Streamlining nonlinear blast analysis for efficient structural design of offshore platforms

Andre L. L. S. Lima[2], Lucas D. F. Lino[1], Eduardo S. S. Silveira[1], Tiago P. S. Lôbo[1], Christian C. Oliveira[1], Gabriel C. Freitas[1], Dilnei Schmidt[2]

[1]*Laboratory of Scientific Computing and Visualization, Federal University of Alagoas*
Av. Lourival Melo Mota, S/N, Tabuleiro do Martins, 57072-900, Maceió/AL, Brazil
lucaslino@lccv.ufal.br, eduardosetton@lccv.ufal.br, tiago@lccv.ufal.br,
christian.oliveira@lccv.ufal.br, gabriel.freitas@lccv.ufal.br
[2]*Leopoldo Américo Miguez de Mello Research and Development Center - CENPES/PETROBRAS*
Av. Horácio Macedo, 950, Cidade Universitária, 21941-915, Rio de Janeiro/RJ, Brazil
andre_ladeira@petrobras.com.br, d.schmidt@petrobras.com.br

Abstract. The design of offshore platforms requires comprehensive blast analyses to ensure safety and structural integrity. However, creating dedicated structural models for nonlinear blast analyses can be complex and time-consuming. This paper describes the development of an innovative application that simplifies and automates steps of the model preparation process for nonlinear blast analyses, by taking advantage of existing structural models used for in-place operational structural analyses. Engineers can use wizards within the application to automate steps, reducing manual work and potential errors. Developed with a Java Spring Boot backend and a React frontend, this tool not only simplifies but also streamlines the model preparation process, ultimately enhancing the efficiency of offshore platform design. As a result, the application has demonstrated substantial efficiency gains, significantly reducing the time required for nonlinear blast analysis model preparation when compared to manual methods for a single structure. This application represents a significant advancement in nonlinear blast analysis workflow, boosting productivity, accuracy, and reliability in the development of offshore structures.

Keywords: Offshore structural design, Blast analysis, Model preparation, Nonlinear analysis,

1 Introduction

Offshore structures play a crucial role in exploring and exploiting underwater resources, providing a robust and effective platform for various industrial operations. This includes various types of platforms, such as fixed and floating structures, each engineered to withstand the challenges posed by the marine environment [1]. Among these types, a multitude of distinct platform designs has emerged, each distinguished by unique attributes fine-tuned to meet precise operational needs and accommodate varying water depths [2]. Despite their variety, ensuring the safety and integrity of these structures remains a central focus, achieved through comprehensive structural analyses.

In the pursuit of safety and structural integrity, the American Petroleum Institute (API) plays a pivotal role. It establishes stringent regulations governing offshore structure design, construction, and operation, ensuring that safety standards are met. These guidelines encompass essential aspects related to material behavior, load distribution, and other critical factors. Nevertheless, the evolving demands and challenges within the offshore industry have underscored the need for advanced approaches, including the careful consideration of geometric nonlinearity. These advanced methods enable a more precise and comprehensive analysis of structural responses to dynamic forces and potential explosion-related hazards [3].

In extreme scenarios, such as explosions, blast analysis is a key factor in evaluating a structure's ability to overcome both natural and adverse loads, with a strong emphasis on preserving structural integrity during the design of offshore platforms [4]. Hence, standards such as API RP 2TOP and ISO 19901 - Part 3 are crucial to ensure safety assessments by setting criteria for offshore structures to endure rare explosion loads, that usually can only be demonstrated with the use of nonlinear structural analyses [5, 6]. This requirement particularly applies to topside structures - those situated above the waterline, on the upper part of the platform.

A development worth noting in the context of blast analysis and structural design is the Joint Industry Project 35 (JIP 35) initiated by the International Association of Oil and Gas Producers (IOPG) [7]. The primary objective of the JIP 35 is to standardize the design of offshore structures, encompassing both business risk performance criteria and life-safety risk performance. It delineates two levels of risk, each requiring its specific structural analysis and associated criteria. The former pertains to structural elements whose failure could lead to substantial financial loss, while the latter focuses on components that, if compromised, would endanger human lives.

Recent recommendations from IOGP's JIP 35 mandate both linear and nonlinear structural analyses for business and life-safety risk criteria verification. This contrasts with the API RP 2FB approach, where linear analysis sufficed for certain cases. Nonetheless, performing blast analysis, especially in nonlinear scenarios, presents considerable challenges due to the need for engineering tools, specialized skills to ensure the effective execution of these analyses and diverse structural models [8].

Engineers rely on the existing in-place structural model to verify the structure's ability to resist operational loads. However, when assessing accidental conditions, such as blast impacts, different models are necessary, leading in a time-intensive and challenging process to create them. Recent advancements in software, such as DNV Group's GeniE, a Finite Element Method (FEM) modeling and analysis tool, have eased this task. Despite the aid of powerful tools like GeniE, the need to assess accidental conditions with separate models and to create alternative models for such scenarios remains a time-consuming effort, particularly during the basic design phase of offshore platforms. The intricacies of accurately capturing geometry, dynamic responses, and material behaviors under accidental circumstances further add to the complexity of the task.

Recognizing the potential for significant time savings, a novel approach is proposed and implemented by the application: reusing the in-place structural model and applying geometry simplifications while retaining the pertinent loads. This innovative strategy represents a substantial efficiency gain, as it minimizes the need to recreate the entire model from scratch while ensuring accurate representation of the forces and stresses involved in the blast scenarios.

The application developed herein is concentrated on evaluating and documenting structural verification to satisfy the life-safety risk criteria established by JIP 35. This criterion specifies that structural components must remain intact, without fracturing or collapsing under ductility level blast (DLB) loading, corresponding to the blast load with an annual probability of exceedance of 10^{-4}. This underscores the tool's alignment with industry standards and its contribution to ensuring the safety and integrity of offshore structures. The following sections will elaborate on the architecture, workflow, a real-world application and the potential for future enhancements of the application.

2 Blast application

As previously mentioned, notable challenges emerge during the modeling process of nonlinear blast analysis for offshore platforms. These challenges become more pronounced due to the constrained time frame of the basic design phase. Revising intricate models within this limited time is a formidable task. Although reusing the in-place models for blast analysis helps save time, there is still a considerable amount of work involved in simplifying and adapting these models into suitable forms for accurate nonlinear analysis. In response to these demands, the application, Blast, introduces an intuitive wizard-based approach that guides users through the various stages of model setup, effectively streamlining the preparation process.

Blast is a web application integrated into the NavalWEB ecosystem - a collaborative platform developed by the LCCV researchers to serve a wide array of naval engineering applications. Within this ecosystem, Blast allows the creation of diverse analysis scenarios, where supplementary applications within NavalWEB are used to specify the structural project and module in which the analysis will be performed.

At its core, Blast's architecture includes a Java Spring Boot backend and a React frontend. The Java Spring Boot backend functions as the logical hub of the application, housing the implementation of every step in the wizard. The React frontend offers users an intuitive interface for interaction and navigation.

When initiating a new analysis in Blast, subsequent to the selection of the structural project and a dedicated module within the platform, users are presented with the screen as depicted in Fig. 1, where the main components that constitute the Blast application are shown. Highlighted in green, it is included all the essential details regarding the newly created analysis, such as the location, project installation and structure. The purple section represents the wizard, which outlines the road map users need to follow. The red portion provides users with detailed information regarding each specific step.

The analysis wizard, positioned to the right of the setup wizard (see Fig. 1), is a forthcoming feature currently in development. This wizard aims to streamline the nonlinear blast analysis process further by generating all the

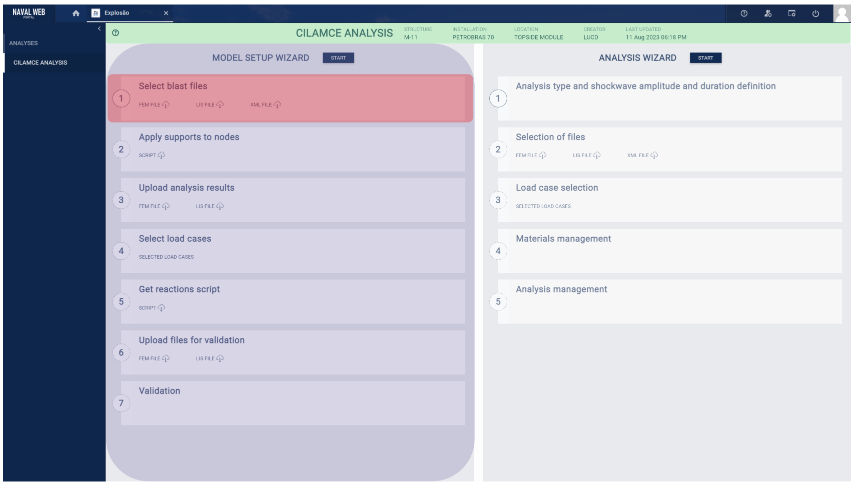


Figure 1. The initial screen of the Blast application. The analysis information is highlighted in green, the wizard with all necessary steps is in purple, and specific step information is marked in red.

requisite inputs for conducting the analysis in USFOS, a nonlinear analysis software. This integration will enable users to seamlessly transition from model preparation within Blast to analysis execution in USFOS, facilitating a cohesive workflow.

Before delving into the comprehensive explanation of each step within the setup wizard, it's essential to clarify the objective: adapting the existing in-place model for nonlinear blast analysis. This adaptation focuses on retaining the primary structure and all relevant active loads initially considered in the in-place model. Achieving this entails the removal of secondary structures while ensuring the preservation of loads transferred from the secondary to the primary structure. To provide an initial understanding of the subsequent steps, the following concise 2D illustration will offer a preview of the process.

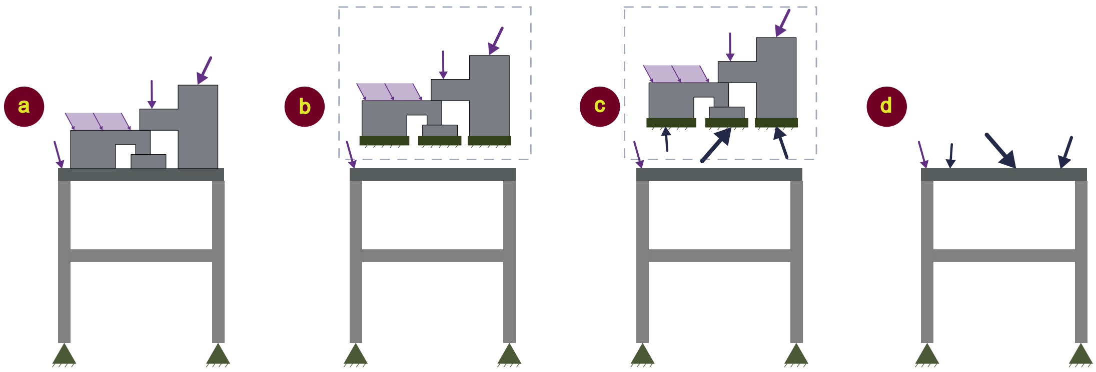


Figure 2. Illustration depicting the four stages of the model simplification process. a) shows the first stage, in which the complete structure is analyzed under various static loads to determine reaction forces and moments. b) shows the second stage, where secondary elements are separated from the structure and supports are applied to them. c) illustrates the third stage, involving the linear analysis of the separated secondary elements with applied supports. d) presents the fourth stage, where reaction forces from the previous stage are applied to the primary structure, followed by a linear analysis to validate the simplified model's integrity.

The illustration in Fig. 2 outlines the technique employed to simplify a structural model. The process begins with the initial structure, which comprises fixed primary elements and secondary elements intended for removal. Primary elements denote the essential load-bearing components that carry and transfer the applied forces and loads throughout the structure. Secondary elements encompass non-essential components that do not play a role in the primary load-bearing path, and therefore are to be removed from the nonlinear structural blast model.

The first stage (Fig. 2a) involves subjecting the complete structure to a linear analysis, assessing its response to various static loads. This analysis yields reaction forces and moments, used for validating the final simplification. In the second stage (Fig. 2b), secondary elements are isolated and provided with supports, constraining all degrees of freedom.

Moving to the third stage (Fig. 2c), the linear analysis focuses on the separated secondary elements, considering the applied supports. This analysis yields reaction forces on the supports. In the final stage (Fig. 2d), these reaction forces are applied to the primary structure with inverted signs, simulating their removal. Subsequently, another linear analysis is conducted on the simplified structure.

A successful simplification is indicated when the reaction forces and moments obtained from both linear analyses - performed on the complete and simplified structures - are consistent. This confirms the integrity of the simplified model, making it suitable for subsequent nonlinear blast analyses.

Within Blast, these four stages are subdivided into seven distinct steps, as already illustrated in Fig. 1. Upon initiation of the setup wizard, users are directed to the screen displayed in Fig. 3. This interface shows the analysis information section (highlighted in green) and the road map component (highlighted in yellow), which outlines all the steps and indicates the current stage. The navigation buttons are highlighted in blue, allowing users to proceed to the next or previous steps. In the center, the unhighlighted section displays the details specific to the current step (this area dynamically changes with each step).

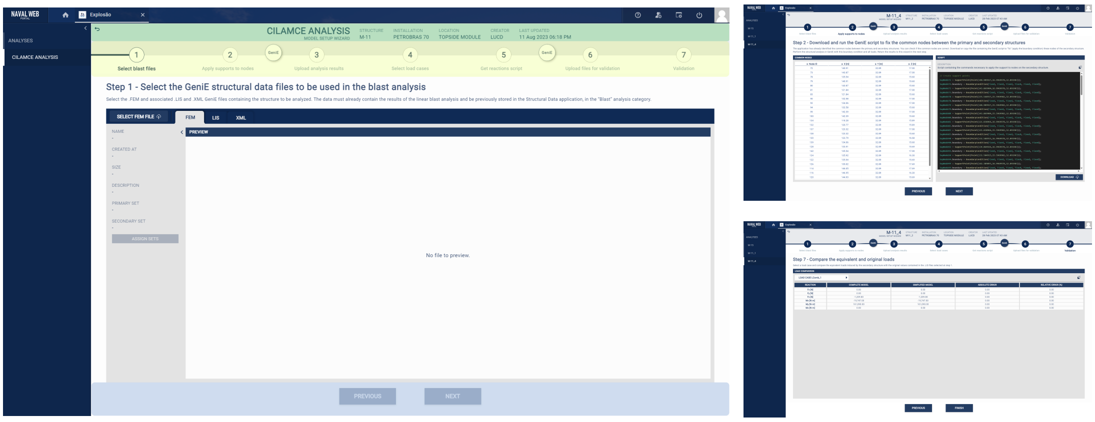


Figure 3. On the left, the setup wizard first step screen, with the road map component in yellow and the navigation buttons in blue. On the upper right, third step screen showing the script automatically generated to apply supports. On the bottom right, seventh step showing the table to compare complete e simplified structures.

In Fig. 3, we also present the screens of the third and seventh steps on the right side of the initial step screen. This arrangement highlights the dynamic nature of the central component, which adapts according to the specific step being undertaken. The seven-step process is designed to work harmoniously with the GeniE software. Throughout the setup wizard, engineers will need to take actions within GeniE to progress through the roadmap and successfully complete the process.

The initial step involves the engineer selecting a .FEM file along with the associated .LIS and .XML GeniE files, which consists of the finite element model with all applied loads, the listing file with load summary and reaction forces and the complete model description, respectively. These files represent the outcomes of a linear analysis conducted in GeniE using the complete structure (stage one in Fig. 2a). Moreover, these files are already uploaded into an auxiliary application that functions as a centralized hub for all analysis files. Additionally, the first step includes checks for specific configurations within the GeniE files to ensure the subsequent steps proceed seamlessly (e.g., ensuring sets have been created to represent primary and secondary structures in GeniE).

After completing the first step and proceeding to the second step, the application automatically computes the nodes shared between the primary and secondary structures. It then presents a table displaying these nodes along with a script to be executed in GeniE for applying support nodes to segregate the primary and secondary structures and running the linear analysis (upper right screen in Fig. 3). This step also permits the download or copying of the provided script for convenience. The third step involves retrieving the files after the execution of a linear analysis, solely within the secondary structure, using the applied support nodes generated in the previous step.

Within GeniE, loads are organized into load cases and load combinations, which are used to encompass various combinations of fundamental loads, including mechanical, live, and blast loads. Moreover, the software allows the formation of load combinations by combining multiple load cases. Recognizing this complexity, the fourth step was designed to enable engineers to selectively designate the load cases or combinations from which they intend to apply reaction forces derived from the secondary-only linear analysis.

After load cases selection, the fifth step automatically generates a script containing reaction forces with inverted signs, incorporating them into all the selected load cases. At this stage, armed with the reaction forces script, the process of defining the simplified structure is concluded. All that remains is for the engineer to initiate the linear analysis using the simplified structure and then compare its results to those of the complete model.

Next comes the sixth step, which involves getting the files after performing the linear analysis on the simplified structure. Finally, the last step displays a table that compares reaction forces and moments, for the chosen load cases, of complete and simplified models, showing the relative and absolute errors (bottom right screen in Fig. 3).

This comprehensive model simplification process guarantees precise outcomes and optimizes the groundwork for subsequent nonlinear blast analyses.

3 Case study results

To illustrate the application's real-world applicability, this chapter will focus on a specific real case where it was employed. This case will demonstrate how the application was used, highlighting its effectiveness to the model preparation process.

The selected case involves the structural design of a typical topside module for a Floating Production, Storage, and Offloading (FPSO) platform. The chosen module from the topside structure is presented in Fig. 4. This 3D model, generated using the GeniE software, provides a comprehensive view of the primary load-bearing elements constituting the core structure. Additionally, the secondary components that are earmarked for removal are visually emphasized in red.

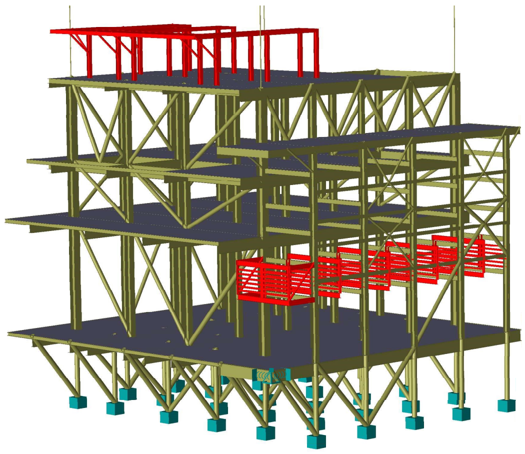
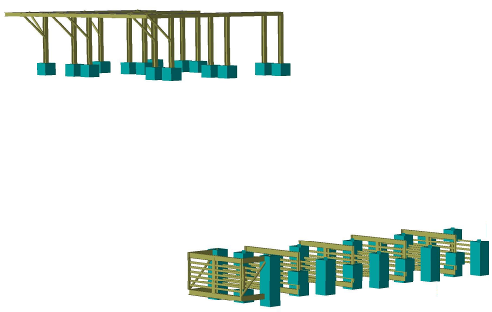


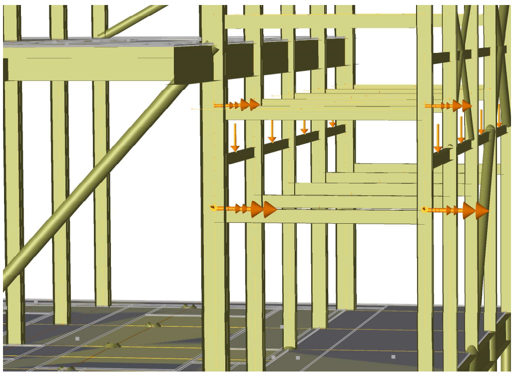
Figure 4. 3D model of the selected module created in GeniE software, highlighting primary load-bearing elements and marking secondary components intended for removal in red.

With this model in hand, the engineer performed a linear analysis using GeniE, resulting in the generation of essential files, including .FEM, .LIS, and .XML. It's important to note in advance that the cumulative values of reaction forces and moments, derived from the linear analysis of the complete structure (specifically, under the BL11_45 load combination and extracted from the .LIS file), are shown in the validation screen (Figure 6) and serve as essential reference data for the upcoming final simplification comparison.

The files generated from the analysis of the complete structure were uploaded to a designated NavalWEB application designed to store and manage them for integration with Blast. Once in the Blast application, the engineer initiated a new analysis and started the setup wizard. During this process, the engineer selected the



(a) 3D model of secondary elements with applied supports, in GeniE.



(b) 3D model, depicted in the GeniE software, displaying the reaction forces corresponding to the BL11_45 load combination, exerted on the elements positioned along the right side of the model.

Figure 5. Illustration of the fourth step within Blast setup wizard workflow.

previously mentioned .FEM, .LIS, and .XML files to complete the first step.

In the subsequent stages, Blast automatically identified common nodes between primary and secondary elements, generating a script to implement supports for segregating these structures (illustrated in Figure 5a). Furthermore, as outlined in section 2, the subsequent tasks encompassed the engineer conducting an exclusive analysis focused solely on the secondary structure, retrieving files from this analysis, specifying particular load combinations (BL11_45 and BL15_315), and receiving a script to apply reaction forces to the selected load combinations. These reactions were integrated into the primary structure while preserving precise alignment with the secondary elements, thereby creating the simplified structure (comprising the primary model with the incorporated reaction forces replacing the secondary elements), as shown in Figure 5b.

Following this integration, a linear analysis was conducted on this streamlined structure, and the resulting files were retrieved, marking the completion of the simplification process. At this stage, the application presents the final step screen (Figure 6), which involves the essential validation and verification of the sum of reaction forces and moments from the analyses conducted on both the complete and simplified structures. This step serves as the conclusive check to ensure the correspondence between the two structures, ultimately assessing its effectiveness.

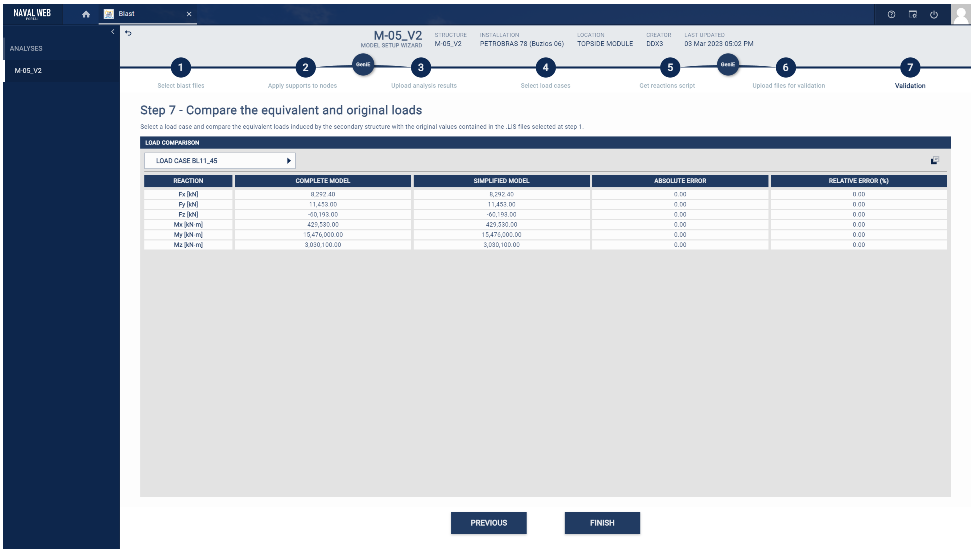


Figure 6. Blast's seventh step wizard screen. Successful simplification achieved, as indicated by negligible absolute and relative errors.

The values from the table displayed in Figure 6 serve as critical indicators of the structural behavior under the applied loads. Notably, the analysis results for the complete structure reveal a substantial force in the F_z direction ($-60193.00\,kN$), indicating a significant vertical load, while the moments, especially in the M_x and M_y directions ($429530.00\,kN \cdot m$ and $15476000.00\,kN \cdot m$, respectively), underscore the twisting and bending moments experienced by the structure's foundations. These values are expected to remain consistent in the simplified structure, as the removal of secondary elements should yield the same structural behavior.

Figure 6 further illustrates that the sum of reaction forces and moments in the simplified structure precisely corresponds with those in the complete structure under the BL11_45 load combination. This congruence is further supported by the absence of any absolute error in this particular study case, affirming the successful preservation of structural integrity throughout the simplification process. The equal sum of reaction forces from both linear analyses unequivocally indicates consistent structural behavior after the simplification process. Forces in all directions show no deviations, and structural integrity remains unchanged. Similarly, moments experienced by the structure exhibit no discernible alterations, affirming successful preservation of its overall behavior.

After integrating Blast into their workflow, engineers observed a significant reduction in time required for model preparation and analysis. The streamlined Blast process resulted in a substantial decrease in the overall duration for these tasks. The key achievement of this enhancement was the ability to use the already validated in-place model. Notably, modifications to the in-place model could be quickly applied to the nonlinear blast analysis model, thereby enhancing the project's overall quality. This seamless integration between the models accentuated the efficiency of the entire process, reflecting a substantial advancement in time-saving potential.

Prior to adopting Blast, the typical practice involved recreating the model, which consumed a significant amount of time and effort. Additionally, integrating alterations made to the in-place model into the nonlinear blast analysis model presented considerable challenges. The application introduces a more efficient workflow, enabling engineers to invest more time in structural design while using the existing in-place model for generating the nonlinear blast analysis model. The benefits of this approach are manifold: 1) Time-saving through the use of the in-place model for generating the nonlinear blast analysis model; 2) Quick incorporation of in-place model changes into the nonlinear blast analysis model; 3) Ensuring alignment between the blast analysis model and the in-place model for enhanced quality; 4) Allowing engineers to focus on structural design rather than extensively creating nonlinear blast analysis models; and 5) Standardizing blast analysis procedures to ensure that the topside structure conforms to business risk and life-safety risk criteria, aligning with the industry trend and recommendations set by JIP 35 from IOGP. Furthermore, the application signifies a substantial stride in the realm of digital transformation, empowering engineers to prioritize critical aspects of the design phase for offshore platform modules.

The application aims for seamless integration of the simplification process, directly incorporating GeniE functionality into the wizard interface to remove intermediate steps. Additionally, an advanced secondary wizard is in development, streamlining file preparation for nonlinear analyses in USFOS. This upcoming enhancement is expected to enhance nonlinear blast analyses, increasing overall efficiency and effectiveness.

4 Conclusions

In summary, the study's main findings demonstrated that the application Blast significantly accelerated the process of nonlinear blast analyses in offshore platform design, particularly for the basic design phase. The case study underscored how the application greatly reduced the overall time for model preparation and simplification, leading to increased efficiency and accuracy. Notably, the results have consistently highlighted that the sum of reaction forces and moments remained unchanged throughout the simplification process, affirming the reliability and integrity of this innovative approach. This innovation not only streamlined the operational aspects but also granted engineers more opportunity to concentrate on critical design considerations. The use of the in-place model to create the blast analysis model not only guaranteed the consistency of the quality of results but also ensured their coherence. Furthermore, the application's potential integration with GeniE and ongoing development of a second wizard for USFOS are expected to provide engineers with additional tools to further streamline the process of conducting nonlinear blast analyses, resulting in time savings and process facilitation. As the field continues to evolve, future research and development could potentially delve into refining the interaction between Blast and other analysis tools, contributing to further enhancement in offshore platform design practices.

Acknowledgments. This study was made possible through the support of the Laboratory of Scientific Computing and Visualization (LCCV). The first author extends sincere appreciation to Petrobras for their instrumental partnership, which greatly enhanced the progress of this work. Additionally, the first author would like to express heartfelt gratitude to the LCCV researchers from the NavalSubWEB research group for their invaluable advice and collaboration throughout the application's development.

Authorship statement. The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors, or has the permission of the owners to be included here.

References

[1] American Petroleum Institute (API) Recommended Practice. Recommended practice for planning, designing and constructing fixed offshore platforms—working stress design. API RP 2A-WSD, 2000.

[2] M. A. El-Reedy. *Offshore structures: design, construction and maintenance*. Gulf Professional Publishing, 2020.

[3] Task Committee on Blast-Resistant Design of the Petrochemical Committee of the Energy Division of ASCE. Design of blast-resistant buildings in petrochemical facilities. American Society of Civil Engineers, 2010.

[4] American Bureau of Shipping (ABS). Guidance notes on accidental load analysis and design for offshore structures, 2013.

[5] American Petroleum Institute (API) Recommended Practice. Recommended practices for topside structures. API RP 2TOP, 2019.

[6] International Organization for Standardization. Petroleum and natural gas industries–specific requirements for offshore structures–part 3: Topsides structure. ISO 19901-3, 2014.

[7] Offshore Structures Specifications Task Force. Standardization of Offshore Structures Specifications. International Oil & Gas Producers Association (IOGP). JIP35 Specification S-631, 2020.

[8] American Petroleum Institute (API) Recommended Practice. Recommended practice for the design of offshore facilities against fire and blast loading. API RP 2FB, 2012.