**Title:** OC7 Project Phase II: Comparison of Global-to-Local Load Transfer Approaches in Floating Structures

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## RESPONSE TO REFEREE #1

### Referee Comment 1.1: Literature Review / Introduction Expansion

- **(1) Comment from Referee:** The manuscript lacks a dedicated literature review section. Including a broader discussion of previous scientific work on global-to-local load transfer and hydroelastic modelling would give additional value to the paper. In particular, it would be valuable to compare the investigated approaches with existing hydroelastic methodologies that have been validated against experimental campaigns or higher-fidelity numerical models and compare the conclusions in the discussion section.
- **(2) Author's Response:** We agree that a broader discussion of previous work strengthens the manuscript. Please take into consideration that the topic addressed in this paper is relatively new to the floating wind industry with previous work and existing approaches lacking general applicability and a broader benchmarking study, or involving substantial model simplifications. Accordingly, we expanded the introduction to include additional discussion of prior scientific work on global-to-local load transfer and hydroelastic modelling, including relevant recent studies.
- **(3) Author's Changes in Manuscript:** In Section 1 (Introduction), the second paragraph has been expanded and three new paragraphs have been added to establish the literature review framework:
    - *Revised Paragraph 2:* "...Especially beyond the front-end engineering design (FEED) level, detailed structural verifications in ultimate limit state (ULS) and fatigue limit state (FLS) as required by certification societies are challenging to conduct within tight commercial project schedules (Karch et al., 2024). Traditional assessment procedures adopted from fixed-bottom offshore foundations or oil-and-gas sectors are inapplicable and the existing approaches applied so far often tried to find a compromise between accuracy and efficiency, but often failed to bridge this gap, leading to either overly conservative designs or severe computational inefficiencies (Karch et al., 2024). Hence, a major effort is currently being undertaken by industry and academia to develop new analysis procedures, with the "global-to-local" load mapping process being a key focus."
    - *Added Paragraph 3:* "Yim et al. (2026) demonstrated that failing to maintain strict physical and geometric consistency between global load and local structural models introduces artificial boundary reactions that distort computed structural stresses, which is an important finding relevant for the commonly applied sequential load mapping approach, where the structural assessment in FEA is separated and follows the global performance analysis (ILA)."
    - *Added Paragraph 4:* "Concurrently, as the industry scales up to multi-megawatt capacities, the classical rigid-body assumption for the substructure hull is increasingly challenged. Omitting structural elasticity in global analysis models can compromise structural response predictions. Aguilera et al. (2026) demonstrated using in situ measurements that neglecting floater flexibility introduces significant errors in tower eigenfrequency predictions, whereas incorporating this effect ensures accurate member-level load assessments."

  - *Added Paragraph 5:* "To bypass the steep computational penalties of full shell-element FEA across thousands of time-domain simulations, the industry has turned toward mid-fidelity and reduced-order modelling techniques. Knezevic et al. (2022) established that deploying fully integrated multi-physics methods utilizing reduced basis finite-element analysis (RB-FEA) enables efficient structural integrity assessments without sacrificing geometric complexity. Alternatively, Serván-Camas et al. (2025) proved that leveraging modal matrix reduction methods successfully condenses structural degrees of freedom in coupled aero-hydro-servo-elastic environments, yielding high-fidelity hotspot stress distributions at a fraction of the computational expense. Similarly, Karch et al. (2024) introduced the global influence superposition (GIS) method, a highly efficient unit load-based approach that maps complex hydrodynamic pressures by applying generalized unit pressure patterns across distinct hull segments, thereby eliminating time-step-by-time-step FEA via linear superposition of scaled unit responses."

### Referee Comment 1.2: Clarification of Section 5.2.2 ("Modal FE analyses")

- **(1) Comment from Referee:** Section 5.2.2 ("Modal FE analyses") would benefit from additional clarification. It is not clear to me if the reported modal analyses are performed in air or as wet modal analyses accounting for hydrodynamic added mass effects.

- **(2) Author's Response:** Section 5.2.2 was revised to state explicitly that the reported modal FE analyses are dry modal analyses performed in the structural FE models without hydrodynamic added mass effects.

- **(3) Author's Changes in Manuscript:** In Section 5.2.2 (Modal FE analyses), the first paragraph has been revised to explicitly detail these boundary and fluid environment conditions:

  - *Revised Paragraph 1:* "The results of modal FE analyses (LC3.1 and 3.2) are shown in Fig. 5. LC3.1 considers a structural model comprising only the substructure hull, whereas LC3.2 additionally includes the tower and a simplified representation of the RNA (modelled as a mass point with associated inertias). The modal analysis is performed in the FEA software without applying boundary conditions (i.e. no supports), assuming a dry structure without hydrodynamic added mass. All FE models show very good agreement in the calculated natural frequencies."

### Referee Comment 1.3: RNA Peak Load Frequency and Resonance Conditions

- **(1) Comment from Referee:** The RNA peak load frequency is not clearly stated. It would be useful to compare it with the eigenfrequencies of the hull-tower system. This could help clarify whether resonance or near-resonance conditions may occur between the RNA excitation frequencies (3P pulsation) and the structural bending modes observed in some flexible models.

- **(2) Author's Response:** In the revised manuscript in Section 7, we clarified the relevant RNA excitation characteristics and added a comparison between the 3P excitation frequency and the first fore-aft bending eigenfrequency of the hull-tower system. This was included to better explain the likelihood of resonance or near-resonance effects in the flexible models. We conclude that significant 3P excitation of the tower is not expected.

- **(3) Author's Changes in Manuscript:** In the introductory overview of Section 7 (Evaluation of numerical models), the third paragraph has been updated to include these technical frequencies and physical conclusions:

  - *Revised Paragraph 3:* "To make the global performance simulations as consistent and comparable as possible, the RNA load was specified through a pre-computed load time series applied on the rotor, see Fig. 10. The time series plot includes a 15 s zoom-in region (300–315 s). The peak RNA load occurs at a frequency of 0.0017 Hz. With a mean rotor speed of 0.782 rad/s, the corresponding 3P rotor frequency is 0.373 Hz. This 3P frequency is approximately 15% higher than the first fore-aft bending eigenfrequency, and it carries only low energy content (see PSD plot in Fig. 10). Therefore, significant 3P excitation of the tower is not expected."

### Referee Comment 1.4: Future Recommendations and Unresolved Gaps

- **(1) Comment from Referee:** Finally, the conclusions section could be expanded to provide more insight into how the identified scientific gaps may be addressed in future work. Further discussion on unresolved hydroelastic aspects (influence of second-order wave loading, or the modelling of ballast-induced internal pressure) would be highly valuable. Additionally, the paper would benefit from recommendations for a dedicated experimental campaign capable of validating hydroelastic load transfer methodologies and local stress predictions.

- **(2) Author's Response:** We appreciate this suggestion. However, in order to keep the manuscript focused on the scope of the present benchmarking study and to avoid introducing recommendations that go beyond what is directly supported by the results presented, we have not expanded the conclusions further in this direction. For example, some modelling simplifications were introduced to allow more institutions to participate (e.g. exclusion of ballast, exclusion of second-order wave loads) which means some aspects were not considered in this study but some tools and workflows applied could model it in general. A dedicated experimental campaign as basis for more validation work is generally supported, though, developing it was not part of the scope for the WP2.2 working group within OC7.

- **(3) Author's Changes in Manuscript:** None. Consistent with the author's response, the conclusions section was not expanded to include these out-of-scope recommendations in order to maintain the original focus of the benchmarking study.

## RESPONSE TO REFEREE #2

### Referee Comment 2.1: Color Coding in the Statistical Plots of Figs. 11, 13–17

- **(1) Comment from Referee:** The stress comparison figures in Section 7, including Figures 11, 13, 14, 15, 16, and 17, contain a substantial amount of useful information. In the statistical plots shown in the middle of these figures, the use of colours could be reconsidered to distinguish different modelling assumptions or techniques, such as rigid versus flexible models, linear versus nonlinear wave pressure, or shell versus beam modelling. This may provide a clearer visual comparison of the effects of different modelling choices. At present, the colours represent different model IDs, which are already distinguished by their positions in the figures.

- **(2) Author's Response:** We appreciate this suggestion and carefully reconsidered the presentation of the statistical plots in Section 7. However, because the compared models differ simultaneously in several modelling aspects (e.g. rigid vs. flexible hull, linear vs. non-linear hydrostatics, software/toolchain, and load transfer methodology), a revised colour scheme intended to highlight these categories did not lead to a clearer overall presentation. On the contrary, applying multiple colour groupings within the same figure reduced readability, while changing colour logic between figures depending on the aspect discussed was found to be potentially confusing for the reader. We therefore decided to retain the original colour scheme, in which colours identify the individual model IDs consistently across all figures. To make it easier for the reader to find the key conclusions, also involving the statistical plots, we added a summary in Section 7.4.

- **(3) Author's Changes in Manuscript:** No changes were made to the color scheme of the statistical plots. Instead, a new summary subsection (Section 7.4) and a comprehensive overview table (Table 4) have been added at the end of Section 7 to synthesize the main findings and clarify the trends associated with the different modeling aspects

### Referee Comment 2.2: Summary Subsection Synthesizing Main Findings

- **(1) Comment from Referee:** The authors provide observations and discussions for each loading case. It would be beneficial to include a summary subsection, for example Section 7.4, to synthesize the main findings. In particular, the variations in fatigue damage index under different modelling techniques and loading conditions may indicate conservative or unconservative estimations arising from different sources. A concise table or summary paragraph outlining the trends associated with the selection of different modelling techniques would better guide future research and industrial applications.
- **(2) Author's Response:** We agree that a synthesis of the main observed trends improves the readability of the results section. Accordingly, we added a new summary subsection, Section 7.4, in which the main findings from Sections 7.1–7.3 are consolidated. This section highlights the observed trends associated with the different modelling techniques and loading conditions and is supported by a summary table to provide a concise overview for the reader.
- **(3) Author's Changes in Manuscript:** A new subsection, Section 7.4 (Synthesis of observed modelling trends), and an extensive analytical table (Table 4) have been added at the end of Section 7:
    - *Added Subsection 7.4 Text:* "The comparisons across LCs 4.1, 6.2/6.3 and 7.2/7.3 show that the influence of the modelling technique depends strongly on the governing excitation mechanism. For RNA-load-dominated cases, the treatment of hydrostatic pressures and structural flexibility has a clear effect on stress ranges and fatigue damage indicators (FDIs). For wave-dominated high-sea-state cases, global hydrodynamic loading and rigid-body motions dominate the stress response, while differences in FDI remain sensitive to structural dynamics, and local load mapping details. The main trends are summarized in Table 4."
    - *Table 4 Additions:* A comprehensive summary matrix has been embedded, explicitly categorizing and tracing the design and fatigue implications of global response alignment, hull flexibility, hydrostatic pressure treatment, non-linear hydrodynamic pressure extent, fluid–structure interaction, FEA load equilibration, simplified beam-based structural models, and unit-load superposition methods.

### Referee Comment 2.3: Fatigue Damage Trends, Non-linear Hydrodynamics, and Load Equilibration

- **(1) Comment from Referee:** The authors observe that the rigid and flexible models exhibit different trends in fatigue damage index when aerodynamic loads are considered in addition to wave loads. Furthermore, when the wave height increases from LC6.X to LC7.X, the trend for the flexible model appears to change. This behaviour may be related to nonlinear hydrodynamic effects. Considering the increasing size of FOWTs and the growing need to account for floater flexibility, this observation is highly relevant to future studies. Further discussion or additional information of this point would be valuable.
- **(2) Author's Response:** We agree that this is an important observation. To better investigate the underlying root causes, we extended the study by incorporating additional Ramboll model variants with non-linear hydrostatics, namely RAM1a (rigid hull) and RAM25a (flexible hull). A

short description of how hydrostatic non-linearity is considered in these new models was added to Section 2. In addition, the naming of the Ramboll models was revised (see Table 1) to improve readability and facilitate comparison. These additional results allowed us to refine the discussion in Section 7 and to draw further conclusions regarding the isolated influence of hydrostatic modelling assumptions and hull flexibility. At the same time, the extended comparison still did not allow us to clearly isolate or confirm the influence of non-linear hydrodynamic effects (i.e. the Froude–Krylov pressures applied to the instantaneous wave surface) in LC7.X. We therefore revised the discussion to reflect this limitation explicitly. We also added that one remaining possible explanation in Section 7.3 for the inconsistencies observed in the calculated FDIs in LC7.2/7.3 is the difference in FEA load equilibration techniques. While this effect could not be proven conclusively within the present benchmark, we believe it may also contribute to some of the observed differences.

- **(3) Author's Changes in Manuscript:**
  - *Section 2 Expansion:* Added descriptive text for the data-driven reduced-order pressure models: "The unit load-based models RAM1a and RAM25a also capture this effect by employing a data-driven reduced-order model, utilizing orthogonal Eigen-pressure modes as unit loads to reconstruct the hydrostatic pressures to instantaneous SWL in the time-domain."
  - *Section 7.2 Revision:* Two new paragraphs were added analyzing the distinct behavioral switches between the structural panels:

    "Comparing AKSE1, CENER1, JMUC1 and PRI1 results and directly comparing RAM1 vs. RAM1a, RAM25 vs. RAM25a and CIMN2 vs. CIMN3 it is evident that the hydrostatic modelling strategy (linearized vs. non-linear) has no impact on the CentCol panel (see Figure 14). In contrast, on panel P1_S3 (close to the fore column) a clear impact of the hydrostatic modelling strategy can be observed in LC6.3 (with RNA load), where the pitch angle is considerable, consistent with the observations from LC4.1 (RNA only)."

    "Including fluid-structure interaction (i.e. two-ways coupling; see CIMN2 vs. CIMN1) appears to amplify the FDIs in LC6.2 (wave only), suggesting an increase in wave loads and/or structural oscillations resulting from them. By contrast, in LC6.3, where platform motions are mainly enforced by external RNA excitation, the inclusion of fluid-structure interaction has a damping effect through waves radiated by elastic displacements, thereby reducing the FDIs."
  - *Section 7.3 Revision:* The discussion surrounding panel P1_S3, non-linear hydrodynamics, and load equilibration was significantly expanded with the following text modifications and additions integrated directly into the manuscript:

    *Lines 488-490 text addition:* "This cannot be attributed to their non-linear treatment of hydrostatic pressures, as this should have no impact on the CentCol panel, and is also not observed in other models, such as CENER1, RAM1a and PRI1, which treat hydrostatic pressures in a similar way."

    *Lines 494-496 text modification:* "in the hydrostatic pressure treatment: RAM1 and RAM25 are similar to RAM1a and RAM25a, respectively, while e.g. AKSE1 significantly deviates from these. They also cannot be attributed to structural dynamics: rigid-body RAM1 behaves similarly as the flexible-body RAM20/21/25, while CIMN1/2 is significantly different."

    *Lines 500-509 text addition:* "The effect of fluid-structure interaction (see CIMN2 vs. CIMN1) in LCs 7.2 and 7.3 is much less pronounced than in LCs 6.2 and 6.3 (Hs = 1.0 m) and is only observed in the increased FDIs of the CentCol panel in LC7.2. This suggests that rigid-body hydrodynamics are the primary contributor to structural loading. The effect on non-linear hydrodynamics (i.e. the Froude–Krylov pressures applied to the instantaneous wave surface) was expected to be visible in LCs 7.2 and 7.3 (Hs = 11.0 m). However, the relevant models (CENER1, JMUC1 and PRI1) are too inconsistent and don't allow to derive robust conclusions in this regard. For CIMN3, no results were available. One remaining possible explanation for the inconsistencies observed in the calculated FDIs in LCs 7.2 and 7.3 is the difference in FEA load equilibration techniques. This becomes relevant if residual loads arise from the ILA-to-FEA load mapping process, which is more likely to occur in LCs 7.2 and 7.3 environments with high loads and motions."