2024 International Nuclear Atlantic Conference – INAC 2024
Escola de Guerra Naval, Rio de Janeiro, RJ May 6 - 10, 2024

ISBN: 978-65-594-1256-3

The effects of support nonlinearities in the piping structural response

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1. Introduction

The structural integrity of piping systems is a major concern for the oil industry and nuclear energy facilities. These systems and your components became vulnerable to failures because of thermal or mechanical loads, as well as natural phenomena. Pipe supports accommodate the weight of the pipe and other components, avoiding excessive loads at the line. In addition, they provide safe conditions for flanges and nozzles, which resist or limit free thermal movement [1].
On the other hand, the geometric nonlinearities (GNL) in the supports can change the flexibility and acceptability of the systems. So, the effect of thermal expansion can affect the stiffness of the constraints on the line, as well as the gap between the pipe and the support increases or decreases. This feature requires doing nonlinear analysis, to solve the problem using an iterative method. Researchers such as that conducted by Sobieszczanski [2] analyzed a pipe geometry with rough surface and sliding support. The efficient arrangement of the brackets in the line keeps the dead weight from loading, but with temperature, the pipe expands in a longitudinal direction. In a similar way, Peng [1] and Anderegg [3] explain three techniques for apply friction in support using computer programs comparing support friction and frictionless analysis. In the fixed and variables stiffness methods, each nonlinear constraint received assign two fictitious orthogonal constraints, in the perpendicular plane to the main support constraint. The result show that the most reliable solving method is to use orthogonal springs as the constraints. The friction force can be influenced by different factors, such as location, quantity of support, and sliding surface. In the same way, Antaal at.al [4] explain that opposing force may restrict the unconstrained thermal growth, leading to create elevated loads in guides and anchors. This work evaluates the effects of GLN in a nuclear piping under mechanical and thermal loads. It is essential to follow ASME B31.1 [5] ASME B31.3 [6] and ASME NF [7] to meet the acceptance criteria for the piping elements, nozzles and supports for safe plant operation.

2. Methodology

One of the most extensively used techniques for assessing the GLN in piping systems is the variable stiffness matrix. The case of study performed here considered the method from Peng [1] and Sobieszczanski [2] following the rules and requirements of ASME B31.1 [5]. The piping was discretized with linear finite elements, with two nodes in straight pipes and three nodes in pipe bend. To define straight pipes, the PIPE 16 element was used, based on the nodal coordinates (I, J, K). In the same way, we discretized the pipe bend with a PIPE 18 element, that offering the choice of including flexibility and stress intensification factors. Both elements enable applying pressure, temperature, internal fluid, and dead weight loads. To represent components such as flanges and valves with massive cross-sections, the MASS21 element was used, as it has the six degrees of freedom. CONTA178 and COMBIN14 elements were used to constrain support conditions in six degrees of freedom and model the support geometries and nozzles [8].

The support was mounted based on design aspects, such as the spacing between them, the load to be carried, and preventing undesired movement. In Figure 1, the arrangement is presented, whereby the pipe support has two configurations that were implemented in the analysis.

a. Support bracket: restriction in the longitudinal direction +Y, allowing displacement longitudinal in directions x and z.
b. Saddle support: the restriction in longitudinal directions y and z, allowing displacement in axial direction in x.

The friction coefficient for steel interfaces in the contact region was based on values varying from 0.2 to 0.8. In the analysis, a friction coefficient of 0.3 and starting clearance of 0.001 mm were used. Besides that, longitudinal stiffness constraints, the standard value of 1.75e14 N/m was used [10]. Give this method, a study was conducted considering dead weight and temperature variation loads. After conducting individual load cases, verifications were executed in joint load cases as well.

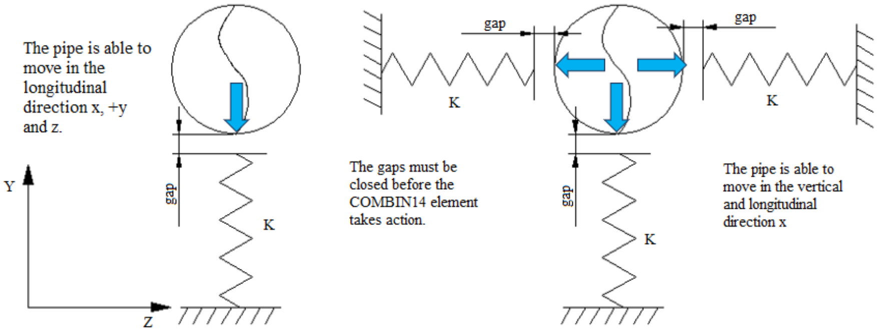

Figure 1: Elements CONTA178 and COMBIN14 need to be implemented. In (a) nonlinear configuration for the resting support and (b) nonlinear configuration for the saddle support.

The geometry was created and simulated using ANSYS software, including contacts and gaps, to accurate representation of the system, as shown in Figure 2.

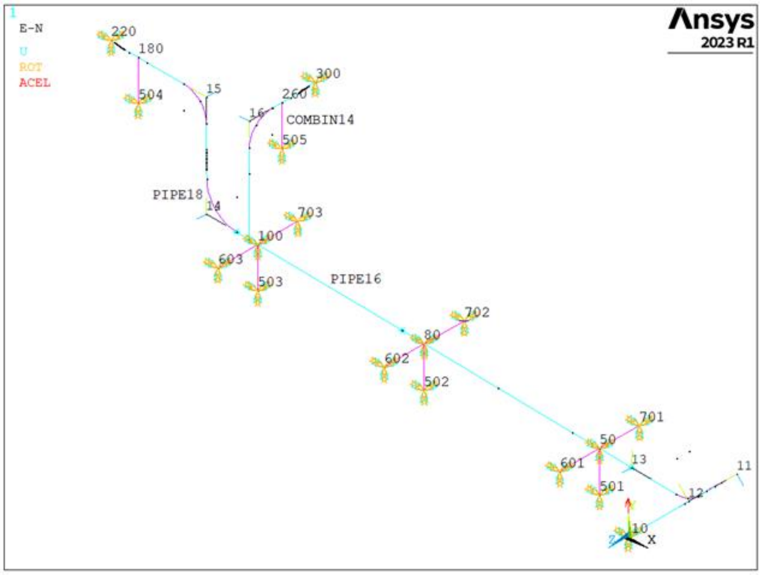

Figure 2: Discretized geometry of the case study.

To discuss the issues of concern, a study of the case will be conducted. Linear spring constraints are used in static linear analysis to load dead weight with temperature variation. The nonlinear constraints are used here, considering the arrangement of Figure 1. At the initial stage gap is used and after that, both boundary conditions gap with friction.

3. Results and Discussion

The results of the linear and nonlinear analysis (gap and friction) were compared. Figure 3 shows the increase in vertical displacement, with a of 0.94 mm between linear and nonlinear analysis (gap/friction) at node 80. But there are meaningful differences in the results considering linear and nonlinear behavior of the supports. For instance, the thermal expansion exceeds the dead-weight, and the piping lifts, leaving the support to become inactive. As a result, there may be relevant loads in the line close to the supports.

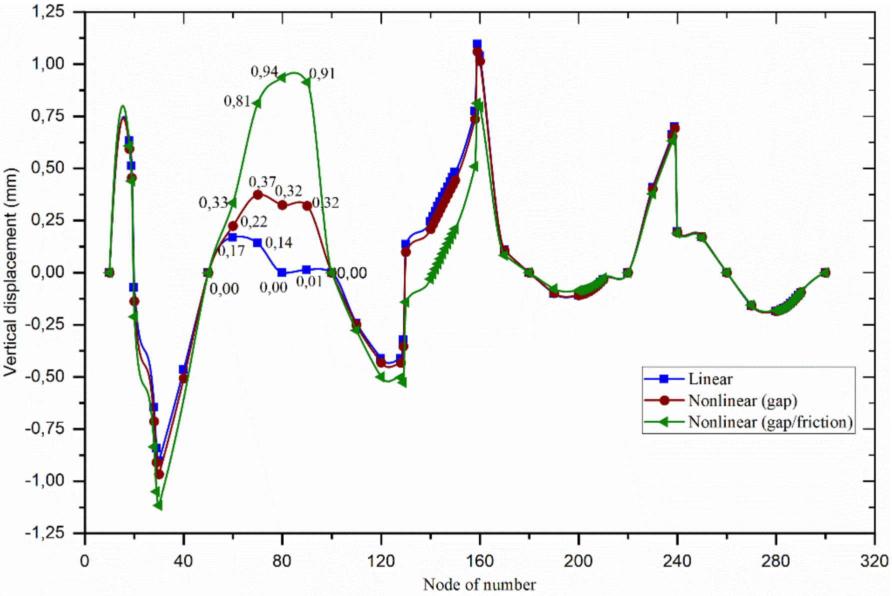

Figure 3: The effect of thermal expansion of pipes.

Another explanation was given in Table 1, comparing the forces from linear against nonlinear.

Table 1: Reaction forces in longitudinal and vertical directions.

		FX (N)			FY (N)	
Node	Linear	Nonlinear (gap)	Nonlinear (gap/friction)	Linear	Nonlinear (gap)	Nonlinear (gap/friction)
10	-60958,00	-60861,00	-67324,00	-16257,00	-15767,00	-16958,00
220	54253,00	54016,00	43749,00	54729,00	53474,00	41104,00
300	6705,30	6834,50	4643,30	74145,00	73574,00	71972,00

In this situation, there is a decrease at nodes 10 and 220, although an increase in the node 300. In the second case, there is a growth at node 10 and a decrease in the nodes 220 and 300. As observed in Peng [1], the friction prevents piping from moving in longitudinal and transversal directions because the piping systems became stiffer. Notably, the comparison of the results between linear and nonlinear (gap) highlighted changes in friction during the moments. Under the current result, the moments found in longitudinal (MX), and transversal (MZ) directions decline, while in the vertical (MY) direction increases 11.5%.

4. Conclusions

This paper addressed the behavior of geometric nonlinearities in the piping supports. It was found that in the dead weight analysis, there are significant change the axial displacements in the line, and therefore, there was no notable change in the loads on the anchors. In contrast, the temperature variation causes high vertical displacements because of thermal expansion. This effect increases the clearance between the pipe and the support, leaving it inactive, as well as overload others nearby. In the longitudinal direction of the pipes, friction can contribute to support by making it stiffer. At elevated temperature variations, friction cannot resist the longitudinal piping thermal expansion and increase at stresses in the pipes, and in the support structures, flanges, and nozzles. This assessment shows that the nonlinear supports behavior changes the forces and moments on the piping system, supports, flanges, and nozzles. So, the GNL must be adequately considered in the piping system's structural analysis, mainly in nuclear installations. The aspects discussed here may be highlighted when considering occasional effects, such as water hammer and earthquakes.

Acknowledgements

Instituto de Pesquisas Energéticas e Nucleares, IPEN-CNEN/SP and Fundação Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, CAPES.

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