

# Tribomechadynamics Challenge 2021: A Multi-harmonic Balance Analysis from Imperial College London

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**Abstract** This work presents the approach and results of the Dynamics Group at Imperial College in face of the Tribomechadynamics 2021 challenge. The challenge encourages to obtain the best blind prediction of a benchmark structure so that a transversal comparison, among the groups working in nonlinear studies, is done. The approach of the Dynamics Group consists in predicting the behaviour due to friction nonlinearities at the location where more energy dissipation is observed. The results show a slight softening in the contact with an overall shifting of the linear frequency of 2.6% and a damping increase of about 1.5% with respect to the linear damping. The effect of the contact is modest, given the lack of dissipated energy and the fact that geometric nonlinearities are not considered throughout this study.

**Keywords** Joints · Tribomechadynamics · Harmonic balance · Nonlinear · FE modelling

## 12.1 Introduction

As part of the 2021 joints community activity, the Tribomechadynamics team introduced a joint modelling challenge to bring the community together during COVID-19 times. The aim of the challenge is to assess the capability to produce blind prediction of a jointed structure. For this purpose, the challenge provides industry standard CAD drawings of a bolted structure, guidelines about the bolt loads, and the excitation of the structure. No further information is provided to let the participants decide on the best way forward.

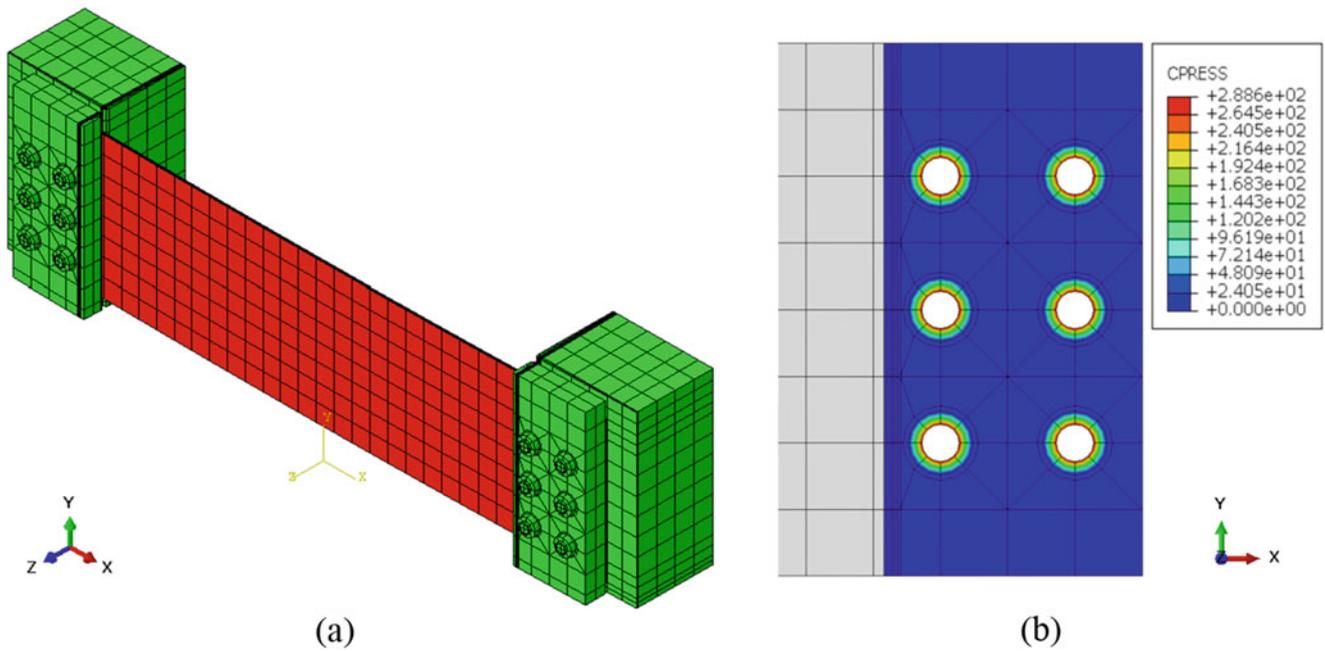
This paper summarises the approach taken by the Dynamics Group at Imperial College London to tackle the problem, purely focusing on the friction nonlinearity and ignoring the presence of the geometric nonlinearity. The approach is based on a detailed discretisation of the nonlinear contact interface with Jenkins elements and the harmonic balance method (Imperial's in-house solver FORSE) to find the steady-state response of the system under base excitation.

The paper will discuss the chosen approach in detail, discuss Imperial's results, and provide recommendations on how to improve the modelling of such bolted joints.

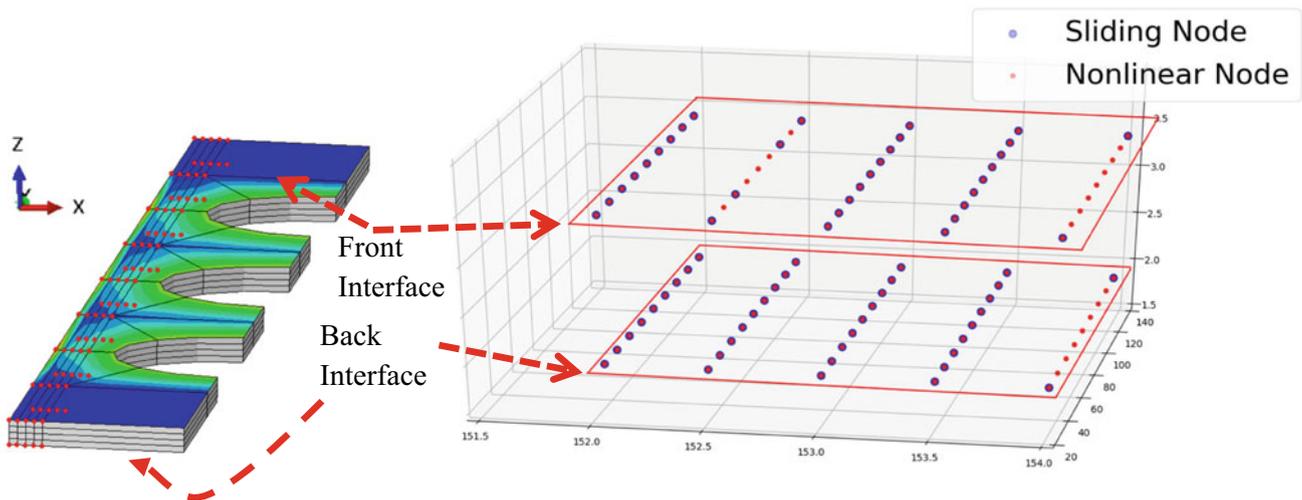
## 12.2 Background

This computational campaign includes three steps. First, a finite element (FE) model is built in Abaqus, and static, modal, and dynamic analyses are carried out. Second, a pre-processing step reads the simulation's output and writes the input files for FORSE [1–3]. Finally, force controlled nonlinear simulations are computed, and the information is post-processed to obtain the results in the format requested for the challenge.

The FE model and static results are displayed in Fig. 12.1. To simplify things, it was decided to remove the base of the support and focus on the plate holder only. The mesh is comprised of quadratic brick elements (C3D20). The simplified support (in green) has 30066 nodes and 6064 elements and the panel (in red), 12881 nodes and 2432 elements. A series of concentric circles around each bolt is included in the mesh to capture the pressure spread due to the pressure cone.



**Fig. 12.1** (a) FE model mesh: support (green), panel (red). (b) Pressure distribution (CPRESS) of the right side of the panel



**Fig. 12.2** Nonlinear mesh, indicating nodes on the front (higher z-values) and back (lower z-values) interfaces of the refined edge

A bolt load of 9900 N is applied using the Bolt Load tool available in Abaqus [4]. The contact conditions are ‘hard contact’ in the normal direction and ‘penalty’ friction formulation, with  $\mu = 0.67$ , in the tangential direction. An intermediate step between the FE simulations and FORSE simulations is required. This step consists of the extraction of the data from the static, modal, and dynamic simulations, to build the corresponding input files for the in-house software FORSE.

To ensure converged results, a single row of nonlinear nodes in the x-direction was added consecutively at 0.5 mm from the edge, starting from 1 up to 5 rows, until the nodes in the last row are stuck and therefore not dissipating energy. Figure 12.2 shows this refinement and the status at resonance of the 5 rows, 180 nonlinear nodes in total.

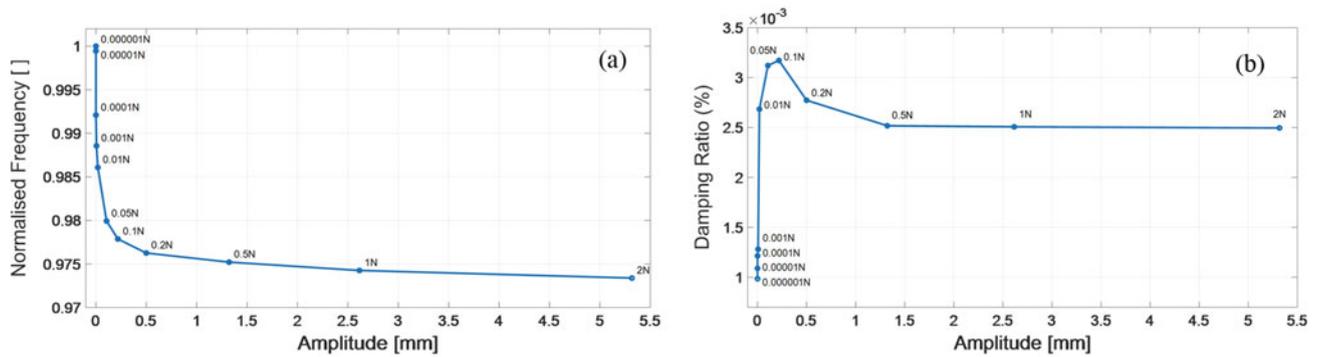


Fig. 12.3 (a) Frequency-amplitude dependency and (b) damping-amplitude dependency, due to different excitation forces

## 12.3 Analysis

With the final mesh in place, the nonlinear simulations are carried out from 2N until 0.000001N (linear case) of excitation in the middle node of the panel, in the z-axis. From these simulations the FRFs are extracted, and a linear modal fitting tool is used to extract the corresponding amplitude and damping at resonance. Since the linear tool is not really appropriate for a nonlinear FRF, an adjustment is applied by using a linear formulation for  $x/F$  at resonance [5] to adjust the amplitude of the fitted FRF to the predicted nonlinear values. It must be noted that this approach is not ideal but will provide a rough guideline for the damping due to friction in the joint.

Figure 12.3 displays frequency and damping dependency on amplitude. Figure 12.3a shows a reduction of 2.6% in the resonance frequency with respect to the linear case at 118.3Hz, with a rapid decay as the nonlinear nodes transition from the stuck to the sliding case.

Figure 12.3b shows the damping dependency on amplitude. It should be noted that a very low linear damping ratio of 1E-3% was used in the simulation to not overpower the frictional effects. For cases close to linear, the damping stays around the expected modal damping. As the load increases, the damping very quickly reaches a peak value of 3.2E-3%, between 0.05N and 0.1N, after which the damping stabilises around 2.5E-3% since more nonlinear nodes detach from the contact, therefore no longer being able to dissipate energy. Overall, this is considered very low damping, highlighting in the authors opinion that the joint does not lead to much damping.

## 12.4 Conclusion

A computational study, in answer to the open Tribomechadynamics challenge 2021, is presented here by the Dynamics Group at Imperial College London. A progressive approach is taken to increase certainty that the nonlinear behaviour in the panel-support interfaces is fully captured. The predictions show that a small amount of friction damping occurs and therefore the contact exhibits some frequency shift and damping variation with respect to the linear case, as more nodes transition from a stuck to sliding condition. By gluing all nodes that are not expected to contribute to the damping, this approach assures that only the elements that would dissipate energy are considered, and no extra solving time is added to include the effect of permanent stuck nodes. Therefore, it is relatively fast to solve; in this case 180 nonlinear nodes were required to capture the behaviour of the edge, and a wall time of approximately 6 mins was required to solve each nonlinear response.

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