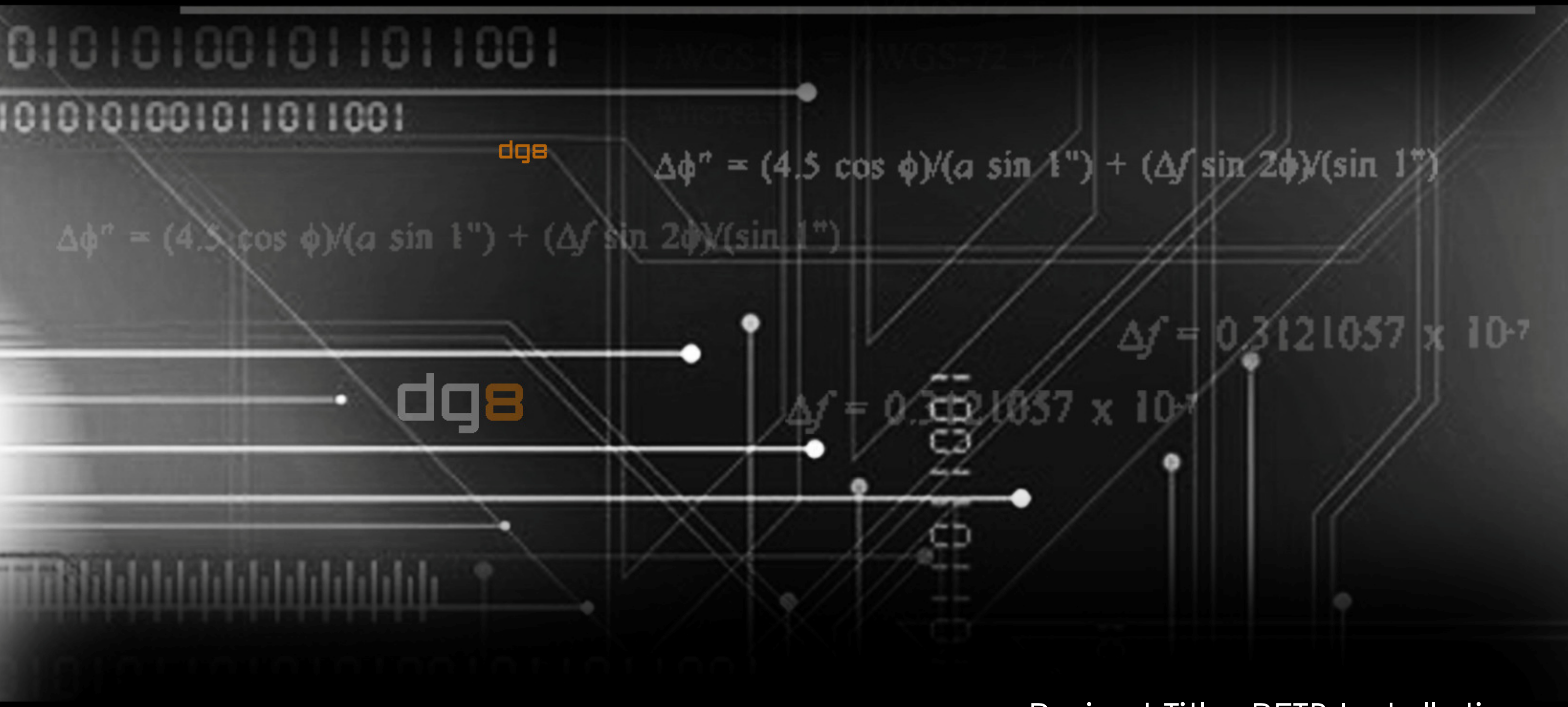
Structural Calculations



Project Title: RETB Installation

Project Number: MP/13/002

Calculation Title: Class 37 RETB Installation

Calculation Number: DG8-CALC-00366

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1. Summary

This calculation demonstrates that the Class 37 RETB installations meet the structural requirements of GM/RT 2100 Issue 5: Section 3.2.

2. Introduction

The RETB installations on Direct Rail Services' and West Coast Railway's Class 37 vehicles comprise a bonnet-mounted antenna installation and a number of driver's cab installations comprising a CDR unit, junction box, handset and loudspeaker.

This calculation has been performed to check the attachment of the items with respect to the Railway Group Standard GM/RT 2100 Issue 5: Section 3.2.

For the inertial loadcases:

- The proof stresses in the components are compared against the yield strength of the material. The tensile and shear loads in the fixings are compared against the allowable loads calculated in Section 6.
- The GM/RT 2100 ultimate loading of the same components are compared against the ultimate strength of the material and the allowable loads calculated in Section 6.
- The GM/RT 2100 fatigue loading of the same components are assessed using the Miner's damage summation and fatigue classifications described in BS 7608.
- Natural frequencies of the items are also assessed.

3. References

Ref	Title
1	GM/RT2100 Issue 5 June 2012 Requirements for Rail Vehicle Structures
2	BS EN 10025-2:2004 Hot rolled products of structural steels — Part 2: Technical delivery conditions for non-alloy structural steels
3	BS 7608 2014 Guide to fatigue design and assessment of steel products
4	BS 3692:2001 ISO metric precision hexagon bolts, screws and nuts - Specification
5	Shigley Mechanical Engineering Design
6	Nordlock Torque Guidelines
7	Eurosert 39006 Datasheet, Avdel
8	FH Pem Stud Datasheet
9	LP3 Antenna Series Data Sheet, Sigma Antennas
10	Interface Control Document, ICD-1051-01, Comms Design

4. Drawings

Drawing	Number	Title	Issue
1	MP-C0-00065	GENERAL ARRANGEMENT CAB TYPE 1 CLASS 37 RETB	P1
2	MP-C0-00066	GENERAL ARRANGEMENT CAB TYPE 2 CLASS 37 RETB	P1
3	MP-C0-00067	CDR INSTALLATION CAB TYPES 1 & 2 CLASS 37 RETB	P1
4	MP-C0-00068	HANDSET INSTALLATION CAB TYPES 1 & 2 CLASS 37 RETB	P1
5	MP-C0-00069	JUNCTION BOX AND SPEAKER INSTALLATION CAB TYPE 1 CLASS 37 RETB	P1
6	MP-C0-00070	ADAPTER PLATE ASSEMBLY AND DETAILS CLASS 37 RETB	P1
7	MP-C0-00071	HANDSET MOUNTING BOX PLINTH ASSEMBLY AND DETAILS CLASS 37 RETB	P1
8	MP-C0-00073	JUNCTION BOX AND SPEAKER INSTALLATION CAB TYPE 2 CLASS 37 RETB	P1
9	MP-C0-00074	JUNCTION BOX ENCLOSURE ASSEMBLY AND DETAILS CAB TYPE 1 CLASS 37 RETB	P1
10	MP-C0-00075	JUNCTION BOX ENCLOSURE ASSEMBLY AND DETAILS CAB TYPE 2 CLASS 37 RETB	P1
11	MP-C0-00076	MISCELLANEOUS DETAILS CLASS 37 RETB	P1
12	MP-C0-00077	VHS WHIP AND GPS ANTENNAS CAB TYPES 1 & 2 CLASS 37 RETB	P1

5. Nomenclature

A	Area	mm²
BF	Bolt factor	
CofG	Centre of gravity	mm
D	Diameter	mm
E	Young's modulus of elasticity	N/mm²
F	Applied Force	N
g	Gravitational constant, 9.81	m/s²
I	Second moment of area	mm⁴
L	Length	mm
μ	Coefficient of friction	
m	Mass	kg
M	Applied moment	Nmm
P	Preload	N
PF	Proof factor	
R	Reaction force	N
σ_P	Material proof strength	N/mm²
σ_m	Material tensile strength	N/mm²
RF	Reserve factor	
σ	Applied axial or bending stress	N/mm²
σ_a	Allowable axial or bending Stress	N/mm²
τ	Applied shear stress	N/mm²
τ_a	Allowable shear stress	N/mm²
T	Applied torque	Nm
T_a	Allowable torque	Nm
UF	Ultimate factor	

6. Materials and fixings

1. Steel, BS EN 10025-2, S275JR

$$\rho_{S275} := 7860 \cdot kg \cdot m^{-3}$$

$$\sigma_{p.S275} := 275 \cdot N \cdot mm^{-2}$$

$$\sigma_{u.S275} := 410 \cdot N \cdot mm^{-2}$$

$$\tau_{p.S275} := \frac{\sigma_{p.S275}}{\sqrt{3}} = 158.771 \cdot N \cdot mm^{-2}$$

$$ratio_{\sigma pu} := \frac{\sigma_{u.S275}}{\sigma_{p.S275}} = 1.491$$

2. Steel, BS 1449, 34/20

$$\sigma_{p.3420} := 200 \cdot N \cdot mm^{-2}$$

$$\sigma_{u.3420} := 340 \cdot N \cdot mm^{-2}$$

$$\tau_{p.3420} := \frac{\sigma_{p.3420}}{\sqrt{3}} = 115.47 \cdot N \cdot mm^{-2}$$

$$ratio_{\sigma pu} := \frac{\sigma_{u.3420}}{\sigma_{p.3420}} = 1.7$$

3. Determine the slip capacity of a Grade 8.8 M5 EZP bolt and plain washer into a Eurosert torqued to 6Nm (Antenna Installation, Junction Box Cover and Conduit P-Clips)

$$T_{M5.EZP.6Nm} := 6 \cdot N \cdot m$$

$$P_{M5.EZP.6Nm} := \frac{T_{M5.EZP.6Nm}}{5 \cdot mm \cdot BF} = 6 \times 10^{3} \, N$$

$$S_{a.M5.EZP.6Nm} := P_{M5.EZP.6Nm} \cdot \mu = 900 \cdot N$$

Maximum fully supported torque:

$$T_{a.M5.39006} := 7.9 \cdot N \cdot m$$ [Ref. 7]

Unsupported Pullout:

$$R_{a.M5.39006} := 7.8 \cdot kN$$

The pullout of the insert is the limiting factor, as the allowable tensile load of an M5 fixing is 8.1kN. Determine the additional dynamic load that can be applied to the insert. This is the minimum of the following:

Tensile load required to separate the joint:

$$R_{axial.sep} := \frac{P_{M5.EZP.6Nm}}{1 - \Phi_{steel}} = 7.712 \times 10^{3} \, N$$

Tensile load to meet the capacity of the Eurosert:

$$R_{axial.tensile} := \frac{R_{a.M5.39006} - P_{M5.EZP.6Nm}}{\Phi_{steel}} = 8.108 \times 10^{3} \, N$$

Minimum:

$$R_{axial} := \min\left(R_{axial.sep}, R_{axial.tensile}\right) = 7.712 \times 10^{3} \, N$$

4. Determine the slip capacity of a Grade 8.8 M6 EZP bolt and plain washer torqued to 11Nm (Junction Box Support Bracket and CDR Bracket).

Bolt size	M6
Washer Type	Plain
Joint Type	Grade 8 Nut
Torque (Nm)	11

$JointStiffness := \Phi_{steel}$ $\quad$ $Friction := \mu$ $\quad$ $ThreadDepth :=$ "N/A"

$HelicoilMat :=$ "N/A" $\quad$ $ThreadMat :=$ "N/A"

$$\begin{pmatrix} P_{M6} \\ S_{M6} \\ R_{a.M6} \end{pmatrix} :=$$

Preload (N)	Slip (assuming zero dynamic load) (N)	Tensile to sepatate (N)	Tensile to meet CSA yield (N)	Strip Helicoil (N)	Strip Parent thread (N)	Maximum Tensile (N)
9167	1375	11782	10511	N/A	N/A	10511

$(JT\ \ Torque\ \ Si\ \ JointStiffness\ \ Friction\ \ ThreadDepth\ \ HelicoilMat\ \ ThreadMat\ \ WT)$

5. Determine the slip capacity of a Grade 8.8 M5 EZP bolt and plain washer torqued to 3.5Nm (Junction Box)

Bolt size	M5
Washer Type	Plain
Joint Type	Grade 8 Nut
Torque (Nm)	3.5

$\text{JointStiffness} := \Phi_{steel}$ $\quad$ $\text{Friction} := \mu$ $\quad$ ThreadDepth := "N/A"

HelicoilMat := "N/A" $\quad$ ThreadMat := "N/A"

$$\begin{pmatrix} P_{M5} \\ S_{M5} \\ R_{a.M5} \end{pmatrix} :=$$

Preload (N)	Slip (assuming zero dynamic load) (N)	Tensile to sepatate (N)	Tensile to meet CSA yield (N)	Strip Helicoil (N)	Strip Parent thread (N)	Maximum Tensile (N)
3500	525	4499	20721	N/A	N/A	4499

(JT Torque Si JointStiffness Friction ThreadDepth HelicoilMat ThreadMat WT)

6. Determine the slip capacity of a Grade 8.8 M5 EZP bolt and Nordlock washer into a Eurosert torqued to 6Nm (Junction box Installation)

$$T_{M5.EZP.6Nm} := 6\cdot N\cdot m$$

$$P_{M5.EZP.6Nm} := \frac{T_{M5.EZP.6Nm}}{6\cdot N\cdot m}\cdot 5.6\cdot kN = 5.6\times 10^{3}\,N$$ [Ref. 6]

$$S_{a.M5.EZP.6Nm} := P_{M5.EZP.6Nm}\cdot \mu = 840\cdot N$$

Maximum fully supported torque:

$$T_{a.M5.39006} := 7.9\cdot N\cdot m$$ [Ref. 7]

Unsupported Pullout:

$$R_{a.M5.39006} := 7.8\cdot kN$$

The pullout of the insert is the limiting factor, as the allowable tensile load of an M5 fixing is 8.1kN. Determine the additional dynamic load that can be applied to the insert. This is the minimum of the following

Tensile load required to separate the joint:

$$R_{axial.sep} := \frac{P_{M5.EZP.6Nm}}{1-\Phi_{steel}} = 7.198\times 10^{3}\,N$$

Tensile load to meet the capacity of the Eurosert:

$$R_{axial.tensile} := \frac{R_{a.M5.39006}-P_{M5.EZP.6Nm}}{\Phi_{steel}} = 9.91\times 10^{3}\,N$$

Minimum:

$$R_{axial} := \min\left(R_{axial.sep}, R_{axial.tensile}\right) = 7.198\times 10^{3}\,N$$

7. Determine the slip capacity of a Grade 8.8 M8 EZP bolt and plain washer into a Eurosert torqued to 25Nm (CDR Installation).

$$T_{M8.EZP.25Nm} := 25 \cdot N \cdot m$$

$$P_{M8.EZP.25Nm} := \frac{T_{M8.EZP.25Nm}}{8 \cdot mm \cdot BF} = 1.563 \times 10^{4} N$$

$$S_{a.M8.EZP.25Nm} := P_{M8.EZP.25Nm} \cdot \mu = 2.344 \times 10^{3} \cdot N$$

Maximum fully supported torque:

$$T_{a.M8.39006} := 32 \cdot N \cdot m$$ [Ref. 7]

Unsupported Pullout:

$$R_{a.M8.39006} := 18.1 \cdot kN$$

The pullout of the insert is the limiting factor, as the allowable tensile load of an M8 fixing is 20.9kN. Determine the additional dynamic load that can be applied to the insert. This is the minimum of the following

Tensile load required to separate the joint:

$$R_{axial.sep} := \frac{P_{M8.EZP.25Nm}}{1 - \Phi_{steel}} = 2.008 \times 10^{4} N$$

Tensile load to meet the capacity of the Eurosert:

$$R_{axial.tensile} := \frac{R_{a.M8.39006} - P_{M8.EZP.25Nm}}{\Phi_{steel}} = 1.115 \times 10^{4} N$$

Minimum:

$$R_{axial} := \min\left(R_{axial.sep}, R_{axial.tensile}\right) = 1.115 \times 10^{4} N$$

8. Determine the slip capacity of a Grade 8.8 M6 Pem stud and plain washer torqued to 5Nm (CDR Stack)

Bolt size	M6
Washer Type	Plain
Joint Type	Grade 8 Nut
Torque (Nm)	5

$\text{JointStiffness} := \Phi_{steel}$ $\quad$ $\text{Friction} := \mu$ $\quad$ ThreadDepth := "N/A"

HelicoilMat := "N/A" $\quad$ ThreadMat := "N/A"

$$\begin{pmatrix} P_{M5} \\ S_{M5} \\ R_{a.M5} \end{pmatrix} :=$$

Preload (N)	Slip (assuming zero dynamic load) (N)	Tensile to sepatate (N)	Tensile to meet CSA yield (N)	Strip Helicoil (N)	Strip Parent thread (N)	Maximum Tensile (N)
4167	625	5356	33033	N/A	N/A	5356

(JT Torque Si JointStiffness Friction ThreadDepth HelicoilMat ThreadMat WT)

The pull-through load of an M6 Pem stud is 11.3kN [Ref. 8]. The maximum tensile load of the fixing of 5356N is the limiting factor.

7. Loadcases

Proof Attachment

GM/RT 2100 Issue 5.

3.2.1 Equipment attached to vehicle bodies shall be designed according to the inertia load values set out in BS EN 12663-1:2010 or BS EN 12663-2:2010 for the relevant vehicle category unless otherwise set out in this document.

6.5.2 In order to calculate the forces on the equipment attachments during operation of the vehicle, the masses of the components shall be multiplied by the specified accelerations in Table 13 [X], Table 14 [Y] and Table 15 [Z]. The load cases shall be applied individually.

As a minimum additional requirement the loads, resulting from the accelerations defined in Table 13, Table 14 and Table 15 shall be separately considered in combination with the maximum loads which the equipment itself may generate. The accelerations defined in Table 13 and Table 14 shall be considered in combination with the load due to 1g vertical acceleration.

Using BS EN 12663. This is a L category vehicle.

Longitudinal acceleration = 3g
Lateral acceleration = 1g
Vertical acceleration = 1 +- 2g

Ultimate Attachment

GM/RT 2100 Issue 5. This is an L category vehicle.

3.2.2 The ultimate strength of the equipment attachments shall be consistent with the inertia load values set out in BS EN 12663-1:2010 or BS EN 12663-2:2010 or the maximum mean deceleration levels for the collision scenarios set out in BS EN 15227:2008, whichever is the greater.

BS EN 15227:2008

6.4.1 The mean longitudinal deceleration in the survival spaces shall be limited to 5g for Scenario 1 and Scenario 2 and 7.5g for Scenario 3.

Fatigue Attachment

GM/RT 2100 Issue 5.

3.2.7 The fatigue design life for equipment attachments shall be determined.

Using BS EN 12663. This is a L category vehicle.

6.6.4 The equivalent dynamic loading in a cumulative damage analysis may be represented accordingly by taking the acceleration levels in Table 16 and Table 17 [and Table 18] and assuming they act for 10^7 cycles each.

Longitudinal acceleration = ±0.15g
Lateral acceleration = ±0.2g
Vertical acceleration = 1±0.25g

Natural Frequency

GM/RT 2100 Issue 5

3.2.5 Locally generated accelerations, forces and resonances acting within and on equipment shall be accounted for.

8. Assumptions

1. The coefficient of friction of steel is 0.15. $\mu \equiv 0.15$

2. The bolt factor for EZP bolts [Ref 5] $BF \equiv 0.2$

3. The stiffness of a Steel/Steel joint is $\Phi_{steel} \equiv 0.222$

4. Assumed vehicle roof material is 34/20 Steel

5. It is assumed that the existing CDR mounting box is fixed to the equipment stack using 4 off M^ Pem stud fixings.

9. Calculations - Type 1 Installations

9.1 Junction Box and Loudspeaker Installation (MP-C0-00069)

9.1.1 GM/RT 2100 Proof Loadcase

The Junction Box (Item D) is mounted to a steel back plate (Item C) using 4 off M5 Pem stud fixings. An enclosure cover (Item E) is mounted to the enclosure using 4 off M5 fixings into Euroserts. The 2mm thick enclosure is fixed to 2 off 4mm thick steel support brackets (Items A & B) using 8 off M5 fixings into Euroserts (4 off per support).

The Junction Box weighs no more than 2kg. Considering the low mass of the box and the method of attachment to the enclosure, the loads in the M5 Pem stud fixings and the stresses in the enclosure are passed by inspection.

The collective mass of the junction box and enclosure is approximately 5kg. As this mass is supported by 8 off M5 fixings, the loads reacted by the fixings and stresses in the enclosure and support brackets are passed by inspection.

The mass of the existing NRN equipment is not known, however it is conservatively assumed to be no more than 15kg and the mass of the 2 off steel support brackets is 3.2kg. Therefore, the total mass to be reacted by the 6 off M6 fixings attaching the equipment to the cab roof is conservatively 24kg. The slip and tensile loads reacted by the 6 off M6 fixings are calculated below:

$$F_x := 24 \cdot kg \cdot axp \cdot PF = 811.991\,N$$

$$F_y := 24 \cdot kg \cdot ayp \cdot PF = 270.664\,N$$

$$F_z := 24 \cdot kg \cdot azpd \cdot PF = 811.991\,N$$

$$F_{z.NRN} := 20 \cdot kg \cdot azpd \cdot PF = 676.659\,N$$

[Assuming existing equipment, 15kg and support brackets, 3.2kg, conservatively 20kg]

$$F_{z.junc.box} := 7.kg \cdot azpd \cdot PF = 236.831\,N$$

[Conservatively assuming junction box, 5kg and section of support brackets, 2kg]

Slip loads:

$$S_{M6.x} := \frac{F_x}{6} = 135.332\,N$$

$$S_{M6.y} := \frac{F_y}{6} = 45.111\,N$$

$$S_{total} := \sqrt{(S_{M6.x})^2 + (S_{M6.y})^2} = 142.652\,N \qquad \boxed{\text{negligible}}$$

Tensile loads:

$$R_{M6.z} := \frac{F_{z.NRN}}{6} = 112.776\,N$$

$$R_{M6.z.bend} := \frac{F_{z.junc.box} \cdot 175 \cdot mm}{2 \cdot 195 \cdot mm} = 106.27\,N$$

$$R_{total} := R_{M6.z} + R_{M6.z.bend} = 219.047\,N$$

Stress in the support bracket:

$$I := \frac{125 \cdot mm \cdot (4 \cdot mm)^3}{12} = 6.667 \times 10^{-10}\,m^4$$

$$\sigma_{bracket} := \frac{(F_{z.junc.box} \cdot 175 \cdot mm) \cdot 2 \cdot mm}{I} = 124.336 \cdot N \cdot mm^{-2}$$

The slip and tensile loads are within the allowable loads calculated in Section 6 and the maximum stress in the support brackets is within the allowable proof strength of S275. The loads and stresses are considered to be acceptable.

The thickness of the vehicle structure to which the equipment is attached is 5mm and so the stresses are passed by comparison with the bracket stress.

The maximum proof stress in the cab roof due to the additional RETB equipment is passed by inspection.

9.1.2 GM/RT 2100 Ultimate Loadcase

The ultimate loads reacted by the fixings and the ultimate stresses in the junction box, junction box enclosure, support brackets and cab roof are passed by inspection due to the high proof reserve factors resulting from the low proof loads and stresses.

9.1.3 GM/RT 2100 Fatigue Loadcase

The fatigue stresses in the enclosure are passed by inspection. The fatigue stresses in the bracket are passed by comparison with the low proof stresses. The proof bolt loads are below the allowable fatigue loads calculated in the appendix and so the fatigue loads are considered to be acceptable.

9.1.4 Natural Frequency

The natural frequency of the junction box installation is calculated below, conservatively assuming a built-in, massless cantilever beam with a point mass at the centre of gravity:

$$E_{s275} := 200 \cdot \mathrm{GPa} = 2 \times 10^{5} \cdot \mathrm{N} \cdot \mathrm{mm}^{-2}$$

$$I := \frac{125 \cdot \mathrm{mm} \cdot (4 \cdot \mathrm{mm})^{3}}{12} = 6.667 \times 10^{-10}\,\mathrm{m}^{4}$$

$$L := 160 \cdot \mathrm{mm}$$

$$f := \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{3 \cdot E_{s275} \cdot I}{6.5 \cdot \mathrm{kg} \cdot L^{3}}} = 19.508 \cdot \mathrm{Hz}$$

The natural frequency is above the recommended minimum natural frequency of 17Hz for body-mounted equipment and so is considered to be acceptable.

9.2 Loudspeaker Installation (MP-C0-00069)

9.2.1 GM/RT 2100 Proof Loads

The RETB loudspeaker of mass 0.3kg replaces an existing NRN speaker using the existing fixings.

Considering the low mass of the speaker and the fixings used, the proof loads reacted by the fixings and the stresses in the enclosure are passed by inspection.

9.2.2 GM/RT 2100 Ultimate Loads

The ultimate loads reacted by the attachments and the stresses in the enclosure are passed by inspection.

9.2.3 GM/RT 2100 Fatigue Loads

The fatigue loads reacted by the fixings and the stresses in the enclosure are passed by inspection.

9.2.4 Natural Frequency

The natural frequency of the loudspeaker is passed by inspection.

9.3 Antenna Installation (MP-C0-00077)

9.3.1 GM/RT 2100 Proof Loadcase

The RETB antenna weighs no more than 1kg and is attached to the vehicle bonnet using 3 off M5 fixings into Euroserts. Due to the low mass of the antenna and the method of attachment, the loads reacted by the fixings and the stresses in the vehicle bonnet are passed by inspection.

The GPS patch antenna weighs no more than 0.5kg and is fixed to the bonnet of the locomotive using an M10 locking nut. Due to the low mass of the antenna and the method of attachment, the load reacted by the attachment and stresses in the vehicle bonnet are passed by inspection.

9.3.2 GM/RT 2100 Ultimate Loadcase

Due to the low mass of the antenna and the method of attachment, the ultimate bolt loads and stresses in the vehicle bonnet are passed by inspection.

9.3.3 GM/RT/2100 Fatigue Loadcase

Due to the low mass of the antenna and the method of attachment, the fatigue bolt loads and stresses in the vehicle bonnet are passed by inspection.

9.4 CDR Installation (MP-C0-00067)

9.4.1. GM/RT 2100 Proof Loadcase

The CDR unit of mass no more than 3.3kg [Ref. 10] is attached to a carrier plate (Item B) using 2 off M8 fixings. The carrier plate is supported by the adapter bracket (Item A) as shown in drawing no. MP-C0-00067. The adapter bracket and dummy connector support bracket are fixed to the existing NRN bracket using 4 off M8 fixings into Euroserts. An FEA of the CDR type 1 installation was completed in Ansys v15 in the following manner:

- The existing fixings attaching the existing brackets to the vehicle structure were conservatively assumed to be M6 fixings and were represented by coupling the translational and rotational degrees of freedom at the bolt holes.
- The joints connecting the adapter bracket and dummy support bracket to the existing NRN bracket were represented by coupling the translational and rotational degrees of freedom at the bolt holes.
- The existing Q-tron Datacord unit was conservatively assumed to weigh no more than 2kg and was represented by a 2kg point mass remotely attached to the front face of the box assembly as shown in Figure 9_1.
- The two existing radio units were conservatively assumed to weigh no more than 0.5kg each and were represented by point passes of 0.5kg each, remotely attached to the inner faces of the lower two boxes.
- The CDR unit and carrier were modelled as a lumped mass, remotely attached to the two wing lock holes and the lower edge of the rectangular cutout.

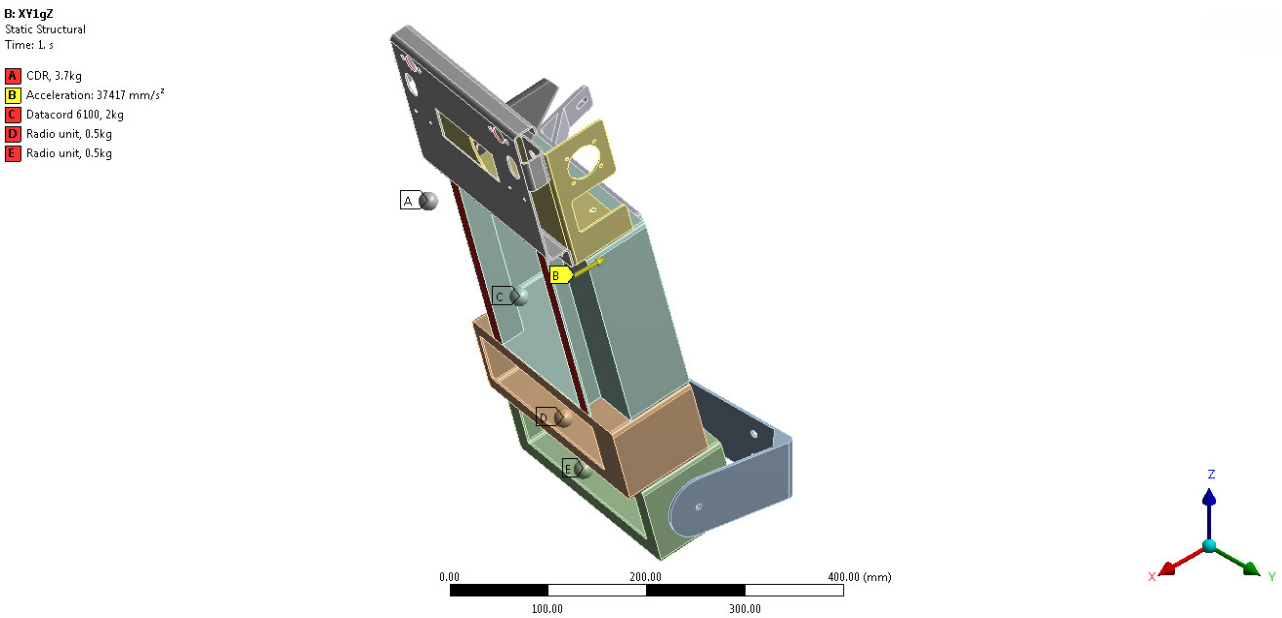


Figure 9_1 - CDR Installation Type 1

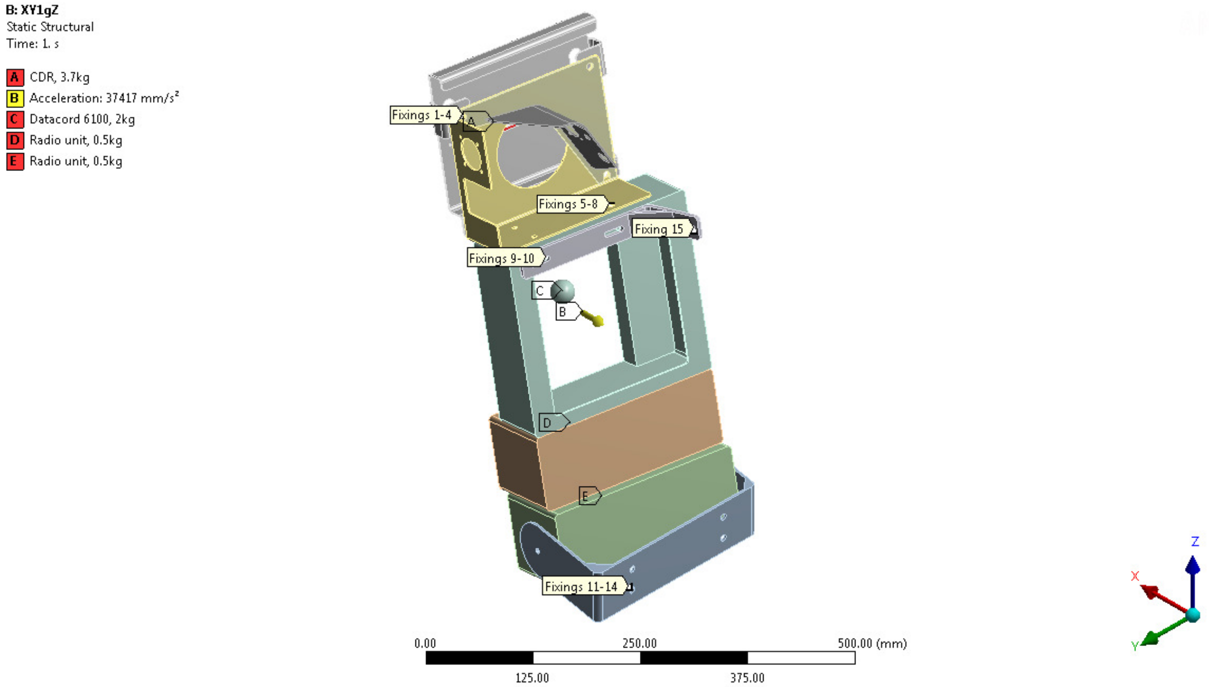


Figure 9_2 - CDR Installation Type 1, fixing locations

Figures 9_3 to 9_7 show the stresses in the brackets due to the GM/RT 2100 proof accelerations. The maximum stress in the equipment stack is approximately 349Nmm^{-2} as shown in Figures 9_3 and 9_4. This stress is localised at a bolt hole discontinuity as shown in Figure 9_4 and so can be disregarded. The stress 2 nodes away from the slot is approximately 100Nmm^{-2} which is below the proof strength of S275 and so is considered to be acceptable.

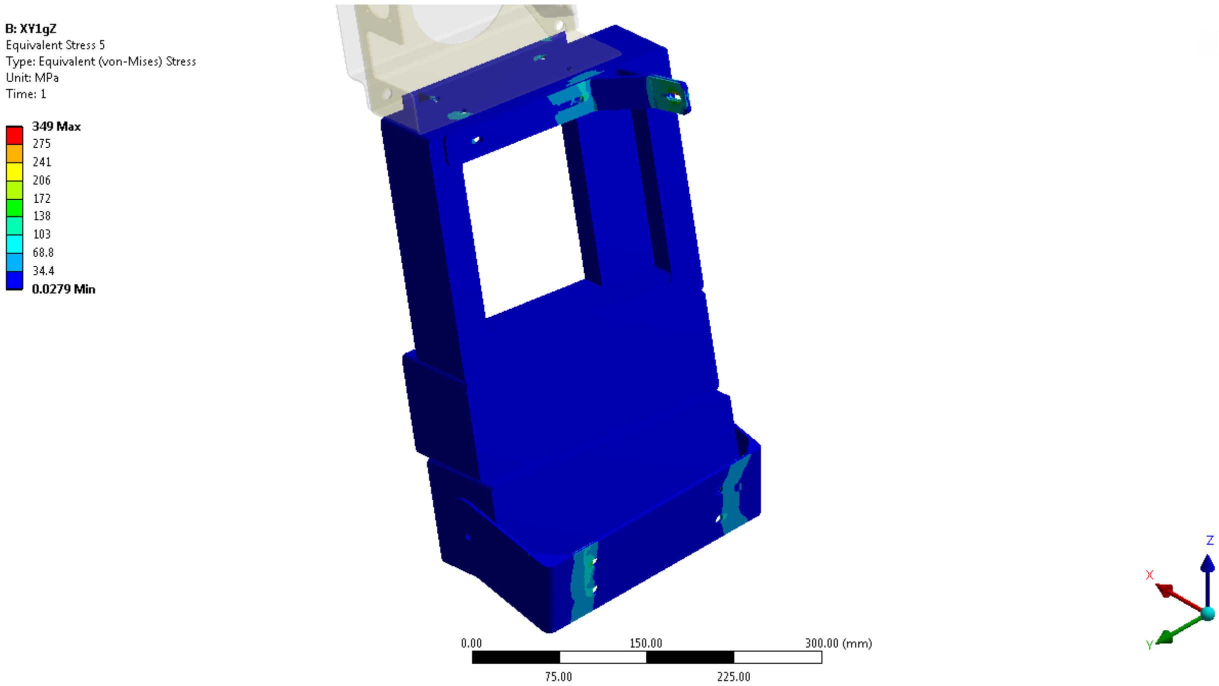


Figure 9_3 - GM/RT 2100 XY1gZ von-Mises stress - Existing equipment stack

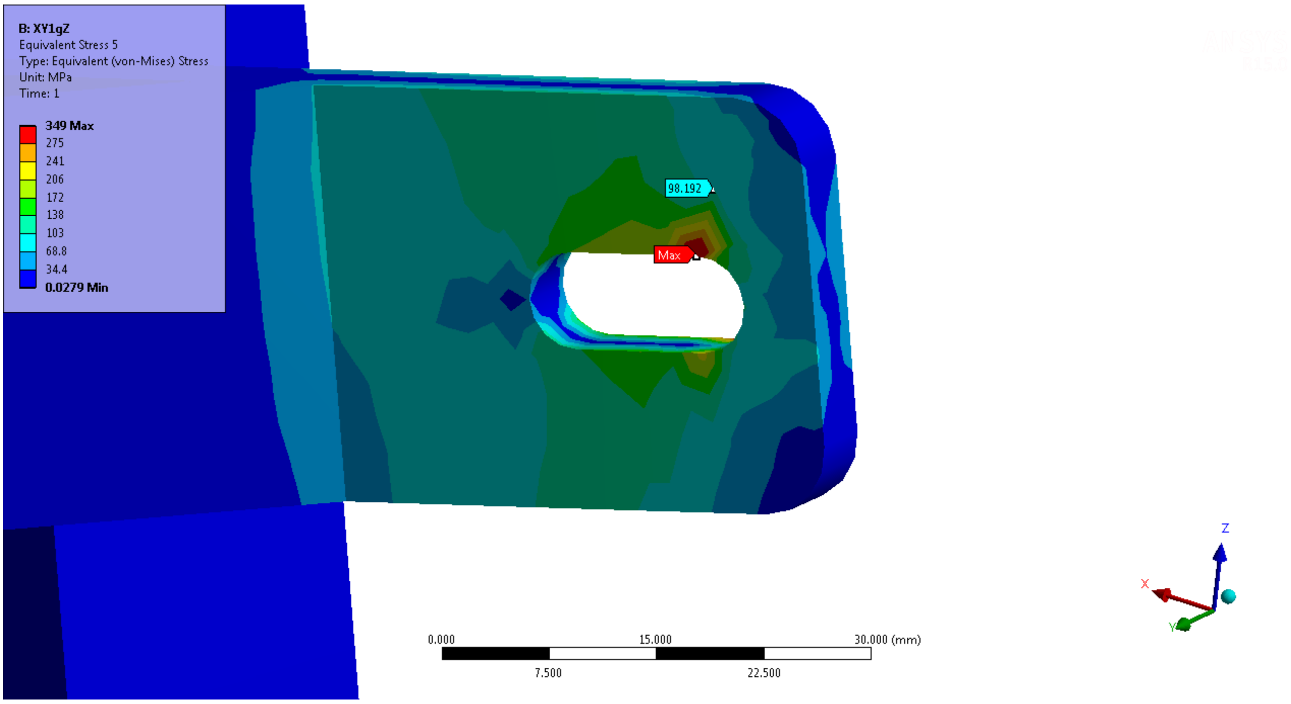


Figure 9_4 - GM/RT 2100 XY1gZ von-Mises stress - Existing equipment stack, close-up

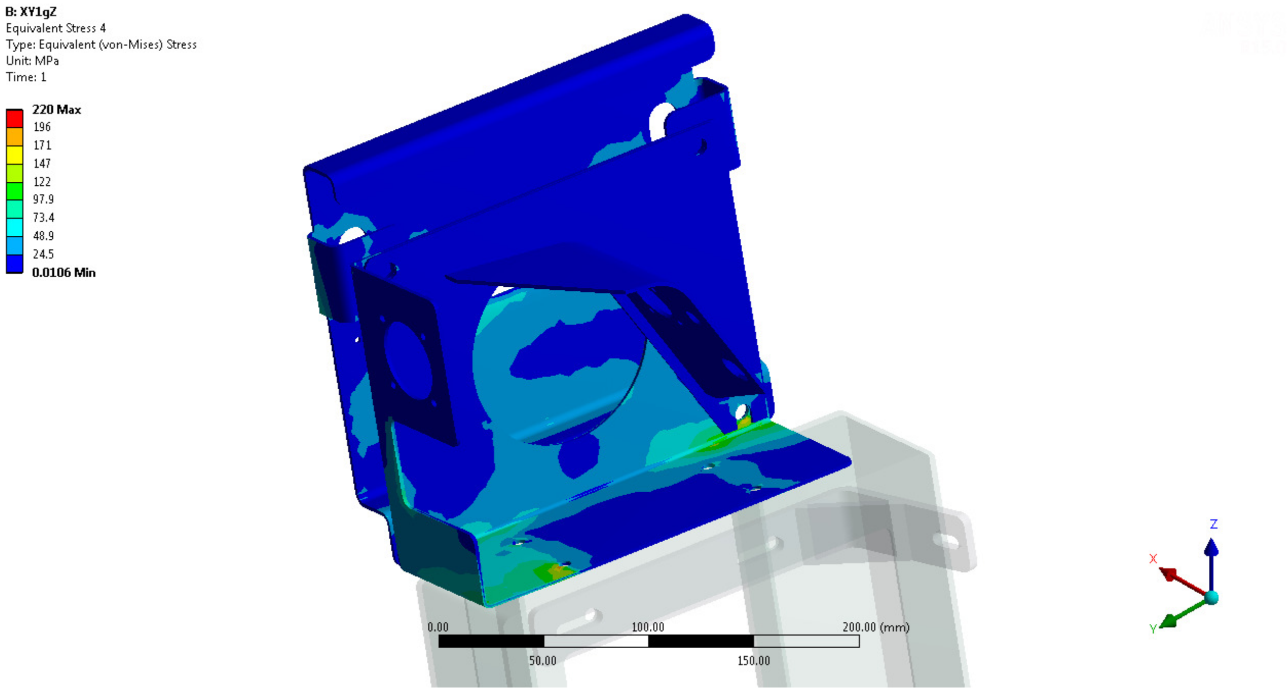


Figure 9_5 - GM/RT 2100 XY1gZ von-Mises stresses - CDR installation and existing bracket

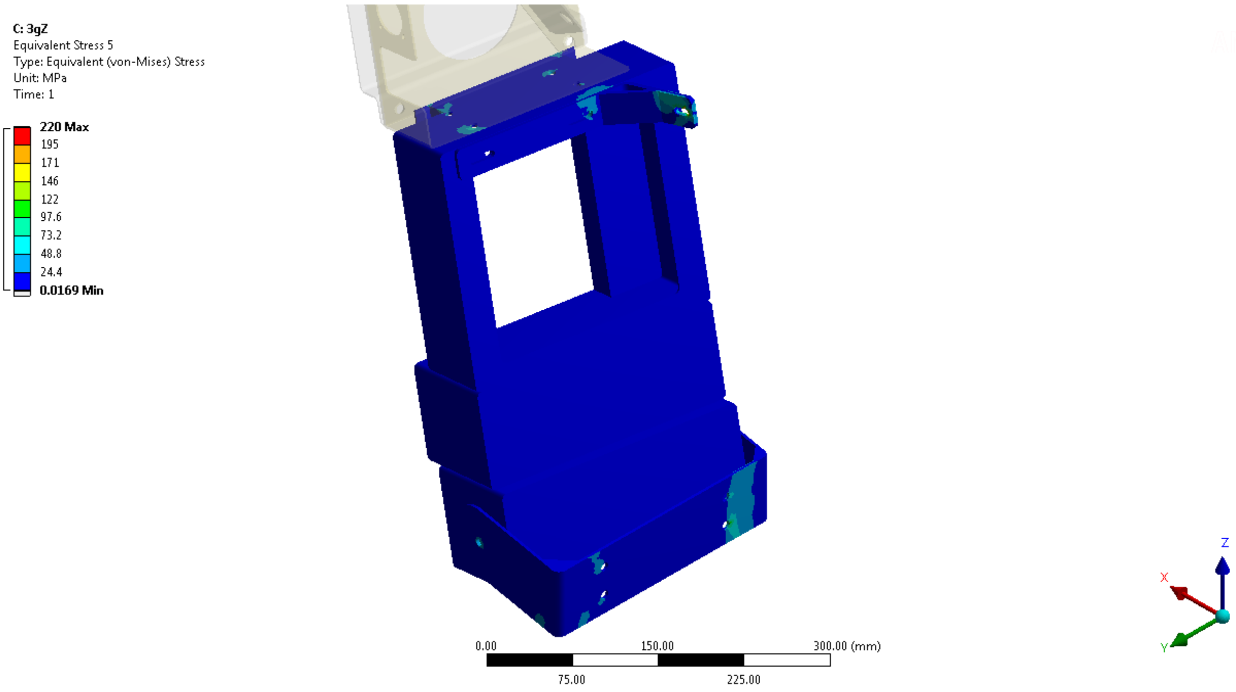


Figure 9_6 - GM/RT 2100 3gZ von-Mises stresses - Existing equipment stack

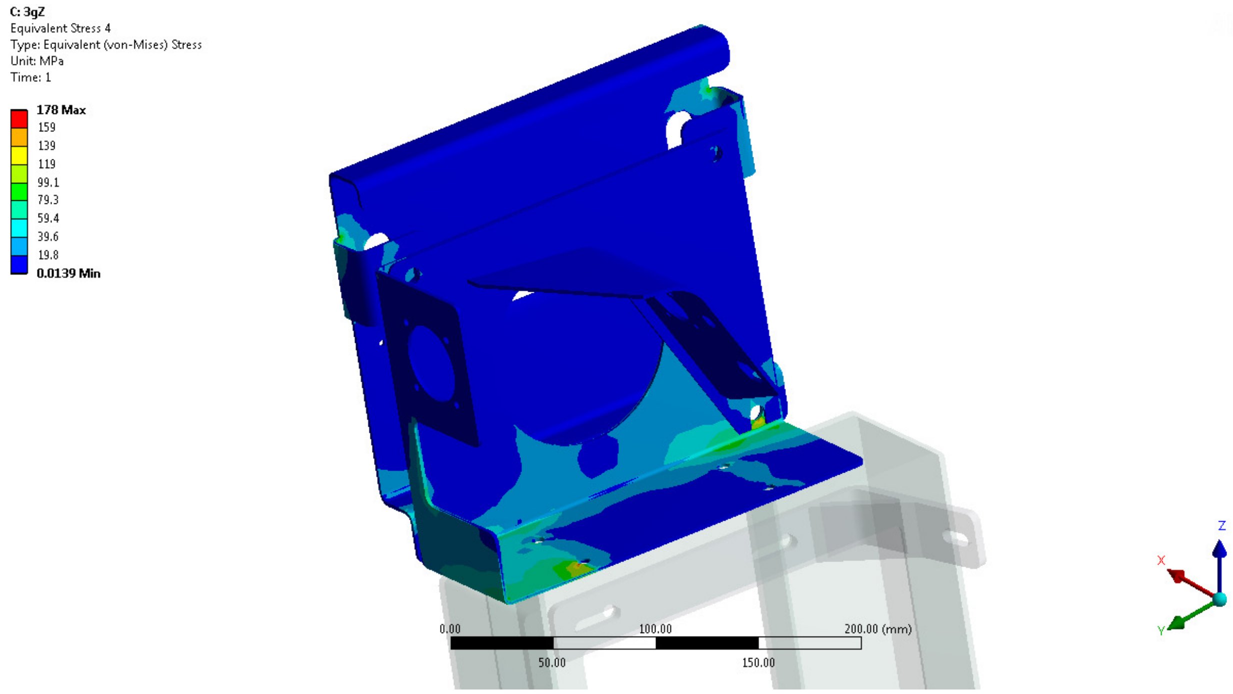


Figure 9_7 - GM/RT 2100 3gZ von-Mises stresses - CDR installation and existing bracket

Table 9_1 - GM/RT 2100 XY1gZ Proof Fixing Loads /N										
Fixing No.	Fixing	X Axis	Y Axis	Z Axis	Tensile	Slip	Tensile Capacity	Slip Capacity	Tensile RF	Slip RF
1	M8 Euro	65	-120	-54	54	137	11150	2344	Large	17
2	M8 Euro	-318	65	-68	68	325	11150	2344	Large	7
3	M8 Euro	-14	-127	-29	29	128	11150	2344	Large	18
4	M8 Euro	307	103	-3	3	324	11150	2344	Large	7.2
5	M6 Stud	337	580	-189	189	671	5356	625	28	0.9
6	M6 Stud	-527	-145	-74	74	547	5356	625	73	1.1
7	M6 Stud	-182	-425	-175	175	462	5356	625	31	1.4
8	M6 Stud	268	-30	-337	337	269	5356	625	16	2.3
9	M6	-383	-714	470	470	810	10511	1375	22	1.7
10	M6	20	-831	-74	74	831	10511	1375	Large	1.7
11	M6	-11	10	1	1	16	10511	1375	Large	88
12	M6	10	-37	-75	75	39	10511	1375	Large	36
13	M6	6	-14	59	59	15	10511	1375	Large	90
14	M6	-15	-17	171	171	23	10511	1375	62	60
15	M6	-357	-180	128	128	400	10511	1375	82	3.4

Table 9_2 - GM/RT 2100 3gZ Proof Fixing Loads /N										
Fixing No.	Fixing	X Axis	Y Axis	Z Axis	Tensile	Slip	Tensile Capacity	Slip Capacity	Tensile RF	Slip RF
1	M8 Euro	309	128	-26	26	334	11150	1875	Large	6
2	M8 Euro	-12	-127	-53	53	128	11150	1875	Large	15
3	M8 Euro	-306	116	9	9	327	11150	1875	Large	6
4	M8 Euro	-14	-127	-29	29	128	11150	1875	Large	15
5	M6 Stud	75	51	-46	46	91	5356	625	Large	7
6	M6 Stud	32	-123	18	18	127	5356	625	Large	5
7	M6 Stud	41	5	-78	78	42	5356	625	69	15
8	M6 Stud	-39	22	-5	5	45	5356	625	Large	14
9	M6	-20	84	-32	32	87	10511	1375	Large	16
10	M6	67	121	-27	27	139	10511	1375	Large	10
11	M6	37	102	-6	6	108	10511	1375	Large	13
12	M6	-42	95	-119	119	104	10511	1375	89	13
13	M6	-45	-118	-98	98	126	10511	1375	Large	11
14	M6	-56	91	73	73	107	10511	1375	Large	13
15	M6	-150	-342	-4	4	373	10511	1375	Large	4

As shown in Tables 9_1 and 9_2 the majority of proof slip and tensile loads reacted by the bolts are within their respective capacities and so are considered to be acceptable. The exception is that of fixing number 5 due to the GM/RT 2100 XY1gZ acceleration. It is assumed that the four pem stud fixings react the loads as a group and considering the slip loads reacted by the remaining 3 studs, it is considered that the slip load reacted by the group is acceptable.

9.4.2 GM/RT 2100 Ultimate Loadcase

As the ratio of ultimate safety factor to proof factor (1.31) is less than the lowest proof reserve factor, the ultimate stresses and bolt loads are considered to be acceptable.

9.4.3 GM/RT 2100 Fatigue Loadcase

It is assumed that a positive to negative fatigue acceleration range can be approximated by twice the positive acceleration. The method of fatigue assessment is described in the appendix.

The maximum stress in the installation due to the GM/RT 2100 fatigue accelerations is 47.5Nmm^{-2} (see Figure 9_10). This stress is at a bolt region. The stress in the FEA plots required to cause a damage of 0.33 at a bolted (class C) region is approximately 63Nmm^{-2} and at a weld region (class W) is approximately 11.8Nmm^{-2}. These are calculated below:

$$\text{damage} := \left(\frac{63.7 \cdot \text{N} \cdot \text{mm}^{-2}}{78 \cdot \text{N} \cdot \text{mm}^{-2}}\right)^{(3.5+2)} = 0.328$$

$$\text{damage} := \left(\frac{11.8 \cdot \text{N} \cdot \text{mm}^{-2} \cdot \sqrt{2}}{21 \cdot \text{N} \cdot \text{mm}^{-2}}\right)^{(3+2)} = 0.317$$

The calculated fatigue stress of 47.5Nmm^{-2} in the enclosure is below the maximum fatigue stress of 63.7Nmm^{-2} for Class C regions. At weld regions, the maximum calculated fatigue stress is approximately 2.5Nmm^{-2} (Figure 9_13) which is below the maximum fatigue stress of 11.8Nmm^{-2} for a class W region. The Miner's damage summation is therefore considered to be acceptable.

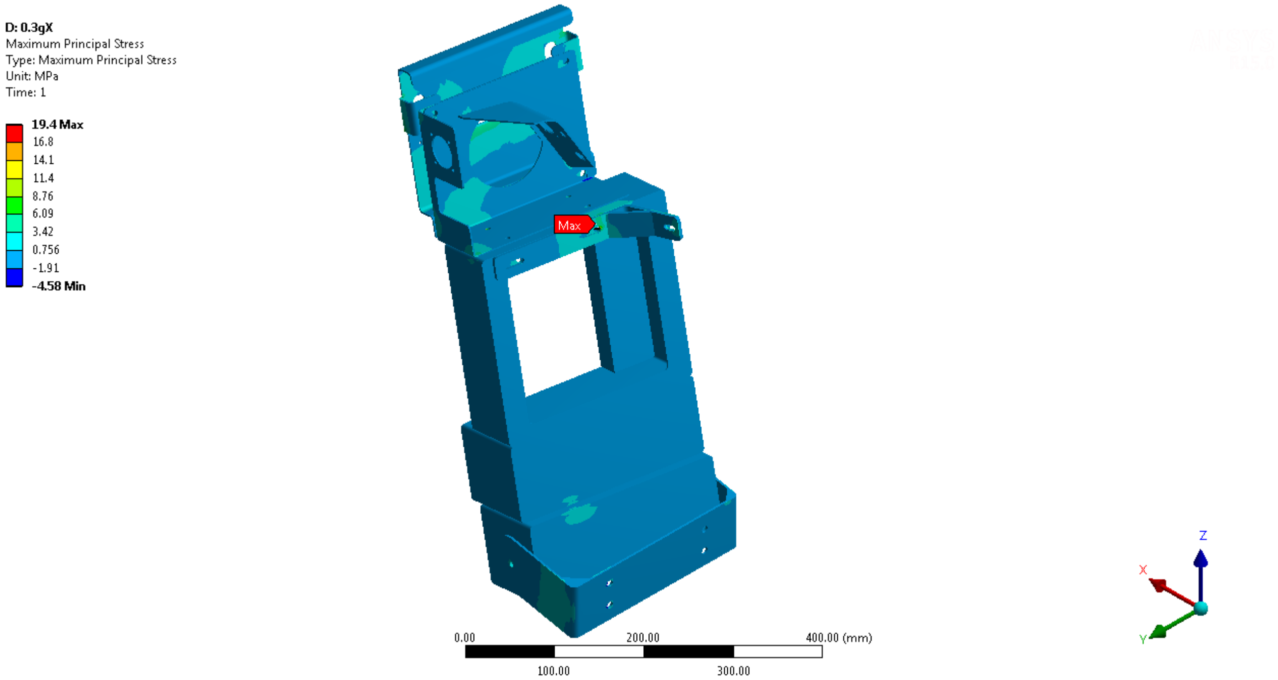


Figure 9_8 GM/RT 2100 0.3gX Principal stress range - CDR type 1 installation

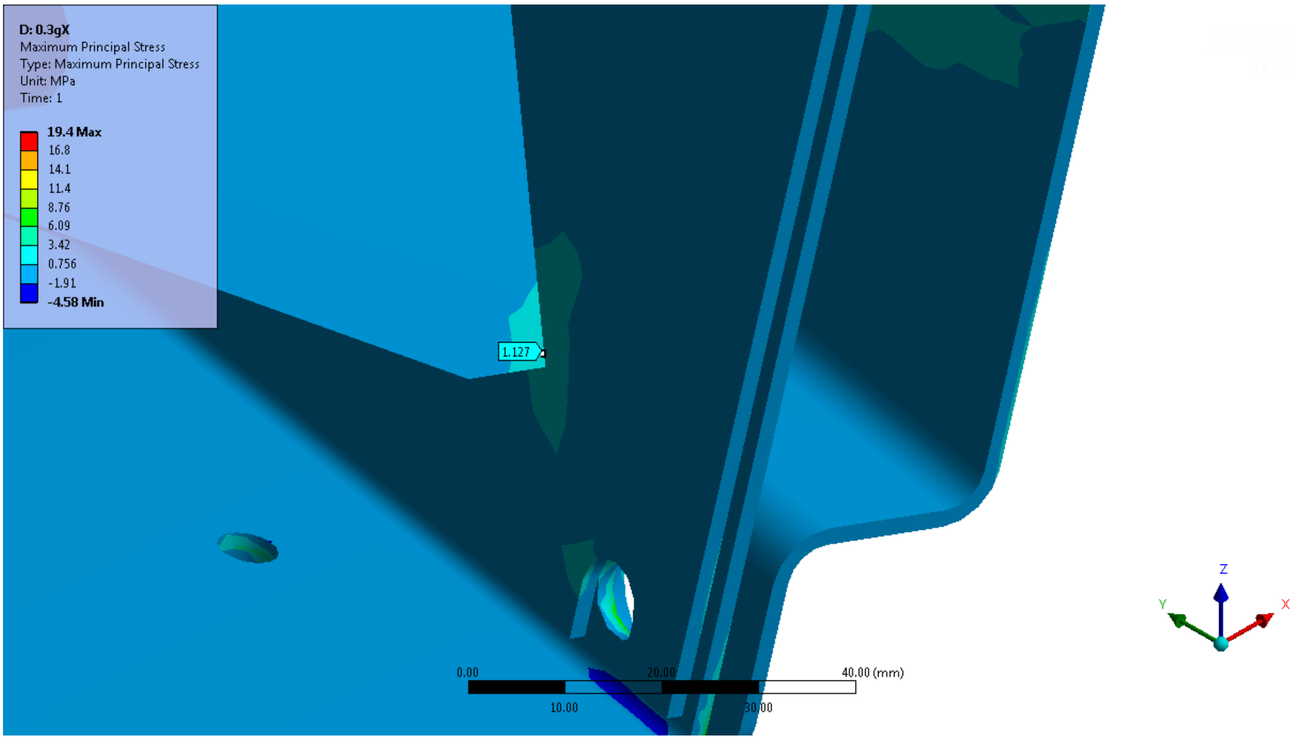


Figure 9_9 - GM/RT 2100 0.3gX Principal stress range - CDR type 1 installation, weld region

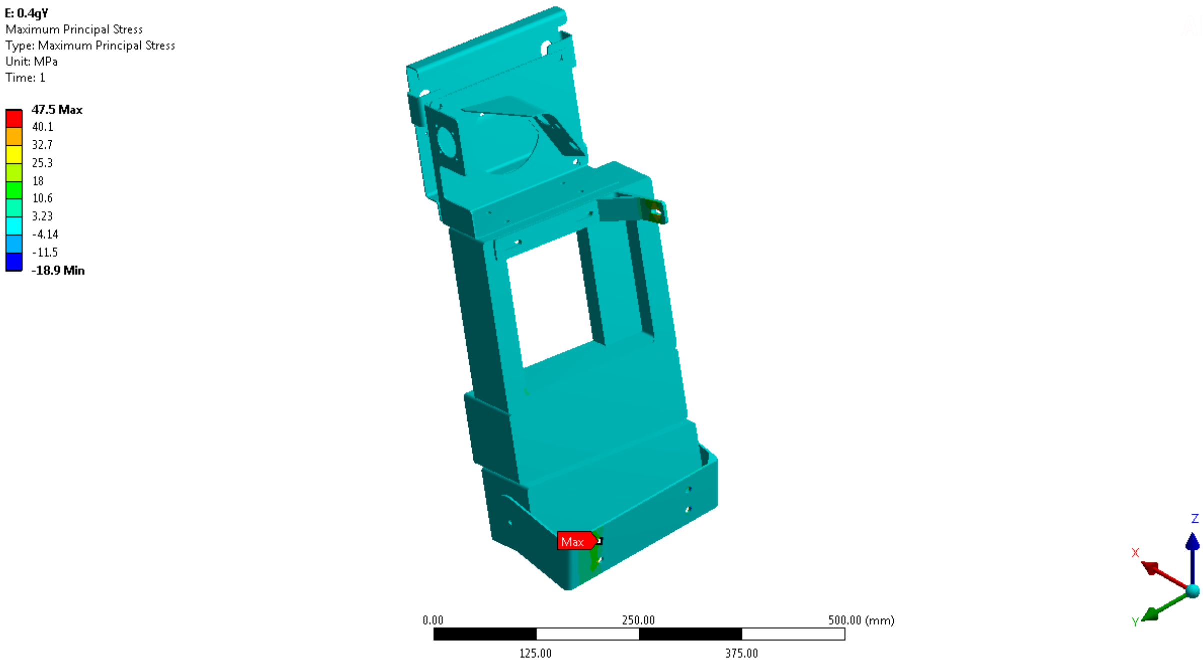


Figure 9_10 - GM/RT 2100 0.4gY Principal stress range - CDR type 1 installation

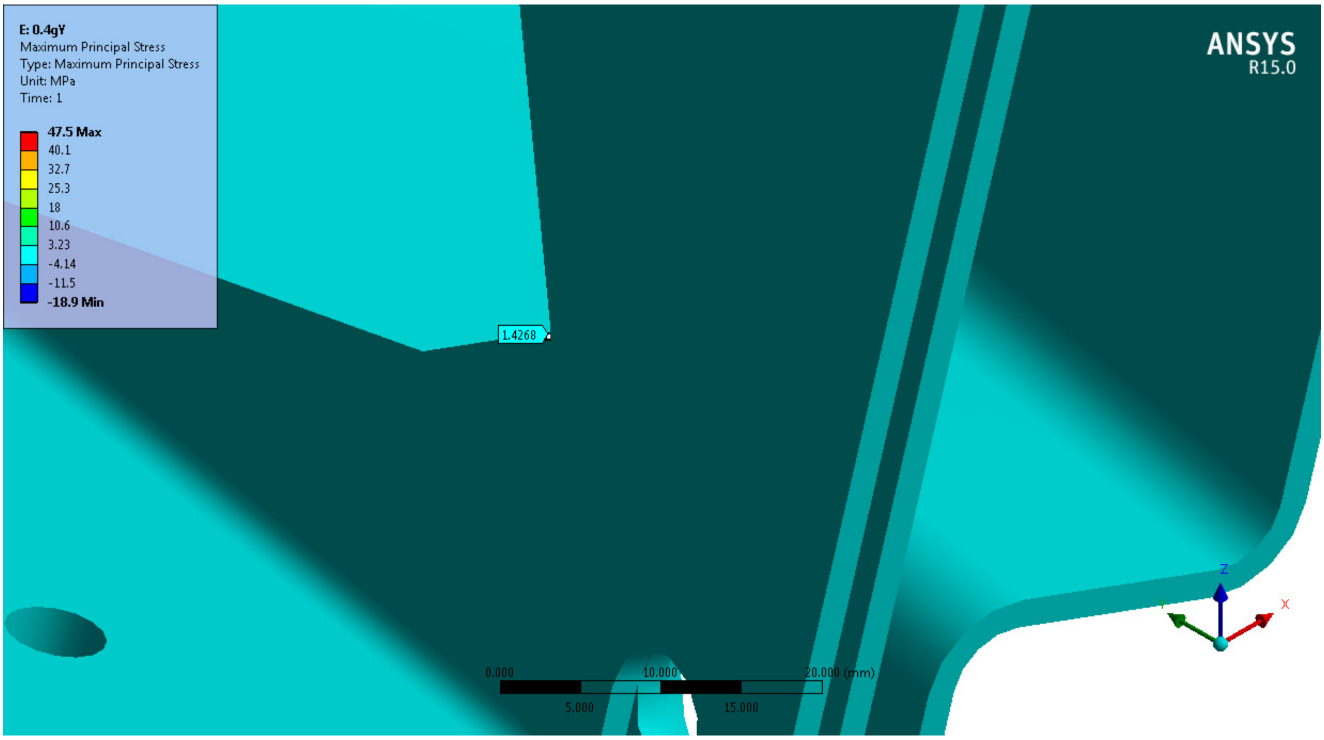


Figure 9_11 - GM/RT 2100 0.4gY Principal stress range - CDR type 1 installation, weld region

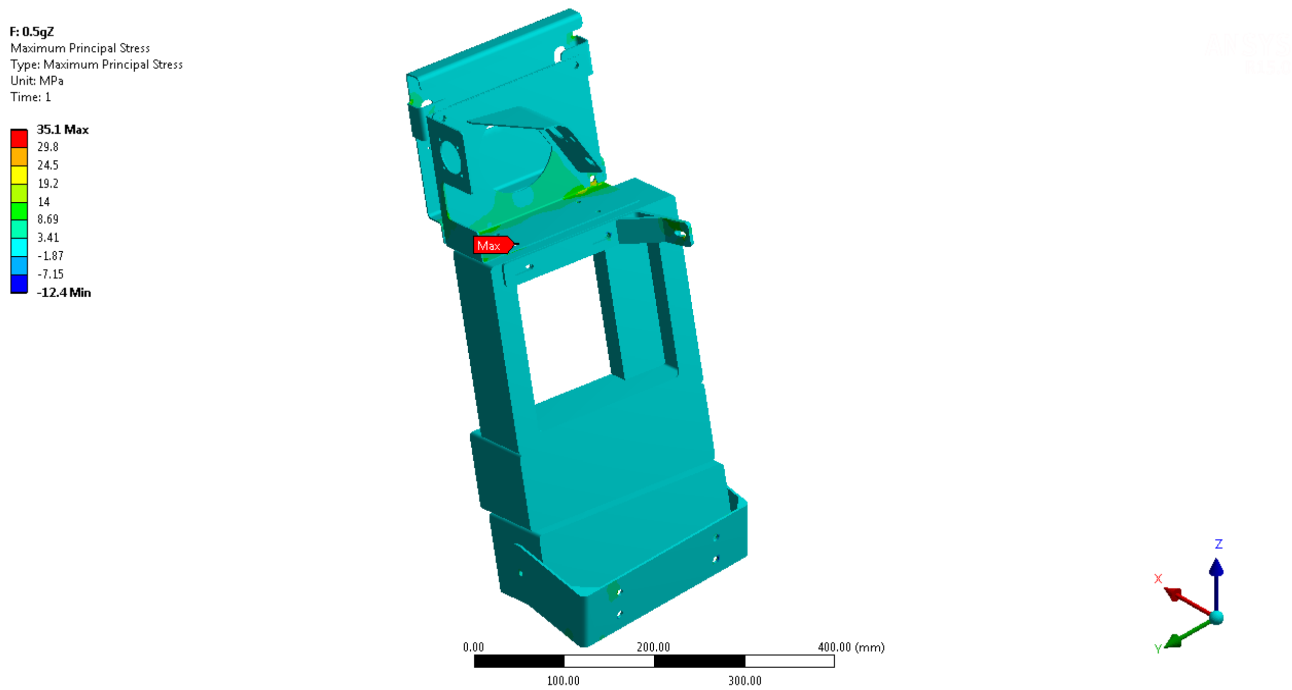


Figure 9_12 - GM/RT 2100 0.5gZ Principal stress range - CDR type 1 installation

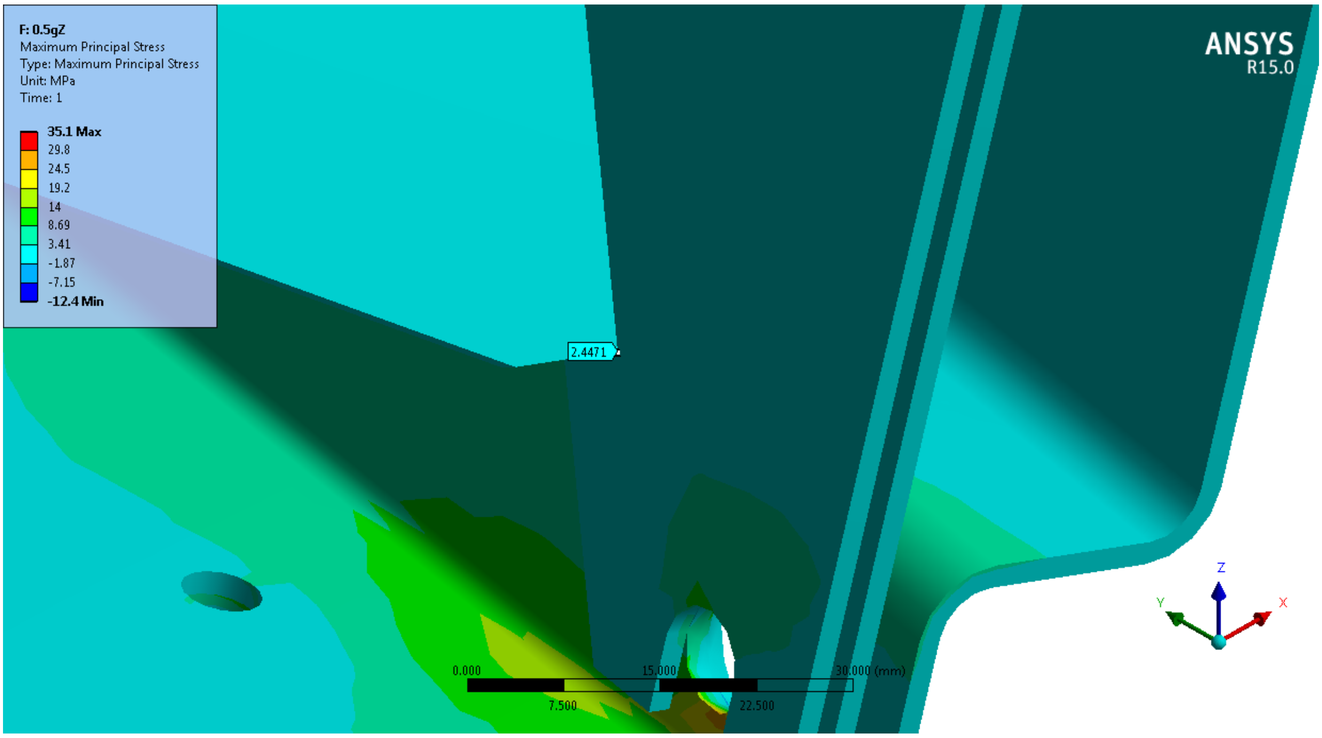


Figure 9_13 - GM/RT 2100 0.5gZ Principal stress range - CDR type 1 installation, weld region

The proof bolt loads are within the allowable fatigue loads calculated in the appendix and so the fatigue bolt loads are considered to be acceptable.

9.4.4 GM/RT 2100 Natural Frequency

To complete the modal analysis of the CDR type 1 installation, it was first prestressed by a 1g inertial load.

The natural frequency of the CDR type 1 installation is approximately 17Hz as shown in Figure 9_14. This meets the recommended minimum natural frequency of 17Hz and so is considered to be acceptable.

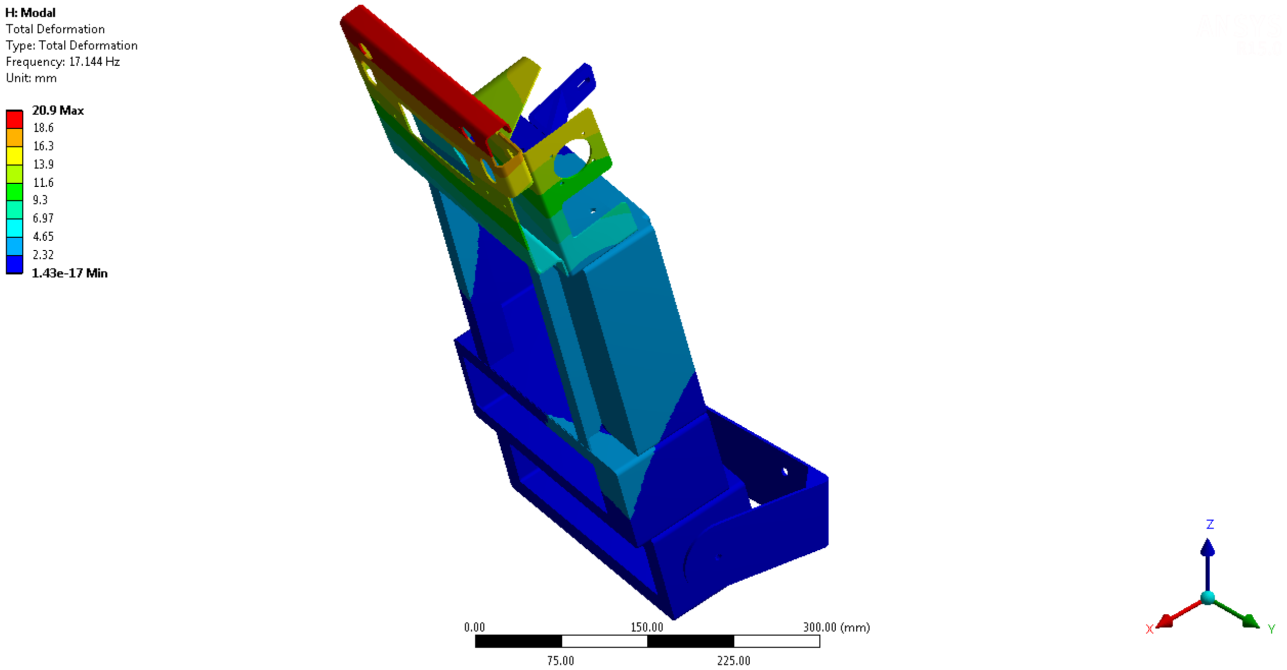


Figure 9_14 - GM/RT 2100 Modal analysis

9.5 Handset Installation (MP-C0-00068)

9.5.1 GM/RT 2100 Proof Loads

The handset is fixed to a steel mounting box using two off M5 fixings into Euroserts. Considering the low mass of the handset and the method of attachment, the proof loads reacted by the M5 fixings and the proof stresses in the mounting box are passed by inspection. The mounting box of mass 1.7kg is fixed to the vehicle using 6 off existing M5 clinch studs. Considering the low mass and the number of M5 fixings used, the loads reacted by the fixings and the stresses in the vehicle structure are passed by inspection.

9.5.2 GM/RT 2100 Ultimate Loads

As the ratio of allowable ultimate to proof stress is larger than the ratio of ultimate to proof load factors, the ultimate stresses in the handset installation are passed by comparison.

9.5.3 GM/RT 2100 Fatigue Loads

The fatigue loads reacted by the fixings and the stresses in the mounting box assembly and vehicle structure are passed by inspection.

9.5.4 Natural Frequency

The natural frequency is considered to be above the recommended minimum natural frequency of 17Hz for body-mounted equipment and so it is passed by inspection.

9.5.5 Handset Pull-off Load

The loads reacted by the M5 fixings and the stresses in the vehicle structure and mounting box due to pull-off loads by the operator are passed by inspection.

10. Calculations - Type 2 Installations

10.1 Junction Box Installation (MP-C0-00073)

10.1.1 GM/RT 2100 Proof Loadcase

The Junction Box (Item B) is mounted to a steel back plate (Item A) using 4 off M5 Pem stud fixings. An enclosure cover (Item C) is mounted to the enclosure using 4 off M5 fixings into Euroserts. The back plate is attached to the cab partition using 4 off M5 fixings into Euroserts.

The total mass of the junction box and enclosure assembly is approximately 5.5kg. Considering the low mass and the method of attachment, the loads reacted by the fixings and the stresses in the enclosure and partition are considered to be acceptable.

10.1.2 GM/RT 2100 Ultimate Loadcase

The ultimate loads reacted by the fixings and the ultimate stresses in the junction box, junction box enclosure, support brackets and cab roof are passed by inspection.

10.1.3 GM/RT 2100 Fatigue Loadcase

The fatigue loads in the bolts and stresses in the enclosure are passed by inspection.

10.2 Loudspeaker Installation (MP-C0-00073)

10.2.1 GM/RT 2100 Proof Loads

The RETB loudspeaker of mass 0.3kg replaces an existing NRN speaker fixed to an existing housing using the existing fixings.

Considering the low mass of the speaker and the fixings used, the proof loads reacted by the fixings and the stresses in the housing are passed by inspection.

10.2.2 GM/RT 2100 Ultimate Loads

The ultimate loads reacted by the attachments and stresses in the roof are passed by inspection.

10.2.3 GM/RT 2100 Fatigue Loads

The fatigue loads reacted by the bolts and stresses in the roof are passed by inspection.

10.2.4 Natural Frequency

The natural frequency of the loudspeaker is considered to be considerably above the recommended minimum natural frequency of 17Hz and so it is passed by inspection.

10.3 Antenna Installation (MP-C0-00077)

The RETB antenna installation on the type 2 Class 37 is the same as that of the type 1 and so the loads reacted by the fixings and the stresses in the vehicle bonnet due to the GM/RT 2100 proof, ultimate and fatigue accelerations are passed by comparison.

10.4 CDR Installation (MP-C0-00067)

10.4.1. GM/RT 2100 Proof Loadcase

The CDR unit weighs no more than 3.5kg [Ref. 10] and is attached to a carrier plate (Item B) using 2 off M8 fixings. The carrier plate is supported by the adapter bracket (Item A) as shown in drawing no. MP-C0-00067. The adapter bracket is fixed to an existing 2mm thick steel bracket which is fixed to an existing NRN radio housing using 4 off studs. This housing is then attached to a 3mm thick steel mounting bracket using 4 off M6 fixings and is attached to the vehicle structure using 5 off M6 fixings.

The installation was assessed by FEA in Ansys v15 in the following manner:

- The existing shelf was grounded at its edges.
- The joints connecting the brackets to one another were represented by coupling the rotational and translational degrees of freedom at the bolt holes.
- The CDR unit [Ref. 10] and adapter bracket (mass from Solid edge) were represented by a point mass of 3.7kg remotely attached to the two upper fixing holes of the adapter bracket, and to the lower surface of the rectangular cut-out in the bracket, as shown in Figure 10_1.

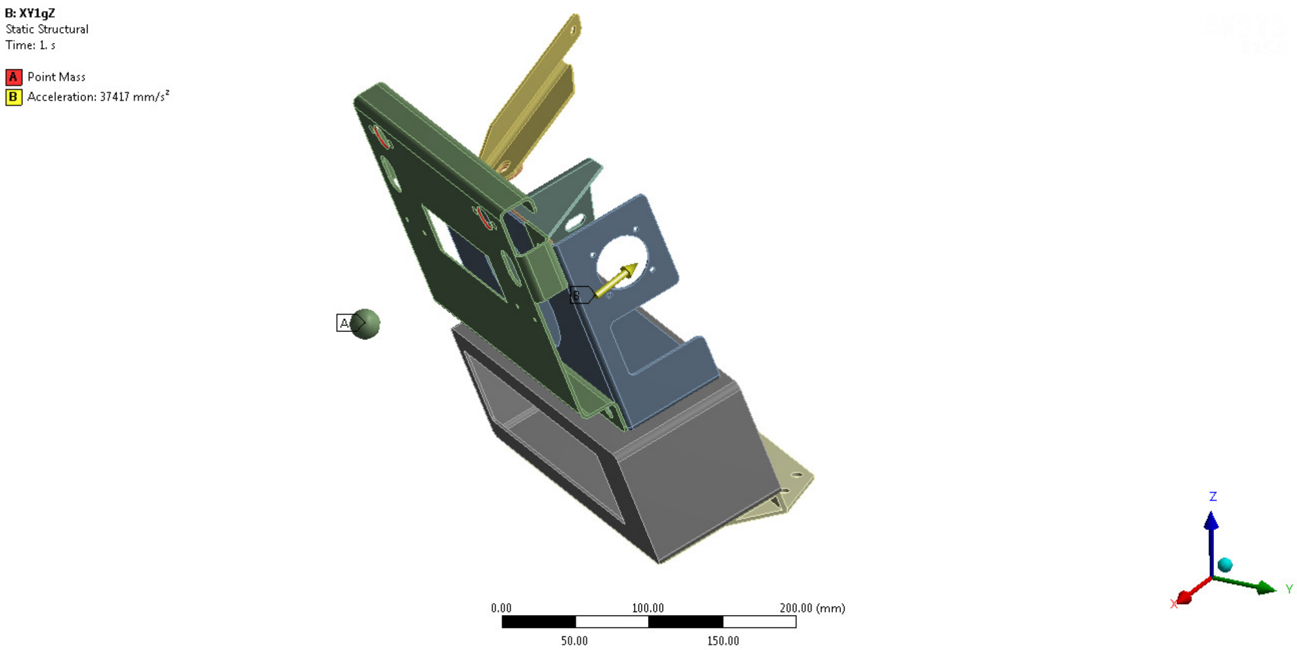
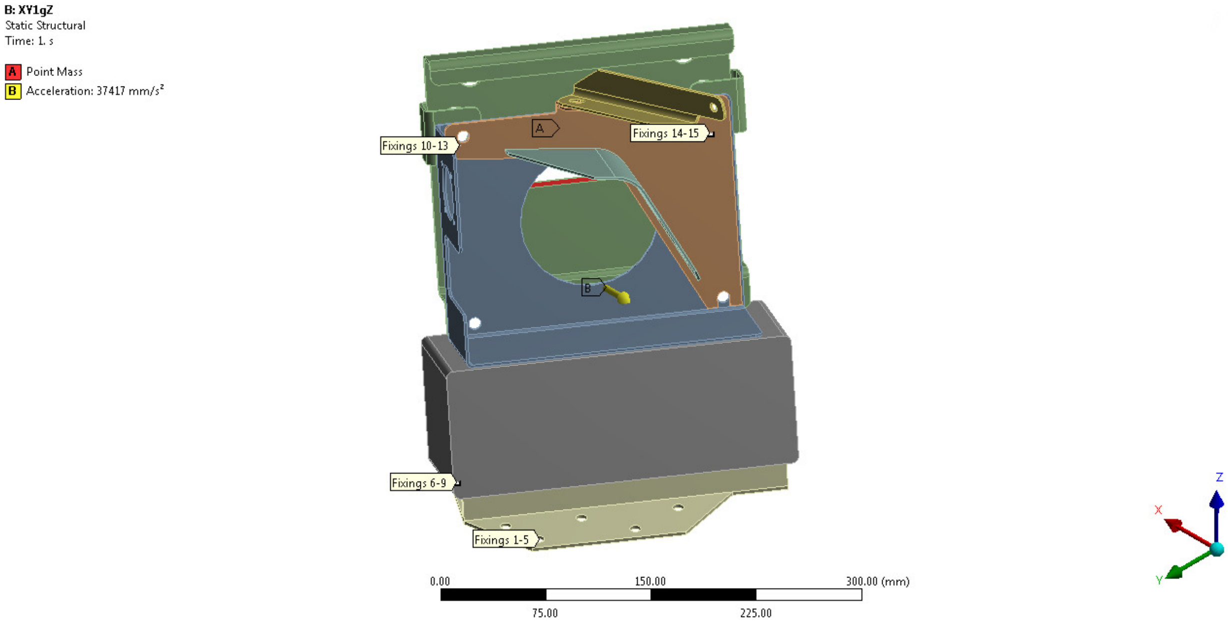


Figure 10_1 - Type 2 CDR Installation Model



Fixing 10_2 - Type 2 CDR Installation, fixing locations

Figures 10_3 - 10_6 show that the maximum stress in the brackets is approximately 177Nmm^{-2}. This is below the maximum allowable proof stress for S275 Steel, with a reserve factor of 1.55 and so is considered to be acceptable.

Conservatively assuming a minimum thickness of 2mm, the maximum stress in the shelf was calculated by multiplying the ratio of t_1^2/t_2^2 to the maximum bracket stress of 115Nmm^{-2} shown in Figure 10_5.

$$\sigma_1 := 115 \cdot N \cdot mm^{-2}$$

$$t_1 := 3 \cdot mm$$

$$t_2 := 2 \cdot mm$$

$$\sigma_2 := \sigma_1 \cdot \left(\frac{t_1^{\ 2}}{t_2^{\ 2}} \right) = 258.75 \cdot N \cdot mm^{-2}$$

The maximum proof stress in the shelf is below the proof strength of steel S275 and so is considered to be acceptable.

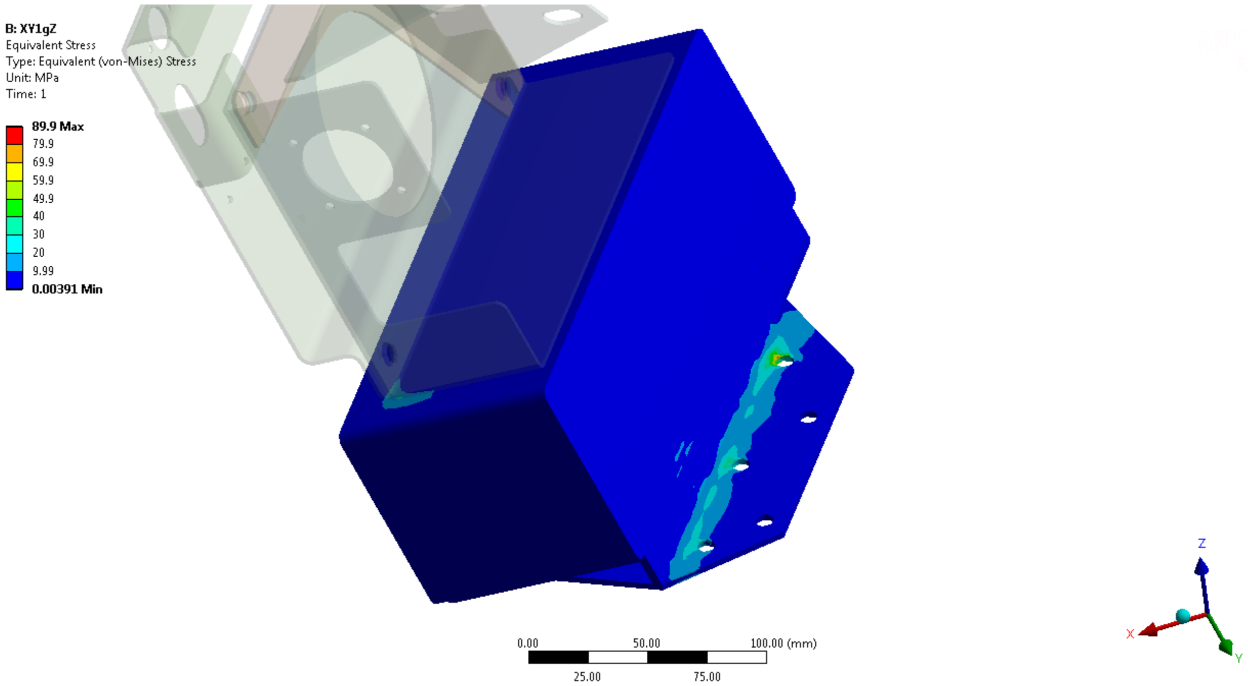


Figure 10_3 - GM/RT 2100 XY1gZ von-Mises stress - Existing equipment stack

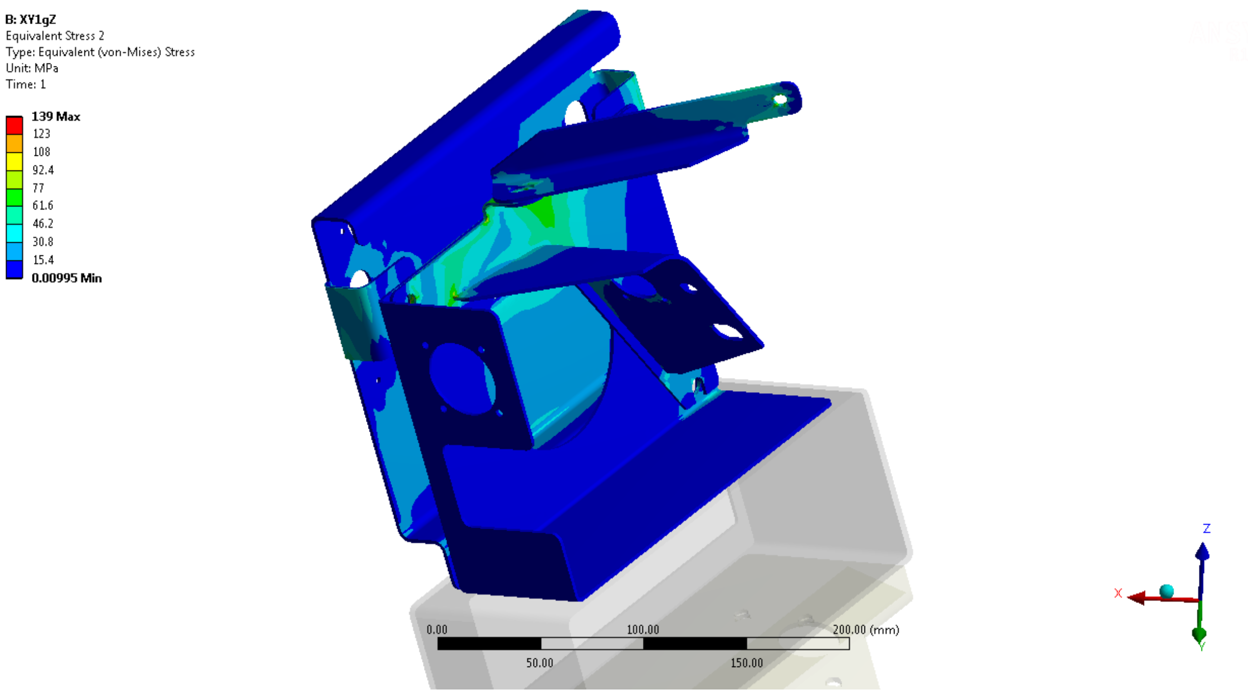


Figure 10_4 - GM/RT 2100 XY1gZ von-Mises stresses - CDR installation and existing bracket

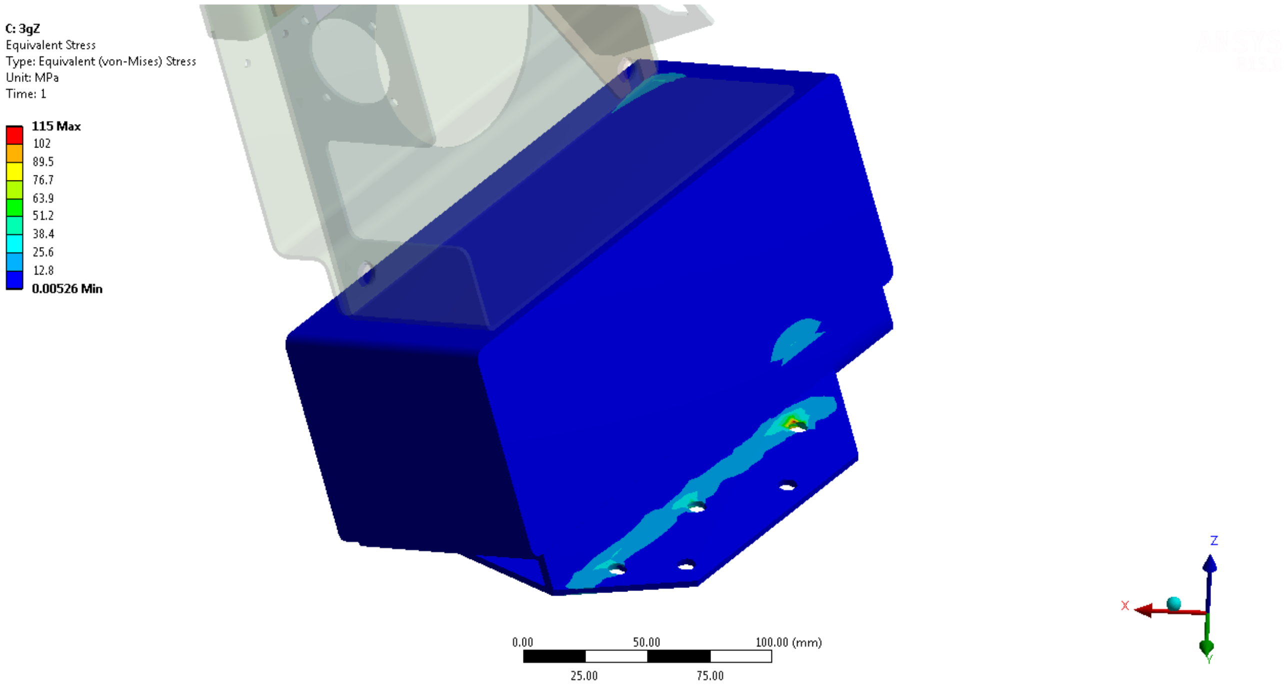


Figure 10_5 - GM/RT 2100 3gZ von-Mises stresses - Existing brackets

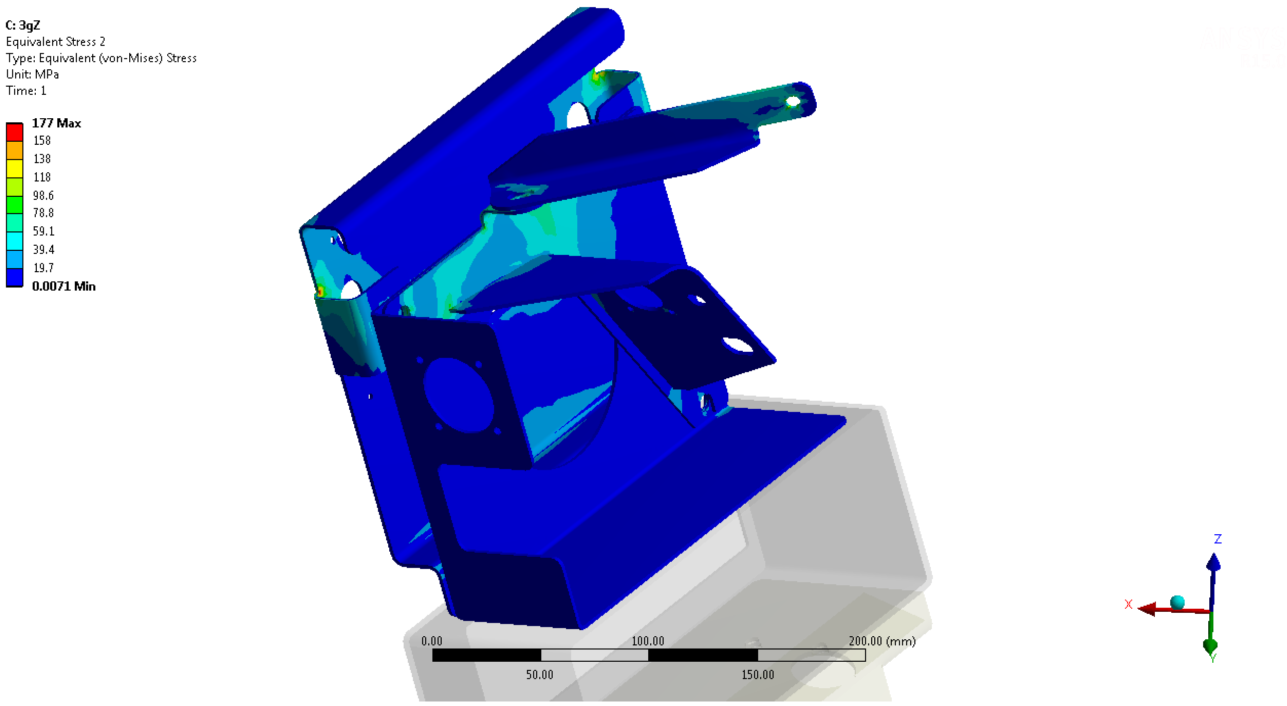


Figure 10_6 - GM/RT 2100 3gZ von-Mises stresses - CDR installation and existing bracket

Table 10_1 - GM/RT 2100 XY1gZ Proof Fixing Loads /N										
Fixing No.	Fixing	X Axis	Y Axis	Z Axis	Tensile	Slip	Tensile Capacity	Slip Capacity	Tensile RF	Slip RF
1	M6	33	-13	29	29	36	10511	1375	Large	38
2	M6	43	46	39	39	63	10511	1375	Large	22
3	M6	29	-26	-7	7	39	10511	1375	Large	35
4	M6	29	24	58	58	37	10511	1375	Large	37
5	M6	92	45	-93	93	102	10511	1375	Large	13.5
6	M6	30	18	-35	35	35	10511	1375	Large	39
7	M6	65	96	-41	41	116	10511	1375	Large	11.9
8	M6	-125	-84	21	21	151	10511	1375	Large	9.1
9	M6	-103	-34	143	143	108	10511	1375	73	12.7
10	M8	39	522	63	63	524	11150	2344	Large	4.5
11	M8	-24	-406	62	62	407	11150	2344	Large	5.8
12	M8	87	-97	-53	53	130	11150	2344	Large	18.0
13	M8	15	3	-14	14	16	11150	2344	Large	150
14	M6	-126	120	7	7	174	10511	1375	Large	8
15	M6	152	17	78	78	153	10511	1375	Large	9.0

Table 10_2 - GM/RT 2100 3gZ Proof Fixing Loads /N										
Fixing No.	Fixing	X Axis	Y Axis	Z Axis	Tensile	Slip	Tensile Capacity	Slip Capacity	Tensile RF	Slip RF
1	M6	32	-89	50	50	95	10511	1375	Large	14
2	M6	43	57	42	42	72	10511	1375	Large	19
3	M6	-47	33	-38	38	57	10511	1375	Large	24
4	M6	8	-7	62	62	11	10511	1375	Large	123
5	M6	-83	-165	-273	273	184	10511	1375	39	7.5
6	M6	75	-11	-38	38	76	10511	1375	Large	18
7	M6	196	59	-48	48	204	10511	1375	Large	6.7
8	M6	-128	39	-177	177	133	10511	1375	59	10.3
9	M6	-105	-156	116	116	188	10511	1375	90	7.3
10	M8	-33	530	64	64	531	11150	2344	Large	4.4
11	M8	-79	-415	61	61	423	11150	2344	Large	5.5
12	M8	145	93	27	27	172	11150	2344	Large	13.6
13	M8	-124	-121	40	40	173	11150	2344	Large	14
14	M6	-110	128	8	8	169	10511	1375	Large	8
15	M6	141	18	86	86	143	10511	1375	Large	9.6

As shown in Tables 10_1 and 10_2 the slip and tensile loads reacted by the fixings are below their respective capacities and so are considered to be acceptable.

10.4.2 GM/RT 2100 Ultimate Loadcase

As the ratio of allowable ultimate to proof stress is larger than the ratio of ultimate to proof load factors, the ultimate stresses in the CDR installation are passed by comparison.

10.4.3 GM/RT 2100 Fatigue Loadcase

As shown in Figures 10_7- 10_12, the maximum fatigue stress in the installation due to the GM/RT 2100 fatigue accelerations is approximately 48Nmm^{-2}. This stress is at a bolt hole as shown in Figure 10_8.

The fatigue stress of 48Nmm^{-2} is below the factored allowable fatigue stress of 63.7Nmm^{-2} at a bolt hole (see Section 9.4.3) and so the Miner's damage summation is considered to be acceptable.

The stress in the FEA plots required to cause a damage of 0.33 at a Class W region is approximately 12Nmm^{-2}. This is calculated below, using the ratio of the weld throat area for a single fillet weld:

$$\text{damage} := \left[\frac{11.8\cdot N\cdot mm^{-2}\cdot\left(\sqrt{2}\right)}{21\cdot N\cdot mm^{-2}}\right]^{(3+2)} = 0.317$$

As shown in Figure 10_12, the maximum fatigue stress at a weld region is approximately 14.5Nmm^{-2} which is above the 0.33 damage stress for a Class W region. However the maximum fatigue stresses at the same region due to 0.3gX and 0.4gY are 5.7Nmm^{-2} and 3.4Nmm^{-2} respectively (Figures 10_10 & 10_11). As shown below, the total damage due to X,Y & Z fatigue accelerations at this location is 0.9 and so the Miner's damage summation is considered to be acceptable.

$$\text{damage}_x := \left[\frac{5.7\cdot N\cdot mm^{-2}\cdot\left(\sqrt{2}\right)}{21\cdot N\cdot mm^{-2}}\right]^{(3+2)} = 8.334\times 10^{-3}$$

$$\text{damage}_y := \left[\frac{3.4\cdot N\cdot mm^{-2}\cdot\left(\sqrt{2}\right)}{21\cdot N\cdot mm^{-2}}\right]^{(3+2)} = 6.293\times 10^{-4}$$

$$\text{damage}_z := \left[\frac{14.5\cdot N\cdot mm^{-2}\cdot\left(\sqrt{2}\right)}{21\cdot N\cdot mm^{-2}}\right]^{(3+2)} = 0.888$$

$$\text{damage}_{total} := \text{damage}_x + \text{damage}_y + \text{damage}_z = 0.897$$

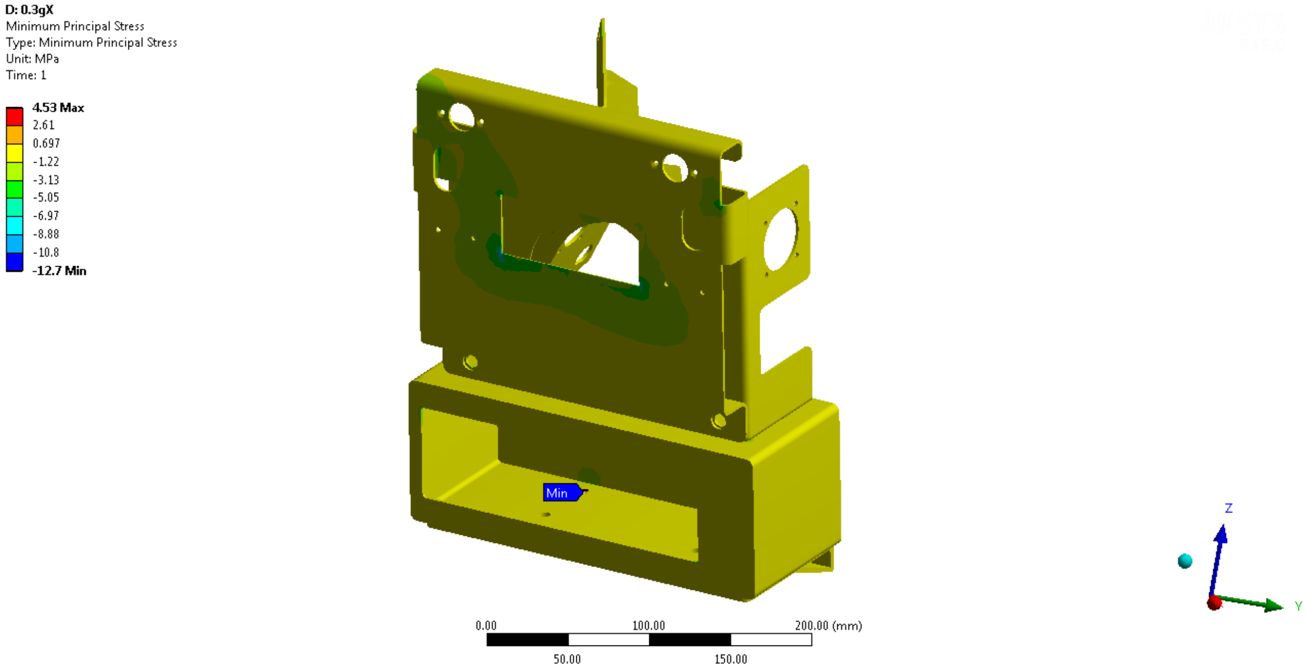


Figure 10_7 - GM/RT 2100 0.3gX Principal stress range - CDR type 2 installation

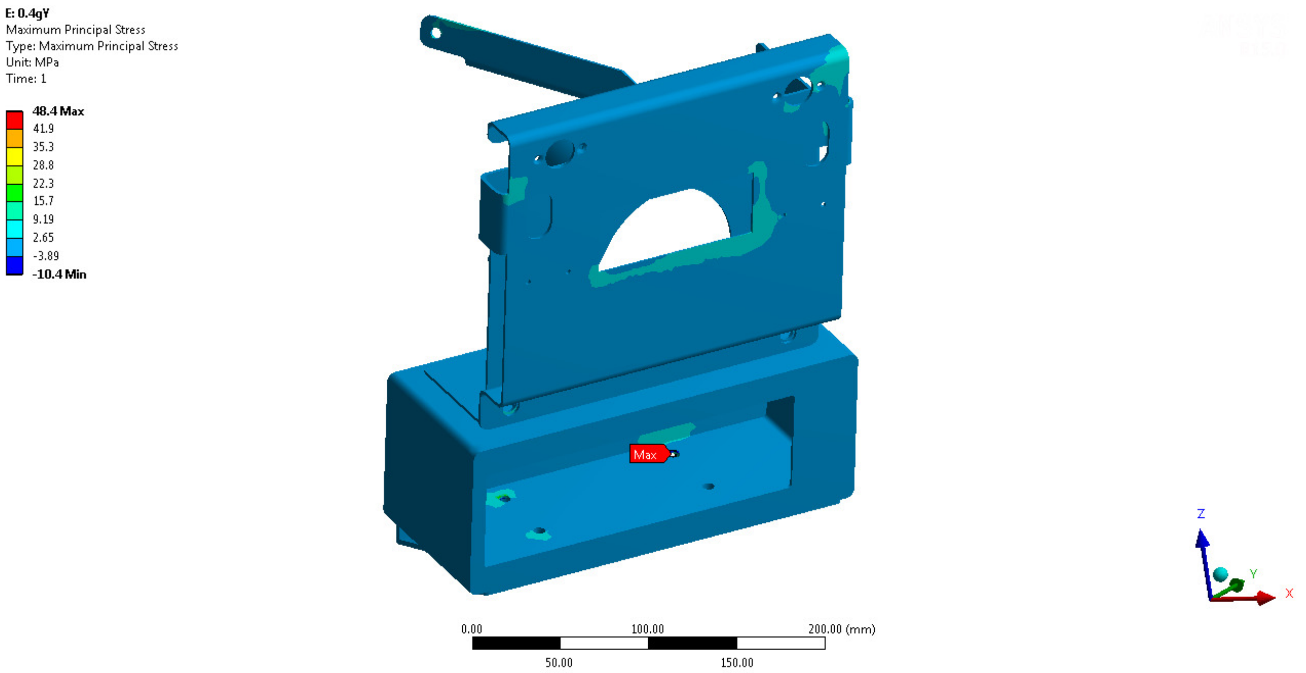


Figure 10_8 - GM/RT 2100 0.4gY Principal stress range - CDR type 2 installation

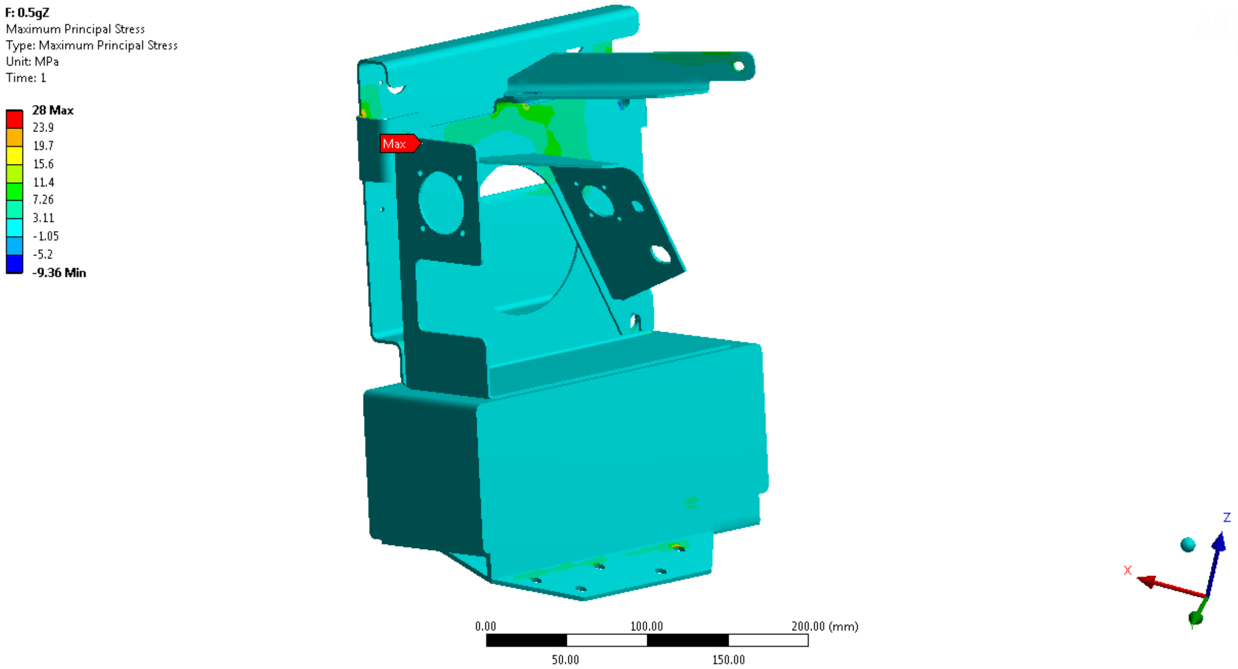


Figure 10_9 - GM/RT 2100 0.5gZ Principal stress range - CDR type 2 installation

Figure 10_10 - GM/RT 2100 0.3gX Principal stress range - CDR type 2 installation, weld region

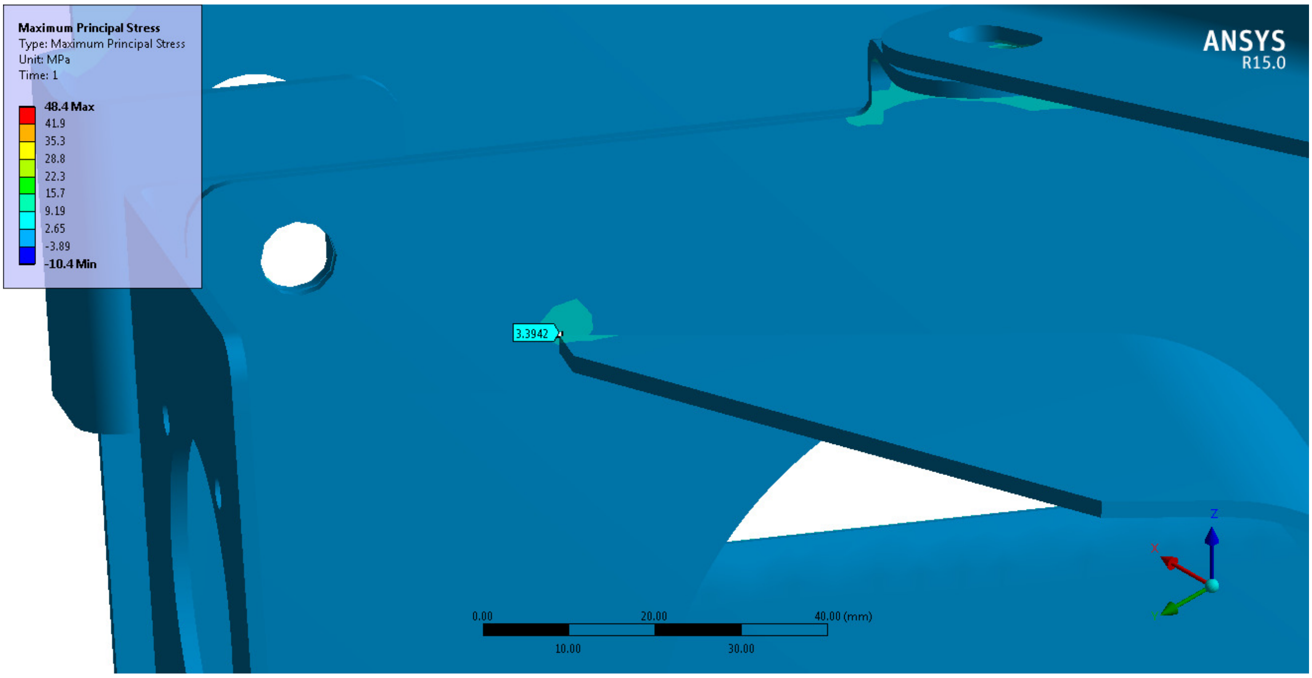


Figure 10_11 - GM/RT 2100 0.4gY Principal stress range - CDR type 2 installation, weld region

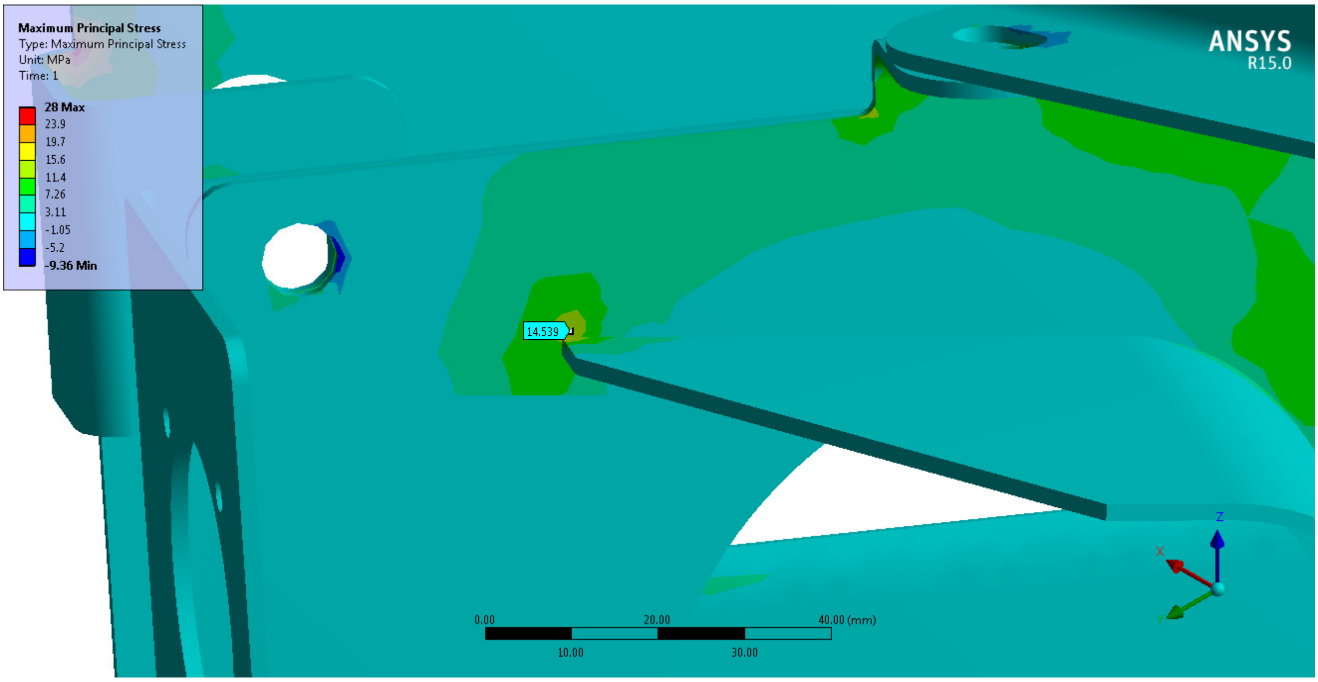


Figure 10_12 - GM/RT 2100 0.5gZ Principal stress range - CDR type 2 installation, weld region

10.4.4 GM/RT 2100 Natural Frequency

The natural frequency of the CDR type 2 installation is approximately 30Hz as shown in Figure 10_13. This is above the minimum recommended natural frequency of 17Hz and so is considered to be acceptable.

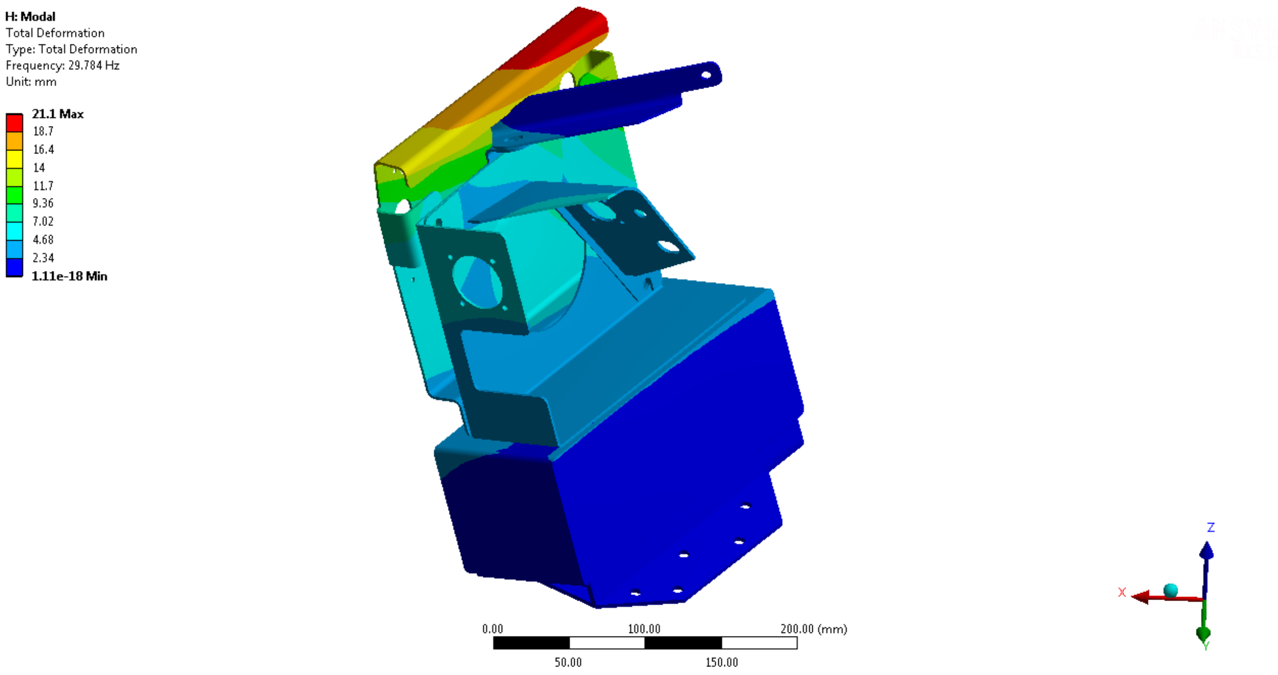


Figure 10_13 - Modal analysis

10.5 Handset Installation (MP-C0-00068)

10.5.1 GM/RT 2100 Proof Loads

The handset is attached directly to the cab corner pillar using 2 off M5 fixings into Euroserts. Considering the low mass of the handset and the method of attachment, the loads reacted by the fixings and the stresses in the pillar due to the handset inertial loads are passed by inspection.

10.5.2 GM/RT 2100 Ultimate Loads

The ultimate loads reacted by the attachments and the stresses in the vehicle structure are passed by inspection.

10.5.3 GM/RT 2100 Fatigue Loads

The fatigue loads reacted by the fixings and the stresses in the vehicle structure are passed by inspection.

10.5.4 Natural Frequency

The natural frequency of the handset is passed by inspection.

10.5.4 Handset Pull-off Load

The loads reacted by the M5 fixings and the stresses in the vehicle structure due to pull-off loads by the operator are passed by inspection.

11. Conclusions

This calculation demonstrates that the Class 37 RETB equipment installations meet the inertial requirements of GM/RT2100 Issue 5 Section 3.2.

12. Appendices

The following inertia loads are applied from GM/RT2100 Issue 5

Longitudinal acceleration,
$axp \equiv 3 \cdot g$

Lateral acceleration, $ayp \equiv 1 \cdot g$

Vertical down acceleration, $azpd \equiv 3 \cdot g$

Vertical up acceleration, $azpu \equiv 1 \cdot g$

With the following load factors

Proof factor, $PF \equiv 1.15$

Ultimate factor, $UF \equiv 1.5$

The following fatigue (ranges) are applied from GM/RT2100 Issue 5

$axf \equiv 0.3 \cdot g$

$ayf \equiv 0.4 \cdot g$

$azf \equiv 0.5 \cdot g$

Horizontal components about zero g mean, vertical about 1g mean. Calculate each case individually and ensure Miner's rule sum of damages < 1.

Bracket Fatigue Stresses

Equipment and mountings shall have a fatigue life of not less than 10^7 cycles with a probability of failure of not more than 2.5%, when subjected to the fatigue loads specified below. Normally each load case shall be considered as acting separately and the damage from individual cases shall be summed [using Miner's damage summation]

Table A.1 - GM/RT2100 Fatigue Loadcases (L)	
X	+/- 0.15g
Y	+/- 0.2g
Z	+/- 0.25g

BS 7608 defines the allowable fatigue stresses at 10^7 cycles at various feature classifications (for mean minus two standard deviation 10^7 cycles); these are shown in Table A.2.

Table A.2 - BS7608 Fatigue Classifications				
Feature type	Classification	Sr (Nmm^-2)	m	Design Stress Area (BS 7608)
Worst case weld	W1	21	3	Effective weld throat
Double fillet weld	F2	35	3	Plain material
Full Penetration weld	F	40	3	Plain material
Bolted Joint	C	78	3.5	Away from the hole stress concentration
Plain material	C	78	3.5	Including any stress concentration

The damage is calculated from the following:

$(n/1E7)*(S/S_r)^m=1$ for $S \geq S_r$

$(n/1E7)*(S/S_r)^{m+2}=1$ for $S < S_r$

Where S = predicted stress range

m = slope of the S-N curve

Bolt fatigue

In fatigue the axial bolt stress range is compared against the BS7608 maximum allowable value for mean minus two standard deviation data:

$$\sigma_a / UTS = (400 / N)^{1/3}$$

Where σ_a is the allowable stress range. Therefore for $2x10^6$ cycles and above

$$\sigma_a / UTS = 0.06$$

The UTS of a grade 8.8 bolt is $800Nmm^{-2}$, therefore

$$\sigma_a := 48 \cdot N \cdot mm^{-2}$$

For an M10 bolt the allowable fatigue load is:

$$csa_{M10} := 58 \cdot mm^2$$

$$R_{a.M10.fat} := \sigma_a \cdot csa_{M10} = 2.784 \times 10^3 N$$

For an M8 bolt the allowable fatigue load is:

$$csa_{M8} \equiv 36.6 \cdot mm^2$$

$$R_{a.M8.fat} := \sigma_a \cdot csa_{M8} = 1.757 \times 10^3 N$$

For an M6 bolt the allowable fatigue load is:

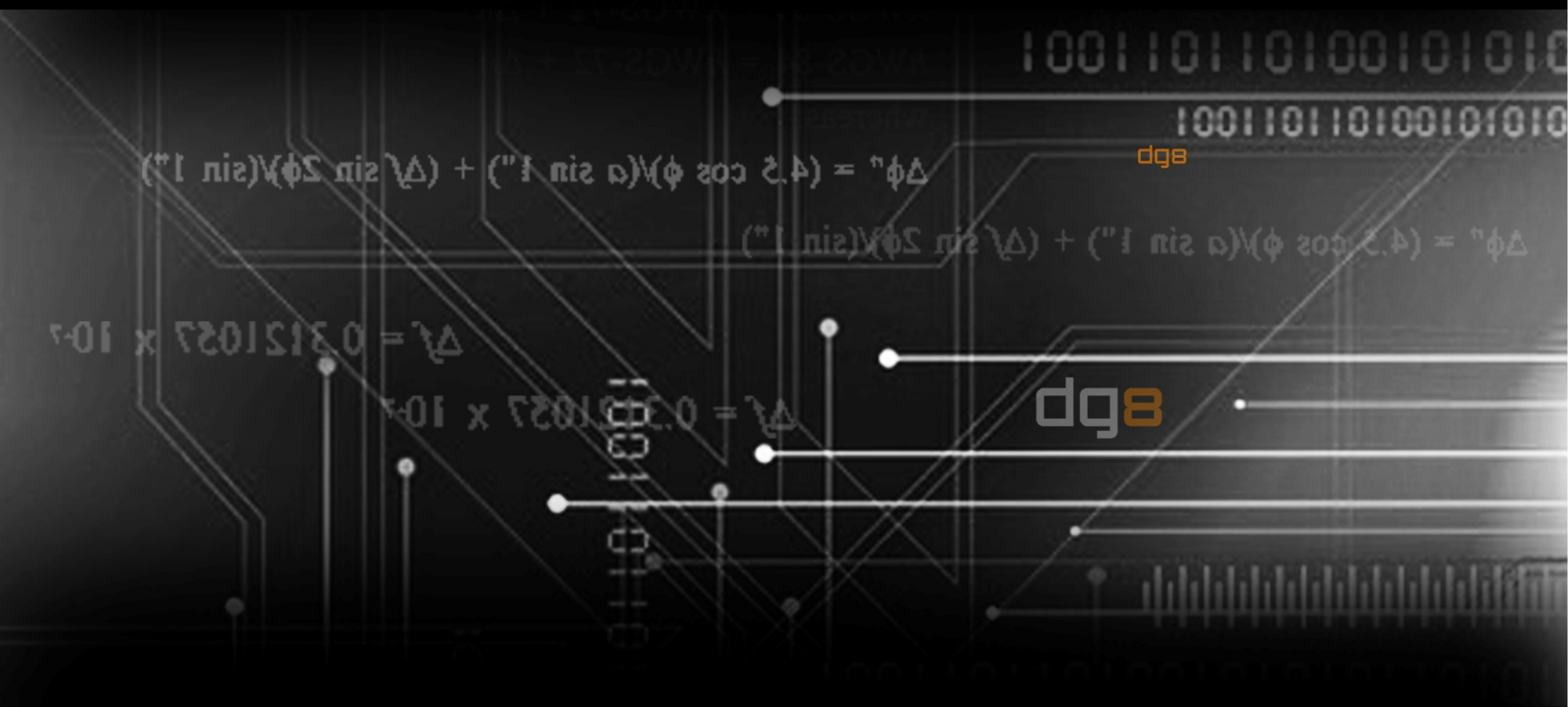
$$csa_{M6} := 20.1 \cdot mm^2$$

$$R_{a.M6.fat} := \sigma_a \cdot csa_{M6} = 964.8 N$$

For an M5 bolt the allowable fatigue load is:

$$csa_{M5} := 14.2 \cdot mm^2$$

$$R_{a.M5.fat} := \sigma_a \cdot csa_{M5} = 681.6 N$$


dg8
dg8