

EXPERIMENTAL AND NUMERICAL MODAL ANALYSIS OF GASTRONORM FOOD-SERVICE CONTAINER

BENEDIKT RUSEK¹, MARTIN SOTOLA¹, JAKUB CIENCIALA¹,
ZDENEK PORUBA¹, MICHAL SOFER¹, ANNA TOSKOVA¹,
MARTIN FUSEK¹, AND PAVEL MARSALEK¹

¹Department of Applied Mechanics, Faculty of Mechanical
Engineering, VSB – Technical University of Ostrava,
17. listopadu 2172/15, 708 00 Ostrava, Czech Republic

DOI: 10.17973/MMSJ.2026_10_2026065

jakub.cienciala@vsb.cz

ABSTRACT

Stainless-steel gastronorm (GN) containers, commonly used in food-service operations, are widely employed for food storage, handling, and transportation. However, despite their extensive industrial utilization, scientific studies addressing their structural dynamics and modal behavior remain very limited. The aim of this study is to identify the modal parameters of the GN container in two distinct states: empty and filled with 10 liters of water. In parallel, a finite element model accounting for the thin-walled geometry of the container is developed to enable numerical simulation of its dynamic behavior. Numerical results are compared with experimental data, and the model is subsequently updated to achieve strong correlation between numerical and experimental modal parameters. The results show that the first natural frequency of the empty container is 133.2 Hz, corresponding to the torsion of the rim. Filling the container with 10 liters of water causes a significant decrease in this frequency to 54.1 Hz and leads to a modification of the mode shape. The obtained results provide deeper insight into the vibration behavior of GN containers and confirm the suitability of combining experimental and numerical approaches for the analysis of thin-walled structures used in food-service applications

KEYWORDS

Gastronorm Container, Experimental Modal Analysis, Numerical Modal Analysis, Vibration Behavior, Thin-walled Structures

1 INTRODUCTION

Stainless-steel containers standardized according to the gastronorm (GN) container system are widely used in food-service operations for food storage, preparation, transportation, and thermal processing. Their standardized dimensions enable compatibility across various kitchen equipment and transport systems, making them an essential component of modern catering and large-scale food production environments. During operation, these containers are frequently subjected to dynamic loading caused by handling, transportation, and mechanical vibrations originating from external equipment or vehicle motion.

Despite their widespread industrial use, the dynamic behavior of GN containers has received limited scientific attention. While existing literature extensively covers large-scale storage tanks and generic rectangular vessels, there is a lack of research specifically addressing standardized thin-walled containers used in the food-service industry. These containers possess unique

geometric features, such as the reinforced rim and specific aspect ratios, which dictate their modal behavior differently than standard industrial tanks. Thin-walled stainless-steel structures are generally characterized by relatively low stiffness and pronounced vibration sensitivity, which may influence structural integrity, noise generation, and operational reliability, particularly when partially filled with liquid.

Modal analysis represents an effective approach for identifying the dynamic characteristics of mechanical structures and validating numerical models. Experimental modal analysis enables the determination of modal parameters under real operating conditions, while numerical simulations based on the finite element method provide insight into structural behavior and allow parametric investigations that are difficult to realize experimentally. Modal analysis of shell and thin-walled structures has been extensively studied in the context of vibration characteristics of curved and composite shells, which are structurally similar to thin-walled GN containers [Bazhenov 2019, Bochenski 2019, Li 2013]. The influence of fluid level in containers has recently been investigated. Jhung and Kang [Jhung 2019] conducted an investigative study of square tank filled with fluid. They performed numerical modeling with various boundary conditions, various geometry (aspect ratio) and various fluid levels. The results showed that the inclusion of fluid inside the tank lowers the natural frequencies. This effect was observed across all boundary conditions, although at different rates. Aspect ratios larger than 2 exhibit nearly identical natural frequencies for each fluid level. Anagha et al. [Anagha 2020] studied the effect of fluid on the modal characteristic of ground supported water tanks. They also focused on the numerical modeling of rectangular tank with various boundary conditions and fluid levels. They found that similarly to previous authors that natural frequencies will decrease with fluid inside the tank. The fluid also has more impact on clamped-clamped condition than others. Drahorad et al. [Drahorad 2025, Drahorad 2026, Drahorad 2023] presented experimental and numerical investigation of the modal behavior of bolted storage tanks, including both filled and empty state. They proposed the validated numerical model with assessment of fluid-structure interaction to prepare studies of bolted tanks. The presence of fluid introduces additional mass effects and fluid-structure interaction phenomena that significantly modify modal properties such as natural frequencies f , damping ratios ξ , and mode shapes.

The necessity of this research stems from the increasing demand for transportation in catering logistics. Uncontrolled resonance in these containers can lead to excessive acoustic emissions in professional kitchen environments, and potential stability issues during handling. The aim of this study is to investigate the modal properties of the GN container in two distinct states: empty and filled with 10 liters of water, using a combined experimental and numerical approach. This comparison provides a fundamental understanding of how maximum liquid capacity alters the dynamic response of the structure. Subsequently, a parametric study is carried out to evaluate the influence of standardized container dimensions, according to the EN 631-1 standard, on the dynamic behavior of the structure. Understanding the dynamic behavior across different GN containers is important for preventing excessive vibrations during transport, reducing noise, and improving structural durability in real operating conditions.

2 MATERIAL AND METHODS

GN containers are standardized according to EN 631, which defines the dimensions and modular system of catering containers. A key feature of this system is its modularity, based

on the GN 1/1 size of 530 mm × 325 mm with a height of 200 mm. Standardization ensures compatibility, interchangeability, and operational efficiency in professional catering environments. For this study, the GN 1/2 container (325 mm × 265 mm) with a height of 200 mm was selected. For typical catering and transport applications, the maximal fill level is 10 liters of water. Accordingly, two experimental conditions were considered: the empty gastronorm container (GN-EC) and the gastronorm container filled with 10 liters of water (full container, GN-FC). No lid was used during the experiments to simplify modal measurements. In the following sections, the geometry of the GN container, the experimental modal analysis procedure, and a detailed description of the numerical model are presented.

2.1 Geometry of Gastronorm Container

The geometry of the GN container is a shell in the shape of a trapezoidal prism with a rectangular base, where the bottom is slightly smaller than the top, see Fig. 1. All edges are rounded, and the top edge is bent outward, forming a rim suitable for a lid. The wall thickness is variable, ranging from 0.5 to 1.0 mm, and was measured using a Mitutoyo External Digital Caliper Gauge (0–30 mm, model 209-913, Mitutoyo, Kawasaki, Japan). To ensure the reliability of these manual measurements, the methodology for estimating measurement uncertainty for hand-held instruments was adopted according to Kozior et al. [Kozior 2024]. The thickness of the container bottom could not be measured and is therefore assumed to be 1 mm. The external dimensions were measured using a Mitutoyo Digital Caliper (0–550 mm, model 500-500-10, Mitutoyo, Kawasaki, Japan).

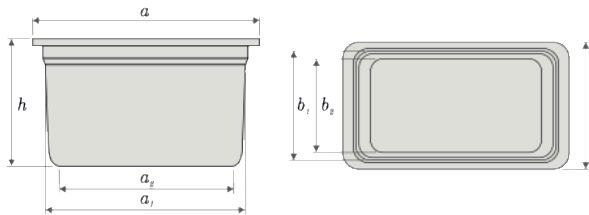


FIGURE 1 GEOMETRY OF GN CONTAINER (SIDE AND TOP VIEW).

The key dimensions are summarized in Tab. 1. The weight of the GN-EC without a lid is 1.32 kg. The container was weighed using a Soehnle Professional digital scale (model 9203, Soehnle Industrial Solutions GmbH, Backnang, Germany).

TABLE 1 KEY DIMENSIONS OF GN CONTAINER.

Dimension	Value
Maximum size a, b	325 mm × 265 mm
Top base a_1, b_1	300 × 237 mm
Bottom base a_2, b_2	225 × 165 mm

The material of the GN container is AISI 304 stainless steel, which is commonly used and suitable for catering applications. The physical properties used for the numerical analysis are listed in Tab. 2. The Young’s modulus was taken from the literature [Baskutis 2021], while the density was calculated based on the volume of geometric model and the measured weight.

TABLE 2 PHYSICAL PROPERTIES OF AISI 304 USED FOR NUMERICAL MODAL ANALYSIS.

Property	Value
Young’s modulus	200 GPa
Poisson ratio	0.30
Density	7800 kg/m ³

2.2 Experimental Modal Analysis

The preparation of the experimental modal analysis was carried out in a laboratory under standard conditions. The GN container was mounted to a test frame using four compliant springs with low stiffness, see Fig. 2. This setup was intended to approximate free–free boundary conditions; however, it may influence the measured damping ratio.



FIGURE 2 MOUNTING OF GN CONTAINER WITH MEASUREMENT GRID TO TEST FRAME.

For experimental modal analysis, hardware from Brüel & Kjær (B&K, Hottinger Brüel & Kjær, Copenhagen, Denmark) was used. The selected triaxial accelerometer B&K type 4524B has a frequency range from 0.2 to 5.5 kHz. The impact hammer B&K type 8202 was used for excitation and has integrated sensor for acting force B&K type 8200. A charge amplifier B&K type 2647 was required due to the hammer design. The data collection was performed by measuring module B&K type 3160-A-042. The collected data were subsequently evaluated using B&K Connect software. The geometry of the container was defined by 92 nodes, which was considered sufficient to represent the geometry accurately; a simplified model was also created in B&K Connect. The accelerometer was attached to the surface at node 32 using beeswax, which provides a stable mechanical connection.

2.3 Numerical modal analysis

The numerical model was created and evaluated in the Simcenter 3D (version 2506, Siemens Digital Industries Software, Plano, Texas, USA). The geometry was simplified by generating midsurfaces of the GN container to create a shell model. The finite element mesh, shown in Fig. 3Chyba! Nenalezen zdroj odkazů., consists of linear shell elements (CQUAD4) with an average edge size of 2 mm. In total, the mesh contains approximately 73,600 elements and 74,000 nodes. The element sections of the container were divided into nine zones, for which the measured thickness values ranging from 0.5 to 1.0 mm were assigned. The greatest thickness was observed at the bottom and the rim of the container, while the smallest thickness occurred in the regions of geometric transitions. The material was described using a linear elastic model, with physical properties defined as listed in Tab. 2. The assembled system was solved as an undamped problem using the Simcenter Nastran solver SOL103 (version 2506, Siemens Digital Industries Software, Plano, Texas, USA) with the Lanczos method. The first 12 natural modes and their corresponding frequencies were extracted. No boundary conditions were applied; consequently, modes 1–6 correspond to rigid body motion with zero natural frequency, and the seventh mode represents the first measured mode.



FIGURE 3 FINITE ELEMENT MESH OF GN CONTAINER.

3 RESULTS

In this section, the results of the experimental and numerical modal analyses are presented. First, the experimental modal analysis results are described for the GN-EC and the GN-FC. The following section focuses on the numerical model of the GN-EC. Finally, the results from both approaches are compared. Six mode shapes and their corresponding natural frequencies were evaluated for both analyses. A parametric study of the GN-EC is presented at the end.

3.1 Experimental results

Mode shapes, frequency and damping ratio of the GN-EC are displayed in Fig. 4. The results indicate that the first natural frequency is 133.2 Hz and the rim is predominantly involved in the vibration. The second and third mode shapes look similar, but the wider walls vibrate in antiphase in the second mode, and in the third mode, mode shapes are in phase. The fourth and sixth modes exhibit similar behavior but on the narrow wall. The fifth mode involves significant excitation of the bottom.

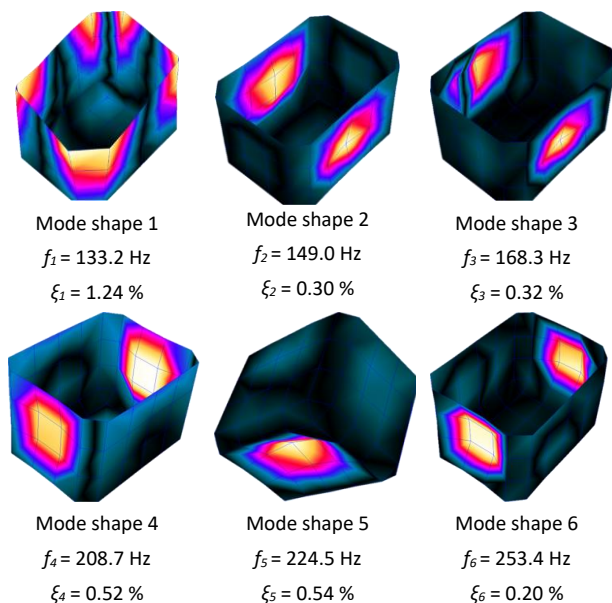


FIGURE 4 NATURAL FREQUENCIES, DAMPING RATIO AND THEIR MODE SHAPES FOR GN-EC, THE THERMAL COLOR SCALE REPRESENTS NORMALIZED TOTAL DISPLACEMENT FROM 0 (BLUE) TO 1 (WHITE).

Mode shapes and frequency for the GN-FC are displayed in Fig. 5. The evaluation of the experiment conducted with 10 liters of water inside the container revealed a distinct decrease in the natural frequencies of all investigated modes. While the first and second mode shapes remain comparable to those observed in the empty state, they appear in a reversed order: the first mode is now characterized by significant in-phase vibration

of the longitudinal walls, whereas the second mode is dominated by the deformation of the upper rim. Finally, mode 6 exhibits a more complex modal pattern, characterized by symmetric vibration of the bottom base accompanied by vibration of the longitudinal side walls.

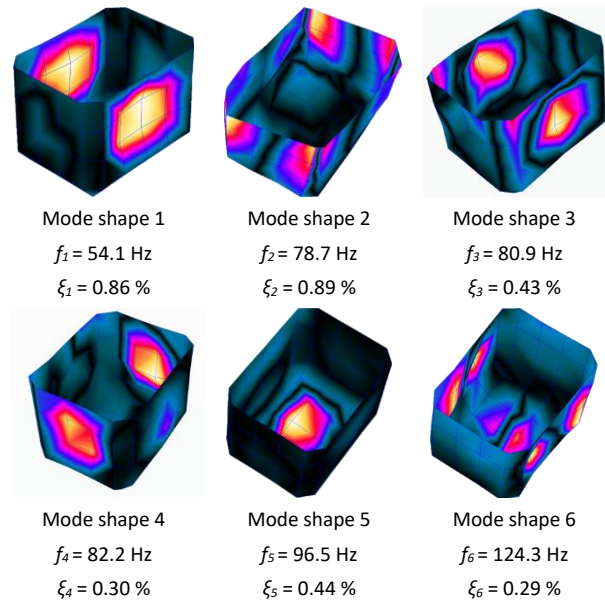


FIGURE 5 NATURAL FREQUENCIES, DAMPING RATIO AND THEIR MODE SHAPES FOR GN-FC, THE THERMAL COLOR SCALE REPRESENTS NORMALIZED TOTAL DISPLACEMENT FROM 0 (BLUE) TO 1 (WHITE).

3.2 Comparison with Numerical Model

As mentioned above, the numerical model was performed for the GN-EC. Mode shapes are displayed in Fig. 6. The numerical model showed a strong correlation with the experimental data, particularly for the first two modes. The relative differences between the experimental data and numerical modeling results are presented in Tab 3. A higher discrepancy of 5.47 % was observed specifically for Mode 3. This is attributed to the geometric simplifications in the numerical model; while the numerical model incorporates nine zones with specific constant thicknesses to approximate the structure, it still assumes perfectly symmetrical geometry. It can be observed that the mode shapes exhibit identical deformation patterns.

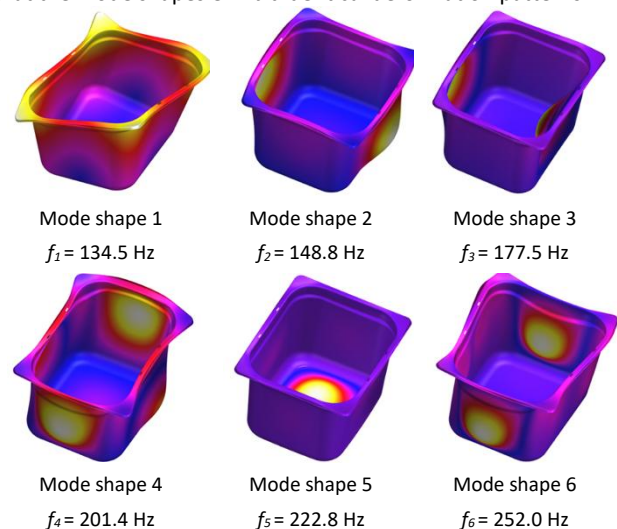


FIGURE 6 NATURAL FREQUENCIES, DAMPING RATIO AND THEIR MODE SHAPES FOR GN-EC, THE THERMAL COLOR SCALE REPRESENTS NORMALIZED TOTAL DISPLACEMENT FROM 0 (BLUE) TO 1 (WHITE).

TABLE 3 COMPARISON OF NATURAL FREQUENCIES RESULTS.

Mode	Experimental result	Numerical result	Relative difference
1	133.2 Hz	134.5 Hz	0.98 %
2	149.0 Hz	148.8 Hz	0.13 %
3	168.3 Hz	177.5 Hz	5.47 %
4	208.7 Hz	201.4 Hz	3.50 %
5	224.5 Hz	222.8 Hz	0.76 %
6	253.4 Hz	252.0 Hz	0.55 %

3.3 Parametric study

The validated numerical model was subsequently employed for a parametric study investigating different standardized dimensions according to the EN 631-1 standard. Specifically, the GN 1/1 (base module) and GN 1/4 sizes were selected to observe the effects of both enlargement and reduction relative to the validated GN 1/2 model. The results of the parametric study indicate that as the dimensions increase (GN 1/1), the natural frequencies decrease, see Tab. 4. Conversely, reducing the dimensions (GN 1/4) leads to an increase in natural frequency values.

TABLE 4 PARAMETRIC STUDY OF GN-EC.

Type	Volume (l)	First frequency (Hz)	Decrease (%)
GN 1/2 container (325 mm × 265 mm)	10.0	134.5	0.0
GN 1/1 container (530 mm × 325 mm)	27.0	55.37	-58.8
GN 1/4 container (265 mm × 162 mm)	5.5	206.1	53.3

For the GN 1/1 study, the first mode shape remained identical to the original GN 1/2 model (torsional vibration of the upper rim). In the case of the GN 1/4 study, a shift in the modal order was observed. The first mode shape of the GN 1/4 container corresponds to the second mode shape of the GN 1/2 (out-of-phase vibration of the longitudinal walls). The second mode of the GN 1/4 corresponds to the third mode of the GN 1/2 (in-phase wall vibration).

4 DISCUSSION

In this paper, two experimental modal analyses of the empty GN container and the GN container filled with 10 l of water were performed. The measurement model was simplified (92 nodes), which limited the accuracy of identifying rim-related mode shapes. This simplification did not allow the evaluation of mode shapes of the rim, but this limitation was compensated by the validated numerical model. The observed decrease in natural frequencies agrees with previously reported fluid–structure interaction effects [Jhung 2019, Anagha 2020], where added mass reduces structural stiffness-to-mass ratio. In further studies, creating an accurate model of the container using 3D scanning could enable even more precise results. It should be noted that the fluid was not explicitly modeled, and its effect is therefore not represented. Future work could also extend

the analysis to different container geometries, wall materials, or operational conditions such as vibrations during transport, to further generalize the findings. Additionally, it would be beneficial to investigate fillings with higher density, more representative of meals typically served in catering facilities. It should be noted that identifying modal parameters in liquid-filled containers requires a cautious experimental approach. Specifically, the use of refined signal processing techniques is necessary to distinguish higher-order modes.

5 CONCLUSION

This study investigated the structural dynamics of Gastronorm (GN) containers through a combined experimental and numerical approach. The main findings can be summarized as follows:

- Filling the GN 1/2 container with 10 liters of water causes a significant reduction in the first natural frequency, dropping from 133.2 Hz to 54.1 Hz.
- The presence of fluid induces a fundamental shift in vibration patterns where the primary mode changes from torsional deformation of the upper rim to bending-dominated vibration of the sidewalls.
- The numerical model, employing a nine-zone thickness approximation, showed strong correlation with experimental data. A maximum discrepancy of 5.47 % in Mode 3 was identified and attributed to manufacturing-induced asymmetries and variations in wall thickness.
- The validated model serves as a tool for wall thickness optimization. Accurate modal characterization allows manufacturers to reduce material usage and weight.
- Evaluation of GN modules according to EN 631-1 confirmed that while larger containers like the GN 1/1 maintain similar mode shapes at lower frequencies, smaller containers such as the GN 1/4 exhibit a shift in modal order.

ACKNOWLEDGMENTS

This work was financially supported by the Specific Research “Advanced Numerical and Experimental Approaches in Mechanics and Biomechanics” (SP2026/O27).

REFERENCES

- [Bazhenov 2019] Bazhenov, V.; Krivenko, O.; Vorona, Y. Modal Analysis Of Thin Parabolic Shells. *Strength of Materials and Theory of Structures* **2019**, 171-179, doi:10.32347/2410-2547.2019.102.171-179.
- [Bochenski 2019] Bochenski, M.; Gawryluk, J.; Kloda, L. Experimental Modal Analysis Of An Active Thin-Walled Composite Structure. *Modelling, Measurement and Control B* **2019**, 88, 112-117, doi:10.18280/mmc_b.882-415.
- [Li 2013] Li, Z.; Adany, S.; Schafer, B.W. Modal Identification For Shell Finite Element Models Of Thin-Walled Members In Nonlinear Collapse Analysis. *Thin-Walled Structures* **2013**, 67, 15-24, doi:10.1016/j.tws.2013.01.019.
- [Jhung 2019] Jhung, M.J.; Kang, S.-S. Fluid Effect On The Modal Characteristics Of A Square Tank. *Nuclear Engineering and Technology* **2019**, 51, 1117-1131, doi:10.1016/j.net.2019.01.012.

- [Anagha 2020] Anagha, B.V.; Nimisha, P.; Jayalekshmi, B.R. A Study On Effect Of Fluid On The Modal Characteristics Of Ground Supported Water Tanks. IOP Conference Series: Materials Science and Engineering 2020, 936, 012027, doi:10.1088/1757-899x/936/1/012027.
- [Drahorad 2025] Drahorad, L.; Marsalek, P.; Sotola, M.; Cienciala, J.; Poruba, Z.; Leskovan, T.; Larys, M. Experimental Modal Analysis Of Bolted Environmental Storage Tank With New Wind Girder. MM Science Journal 2025, 2025, doi:10.17973/mmsj.2025_06_2025062.
- [Drahorad 2026] Drahorad, L.; Marsalek, P.; Poruba, Z.; Cienciala, J.; Hunady, R.; Toskova, A.; Fusek, M.; Larys, M. Lightweight Bolted Storage Tank Design: Experimental And Numerical Modal Analysis. Thin-Walled Structures 2026, 223, 114603, doi:10.1016/j.tws.2026.114603.
- [Drahorad 2023] Drahorad, L.; Marsalek, P.; Hroncek, J.; Rybansky, D.; Sotola, M.; Poruba, Z.; Larys, M. Design And Non-Linear Modeling Of New Wind Girder Used For Bolted Tanks. Buildings 2023, 13, 2724, doi:10.3390/buildings13112724.
- [Kozior 2024] Kozior, T.; Bochnia, J.; Bochenek, A.; Malara, D.; Nawotka, M.; Jansa, J.; Hajnys, J.; Wojtowicz, A.; Mesicek, J. Estimating the Uncertainty of Measurements for Various Methods and 3D Printed Parts. Applied Sciences 2024, 14, 3506, doi:10.3390/app14083506.
- [Baskutis 2021] Baskutis, S.; Baskutiene, J.; Bendikiene, R.; Ciuplys, A.; Dutkus, K. Comparative Research Of Microstructure And Mechanical Properties Of Stainless And Structural Steel Dissimilar Welds. Materials 2021, 14, 6180, doi:10.3390/ma14206180.

CONTACTS:

Ing. Jakub Cienciala
 Department of Applied Mechanics,
 Faculty of Mechanical Engineering,
 VSB - Technical University of Ostrava,
 17. listopadu 2172/15, 708 00 Ostrava, Czech Republic
jakub.cienciala@vsb.cz

LICENSE CREATIVE COMMONS:

The article is published under the terms and conditions of the Creative Commons Attribution 4.0 International License (CC BY 4.0).