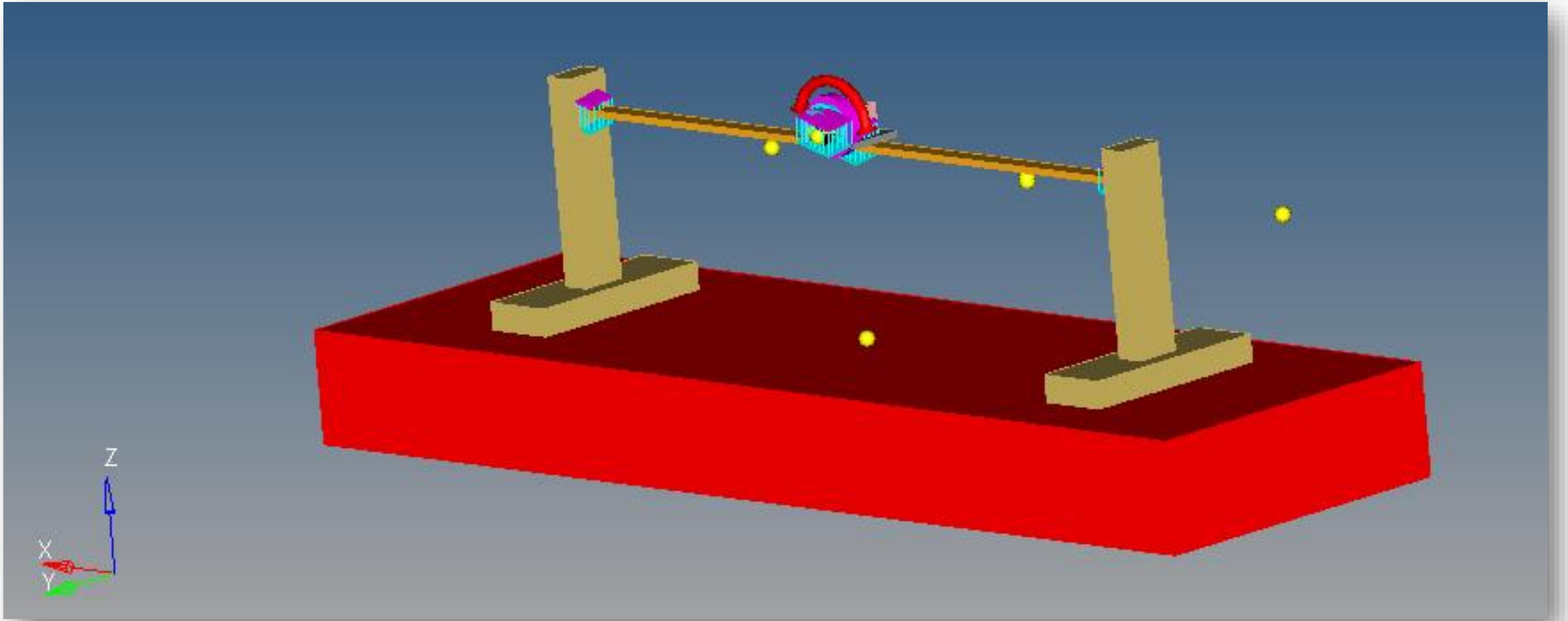
Test Rig for Vibration Analysis of Beams due to Eccentric Mass Rotation

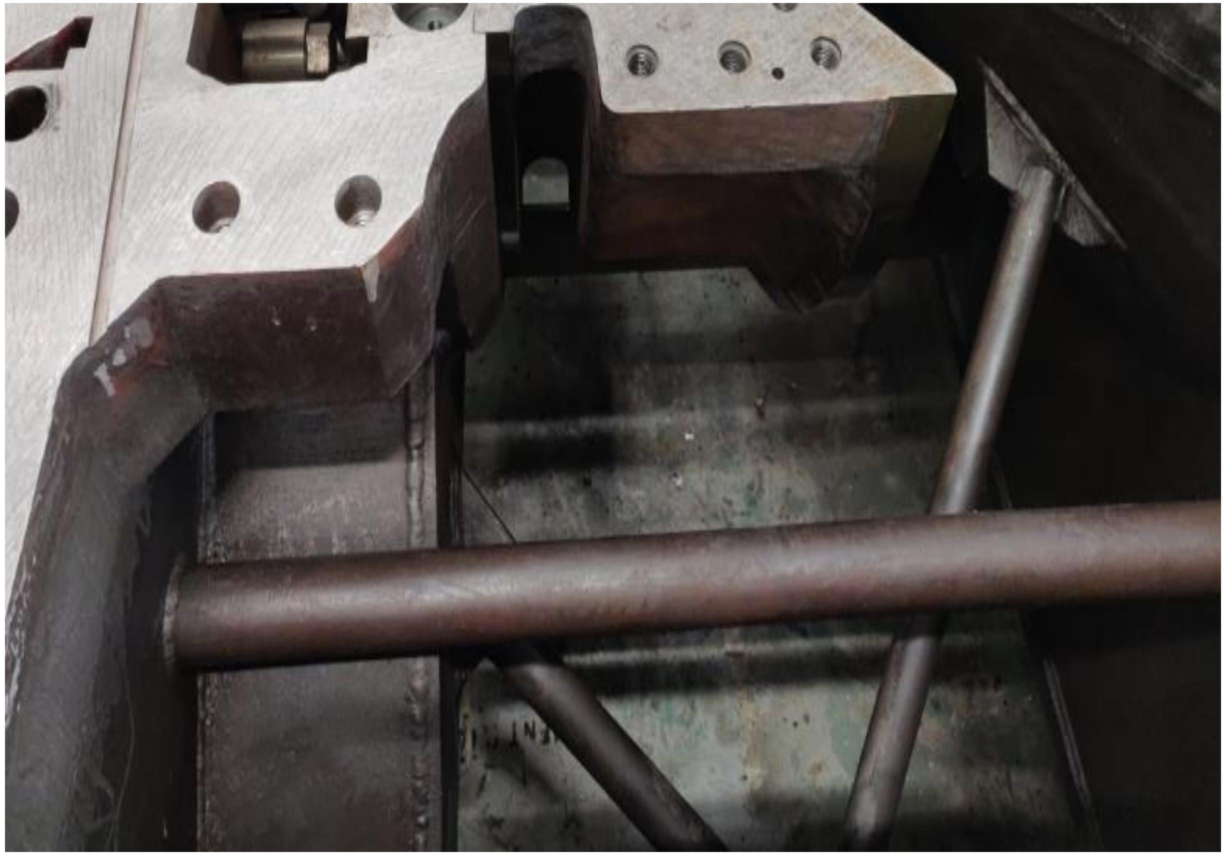


Objectives

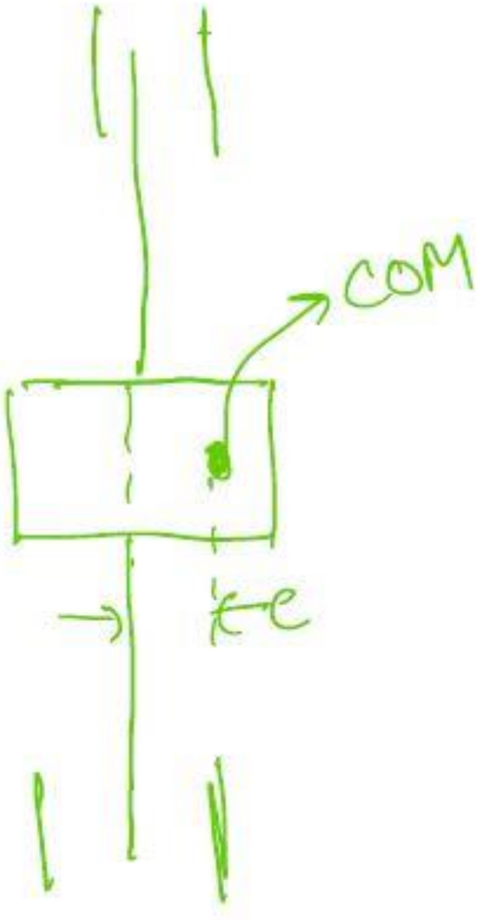
- Designing and development of a test rig which can be used to study the transverse vibrations in flexible beams due to **excitations from rotating eccentric masses**.
- Several test cases formed on the basis of beam dimensions and end conditions. Sensitivity analysis of the transverse vibrations in beams have been carried out with the help of these test cases.
- Two types of beams considered: flexible and rigid; for rigid beams, variation of reaction forces are calculated, for flexible beams, amplitude has been calculated.
- The ultimate purpose of this project is to conceptualize an appropriate test equipment/apparatus which can be utilised by various labs for different purposes.

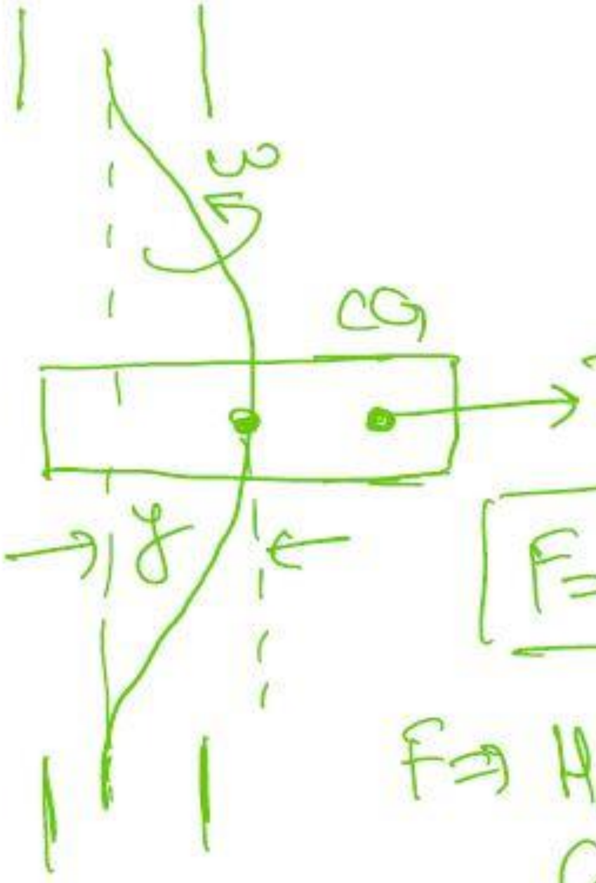
Engineering Background

- Steam turbine exhaust casings:



Harmonic Force due to eccentricity



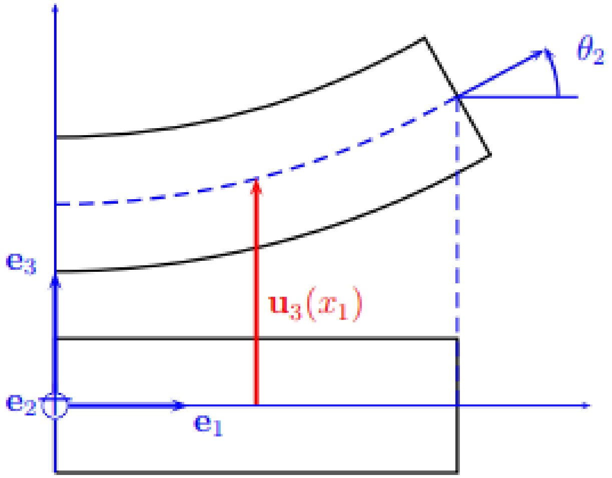


$$\boxed{F = m(y+e)\omega^2}$$

F ⇒ Harmonic Centrifugal Force

Transverse Vibrations of a continuous system like beam

- Euler Bernoulli Beam theory



The deflection of the beam at any point can be written as:

$$y = y(x, t)$$
$$y(x, t) = X(x).T(t)$$

The equation for X represents the shape of a normal mode of vibration (the ith mode) which has a eigen mode frequency of ωi. Equation for T represents the equation of motion with respect to time for the beam particles undergoing vibration.

Test Cases

1. **RIGID BEAM ANALYSIS**

CASE A: Fixed-fixed beam, length= 1000mm, width= 30mm, thickness= 10mm
CASE B: Fixed-fixed beam, length= 1000mm, width= 30mm, thickness= 15mm
CASE C: Fixed-fixed beam, length= 800mm, width= 30mm, thickness= 10mm
CASE D: Cantilever beam, length= 1000mm, width= 30mm, thickness= 10mm
CASE E: Lying Beam, length= 1000mm, width= 30mm, thickness= 10mm
CASE F: Simply Supported Beam= 1000mm, width= 30mm, thickness= 10mm

2. **FLEXIBLE BEAM ANALYSIS**

CASE A: e1= 25mm m1= 0.0123 kg w1= 50.265 rad/s

CASE B:e2= 15mmm1= 0.0123 kgw1= 50.265 rad/s

CASE C:e3= 10mm m1= 0.0123 kg w1= 50.265 rad/s

CASE D:e1= 25mmm2= 0.0009 kgw1= 50.265 rad/s

CASE E:e1= 25mmm3= 0.0740 kgw1= 50.265 rad/s

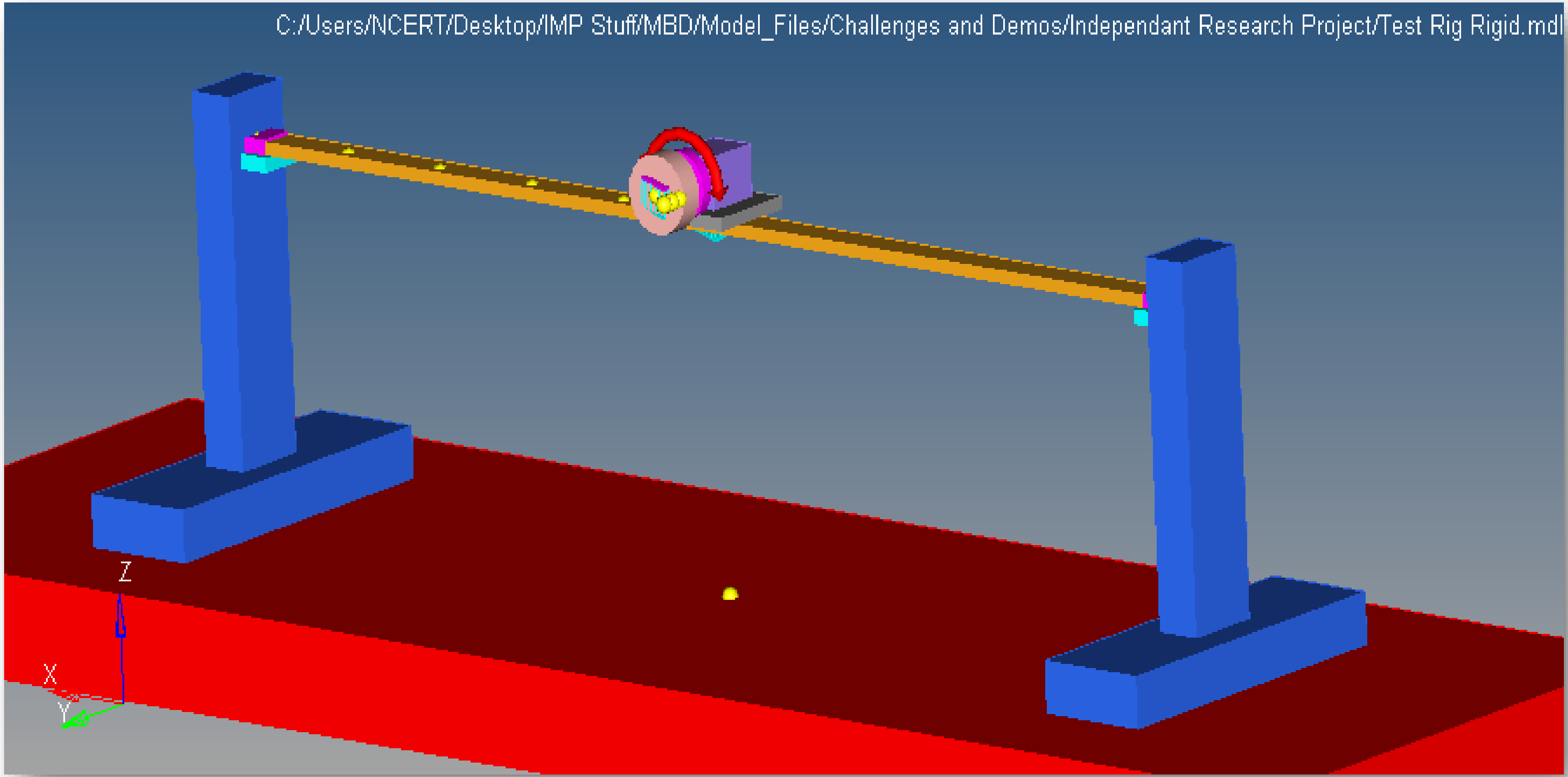
CASE F:e1= 25mm m1=0.0123 kg w2= 100 rad/s

CASE G:e1= 25mm m1= 0.0123 kgw3= 20 rad/s

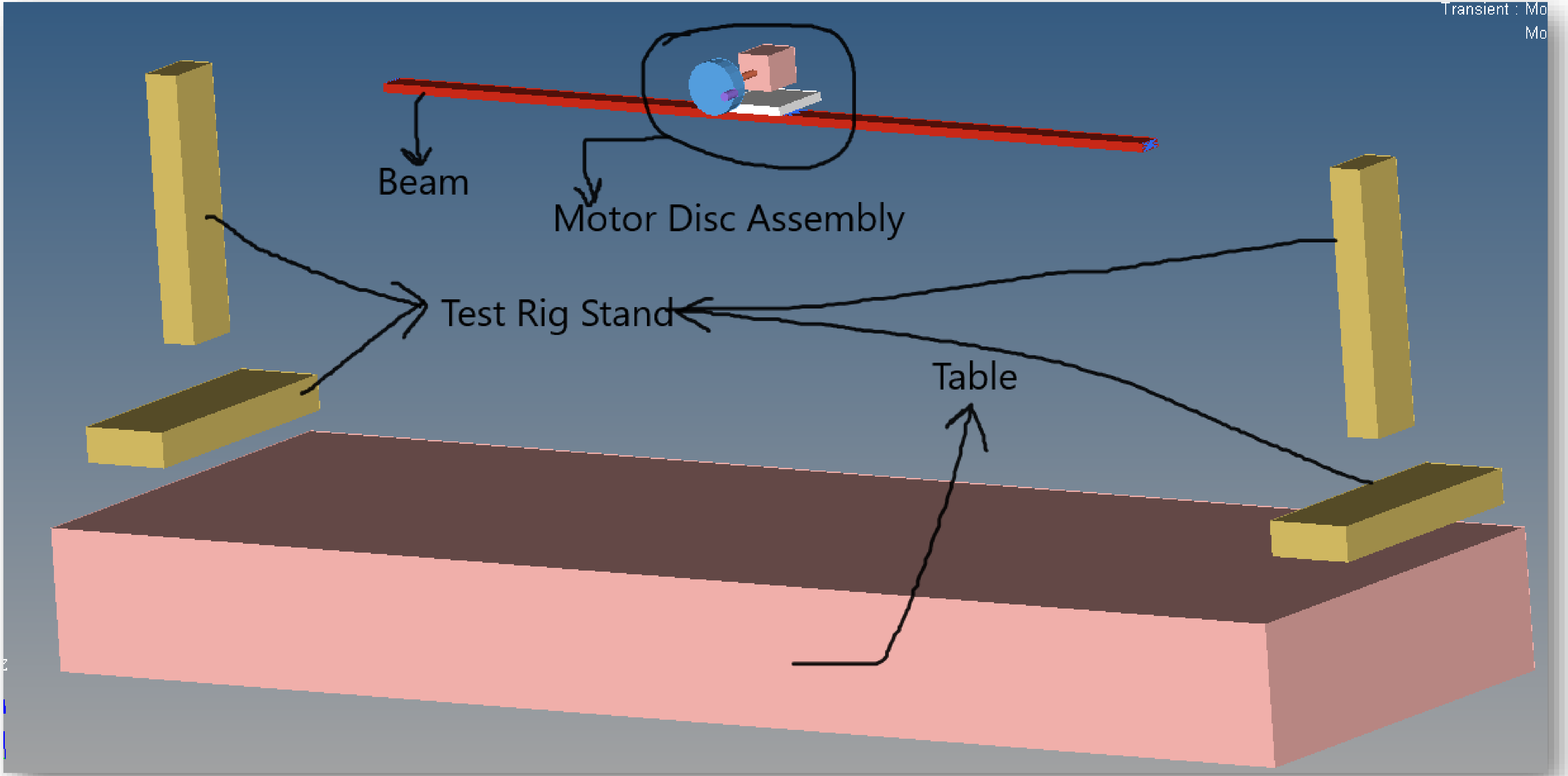
Model Construction

1. Rigid Construction

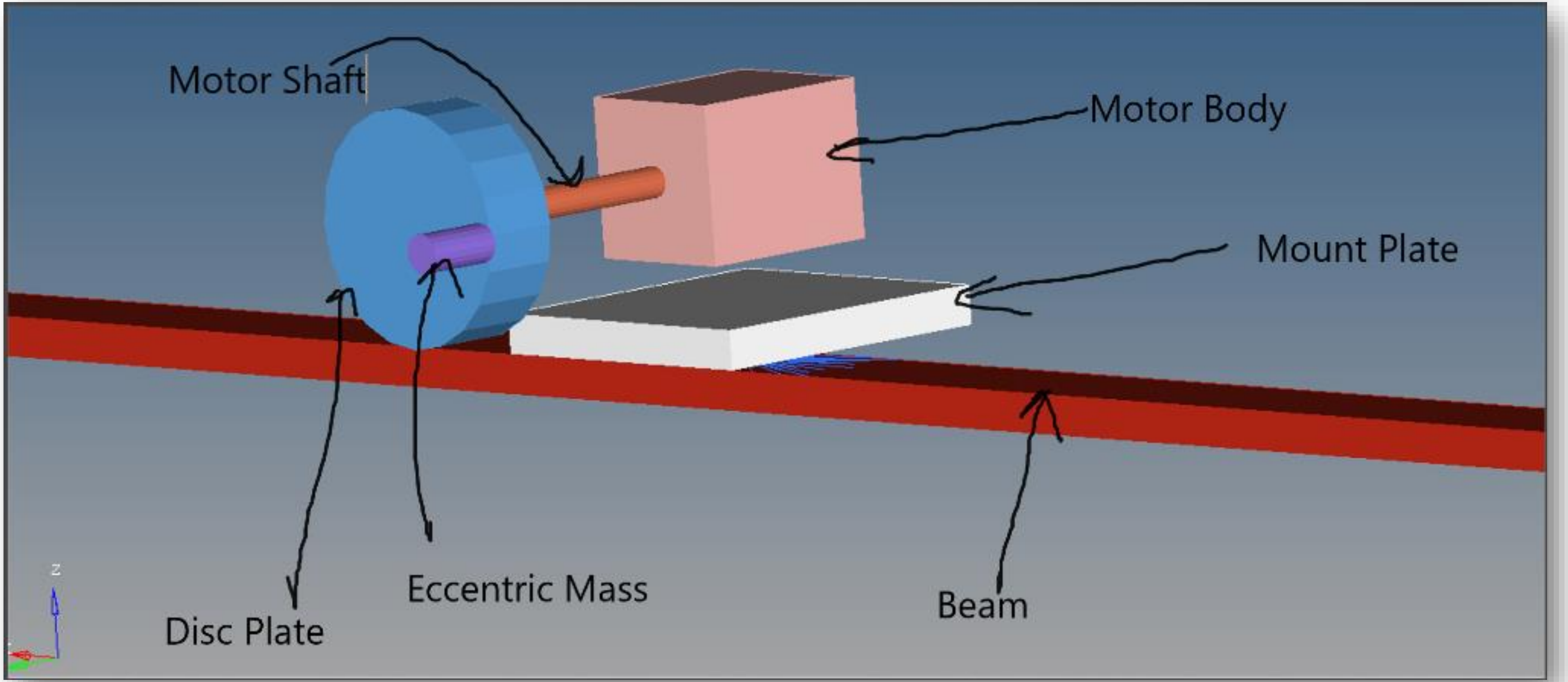
- **Fixed Beam**



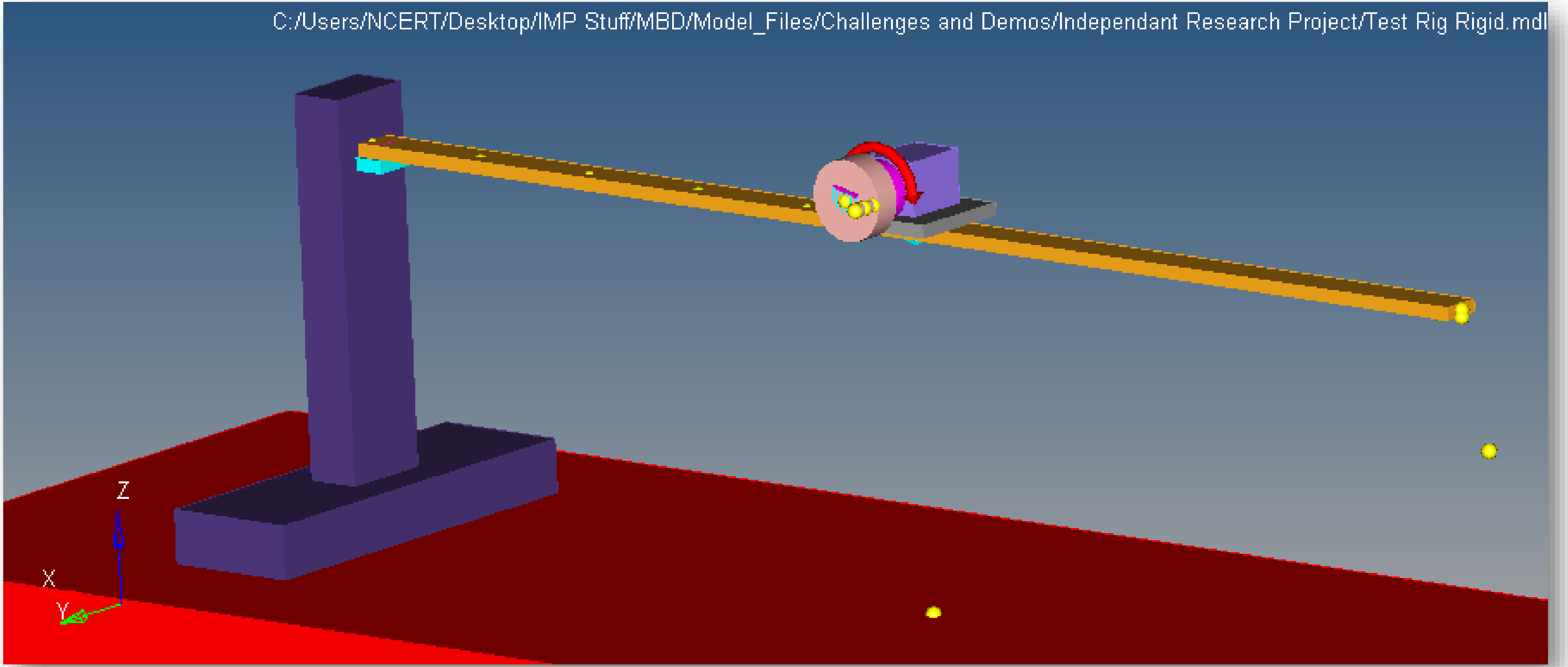
Model Exploded View



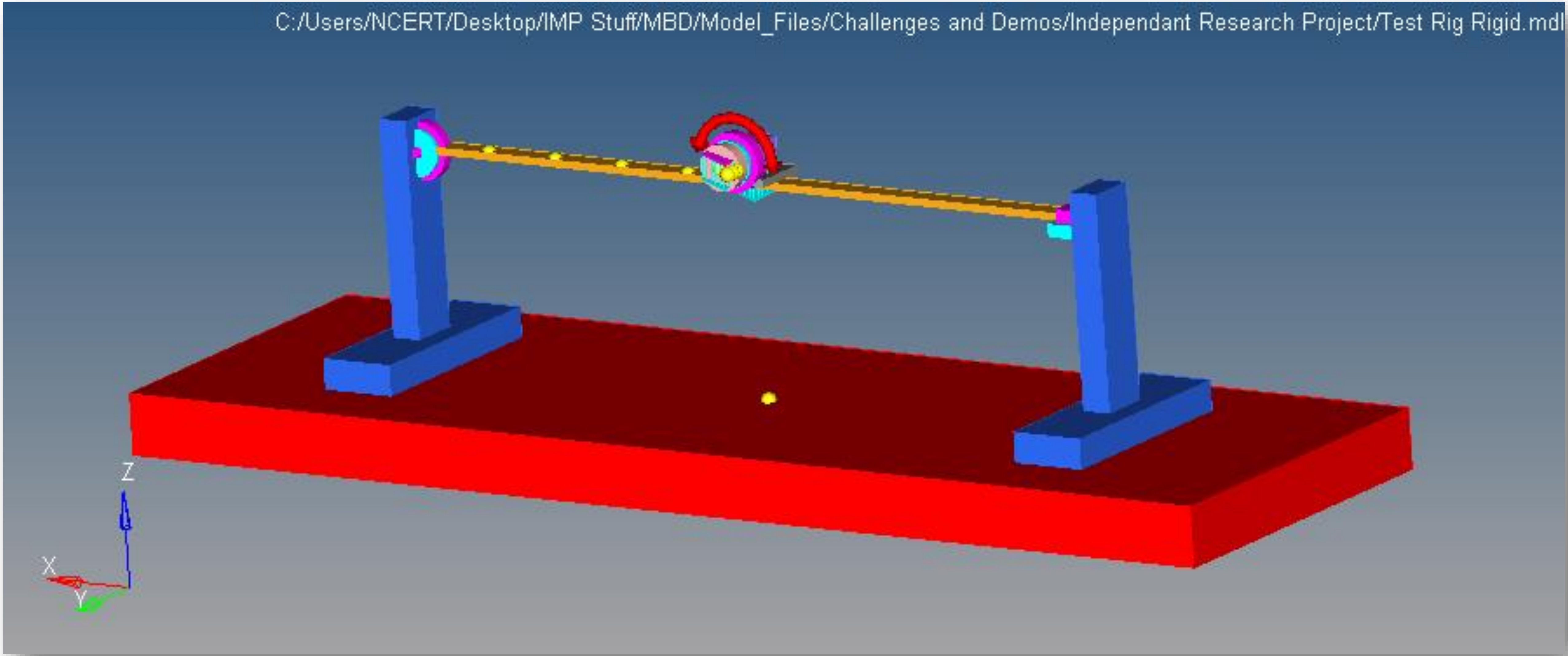
- **Motor and disc assembly**



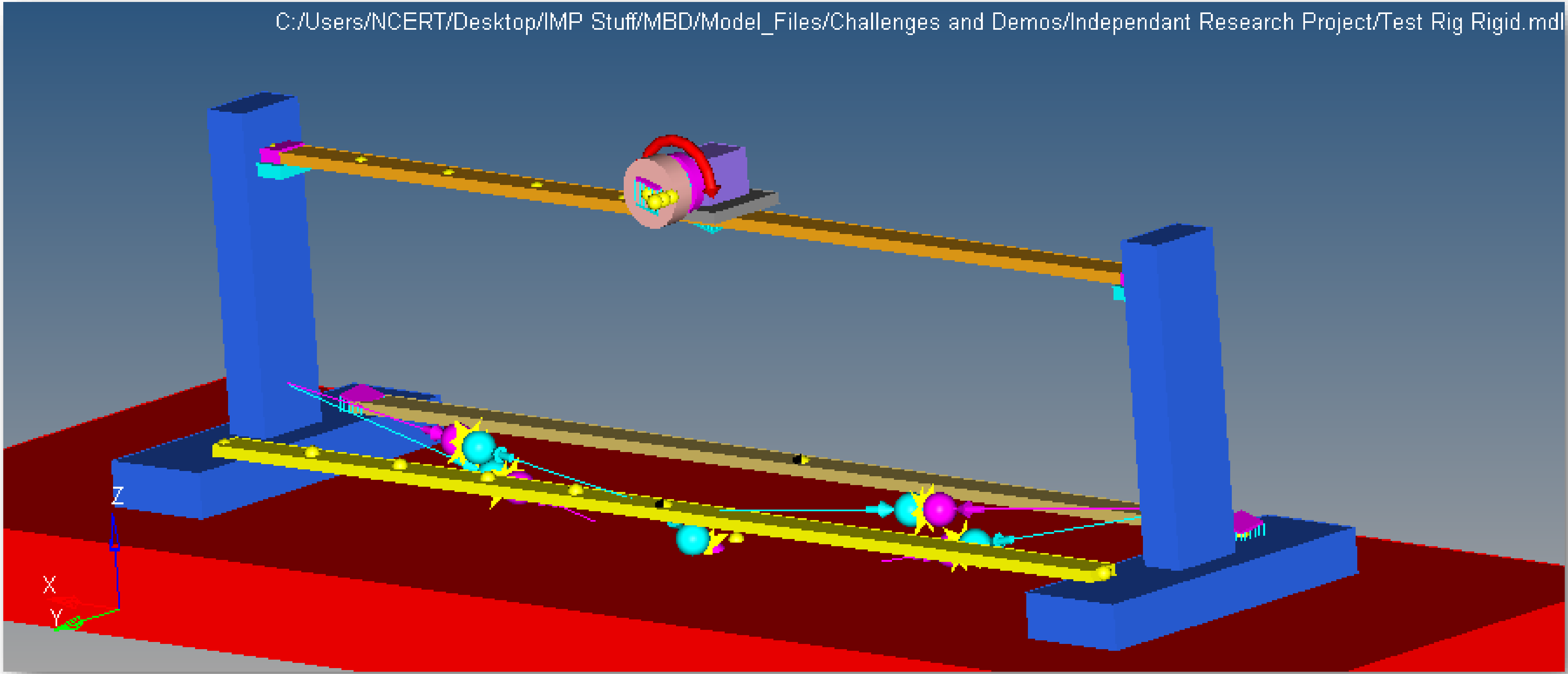
- **Cantilever Beam**



- **Simply Supported Beam**

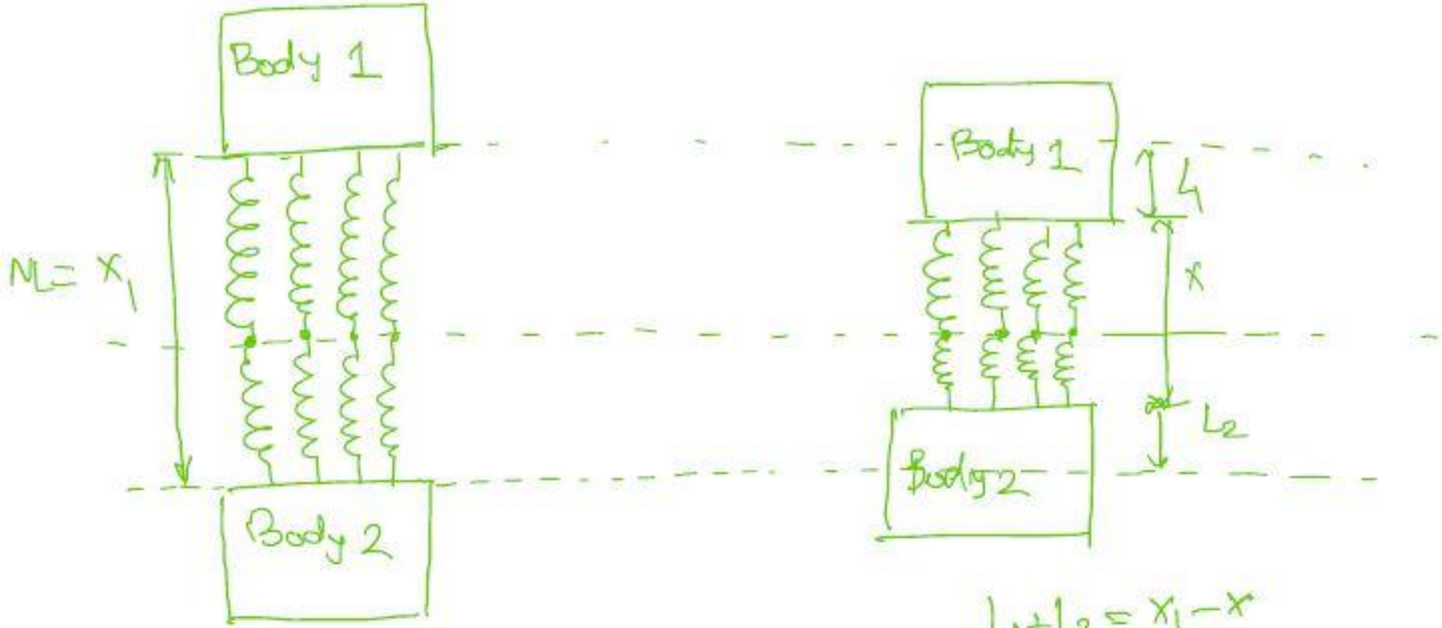


- **Beam lying without any support (with 3D contacts) and a reference fixed beam**



3D CONTACT PARAMETERS

1). Normal Force Calculation (Impact Contact Model):



$L_1 + L_2 = x_1 - x$
$= \text{Penetration Depth}$

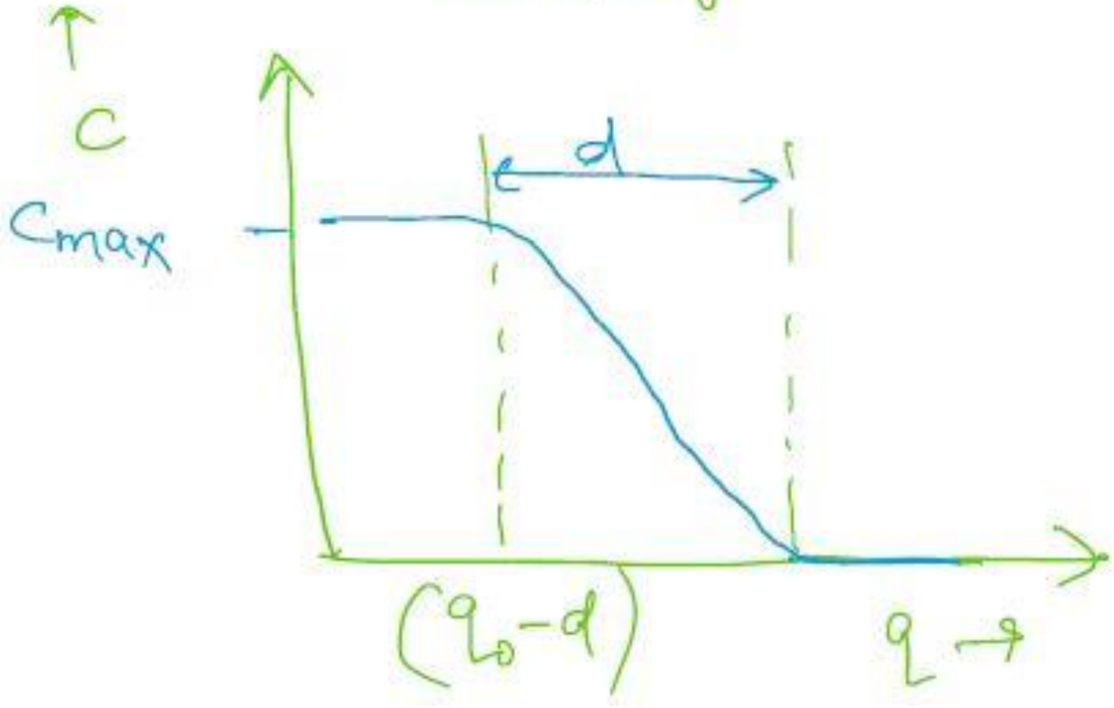
$$F_{normal} = F_{spring} + F_{damping}$$

$$= k_c (x_1 - x)^e - C_{max} \cdot \dot{x} * STEP(x, x_1 - d, 1, x_1, 0)$$

$$F_{normal} = IMPACT(x, x1, x1, k_c, e, C_{max}, d)$$

Penetration depth of maximum damping:

$d \Rightarrow$ Penetration Depth @ which maximum Damping occurs



$q = x_1 - x$

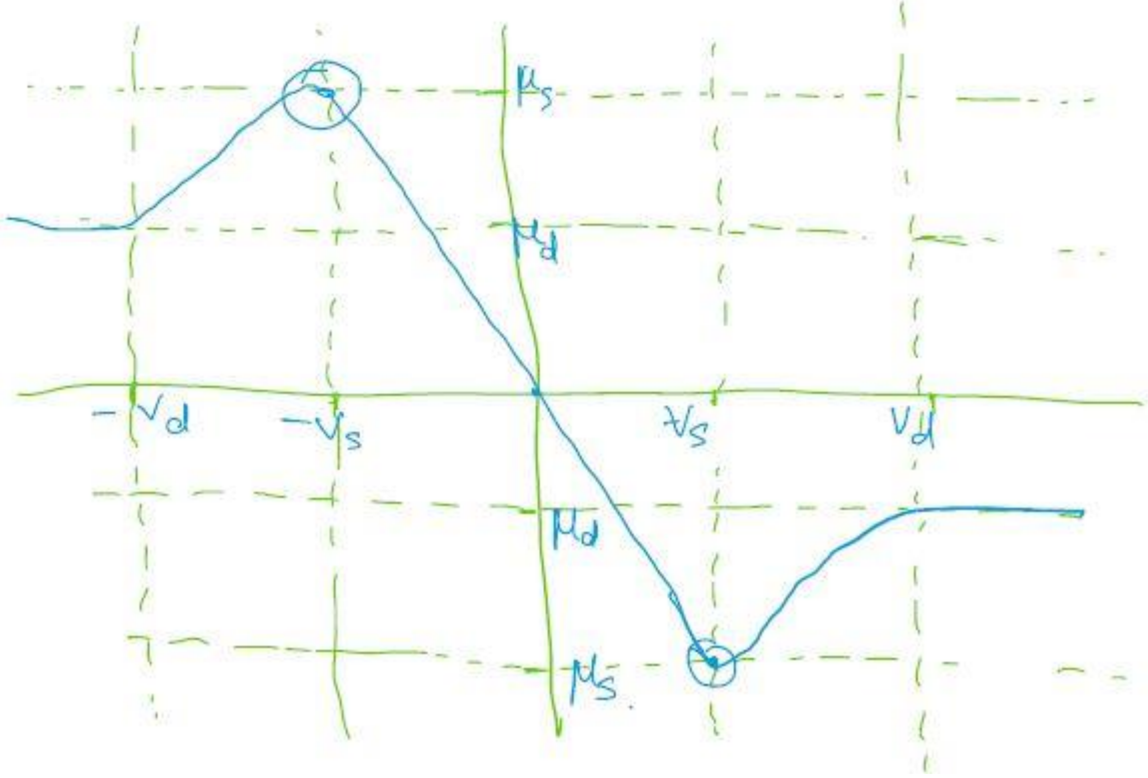
$q_0 = x_1$

Frictional Force Calculation (Columb Frictional Model)

$\mu = f$ (slip velocity)

V_s = Stiction Transition velocity

V_d = Friction Transition velocity



3D Contact Parameters

- Between table and stand

Normal force calculation:
Impact model used
Contact stiffness = 1000 N/mm^2
Maximum damping coefficient= 1 N-s/mm
Stiffness exponent= 2.1
Penetration depth for maximum damping= 0.1 mm

Friction calculation:
Columb model
Coefficient of friction, static= 0.2
Coefficient of friction, dynamic= 0.1
Stiction transition velocity= 1mm/s
Friction transition velocity= 1.5mm/s

- Between table and Aluminium Beam

Normal force calculation:
Impact model used
Contact stiffness = 10 N/mm^2
Maximum damping coefficient= 6 N-s/mm
Stiffness exponent= 2.1
Penetration depth for maximum damping= 2.1 mm

Friction calculation:
Columb model
Coefficient of friction, static= 10
Coefficient of friction, dynamic= 5
Stiction transition velocity= 0.5mm/s
Friction transition velocity= 1mm/s

- Between table and Mild steel Beam

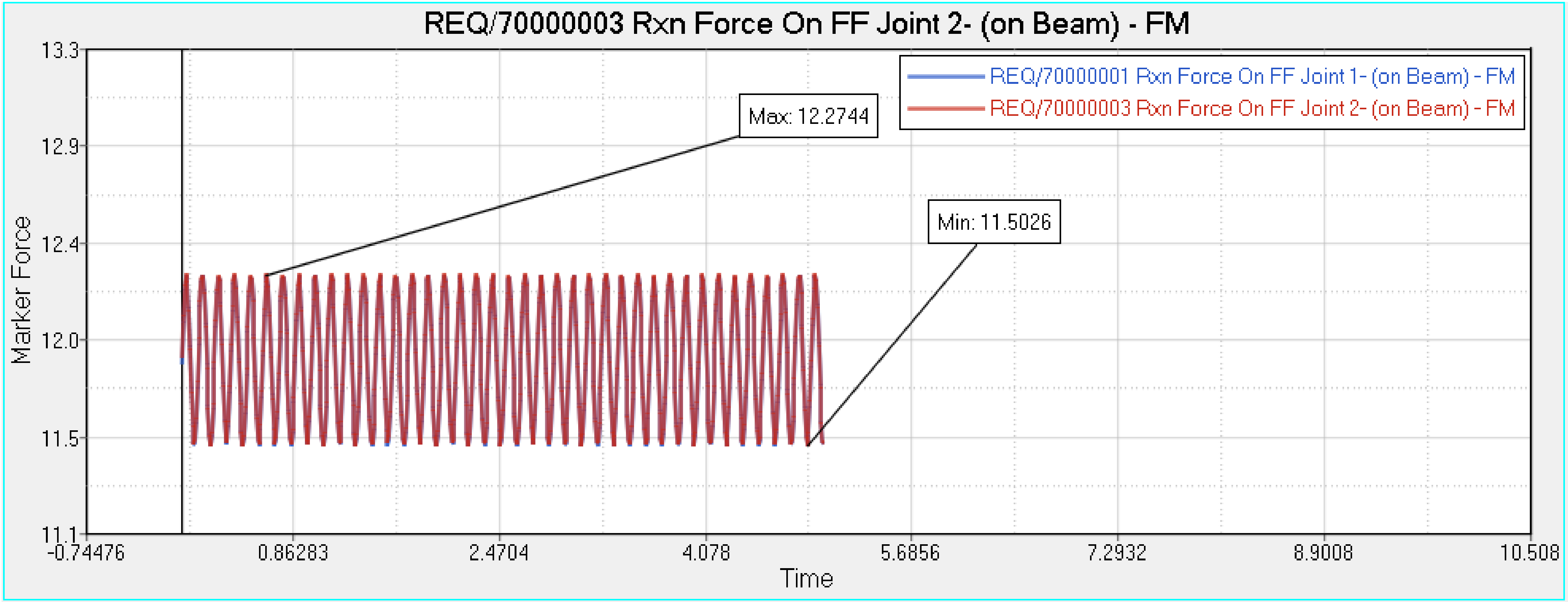
Normal force calculation:
Impact model used
Contact stiffness = 10 N/mm^2
Maximum damping coefficient= 8 N-s/mm
Stiffness exponent= 2.1
Penetration depth for maximum damping= 4 mm

Friction calculation:
Columb model
Coefficient of friction, static= 10
Coefficient of friction, dynamic= 5
Stiction transition velocity= 0.5mm/s
Friction transition velocity= 1mm/s

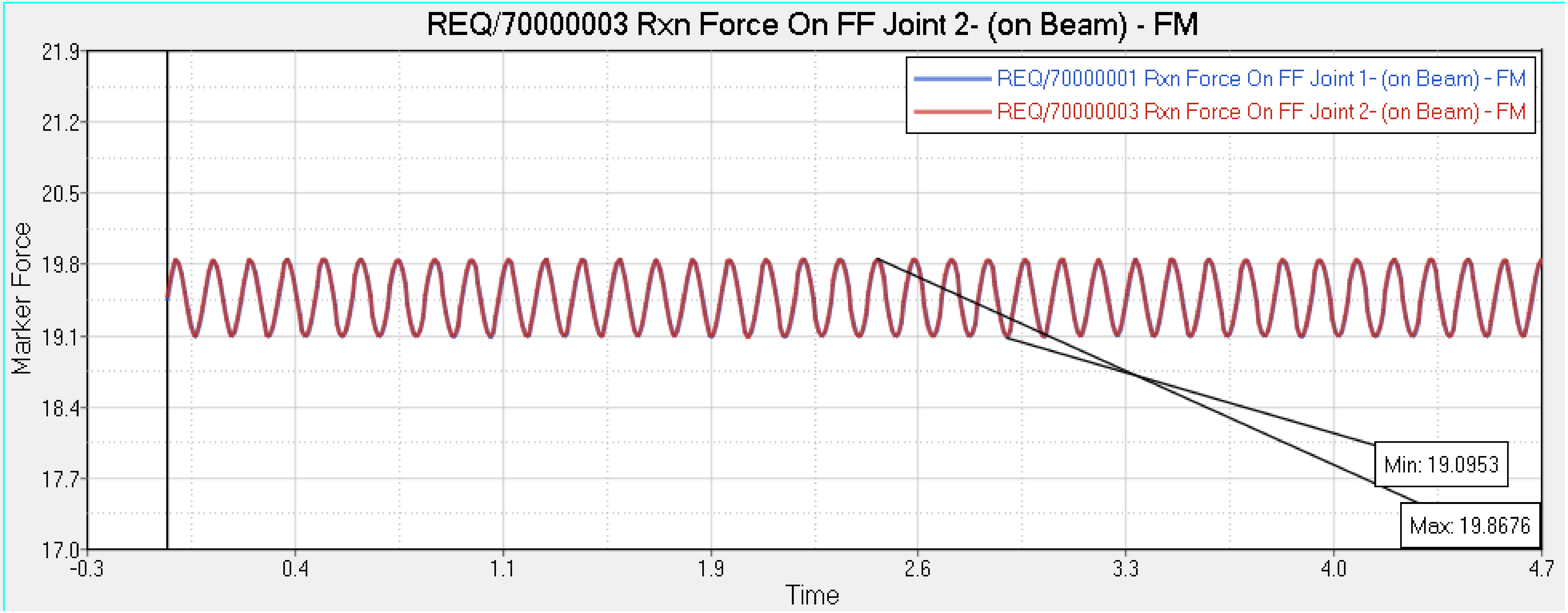
RESULTS

1. Rigid Beam:

CASE A: Fixed-fixed beam, length= 1000mm, width= 30mm, thickness= 10mm (Aluminium)



Mild Steel



REQ/70000003 Rxn Force On FF Joint 2- (on Beam) - FM
REQ/70000001 Rxn Force On FF Joint 1- (on Beam) - FM
REQ/70000003 Rxn Force On FF Joint 2- (on Beam) - FM
Marker Force
21.9
21.2
20.5
19.8
19.1
18.4
17.7
17.0
Time
-0.3
0.4
1.1
1.9
2.6
3.3
4.0
4.7
Min: 19.0953
Max: 19.8676

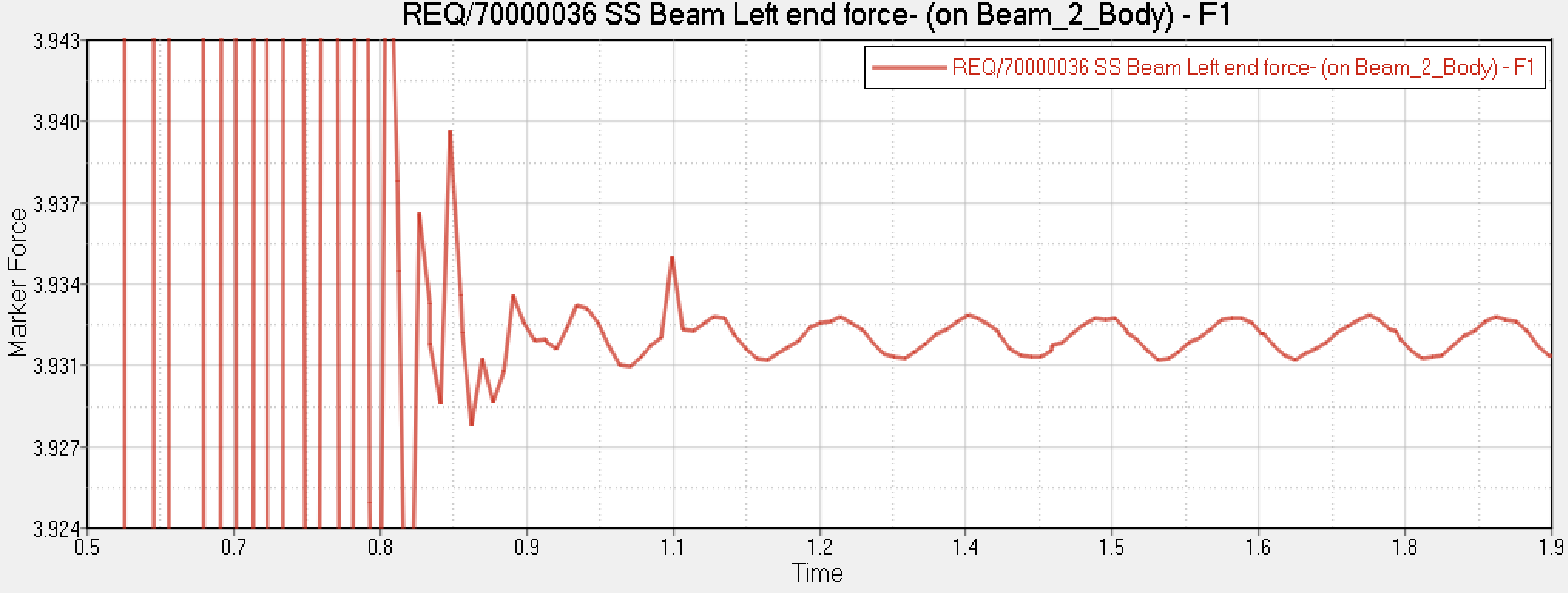
Other Cases:

VARYING THICKNESS (FOR FIXED FIXED BEAM)		
Beam Material	t1=10 mm	t2= 15mm
Aluminium	11.5026N-12.2744N	13.4891N-14.2633N
Steel (Mild Steel)	19.0953N-19.8676N	24.8782N-25.6508N

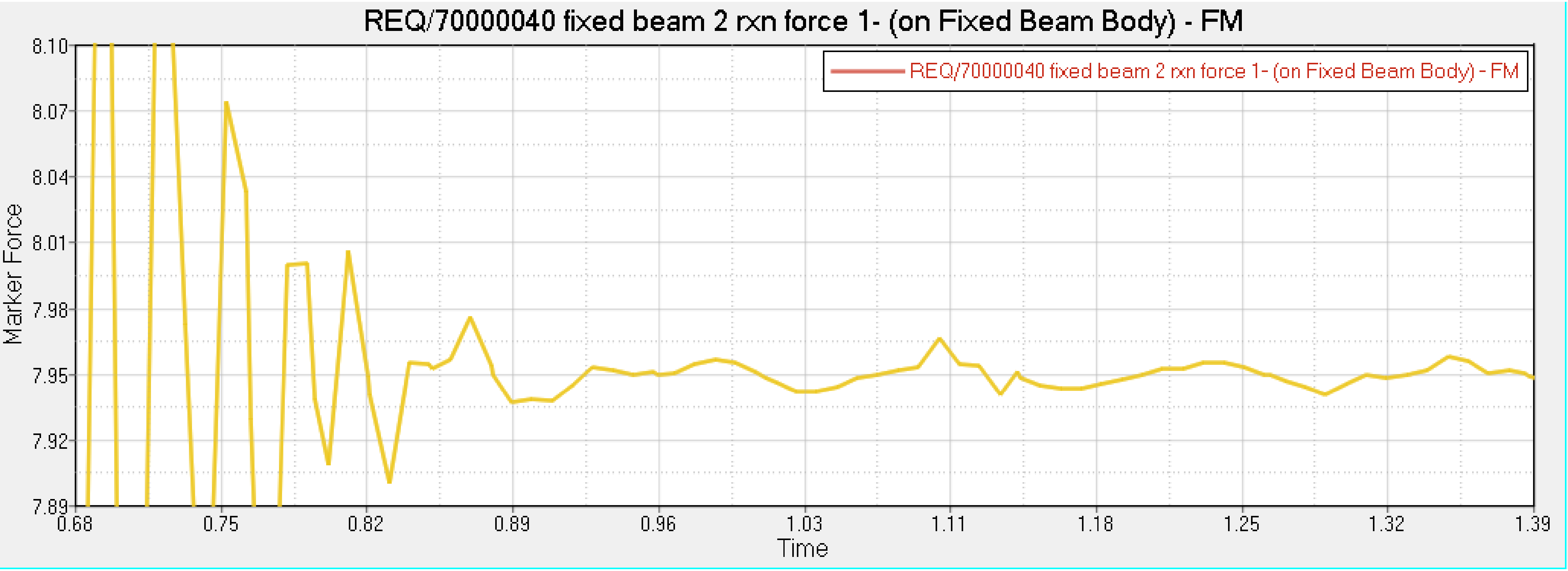
VARYING LENGTH (FOR FIXED FIXED BEAM)		
Beam Material	L1= 1000mm	L2= 800mm
Aluminium	11.5026N-12.2744N	10.7073N-11.4793N
Steel (Mild Steel)	19.0953N-19.8676N	16.7813N-17.5538N

VARYING END CONDITIONS (with length 1000mm width 30mm and thickness 10mm)			
Beam Material	Fixed Fixed Beam	Cantilever Beam	Simply Supported Beam
Alumnium	11.5026N-12.2744N	23.0111N-23.5218N	23.9254N-24.6937N
Steel (Mild Steel)	19.0953N-19.8676N	38.197N-39.7403N	38.1882N-39.7598N

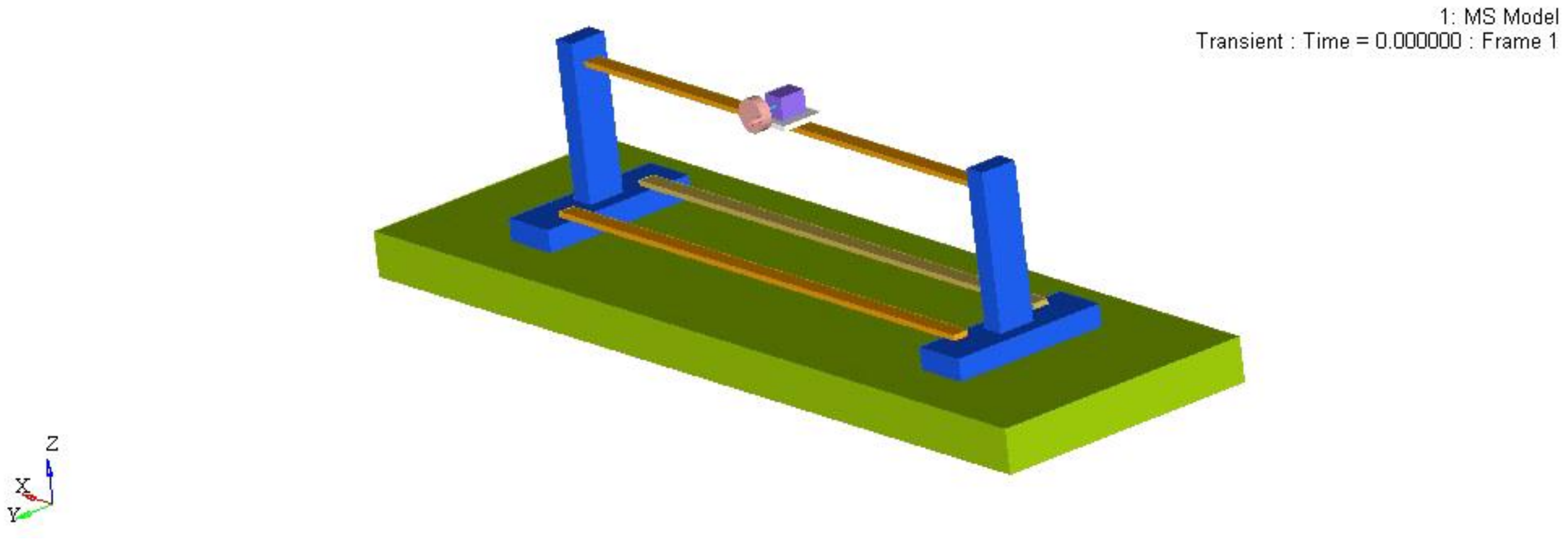
CASE E: Lying Beam, length= 1000mm, width= 30mm, thickness= 10mm (Aluminium)



Reference Fixed Beam



Lying Beam Animation (Aluminium)



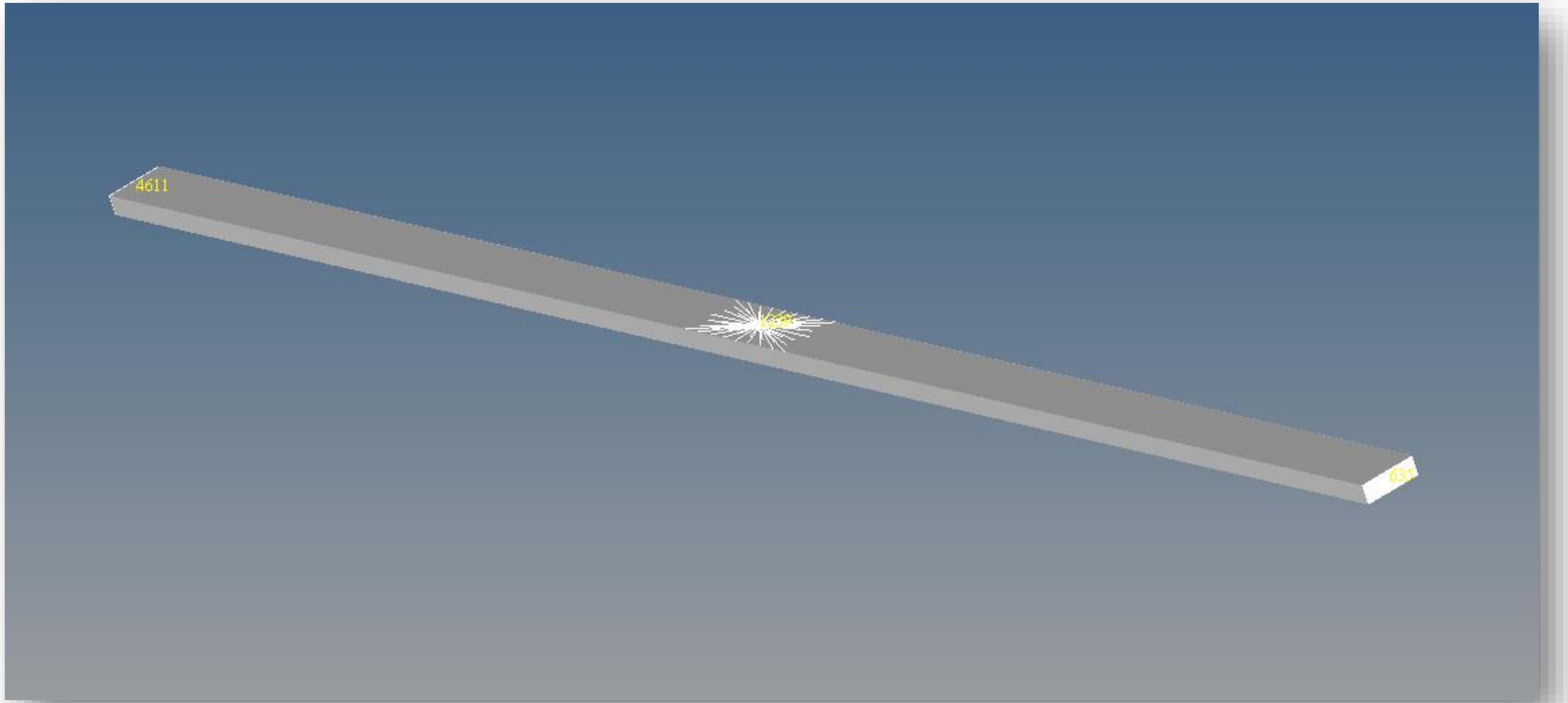
2. Flexible Beam Analysis

Parameters calculated:

- Beam maximum amplitude
- Time stamp of maximum frequency
- Maximum Von-Mises stress (distortion strain energy per unit volume) in the beam for the simulation time of 5 seconds
- Factor of safety (Yield strength of beam/max. VM stress)
- Fatigue life (in terms of number of cycles) for each beam material.

The first two parameters are calculated by extracting the plot data from hypergraph to a spreadsheet.
The von mises stress is calculated in HyperView by deriving the contour plots.
Fatigue analysis is done analytically with the help of S/N curves.

Flexible Beam construction:



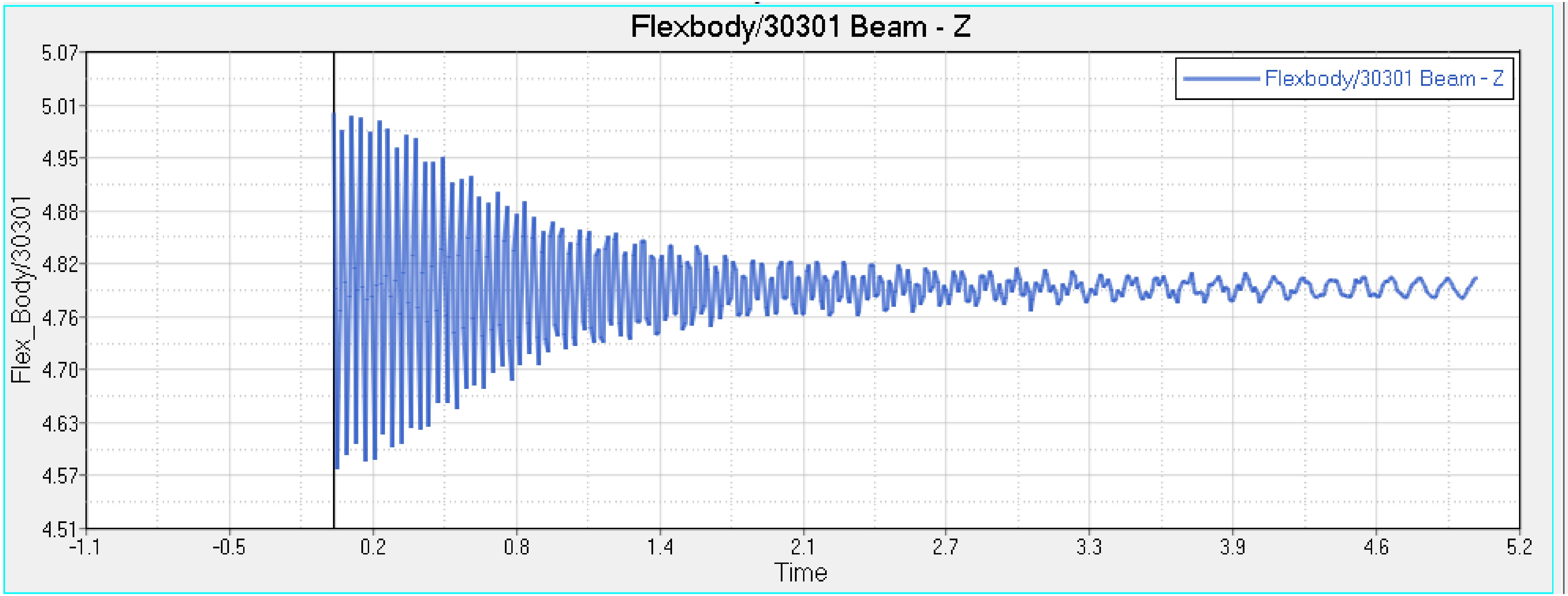
Two flexible beams, one aluminium and one mild steel, are constructed via the flex body prep tool in motionview.

3 RBE2 spiders created at the interface node locations:

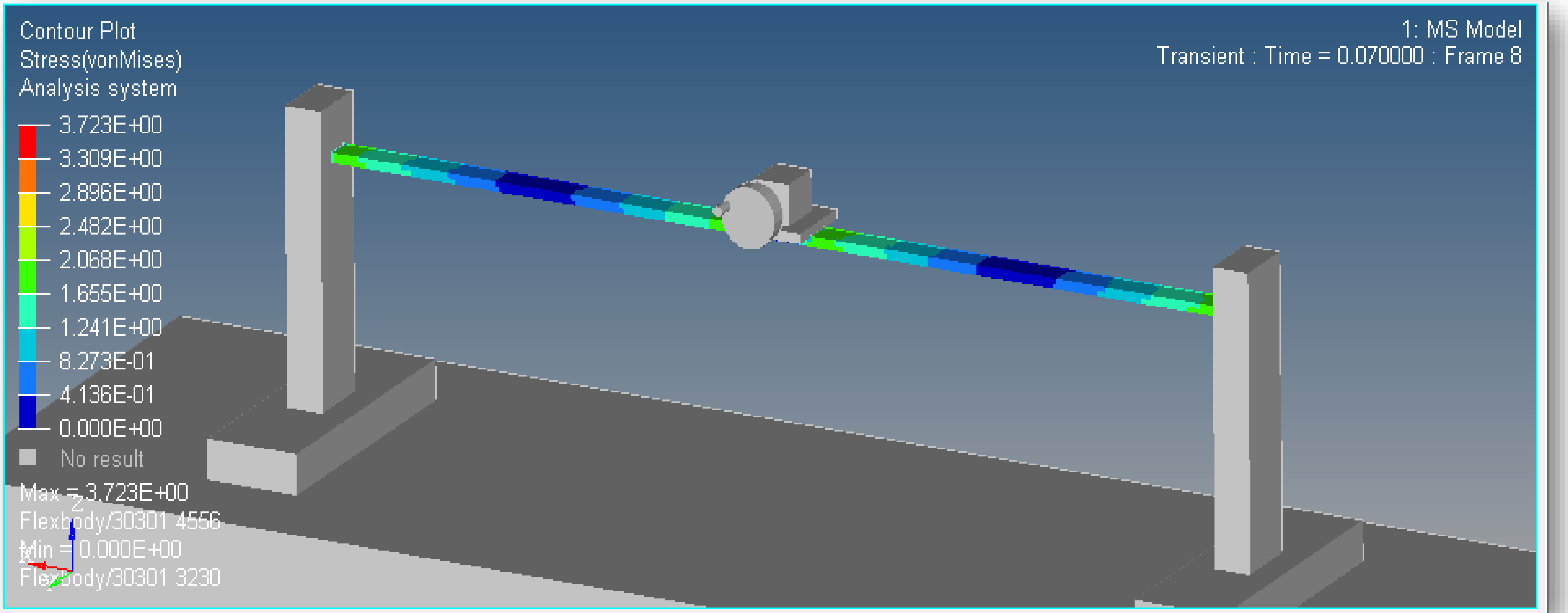
Two fixed joint locations (Node ID: 635 and 4611)

Mount plate and beam bolting location (Node ID: 1239)

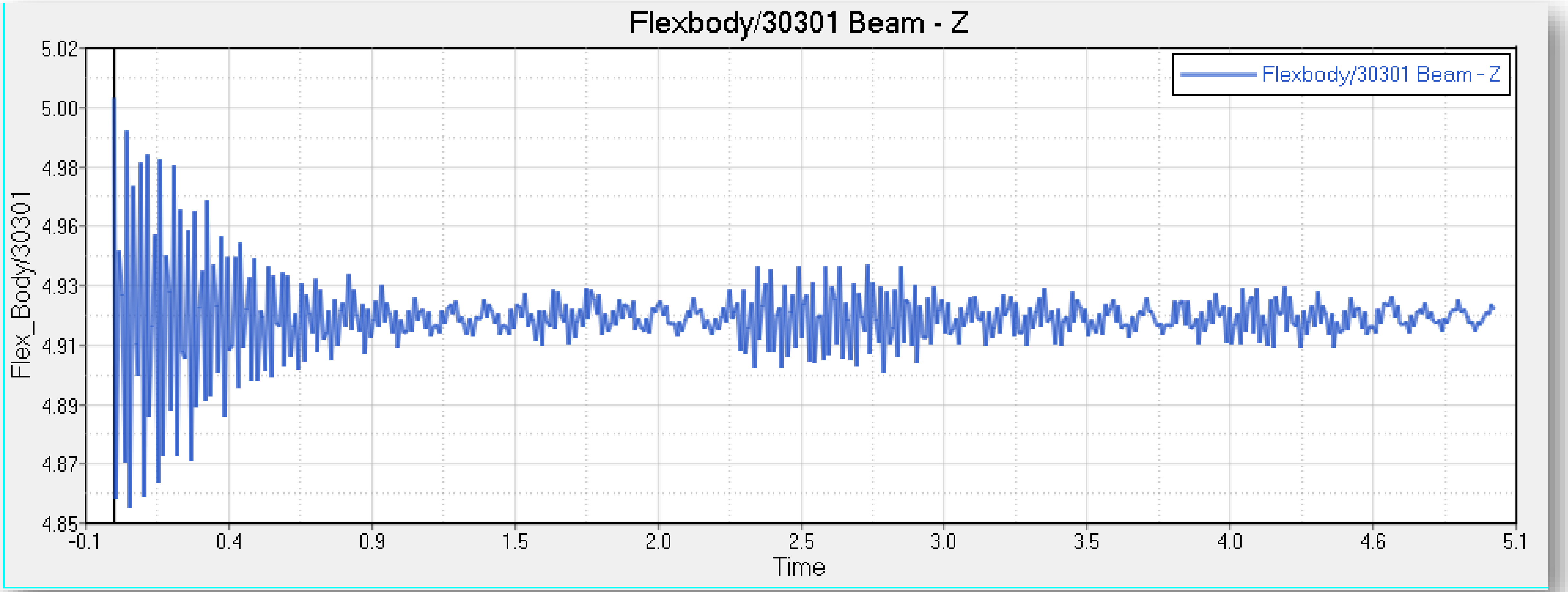
CASE A (Aluminium)
Plot:



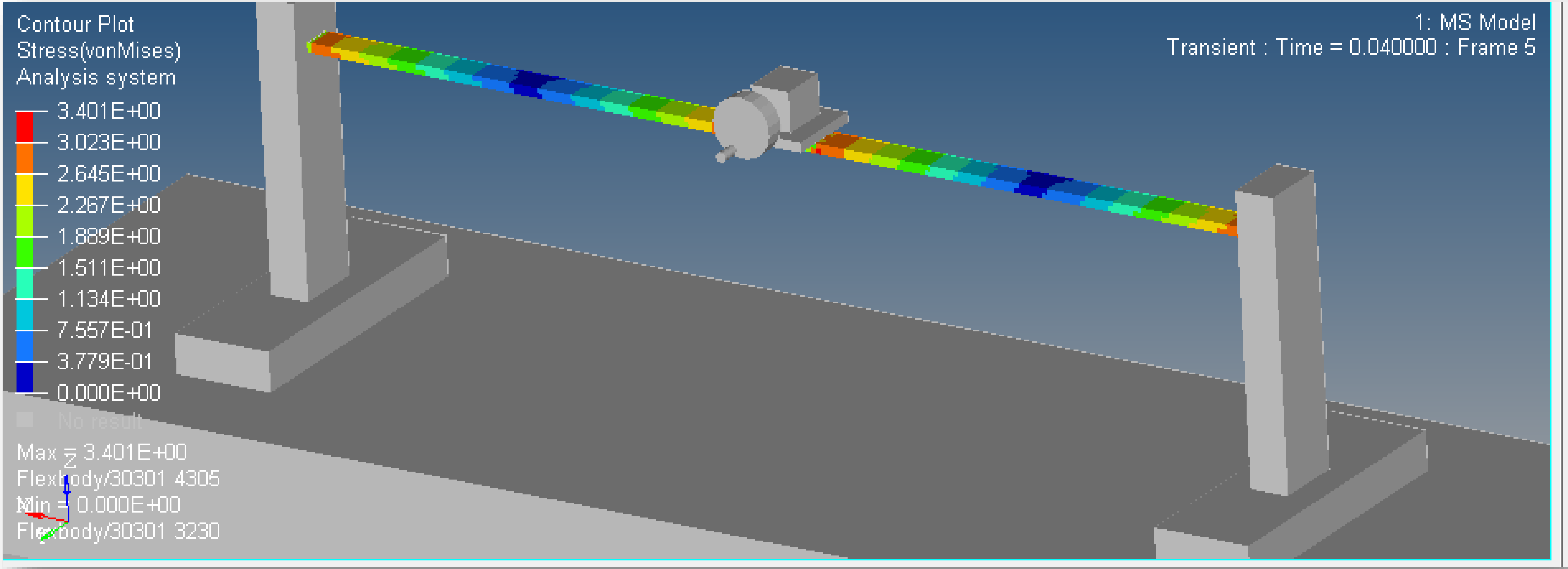
CASE A (Aluminium)
Contour Plot:



CASE A (Mild Steel)
Plot:



CASE A (Mild Steel)
Contour Plot:



VARYING ECCENTRICITY

Beam Material	e1=25mm	e2=15mm	e3=10mm	Maximum VM stress for transient simulation (e1)	Maximum VM stress for transient simulation (e2)
Aluminium	0.21	0.21	0.209	3.723	3.694
Steel (Mild Steel)	0.0712	0.0711	0.0711	3.401	3.417

VARYING MASS

Beam Material	m1=0.0123kg	ı2=0.0009k	m3=0.0740kg	Maximum VM stress for transient simulation (m1)	Maximum VM stress for transient simulation (m2)
Aluminium	0.21	0.205	0.251	3.723	3.611
Steel (Mild Steel)	0.0712	0.0722	0.0872	3.401	3.548

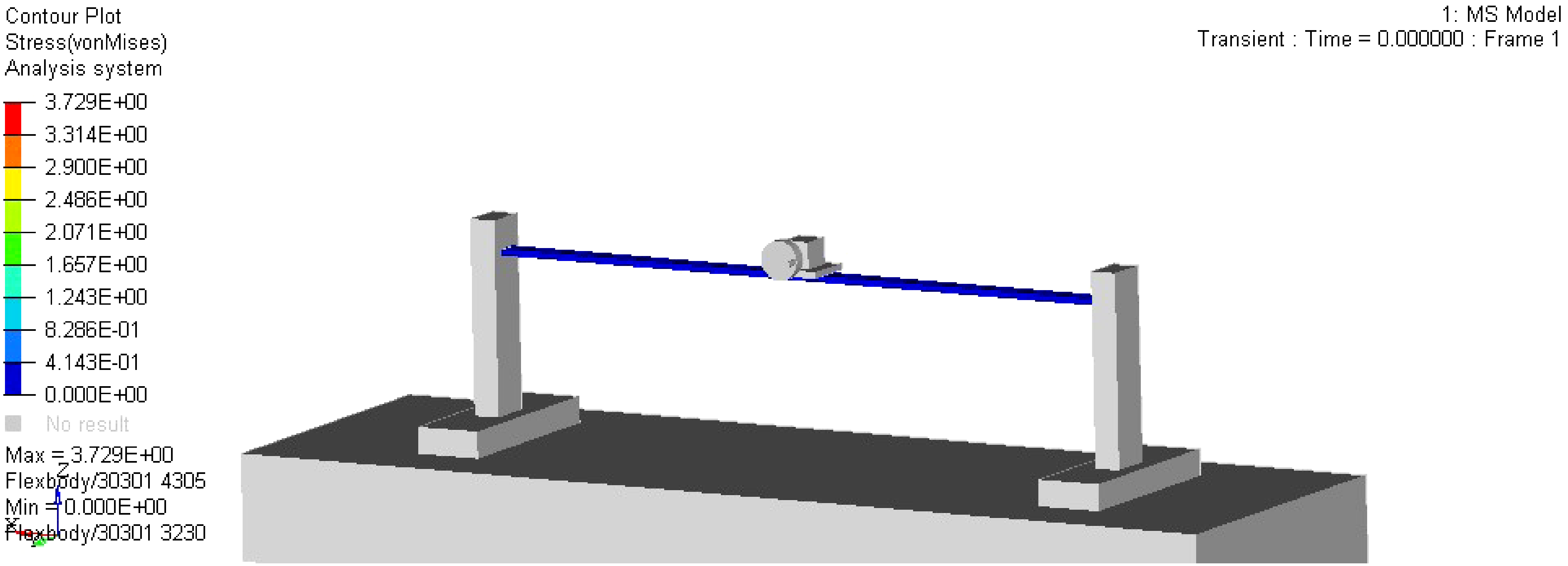
VARYING ANGULAR VELOCITY OF ECCENTRIC MASS

Beam Material	1= 50.265 rad	2= 100 rad,	w3= 20 rad/s	Maximum VM stress for transient simulation (w1)	Maximum VM stress for transient simulation (w2)
Auminium	0.21	0.26	0.212	3.723	4.198
Steel (Mild Steel)	0.0712	0.079	0.0753	3.401	3.656

THE ABOVE VALUES DENOTE THE APPROXIMATE MAXIMUM AMPLITUDE OF VIBRATIONS RECORDED IN THE ABOVE BEAMS IN MM, THE AVERAGE AMPLITUDES MAY VARY

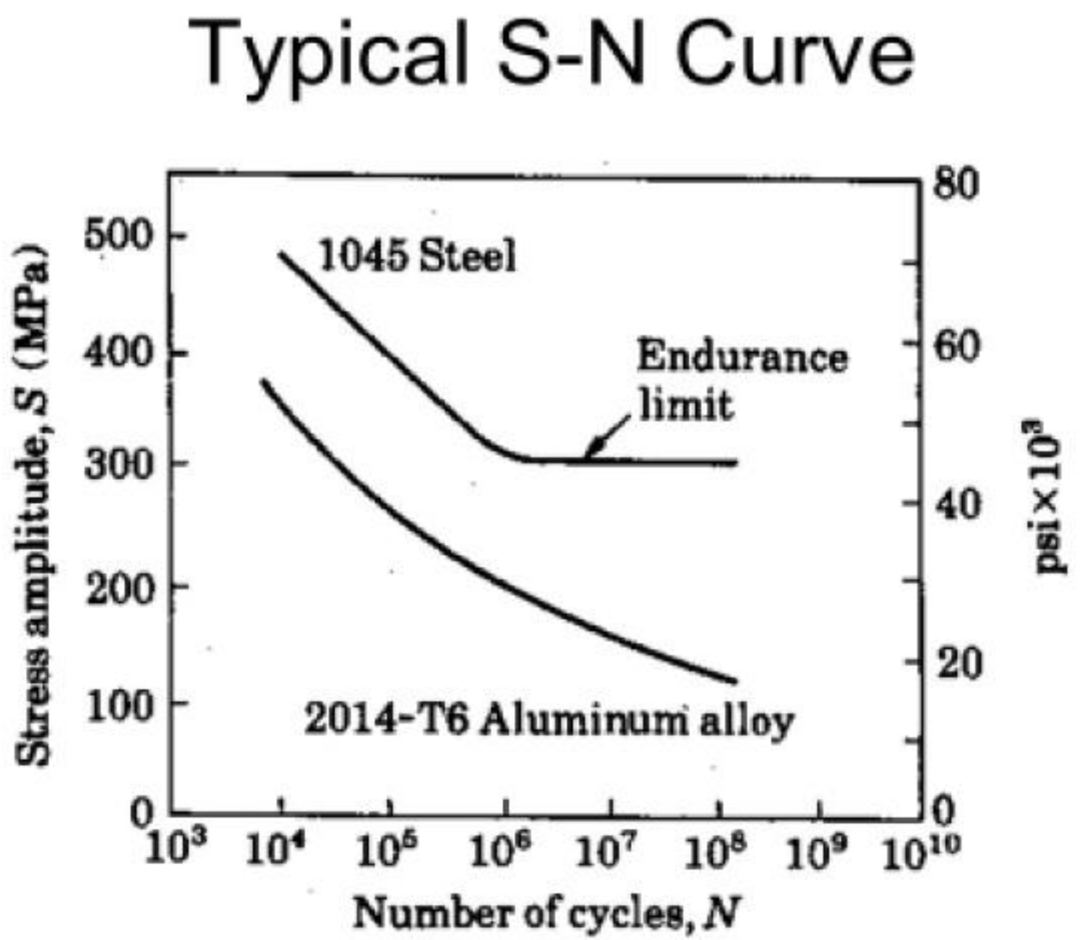
NOTE: **More accurate results can be obtained by using instruments like vibrometer on an actual test rig of such kind.**

Flexible Beam Animation:



Fatigue Analysis:

S/N Curves:



For an S/N curve the mean stress being applied can be related to the number of cycles the material can bear by the following relation:

$$S_n = a.\,(N)^b$$

The endurance strength for aluminium and mild steel specimen is given by:

$$S_{e'}=0.5.\ S_{ut} \text{ for mild steel}$$

$$S_{e'}=0.4.\ S_{ut} \text{ for aluminium}$$

Se denotes the endurance strength for the actual material at critical locations (where stress concentration is high) whereas Se′ denotes the idealised endurance strength of a specimen of that material:

$$S_e = K_a.\,K_b.\,K_c.\,K_d.\,K_e.\,K_f.\,S_{e'}$$

k_a = surface condition modification factor

k_b = size modification factor

k_c = load modification factor

k_d = temperature modification factor

k_e = reliability factor[13]

k_f = miscellaneous-effects modification factor

S'_e = rotary-beam test specimen endurance limit

S_e = endurance limit at the critical location of a machine part in the geometry and condition of use

FATIGUE ANALYSIS PARAMETERS	Ultimate Strength (Sut)	Endurance Strength(specimen) (Se')	Ka	Kb	Kc	Kd	Ke	Kf	En
Aluminium	228	91.2	1.22581	1.06721	1	1	0.897	1	
Mild Steel	841	420.5	0.3345	1.06721	1	1	0.897	1	

For finite life:		
Sn = a(N)^b	N= cycles till failure	For Mild steel:
	Sn= Mean stress being applied	Sn= 0.9.Sut at N= 10^3 cycles
		Sn= Se at N= 10^6 cycles
For mild steel:	Values	
a= ((0.9Sut)^2)/Se Mpa	4254.728558	For Aluminium:
b-= (-1/3)log((0.9Sut)/Se)	-0.249944451	Sn= 0.9.Sut at N= 10^3 cycles
		Sn= Se at N= 5*10^8 cycles
For Aluminium:	Values	
a= ((0.9.Sut)^1.526)/((Se)^0.526) MPa	288.9922841	
b= (-1/5.698)log((0.9*Sut)/Se)	-0.049616799	
Number of cycles till failure:		
N= (Sn/a)^(1/b)		
CASE 1: (e1,m1,w1)	Mean Stress (Sn) (MPa)	Number of cycles till failure (N)
Aluminium	2.896	1.95227E+40
Mild Steel	3.023	3.94942E+12
CASE 2: (e2,m1,w1)		
Aluminium	3.284	1.54887E+39

<u>THANK YOU</u>