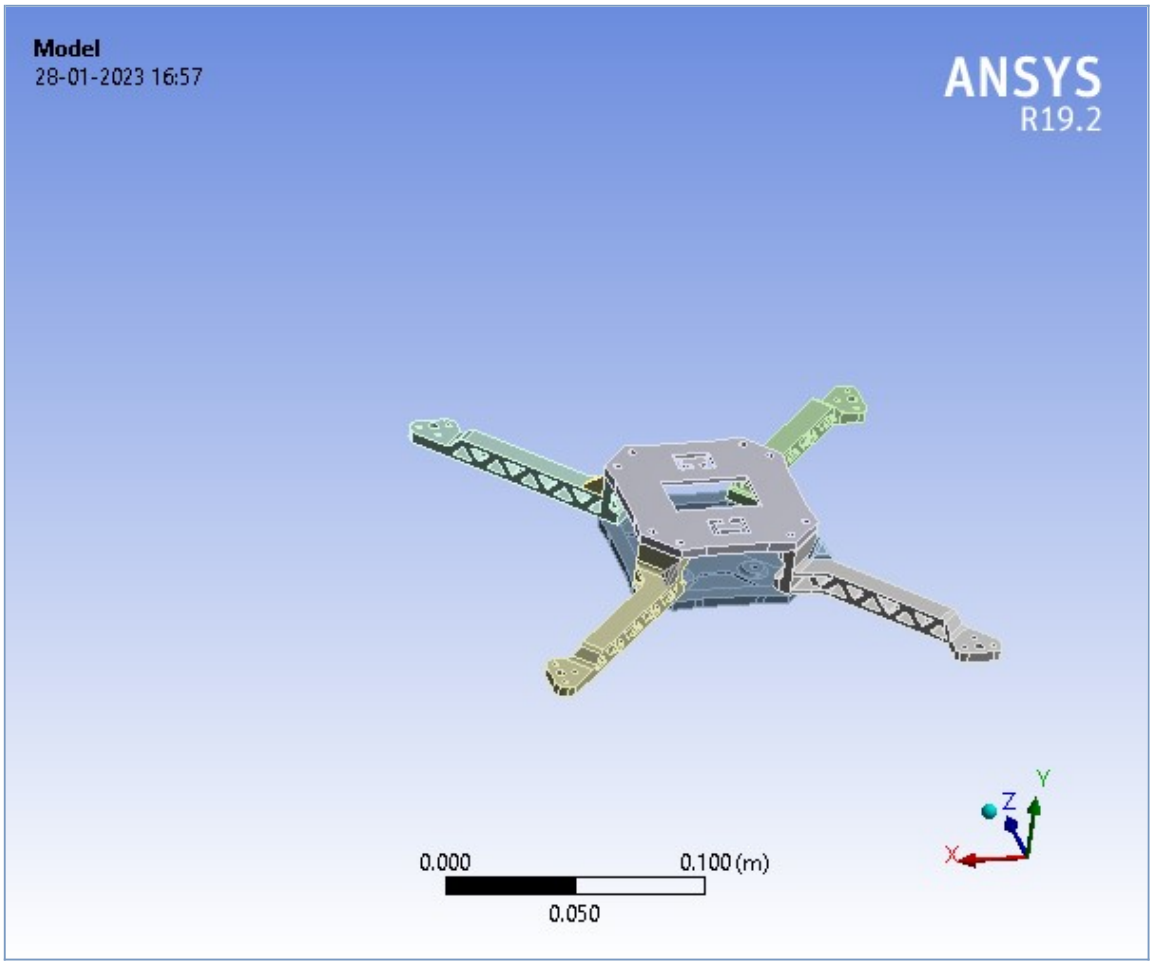
# Project

| | |
|---|---|
| First Saved | Saturday, January 28, 2023 |
| Last Saved | Saturday, January 28, 2023 |
| Product Version | 19.2 Release |
| Save Project Before Solution | No |
| Save Project After Solution | No |



# Contents



# Units

**TABLE 1**

| | |
|---|---|
| Unit System | Metric (m, kg, N, s, V, A) Degrees rad/s Celsius |
| Angle | Degrees |
| Rotational Velocity | rad/s |
| Temperature | Celsius |

# Model (A4)

## *Geometry*

**TABLE 2**
**Model (A4) > Geometry**

| | |
|---|---|
| Object Name | *Geometry* |
| State | Fully Defined |
| **Definition** | |
| Source | C:\Users\Shankar Naik\AppData\Local\Temp\WB_LAPTOP-V72I8C3K_Shankar Naik_14540_2\unsaved_project_files\dp0\SYS\DM\SYS.agdb |
| Type | DesignModeler |
| Length Unit | Meters |
| Element Control | Program Controlled |
| Display Style | Body Color |
| **Bounding Box** | |
| Length X | 0.18956 m |
| Length Y | 2.81e-002 m |
| Length Z | 0.18956 m |

| Properties | |
|---|---|
| Volume | 5.2122e-005 m³ |
| Mass | 0.40916 kg |
| Scale Factor Value | 1. |
| **Statistics** | |
| Bodies | 10 |
| Active Bodies | 10 |
| Nodes | 131395 |
| Elements | 74764 |
| Mesh Metric | None |
| **Update Options** | |
| Assign Default Material | No |
| **Basic Geometry Options** | |
| Parameters | Independent |
| Parameter Key | |
| Attributes | Yes |
| Attribute Key | |
| Named Selections | Yes |
| Named Selection Key | |
| Material Properties | Yes |
| **Advanced Geometry Options** | |
| Use Associativity | Yes |
| Coordinate Systems | Yes |
| Coordinate System Key | |
| Reader Mode Saves Updated File | No |
| Use Instances | Yes |
| Smart CAD Update | Yes |
| Compare Parts On Update | No |
| Analysis Type | 3-D |
| Clean Bodies On Import | No |
| Stitch Surfaces On Import | No |
| Decompose Disjoint Geometry | Yes |
| Enclosure and Symmetry Processing | Yes |

**TABLE 3**
**Model (A4) > Geometry > Parts**

| Object Name | *arm* | *arm* | *arm* | *arm* | *arm* | *arm* | *part2 base* | *arm* | *arm* | *part 1 base* |
|---|---|---|---|---|---|---|---|---|---|---|
| State | Meshed | | | | | | | | | |
| **Graphics Properties** | | | | | | | | | | |
| Visible | Yes | | | | | | | | | |
| Transparency | 1 | | | | | | | | | |
| **Definition** | | | | | | | | | | |
| Suppressed | No | | | | | | | | | |
| Stiffness Behavior | Flexible | | | | | | | | | |
| Coordinate System | Default Coordinate System | | | | | | | | | |
| Reference Temperature | By Environment | | | | | | | | | |
| Behavior | None | | | | | | | | | |

| Material | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Assignment | Structural Steel | | | | | | | | | |
| Nonlinear Effects | Yes | | | | | | | | | |
| Thermal Strain Effects | Yes | | | | | | | | | |
| **Bounding Box** | | | | | | | | | | |
| Length X | 7.5835e-002 m | 1.069e-002 m | 7.0804e-002 m | 6.4528e-003 m | 7.5835e-002 m | 1.069e-002 m | 7.2912e-002 m | 7.0804e-002 m | 6.4528e-003 m | 7.2217e-002 m |
| Length Y | 2.e-002 m | 8.9802e-003 m | 2.e-002 m | 8.9802e-003 m | 2.e-002 m | 8.9802e-003 m | 4.1e-003 m | 2.e-002 m | 8.9802e-003 m | 4.e-003 m |
| Length Z | 7.0804e-002 m | 6.4528e-003 m | 7.5835e-002 m | 1.069e-002 m | 7.0804e-002 m | 6.4528e-003 m | 7.2912e-002 m | 7.5835e-002 m | 1.069e-002 m | 7.2217e-002 m |
| **Properties** | | | | | | | | | | |
| Volume | 7.4034e-006 m³ | 1.579e-007 m³ | 7.4034e-006 m³ | 1.579e-007 m³ | 7.4034e-006 m³ | 1.579e-007 m³ | 1.1024e-005 m³ | 7.4034e-006 m³ | 1.579e-007 m³ | 1.0853e-005 m³ |
| Mass | 5.8117e-002 kg | 1.2395e-003 kg | 5.8117e-002 kg | 1.2395e-003 kg | 5.8117e-002 kg | 1.2395e-003 kg | 8.6536e-002 kg | 5.8117e-002 kg | 1.2395e-003 kg | 8.5197e-002 kg |
| Centroid X | -1.6696e-002 m | -1.5806e-003 m | -1.2441e-002 m | 8.3273e-003 m | 8.6752e-002 m | 7.1636e-002 m | 3.5435e-002 m | 8.2496e-002 m | 6.1729e-002 m | 3.5028e-002 m |
| Centroid Y | 4.2408e-002 m | 4.9227e-002 m | 4.2408e-002 m | 4.9227e-002 m | 4.2408e-002 m | 4.9227e-002 m | 5.8878e-002 m | 4.2408e-002 m | 4.9227e-002 m | 3.399e-002 m |
| Centroid Z | 5.9343e-003 m | 2.6702e-002 m | 0.10513 m | 9.0011e-002 m | 0.10087 m | 8.0103e-002 m | 5.3803e-002 m | 1.6786e-003 m | 1.6794e-002 m | 5.3403e-002 m |
| Moment of Inertia Ip1 | 2.1418e-006 kg·m² | 6.5708e-009 kg·m² | 4.8595e-005 kg·m² | 9.1609e-009 kg·m² | 2.1418e-006 kg·m² | 6.5708e-009 kg·m² | 4.2906e-005 kg·m² | 4.8595e-005 kg·m² | 9.1609e-009 kg·m² | 3.9874e-005 kg·m² |
| Moment of Inertia Ip2 | 4.8376e-005 kg·m² | 6.0497e-009 kg·m² | 4.8376e-005 kg·m² | 6.0497e-009 kg·m² | 4.8376e-005 kg·m² | 6.0496e-009 kg·m² | 8.649e-005 kg·m² | 4.8376e-005 kg·m² | 6.0497e-009 kg·m² | 7.9538e-005 kg·m² |
| Moment of Inertia Ip3 | 4.8595e-005 kg·m² | 9.1609e-009 kg·m² | 2.1417e-006 kg·m² | 6.5708e-009 kg·m² | 4.8595e-005 kg·m² | 9.1609e-009 kg·m² | 4.3793e-005 kg·m² | 2.1418e-006 kg·m² | 6.5708e-009 kg·m² | 3.9874e-005 kg·m² |
| **Statistics** | | | | | | | | | | |
| Nodes | 19308 | 437 | 19301 | 419 | 19368 | 428 | 25570 | 19321 | 421 | 26822 |
| Elements | 11087 | 217 | 11083 | 203 | 11129 | 210 | 14531 | 11092 | 205 | 15007 |
| Mesh Metric | None | | | | | | | | | |

## *Coordinate Systems*

**TABLE 4**
**Model (A4) > Coordinate Systems > Coordinate System**

| Object Name | *Global Coordinate System* |
|---|---|
| State | Fully Defined |
| **Definition** | |
| Type | Cartesian |
| Coordinate System ID | 0. |
| **Origin** | |
| Origin X | 0. m |
| Origin Y | 0. m |
| Origin Z | 0. m |
| **Directional Vectors** | |
| X Axis Data | [ 1. 0. 0. ] |
| Y Axis Data | [ 0. 1. 0. ] |
| Z Axis Data | [ 0. 0. 1. ] |

## Connections

**TABLE 5**
**Model (A4) > Connections**

| Object Name | *Connections* |
|---|---|
| State | Fully Defined |
| **Auto Detection** | |
| Generate Automatic Connection On Refresh | Yes |
| **Transparency** | |
| Enabled | Yes |

**TABLE 6**
**Model (A4) > Connections > Contacts**

| Object Name | *Contacts* |
|---|---|
| State | Fully Defined |
| **Definition** | |
| Connection Type | Contact |
| **Scope** | |
| Scoping Method | Geometry Selection |
| Geometry | All Bodies |
| **Auto Detection** | |
| Tolerance Type | Slider |
| Tolerance Slider | 0. |
| Tolerance Value | 6.7387e-004 m |
| Use Range | No |
| Face/Face | Yes |
| Face Overlap Tolerance | Off |
| Cylindrical Faces | Include |
| Face/Edge | No |
| Edge/Edge | No |
| Priority | Include All |
| Group By | Bodies |
| Search Across | Bodies |
| **Statistics** | |
| Connections | 12 |
| Active Connections | 12 |

**TABLE 7**
**Model (A4) > Connections > Contacts > Contact Regions**

| Object Name | *Contact Region* | *Contact Region 2* | *Contact Region 3* | *Contact Region 4* | *Contact Region 5* | *Contact Region 6* | *Contact Region 7* | *Contact Region 8* | *Contact Region 9* | *Contact Region 10* | *Contact Region 11* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| State | Fully Defined | | | | | | | | | | |
| **Scope** | | | | | | | | | | | |
| Scoping Method | Geometry Selection | | | | | | | | | | |
| Contact | 3 Faces | 1 Face | | 3 Faces | 1 Face | | 3 Faces | 1 Face | | | 3 Faces |
| Target | 4 Faces | 1 Face | | 4 Faces | 1 Face | | 4 Faces | 1 Face | | | 4 Faces |
| Contact Bodies | arm | | | | | | | | | part2 base | arm |
| Target Bodies | arm | part2 base | part 1 base | arm | part2 base | part 1 base | arm | part2 base | part 1 base | arm | |
| Protected | No | | | | | | | | | | |
| **Definition** | | | | | | | | | | | |
| Type | Bonded | | | | | | | | | | |
| Scope | Automatic | | | | | | | | | | |

| | |
|---|---|
| Mode | |
| Behavior | Program Controlled |
| Trim Contact | Program Controlled |
| Trim Tolerance | 6.7387e-004 m |
| Suppressed | No |
| **Advanced** | |
| Formulation | Program Controlled |
| Small Sliding | Program Controlled |
| Detection Method | Program Controlled |
| Penetration Tolerance | Program Controlled |
| Elastic Slip Tolerance | Program Controlled |
| Normal Stiffness | Program Controlled |
| Update Stiffness | Program Controlled |
| Pinball Region | Program Controlled |
| **Geometric Modification** | |
| Contact Geometry Correction | None |
| Target Geometry Correction | None |

**TABLE 8**
**Model (A4) > Connections > Contacts > Contact Regions**

| Object Name | *Contact Region 12* |
|---|---|
| State | Fully Defined |
| **Scope** | |
| Scoping Method | Geometry Selection |
| Contact | 1 Face |
| Target | 1 Face |
| Contact Bodies | arm |
| Target Bodies | part 1 base |
| Protected | No |
| **Definition** | |
| Type | Bonded |
| Scope Mode | Automatic |
| Behavior | Program Controlled |
| Trim Contact | Program Controlled |
| Trim Tolerance | 6.7387e-004 m |
| Suppressed | No |
| **Advanced** | |
| Formulation | Program Controlled |
| Small Sliding | Program Controlled |
| Detection Method | Program Controlled |
| Penetration Tolerance | Program Controlled |
| Elastic Slip Tolerance | Program Controlled |
| Normal Stiffness | Program Controlled |
| Update Stiffness | Program Controlled |

| | |
|---|---|
| Pinball Region | Program Controlled |
| **Geometric Modification** | |
| Contact Geometry Correction | None |
| Target Geometry Correction | None |

## *Mesh*

**TABLE 9**
**Model (A4) > Mesh**

| | |
|---|---|
| Object Name | *Mesh* |
| State | Solved |
| **Display** | |
| Display Style | Use Geometry Setting |
| **Defaults** | |
| Physics Preference | Mechanical |
| Element Order | Program Controlled |
| Element Size | 1.e-003 m |
| **Sizing** | |
| Use Adaptive Sizing | Yes |
| Resolution | Default (2) |
| Mesh Defeaturing | Yes |
| Defeature Size | Default |
| Transition | Fast |
| Span Angle Center | Coarse |
| Initial Size Seed | Assembly |
| Bounding Box Diagonal | 0.26955 m |
| Average Surface Area | 6.8051e-005 m² |
| Minimum Edge Length | 2.3315e-004 m |
| **Quality** | |
| Check Mesh Quality | Yes, Errors |
| Error Limits | Standard Mechanical |
| Target Quality | Default (0.050000) |
| Smoothing | Medium |
| Mesh Metric | None |
| **Inflation** | |
| Use Automatic Inflation | None |
| Inflation Option | Smooth Transition |
| Transition Ratio | 0.272 |
| Maximum Layers | 5 |
| Growth Rate | 1.2 |
| Inflation Algorithm | Pre |
| View Advanced Options | No |
| **Advanced** | |
| Number of CPUs for Parallel Part Meshing | Program Controlled |
| Straight Sided Elements | No |
| Number of Retries | Default (4) |
| Rigid Body Behavior | Dimensionally Reduced |
| Triangle Surface Mesher | Program Controlled |
| Topology Checking | Yes |
| Pinch Tolerance | Please Define |
| Generate Pinch on Refresh | No |
| **Statistics** | |
| Nodes | 131395 |
| Elements | 74764 |

**TABLE 10**
**Model (A4) > Mesh > Mesh Controls**

| | |
|---|---|
| Object Name | *Body Sizing* |
| State | Fully Defined |
| **Scope** | |
| Scoping Method | Geometry Selection |
| Geometry | 10 Bodies |
| **Definition** | |
| Suppressed | No |
| Type | Element Size |
| Element Size | 2.e-003 m |
| **Advanced** | |
| Defeature Size | Default |
| Behavior | Soft |

# Modal (A5)

**TABLE 11**
**Model (A4) > Analysis**

| | |
|---|---|
| Object Name | *Modal (A5)* |
| State | Solved |
| **Definition** | |
| Physics Type | Structural |
| Analysis Type | Modal |
| Solver Target | Mechanical APDL |
| **Options** | |
| Environment Temperature | 22. °C |
| Generate Input Only | No |

**TABLE 12**
**Model (A4) > Modal (A5) > Initial Condition**

| | |
|---|---|
| Object Name | *Pre-Stress (None)* |
| State | Fully Defined |
| **Definition** | |
| Pre-Stress Environment | None Available |

**TABLE 13**
**Model (A4) > Modal (A5) > Analysis Settings**

| | |
|---|---|
| Object Name | *Analysis Settings* |
| State | Fully Defined |
| **Options** | |
| Max Modes to Find | 6 |
| Limit Search to Range | No |
| **Solver Controls** | |
| Damped | No |
| Solver Type | Program Controlled |
| **Rotordynamics Controls** | |
| Coriolis Effect | Off |
| Campbell Diagram | Off |
| **Output Controls** | |
| Stress | No |
| Strain | No |
| Nodal Forces | No |
| Calculate Reactions | No |
| General Miscellaneous | No |

| Analysis Data Management | |
|---|---|
| Solver Files Directory | C:\Users\Shankar Naik\AppData\Local\Temp\WB_LAPTOP-V72I8C3K_Shankar Naik_14540_2\unsaved_project_files\dp0\SYS\MECH\ |
| Future Analysis | None |
| Scratch Solver Files Directory | |
| Save MAPDL db | No |
| Contact Summary | Program Controlled |
| Delete Unneeded Files | Yes |
| Solver Units | Active System |
| Solver Unit System | mks |

**TABLE 14**
**Model (A4) > Modal (A5) > Loads**

| Object Name | *Fixed Support* |
|---|---|
| State | Fully Defined |
| **Scope** | |
| Scoping Method | Geometry Selection |
| Geometry | 1 Face |
| **Definition** | |
| Type | Fixed Support |
| Suppressed | No |

## *Solution (A6)*

**TABLE 15**
**Model (A4) > Modal (A5) > Solution**

| Object Name | *Solution (A6)* |
|---|---|
| State | Solved |
| **Adaptive Mesh Refinement** | |
| Max Refinement Loops | 1. |
| Refinement Depth | 2. |
| **Information** | |
| Status | Done |
| MAPDL Elapsed Time | 21. s |
| MAPDL Memory Used | 4.2266 GB |
| MAPDL Result File Size | 47.25 MB |
| **Post Processing** | |
| Beam Section Results | No |

The following bar chart indicates the frequency at each calculated mode.

**FIGURE 1**
**Model (A4) > Modal (A5) > Solution (A6)**

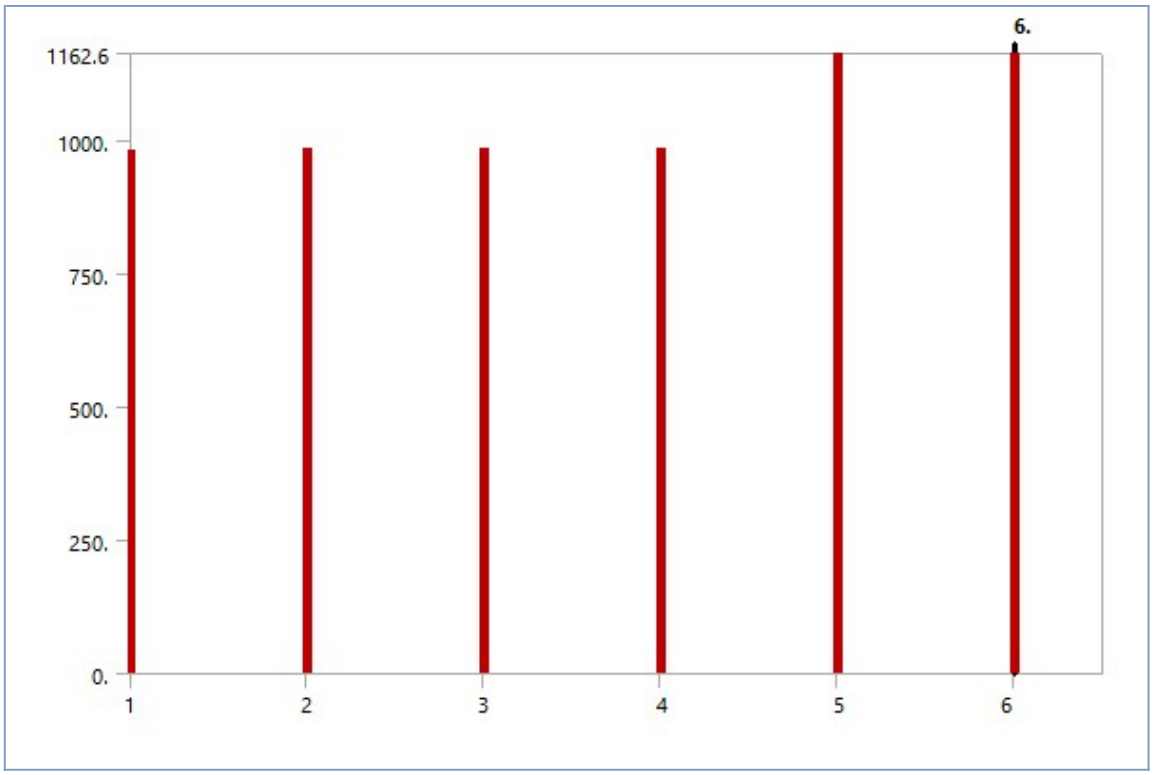



**TABLE 16**
**Model (A4) > Modal (A5) > Solution (A6)**

| Mode | Frequency [Hz] |
|---|---|
| 1. | 982.42 |
| 2. | 982.72 |
| 3. | 983.28 |
| 4. | 984.17 |
| 5. | 1161.2 |
| 6. | 1162.6 |

**TABLE 17**
**Model (A4) > Modal (A5) > Solution (A6) > Solution Information**

| Object Name | *Solution Information* |
|---|---|
| State | Solved |
| **Solution Information** | |
| Solution Output | Solver Output |
| Newton-Raphson Residuals | 0 |
| Identify Element Violations | 0 |
| Update Interval | 2.5 s |
| Display Points | All |
| **FE Connection Visibility** | |
| Activate Visibility | Yes |
| Display | All FE Connectors |
| Draw Connections Attached To | All Nodes |
| Line Color | Connection Type |
| Visible on Results | No |
| Line Thickness | Single |
| Display Type | Lines |

**TABLE 18**
**Model (A4) > Modal (A5) > Solution (A6) > Results**

| Object Name | *Total Deformation* |
|---|---|
| State | Solved |
| **Scope** | |
| Scoping Method | Geometry Selection |
| Geometry | All Bodies |
| **Definition** | |
| Type | Total Deformation |
| Mode | 3. |
| Identifier | |
| Suppressed | No |
| **Results** | |
| Minimum | 0. m |
| Maximum | 5.9865 m |
| Average | 0.84146 m |
| Minimum Occurs On | part 1 base |
| Maximum Occurs On | arm |
| **Information** | |
| Frequency | 983.28 Hz |

**TABLE 19**
**Model (A4) > Modal (A5) > Solution (A6) > Total Deformation**

| Mode | Frequency [Hz] |
|---|---|
| 1. | 982.42 |
| 2. | 982.72 |
| 3. | 983.28 |
| 4. | 984.17 |
| 5. | 1161.2 |
| 6. | 1162.6 |

# Material Data

## *Structural Steel*

**TABLE 20**
**Structural Steel > Constants**

| | |
|---|---|
| Density | 7850 kg m^-3 |
| Coefficient of Thermal Expansion | 1.2e-005 C^-1 |
| Specific Heat | 434 J kg^-1 C^-1 |
| Thermal Conductivity | 60.5 W m^-1 C^-1 |
| Resistivity | 1.7e-007 ohm m |

**TABLE 21**
**Structural Steel > Color**

| Red | Green | Blue |
|---|---|---|
| 132 | 139 | 179 |

**TABLE 22**
**Structural Steel > Compressive Ultimate Strength**

| Compressive Ultimate Strength Pa |
|---|
| 0 |

**TABLE 23**
**Structural Steel > Compressive Yield Strength**

| Compressive Yield Strength Pa |
|---|
| 2.5e+008 |

**TABLE 24**
**Structural Steel > Tensile Yield Strength**

| Tensile Yield Strength Pa |
|---|
| 2.5e+008 |

**TABLE 25**
**Structural Steel > Tensile Ultimate Strength**

| Tensile Ultimate Strength Pa |
|---|
| 4.6e+008 |

**TABLE 26**
**Structural Steel > Isotropic Secant Coefficient of Thermal Expansion**

| Zero-Thermal-Strain Reference Temperature C |
|---|
| 22 |

**TABLE 27**
**Structural Steel > S-N Curve**

| Alternating Stress Pa | Cycles | Mean Stress Pa |
|---|---|---|
| 3.999e+009 | 10 | 0 |
| 2.827e+009 | 20 | 0 |
| 1.896e+009 | 50 | 0 |
| 1.413e+009 | 100 | 0 |
| 1.069e+009 | 200 | 0 |
| 4.41e+008 | 2000 | 0 |
| 2.62e+008 | 10000 | 0 |
| 2.14e+008 | 20000 | 0 |
| 1.38e+008 | 1.e+005 | 0 |
| 1.14e+008 | 2.e+005 | 0 |
| 8.62e+007 | 1.e+006 | 0 |

**TABLE 28**
**Structural Steel > Strain-Life Parameters**

| Strength Coefficient Pa | Strength Exponent | Ductility Coefficient | Ductility Exponent | Cyclic Strength Coefficient Pa | Cyclic Strain Hardening Exponent |
|---|---|---|---|---|---|
| 9.2e+008 | -0.106 | 0.213 | -0.47 | 1.e+009 | 0.2 |

**TABLE 29**
**Structural Steel > Isotropic Elasticity**

| Young's Modulus Pa | Poisson's Ratio | Bulk Modulus Pa | Shear Modulus Pa | Temperature C |
|---|---|---|---|---|
| 2.e+011 | 0.3 | 1.6667e+011 | 7.6923e+010 | |

**TABLE 30**
**Structural Steel > Isotropic Relative Permeability**

| Relative Permeability |
|---|
| 10000 |