Modelling UAP 'Zero Backlash' Joints Within 3D Analysis

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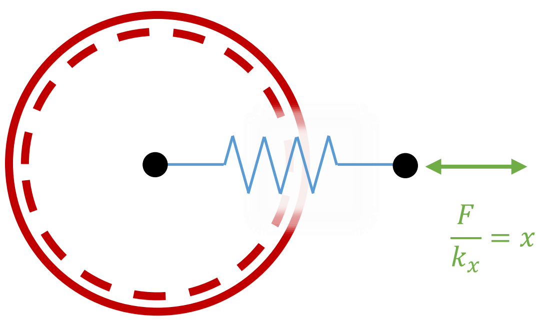
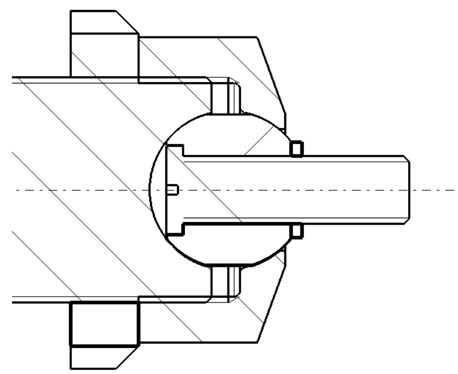
1 Introduction

This report follows on from the previous report 'Zero Backlash Joint Stiffness Analysis Report' and covers using the results of that previous analysis within a large 3D structural or modal analysis. That report should be read first in order to understand this one.

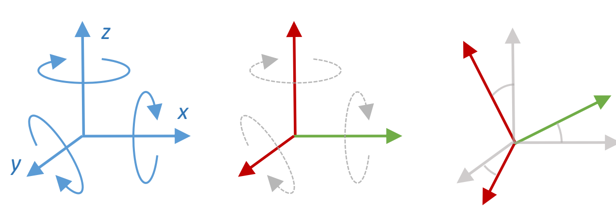
2 Modelling Ball Joint

As previously discussed, the zero-backlash joints being considered here rely upon two spherical-bearing joints. Within the large 3D structural analysis these joints are simplified using a combination of the predefined 'slot' joint type (which allows revolution around all axes and translation in the x axis) and a non-linear spring; as shown in the diagram below:





This combination means that forces in the axis of the joint (here defined as the x axis) will produce a displacement according to the spring stiffness. Since these ball joints are assembled in pairs, an applied load perpendicular to the axis of the joint will produce a revolution around the other joint, therefore assuming a rigid connection with the y and z axes is not an over constraint. The suitability of this methodology depends upon the determination of a spring stiffness which accurately replicates the force/displacement behavior of the whole joint. This will be covered in a following section.

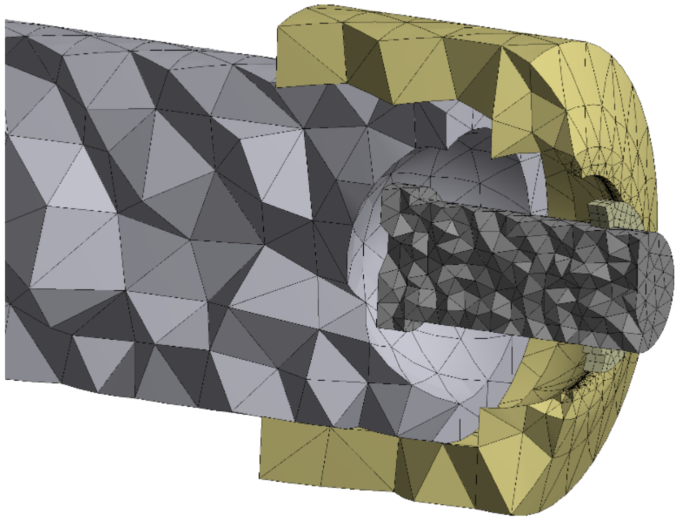


Degrees of Freedom:

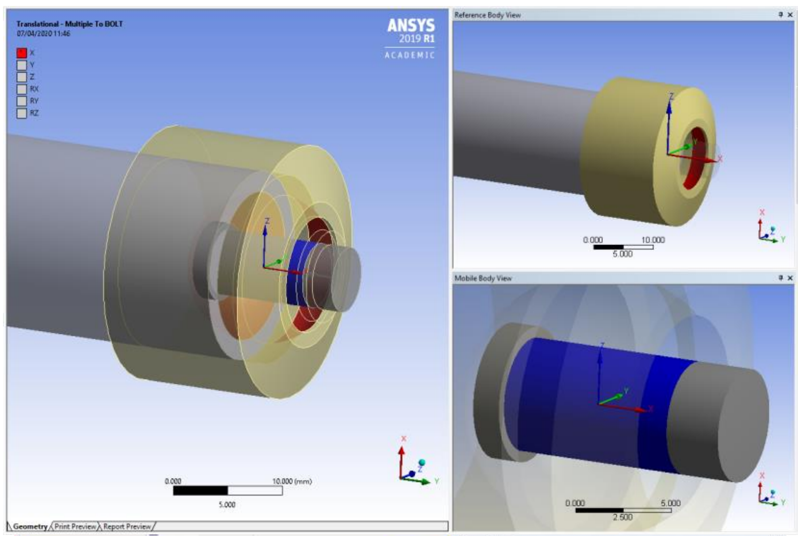
- All revolute degrees of freedom are free.
- Perpendicular axes (z and y) are treated as perfectly rigid.
- The principle x-axis is assumed to have a certain (non-linear) stiffness.

Note: an additional (artificial) constraint equation is added to one of each pair of joints which locks the rotation of the joint around the x axis, which prevents the joint rotating infinitely and preventing the analysis solving. The model used in this analysis is shown below:

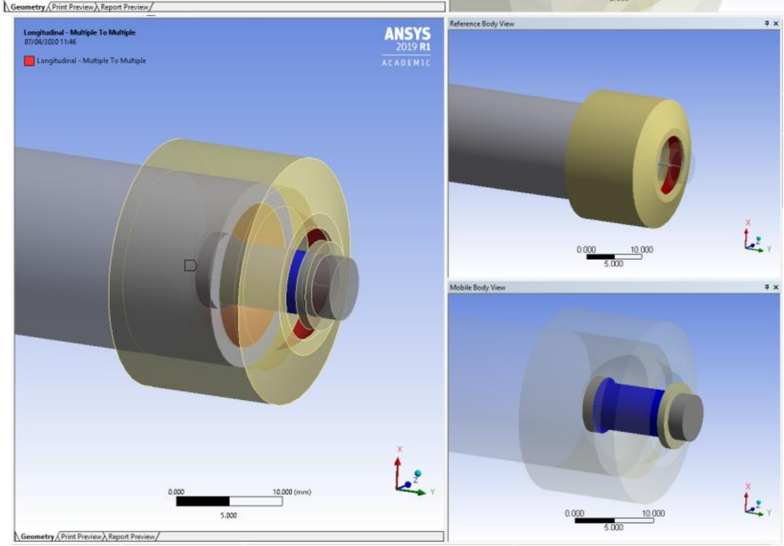
Mesh:



Joint::

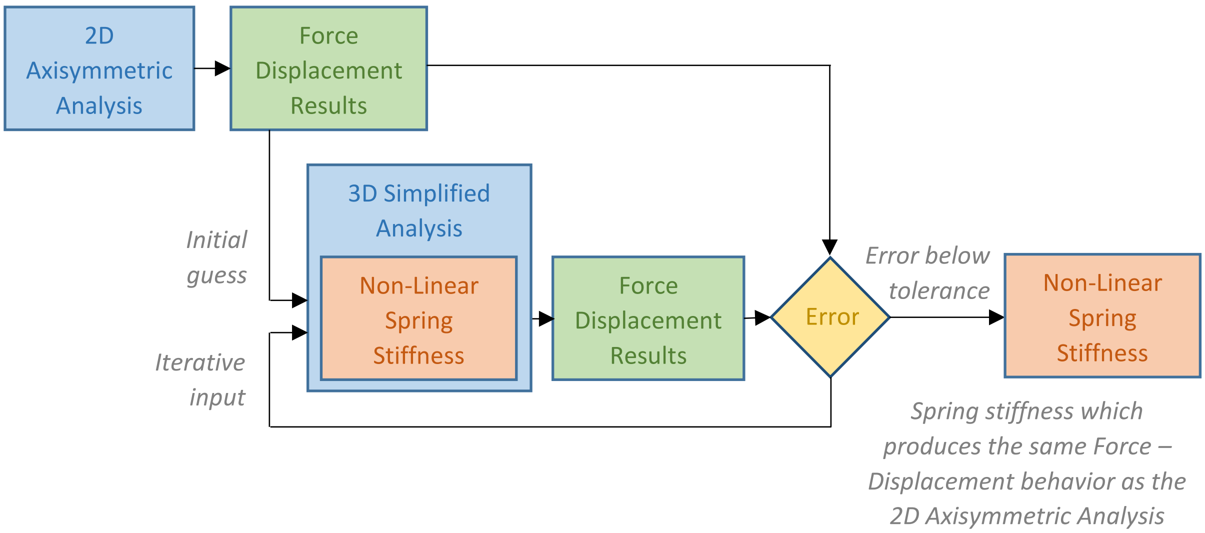


Spring:

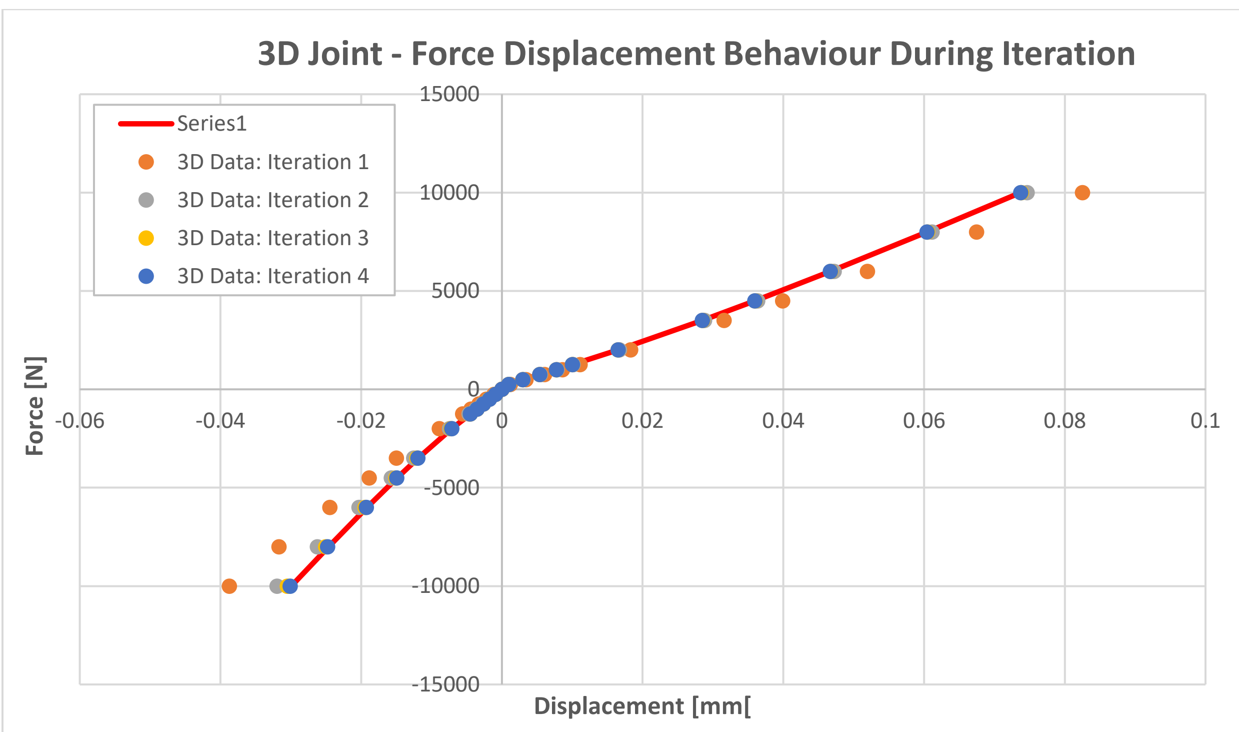


3 Spring Stiffness

The stiffness of the spring within the joint is key to accurately replicating the behavior of the ball joint assembly. An appropriate stiffness for this spring is found using the (previously detailed) 2D analysis and using the following method: the force-displacement results of the 2D analysis are used to initially define the force-displacement behavior of the spring within the 3D assembly. This will inevitably be insufficiently stiff as the stiffness of the other components is not taken into account, however an iterative process can then be followed to determine a spring stiffness which produces the same force-displacement behavior as the original 2D analysis. This is shown in the diagram below:

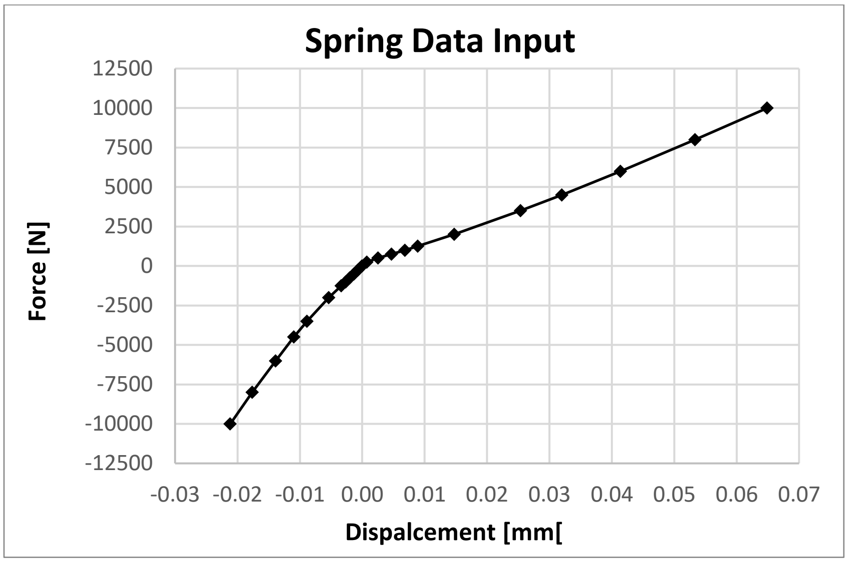


An example of this process is shown below, where the red line is the 2D or 'Goal' response.

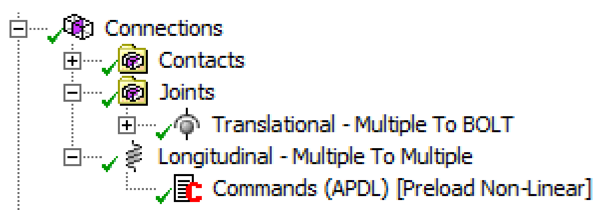


4 Non-Linear Spring Stiffness within ANSYS

Non-linear springs within ANSYS can be utilised using the COMBIN39 element type. These can be used by creating a linear spring with a nominal stiffness, before inserting an ADPL command to transform the COMBIN14 element to a COMBIN39 with a user defined force-displacement behaviour. An example of the force-displacement data which can be inputted within a non-linear spring is shown (below), note the linear interpolation between the known data points.



Inputting the ADPL file within the ANSYS mechanical workbench is shown below:



And the ADPL code inputted is shown below:

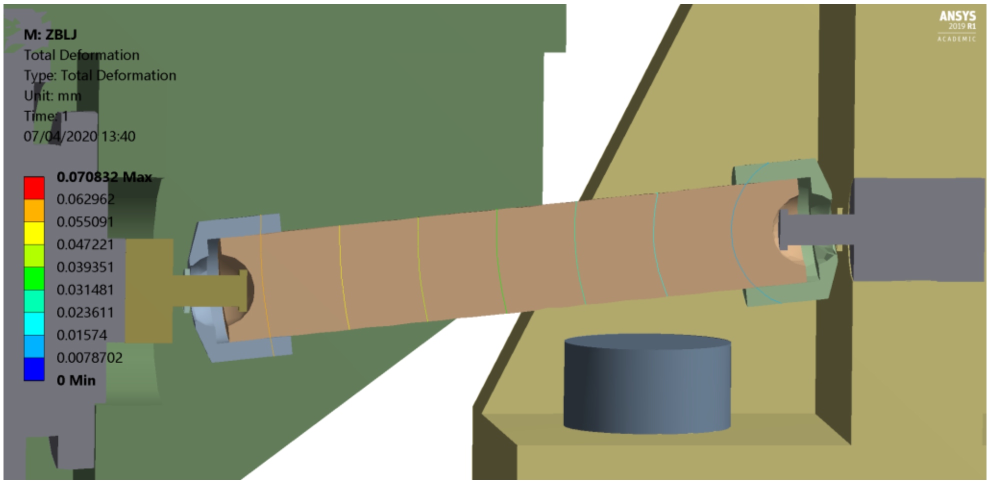
```
ET,_sid,COMBIN39,0,0,,1

R,_sid,-0.02814387655,-10000,-0.02582975853,-9000,-0.02348140022,-8000,
RMORE,-0.02108191115,-7000,-0.0186282643,-6000,-0.01609176316,-5000,
RMORE,-0.01478782441,-4500,-0.01344499189,-4000,-0.01206433267,-3500,
RMORE,-0.01062478148,-3000,-0.00912222474,-2500,-0.00753233402,-2000,
RMORE,-0.00580099807,-1500,-0.00486738177,-1250,-0.00386475991,-1000,
RMORE,-0.00278125978,-750,-0.00191781159,-500,-0.00101358332,-250,
RMORE,-0.00051546094,-125,0,0,0.00053476249,125,
RMORE,0.00110090256,250,0.00305598187,500,0.0056793966,750,
RMORE,0.00820958934,1000,0.01066386282,1250,0.01305120917,1500,
RMORE,0.01766186051,2000,0.02208937375,2500,0.02637757773,3000,
RMORE,0.03055444878,3500,0.03463475209,4000,0.03863701863,4500,
RMORE,0.042572494,5000,0.05028165167,6000,0.05780647802,7000,
RMORE,0.06520023022,8000,0.07249254995,9000,0.07968787104,10000,
```

Note: the data is inserted in pairs of <displacement>,<force> with a maximum of three pairs per line.

5 Non-Linear Spring Stiffness within ANSYS

The displacement of the girder longitudinal flexure due to gravity is shown below. The right hand side of the flexure is fixed to the ground and the left hand side is attached to the main-beam girder. It can be seen that the girder has dropped slightly due to gravity, and the longitudinal flexure has accommodated this deformation as expected (Note: deformation is exaggerated for clarity).



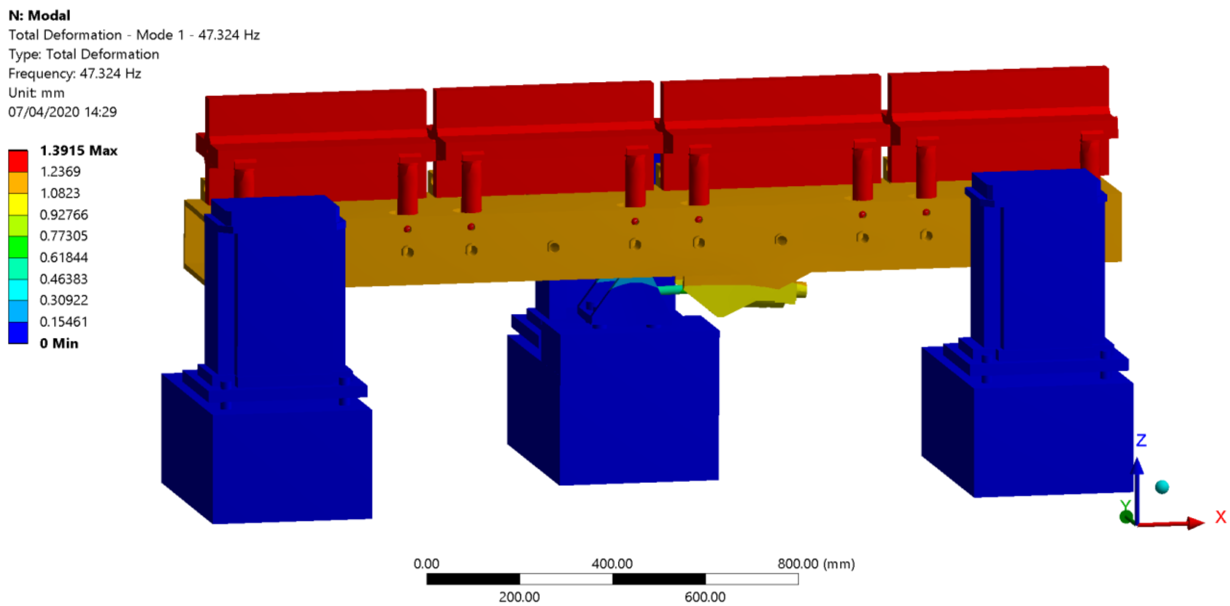
The natural harmonic oscillation of the main beam girder causes the girder to vibrate longitudinally with respect to the fixed point on the ground. This oscillation causes an elongation within the longitudinal flexure shown, something which is accommodated by the non-linear spring detailed previously. The un-deformed and elongated flexures are shown below ((Note: deformation is exaggerated for clarity).

Un-deformed:

Deformed During Natural Oscillation:

6 Results of Modal Analysis

The primary oscillation mode produces causes the main beam girder to vibrate longitudinally, as shown below:



Previous analysis using ideal, and perfectly stiff, ball joints produced a fundament frequency of around 59Hz. Using the stiffness expected of a zero-backlash ball joint with a 14mm bearing this fundamental frequency drops to 47Hz, below the 50Hz goal frequency.

Increasing the diameter of the bearing from 14mm to 22mm increases this fundamental frequency to 53Hz. Further modifying the 22mm joint design (e.g. increasing the thickness of the cap, and reducing the diameter of the hole in the cap) has been shown to increase the fundamental frequency to 55Hz. It is likely that further optimisation is also possible.