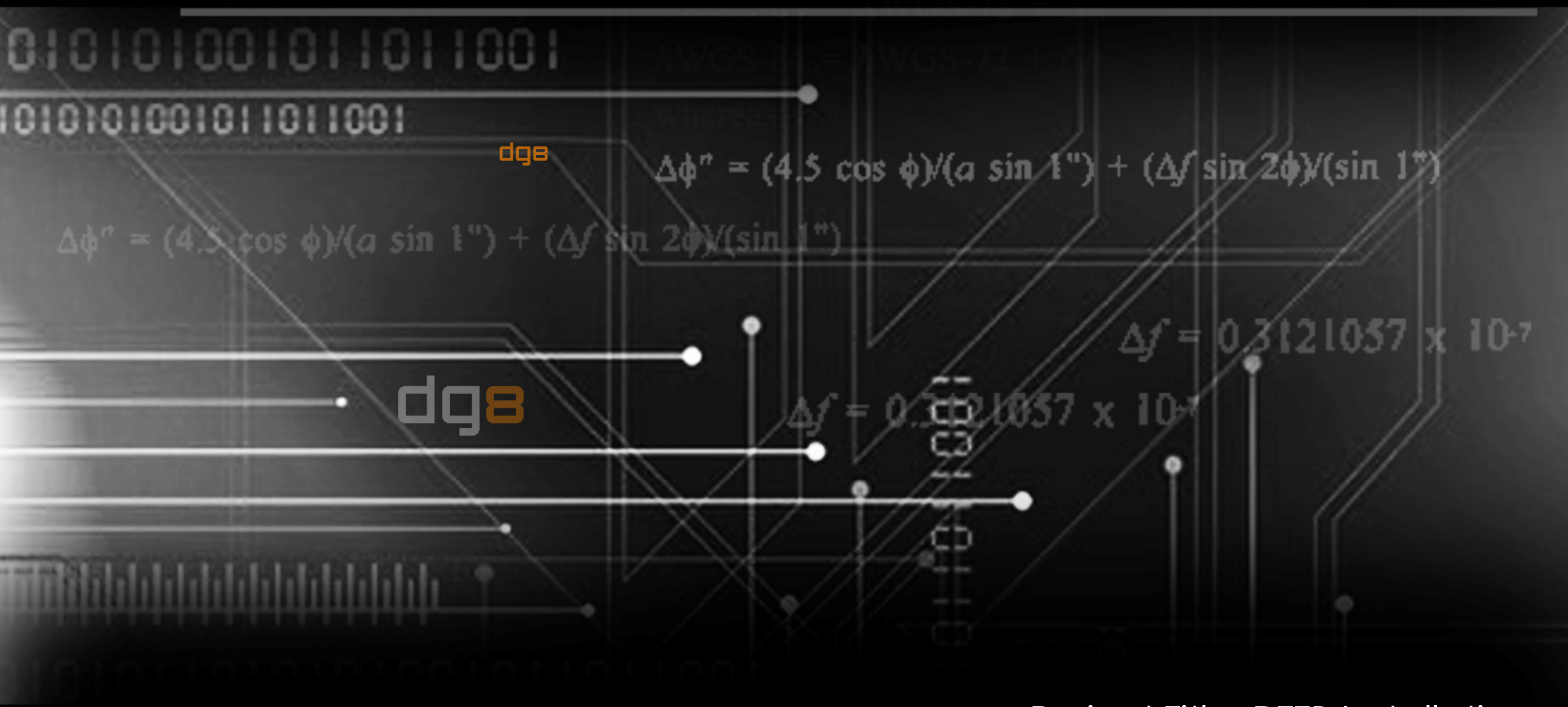
Structural Calculations



Project Title: RETB Installation

Project Number: MP/13/002

Calculation Title: Class 47 RETB Installation

Calculation Number: DG8-CALC-00327

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1. Summary

This calculation demonstrates that the Class 47 RETB installations meet the structural requirements of GM/RT 2100 Issue 5: Section 3.2.

2. Introduction

The RETB installations on West Coast Railway's Class 47 vehicles comprise a roof-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	LP3 Antenna Series Data Sheet, Sigma Antennas
9	Interface Control Document, ICD-1051-01, Comms Design

4. Drawings

Drawing	Number	Title	Issue
1	MP-C0-00047	General Arrangement Class 47 RETB	P1
2	MP-C0-00048	Roof Antennas Installation Class 47 RETB	P1
3	MP-C0-00054	CDR, Handset & Speaker Installation Class 47 RETB	P1
4	MP-C0-00055	Junction Box Sub Assembly Class 47 RETB	P1
5	MP-C0-00056	Miscellaneous Details Class 47 RETB	P1
6	MP-C0-00057	Junction Box Installation Class 47 RETB	P1
7	MP-C0-00072	GPS Antenna Details Class 47 RETB	P1
8	MP-C0-00091	Junction Box Support Fabrication Assembly Class 47 RETB	P1
9	MP-C0-00092	Junction Box Cover Assembly & Details Class 47 RETB	P1

5. Nomenclature

A	Area	mm^2
BF	Bolt factor	
CofG	Centre of gravity	mm
D	Diameter	mm
E	Young's modulus of elasticity	N/mm^2
F	Applied Force	N
g	Gravitational constant, 9.81	m/s^2
I	Second moment of area	mm^4
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/mm^2
σ_m	Material tensile strength	N/mm^2
RF	Reserve factor	
σ	Applied axial or bending stress	N/mm^2
σ_a	Allowable axial or bending Stress	N/mm^2
τ	Applied shear stress	N/mm^2
τ_a	Allowable shear stress	N/mm^2
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

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

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

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

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:

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

4. Determine the slip capacity of a Grade 8.8 M6 EZP bolt and plain washer torqued to 11Nm.

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)

6. An M6 Eurosert can withstand a tensile load of 15.8kN, this is larger than the M6 fixing with a nut.

7. Determine the slip capacity of a Grade 8.8 M5 EZP bolt and plain washer torqued to 5Nm (Antenna Installation)

Bolt size	M5
Washer Type	Plain
Joint Type	Threaded
Torque (Nm)	5

$JointStiffness := \Phi_{steel}$ $\quad$ $Friction := \mu$ $\quad$ $ThreadDepth := 6 \cdot mm$

$HelicoilMat :=$ "N/A" $\quad$ $ThreadMat := \tau_{p.S275}$

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

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)
5000	750	6427	13964	N/A	5535	5535

(JT Torque Si JointStiffness Friction ThreadDepth HelicoilMat ThreadMat WT)

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 material is 34/20 Steel

9. Calculations

9.1 Junction Box Installation (MP-C0-00057)

9.1.1 GM/RT 2100 Proof Loadcase

The junction box is mounted to the bracket using 4 off M5 fixings. The junction box weighs approximately 2kg. Considering the low mass of the box and the method of attachment, the loads in the fixings and the stresses in the box are passed by inspection. The stresses in and attachment of the cover are passed by inspection.

The junction box bracket is mounted between two partitions. An ANSYSv15 model of the bracket was completed. This is shown in Figure 9_1. Figures 9_2 and 9_3 show the stresses in the bracket due to the 3gX,1gY,1gZ and 3gZ inertial loadcases. The stresses are within the allowable limit of S275, with a reserve factor above 2.

The maximum shear and tensile loads in the connections to the vehicle are approximately 70N and 110N respectively. These are below the allowable limits calculated in Section 6.

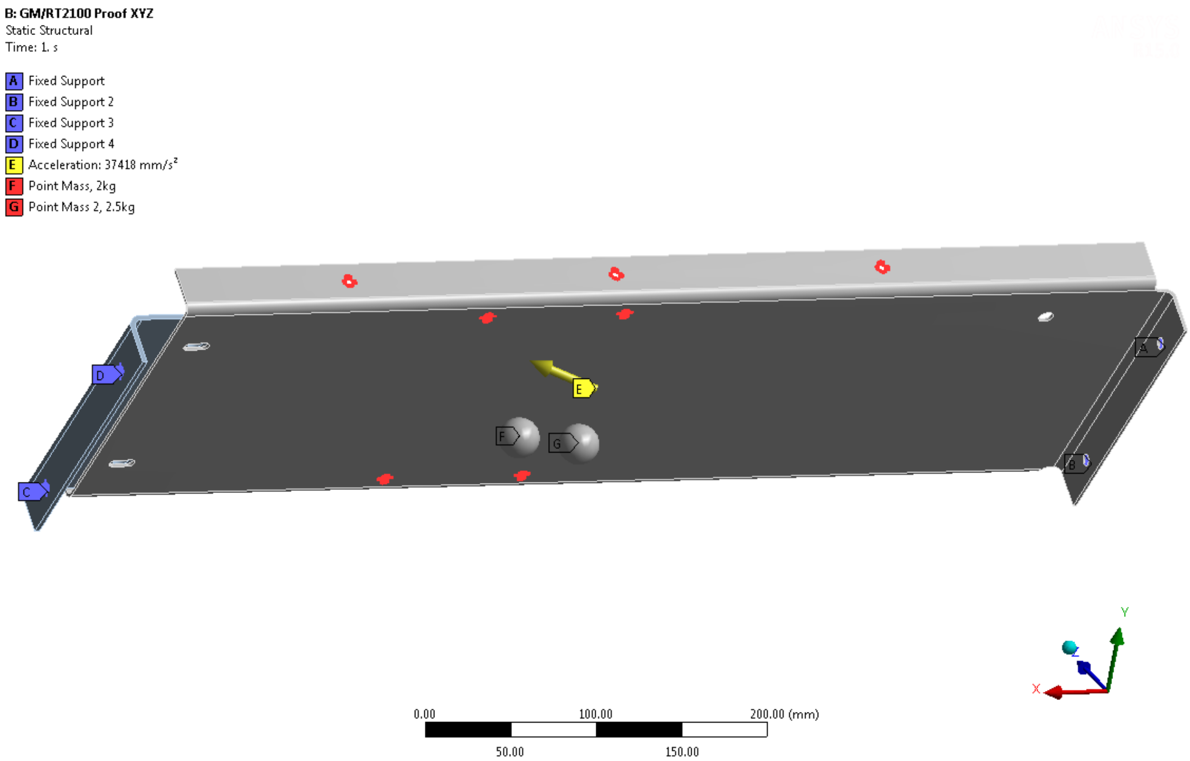


Figure 9_1 : Junction Box Bracket Model

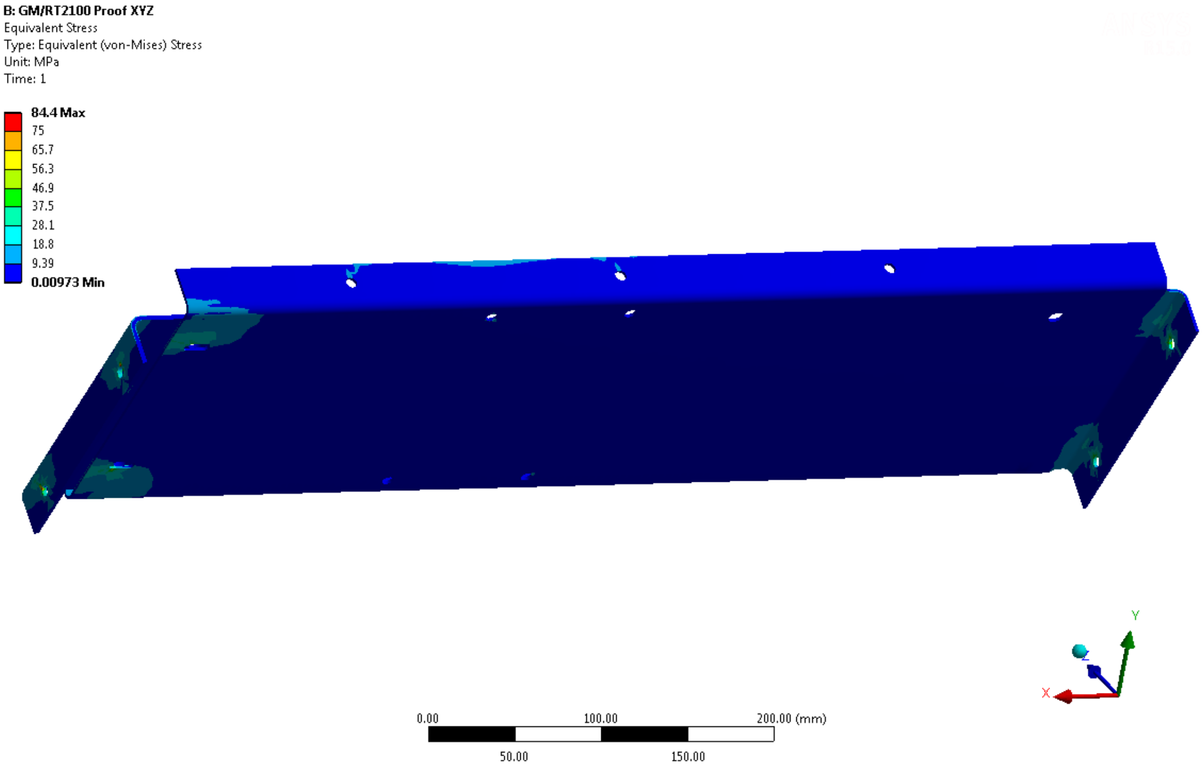


Figure 9_2 : GM/RT2100 Proof 3gX,1gY,1gZ, von-Mises stresses

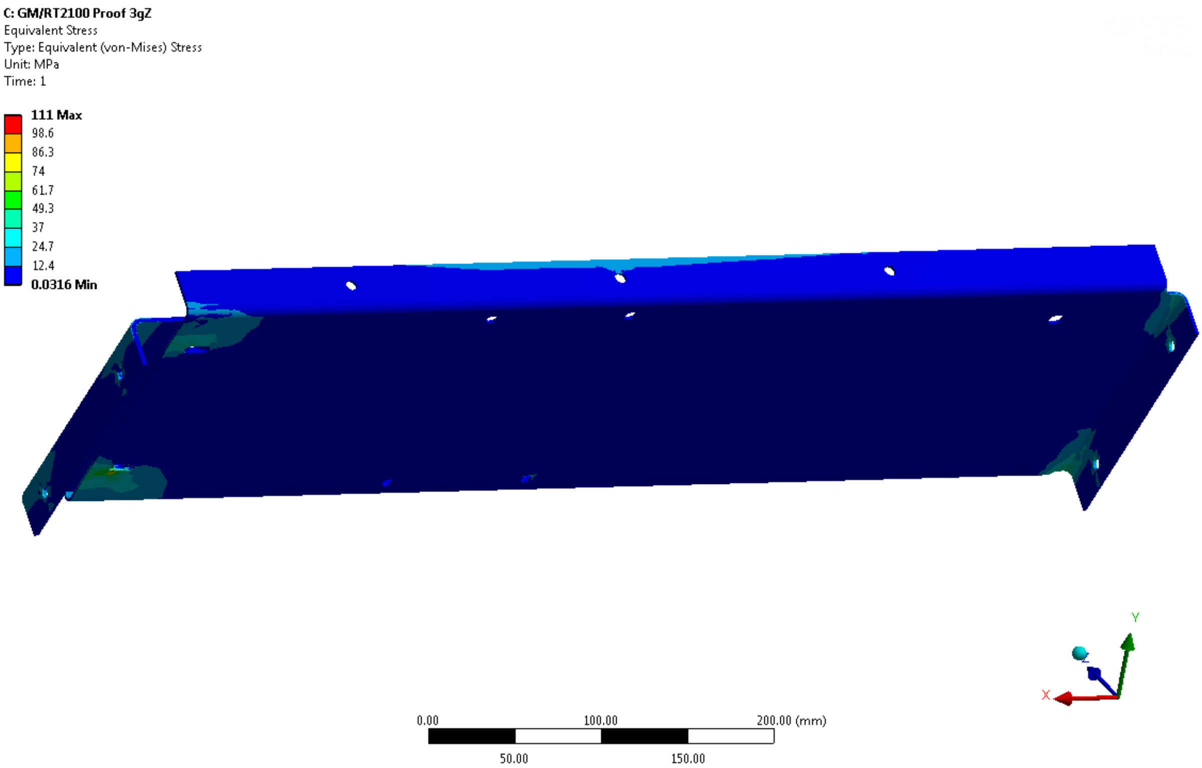


Figure 9_3 : GM/RT2100 Proof 3gZ, von-Mises stresses

9.1.2 GM/RT 2100 Ultimate Loadcase

The ultimate loads reacted by the fixings and the ultimate stresses in the assembly are passed by comparison with the low proof loads.

9.1.3 GM/RT 2100 Fatigue Loadcase

The method of fatigue assessment is described in the Appendix. Assuming that a positive to negative fatigue range can be approximated by twice the positive acceleration, the ratio of proof to fatigue range accelerations are.

$$\text{ratio}_x := \frac{\text{axf}}{\text{PF}\cdot\text{axp}} = 8.696\cdot\%$$

$$\text{ratio}_y := \frac{\text{ayf}}{\text{PF}\cdot\text{ayp}} = 34.783\cdot\%$$

$$\text{ratio}_{zd} := \frac{\text{azf}}{\text{PF}\cdot\text{azpd}} = 14.493\cdot\%$$

Ratioing the maximum proof stress in the mounting plate by the maximum ratio (conservative assessment):

$$\sigma_{\text{platefat}} := \text{ratio}_y\cdot 111\cdot\text{N}\cdot\text{mm}^{-2} = 38.6\cdot\text{N}\cdot\text{mm}^{-2}$$

This is significantly lower than the limit of 78N/mm^2 for bolted joints in steel [Ref 3], and so the Miner's damage summation is considered to be acceptable.

The fatigue loads in the bolts are low by inspection. They are passed by comparison with the allowable loads calculated in the Appendix.

9.1.4 GM/RT2100 Natural Frequency

To determine the natural frequency of the assembly, a 1g down static model was completed in ANSYS v15 and then used to create a pre-stressed modal analysis. The lowest natural frequency of the bracket was calculated as approximately 54Hz, this is above the limit of 17Hz and therefore is considered to be acceptable.

9.2 Loudspeaker Installation (MP-C0-00054)

9.2.1 GM/RT 2100 Proof Loads

The speaker is fitted to the NRN cupboard using 4 off M4 fixings.

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

9.2.2 GM/RT 2100 Ultimate Loads

The ultimate loads reacted by the attachments are passed by inspection.

9.2.3 GM/RT 2100 Fatigue Loads

The fatigue loads are passed by inspection.

9.2.4 GM/RT2100 Natural Frequency

The natural frequency of the speaker is passed by inspection.

9.3 Antenna Installation (MP-C0-00048)

The GPS patch antenna (approximately 1kg) is attached to mounting plate MP-C0-00048 Item H using the supplied locknut. The mounting plate is in turn attached to a baseplate using 4 off M5 fixings, which is in turn attached through the cab skin to a backplate using 4 off M5 fixings. Due to the low mass of the antenna, the installation is considered to meet the proof, ultimate, fatigue and natural frequency requirements of GM/RT2100.

The VHF whip antenna (approximately 1kg) is attached to the vehicle using 3 off M5 fixings and replaces the original NRN antenna. Due to its low mass and the number of fixings, the installation is therefore considered to meet the proof, ultimate, fatigue and natural frequency requirements of GM/RT2100.

9.4 CDR Installation (MP-C0-00054)

9.4.1. GM/RT 2100 Proof Loadcase

The CDR unit is mounted to the bracket using 2 off M8 fixings. The loads reacted by the fixings are passed by inspection. The loads in the adaptor bracket are also passed by inspection.

The CDR unit is to be attached to an existing bracket. To determine the stresses in the bracket, an ANSYS v15 finite element analysis was completed, this is shown in Figure 9_4. The CDR unit and adaptor bracket were modelled as a lumped mass at their approximate CofG. The dummy receptacles were also modelled as a lumped mass.

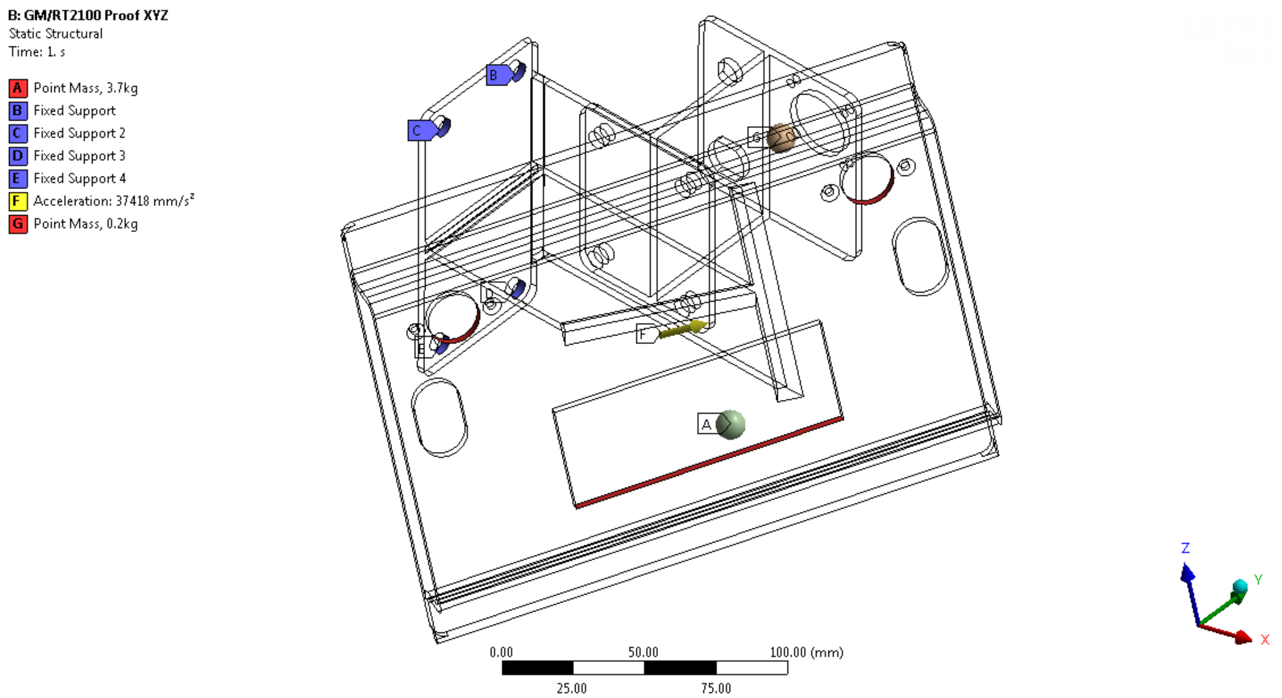


Figure 9_4 - CDR Bracket

Figures 9_5 and 9_6 show the stresses in the CDR bracket due to GM/RT 2100 3gX,1gY,1gZ and 3gZ proof accelerations. The maximum proof stress in the bracket is approximately 200Nmm^{-2}. As this is below the maximum allowable proof stress for steel S275, the stresses in the bracket are considered to be acceptable.

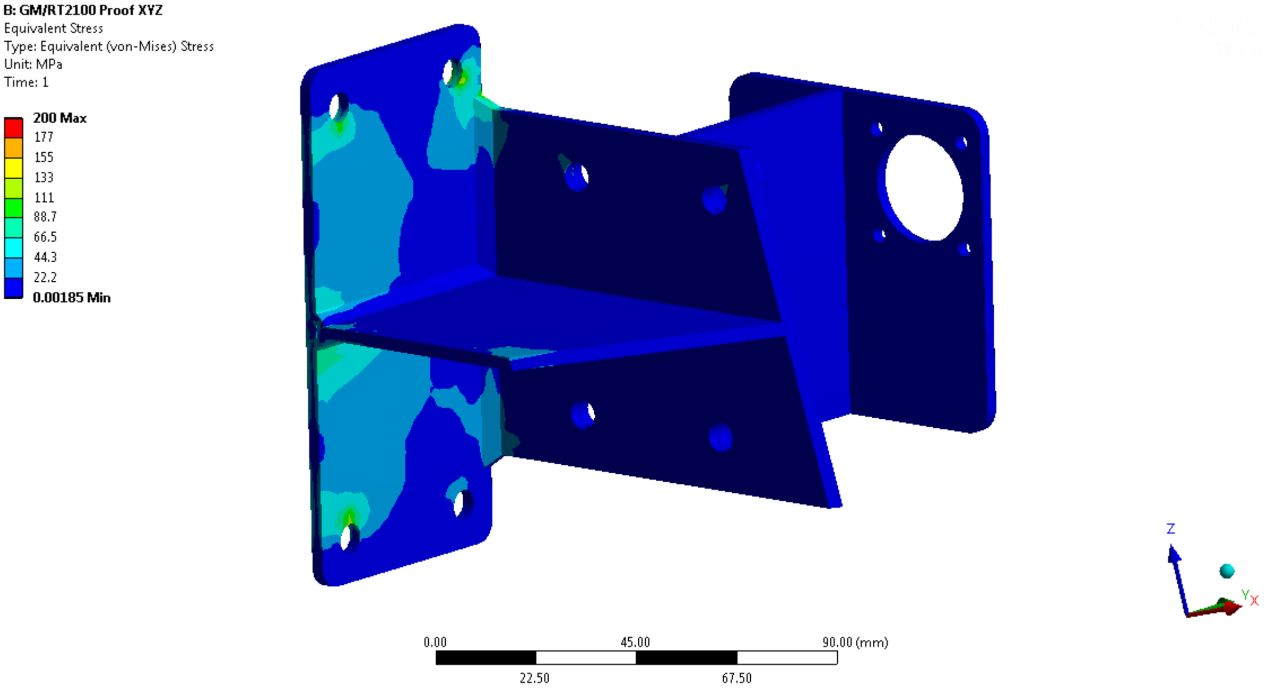


Figure 9_5 - X,Y,1gZ von-Mises Stress - CDR Bracket

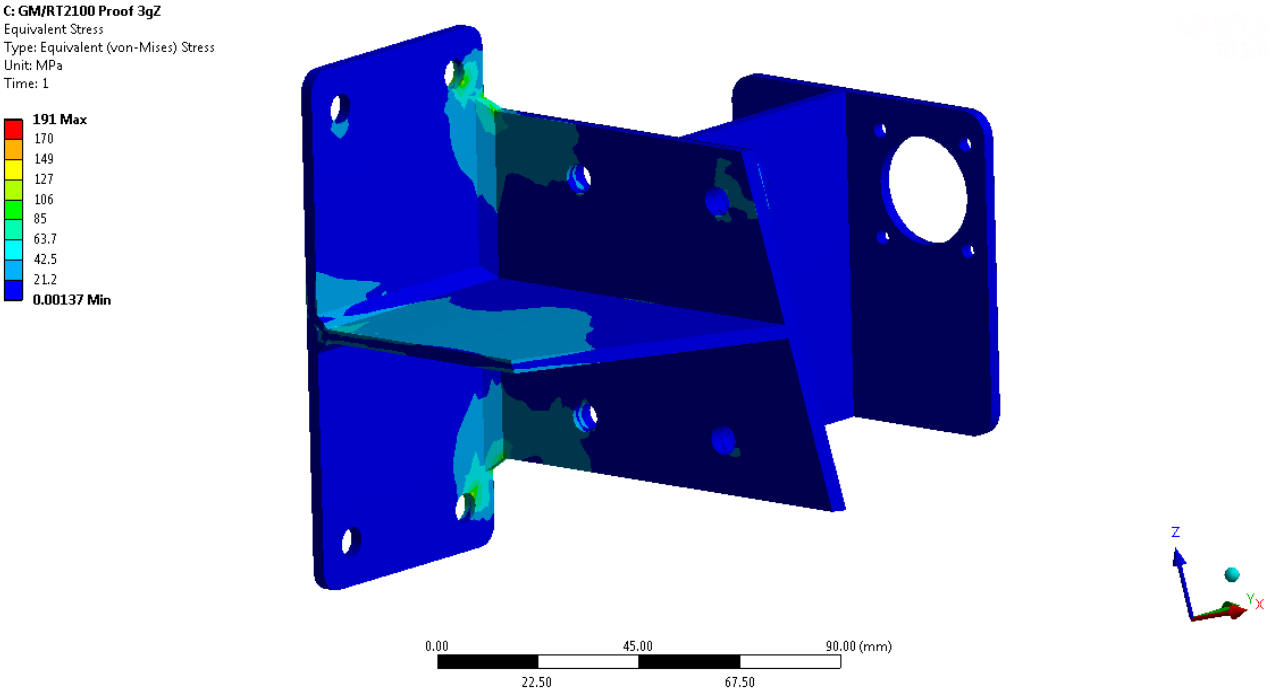


Figure 9_6 - 3gZ von-Mises Stress - CDR Bracket

The maximum slip and tensile loads reacted by the fixings to the vehicle are 120N and 285N. These are below the allowable limit of M6 fixings.

The CDR bracket is mounted to the 2mm thick vehicle skin. A conservative assessment of the local stress in the vehicle is:

$$\sigma_{local} := \frac{3 \cdot 285 \cdot N}{(2 \cdot mm)^2} = 213.75 \cdot N \cdot mm^{-2}$$

Assuming that the vehicle is manufactured from 34/20, and as the above stress is very conservative, it is considered that the stresses in the vehicle are acceptable.

9.4.2 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 assembly are passed by comparison with the proof case.

As the bolt load reserve factors due to proof accelerations are high, the ultimate loads reacted by the CDR brackets are passed by comparison.

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.

Figures 9_7 - 9_9 show the stress ranges for the mounting bracket due to the GM/RT 2100 fatigue accelerations.

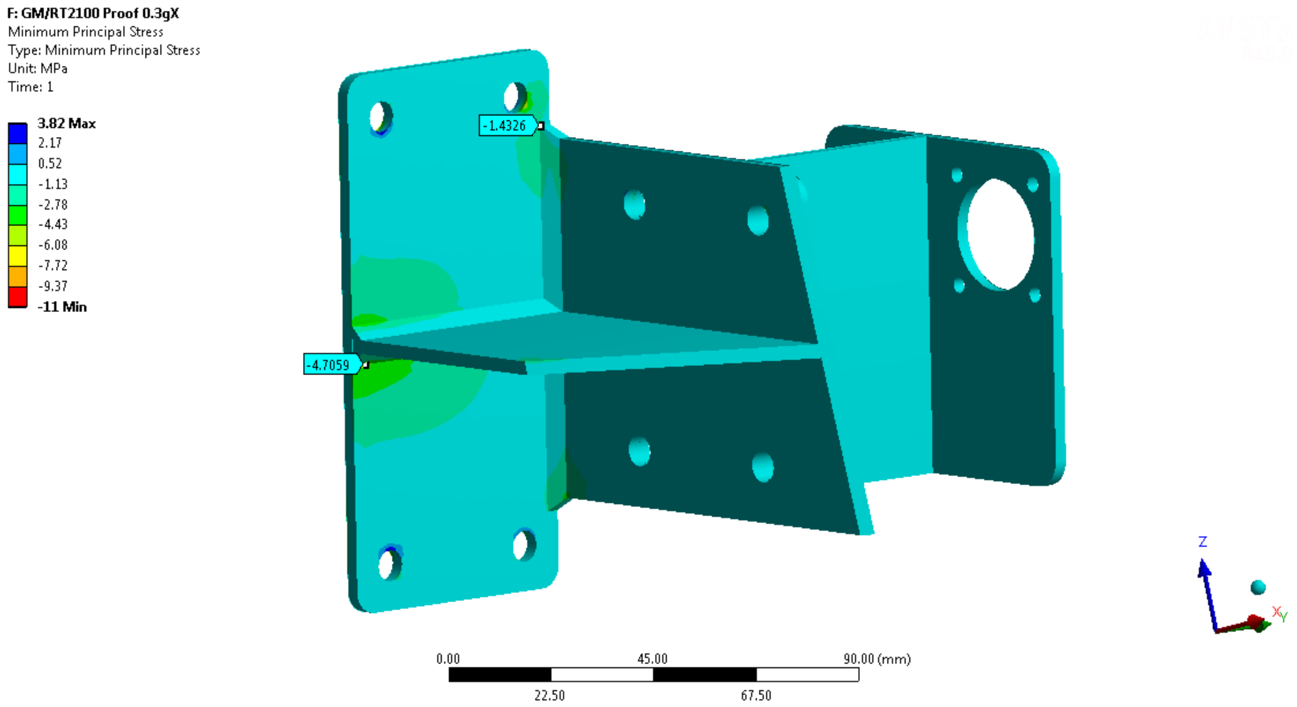


Figure 9_7 - 0.3gX Maximum Principal Stress Range - CDR Bracket

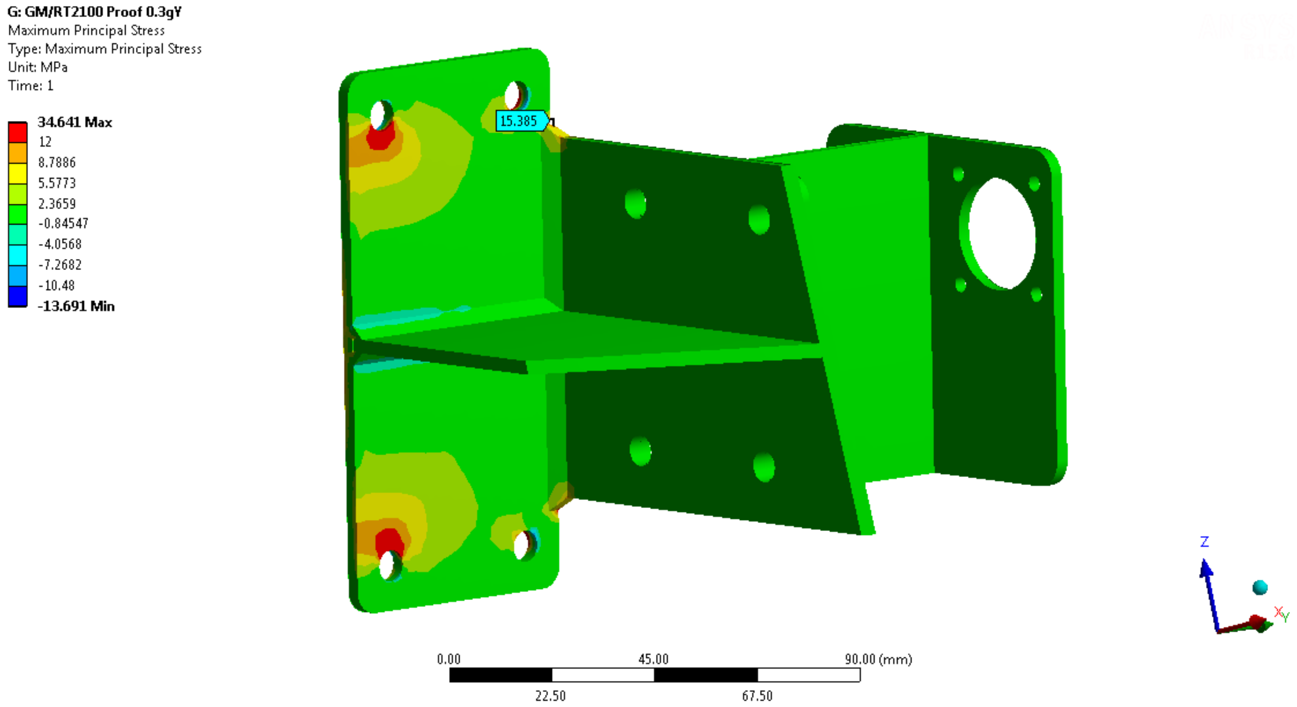


Figure 9_8(a) - 0.4gY Maximum Principal Stress Range - CDR Bracket

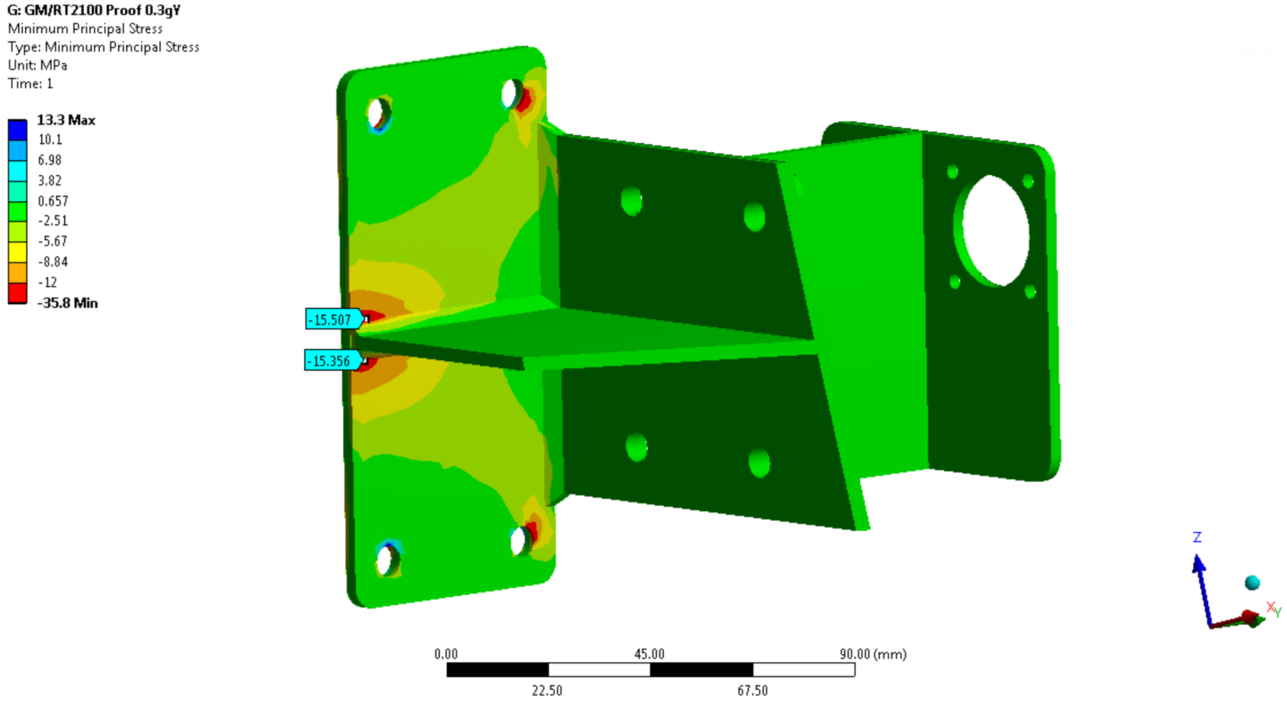


Figure 9_8(b) - 0.4gY Minimum Principal Stress Range - CDR Bracket

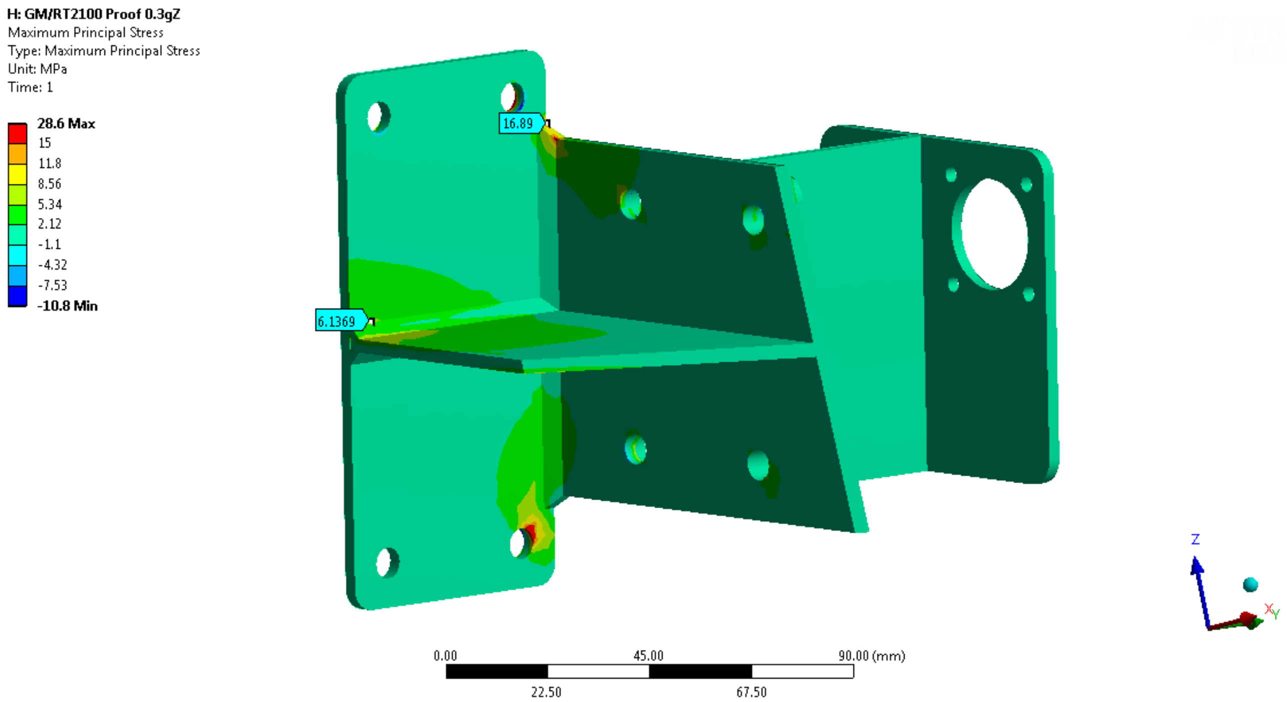


Figure 9_9 - 0.5gZ Maximum Principal Stress Range - CDR Bracket

The maximum fatigue stress is approximately 35Nmm^{-2}. This stress is at a bolt hole, and so is significantly below the maximum allowable fatigue stress of 78Nmm^{-2} for a class C joint, the Miner's damage summation is therefore considered to be acceptable. At the weld, the maximum stresses are identified at the weld foot. The two locations identified in the figures result in the following damages at the (conservative) Class W1 region:

$$\text{damage}_1 := \left(\frac{1.5}{21}\right)^5 + \left(\frac{15.4}{21}\right)^5 + \left(\frac{16.9}{21}\right)^5 = 0.55$$

$$\text{damage}_2 := \left(\frac{4.7}{21}\right)^5 + \left(\frac{15.5}{21}\right)^5 + \left(\frac{6.2}{21}\right)^5 = 0.222$$

The Miner's damage summations are below one and so are considered to be acceptable. The allowable fatigue loads calculated in the Appendix are significantly larger than the experienced fatigue loads, therefore the fatigue of the bolts can be passed by inspection.

9.4.5 GM/RT 2100 Natural Frequency

The natural frequency of the CDR bracket is approximately 40Hz. This is above the minimum recommended frequency of 17Hz and so the natural frequency is considered to be acceptable.

9.5 Handset Installation (MP-C0-00054)

9.5.1 GM/RT 2100 Proof Loads

The handset is attached to its mounting box (MP-C0-00054 Item H) using 2 off proprietary M5 fixings. The mounting box is a welded 2mm thick steel fabrication and is attached to the vehicle using 3 off M5 fixings. Due to the low mass of the complete assembly and the size and number of fixings, the installation is considered to meet the proof, ultimate, fatigue and natural frequency requirements of GM/RT2100.

9.5.2 Handset Pull-off Load

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

10. Conclusions

This calculation demonstrates that the Class 57 RETB equipment and installations meet the inertial requirements of GM/RT2100 Issue 5 Section 3.2.

11. 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:

σ_a / UTS = $(400 / N)^{1/3}$

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

σ_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:

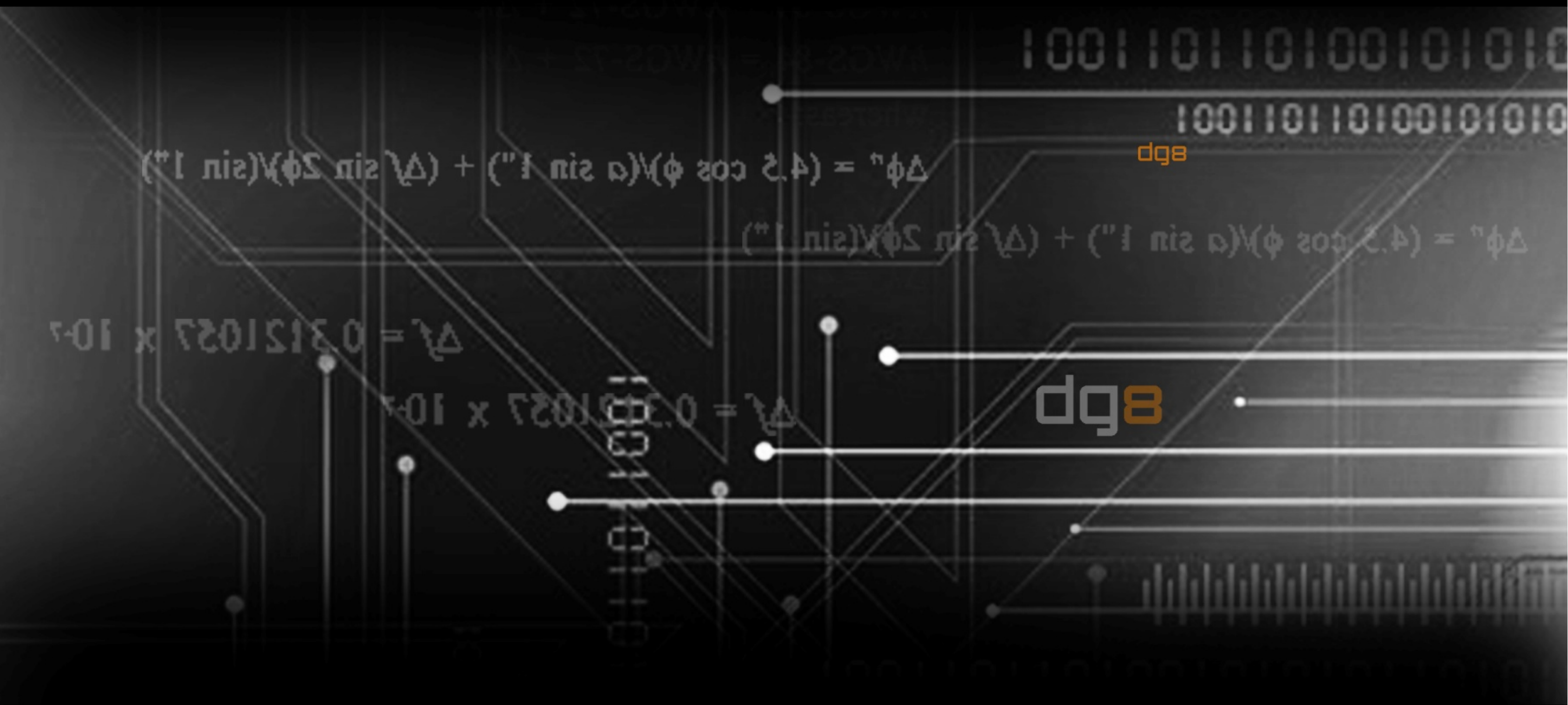
$$csa_{M6} := 20.1 \cdot mm^2$$

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

For an M5 bolt the allowable fatigue load is:

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

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