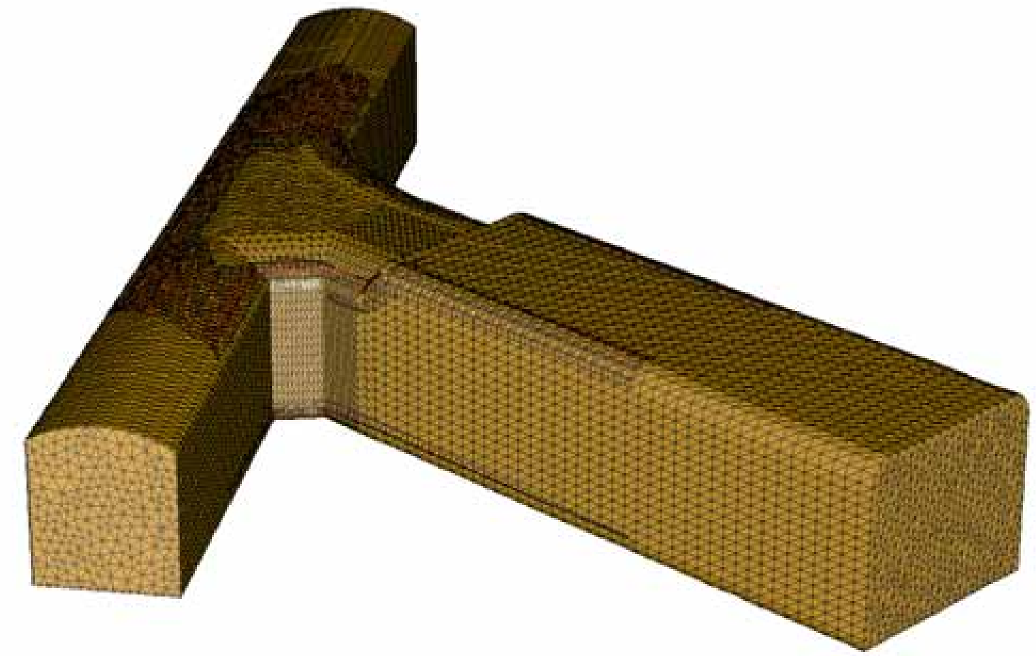
ZONES OF OVERSTRESS ACCESS TUNNEL DGR FOR L&ILW

FIGURE 4-2





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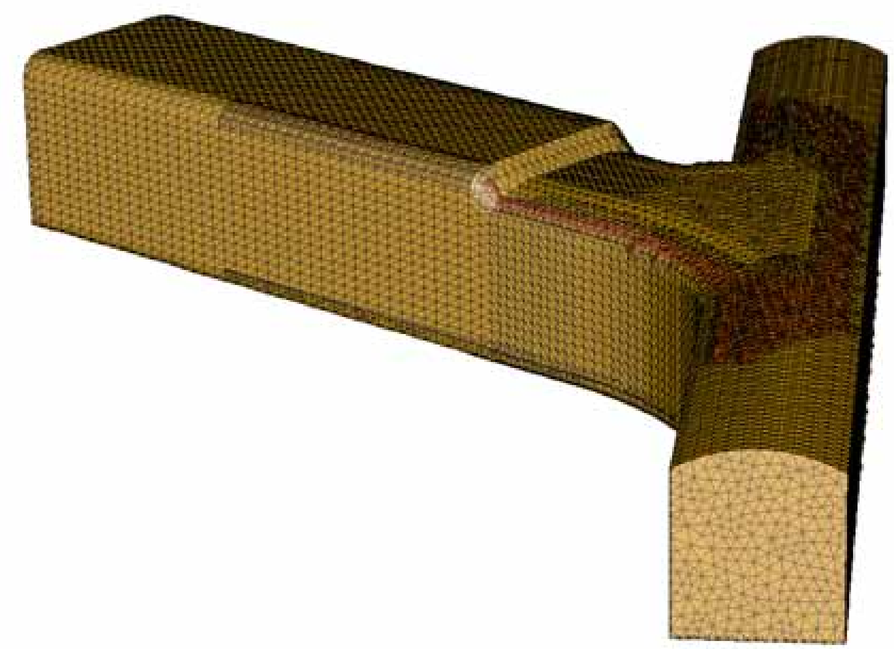

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OVERSTRESSED ROCK MASS ZONE

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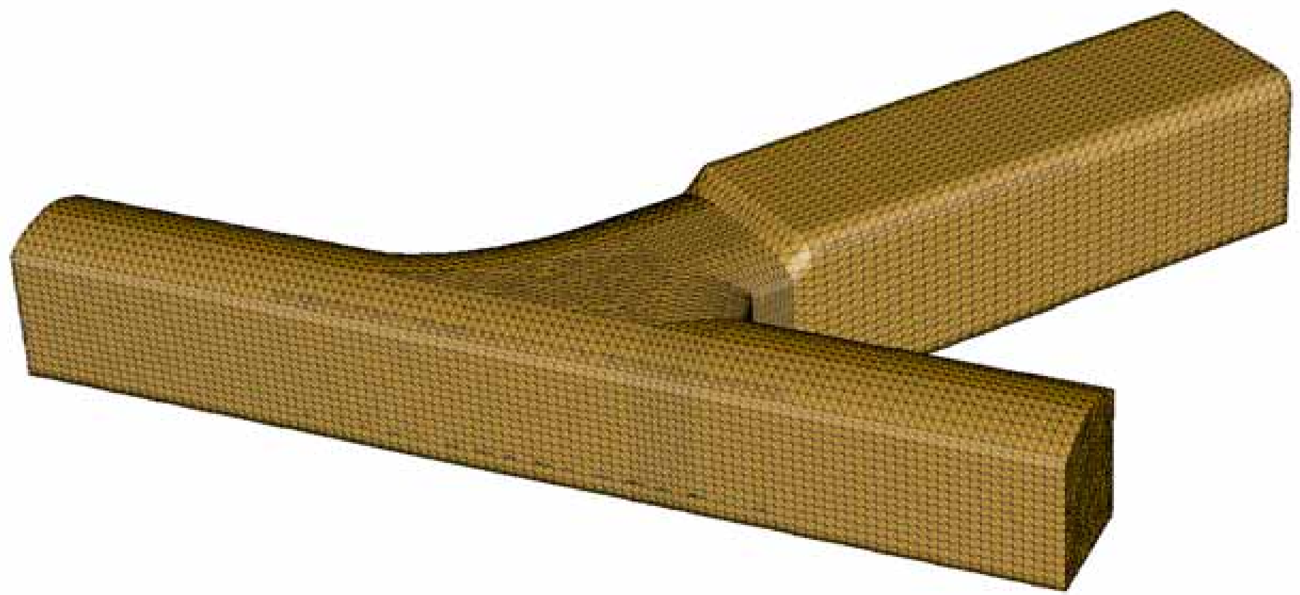
Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

ZONES EXCEEDING TENSILE
ACCESS TUNNEL
DGR FOR L&ILW

FIGURE 4-3



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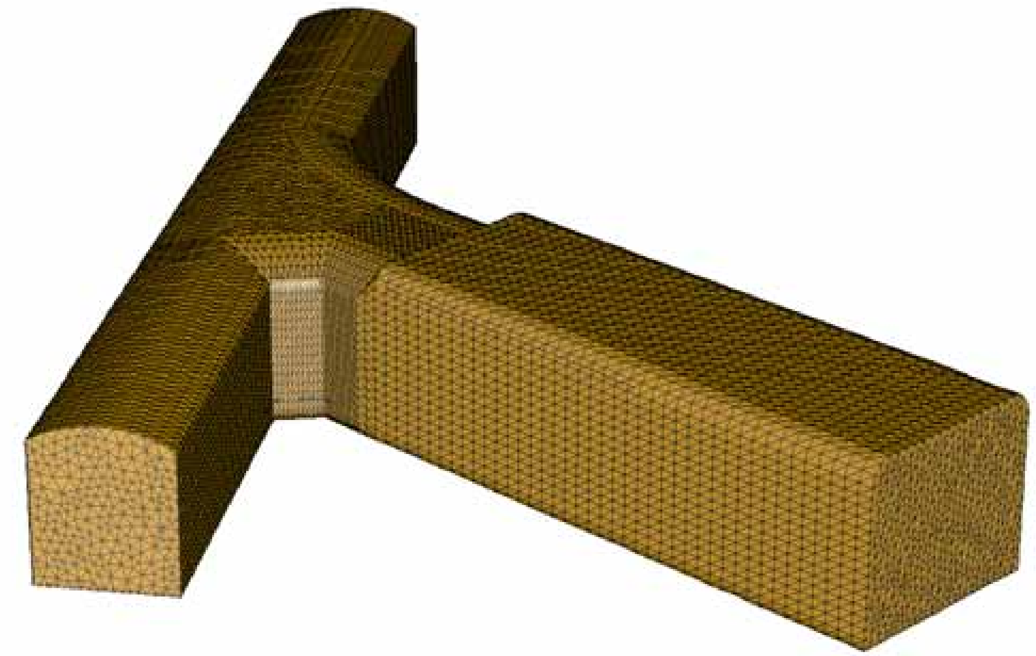

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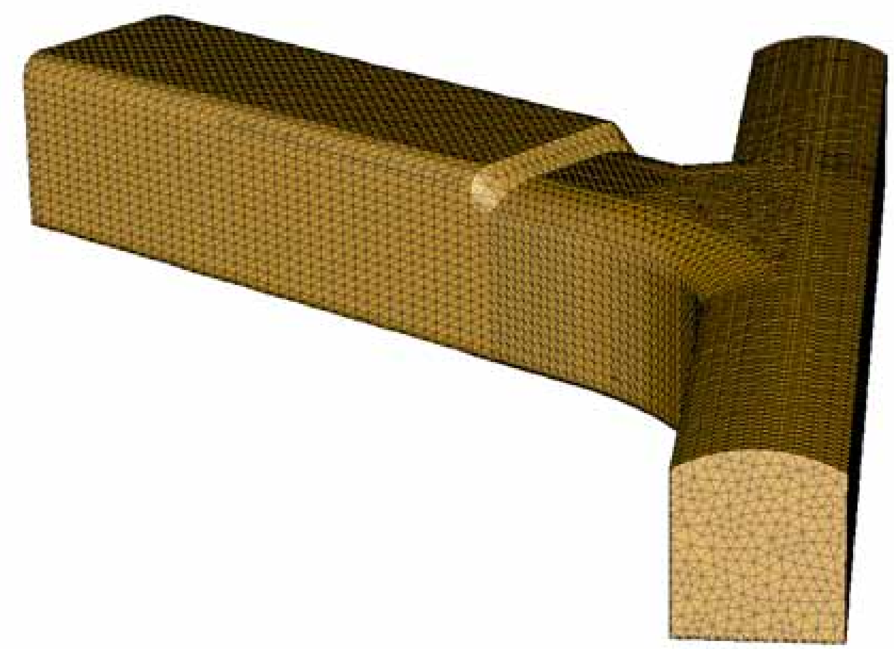

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■ ZONE EXCEEDING ROCK MASS TENSILE STRENGTH

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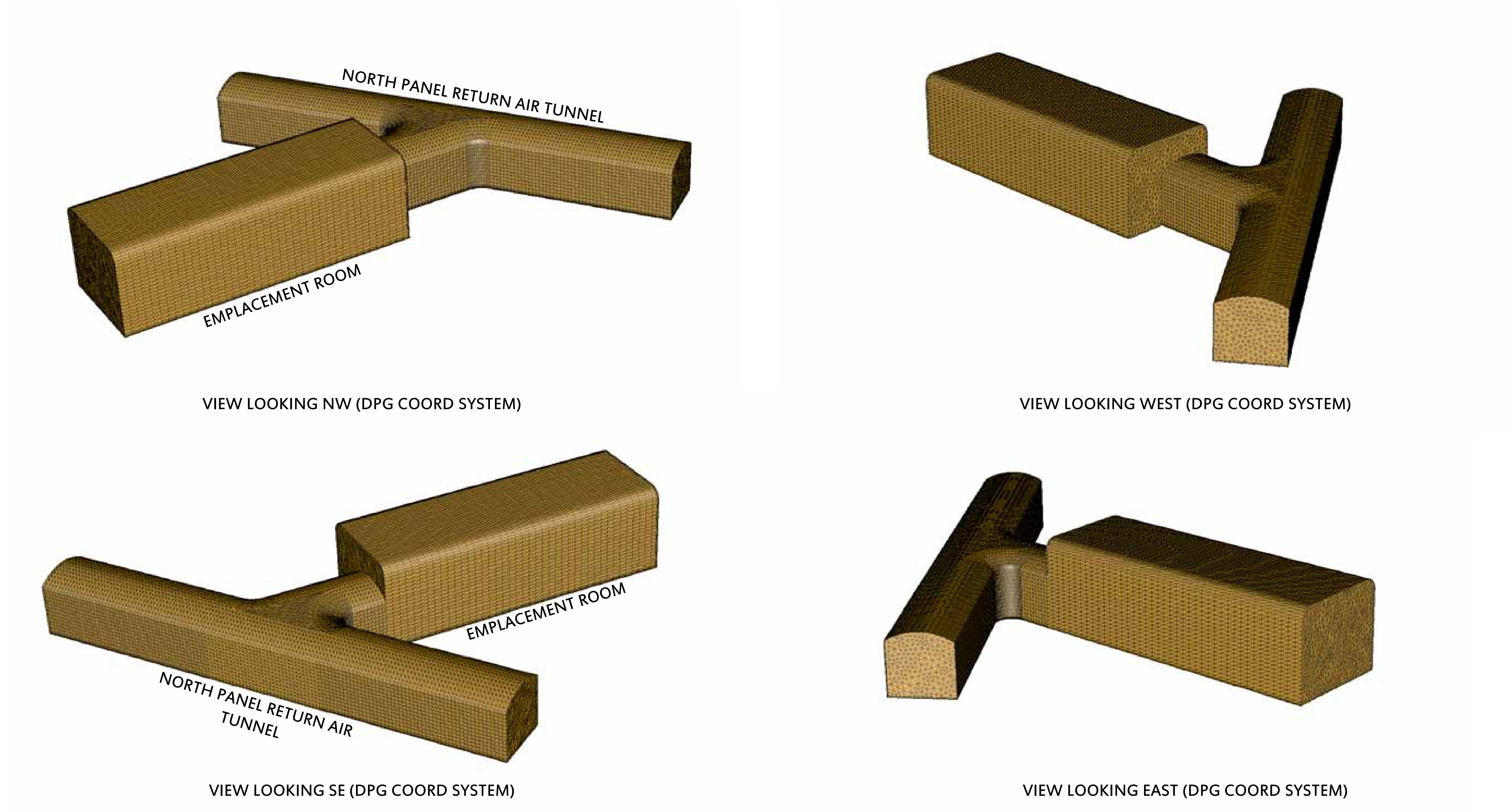
Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

GEOMETRY AND MESH RETURN AIR TUNNEL-NORTH PANEL DGR FOR L&ILW

FIGURE 4-4



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DOC: J.L.C.
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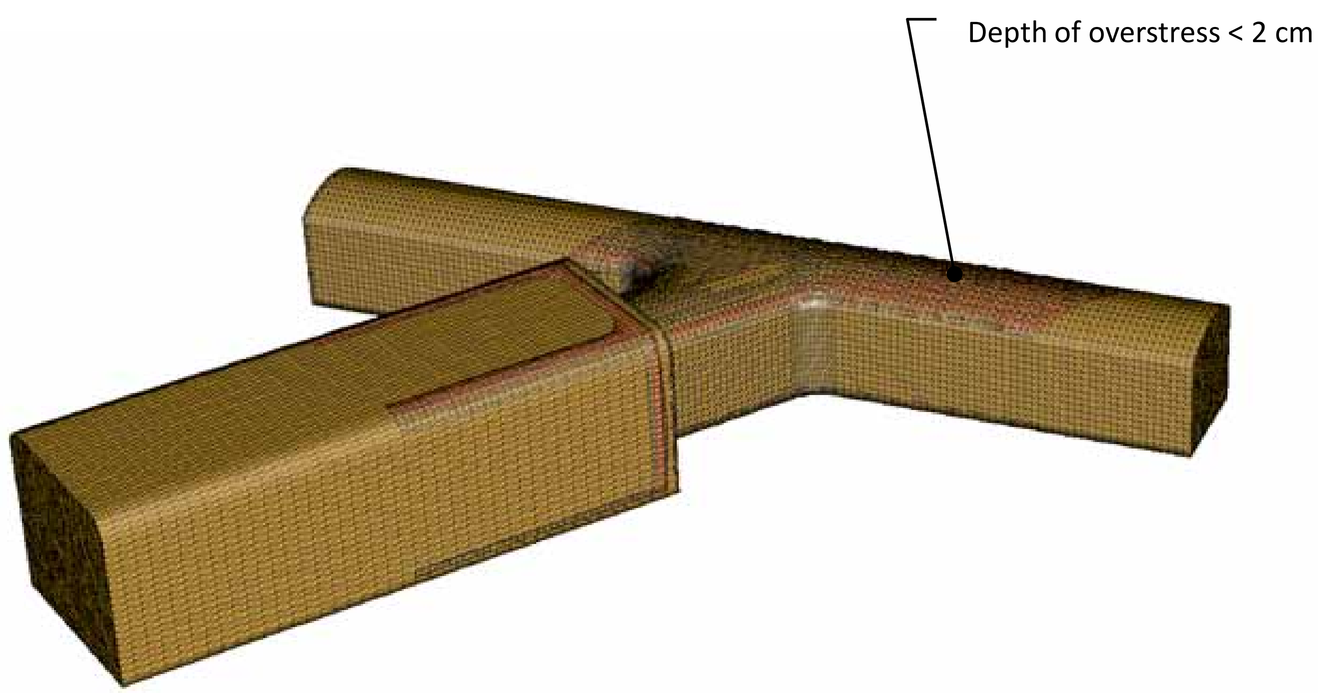
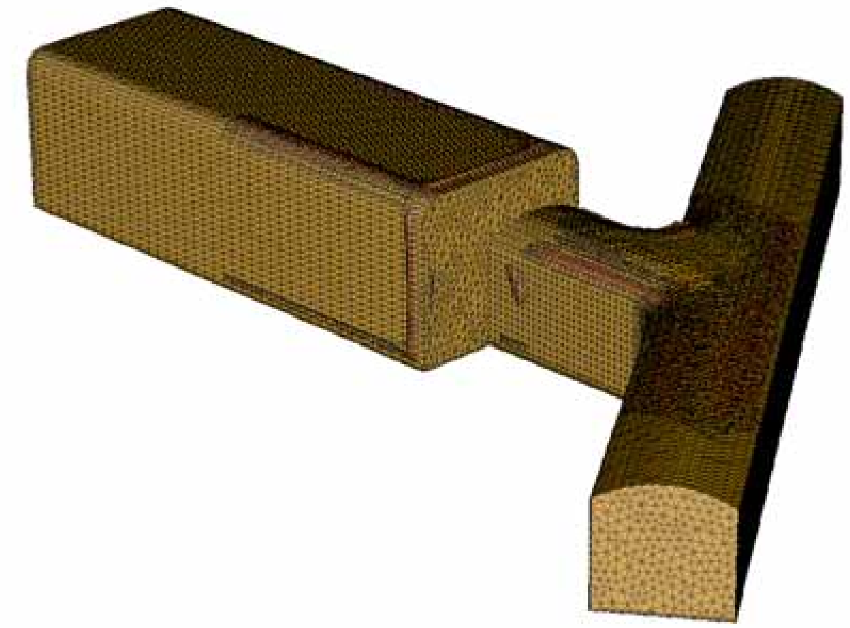
Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

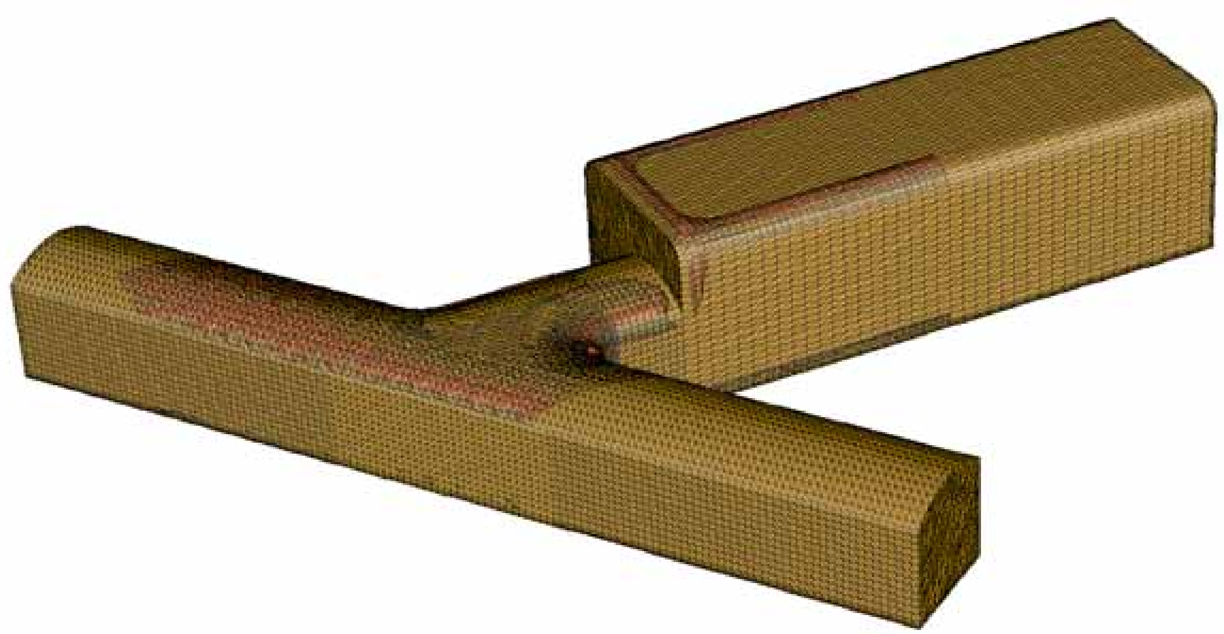
ZONES OF OVERSTRESS
RETURN AIR TUNNEL-NORTH PANEL
DGR FOR L&ILW

FIGURE 4-5

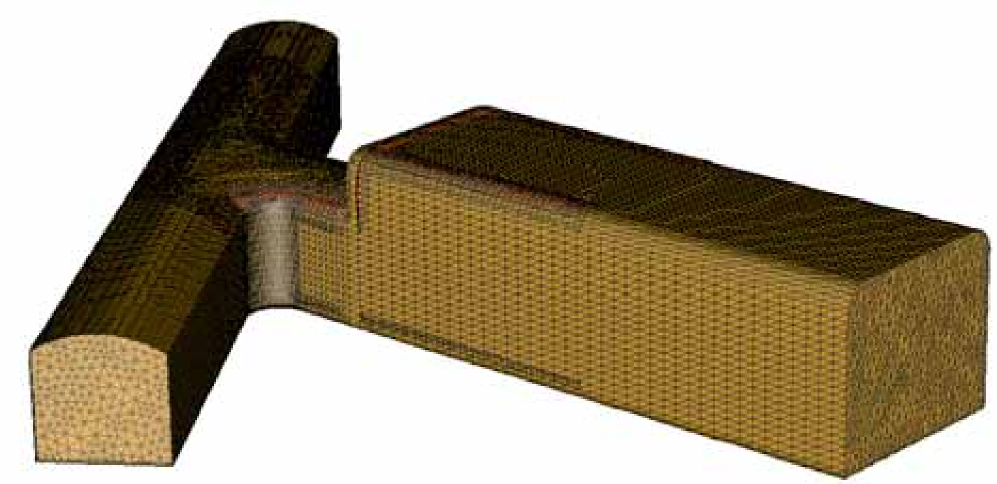




VIEW LOOKING WEST (DPG COORD SYSTEM)



VIEW LOOKING SE (DPG COORD SYSTEM)



VIEW LOOKING EAST (DPG COORD SYSTEM)

OVERSTRESSED ROCK MASS ZONE

DATE: October-2012

PROJECT: 10-1117-0042

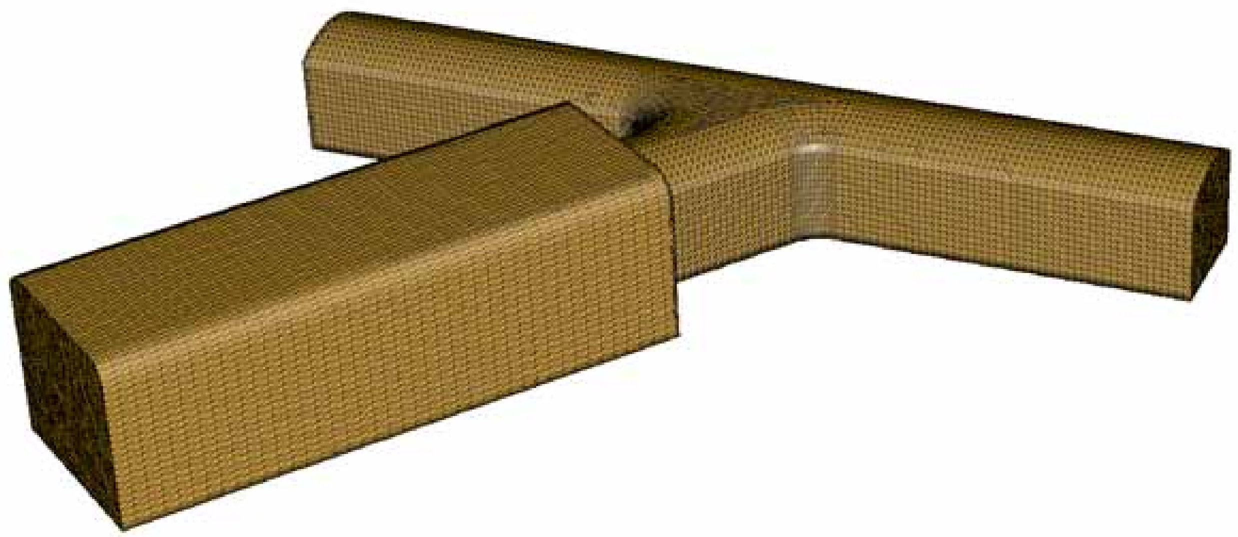
Golder Associates

DOC: J.L.C.

CHK: C.M.S. APD: C.M.S.

Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

ZONES EXCEEDING TENSILE RETURN AIR TUNNEL-NORTH PANEL DGR FOR L&ILW | **FIGURE 4-6**



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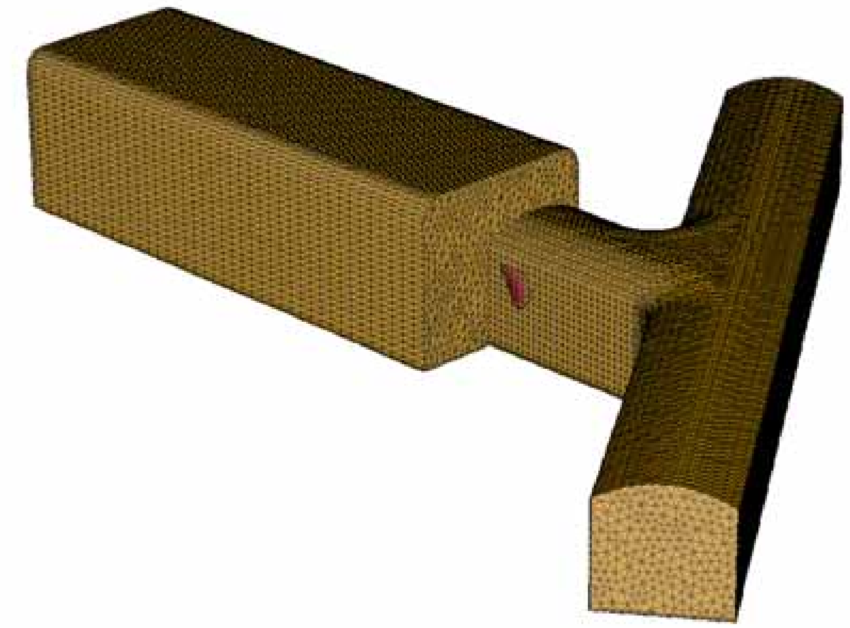
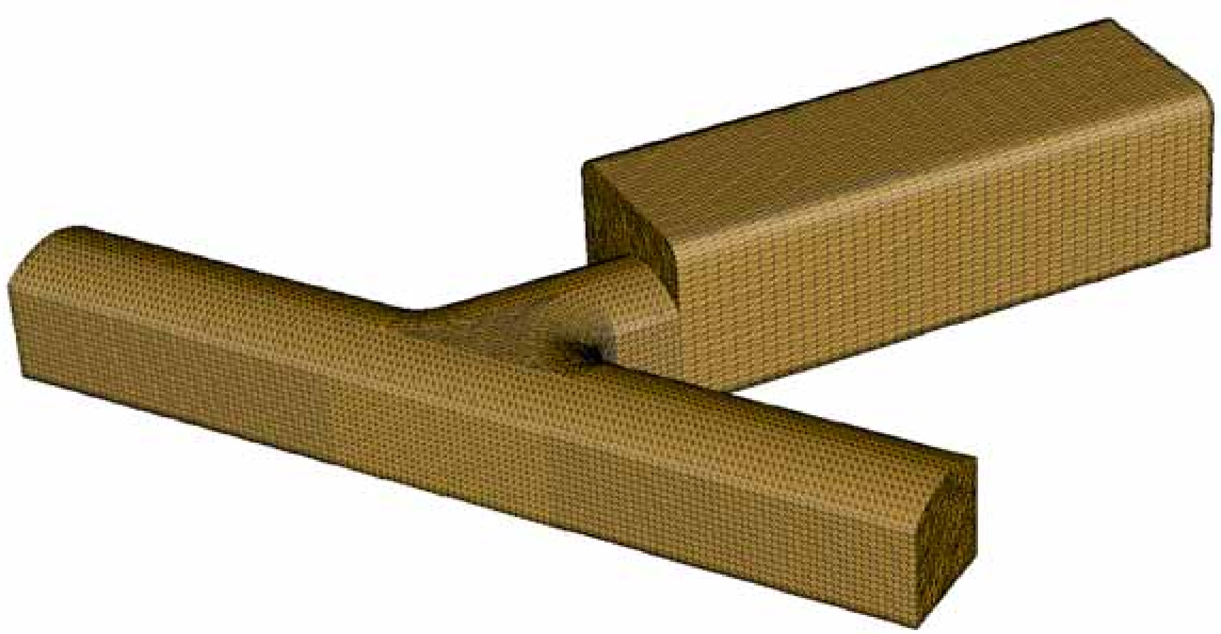


VIEW LOOKING WEST (DPG COORD SYSTEM)



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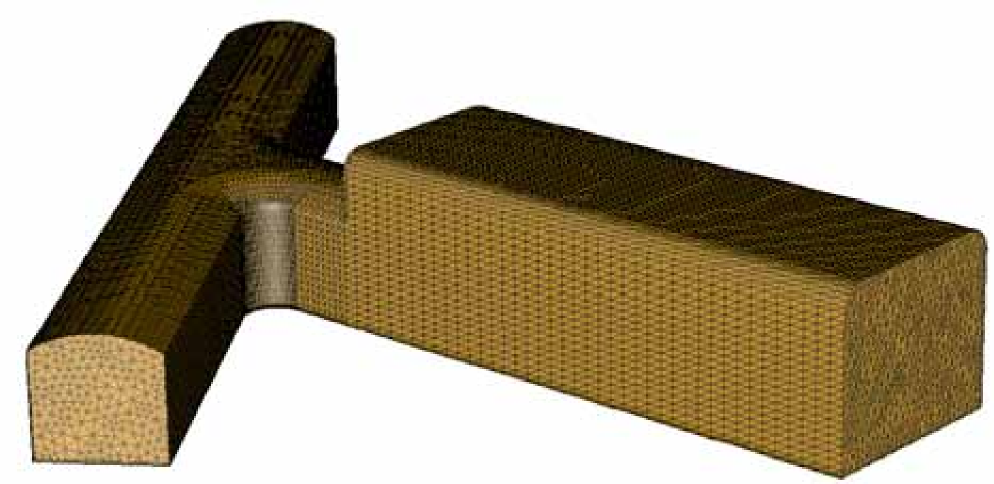


VIEW LOOKING EAST (DPG COORD SYSTEM)

ZONE EXCEEDING ROCK MASS TENSILE STRENGTH

DATE: October-2012
PROJECT: 10-1117-0042

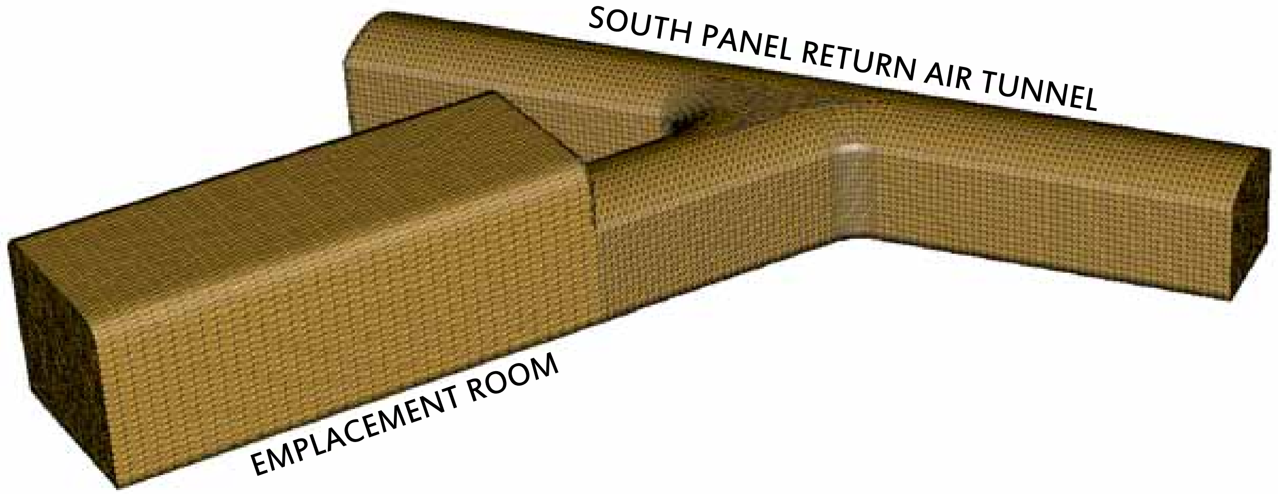
Golder Associates

DOC: J.L.C.
CHK: C.M.S. APD: C.M.S.

Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

GEOMETRY AND MESH RETURN AIR TUNNEL-SOUTH PANEL DGR FOR L&ILW

FIGURE 4-7



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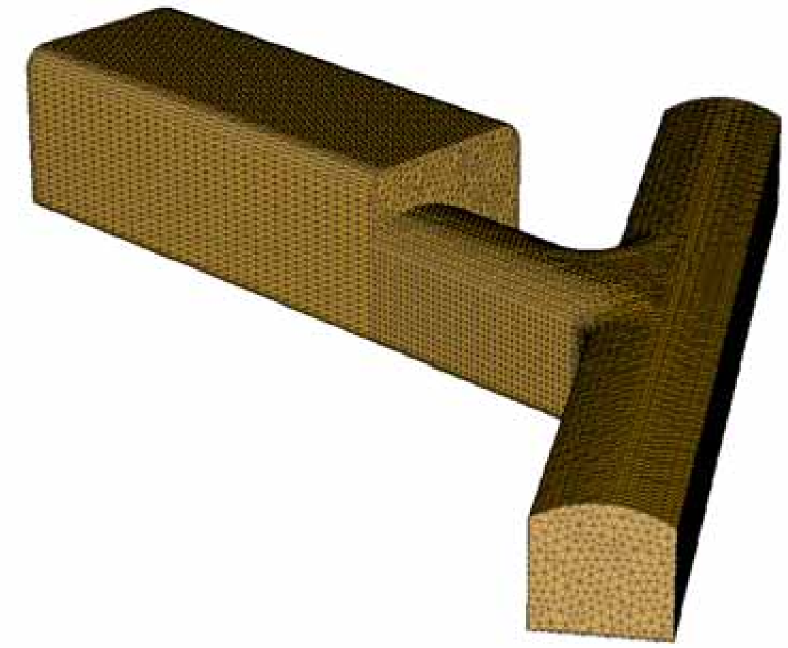

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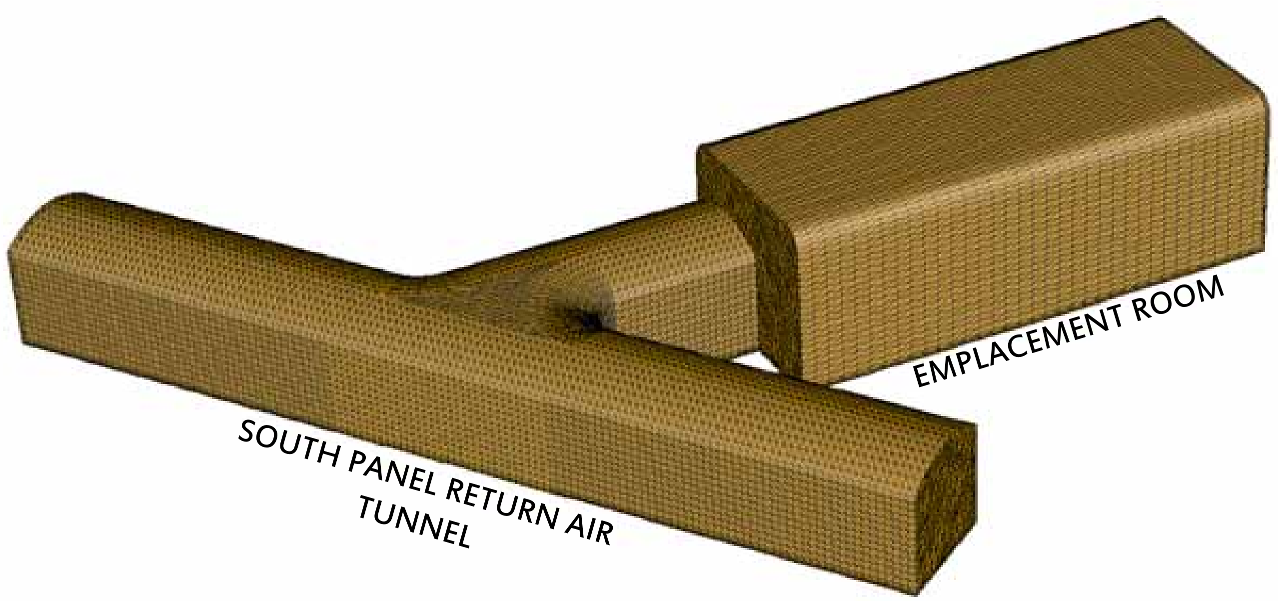
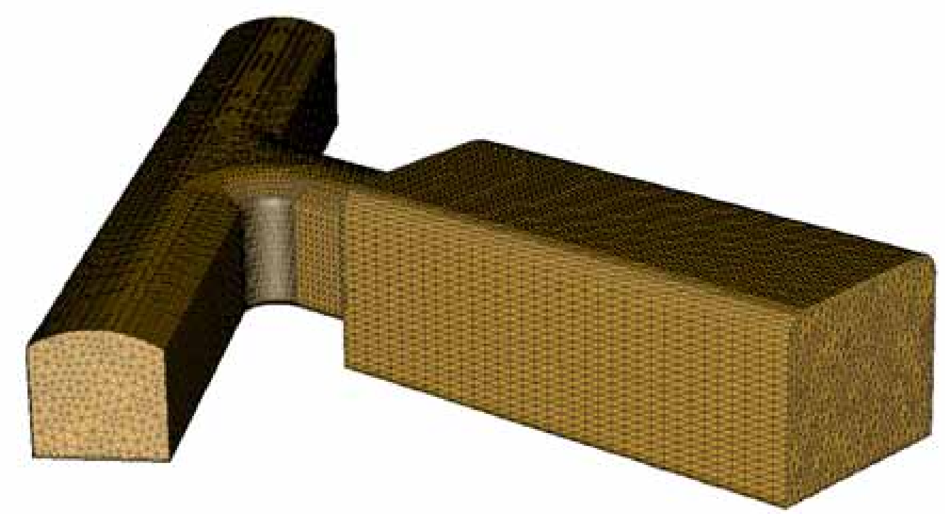


VIEW LOOKING SE (DPG COORD SYSTEM)



VIEW LOOKING EAST (DPG COORD SYSTEM)

DATE: October-2012
PROJECT: 10-1117-0042

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DOC: J.L.C.
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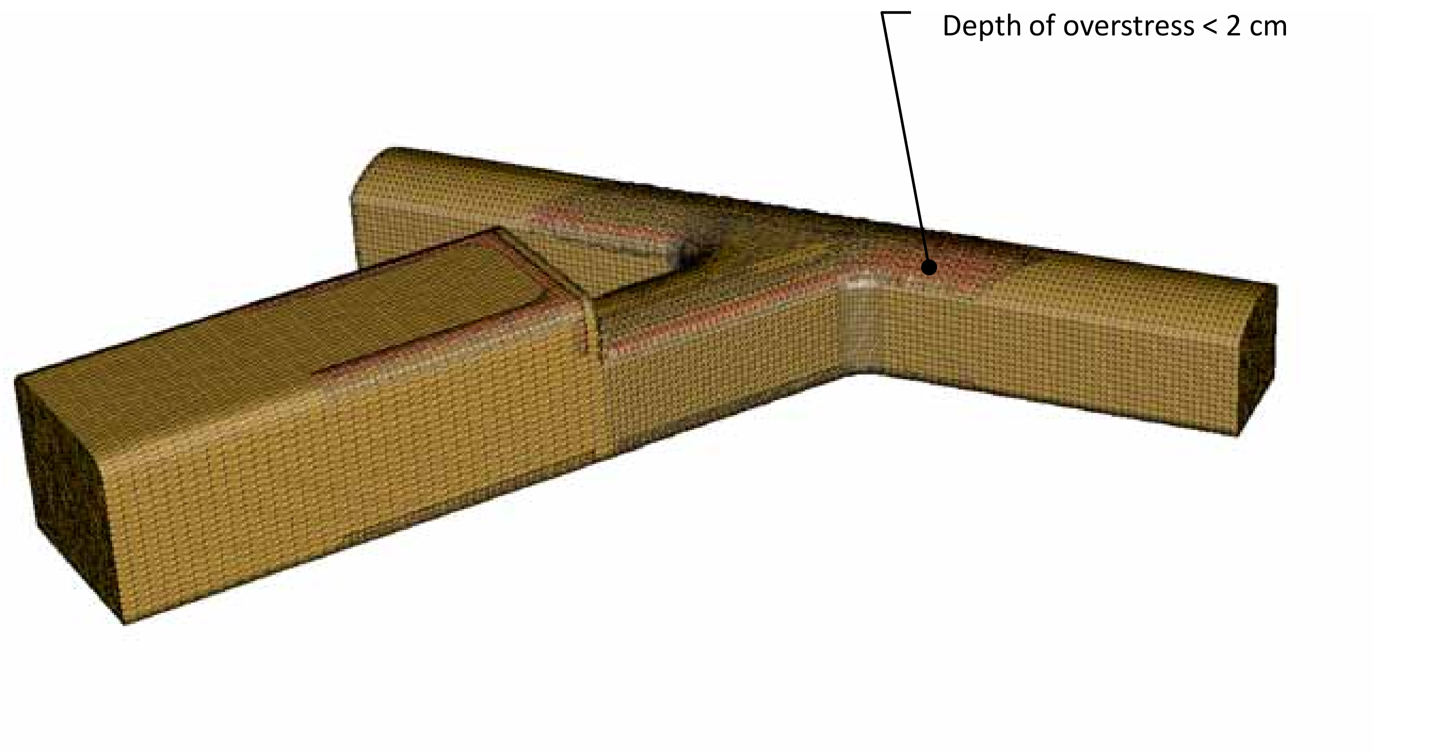
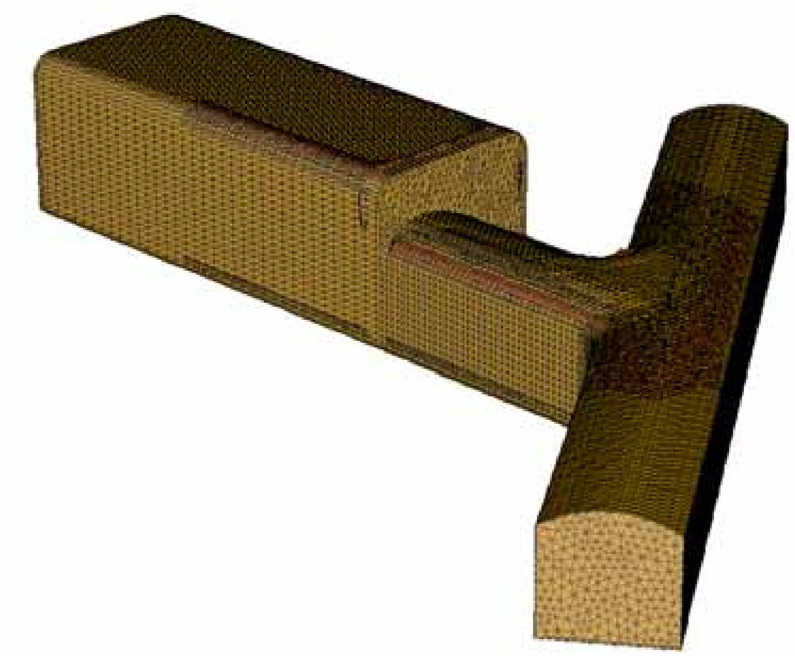
Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

ZONES OF OVERSTRESS
RETURN AIR TUNNEL-SOUTH PANEL
DGR FOR L&ILW

FIGURE 4-8





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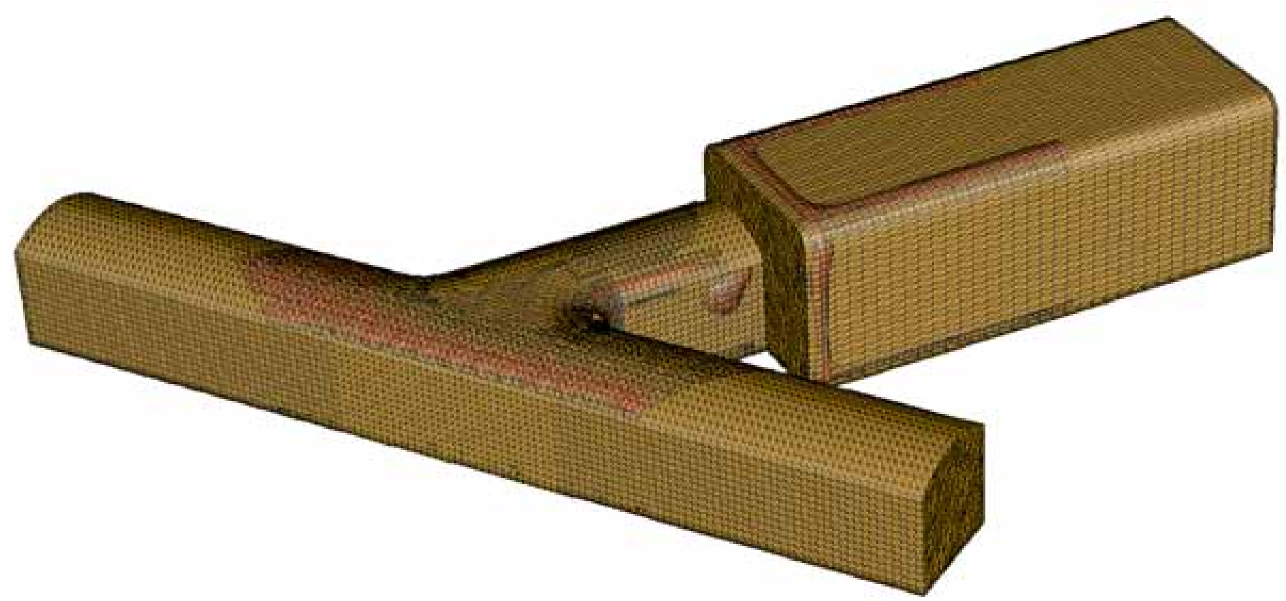

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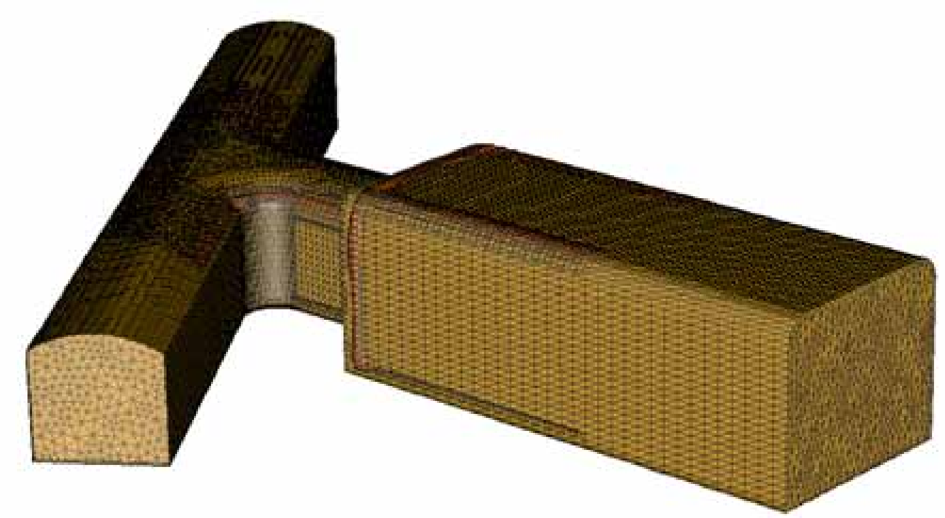


VIEW LOOKING EAST (DPG COORD SYSTEM)

■ OVERSTRESSED ROCK MASS ZONE

DATE: October-2012

PROJECT: 10-1117-0042

Golder Associates

DOC: J.L.C.

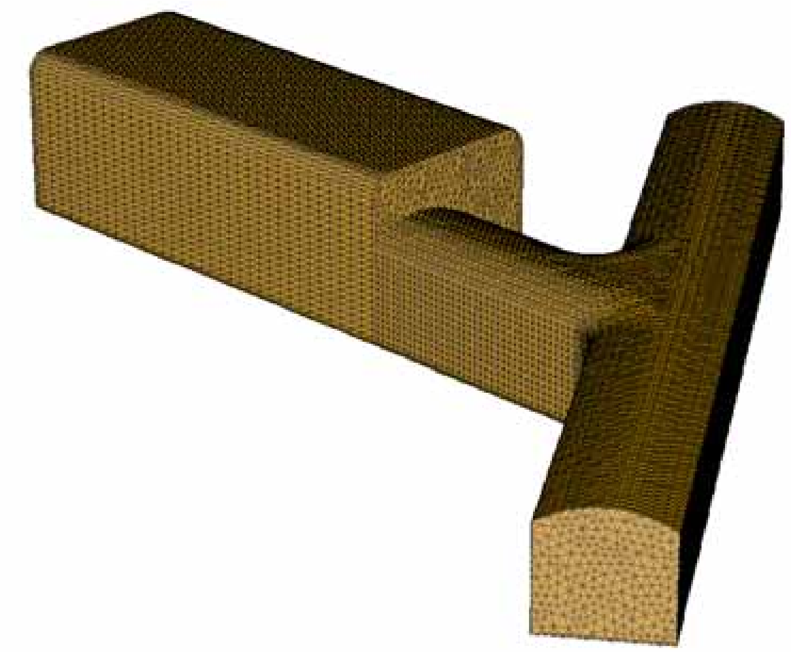
CHK: C.M.S. APD: C.M.S.

Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

ZONES EXCEEDING TENSILE RETURN AIR TUNNEL-SOUTH PANEL DGR FOR L&ILW

FIGURE 4-9

VIEW LOOKING NW (DPG COORD SYSTEM)



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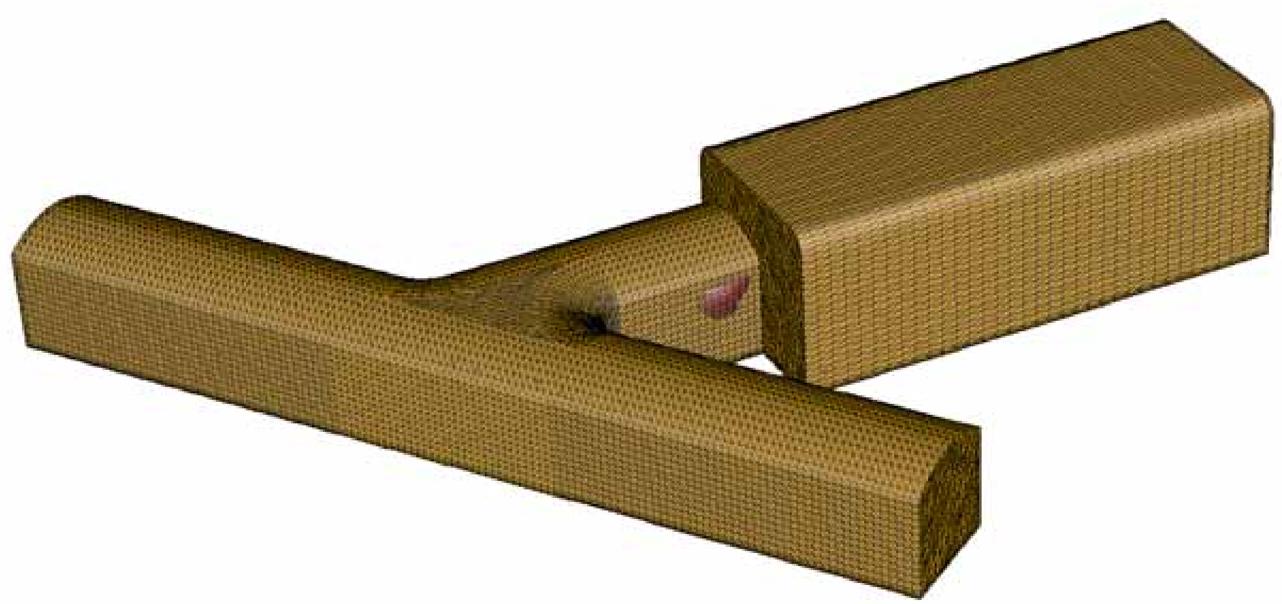

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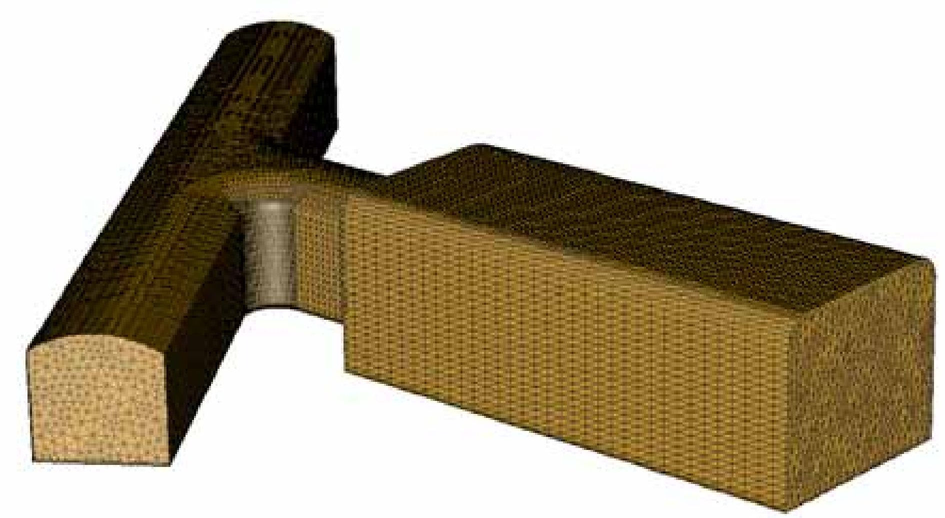


VIEW LOOKING EAST (DPG COORD SYSTEM)

ZONE EXCEEDING ROCK MASS TENSILE STRENGTH

DATE: October-2012

PROJECT: 10-1117-0042

Golder Associates

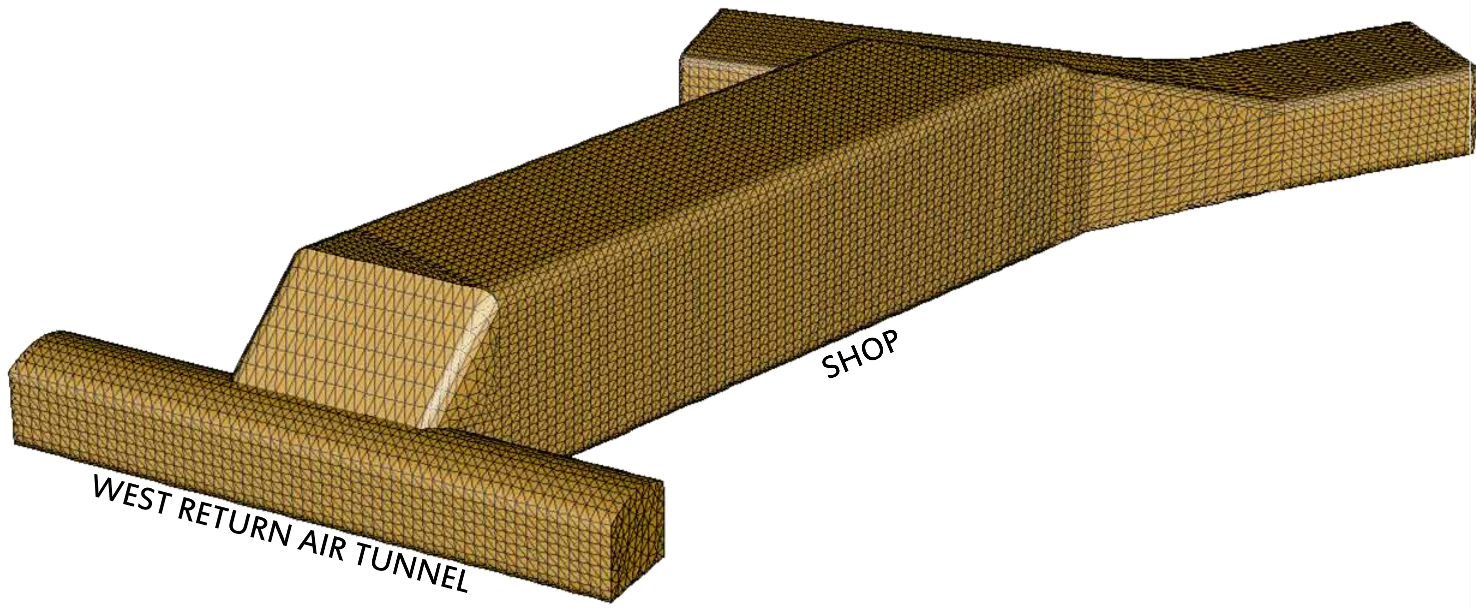
DOC: J.L.C.

CHK: C.M.S. APD: C.M.S.

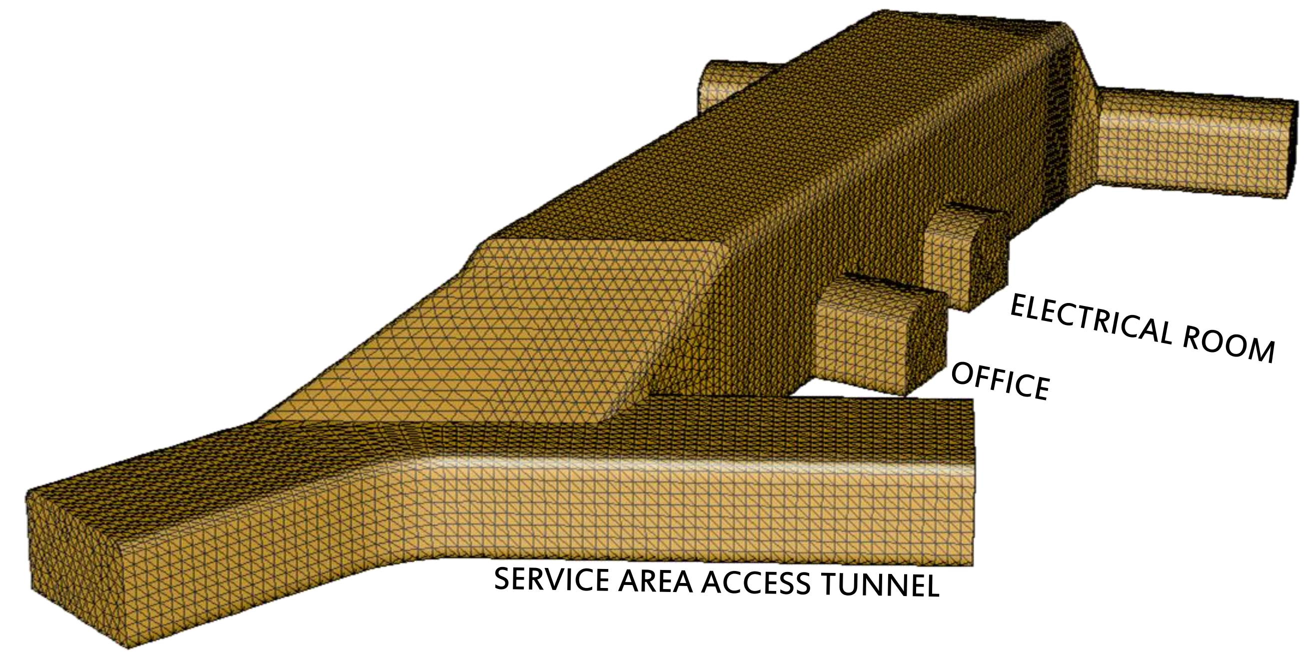
Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

GEOMETRY AND MESH
SHOP
DGR FOR L&ILW

FIGURE 4-10



LOOKING NE (DPG COORDINATE SYSTEM)



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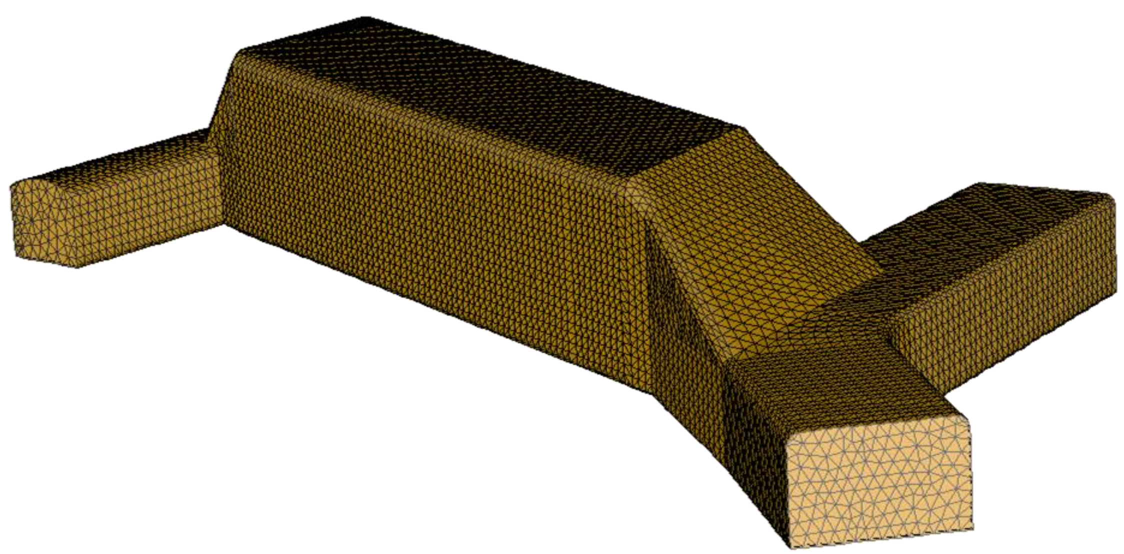

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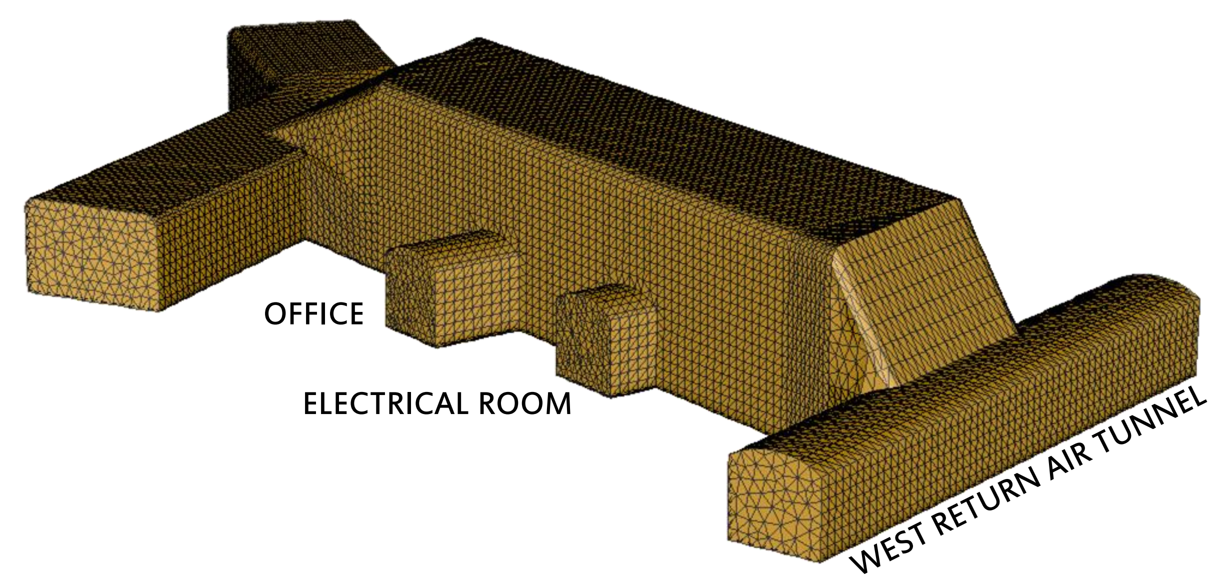

LOOKING SE (DPG COORDINATE SYSTEM)

DATE: October-2012
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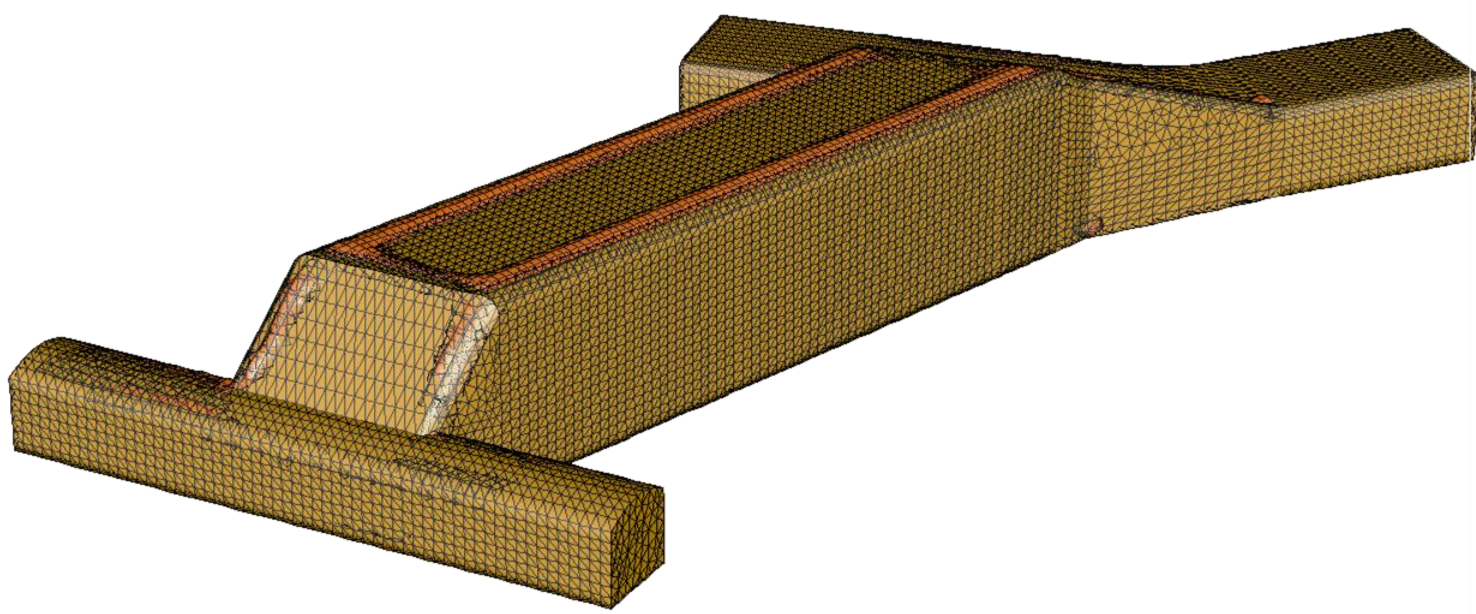
ZONES OF OVERSTRESS
SHOP
DGR FOR L&ILW

FIGURE 4-11



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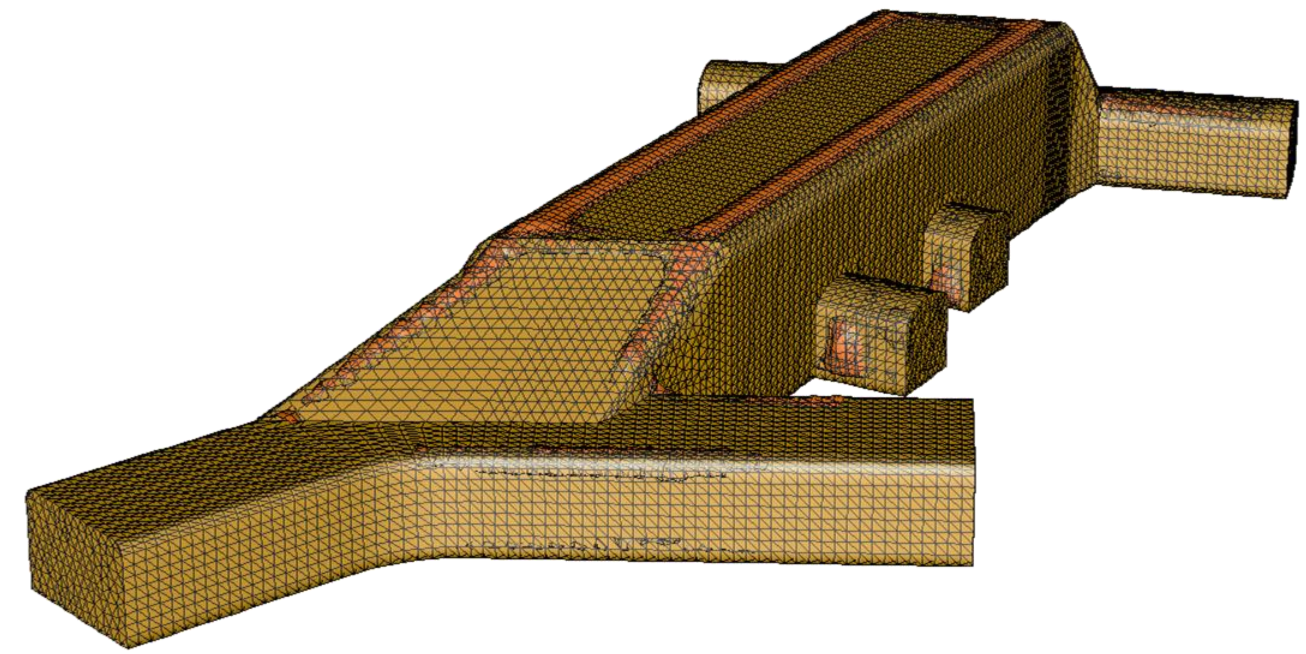

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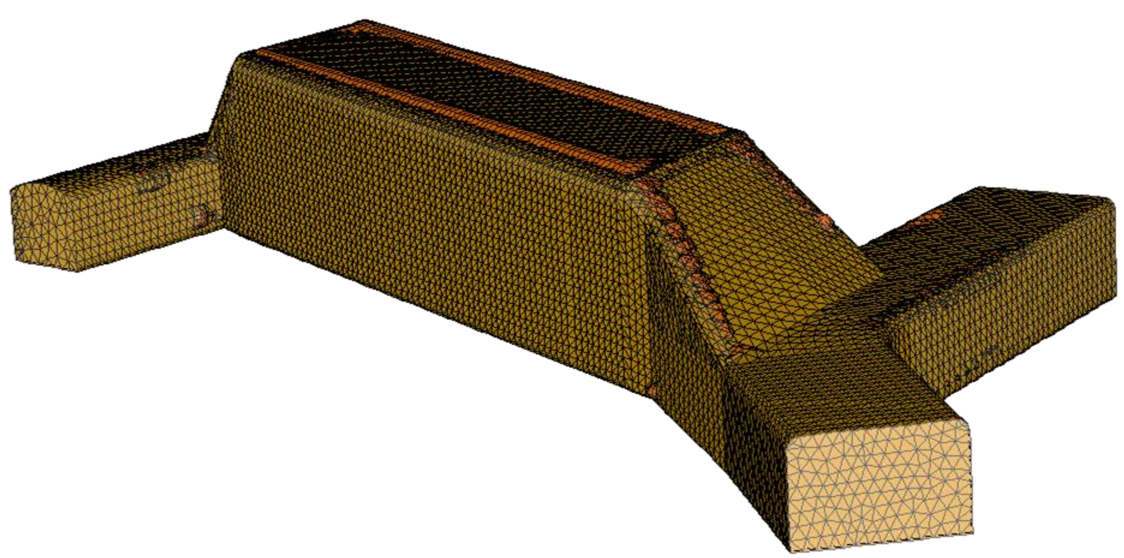

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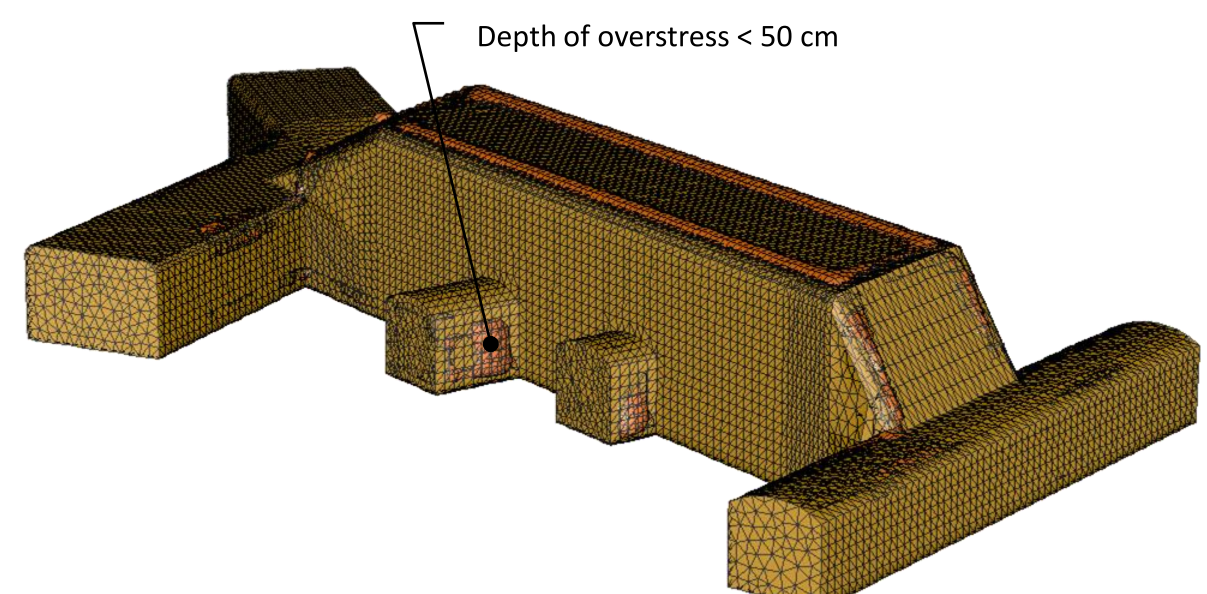

LOOKING SE (DPG COORDINATE SYSTEM)

■ OVERSTRESSED ROCK MASS ZONE

DATE: October-2012

PROJECT: 10-1117-0042

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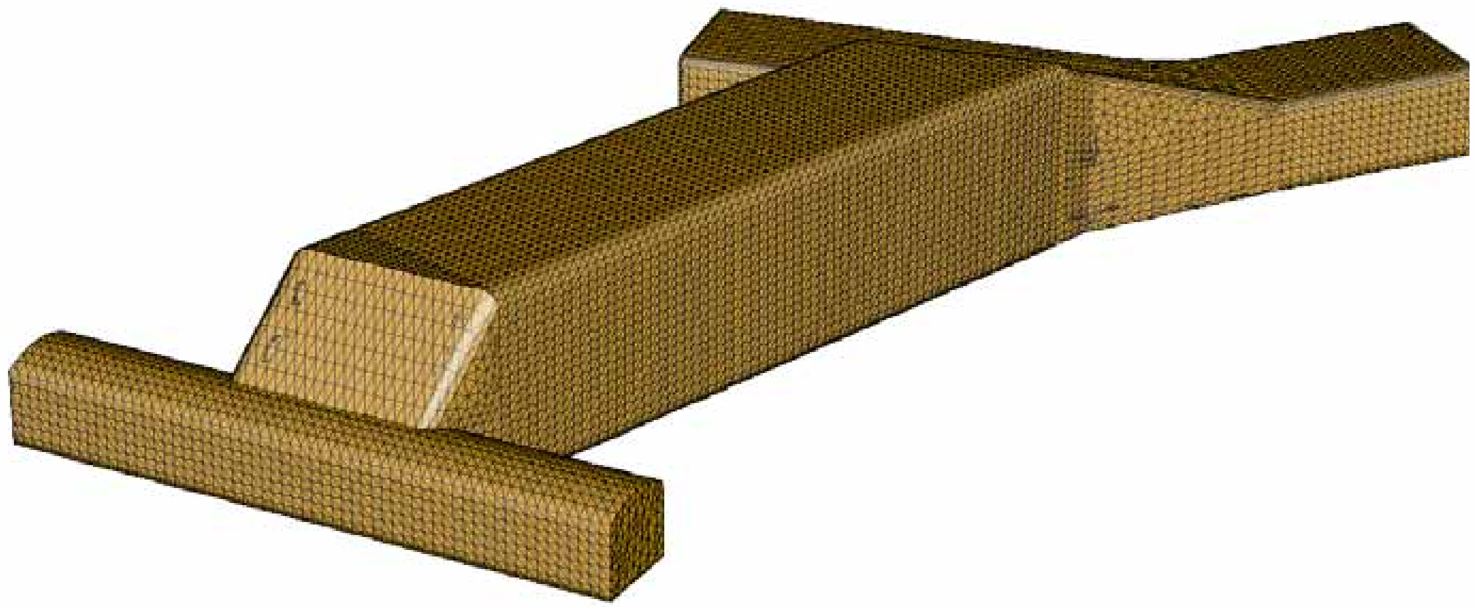
ZONES EXCEEDING TENSILE STRENGTH – SHOP DGR FOR L&ILW

FIGURE 4-12



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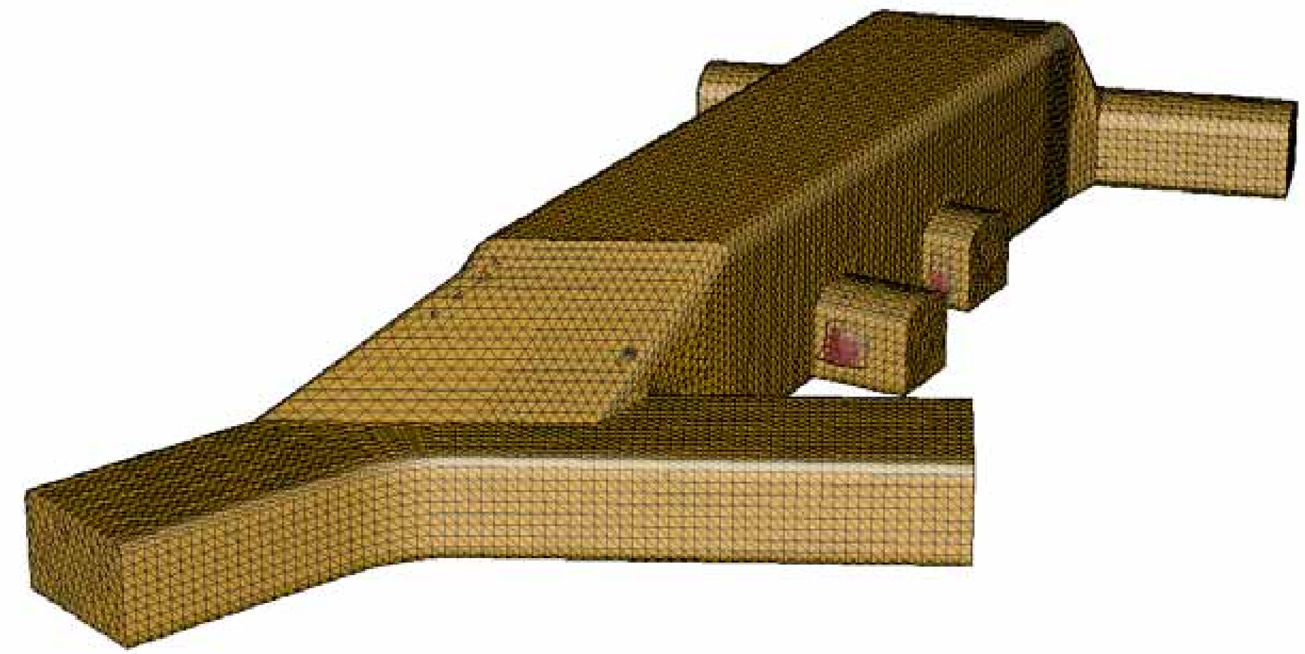

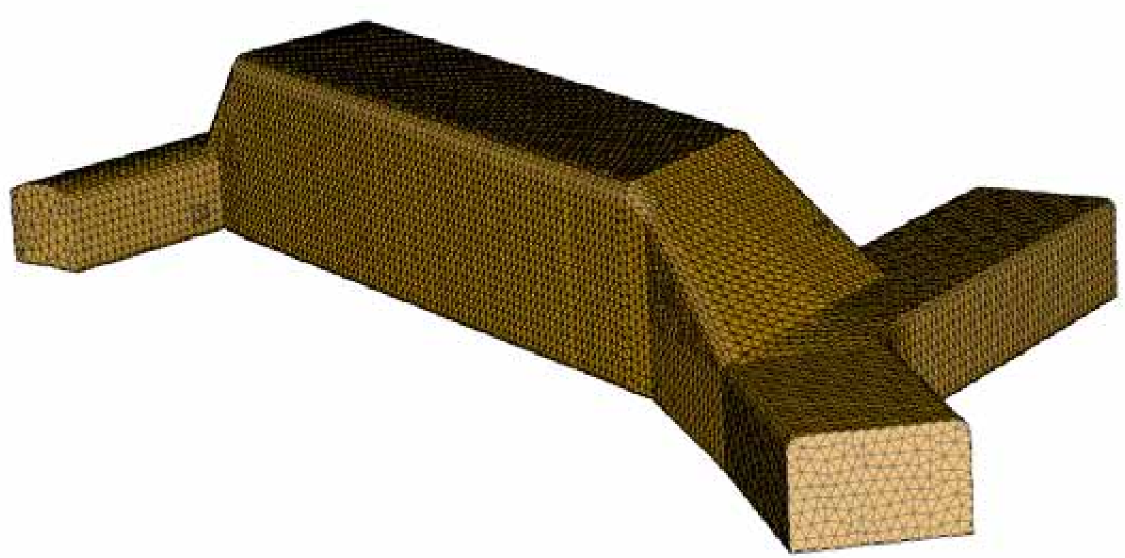

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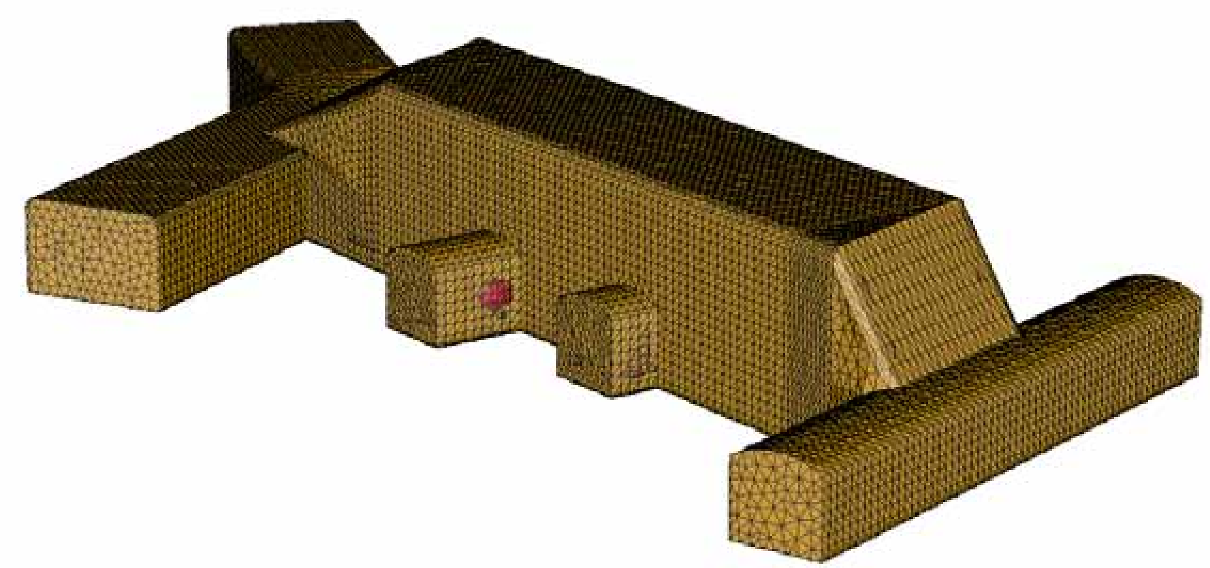

LOOKING SE (DPG COORDINATE SYSTEM)

■ ZONE EXCEEDING ROCK MASS TENSILE STRENGTH

DATE: October-2012

PROJECT: 10-1117-0042

DOC: J.L.C.

CHK: C.M.S. APD: C.M.S.

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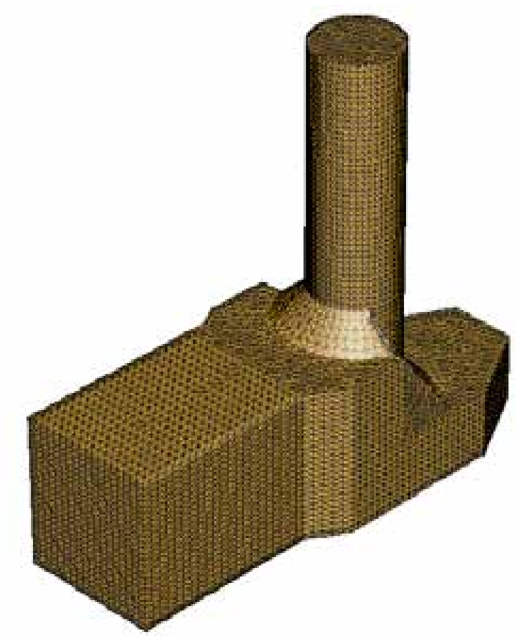
EXCAVATION SEQUENCE AND MESH
MAIN SHAFT
DGR FOR L&ILW

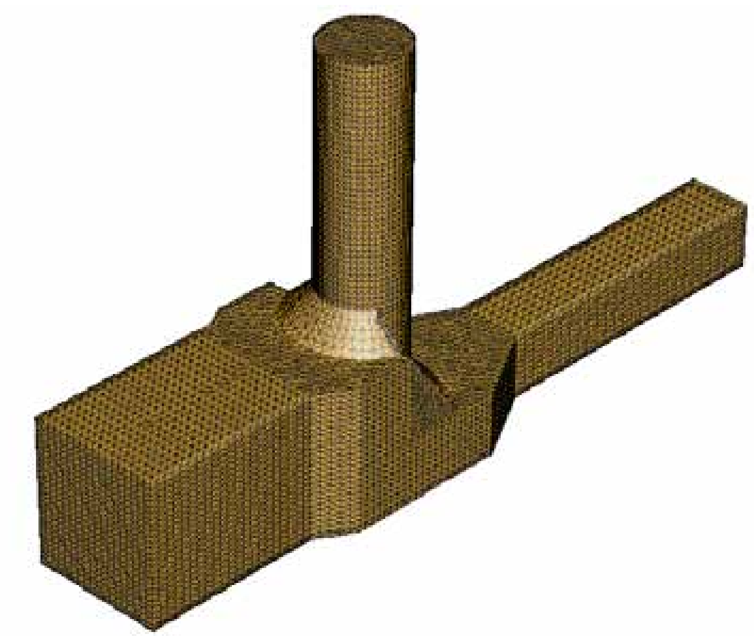
FIGURE 4-13

SINK SHAFT TO REPOSITORY LEVEL

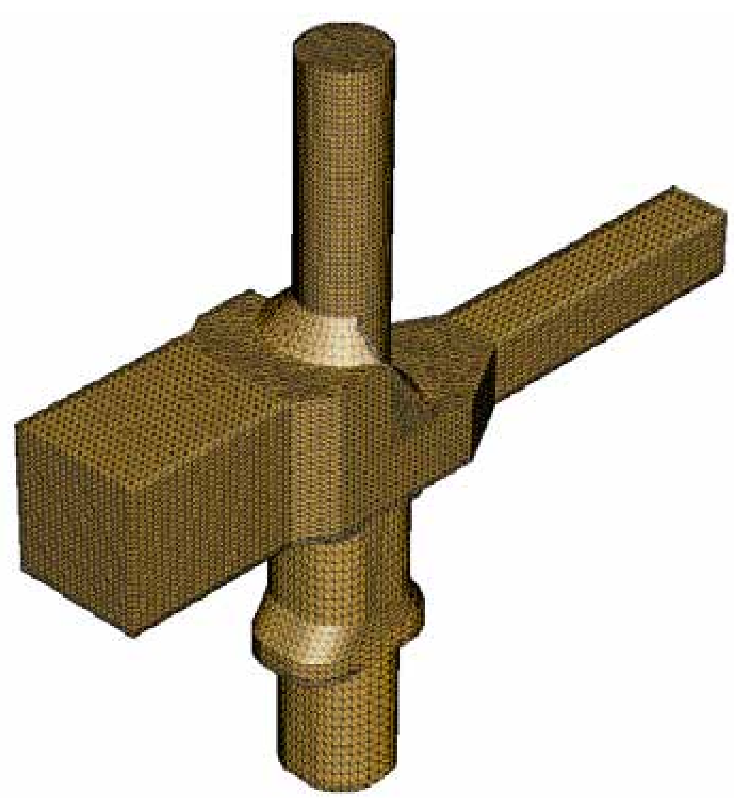
STUB IN ELECTRICAL SUBSTATION & I&C ROOM



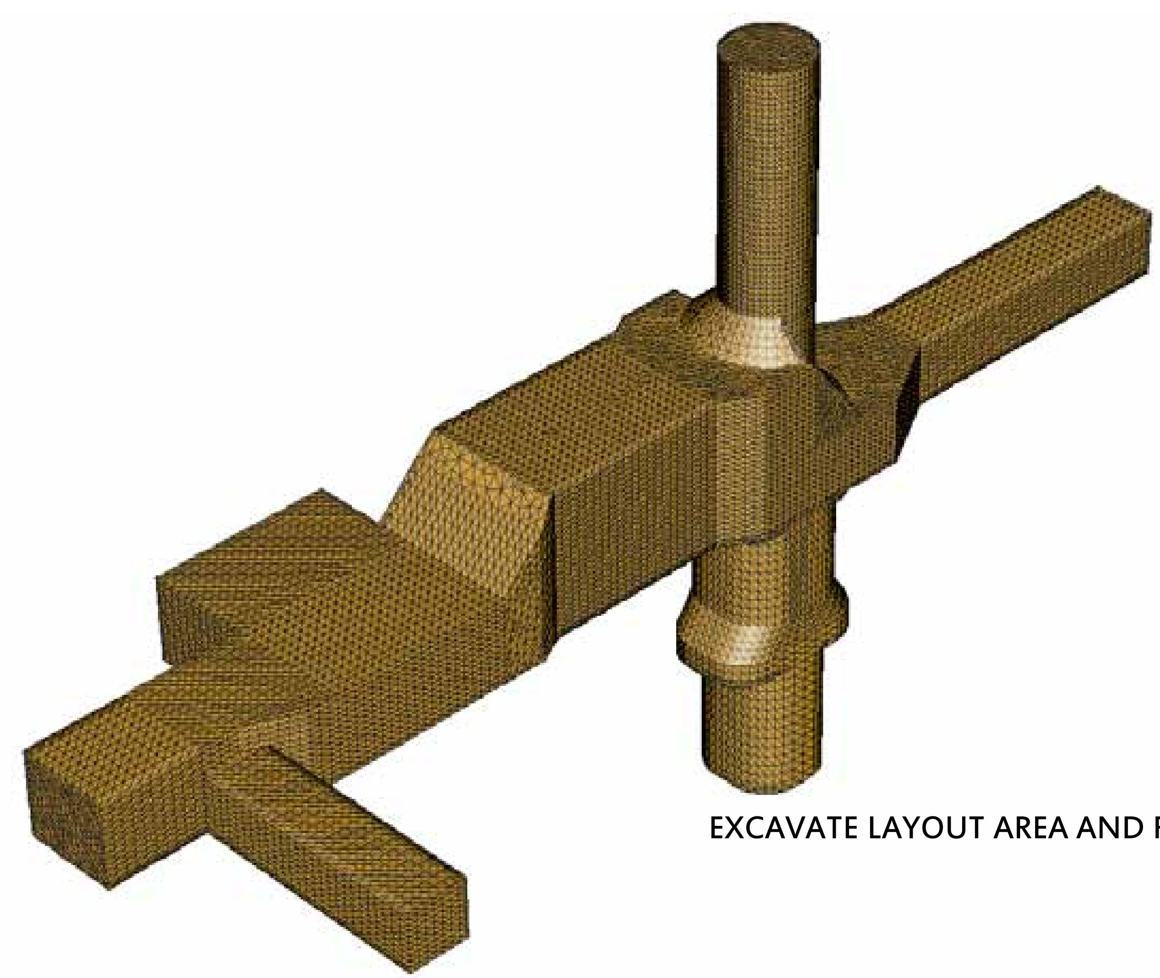
STUB IN SHAFT STATION



COMPLETE ELECTRICAL SUBSTATION & I&C ROOM



SINK SHAFT TO BOTTOM



EXCAVATE LAYOUT AREA AND REFUGE AREA

DATE: October-2012

PROJECT: 10-1117-0042

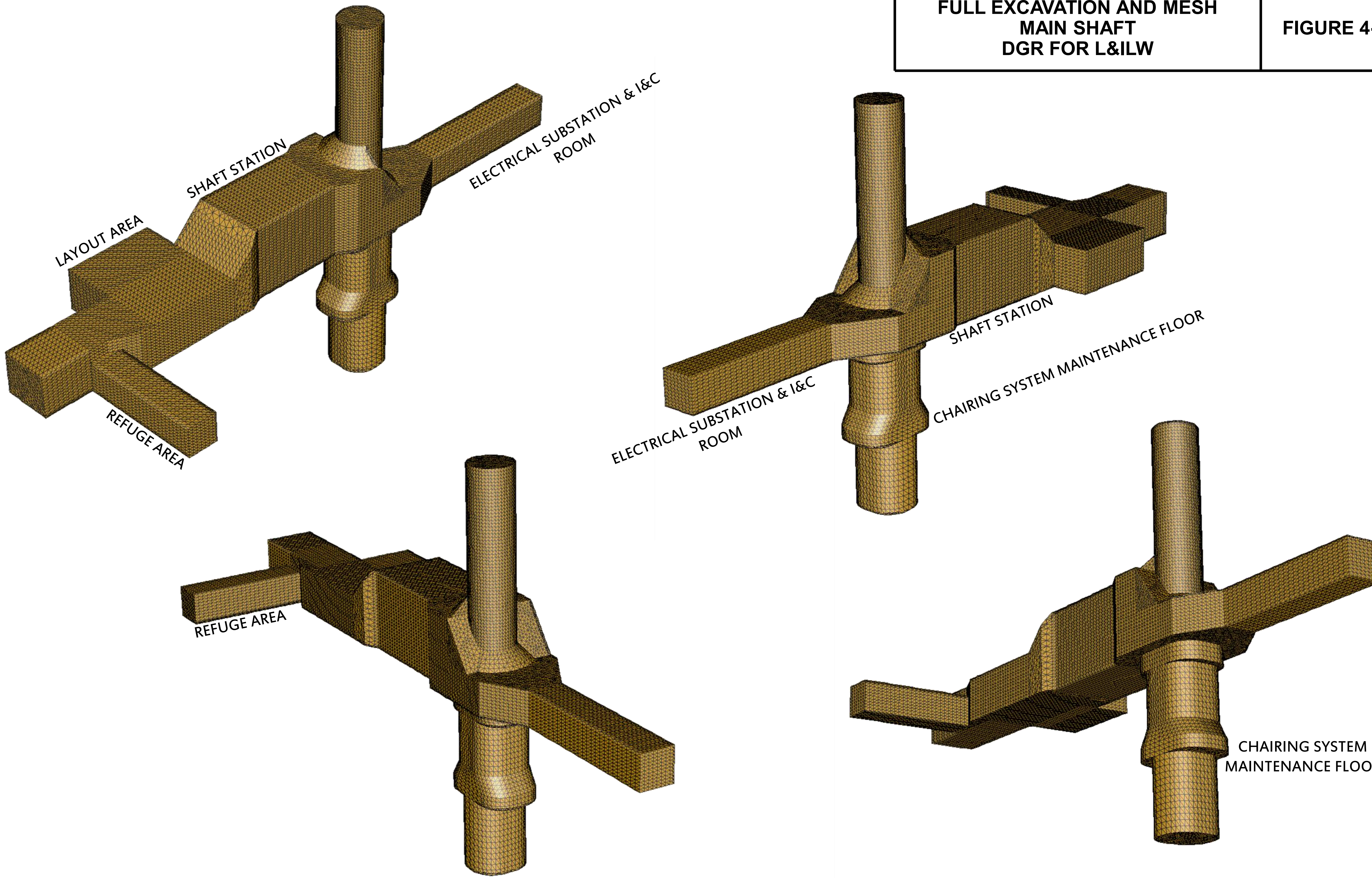
DOC: J.L.C.

CHK: C.M.S. APD: C.M.S.

Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

FULL EXCAVATION AND MESH
MAIN SHAFT
DGR FOR L&ILW

FIGURE 4-14



DATE:	October-2012	DOC:	J.L.C.
PROJECT:	10-1117-0042	CHK:	C.M.S.
		APD:	C.M.S.

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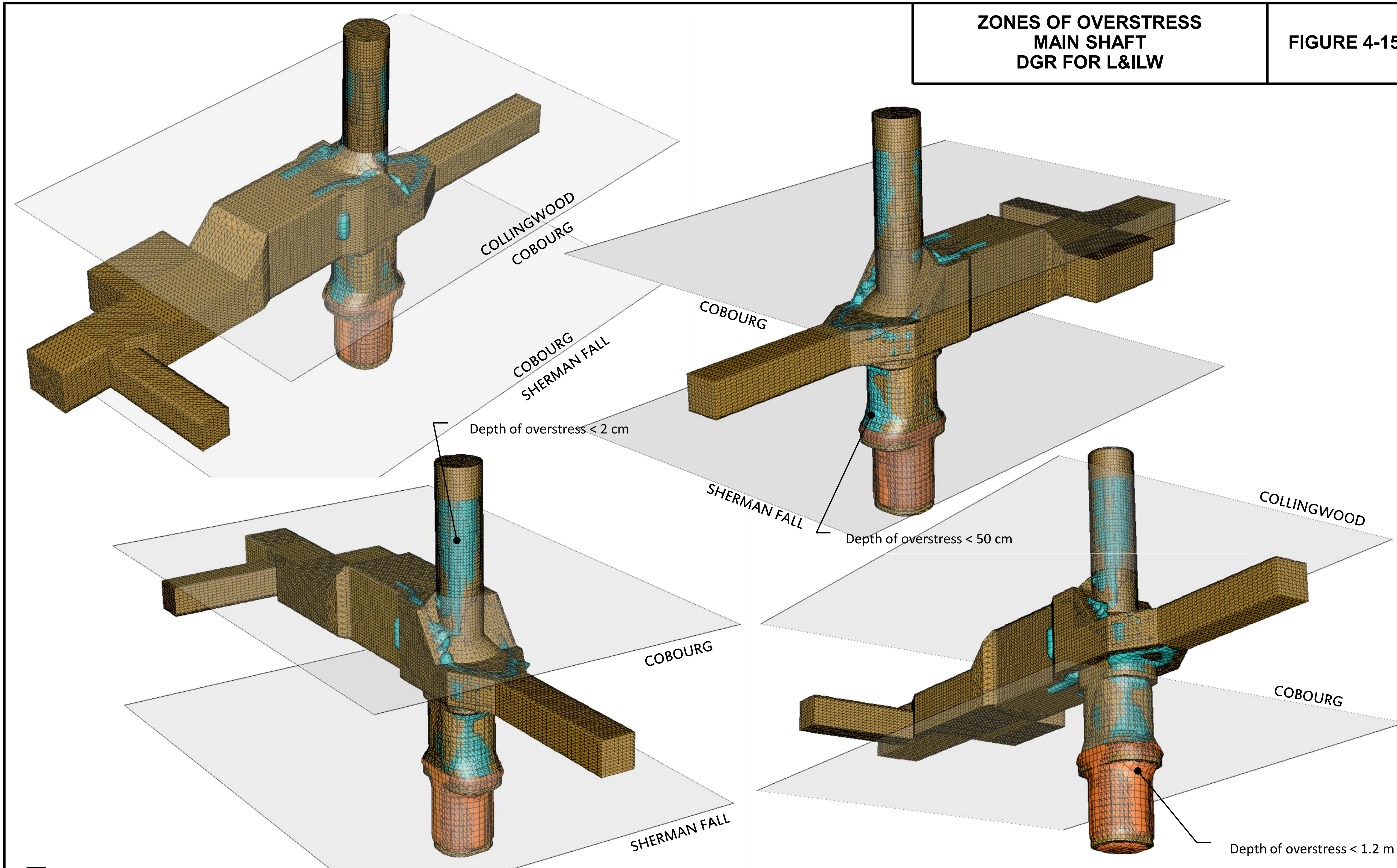
Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

ZONES OF OVERSTRESS
MAIN SHAFT
DGR FOR L&ILW

FIGURE 4-15



OVERSTRESSED ROCK MASS ZONE IN THE COBOURG MEMBER
OVERSTRESSED ROCK MASS ZONE IN THE SHERMAN FALL FORMATION

DATE: October-2012
PROJECT: 10-1117-0042

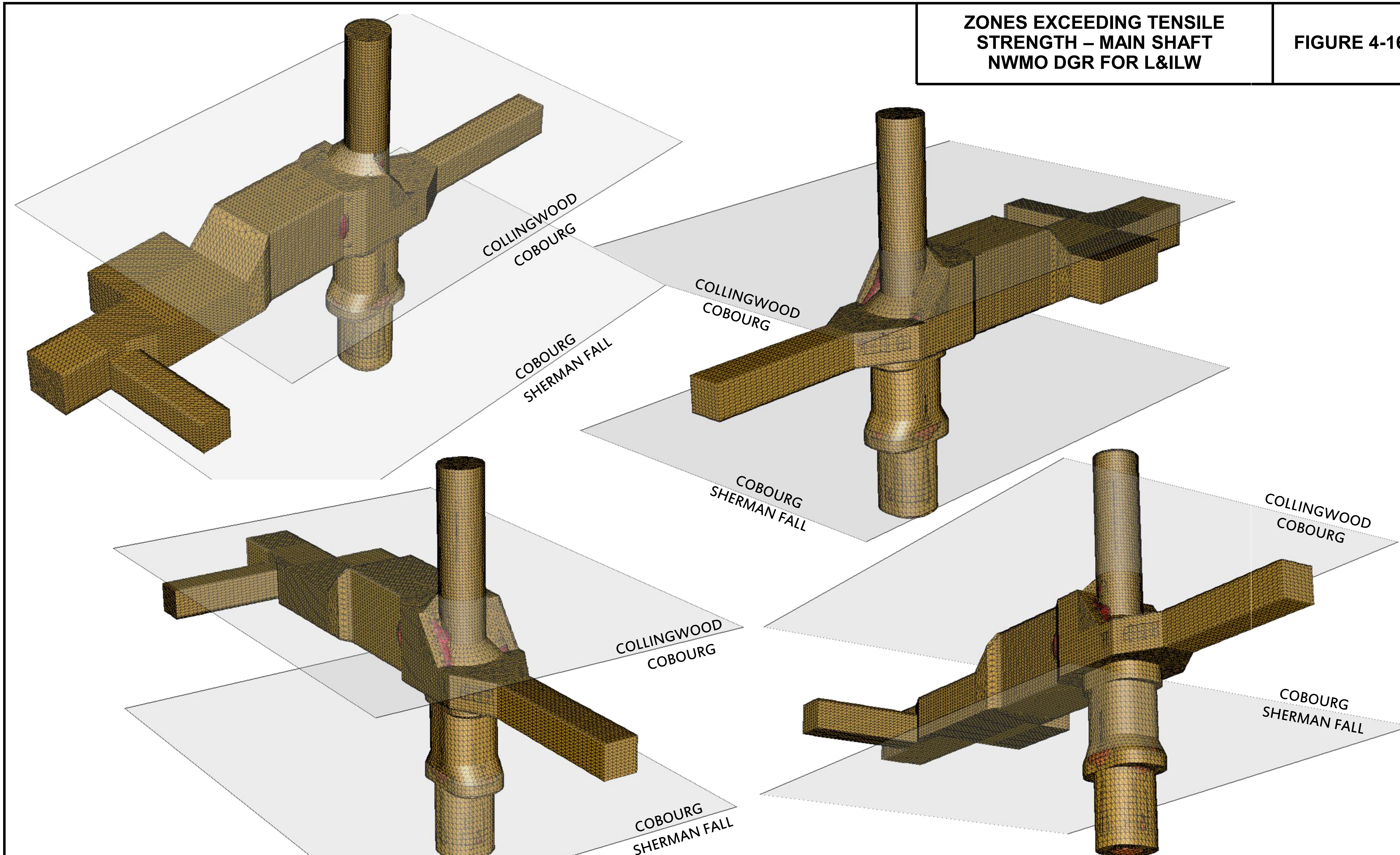
Golder Associates

DOC: J.L.C.
CHK: C.M.S. APD: C.M.S.

Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

ZONES EXCEEDING TENSILE STRENGTH – MAIN SHAFT NWMO DGR FOR L&ILW

FIGURE 4-16



- ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE COBOURG MEMBER
- ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE SHERMAN FALL FORMATION

DATE: October-2012
PROJECT: 10-1117-0042

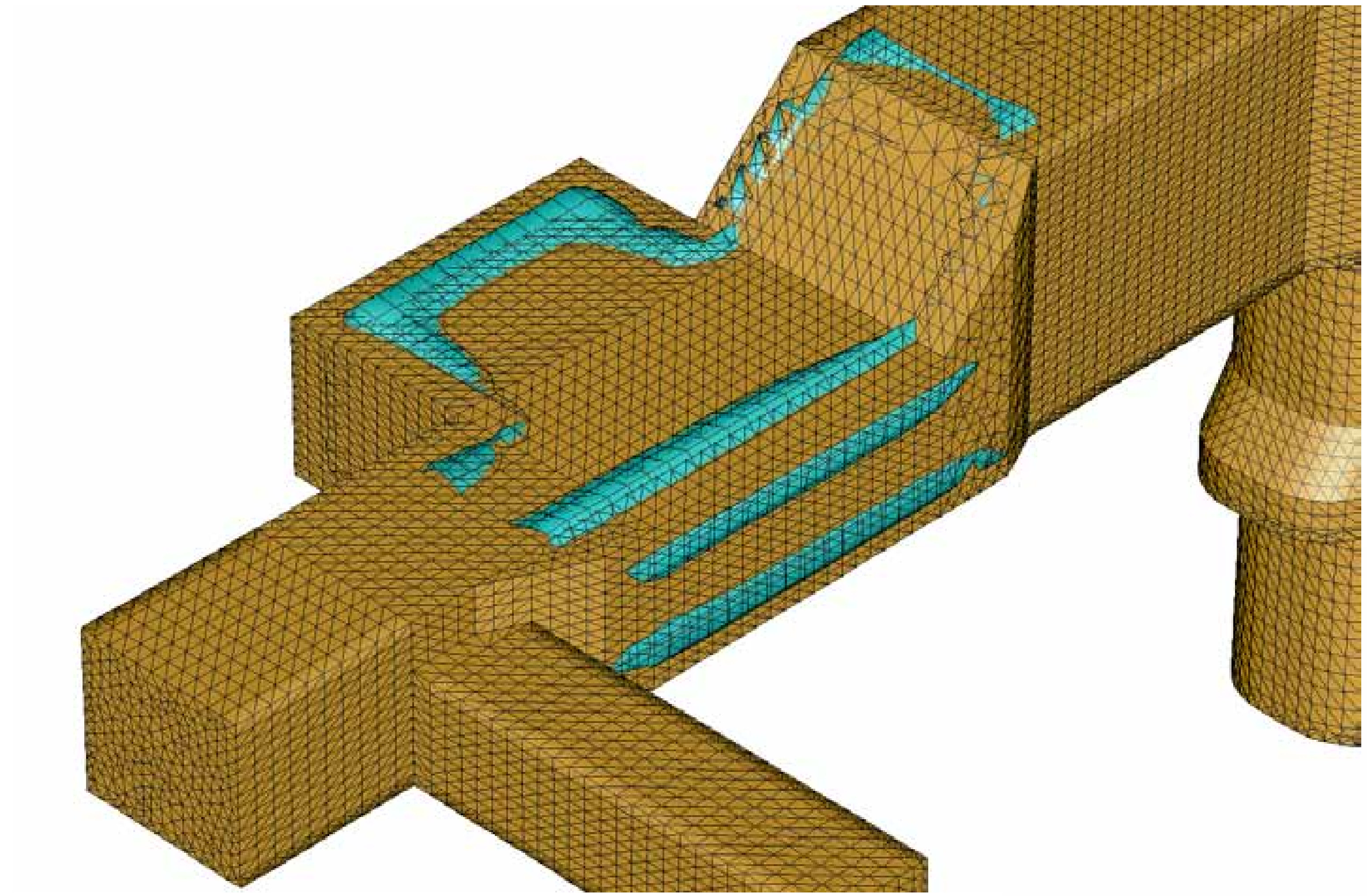
Golder Associates

DOC: J.L.C.
CHK: C.M.S. APD: C.M.S.

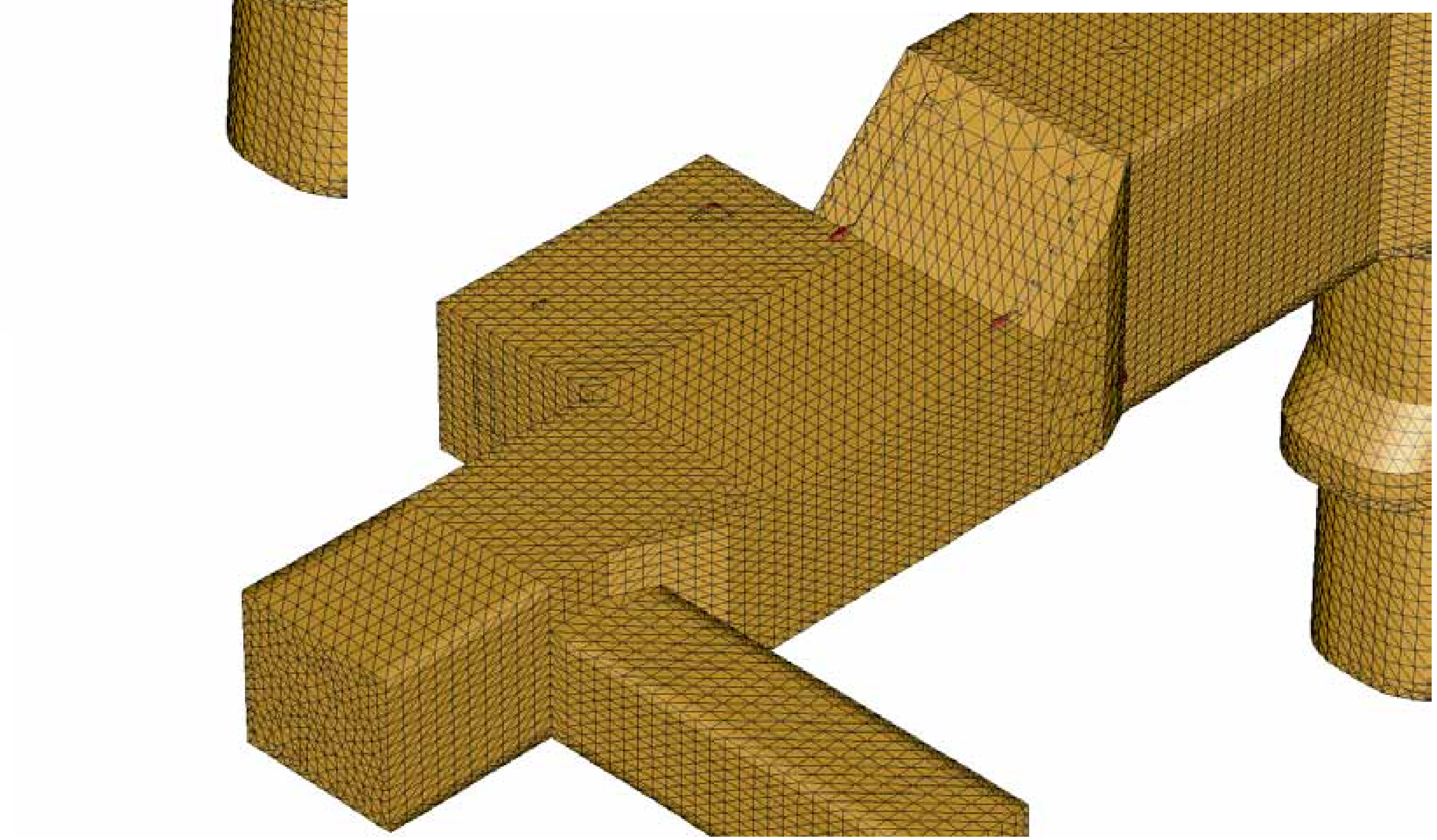
Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

LAYOUT AREA NEAR
MAIN SHAFT STATION
NWMO DGR FOR L&ILW

FIGURE 4-17



OVERSTRESSED ROCK MASS



TENSILE ZONES

OVERSTRESSED ROCK MASS ZONE IN THE COBOURG MEMBER

ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE COBOURG MEMBER

DATE: October-2012

PROJECT: 10-1117-0042

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DOC: J.L.C.

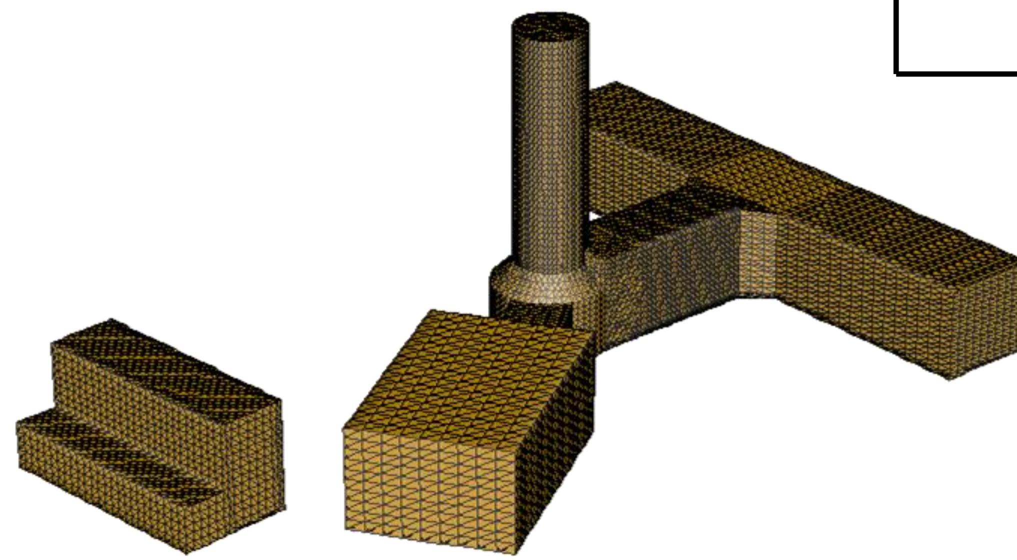
CHK: C.M.S. APD: C.M.S.

Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

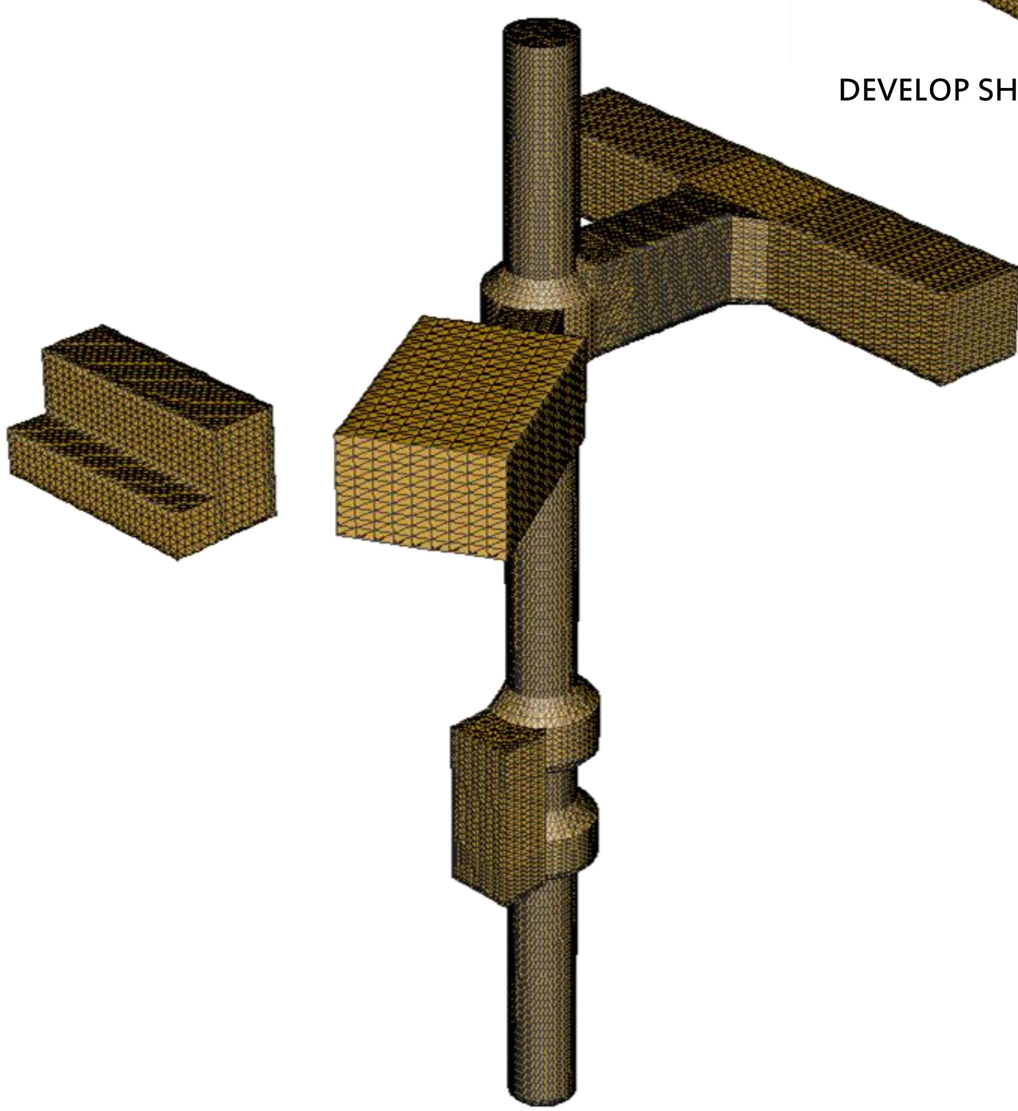
EXCAVATION SEQUENCE AND MESH VENTILATION SHAFT DGR FOR L&ILW

FIGURE 4-18

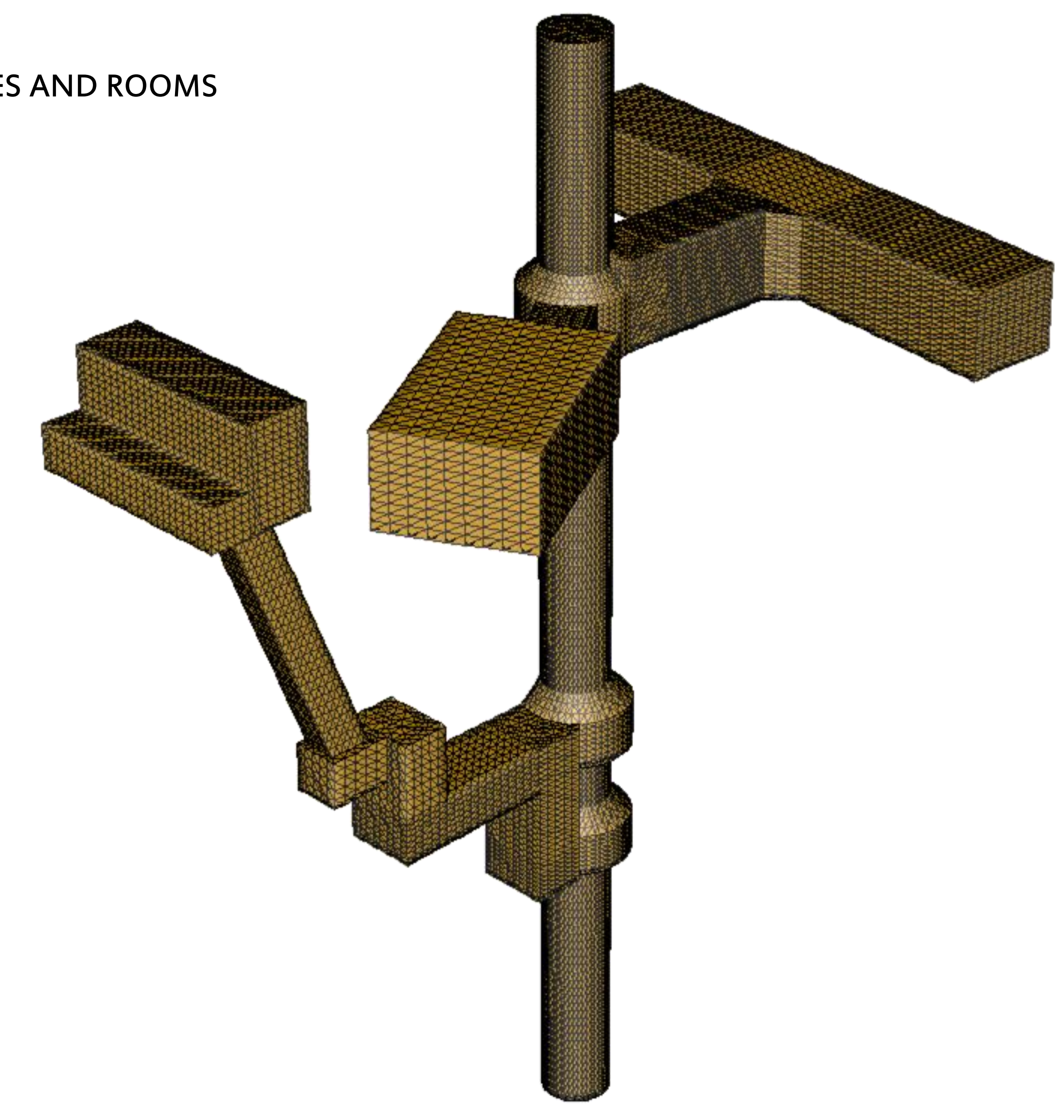
SINK SHAFT TO REPOSITORY LEVEL



DEVELOP SHAFT STATION AND REPOSITORY LEVEL ACCESSES AND ROOMS



SINK SHAFT TO BOTTOM – STUB IN LOADING POCKET



EXCAVATE CONVEYOR TUNNEL, CHAIN FEEDER ROOM, AND ORE PASS

DATE: October-2012

PROJECT: 10-1117-0042

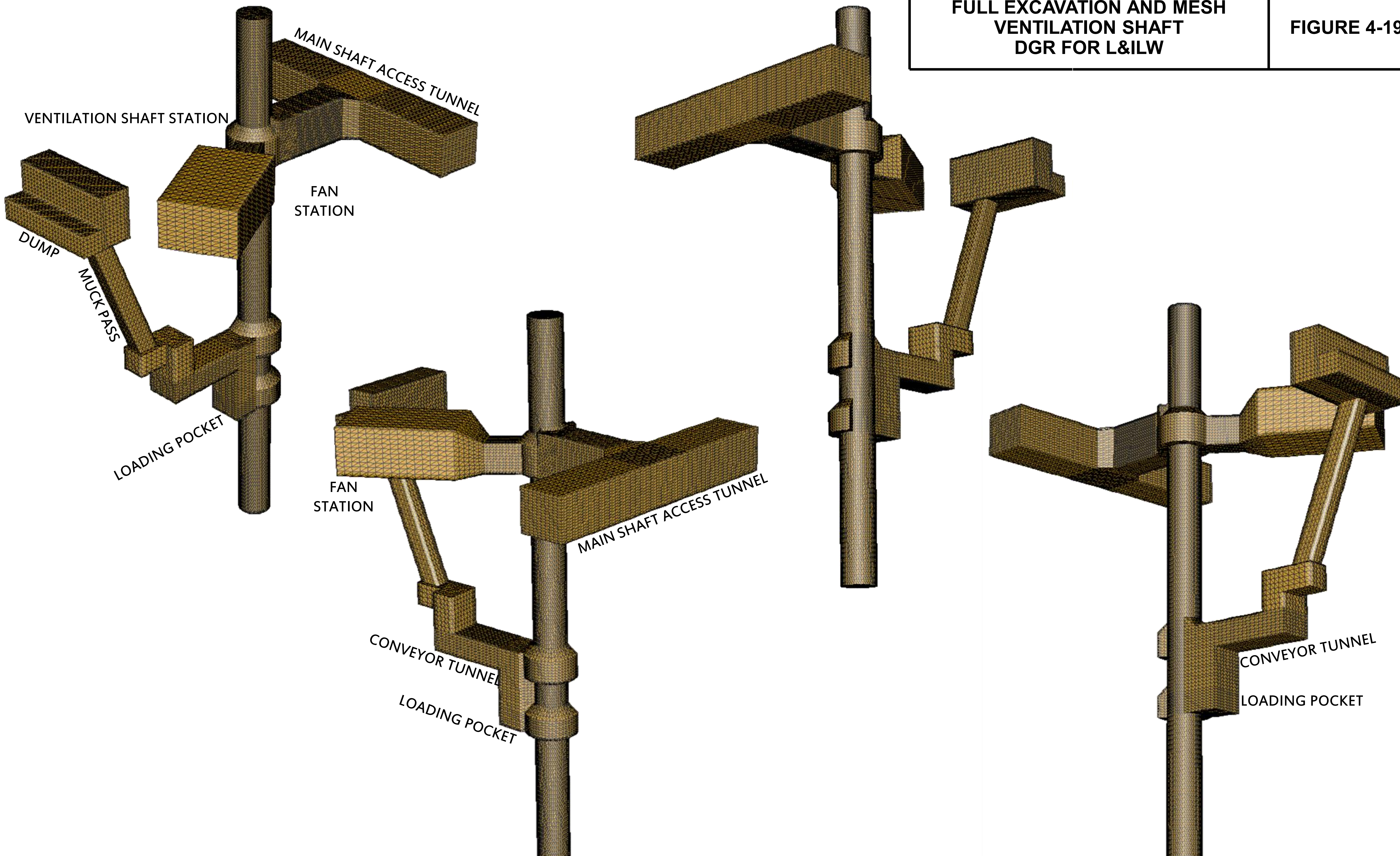
DOC: J.L.C.

CHK: C.M.S. APD: C.M.S.

Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

FULL EXCAVATION AND MESH VENTILATION SHAFT DGR FOR L&ILW

FIGURE 4-19



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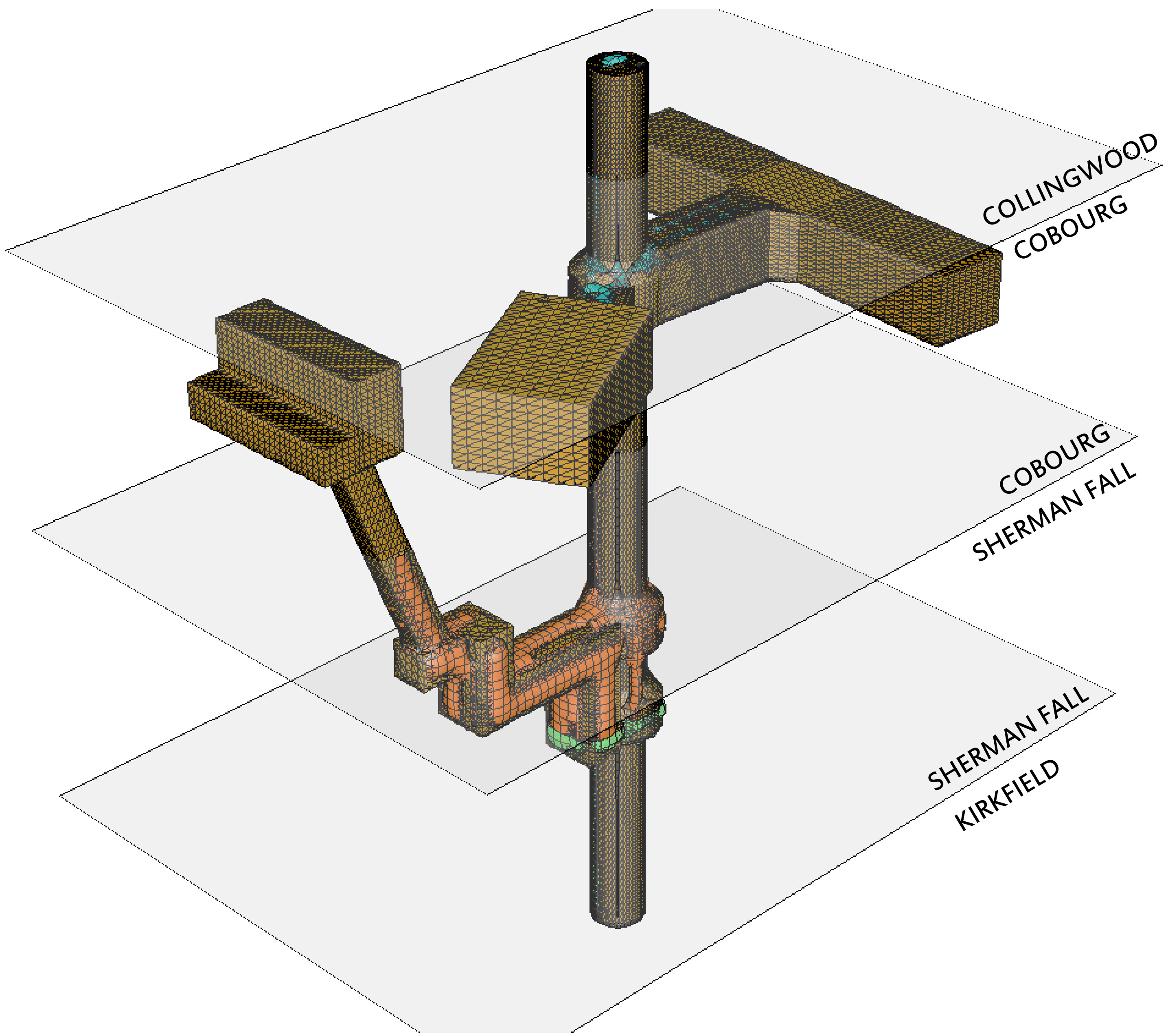
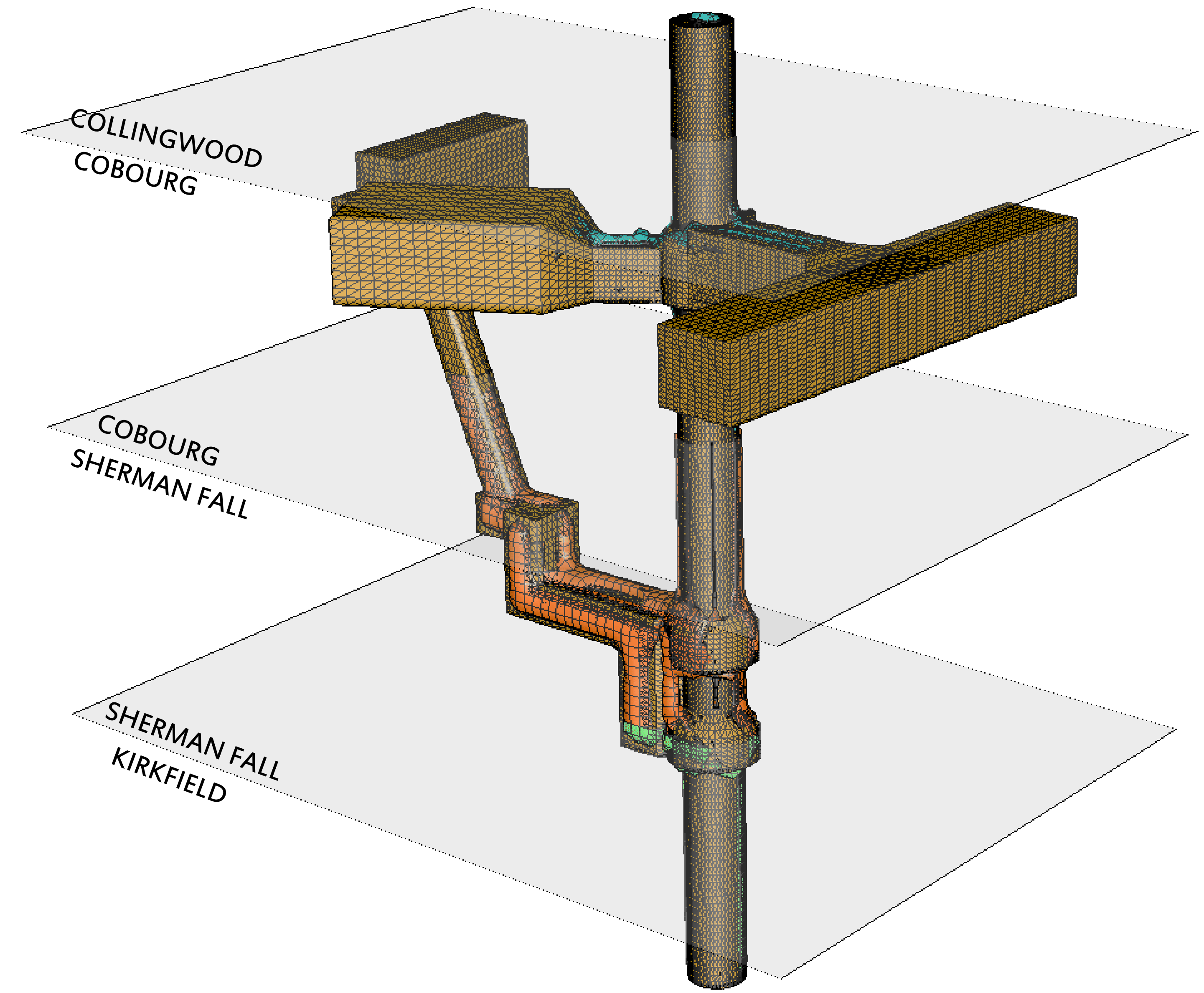
DATE: October-2012
PROJECT: 10-1117-0042
Golder Associates
DOC: J.L.C.
CHK: C.M.S. APD: C.M.S.

ZONES OF OVERSTRESS
VENTILATION SHAFT
DGR FOR L&ILW

FIGURE 4-20



LOOKING SE (DPG COORDINATE SYSTEM)



LOOKING NE (DPG COORDINATE SYSTEM)

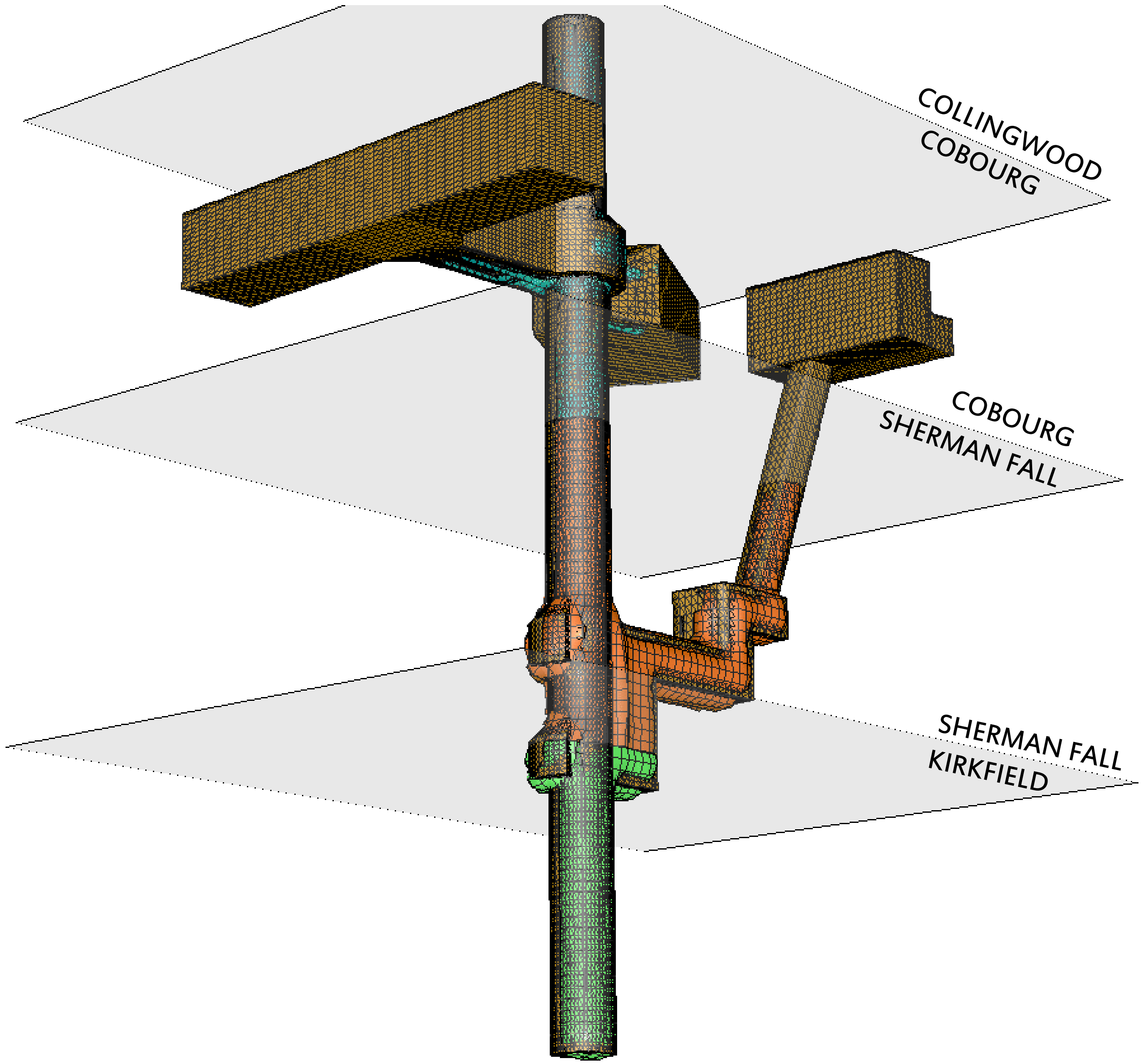
- OVERSTRESSED ROCK MASS ZONE IN THE COBOURG MEMBER
- OVERSTRESSED ROCK MASS ZONE IN THE SHERMAN FALL FORMATION
- OVERSTRESSED ROCK MASS ZONE IN THE KIRKFIELD FORMATION

DATE: October-2012		DOC: J.L.C.	
PROJECT: 10-1117-0042	Golder Associates	CHK: C.M.S.	APD: C.M.S.

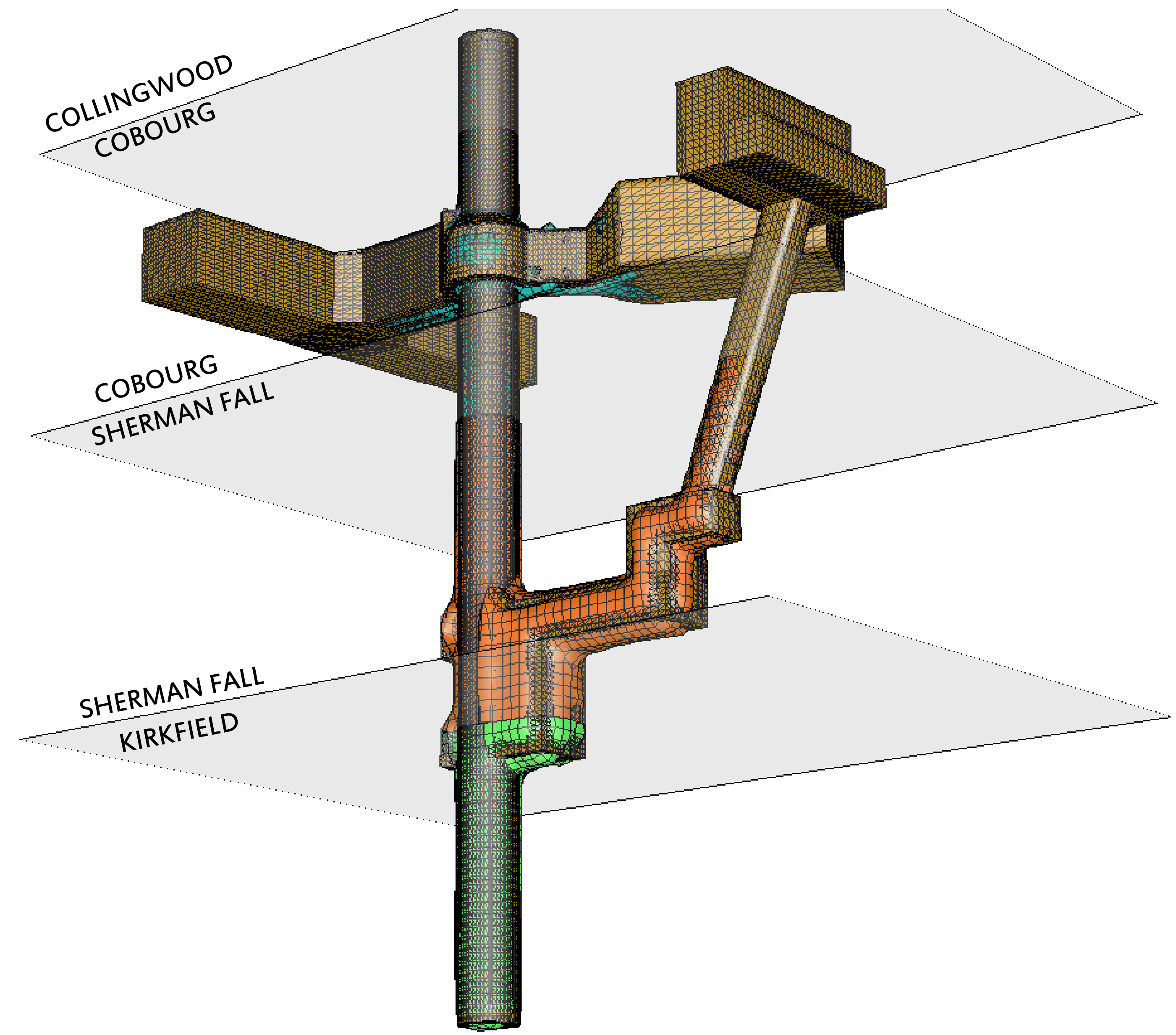
Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

ZONES OF OVERSTRESS VENTILATION SHAFT DGR FOR L&ILW

FIGURE 4-21



LOOKING NW (DPG COORDINATE SYSTEM)



LOOKING SW (DPG COORDINATE SYSTEM)

- OVERSTRESSED ROCK MASS ZONE IN THE COBOURG MEMBER
- OVERSTRESSED ROCK MASS ZONE IN THE SHERMAN FALL FORMATION
- OVERSTRESSED ROCK MASS ZONE IN THE KIRKFIELD FORMATION

DATE: October-2012
PROJECT: 10-1117-0042

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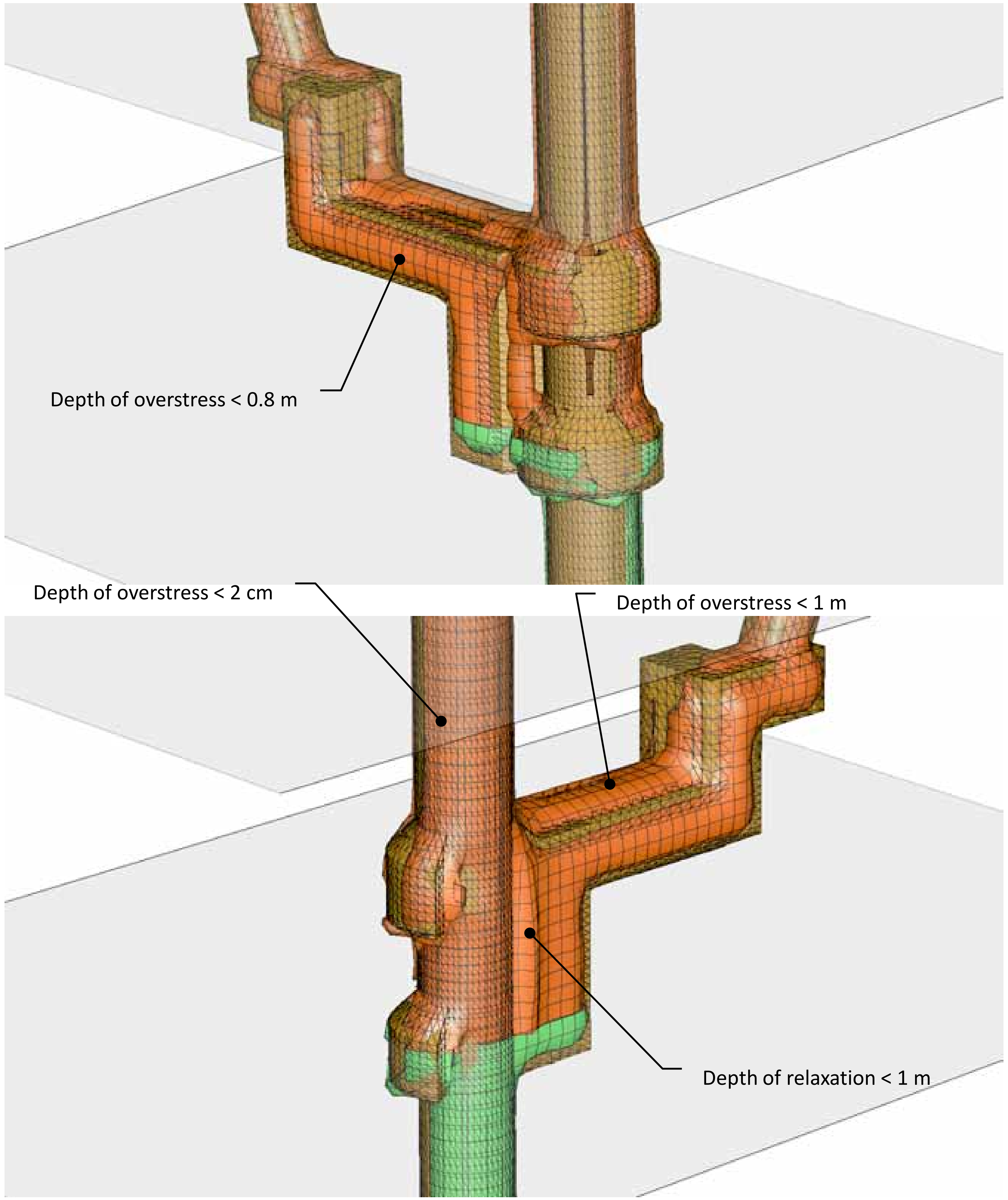
CHK: C.M.S. APD: C.M.S.

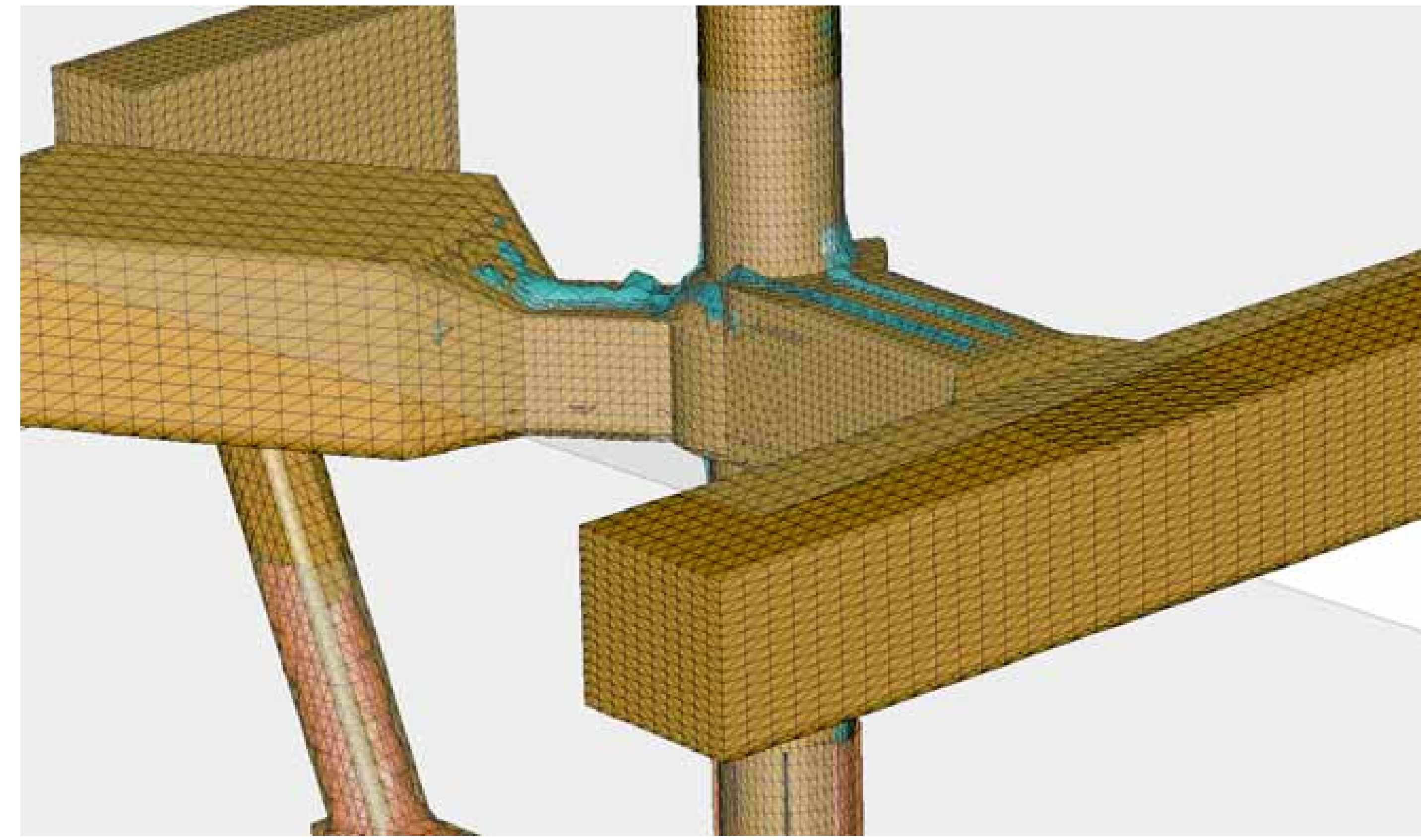
Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

ZONES OF OVERSTRESS
VENTILATION SHAFT
DGR FOR L&ILW

FIGURE 4-22



LOADING POCKET



VENTILATION SHAFT AT REPOSITORY LEVEL

- OVERSTRESSED ROCK MASS ZONE IN THE COBOURG MEMBER (blue)
- OVERSTRESSED ROCK MASS ZONE IN THE SHERMAN FALL FORMATION (orange)
- OVERSTRESSED ROCK MASS ZONE IN THE KIRKFIELD FORMATION (green)

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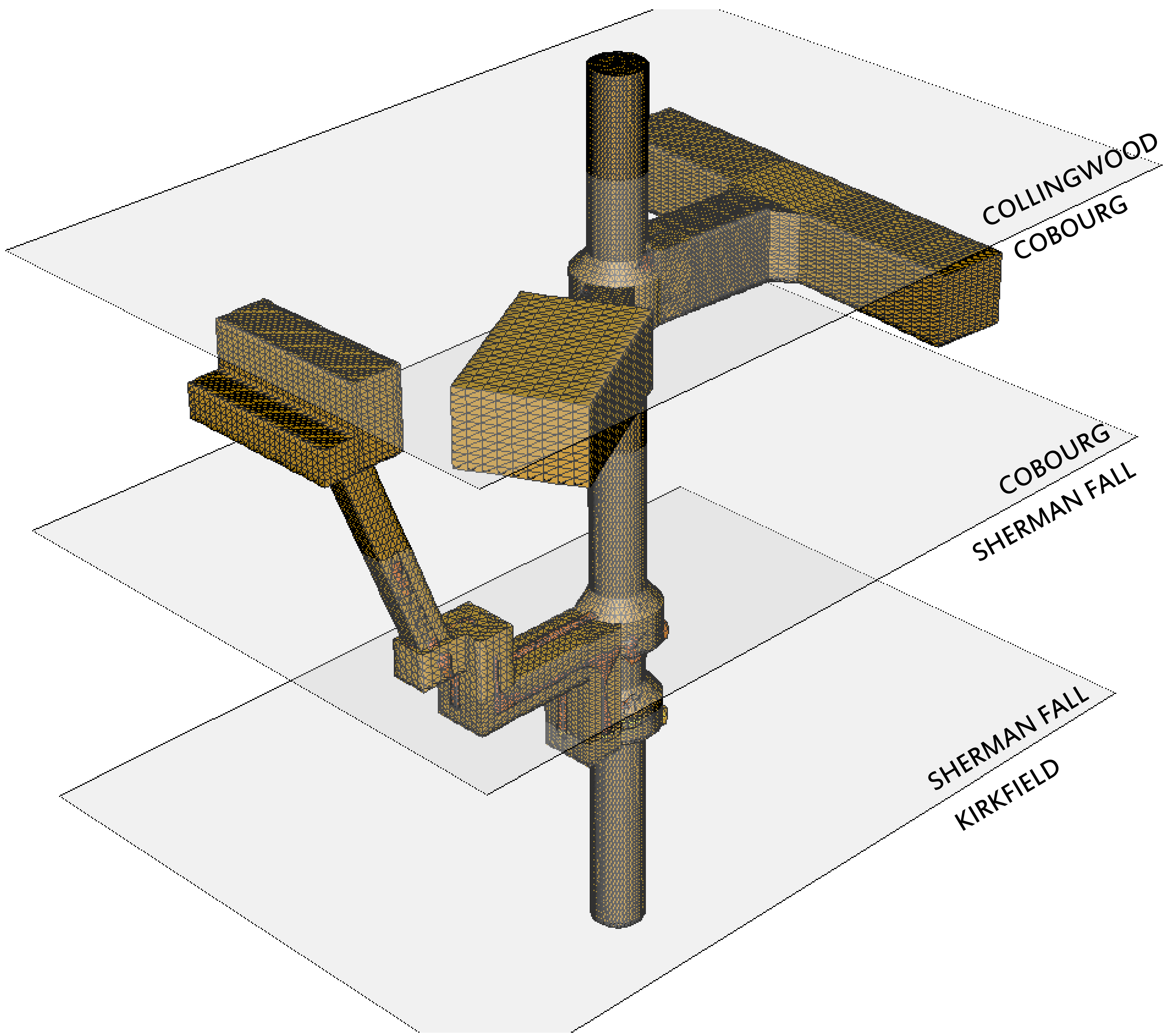
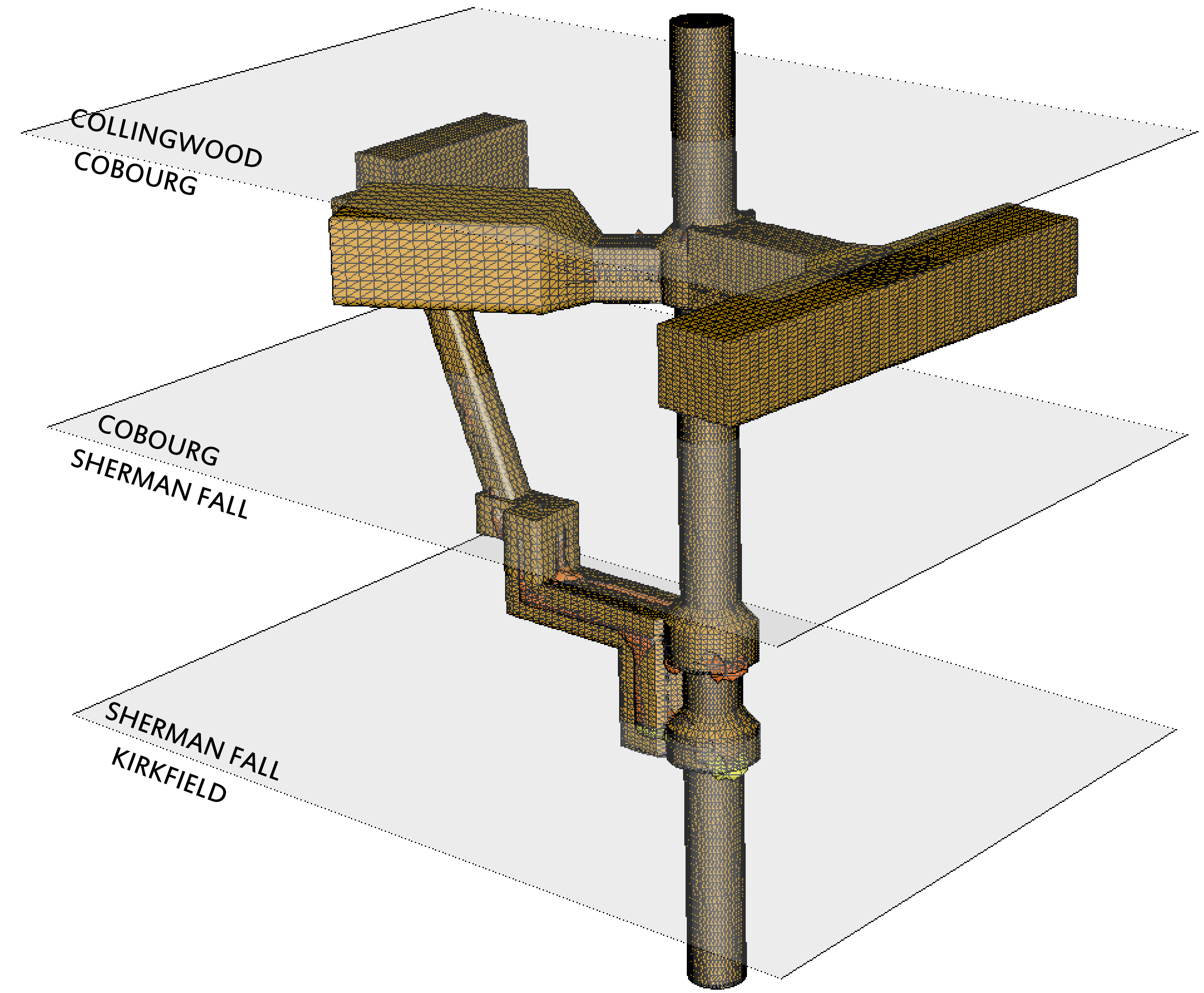
Project: 10-1117-0042 Drawn: JLC Reviewed: CMS Rev.: 10-September-2012 N:\ACTIVE\2010\1117\10-1117-0042 NWMO DGR

ZONES EXCEEDING TENSILE STRENGTH – VENTILATION SHAFT DGR FOR L&ILW

FIGURE 4-23



LOOKING SE (DPG COORDINATE SYSTEM)



LOOKING NE (DPG COORDINATE SYSTEM)

- (red) ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE COBOURG MEMBER
- (orange) ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE SHERMAN FALL FORMATION
- (yellow) ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE KIRKFIELD FORMATION

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		APD:	C.M.S.

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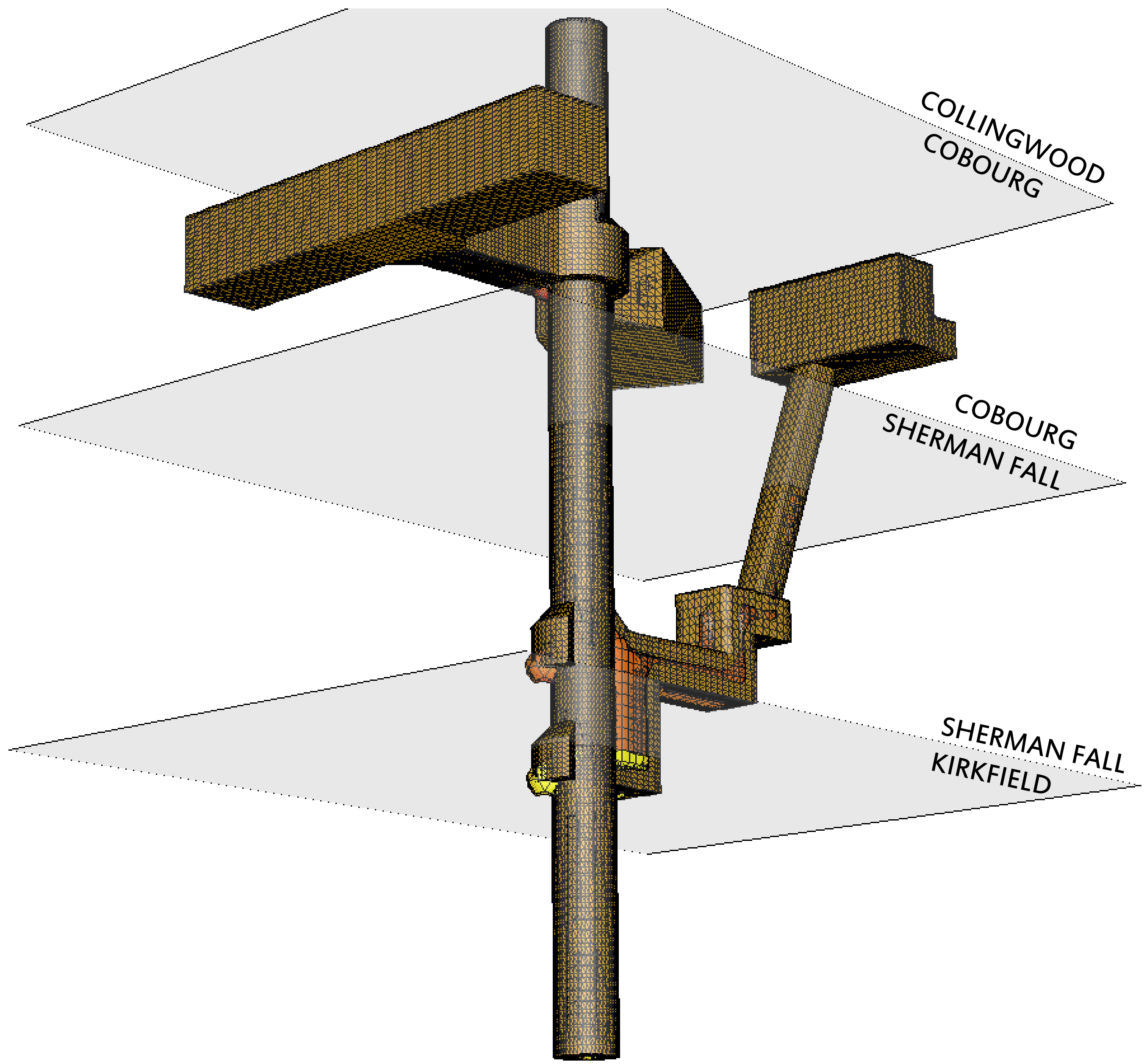
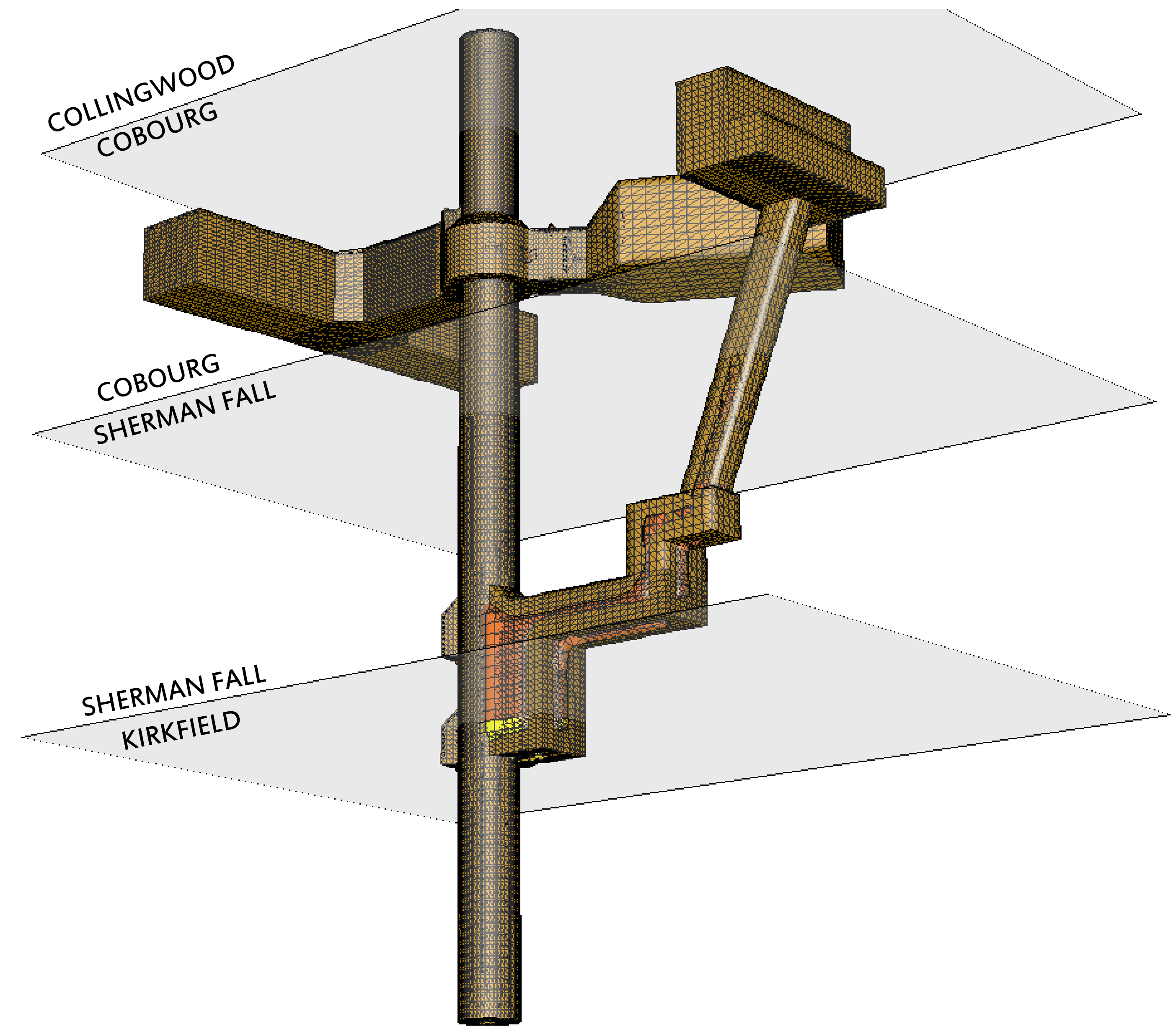
ZONES EXCEEDING TENSILE STRENGTH – VENTILATION SHAFT DGR FOR L&ILW

FIGURE 4-24



LOOKING NW (DPG COORDINATE SYSTEM)



LOOKING SW (DPG COORDINATE SYSTEM)

- (Red) ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE COBOURG MEMBER
- (Orange) ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE SHERMAN FALL FORMATION
- (Yellow) ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE KIRKFIELD FORMATION

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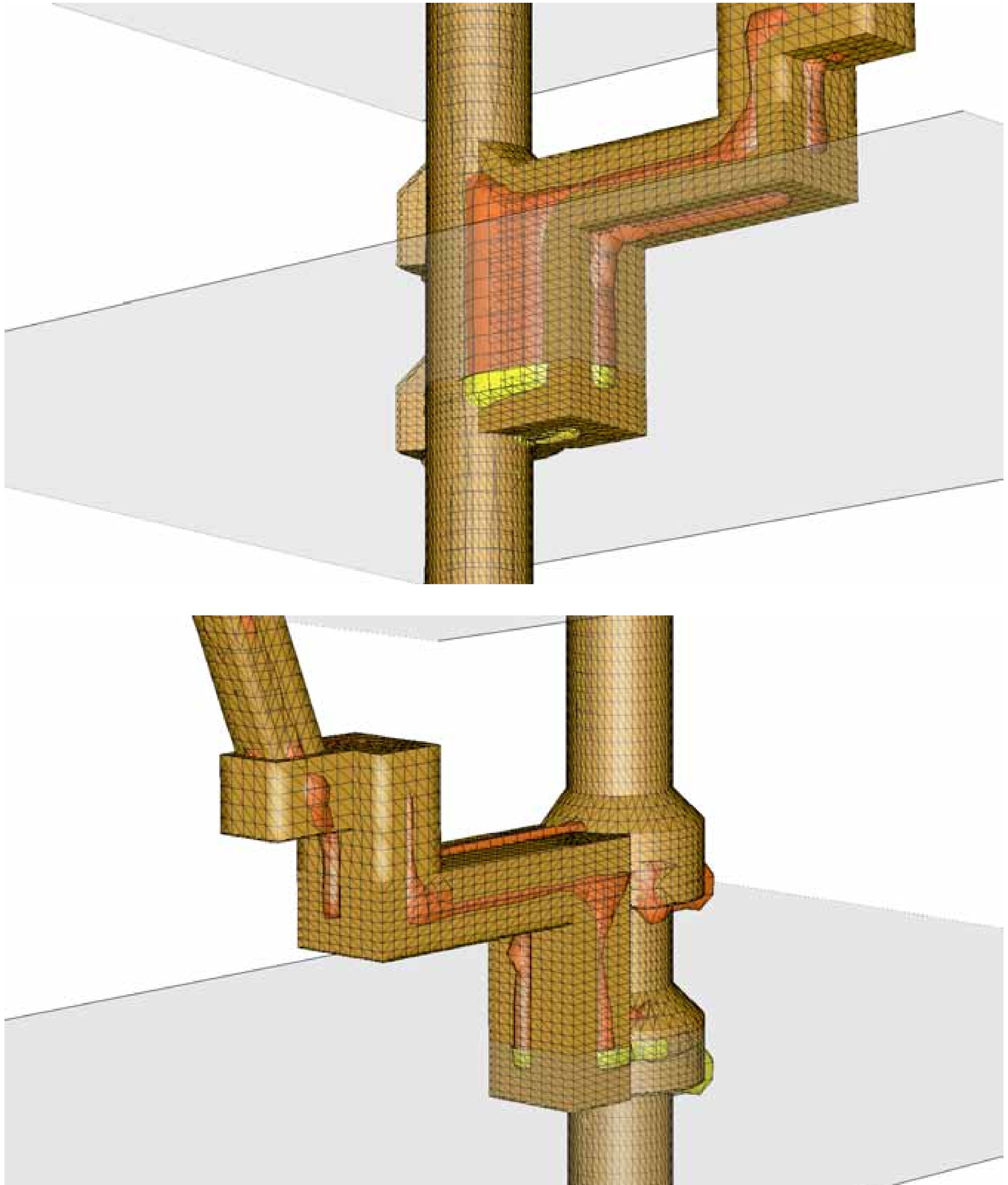
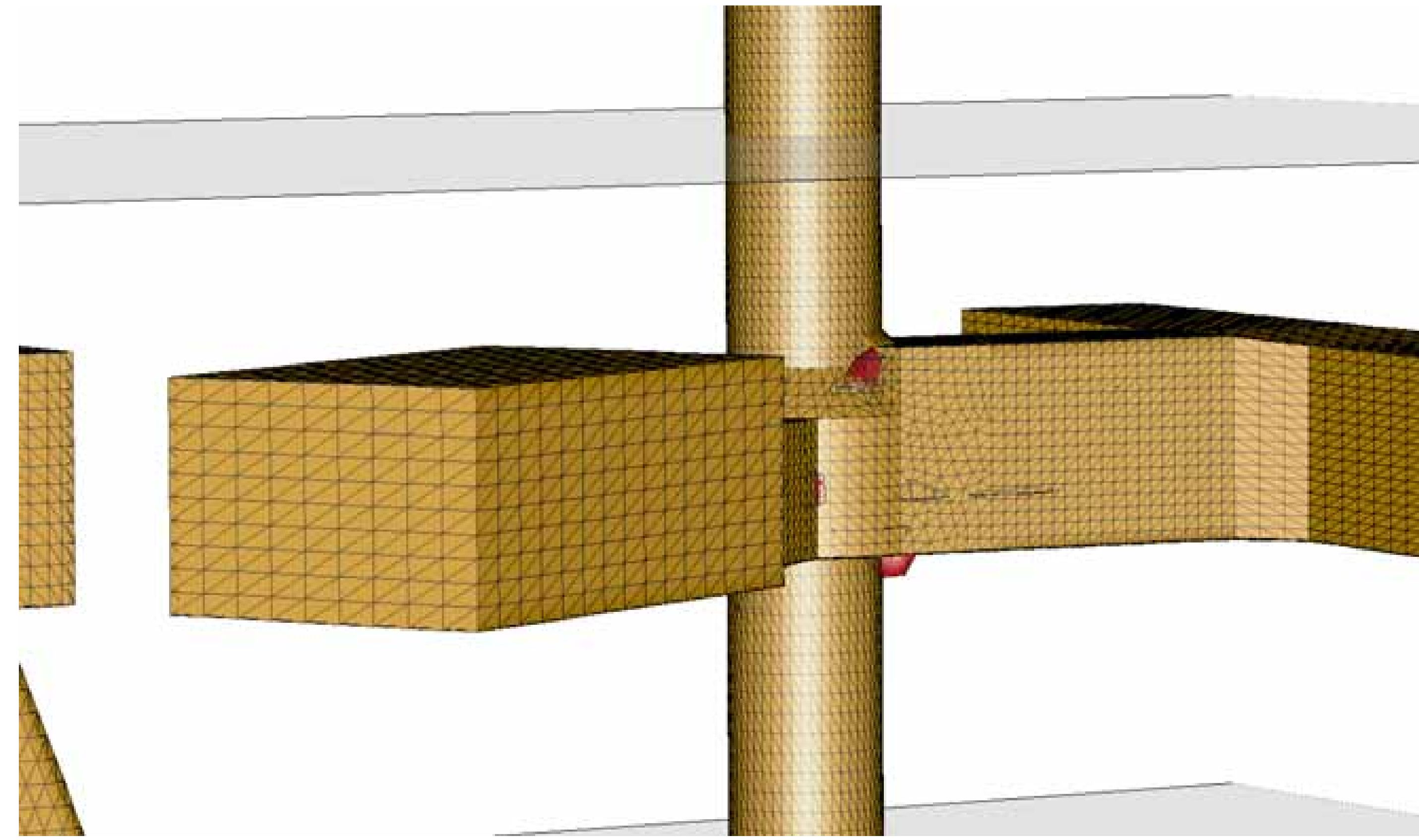
ZONES EXCEEDING TENSILE STRENGTH – VENTILATION SHAFT DGR FOR L&ILW

FIGURE 4-25



LOADING POCKET



VENTILATION SHAFT AT REPOSITORY LEVEL

- ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE COBOURG MEMBER
- ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE SHERMAN FALL FORMATION
- ZONE EXCEEDING ROCK MASS TENSILE STRENGTH IN THE KIRKFIELD FORMATION

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Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
6700 Century Avenue
Mail: 2390 Argentia Road, Mississauga, Ontario, L5N 5Z7
Canada
T: +1 (905) 567 4444

Golder Associates